Biosphere Models for Safety Assessment of radioactive waste disposal based on the application of the Reference Biosphere Methodology

BioMoSA

(EC contract: FIKW-CT2001-20184)

Final report

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Executive Summary

The management of radioactive waste requires the implementation of disposal systems that ensure an adequate degree of isolation of the radioactivity from the environment and humans. Aims and principles for disposal of radioactive waste have been a top issue of discussions since more than two decades on an international level and have led to agreement on criteria to be fulfilled for the realisation of nuclear waste disposal project

The aim of the BioMoSA project has been to contribute in the confidence building of biosphere models, for application in Performance Assessments (PAs) of radioactive waste disposal. The detailed objectives of this project are:

- Development and test of practical biosphere models for application in long-term safety studies of radioactive waste disposal to different European locations,
- Identification of features, events and processes (FEP's) that need to be modelled on a site-specific rather than on a generic base,
- Comparison of the results and quantification of the variability of site-specific models developed according to the reference biosphere methodology ,
- Development of a generic biosphere tool for application in long term safety studies,
- Comparison of results from site-specific models to those from generic one,
- Identification of possibilities and limitations for the application of the generic biosphere model.

Within BioMoSA, both, site-specific and generic biosphere models were derived following the Reference Biosphere Methodology that was developed within the international project BIOMASS in order to ensure the development of consistent and scientifically justified biosphere models for application in long-term performance assessments for nuclear waste disposals. For these purposes, five European locations, covering a wide range of environmental and agricultural conditions were described and characterised.

In the BioMoSA study the radionuclides ^{36}Cl, ^{79}Se, ^{99}Tc, ^{129}I, ^{135}Cs, ^{226}Ra, ^{231}Pa, ^{230}Th, ^{237}Np, ^{239}Pu, and ^{238}U were considered which are usually most relevant in performance assessment studies of nuclear waste disposals.

For each of the sites, a biosphere model has been developed specifically. The geosphere-biosphere interface is site-specific and radionuclides may enter the biosphere via the withdrawal of groundwater or the release of radionuclides into freshwater bodies or via the contamination of soil due to rising groundwater. However, for all sites the use of contaminated water as drinking water for humans and cattle and as irrigation water is common for all sites.

Inhalation of resuspended soil particles and external exposure due to residence on contaminated land are common pathways in all models. Among the ingestion pathways, the intake of drinking water, cereals, leafy vegetables, potatoes, milk, beef and freshwater fish are included in all models. The selection of the other foods reflects site-specific living habits; e.g. citric fruit are only included in the Spanish model.

For each of the sites, as far as possible, site-specific parameters have been selected for

element-independent parameters (e.g. irrigation rates, agricultural practices, human consumption rates, potential critical groups) and element-dependent parameters (e.g. transfer factors soil-plant, distribution coefficients, migration of radionuclides in soil). Site-specific calculations have been performed for each of the sites considered. Annual individual doses were calculated, important processes and parameters were identified and the uncertainties of the results were estimated by means of stochastic calculations. To enable a comparison, all results were normalised to an activity concentration in groundwater of 1 Bq/m³ for each of the radionuclides considered.

An uncertainty analysis was performed for all sites with the different models. For this purpose, for all parameters of the models, frequency distributions were defined that represent the uncertainty and variability of the parameters. The frequency distributions of the resulting normalised annual effective exposures were calculated by means of Monte-Carlo techniques. Larger uncertainties are expressed by some models for ^{36}Cl, ^{79}Se and ^{135}Cs. Again the interpretation of data, especially when the data base is very poor, is still a major source of uncertainty. The careful consideration of the speciation and the interaction of these elements with soil constituents is an essential need.

Additionally, a generic model has been developed within BioMoSA that contains all features and processes that are included in the site-specific models. The generic model is used to estimate the same endpoints as the site-specific models.

From the BioMoSA study, the following conclusions can be drawn for the development of site-specific assessment tools that are going to be applied in long-term safety studies:

- The methodology developed within the BIOMASS project for the setup of a reference model is considered to be useful. The FEP-list is a good starting point for identification of pathways and processes; however it does not replace the experience of the modeller. Despite the guidance of Reference Biosphere Methodology, the model approaches applied are subject to individual interpretation of the processes and the available parameters.
- Although the models consider the same basic processes, different approaches are applied in some cases. The main differences concern the modelling of the radionuclide contamination of plants by irrigation which covers the processes interception, post-deposition retention, translocation and root uptake. All models assume a plant-dependent interception factor, however only the German and Swedish models consider that this parameter depends on the element as well.
- The variations of the normalised exposures [in Sv/a per Bq/m³] for the well scenario among the sites are in general less than a factor of 10. For all sites, the intake of drinking water is an important or even dominating contributor to the exposure. Due to physiological restrictions, the variation of the intake of drinking water is low. Therefore, the intake of drinking water represents a kind of a “baseline” with relatively little variations among the sites, on top of which the ingestion of foods have to be considered.
- The amount of food consumed is also constrained for physiological reasons. The consumption habits among the sites vary in terms of the food items, but not in terms of the total amount of foods. Therefore the variation of the ingestion dose in general is limited.
- In general, there is acceptable agreement between the results obtained with the generic and the site-specific models respectively. The interpretation of data, especially when the data base is very poor, is still a major source of uncertainty. This is especially true for Cl-36, I-129 and Se-79. The careful consideration of the

speciation and the interaction of these elements with soil constituents is an essential need.

- The results for the lake, marine and a release to the deep soil are associated with larger uncertainty which is due to the much higher complexity of the specific sites.
- The experimental data base to model the exchange from the deep soil to the upper soil is still very poor which causes considerable uncertainties in this field. This is especially important, if the deep soil is considered as the geosphere-biosphere-interface.
- In general, the intake of water, the irrigation rates and the dust load in air are the most important parameters influenced by climate. The intake of water has physiological constraints. In the assessment context, it is defined that the agricultural practices should allow a sustainable land-use. This condition limits the amount of irrigation water to be applied, since under very dry and arid conditions sustainable agriculture requires a careful and expensive water management.
- From the stochastic calculations, the 5 most sensitive parameters were determined. From the more than hundred parameters, which were used to run the different models, only 20 seem to be having a significant contribution to the total dose. The most important parameters are the transfer-factors for soil-to-plant and soil-to-beef, food consumption, irrigation water applied and distribution coefficient for soil. These parameters were significant for 3 or more than 3 sites for at least one radionuclide.
- A generic model, BioGeM, has been developed and is available for use, subject to purchase of a software licence for the numerical solution method. It has been successfully used to model 5 sites with a range of climates and geosphere/ biosphere interfaces. The results agree well with the site specific runs. The calculations with the generic model allow the variability between sites to be investigated on a common basis. Both the generic model and site specific models agree on the important parameters.
- As recommendation to the adaptation (simplification) of the generic model, it could be said that all pathways are potentially important if the large number of different radionuclides are kept in mind that can be released by a repository.
- BioMoSA provides a large amount of data for 5 sites, including detailed biosphere descriptions, concentrations in the environment and associated doses. These can be used as a benchmark for other studies.
- Within the BioMoSA study, 10 radionuclides are involved that are considered to be most relevant in performance assessment studies. The conclusions drawn refer to these radionuclides only.

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1. Introduction

1.1. Problem

The management of radioactive waste requires the implementation of disposal systems that ensure an adequate degree of isolation of the radioactivity from the environment and humans. Aims and principles for disposal of radioactive waste have been a top issue of discussions since more than 2 decades on an international level and have led to agreement on criteria to be fulfilled for the realisation of nuclear waste disposal projects. However, there is still a lack of consensus on how to demonstrate compliance with these principles, how to fulfil legislative requirements, and how to acquire acceptance from the public for nuclear waste disposal systems. There is also a lack of consensus regarding which ecosystems and exposure pathway are the most important for exposure of man.

Several indicators exist to evaluate the performance of nuclear waste disposals. The most important, however, is the radiation exposure to members of a hypothetical population group living in the vicinity of the location where the radionuclides potentially released from the disposal site enter the biosphere.

An inherent and general difficulty of the evaluation of the performance of a nuclear waste disposal system is due to the long time frames that have to be considered. This is especially the case for the assessment of the potential radiation exposure of man, since the conditions leading to the exposure will vary with time due to environmental changes and the socio-economic development. Until now, the uncertainties about future exposure conditions are a major difficulty in showing compliance of hypothetical exposures to future population groups with present day radiation protection standards.

Therefore, there is an urgent need and a big interest in a practical, comprehensible and robust assessment tool for application in performance assessment studies to support legislators, operators and regulators in deciding on waste management options on both national and international levels.

1.2. Objectives

The BioMoSA project aims at the improvement of the scientific basis for the application of biosphere models in the framework of long-term safety studies of radioactive waste disposal facilities for increasing the transparency of biosphere modelling in long-term safety studies. The detailed objectives of the work are:

- To develop site-specific biospheres for different European locations,
- To identify relevant site-specific and generic features, events and processes
- To compare results and quantify the variability of site-specific models
- To conclude on a generic biosphere tool for application in long term safety studies,
- To compare results from site-specific models to those from generic ones.
- To provide guidance for application of the generic biosphere tool to real sites,
- Finally, an assessment tool is provided for both operators and authorities for

the management of nuclear waste disposals during all the various stages involved in a whole construction period.

1.3. Outline

Within BioMoSA, both, site-specific and generic biosphere models were derived following the Reference Biosphere Methodology[1] that was developed within the international project BIOMASS in order to ensure the development of consistent and scientifically justified biosphere models for application in long-term performance assessments for nuclear waste disposals.

For these purposes, five European locations, covering a wide range of environmental and agricultural conditions are described and characterised. For each of the sites a biosphere model is developed specifically. For each of the sites, as far as possible, site-specific parameters are selected for element-independent parameters (e.g. irrigation rates, agricultural practices, human consumption rates, potential critical groups) and element-dependent parameters (e.g. transfer factors soil-plant, distribution coefficients, migration of radionuclides in soil).

Site-specific calculations are performed for each of the sites considered. Annual individual doses were calculated, important processes and parameters are identified and the uncertainty of the results is estimated by means of stochastic calculations.

The results of the stochastic model runs allowed a comparison of the overall model uncertainty against the variability for the different sites considered. The results are compared against the results of a generic biosphere model that is used as a benchmark and conclusions are drawn on the application of a generic model.

1.4. Context within the 5^th^ framework and links to BIOCLIM I think it is fine here!!

The BioMoSA study was performed within 5th Framework Programme of EURATOM, key action 2: "Nuclear Fission" under the topic "Safety of the Fuel Cycle". The key topics of this programme are the improvement of the scientific basis for the application of biosphere models in the framework of long-term safety studies of nuclear waste disposals

- in order to reduce the uncertainty of the dose assessment to population groups far in the future, and
- to increase the transparency of biosphere modelling in long-term safety studies.
- to provide guidance for implementers and regulator in performance assessments of repository systems.

The outcome of the BioMoSA project is to maintain and enhance public confidence in the results of the assessment of potential radiological impact to members of future hypothetical groups.

The range of environmental conditions all over Europe ensures the applicability of conclusions and recommendations derived from the project results to a wide range of

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[1] Long Term Releases from Solid Waste Disposal Facilities: The Reference Biosphere Concept. Draft TECDOC, BIOMASS Theme1. Working Document: BIOMASS/T1/WD01. Vienna, 1999.

conditions within the European Union.

The BioMoSA study links the improvement of radioecological modelling for long-term safety studies with practical radiation protection. This project complements (at least to some extent) the EU BIOCLIM Project, which dealt with the consideration of climate change and the identification of relevant biosphere systems.

2. Methodology

2.1. Reference Biosphere Methodology

The models developed within the BioMoSA project are derived following the guidance provided in the Reference Biosphere Methodology (RBM) which is described in detail in IAEA (2001). This approach provides a formal procedure for the development of the assessment biosphere. It is defined by several consecutive steps:

A Assessment context:

The assessment context defines a number of issues that define the boundary conditions of the assessment as the aim and purpose of the assessment; the endpoints; the general nature of the site and repository; the radionuclide involved, the interface between geosphere and biosphere; the timeframe, considered, the underlying assumptions about the society as well as the assessment philosophy.

B Biosphere system identification and justification:

The purpose of this step is – based on the assessment context - to define the assessment biosphere that is to be modelled and to provide a rational for the items that are defined. Within this process 3 points have to be considered:

- The main components of the biosphere system have to be identified and characterised. These components include the climate type, the geographical extent, the topography, and the human activities. Guidance is provided by a series of tables.
- It has to be decided whether or not the assessment context requires the consideration of biosphere change, which depends in particular on two components of the assessment: the timeframe of the assessment and the geosphere-biosphere interface.
- If a need has been identified for a biosphere change within the assessment, it has to be decided whether the biosphere change is to be simulated in a sequence of discrete states or as a continuous dynamic process.

C Biosphere system description

In the next stage of the RBM, the biosphere system identified has to be described. The details provided should enable the setup of a conceptual model for the radionuclide transfer and exposure pathways. The description should cover issues such as climate and atmosphere, near-surface lithostratigraphy, topography, water bodies, biota (fauna and flora) and human activities

D Model development

Based on the biosphere description, a conceptual model is generated by listing the ‘media of interest’ such as water, soil, crops, animals. The radionuclide pathways through these media and the interactions between biosphere components are identified. Mathematical equations have to be constructed for the mathematical model. The description of the biosphere has to be detailed enough to select and to justify appropriate data and parameters.

E Calculation of endpoints and iteration

The endpoints defined in the assessment context are calculated and evaluated. The

Methodology includes an iteration process, which allows for changes to reflect improvements in understanding and insight brought about by the Methodology's application.

2.2. BioMoSA approach

In BioMoSA, the model development for the 5 European sites and the generic tool follows the guidance described in the previous chapter.

For each of the sites, as far as possible, site-specific parameters are selected for element-independent parameters (e.g. irrigation rates, agricultural practices, human consumption rates, potential critical groups) and element-dependent parameters (e.g. transfer factors soil-plant, distribution coefficients, migration of radionuclides in soil).

Site-specific calculations are performed for each of the sites considered. Individual, annual effective doses to the critical groups are calculated and the ranking of the importance of the pathways. The most important parameters are identified for all sites and their sensitivity to the endpoints is estimated. Furthermore, the uncertainty of the results is estimated by means of stochastic calculations (Monte Carlo analysis).

The results of the stochastic model runs allow a comparison of the overall model uncertainty against the variability for the different sites considered. The sites modelled cover a wide range of environmental conditions found in Europe enabling conclusion of a more general validity. The results are compared against the results of a generic biosphere model that is used as a benchmark. The results are analysed in view of conclusion for safety studies of nuclear waste disposal.

3. Assessment context

The definition of the assessment context is the first step in the BIOMASS methodology [IAEA, 2001b] to set up reproducible models for the application in performance assessment studies of radioactive waste disposal facilities. The assessment context gives answers to fundamental questions on the performance assessment. It consists of several components as:

- The assessment purpose (Why is the assessment being done?)
- The assessment endpoint (What is going to be assessed?)
- The assessment philosophy (Should the assessment be cautious or realistic?)
- The site context (What is the location of the repository?)
- The source term (Which radionuclides are released?)
- The geosphere-biosphere interface (What is the entrance point of the radionuclides to the environment?)
- The timeframes to be considered (How long is the period of time that is considered?)
- The societal assumptions (What are the underlying societal conditions?)

The definitions of the assessment context components are summarised below. They were agreed among the participants of the BioMoSA consortium during the first phase of the project. Each definition of the assessment context component is accompanied by a justification for the selection made.

3.1. Assessment purpose

In general, the aim of the biosphere models applied in the framework of performance assessment studies is to demonstrate compliance with principles and regulations that are set up to limit the possible impact of the waste repository on human health and on the environment and to ensure that future generations will not be exposed with higher levels than those that would be acceptable today.

The assessment purpose of the BioMoSA study is to quantify variability in doses among different sites and environmental conditions.

Although the project does not directly tackle the demonstration of regulatory compliance, a main objective of the study is to provide tools to assess the impact of radioactive releases to the environment from waste disposals.

3.2. Assessment endpoint

Within the BioMoSA study, the following assessment endpoints will be considered:

- Annual effective dose for infants (1-2 y) and adults. This quantity is one of the most important criterions in licensing.
- The concentration in various environmental media. These are needed for identifying differences and similarities between the sites considered.
- The uncertainties of doses and activity concentrations. The quantification of uncertainties enables the evaluation of the reliability of the models.

3.3. Assessment philosophy

The assessment philosophy is equitable. The models to be developed should reflect realistic conditions at each site. A conservative bias would complicate the comparison of the different sites as well as the conclusions to be drawn on reliability and credibility.

3.4. Repository system

A specific repository system has not been defined, since the project deals with the radionuclide transport in the biosphere only. The results are generally applicable and necessarily not dedicated to a specific repository system.

3.5. Site context

BioMoSA will provide 5 site-specific models and one generic model. Therefore, the study will deal with 5 specific site-contexts, which will be defined during the site description.

Biosphere changes will be considered due to climate and for one site due to land rise. The evolution of the biosphere will not be explicitly considered, since it is thought that such considerations would be too speculative. However, possible steps within evolutions will be taken into account and specific calculations will be done for such modified environmental conditions.

These additional estimations help to answer the question "What would be the influence on the endpoints, if the climate changes in a predefined manner?"

3.6. Source Term

BioMoSA is going to develop models and tools to evaluate releases from waste disposals to the environment. The type and number of radionuclides selected was limited to those of relevance for nearly all safety performance assessment studies for waste repositories. The nuclides ^{36}Cl, ^{79}Se, ^{99}Tc, ^{129}I, ^{135}Cs, ^{226}Ra, ^{231}Pa, ^{237}Np, ^{239}Pu, ^{238}U are considered which cover a wide range of environmental behaviour.

3.7. Geosphere-biosphere interface

The geosphere-biosphere interface defines the point where the radionuclides from underground enter the biosphere. The geosphere-biosphere interface (GBI) is site-specific, given by the radionuclides transport media, the geosphere and the biosphere conditions. Those site-specific factors are not always very clearly defined due to a lack of characterisation and consideration of geosphere transport models. For the five sites considered, the following geosphere-biosphere interfaces were defined:

Country	Geosphere-biosphere interface
Hungary	Well, lake
Spain	Well, dam, river, sub-surface soil
Germany	Well
Belgium	Well, river
Sweden	Well, lake, sub-surface soil
Generic model	Ocean, surface waters, well, sediment, near-surface soils

For comparison purposes, the activity concentration in water that is used for preparing drinking water, irrigation and watering cattle is set to a unit concentration. The results of the endpoints are then normalized to the activity concentration in the raw water.

The results will then be given and compared in units of e.g. [Sv/a per Bq/m^3]. This normalization allows the direct comparison of the differences in environmental transfer between the different sites considered.

On the other hand, a unit release rate (Bq/a) is considered to reach the GBI from underground, which allows to compare the differences in the transport in the near-surface part of the geosphere, which gives an indication of the dilution at the different sites.

3.8. Time frame

A continuous release of radionuclides to the biosphere is assumed. The time, when the release starts after the closure of the waste disposal is not specified. The results will be given at equilibrium in the environment. The maximum period for which calculations are performed is 10000 years.

3.9. Societal assumptions

Present actual conditions are assumed. The technological level, the agricultural practices, and habits should be assumed as far as possible according to the site-specific conditions.

4. Development and application of a generic tool BIOGEM

As noted in the earlier chapters of this report, one of the aims of the project was to create a generic biosphere model and to apply it to the five sites considered in this study. This chapter describes the generic model and presents the results of the analyses carried out using this model for the five sites in turn.

The development of the generic biosphere model BIOGEM was based on the application of the Biomass Reference Biosphere Methodology for establishing a logical audit trail. This methodology was first developed in the BioMOVS project for biosphere assessments applied to solid radioactive waste disposal (BIOMOVS 1996). It was further developed in the subsequent BioMASS project (BIOMASS 2003). This section describes the principle elements in the biosphere, including climate, geological conditions, hydrology and hydrogeology, biota and their interactions, to be considered in the generic biosphere model. Human activities are also included in order to identify the important exposure pathways and critical groups. In order to be generic and useful for a broad range of biospheres, the proposed “generic biosphere model” must at least take account of all the important features (e.g. climate conditions) and pathways identified in the following sites studied in BioMoSA: Belgium, Germany, Hungary, Spain and Sweden.

4.1. Considerations for the generic model

4.1.1. Location

For the purposes of this study, solid radioactive waste is assumed to be disposed in a deep underground repository. Over 100,000 years post-closure, there is a possibility that radionuclides migrate from the repository and into the biosphere. A generic model should be able to represent any site within the EU, so covering a range of environmental and societal conditions.

4.1.2. Climate

There are a variety of climate types over Europe, but most of the continent is dominated by mild weather. This is caused by winds that blow across the continent from the Atlantic Ocean. The winds are warmed by the Gulf Stream which carries warm water from the Gulf of Mexico to the western coast of Europe. The winds affect most of the continent because no mountain barrier is large enough to block them and because much of Europe is located within 480 kilometres of the Atlantic Ocean. The meteorological conditions of European countries are classified based on their geographic layout and weather conditions as shown in Figure 4-1 According to the “Koppen classification system”, the climates of the five sites studied here are classified as Dfb (Sweden), Cfa/Cfb (Germany, Belgium and Hungary) and Csa/Csb (Spain). For detailed characteristics of the above classes, see Table 4-1.

Table 4-1 Köppen Climate classification[a]

A Tropical humid	Af	Tropical wet	No dry season
	Am	Tropical monsoon	Short dry season; heavy monsoon rains in other months
	Aw	Tropical savannah	Winter dry season
B Dry	BWh	Subtropical desert	Low-latitude desert
	BSh	Subtropical steppe	Low-latitude dry
	BWk	Mid-latitude desert	Mid-latitude desert
	BSk	Mid-latitude steppe	Mid-latitude dry
C Mild Mid-Latitude	Csa	Mediterranean	Mild with dry, hot summer
	Csb	Mediterranean	Mild with dry, warm summer
	Cfa	Humid subtropical	Mild with no dry season, hot summer
	Cwa	Humid subtropical	Mild with dry winter, hot summer
	Cfb	Marine west coast	Mild with no dry season, warm summer
	Cfc	Marine west coast	Mild with no dry season, cool summer
D Severe Mid-Latitude	Dfa	Humid continental	Humid with severe winter, no dry season, hot summer
	Dfb	Humid continental	*Humid with severe winter, no dry season, warm summer*
	Dwa	Humid continental	Humid with severe, dry winter, hot summer
	Dwb	Humid continental	Humid with severe, dry winter, warm summer
	Dfc	Subarctic	Severe winter, no dry season, cool summer
	Dfd	Subarctic	Severe, very cold winter, no dry season, cool summer
	Dwc	Subarctic	Severe, dry winter, cool summer
	Dwd	Subarctic	Severe, very cold and dry winter, cool summer
E Polar	ET	Tundra	Polar tundra, no true summer
	EF	Ice Cap	Perennial ice

a: For more information, see http://geography.about.com/library/weekly/aa011700b.htm

Important meteorological factors, such as temperature, precipitation, evaporation and wind data, are considered in connection with local irrigation demand and vegetation pattern.

4.1.3. Hydrology and hydrogeology

The surface water bodies considered in the biosphere model refer to rivers (river network), lakes (or dam) and marine oceans. Subsurface water bodies (groundwater in the aquifers) are not considered explicitly.

The groundwater flow direction is dominated by the local geological structure and topographical condition. It eventually comes into contact with a surface water body or deep soil, and appears as springs, lake, wetland or soil moisture. Groundwater can also be withdrawn from wells for irrigation and domestic purposes, normally for the garden plots of local residents as in Sweden, but can serve as a major water source for irrigation purpose in area where surface water is scarce, such as Hungary and Spain. Therefore use of well water is considered in the generic biosphere model.

Water in rivers and lakes is freshwater and can be used for crop irrigation, animal watering and human consumption. For a large river or lake, aquatic life in the water is also considered as a source of food. People may also spend certain time fishing or swimming in a river or lake during hot seasons.

River water and its sediments flow downstream at different rates. The distribution of the river network is mainly controlled by the topography of the site. For an inland site, the river will probably join with another river outside the site; while for a coastal site, the river and its sediment will flow into the local marine environment, and then disperse into the regional oceans by ocean currents. River water and surface water runoff may erode the river banks and the adjacent land to form new river sediment, and conversely river sediment can be transformed into surface soil through dredging, river course change and other ageing processes.

Compared with a river, the turnover rate of a lake is fairly low. Lake water and its sediment will flow at much slower speed than that of a river. Nevertheless, the natural processes considered for a river ecosystem may also occur in a lake, therefore similar consideration is given for the lake system.

4.1.4. Geology and lithology

The geological conditions determine the general characteristics of site aquifers, such as the abundance of groundwater, recharge and discharge zones, flow rate, retardation factor and water chemistry.

Soil types at the sites will largely depend on the regional geological materials. Soil characteristics (such composition, clay content, cation exchange capacity etc) within the depth up to 1 to 2 meters below the surface may help to decide which types of vegetation are the most suitable ones to grow. From the modeller's point of view, it will also control the movement of radioactivity in the soil. There are a wide variety of soil types found at sites across the EU, therefore the generic model should be able to represent all the important soil types if possible.

The exchange of radionuclides in the top soil and deep soil regions is governed by infiltration, pore water diffusion and bioturbation processes as well as groundwater flow in the deep soil zone.

4.1.5. Geosphere/biosphere interface

Groundwater flow is the primary mechanism by which radioactivity in a repository migrates into the biosphere. The contaminated groundwater could enter fresh terrestrial water bodies or saline marine water bodies, soil or wells. The generic model should therefore be able to represent all of the following interfaces:

- Well - contaminated groundwater withdrawn from aquifers is used as irrigation water and drinking water for human and farm animals.
- River or lakes – contaminated water is used for irrigation and drinking purposes. Both arable land and pasture are irrigated. Fish in large rivers and lakes are caught for human consumption.
- Deep soil – soil water in the topsoil is directly contaminated by the upward movement of groundwater when the water table is high. Plants may grow on the soil and be used for food or animal feed.
- Local ocean – groundwater emerges from the outcrop of the aquifers in the local ocean and contaminates the sea water and marine animals. Sea spray to inland may also transfer radioactivity onshore

4.1.6. Animals & Plants (Biota)

Agricultural land use can be classified into arable land and pasture.

For arable land, four types of crops are considered, i.e. grain (including barley, sweet corn, cereal etc), root vegetables (including potato and carrots etc), green vegetables (including cabbage, asparagus, celery, lettuce etc) and fruits (including orchard fruits such as apples and oranges, and soft fruits, such as strawberries). Vegetables are harvested one or more times a year, with some parts consumed and the remaining parts discarded (Brown and Simmonds 1994).

Pasture is used to raise meat cattle, milk cows, sheep, pigs and chickens. Each animal ingests a certain amount of fresh grass and dry hay each year from the pasture as well as cereal/grains from arable land. The meat products from each animal are assumed to be solely provided for human foodstuffs. The population density of animals on the pasture will affect the cropping rate of the pasture.

Ploughing of arable land results in relatively homogeneous soil down to a depth of about 30cm, whereas pasture land tends to be heterogeneous due to fewer disturbances of the soil layers.

4.1.7. Human activities (exposure pathways, exposure groups)

The exposure groups considered here are two age groups with different diets and habits: infant and adults. They live adjacent to the site and are exposed to the contamination via various pathways:

- Consumption of local animal foodstuffs: including beef, lamb, chicken, offal, milk, egg, poultry, freshwater fish, marine fish and other marine food
- Consumption of local crops, including green and root vegetables, fruits and grain
- Drinking water from well and river
- Spending time on contaminated soil, such as fishing, farming or gardening and local beaches (if near the coast)

The diets and habits of the exposure groups will determine the significance of these pathways as well as the degree of their exposure to the contaminated environmental media.

4.1.8. Time frame

Timescales up to 1,000,000 years are commonly considered for deep repositories. However, the climate changes for such long time span have been recognised to be of high degree of uncertainty (BIOMASS 2003). As agreed in the BioMoSA meetings, the time frame considered in the generic model is limited to 10,000 years.

4.1.9. Radionuclides

Ten typical long-lived radionuclides of radioactive waste from nuclear power station were selected, they are Cl-36, Se-79, Tc-99, I-129, Cs-135, Ra-226, Pa-231, U-238, NP-237 and Pu-239. Four of these nuclides, Ra-226, Pa-231, Np-237 and U-238, are considered along with their decay chains. Short-lived daughters are assumed to be in secular equilibrium with their longer lived parents and therefore the complete decay chain can be divided into a number of chain segments headed by longer-lived daughter nuclides. The chain segments, and the daughter nuclides considered in each, are listed in Table 4.2. Chain segment heads, ie nuclides with short lived daughters that have been assumed to be in equilibrium, are denoted by a '+' symbol in Table 4.2 eg Ra+226 denotes Ra-226 plus Rn-222, Po-218, Pb-214, Bi-214, and Po-214. The dose coefficients used for these chain segment heads therefore include those of the short lived daughters. The source was always just the parent nuclide; daughter activities were obtained from modelling subsequent decay within the biosphere. In some cases results were presented separately for the parent nuclide and the longer lived daughter nuclides (chain segment heads); in other cases the results were presented summed over all progeny. This is indicated in Table .4.2

Among the radionuclides, Cl-36, Se-79, Tc-99, I-129 and Cs-137 are relatively mobile, while Ra-226, Pa-231, U-238, Np-237 and Pu-239 are relatively immobile. Caesium shows a tendency to become fixed in clay so that it takes only a little soil clay to strongly (virtually irreversibly) fix caesium[1], so a slightly different soil model was developed for Caesium.

4.1.10. Endpoints

The endpoints are the annual effective dose to the exposed group and the activity concentration in the various foodstuffs after equilibrium has been reached in the soil.

4.2. Development of the conceptual model

Following the considerations above, the conceptual model for the generic model was developed and this is presented in Figure 4-2. The interactions between the elements in the diagram are presented in the interaction matrices given in Table 4-3 and Table 4-4.

The FEP list developed in the BIOMASS project (BIOMASS 2003) was used to audit the conceptual model and biosphere description. The results are given in Table4-5 The five sites and the geosphere-biosphere interfaces considered for each are given in Table 4-6.

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[1] Although highly sorbed on the clay, upward migration of caesium in soil was observed by Sandford et al (1998)

Table 4-2 Radionuclides and decay chains considered in generic model

Parent	Progeny/chain segment head	Half-life (y)	Mobility in soil and subsurface
Cl-36		3.01E+05	High, soluble
Se-79		6.5E+04	Low
Tc-99		2.13E+05	High, soluble
I-129		1.57E+07	High, soluble
Cs-135		2.30E+06	Low, highly sorbed
Ra+226□	Includes Rn-222, Po-218, Pb-214, Bi-214, Po-214	1.60E+03	Low
	Pb+210□ (includes Bi-210)	2.23E+01	Medium
	Po-210□	3.79E-01	Medium
Pa-231□		3.28E+04	Medium
	Ac+227□ (includes Th-227, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207)	2.18E+01	Low
Np+237♦	Includes Pa-233	2.14E+06	High
	U-233	1.58E+05	Medium
	Th+229 (includes Ra-225, Ac-225, Fr-221, At-217, Bi-213, Po-213, Pb-209)	7.34E+03	Low
U+238♦	Includes Th-234, Pa-234m, Pa-234	4.47E+09	Medium
	U-234	2.44E+05	Medium
	Th-230	7.70E+04	Low
	Ra+226 (see above for included nuclides)	1.60E+03	Low
	Pb+210 (see above for included nuclides)	2.23E+01	Medium
	Po-210	3.79E-01	Medium
Pu-239		2.41E+04	Low, not soluble
	U-235*		
	Pa-231*		
	Ac-227*		

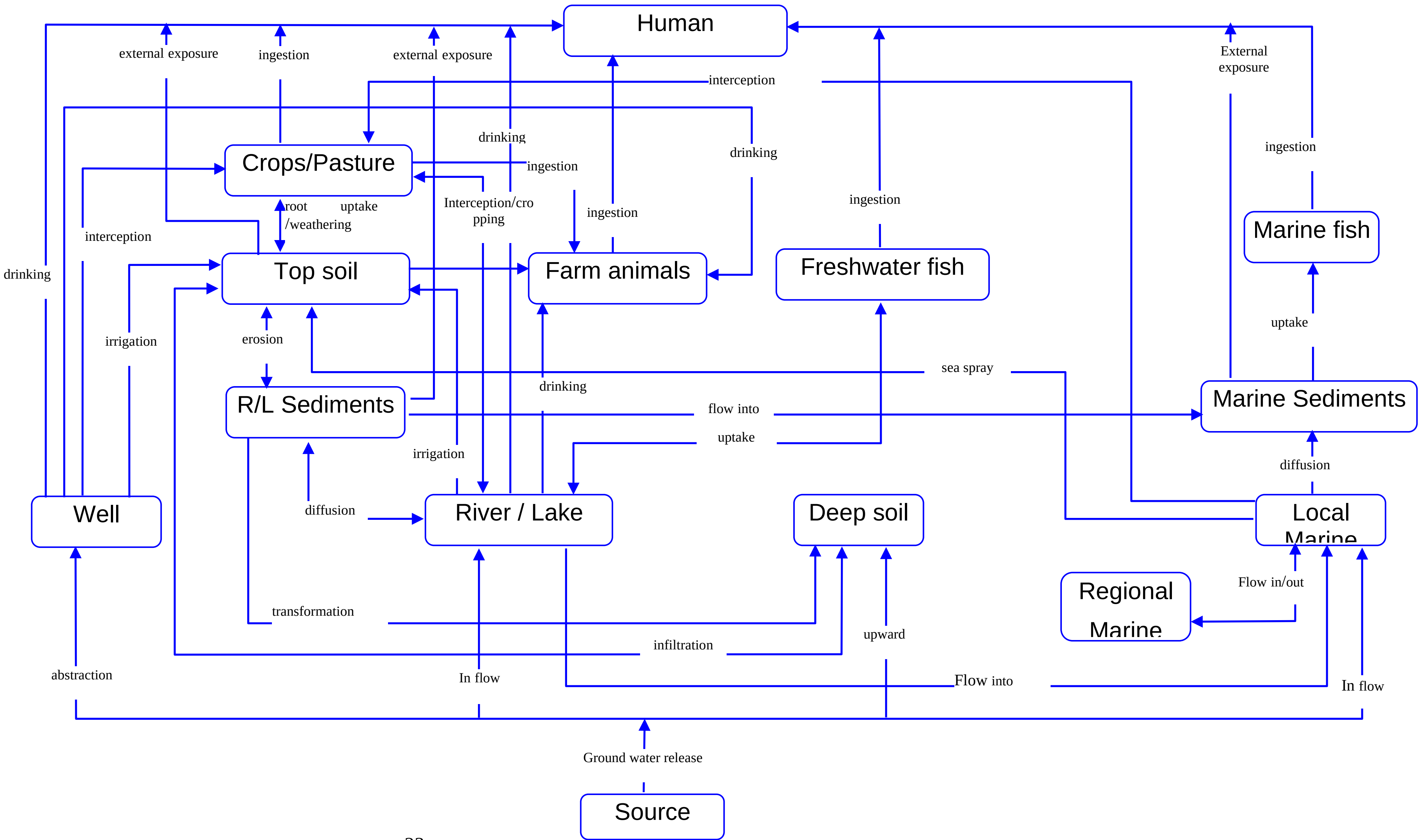
* Not considered by NRPB but may be considered in site models

♦ Only the summed dose from parent and all progeny considered

Parent and chain segment head (longer lived progeny) results considered separate

Figure 4-1: The climate types in Europe

Figure 4-2: Conceptual model of radionuclide release into the biosphere and exposure pathways



	1	2	3	4	5	6	7	8	9
1	Ground water	Natural discharge	Diffusive flux (deep layer)	Irrigation, Capillary upward flux	Drinking	Irrigation	Discharge (local marine)	Drinking	Drinking
2	Natural recharge	Surface water (lake/ river) exchange	Partition, Sedimentation, Bioturbation	Irrigation Interception	Drinking	Irrigation Interception	Discharge (local marine)	Drinking	Drinking, External irradiation
3	Percolation recharge	Diffusion and suspension (top layer)	FW sediments (top/ middle/ bottom layers) Diffusion	Dredging Flooding Changes path	X	X	Move to sea sed., Diffusion into sea water	X	External irradiation
4	Percolation recharge	Erosion into local river/lake	X	Topsoil (arable/pasture land) sorption,	Inadvertent ingestion, Inhalation	Root uptake, Suspension, Soil contamination	Erosion to sea water and sea sediment	Inadvertent ingestion	Inadvertent ingestion, inhalation External
5	X	X	X	Bioturbation	Animals (farm: sheep/cow, chicken,	X	X	Animal foodstuffs Animal milk Fish meat	Ingestion
6	X	Evaporation Cropping into local river/lake	X	Weathering, Translocation	Ingestion of fodder	Plants (green veg, root veg, grain, fodder	Cropping (local marine)	Foodstuff	Ingestion
7	X		solute flux by diffusion	Sea spray to coastal land	X	Sea spray	Marine & marine sediments (near seas, far	Use of beach Fishing	Seaspray external irradiation on beach
8	X	pollution	X	X	X	X	X	Human activity	Fishing
9									Dose to man

Key: FW Freshwater; X not relevant

Table 4-3 interactive matrix for release models in the generic biosphere except water-well release

	1	2	3	4	5	6	7
1	Groundwater Well abstraction	Irrigation	Drinking	Irrigation	X	Drinking	Drinking, Domestic use
2	X	Topsoil (arable) sorption, desorption	Inhalation Inadvertent ingestion	root uptake, suspension, deposition, Interception	Erosion, to marine water and marine sediment	Inadvertent consumption	Inadvertent Ingestion External Irradiation Inhalation
3	X	Bioturbation	Animals (Farm: sheep, cow, chicken)	X	X	Meat Fish Milk	Ingestion
4	X	Weathering	Ingestion of fodder	Plant (green veg, root veg, grain) (translocation)	cropping if not linked with river	Food	Ingestion, External irradiation
5	X	Sea spray to coastal land	X	X	marine & marine sediments (near seas, far seas)	Use of beach fishing	Seaspray External irradiation
6	X	X	X	X	X	Human activity	Fishing
7	X	X	X	X	X	X	Dose to man

Table 4-4 interaction matrix for groundwater well model in the generic biosphere

Table4-5: Comparison of the generic conceptual model with the BIOMASS FEP list.

FEP Identifie r	**FEP Name**	**Comments**
1	Assessment context	
1.1	Assessment purpose	Assess the risk of radioactive waste disposal to man in a long term. The purpose for conducting a assessment could be testing a initial proposal, supporting a disposal licence, or carrying out a performance assessment (PA) against regulatory criteria
1.2	Assessment endpoints	The endpoints are calculated for the hypothetical critical and average groups (age, location, metabolism etc) including: Individual dose (annual) and risk; Collective dose or biota are not considered
1.2.10	Uncertainty analysis	Uncertainty analysis for key parameters
1.3	Assessment philosophy	Equitable (as realistic as possible)
1.4	Repository system	Deep or shallow repositories for radioactive waste, inland or near the coast
1.5	Site context	Land use, climate conditions (precipitation, evaporation, wind), environments, social-economic conditions. At least it should cover the context of all 5 selected sites. In-land repository,evolution is not considered
1.6	Source terms	All processes that release radionuclides from repository into biosphere; Wide range of radionuclides and their daughters (provisional list for long-lived solid radioactive waste is Cl-36, Se-79, Tc-99, I-129, Cs-135, Ra-226, Th-230, Np-237, U-238, Pu-239
1.6.1	Geosphere/biosphere interface	Difficult to define. A geosphere model represents the migration of nuclides in the subsurface, and the geosphere/biosphere interface lies at the border of biosphere model. Geosphere provides source term for biosphere. At least the model should include the following interfaces: Groundwater/surface water Groundwater/sea Groundwater/near surface soil Surface water/sediments Sea/neighbouring seas (including sediments)
1.6.2	Release mechanism	Flux of groundwater from source due to natural discharge into surface water, abstraction well, flux into unsaturated zone. Degassing is not considered.
1.6.3	Source term characteristics	Solid, liquid. Gaseous not considered
1.7	Time frame	Both short- and long-term. Normally be limited to 1 million years
1.8	Societal assumptions	Climate change is considered using uncertainty analysis
2	Biosphere system features	Identification of a biosphere system

2.1	Climate	
2.1.1	Description of climate change	No.
2.1.2	Climate categorisation	Included in the site context (1.5)
2.2	Human society	Not explicitly expressed
2.3	Systems of exchange	
2.3.1	Environment types	Covered in the site context (1.5)
2.3.2	Ecosystems	Site specific, radiological impact assessment is limited to man only
2.3.2.1	Living components of ecosystems	Not explicitly expressed
2.3.2.2	Non-living components of ecosystems	Not explicitly expressed
3	Biosphere events and processes	Theoretically, events are regarded as short term, and processes are continuous
3.1	Natural events and processes	Not explicitly expressed
3.1.1	Environmental change	Not explicitly expressed
3.1.2	Environmental dynamics	No
3.1.2.1	Diurnal variability	No
3.1.2.2	Seasonal variability	Dependent
3.1.2.3	Interannual and longer timescale variability	Maybe
3.1.3	Cycling and distribution of materials in living components	
3.1.3.1	Transport mediated by flora and fauna	
3.1.3.1.1	Root uptake	Uptake of water by roots in the entire root zone
3.1.3.1.2	Respiration	For effective precipitation
3.1.3.1.3	Transpiration	For effective precipitation
3.1.3.1.4	Intake by fauna	For effective precipitation
3.1.3.1.5	Interception	For effective precipitation
3.1.3.1.6	Weathering	yes
3.1.3.1.7	Bioturbation	Similar to ploughing
3.1.3.2	Metabolism by flora and fauna	Not explicitly expressed
3.1.4	Cycling and distribution in non-living components	
3.1.4.1	Atmospheric transport	
3.1.4.1.1	Evaporation	Yes

3.1.4.1.2	Gas transport	No
3.1.4.1.3	Aerosol formation and transport	No
3.1.4.1.4	Precipitation	Rainfall
3.1.4.1.5	Washout and wet deposition	Washout coefficient
3.1.4.1.6	Dry deposition	Deposition rate
3.1.4.2	Water-borne transport	Flow field in aquifer relative to spatially distribute r/n release is fundamental to determining concentrations in water
3.1.4.2.1	Infiltration	Included as an assumed external influence on water flow in aquifer
3.1.4.2.2	Percolation	Included as an assumed external influence on water flow in aquifer
3.1.4.2.3	Capillary rise	Evaporation/transpiration relevant to net water balance, covered in (3.1.3.1)
3.1.4.2.4	Groundwater transport	Flow system in saturated zone is fundamental to determining concentrations in abstracted water
3.1.4.2.5	Multiphase flow	No
3.1.4.2.6	Surface run-off	Included as an assumed external influence on water flow in aquifer
3.1.4.2.7	Discharge	Included as an external influence on flow field in the aquifer and water balance
3.1.4.2.8	Recharge	Included as an external influence on flow field in the aquifer and water balance
3.1.4.2.9	Transport in surface water bodies	Surface water bodies are relevant only in terms of effect on groundwater flow boundary conditions
3.1.4.2.10	Erosion	yes
3.1.4.3	Solid-phase transport	
3.1.4.3.1	Landslides and rock falls	No
3.1.4.3.2	Sedimentation	Settling of suspended sediments in the water distribution/storage system
3.1.4.3.3	Sediment suspension	Remobilization of sediment during periodic maintenance of supply system
3.1.4.3.4	Rain splash	No
3.1.4.4	Physicochemical changes	
3.1.4.4.1	Dissolution/precipitation	Possibility of passive chemical transformation in well or within water supply system
3.1.4.4.2	Adsorption/desorption	Potentially relevant to the concentration if there are changes in sediment load, or as surface reactions within the well. Considered in soil.
3.1.4.4.3	Colloid formation	No
3.2	Events and processes related to human activity	
3.2.1	Chemical changes (artificial soil fertilisation/chemical pollution/acid rain)	‘External’ human actions may affect water quality in aquifer system – infiltration etc.

3.2.2	Physical changes	
3.2.2.1	Construction	No
3.2.2.2	Water extraction by pumping	Water balance
3.2.2.3	Water recharge by pumping	Water balance
3.2.2.4	Dam building	Not considered
3.2.2.5	Land reclamation	Not considered
3.2.3	Recycling and mixing of bulk material	'External' human actions may affect water quality in aquifer system – infiltration etc.
3.2.3.1	Ploughing	Ploughing increases the homogeneous of sediment layers, Undisturbed land tends to have a number of soil layers
3.2.3.2	Well supply	Groundwater abstraction
3.2.3.3	Other water supply	Abstraction from freshwater bodies, e.g. Lakes, rivers
3.2.3.4	Irrigation	Linked to groundwater and surface water
3.2.3.5	Recycling of bulk solid materials	No
3.2.3.6	Artificial mixing of water bodies	Dilution, link with (3.2.3.3)
3.2.3.7	Dredging	Periodic cleaning/dredging of water supply and distribution system?
3.2.3.8	Controlled ventilation	No
3.2.4	Redistribution of trace materials	
3.2.4.1	Water treatment	No
3.2.4.2	Air filtration	No
3.2.4.3	Food processing	yes
4	Human exposure Features, Events and Process	
4.1	Human habits	
4.1.1	Resource usage	Exploitation of water resources implicit in system description; other resources excluded by assessment context
4.1.1.1	Arable food resources	From farm: root vegetables, green vegetables, grain products, fruits, cereal
4.1.1.2	Animal-derived food resources	Obtained from livestock farming: meat, milk, eggs, fish
4.1.1.3	Fodder products	Pastures consumed by livestock
4.1.1.4	Natural food resources	Fish and sea-food considered. Fruits/nuts, fungi, game birds and animals not considered
4.1.1.5	non-food uses of biosphere	Handling and use, walking on soil
4.1.1.6	Water	Drinking by man and livestock
4.1.2	Storage of products	Water may be stored in distribution system prior to consumption

4.1.3	Location	Occupancy (In door, Outdoor %) At proximity of waste disposal or critical area
4.1.4	Diet	Consumption rates of different food
4.2	External irradiation	
4.2.1	External irradiation from the atmosphere	No
4.2.2	External irradiation from soils	Yes
4.2.3	External irradiation from water	Seaspray, fishing, swimming, bathing
4.2.4	External irradiation from sediments	Contaminated soil
4.2.5	External irradiation from non-food products	Not considered
4.2.6	External irradiation from flora and fauna	Not considered
4.3	Internal exposure	
4.3.1	Inhalation	Inhalation rates of air, suspended solid and water, volatiles
4.3.2	Ingestion	Consumption of contaminated water (including suspended sediment) as supplied, or in water-based drinks etc.
4.3.2.1	Drinking	Drinking water, milk, water-based drinks
4.3.2.2	Food	Meat and offal, dairy products, fish, eggs, fruits, vegetables, grain
4.3.2.3	Soil and sediments	Inadvertently ingesting (man and animals)
4.3.3	Dermal absorption	Adsorption of substances through skin not considered

Table 4-6 Geosphere-Biosphere interfaces considered for the five sites

Site location	Release position			
Mol-dessel, Belgium	Well	River		
Gorleben, Germany	Well	Pond (well water)		
Üveghuta-Bátaapáti, Hungary	Well	Lake		
Central Spain	Well	Lake	River	
Fosmark Region, Sweden	Well	lake	agriculture land	Coast

4.3. Mathematical description of BioGeM

The generic biosphere model is called BioGeM (Biosphere Generic Model). The model divides the area under investigation into a number of idealised compartments: deep soil, surface soil, rivers, lakes, marine and sediments so that it can represent the local, regional and global sections of the biosphere and the interaction processes between them.

The compartmental model BioGeM is sufficiently flexible to take account of all the features and pathways identified to be important in the five specific sites considered in the BioMoSA project, i.e. Belgium, Germany, Hungary, Spain, and Sweden.

This section gives an overview of the exposure pathways considered in BioGeM and the mathematical formulae describing the water, sediment, soil, and marine compartments of the biosphere.

4.3.1. Exposure pathways

BioGeM consists of two separate programs: one which allows the simulation of coast, lake, agricultural land, and dam scenarios, and one appropriate for wells. For each site, the model can use the interaction matrix and FEP-list to select the appropriate pathways. This selects a set of governing equations which can be solved, given set of input data, to give the activity at selected output times in each compartment.

4.3.2. Concentrations in the environmental media

The BioGeM code calculates the concentration in the terrestrial and marine compartments at each output time. For each freshwater compartment it calculates the following: unfiltered concentration in freshwater, concentrations in top/middle and bottom freshwater sediments, concentrations in soil compartments. For each marine compartment it calculates: unfiltered seawater concentration, concentrations in top/middle marine sediment. These activities are used directly in dose calculations though unfiltered concentrations are converted to filtered water concentrations.

The dissolved radionuclide (or filtered) concentration in surface water (C_{wr_l}) can then be calculated within BioGeM by:

$$C_{wr\_l} = \frac{C_{wr}}{1 + Kd_{sed\_wr} \cdot m_{wr}}$$

where C_{wr} is the unfiltered concentration in river water (Bq m^{-3}), Kd_{sed_wr} is the partition coefficient between water and sediment in river and m_{wr} the mass load in river water.

The radionuclide concentration on suspended sediments (C_{sed_wr}) is given by:

$$C_{sed\_wr} = \frac{Kd_{sed\_wr} \cdot C_{wr}}{1 + Kd_{sed\_wr} \cdot m_{wr}}$$

Similarly for the unfiltered seawater concentration, and suspended sediments.

4.3.3. Terrestrial and marine pathways

The activity calculated in the compartments can then be used to calculate doses for individual exposure for a range of pathways associated with each of the terrestrial and marine compartments. Individual doses due to the marine pathways are calculated using the activity concentration in the local marine compartment.

Exposure pathways include: consumption of freshwater, agricultural produce (green vegetables, root vegetables, grain, fruit), animals (cattle, sheep, chickens, pigs), fish (freshwater and marine) and other marine foodstuffs (crustacea, molluscs, seaweed) ; inhalation of seaspray, resuspended soil and beach sediments; external (gamma) irradiation from soil, beach sediments and contaminated fishing gear.

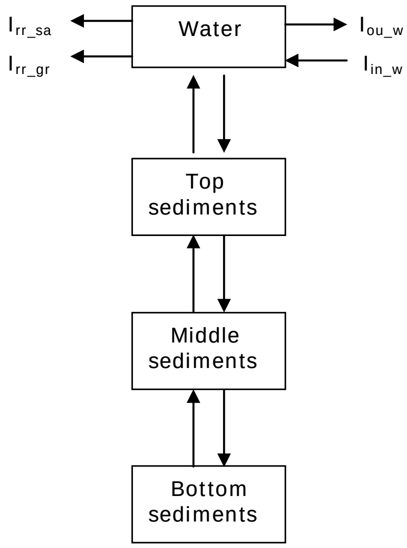


Figure 4-3: Activity transfer within water model

A scheme of the of the river and lake model is given in Figure 4-3. Three associated sediment compartments are shown for each water compartment, however only one is used for rivers (all 3 are used for lakes). In both cases, the surface water represents the activity in the surface water plus that sorbed onto suspended sediments. Water flows between adjacent water compartments at rates I_{ou_w}, I_{in_w}. In addition there is irrigation loss to pasture I_{rr_gr} and to arable land I_{rr_sa}. Only the top sediment compartment is used for the river and hence transfers between the other sediment compartments are set to zero. The river bed moves with the river flow via viscous drag and there is transfer between adjacent bed sediments. The removal of radionuclides in the river water to the river bed sediments is calculated using the Schaeffer model (1976) which accounts for sedimentation and radioactive decay. This model introduces a nuclide-dependent depletion factor K', and the rate of loss from the water column is given by

$$\frac{dC_{wr}}{dt} = -V_{wr} K' C_{wr}$$

Return from the river sediment to the river water is included in the parameter K' and therefore is set to zero for river. The transfer of river sediment onto the soil compartments adjacent to the river takes place by dredging, flooding or by changes in the path of the river and is modelled using a transfer coefficient.

A special river box is set up to enable the sea-spray pathway to be modelled. This river section is the same as all the other river sections but is not physically connected to other river sections. Instead it has a river water exchange with the water of the local marine compartment, a river sediment exchange with the local marine water and a river sediment exchange with the top marine sediment compartment.

The water compartment of the lake model is treated in the same way as a river so that the model can represent the exchanges with other lakes and rivers. Sedimentation is treated differently because of the lower exchange rates characteristic of lakes. Removal of activity from the water column to the top sediment compartment is by the processes of sedimentation, diffusion and bioturbation giving a transfer coefficient

$$k_{w\_sed} = kd_{sedw} v_{sed\_w} Filw + \frac{Bio_{sed}(1-Fbl) + D_{sed} Fbl}{d_w \min(d_{sed1}, \min(\max bl, d_w))}$$

where

v_{sed_w} = the freshwater sedimentation rate (t m^{-3} y^{-1}),

Filw =1/(1+$m_{sedw}$$kd_{sed}$)

Bio_{sed} = the bioturbation rate in fresh and coastal sediments (y^{-1})

Fbl = 1/(1+$\alpha_{sed}$$kd_{sed}$)

α_{sed} = 0.001*(1-θ_{sed}) ρ_{sed}/min(maxbl,d_w)

ρ_{sed} = density of sediments (t m^{-3})

d_{sed1} = the depth of the top sediment (m)

maxbl is the maximum depth of the boundary layer (m)

The return from top sediment to lake water is due to bioturbation and diffusion with a transfer coefficient:

$$k_{sed\_w} = \frac{Bio_{sed}(R_{sed}-1) + D_{sed}}{d_{sed} \min(d_{sed1}, \min(\max bl, d_w)) R_{sed}}$$

where R_{sed} is the retardation coefficient in sediments given by

R_{sed} = 1+(1-θ_{sed}) ρ_{sed} kd_{sed} /θ_{sed}

Top sediment to middle sediment transfers are governed by sedimentation and diffusion in the pore water at a rate

$$k_{sed1\_sed2} = v_{sed\_w}(R_{sed}-1)d_w / (\rho_{sed} d_{sed1}(1-\theta_{sed}) * R_{sed}) + D_{sed} / (d_{sed1} \min(d_{sed1}, d_{sed2}) * R_{sed})$$

where

d_{sed2} = the depth of the middle sediment (m)

Middle sediment to top sediment transfers is due to diffusion alone at a rate

$$k_{sed2\_sed1} = D_{sed} / (d_{sed2} \min(d_{sed1}, d_{sed2}) * R_{sed})$$

Activity is removed from the middle sediments to the bottom sediments by sedimentation only at a rate

$$k_{sed2\_sed3} = v_{sed\_w}(R_{sed} - 1)d_w / (\rho_{sed} d_{sed2}(1 - \theta_{sed}) * R_{sed})$$

There is no return from bottom to middle sediments hence the bottom sediments act as a sink for radionuclides.

4.3.4. Marine model

The marine model in BioGeM consists of a local marine compartment plus an ocean model comprised of either 4 or 36 regional compartments. For the land locked sites the marine structure is not important and a simple 4 box default model is employed. For the coastal scenarios a detailed 36 box ocean model is used which defines the local compartment and the regional sea characteristics and their exchanges more accurately. The structure of each ocean compartment is the same as that in Figure 4-3. Exchanges between ocean water compartments are given as ocean volumetric fluxes in m^3 y^{-1}. The sedimentation processes are treated in the same way as for lakes with three distinct sediment layers associated with each ocean compartment. The difference is in the Kd_{sed} values for marine and freshwater. Two different marine Kd_{sed} values are defined for deep water (>200m) and coastal waters.

4.3.5. Soil model

The structure for arable land consists of a single well mixed soil compartment (30cm depth) overlying a deep soil compartment where the deep soil is common to the two land types (Figure 4-4). Activity reaches the top soil by irrigation, sediment transfer or by upward movement from the deep soil. Activity reaches the deep soil via movement downwards from the top soil or from contaminated groundwater. In addition there is a groundwater transfer pathway between deep soil and river water.

Under irrigation activity is transferred out of the surface water (river or lake) and onto the soil surface with a fraction If_{sa} being intercepted by plants which is represented by the equation

$$\frac{dSOIL1}{dt} = I_{irr\_sa}(1 - If_{sa})C_{wr}$$

where

$I_{irr\_sa} = I_{rr\_sa} S_s(1\text{-}Fr_{gr})/V_w$

$(1\text{-}Fr_{gr})$ is the fraction of irrigated land used for arable farming

For the soil box associated with the seaspray compartment there is an additional activity in which

$$\frac{dSOIL1}{dt} = L_{lc} K_{ss} seaspray(1 - Fr_{qr})(1 - If_{sa})C_{lc} / V_{lc}$$

where

L_{lc} is the length of the local marine compartment
V_{lc} is the volume of the local marine compartment
Seaspray is the volume of seaspray returned to coastline per year (m^3 y^{-1} m^{-1})
Kss is the element dependent seaspray enhancement factor
C_{lc} is the activity in the local marine compartment

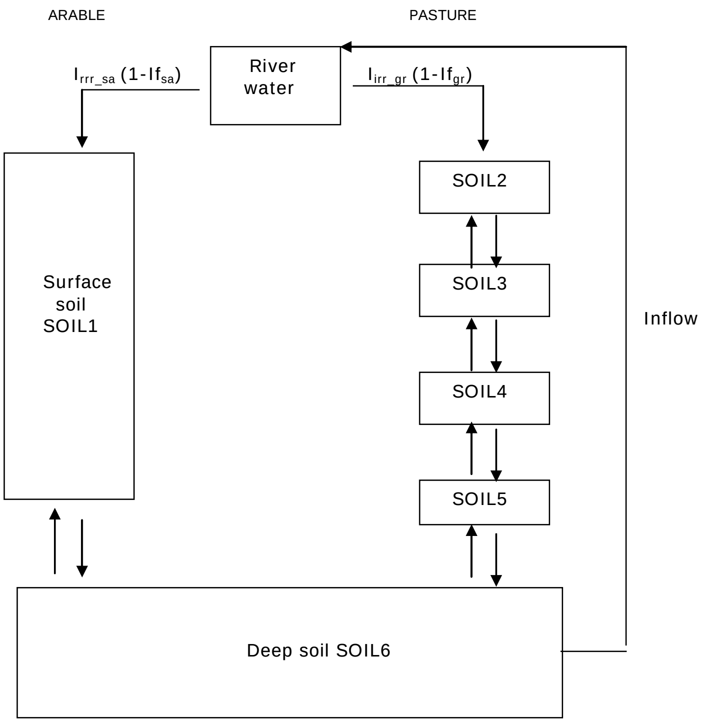


Figure 4-4: Activity transfer within soil compartments

Transfer from surface soil to deep soil is governed by infiltration, diffusion and bioturbation and is given by

$$k_{s1\_s5} = 2D_s/(d_{s6}(d_{s1}+d_{s6})R_{eff}) + perc/(d_{s1}R_{eff}\theta_s) + Bio_s/d_{s6}$$

where

$1/R_{eff}=Fr_{mob}/R_{mob}+(1-Fr_{mob})/R_{imm}$
$R_{mob}=1+(Fr_{kd}kd_{s1}\rho_{sed})/((1-Fr_{mob})\theta_s$
$R_{imm}=1+(Fr_{kd}kd_{s1}Imm)/((1-Fr_{mob})\rho_s$
Fr_{mob} is the fraction of pore water in the dynamic zone
Fr_{kd} is the fraction of sorption sites dynamic zone
Perc is the sum of the rainfall rate plus the depth of irrigation (d_I)
Bio_s is the bioturbation rate in soil (y^{-1})
Imm is an enhancement factor

Transfer from deep soil surface soil to top soil is governed by flow of groundwater, diffusion and bioturbation and is given by

$$k_{s6\_s1} = (1-Fr_{gr})[2D_s/(d_{s6}(d_{s1}+d_{s6})R_{eff}) + gflow.upwat/(d_{s6}S_s\theta_s R_{eff}) + Bio_s/d_{s6}]$$

where

gflow is the groundwater flow
upwat is the fraction of groundwater flow that enters the surface soil

The exchange between the deep soil compartment and the river water is also dependent on the groundwater velocity, specifically

$$k_{s6\_wr} = glow.upwat/(d_{s6}S_s\theta_s R_{eff})$$

Erosion of surface soil is assumed to result in a transfer of soil to the adjacent river box at a rate SOILR, so that

$$\frac{dSOIL1}{dt} = -SOILR.SOIL1$$

The pasture model has a deep soil compartment common to the arable soil (Figure 4-4). The top 30 cm is divided into four additional layers (SOIL2 to SOIL5) representing undisturbed soil. The processes to be represented (irrigation, sediment transfer, advection, infiltration, bioturbation and diffusion) are the same as for arable land.

Irrigation from the surface water (river or lake) and onto the pasture soil is represented by the equation

$$\frac{dSOIL2}{dt} = I_{irr\_gr}(1 - If_{gr})C_{wr}$$

where

$I_{irr\_gr} = I_{rr\_gr}\, S_s Fr_{gr}/V_w$
If_{gr} is the fraction being intercepted by grass

For the soil box associated with the seaspray compartment there is an additional activity in which

$$\frac{dSOIL2}{dt} = L_{lc}K_{ss}seasprayFr_{qr}(1 - If_{gr})C_{lc}/V_{lc}$$

The downwards exchanges between the four surface soil compartments are due to infiltration and bioturbation and have the form

$$k_{sn\_sn+1} = perc/(d_{sn}R_{eff}\theta_s) + Bio_s/d_{sn}$$

The upwards transfers are due to bioturbation only and have the form

$$k_{sn\_sn11} = Bio_s/d_{sn}$$

except for k_{s5_s4} which includes a residual upward flux term from the deep soil compartment

$$k_{s4\_s5} = 0.0015 + Bio_s/d_{s5}$$

The transfer between the deep soil SOIL6 and the adjacent soil compartment SOIL5 is the same as for arable soil except that d_{s5} replaces d_{s1} and Fr_{gr} replaces $(1\text{-}Fr_{gr})$. Similarly the transfer between SOIL5 and SOIL6 is the same as for arable soil except that d_{s5} replaces d_{s1}.

Soil erosion is again modelled using the erosion rate SOILR with all four compartments being eroded into the river at the same rate.

Caesium has a slightly more complicated model with two extra surface compartments to represent the fixation of caesium onto soil where it is unobtainable for root uptake.

4.3.6. Plant model

Figure 4-5 shows the main features to describe the transfers of nuclides in plants. The compartment marked ‘Soil’ represents the well-mixed arable soil model shown in Figure 4-4 for leafy green vegetables, root vegetables, grain and fruit. For grass the ‘Soil’ represents the undisturbed pasture soil structure Figure 4-4 associated with grass.

Here the external plant and internal plant may represent several different plant parts associated with each of the different transfer processes listed below plus any additional plant part characteristic to the plant type. Each plant part is represented by a compartment in the model. For example, leafy green vegetables have two external plant and two internal plant compartments, grass has two external and three internal plant compartments.

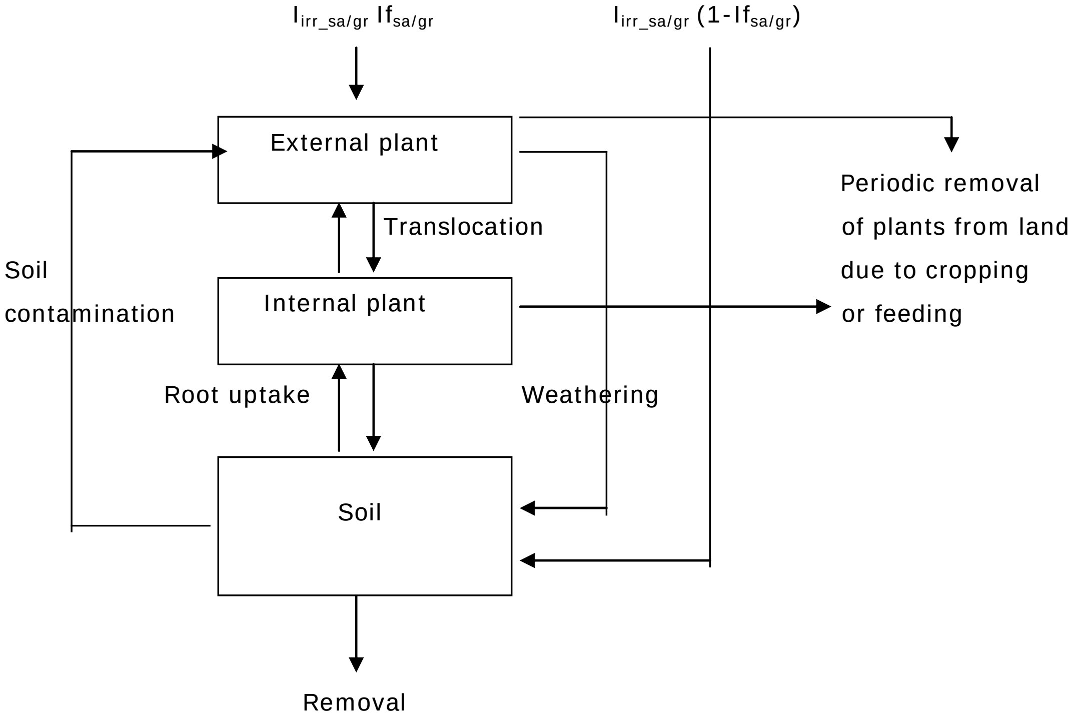


Figure 4-5: Principle mechanisms for the transfer of radionuclides in plants

4.3.7. Transfer processes

Contamination of both the plant surface and internal parts of the plant are considered: transfer to the plant surface may occur due to interception of depositing activity or by resuspension of activity from soil; transfer to the internal plant occurs via root uptake and by absorption from the surface of the plant and subsequent translocation. Each process is discussed in turn below and described in detail in Brown and Simmonds (1994).

Interception

Interception of activity on the external plant surface will vary according to the nature of the activity, the meteorological conditions present, and the type of vegetation and its stage of growth. The interception factors If_{sa} and If_{gr} are determined by

$$If_{sa/gr} = 1-\exp(-\phi\rho_p)$$

where

ϕ is the uptake coefficient ($m^2\ kg^{-1}$)

ρ_p is the herbage density for plant type p (kg m^{-2})

Root uptake

Absorption of activity by the internal plant part varies considerably with soil type, plant type, and the form of the activity. The transfer rate for root uptake from soil compartment n to internal plant type p is given by

$$k_{sn\_ip} = \frac{wet.mass.p}{mass.soil} B_{vp} EF$$

where

wet mass of plant = $Y_{vp}S_p$

mass soil = $\rho_s d_{sn} S_s$

B_{vp} is the root uptake concentration factor for plant type p

EF is transfer from root compartment to soil set at a high value ($8.64\ 10^4\ d^{-1}$) to achieve equilibrium

Soil contamination

The resuspension of soil particles is due to a variety of processes. The transfer rate for contamination by soil compartment n to external plant type p is given by

$$k_{sn\_ep} = \frac{wet.mass.p}{mass.soil} P_p EF$$

where

P_p is the percentage of the plant's dry weight present as soil

Weathering

Activity is lost from the plants surface due to washoff by rain and wind and loss of fragments of the plant surface itself. It is represented in the model by a weathering half-life which is different for each plant type.

Translocation

Part of the surface deposited activity may be absorbed and transferred to other parts of the plant. This process is significant for mobile elements such as caesium but less so for immobile elements such as the actinides. Translocation is represented by element dependent rates that vary between plant types and the plant compartments between which the exchanges are considered.

Cropping

All plant parts have a loss rate due to harvesting, and in the case of grass due to cropping by animals. The activities in edible parts of the agricultural plants are used directly in the dose calculations for humans or in calculation of activity in animals. The inedible parts of the arable plants are assumed to be ploughed back so that the activity is returned to the soil compartments. The loss due to cropping is represented by a constant annual rate (different for plant types).

4.4. Well model

A well is simulated in BioGeM by a single freshwater compartment. This contains a source of activity, representing transfer of activity from ground water. Water from this compartment is used for irrigating crops and for human and animal consumption. The model therefore has the same terrestrial exposure pathways as the river model but with no marine doses. The well model is derived from the river model with the following changes:

- There is only one freshwater compartment with no sea-spray compartment
- There is no river top sediment, middle sediment or bottom sediment
- The well water compartment does not link to any other water/sediment compartment
- There are no marine compartments or sea-spray compartments and associated transfers

- The well water compartment is used to irrigate arable and pasture land
- There is no erosion or cropping leading to transfer of activity to the well water compartment
- Groundwater movement from deep soil to well water is implicitly included in the calculation of source in the well water

4.5. Computer software, codes used

The BioGeM interface is written in Delphi. This aids the user in setting up site data and pathways. It also controls the suite of calculational codes written in FORTRAN and compiled using the *Compaq Visual Fortran* software. The model numerical solution method uses a NAG routine D02EJF (NAG, 1999). Hence, users of the BioGeM model need to purchase a licence for the supporting NAG software. The BioGeM model itself is available for other users. The codes used in the uncertainty analysis are the SANDIA LHS program for sampling (part of the ARRAMIS program, Wyss and Jorgensen, 1998) and the SANDIA analysis program PATTRN (Shortencarier and Helton, 1999).

5. Site-specific biosphere models

For 5 sites in Europe, specific biosphere models are developed. In order to achieve a consistency in the model derivation, the models were derived following the steps defined in the Reference Biosphere Methodology consisting of

- Description of site-specific biosphere systems
- Identification of Features, Events and Processes
- Derivation of conceptual models
- Mathematical formulation of models

The site descriptions cover the principal components defined in BIOMASS as location and geographical extent, climate and atmosphere, geology, lithology, edaphology, topography, hydrology and hydrogeology, biota and human community. The geo-biosphere-interfaces are described as well, given here more detailed information for the national interfaces identified previously in the Assessment Context.

Based on the site description, interaction matrices were set up and conceptual models were derived. The processes identified are checked against the BIOMASS FEP-list. The interactions and processes are then formulated in mathematical models.

The sites considered cover a wide range of environmental and agricultural conditions within Europe as:

- A location in Hungary with intensive agriculture, cold winters, hot summers and a pronounced rain deficit during the vegetation period
- A location in Spain with extensive land use, mild winters, hot and very dry summers
- A location in Belgium (maritime climate) with intensive agriculture, mild winters, cool summers and sufficient precipitation to ensure plant growth during the vegetation period
- A location in Northern Germany with a moderate continental climate characterised by a moderate water deficit during the vegetation period.
- A location in Sweden with agriculture of little intensity, potential importance of freshwater fish as exposure pathway as well as exposure through the use of peat in soil improvement and as fuel.

This chapter gives a short overview about the site-specific biosphere. The derivation of all site specific models is described in detail in Annex 1.

5.1. Interface

The geosphere-biosphere interface defines the point at which the radionuclides released from the repository enter the biosphere. All sites have the well as a common release point. For Belgium and Spain, additionally the release to a river is considered, whereas for the Hungarian, Swedish and Spanish sites the releases to a lake are taken into consideration. Due to the specific geographical situation, for the Swedish site the release to a coastal area and directly to agricultural land via deep soil is modelled.

5.2. Exposure pathways

The exposure pathways considered are summarized in Table 5-1. Inhalation of resuspended soil particles and external exposure due to residence on contaminated land are common pathways in all models. Among the ingestion pathways, the intake of drinking water, cereals, leafy vegetables, potatoes, milk, beef and freshwater fish are included in all models. The selection of the other foods reflects site-specific living habits; e.g. citric fruit are only included in the Spanish model.

Pathway	Model				
	Germany	Belgium	Spain	Sweden	Hungary
Ingestion					
Drinking water	x	x	x	x	x
Cereals	x	X*	x	x	x
Potatoes & root veg.	x	X	x	x	x
Leafy vegetables	x	X	x	x	x
Fruit vegetables	x	X	x		x
Milk	x	X	x	x	x
Beef	x	X**	x	x**	x
Pork	x		x		x
Lamb	x		x		x
Freshwater Fish	x	x	x	x	x
Soil	-	-	x	x	-
Chicken	-	-	x		x
Eggs	-	-	x	-	x
Citrics			x		
Fruit			x		
Leguminosae			x		
Inhalation					
Resuspended soil	x	x	x	x	x
External exposure					
Contaminated land	x	x	x	x	x

Table 5-1: Exposure pathways considered in the site-specific models (* : not irrigated ** : total meat consumption)

5.3. Principal contamination routes

In the well scenario, which is common for all sites, irrigation causes a contamination of plants due to interception and post-deposition retention of radionuclides on the foliage. The impact of radionuclides to farmland leads to a contamination of the soil which represents a long-term source for the contamination of plants via root uptake.

Another long-term source of plant contamination is due to resuspension of contaminated soil particles and its re-deposition onto plants. Radioactivity from soil is lost via physical decay and due to the migration into deeper soil layers in which the radionuclides are not available for root uptake. For nuclides with radioactive daughters, their accumulation in the soil and the subsequent uptake by plants is considered. Only in the soil the generation of radioactive daughter products is taken into account; in the other compartments their contribution is negligible due to short times available for their built-up.

The activity loss with the harvested products is not taken into account because this fraction is very small.

Contaminated plants are fed to animals which lead to a contamination of meat, milk and eggs. For grazing cattle, also the involuntary intake of activity due to soil-eating is modelled.

The consumption of fish living in contaminated freshwater bodies is also considered as a potential source of activity intake for humans.

The annual effective dose equivalent via these pathways is calculated for infants and adults assuming that the activity concentration in soil and in freshwater has reached equilibrium. For the dose estimation it is assumed that all foodstuffs are produced by the use of contaminated water.

In case of the other interfaces, it is assumed that a given activity is released to the biosphere via the site-specific interfaces and the subsequent transfer of radionuclides in the biosphere is modelled. For releases to freshwater bodies, the ingestion of fish and drinking water as well as external exposure due to residence on contaminated sediments are taken into account. Other potential pathways are due to the withdrawal of water from fresh water bodies for irrigation purposes, which causes similar transfer routes as in the well scenario described above.

In the Swedish case, where the release to coast water is considered as a potential possibility for a release to the biosphere, the ingestion of fish and the external exposure are modelled.

Due to the specific conditions in Sweden, the contamination of soil (and subsequently the biosphere) due to the rise of contaminated groundwater is modelled specifically. The release to the biosphere via the interface soil causes the contamination of feeds and foods via root uptake and resuspension. Furthermore the inhalation of resuspended soil particles and the external exposure due to residence on contaminated land are taken into account.

5.4. Modelling approaches

Since all models are described in detail in the annex, this section is limited to the comparison of the principal approaches used for modelling the transfer process for radionuclides in the biosphere which is summarised in Table 5-2. It illustrates that the approaches to simulate radionuclide transport in the biosphere are relatively similar. However, this is not surprising, since all models work on the same problem.

The main differences concern the modelling of the radionuclide contamination of plants by irrigation which covers the processes interception, post-deposition retention, translocation and root uptake. All models assume a plant-dependent interception factor, however only the German and Swedish models consider that this parameter depends on the element as well.

The post-deposition retention is treated relatively similar by means of a weathering half-life which is in some cases modified for specific plants. In the Swedish model, the weathering process is not explicitly modelled, because the approach focuses on the activity in harvest and weathering is implicitly taken into account. In the German model, weathering is explicitly considered only in case of plants that are totally used; otherwise the approach is similar to the Swedish model.

Translocation quantifies the systemic transport of radionuclides in plants. The Spanish model does not model it, the Swedish and Belgium model only for root crops. The German model takes into account the dependence on crop and element, whereas the Hungarian model assumes only dependence on crop, but not on element.

Process	Description
Drinking water	B: Well water: no processing, river water: removal of solids H: Filtration of ground and river water E,G,S: Water is used without processing
Irrigation	Amount of irrigation derived from climatic conditions
Yield	All models: Site-specific, crop-dependent yields
Interception	B,E,H: Interception is element-independent, varies with plant type G,S: Interception is element and crop-dependent
Post-deposition retention	B: Weathering half-life for pasture and crops, specific value for ^{129}I E: Weathering half-life for fruit (incl. citric) and other crops G: Totally used plants (e.g. grass): weathering half-life Edible part: not explicitly modelled, included in translocation facto H: Crop-dependent weathering half-life S: Not explicitly modelled
Translocation	B,S: For potatoes and roots, translocation is element-dependent, for other crops not explicitly modelled E: Translocation not explicitly considered G: Dependent on element and plant development at time of application; derivation of a mean translocation representative for the irrigation period H: Dependent on crop, but not on element
Root uptake	All sites: Element-specific equilibrium transfer factors soil-plant
Migration in soil	B,E,H,S: Retardation factor derived from k_D-value and water velocity G: Element-specific migrations rates derived from investigations of fallout nuclides
Resuspension	All sites: Plant-specific soil adhesion
Transfer to animals	All sites: Element-specific equilibrium transfer factors
Feeding rates	All sites: Site-specific feeding rates
Fish	B,E,S: Equilibrium CF water-fish, sedimentation not considered for activity in water G,H: Equilibrium CF water-fish, sedimentation considered for activity in water
Resuspension (Inhalation)	All models :: Dust load in air B,E,H,S: Dust concentration = soil concentration G: Activity in the dust is enriched compared to soil for cations
Activity in sediments	E,G,H,S: Equilibrium with activity in water column according to k_D B: Equilibrium with activity in water column according to depletion factor for (k)
External exposure	B,E: Residence on contaminated river banks All sites: Residence on land contaminated by irrigation

B: Belgium, E: Spain, G: Germany, H: Hungary, S: Sweden

Table 5-2: Comparison of modelling approaches used in the site-specific models

For quantifying the uptake from soil all models use equilibrium transfer factors defined as the concentration ratio of the activity in plant and soil. In all models, the activity in soil is estimated from the activity input and the loss via physical decay and migration to deeper soil layers. Some models explicitly consider the loss of activity with harvested material. Except for the German site, the migration in soil is based on a k_D-approach, whereas

For the contamination of plants due to re-deposition of resuspended soil particles, all models assume a plant-specific amount of soil that adheres to the plant.

The approaches to estimate the activities in animal food products, fish as well as the approaches for the assessment of the exposure due to inhalation and external irradiation are very similar. All details are described extensively in Annex 1.

5.5. Parameters

The parameters used in the models are summarised in Annex 2. The parameters are differentiated according to nuclide-independent and nuclide-dependent parameters. The parameters are given for the models developed for all 5 sites as well as for the generic model. The approaches used in the different models to simulate the environmental transfer of radionuclides are partly similar and partly different. Therefore, the parameters are not always directly comparable. Nevertheless, it was tried to express the parameters in a way that they can be compared with those used in other models. However, some processes are not explicitly modelled in all models.

A summary of the comparison of the parameters is given in Table 5-3 for nuclide-independent and in Table 5-4 for nuclide-dependent parameters.

For each of the items considered, the variation of the parameters is indicated by the ratio of the maximum and minimum value used in the one of the site-specific models. These ratios include the variation over nuclides as well, so they are more of qualitative nature. Nevertheless, it is thought, that the summary reflects the differences among the models. Furthermore, Table 5-4, summarizes the reasons for the differences between the models and the potential impact of the parameters on the endpoints considered.

The differences in the nuclide-independent parameters reflect especially the differences in the environmental and agricultural conditions of the sites considered. The intake rates differ considerably for some food items, specific foods are only considered at specific sites; e.g. only the Spanish model considers citric fruit. It is interesting to note, that the variations in food intake for infants are more pronounced than for adults. Detailed statistics for intake mainly focus on adults, whereas the data for infants are relatively poor.

The intake of freshwater fish is highest in the Swedish model, which is due to the presence of lakes, whereas the consumption of fish is much less at the other sites. On the other hand, the variations in the intake of drinking water and milk are relatively small between the sites.

There are various parameters such as the inhalation rates, growing period, weathering half-life, yields, soil mass, feeding and watering rates where the differences between the models are of minor importance.

Pronounced differences in the model parameters can be observed for the following nuclide-dependent parameters (Table 5-4) Interception factors

- Translocation factors
- Migration of radionuclides to deeper soil layers
- Transfer factors soil-plant
- Concentration factor water fish
- K_d–values water-sediment

The interception, which quantifies the fraction of activity that is initially retained by the vegetation, also varies considerably. The models that take into account the amount of irrigation water applied (Germany, Sweden) estimate in all cases lower interception fractions. Irrigation water is applied in doses of 20-30 mm (l/m²), under those conditions the activity fraction retained is relatively little.

Parameter	Variation among sites (Ratio maximum/minimum or range)	Reason for variation	Potential impact on endpoints
Intake rates (infants)	~ 2.5 (drinking water) <2 (cereals) ~ 3 (potatoes & roots) 8 (leafy vegetables) 5 (milk) 100 (beef)	Site specific conditions, interpretation of scenario	Medium
Intake rates (adults)	<1.8 (drinking water) <1.7 (cereals) ~ 6 (potatoes & roots) 3 (leafy vegetables) <2 (milk) 12 (beef) 70 (fish)	Site specific conditions, interpretation of scenario	Medium
Inhalation rates	<1.5 (infants) <1.3 (adults)	Interpretation of data/scenario	Low
Residence on contaminated areas	20 (infants) 6 (adults)	Scenario	Low
Growing period	<1.5 (grass)	Site specific conditions	Low
Weathering	<1.5	Interpretation of data	Low
Irrigation rates	>10	Site-specific conditions	Medium/high
Yield	>3 for grass and fruit veg. <2 for al other crops	Site-specific conditions	Low
Soil mass	~ 2	Site-specific conditions	Low
Dry matter intake of animals	<2 (dairy cow) < 3.5 (beef cattle) < 2 (pigs, lamb, chicken)	Site-specific conditions	Low
Water intake of animals	< 1.5	Site-specific conditions	Low
Parameters for freshwater bodies	Considerable differences	Site-specific conditions	

Table 5-3 Summary of comparison of nuclide-independent parameters applied in the 5 site-specific models

Pronounced variations can be observed for the systemic transport of radionuclides (translocation) subsequent to retention by the foliage. Some models model the element-dependence of translocation while others do consider it but use element-independent values for translocation which leads – in general - to an overestimation of the systemic transport.

The largest differences in the parameters used by the models can be observed for selenium, where the deviations for the soil-plant transfer factors, the migration rates in soil and the transfer to feed for beef cover a factor of 100 to more than 1000. The data base for selenium is very poor. Furthermore, selenium undergoes a complex speciation in soil, during which the availability, root uptake and migration may change drastically (Koch-Steindl and Pröhl, 2001). Therefore, the uncertainty in uptake is more pronounced than for other radionuclides, which in general tends to cause a conservative bias during the data evaluation and parameter selection.

However, in some cases, some issues may not have been adequately considered in the selection of the parameters. In one model, the migration rate of selenium is assumed to be very low, indicating a very low mobility of selenium in soil, which is typical for reduced selenium species (e.g. selenide). In the same model, the root uptake is very high which indicates oxidised selenium species (e.g. selenate, selenite). The combination of such – obviously conflicting – parameters then leads to very high ^{79}Se-activities in plants and very likely to pronounced overestimations in dose.

Parameter	Variation among sites (Ratio maximum/minimum or range)	Reason for variation	Potential impact on endpoints
DF, ingestion	No difference	All model use ICRP DF	-
DF, inhalation	E,G,H,S: same values B: ~ factor of 3 higher values	Interpretation of data	Low
DF external exposure	Up to 1000 and more	Integration of daughters in the dose factors	Low (except ^{226}Ra)
Processing factor for water	<1.5		Low
Interception factor	7-20 (grass) 3-8 (cereals) 4-16 (potatoes & roots) 2-8 (leafy veg.) 3-10 (fruit veg)	element-dependent, underlying approach for modelling	High
Translocation (not explicitly modelled for all sites)	2-40 (cereals) 1-10 (potatoes & roots) 2-60 (fruit veg.)	element-dependent, underlying approach for modelling	High
Migration rate in soil	20-200 (arable soil) 20-1000 (pasture)	Nuclide and site-specific, modelling approach , interpretation of data	High
Transfer factors soil-plant	6-1000 (grass) 15-250 (cereals) 4-1500 (potatoes & roots) 3-800 (vegetables)	Nuclide and site-specific, (highest variations for Se) interpretation of data	Very high
Transfer factors feed-animals	1-100 (milk) 5-80 (beef) 6-100 (pork)	Nuclide and site-specific, (highest variations for Se, Tc) interpretation of data	Mostly low, high for Se
CF water-fish	1-25	interpretation of data	Medium
K_d water sediment	20-3000	Nuclide and site-specific (highest variations for Se, Tc) interpretation of data	Medium

Table 5-4: Summary of comparison of nuclide-dependent parameters applied in the 5 site-specific models.

Pronounced variations are also observed in parameters that quantify the behaviour of technetium in soil, which is also subject to a complex speciation in soil. The chemical form of technetium depends especially on the redox potential in soil, high redox potentials favour the occurrence of the very mobile pertechnetate, whereas under less aerobic or unaerobic conditions, pertechnetate is reduced to less mobile forms. Again, the root uptake and migration is controlled by the chemical form and realistic results can only be obtained if those mechanisms are adequately considered in the derivation of parameters.

6. Results

This section describes the results of the application of the site–specific and the generic models. The following results are provided:

- Deterministic results for the five sites considered. For each site, the geosphere-biosphere interfaces were taken into account as they were defined in the assessment context. The deterministic results are given for adults and infants, furthermore the contributions of the pathways are provided.

  A problem arises because the geosphere- biosphere interfaces are not the same for the different sites. However, one common step in all models is the activity concentration in water that is used for drinking, irrigation. Therefore, the results for the endpoints are normalised to the activity in the water. The results will then be given and compared in units of e.g. [mSv/a per Bq/m³]. This normalization has the advantage that it shows directly the differences in environmental transfer between the different sites considered.

- The uncertainty of the results is estimated. For this purpose, for the model parameters, frequency distributions were defined and processed by mean of Monte-Carlo techniques. The uncertainty of the results is quantified by the ratio of the 95th and 5th percentile. The stochastic results of the site-specific models are compared with those obtained by the Generic model.

- Based on the results of the deterministic and stochastic calculations, the important parameters are identified.

6.1. Deterministic results

The annual effective dose to adults and infants are calculated for each site, assuming a normalised activity of 1 Bq/m³ respectively. The water is used as described above in the sections on the sites and the site-specific models. Usually, the water is used as drinking water for humans, for watering cattle and for irrigation of crops. External exposure may arise from staying on areas contaminated by irrigation. The inhalation of contaminated resuspended soil particles causes an internal exposure as well.

If a surface water body is assumed as the geosphere-biosphere interface, the consumption of fish is taken into account. Furthermore, the residence on contaminated river or lake sediments causes external exposures.

The normalised exposures for adults are presented and compared in Figure 6-1. The values are given in terms of [mSv/a per Bq/m³]. Although the sites cover a wide range of agricultural, climatic and social conditions, the variation among the models for a given radionuclide are relatively small. For all models, the intake of drinking water is a very important pathway, the variations of which is relatively little, since it is constrained by physiological factors.

One exception is Se-79, where the differences among the sites may be as high as two orders of magnitudes. However, especially the data on the uptake from soil as well as for the transfer from feed to animal are very poor. Due to the complex speciation of selenium in soil, the interpretation of the existing data by the models involved is the source of these variations.

Figure 6-2 shows the ratio of the normalised annual exposures for adults and infants. The ratios cover a range of less than 0.2 to about 2.6 according to my impression of the figure.3.5 (This need to be checked ???????). The exposures for adults are consistently lower for Cl-36, Se-79 and Tc-99.

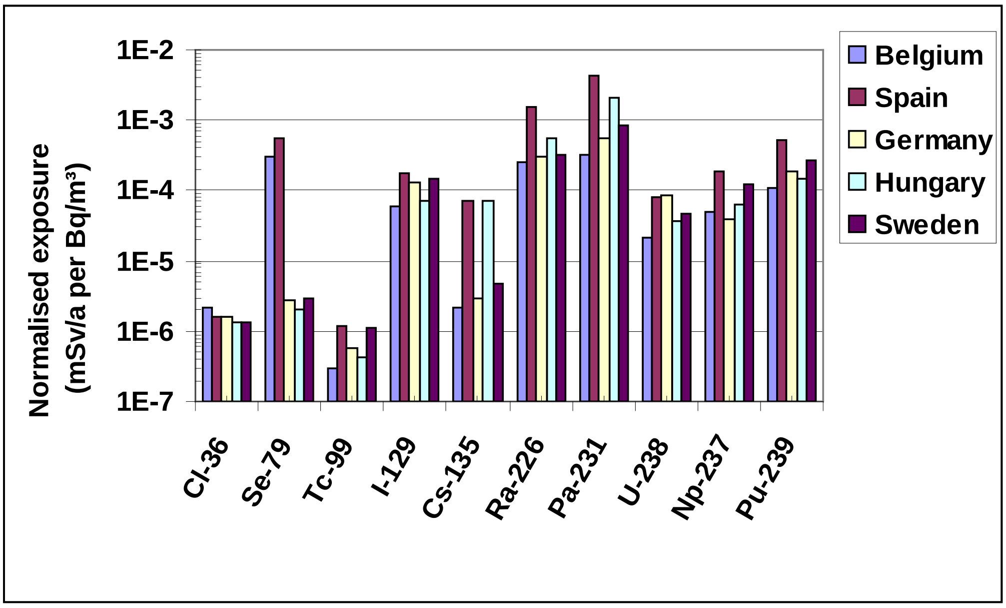


Figure 6-1: Comparison of normalized exposures for the well scenario [mSv/a per Bq/m³]

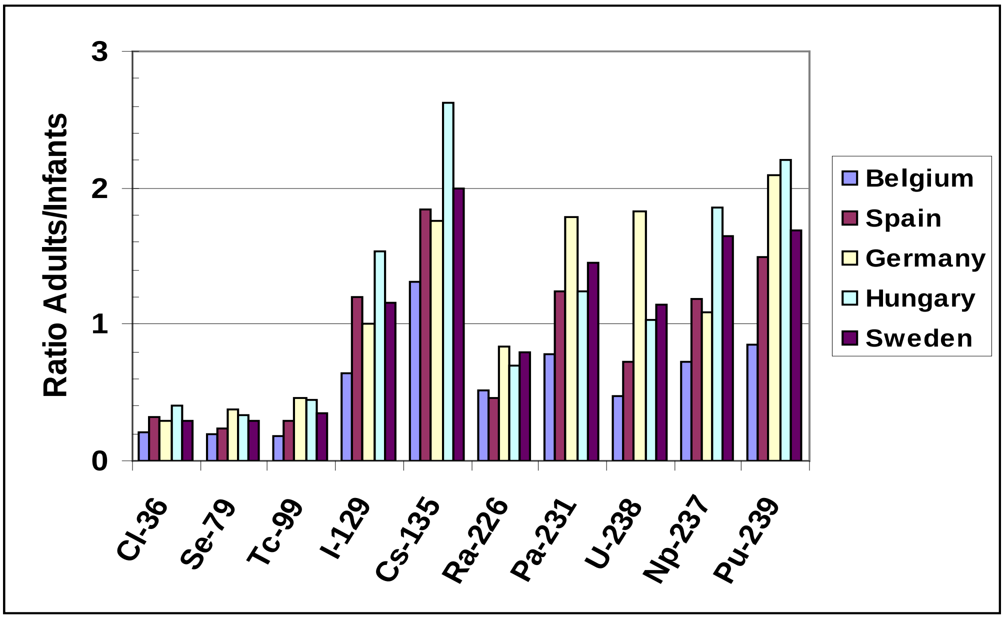


Figure 6-2: Ratio of normalised exposures adults/infants for the 5 site-specific models

The contributions of the pathways to the total doses are given for adults and infants in Table 6-1 to 6-10. Except in the Spanish case, ingestion is the dominating exposure route. External exposure is only relevant for Ra-226 and U-238, the maximum contribution is less than 25 % and mostly far below 10 %. Inhalation of resuspended soil particles is considered in all models. In general, the contribution is not more than a few percent. However, the Spanish model predicts for Pa-231 a contribution of about 60 %.

One of the most important ingestion pathways for almost all the radionuclides is the consumption of drinking water. For most models this relative contribution is more than 50% of the total dose. All the values given by the different models are in the same order of magnitude, which is due to the low variability of the parameters that determine the dose. The most important factor is the intake of drinking water which is determined by physiological constraints.

In some models, for specific radionuclides, the water intake is less important as is the case for Cl-36, Pa-231, Cs-135 and Se-79 because of high contributions of other pathways such as (for Pa-231) air inhalation for the Spanish model, (for Se-79) pork, root crops and beef ingestion for the Spanish and Belgian model and (for Cs-135), fruit vegetables and pork ingestion for the Hungarian and Spanish model. However, as discussed in the section before, due to the poor data base, the interpretation of data and the subsequent derivation of parameters with a cautious bias may tend to overestimate those pathways.

Other potential important pathways are the ingestion of cereals, root crops, fruit vegetables, beef, milk, pork and fruit. There is no general pattern, the varying importance of the foods is the result of the model approaches used and the parameters selected. The variation in intake rates also reflects national consumption habits.

ALL THE DATA FROM THE SPANISH SITE ARE NOT CORRECT. THIS ARE OLD DATA: INMA CHANGED THEM IN SEPTEMBER 2003. PLEASE CHECK D11 !!!!

	Adults					Infants				
Component	B	E	G	H	S	B	E	G	H	S
Drinking water	17.6	30.6	40.6	39.2	43.1	17.0	25.9	23.6	31.3	16.0
Cereals	0.0	17.6	6.9	13.8	0.0	0.0	15.7	3.6	13.1	0.0
Leafy veget.	6.2	2.7	0.8	3.8	15.4	2.6	2.6	0.7	1.2	15.1
Fruit veget.	2.2	6.5	4.6	5.6	0.0	7.0	2.6	2.0	5.9	0.0
Root crops	34.8	4.2	2.8	7.6	27.7	14.0	8.7	4.0	4.1	24.4
Citrics	0.0	1.2	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0
Fruit	0.0	6.5	0.0	0.0	0.0	0.0	14.3	0.0	0.0	0.0
Leguminosae	0.0	15.9	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0
Cow milk	12.9	10.6	25.6	12.3	10.0	32.0	15.4	61.8	29.4	44.4
Beef	27.1	2.1	2.1	0.4	4.0	31.0	1.7	0.5	0.1	1.0
Mutton,lamb	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0
Pork	0.0	4.1	13.1	16.2	0.0	0.0	1.8	3.8	12.2	0.0
Chicken/birds	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	1.1	0.0
Eggs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fish	0.0	2.2	1.4	0.2	0.0	0.0	0.2	0.3	0.5	0.0
Soil ingestion	0.0		0.0	0.0	0.0	0.0		0.0	0.0	0.0
Total ingestion	100.0	100.0	87.5	100.0	100.0	100.0	100.0	96.4	100.0	100.0
External irradiation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inhalation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total dose (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total dose (mSv/y)	2.1E-6	1.7E-6	1.6E-6	1.3E-6	1.3E-6	1.0E-5	5.4E-6	5.5E-6	3.2E-6	4.5E-6

Table 6-1: Normalised exposure for infants and adults and contribution of pathways for ^{36}Cl

Component	Adults					Infants				
	B	E	G	H	S	B	E	G	H	S
Drinking water	0.4	0.1	71.4	80.0	56.7	0.5	0.2	74.7	76.3	32.0
Cereals	0.0	3.2	7.9	0.4	0.0	0.0	4.1	7.9	0.5	0.0
Leafy veget.	7.3	2.0	0.4	4.0	12.0	4.1	2.9	0.7	0.8	18.0
Fruit veget.	1.3	5.3	3.0	0.7	0.0	5.6	3.2	2.4	0.8	0.0
Root crops	53.3	2.5	1.0	0.5	20.7	29.3	7.9	2.8	0.3	27.0
Citrics	0.0	3.1	0.0	0.0	0.0	0.0	7.9	0.0	0.0	0.0
Fruit	0.0	5.0	0.0	0.0	0.0	0.0	16.2	0.0	0.0	0.0
Leguminosae	0.0	0.8	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
Cow milk	1.4	1.1	1.7	3.1	3.0	4.7	2.4	7.7	8.6	21.0
Beef	36.7	0.3	0.8	0.8	4.0	56.7	0.3	0.4	0.2	2.0
Mutton,lamb	0.0	0.2	0.0	1.5	0.0	0.0	0.4	0.0	0.0	0.0
Pork	0.0	76.4	0.6	6.5	0.0	0.0	50.0	0.4	6.1	0.0
Chicken/birds	0.0	1.7	0.0	2.2	0.0	0.0	5.3	0.0	2.4	0.0
Eggs	0.0	1.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0
Fish	0.0	0.1	10.4	1.0	0.0	0.0	0.0	3.7	4.7	0.0
Soil ingestion	0.0		0.0	0.0	0.0	0.0		0.0	0.0	0.0
Total ingestion	100.0	100.0	96.4	100.0	96.7	100.0	100.0	100.0	100.0	100.0
External irradiation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inhalation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total dose (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total dose (mSv/y)	3.0E-4	1.1E-3	2.8E-6	2.0E-6	3.0E-6	1.5E-3	3.4E-3	7.5E-6	5.9E-6	1.0E-5

Table 6-2: Normalised exposure for infants and adults and contribution of pathways for ^{79}Se

Component	Adults					Infants				
	B	E	G	H	S	B	E	G	H	S
Drinking water	86.7	30.0	80.4	81.4	34.5	76.5	25.0	80.0	80.0	17.4
Cereals	0.0	16.7	6.4	1.3	0.0	0.0	16.0	6.1	1.5	0.0
Leafy veget.	5.3	4.4	3.0	6.7	28.2	2.0	4.5	5.0	6.3	38.7
Fruit veget.	2.8	10.8	7.5	7.7	0.0	8.2	4.8	6.0	10.0	0.0
Root crops	1.4	3.7	2.0	0.6	37.3	0.5	8.0	4.9	0.4	45.2
Citrics	0.0	3.9	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0
Fruit	0.0	10.8	0.0	0.0	0.0	0.0	24.8	0.0	0.0	0.0
Leguminosae	0.0	15.0	0.0	0.0	0.0	0.0	8.5	0.0	0.0	0.0
Cow milk	4.3	0.0	0.3	0.2	0.0	9.4	0.0	1.4	0.7	0.1
Beef	0.7	0.0	0.1	0.0	0.0	0.7	0.0	0.0	0.0	0.0
Mutton,lamb	0.0	0.1	0.0	0.4	0.0	0.0	0.2	0.0	0.0	0.0
Pork	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chicken/birds	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0
Eggs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fish	0.0	1.1	1.1	0.5	0.0	0.0	0.1	0.4	0.5	0.0
Soil ingestion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total ingestion	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
External irradiation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inhalation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total dose (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total dose (mSv/y)	3.0E-7	1.2E-6	5.6E-7	4.3E-7	1.1E-6	1.7E-6	4.0E-6	1.2E-6	9.5E-7	3.1E-6

Table 6-3: Normalised exposure for infants and adults and contribution of pathways for ^{99}Tc

Component	Adults					Infants				
	B	E	G	H	S	B	E	G	H	S
Drinking water	75.9	33.9	59.2	83.3	44.7	66.7	30.0	33.8	74.5	19.2
Cereals	0.0	18.9	6.6	0.1	0.0	0.0	18.1	3.6	0.1	0.0
Leafy veget.	0.7	2.7	0.7	4.3	26.7	0.3	2.8	0.6	1.7	31.5
Fruit veget.	1.3	6.1	4.5	0.7	0.0	3.8	2.7	2.1	0.9	0.0
Root crops	7.9	4.3	2.4	0.4	12.0	3.0	9.4	3.5	0.3	12.3
Citrics	0.0	0.8	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0
Fruit	0.0	6.1	0.0	0.0	0.0	0.0	15.0	0.0	0.0	0.0
Leguminosae	0.0	17.2	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0
Cow milk	8.6	2.8	23.1	8.3	5.9	20.0	10.0	56.9	21.3	31.5
Beef	5.9	0.9	1.9	0.8	8.7	6.0	1.9	0.5	0.2	3.0
Mutton,lamb	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Pork	0.0	0.5	0.0	0.2	0.0	0.0	0.6	0.5	0.2	0.0
Chicken/birds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eggs	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Fish	0.0	2.4	0.0	0.9	0.0	0.0	0.2	0.0	0.0	0.0
Soil ingestion	0.0	0.0	0.0	0.0	1.0	0.0		0.0	0.0	3.0
Total ingestion	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
External irradiation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inhalation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total dose (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total dose (mSv/y)	5.8E-5	1.8E-4	1.3E-4	7.2E-5	1.5E-4	9.0E-5	1.6E-4	1.3E-4	4.7E-5	1.3E-4

Table 6-4: Normalised exposure for infants and adults and contribution of pathways for ^{129}I

Component	Adults					Infants				
	B	E	G	H	S	B	E	G	H	S
Drinking water	38.1	0.8	46.7	1.5	25.0	39.4	1.0	27.1	1.3	11.3
Cereals	0.0	1.5	9.7	3.9	0.0	0.0	1.9	5.4	4.1	0.0
Leafy veget.	7.1	2.5	2.0	2.8	27.1	3.1	3.5	1.9	0.1	33.3
Fruit veget.	1.8	2.9	7.0	38.0	0.0	6.1	1.6	3.2	44.4	0.0
Root crops	34.3	3.2	7.7	21.1	35.4	15.0	9.0	11.8	12.2	35.0
Citrics	0.0	3.8	0.0	0.0	0.0	0.0	8.8	0.0	0.0	0.0
Fruit	0.0	6.2	0.0	0.0	0.0	0.0	18.5	0.0	0.0	0.0
Leguminosae	0.0	0.6	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Cow milk	9.5	2.8	16.7	6.5	2.9	25.0	5.6	41.8	16.7	14.2
Beef	11.9	0.8	2.4	1.2	6.0	14.4	0.9	0.6	0.4	2.0
Mutton,lamb	0.0	0.2	0.0	1.3	0.0	0.0	0.3	0.0	0.0	0.0
Pork	0.0	71.5	5.7	19.7	0.0	0.0	42.3	6.5	17.0	0.0
Chicken/birds	0.0	2.4	0.0	3.5	0.0	0.0	7.1	0.0	3.5	0.0
Eggs	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Fish	0.0	3.1	1.0	0.9	0.0	0.0	0.3	0.2	0.0	0.0
Soil ingestion	0.0		0.0	0.0	2.0	0.0		0.0	0.0	5.0
Total ingestion	100.0	100.0	93.3	100.0	100.0	100.0	100.0	94.1	100.0	100.0
External irradiation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inhalation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total dose (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total dose (mSv/y)	2.1E-6	1.3E-4	3.0E-6	7.1E-5	4.8E-6	1.6E-6	5.2E-5	1.7E-6	2.7E-5	2.4E-6

Table 6-5: Normalised exposure for infants and adults and contribution of pathways for ^{135}Cs

	Adults					Infants				
Component	B	E	G	H	S	B	E	G	H	S
Drinking water	44.0	13.8	66.7	26.3	53.1	54.2	9.7	52.8	18.3	27.5
Cereals	0.0	19.4	13.0	13.9	0.0	0.0	18.9	15.8	18.3	0.0
Leafy veget.	9.2	4.9	2.9	5.1	37.5	5.2	4.1	5.3	2.3	52.5
Fruit veget.	1.9	6.9	5.3	24.6	0.0	8.3	2.7	4.7	26.8	0.0
Root crops	23.6	5.4	3.7	7.0	9.1	16.0	14.1	10.6	6.3	10.8
Citrics	0.0	6.2	0.0	0.0	0.0	0.0	9.2	0.0	0.0	0.0
Fruit	0.0	12.5	0.0	0.0	0.0	0.0	23.2	0.0	0.0	0.0
Leguminosae	0.0	7.5	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0
Cow milk	1.2	0.8	0.7	3.9	1.0	5.6	0.9	2.3	10.9	6.0
Beef	3.0	0.1	0.4	0.2	0.0	8.8	0.1	0.1	0.1	0.0
Mutton,lamb	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Pork	0.0	8.1	0.1	0.1	0.0	0.0	3.8	0.0	0.1	0.0
Chicken/birds	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.6	0.0
Eggs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fish	0.0	1.9	2.3	0.4	0.0	0.0	0.2	0.7	0.3	0.0
Soil ingestion	0.0		0.0	0.0	1.0	0.0		0.0	0.0	4.0
Total ingestion	84.0	87.5	93.3	82.5	100.0	97.9	89.2	94.4	84.1	100.0
External irradiation	13.6	13.1	4.7	17.5	0.0	1.6	9.7	6.4	15.9	0.0
Inhalation	3.8	2.1	0.0	0.1	0.0	0.3	0.8	0.0	0.0	0.0
Total dose (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total dose (mSv/y)	2.5E-4	1.6E-3	3.0E-4	5.7E-4	3.2E-4	4.8E-4	3.7E-3	3.6E-4	8.2E-4	4.0E-4

Table 6-6: Normalised exposure for infants and adults and contribution of pathways for ^{226}Ra

	Adults					Infants				
Component	B	E	G	H	S	B	E	G	H	S
Drinking water	84.8	19.5	87.7	18.1	50.6	85.7	17.5	81.3	11.8	26.3
Cereals	0.0	14.0	4.2	31.4	0.0	0.0	13.8	5.3	24.7	0.0
Leafy veget.	4.8	3.5	1.9	6.2	33.7	2.3	3.6	3.1	0.6	45.6
Fruit veget.	3.0	8.5	2.3	7.1	0.0	9.8	3.8	2.4	44.7	0.0
Root crops	4.2	4.9	1.5	33.8	8.0	2.9	10.6	5.3	14.7	8.9
Citrics	0.0	3.5	0.0	0.0	0.0	0.0	6.3	0.0	0.0	0.0
Fruit	0.0	9.5	0.0	0.0	0.0	0.0	21.9	0.0	0.0	0.0
Leguminosae	0.0	11.0	0.0	0.0	0.0	0.0	6.1	0.0	0.0	0.0
Cow milk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Beef	0.1	0.2	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0
Mutton,lamb	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Pork	0.0	0.1	0.1	0.4	0.0	0.0	0.0	0.0	0.4	0.0
Chicken/birds	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0
Eggs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fish	0.0	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Soil ingestion	0.0		0.0	0.0	7.0	0.0		0.0	0.0	19.3
Total ingestion	97.0	75.0	96.5	95.2	100.0	100.0	81.3	96.9	100.0	100.0
External irradiation	1.2	0.2	0.4	0.8	0.0	0.2	0.4	1.2	1.1	0.0
Inhalation	0.4	130.0	2.3	0.9	0.2	0.0	118.8	2.2	0.4	0.1
Total dose (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total dose (mSv/y)	3.3E-4	2.0E-3	5.7E-4	2.1E-3	8.3E-4	4.2E-4	1.6E-3	3.2E-4	1.7E-3	5.7E-4

Table 6-7: Normalised exposure for infants and adults and contribution of pathways for ^{231}Pa

Component	Adults					Infants				
	B	E	G	H	S	B	E	G	H	S
Drinking water	90.9	29.0	91.7	72.2	56.3	87.2	27.5	91.3	65.7	33.3
Cereals	0.0	16.1	3.0	0.2	0.0	0.0	16.7	2.8	0.2	0.0
Leafy veget.	4.3	2.3	1.7	4.2	35.4	1.7	2.5	2.6	3.4	57.1
Fruit veget.	2.9	5.3	1.4	1.1	0.0	8.9	2.4	1.2	1.4	0.0
Root crops	1.9	3.5	0.8	1.2	6.0	0.7	8.3	2.0	0.7	8.1
Citrics	0.0	0.9	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0
Fruit	0.0	6.7	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0
Leguminosae	0.0	15.1	0.0	0.0	0.0	0.0	9.2	0.0	0.0	0.0
Cow milk	0.4	0.2	0.0	0.4	0.0	1.1	0.4	0.0	1.0	2.0
Beef	0.1	0.1	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0
Mutton,lamb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pork	0.0	21.5	0.4	1.4	0.0	0.0	10.8	0.0	1.2	0.0
Chicken/birds	0.0	0.3	0.0	0.5	0.0	0.0	0.8	0.0	0.5	0.0
Eggs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fish	0.0	0.5	0.0	0.2	0.0	0.0	0.1	0.0	0.0	0.0
Soil ingestion	0.0		0.0	0.0	1.0	0.0		0.0	0.0	2.0
Total ingestion	100.0	100.0	98.8	80.6	100.0	100.0	91.7	100.0	74.3	100.0
External irradiation	0.4	0.0	0.2	17.8	0.0	0.0	0.0	0.5	23.4	0.0
Inhalation	0.0	0.1	0.5	0.0	0.0	0.0	0.1	0.4	0.0	0.0
Total dose (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total dose (mSv/y)	2.2E-5	9.3E-5	8.4E-5	3.6E-5	4.8E-5	4.7E-5	1.2E-4	4.6E-5	3.5E-5	4.2E-5

Table 6-8: Normalised exposure for infants and adults and contribution of pathways for ^{238}U

Component	Adults					Infants				
	B	E	G	H	S	B	E	G	H	S
Drinking water	89.8	29.0	89.5	90.8	55.0	88.1	28.2	85.7	94.3	32.9
Cereals	0.0	16.2	3.9	0.1	0.0	0.0	17.1	3.7	0.2	0.0
Leafy veget.	4.5	2.3	2.2	5.4	35.8	1.8	2.6	3.4	3.4	57.5
Fruit veget.	3.1	5.7	1.8	1.1	0.0	9.3	2.6	1.4	1.5	0.0
Root crops	1.4	3.7	1.0	0.6	5.8	0.6	8.8	2.6	0.5	7.0
Citrics	0.0	1.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
Fruit	0.0	7.1	0.0	0.0	0.0	0.0	17.6	0.0	0.0	0.0
Leguminosae	0.0	15.2	0.0	0.0	0.0	0.0	9.4	0.0	0.0	0.0
Cow milk	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.9	0.0	0.0
Beef	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Mutton,lamb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pork	0.0	21.4	1.8	0.0	0.0	0.0	11.2	0.0	0.0	0.0
Chicken/birds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eggs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fish	0.0	1.6	0.1	1.5	0.0	0.0	0.2	0.0	0.0	0.0
Soil ingestion	0.0		0.0	0.0	1.0	0.0		0.0	0.0	2.1
Total ingestion	100.0	100.0	97.4	100.0	100.0	100.0	100.0	97.1	100.0	100.0
External irradiation	0.3	0.1	1.0	0.3	0.0	0.0	0.3	1.8	0.7	0.0
Inhalation	0.0	0.6	0.3	0.0	0.0	0.0	0.4	0.2	0.0	0.0
Total dose (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total dose (mSv/y)	4.9E-5	2.1E-4	3.8E-5	6.5E-5	1.2E-4	6.7E-5	1.7E-4	3.5E-5	3.5E-5	7.3E-5

Table 6-9: Normalised exposure for infants and adults and contribution of pathways for ^{237}Np

Component	Adults B	Adults E	Adults G	Adults H	Adults S	Infants B	Infants E	Infants G	Infants H	Infants S
Drinking water	90.9	27.5	94.7	86.7	55.6	92.3	26.8	92.3	92.6	29.4
Cereals	0.0	15.3	1.9	0.1	0.0	0.0	16.2	1.9	0.1	0.0
Leafy veget.	4.4	2.2	1.6	6.4	35.6	1.8	2.5	2.6	3.5	51.3
Fruit veget.	3.0	4.9	1.1	1.2	0.0	9.2	2.4	0.9	1.8	0.0
Root crops	2.7	3.3	0.5	1.0	1.0	1.2	8.2	1.3	0.7	1.0
Citrics	0.0	0.8	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0
Fruit	0.0	6.3	0.0	0.0	0.0	0.0	16.5	0.0	0.0	0.0
Leguminosae	0.0	14.1	0.0	0.0	0.0	0.0	8.8	0.0	0.0	0.0
Cow milk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Beef	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mutton,lamb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pork	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chicken/birds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Eggs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fish	0.0	1.5	0.0	2.2	0.0	0.0	0.1	0.0	0.0	0.0
Soil ingestion	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	19.4
Total ingestion	100.0	76.5	100.0	100.0	100.0	100.0	82.4	98.9	100.0	100.0
External irradiation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inhalation	0.9	25.5	0.9	2.1	0.3	0.0	15.9	0.7	1.1	0.3
Total dose (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total dose (mSv/y)	1.1E-4	5.1E-4	1.9E-4	1.5E-4	2.7E-4	1.3E-4	3.4E-4	9.1E-5	6.8E-5	1.6E-4

Table 6-10: Normalised exposure for infants and adults and contribution of pathways for ^{239}Pu

6.2. Results of stochastic calculations

6.2.1. Results of the site-specific models

An uncertainty analysis was performed for all sites with the different models. For this purpose, for all parameters of the models, frequency distributions were defined that represent the uncertainty and variability of the parameters. The frequency distributions of the resulting normalised annual effective exposures were calculated by means of Monte-Carlo techniques. The frequency distributions of the parameters are summarised in Annex 3.

Figure 6-3 shows the ratios of the 95- and 5-percentile of the resulting distributions for each of the radionuclides considered. In general, the ratios are below a factor of 10, which is surprisingly small. This is due to the drinking water pathway, which is an important or even dominating contributor to the exposure for all sites. Due to physiological restrictions, the variation of the consumption rate of drinking water is relatively low. Therefore, the intake of drinking water represents a kind of a “baseline” with relatively little variations among the sites, on top of which the ingestion of foods have to be considered. Furthermore, the amount of food consumed is also constrained by physiological reasons. The consumption habits among the sites vary in terms of the food items, but not in terms of the total amount of foods. Therefore the variation in the ingestion dose, in general, is limited.

Larger uncertainties are expressed by some models for ^{36}Cl, ^{79}Se and ^{135}Cs. Again the interpretation of data, especially when the data base is very poor, is still a major source of uncertainty. The careful consideration of the speciation and the interactions of these elements with soil constituents is an essential need.

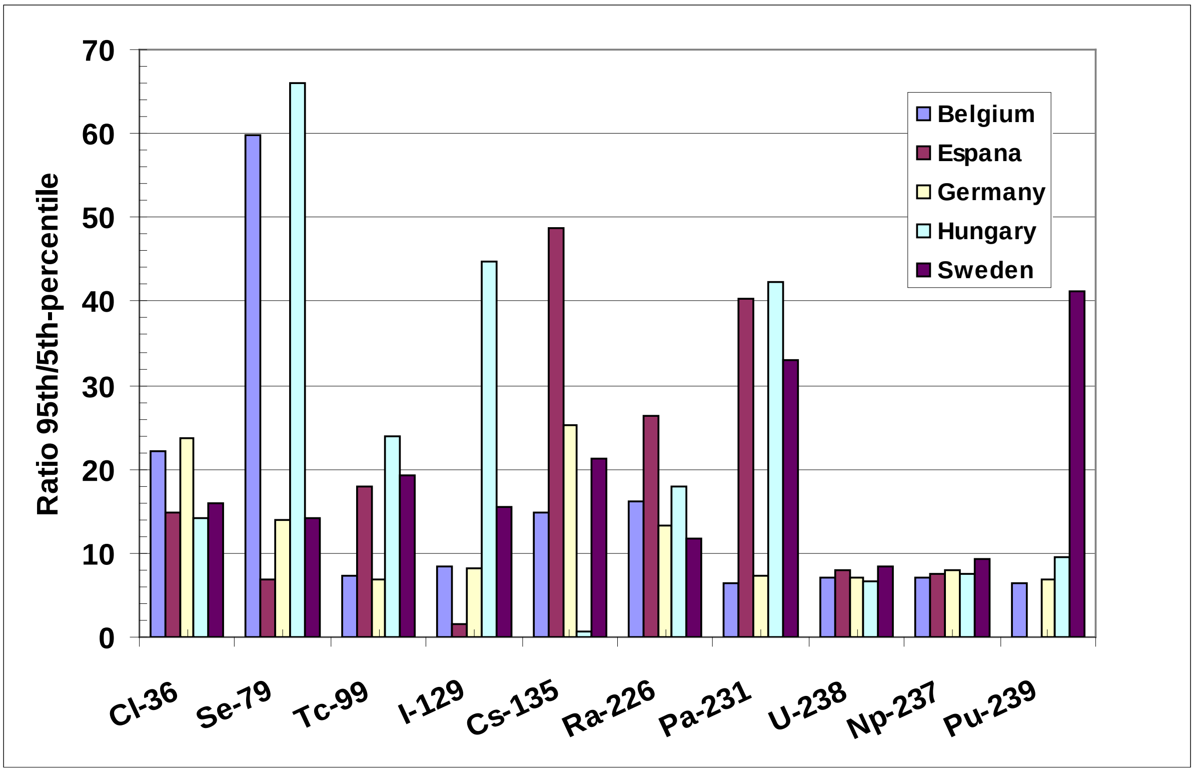


Figure 6-3: Ratio of the 95th and 5th percentile of the normalised exposure of adults for the well scenario for the different sites. The normalised exposure includes the contribution of daughter nuclides

FOR CS-135 AND PU-239, IT SEEM THAT IN FIGURE 6-3, THE RATIO IS LESS THAN 1 FOR THE HUNGARIAN AND SPANISH SITE, RESPECTIVELY. I agree

6.2.2. Uncertainty analysis with the generic model BIOGEM

The generic model, BioGeM, was used to carry out an uncertainty analysis for each of the scenarios considered for the five sites. BioGeM includes a complex model which gives the time variation of the concentration in plants following either a single or a continuing input into the soil or directly onto the plant. The run time for BioGeM depends on the number of compartments in the model, the number of chain members N for the nuclide under consideration, and the number of time steps required. As such the version of BioGeM used for the deterministic runs requires too much processing time for the multiple runs required for uncertainty analyses. For this reason an alternative version of BioGeM was created for the uncertainty analyses. This version of BioGeM does not use the detailed model for the activity concentration in plants; instead the concentration in the plant resulting from root uptake is calculated directly from the soil concentration using the soil/plant concentration ratios. This removes 37xN plant compartments from the model, a sufficient reduction in model compartments to allow a reasonable run time for the uncertainty analysis.

The BioGeM model describes arable soil using a single compartment, so that the concentration in the plant type i C_{vi} is given by

$$C_{vi} = B_{vi} C_{s1}$$

where B_{vi} is the root uptake concentration factor for plant type i and C_{s1} is the concentration in arable soil.

The grass model in BioGeM assumes three internal plant parts which exchange via root uptake with pasture soil compartments. In the uncertainty analysis version of the model the three internal plant compartments now form a single compartment in which the activity is the sum of the activity transferred from the three associated soil compartments via root uptake.

The concentration in the grass root compartment C_{vgr} is given by

$$C_{vgr} = B_{vgr}(C_{s2} + C_{s3} + C_{s4})$$

where B_{vgr} is the root uptake factor for grass and C_{si} is the concentration in the i^{th} soil compartment.

The model still considers the interception of irrigation water by the plant external surfaces, even though they are not explicitly represented in the model. However, it ignores the translocation of that activity into the internal plant. This is consistent with the approach taken in the site specific models.

This simplified plant model was compared with the complex plant model for the Belgian well scenario for Tc-99. It was found that the concentrations in the plants were smaller: the ratios were 0.53 for green veg, 0.33 for root veg, 0.027 for fruit and 0.006 for grass. These differences are believed to be due to the removal of the interception and incorporation of activity on the external plant, which are particularly important in fruit and grass.

Some of the parameters of BioGeM were assumed to be uncertain (see below), and probability distributions were assigned to the values of each of these parameters. 100+ values were then sampled from each of the distributions using the LHS program, a part of the ARRAMIS suite of programs developed at Sandia National Laboratory, USA (Wyss and Jorgensen, 1998). The sampled values were combined with default values for those parameters that were fixed to give 100+ sets of input parameters for BioGeM. BioGeM was then run 100+ times for each scenario for each site, generating 100+ values for each of the output quantities, for each scenario. (The exact number of runs depended on the site and nuclide being considered).These values were used to create probability distributions of the output quantities, and the 5^{th} and 95^{th} percentiles of those distributions were adopted to describe the uncertainty of the BioGeM output. The Sandia program PATTRN (Shortencarier and Helton 1999) was then used to identify those parameters whose uncertainty makes a major contribution to the uncertainty of the output quantity. PATTRN includes a number of ways of identifying the important input parameters; for this analysis the parameters were identified using partial rank correlation coefficients between the input and output quantities.

6.2.2.1. Identification of parameters for uncertainty analysis

The BioMoSA participants have varied different parameters for their uncertainty analyses. There are some parameters which have been varied by all of the participants, namely: animal intake rates, root uptake factors, transfer factors to animals, soil distribution coefficients and others. There are however, parameters particular to each site which have also been varied, leading to over 40 parameters that have been considered to be uncertain in at least one of the site specific analyses. However, none of the site specific analyses considered all of these parameters, with the various site specific uncertainty analyses considering between 6 and 30 parameters. It was felt that it was not reasonable to consider over 40 parameters in the BioGeM uncertainty analyses, and so only those parameters considered by two or more partners were automatically assumed to be uncertain in the BioGeM analyses. Further uncertain parameters were included on a case-by-case basis if it was considered to be appropriate. For instance, rainfall was included as this can have a major effect on the equilibrium time. The list of selected parameters is given in Table 6-11.

Parameter	Description
Q_I	Human intake rates for water, inhalation and food (leafy vegetables, root crops, grain, fruit, milk, beef, mutton, chicken, eggs and pork)
U_I	Animal intake rates of water and food (pasture grass and grain)
If_I	Interception factor for plant type i (leafy vegetables, root crops, grain, fruit, grass)
I_{irr}	Irrigation rate
R	Rainfall
m_{sa}	Dust loading factor
θ_s	Porosity of soil
Er_s	Soil erosion rate
Oc	Occupancy factor
Kds	Partition coefficient in soil
Kd_{sed}	Partition coefficient in freshwater sediment
B_{vi}	Concentration ratio plant/soil for plant type i
F_I	Transfer factor to animal products i (milk, beef, mutton, chicken, eggs and pork)

Table 6-11: Independent (uncertain) parameters used in uncertainty analysis with generic model

6.2.2.2. Distributions for the uncertain parameter values

There are several considerations when selecting the probability distribution for a parameter. In general, where several partners have used the same type of distribution, that distribution type was adopted. In other cases, the distributions adopted for one particular site were adopted for groups of related parameters.

The uncertainties were expressed in terms of normal, triangular or uniform distributions. The distribution used for each of the parameters is given in Table 6-12. Normal distributions were defined so that the mean value of the distribution was the value used for that parameter in the deterministic run for the particular site and the standard deviation was equal to one half of the mean value. The distributions were truncated so that the parameter values could not be negative. Triangular distributions were expressed in terms of the minimum, maximum and most probable value (designated apex in the table). Uniform distributions were expressed in terms of their minimum and maximum values.

6.2.2.3. Correlations between parameters

It is reasonable to assume that the values of some variables are correlated, i.e. if one parameter has a high value then the other parameter also has a high (positive correlation) or low (negative correlation) value. The correlations are expressed in the LHS sampling program in terms of rank correlations between the parameters. If the correlation used in the site specific uncertainty analyses was specified, then that value was also used in the BioGeM analysis. If the value was not specified for the site specific analysis, then the correlations used by Karllson et al (2001) were used. The correlations adopted for this analysis are given in Table 6-13.

Nuclide independent			
Parameter	Distribution Type	Specifications of distribution	Country
Q_I	BN	E=value, σ=E/2, min=0, max=10E	Germany
U_I	T	Min=value/2, apex=value, max=1.5value	Sweden
If_I	T	Min=value/10, apex=value, max=3value	Spain
I_{irr}	U	Min=0, max=value	Belgium
R	U	Min=0, max=value	Belgium
M_{sa}	T	Min=value/2, apex=value,max=1.5value	Sweden
θ_s	T	Min=0.75value,apex=value, max=1.25value	Sweden
Er_s	T	Min=0.75value,apex=value, max=1.25value	Sweden
Oc	BN	E=value, σ=E/5, min=0, max=10E	Germany
Nuclide dependent			
Parameter	Distribution	Specifications	Country
Kds	T	Min=value/10, apex=value, max=5value	Hungary
Kdsed	T	Min=value/10, apex=value, max=5value	Hungary
B_I	T	Min=value/10, apex=value, max=5value	Hungary
F_I	T	Min=value/10, apex=value, max=5value	Hungary

Table 6-12: Distribution data for independent parameters (BN = bounded normal with parameters average value, standard deviation, LN is log normal with parameters ln(average), ln(standard deviation), T = triangular with parameters average value, minimum value, maximum value, U = uniform with parameters minimum value, maximum value)

WHERE DO THESE SPECIFICATIONS STAND FOR AND WHY ONLY ONE COUNTRY IS MENTIONED??

Specifications are the details of the values used each distribution, country is the country from which the specification of the distribution is adopted.

Detailed results of the uncertainty analysis for each radionuclide considered are summarised in Annex 4. The uncertainties are quantified by the 5^{th} and 95^{th} percentile. The results are given for all geosphere biosphere interfaces that are potentially relevant for each site. The results are broken down to the main exposure routes as ingestion, inhalation and external exposure. Due to the dominating contribution, the 5^{th} and 95^{th} percentile of the drinking water pathway is given as well.

At the Belgian, Spanish and Hungarian site, the difference between the well and the river/reservoir as geosphere-biosphere interface is mainly due to the ingestion of fish. The most complex system is considered at the Swedish site, where the input of radionuclides to the biosphere is considered via the contamination of a well, lake and coastal water. Furthermore, the contamination of crops via the rise of contaminated groundwater from the aquifer to the top soil is modelled. However, although these numbers are also normalised to the activity per unit water, the results achieved are not directly comparable with the cases where water is withdrawn from a well or a surface water body.

Belgium well and river		
Parameter 1	Parameter 2	Correlation coefficient
Kd_s	B_{vl}	-0.8
B_{vi}	Bvj (for all i ≠ j)	0.64
Germany well and river		
Parameter 1	Parameter 2	Correlation coefficient
Kd_s	B_{vl}	-0.7
B_{vi}	Bvj (for all i ≠ j)	0.64
F_I	Fj (for all i ≠ j)	1.0
If_I	Ifj (for all i ≠ j)	1.0
Swedish well		
Parameter 1	Parameter 2	Correlation coefficient
Kd_s	B_{vl}	-0.7
Kd_s	B_{vr}	-0.56
B_{vl}	B_{vr}	0.8
Swedish lake		
Parameter 1	Parameter 2	Correlation coefficient
Q_b	Q_f	-0.7
Kd_s	B_{vr}	-0.8
Kd_s	B_{vc}	-0.8
Kd_s	B_{vgr}	-0.8
B_{vc}	B_{vgr}	0.64
B_{vc}	B_{vr}	0.64
B_{vgr}	B_{vr}	0.41
Q_{vc}	Q_{vr}	-0.7
Swedish agricultural land model		
Parameter 1	Parameter 2	Correlation coefficient
Kd_s	B_{vr}	-0.8
Kd_s	B_{vc}	-0.8
Kd_s	B_{vgr}	-0.8
B_{vc}	B_{vgr}	0.64
B_{vc}	B_{vr}	0.64
B_{vgr}	B_{vr}	0.41
Q_{vc}	Q_{vr}	-0.7
Swedish coastal model		
Parameter 1	Parameter 2	Correlation coefficient
Q_b	Q_f	-0.7
Kd_{sed}	F_f	-0.8

Table 6-13: Correlation coefficients used in uncertainty analysis

6.2.2.4. Comparison of stochastic results of the site-specific models and BioGeM

The stochastic results of the site-specific models and the generic model applied for the specific sites are summarised in Figure 6-4 to Figure 6-11 (the results obtained with the BioGeM are indicated by the suffix “nrpb”). In order to maintain clearness, the results are presented for adults only.

Figure 6-4 shows a direct comparison of the normalised adult total doses obtained using the Belgian site specific model and BioGeM. It shows that the 5th and 95th percentiles of the uncertainty distributions of doses to adults obtained by the two models overlap for all nuclides.

Figure 6-5 show a direct comparison of the normalised adult and infant total doses for the well and pond scenarios obtained using the German site specific model and BioGeM. The uncertainty ranges specified by the 5th and 95th percentiles of the doses to adults and infants obtained by the two models overlap and is in good agreement for all nuclides.

Figure 6-6 shows a direct comparison of the 5^{th} and 95^{th} percentile normalised adult total doses for the well scenario for the Hungarian results and BioGeM. The results for the Hungarian 5^{th} and 95^{th} percentile doses fall within the BioGeM results other than for Cs-36, Cs-135, Ra-226 and Pa-231. In general, the uncertainty (expressed as the ratio of the 95^{th} to 5^{th} percentile) as predicted by BioGeM is greater than that predicted by the Hungarian model.

Figure 6-7 show a direct comparison of the adult total doses summed over the well, river and reservoir scenarios between the Spanish site specific model results and BioGeM. The figure shows that ranges defined by the 5^{th} and 95^{th} percentiles of the doses to adults obtained by the two models overlap for all nuclides except for Ra-226.

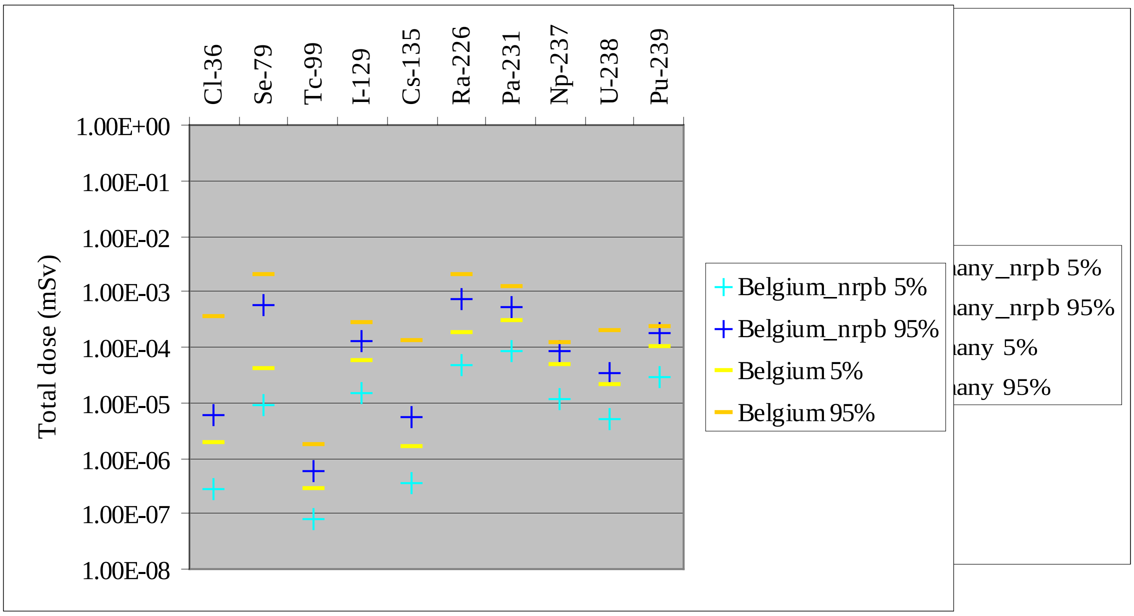
Figure 6-8 to Figure 6-11 show a comparison of the 5^{th} and 95^{th} percentile total dose for the scenarios for the Swedish results and BioGeM. For well doses in Figure 6-8, the Swedish 5^{th} and 95^{th} percentile doses fall within the BioGeM results except for Ra-226 and U-238. It is also noted that there is more spread in the 5^{th} and 95^{th} percentile BioGeM doses. For the adult lake doses in Figure 6-9 only the U-238 Swedish 5^{th} and 95^{th} percentile doses lie outside the BioGem doses.

The exposures for the scenario of rising ground water are presented in Figure 6-10. There is no overlap of the Swedish 5^{th} and 95^{th} percentile doses and BioGeM doses, with the BioGeM doses being several orders of magnitude greater than the Swedish results. This may be due to different normalisation methods.

For the adult coast doses in Figure 6-11 Swedish 5^{th} and 95^{th} percentile doses lie outside the BioGeM doses, with the Swedish doses being higher than the BioGeM doses. This may also be due to different normalisation methods.

Belgium Adult well doses added for consistency of figures, please exchange for figure 6-4.

There are also two figures 6-5 superposed on each other, please delete one of them.



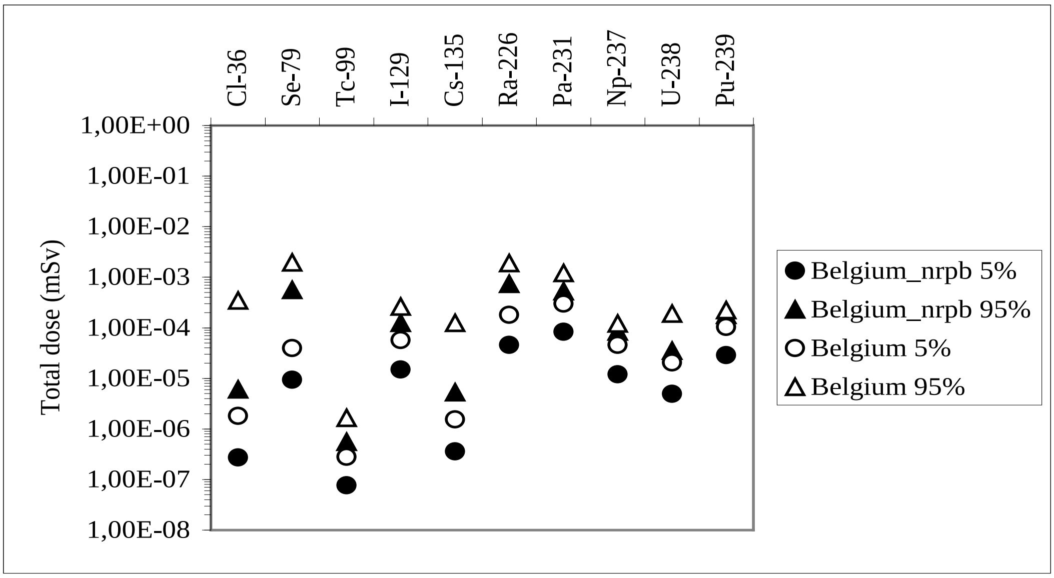


Figure 6-4: Belgian site, comparison of the 5th and 95th percentiles of the normalised **adult** total dose for the **well** scenario according the generic assessment tool BIOGEM and the site specific Belgian model

MAYBE IT WOULD BE USEFULL TO CHANGE THE FIGURES MORE IN THE LATTER STYLE ??

Figure 6-5: German site, comparison of the 5th and 95th percentiles of the normalised **adult** total dose summed over the **well** and **pond** scenarios according the generic assessment tool BIOGEM and the site specific German

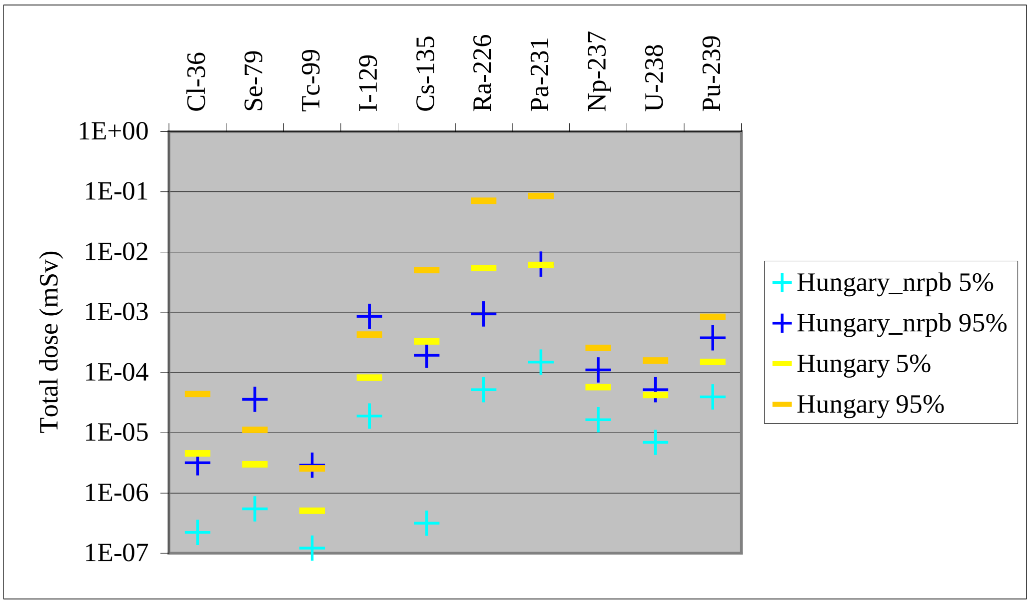


Figure 6-6: Hungarian site, comparison of the 5th and 95th percentiles of the normalised **adult** total dose for the **well** scenario according the generic assessment tool BIOGEM and the site specific Hungarian model

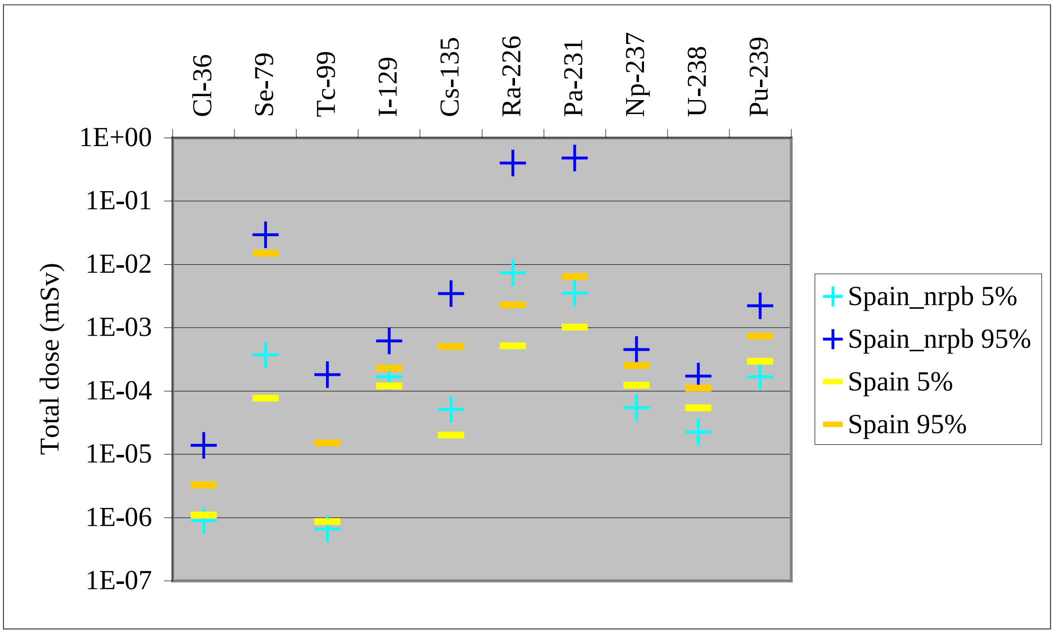


Figure 6-7: Spanish site, comparison of the 5th and 95th percentiles of the normalised **adult** total dose summed over the **well, river** and **reservoir** scenarios according the generic assessment tool BIOGEM and the site specific Spanish model

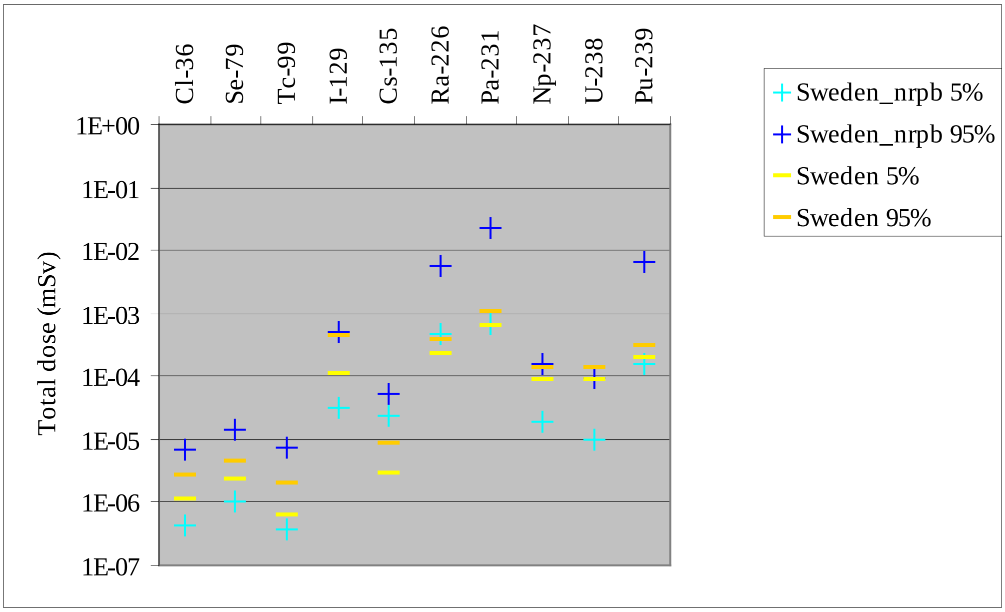


Figure 6-8: Swedish site, comparison of the 5th and 95th percentiles of the normalised **adult** total dose for the **well** scenario according the generic assessment tool BIOGEM and the site specific Swedish model

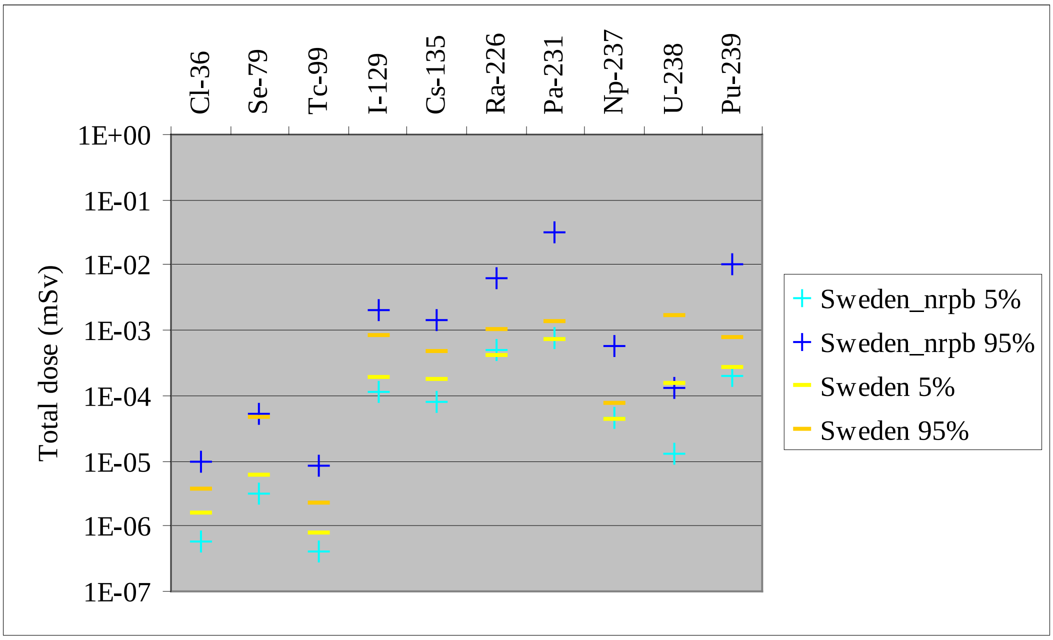


Figure 6-9: Swedish site, comparison of the 5th and 95th percentiles of the normalised **adult** total dose for the **lake** scenario according the generic assessment tool BIOGEM and the site specific Swedish model

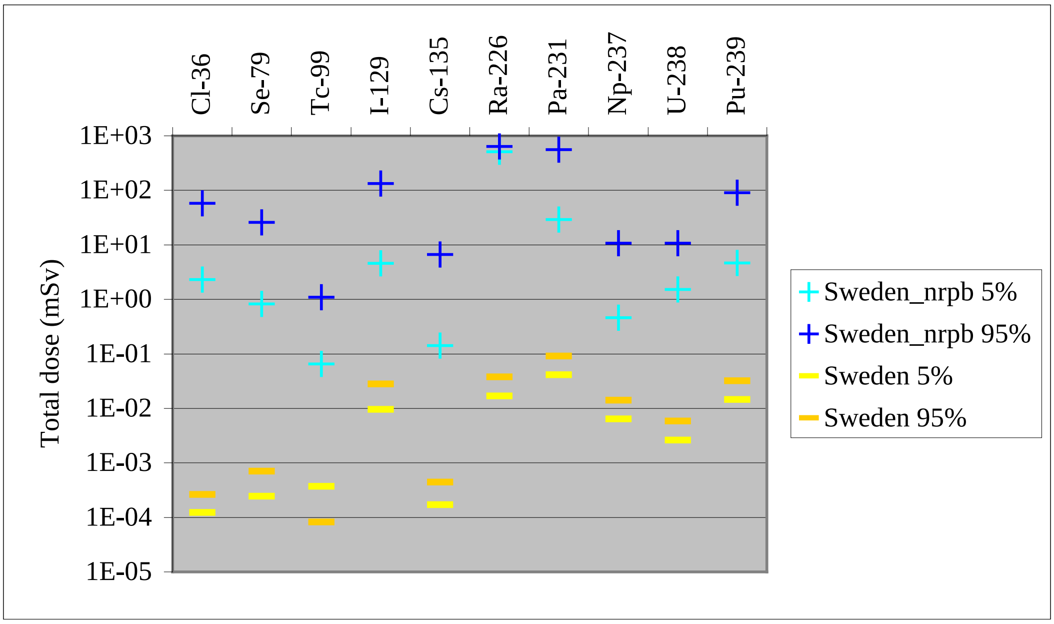


Figure 6-10: Swedish site, comparison of the 5th and 95th percentiles of the normalised **adult** total dose for the **rising groundwater** scenario according the generic assessment tool BIOGEM and the site specific Swedish model

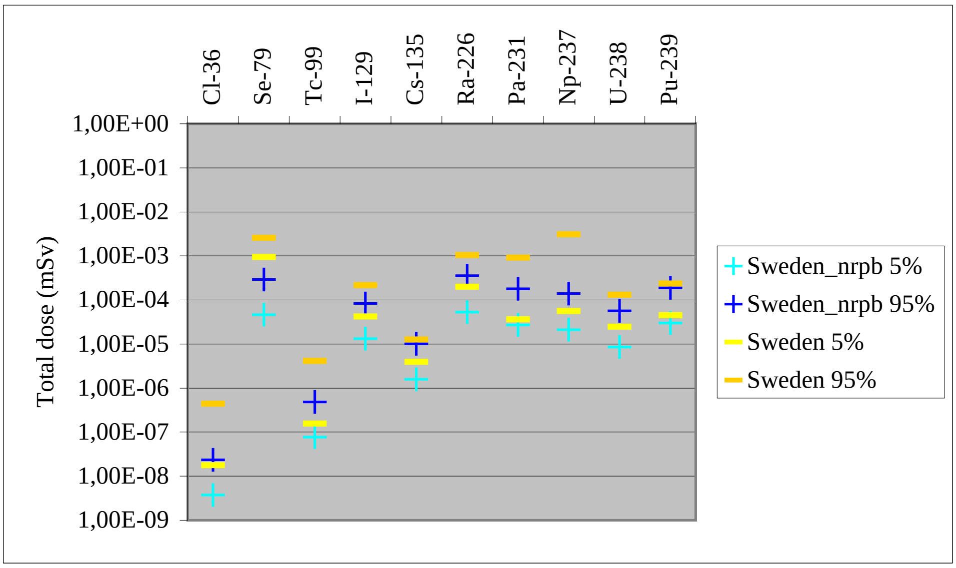


Figure 6-11: Swedish site, comparison of the 5th and 95th percentiles of the normalised **adult** total dose for the **coast** scenario according the generic assessment tool BIOGEM and the site specific Swedish model

6.3. Determination of the most important parameters

The nonparametric (distribution-free) rank statistic proposed by Spearman in 1904 (Spearman 'rho' or Spearman rank coefficient) was used as a measure of the strength of the associations between the variables and the calculated results. The Spearman rank correlation coefficient can be used to give an R-estimate, and is a measure of monotone association that is used when the distribution of the data make Pearson's correlation coefficient undesirable or misleading. The Spearman rank correlation coefficient is defined by:

$$R = 1 - \frac{6\sum_{i=1}^{n} D_i^2}{n(n^2 - 1)}$$

The procedure is to rank the *X* sample from 1 to *n* and, independently, the *Y* sample form 1 to *n*, keeping track of the originals pairs. Than the test statistic is a function for the sum of squares of the differences D between corresponding ranks of the *X* and *Y* variables. The value *R* = 1 describes a perfect direct, or positive, relationship between ranks; *R* = -1 describes a perfect indirect, or negative, relationship between ranks; while *R* = 0 describes no relationship.

Only the parameters which are significant are represented in the next tables. The threshold value for each model for determining the significance was calculated by the equation:

$$w = \frac{1.96}{\sqrt{n-1}}$$

Where *n* is the number of samples (runs) used in each model. The parameters with a Spearman rank correlations coefficient that was lower than this threshold value *w* was omitted.

In the following part the 5 most important parameters are identified for each radionuclide with a significant influence on the total dose for each model.

The most sensitive parameters for adults were listed in Table 6-14 for adults and Table 6-15 for infants. From the sensitivity analysis was derived that, depending of the model and the type of plant species, the interception factor was a sensitive parameter for the dose received by Tc-99, I-129; Ra-226, Np-237, U-238 and Pu-239, and this for both critical groups. The Kd value for soil was significant for all radionuclides except for Pb-210, Po-210 and Pa-233. The sensitivity of the transfer factors from soil to plant is very plant specific. For the adult critical group, depending on the model, this transfer factor can be considered as a sensitive parameter for all radionuclides except for Rn-222. For the infant critical group also Np-237 and U-238 can be omitted. Depending on the animal product considered, the transfer factor for feed is sensitive for Cl-36, Se-79, Tc-99, I-129, Cs-135 Ra-226, U-238 and Pb-210 for both critical groups. Nevertheless this sensitivity is also model-dependent. In the well scenario, the concentration factor for fish is considered as a sensitive factor (spearman 'rho' coefficient of 0.15) by the German model. The variability of the food consumption by infants and adults also has a high influence on the end dose received by all radionuclides except for Rn-222. The influence of the inhalations rate is considered as being a important factor by the Hungarian model. This is the case for Ra-226 and Rn-222 for adults and for Ra-226, Rn-222 and Pa-231 for infants. For the Spanish model, the variability on the water storage capacity has a high influence on the dose received by Ra-226, Pa-231 and Rn-222 for infants and on the dose received by Ra-226, Pa-231, Np-237, U-238 and Rn-222 for adults.

Parameter	*Cl-36*	*Se-79*	*Tc-99*	*I-129*	*Cs-135*	*Ra-226*	*Pa-231*	*Np-237*	*U-238*	*Pu-239*	*Pb-210*	*Po-210*	*Rn-222*	*Ac-227*	*Pa-233*
Interception factor			D^{1-6}	E^{3}		E^{7}		$B^{5,6}$	D^{1-6}	$B^{5,6}$					
Kd value soil	H B S	E B	B S	B	H B S	H B	H E B	B	H B	B			H	E	
Transfer factors soil-plant	$E^{1,3-6}$ D^{1-6} B^{1}	D^{1-6} B^{1} S^{4}	D^{1-6} $B^{1,5}$ S^{4}	D^{1-6} B^{1} $S^{4,5}$	D^{1-6} B^{1} $S^{4,5}$ H^{6}	D^{1-6} B^{1Po} B^{4Pb}	D^{1-6} B^{4aAc} B^{4bAc}	B^{4b}	B^{1} B^{4a}	B^{4b}	$H^{3,6}$	$H^{4,5}$		$H^{5,6}$	H^{4}
Transfer factors feed	D^{8-10} B^{9} H^{10}	$H^{8,10}$ B^{9} E^{10}	B^{8}	D^{8-10} H^{8} B^{9}	D^{8-10} H^{10} B^{9}	B^{8Pb}			B^{9}			E^{8}			
Concentration factor water fish		D													
Food consumption	$E^{0,3,13}$ $D^{0,8}$ $H^{8,10}$	$D^{0,11}$ S^{0} $H^{5,8,10}$	$D^{0,6}$ $H^{5,6}$ $E^{8,9,12,13}$	$H^{0,5,8}$ $E^{0,7,13}$ $D^{0,8}$	$D^{0,8}$ H^{10}	$E^{0,13}$ S^{0} $D^{0,3}$	D^{0} S^{0}	$H^{0,5}$ D^{0} S^{0} $E^{9,13}$	H^{5} D^{0} S^{0} $E^{7,9,13}$	H^{5} D^{0} S^{0} E^{13}	$H^{3,6}$ $E^{9,11}$	$E^{3,9,13}$ $H^{4,5}$		$E^{0,11}$ $H^{5,6}$	$H^{3,4}$
Inhalation rate						H							H		
Water storage of vegetation						S	S	S	S	S					
Irrigation water applied	$E^{1,3-7,13,14}$ D^{1-6} $S^{1,3-5}$ H^{6} B^{1}	D^{1-6} $S^{1-3,5}$ B^{1}	$E^{1,3-7,13,14}$ D^{1-6} $S^{1,3-5}$ H^{6} B^{1}	$E^{1,3-7,13,14}$ D^{1-6} $S^{1,3-5}$ $B^{1,4}$	D^{1-6} $S^{1,3-5}$ H^{6} B^{1}	D^{1-6} H^{6} B^{1}	D^{1-6} $S^{1,3-5}$ B^{4} H^{6}	$E^{1,3-7,13,14}$ H^{5}	D^{1-6} $E^{1,3-7,13,14}$ B^{4} $H^{5,6}$	$E^{1,3-7,13,14}$ H^{5}		$E^{1,3-7,13,14}$	H^{6}		
Number of irrigation events	S	S	S		S	S	S	S	S	S					
Yield						S^{5}	S^{5}	S^{5}	S^{5}	S^{5}					
Feed of dairy cow				H^{0}											
Element-specific retention factor						S		S	S	S					
Infiltration rate for soil	B	B			B		B								
Preparation factor for vegetables			H				H	H	H	H	H	H		H	H
Rn/Ra-Factor						H	H						H		
Weathering half live								H B		H B					
Shielding factor															H
Migration in Soil							D		D						

Table 6-14: Illustration of the 5 most important parameters for each radionuclide with a significant influence on the total dose received by adults for each model. Sensitivity was evaluated according to the Spearman 'rho' coefficient. (superscript: ^{0} Water — ^{1} Grass — ^{2} Maize — ^{3} Cereals — ^{4} Potatoes(^{a}) & roots(^{b}) — ^{5} Leafy vegetables — ^{6} Fruit vegetables — ^{7} Fruit — ^{8} Milk — ^{9} Beef— ^{10} Pork — ^{11} Fish — ^{12} Chicken — ^{13} Leguminosae *— ^{14} Citrics — ^{15} Mutton/Lamb — ^{16} Eggs — ^{Po} Po-210 — ^{Pb} Pb-210 — ^{Ac} Ac-277)*

	Cl-36	Se-79	Tc-99	I-129	Cs-135	Ra-226	Pa-231	Np-237	U-238	Pu-239	Pb-210	Po-210	Rn-222	Ac-227	Pa-233
Interception factor			D^{1-6}	E^{3}		E^{7}		D^{1-6} B^{5} H^{5}		B^{5}					
Kd value soil	H B S	E B S	B S	B	H B	H B	H E B	B	H B	B S			H	E	
Transfer factors soil-plant	$E^{1,3-6}$ D^{1-6} B^{1}	D^{1-6} B^{1} S^{4}	D^{1-6} B^{5} $S^{4,5}$ H^{6}	D^{1-6} B^{1} S^{4}	D^{1-6} B^{1} $S^{4,5}$ H^{6}	D^{1-6} B^{1Po}	D^{1-6} B^{4aAc}			D^{1-6}	$H^{3,6}$	$H^{4,5}$		$H^{5,6}$	$H^{3,4}$
Transfer factors feed	D^{8-10} B^{9} $H^{8,10}$	D^{8-10} $B^{8,9}$ $H^{8,10}$ S^{8} E^{10}	B^{8}	D^{8-10} $B^{8,9}$ H^{8} S^{8}	D^{8-10} $B^{8,9}$ H^{10} S^{8}	B^{8Pb}			D^{8-10} B^{9}			E^{8}			
Concentration factor water fish		D													
Food consumption	$E^{0,3,13}$ $D^{0,8}$ H^{8}	$D^{0,11}$ $H^{0,8,10}$	$D^{0,6}$ $H^{5,6}$ $E^{8,9,12,13}$	$H^{0,5,8}$ $E^{0,7,13}$ $D^{0,8}$	$D^{0,8}$	$E^{0,13}$ $D^{0,3}$	D^{0}	$H^{0,5}$ D^{0} S^{5} $E^{9,13}$	H^{0} D^{0} $E^{7,9,13}$	$H^{0,5}$ D^{0} E^{13}	$H^{3,6}$ $E^{9,11}$	$E^{3,9,13}$ $H^{4,5}$		$E^{0,11}$ $H^{5,6}$	H^{4}
Inhalation rate						H	H						H		
Water storage of vegetation							S	S		S					
Irrigation water applied	$E^{1,3-7,13,14}$ D^{1-6} $S^{1,3-5}$ H^{6} B^{1}	$S^{1,3-5}$ B^{1}	$E^{1,3-7,13,14}$ D^{1-6} $S^{1,3-5}$ H^{6} B^{6}	$E^{1,3-7,13,14}$ D^{1-6} $S^{1,3-5}$ B^{1}	D^{1-6} $S^{1,3-5}$ H^{6} B^{1}	D^{1-6} H^{6} B^{1}	D^{1-6} $S^{1,3-5}$ B^{6} H^{6}	$E^{1,3-7,13,14}$ D^{1-6} B^{6}	D^{1-6} $E^{1,3-7,13,14}$ B^{6} $H^{5,6}$	D^{1-6} $E^{1,3-7,13,14}$ $S^{1,3-5}$ B^{6}		$E^{1,3-7,13,14}$	H^{6}		
Number of irrigation events	S	S	S		S		S	S		S					
Yield							S^{5}	S^{5}		S^{5}					
Feed of dairy cow				H^{0}											
Element-specific retention factor								S							
Infiltration rate for soil	B					B									
Preparation factor for vegetables			H		H		H	H		H	H	H		H	H
Rn/Ra-Factor						H	H						H		
Weathering half live							B	H B	B	H B					
Shielding factor									H						H
Translocation factor			B^{6}				B^{6}	B^{6}	B^{6}	B^{6}					

Table 6-15:Illustration of the 5 most important parameters for each radionuclide with a significant influence on the total dose received by infants for each model .The sensitivity was evaluated according to the Spearman 'rho' coefficient. (superscript: ^{0} Water — ^{1} Grass — ^{2} Maize — ^{3} Cereals — ^{4} Potatoes(^{a}) & roots(^{b}) — ^{5} Leafy vegetables — ^{6} Fruit vegetables — ^{7} Fruit — ^{8} Milk — ^{9} Beef— ^{10} Pork — ^{11} Fish — ^{12} Chicken — ^{13} Leguminosae *— ^{14} Citrics — ^{15} Mutton/Lamb — ^{16} Eggs — ^{Po} Po-210 — ^{Pb} Pb-210 — ^{Ac} Ac-277)*

A parameter with a high impact on the dose received by almost all radionuclides (except for Pb-210, Ac-227 and Pa-233) is the irrigation rate. Also this factor is model and plant species dependent. For the Spanish model, the number of irrigation events also is a sensitive factor and this for Cl-36, Se-79, Tc-99 Cs-135, Ra-226 (only for adults), Pa-231, Np-237,U-238 (only for adults) and Pb-210. The yield of the leafy vegetables has a high influence on the total dose received by Ra-226 (only for adults), Pa-231, Np-237, U-238 (only for adults) and Pu-239. Only for the Hungarian model, the ingestion of water contaminated with I-129, is a sensitive parameters for the total dose. The element specific retention factor is considered as a sensitive factor by the Spanish model and this for the radionuclides Ra-226, Np-237, U-238 and Pu-239 for adults but only for Np-237 for infants. The probabilistic analysis of the Belgian models derived that infiltration rate for soil has a high influence on the total dose received by Cl-36, Se-79 Cs-135 and Pa-231 contamination towards adults and Cl-36 and Ra-226 towards infants. The values of the preparation factor for vegetables had a high influence on the impact of the radionuclides (Tc-99, Pa-231, Np-237, U-238, Pu-239, Pb-210, Po-210, Ac- and Pa-233 for adults and Tc-99, Cs-135, Pa-231, Np-237, Pu-239, Pb-210, Po-210, Ac- and Pa-233 for adults). For the calculation of the total dose of Ra-226, Pa-231 and Rn-222, the Rn/Ra-factor is also important. For the Belgian and Hungarian model, the half life for weathering for the radionuclides Np-237 and Pu-239 is a very sensitive factor for both adults and infants. For infants the factor is also important for the impact of Pa-231 and U-238. The shielding factor is only important for the Hungarian model for Pa-233.

The migration in soil was only significant for Pa-231 and U-238 for the German adult group. The translocation factor for fruit vegetables (pods) was only significant for Tc-99, Pa-231, Np-237, U-238 and Pu-239 for Belgian infants

7. Discussion and Conclusions

In the framework of the BioMoSA project, biosphere models for the application in performance assessment studies of nuclear waste disposals were developed on the basis of the Reference Biosphere Methodology that has been developed within the international BIOMASS project. The model development in the BioMoSA study was done for five European sites that cover a wide range of agricultural, climatic and social conditions. In parallel, a generic model was developed that is able to simulate all features, events and processes that are considered in the site-specific models. The models were compared on the base of both deterministic and stochastic results. Furthermore, the results obtained with the site-specific models are compared against those obtained by the generic model. From the study, the following conclusions for the performance of safety studies can be drawn:

- The methodology developed within the BIOMASS project for the setup of a reference model is considered to be useful. The FEP-list is a good starting point for identification of pathways and processes; however it does not replace the experience of the modeller. Despite the guidance of Reference Biosphere Methodology, the model approaches applied are subject to individual interpretation of the processes and the available parameters.
- The model complexity should be consistent with the available data base for the parameters required. Simpler models facilitate uncertainty analysis. They are in general more transparent and easier to communicate.
- The foods considered in the models reflect to some extent national consumption habits. The Spanish model explicitly takes into account the consumption of citric fruit, whereas the Swedish habits reflect the importance the fresh water fish.
- Although the models consider the same basic processes, different approaches are applied in some cases. The main differences concern the modelling of the radionuclide contamination of plants by irrigation which covers the processes interception, post-deposition retention, translocation and root uptake. All models assume a plant-dependent interception factor, however only the German and Swedish models consider that this parameter depends on the element as well.

  The post-deposition retention is treated relatively similar by means of a weathering half-life which is in some cases modified for specific plants. In the Swedish model, the weathering process is not explicitly modelled, because the approach focuses on the activity at harvest and weathering is implicitly taken into account. In the German model, weathering is explicitly considered only in case of plants that are totally used; otherwise the approach is similar to the Swedish model.

  Translocation quantifies the systemic transport of radionuclides in plants. The Spanish model does not model it, the Swedish and Belgium model only for root crops. The German model takes into account the dependence on crop and element, whereas the Hungarian model assumes only dependence on crop, but not on element.
- The variations of the normalised exposures [in Sv/a per Bq/m^3] for the well scenario among the sites are in general less than a factor of 10. For all sites, the intake of drinking water is an important or even dominating contributor to the exposure. Due to physiological restrictions, the variation of the intake of drinking water is low. Therefore, the intake of drinking water represents a kind of a "baseline" with relatively little variations among the sites, on top of which the ingestion of foods have to be considered.

- The amount of food consumed is also constrained for physiological reasons. The consumption habits among the sites vary in terms of the food items, but not in terms of the total amount of foods. Therefore the variation of the ingestion dose in general is limited.
- In general, there is acceptable agreement between the results obtained with the generic and the site-specific models respectively. The interpretation of data, especially when the data base is very poor, is still a major source of uncertainty. This is especially true for Cl-36, I-129 and Se-79. The careful consideration of the speciation and the interaction of these elements with soil constituents is an essential need.
- The results for the lake, marine and a release to the deep soil are associated with larger uncertainty which is due to the much higher complexity of the specific sites.
- The k_d-concept to model migration of radionuclides in soil is used in 4 of the site-specific models. However, the determination of the underlying k_d-values should be carefully analysed. Should they be based on batch-experiments, the applicability is very likely to be limited, since then they consider only sorption/desorption processes.
- Apart from sorption/desorption processes that are quantified by the k_d–value the depth distribution of radionuclides in soil is also subject to erosion and bioturbation. Furthermore, the migration of radionuclides that are attached to soil particles is a process of potential importance. In general, the migration of radionuclides in soil has to be derived from experiments or investigations that are relatively short compared to the time periods considered in performance assessment of radioactive waste disposals.
- The experimental data base to model the exchange from the deep soil to the upper soil is still very poor which causes considerable uncertainties in this field. This is especially important, if the deep soil is considered as the geosphere-biosphere-interface.
- The sites considered in BioMoSA cover a wide range of environmental and climatic conditions. Although the influence of the climate is not a major objective of the BioMoSA project, the comparison of the results for the five sites indicate that the impact of climatic factors is relatively low due to the levelling effect of the exposure arising from the intake of drinking water.
- In general, the intake of water, the irrigation rates and the dust load in air are the most important parameters influenced by climate. The intake of water has physiological constraints. In the assessment context, it is defined that the agricultural practices should allow a sustainable land-use. This condition limits the amount of irrigation water to be applied, since under very dry and arid conditions sustainable agriculture requires a careful and expensive water management.
- From the stochastic calculations, the 5 most sensitive parameters were determined. From the more than hundred parameters, which were used to run the different models, only 20 seem to be having a significant contribution to the total dose. The most important parameters are the transfer-factors for soil-to-plant and soil-to-beef, food consumption, irrigation water applied and distribution coefficient for soil. These parameters were significant for 3 or more than 3 sites for at least one radionuclide.
- A generic model, BioGeM, has been developed and is available for use, subject to purchase of a software licence for the numerical solution method. It has been successfully used to model 5 sites with a range of climates and geosphere/ biosphere interfaces. The results agree well with the site specific runs. The calculations with the

generic model allow the variability between sites to be investigated on a common basis. Both the generic model and site specific models agree on the important parameters.

- As recommendation to the adaptation (simplification) of the generic model, it could be said that all pathways are potentially important if the large number of different radionuclides are kept in mind that can be released by a repository.
- BioMoSA provides a large amount of data for 5 sites, including detailed biosphere descriptions, concentrations in the environment and associated doses. These can be used as a benchmark for other studies.
- Within the BioMoSA study, 10 radionuclides are involved that are considered to be most relevant in performance assessment studies. The conclusions drawn refer to these radionuclides only.

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