Migration and uptake of radionuclides in the biosphere

PA-model 'Biosphere'

OPERA-PU-SCK631&NRG7232

Radioactive substances and ionizing radiation are used in medicine, industry, agriculture, research, education and electricity production. This generates radioactive waste. In the Netherlands, this waste is collected, treated and stored by COVRA (Centrale Organisatie Voor Radioactief Afval). After interim storage for a period of at least 100 years radioactive waste is intended for disposal. There is a world-wide scientific and technical consensus that geological disposal represents the safest long-term option for radioactive waste.

Geological disposal is emplacement of radioactive waste in deep underground formations. The goal of geological disposal is long-term isolation of radioactive waste from our living environment in order to avoid exposure of future generations to ionising radiation from the waste. OPERA (OnderzoeksProgramma Eindberging Radioactief Afval) is the Dutch research programme on geological disposal of radioactive waste.

Within OPERA, researchers of different organisations in different areas of expertise will cooperate on the initial, conditional Safety Cases for the host rocks Boom Clay and Zechstein rock salt. As the radioactive waste disposal process in the Netherlands is at an early, conceptual phase and the previous research programme has ended more than a decade ago, in OPERA a first preliminary or initial safety case will be developed to structure the research necessary for the eventual development of a repository in the Netherlands. The safety case is conditional since only the long-term safety of a generic repository will be assessed. OPERA is financed by the Dutch Ministry of Economic Affairs and the public limited liability company Electriciteits-Produktiemaatschappij Zuid-Nederland (EPZ) and coordinated by COVRA. Further details on OPERA and its outcomes can be accessed at www.covra.nl.

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Contents

Summary

The transport and uptake of radionuclides in the biosphere forms the topic of the present report. The biosphere is the fourth and last compartment of the repository system in Boom Clay succeeding the source, the Boom Clay as host formation and the host rock surrounding rock formations.

Dose conversion coefficients were calculated by SCK•CEN with the model 'BIOSPHERE' developed by SCK•CEN and applied in the Belgian radioactive waste disposal research program. That work resulted in three sets of dose conversion coefficients, relating the interface between the biosphere and the overburden to dose rates of individuals in the biosphere. Three stylized biospheres were considered related to either present climate, a warmer climate or a colder climate.

In the PA-model the biosphere was modelled as a single compartment with homogeneous properties. The calculations were carried out using the ORCHESTRA code. The benchmark of the computed results has been done by application of EXCEL. By benchmarking it was shown that ORCHESTRA is a suitable tool and the model is implemented correctly.

The present results describe the expected behaviour of the system - the Normal Evolution Scenario. For further scenarios, the same PA-model can be used.

Samenvatting

Het transport en de opname van radionucliden in de biosfeer vormt het onderwerp van dit rapport. De biosfeer is het vierde en laatste compartiment van een eindopslagfaciliteit in Boomse Klei dat volgt na de bron, de Boomse Klei als gastgesteente en de geologische formaties rond het gastgesteente.

De gebruikte dosisconversiecoëfficiënten werden berekend door het SCK·CEN met het model 'BIOSPHERE', dat werd ontwikkeld door het SCK·CEN en toegepast in het Belgische onderzoeksprogramma naar geologische eindberging van radioactief afval. Dat werk resulteerde in drie sets van dosisconversiecoëfficiënten, die het verband beschrijven tussen concentraties op het grensvlak tussen de biosfeer en rond het gastgesteente liggende geologische formaties (overburden) en de individuele dosis. Er zijn drie gestileerde biosferen beschouwd, die gerelateerd zijn aan respectievelijk het huidige klimaat, een warmer klimaat of een kouder klimaat.

In het PA-model werd de biosfeer gemodelleerd als een enkel compartiment met homogene eigenschappen. De berekeningen zijn uitgevoerd met behulp van de ORCHESTRA code. De benchmark van de berekende resultaten is gedaan door middel van EXCEL. Door benchmarking werd aangetoond dat ORCHESTRA een geschikt instrument is en dat de PA-model voor biosfeer correct is geïmplementeerd.

De resultaten geven het verwachte gedrag van het systeem weer - het Normale Evolutie Scenario. Voor andere scenario's kan hetzelfde PA-model worden gebruikt.

1. Introduction

1.1. Background

The five-year research programme for the geological disposal of radioactive waste - OPERA - started on 7 July 2011 with an open invitation for research proposals. In those proposals, research was proposed for the tasks described in the OPERA Research Plan (Verhoef & Schröder, 2011).
The present report describes the execution and results of the research proposed for task 7.2.3 with the following title in the Research Plan: *PA model for radionuclide migration and uptake in the biosphere*. The main objective of that task is to develop a code for the calculation of the exposure to radionuclides that have reached the biosphere. The proposed modelling and calculation approach is based on the findings of Task 6.3.1 (Modelling approach for transport & uptake processes) and will serve as direct input to Task 7.2.4 (Integrated modelling environment for safety assessment) that will be used for sensitivity analyses and safety assessment calculations within Task 7.3.3.

1.2. Objectives

The conceptual PA-model applied in OPERA represents the region between the disposed waste and potential receptors (i.e. humans) in our environment. The region between the waste and the receptor is conceptually divided into compartments: the waste matrix, the engineered barriers, the clay host rock, the host rock surrounding rock formations, and the biosphere.
The basic premise is that the radionuclides have to move from the waste through these compartments to reach the receptors in the biosphere. The various scenarios differ in the processes that drive the radionuclide migration through each of the compartments and/or the pathways available for radionuclide transport through the compartments.
The complete PA model consists of the models "Waste" (including the EBS), "Clay", "Aquifer" and "Biosphere". In line with this, the implementation of the PA-model for the calculation of the exposure to the radionuclides that reach the biosphere is referred to as the PA-model "Biosphere".

1.3. Realization

This report was compiled by NRG, TNO and SCK·CEN. TNO compiled information on the geomorphological and climatic evolution of The Netherlands. The dose conversion coefficients were calculated by SCK·CEN using the 'BIOSPHERE' model based on the modelling approach for transport & uptake processes, set out in Task 6.3.1. The implementation and verification of the PA-model for biosphere were carried out by NRG.

1.4. Explanation contents

General information on the project and an introduction to this report are given in the present Chapter. The OPERA safety assessment methodology and the conceptual model for the performance assessment (PA) are summarised in Chapter 2, which also includes a description of the interface of the biosphere with the adjacent compartment (overburden Chapter 3 defines the mathematical PA-model for the biosphere compartment. The numerical implementation of the PA-model is described in Chapter 4. Chapter 4 includes also an overview of the required input parameters and of the output parameters to be calculated. Chapter 5 provides the conclusions and recommendations.

Extensive appendices give background information for the subjects described in the main report. Appendix A provides an overview of main projects and programmes on the modelling of the biosphere in safety assessments of geological waste repositories. The conceptual biosphere model is described in Appendix B. Information on the quality of groundwater in the Netherlands is given in Appendix C and the results of the ranking of the processes by their significance for the water well receptor are presented in Appendix D. Finally, the relative contributions of different pathways to the dose are listed in Appendix E.

2. Conceptual model for the Biosphere PA-model

2.1. OPERA Safety assessment methodology

The present report describes the formulation and implementation of the assessment model for the biosphere compartment as defined in step four of the recommended safety assessment methodology for the OPERA project ([Grupa, 2014; p.11, p.14]). Step 4 of the assessment methodology *Formulation and Implementation of Assessment Models* requires:

1. A conceptual model that provides a description of the components of the system and the interactions between these components.
2. A mathematical model, which is a mathematical representation of the features and processes included in the conceptual model.
3. A computer code, which is a software implementation of the mathematical model that facilitates performance of the assessment calculations.

The present chapter provides the description of the conceptual model for radionuclide release and uptake in the biosphere. Chapter 3 describes the mathematical model chosen to represent this processes. The computer code and the testing of the implementation of the mathematical model are presented in Chapter 4.

2.2. Compartment Biosphere

The conceptual model applied in OPERA represents the region between the disposed waste and potential receptors (i.e. humans) in our environment. The region between the waste and the receptor is conceptually divided into compartments, which are in line with the multi-barrier system approach described in [Verhoef, 2011; p. 8].

The following compartments are defined in the PA model:

- The Waste-EBS (consisting of the waste form, waste package[1] and the repository buildings & affected materials
- The Host Rock Boom Clay)
- The Overburden (host rock surrounding rock formations)
- The Biosphere

In order to determine the consequences of the release of radionuclides to the biosphere the resulting radiation dose to humans has to be calculated with a model of the biosphere. For this purpose the OPERA-biosphere model was developed.

Radionuclides entering the overburden will be transported by moving groundwater and may be intercepted by water wells used for irrigation and/or drinking water. Radionuclides may also reach the surface water as a result of groundwater being drained by surface water bodies such as rivers and lakes or may be released directly into the top soil (wetland). The biosphere can also feed on the sea, but the radionuclide transport is minor compared to other pathways because of the enormous dilution in the large amount of sea water. In effect, the concentration of radionuclides in the biosphere is in equilibrium with the concentration of radionuclides in the overburden water that the biosphere is in contact with.

[1] The waste package compartment includes the waste matrix, container, and overpack if used [Verhoef, 2011, p. 8]

Further dispersion of radionuclides is treated in the biosphere compartment. Biosphere models provide the relation between the concentration of radionuclides in the biosphere water and the distribution of radionuclides over the various organisms in the biosphere, among which humans. There are three main types of water resources that take water from near-surface aquifers[2], see Figure 2-1 (Based on Fig. 2-2 of [Semioshkina, 2012]).

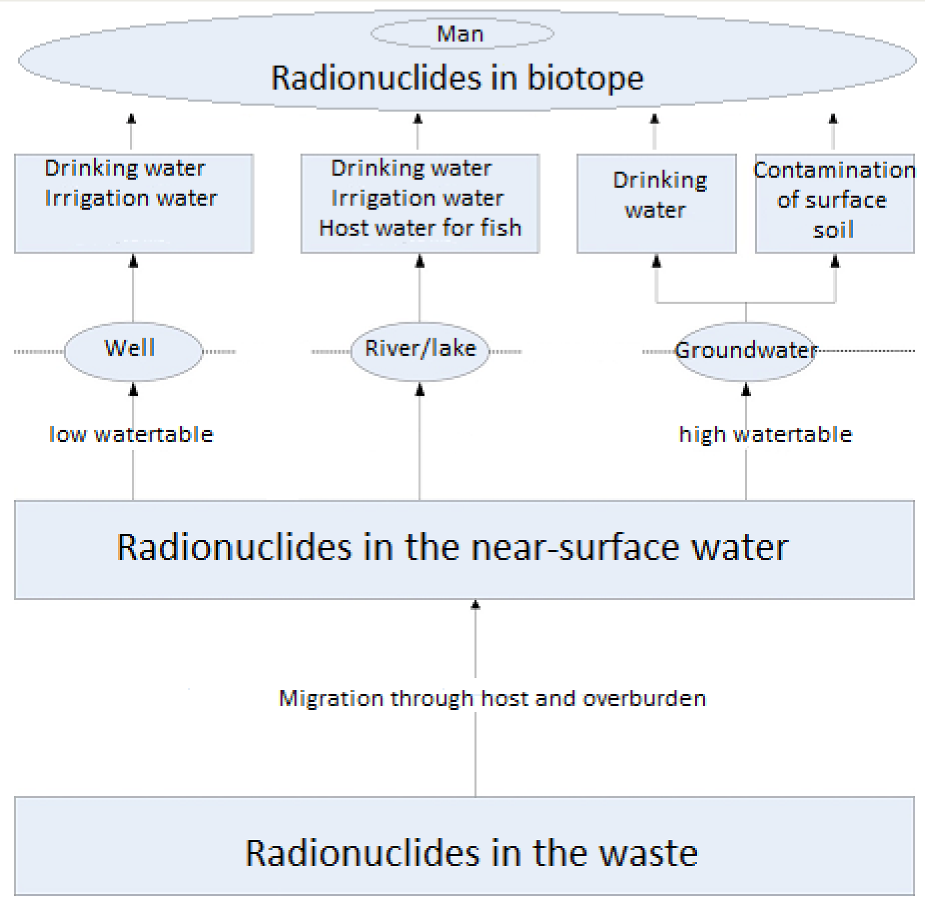

Figure 2-1 Schematic overview of the nuclide pathways to the biosphere

The *deep well* pathway considered in this study but not represented Figure 2-1 represents a variation of the well pathway with radionuclides from the deep aquifers entering the deep well.

2.3. Model of the biosphere

The biosphere draws water from its water resources including the pollutants in that water. These pollutants progress through the biosphere and a fraction can reach man. The most important part of the biosphere model is the food chain - including drinking water. Other exposure modes in the biosphere model are external exposure to contaminated soil and inhalation of contaminated dust particles and gaseous contaminants.

[2] Aquifer - underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt) from which groundwater can be extracted using a water well

Figure 2-2 shows the biosphere on the left as an adaptation of the ecological food and energy pyramid, showing some generic trophic levels, and on the right a generic food chain or food web.

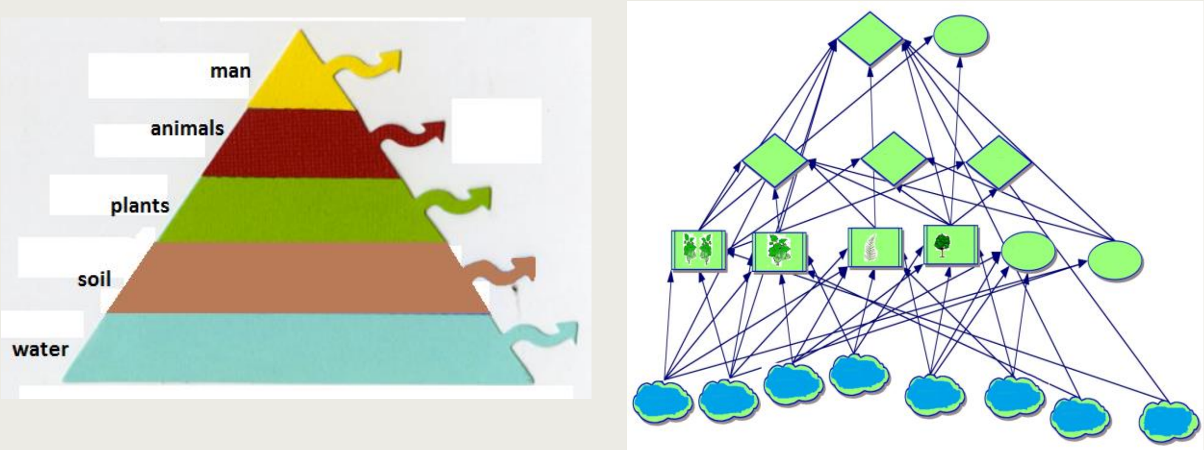

Figure 2-2 Conceptual illustration of the biosphere model

For each water source the model contains the following:

- the amount of water taken from that source;
- the food chain that covers the pathways from water to man;
- the contaminant specific transport factors of the contaminant through these pathways;
- the dose ingestion coefficients that give the dose for a given intake of radionuclides.

Although the contaminant concentrations in the various sub-compartments of the biosphere vary strongly from day to day and week to week, the long term averages (averaged over years) are proportional to the contaminant concentrations in the water sources.

There are two non-ingestion pathways in the common biosphere models: external radiation from soils and inhalation of resuspended or volatile radioactive material. These pathways can be fitted into the above calculation concept, only the dose conversion coefficients should reflect external radiation and inhalation instead of ingestion.

The shape of the food web, the water uptake and the transfer factors depend strongly on the topographic morphology, human behaviour and the climate.

2.4. Factors that have to be accounted for in the biosphere model

2.4.1. Climate evolution

Climate types in terms of temperature and precipitation are linked to specific life form associations or biomes [Ten Veen, 2015] (see Figure 2-3).

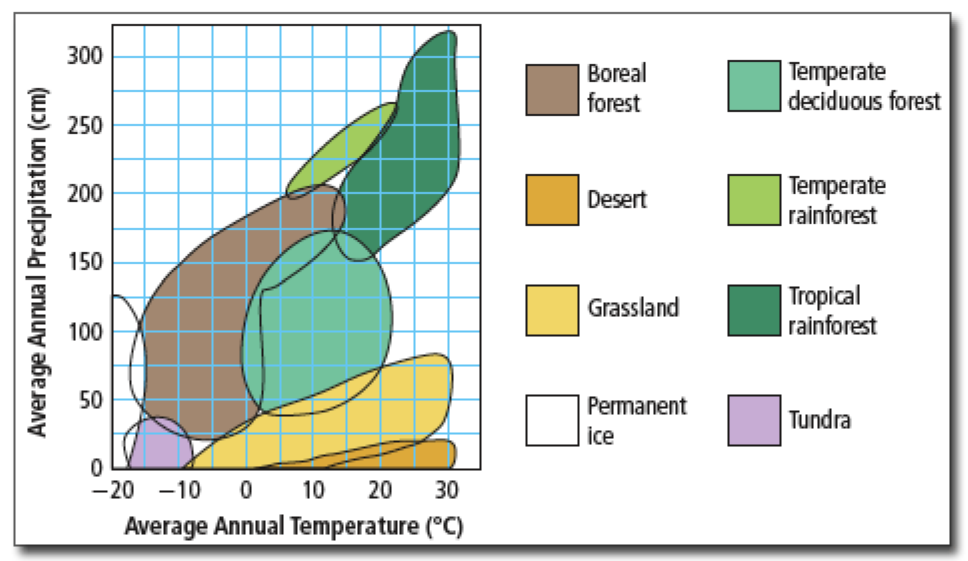

Figure 2-3 **Biomes as defined by average annual precipitation and average annual temperature; note the overlap in biomes (source: http://sciencebitz.com)**

On the timescales considered in the performance assessment of the radioactive waste disposal, changes in flora and fauna will occur. Changes in vegetation as a result of climate change will have consequences for some of the important processes in the hydrological cycle (runoff and evapotranspiration). In addition, vegetation changes can potentially affect the transfer of contaminants from plants to humans (for example soil moisture can have an effect on the plant uptake of radionuclides, while different plants may exhibit different soil-to-plant transfer factors). Climate change impacts to the environment will further force fauna living in the area to adapt or migrate to different environmental conditions. Migration of species is one of the first impacts of climate change on fauna; It is generally obvious from the recent fossil record that, on a much longer time scale, fauna could evolve into species that are quite different from the ones observed today. Changes in fauna can potentially affect the transfer of contaminants to humans (e.g. other animal transfer factors in different animal species).

Although agriculture and forestry are known to be highly dependent on climate, there is little evidence of recently observed changes related to regional climate changes [22]. This is probably due to the strong influence of non-climate factors on agriculture and, to a lesser extent, on forestry, especially due to human management practices and technological changes. In natural ecosystems, terrestrial vegetation responds to weather and climate through a variety of physiological, demographic, and ecosystem processes [Bonan, 2008]. These processes determine where the plant species grow, how well they grow, and how the composition and structure of vegetation change over time. By consequence, changes in temperature, precipitation, CO_2 and nutrients affect the productivity, seasonality and the geographic distribution of vegetation. In turn, the changes in vegetation physiology and morphology may have an impact on the land surface and the atmosphere. For example, an increase in atmospheric CO_2 concentration would lead to an increase in carbon uptake and a decrease in transpiration rate by vegetation [Kimball, 2002]. This would improve water use efficiency and increase soil moisture content. A rise in mean temperature tends to speed up the development, transpiration and respiration rates, which in turn affects biomass production, and might offset the positive effect of CO_2 fertilisation [Bazzaz, 1996]. A change in the pattern of the growing season might have an impact on the hydrological cycle as well.

Changes in precipitation regimes have a strong impact on the ecosystem through changes in the regional water balance. This affects the runoff, river discharge, water availability, and soil moisture [Baguis, 2009], [Bierkens, 2008]. For example, increased summer drying with additional consumption of water for irrigation may create depletion of water surface reservoirs and groundwater. An increase in rainfall during periods when soils will be saturated could increase the frequency and severity in floods. Results from this study demonstrate that changes in infiltration rate are relatively small (increase/decrease are limited to respectively 20 /10 %).

Furthermore, climate directly determines rates of substrate breakdown, organic matter decomposition and soil erosion and indirectly determines other soil features through its effect on the vegetation. Finally, dust load has been recognized as an important topic related to the climate.

Over the time scale considered in the performance assessment, the climate will change and beside the present-day temperate climate, a Mediterranean climate, a boreal climate, a periglacial climate and a glacial climate are likely to occur.

Present-day temperate climate
The description can be based on information for the present-day climate in the Netherlands. Current depth of the fresh water- saline water transition in the Netherlands is between 50 and more than 300 m below the earth's surface. Main determinants for the depth are the amount of infiltration of meteoric water in the subsurface, sea level and nearness to the sea. The quality of the water can be derived from the regional groundwater monitoring surveys in the Netherlands (see summary statistics of hydrochemistry in tables from [Brink, 2007] and [Griffioen, 2013].

Mediterranean climate
For the Mediterranean climate state, little changes would be expected over the current diversity of flora and fauna.

Mediterranean vegetation includes the following trees, shrubs, grasses and herbs [Ten Veen, 2015]:

- Evergreen trees: such as Pines, Cypresses, and Oaks
- Deciduous trees: such as Sycamores, Oaks, and Buckeyes
- Fruit trees such as Olives, Figs, Citrus, Walnuts and Grapes
- Shrubs: Bay laurel, Ericas, Banksias, and Chamise
- Sub-shrubs: such as Sages, Artemisias, and Sagebrush
- Grasses: Grassland types, Themeda triandra, Bunchgrasses; Sedges, and Rushes
- Herbs: such as fragrant Rosemary, Thyme, and Lavender.

Boreal climate
The vegetation will develop features typical of a boreal forest in a cold climate without permafrost. Boreal forest is also known as taiga, a term that is sometimes also applied to the associated climate state. A low amount of precipitation and a high temperature range between winters and summers will lead to sparse vegetation, as only hardy species can survive these conditions. Trees would be mostly limited to ferns and evergreen conifers, as few broad-leafed trees are able to survive the very low temperatures in winter. Other plants would include ericaceous shrubs, mosses, willow, alder, sedges and steppic grasses. Fauna adapted to a cold climate would come to occupy the boreal habitats. Mammals would include evolved herbivores, similar to deer, moose, beaver, hare, and squirrel, and adapted carnivores similar to bear, wolf, wild cat, and fox.

The taiga, which is a coniferous forest with pines, firs, spruces and larches, is the typical biome under boreal climate conditions [Ten Veen, 2015]. The types of trees vary with the geography and climate.

The frost-free season is very short, varying from about 45 to 100 days at most, and frost can occur during any month in many areas. Some taigas in areas with subarctic climates located near oceans, have milder winters and no or discontinuous permafrost and are more suited for farming unless precipitation is excessive. The low evapotranspiration leads to water-saturated terrain with snow cover during winter. For the conditions in the Netherlands close to the sea permafrost conditions are unlikely during a boreal climate [Ten Veen, 2015: Section 4.2.3, p.21].

Periglacial climate
In a cold climate with permafrost, the permafrost will make it difficult or impossible for trees to root down into the soil. Soils are formed at a very slow pace and they are not well developed. When water saturates the upper surface, bogs and ponds may form, providing moisture for plants. There are no deep root systems in the vegetation of the Arctic tundra [Ten Veen, 2015]. Tundra is often treeless and barren in appearance, with a predominance of lichens, mosses, sedges, perennial forbs, and dwarfed shrubs. In the tundra, mammals would include shrews, hares, rabbits, rodents, wolves, foxes, bears and deer that have adapted to the severe environmental conditions. There would also be insects and migratory birds, and fish would live in the rivers.

Polar tundra climates occur principally in areas where intense freezing leads to the formation of permanently frozen subsoil called permafrost with an active layer of seasonal freezing and thawing near the surface. Thaw occurs during a brief period in summer.

About 1,700 kinds of plants are present in the Arctic and Subarctic, which include:

- low shrubs, sedges, reindeer mosses, liverworts, and grasses;
- 400 varieties of flowers;
- crustose and foliose lichens.

All of these plants are adapted to sweeping winds and disturbances of the soil. Plants are short and group together to resist the cold temperatures and are protected by the snow during the winter. They can carry out photosynthesis at low temperatures and low light intensities. The growing season is short and most plants reproduce by budding and division rather than sexually by flowering [Ten Veen, 2015].

Glacial climate
During the glacial state (with ice sheet), there is no vegetation and the only fauna might be polar mammals and visiting birds.

2.4.2. Human behaviour

The time scale for the PA is about one million years. The actual exposure of individuals in the future and far future will depend on their behaviour and their biological characteristics. Presently, our food is imported from all over the world, drinking water is drawn from various places and a strict food and drinking water control system is in place. In practice this means that doses cannot get higher than the (legally) accepted level, and are usually much lower. Higher doses can occur if such controls are not in place, and much food and drinking water is taken from the location where the radioactively contaminated aquifer discharges.

The common policy for the protection of the public from ionizing radiation is based upon the principle that that subgroup of the population who, in comparison with the rest of the population, is at a greater risk from a given source of ionising radiation should be protected. This group is called the reference group (or critical group) for that particular source. The group should possess a common set of characteristics which have an influence on the level of risk which individuals in the group incur. These characteristics can be either biological (such as age or sex) or cultural (such as consumption pattern).

According to our present knowledge, for the next million years the reference group is a relative small community that lives in a closed agricultural society near the discharge points of the aquifer, which could be a natural discharge point or a human built well. The community lives on the exit point of the aquifer that discharges the water that originates from the deep aquifers that takes the radionuclides that leave the clay host rock of the disposal facility. For these conditions, the transfer of nuclides through the biosphere to individuals is at its maximum. Moreover, it is probable that this situation will occur one or more or even many times in the next million years.

It can be expected that human actions (of the reference group) will aim at increasing the agricultural production, in particular by implementing some type of water control (digging wells, building irrigation and/or drainage systems) to compensate for too wet or too arid climate conditions, and may use e.g. greenhouses if temperature is low. The consequences of these actions on the nuclide migration must be treated consistently in the overburden and biosphere modelling.

Reference group in a temperate climate
The reference group is assumed to be a small subsistence farming community living of local grown vegetables and meat products. Water is taken from a human built well and/or local natural water resources.

Food crops (cereals, root vegetables, tubers, leafy vegetables, non-leafy vegetables, legumes, fruit and berries), pasture and fodder crops are irrigated. The livestock includes chicken, sheep and cattle for both dairy and meat. The cattle and sheep are grazed on pasture, whereas the chickens are fed on locally produced grain.

Reference group in a Mediterranean climate
Subsistence agricultural communities also exist in semi-arid regions, such as northwest Spain, and can therefore be considered feasible under Mediterranean climate states. Such communities serve as the reference group.

Reference group in a boreal climate
Subsistence agricultural communities also exist in boreal regions, such as in the south of Sweden and can therefore be considered feasible under boreal climate states. Such communities serve as the reference group.

Reference group in a periglacial climate
For a biosphere system characterised by permafrost (periglacial conditions), agricultural activities are not so common. Agricultural practices are harsh and not sustainable. Growing cool-season crops, raising traditional livestock (cattle, sheep, goats, pigs, and poultry) and herding reindeer are then the main activities but remain small-scaled. Hence, wild food products obtained by hunting and gathering (such as meat from caribou herds, supplemented with some wild berries, fish and migratory wild birds) will complete the human diet.

In areas with discontinuous permafrost, groundwater can locally be discharged to the surface (open taliks). Drinking water wells may be drilled in these areas (NISDC 2014). Close to the ice sheet margin melt water discharges to the groundwater system and surface water leading to a change in the water yield and water quality. Release of radionuclides might happen via wells, lakes or rivers in unfrozen zones or taliks in between permafrost. Volumes of potable water are smaller and more localized in continuous permafrost areas and it is thus less likely to find potable groundwater resources in such regions.

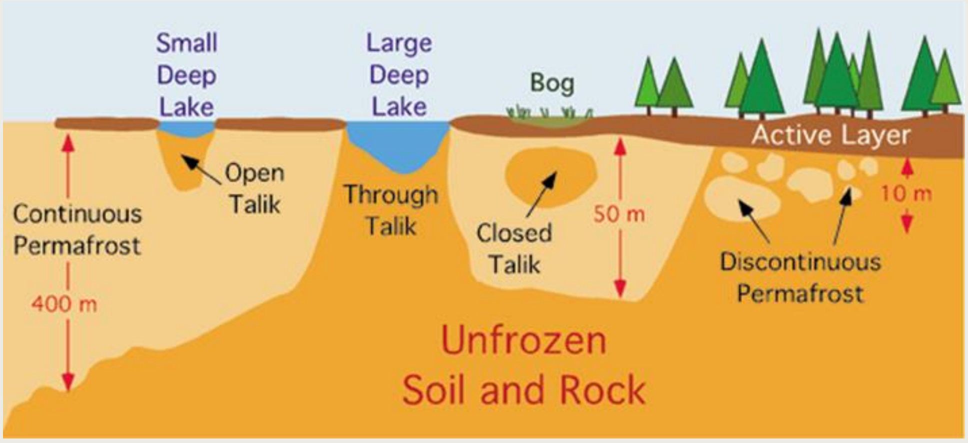

Figure 2-4 Schematic profile through the subsurface with the distribution of permafrost and discontinuities (http://www.physicalgeography.net/fundamentals/10ag.html)

Reference group in a glacial climate
During the ice sheet state, it can be assumed that there are no humans living near the site. However, compression of the geological formations due to the weight of the ice sheet, and/or channels of melting water at the bottom of the ice sheet could lead to transport of water and radionuclides towards the ice margin entering river and lake systems. The reference group, using these waters, would live in periglacial and boreal conditions.

2.4.3. Geomorphological evolution

The topography in The Netherlands is mainly determined by exogenous processes: i.e. mainly by weathering, erosion, transportation and sedimentation. The larger part of the Netherlands is subsiding except for its most eastern and south-eastern parts. Major changes in the topography are not to be expected in the coming one million years, although climate changes and human actions will redistribute and change the topographic pattern of land and water, and the land and water usage.

Present temperate maritime climate
The natural vegetation in the Netherlands for the present conditions is the temperate deciduous forest and grassland [Ten Veen, 2015] (Figure 2-3).

The Netherlands has a very diverse landscape with different topographies and origins. The following description of the geomorphology of the Netherlands has been derived from [Steur et al., 1987]. Zuid-Limburg has the most outspoken relief with height variations of 30 to 100 m over short distances. This area is 100 to more than 300 m above sea level (NAP).

The western and northern part of the Netherlands landscape has a very young history, which originated in the last 10,000 years (Holocene; Figure 2-5). Along the coast a zone of dunes is present separating the shore area from the inland areas. Behind the dunes a flat area of tidal origin and of peat formation is present. Lakes which are formed as a consequence of peat production and natural erosion were reclaimed and lie a few metres below sea level.

Figure 2-5 Distribution of soil types, their origin and age [Steur et al., 1987]

The southern and eastern parts of the Netherlands landscape have a somewhat older Pleistocene origin. Large area of Drente ("till plateau" and De Hondsrug), De Veluwe and de Utrechtse Heuvelrug and eastern parts of Gelderland and Overijssel have a glacial origin, shaped by the ice of the Saalian glaciation. In these areas glacial hills and ridges have been created with a height of tens of metres to more than 100 m. To the South a Pleistocene sand plain is present, the relief of which is overprinted by tectonic processes in the Roer Valley Graben and the Peel Horst. The Pleistocene landscape is dissected by a number of smaller river systems.

The south-eastern and central area of the Netherlands is dissected by the large river systems of the Rhine and Meuse. The reclaimed areas, the large rivers and part of the shore area are marked by man-made dykes to protect the living areas from flooding.

The hydrologic description can be based on information for the present-day climate in the Netherlands. Current depth of the fresh water- saline water transition in the Netherlands is between 50 and more than 300 m below the earth's surface. Main determinants for the depth are the amount of infiltration of meteoric water in the subsurface, sea level and nearness to the sea. The quality of the water can be derived from the regional groundwater monitoring surveys in the Netherlands (see summary statistics of hydrochemistry in tables from [Brink, 2007] and [Griffioen, 2013].

Warmer ("Mediterranean") climate
A climate warming will likely coincide with a sea-level rise as a consequence of melting of the polar ice sheets. In the assessment performed by KNMI (2014) sea level will rise by 45 to 80 cm in 2085 according to the WH scenario. In 2300 sea level will have risen by halve a metre up to several metres.

It is unknown for how long and to what extent temperature will rise and climate will change. If there is no control of emissions and the atmospheric concentrations of greenhouse gases will continue to rise, ice sheets may further melt so that large parts will disappear altogether. If the Greenland and West-Antarctic ice sheets will melt completely this will lead to a sea-level rise of about 10 m. If all ice sheets melt, sea level will rise by 60 m or more relative to the current level. The current water management in the Netherlands system of polders will not be able to cope with these changes and large parts of the country will be drowned and consequently marine conditions will prevail. Wave actions and currents will abrade the existing topography and new delta sediment wedges and barrier island systems may form depending also on the sediment supply by the rivers and its redistribution by waves and currents.

The availability of fresh water resources will be under stress due to rising sea level, and possibly lower precipitation and higher evapotranspiration. In Mediterranean conditions, the net infiltration of water may diminish which results in a deepening of the water table and a shallower level of the fresh-saline water transition, and Infiltration of sea water in the near shore zone.

Warming of the current climate could coincide with a rise of the sea level which ultimately could lead to a complete displacement of the fresh water zone when the land area is permanently flooded by the sea.

Colder (boreal) climate
As colder periods are expected to be correlated with growth of continental ice sheets, the seal level may be lower than today. Sea level may drop with several metres, to tens of metres as a consequence of the cooling of ocean water and initiation of the growth of mid-latitude continental ice sheets.

Periglacial (polar tundra) climate
Periglacial conditions can be expected when climate deteriorates in the course of a glacial cycle with growing continental ice sheets.

As result of the low permeability of the permafrost, arctic freshwater ecosystems are extremely numerous, and include three main types: flowing water (rivers and streams), permanent standing water (lakes and ponds), and wetlands such as peat lands and bogs. These freshwater ecosystems can be fed by precipitation and/or groundwater via taliks.

River systems in polar tundra conditions like in northern Canada, Alaska and Siberia have a very strong erosive capacity due to the fact that large areas are being flooded further downstream because of obstructing river ice. When these dams melt or break large amounts of water are released with destructive and erosive power.

The lack of vegetation increases wind (aeolian) action resulting in the formation of dunes and loess deposits. Due to the freezing of groundwater ice lenses may form in the subsurface creating isolated hills in the terrain, which are named pingos. These so called pingos turn into pingo lakes when the ice melts in a climate warming phase.

With 5 to 7 consecutive months where the average temperature is below 0 °C, all moisture in the soil and subsoil freezes solidly to depths of several meters to hundreds of metres. Summer warmth is insufficient to thaw more than a few surface meters, so continuous permafrost prevails (Figure 2-4). For the Netherlands a maximum thickness of the permafrost of about 140 to about 185 m has been calculated depending on the geographical location [Ten Veen, 2015]. In areas with large lakes and river systems the permafrost thickness might be reduced or even absent (Figure 2-4).

During climate deterioration, continental ice sheets will build up leading to a lowering of the sea level. During the latest glacial maximum in the Weichselian, sea level fell to -120 m below present sea level [Ten Veen, 2015]. Such a sea level fall will lead to a lowering of the erosion base of 20 m maximum. At the same time the earth’s surface at a distance of about 150 km before the ice front will rise as a response to ice loading. This forebulge can reach a height of 50 m [Ten Veen, 2015].

At the bottom of the ice sheet meltwater may be produced which - depending on the subsurface properties - may infiltrate in the subsurface. The hydraulic head increases significantly depending on the thickness of the ice sheet and creates a significant driving force for groundwater flow towards the ice margin [Boulton & Curle, 1997].

Glacial (polar frost) climate
The disposal site is covered by an ice sheet with polar or subpolar conditions above the ice sheet. Melt water is being produced at the bottom of the ice sheet and will partly be discharged into the subsurface fresh water aquifers and partly transported to the front of the ice sheet.

In a polar frost climate the temperature stays below 0 °C through all months of the year. As the melting point of water is not exceeded, any snow or ice that accumulates remains there permanently building a large ice sheet over time. Glaciated terrains are not covered by vegetation.

Glacial conditions will be marked by the presence of an ice sheet with a thickness of up to several 100s of metres. In front of the ice sheet push moraines can be formed with a height of up to 100 metre or more. Due to the loading of the ice the earth's surface in front of the ice sheet is subsiding resulting in a gentle depression in front of the ice sheet. Melt water erosion may occur below the ice sheet which can result in depressions of tens of metres to many hundreds of metres (De Groot 1993). These depressions are filled with ice and water. Once the ice sheet has disappeared, the depressions will be rapidly filled with sediments. Sometimes positive topographic elements can be formed below the ice sheet in case a lot of sediment is dumped in melt water zones resulting in ridges of several metres high.

Ice sheets are very dynamic bodies shaping the landscape below and in front of the ice body. Below the ice channels and valleys can be formed due to the erosive power of the ice and meltwater. In front of the ice sheet the ice can deform the substrate leading to the creation of ice-pushed hills and ridges. The topography of the Veluwe and the

Utrechtse Heuvelrug are remnants of such activities during the Saalian glaciation. The loading of the ice sheet leads to subsidence of the area below and just in front of the ice sheet creating a topographical low area where proglacial lakes can be formed. The location of river systems and lakes will be determined by these deformations at various spatial scales.

The temperature in the ice sheet increases with depth and under specific conditions the temperature may reach melting conditions at the base of the ice sheet resulting in the production of meltwater which partly penetrates in the subsurface and partly is drained via channels at the bottom of the ice sheet towards the ice margin. Meltwater at the basis of the ice sheet will dump glacial debris leading to the formation of alluvial fans (sandrs).

2.5. *Basic data for modelling of the response to different climates*

It was considered to improve the classical PA compartment model by including a limited number of climatic factors (such as yearly precipitation, average temperature) in the PA-biosphere model. However, the dose conversion coefficients that can be derived with the detailed climate model described in Appendix B Section B.2 are in a non-linear relation with the general climatic factors such as yearly precipitation and average temperature. Therefore it was decided to represent the climate change in a non-sequential way (to switch between constant climates) instead of a sequential way (to consider also the transitions between climate states).

To characterize the possible future evolution of the biosphere, 5 climate states have been identified (see Table 2-1), which will be discussed in the next sections:

- Present temperate maritime climate
- Warmer ("Mediterranean") climate
- Colder (boreal) climate
- Periglacial (polar tundra) climate
- Glacial (polar frost) climate

Table 2-1 Future climate and natural vegetation types [Ten Veen, 2015: Table 2-1]; chaparral = tight bushes; paraglacial = unstable conditions after a glaciation

Climate classes used here	*Walter climate type classification (IAEA, 2003)*	*Köppen-Geiger*	*Vegetation (biomes)*
Present-day : Typical maritime temperate with a short period of frost	ZB VI	Cfb: continental, fully humid, warm summer	Deciduous Forest
Mediterranean (Winter rain and summer drought, arid-humid)	ZB IV	Csa: continental, dry summer, hot summer	Chaparral
Boreal (cold continental climate)	ZB VIII	Dfc: snow, fully humid, cool summer	Taiga
Periglacial (permafrost in near glaciated areas -tundra)	ZB IX	ET: polar tundra	Tundra
Subglacial (Arctic/ Antarctic, polar) or paraglacial	ZB IX	EF: polar frost	None

Climate is a very dynamic system where climate states happen in succession at different time scales. A dominant time scale for the last 800,000 years is the 100 ka scale in which glacial and interglacial conditions succeed one another. Next to the analysis of the consequences of the equilibrium climate states for the exposure to radionuclides, attention has to be paid to transient conditions when changing from one climate state to another.

Present temperate maritime climate
The temperature is moderate and shows limited variation across the seasons. The presence of nearby seas and oceans has a strong levelling effect on the nearby onshore regions.

Based on measurements at De Bilt over the past century the annual precipitation varies between 425 and 1109 mm and it has an average of 766 mm/a. The average annual temperature at De Bilt over the years 1906 to 2013 is about 9.4 °C [see Ten Veen, 2015] (Table 2-2).

Warmer ("Mediterranean") climate
The anthropogenic emission of greenhouse gases very likely leads to warming of the atmosphere, changing weather conditions, e.g. precipitation patterns and storm intensity [KNMI, 2014; p.12 and txt box on p.28]. We do not know whether and to what extent man can mitigate these changes and to what extent man has to adapt to these changes. Current mitigation scenarios are directed to limit the temperature increase to 2 °C, which is thought to be equivalent to a future atmospheric CO_2 concentration of 450 ppmv [IPCC, 2014].

KNMI performed assessments of expected climate changes in 2050 and 2085 for two scenarios of global warming (2014). In the most extreme scenario (WH) for 2085 the annual precipitation would increase by 7 % and the potential evaporation (Makkink) by 10%. The annual temperature would increase by 3.7 °C.

In the longer run a "Mediterranean" climate might prevail if the emissions of greenhouse gases will not be sufficiently mitigated. A Mediterranean climate is characterized by warm to hot, dry summers and mild to cool, wet winters [Ten Veen, 2015]. In Table 2-2 an analogue for "Mediterranean" climate in the Netherlands has been included. This analogue is an area south of Porto (Portugal) in an oceanic setting. The average annual precipitation is 1237 mm/a and the average annual temperature is 15.2 °C with an average temperature of 9.5 °C in the coldest month and of 20.8 °C in the warmest month. A large uncertainty is the amount of precipitation and the pattern of precipitation over the year.

Colder (boreal) climate
A boreal or subpolar climate is characterized by long winters and short cool to mild summers. Coastal regions, however, may experience milder winters and high precipitation [Ten Veen, 2015]. The chosen analogue is the Murmansk area [Ten Veen, 2015] (Table 2-2) which has a temperate cold climate with significant precipitation. The average annual temperature is -1.6 °C and an average annual precipitation of 606 mm based on historical statistics of more than 100 years. The annual evapotranspiration is 365 mm.

Periglacial (polar tundra) climate
This climate is characterized by intense freezing with the formation of permafrost [Ten Veen, 2015] (see also Section 3.2). The Last Glacial Maximum in the lowlands of north-western and central Europe is chosen as an analogue for this climate state [Ten Veen, 2015]. The average annual temperature is -6.5 °C and the temperature of the coldest month is between -20 and -26 °C and between 7 and 11 °C for the warmest month (Table 2-2). The annual precipitation is between 150 and 250 mm, which is relatively low [Ten Veen, 2015].

Glacial (polar frost) climate

This climate type is marked by temperatures which are below 0 °C for all months of the year. Since the temperature never exceeds the melting point of water, any snow or ice that accumulates remains there permanently, over time forming a large ice sheet [Ten Veen, 2015].

[Ten Veen, 2015] has chosen the Greenland climate as an analogue for a glacial climate (Table 2-2). The average annual precipitation is 40 mm and the average evapotranspiration is 3.5 mm. The average annual temperature is -17 °C. The average temperature of the coldest month is -28 °C and is -2 °C for the warmest month.

Table 2-2 Summary of available climate data for the 5 climate zones described [Ten Veen, 2015]

		min	max	average	period
source: KNMI					
NL	Annual rainfall (mm)	425	1109	766	1906-2011
Present-day, maritime temperate	Annual evapotranspiration (mm)	541	607	578	1981-2014
	Annual Runoff (mm)	120	400	?	
	Mean annual ambient air temperature (°C)	7,89	11,52	9,43	1906-2015
	Air temperature of warmest month (°C)	13,82	22,59	17,1	1906-2015
	Air temperature of coldest month (°C)	-7,02	7,41	2,13	1906-2015
source: CRU TS 3.1	Annual rainfall (mm)	-	-	606,2	109 years
Murmansk, Boreal	Annual evapotranspiration (mm)	-	-	365,4	5 years
	Annual Runoff (mm)	-	-		
	Mean annual ambient air temperature (°C)	-	-	-1,55	109 years
	Air temperature of warmest month (°C)			12,7	109 years
	Air temperature of coldest month (°C)			-17,8	109 years
Source: Instituto de Meteorologia	Annual rainfall (mm)	-	-	1237	?
Hong Kong Observatory	Annual evapotranspiration (mm)	-	-	650	
south of Porto	Annual Runoff (mm)	-	-	?	
Mediterranean	Mean annual ambient air temperature (°C)	-	-	15,2	
	Air temperature of warmest month (°C)			20,8	
	Air temperature of coldest month (°C)			9,5	
Huizer & Vandenberghe, 1998	Annual rainfall (mm)	-	-	?	
Periglacial, LGM	Annual evapotranspiration (mm)	-	-	0	
	Annual Runoff (mm)	-	-		
	Mean annual ambient air temperature (°C)	-9	-4	-6,5	
	Air temperature of warmest month (°C)	7	11	9	
	Air temperature of coldest month (°C)	-26	-20	-23	
source: CRU TS 3.1	Annual rainfall (mm)	-	-	40	
subglacial, paraglacial	Annual evapotranspiration (mm)	-	-	3,5	
Greenland	Annual Runoff (mm)	-	-		
	Mean annual ambient air temperature (°C)	-	-	-17	1900-2009
	Air temperature of warmest month (°C)	-	-	-2	1900-2009
	Air temperature of coldest month (°C)	-	-	-28	1900-2009

Note that for the aquifer model for transport through the overburden, parameter values for each climate type of this set have been determined [Schröder, 2017], so a 'climate-consistent' coupling between the aquifer and biosphere models can be obtained.

2.6. Interfaces of the overburden with the adjacent compartments

The biosphere interfaces with the adjacent aquifers in the overburden (or surrounding rock formations) compartment. The aquifer-biosphere interface defines the point where the radionuclides from the overburden enter the biosphere. This section describes the conceptual models for this interface.

For the present study the following aquifer-biosphere interfaces were selected:

- Well: contaminated groundwater drawn from aquifers is used as irrigation water and drinking water for humans and farm animals.
- Surface water bodies (river, lake or pond): 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.
- Wetland (polder): 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.

The conceptual model is based on the concentration of radionuclides in the biosphere water (well, river/lake/pond) and wetlands (polder). The concentration in the water is not determined by biological factors at all. Therefore, the calculation of the concentration in the surface water bodies is *technically* considered to be part of the hydrological model.

The water body dilution factors and biosphere dose conversion coefficients depend on the climate, and will therefore be derived for various climates.

3. Mathematical PA-model for Biosphere

3.1. General description of the PA-model

In the most simple case, for a given climate condition and biosphere geomorphology associated to this climate condition, water resource and radionuclide, and considering only ingestion, the exposure to radioactive material can be estimated as follows:

- Determination of the radionuclide concentration in the water resource, *C* (Bq/m^3),
- Determination of the water intake by the biosphere from the resource, Q^{bio} (m^3/yr),
- Determination of the amount of radionuclide reaching man, *f (-)*,
- Determination of the exposure to the radioactive material, *D (Sv/yr)*.

The yearly dose D in this case can be calculated using the equation:

$$D_{climate} = \sum_{water\ resource\ j} \sum_{nuclide\ i} C_{i,j,climate} Q^{bio}_{j,climate} f_{i,j,climate} e(50)_i$$

with:

$D_{climate}$	yearly ingestion dose occurring during the considered climate (Sv/year),
$C_{i,j,climate}$	concentration of nuclide *i* in water resource *j* during the considered climate (Bq/m^3),
$Q^{bio}_{j,climate}$	yearly water uptake by the biosphere from the resource *j* corresponding to a given climate (m^3/year),
$f_{i,j,climate}$	fraction of nuclide *i* from source *j* reaching man through ingestion,
$e(50)$	ingestion dose coefficient $e(50)_i$ representing the dose caused by ingestion of radionuclide *i* (Sv per Bq intake).

This model forms the basis of the well screening model discussed in Section 3.3 and it was used for the selection of relevant radionuclides (see Section 3.4.2).

Beside ingestion, other pathways can contribute to the total exposure of individuals to radiation. The use of contaminated water from a well, river or lake for irrigation will lead to ingestion of contaminated food products, but also to exposure to external radiation from irrigated fields and inhalation of contaminated dust particles. The sediments in the riverbeds and lakes adsorb a part of the radioactive materials in contaminated water and subsequently may contribute to the total exposure by external radiation. Since these soils might also be used for fertilization in agricultural fields, materials adsorbed to the sediments may enter the food web. In these conditions besides direct exposure of the individuals, also exposure through inhalation of resuspended soil as a result of human activities, such as traffic or ploughing, or disturbance by wind may occur. Also swimming in contaminated water would lead to exposure.

To estimate the exposure to radioactive material the most relevant exposure pathways need to be considered. In this case also the dose coefficients for external radiation and inhalation need to be used in calculations. Essentially, all these exposure pathways are proportional to concentration of a radionuclide in the biosphere water and this proportionality is summarized in dose conversion coefficients (DCCs). The DCCs are pre-calculated for each climate and representative biotope, each water source and each nuclide, based on the conceptual biosphere model developed and described in Appendix B and using the mathematical model and the calculation tool 'BIOSPHERE' developed by SCK•CEN and applied in the Belgian radioactive waste disposal program. More details can be found in Section 3.4 and [Olyslaegers, 2011].

The yearly dose can be calculated as follows:

$$D_{j,climate} = \sum_{nuclide\ i} C_{i,j,climate} DCC_{i,j,climate}$$

where:

$D_{j,climate}$ yearly dose (Sv/year) due to using water from resource *j* ,

$C_{i,j,climate}$ concentration of nuclide *i* in water resource *j* during *climate* (Bq/m^3),

$DCC_{i,j,climate}$ dose conversion coefficient of nuclide *i* from water resource *j* reaching man in the representative biosphere associated to *climate*, including all exposure pathways ((Sv/year)/(Bq/m^3)).

The equation above forms the mathematical model of the PA-model for the biosphere and was implemented in ORCHESTRA (see Chapter 4).

In Section 2.4.2 the reference group for calculating the exposure was defined. Over time the main water resource for this group will vary. Therefore, the relevant interfaces (well, river/lake, wetland) can be considered independently from each other.

3.2. Interfaces with the overburden

The PA-model for transport through the overburden [Grupa, 2017] gives a good prediction of the nuclide flux, but does not consider any dilution at the end of the transport path, resulting in high concentrations at the top of the overburden. Actually, the refreshment rate of surface waters is high in comparison to the influx of the water from the overburden compartment. Therefore, for each surface water body, a dilution factor has to be determined and considered in calculations.

Generic mathematical model

Each water body where the biotope feeds on can be characterized by:

- the volume of water: *V* (m^3);
- inflows of water:
  - ✓ a 'fresh water' inflow (including precipitation) $Q_{in,fresh}$ (m^3/year)
  - ✓ an inflow of contaminated water from the overburden $Q_{in,OV}$ (m^3/year) and a nuclide inflow of Q_{OV} (Bq/year)
- outflows of water:
  - ✓ water uptake by the biotope $Q_{out,bio}$ (m^3/year)
  - ✓ evaporation $Q_{out,evaporation}$ (m^3/year)
  - ✓ flow of water to the next water compartment, eventually the sea $Q_{out,flow}$ (m^3/year)

Provided that *V* is constant:

$$Q_{in,fresh} + Q_{in,OV} = Q_{out,bio} + Q_{out,evaporation} + Q_{out,flow}$$

Since the nuclide inflow changes only very slowly (hundreds of years), the concentration of radionuclides in the water C (Bq/m^3) is quasi stationary:

$$C = \frac{Q_{OV}}{Q_{in,fresh} + Q_{in,geo} - Q_{out,evaporation}} = \frac{Q_{OV}}{Q_{out,bio} + Q_{out,flow}}$$

Generally:

$$Q_{in,fresh} \approx Q_{out,flow} \gg \max(Q_{in,OV}, Q_{out,evaporation}, Q_{out,flow})$$

So:

$$C = \frac{Q_{OV}}{Q_{in,fresh}} = \frac{Q_{OV}}{Q_{out,flow}}$$

Since the water uptake by the biotope is usually small compared to the other flows, the concentration in the water is not determined by biological factors at all. Therefore, this calculation is technically considered to be part of the hydrological model.

3.3. Drinking water well model

The drinking water well model can be applied if the reference group takes its drinking water from a well that draws its water from an aquifer that carries radionuclides originating from the repository, while all other water resources of the reference group do not carry such radionuclides. This leads to a very simple climate independent biosphere model, that is internationally referred to as the ERB1 [IAEA, 2003, p. 253].

Example Reference Biosphere 1 (ERB1) is deliberately designed to be very simple, being focused on a simple biosphere system and single exposure pathway. It is characterized by a drinking water well drilled through the overburden into an aquifer that has been contaminated by radionuclide releases from the repository. Previous experience from more comprehensive biosphere modelling studies has shown that a drinking water well may represent a significant or, depending on other aspects of the assessment context, even a dominant pathway for exposure.

ERB1 has been explored in two variants. In the first (ERB1A), it is assumed that a geosphere model for the site of interest is able to support the calculation of radionuclide concentrations in well water. In the second (ERB1B), it is assumed that the biosphere model domain includes the near surface aquifer from which the well water is drawn. Relatively, these two models show the same results (see Table 3-1) which permits the restriction of the screening model to the ERB1A model (see Section 3.4.2 for more information).

Table 3-1 Dose conversion coefficients calculated for example reference biosphere 1 (Variants A and B), (from [IAEA, 2003])

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

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

One can describe the mathematical model as a proportional relationship between annual individual effective dose and the bulk concentration of radionuclides in water delivered at the well head (see also [IAEA, 2003, p. 272]. Thus:

$$D_{ERB1} = \sum_{nuclide\ i} C_{i,well,climate} \cdot I \cdot e(50)_i$$

where:

D_{ERB1} yearly dose (Sv/year),
$C_{i,well,climate}$ concentration of nuclide *i* in the well water during *climate* (Bq/m^3),
I consumption rate of drinking water (m^3/year),
e(50) ingestion dose coefficient $e(50)_i$ representing the dose caused by ingestion of radionuclide i (Sv per Bq intake).

Ingestion dose coefficient

The ingestion dose coefficient *e(50)* is a measure of the radiological impact associated with the ingestion of a given radionuclide, and is to be specified here for a range of different radionuclides. Available reference information includes relevant ICRP documentation and international safety standards. This means that for practically all known radionuclides ingestion dose coefficients are readily available.

In the context of safety assessment for radioactive waste disposal, the ingestion dose coefficients fall into the category of parameters that are assigned definitive values according to data provided by authoritative national and/or international sources. In the Netherlands, ingestion coefficients values are specified in (Appendix 1.4 in [EZ, 2013]), and are consistent with ICRP-publication 72 and ICRP-publication 57.

Consumption rate of drinking water

The drinking water consumption rate, *I* (m^3/year), depends on age and habits. [IAEA, 2003; p. 275] reports for young adults an average value of 0.6 m^3/year, and 1.2 m^3/year as 95% value from the distribution of consumption rates for young adults. From [EZ, 2013; Table 6.1] it can be derived that for The Netherlands the average consumption rate is about 0.5 m^3/year. Conservatively, the value of 1.2 m^3 year is adopted for ERB1A calculations.

Ingestion dose coefficients for ERB1

The ingestion dose coefficients give a measure of the radiological impact associated with the ingestion of a given radionuclide. The dose coefficients applying to adult members of the public used in ERB1 are presented in Table A7 in [IAEA, 2003; p.38].

3.4. Agricultural well, river/lake and wetland model

Given the generic site context, different types of water bodies are possible such as rivers, lakes, ponds, sea. Up to now, only rivers fed by groundwater have been considered as biosphere receptors. The sea is not considered because the large dilution of the radionuclides in that water body will be much higher than for a river or lake/pond. Currently, in the assessment no lake is considered because for that assumptions have to be made about the dimensions of the lake and the contribution of groundwater and precipitation. Consideration of the water needs of a self-sustaining community of several hundred people indicates that a lake should have a volume of some 10^6 m^3 or more.

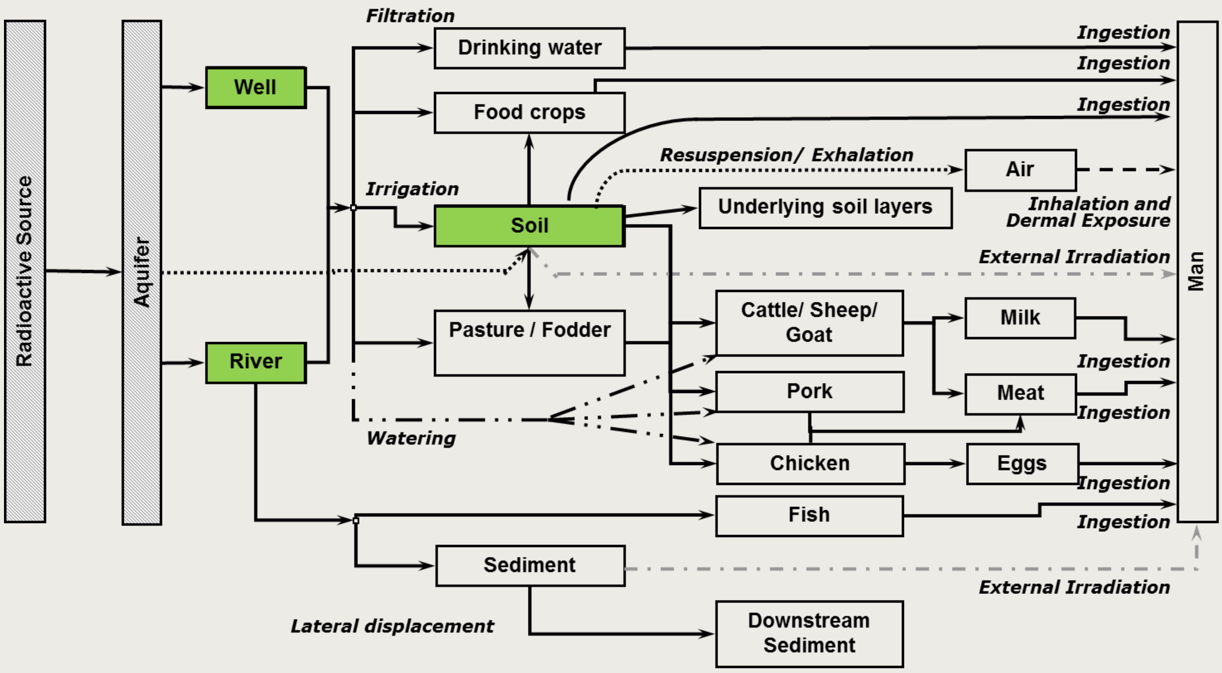

Figure 3-1 **Schematic illustration of the biosphere model. The considered biosphere receptors are shaded green. The grey shaded compartments (i.e. radioactive source, aquifer), which are no part of the biosphere model, provide the flux of the radionuclides released into the biosphere.**

- Biosphere receptor: well

  One of the direct pathways, which may lead to human exposure through the use of well water is ingestion of the groundwater. Well water can be directly used as drinking water. Besides for human consumption, it is also used for irrigation of food crops and pasture. This does not only result in the contamination of foods and fodder, but also of soil. The contaminated food crops ingested by man result in internal exposure. Meat and milk from cattle, sheep and goats ingesting radionuclides by grazing on contaminated pasture or by being watered with contaminated well water, are ingested by man. Other contaminated food products ingested by man are pork, poultry and chicken eggs. Poultry and pigs are presumed to be fed contaminated well water and maize, whereas they will ingest contaminated soil as well due to their consumption behaviour.

  Another way of internal exposure is the inhalation of dust, resuspended in the air on fields contaminated by irrigation and inhalation of radon, being released from irrigated soil.

  Resuspension may also give rise to skin contamination and external exposure from air submersion, which is, however, insignificant. External irradiation exposure can occur on fields contaminated by irrigation.

- Biosphere receptor: river

  River water can also be used for irrigation purposes. Rivers are occasionally dredged, which leads to an accumulation of sediment on the river bank. Angling is a common sport activity. Hence, for rivers the same exposure pathways apply as for the well, except that no drinking water is extracted from small rivers. Additional pathways for this receptor are the external irradiation through the sediment and the ingestion of contaminated fish.

- Biophere receptor: soil

  For the wetland, arable soil contaminated by upwelling groundwater, the same exposure pathways apply as for the well, with exception of the pathways related to the use of water for human or animal consumption and irrigation purposes.

The DCCs were calculated by means of the biosphere model ‘BIOSPHERE’, developed and applied by SCK·CEN in the Belgian radioactive waste disposal research program [Olyslaegers, 2011]. The calculations were performed for the most radiotoxic radionuclides. The selection of these radionuclides was based on the maximum expected nuclide concentrations in groundwater, reported in more detail in Section 3.4.2.

The SCK·CEN biosphere model is a compartment model. A representation of the model is given in Figure 3-1. The model calculates the transport and distribution of radionuclides released in the surface environment in a system of homogeneous compartments. The focus of the biosphere model is the local environment in which radionuclides from the disposal system are assumed to be released and where radionuclide concentrations are expected to be the highest. The release of radionuclides into the biosphere is represented as a flux from the geosphere into a relevant biosphere receptor, representing the interface between the geosphere and the biosphere. As mentioned in Appendix B Section B.2, the following three biosphere receptors can be considered: a well, a water body and upwelling groundwater in a (sub)surface soil.

The ‘BIOSPHERE’ model calculates the transport and distribution of radionuclides in the soil, river and food chain and converts the radionuclide concentrations in these compartments into doses to humans via the exposure pathways (ingestion, inhalation, external irradiation).

Because the release of radionuclides from the repository will be very slow and continuous, and the times which the radionuclides in the biosphere need to achieve equilibrium in the different compartments (media) are usually much shorter than the times over which the release can vary to any degree, equilibrium can be assumed between the radionuclide concentrations in the various model components. We can therefore apply a model of equilibrium in which the concentrations of radionuclides in the various biosphere components can be derived from each other on the basis of simple ratios or analytical solutions (taken at certain times) of linear differential equations that describe the transfers of radionuclides between the components. The resulting exposure and individual dose is then calculated from the concentrations of radionuclides in the biosphere media.

To determine the effective dose coefficients, the radionuclides in the decay chains of the long-lived radionuclides have to be considered. For short-lived decay products (less than a few tens of years), as well as for intermediate lived decay products (more than a few tenths of years) with environmental behaviour similar to the parent radionuclide, it is assumed that (secular) equilibrium with their longer-lived parent radionuclide is obtained. For intermediate lived progeny radionuclides with a quite different behaviour (e.g. leaching rate) in the root zone soil and sediment, (secular) equilibrium with their parent radionuclide cannot be reached. The dose contribution of these radionuclides are calculated separately in the biosphere assessment and added to the dose of the parent radionuclide.

The results of the biosphere calculations are expressed as so-called dose conversion coefficients (DCCs). These are annual individual effective doses for a representative person per unit of input flux or per unit of concentration of the radionuclide in the affected biosphere receptor. The mathematical equations of the model, and the rationale behind them, are given in NIROND-TR 2008-19E Version 2 [Olyslaegers, 2011]. The parameter values used to calculate the DCC values for the different climate states are, with exception of the parameter values listed below, taken from NIROND-TR 2008-26E Version 2 [ONDRAF/NIRAS, 2010a], NIROND-TR 2008-27E Version 2 [ONDRAF/NIRAS, 2010b] and NIROND-TR 2008-28E Version 2 [Olyslaegers, 2012].

3.4.1. Input data for the DCC calculations

For the human consumption, data from the Dutch National Food Consumption Survey of 2007-2010 [van Rossum, 2011] were used. The climate independent parameters used for human consumption are given in Table 3-2.

Table 3-2 Derived consumption rate values (kg fw[1]/y) for main food categories

	Adult (> 18 years)
Drinking water (l/y)	736
Potatoes and other tubers[2]	61.8
Vegetables[3]	55.3
Leafy vegetables	26
Non-leafy vegetables	21.2
Legumes	2.3
Root vegetables	5.8
Fruit	42.9
Milk (l/y)[4]	142.1
Cereals	81.4
Meat	40.2
Fish	6.2
Eggs	10.2

1 fw: fresh weight

2 We assume that rice and pasta are replaced by potatoes. With the assumption of the subsistence farmer family, consumption of potatoes is most relevant.

3 Relative contribution of each vegetable derived from Belgian survey

4 Density of milkis 1.03 kg/l

The climate dependent input parameters for the Mediterranean and boreal climate states, given in Table 3-3, were derived from the EC BIOMOSA study [Pröhl, 2004; Annex 2, Table 1]. In that study reference biospheres for five European sites (located in Belgium, Germany, Hungary Spain, Sweden) covering a wide range of living habits and agricultural and climatic conditions were developed [Pröhl, 2004; Chapter 5]. For missing data, as is the case for the chicken feed, the values for the temperate climate are used.

Table 3-3 List of climate dependent biosphere parameters

Parameter	*Temperate climate (Belgium)*	*Mediterranean climate (Spain)*	*Boreal climate (Sweden)*
Weathering rate (1/d)			
Pasture			
I,Cl	0.022	0.09	0.046
H	0.01	0.09	0.046
Other elements	0.032	0.09	0.046
Food crops			
I,Cl	0.026	0.07	0.046
H	0.01	0.07	0.046
Other elements	0.047	0.07	0.046
Dust load in air (kg/m^3)	2.3E-07	1E-05	2E-06
Feed of cattle			

Parameter	*Temperate climate (Belgium)*	*Mediterranean climate (Spain)*	*Boreal climate (Sweden)*
Feedstuff (kg dw[1]/d)	15	14	14
Water (l/d)			
Dairy cattle	78	75	70
Beef cattle	46	60	40
Soil (kg dw/d)	0.56	0.7	0.4
Feed of chicken			
Feedstuff (kg dw/d)	0.1	0.07	Not available
Water (l/d)	0.2	0.3	Not available
Soil (kg dw/d)	1.21E-02	Not available	Not available
Irrigation rate (m/y)			
Cereals	0.029	0.161	0
Leafy vegetables	0.15	0.436	0.15
Legumes	0.1	0.375	0
Fruit and berries	0.15	0.396	0
Non-leafy vegetables	0.15	0.414	0
Tubers	0.19	0.375	0.15
Root crops	0.26	0.375	0.15
Grasses and pastures	0.029	0.126	0
Exposure time to contaminated soil (h/y)	1500	298	460

[1] dw: dry weight

3.4.2. Selection of the radionuclides

Based on the inventories intended for disposal reported in [Verhoef et al., 2016] and [Hart, 2015] a list of radionuclides relevant for the long-term safety was compiled. The resulting inventory consists of 69 radionuclides, distributed over 42 elements (Table 3-4).

Table 3-4: Overview of all radionuclides considered (based on [Verhoef et al., 2016])

Nuclides	Nuclides	Nuclides
H-3	Nb-93m, Nb-94	Re-187, Re-186m
Be-10	Zr-93	Pb-202, Pb-210
C-14	Tc-99	Bi-207
Si-32	Pd-107	Po-209
Cl-36	Ag-108m	Ra-226
Ar-39	Cd-113m	Ac-227
K-40	Sn-121m, Sn-126	Th-229, Th-230, Th-232
Ca-41	I-129	Pa-231
Ti-44	Ba-133	Np-237
Ni-59, Ni-63	Cs-135, Cs-137	U-232, U-233, U-234, U-235, U-236, U-238
Se-79	Pm-145	Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Pu-244
Kr-81, Kr-85	Sm-146, Sm-147, Sm-151	Am-241, Am-242m, Am-243
Sr-90	Eu-152	Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, Cm-248
Mo-93	Ho-166m	Cf-249

A part of these radionuclides will reach the biosphere in negligible quantities and thus will have a negligible contribution to the radiotoxicity in the biosphere. A screening of the radionuclides list was performed in order to exclude those that are contributing insignificantly to the total radiotoxicity from the DCC calculations. The inventories from both [Verhoef et al., 2016] and [Hart, 2015] have been screened. The results of these screenings are given in Table 3-5 and Table 3-6, respectively.

For each inventory two screening calculations were carried out using the well screening model described in Section 3.3. In a first step, a transport calculation was performed for a layer of 50 m of clay with no retardation considered. The maximum radiotoxicity at the top of the clay layer was estimated and the radionuclides were ranked according their contribution to the total radiotoxicity.

To account for the radionuclides relevant in the alternative scenarios a second calculation was carried out for a layer of 5 m of clay and no retardation considered. The radionuclides were ranked again according their contribution to the total radiotoxicity at the top of the clay layer.

Table 3-5 Screening calculations results based on the inventory given in [Verhoef et al., 2016] representing the individual contribution of each radionuclide to the total radiotoxicity for two calculation cases: Case 1 - no retardation considered, migration through 5 m Boom Clay and Case 2 - no retardation considered, migration through 50 m Boom Clay.

Radionuclide	*Case 1 [%]*	*Case 2 [%]*	*Radionuclide*	*Case 1 [%]*	*Case 2 [%]*
H-3	3.97E-17	1.51E-14	Po-209	2.95E+00**	3.53E+01**
Be-10	1.01E-07	3.33E-07	Ra-226	1.20E+00	1.43E+01
C-14	6.91E-04	2.74E-04	Ac-227	1.76E-01	2.07E+00
K-40	1.19E-06	3.97E-06	Th-229	2.18E-02	2.63E-01
Ca-41	1.57E-07	4.38E-07	Th-230	9.29E-01	1.11E+01
Ni-59	5.18E-04	1.30E-03	Th-232	1.74E-06	2.09E-05
Ni-63	6.04E-05	3.51E-14	Pa-231	1.13E-01	1.33E+00
Se-79	9.86E-04	2.99E-03	Np-237	1.22E-01	4.11E-01
Kr-81	n.a.*	n.a.*	U-232	4.51E-06	4.95E-11
Kr-85	n.a.*	n.a.*	U-233	2.65E-03	3.19E-02
Sr-90	3.07E-09	1.00E-11	U-234	2.51E+00	8.28E+00
Mo-93	3.22E-04	6.67E-05	U-235	4.81E-02	1.61E-01
Nb-93m	2.54E-04	7.63E-04	U-236	5.70E-01	1.90E+00
Nb-94	1.95E-03	2.83E-03	U-238	1.99E+00	6.63E+00
Zr-93	2.21E-03	7.00E-03	Pu-238	7.16E-03	2.71E-11
Tc-99	1.46E-02	4.27E-02	Pu-239	3.95E+00	1.16E+01
Pd-107	4.16E-06	1.32E-05	Pu-240	4.32E+00	2.05E+00
Ag-108m	1.86E-05	7.32E-10	Pu-241	2.15E-04	1.43E-04
Cd-113m	4.43E-14	1.68E-11	Pu-242	2.23E-02	7.70E-02
Sn-121m	3.14E-13	7.14E-14	Pu 244	8.32E-06	2.65E-05
Sn-126	1.76E-02	5.15E-02	Am-241	7.31E+01	6.28E-03
I-129	3.23E-04	1.06E-03	Am-242m	7.40E-06	1.29E-11
Ba-133	3.87E-15	1.47E-12	Am-243	7.74E+00	4.29E+00
Cs-135	1.25E-03	3.97E-03	Cm-243	1.06E-10	5.44E-11
Cs-137	5.66E-09	4.47E-12	Cm-244	1.81E-13	6.89E-11
Pm-145	1.69E-16	6.41E-14	Cm-245	9.41E-03	6.27E-03
Sm-151	4.20E-05	1.22E-14	Cm-246	1.43E-01	4.06E-02
Eu-152	2.81E-15	1.07E-12	Cm-247	3.62E-06	1.16E-05
Re-187	2.52E-15	6.85E-34	Cm-248	8.82E-05	2.67E-04
Pb-202	3.59E-16	1.75E-15	Cf-249	2.96E-13	1.01E-11
Pb-210	1.11E-15	4.23E-13			

* noble gas with poor solubility in water, no ingestion dose coefficient available to estimate the contribution to the total radiotoxicity

Table 3-6 Screening calculations results based on the inventory given in [Hart, 2015] representing the individual contribution of each radionuclide to the total radiotoxicity for two calculation cases: Case 1 - no retardation considered, migration through 5 m Boom Clay and Case 2 - no retardation considered, migration through 50 m Boom Clay.

Radionuclide	*Case 1 [%]*	*Case 2 [%]*	*Radionuclide*	*Case 1 [%]*	*Case 2 [%]*
H-3	3.98E-19	4.17E-14	Re-187	4.60E-14	4.04E-11
Be-10	9.37E-10	8.12E-07	Pb-202	2.47E-12	1.55E-09
C-14	6.27E-06	6.65E-04	Pb-210	1.12E-17	1.17E-12
Si-32	3.41E-18	1.21E-13	Bi-207	3.02E-11	2.65E-08
Cl-36	5.81E-09	4.78E-06	Po-209	5.77E-03**	1.92E+01**
Ar-39	n.a.*	n.a.*	Ra-226	2.34E-03	7.78E+00
K-40	1.29E-08	1.13E-05	Ac-227	1.46E-03	4.73E+00
Ca-41	1.64E-09	1.20E-06	Th-229	1.74E-04	5.81E-01
Ti-44	2.64E-17	2.76E-12	Th-230	1.81E-03	6.03E+00
Ni-59	1.01E-05	6.96E-03	Th-232	4.93E-05	4.32E-02
Ni-63	8.18E-07	1.40E-13	Pa-231	9.38E-04	3.05E+00
Se-79	3.42E-06	2.85E-03	Np-237	9.51E-04	9.09E-01
Kr-81	n.a.*	n.a.*	U-232	2.15E-12	1.37E-10
Kr-85	n.a.*	n.a.*	U-233	2.12E-05	7.03E-02
Sr-90	5.60E-11	2.78E-11	U-234	4.02E-03	4.47E+00
Mo-93	6.56E-06	3.74E-04	U-235	4.22E-04	3.70E-01
Nb-93m	3.10E-06	2.47E-03	U-236	1.13E-05	1.15E-02
Nb-94	3.95E-05	1.58E-02	U-238	1.56E-02	1.37E+01
Zr-93	2.61E-05	2.26E-02	Pu-238	3.37E-05	7.50E-11
Tc-99	1.77E-04	1.42E-01	Pu-239	2.20E-02	2.29E+01
Pd-107	5.49E-08	4.80E-05	Pu-240	3.65E-02	4.76E+00
Ag-108m	3.05E-10	3.62E-12	Pu-241	1.93E-05	3.53E-03
Cd-113m	4.45E-16	4.66E-11	Pu-242	7.60E-05	6.33E-02
Sn-121m	8.14E-17	1.98E-13	Pu 244	1.16E-11	1.02E-08
Sn-126	9.07E-05	7.32E-02	Am-241	8.36E-01	1.55E-01
I-129	9.91E-06	8.68E-03	Am-242m	5.27E-08	3.57E-11
Ba-133	3.88E-17	4.07E-12	Am-243	7.04E-02	1.08E+01
Cs-135	1.32E-05	1.15E-02	Cm-243	1.44E-15	1.50E-10
Cs-137	1.03E-10	1.24E-11	Cm-244	1.82E-15	1.91E-10
Sm-146	7.31E-14	6.41E-11	Cm-245	8.43E-04	1.55E-01
Sm-147	2.81E-12	2.47E-09	Cm-246	3.74E-07	2.94E-05
Sm-151	8.95E-10	3.11E-14	Cm-247	2.16E-12	1.89E-09
Eu-152	2.82E-17	2.96E-12	Cm-248	5.39E-11	4.48E-08
Ho-166m	1.28E-09	2.54E-09	Cf-249	3.59E-10	2.80E-11

* noble gas with poor solubility in water, no ingestion dose coefficient available to estimate the contribution to the total radiotoxicity

The radionuclides contributing less than 1.0E-09% to the total radiotoxicity at the top of the considered clay layer will be omitted from DCC calculations and attributed conservative DCC-values.

The remaining radionuclides were combined in a common list. For some elements (e.g. Sm, Ho, Po, Cf) in the resulting list no firm data are available to carry out DCC calculations. Similar to the previous step, conservative DCC-values will be attributed to these elements.

The resulting radionuclide list is summarized in Table 3-7. For these radionuclides dose conversion coefficients were calculated (see Section 3.5) and used in the biosphere calculations. For the rest of the radionuclides of the OPERA inventory the most conservative DCC-value will be used in the biosphere calculations.

Table 3-7 List of radionuclides for which DCCs have been calculated by SCK using their calculation tool 'BIOSPHERE'

		Radionuclide			
^{10}Be	^{90}Sr	^{129}I	^{229}Th	^{238}U	^{241}Am
^{14}C	^{93}Mo	^{135}Cs	^{230}Th	^{237}Np	^{242m}Am
^{36}Cl	^{93}Zr	^{137}Cs	^{232}Th	^{238}Pu	^{243}Am
^{40}K	^{94}Nb	^{202}Pb	^{232}U	^{239}Pu	^{244}Cm
^{41}Ca	^{99}Tc	^{210}Pb	^{233}U	^{240}Pu	^{245}Cm
^{59}Ni	^{107}Pd	^{226}Ra	^{234}U	^{241}Pu	^{246}Cm
^{63}Ni	^{108m}Ag	^{227}Ac	^{235}U	^{242}Pu	^{248}Cm
^{79}Se	^{126}Sn	^{231}Pa	^{236}U	^{244}Pu	

3.4.3. DCC values for the PA model 'Biosphere'

Dose conversion coefficients for Temperate, Mediterranean and Boreal climates were calculated by SCK and are summarized in Table 3-8, Table 3-9 and Table 3-10 below. The DCCs calculated for Boreal climate can be used conservatively also for the periglacial and glacial climates. The results from the SCK•CEN biosphere model calculations are normalised to an activity concentration in groundwater feeding the well, surface waters and wetland of 1 Bq/m^3. Such normalization allows a direct comparison of the environmental transfer between the overburden and biosphere.

Table 3-8 Dose conversion coefficients (Sv/y per Bq/m^3 groundwater) calculated for an adult. Temperate climate for the well, river/lake and wetland receptors

Radionuclide	Well	*DCC* River/lake	Wetland
^{227}Ac	1.55E-06	9.51E-07	1.05E-06
^{108m}Ag	1.26E-08	2.46E-07	3.91E-08
^{241}Am	2.28E-07	1.30E-07	4.17E-08
^{242m}Am	2.27E-07	1.30E-07	4.23E-08
^{243}Am	2.47E-07	1.75E-07	7.21E-08
^{10}Be	1.40E-09	1.74E-09	5.01E-10
^{14}C	4.65E-10	1.84E-08	9.13E-11
^{41}Ca	2.74E-10	3.19E-10	2.45E-11
^{36}Cl	2.73E-09	3.02E-09	1.50E-08
^{244}Cm	1.36E-07	1.14E-07	2.40E-08
^{245}Cm	2.52E-07	2.16E-07	4.99E-08
^{246}Cm	2.47E-07	2.09E-07	3.90E-08
^{248}Cm	9.27E-07	7.88E-07	1.41E-07
^{135}Cs	5.26E-09	1.72E-08	6.23E-09
^{137}Cs	2.68E-08	1.45E-07	6.94E-08
^{129}I	1.32E-07	2.00E-07	2.45E-09
^{40}K	1.28E-08	6.44E-08	2.27E-09
^{93}Mo	4.64E-09	4.52E-09	3.65E-09

Radionuclide	DCC Well	River/lake	Wetland
^{94}Nb	2.13E-08	2.84E-08	4.94E-08
^{59}Ni	9.08E-11	1.17E-10	7.48E-11
^{63}Ni	2.01E-10	2.63E-10	1.78E-10
^{237}Np	1.26E-07	1.32E-07	8.01E-10
^{231}Pa	1.48E-06	1.28E-06	3.58E-06
^{202}Pb	1.18E-08	1.21E-08	2.17E-09
^{210}Pb	8.89E-07	7.07E-07	1.71E-07
^{107}Pd	6.28E-11	5.15E-11	9.29E-11
^{238}Pu	2.61E-07	1.52E-07	1.61E-08
^{239}Pu	2.90E-07	1.72E-07	1.75E-08
^{240}Pu	2.89E-07	1.71E-07	1.75E-08
^{241}Pu	5.44E-09	3.17E-09	3.23E-10
^{242}Pu	2.79E-07	1.65E-07	1.68E-08
^{244}Pu	3.21E-07	4.11E-07	1.20E-07
^{226}Ra	5.96E-07	7.05E-07	6.83E-06
^{79}Se	1.61E-08	1.97E-08	5.53E-08
^{126}Sn	2.80E-08	2.78E-07	5.62E-08
^{90}Sr	3.90E-08	4.00E-08	9.27E-09
^{99}Tc	7.66E-10	8.25E-10	1.09E-10
^{229}Th	7.52E-07	8.67E-07	2.42E-07
^{230}Th	2.58E-07	2.85E-07	7.24E-08
^{232}Th	1.41E-06	1.93E-06	6.42E-07
^{232}U	5.45E-07	5.57E-07	5.62E-08
^{233}U	5.92E-08	5.84E-08	3.77E-09
^{234}U	5.69E-08	5.61E-08	3.62E-09
^{235}U	5.55E-08	5.63E-08	4.97E-09
^{236}U	5.46E-08	5.38E-08	3.47E-09
^{238}U	5.63E-08	5.58E-08	3.85E-09
^{93}Zr	1.86E-09	2.92E-09	9.69E-12

Table 3-9 Dose conversion coefficients (Sv/y per Bq/m^3 groundwater) calculated for an adult. Mediterranean climate for the well, river/lake and wetland receptors

Radionuclide	*DCC Well*	*River/lake*	*Wetland*
^{227}Ac	3.50E-06	2.90E-06	2.04E-06
^{108m}Ag	1.38E-08	1.84E-07	8.66E-09
^{241}Am	5.44E-07	4.45E-07	2.46E-07
^{242m}Am	5.27E-07	4.29E-07	2.42E-07
^{243}Am	6.83E-07	6.03E-07	2.46E-07
^{10}Be	3.37E-09	3.70E-09	6.47E-10
^{14}C	5.24E-10	1.85E-08	9.13E-11
^{41}Ca	6.06E-10	6.51E-10	2.48E-11
^{36}Cl	8.55E-09	8.84E-09	1.42E-08
^{244}Cm	3.11E-07	2.90E-07	1.41E-07
^{245}Cm	7.04E-07	6.67E-07	2.24E-07
^{246}Cm	6.74E-07	6.36E-07	2.22E-07
^{248}Cm	2.76E-06	2.62E-06	7.94E-07
^{135}Cs	1.21E-08	2.41E-08	6.76E-09
^{137}Cs	5.68E-08	1.64E-07	4.97E-08

Radionuclide	DCC Well	River/lake	Wetland
^{129}I	3.39E-07	4.07E-07	2.48E-09
^{40}K	2.77E-08	7.54E-08	2.17E-09
^{93}Mo	1.12E-08	1.11E-08	3.64E-09
^{94}Nb	1.44E-08	2.02E-08	1.01E-08
^{59}Ni	2.17E-10	2.43E-10	8.00E-11
^{63}Ni	4.61E-10	5.23E-10	1.90E-10
^{237}Np	2.88E-07	2.94E-07	1.15E-09
^{231}Pa	6.10E-06	5.90E-06	5.94E-06
^{202}Pb	2.68E-08	2.71E-08	2.03E-09
^{210}Pb	2.00E-06	1.81E-06	1.58E-07
^{107}Pd	1.59E-10	1.48E-10	9.43E-11
^{238}Pu	6.01E-07	4.93E-07	9.58E-08
^{239}Pu	7.44E-07	6.26E-07	1.04E-07
^{240}Pu	7.33E-07	6.15E-07	1.04E-07
^{241}Pu	1.24E-08	1.02E-08	1.88E-09
^{242}Pu	7.18E-07	6.05E-07	1.00E-07
^{244}Pu	7.39E-07	7.74E-07	1.19E-07
^{226}Ra	1.33E-06	1.43E-06	4.97E-06
^{79}Se	4.46E-08	4.82E-08	5.71E-08
^{126}Sn	2.82E-08	2.23E-07	1.54E-08
^{90}Sr	1.76E-07	1.64E-07	5.63E-08
^{99}Tc	1.78E-09	1.84E-09	1.08E-10
^{229}Th	1.97E-06	2.08E-06	5.32E-07
^{230}Th	7.03E-07	7.29E-07	1.81E-07
^{232}Th	3.27E-06	3.69E-06	6.12E-07
^{232}U	1.24E-06	1.25E-06	5.27E-08
^{233}U	1.37E-07	1.36E-07	4.69E-09
^{234}U	1.31E-07	1.30E-07	4.52E-09
^{235}U	1.27E-07	1.27E-07	4.57E-09
^{236}U	1.26E-07	1.25E-07	4.28E-09
^{238}U	1.30E-07	1.29E-07	4.36E-09
^{93}Zr	4.08E-09	5.14E-09	1.12E-11

Table 3-10 Dose conversion coefficients (Sv/y per Bq/m^3 groundwater) calculated for an adult. Boreal climate for the well, river/lake and wetland receptors

Radionuclide	DCC Well	River/lake	Wetland
^{227}Ac	1.10E-06	4.99E-07	1.24E-06
^{108m}Ag	4.36E-09	2.37E-07	1.27E-08
^{241}Am	1.60E-07	6.19E-08	8.49E-08
^{242m}Am	1.59E-07	6.16E-08	8.40E-08
^{243}Am	1.71E-07	9.89E-08	9.28E-08
^{10}Be	9.59E-10	1.29E-09	4.96E-10
^{14}C	4.29E-10	1.84E-08	9.13E-11
^{41}Ca	1.95E-10	2.39E-10	2.39E-11
^{36}Cl	1.35E-09	1.63E-09	1.43E-08
^{244}Cm	9.53E-08	7.36E-08	4.95E-08
^{245}Cm	1.77E-07	1.40E-07	8.21E-08
^{246}Cm	1.75E-07	1.37E-07	7.87E-08

^{248}Cm	6.57E-07	5.18E-07	2.83E-07
^{135}Cs	3.64E-09	1.56E-08	5.94E-09
^{137}Cs	1.93E-08	1.37E-07	4.75E-08
^{129}I	1.08E-07	1.76E-07	2.28E-09
^{40}K	9.26E-09	6.08E-08	2.16E-09
^{93}Mo	3.08E-09	2.96E-09	3.62E-09
^{94}Nb	4.12E-09	1.13E-08	1.54E-08
^{59}Ni	5.87E-11	8.45E-11	7.10E-11
^{63}Ni	1.38E-10	2.00E-10	1.69E-10
^{237}Np	8.82E-08	9.46E-08	7.84E-10
^{231}Pa	9.09E-07	7.08E-07	4.06E-06
^{202}Pb	8.30E-09	8.59E-09	1.99E-09
^{210}Pb	6.52E-07	6.74E-07	1.57E-07
^{107}Pd	3.85E-11	2.72E-11	9.23E-11
^{238}Pu	1.83E-07	7.44E-08	3.35E-08
^{239}Pu	2.04E-07	8.63E-08	3.64E-08
^{240}Pu	2.04E-07	8.56E-08	3.64E-08
^{241}Pu	3.81E-09	1.55E-09	6.63E-10
^{242}Pu	1.96E-07	8.31E-08	3.49E-08
^{244}Pu	2.03E-07	2.93E-07	6.60E-08
^{226}Ra	3.61E-07	4.70E-07	4.81E-06
^{79}Se	8.82E-09	1.24E-08	5.10E-08
^{126}Sn	7.98E-09	2.58E-07	2.05E-08
^{90}Sr	4.30E-08	3.10E-08	2.25E-08
^{99}Tc	5.38E-10	5.98E-10	1.08E-10
^{229}Th	5.22E-07	6.38E-07	2.85E-07
^{230}Th	1.81E-07	2.08E-07	9.46E-08
^{232}Th	9.13E-07	1.43E-06	4.63E-07
^{232}U	3.81E-07	3.93E-07	4.17E-08
^{233}U	4.15E-08	4.07E-08	3.64E-09
^{234}U	3.99E-08	3.91E-08	3.50E-09
^{235}U	3.86E-08	3.93E-08	3.81E-09
^{236}U	3.82E-08	3.75E-08	3.35E-09
^{238}U	3.94E-08	3.89E-08	3.50E-09
^{93}Zr	1.33E-09	2.40E-09	9.94E-12

4. Biosphere model computer code, input data and parameters

4.1. The ORCHESTRA computer code

The PA model for the biosphere compartment was modelled using the open source reactive transport modelling framework ORCHESTRA [Meeussen, 2003]. ORCHESTRA stands for Objects Representing CHEmical Speciation and TRAnsport and is a versatile framework that is widely used for development of state-of-the-art mechanistic models [Filius et al., 2000], [Weng et al., 2005 & 2008], but also for applying these models for risk assessment of complex soil or cement-based systems [Schröder et al, 2005 & 2008], [Sarkar et al., 2010].

Unlike other programmes used in PA, the open, object-oriented structure of ORCHESTRA enables the user to define new sub-models enabling bridging of the different conceptual levels. Different from other programmes, the model definitions within ORCHESTRA are not embedded in the source code but can be defined as input at runtime enabling storage of the model definitions in a data base that can be accessed and adjusted by the user. The ORCHESTRA code is accompanied by a standard object database (in text format) containing predefined model objects that can be extended and/or combined with user defined models. There are no restrictions on the choice of the mathematical model; new models can be implemented without adjustment of the source code.

ORCHESTRA meets following requirements, which make it very suitable for PA calculations including uncertainty analysis:

- stochastic treatment of the relevant input parameters,
- specification of the stochastic parameter values as input at runtime,
- computational efficiency.

For the representation of the PA model for uptake in the biosphere, the biosphere compartment is modelled as a single cell. The transport within the biosphere is assumed to be included in the DCC input values. The contaminants released into the compartment are instantly mixed[3] with the biosphere water. To indicate the possible impact of different release points, the following interfaces with the biosphere were considered:

- Well
- Surface water bodies (river, lakes, ponds)
- Wetland (polder)

The implemented model has the same mathematical formulation for all considered interfaces with the biosphere:

$$D_{j,climate} = \sum_{nuclide\ i} C_{i,j,climate} DCF_{i,j,climate} = \sum_{nuclide\ i} \frac{J_{i,climate} DCC_{i,j,climate}}{V_{j,climate}}$$

with:

D effective dose rate (Sv/a),
DCC radionuclide, interface and climate specific dose conversion coefficient $(\mathrm{Sv\ a^{-1}})/(\mathrm{Bq\ m^{-3}})$,
J radionuclide release at the considered interface (Bq/a),
V dilution volume at the considered interface (m^3/a),
i radionuclide,
j interface overburden/biosphere (well, river/lake/pond or wetland).

[3] Valid because of the small variation of nuclide flux compared to transport times in the biosphere

The PA-model for biosphere calculates the radionuclide concentrations in the biosphere water at each time step.

The differences between different overburden/biosphere interfaces is captured by using interface-specific values for the dilution volume (V), dose conversion coefficient (DCC) and radionuclide release into the biosphere (J). The element specific behaviour is taken into account by using element-specific values for DCCs as well as element specific releases into the biosphere. The temporal variability is reflected by the evolution in time of the radionuclide release into the biosphere.

Well

The release into a well was modelled as indicated in Figure 4-1. It is assumed that 100% of the total release from the host rock ends up in the aquifer on which the well draws. The contaminated well-water is used as irrigation water and drinking water for human and farm animals. In this approach the deep well is represented by a single compartment with a given yearly capacity. The distance between the well and the top of the clay layer is assumed to be zero, so radionuclides leaving the clay layer by diffusion enter the aquifer water instantly. The aquifer should be at an accessible depth and provide sufficient water for domestic uses. Such a well at the point of maximum radionuclide concentration would lead to an undiluted intake of overburden water. This assumption is conservative with respect to the dilution of radionuclides in the aquifer, resulting in high estimated nuclide concentrations in the well.

It is assumed that this deep well is used to extract a certain amount of water per year. Assumption is that a self-sustaining adult needs at least 3500 m^3 per year. That amount of water combined with the nuclide flux from the clay into the overburden serve as input for the calculation of radionuclide concentrations in the well water.

Assuming that the yield of the well exceeds the groundwater flow in the aquifer passing the release area of the clay, the complete nuclide flux from the clay is captured in the well water, and the resulting average concentrations will be equal to the total yearly nuclide flux from the clay divided by total amount of water extracted yearly from the well.

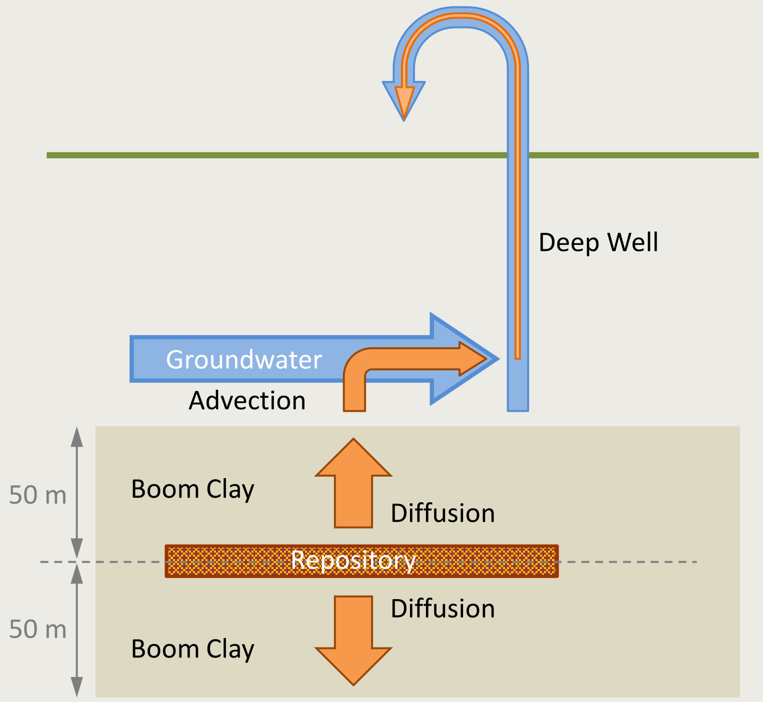

Figure 4-1 Schematic overview of release into a well

Van Beek (2010) mentions capacities of 40 to 100 m^3/h for wells pumping water from depths between 20 and 250 m that translate to annual yields (well capacities) of 350 000 m^3 or more.

Surface water body
For the release into a river, lake or pond, it is assumed that the total release from the overlying rock formations (overburden) ends up in the surface water body with a given volume. The 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.

The release into surface water was modelled as indicated in Figure 4-2. The surface water body represents a river, lake or pond with a given flow rate or outflow, respectively.

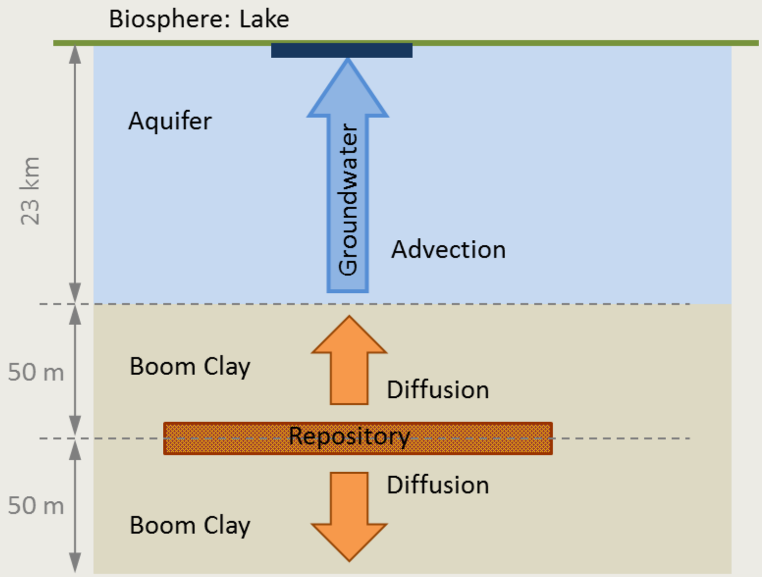

Figure 4-2 Schematic overview of a release into a lake

For release into a river it is assumed that the river's flow rate varies between 10^7 m^3/a in case of a small river and 10^{11} m^3/a in case of a large one [Prij, 1993; Section 8.33, Table 8.8]. The dilution volume for a release into a river equals the average annual river flow.

Consideration of the water needs of a self-sustaining community of a few hundred people indicates that a lake with a volume of approximately 10^6 m^3 or more is needed. Compared to a river, the turnover rate of a lake is fairly low. Retention time (also called turnover, residence time of lake water, or water age or flushing time) is a calculated quantity expressing the mean time that water (or some dissolved substance) spends in a particular lake. Under the assumption that water in the lake is well mixed, the retention time for a lake (the overall mean time that water spends in the lake) can be calculated, by dividing the lake volume by either the mean rate of inflow of all tributaries, or by the mean rate of outflow. The dilution volume for retention times shorter than one year will be equal to the volume of the lake divided by its retention time. For a lake with retention times longer than one year, the dilution volume could be assumed to be equal to the outflow of the lake.

Wetland
For the wetland receptor it is assumed that the soil water in the topsoil is directly contaminated by the upwelling groundwater when the water table is high. Plants may grow

on the soil and be used for food or animal feed. The release into wetland is modelled as indicated in Figure 4-3.

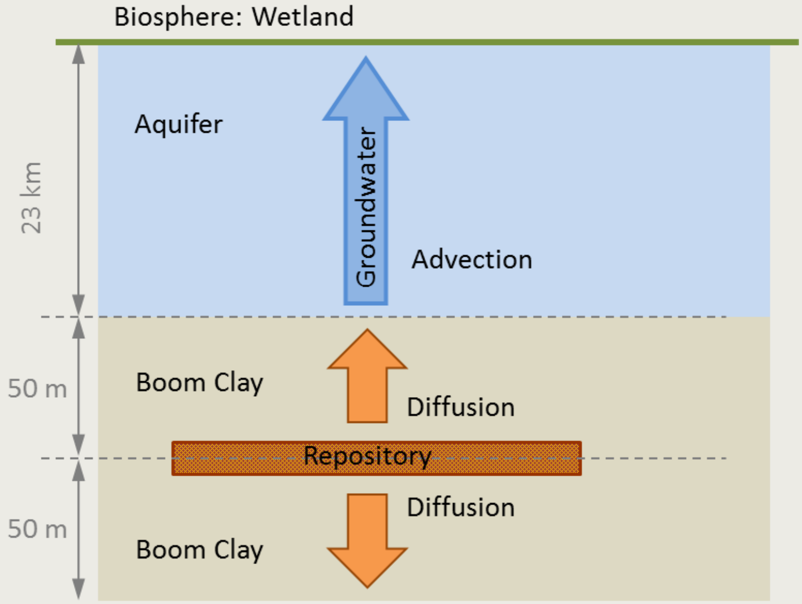

Figure 4-3 Schematic overview of wetland receptor

It is assumed that 100% of the total release from the overburden ends up in wetland water. In this approach wetland water is represented by a single compartment with a given yearly refreshed volume. The distance between the wetland and the top of the overburden is assumed to be zero, so radionuclides leaving the overburden by advection instantaneously enter the wetland water.

4.2. Input

The input required for the PA model for the biosphere compartment reduces to three sets of data:

- radionuclide, interface and climate specific dose conversion coefficients (*DCCs*),
- radionuclide, interface and climate specific release into the biosphere (*J*),
- interface and climate specific biosphere water volume characteristics (refreshment rate).

The dose conversion coefficients (DCCs) for the radionuclides which may be released in the biosphere are calculated by SCK for releases in a (1) river, pond or lake, (2) well, and (3) wetland for Temperate, Mediterranean and Boreal climates (see Section 3.4). Relative contributions of the different pathways to the dose (%) are given in Appendix E.

The radionuclide release into the biosphere is calculated by the ORCHESTRA models for reactive transport through the compartments Boom clay and overburden.

Dilution factors for present day and future conditions were estimated in OPERA WP6.2.

4.3. Output: Safety and performance indicators

The OPERA biosphere model together with other compartment models will be integrated in *a PA integrated modelling environment* enabling repeated calculations of predefined scenarios. This *PA integrated modelling environment* has to allow the calculation of the Safety and Performance indicators, summarized in Table 4-1.

Table 4-1 Indicators for the OPERA Safety Case related to biosphere

Indicator	*Type*	*Output from the biosphere model as input for the calculation of the indicator*
Effective dose rate	SI	activity concentration [Bq/m^3] of radionuclide n in the biosphere water
Power density in ground water	SI	activity concentration [Bq/m^3] of radionuclide n in the biosphere water
Radiotoxicity concentration in biosphere water	SI, PI	activity concentration [Bq/m^3] of radionuclide n in the biosphere water
Radiotoxicity in the compartment 'biosphere'	PI	activity [Bq] of radionuclide in compartment "biosphere"

SI: safety indicator; PI: performance indicator

The *Effective dose rate* is the annual individual effective dose to an average member of the group of the most exposed individuals (i.e. the reference group, see Section 2.4.2). It takes into account dilution and accumulation in the biosphere, different exposure pathways as well as living and nutrition habits.

The indicator *Power density in groundwater* is a physical parameter independent of any specific biological species. It is composed of the contribution of all radionuclides to the power density and can be seen as a criterion for the impact of hazardous radionuclides on biota in general.

The *Radiotoxicity concentration in biosphere water* is a safety indicator representing the radiotoxicity of the radionuclides in 1 m^3 of biosphere water. It also can be understood as the dose which is received by drinking of 1 m^3 of biosphere water. This indicator is actually equivalent with the performance indicator *Radiotoxicity concentration in compartment water* applied for the compartment biosphere. Therefore, in Table 4-1, this indicator is indicated as both safety and performance indicator.

Based on the calculation methodology of the indicators, the output from the biosphere model necessary for the calculation of the related indicators IS:

- (average) activity concentration (Bq/m^3) of radionuclide *n* in the biosphere water,
- (total) activity (Bq) of radionuclide *n* in compartment "biosphere",

The PA-model for the compartment biosphere was setup to provide these data for each of the radionuclides considered in the PA. These data are used thereafter in the calculation of the indicators related to the biosphere compartment.

4.4. Testing and validation of the PA-model for biosphere

The biosphere calculations are straightforward and based on simple mathematical operations. The verification of the implemented model can therefore be carried out by a model implemented in Excel having the same mathematical formulation as given in Sections 3.1.

The flow of radionuclides from the overburden to the biosphere used in the test calculation has been taken from [Grupa, 2017] and is shown in Figure 4-4 for a selection of radionuclides.

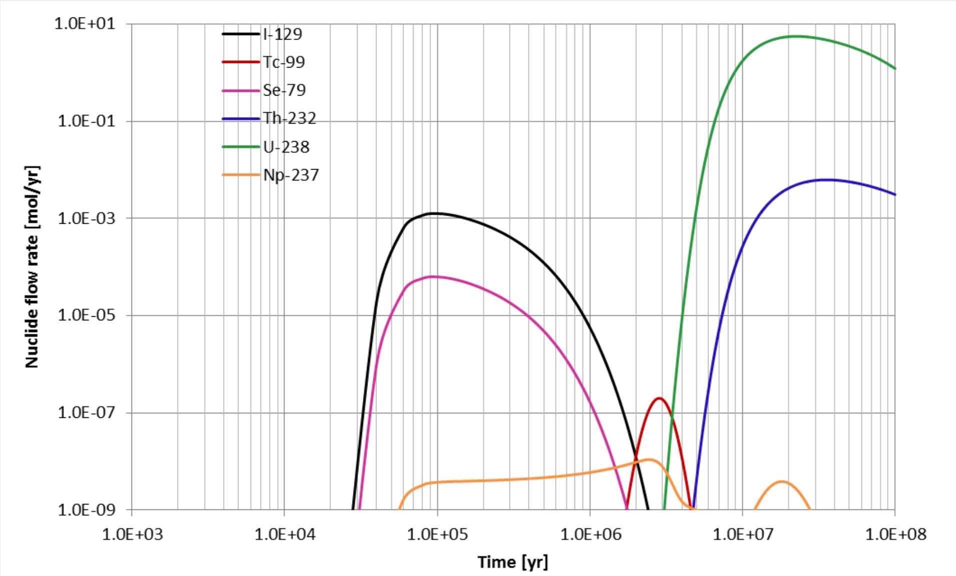

Figure 4-4 Nuclide flow rates at the overburden/biosphere interface calculated by ORCHESTRA

For this test calculation, the dilution in the wetland water was taken arbitrarily as 7.8E+04 m^3/a. The results of the excel calculations of the dose rates for six selected radionuclides for Temperate climate and release point wetland are shown as solid lines, those of the ORCHESTRA calculations as small x-es in Figure 4-5 below.

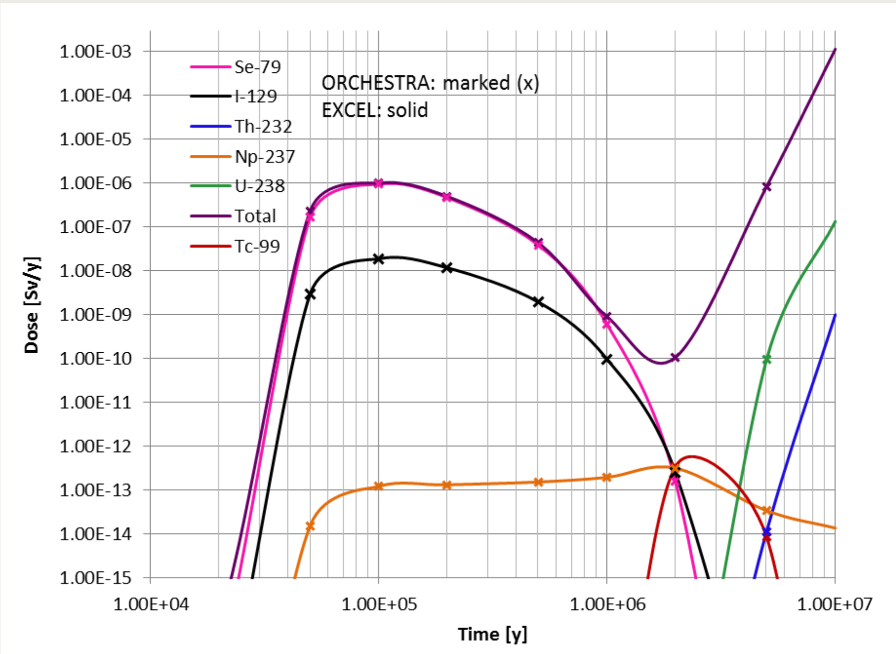

Figure 4-5 Evolution of the dose rate calculated in Excel (solid lines) and ORCHESTRA (marked) for Temperate climate and wetland receptor

The Excel and ORCHESTRA results show excellent agreement of the calculated dose rates within the analysed time range (see Figure 4-5). This benchmark was in particular meant to exclude implementation errors.

5. Conclusion and discussion

The biosphere is the fourth and last compartment of the repository system in Boom Clay succeeding the source, the host rock and the overburden. It consists of a single layer with average characteristics. In the present project task a PA model for migration and uptake in the biosphere was implemented and tested. This model uses fixed biosphere dose conversion coefficients. It was considered to improve the classical PA compartment model by including a limited number of climatic factors (such as yearly precipitation, average temperature) in the PA-biosphere model. However, the dose conversion coefficients that can be derived with the detailed climate model have a non-linear relation with the general climatic factors such as yearly precipitation and average temperature. Therefore it was decided to represent the climate change in a non-sequential way (to switch between constant climates) instead of a sequential way (to consider also the transitions between climate states). The element specific behaviour is taken into account by using element-specific dose conversion coefficients as well as element specific releases into the biosphere. The temporal variability is reflected by the evolution in time of the radionuclide release into the biosphere.

The calculations for the biosphere system were performed by the computer code ORCHESTRA, which is used for all compartments of the system. The benchmark of the computed results was done by means of EXCEL. The ORCHESTRA codes for migration and uptake in the biosphere permits the stochastic treatment of the relevant input parameters by specification of the stochastic parameters values as input at runtime.

Dose conversion coefficients for Temperate, Mediterranean and Boreal climates as well as for releases into a surface water body, deep well and wetland were calculated by SCK·CEN with the model 'BIOSPHERE' developed by SCK·CEN, which is applied in the Belgian radioactive waste disposal research program as well.

The results of the calculations were shown for 6 selected radionuclides. The benchmark showed good agreement of the results of the calculations with the two computer codes: no difference in the resulting concentrations and calculated dose rates occurred proving a correct implementation of the mathematical model. Thus, as in earlier investigations, ORCHESTRA turned out to be an adequate tool.

The calculations presented in this report have been performed for the normal evolution scenario. For further scenarios, the same instruments can be used, if the transport path can also be modelled as one-dimensional.

The present calculations are based on preliminary value ranges of the input parameters and serve for verification purpose only. More realistic values for these parameters will be established in related WP's of the OPERA programme and will be used in the final PA calculations.

The PA-model for the compartment biosphere was setup to provide the data necessary for the calculation of the indicators related to the biosphere compartment. For this report, the effective dose rate and total amounts and concentrations of radionuclides (either in radiotoxicity, activity or in amount) were sufficient to explain all the results and to proof the correct implementation of the model. Further indicators, such as *Power density in groundwater*, *Transport time through compartments* and *Radiotoxicity flux from biosphere*, may be appropriate in future calculations to highlight special effects in the calculations.

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Appendix A Previous work

The modelling of the biosphere in safety assessments of geological waste repositories has been subject of intensive research and analysis in all countries adopting geological disposal, and in dedicated projects performed under the hood of the European Commission and the IAEA. The modelling of the biosphere comprises many areas of expertise and usually consists of several subsequent stages such as:

- the definition of the context of the assessment, which is generally determined by national regulations;
- the distinction and treatment of various features, events and processes (FEPs) of the system under investigation;
- the consideration of future evolutions of climate and human behaviour;
- the development of conceptual models which correspond to an adequate approximation to the (future) biosphere;
- the mathematical representation of those conceptual models; and
- the choice of parameter values to adopt within those mathematical representations.

This appendix does not intend to provide a comprehensive overview of all these aspects of biosphere modelling. Instead, a summarily overview is provided of main projects and programmes on this topic.

A.1. Netherlands

In the Netherlands, the last and main biosphere modelling effort in relation to geological disposal of radioactive waste was performed within the PROSA project which was executed as part of the Dutch OPLA-1A programme [Prij, 1993]. As a first step FEPs were identified, related to the biosphere, which were judged to affect the post-closure long-term safety of the repository under consideration [Prij, 1993; Table 4.16]. It was acknowledged that on the time scales involved in a safety assessment of the disposal of radioactive waste, predictions on human behaviour are speculative. Therefore, the level of technology of the human populations was assumed equal to the present-day level of technology.

For the calculation of the dose conversion coefficients when the radionuclides enter the biosphere via the groundwater, a same standard biosphere was used as the biosphere in the preceding project VEOS [Köster, 1989]. The biosphere was modelled as a river compartment with adjacent agricultural land. Radionuclides would enter the biosphere through the discharge of the contaminated groundwater into the river. That flux was calculated with a separate computer model (METROPOL). The river water was assumed to be used both for drinking and irrigation. Radiation doses were then calculated, using the EXPOS code, for a farmer consuming only the production of his own land. The consumption pattern was assumed to resemble the present-day average consumption pattern of an adult. An overview of the most important exposure pathways is given in Figure A-1 [Prij, 1993; p. 6.56].

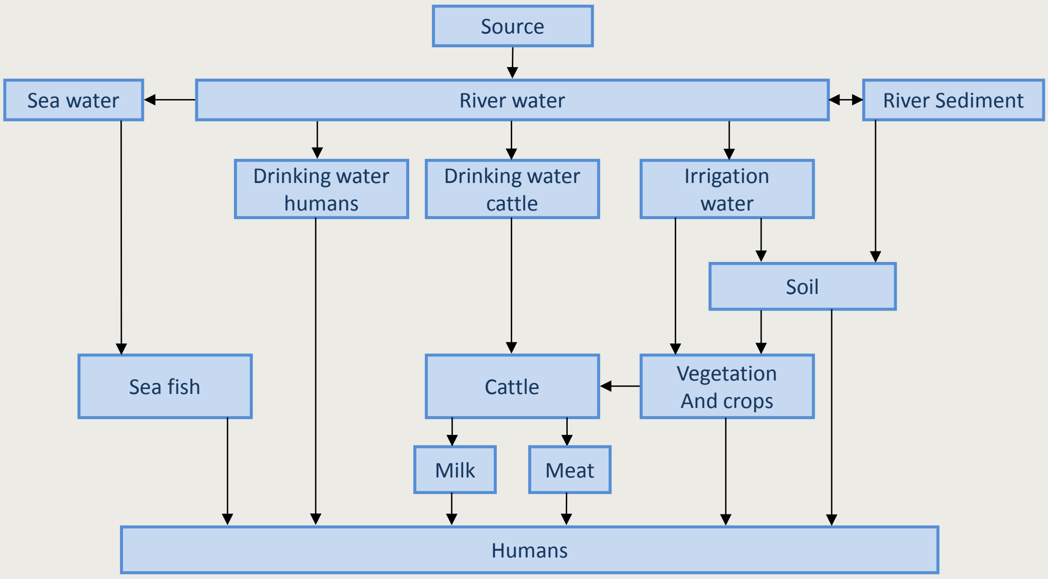

Figure A-1 **Contamination pathways for the biosphere**

The values of the dose conversion coefficients were determined using the environmental transfer model MiniBIOS, where several transfer compartments were considered in which individual radionuclides could be more or less retarded. This methodology was applied to generate stochastic distributions of dose conversion coefficients, which were subsequently used in the probabilistic safety assessment to investigate the uncertainty and sensitivity of the DCCs on the exposure. In the modelling of the biosphere, a distinction was made between dose conversion coefficients calculated for the transport with groundwater and for the diapirism scenarios without subrosion [Prij, 1993; Section 6.5].

A.1. IAEA

The IAEA has undertaken a number of projects in the field of biosphere assessment over the past 20 years. These projects have included consideration of the data and scientific understanding underpinning both conceptual and mathematical biosphere assessment models, and the definition of biosphere systems and scenario definition. Human and non-human biota have both been regarded as the end point of the assessment, and in some instances comparisons have been made between models, and where possible, between models and experimental or field data. That work has served to further underpin the scientific basis of the Safety Case in the biosphere, and also the assessment strategy and tools used in the biosphere part of the Safety Case.

The VAMP (VAlidation of Model Predictions; 1986-1996) programme was established following the Chernobyl disaster in 1986, and was aimed at collating data from different IAEA Member countries and coordinating model testing studies. It was concerned with models and data relevant to the terrestrial, aquatic and urban environments. It did not deal with models for atmospheric transport, but, however, did consider the interactions of aerosols in the surface air with terrestrial and aquatic surfaces.

The BIOMASS (BIOsphere Modelling and ASSessment; 1996-2001) programme was concerned with developing and improving models to predict the transfer of radionuclides in the environment. The programme had three themes: radioactive waste disposal, environmental releases and biosphere processes. In addition, within the BIOMASS programme, a modelling approach was developed for predicting the radiological impact of releases in the far future from the underground disposal of radioactive waste, viz. the ‘Reference Biosphere’ [IAEA, 2003].

The BIOMASS Methodology provides a formal procedure for the development of assessment biospheres in general. It was developed through the creation of the BIOMASS Example Reference Biospheres. The BIOMASS Methodology is based on a staged approach in which each stage introduces further detail so that a coherent biosphere system description and corresponding conceptual, mathematical and numerical models can be constructed. The methodology is summarised in Figure A-2 [IAEA, 2003; p.1].

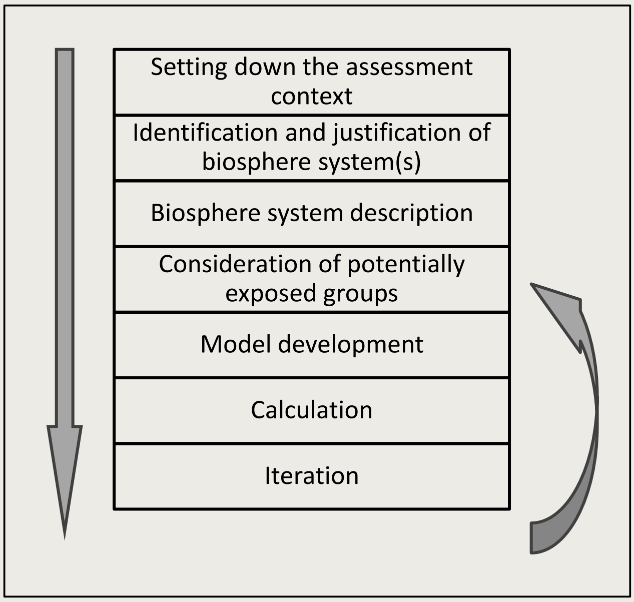

Figure A-2 Summary of the BIOMASS Methodology

Within BIOMASS, a number of Example Reference Biospheres (ERBs) have been developed, demonstrating the application of the BIOMASS methodology. In particular, three ERBs have been developed that relate to a temperate climate and unchanging biosphere conditions. These ERBs were intended as generic examples and are not related a specific location:

- ERB 1 – Drinking water well intruding into a contaminated aquifer;
- ERB 2A – Agricultural irrigation well intruding into a contaminated aquifer;
- ERB 2B – Natural discharge from a contaminated aquifer into a number of different habitats, including arable, pasture, semi-natural wetland and lake.

Additionally, the project has also produced three further ERBs that have been used to develop the BIOMASS methodology to allow it to be used to address biosphere conditions changing with time.

The ERBs developed in BIOMASS serve as the basis for further development of specific biosphere modelling efforts performed in several countries' disposal programmes.

The IAEA EMRAS (*Environmental Modelling for Radiation Safety*, 2003-2007) programme focused on areas where uncertainties remain in the predictive capability of models developed in the previous programmes, notably in relation to the consequences of releases of radionuclides to particular types of environment (e.g. urban and aquatic environments), restoration of sites with radioactive residues, and impact of environmental radioactivity on non-human species.

The EMRAS II (2009-2011) programme was a sequel of the EMRAS programme. There were three broad themes, with three working groups for each theme: reference approaches for human dose assessment, reference approaches for biota dose assessment, and approaches for assessing emergency situations.

The MODARIA (*Modelling and Data for Radiological Impact Assessments*; 2012-2015) programme was set up to continue the IAEA's activities in the field of testing, comparing and developing guidance on the application of models to assess exposures to humans and radiological impacts on the environment. MODARIA has four themes: remediation of contaminated areas, uncertainties and variability, exposures and effects on biota, and marine modelling. Specific objectives of MODARIA in the areas of radioactive release assessment, restoration of sites with radioactive residues, and environmental protection are:

- To test the performance of models developed for assessing the transfer of radionuclides in the environment and radiological impact to man and environment;
- To develop and improve models for particular environments and, where appropriate, to agree on data sets that are generally applicable in environmental transfer models;
- To provide an international forum for the exchange of experience, ideas and research information.

The IAEA reports are available at the IAEA website[4].

A.2. EC Framework Programme

During the last 15 years the topic of biosphere modelling and assessment has been the subject of several EC Framework Programme projects:

- (*2000-2003*) The EC 5th Euratom framework project FASSET (*Framework for assessment of environmental impact*) began the development of a framework for the assessment of environmental impact in radiation protection. More information about the project, and associated publications, can be found at the project website: https://wiki.ceh.ac.uk/display/rpemain/FASSET.
- (*2000-2003*) The EC 5th Euratom framework project BIOCLIM (*Modelling Sequential Biosphere Systems under Climate Change for Radioactive Waste Disposal*) aimed at providing a scientific basis and practical methodology for assessing the possible long term impacts on the safety of radioactive waste repositories in deep formations due to climate and environmental change in biosphere systems for regions in Europe (Central/Southern Spain, Northeast France, Central England). The project website provides additional information: http://www.andra.fr/bioclim/.
- (*2000-2003*) The EC 5th Euratom framework project EPIC (*Environmental protection from ionising contaminants in the arctic*) aimed to develop a framework for the protection of a pristine environment (Arctic) from radioactivity. More information on the project, and associated publications, can be found at the project website: https://wiki.ceh.ac.uk/display/rpemain/EPIC. Many of the outputs of this project were superseded by those of the subsequent ERICA project.
- (*2004-2007*) The EC 6th Euratom framework project ERICA (*Environmental Risk from Ionising Contaminants: Assessment and Management*) aimed to provide an integrated approach to scientific, managerial and societal issues concerned with the environmental effects of contaminants emitting ionising radiation, with emphasis on biota and ecosystems. The project was partly built on the achievements of the FASSET project, which provided a basic framework for the assessment of environmental impact of radionuclides. The final outcome of the project was the development of a user-friendly assessment tool with risk characterisation methodologies coupled with

[4] http://www-ns.iaea.org/projects/emras/emras-publications.asp?s=8

communication strategies aimed at decision-making. More details about the project and the tool can be found at the project website: https://wiki.ceh.ac.uk/display/rpemain/ERICA.

- (*2006-2008*) The EC 6th Euratom framework project PROTECT (*Protection of the Environment from Ionising Radiation in a Regulatory Context*) aimed to develop dose rate thresholds for wildlife to help to determine the risk of exposure to ionizing radiation. The project website provides additional information: https://wiki.ceh.ac.uk/display/rpemain/PROTECT.

A.3. BIOPROTA

Building on the IAEA-BIOMASS-6 "Reference Biospheres" (see above) for solid radioactive waste disposal, the collaborative research forum BIOPROTA was established for exchange of information to support resolution of key issues in biosphere aspects of assessments of the long-term radiological impact of contaminant releases associated with radioactive waste and contaminated land management. Currently 17 organisations participate in BIOPROTA, consisting of operators and regulators, as well as scientific support organisations. The project’s output so-far relates to:

- Long term models for dose assessment;
- Spray irrigation;
- Accumulation in soil and inhalation;
- Accumulation in soil and uptake into the foodchain;
- C-14 model review;
- Cl-36 accumulation in soil and plant uptake;
- Use of analogue data;
- Site characterisation;
- Se-79 behaviour in the environment;
- Cl-36 behaviour in the environment;
- Processes at the geosphere biosphere interface;
- Long term dose assessment of non-human biota;
- Evaluation of codes for transfer modelling;
- Database for special radionuclides.

Additional information can be found at the project’s website: http://www.bioprota.org.

A.4. NEA

The NEA IGSC discussed “*The Role of the Biosphere in a Safety Case*” in a topical session at the third IGSC meeting in 2001 [NEA, 2002]. The topical session focused on the scientific developments in international programs such as IAEA BIOMASS, EC BIOCLIM, the views of regulators and the strategies being adopted by several implementers for incorporating the biosphere in their safety assessments. The report summarized the different oral presentations and written contributions as well as the various exchanges during the session. It intended to provide a state of the art overview of the different manners on how to be involved in the biosphere, either from research, implementer or a regulator body.

A.5. United Kingdom

The Nuclear Decommissioning Authority (NDA) Radioactive Waste Management Directorate (RWMD) has appointed Quintessa to work with NDAs Safety Case Group to support the maintenance and further development of its biosphere assessment capability. The objective is to ensure that the position taken by NDA RWMD in its biosphere assessment work, as part of its overall approach to long-term safety assessment, is fit-for-purpose, taking into account to generic and site-specific assessment studies that will be required in the future in the UK. The work encompasses maintenance of the NDA RWMD biosphere assessment capability, aiming to ensure that key components are up to date and ready for the next phase of its programme.

In a series of reports[5] Quintessa and NDA-RWMD reviewed the biosphere characterisation programmes that had been undertaken by other waste management organisations, and the implications for its own site characterisation efforts in the future [Thorne, 2011].

The approach used to develop and justify the NDA RWMD methodology for biosphere modelling is based on the guidance developed through the International Atomic Energy Agency's BIOMASS programme [IAEA, 2003] and the European Union (EU) BIOCLIM[6] project (BIOCLIM, 2004). It also takes into account discussions and results from model inter-comparisons from the on-going BIOPROTA programme. The approach is summarised in Figure A-3, including key questions/components for each stage.

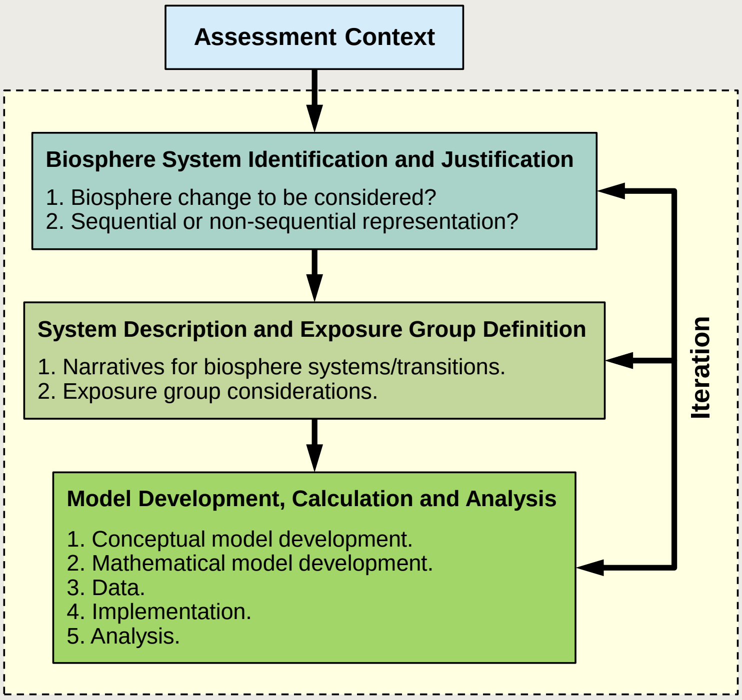

Figure A-3 Biosphere Assessment Methodology

A.6. Germany

In Germany the application of a biosphere model is mandatory under the regulations published in [AVV, 2012]. This regulation defines the approach to calculate effective doses from radionuclide concentrations in aquifers by the use of dose conversions coefficients (DCC). The following exposure pathways have to be considered for contaminated groundwater:

- uptake of drinking water,

[5] http://www.nda.gov.uk/publication/quintessa-report-biosphere-assessment-studies-qrs-1378zm-2v1_screening/
[6] http://www.andra.fr/bioclim/

- ingestion of fresh water fish from ponds,
- ingestion of plants irrigated with contaminated water,
- ingestion of milk and meat from cattle whose feed has been irrigated with contaminated water, and
- external radiation by dwelling on contaminated riparian sediments.

In the implementation of the AVV by [Pröhl, 2002] further exposure pathways were added:

- Unintended ingestion of soils;
- Inhalation of resuspended contaminated soil particles;
- Uptake of contaminated soil by cattle, and
- External radiation by dwelling on irrigated areas and in buildings erected with contaminat-ed materials.

Figure A-4 [Bollingerfehr, 2013; p.111] shows the exposure pathways applied for the calculation of corresponding DCC according to [Pröhl, 2002].

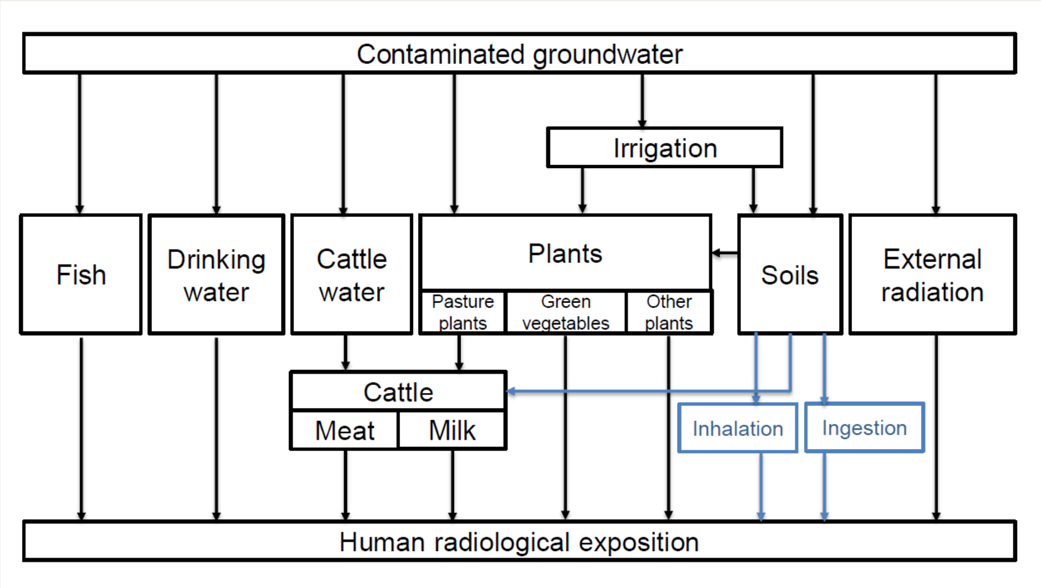

Figure A-4 Exposure pathways to be modeled according to [AVV, 2012]. Blue arrows and boxes represent exposure pathways added according to [Pröhl, 2002].

Additional details about the biosphere modelling efforts in Germany, including the effects of climate change, are provided in, for example [Lührmann, 2000; Rübel, 2007; Noseck, 2009; Semioshkina, 2012].

A.7. Finland

As part of the Safety Case for the disposal of spent nuclear fuel at Olkiluoto, Posiva, the Finnish expert organisation in nuclear waste management, compiled a set of comprehensive reports on the modelling of the biosphere at the selected site. The most recent publications on this topic date from 2013 and 2014 and comprise the description of the biosphere assessment [Posiva, 2013] and extensive data reports [Posiva, 2014].

An general overview of the methodology of the biosphere assessment process applied by Posiva is depicted in Figure A-5 [Posiva, 2013; p.41]. A more detailed description of the biosphere assessment methodology, the modelling approaches, and their place in the overall safety assessment, are described in Chapter 2 of [Posiva, 2013].

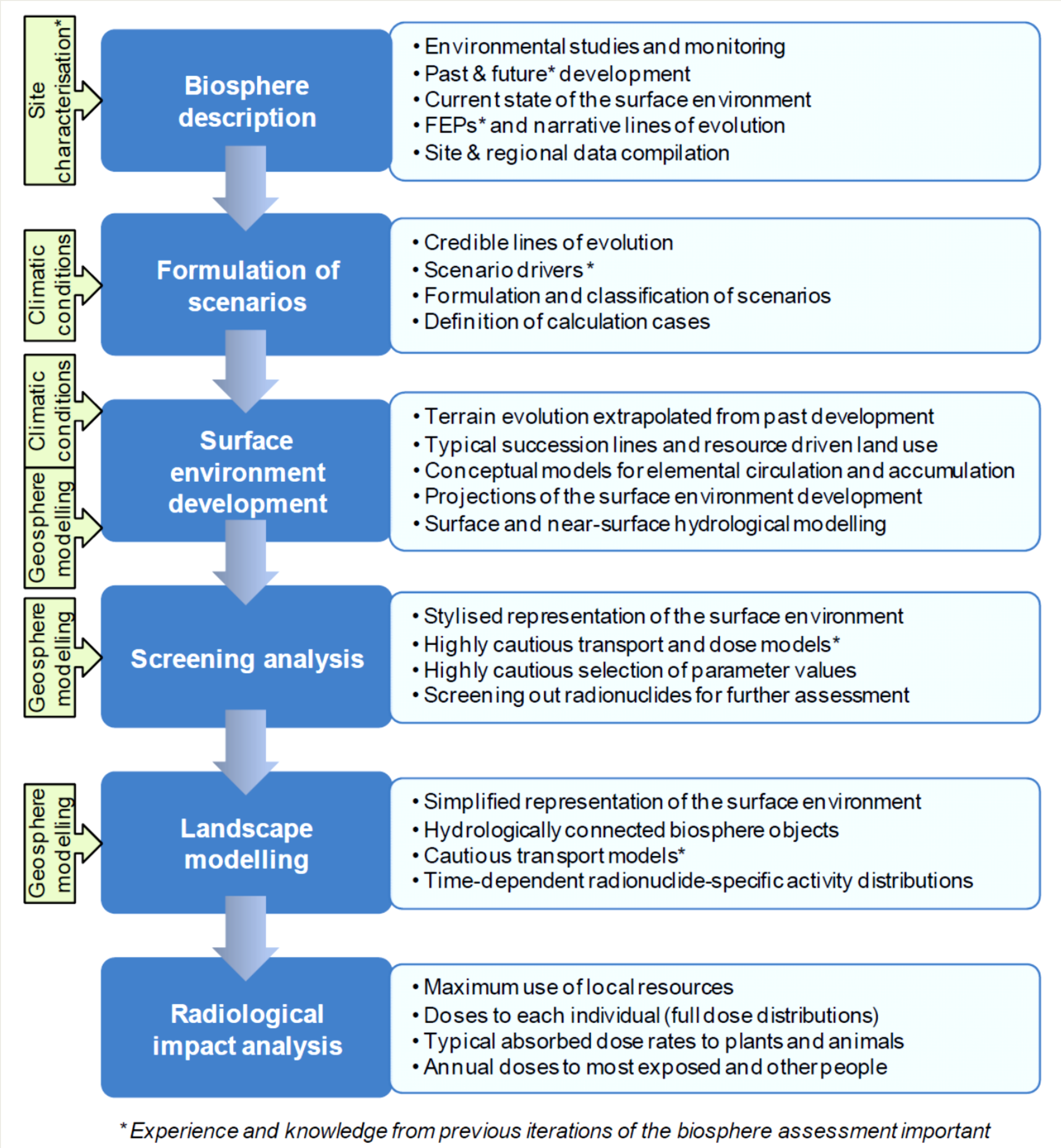

Figure A-5 The conceptual process of biosphere assessment, its sub-processes (blue boxes) and key features and products of each sub-process. The green boxes show the main inputs from activities external to the biosphere assessment in the safety case.

A.8. Sweden

In Sweden, biosphere analyses have been and are still being undertaken in assessments of the long-term safety of the anticipated deep geological facility for spent fuel, the SR-Site [SKB, 2010], and the low- and intermediate-level waste repository SFR in Forsmark, the SR-PSU safety assessment, which supports SKB's licence application to extend SFR [SKB, 2014].

In essence, the Swedish biosphere analyses follow closely the BIOMASS methodology [IAEA, 2003]; (see also Figure A-2). The first step was critically noting the locations of possible releases into the biosphere and describing the biosphere objects at those locations. Similarly to BIOMASS, interaction matrices were used to develop an understanding of how these biosphere objects exist together over the area and ecosystems of interest. A systematic approach was used to check the inclusion or justified exclusion of potential FEPs. Two stages were then adopted to model development: firstly, the development of potential discharge areas within the Forsmark landscape was modelled, and secondly the transport of radionuclides within the evolving biosphere objects were modelled. The calculation step in the biosphere assessment includes the description of the selection and application of appropriate data to the mathematical formulations, similar to the BIOMASS protocol for parameter selection.

A.9. References Appendix A

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Appendix B Radionuclide migration and uptake in the biosphere

The present section describes the biosphere approach for long term safety assessments of radioactive waste disposals.

The evolution of human societies, their lifestyles and eating habits and their impact upon and exchange with evolving ecosystems in the far future is highly uncertain. Nevertheless, there is a need to quantify future dose impact of radionuclides released from the repository into the biosphere. As result, assumptions have to be made regarding the future behaviour of people and the future conditions of the biosphere. To ensure that these assumptions are plausible and internally consistent, a methodology, called “The Reference Biosphere Methodology”, has been developed. This methodology, developed via an international IAEA programme and described in this report, is used to define the future biosphere(s) in terms of climate, geology, hydrology, flora, fauna, and local human activities. The methodology or similar approach has been used as guidance by several countries such as Belgium, Canada, France, Japan, Sweden, UK, United States.

In this report, also an overview is given of the main biosphere processes that could have a potential influence on the migration and distribution of radionuclides in the biosphere. Based on this more detailed overview and existing FEP lists, a generic conceptual biosphere model has been developed and guidance on the importance of the processes for the different biosphere receptors is given.

B.1. Factors affecting the migration and transfer of radionuclides in the biosphere

B.1.1. Introduction

The most important pathway by which radionuclides can migrate from the geosphere to the biosphere is the groundwater pathway. Groundwater (FEP 5.1.05)[7] can feed rivers, lakes and other surface waters and/or discharge directly into the soil (wetland). Groundwater can also be used as drinking water, for irrigation, etc. and as such expose people to radionuclides. There are a number of features, events and processes (FEPs) that have an important effect on the migration and transfer of radionuclides released in the biosphere and must be addressed in the biosphere assessment model. In the following chapters, an overview will be given of potential relevant features and processes.

This chapter is mainly based on the FEP lists developed by Egan (2001), IAEA (2003), NEA (2006) and the latter FEP list is also described in Schelland (2013). Where possible and relevant the FEP codes of the NEA FEP database as recorded in Schelland (2013) have been mentioned in this section. One must realize though that this txt contains a lot more detail on specific FEP items than have been captured in the generic NEA FEP database with lumped FEP categories.

[7] The code FEP XX.YY.ZZ refers to the corresponding FEP code in the NEA FEP database as recorded in Schelland (2013).

B.1.2. Physico-chemical properties of the radionuclide (FEP 5.3.01/02)

The physico-chemical properties of a radionuclide in a given biosphere system determine its mobility and bioavailability. The contaminant may be present in many different forms in a biosphere compartment, each of them characterized by different mobility (FEP 5.3.01.07-11), transfer factors to and between living matter. Some radionuclides such as radiocesium, radioiodine are mobile and transfer rather easy between the different biosphere components. In contrast, radionuclides with low solubility (FEP 5.3.01.07) such as actinides are relatively immobile.

Important physico-chemical properties of a radionuclide that influence the extent to which radionuclides are transferred in the biosphere are: radioactive decay and ingrowth, volatility and volatilisation (FEP 5.3.02.03), chemical stability. The chemical form and speciation (FEP 5.3.01.08) of a contaminant in the biosphere may be affected directly by chemical, physical and biological processes within the biosphere system as explained in section 5.4.4.

B.1.3. Natural cycling and distribution of radionuclides by living organisms

Distribution and redistribution of environmental materials occurs continuously as a result of the cycling of materials in a biosphere system. Cycling processes mediated by living components of ecosystems (FEP 5.1.14) include bulk movements of solids and liquids by flora and fauna, as well as food chain transfer and metabolic processing of nutrients and other materials.

Plants may become contaminated either as result of direct deposition of radionuclides onto their surfaces or indirectly as a result of uptake from contaminated soils or water via the roots. Animals may become contaminated with radionuclides as a result of ingesting contaminated plants and animals, or directly as a result of ingesting contaminated soils, sediments and water resources, or via inhalation of contaminated particulates, aerosols or gases. Changes in radionuclide content of food products (e.g. through radioactive decay) may arise as result of the storage of foods or other biosphere products before use or consumption.

Potentially relevant phenomena include:

- Root uptake of water and nutrients/contaminants from soil solution
- Uptake of water and nutrients/contaminants from decomposing organic material via fungal mycelia
- Plant respiration
- Plant transpiration
- Translocation of materials within plants
- Animal respiration (includes inhalation of aerosols)
- Consumption of soil, sediment and food by animals
- Metabolism of materials within organism body tissue
- Interception of precipitation, aerosol or suspended soil/sediment by plants and animal surfaces
- Weathering (and/or volatilisation) of materials from plant and animal surfaces
- Redistribution and mixing of soils or sediments by the activities of plants or burrowing animals (bioturbation)
- Recycling associated with death and decay of organisms or part of organisms

B.1.3.1. Plant component (FEP 5.1.09 & FEP 5.3.06/07)

Root uptake of radionuclides

The uptake of radionuclides is influenced by various soil and plant factors such as the physiological properties of the plant (the growth rate/stage of the plant, the microbial activity in the rhizosphere, ..), the soil characteristics (FEP 5.1.03; pH, cation exchange capacity, organic matter, clay content, chemical composition and concentration of the soil solution,…), environmental conditions and soil management practices (e.g. fertilisation, irrigation). Also the physicochemical properties of the element under consideration are important (e.g. elements with low mobility in plants are primarily retained in the roots).

The influences of all these factors are qualitatively known, but difficult to quantify. Traditionally, the radionuclide concentration in the plant is calculated by using an empirical soil-to-plant transfer factor defined as the ratio of the radionuclide concentration in the plant to the radionuclide concentration in soil. This parameter is, similar to the Kd, a simple parameter, easy to use but characterised by large uncertainty ranges, because of the lack of quantitative insights in the underlying processes. Even for a given soil, crop and radionuclide, measured data can vary by several orders of magnitude.

Elements highly adsorbed on soil particles are generally present in low concentrations in the soil solution and less available to plant roots and therefore will be characterised by a low soil-to-plant transfer factor.

Other elements in the soil solution can influence the uptake of radionuclides at the root directly by competition for the same adsorption sites and indirectly by influencing their solid/liquid equilibrium in the soil.

The chemical speciation of an element in soil has an important impact on the plant uptake. Especially iodine, technetium, neptunium and selenium behave quite differently depending on the speciation of the element. Iodine is much less available under aerobic conditions due to its increasing incorporation into and interaction with the organic matter. Technetium, neptunium, selenium are most available under aerobic conditions and are gradually reduced to less available chemical forms in badly aerated soils. In view of dose assessment issues, it is important to identify soil types and soil characteristics that cause high transfer of radionuclides from soil to plant.

Also biological activities in soil play a vital part in nutrient cycling, element mobilisation and availability to plants. Among the soil microflora, mycorrhizal fungi occupy a unique location at the interface between soil and plant. These root symbionts develop extended hyphae in soils and can readily contribute to the soil-to-plant transfer of contaminants especially from soils in nutrient-poor ecosystems such as forest ecosystems.

There is some cycling of radionuclides between soil and plants. Radionuclides stored within the root tissue can become available following root death or due to root exudation. Quite often, the transfer factors for generative plant parts (grains, tubers) are lower than those for vegetative plant parts (leaves, stems).

Interception of wet-deposited radionuclides

Irrigation with contaminated water will lead to contamination of the plants and soil. A certain amount of the radionuclides deposited on the plant surface will be retained by the plant. The interception of wet deposited radionuclides is the result of a complex interaction of the vegetative development of the plant canopy, the amount of rainfall, and the chemical form of radionuclides. In general, very simple approaches are used to estimate the interception in assessment models. The intercepted fraction is a very important quantity in any radioecological model, because direct deposition may cause relatively high activity concentrations in feed and foods.

Interception is defined as the fraction of deposited radioactivity (by wet and dry deposition processes) that is initially retained by the plant. The value of the interception factor depends on the stage of development of the plant. There are two approaches to represent plant development; the standing biomass per unit soil surface area and the leaf area per unit soil surface area (leaf area index: LAI). Although the standing biomass is easy to determine (the sample has simply to be dried and the mass determined), the key characteristics of the rain/plant interface are better represented by the LAI. During the first period of growth, there is good correlation between biomass and leaf area which fades away towards the end of growth. Then, the biomass still increases due to growth of storage organs as seeds or tubers while the leaf area already decreases substantially due to dying off of the foliage. The disadvantage of the leaf area index however is that quantification is a complicated determination that requires specific optical devices which are usually not available. As a result, mass interception fractions, defined as the interception normalised to the standing biomass (dry weight) are more often measured and used in the assessment models than the interception factor normalised to the leaf area index.

The chemical form of the deposit has also an important influence on the intercepted fraction. The differences in interception between different elements are due to their different valences. Due to the negative charge of plant surfaces, the adsorption of cations is much more effective than that of anions (Kinnersly 1997). A study done by Hoffman (1995) showed that the initial retention of anions such as iodide is 6 times less than for polyvalent cations, such as Be, Cd.

For modelling the contamination of the different plant types also the irrigation schedule needs to be considered. The different time frames of importance are:

- the total duration of the irrigation period for food crop
- the duration of the external deposition on the cultivations
- the period between end of the irrigation period and the harvest

There are simple and relatively robust models available that can calculate the irrigation needs and schedules based on the soil properties, plant characteristics and meteorological data.

Weathering

Weathering is the loss of deposited activity from plants. It includes contributions from the wash-off of previously intercepted material by rain or irrigation, surface abrasion and leaf bending from the action of the wind, tissue ageing, leaf fall or herbivore grazing, plant development (growth dilution), volatilisation or evaporation (IAEA 2010).

The magnitude of the weathering loss of a radionuclide depends on:

- element dependent factors – with specific considerations for iodine/chlorine and tritium, the element’s solubility, strength of adsorption to the plant surface, degree of penetration into the inner tissue, leachability from the interior; and
- biological factors – e.g. the structure of the epidermis, plant senescence and defoliation, and shedding of old epicuticular wax layer.

These very complex interactions are probably the cause of the observed difference in weathering loss among radionuclides, plant species and their growth stages.

Translocation within plants

Radionuclides entering the plant root system can be distributed to above-ground plant components, including grain storage. Alternatively, radionuclides deposited on the above-ground part of the plant and absorbed by the leaves can be translocated within the plant. In radiological assessments, the term 'translocation' is generally used to describe the latter process. The distribution of radionuclides from root to the above-ground plant parts is covered by the root-to-plant transfer factors or rates.

Consideration of the translocation is especially important for plants that are partly used as food or feed, such as cereals (grains) and potatoes (tubers). For plants such as leafy vegetables or maize silage that are used as a whole, translocation is relevant only in that it may reduce the activity that is lost by weathering.

The most important factors influencing translocation are the physiological behaviour of the radionuclides in the plant and the time at which deposition occurs during growth period. Concerning the physiological behaviour, generally speaking, elements and hence radionuclides can be differentiated according to their mobility in the plants. There are two transport systems in the plant: the xylem and the phloem. Mobile elements can be transported in either system. The xylem transports water and soluble minerals from the soil to upper plant parts. The rate of upward translocation depends mainly on the transpiration intensity. There is no discrimination between elements to be transported in the xylem once they have reached that system (e.g. by penetration from soil to roots). Not all elements are dependent on transpiration when translocated in an upward direction. Some elements are also transported in the phloem sap. The main function of the phloem is to transport carbohydrates produced during photosynthesis from the leaves to the storage organs (such as tubers) or reproductive organs (such as grain). Transport in the phloem is possible in both upward and downward directions. Transport in the phloem is element specific. Alkali elements, magnesium, sulphur, chlorine and phosphate are transported in the phloem, whereas, calcium and other the alkaline earth metals, lead, plutonium, lanthanides, and actinides are not (Thiessen 1999). Similar findings (Marschner 2002) report that macronutrients such as potassium, magnesium, phosphorus, sulphur, nitrogen, chlorine and sodium have a high mobility in the phloem, micronutrients such as iron, zinc, copper, boron and molybdenum have an intermediate mobility, and in contrast, calcium and manganese have a low mobility. The difference in mobility in the phloem relate to physiological differences. For example, potassium and magnesium are involved in osmotic adjustments and electro-potential regulation and thus, are commonly found in ionic form in the cells. Since Mg is also important in the photosynthesis, translocation to the shoot is important. On the other hand, cellular uptake of other elements such as calcium is more or less avoided since the latter can cause harm to the cellular activity such as binding to phosphorus, thereby causing phosphorus-deficiency and lack of energy (ATP) (Greger 2004). Translocation from leaves to other plant compartments takes place in the phloem. This means that once calcium gets into the leaves, it cannot be recirculated. The amount of translocated activity is highly dependent on the stage of development at which the deposition occurs. According to experimental results, the amount of caesium translocated from the leaves to the grain varies by more than two orders of magnitude during the growth period, underlining the importance and sensitivity of this process for dose assessments.

Plant respiration

Gases can be taken up by or released from plants by respiration. Respiration is considered to be important for reactive gases and volatile elements, e.g. I_2, CO_2, SO_2. These substances can be taken up by plants via the stomata and subsequently be metabolised.

For example, elemental iodine is bound by starch produced during photosynthesis, CO_2 is reduced to carbohydrates and SO_2 is also reduced.

Plant transpiration

Transfer of water from the soil to the atmosphere by transpiration in plants can have an influence on the radionuclide concentration in the plant. Transpiration and root uptake are closely related. Most radionuclides are taken up by plants passively via soil water or via mycorrhizal fungi. Generally, the higher the water needs of the plant, the more radionuclides are transferred to the plant. If soil water is non-limiting, transpiration rates will be determined by meteorological variables. As the soil dries, the plant finds progressively greater difficulty in meeting the atmospheric demand for transpiration, and stomatal closure restricts the transpiration rate.

B.1.3.2. Transfer to animals (FEP 5.1.10 & FEP 5.3.06/07)

The consumption and inhalation of materials by animals includes: food consumption (plant and animal foodstuffs); aerosol inhalation; soil consumption, sediment consumption, drinking water, direct uptake from the water column in case of aquatic organisms.

The contribution of aerosol inhalation, soil and sediment consumption to the activity concentration in animals is mostly rather small compared to the food ingestion. An exception may be for burrowing terrestrial animals and fish where the uptake of some contaminants present in water can occur predominately via the gills.

In radiological assessments, the transfer of radionuclides from feed to milk, meat and other animal products is often calculated by using element-dependent transfer factors, defined as the ratio of the activity in milk or meat to the daily activity intake under equilibrium conditions.

B.1.3.3. Bioturbation (FEP 5.1.10 & FEP 5.3.06/07)

Burrowing animals (e.g. earthworms), deep rooting plants and movement of contaminated microbes may enhance the solid, gaseous and liquid phase transport of materials within soils and sediments. The redistribution and mixing of soil or sediments by the activities of plants and burrowing animals is referred to as bioturbation. In particular for less mobile radionuclides, transport of solid particles in the soil may be an important migration process. Earthworms may play a significant role in material displacement in the agricultural areas of central Europe. It takes around 5 to 20 years for the earthworms to more or less homogeneously mix the top soil of grass lands and transport strongly adsorbed radionuclides upwards and downwards (Müller-Lemans 1996). Bioturbation does mainly occur in the upper 10 to 45 cm of the soil (Bishop 1989).

There are more complex compartment models to describe the kinetics of the radionuclides in animals by means of a set of differential equations. Such models need however numerous transfer rates to quantify the radionuclide exchange among compartments. In general, only a few of these parameters are actually known. The other parameters are derived from measured equilibrium or semi-equilibrium transfer factors and as such the complex models do not necessarily result in a higher reliability of predictions.

For many elements, animal transfer data are scarce. Most data are also derived from short-term experiments and the application of such data for long-term studies may lead to underestimates of the radionuclide concentrations in milk and meat.

The influence of soil ingested during grazing or feed intake on the transfer of radionuclides to milk, meat and other animal products is mostly taken into account as a percentage of soil to the total feed intake rate fixed fraction of the amount of grass ingested. Unfortunately the data on soil ingestion are too limited to consider a detailed approach.

B.1.4. Natural cycling and distribution of radionuclides by non-living components

B.1.4.1. Water-mediated transport of contaminants (FEP 5.3.01/02)

Water-mediated transport of radionuclides includes all processes leading to the transport of radionuclides in water. Radionuclides may travel in water as aqueous solutes (including dissolved gases), associated with colloids or, if flow conditions permit, with larger particulates/sediments. Relevant processes include:

- Advection, i.e. movement of dissolved and suspended materials with the (laminar) bulk movement of the fluid
- Molecular diffusion, i.e. random movement of individual atoms and molecules from regions of higher concentrations to regions of lower concentrations within the fluid in the absence of bulk flow. Flux of matter due to diffusion is proportional to concentration gradient.
- Dispersion, i.e. the spread of spatial distribution with time due to (turbulent) differential advection
- Infiltration (FEP 5.3.01.02) of water into soil (i.e. downward movement of water from the surface into the soil). Factors that influence the infiltration are the precipitation/irrigation, the evapotranspiration, the surface run-off, soil infiltration capacity.
- Surface run-off (FEP 5.3.01.04). A fraction of incident precipitation may be transferred directly from land to surface waters by overland flow, without entering the soil column. This includes delayed run-off (e.g. as a result of snow melt).
- Transport by interflow (FEP 5.3.01.05). The lateral movement of water through the soil into surface-water courses can occur during or following significant precipitation events when the rate of infiltration of water at the top of the soil profile exceeds the exfiltration rate from the base of the soil profile.
- Percolation of water through soils and sediments under influence of gravity (i.e. downward (or sub-horizontal) movement of water, with dissolved and suspended materials through soil and sediment materials towards the water table.
- Groundwater transport (i.e. transport of water, with dissolved and suspended materials in saturated porous media).
- Groundwater recharge (i.e. percolation of incident precipitation and other surface waters to groundwater systems) and discharge (i.e. release of groundwater into the surface environment).
- Saturated zone groundwater transport
- Matrix diffusion, i.e. the diffusion or micro-advection of solute/colloids etc., into non-flowing pores
- Multiphase transport processes (i.e. combined flow of different fluids and/or gases in porous media)
- Aerosol generation by wave and wind action
- Capillary rise (FEP 5.3.01.03; i.e. upward movement of water through soil layers above the water table as a result of capillary forces related to evaporation and transpiration)
- Erosion (FEP 5.1.13; i.e. suspension of solid particles, set free from the bed sediment into the surface water (by the action of flowing water) or by surface run-off.

B.1.4.2. Solid-phase transport of contaminants (FEP 5.1.08 & FEP 5.3.05)

A variety of processes may contribute to the bulk movement of solid materials within the terrestrial and aquatic environments. These processes include:

- Landslides and rock falls. Overland transport of solid material by landslides and rock falls, sedimentation, gravitational settling and deposition of suspended particles within water bodies to form sediments.
- Sediment suspension and erosion of bed sediments from surface water courses by the action of flowing water
- Coastal erosion
- Deposition of sediment during flooding
- Rain splash. Localised transport of soil material to other media (e.g. onto plant) caused by the mechanical energy of incident rainfall.
- Wind-driven aerosol generation
- Aerosol generation by fire
- Movement of solid material by volcanic and magmatic activity

B.1.4.3. Atmospheric transport of contaminants in terrestrial environment

A variety of processes linked to the atmosphere contribute to the natural movement of materials within the biosphere system. Radionuclides from the surface environment may be released (along with non-radioactive gases) into the atmosphere as result of a variety of processes such as transpiration, (re)suspension of radioactive dust, particulates or aerosols or gases may expel contaminated groundwater ahead of them. The atmospheric system represents a significant source of dilution for these radionuclides. It may also provide exposure pathways e.g. inhalation, immersion. The atmospheric transport is mostly wind-driven.

The atmospheric transport processes that are potentially important include:

- Evaporation, i.e. emission of water vapour and other volatile materials from a free surface at a temperature below their boiling point
- Gas transport, by convection and diffusion in the atmosphere
- Aerosol formation and transport, i.e. suspension and transport of solid and liquid materials in the atmosphere, typically as a result of wind action and man-made activities such as soil cultivation, traffic, etc. Special examples of aerosol formation is aerosol formation arising from the burning of materials in fire and formation of sea spray aerosols from bubbles bursting at the air-sea Interface and, at higher wind speed, by direct tearing from the wave crests.
- Precipitation, i.e. solid or liquid water that falls from clouds, including rain, snow, hail and sleet
- Washout and wet deposition, i.e. the removal of gaseous or particulate material from the atmosphere by precipitation, causing deposition of material onto surfaces. The precipitation intensity and type (rain, snow, etc.), chemical form of the radionuclides, canopy structure, etc. will Influence these processes and hence the contamination of the food chain. The timing of the contamination event in relation to the development and harvest of the crop is crucial. Due to the dependence on plant development, the wet deposition is subject to pronounced seasonality.
- Dry Deposition, i.e. the removal of gaseous or particulate material from the atmosphere as a result of interception and gravitational settling. The deposition velocity depends on a variety of factors, the most important being the particle size which depends on the characteristics of the release and typically decreases with Increasing distance from the release point. Dry deposition is the result of the

interaction of meteorology, chemical and physical characteristics of the contaminant, and is influenced by the properties of the canopy. Generally, dry deposition is more effective for well-developed canopies, since the area of interface between vegetation and atmosphere is increased and hence also subject to pronounced seasonality. For iodine isotopes the chemical form has a dominating influence on the deposition.

- Gaseous radionuclides can be classified by their incorporation into non-reactive or reactive gases. Noble gases (FEP 3.3.08) do not interact with other substances or surfaces; therefore, their deposition is negligible. Reactive gases (e.g. I_2, CO_2 and SO_2) are characterized by intensive interactions with plants. These substances may enter plants through the stomata and subsequently be metabolised.
- Resuspension refers to the removal of deposited material from the ground to the atmosphere as result of natural processes such as wind erosion, traffic, laughing, irrigation and other activities. Resuspension is influenced by a variety of factors, such as the time since deposition, meteorological conditions, surface characteristics, and also human activities. Potentially, resuspension is a persistent source for radioactivity in air subsequent to deposition on the ground. It can be a secondary source of contamination after a release has stopped, i.e. a source of contamination for people and areas not exposed to the original release or a source of recontamination of cleaned surfaces. Due to the complexity of the process, assessment models utilize relatively simple, empirically derived approaches to quantify the resuspension. The resuspension factor defined as the ratio of concentration in air to the surface deposit is commonly used. This parameter can be easily derived from measurements; however, it must be decided at what height above the ground the air concentrations are to be measured and to what soil depth the activity is assumed to be available for resuspension. The parameters make no allowance for the effects of the many environmental variables that may influence resuspension. Therefore the results of empirical models for resuspension have large uncertainties. Resuspension is influenced by various factors such as the soil type, texture and moisture, the vegetation cover and the wind speed.

B.1.4.4. Physico-chemical Changes

The chemical form and speciation of a contaminant in the biosphere may be affected directly by chemical, physical and biological processes within the biosphere system.

The main processes are:

In liquid phase (FEP 5.3.01);

- Complexation reactions (FEP 5.3.01.10; with organic and inorganic ligands), through hydrolysis, dissociation and association / polymerization
- Oxidation state changes / redox reactions (FEP 5.3.01.08)
- Physical and chemical adsorption/desorption onto mineral surfaces, ion exchange (FEP 5.3.01.09)
- Precipitation and dissolution of solid phases, co-precipitation (inclusion & surface precipitation) of trace components, formation of solid solutions (FEP 5.3.01.07)
- Formation of colloids and aerosols (FEP 5.301.11)
- Matrix diffusion of dissolved contaminant with the solid phase
- Processes involving biological material, like biosorption, biologically catalysed redox reactions, enzymatic reactions (FEP 5.3.06)

In atmospheric phase (FEP 5.3.05);

- Complexation reactions (with organic and inorganic ligands), through hydrolysis, dissociation and association / polymerization
- Oxidation state changes / redox reactions
- Formation of aerosols

Adsorption/desorption (including ion exchange) and precipitation/dissolution are considered the most important processes affecting the chemical form and speciation of a radionuclide in soil. Precipitation/dissolution is more likely to be an important process where elevated concentrations of dissolved radionuclides exist, for example in the near-field environment of radioactive waste disposal facilities or the spill sites of radionuclide-containing wastes or where steep pH or redox gradients exist.

Adsorption/desorption will likely be the key process controlling radionuclide retardation in areas where trace concentrations of dissolved radionuclides exist, such as those associated with far field environments of disposal facilities or spill sites or In areas of where soils are to be irrigated using radionuclide-contaminated water.

Generally, the generic term “sorption” is used to describe the partitioning of dissolved aqueous-phase constituents to a solid phase. Whether a radionuclide is associated with soil material by adsorption onto the surface of the solid, absorbed into the structure of the solid, precipitated as a three-dimensional molecular structure on the surface of the solid, or partitioned into the organic matter, the term “sorption” encompasses all of the above processes.

The sorption of radionuclides on solids (e.g. soils and sediments) is frequently quantified by the partition (or distribution) coefficient (Kd). The Kd parameter is a factor related to the partitioning of a radionuclide between the solid and aqueous phases and is defined as the ratio of the quantity of the adsorbate adsorbed per mass of solid to the amount of the adsorbate remaining in solution under equilibrium conditions, assuming a totally reversible and instantaneous exchange.

Radionuclides that adsorb very strongly to soil have large Kd values (typically > 0.1 m^3/kg) compared to radionuclides that are not significantly fixed by adsorption. Radionuclides that do not adsorb to soil and migrate essentially at the same rate as the water flow have Kd values near 0 m^3/kg. The Kd model is the simplest sorption model available and is most commonly used in hydrologic transport and biosphere codes to describe the extent to which contaminants are sorbed to soils. The main advantage of the Kd model is that it can easily be inserted into computer codes to quantify the retarded transport of the radionuclide relative to the water flow. The disadvantage of the Kd is that it is an empirical unit of measurement that attempts to account for various chemical and physical processes that are influenced by various variables and assumes instantaneous equilibrium and reversibility. This results in Kd values that are characterized by large uncertainties.

By replacing the single Kd model by a parametric Kd model which takes into account the key soil factors, a more robust approach that is not limited to a single set of environmental conditions is obtained. The Absalom model is an example of such an approach (Absalom 1999).

B.1.5. Human-action-mediated transport of contaminants (FEP 5.3.04)

Human-action-mediated transport of radionuclides and other contaminants may vary from major industrial development of an area to low-level changes in the natural physical and biogeochemical cycles. It includes processes such as human intrusion in waste repositories, dredging of contaminated sediments from lakes, rivers and estuaries and placing them on land. Earthworks and dam construction may result in the significant movement of solid material from one part of the biosphere to another. Ploughing results in the mixing of the top layer of agricultural soil, usually on an annual basis.

B.1.5.1. Changes to natural phenomena associated with human actions

Certain practices and activities undertaken by the local community may modify significantly the natural dynamics of physical and biogeochemical cycling and distribution of materials within the biosphere system. These include:

- Modification of plant and animal communities by agricultural practices (see also FEP 5.2.09)
- Physical and chemical changes from the use of imported materials for soil improvement (see also FEP 5.2.09)
- Chemical changes associated with pollution by industrial activities. Chemical phenomena related to human activity that can cause significant change to the biosphere system, modifying the situation represented in the assessment. Human activity at global, regional and local levels needs to be taken into account in establishing the chemical environment within which a biosphere system exists. The existence of chemical pollution may be a contributory factor in identifying and characterising biosphere systems relevant to assessment. (see also FEP 5.2.10)
- Acid rain. Acid precipitation or deposition capable of causing acidification in soil and water bodies. Acid rain is the result of chemical pollution. Precursors of acid rain include emissions of sulphur dioxide and nitrogen oxides from man-made sources on a regional and local scale.
- Artificial soil fertilisation. The import of artificial fertiliser to enhance crop productivity. The use of imported fertiliser can have an impact on the cycling of trace materials in the biosphere, as well as on the overall materials budget. (see also FEP 5.2.09).
- Alteration of natural water potentials by the pumped extraction (or recharge) of water from (or to) aquifers
- Modification of natural infiltration and drainage systems by construction activities
- Artificial mixing of water bodies
- Fire prevention and response measures in forest systems
- Drainage and reclamation of areas that were formerly wetland or covered by rivers, lakes or the sea

B.1.5.2. Bulk material phenomena linked to human actions (see also FEP category 1.4)

Human activities can affect the local landscape and artificially enhance the movement of bulk materials within the biosphere over and above the cycling associated with natural processes. Potentially relevant phenomena include:

- Gross movement of material and/or changes to natural water flow patterns by construction activities (excavation of foundations and other structures, building of surface features, ground levelling, dam building, urbanization, etc.)
- Ploughing. Agricultural practices enhancing the mixing of upper soil horizons.
- Extraction and use of water from aquifers and/or surface water bodies
- Irrigation of gardens and/or agricultural crops. Use of abstracted water to supplement natural supplies to gardens and/or agricultural crops.
- Recycling of bulk solid materials. Re-use of crop residues, manure, ash or sewage sludge on land in order to recycle nutrients or to act as mulch.

- Removal of sediments from lakes, rivers, estuaries etc. by dredging - either to provide materials for soil improvement or simply to maintain transport channels in the water body
- Transfer of dredged sediments to land
- Artificial Mixing of Water Bodies. Enhanced mixing of lake and other surface waters as a direct, or indirect, effect of human actions.
- Controlled ventilation of buildings. Actions taken to enhance (or reduce) the mixing of air in enclosed spaces.
- Resuspension refers to the removal of deposited material from the ground to the atmosphere as result of anthropogenic processes such as traffic, soil cultivation, and other activities. Resuspension can be the result of natural processes (see above) or human activities such as ploughing, etc.

B.1.5.3. Trace material distribution phenomena linked to human actions (see also FEP category 1.4)

Certain human activities are deliberately intended to modify the quality of biosphere products and as result change the natural distribution of trace materials in environmental media (irrespective of the possible presence of radionuclide contamination). Potentially relevant phenomena include:

- Water Treatment: Processing of water supplies (filtering, chemical treatment, storage, etc.) to make them suitable for drinking water or other uses.
- Air Filtration. The enhanced removal of aerosols and gases from air supplies through air filters.
- Food Processing. Actions taken in the preparation of foods that may modify the constituents of what is finally consumed. Food processing can decrease or increase the radionuclide concentrations. Knowledge of the effects of food processing is needed when assessing the radiation dose to man from the ingestion of contaminated food products or estimating their effectiveness as possible countermeasures for reducing the ingestion dose to man. The effects of processing on the behaviour of radionuclides depend on the radionuclide, on the type of product and on the method of processing (e.g. peeling, washing, blanching, cooking etc. and also industrial versus domestic scale). The food processing retention factor, defined as the ratio of the total amount of a radionuclide in processed food to the total amount of this radionuclide in the original raw food, is commonly used to quantify the fraction of radionuclides which is retained in the food after processing. The effects of processing on vegetables and fruits are rather unpredictable, especially when the radionuclides are adsorbed on the surface of the plants.

B.1.5.4. External events and processes

Processes and factors related to the future evolution of the system (IAEA, 2003). Apart from processes, such as small-scaled erosion and sedimentation, that are internal to the biosphere system, the external driving mechanisms responsible for environmental change can be divided into natural mechanisms and human actions. Primary factors affecting landform change and biosphere evolution are considered to be: geological processes and their effects; climate processes and their effects; future human actions. The difference with the processes and events discussed earlier is somewhat subjective. Principally the processes listed here relate to long timescales involving significant changes in the biosphere system.

B.1.6. Geomorphological processes and events (FEP 5.1.01; see also FEP 1.3.10/13)

A variety of processes of geological origin may have an impact on the long-term evolution of the biosphere system. Many of these are relevant primarily to the description of the geological environment and the potential effect on groundwater flow rates, release from the near-field and contaminant transport pathways. However, certain processes may be responsible for landform change to the extent that they directly influence the characterisation of the biosphere.

Potentially relevant mechanisms on the timescales of interest to biosphere assessment include:

- Inundation by tidal wave generated by a seismic event (tsunami) or exceptional rainfall (see also FEP 1.2.04)
- Changes in topography/coastline associated with large-scale erosion processes (FEP 5.1.06/13)
- Changes in topography/coastline in response to isostatic depression and rebound (see also FEP 1.3.03)
- Soil conversion (FEP 5.1.03.01

Changes in topography/coastline due to erosion processes will occur on a wide range of spatial and temporal timescales. More localised processes, such as river bank erosion and landslides, can occur on smaller temporal and spatial scales.

Isostatic depression and rebound is, strictly, a geomorphological response to the climate-driven processes of global and regional sea-level change and ice-loading, rather than a geological process per se.

On much longer timescales, tectonic and orogenic processes within the lithosphere may more accurately be considered as geological factors responsible for topographic change.

Finally, it is important to recognise that soil conversion is a continuous geomorphological process of direct relevance to providing a description of the terrestrial biosphere. Typically, soil conversion is not represented explicitly within a dynamic system model; however, it is important to ensure that the characterisation of soil/sediment types within the biosphere system description is consistent with other assessment assumptions. In the context of long-term assessments, soil conversion is perhaps most important as a consideration associated with responses to climate and ecological change or climate-driven effects, such as sea-level change.

B.1.6.1. Climate change processes and events (FEP 5.1.11)

Potentially relevant mechanisms on the timescales of interest to biosphere assessment include:

- Change of global climate (with associated eustatic sea level change)
- Change of local and regional climate characteristics (with associated ecosystem, hydrological and human community responses)
- Ice sheet development and its effects
- Geomorphological response to specific climate effects

Change of global climate (FEP 1.3.01)

The Quaternary period has been characterised by climate cycling on a global scale between glacial and interglacial periods. Such global changes are understood to be caused by long-term changes in the seasonal and latitudinal distribution of solar insolation, due to periodic variations in the Earth's orbit around the Sun. These direct effects are modulated by feedback via albedo and atmospheric composition. Global climate change on a shorter timescale (and generally to a less significant degree) is also influenced by shifts in ocean circulation (e.g. the 'El Niño' effect) and sunspot activity. The interaction between anthropogenic greenhouse gas emissions and other factors affecting global climate is not yet well understood; however, it is thought that global warming may delay the onset of the next global ice age for several tens of thousands of years. The principal effects of global climate change in the context of biosphere assessment for geological disposal are (a) its impact on local and regional climate characteristics at particular locations, and (b) changes in eustatic sea level as a result of thermal expansion and contraction and the growth and decay of ice sheets.

Change of regional and local climate (FEP 1.3.02)

Climate is characterised by a range of factors, including temperature, precipitation and pressure and their seasonal variations. Broad climate categories, based on classification schemes for present-day biomes (FEP 5.1.02) across the globe, are typically distinguished in performance assessments of waste repositories in order to characterise potential future conditions at the site of interest. Downscaling from simulations of future global climate to regional and local conditions can involve additional uncertainties regarding the detailed climate characteristics and the sequence of particular changes. The situation is further complicated by the possibility of fluctuations on timescales of a few decades or less.

The identification and definition of future biomes (FEP 5.1.02) should be based on a coherent scheme, taking account of the overall assessment context. Identification of a particular climate analogue will involve consideration of the latitude, longitude, altitude and aspect of the region of interest, taking account of best understanding of the relevant factors determining global climate. Characterisation of climate states would be expected to rely predominantly on accepted classification schemes, including diurnal, seasonal and other variations in the primary climate parameters.

Effects of ice sheet development (FEP 1.3.05)

Isostatic depression and rebound effects associated with ice loading and unloading effects have already been discussed above. As far as the biosphere component of the assessment is concerned, perhaps the most important considerations linked to local ice sheets are pro-glacial effects on surface hydrological features associated with melt waters and outwash.

Cold climate effects (FEP 1.3.04)

Physical processes in cold, but ice-free, environments include the potential for large-scale water movements associated with seasonal thaws. Permafrost will restrict such movements to the surface environment, while potentially serving to isolate deep (contaminated) groundwater from the surface hydrological regime. Regional groundwater flow may become focused at localised unfrozen zones, under lakes, large rivers or at regions of groundwater discharge (creations of pangs, taliks).

Warm climate effects (FEP 1.3.06)

Regions with a tropical climate may experience extreme weather patterns (monsoon, typhoon), associated with flooding, storm surge, etc. These, in turn may have implications for local hydrological and erosional processes. High temperatures and humidity can also result in rapid biological degradation, causing tropical soils to be thin. In hot arid climates, total rainfall, erosion and recharge may be dominated by infrequent storm events.

Responses to regional and local climate change

Certain climate categories will be associated with specific geomorphological processes such as the formation of ice sheets, periglacial landforms and thin soils in warm climate. In addition, however, it is important to take into account within an assessment the more general responses associated with climate change.

- Hydrological responses to climate change (FEP 1.3.07). The hydrology of a region is closely coupled to climate. Climate controls the amount of precipitation and evaporation, seasonal ice and snow cover, and thus may affect the near-surface hydrological regime, such as changes in evapotranspiration, Infiltration, soil water balance, degree of soil saturation, changes in sediment load characteristics, groundwater recharge and surface runoff that are likely to have significant impacts on ecosystems. Vegetation and human actions may modify these responses. Potential effects include climate-induced evolution of surface-water bodies, such as the formation of lakes and rivers, or their loss by sedimentation and infilling, river-course meander and long-lasting flooding or drying of low-lying areas.
- Ecological responses to climate change (FEP 1.3.08) on a regional and/or local scale include changes to soil types and modifications to the equilibrium between plant and animal species, resulting in the development of new ecosystems
- Human behavioural response to climate changes (FEP 1.3.09; FEP category 5.2). Human behaviour (including habits, diet, size of communities and dwelling types and location) changes in response to climate changes. Climate affects the abundance and availability of natural resources such as water and the types of crops that can be grown. Human responses may include changes to the control over natural resources (e.g. storage of water), use of irrigation systems and modifications to farming methods (e.g. use of glasshouses). It also affects the activities and needs of humans; for instance, a colder climate would likely increase the time spent indoors and heating fuel needs. The more extreme a climate, the greater the extent of human control over the resources required to maintain agricultural productivity, e.g., through the use of controlled agricultural environments (greenhouses). Some climate changes may be sufficiently extreme that the region becomes uninhabitable on a permanent basis. Conversely, some climate changes may make a region more attractive for human habitation. These latter effects would influence the location and habits of a critical group.

B.1.6.2. Future human actions and events (FEP category 1.4)

The description of the biosphere system domain needs to take into account basic assumptions related to the effects of human activities on the environment. A coherent description of human society should therefore be adopted, consistent with other assumptions regarding climate, landscape and (where appropriate) ecology, and taking account of the overall socioeconomic context assumed as a basis for assessment.

Where the assessment context dictates that future environmental change should be taken into account, an appropriate response is to consider human behaviours based on present-day (or, if available, historical) land-use and resource exploitation practices in analogue regions, selected for the representativeness of their climate and landform characteristics.

The potential for human actions to cause acute changes to the environment with long lasting consequences (e.g. land reclamation, earthworks, forest clearance) needs to be recognised.

Principal features of human society relevant to the description of the biosphere system include:

- The identification of different types of land management systems that describe the level of human influence on the environment. Patterns of vegetation and associated soil characteristics can be influenced by, or indeed almost completely determined by, land management practice. Land use (FEP 1.4.02), in conjunction with vegetation patterns and soil characteristics, has a major Influence on regional hydrology by determining how precipitation is partitioned between surface flow, interflow and groundwater recharge. Surface and subsurface patterns of flow and the shape of the land surface then determine how the drainage network develops. The nature and characteristics of the drainage network are then, in turn, factors affecting ongoing erosion and deposition processes.
- The description of specific resource exploitation practices associated with the management of water resources (FEP 1.4.08/09), land, flora and fauna, and their effect on natural cycles within the biosphere system. Within a given environment, the particular resource exploitation practices can have an important impact on the way in which bulk materials and contaminants are distributed and/or give rise to radiological exposures. Important considerations are the way in which terrestrial and aquatic resources are used and the extent to which human actions influence natural hydrological and biogeochemical cycles. More detailed consideration of specific processes associated with particular types of land use is considered as part of the system description. Agricultural practices involve a variety of activities that may significantly influence the turnover and distribution of bulk materials and associated contaminants. These include the possible import and export of materials such as fertilisers and other nutrients, irrigation and land use rotation. The industrialised exploitation of natural resources (e.g., mining and processing of minerals, pumping of groundwater, use of reservoirs) can have a marked effect on natural hydrological and biogeochemical cycles. Construction activities might lead to the large-scale redistribution of contaminated materials, and may be associated with exposure groups linked to ‘specialist’ activities (e.g. the handling of contaminated materials over extensive periods) that would not be a feature within other biosphere systems. Industrial activities on a regional scale may influence local air quality (and thereby local climate) or water quality. Human activity in urban and industrial environments can also lead to major changes to the natural topography (e.g. via land reclamation or levelling) and hydrological cycles (e.g. through artificial drainage).
- Effects on climate (FEP 1.4.01): Human influences on global climate are addressed elsewhere. As a result of local anthropogenic effects (e.g. sulphate aerosol production, production of heat domes due to industrialisation and urbanisation), climate parameters associated with a region may differ slightly from those determined by downscaling from models for global climate change. Nevertheless, such effects are expected to be small compared with the uncertainties associated with attempting to define precise seasonal temperature and precipitation characteristics for any given climate regime.

B.1.7. Conclusions

As shown in this chapter, numerous factors have an influence on the migration and transport of radionuclides in the biosphere. Which of these processes will be important depends on the characteristics of the site, in terms of the geology, hydrogeology, topography, soil system, climate and vegetation as well on the assessment context which defines the biosphere system (for example protection of the natural ecosystem versus human protection). Since the main objective of the safety performance of the radioactive waste disposal is to demonstrate that future human generations are protected, the focus is on impact scenarios that include all major pathways to man. In case of a normal evolution scenario whereby radionuclides reach the biosphere via groundwater, the scenario that leads to the highest dose impact to humans is considered to be an agricultural exposure scenario with a high degree of subsistence lifestyle. In the next chapter, a generic conceptual model will be developed for such a group of representative persons.

During the screening of the FEPs with the FEP items in the NEA FEP database (Schelland (2013) some discrepancies were observed. Little attention was paid to the NEA FEP items related to human behaviour (FEP 5.2) and exposure (FEP 5.4) although the aspects were considered in the Reference biosphere approach and in the conceptual biosphere model (see sections B.2 and B.3 below). Also little detail has been provided on marine features (FEP 5.1.07). On the other hand a lot of detail is provided for several NEA FEP items including RN transfer phenomena in plants and animals, and solid phase and atmospheric transport. It is recommended to make a more detailed programme-specific or project-specific FEP database version which will include these more detailed FEP items as well.

B.2. Reference biosphere approach

B.2.1. Introduction

The reference biosphere methodology developed by the IAEA-BIOMASS international collaboration (IAEA, 2003) has been used by different countries such as Belgium (applied by NIRAS/ONDRAF), Japan (applied by JNC), Spain (applied by CIEMAT) and the UK (applied by NDA). In the following chapters, a brief summary of the different steps of the methodology is given.

B.2.2. General structure

The reference biosphere approach has been developed for scenarios characterized by biosphere changes. Since the long term biosphere changes are highly uncertain, hypothetical assumptions have to be made concerning the state of the biosphere and human behaviour at the time when the radionuclides reach the biosphere. This has led to the necessity of the creation of a methodology for the construction of "stylised" biospheres.

The BIOMASS reference biosphere methodology (IAEA 2003) provides a logical and systematic structure for developing such stylised biospheres whereby the reference biosphere is defined as the set of assumptions and hypotheses that it is necessary to provide a consistent basis for the calculations of the radiological impact arising from long-term releases of repository derived radionuclides Into the biospheres. In order to circumvent the difficulties Inherent with the long time frames, it consists of a "stylised" or reference approach, based on general human habits and biosphere conditions of today.

The methodology is based on a staged approach, in which each further stage provides more detail so that a coherent biosphere system and corresponding conceptual model can be developed (Figure B-1). The different stages highlight the importance of a full characterisation of the biosphere system.

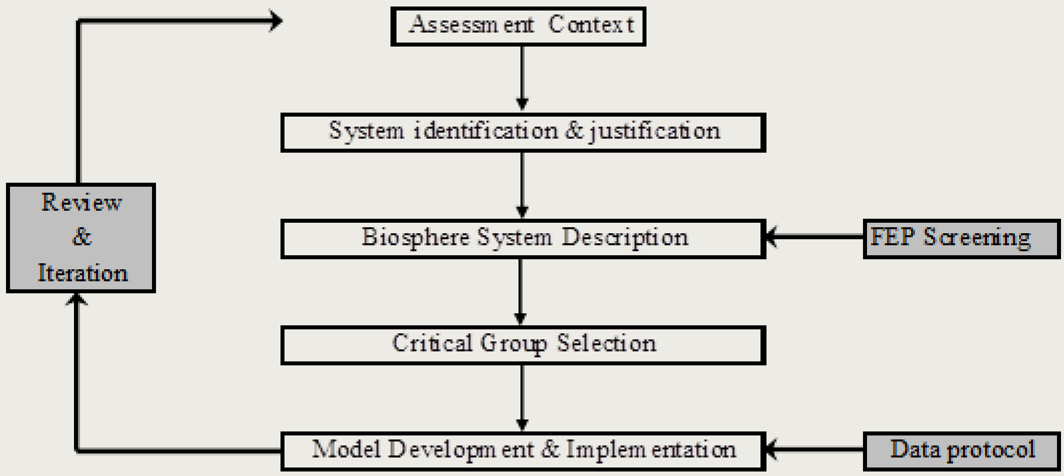

Figure B-1 - The BIOMASS reference biosphere methodology

As seen in Figure B-1 and described in the IAEA BIOMASS-6 report (IAEA, 2003), the first step is the assessment context which is a formal description of what is assessed and why. It is a fundamental stage in the determination of a suitable assessment biosphere and involves the consideration of 8 items that are essential for the definition of the assessment biosphere. These items are the purpose of the assessment; the calculational endpoints; the site and repository context; the radionuclide source term; the geosphere-biosphere Interface; the calculational timeframe; basic assumptions about society and the assessment philosophy. Because several components of the assessment context are interrelated, decisions relating to one component can influence other components.

The second step of the methodology is the biosphere system identification and justification. Its purpose is based on the assessment context, to identify and justify the assessment biosphere(s) that is/are to be modelled. Identification and justification takes place in three main steps:

1 Identification of the typology of the main components of the biosphere system (e.g. climate type, geographical extent and topography, human activities etc.)

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

3. If biosphere change is to be represented, the third step considers how this should be done. This may be done in a non-sequential way by considering a set of separate, unchanging biospheres, to encompass the range of possible futures of interest or in a sequential way by considering the changes from one system to another.

The next step of the methodology is to construct a biosphere system description. The identification of the characteristics of the biosphere system should provide enough detail about the biosphere system (or systems) to be considered in the assessment to justify the selection and use of conceptual models for radionuclide transfer and exposure pathways. An important part of this stage is the identification of human activities. Consideration of the socio-economic context of the local human community provides a basis for the subsequent identification of potentially exposed groups for which radiological exposures are to be considered within the assessment model.

The model development step of the methodology uses information generated by the second and third step to construct a conceptual model. The construction of the conceptual model begins by listing the contaminated environmental media, namely air, water, soil, crops, animals etc. in which radionuclides may migrate or accumulate. The media are not confined to those that make a direct contribute to radiation exposure so that, for instance, subsoil units may need to be included. Next, the radionuclide pathways through these media are identified. A useful tool developed during the course of this work is a 'radionuclide transfer matrix': a matrix that describes the conceptual model by tabulating the interactions between the media of interest. The matrix would typically be developed through several iterations and in its final form, it shows all the relevant radionuclide transfer and exposure pathways. The list of possibly relevant features, events and processes (FEPs), described in Schelland (2013) is a good starting point for identification of pathways and processes. Cross checks should be made to ensure that the conceptual model incorporates – or at least acknowledges – all the FEPs that were identified as being relevant within the system description.

The conceptual model should describe the system with sufficient detail and clarity to allow the mathematical equations to be constructed for the mathematical model. There may be a number of alternative mathematical models for any one conceptual model. The availability of data to parameterise the model is an important consideration at this point since this may decide the choice of mathematical model. This and the fact that the data need to be fit for purpose are reasons why data selection is seen as an important activity within the methodology. The combination of data and mathematical model allows the calculation, first of the radionuclide concentrations in the various media of interest and second, of the radiation doses (or other endpoints) resulting from the calculated concentrations in those media. It should be noted that doses and risks calculated on the basis of stylised approaches and simplified models should be interpreted as illustrations based on agreed sets of assumptions for particular scenarios and well-defined, but not necessarily realistic, model assumptions, and not as actual measures of future health detriments and risks (ICRP 2000).

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

The EC funded BIOCLIM project extended the work of BIOMASS program in relation to climate change and tried to answer on how long-term climate projections should be generated for and taken into account in post-closure radiological impact assessments. A methodology for considering the transitions between different climate sites was developed. The need for considering the climate change in a non-sequential or sequential way should be based on the potential accumulation of radionuclides during the climate transitions. If there is evidence that accumulation of radionuclides may occur during one climate state, leading to peak releases in the next climate state, consideration of an interrelated sequence of biospheres may be necessary (Garisto F. 2010).

B.2.3. Application of the BIOMASS reference biosphere methodology to the Dutch situation

B.2.3.1. Assessment context

Assessment purpose

Concerning the assessment purpose, it is stated in Verhoef (2011):

The aim of the OPERA Safety Case report is to demonstrate the possibility of safe long-term disposal of radioactive waste in the Netherlands.

The main assessment purpose of the biosphere assessment during these early stages of the safety case is thus to provide a proof of concept for the disposal concept in clay. Outcomes of this assessment will probably also guide future research priorities.

Assessment endpoints

The object of biosphere modelling is mainly to calculate the radiological dose impact on exposed humans of the release of radionuclides from a repository into the biosphere. The assessment endpoints will be site-independent stylised biosphere dose conversion factors between the radionuclide flux from the geosphere into the biosphere and effective doses to representative persons for various environmental states. These calculated doses are to be compared with the maximum permitted dose. ICRP (ICRP 2000) recommends the use of 0.3 mSv per year for normal gradual releases from a deep repository.

Beside the doses to humans, also other endpoints may be necessary in development of the safety case. For example, there is an increasing interest in environmental impact studies, assessing the potential significance of radiological impacts of waste disposal practices on non-human biota [(IAEA1992), (UNSCEAR1996)]. At present however, there are no internationally established criteria for determining radiological protection of the environment.

B.2.3.2. Assessment philosophy

Beside the nature of the assessment endpoints, also the nature of the assumptions used within the assessment needs to be made clear. Due to the uncertainties associated with the long-term evolution of the biosphere, a certain degree of conservatism in choosing parameter values and in other model assumptions (termed 'assessment philosophy') will be adopted, similar to the practice in other countries (Belgium, Switzerland …). The assessment philosophy (from reasonable to cautious) should be consistent with the assessment purpose and influences the level of confidence required (safety factors, constants/confidence intervals, link between endpoints and constraints for accepting/rejecting an assessment). Part of caution is introduced by defining the characteristics of the representative persons (degree of self-sufficiency) and their location (located at the area with maximum activity).

The type of repository system

This type of question is of more interest to the geological modelling than the biosphere modelling since traditionally the biosphere assessment starts from the releases of radionuclides at the geosphere/biosphere interfaces and then calculates the transfer and accumulation of the radionuclides in the different biosphere media.

The site context

This item can only be addressed appropriately when the site is known. It includes the physical features around a repository site such as surface topography, climate, lithology and soil types all of which may help to determine the current and future biospheres.

Regarding the climate, it has been decided to consider climate change. As mentioned earlier, the following four climate states are considered within the normal evolution scenario:

Climate	Walter climate type classification (IAEA, 2003)
Present-day	ZB VI
Mediterranean	ZB IV
Boreal	ZB VIII
Periglacial	ZB IX

Source term and the geosphere-biosphere interface

The preliminary radionuclides (and activity concentrations) to be considered will be derived from the list given in Meeussen (2014).

Groundwater flow is the primary mechanism (in case of normal evolution) by which radionuclides released from the repository migrate into the biosphere. Except for simple well-water extraction scenarios, the configuration and characteristics of the interface between geosphere and biosphere is likely to be site specific and may also be time dependent because of the evolution of the biosphere.

As mentioned earlier the following three types of biosphere-geosphere interfaces will be considered for the normal evolution scenario:

- Well drilled into the nuclide-bearing aquifer down gradient from the disposal facility at the point of maximum radionuclide concentration
- Surface water bodies (River, lake, pond)
- Soil (Wetland)

In all these interface types, contamination of the fresh water aquifer plays a central role. From these biosphere-geosphere interfaces, the radionuclides can be dispersed into the biosphere by all kinds of natural processes and by human actions, and accumulated in certain biosphere media (soil, plant, animal).

Since the site is unknown, the geosphere-biosphere interface considered in this report will be the well and it will be assumed that this well is located at the maximal activity (conservative assumption). The well is drilled into a fresh water aquifer with a production rate which is consistent with domestic demand. Once candidate sites are chosen and assessments become more site-specific, the geosphere modelling can provide further information on the location and the area over which the discharge to the near-surface system and other water bodies occurs.

Van Beek (2010) mentions capacities of 40 to 100 m^3/h for wells pumping water from depths between 20 and 250 m. This would translate to annual yields of 350 000 m^3 or more. Information on the quality of groundwater in the Netherlands has been derived from Van den Brink (2007) and Griffioen (2013) and is given in Appendix C. Groundwater is used as drinking water and for irrigation.

Societal assumptions

As there is little technical basis for predicting the nature or probability of future human activities, it is necessary to make assumptions about future human habits in order to calculate radiation doses and associated risks. In broad terms, such assumptions relate to factors such as level of technological development and type of society (e.g. urban or rural). These societal assumptions must be consistent with the types of potential exposure groups identified. Not only the radiological impact of the environment on people but also the impact of people on the environment needs to be addressed. A variety of possible human actions and habits therefore needs to be considered. These include aspects of behaviour (such as diet, occupation and general lifestyle) that may lead to interaction with, or consumption of, contaminated materials. They also include activities (e.g. soil movement, recycling) that may lead to the redistribution of materials and/or radioactivity in the environment.

Habits, behaviour and metabolic characteristics are taken to be similar to those observed in present-day or past populations, though not necessarily at the site or region of interest (e.g. from analogue regions if climatic conditions that differ from those at the present-day are being addressed as part of the definition of the assessment biosphere).

Time frames

Radioactive waste disposal intends to ensure equitable protection of both current and future generations. This involves taking into account the greater uncertainties that exist over longer time periods. Since the assessment purpose is to ensure the safety of current and future generations, it is necessary to consider very long timeframes in the calculations to ensure that the peak dose impact values are taken into account. Safety assessments are carried out for periods up to 1 million years after present (AP). Beyond that time frame, radiological dose calculations have little relevance because the uncertainties become so large that quantitative assessments become meaningless. When considering the long-term evolution of the disposal system, major climate changes are expected. As mentioned earlier, it has been decided, based on paleo-environmental data, to consider 4 different climate states in the safety assessment calculations of the Dutch geological waste disposal.

B.2.3.3. Biosphere system identification and justification

This step reviews the assessment context to see whether the biosphere system is predefined by legislation or guidance and whether and how biosphere change is considered. The biosphere system is defined as (IAEA 2003):

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

The principal components of the biosphere system that need to be identified and justified are human activities; climate; topography; location and geographical extent; flora and fauna; near-surface lithology; and water bodies.

In this step, it is necessary to identify whether the assessment needs to involve the biosphere system’s evolution. There are various possible approaches to representing the effects of climate change within a biosphere assessment. At a very basic level, climate change might be ignored and the assessment based on the assumption that current conditions persist indefinitely into the future. Alternatively, there is the option of modelling the evolution of the biosphere system in a non-sequential manner by considering release into a variety of time-invariant biospheres, each of which is consistent with the chosen set of representative climate states or in a sequential manner (with transitions between climate states). Time sequences of transition between climate states may be considered to represent a more realistic approach, but there is substantial scientific uncertainty concerning the future sequence of climate development, especially when the possible long-term effects of anthropogenic "greenhouse-gas" emissions are taken into account. Moreover, the temporal relationship between climate change and landform or ecological transition would also need to be considered in the context of such a ‘dynamic’ approach which is also subject to considerable scientific uncertainty.

The choices made in respect of modelling climate (and its effects on the biosphere system) can have a strong influence on the overall structure and composition of the biosphere model.
The approach taken in practice will depend, in part, on the overall assessment philosophy with respect to the management of uncertainty, and the extent to which this is prescribed by the way in which regulatory criteria are interpreted.
For the generic inland site considered in this report, a non-sequential approach for representing the biosphere is chosen. The present-day biosphere in the Netherlands is used to describe the temperate biosphere system. For the other climate states, information from analogue regions (e.g. similar topography, inland/coastal, etc.) will be used.

Description of the principal biosphere components
It is important to include a considerable level of detail in the description of the biosphere system components because it helps to identify all relevant features, events and processes and the interactions among them. The description of the biosphere system begins with the identification of relevant features and classification of their important characteristics.

Potentially relevant features of the biosphere domain include the following:
- Climate characteristics
- Topography and morphology
- Location
- Near-surface lithostratigraphy (hydrogeology, soils and sediments)
- Geographical extent
- Surface waters (fresh and marine)
- Environmental systems (flora and fauna)
- Human community characteristics

For future assessments, the characterisation of the ecological systems and human communities needs to be consistent with possible land use, climatological changes and landform developments that may be relevant over the timescales of the assessment.

Climate characteristics and long-term climate changes
At a minimum, information should be provided concerning the broad classification of the assumed climate state(s) e.g. temperate, boreal etc. Climate will often have a profound effect on many of the other biosphere system principal components.

Understanding the impact of long-term climate changes on the groundwater flow and radionuclide transport is essential for modelling the potential release rates from the repository into the biosphere and subsequent impacts on man. Changes in climate will lead to changes in the seasonal patterns of temperature, changes in precipitation patterns (which can affect watercourses and aquifers). The influence of climate on the hydrological cycle may also change the boundary conditions of the geosphere/biosphere interface. For example, changes to river networks significantly impact the flow network of near-surface hydrology. Also the landscape and animal and human habits may change. Climate is also one of the major controls on the geochemistry of natural water systems, as it affects the chemical and physical processes controlling rock weathering, which in turn controls the pH, oxygen content and redox potential (Eh) of the water environment.

The BIOCLIM study (BIOCLIM 2004), which ran from 2000 to 2003 and brought experts in both climatology and post-closure safety assessment together, used Earth Models of Intermediate Complexity (EMICs) to undertake multi-millennial forward projections of climate. Also various techniques to downscale results from the EMICs to derive climatic conditions at the local scales of interest were applied. Future patterns of climate change were calculated for several typical regions in Europe such as Northeast France, Central

England, Central Spain, North Germany, and South of Czech Republic. It can be expected that the future climate In the Netherlands will be very similar to the respective climates in Central England, North-east France and North Germany. The future climate of North Germany has not been analysed as thoroughly as the future climates in the other regions and will therefore not be considered further.

The modelling work within BIOCLIM evaluated several scenarios of future atmospheric CO_2 concentrations using the LLN two-dimension Northern Hemisphere climate model (Loutre and Berger 2000, Pépin, Raynaud, Barnola and Loutre 2001). This climate model links the atmosphere, the mixed layer of the ocean, the sea-ice, the continents, the ice sheets and their underlying lithosphere of the Northern Hemisphere. From a total of 15 CO_2 scenarios, three were chosen for further analysis, i.e. scenarios B3 and B4 for increased CO2 levels (i.e. natural CO_2 variations + fossil fuel contribution) and the natural scenario A4 to evaluate the role of natural CO_2 variations on the simulated climate:

- B3: representing a relatively low contribution to atmospheric CO_2 from fossil fuel combustion (low fossil fuel usage).
- B4: representing a relatively high contribution to atmospheric CO_2 from fossil fuel combustion (high fossil fuel usage)
- A4: natural variations in insulation and natural atmospheric carbon dioxide concentrations.

The results for the anthropogenic scenarios B3 and B4 demonstrates that climates as warm as or warmer than that of the present day are likely to persist. For Central England and the Northeast of France a subtropical climate with subtropical winter rain persists within the next tens of thousands of years:

- until 73 500 years after present (AP) for the low CO_2 scenario (B3); and
- apart from a couple of minor cooling events, until 165 500 years AP in the high CO_2 scenario (B4).

Thereafter, the present day temperate oceanic climate does not reappear until 93 000 years AP for the B3 scenario, and 168 500 years AP for the B4 scenario. Overall, the period from present day through to 170 000 years AP is characterised by a climate that is only moderately warmer than at present day and that is associated with a similar degree of water availability through the year, though with somewhat drier summers. Atmospheric CO_2 concentrations return to near baseline levels after about 250 000 years, resulting in the distinction between the two fossil fuel usage cases being lost (BIOCLIM, 2003). The same sequence of evolving climate can therefore be adopted for both fossil fuel usage cases beyond that time. It is reasonable to adopt the last glacial cycle as the basis for modelling climate change beyond 250 000 years.

In scenarios B3 and B4, there is generally a smaller global ice volume throughout the next 170 000 years than at the present day. Thus, sea level will be at, or a few metres above, its present level throughout the period. Global sea-level rise of a few metres would result in inundation of estuaries and low-lying farmland and wetland areas. There are indications that continued sea-level rise will amount to 20-25 m within the next 10 000 years (based on extrapolations from Fichefet (2007).

Even in the natural A4 scenario, conditions as warm as the present day persist for a considerable time: up to 53 000 years AP for Central England and the Northeast of France. Central England and the Northeast of France experience a brief period of polar climate and tundra just after 100 000 years AP. Thus, only if scenario A4 is considered does a cooling period become pertinent, starting from about 53 000 years AP. When full glaciation occurs at about 100 000 years AP, climatic conditions become considerably different from present day conditions and a revised infiltration rate needs to be considered.

Based on the BIOCLIM results and paleo-environmental data, the range of likely future climate states in the Netherlands are the present-day temperate maritime climate, the Mediterranean climate, the boreal climate, the periglacial climate and the glacial climate. To assess the biosphere change, four constant biosphere systems, reflecting the first 4 climate states mentioned will be considered.

Present-day temperate maritime climate (ZB VI);
The above characterisation of the geosphere-biosphere interfaces is based on information for the present-day climate in the Netherlands. Current depth of the fresh water- saline water transition in the Netherlands is between 50 and more than 300 m below the earth's surface. Main determinants for the depth are the amount of infiltration of meteoric water in the subsurface, sea level and nearness to the sea. The quality of the water can be derived from the regional groundwater monitoring surveys in the Netherlands (see summary statistics of hydrochemistry in tables from Griffioen et al., 2013 and Van den Brink et al., 2007).

Mediterranean climate (ZB IV)
In Mediterranean conditions the net infiltration of water may diminish which results in a deepening of the water table and a shallower level of the fresh-saline water transition, and Infiltration of sea water in the near shore zone. Warming of the current climate could coincide with a rise of the sea level which ultimately could lead to a complete displacement of the fresh water zone when the land area is permanently flooded by the sea.

Boreal climate (ZB VIII)
Climate cooling may coincide with changes in the net infiltration of water and larger seasonal variations In Infiltration rate. At the same time sea level may drop because of growing continental ice sheets which Influences the depth of the fresh-saline water interface.

Periglacial climate (ZB IX)
Continuous permafrost prevents water to infiltrate. Groundwater below continuous permafrost is often mineralized and not suitable as drinking water without any treatment. The non-frozen residual water below the permafrost may have deviating chemical composition resulting from the fractionation during freezing. Locally non frozen fresh ground water bodies may be present below lakes and rivers. Another source of drinking water can be created by melting ice or snow.

In areas with discontinuous permafrost groundwater can locally be discharged to the surface (open taliks). Drinking water wells may be drilled in these areas (NISDC 2014). Close to the ice sheet margin melt water discharges to the groundwater system and surface water leading to a change in the water yield and water quality.

Release of radionuclides might happen via wells, lakes or rivers in unfrozen zones or taliks in between permafrost.

Volumes of potable water are smaller and more localized in continuous permafrost areas and it is thus less likely to find potable groundwater resources in such regions (McEwen 1991).

(Glacial climate)
The disposal site is covered by an ice sheet with polar or subpolar conditions above the ice sheet. Melt water is being produced at the bottom of the ice sheet, partly discharged into the subsurface fresh water aquifer and partly transported to the front of the ice sheet. It is highly unlikely that radionuclides which migrate to the fresh water aquifer will be reaching the top of the ice sheet and lead to exposure of humans. This climate state likely do not require quantitative biosphere assessments since there is no vegetation and there will be low human occupancy and low resource usage.

Topography
An understanding of the relief and shape of the surface environment is clearly relevant to determining groundwater recharge and flow on a regional scale; on the local scale, there may be topographic effects on surface drainage that are relevant to describing near-surface hydrological pathways. A description of topography is however normally not incorporated directly in a biosphere assessment model; instead, its influence is incorporated in the parameterisation of specific processes, such as interflow.

The topography in the Netherlands is mainly determined by exogenous processes. The larger part of the Netherlands is subsiding except for its most eastern and south-eastern parts.

Mediterranean climate conditions may coincide with a sea-level rise of a few metres to 10 metre due to global warming and melting of part of the continental ice sheets. Larger part of the Netherlands may be flooded and a lagoonal to shallow marine environment may be created. Wave actions and currents will level the topography.

Periglacial conditions can be expected when climate deteriorates in the course of a glacial cycle with growing continental ice sheets. As a consequence the erosion base will drop leading to a maximum erosion of 20 metre in the river flood plains (De Groot 1993). In permafrost conditions, ice lenses can be formed in the shallow subsurface leading to positive relief elements of several metres high. These so called pingos turn into pin go lakes when the ice melts in a climate warming phase.

Glacial conditions will be marked by the presence of an ice sheet with a thickness of up to several 100s of metres. In front of the ice sheet push moraines can be formed with a height of up to 100 metre or more. Due to the loading of the ice the earth's surface in front of the ice sheet is subsiding resulting in a gentle depression In front of the ice sheet. Melt water erosion may occur below the ice sheet which can result In depressions of tens of metres to many hundreds of metres (De Groot 1993). These depressions are filled with ice and water. Once the ice sheet has disappeared, the depressions will be rapidly filled with sediments. Sometimes positive topographic elements can be formed below the ice sheet in case a lot of sediment is dumped in melt water zones resulting in ridges of several metres high.

Location
In site specific assessments, the location can be defined in terms of latitude and longitude. For more generic assessments, the location is more broadly described, e.g. a coastal or inland site in current temperate latitudes.

For the generic assessments of the Dutch site, we assume that the site is located inland and terrestrial exposure pathways need to be considered.

Geographical extent
The spatial domain of the biosphere system should be consistent with the requirements of the assessment context. In case of the well scenario, the aquifer should be at an 'accessible depth' and provide sufficient water for domestic uses.

Water bodies
At a minimum, information should be provided as to whether surface and subsurface water masses e.g. lakes, rivers, wetlands, seas, and estuaries are present in the biosphere system. Features such as near-surface aquifers and ice sheets may be included, as appropriate. The volume of these water bodies needs to be large enough to accommodate the habits of the representative persons.

Human community
A description of the assumed human community is a necessary part of any biosphere system description. Human activities have a major influence on the status of the environment. The definition of future biosphere systems will therefore involve implicit or explicit hypotheses concerning social-economic structures (e.g. industrial, agrarian), land use, their level of technology, their degree of subsistence, etc. Such hypotheses will influence both the definition of the biosphere system and the assumed behaviour of potential exposure groups.

For the biosphere assessments of the generic site under temperate conditions, a small subsistence farming community living of local grown vegetables and meat products is assumed. The food crops (cereals, root vegetables, tubers, leafy vegetables, non-leafy vegetables, legumes, fruit and berries), pasture and fodder crops are irrigated. The livestock includes chicken, sheep and cattle for both dairy and meat. The cattle and sheep are grazed on pasture, whereas the chickens are fed on locally produced grain.
Subsistence agricultural communities also exist in semi-arid regions, such as northwest Spain, as well as in the south of Sweden and can therefore be considered feasible under Mediterranean and boreal climate states.
A certain degree of self-sufficiency is also possible under periglacial conditions, but agricultural activities will be limited so a large part of the human diet will consist of natural products such as fish, berries, reindeer.

Biotas
Information about the terrestrial and aquatic plant and animal life in the area of interest should be given. Distinctions can be made between domestic and wild flora and fauna, and also between those involved in the human food chain and those which are not so involved.

If an environmental assessment is required, a good description of the natural ecosystems (native plants and animals) is needed, with special attention for areas and species of high biological/ecological value and endangered and rare species.

The ecosystem considered in the biosphere assessments will be a managed agricultural system. In case of releases of radionuclides into surface water bodies, also the surface water and the biota present need to be considered, according to the demands of the assessment context.

Near-surface lithostratigraphy
The near-surface lithostratigraphy describes the general characteristics of soils and sediments including both their composition and structure. Climate, topography, parent rock and vegetation together determine whether or not a soil layer is developed and, if so, its specific properties. The soil types and vegetation need to be representative for the different climate states considered

Soils

Soil properties in the Netherlands strongly depend on location. A concise overview is given by Hartemink (2013): "About half of the country is below sea level and would be inundated in the absence of dikes, dunes and pumping plants. It is also a wet country and more than 90% of the soils have groundwater within 140 cm of the soil surface during the winter. As a result, most Dutch soils have hydromorphic properties and require artificial drainage when taken in use. There is hardly soil derived from consolidated rock. Non-urban areas are dominant by sandy soils (43%), marine clays (24%), fluvial clays and loams (8%) or organic soils (14%). Soils developed in loess deposits (1.4%) occur mainly in the southern part of the country."

Detailed information on the various soils of the Netherlands can be found in soil map of The Netherlands and the accompanying report (de Vries 2003).

The variation in soil organic carbon (SOC) in the Netherlands is very high. In Lugato (2014), the soil organic carbon content of the upper 30 cm of agricultural soils in The Netherlands is estimated between 100 and 151 ton C/ha. In the figures below (Figure B-2), where collected data (left) are compared to modelled data (right), the average SOC content calculated is respectively 3,5% (corresponding to the 100 ton C/ha) and 7,0%.

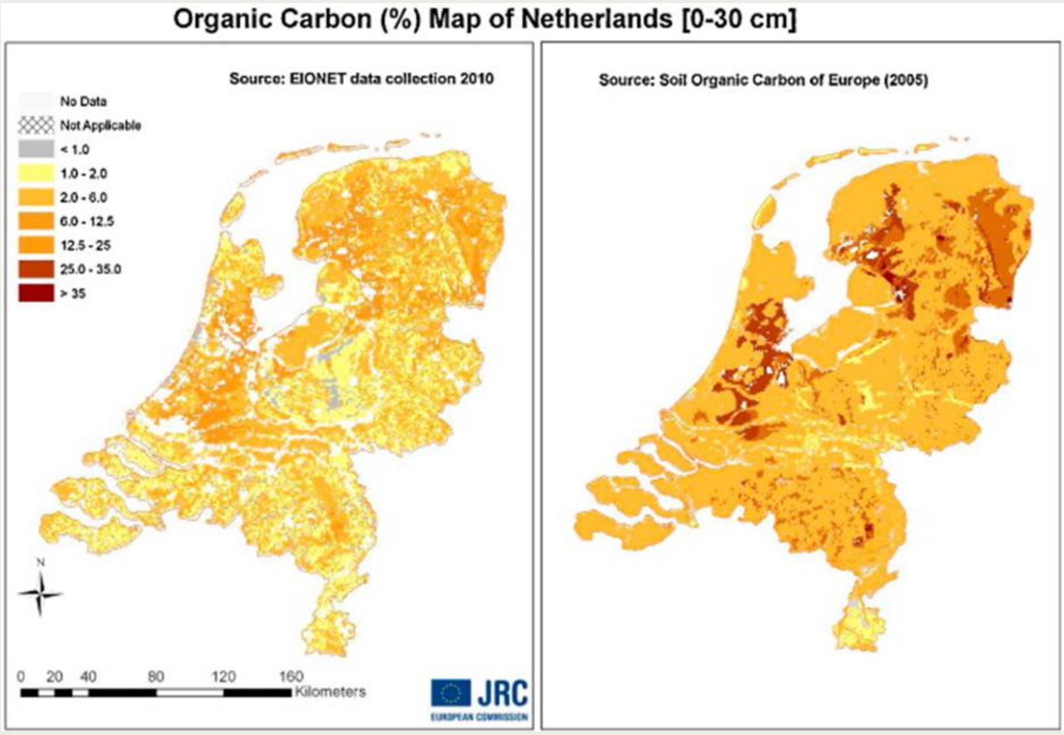

Figure B-2 SOC content in the Netherlands (Panagos 2013)

Since a generic waste disposal site is considered, all potentially relevant components are taken into account and the description of these components in the biosphere system description is limited and not site-specific. The biosphere assessment approach for the normal-evolution scenario assumes that the biosphere characteristics are constant and do not evolve over time.

B.2.3.4. Biosphere system description

In this step, the relevant characteristics of the identified principal biosphere system components are determined. The selection of the potentially relevant FEPs is based on expert judgment using the generic FEP lists given in IAEA (2003) and Schelland (2013) as screening tool. In situations, in which it is unclear, whether or not particular characteristics are relevant to the biosphere system description, these have to be retained for review later. Exclusion of FEPs is not possible without documenting the reason. By using this procedure, the identification and selection of the relevant FEPs, and decisions on treatment, are transparent and traceable.

B.2.3.5. Selection of representative persons

The evaluation of individual exposures is based on the identification of representative persons, whereby the "representative person is defined as (ICRP 2006):

An individual, who will almost always be a hypothetical construct, receiving a dose that is representative of the more highly exposed individuals in the population

The assessment endpoint can be the maximum annual individual committed effective dose to a representative person. Committed dose means the dose to an individual after lifetime exposure; i.e. over 70 years for a child, over 50 years for an adult. Effective dose is the sum of the radiation weighted doses to the exposed organs, after multiplication with the respective tissue weighting factors.

The radioactive waste facility should be managed in such a way that the expected radiological impact on the health of future generations will be no greater than the levels regarded as acceptable now.

Traditionally as mentioned before, some sort of subsistence farming lifestyle is considered to define the exposure pathways and calculate the radiological doses. This is because agricultural systems with high degree of subsistence tend to lead to the highest potential radiological impacts on individuals as demonstrated by several studies such as Garisto F. (2010), IAEA (2003).To ensure that the radiological doses are not likely to be underestimated, the same approach is used in the Dutch biosphere assessment. Thus pessimistic assumptions are adopted concerning the location and habits of the exposed population (cautious assessment philosophy). We will assume as representative persons a subsistence farmer community consisting of adult farmers and their children, using present-day farming practices, spending a large part of their time on (contaminated) fields or pasture, consuming the same average diet as the other local residents but extracted from the area assessed to be the most contaminated as result of possible future discharges from the repository. The assumptions on human diet and behaviour are adjusted to be consistent with the past and current status of each of the climate states. In case of probabilistic assessments, the representative person should be defined such that the probability is less than about 5% that a person drawn at random from the population will receive a greater dose (ICRP, 2006).

The possible exposure pathways depend on the considered biosphere receptor:

- Well; the water is used for human consumption, irrigating crops and pasture, watering livestock. The well is assumed to have a sufficient yield for these purposes.
- River, lake, pond; the water is used for production of drinking water, irrigating crops and pasture, watering cattle, fishing and leisure.
- Soil: crops and pasture are grown on the contaminated soil.

This lead to the following possible ways of radiological exposure:

- Ingestion of contaminated drinking water and foods (e.g., fruit, vegetables, milk, meat, fish)

- Inhalation of dust in suspension In the air above contaminated fields and radon exhaled by the soil from radium-bearing waste
- External irradiation of individuals from direct ground surface radiation on contaminated fields or riverbanks containing contaminated sediments

The approach then consists of combining the relevant exposure pathways and calculating the individual dose. Transfer factors between the various compartments of the biosphere (e.g., soil to pasture, cow to milk, etc.) are used to calculate the concentrations of radionuclides in the exposure media as a function of the concentrations in the receptors.

The biosphere assessments should be carried out for various age groups. It is common practice to estimate the annual dose or risk for adult individuals. However, it is important to show that other age groups are also considered and adequately protected, as members of the public generally are well aware of the fact that children show higher radiation sensitivity than adults. The ICRP recommends in its Publication 101A (2006) that

> "*…for the purpose of compliance with the dose constraint for continuing exposure, the Commission recommends that the annual dose for the representative person should be defined by three age categories. These categories are 0-5 years (Infant), 6-15 years (child) and 16-70 years (adult)... For practical implementation of this recommendation, dose coefficients and habit data for a 1-year-old (infant), a 10-year-old (child), and an adult should be used to represent the three age categories.*"

Use of these three age categories is sufficient to characterise the radiological impact of a source and to ensure consideration of younger, more sensitive populations. In particular, exposure pathways may be different for different age groups, and, also, different exposure pathways may give the highest contribution to the total dose for different age groups.

Important characteristics of the representative person, as mentioned In the BIOMASS methodology, include:

- General description of activities leading to radiation exposure. Relevant activities to be considered include: eating and drinking; washing; type of work (Including activities linked to biosphere resource exploitation); recreation; sleeping.
- Physiological characteristics – factors contributing to physiological differences including age, sex and metabolic characteristics.
- Location – a description of the environmental surroundings occupied by members of the exposed group. In addition to general location considerations (e.g. inland/coastal; agricultural or natural ecosystem), further qualification (e.g. indoor/outdoor) may be appropriate in order better to characterise factors such as dust levels or the degree of shielding from external irradiation.
- Mode of exposure. The principal modes of exposure relevant to radiological exposure assessment are ingestion, inhalation and external irradiation.
- Rate and duration of exposure. Relevant parameters correspond to the information necessary to quantify annual average exposures from each potential source; for example: ingestion rates of different foodstuffs and occupancy times at different locations.

Human habits, behaviour and metabolic characteristics are based on present-day conditions observed at the site/region of interest and analogue regions when the climate states that differ from those at the present-day are being addressed. The biosphere under the different climate states are assumed separately. It is assumed that the biosphere is constant and as such human habits do not evolve over time. Regarding data sources for human behaviour, generalised data, based on national statistics can provide a useful source of information on a wide range of behaviour patterns.

Habits and diet of the Dutch population

In 2013, 2.2 % of the working population was active in agriculture on a total of 8.7 million (Centraal Bureau voor de Statistiek 2014). If we assume that people in these jobs spend 50% of the day outside, this results in an outdoors occupancy rate of approximately 1500 hours per year, a value which is reported in CEC (1986).Data from 2006 show that Dutch children aged 10-13 spend on average around 2 hours per day of their free time outside (Boorn 2007). Assuming that 50% of their free time will be spend on the agricultural land, this will result in an outdoors occupancy rate of approximately 300 hours per day on the contaminated fields, a value that is reported in Jones (2002).

The present-day Dutch diet consists of the following main food groups (selection based on (van Rossum 2011): potatoes, leafy vegetables, fruiting vegetables, root vegetables, fruits, dairy products (cow's milk), cereals and cereal products, beef, pork, chicken, fish, egg. In Table B-B-1, the dietary habits are represented quantitatively, for the age groups 9-13 and 19-69.

Table B-B-1 – Average food intake of children and adults of the Dutch population

Food groups based on EPIC-Soft classification	children aged 9-13 yrs., mean kg/year	Adults aged 19-69 yrs., mean kg/year
Potatoes and other tubers[8]	31,0	34,0
Vegetables	26,6	47,5
Fruits, nuts and olives[9]	31,6	42,9
Dairy products	146,3	136,4
Cereals and cereal products	67,3	75,7
Meat and meat products	32,7	40,2
Fish and shellfish	2,7	6,2
Eggs and egg products	3,0	4,5
Fat[10]	7,9	9,9
Sugar and confectionery[11]	28,7	16,0
Cakes[12]	21,8	17,0
Non-alcoholic beverages[13]	372,5	649,3
Alcoholic beverages[14]	0,6	78,4
Condiments and sauces[15]	9,5	11,8

8 Potatoes make up more than 99% of this category. About 55% of the days 'Potatoes' (cooked in different ways) were eaten at dinner. Pasta and rice were consumed twice a week.

9 Fruits make up more than 90% of this category.

10 78% of this category consists of vegetable oils and margarines.

11 Sugar in the Netherlands mostly originates from sugar beet, which is a root vegetable.

12 We propose to account for this consumption by adding one third to each of the categories cereals, eggs and dairy products.

13 6% are fruit and vegetable juices, the rest is water, coffee, tea and diluted syrups or soft drinks.

14 Alcoholic beverages consumed in the Netherlands are 71% "beer and cider" and 24% wine. Wine is mostly imported; beer contains cereals, but not to a significant degree for our purposes. Both non-alcoholic and alcoholic beverages add to the water intake.

15 As condiments and sauces contain ingredients of almost all other categories in varying proportions, and are responsible for a relatively small part of the diet, we propose to neglect this category.

Food groups based on EPIC-Soft classification	children aged 9-13 yrs., mean kg/year	Adults aged 19-69 yrs., mean kg/year
Soups, bouillon[16]	12,7	23,3
Miscellaneous[17]	5,4	6,7

Irrigation is an often used practice in the Netherlands. About 9% of the cultivated soils is irrigated regularly. At some regions Noord-Brabant, Noord-Limburg), it can even be 30% of the soil. Of the cultivated crops, grass is irrigated the most, followed by potatoes, field crops and fodder. Sprinklers are used at large scale in the Netherlands; mostly for grasslands, potatoes, cultivation of vegetables and fodder maize.

Sprinkling is an important form of using water in agriculture and horticulture in the Netherlands and is applied on grassland, agriculture of potatoes, sugar beets and green maize, horticulture in the open air and in greenhouses (CBS 2014).

The order of magnitude of the water yield for irrigation purposes is 1000 to 100 000 m^3 of fresh water per well per annum. These numbers are derived from the regulation for production of irrigation water for agricultural purposes (Stoof 2006). The irrigation amounts will depend on the considered soil types, crops and the area that needs to be irrigated. Data on additional water need for grass and potatoes (Oosterbaan 1986), water need of several individual crops (Janssen 2012) are given in Appendix C.

B.2.3.6. Model development

The first phase in the development of a biosphere model is the construction of a conceptual model. According to the BIOMASS methodology, this phase comprises three sections:

- the identification of the contaminated environmental media (conceptual model objects);
- the construction of the conceptual model, considering the interactions between the contaminated media. Therefore an interaction matrix can be used. Figure B-3 illustrates the concept of interaction matrices, where the identified principal biosphere components are placed on the diagonal. The interactions between them are considered in the off-diagonal elements. The matrix is always read clockwise
- the verification that no potentially important biosphere FEPs (IAEA 2003) are omitted from the conceptual model. The interrelationships between the biosphere system components can be established by constructing a (phenomenological) interaction matrix. Hereby important phenomena can be identified based on analysis of the interactions (i.e. relationships and dependencies) between the biosphere system components.

[16] We propose to account for this consumption by adding one third to the category vegetables and one third to water intake.

[17] This category is made up of roughly one third soya products (soya is imported from the Americas), and two thirds “snacks”. For snacks, the same reasoning holds as for condiments and sauces; we therefore propose to neglect this category.

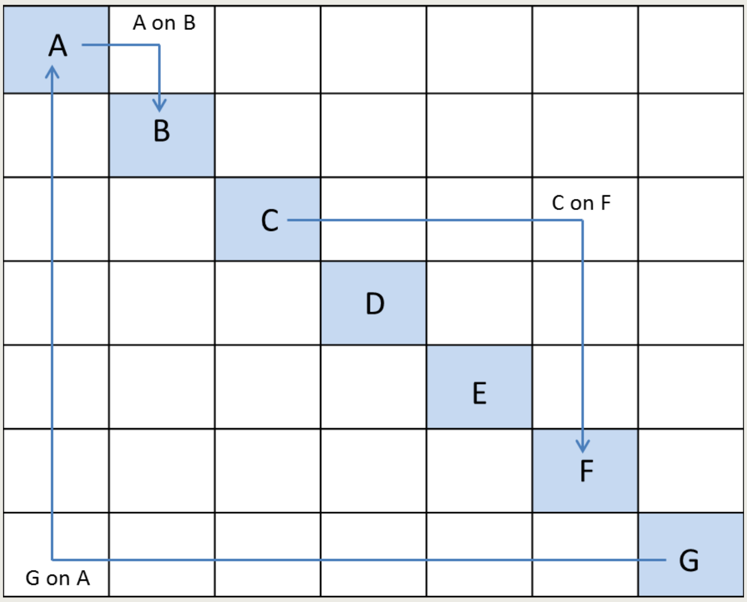

Figure B-3 Interaction Matrix Approach used for Developing Conceptual Models. The diagonal elements A, B and C are main biosphere components. The off-diagonal elements (white boxes) represent one or more processes. The arrows illustrates e.g. how component A affects component B, component C affects component F, component G affects component A, etc.

The second phase in the development of a biosphere model is the construction of a mathematical model. According to the BIOMASS methodology, this encompasses two stages:

- the elaboration of the mathematical model, taking account of available data sources, from which to derive relevant parameter values;
- the incorporation of the quantitative information on the exposure group(s).

Included in the BIOMASS Methodology is a data protocol that is intended to ensure that the data used in the models are fit for the purpose. Data may sometimes be easily available and widely accepted or even prescribed by regulation. Often, data may be unavailable, ambiguous or else not widely accepted. Data selection then becomes more difficult. An important consideration at this point is whether the specific data required are, or are not, key to the assessment (i.e. whether they can have an important effect on the calculated outcome). For those cases in which data are both key and unavailable, the protocol recommends expert elicitation. However this puts high demands on expert resources in such a way that it was only found possible rigorously to apply this part of the protocol to a few parameters.

B.3. Generic conceptual biosphere model

A generic interaction matrix between biosphere components and processes will be constructed from which conceptual models for the 3 biosphere receptors i.e. well, surface water and wetland can be derived. Once candidate sites are selected and characterised, the conceptual models can be made more site-specific.

For the generic interaction matrix, the following principal biosphere components have been identified:

- Deep or Near-surface aquifer: The potential source term to the biosphere may be the release of contaminated groundwater into a near-surface aquifer and/or use of groundwater from a deep well.
- Deep-soil: Region between the near-surface aquifer and the more biologically active surface soil. Plant roots and biological activity (including burrowing) can occur but are limited in this soil layer.
- Root zone soil/active layer: Most biologically active layer of the soil within which the highest root densities occur. In case of an agricultural scenario, the root zone is typically well mixed through ploughing.
- Surface water bodies: Rivers, lakes, ponds supplying water to the human community, in the absence of a well
- Atmosphere: Atmosphere above the considered biosphere system, including water (vapour/clouds) and suspended particulates (dust).
- Vegetation: Primarily food crops and pasture. The biosphere may include other, more natural vegetation and food products such as berries, mushrooms (more important part in diet of community living in periglacial climate). Aquatic vegetation is also included but ingestion of aquatic vegetation by humans is considered to be a minor exposure pathway.
- Animals: Primarily the farm animals, but also include aquatic organisms (such as fish, molluscs) and (other) natural wildlife.
- Humans: Representative persons that maximise their use of local resources.

Within each of the biosphere components, further discretisation, depending on the assessment purpose may be necessary. For example within the ‘soil’ component, one may need to distinguish between different soil constituents (solution, atmosphere, organic matter, Inorganic matter). However, a very detailed representation of the processes involved in the transfer from one biosphere compartment to another compartment is far beyond the needs for the biosphere assessments of the long-term safety of radioactive waste disposals, given the fact that the assessments are inhibited by large uncertainties related to the long time frames.

It should also be noted that the physico-chemical processes related to the radionuclides such as radioactive decay and sorption/desorption processes are not listed in the generic conceptual model. These processes are implicitly included within each of the biosphere components.

The generic conceptual model for radionuclide migration and uptake in terrestrial and aquatic biospheres is given in Figure B-4 and includes all components and processes considered relevant with regard to the migration and uptake of radionuclides from groundwater into the biosphere under temperate climate. The starting point is the release of radionuclides in the aquifer and the end point will be the dose to humans.

To ensure that no relevant processes are ignored, the FEPs in the interaction matrix have been screened against the general FEP list reported in Schelland (2013) and the more detailed list of features and processes reported in Section B.1. External features and processes that account for changes in environmental conditions will not be explicitly considered in this conceptual model.

Because it is impossible to use the conceptual model for the development of the mathematical model without some ranking of the processes in order of significance, the processes included in the interaction matrix were evaluated in terms of their importance for the respective biosphere receptor.

Deep or near surface aquifer	advection,diffusion, capillary rise	irrigation, advection, diffusion, capillary rise		discharge	irrigation (interception, translocation)	ingestion	spray degassing	ingestion, external irradiation (e.g. bathing)	advection
recharge, diffusion	**Deep soil**	advection, diffusion, bioturbation, degassing, capillary rise		seepage					
	leaching, diffusion, bioturbation	**Root zone/active layer**	seepage, erosion (run-off)		root uptake, external contamination, rain splash	ingestion, external contamination	evaporation, resuspension, degassing	ingestion, external irradiation	erosion
		irrigation, flooding	**Water column (surface water bodies)**	sedimentation, diffusion, water exchange	irrigation (interception, translocation), adsorption	ingestion external contamination	evaporation, degassing, spray	ingestion, external irradiation	advection
recharge, diffusion		dredging, material use (fertilizer),	erosion, resuspension, bioturbation, water exchange	**Bottom sediment (surface water bodies)**	root uptake, external contamination	ingestion external contamination		ingestion, external irradiation	sedimentation (burial), diffusion, advection
		weathering, senescence, death, root exudation, root respiration, bioturbation	desorption, death	excretion, death, bioturbation	**Vegetation (terrestrial/aquatic)**	ingestion	transpiration, respiration, pollen and gas release	ingestion	harvest removal
		excretion/use of manure, death, bioturbation	excretion, death	excretion, death, bioturbation	excretion, death	**Animals (terrestrial/aquatic)**	exhalation	ingestion	produce
		deposition (dust)	deposition		deposition, photosynthesis	inhalation, immersion	**Atmosphere**	inhalation immersion	air exchange
		excretion, agricultural practices (ploughing, fertilisation, ect),	excretion				exhalation	**Humans**	
									Transfer out of the biosphere system

Figure B-4 Generic interaction matrix for radionuclide migration and uptake in terrestrial and aquatic biospheres

It should be noted that the assessment model development and implementation on the biosphere systems is an iterative process. In the first step of the development of the model, the number of processes will be limited to those considered very important for an agricultural ecosystem under temperate conditions. Later on, less important processes can be included. The need for iterations depends on whether the model is adequate for its purpose.

Conservatively, some of the processes can be ignored while other processes will be considered implicitly or are less important. At the end, only those processes that need to be considered explicitly in the mathematical model need to be retained.

B.3.1. Water well

The results of the ranking of the processes by their significance for the water well receptor are given in Appendix D. The derived conceptual model for the water well is given in Figure B-5. Processes that were identified as potentially less important or considered implicitly are given in italic. Since water bodies (water column and bottom sediments) are not considered in water well scenario, these components are not listed in the figure.

B.3.2. Surface water

The results of the ranking of the processes by their significance for the surface water receptor are given in Appendix D. The derived conceptual model for the surface water is given in Figure B-6. Processes that were identified as potentially less important or considered implicitly are given in italic.

B.3.3. Wetland

The results of the ranking of the processes by their significance for the wetland receptor are given in Appendix D. The derived conceptual model for the wetland is given in Figure B-7. Processes that were identified as potentially less important or considered implicitly are given in italic. Since water bodies (water column and bottom sediments) are not considered in water well scenario, these components are not listed in the figure.

B.3.4. Considerations regarding the mathematical model

The conceptual model can be the basis of a set of mathematical models of different level of detail depending on the assessment purpose.

Because the transfers between the biosphere compartments (soil, surface water, vegetation, animals and humans) are relatively rapid in comparison to timescales of radionuclide release, these components can be adequately represented as being in equilibrium with the source term to the biosphere. As a consequence an equilibrium model can be applied in which the concentrations of radionuclides in the various biosphere compartments can be derived from each other on the basis of simple ratios or analytical solutions (taken at certain times) of linear differential equations that describe the transfers of radionuclides between the compartments. The exposure and individual dose is then calculated from the concentrations of radionuclides in the biosphere receptors.

A mathematical model developed for the normal evolution scenario under temperate climate conditions can be used for the normal evolution scenario under other climate conditions provided the biosphere components remain the same and the values of the parameters which are affected by the climate state, such as those of irrigation needs, are altered.

Deep or near surface aquifer	advection, *diffusion, capillary rise*	irrigation	irrigation (interception, translocation)	ingestion	*spray degassing*	ingestion, *external irradiation (e.g. bathing)*	*advection*
recharge, diffusion	**Deep soil**	advection, *diffusion, bioturbation, degassing, capillary rise*					
	leaching, *diffusion, bioturbation*	**Root zone/active layer**	root uptake, *external contamination, rain splash*	ingestion, *external contamination*	*evaporation, resuspension, degassing*	ingestion, external irradiation	*erosion*
		weathering, *senescence, death, root exudation, root respiration,* bioturbation	**Vegetation**	ingestion	*transpiration, respiration, pollen and gas release*	ingestion	*harvest removal*
		excretion/use of manure, death, bioturbation	excretion, death	**Animals**	*exhalation*	ingestion	*produce*
		deposition (dust)	deposition, photosynthesis	*inhalation, immersion*	**Atmosphere**	inhalation *immersion*	*air exchange*
		excretion, agricultural practices (ploughing, fertilisation, ect),			*exhalation*	**Humans**	
							Transfer out of the biosphere system

Figure B-5: Generic interaction matrix for radionuclide migration and uptake in biosphere considering the well water receptor

Deep or near surface aquifer	advection, *diffusion, capillary rise*			discharge		ingestion			*advection*
recharge, diffusion	**Deep soil**	advection*, diffusion, bioturbation, degassing, capillary rise*		*seepage, erosion*					
	leaching, *diffusion* , *bioturbation*	**Root zone/active layer**	*seepage, erosion (run-off)*		root uptake, *external contamination, rain splash*	ingestion, external contamination	*evaporation,* resuspension, *degassing*	ingestion, external irradiation	*erosion*
		irrigation *flooding*	**Water column (surface water bodies)**	sedimentation, *diffusion, water exchange*	irrigation (interception, translocation), *adsorption*	ingestion *external contamination*	*evaporation, degassing, spray*	ingestion, external irradiation	*advection*
recharge, diffusion		dredging, material use (fertilizer)	erosion/ resuspension, bioturbation, *water exchange*	**Bottom sediment (surface water bodies)**	*root uptake, external contamination*	ingestion *external contamination*		ingestion, external irradiation	*sedimentation (burial), diffusion, advection*
		weathering, *senescence, death, root exudation, root respiration, bioturbation*	*desorption, death*	*excretion, death, bioturbation*	**Vegetation (terrestrial/aquatic)**	ingestion	*transpiration, respiration, pollen and gas release*	ingestion	*harvest removal*
		excretion/use of manure, death, bioturbation	*excretion, death*	*excretion, death, bioturbation*	*excretion, death*	**Animals (terrestrial/aquatic)**	*exhalation*	ingestion	*produce*
		deposition (dust)	*deposition*		*deposition,* photosynthesis	*inhalation, immersion*	**Atmosphere**	inhalation *immersion*	*air exchange*
		excretion, agricultural practices (ploughing, fertilisation, ect),	*excretion*				*exhalation*	**Humans**	
									Transfer out of the biosphere system

Figure B-6: Generic interaction matrix for radionuclide migration and uptake in biosphere considering the surface water receptor

Deep or near surface aquifer	advection, *diffusion* , capillary rise	*irrigation,* advection,*diffusion,* capillary rise	*irrigation (interception, translocation)*	ingestion	*evaporation, spray degassing*		*advection*
recharge, diffusion	**Deep soil**	advection,*diffusion, bioturbation, degassing,* capillary rise					
	leaching, *diffusion, bioturbation*	**Root zone/active layer**	root uptake, *external contamination, rain splash*	ingestion, *external contamination*	*evaporation,* resuspension, *degassing*	ingestion, external irradiation	*erosion*
		weathering, *senescence, death, root exudation, root respiration, bioturbation*	**Vegetation**	ingestion	*transpiration, respiration, pollen and gas release*	ingestion	*harvest removal*
		excretion/use of manure, death, bioturbation	*excretion, death*	**Animals**	exhalation	ingestion	*produce*
		deposition (dust)	*deposition* , photosynthesis	*inhalation, immersion*	**Atmosphere**	inhalation *immersion*	*air exchange*
		excretion, agricultural practices (ploughing, fertilisation, ect),			*exhalation*	**Humans**	
							Transfer out of the biosphere system

Figure B-7: Generic interaction matrix for radionuclide migration and uptake in biosphere considering the wetland receptor

B.4. References Appendix B

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Appendix C Agricultural practices

Table C-1 Data on additional water needs for grass and potatoes (Oosterbaan 1986)

Tabel 1. Aanvullende waterbehoefte voor gras en aardappelen (in mm) in een jaar dat eens in de twee (50% jaar) respektievelijk eens in de 10 jaar (10% jaar) voorkomt (SWLT)

Gebied	Gras		Aardappelen	
	50% jaar	10% jaar	50% jaar	10% jaar
Noordelijk zeekleigebied	45	125	0	45
Zuidwestelijk zeekleigebied	60	155	0	60
Noordelijk weidegebied	5	70	0	40
Noordelijk zandgebied	40	110	0	60
Veenkoloniën	20	75	0	30
Oostelijk zandgebied	30	90	0	45
Zuidelijk zandgebied	70	150	15	80

Table C-2 Water use in agriculture and horticulture

Watergebruik in de land- en tuinbouw

Volgens Standaard output (SO)	2001[1]	2002[1]	2003	2004	2005	2006	2007	2008	2009	2010	2011
	miljoen m³										
Watergebruik	132	134	256	137	122	168	118	116	140	166	162
w.o. leidingwater	50	50	57	50	47	46	46	44	47	44	43
w.v. drenking vee	29	30	30	28	28	26	25	25	26	25	24
gietwater [2]	0,1	2,8	5,9	4,1	2,5	1,2	2,5	2,1	2,3	2,2	2,2
grondwater (irrigatie)	23	23	101	23	24	62	19	19	39	54	60
oppervlaktewater (irrigatie)	12	12	32	13	6,3	15	8,8	7,6	6,5	14	19
oppervlaktewater of grondwater (irrigatie)	8,0	8,2	22	9,0	5,8	12	8,9	7,9	8,2	12	0
oppervlaktewater of grondwater (drenking)	39	38	38	38	36	32	33	36	37	40	38
	m3 per bedrijf										
Gemiddeld gebruik	1430	1496	3003	1638	1496	2118	1534	1541	1939	2289	2301
w.o. leidingwater	542	557	673	593	581	584	598	587	652	603	605
akkerbouw	357	357	1462	413	500	1534	730	862	881	1567	1385
w.o. leidingwater	85	70	86	83	79	138	94	81	80	85	90
tuinbouw	1565	1679	3426	2436	1866	1703	1966	1806	1775	2032	1920
w.o. leidingwater	601	513	964	746	571	550	560	527	543	488	471
fruit	2628	3479	4833	3852	1043	948	805	788	911	1365	2107
w.o. leidingwater	106	521	781	418	407	500	494	380	479	641	621
veehouderij	1555	1602	2814	1633	1626	2175	1621	1639	2058	2396	2527
w.o. leidingwater	667	703	770	721	737	716	755	749	828	770	784
overige landbouw	2014	2049	6498	1869	2031	4633	1964	1990	4578	4474	3853
w.o. leidingwater	527	583	456	383	493	625	497	514	722	594	544
	1 000 ha										
Beregend areaal[3]	.	.	.	100	87	155	111	85	124	174	156
w.v. akkerbouw	.	.	.	18	18	36	38	26	30	43	47
tuinbouw	.	.	.	30	25	25	31	27	37	47	17
fruit	.	.	.	7,8	1,8	1,7	0,7	1,5	1,5	1,4	1,5
veehouderij	.	.	.	32	29	68	28	20	36	66	73
overige landbouw	.	.	.	12	13	26	14	9,8	19	17	18

Bron: Bedrijven-Informatienet van LEI.

1) Irrigatie op basis van het gebruik in 2004. De neerslag in het jaar 2004 benadert de neerslag in de groeiperioden in 2001 en 2002 het beste.

2) Gezuiverd oppervlaktewater, van mindere kwaliteit dan drinkwater.

3) Minimaal één keer beregend oppervlak; het totaal beregende oppervlak ligt dus hoger. In 2009 bedroeg dit ruim 390 duizend ha.

Referentiecode: CBS/CLO/sep13

Indicatorcode: i-nl-0014

Indicatorversie: 10

http://www.compendiumvoordeleefomgeving.nl/indicatoren/nl0014-Watergebruik-landbouw.html?i=11-61

Table C-3 Agriculture; crops, animals, land use per region

					Regio's	Nederland				
Onderwerpen					Perioden	2000	2005	2011	2012	2013
Akkerbouw	Oppervlakte	Akkerbouw, totaal			*are*	63 443 967	60 405 424	53 504 248	52 080 287	53 241 217
		Aardappelen	Aardappelen, totaal			18 016 160	15 578 061	15 968 595	14 993 220	15 582 213
		Akkerbouwgroenten	Akkerbouwgroenten, totaal			4 599 339	4 704 321	5 488 466	5 174 682	5 430 709
		Granen	Granen, totaal			22 574 767	22 328 734	21 383 169	20 895 309	21 022 038
			Gerst	Gerst, totaal		4 700 286	5 050 685	3 410 690	2 984 359	2 961 779
			Tarwe	Tarwe, totaal		13 663 600	13 657 270	15 152 444	15 162 489	15 275 326
		Graszaden				2 196 001	2 765 308	1 054 813	1 366 848	1 230 866
		Handelsgewassen	Handelsgewassen, totaal			1 150 575	1 202 518	953 137	948 560	1 168 070
		Peulvruchten	Peulvruchten, totaal			294 529	387 474	229 303	270 688	282 989
		Suikerbieten				11 094 644	9 131 265	7 332 911	7 272 396	7 319 435
		Overige akkerbouwgewassen				1 070 187	818 942	369 536	364 513	386 419
		Braak				2 447 765	3 488 801	724 318	794 071	818 478
Tuinbouw open grond	Oppervlakte	Tuinbouw open grond, totaal				8 106 079	8 139 184	8 855 224	8 642 095	8 635 971
		Bloembollen en -knollen	Bloembollen en -knollen, totaal			2 251 266	2 298 728	2 412 642	2 348 803	2 329 139
		Bloemkwekerijgewassen	Bloemkwekerijgewassen, totaal			292 972	284 341	292 841	290 962	290 482
		Boomkwekerijgewassen en vaste planten	Boomkwekerij en vaste planten, totaal			1 264 110	1 457 553	1 718 421	1 700 160	1 701 593
		Fruit open grond	Fruit open grond, totaal			2 059 960	1 856 800	1 922 989	1 878 433	1 906 174
		Tuinbouwgroenten	Tuinbouwgroenten, totaal			2 237 771	2 241 762	2 508 331	2 423 737	2 408 583
Tuinbouw onder glas	Oppervlakte	Tuinbouw onder glas, totaal			*m2*	105 208 811	105 396 583	102 491 890	99 616 624	98 174 658
		Bloemkwekerijgewassen	Bloemkwekerijgewassen, totaal			59 220 425	56 159 332	47 051 040	45 546 630	43 961 038
		Boomkwekerijgewassen en vaste planten	Boomkwekerij en vaste planten, totaal			3 687 178	4 331 312	4 947 233	4 858 306	4 828 211
		Fruit onder glas				298 925	456 259	606 631	560 837	528 916
		Glasgroenten	Glasgroenten, totaal			42 002 283	44 449 680	49 886 986	48 650 851	48 856 493
Tuinbouw overig	Oppervlakte, hoeveelheid	Bollenbroei	Overige bollenbroei		*1000 kg*	.	.	.	1 445	1 519
		Paddenstoelenteelt	Substraatverbruik paddenstoelen		*ton*	122 410	48 850	548 066	540 168	579 802
	Aantal bedrijven	Paddenstoelenteelt	Substraatverbruik paddenstoelen		*aantal*	130	71	177	162	157
		Witloftrek				278	154	81	81	78
Grasland en groenvoedergewassen	Oppervlakte	Grasland en groenvoedergewassen, totaal			*are*	124 948 293	124 170 929	122 454 892	122 451 298	121 898 207
		Grasland	Grasland, totaal			103 667 499	99 997 634	98 826 206	98 652 367	98 294 829
			Blijvend grasland			90 001 743	77 058 384	76 638 866	74 617 015	72 208 864
			Natuurlijk grasland			2 665 752	2 431 587	4 956 381	4 869 337	5 100 576
		Groenvoedergewassen	Groenvoedergewassen, totaal			21 280 794	24 173 295	23 628 686	23 798 931	23 603 378
	Aantal bedrijven	Groenvoedergewassen	Snijmaïs		*aantal*	31 229	27 933	25 972	25 621	25 221
			Voederbieten			953	470	287	264	261
Graasdieren	Aantal dieren	Rundvee	Vleeskalveren	Vleeskalveren voor rosé-vlees (< 1 jaar)		145 811	204 227	303 553	329 556	337 046
			Stieren (>= 2 jaar)	Stieren voor de fokkerij (>= 2 jaar)		10 401	12 382	7 599	6 592	.
		Schapen	Ooien			679 776	646 993	546 293	544 373	551 380
		Geiten	Overige geiten	Overige geiten, jonger dan 1 jaar		.	.	101 204	97 046	104 174
	Aantal bedrijven	Paarden en pony's	Pony's	Pony's, jonger dan drie jaar		.	4 028	3 020	2 850	2 692
Hokdieren	Aantal dieren	Varkens	Biggen	Biggen tot 20 kg, nog bij de zeug		2 087 684	1 825 748	2 036 874	2 028 127	2 066 237
			Fokvarkens	Beren, 50 kg of meer, nog niet dekrijp		6 917	6 486	2 864	2 698	2 329
			Vleesvarkens	Vleesvarkens, 50 kg of meer Vleesvarkens, 80 tot 110 kg		.	.	1 744 704	1 737 942	1 735 626
				Vleesvarkens, 110 kg of meer		.	.	313 531	369 878	357 945
		Kippen	Ouderdieren van leghennen	Ouderdieren van leghennen, < 18 weken		.	252 380	281 718	286 122	232 654

Ref. table above: Centraal Bureau voor de Statistiek, *Landbouw; gewassen, dieren en grondgebruik naar regio*, February 19, 2014 (http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=80780NED&D1=23-24,32,50-51,59,64-65,79,86-88,155-156,167,170,180,194,295-296,317,320-321,384,388,399-404,406,417-418,427,440,444,451,500,504,512,518-519,526&D2=0&D3=0,5,(l-2),(l-1),l&HDR=G1,G2&STB=T&VW=T)

Table C-4 Water needs of individual crops (Janssen 2012)

Gewas	Waterbehoefte per jaar	Opbrengst per ha in €	Opbrengst van 1 mm water per ha in €
Gras	350-500	1.400	3
Maïs	300	2.210	7
Aardappelen	300	4.960	17
Bieten	400	2.990	7
Granen	350	1.280	4
Overig akkerbouw	...	2.500	
Open tuinbouw	300-1.000	20.900	32
Boomteelt	350	49.700	142
Fruitteelt	3.500-7.000	30.900	6
Bollenteelt	300	19.700	66
Containerteelt	750-1.700	100.000	82
Glastuinbouw	750-1.350	500.000	500
Champignonteelt	500	2.573.000	5.000

Appendix D Analysis of the generic conceptual model

D.1. Well water

The results of the ranking of the processes by their significance for the water well receptor are given in Table D-1. The processes that were identified as potentially less important or considered implicitly are given in italic and screening-out arguments are given. Since water bodies (water column and bottom sediments) are not considered in water well scenario, these components are not listed in the table.

Table D-1 Preliminary analysis of the importance of the processes

Biosphere component 1	Biosphere component 2	Process	Justification
Deep/near surface aquifer	Deep soil	advection *diffusion* *capillary rise*	Transport of contaminants by advection dominates over transport by diffusion in the biosphere, so diffusion can be ignored. Generally, aquifer is well below root zone and capillary rise can be ignored.
Deep/near surface aquifer	Root zone/active layer	irrigation, *advection, diffusion, capillary rise*	Irrigation is the most important way by which the biosphere becomes contaminated
Deep/near surface aquifer	Vegetation	irrigation (interception, translocation)	Vegetation becomes contaminated by irrigation. Radionuclides are intercepted by the canopy (sprinkling irrigation) and for root crops translocation to edible parts of plant is considered.
Deep/near surface aquifer	Animals	ingestion	Watering of livestock
Deep/near surface aquifer	Atmosphere	*evaporation, spray degassing*	Gaseous evasion of radionuclides (such as ^{3}H, ^{14}C, ^{222}Rn, ^{129}I) from the water to the atmosphere. For the agricultural system these losses are ignored (conservative assumption)
Deep/near surface aquifer	Humans	ingestion *external irradiation*	Ingestion of drinking water much more important than external exposure by water uses (e.g. bathing).
Deep/near surface aquifer	*Transfer out of the biosphere system*	*advection*	Conservatively, losses from the system can be ignored
Deep soil	Deep/near surface aquifer	*recharge* *diffusion*	These processes are often ignored
Deep soil	Root zone/active layer	*advection* *diffusion* *bioturbation* *degassing* *capillary rise*	Processes less important, but if needed can be considered later. In case of a natural ecosystem, these processes will be more important.
Root zone/active layer	Deep soil	leaching *diffusion* *bioturbation*	Leaching (infiltration) dominates over diffusion and bioturbation

Biosphere component 1	**Biosphere component 2**	**Process**	**Justification**
Root zone/active layer	Vegetation	root uptake *external contamination, rain splash*	External contamination of plants not important because assessment endpoint is the human dose and not the non-human dose
Root zone/active layer	Animals	ingestion *external contamination*	External contamination not important because assessment endpoint is the human dose and not the non-human dose
Root zone/active layer	Atmosphere	*evaporation* resuspension degassing	Gaseous evasion of ^{14}C, ^{222}Rn from soil to the atmosphere is generally taken into account explicitly.
Root zone/active layer	Humans	ingestion external irradiation	Considered. Soil ingestion can be inadvertent or deliberate
Root zone/active layer	Transfer out of the biosphere system	erosion	Conservatively, losses from the system can be ignored
Vegetation	Root zone/active layer	weathering, *senescence, death, root exudation, root respiration, bioturbation*	Weathering is considered. Senescence, death, bioturbation are less important in an agricultural system. Root exudation and respiration are not modelled explicitly.
Vegetation	Animals	ingestion	Ingestion of pasture and other feed leads to contamination of meat.
Vegetation	Atmosphere	*transpiration, respiration, pollen and gas release*	Transpiration and respiration are mostly considered implicitly. Root uptake is facilitated via transpiration. Pollen and gas release are ignored.
Vegetation	Humans	ingestion	Ingestion of vegetables
Vegetation	Transfer out of the biosphere system	harvest removal	Conservatively, losses from the system can be ignored
Animals	Root zone/active layer	*excretion/use of manure, death, bioturbation*	Generally, not considered explicitly in model
Animals	Vegetation	excretion, death	Generally, not considered explicitly in model. Also more important for natural ecosystem than for agricultural ecosystem
Animals	Atmosphere	*exhalation*	Considered not to be important
Animals	Humans	ingestion	Ingestion of animal products
Animals	Transfer out of the biosphere system	produce	Conservatively, losses from the system can be ignored
Atmosphere	Root zone/active layer	*deposition*	Natural dry and wet deposition of dust smaller than contamination due to irrigation
Atmosphere	Vegetation	*deposition, photosynthesis*	Natural dry and wet deposition of dust smaller than contamination due to irrigation. Photosynthesis (important for $^{14}CO_2$) is generally not modelled explicitly

Biosphere component 1	Biosphere component 2	Process	Justification
Atmosphere	Animals	*inhalation, immersion*	Contribution to dose considered to be small in case of agricultural ecosystem
Atmosphere	Humans	inhalation, *immersion*	Dose due to external exposure to contaminated air considered to be small compared to the other exposure pathways
Atmosphere	Transfer out of the biosphere system	aiAir exchange	Conservatively, losses from the system can be ignored
Humans	Root zone/active layer	*excretion, agricultural practices*	Fertilisation is generally not considered explicitly in model. It is assumed that root zone depth is equal to ploughing depth.
Humans	Atmosphere	*exhalation*	Process can be ignored

D.2. Surface water bodies

The results of the ranking of the processes by their significance for the surface water receptor are given in Table D-2. The processes that were identified as potentially less important are given in italic and screening out arguments are given.

Table D-2 Preliminary analysis of the importance of the processes

Biosphere component 1	Biosphere component 2	Process	Justification
Deep/near surface aquifer	Deep soil	*advection diffusion capillary rise*	Not considered
Deep/near surface aquifer	Root zone/active layer	*irrigation, advection, diffusion, capillary rise*	Not considered
Deep/near surface aquifer	*Bottom sediment*	discharge	Mostly considered implicitly by calculating the dose per unit flux. The discharge of radionuclides from groundwater to surface water leads to contamination of sediment and water column
Deep/near surface aquifer	Vegetation	irrigation (interception, translocation)	Not considered
Deep/near surface aquifer	Animals	ingestion	Not considered
Deep/near surface aquifer	Atmosphere	*evaporation, spray degassing*	Not considered
Deep/near surface aquifer	Humans	Ingestion external irradiation	Not considered
Deep/near surface aquifer	*Transfer out of the biosphere system*	*advection*	Not considered
Deep soil	Deep/near surface aquifer	*recharge diffusion*	See water well

Biosphere component 1	Biosphere component 2	Process	Justification
Deep soil	Root zone/active layer	*advection* *diffusion* *bioturbation* *degassing* *capillary rise*	See water well
Deep soil	*Bottom sediment*	*seepage*	Considered less important than discharge
Root zone/active layer	Deep soil	leaching *diffusion* *bioturbation*	See water well
Root zone/active layer	*Water column*	*seepage* *erosion*	Considered less important than discharge
Root zone/active layer	Vegetation	root uptake *external contamination, rain splash*	See water well
Root zone/active layer	Animals	ingestion *external contamination*	See water well. Ingestion of aquatic animals (e.g. fish) is an additional exposure pathway
Root zone/active layer	Atmosphere	evaporation resuspension degassing	Gaseous evasion of ^{14}C from soil to the atmosphere is generally taken into account explicitly, while those for others volatile elements are ignored or considered implicitly.
Root zone/active layer	Humans	ingestion external irradiation	See water well
Root zone/active layer	Transfer out of the biosphere system	erosion	See water well
Water column	Root zone/active layer	irrigation, *flooding*	Flooding is not considered in the given context
Water column	Bottom sediment	sedimentation *diffusion* *water exchange*	Diffusion and water exchange are less important than net sedimentation
Water column	Vegetation	irrigation, *adsorption*	Adsorption and not irrigation is relevant in case of aquatic vegetation. However, ingestion of aquatic vegetation is considered to be less important for the given context.
Water column	Animals	ingestion *external irradiation*	External contamination not important because assessment endpoint is the human dose and not the non-human dose
Water column	Atmosphere	*evaporation, degassing, spray*	Not considered important in the given context
Water column	Humans	ingestion external irradiation	Ingestion of drinking water much more important than external exposure by water uses (e.g. bathing, swimming)
Water column	Transfer out of the biosphere system	advection	Conservatively, losses from the system can be ignored
Bottom sediment	Root zone/active layer	*dredging, material use*	Mostly considered implicitly

Biosphere component 1	Biosphere component 2	Process	Justification
Bottom sediment	Water column	*erosion resuspension bioturbation, water exchange*	Erosion and resuspension considered implicitly Net sedimentation rate is generally used. Other processes are considered to be less important.
Bottom sediment	Vegetation	*root uptake external contamination*	Root uptake by aquatic plants and external contamination not important because assessment endpoint is the human dose and not the non-human dose. Ingestion of aquatic plants by animals and humans is considered the less important exposure pathway.
Bottom sediment	Animals	*ingestion external irradiation*	External contamination not important because assessment endpoint is the human dose and not the non-human dose
Bottom sediment	Humans	*ingestion*, external irradiation	Ingestion considered to be less important
Bottom sediment	Transfer out of the biosphere system	sedimentation, diffusion, advection	Conservatively, losses from the system can be ignored
Vegetation	Root zone/active layer	Weathering, *senescence, death, root exudation, root respiration, bioturbation*	See water well
Vegetation	Water column	Desorption, death	Not considered important for given context
Vegetation	Bottom sediment	Excretion, death, bioturbation	Not considered important for given context
Vegetation	Animals	ingestion	Ingestion of pasture and other feed leads to contamination of meat. Ingestion of aquatic vegetation is considered to be less important for the given context.
Vegetation	Atmosphere	*Transpiration, respiration, pollen and gas release*	See water well
Vegetation	Humans	ingestion	Ingestion of vegetables. Ingestion of aquatic vegetation is considered to be less important for the given context.
Vegetation	Transfer out of the biosphere system	Harvest removal	See water well
Animals	Root zone/active layer	*Excretion/use of manure, death, bioturbation*	See water well
Animals	Water column	Excretion, death	Not considered important for given context
Animals	Bottom sediment	Excretion, death, bioturbation	Not considered important for given context
Animals	Vegetation	Excretion, death	See water well
Animals	Atmosphere	*exhalation*	See water well

Biosphere component 1	Biosphere component 2	Process	Justification
Animals	Humans	ingestion	See water well
Animals	Transfer out of the biosphere system	produce	See water well
Atmosphere	Root zone/active layer	*deposition*	See water well
Atmosphere	Water column	deposition	Not considered important for given context
Atmosphere	Vegetation	*Deposition, photosynthesis*	See water well
Atmosphere	Animals	*Inhalation, immersion*	See water well
Atmosphere	Humans	Inhalation, *immersion*	See water well
Atmosphere	Transfer out of the biosphere system	*Air exchange*	See water well
Humans	Root zone/active layer	*Excretion, agricultural practices*	See water well
Humans	Water column	excretion	Not considered important for given context
Humans	Atmosphere	*exhalation*	See water well

D.3. Wetland

The results of the ranking of the processes by their significance for the wetland receptor are given in Table D-3. The processes that were identified as potentially less important are given in italic and screening out arguments are given. Since water bodies (water column and bottom sediments) are not considered for the wetland receptor, these components are not listed in the table.

Table D-3 Preliminary analysis of the importance of the processes

Biosphere component 1	Biosphere component 2	Process	Justification
Deep/near surface aquifer	Deep soil	advection *diffusion* capillary rise	Groundwater will directly enter terrestrial by advection and capillary rise.
Deep/near surface aquifer	Root zone/active layer	*irrigation*, advection, diffusion, capillary rise	Irrigation is not considered. Wetlands are contaminated by upward movement of groundwater and then converted to agricultural use by drainage.
Deep/near surface aquifer	Vegetation	Irrigation (interception, translocation)	Irrigation not considered
Deep/near surface aquifer	Animals	ingestion	Not considered
Deep/near surface aquifer	Atmosphere	*evaporation, spray degassing*	Not considered
Deep/near surface aquifer	Humans	Ingestion external irradiation	Not considered
Deep/near surface aquifer	*Transfer out of the biosphere system*	*advection*	Conservatively, losses from the system can be ignored
Deep soil	Deep/near surface aquifer	*Recharge diffusion*	Not considered

Biosphere component 1	Biosphere component 2	Process	Justification
Deep soil	Root zone/active layer	Advection *diffusion bioturbation degassing* capillary rise	Groundwater will directly enter terrestrial by advection and capillary rise.
Root zone/active layer	Deep soil	*Leaching diffusion bioturbation*	Not considered explicitly
Root zone/active layer	Vegetation	Root uptake *external contamination, rain splash*	See water well
Root zone/active layer	Animals	Ingestion *external contamination*	See water well
Root zone/active layer	Atmosphere	*Evaporation* resuspension degassing	See water well.
Root zone/active layer	Humans	Ingestion external irradiation	See water well
Root zone/active layer	Transfer out of the biosphere system	erosion	See water well
Vegetation	Root zone/active layer	Weathering, *senescence, death, root exudation, root respiration, bioturbation*	See water well.
Vegetation	Animals	ingestion	See water well
Vegetation	Atmosphere	*Transpiration, respiration, pollen and gas release*	See water well
Vegetation	Humans	ingestion	See water well
Vegetation	Transfer out of the biosphere system	Harvest removal	See water well
Animals	Root zone/active layer	*Excretion/use of manure, death, bioturbation*	See water well
Animals	Vegetation	Excretion, death	See water well
Animals	Atmosphere	*exhalation*	See water well
Animals	Humans	ingestion	See water well
Animals	Transfer out of the biosphere system	produce	See water well
Atmosphere	Root zone/active layer	*deposition*	See water well
Atmosphere	Vegetation	*Deposition, photosynthesis*	See water well
Atmosphere	Animals	*Inhalation, immersion*	See water well
Atmosphere	Humans	Inhalation, *immersion*	See water well
Atmosphere	Transfer out of the biosphere system	*Air exchange*	See water well
Humans	Root zone/active layer	*Excretion, agricultural practices*	See water well
Humans	Atmosphere	*exhalation*	See water well

Appendix E Relative contributions of the different pathways to the dose

Table E-1 Relative contributions of the different pathways to the dose (%) for the river receptor for an adult considering temperate climate

	DW	FISH	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	EX_SED	SOIL_ING
^{227}Ac	1,04E+01	1,98E+01	1,18E+01	6,03E+00	2,85E+00	2,77E+00	2,52E+01	1,87E+01	1,92E+00	4,21E-03	7,20E-02	4,38E-03	9,34E-02	1,92E-02	4,42E-01	1,41E-02
^{108m}Ag	2,55E-01	6,38E-01	9,47E-02	4,43E-02	2,14E-02	2,35E-02	1,85E-01	6,95E-01	7,07E-02	1,27E-02	1,16E-02	1,13E-03	2,15E-04	3,28E+00	9,43E+01	9,39E-04
^{241}Am	1,26E+01	2,38E+01	1,41E+01	7,28E+00	3,44E+00	3,30E+00	3,05E+01	2,28E+00	2,61E-01	7,99E-03	4,77E-02	4,18E-03	9,08E-01	5,03E-02	9,92E-01	3,05E-01
^{242m}Am	1,26E+01	2,38E+01	1,41E+01	7,27E+00	3,44E+00	3,30E+00	3,05E+01	2,26E+00	2,42E-01	7,45E-03	4,28E-02	3,42E-03	3,15E-01	2,92E-02	1,60E+00	1,08E-01
^{243}Am	9,37E+00	1,78E+01	1,06E+01	5,50E+00	2,58E+00	2,47E+00	2,28E+01	1,83E+00	3,05E-01	7,93E-03	5,31E-02	7,65E-03	4,03E+00	5,01E+00	1,64E+01	1,39E+00
^{10}Be	2,53E+01	3,92E+01	6,67E+00	3,69E+00	1,64E+00	1,88E+00	1,28E+01	4,75E+00	3,28E-01	3,63E-03	2,84E-01	2,70E-02	4,09E-01	7,36E-01	1,19E+00	9,08E-01
^{14}C	2,23E+00	9,78E+01	1,07E-01	3,22E-03	2,16E-03	7,66E-03	1,78E-03	1,92E-02	1,05E-03	3,22E-02	2,82E-02	5,49E-03	7,99E-06	8,86E-08	1,63E-04	5,26E-06
^{41}Ca	4,29E+01	1,48E+01	5,64E+00	2,89E+00	1,90E+00	1,44E+00	1,18E+01	8,81E+00	9,44E-01	8,21E+00	3,33E-01	9,72E-02	1,98E-05	0,00E+00	0,00E+00	2,79E-03
^{36}Cl	2,26E+01	9,54E+00	7,72E+00	2,24E+00	8,58E-01	3,87E-01	4,14E+00	1,27E+01	1,45E+00	2,82E+01	9,01E+00	9,97E-01	6,36E-05	1,35E-03	9,17E-05	5,70E-04
^{244}Cm	2,58E+01	3,26E+01	9,65E+00	4,97E+00	2,35E+00	2,26E+00	2,09E+01	1,54E+00	1,60E-01	6,59E-03	3,45E-03	1,08E-03	3,11E-02	6,41E-06	3,30E-04	9,74E-03
^{245}Cm	2,38E+01	3,01E+01	8,94E+00	4,63E+00	2,20E+00	2,60E+00	1,93E+01	1,50E+00	2,06E-01	8,75E-03	5,39E-03	3,26E-03	3,22E+00	1,47E+00	7,50E-01	1,14E+00
^{246}Cm	2,46E+01	3,11E+01	9,23E+00	4,78E+00	2,27E+00	2,60E+00	2,00E+01	1,54E+00	2,02E-01	8,74E-03	5,32E-03	2,96E-03	2,75E+00	3,40E-04	2,11E-04	9,67E-01
^{248}Cm	2,40E+01	3,03E+01	9,00E+00	4,67E+00	2,22E+00	2,80E+00	1,94E+01	1,54E+00	2,27E-01	9,26E-03	5,82E-03	4,07E-03	4,26E+00	1,12E-04	4,23E-05	1,55E+00
^{135}Cs	6,10E+00	7,21E+01	1,91E+00	1,25E+00	4,08E-01	4,08E-01	2,42E+00	1,27E+01	6,92E-01	1,23E+00	9,88E-01	2,48E-02	2,31E-04	6,74E-04	2,70E-03	4,72E-02
^{137}Cs	4,71E+00	5,56E+01	8,48E-01	4,43E-01	2,04E-01	1,97E-01	1,78E+00	6,68E+00	4,11E-01	5,95E-01	3,97E-01	9,42E-03	6,72E-06	2,92E-01	2,75E+01	1,34E-03
^{129}I	4,04E+01	3,41E+01	3,19E+00	6,30E-01	7,65E-01	2,85E-01	6,80E+00	8,05E+00	8,35E-01	3,12E+00	1,36E+00	6,85E-01	6,80E-06	1,13E-04	5,30E-04	1,47E-03
^{40}K	5,06E+00	5,96E+01	1,02E+00	5,00E-01	2,33E-01	2,81E-01	1,93E+00	7,28E+00	4,57E-01	6,32E-01	4,18E-01	1,04E-02	2,44E-06	7,24E-02	2,24E+01	5,08E-04
^{93}Mo	4,87E+01	8,36E-01	1,12E+01	4,00E+00	2,83E+00	1,87E+00	1,46E+01	1,24E+01	1,32E+00	1,35E+00	5,24E-01	2,23E-01	6,57E-04	5,09E-03	3,85E-02	3,83E-02
^{94}Nb	4,37E+00	7,43E+00	6,02E-01	2,92E-01	1,39E-01	1,49E-01	1,19E+00	9,40E-01	9,58E-02	5,06E-03	3,89E-06	3,03E-05	5,74E-03	6,73E+01	1,78E+01	1,41E-02
^{59}Ni	2,83E+01	3,34E+01	6,08E+00	2,79E+00	3,71E+00	2,30E+00	1,08E+01	1,32E+00	2,73E-01	9,32E+00	1,35E+00	2,38E-02	5,95E-03	0,00E+00	0,00E+00	6,01E-02
^{63}Ni	3,00E+01	3,54E+01	5,63E+00	2,78E+00	2,12E+00	1,61E+00	1,13E+01	1,02E+00	1,51E-01	8,73E+00	1,19E+00	2,11E-02	2,49E-03	0,00E+00	0,00E+00	2,02E-02
^{237}Np	6,07E+01	5,21E+00	7,73E+00	4,00E+00	1,88E+00	1,81E+00	1,67E+01	1,25E+00	1,34E-01	5,17E-03	2,03E-02	2,87E-03	1,91E-02	5,26E-02	8,48E-01	6,50E-03
^{231}Pa	2,04E+01	3,79E+00	1,81E+01	4,93E+00	2,50E+00	6,16E+00	1,23E+01	1,64E+01	1,42E+00	1,78E-02	3,72E-01	1,12E-02	9,13E+00	1,65E+00	9,95E-01	1,75E+00
^{202}Pb	4,46E+01	1,12E+01	7,35E+00	5,03E+00	1,75E+00	1,67E+00	1,45E+01	1,14E+01	1,46E+00	1,55E-01	5,46E-02	3,88E-01	2,64E-03	1,09E-04	6,62E-05	1,49E-01
^{210}Pb	3,08E+01	1,51E+01	9,01E+00	4,72E+00	2,19E+00	2,11E+00	1,94E+01	1,44E+01	1,50E+00	1,71E-01	5,49E-02	3,71E-01	2,15E-04	1,01E-04	2,98E-02	1,06E-02
^{107}Pd	2,64E+01	4,45E+00	1,51E+01	6,47E+00	3,09E+00	7,44E+00	1,57E+01	1,71E+01	1,36E+00	2,47E+00	1,67E-01	1,16E-03	4,23E-02	0,00E+00	0,00E+00	1,88E-01
^{238}Pu	3,71E+01	2,82E+00	1,39E+01	7,17E+00	3,38E+00	3,25E+00	3,00E+01	2,22E+00	2,30E-01	2,84E-03	9,55E-04	9,93E-04	1,82E-01	2,88E-05	2,04E-03	6,39E-02
^{239}Pu	3,56E+01	2,70E+00	1,33E+01	6,86E+00	3,24E+00	3,12E+00	2,91E+01	2,25E+00	2,48E-01	3,22E-03	1,17E-03	1,93E-03	2,49E+00	8,20E-04	4,30E-03	8,78E-01
^{240}Pu	3,58E+01	2,72E+00	1,34E+01	6,90E+00	3,26E+00	3,14E+00	2,92E+01	2,25E+00	2,46E-01	3,20E-03	1,16E-03	1,82E-03	2,22E+00	3,12E-04	1,85E-03	7,84E-01
^{241}Pu	3,72E+01	2,82E+00	1,39E+01	7,16E+00	3,38E+00	3,25E+00	3,00E+01	2,22E+00	2,29E-01	2,78E-03	9,26E-04	9,31E-04	2,94E-02	3,50E-05	1,11E-02	1,11E-02

	DW	FISH	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	EX_SED	SOIL_ING
^{242}Pu	3,57E+01	2,70E+00	1,33E+01	6,85E+00	3,25E+00	3,13E+00	2,92E+01	2,25E+00	2,49E-01	3,23E-03	1,18E-03	1,99E-03	2,61E+00	3,37E-04	1,68E-03	9,21E-01
^{244}Pu	1,44E+01	1,09E+00	5,38E+00	2,77E+00	1,31E+00	1,26E+00	1,18E+01	9,10E-01	1,00E-01	1,30E-03	4,77E-04	8,02E-04	1,03E+00	9,95E+00	4,96E+01	3,72E-01
^{226}Ra	2,77E+01	1,23E+01	6,34E+00	1,04E+01	1,42E+00	1,92E+00	8,03E+00	9,64E+00	2,95E+00	8,85E-01	1,10E+00	1,77E+00	2,10E+00	7,14E+00	4,53E+00	1,64E+00
^{79}Se	1,06E+01	1,83E+01	2,03E+00	8,22E-01	5,07E-01	1,02E+00	3,10E+00	4,37E+00	2,49E-01	1,60E+00	5,70E+01	3,41E-01	5,08E-05	4,43E-05	8,58E-05	9,44E-03
^{126}Sn	8,38E-01	1,70E+01	2,69E-01	1,01E-01	4,64E-02	6,22E-02	3,67E-01	4,75E-01	4,42E-02	2,80E-02	4,46E-02	1,01E-02	2,98E-04	7,30E+00	7,34E+01	3,74E-03
^{90}Sr	5,43E+01	4,75E+00	7,40E+00	4,63E+00	2,12E+00	1,75E+00	1,53E+01	1,69E+00	5,98E+00	1,55E+00	4,47E-01	8,28E-02	8,80E-05	5,98E-03	1,97E-02	5,08E-03
^{99}Tc	5,71E+01	7,21E+00	7,27E+00	6,97E+00	1,76E+00	2,21E+00	1,55E+01	6,51E-01	3,20E-01	2,48E-01	3,28E-03	7,92E-01	4,10E-05	6,95E-05	1,47E-04	4,62E-04
^{229}Th	2,61E+01	3,51E+01	7,08E+00	4,41E+00	1,60E+00	1,98E+00	1,41E+01	2,01E+00	2,94E-01	6,04E-03	2,76E-02	5,51E-02	1,52E+00	1,13E+00	4,28E+00	5,28E-01
^{230}Th	2,71E+01	3,65E+01	7,51E+00	4,84E+00	1,67E+00	2,17E+00	1,46E+01	2,31E+00	3,48E-01	6,48E-03	3,00E-02	6,51E-02	1,94E+00	3,02E-03	9,44E-03	6,70E-01
^{232}Th	2,02E+01	2,73E+01	5,60E+00	3,63E+00	1,24E+00	1,63E+00	1,09E+01	1,74E+00	2,64E-01	4,85E-03	2,25E-02	4,91E-02	6,22E-01	6,53E+00	1,99E+01	5,11E-01
^{232}U	6,01E+01	1,05E+00	7,83E+00	4,17E+00	1,90E+00	1,85E+00	1,68E+01	1,37E+00	1,35E-01	4,94E-01	1,32E-01	1,99E-01	3,39E-02	4,02E-01	3,55E+00	2,23E-02
^{233}U	6,18E+01	1,08E+00	8,20E+00	4,73E+00	1,95E+00	1,95E+00	1,73E+01	1,75E+00	1,58E-01	5,21E-01	1,41E-01	2,33E-01	8,37E-02	1,85E-03	4,74E-03	8,37E-02
^{234}U	6,19E+01	1,08E+00	8,20E+00	4,72E+00	1,96E+00	1,94E+00	1,73E+01	1,74E+00	1,58E-01	5,20E-01	1,41E-01	2,33E-01	8,48E-02	5,20E-04	1,34E-03	8,38E-02
^{235}U	5,95E+01	1,04E+00	7,89E+00	4,55E+00	1,88E+00	1,87E+00	1,67E+01	1,67E+00	1,52E-01	5,00E-01	1,35E-01	2,24E-01	7,50E-02	1,04E+00	2,68E+00	8,06E-02
^{236}U	6,19E+01	1,08E+00	8,20E+00	4,72E+00	1,95E+00	1,95E+00	1,73E+01	1,74E+00	1,58E-01	5,21E-01	1,41E-01	2,33E-01	8,09E-02	2,81E-04	7,21E-04	8,38E-02
^{238}U	6,15E+01	1,08E+00	8,14E+00	4,70E+00	1,95E+00	1,94E+00	1,72E+01	1,73E+00	1,57E-01	5,17E-01	1,40E-01	2,31E-01	7,10E-02	2,08E-01	5,34E-01	8,32E-02
^{93}Zr	2,56E+01	4,14E+01	3,84E+00	1,99E+00	9,32E-01	9,08E-01	8,29E+00	1,53E+01	1,58E+00	5,33E-03	2,18E-03	1,24E-04	2,67E-03	1,02E-03	2,48E-02	1,95E-02

Table E-2: Relative contributions of the different pathways to the dose (%) for the wetland receptor for an adult considering temperate climate

	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	SOIL_ING
^{227}Ac	5,87E+01	2,01E+00	1,65E+00	4,34E+00	1,10E+00	1,08E+01	6,74E-01	1,25E-01	3,26E+00	7,25E-02	1,26E+01	2,59E+00	1,90E+00
^{108m}Ag	1,34E+00	1,53E-03	2,25E-02	9,90E-02	3,09E-03	2,46E-01	2,20E-03	3,96E-01	5,01E-01	3,30E-02	6,37E-03	9,74E+01	2,79E-02
^{241}Am	3,38E+00	1,23E+00	4,56E-01	1,76E-01	4,80E-01	1,76E+00	1,15E+00	1,85E-01	1,66E+00	4,22E-01	6,40E+01	3,55E+00	2,15E+01
^{242m}Am	3,33E+00	1,21E+00	4,49E-01	1,74E-01	4,73E-01	1,74E+00	1,13E+00	1,83E-01	1,63E+00	4,16E-01	6,22E+01	5,77E+00	2,12E+01
^{243}Am	1,97E+00	7,13E-01	2,65E-01	1,02E-01	2,79E-01	1,02E+00	6,69E-01	1,08E-01	9,63E-01	2,45E-01	3,62E+01	4,49E+01	1,25E+01
^{10}Be	3,89E+01	6,05E+00	2,99E+00	4,49E+00	2,02E+00	1,96E+01	6,81E-01	6,21E-02	6,39E+00	8,92E-01	3,57E+00	6,45E+00	7,94E+00
^{14}C	5,17E+01	1,51E+00	1,03E+00	3,60E+00	8,35E-01	8,90E+00	4,79E-01	1,57E+01	1,37E+01	2,67E+00	4,88E-04	5,40E-06	2,56E-03
^{41}Ca	3,24E+01	2,47E+00	2,76E+01	5,14E+00	1,31E+00	2,62E+00	8,37E-01	2,54E+01	1,62E+00	3,70E-01	6,49E-04	0,00E+00	9,14E-02
^{36}Cl	1,53E+01	9,40E-01	3,21E-01	1,16E-01	1,71E-01	3,23E+00	2,83E-01	5,81E+01	2,05E+01	1,27E+00	3,21E-05	6,87E-04	2,89E-04
^{244}Cm	2,46E+00	7,67E-01	8,13E-01	8,96E+00	5,71E-01	1,05E+00	5,92E-01	2,26E-01	1,88E-01	2,04E-01	6,42E+01	1,33E-02	2,01E+01
^{245}Cm	2,06E+00	6,45E-01	6,83E-01	7,54E+00	4,81E-01	8,84E-01	4,97E-01	1,90E-01	1,58E-01	1,72E-01	4,79E+01	2,18E+01	1,69E+01
^{246}Cm	2,64E+00	8,26E-01	8,74E-01	9,64E+00	6,15E-01	1,13E+00	6,36E-01	2,43E-01	2,02E-01	2,19E-01	6,13E+01	7,59E-03	2,16E+01
^{248}Cm	2,69E+00	8,37E-01	8,87E-01	9,79E+00	6,24E-01	1,15E+00	6,44E-01	2,47E-01	2,05E-01	2,23E-01	6,06E+01	1,59E-03	2,19E+01
^{135}Cs	2,99E+01	4,77E+00	1,51E+00	1,08E+00	7,69E-01	2,23E+01	6,50E-01	1,88E+01	1,94E+01	4,62E-01	1,61E-03	4,67E-03	3,29E-01

	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	SOIL_ING
^{137}Cs	1,74E+01	2,78E+00	8,83E-01	6,33E-01	4,48E-01	1,30E+01	3,79E-01	1,10E+01	1,13E+01	2,69E-01	9,61E-04	4,18E+01	1,92E-01
^{129}I	5,76E+01	4,16E+00	8,65E-01	1,73E+00	1,75E+00	3,21E+00	7,02E-01	1,27E+01	8,98E+00	7,96E+00	1,40E-03	2,32E-02	3,01E-01
^{40}K	5,20E+01	3,12E+00	1,97E+00	5,20E+00	1,33E+00	1,29E+01	8,06E-01	8,46E+00	8,72E+00	2,62E-01	1,74E-04	5,15E+00	3,63E-02
^{93}Mo	7,70E+01	2,07E+00	5,92E+00	1,10E+00	1,56E+00	4,99E+00	4,47E-01	3,62E+00	2,04E+00	1,02E+00	2,10E-03	1,63E-02	1,23E-01
^{94}Nb	4,05E-01	1,38E-02	1,13E-02	3,00E-02	7,63E-03	7,43E-02	4,64E-03	3,62E-03	4,25E-06	7,65E-05	8,54E-03	9,96E+01	2,09E-02
^{59}Ni	2,29E+01	9,72E-01	1,46E+01	4,43E+00	4,04E-01	1,64E+00	4,26E-01	4,52E+01	9,18E+00	1,13E-01	2,35E-02	0,00E+00	2,38E-01
^{63}Ni	2,29E+01	9,72E-01	1,46E+01	4,43E+00	4,04E-01	1,65E+00	4,27E-01	4,52E+01	9,21E+00	1,13E-01	2,92E-02	0,00E+00	2,38E-01
^{237}Np	3,66E+01	1,22E+01	2,63E+00	3,87E+00	3,06E+00	6,72E+00	1,75E+00	9,40E-02	5,86E-01	9,65E-02	7,93E+00	2,18E+01	2,70E+00
^{231}Pa	6,37E+01	2,18E+00	1,78E+00	4,71E+00	1,20E+00	1,17E+01	7,29E-01	7,89E-02	1,88E+00	5,11E-02	8,81E+00	1,59E+00	1,70E+00
^{202}Pb	4,84E+01	2,20E+01	2,61E+00	1,50E+00	1,53E-01	8,16E+00	2,88E+00	2,33E+00	1,18E+00	8,53E+00	3,71E-02	1,53E-03	2,09E+00
^{210}Pb	4,84E+01	2,19E+01	2,60E+00	1,49E+00	1,53E-01	8,13E+00	2,87E+00	2,32E+00	1,18E+00	8,54E+00	4,25E-02	1,98E-02	2,08E+00
^{107}Pd	6,04E+01	4,22E+00	3,06E+00	8,07E+00	2,06E+00	1,28E+01	6,47E-01	7,86E+00	6,79E-01	4,17E-03	5,92E-02	0,00E+00	2,62E-01
^{238}Pu	1,19E+00	1,83E-01	7,14E-02	8,39E-02	7,95E+00	2,42E+00	4,13E-01	7,76E-02	4,09E-02	1,39E-01	6,46E+01	1,03E-02	2,29E+01
^{239}Pu	1,19E+00	1,83E-01	7,14E-02	8,40E-02	7,94E+00	2,42E+00	4,13E-01	7,71E-02	4,09E-02	1,39E-01	6,46E+01	2,14E-02	2,29E+01
^{240}Pu	1,19E+00	1,83E-01	7,14E-02	8,40E-02	7,94E+00	2,42E+00	4,13E-01	7,71E-02	4,09E-02	1,39E-01	6,46E+01	9,14E-03	2,29E+01
^{241}Pu	1,24E+00	1,90E-01	7,43E-02	8,73E-02	8,27E+00	2,52E+00	4,30E-01	8,05E-02	4,24E-02	1,45E-01	6,32E+01	7,55E-02	2,38E+01
^{242}Pu	1,19E+00	1,83E-01	7,14E-02	8,39E-02	7,92E+00	2,42E+00	4,13E-01	7,74E-02	4,08E-02	1,39E-01	6,49E+01	8,39E-03	2,29E+01
^{244}Pu	1,68E-01	2,58E-02	1,00E-02	1,18E-02	1,12E+00	3,40E-01	5,80E-02	1,08E-02	5,74E-03	1,96E-02	8,92E+00	8,58E+01	3,21E+00
^{226}Ra	2,58E+01	1,57E+01	1,48E+00	1,96E+00	3,22E-01	5,54E+00	2,48E+00	3,85E+00	6,27E+00	1,64E+01	3,93E+00	1,33E+01	3,07E+00
^{79}Se	3,09E+00	1,10E-01	2,35E-01	6,20E-01	1,58E-01	1,54E+00	1,38E-02	1,84E+00	9,20E+01	3,82E-01	4,56E-05	3,98E-05	8,48E-03
^{126}Sn	6,44E+00	1,89E-01	1,08E-01	2,85E-01	7,26E-02	7,06E-01	2,06E-02	2,40E-01	5,68E-01	2,51E-01	3,72E-03	9,09E+01	4,68E-02
^{90}Sr	3,65E+01	1,93E+01	1,18E+01	1,95E+00	2,21E+00	8,50E+00	1,93E+00	1,22E+01	5,29E+00	2,68E-01	1,73E-03	1,18E-01	9,96E-02
^{99}Tc	1,56E+01	6,13E+01	6,16E-01	1,00E+01	2,54E+00	1,22E+00	2,80E+00	4,90E+00	9,27E-02	7,66E-01	7,73E-04	1,31E-03	8,72E-03
^{229}Th	3,45E+01	1,18E+01	3,22E-01	5,12E+00	2,17E-01	8,43E+00	1,19E+00	9,59E-02	5,95E-01	1,89E+00	1,71E+01	1,27E+01	5,95E+00
^{230}Th	3,95E+01	1,35E+01	3,69E-01	5,86E+00	2,49E-01	9,67E+00	1,36E+00	1,10E-01	6,84E-01	2,17E+00	1,98E+01	3,07E-02	6,80E+00
^{232}Th	2,24E+01	7,69E+00	2,10E-01	3,33E+00	1,42E-01	5,50E+00	7,76E-01	6,25E-02	3,89E-01	1,23E+00	4,69E+00	4,95E+01	3,86E+00
^{232}U	2,37E+01	1,43E+01	3,31E-01	1,75E+00	5,21E-01	8,68E+00	3,63E-01	2,63E+00	1,11E+00	4,77E+00	3,10E+00	3,68E+01	2,03E+00
^{233}U	3,79E+01	2,30E+01	5,33E-01	2,81E+00	8,38E-01	1,40E+01	5,81E-01	4,24E+00	1,79E+00	7,67E+00	3,26E+00	7,21E-02	3,26E+00
^{234}U	3,81E+01	2,30E+01	5,33E-01	2,82E+00	8,37E-01	1,40E+01	5,83E-01	4,25E+00	1,79E+00	7,65E+00	3,31E+00	2,04E-02	3,26E+00
^{235}U	2,68E+01	1,62E+01	3,74E-01	1,98E+00	5,90E-01	9,82E+00	4,10E-01	2,98E+00	1,26E+00	5,39E+00	2,13E+00	2,98E+01	2,29E+00
^{236}U	3,80E+01	2,30E+01	5,33E-01	2,82E+00	8,39E-01	1,40E+01	5,82E-01	4,27E+00	1,79E+00	7,67E+00	3,17E+00	1,10E-02	3,29E+00
^{238}U	3,53E+01	2,14E+01	4,94E-01	2,62E+00	7,79E-01	1,30E+01	5,40E-01	3,95E+00	1,66E+00	7,12E+00	2,59E+00	7,61E+00	3,04E+00
^{93}Zr	4,64E+01	9,02E+00	3,32E-01	8,22E+00	5,09E-01	1,51E+01	2,04E+00	3,72E-01	2,39E-01	4,08E-02	2,03E+00	7,71E-01	1,49E+01

Table E-3 Relative contributions of the different pathways to the dose (%) for the well receptor for an adult considering Mediterranean climate

	DW	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	SOIL_ING
^{227}Ac	2,55E+01	2,25E+01	9,00E+00	3,69E+00	3,74E+00	2,41E+01	1,01E+01	7,57E-01	2,13E-03	5,06E-02	3,34E-03	5,40E-01	2,56E-03	9,40E-03
^{108m}Ag	1,22E+01	1,17E+01	4,34E+00	1,81E+00	1,95E+00	1,17E+01	2,44E+01	1,82E+00	5,58E-01	6,71E-01	4,91E-02	8,12E-02	2,86E+01	4,13E-02
^{241}Am	2,70E+01	2,39E+01	9,58E+00	3,93E+00	3,95E+00	2,57E+01	1,08E+00	9,01E-02	3,93E-03	3,25E-02	2,05E-03	4,61E+00	5,88E-03	1,80E-01
^{242m}Am	2,79E+01	2,47E+01	9,89E+00	4,04E+00	4,08E+00	2,66E+01	1,10E+00	8,61E-02	3,35E-03	2,72E-02	2,12E-03	1,65E+00	3,53E-03	6,53E-02
^{243}Am	2,17E+01	1,92E+01	7,73E+00	3,16E+00	3,18E+00	2,05E+01	9,25E-01	1,13E-01	5,86E-03	5,02E-02	1,65E-03	2,20E+01	6,28E-01	8,78E-01
^{10}Be	2,40E+01	2,37E+01	9,55E+00	3,95E+00	4,21E+00	2,31E+01	4,84E+00	2,44E-01	5,50E-03	5,44E-01	1,11E-02	4,48E+00	1,85E-01	1,15E+00
^{14}C	8,15E+01	9,50E+00	2,86E-01	1,93E-01	6,77E-01	1,57E-01	1,67E+00	9,01E-02	2,88E+00	2,52E+00	4,90E-01	3,38E-04	1,58E-06	4,71E-04
^{41}Ca	2,31E+01	2,10E+01	8,28E+00	4,47E+00	3,60E+00	2,19E+01	9,16E+00	7,16E-01	7,36E+00	4,24E-01	1,46E-01	2,21E-04	0,00E+00	3,61E-03
^{36}Cl	8,00E+00	1,87E+01	4,78E+00	1,73E+00	1,39E+00	7,92E+00	8,88E+00	7,42E-01	3,45E+01	1,20E+01	1,27E+00	4,76E-04	2,34E-04	4,96E-04
^{244}Cm	2,84E+01	2,50E+01	1,00E+01	4,12E+00	4,15E+00	2,69E+01	1,12E+00	8,42E-02	4,06E-03	3,03E-03	1,11E-03	2,41E-01	1,15E-06	8,78E-03
^{245}Cm	2,20E+01	1,95E+01	7,81E+00	3,22E+00	3,62E+00	2,09E+01	9,08E-01	9,11E-02	7,56E-03	6,02E-03	8,62E-04	2,10E+01	2,20E-01	8,58E-01
^{246}Cm	2,30E+01	2,02E+01	8,15E+00	3,35E+00	3,71E+00	2,18E+01	9,41E-01	9,04E-02	7,39E-03	5,86E-03	9,01E-04	1,81E+01	5,15E-05	7,39E-01
^{248}Cm	2,05E+01	1,82E+01	7,32E+00	3,02E+00	3,53E+00	1,95E+01	8,66E-01	9,38E-02	7,82E-03	6,23E-03	8,07E-04	2,59E+01	1,56E-05	1,08E+00
^{135}Cs	1,21E+01	1,74E+01	7,19E+00	2,55E+00	2,37E+00	1,20E+01	3,55E+01	1,42E+00	4,78E+00	4,75E+00	6,79E-02	6,98E-03	4,67E-04	1,65E-01
^{137}Cs	1,68E+01	1,52E+01	6,11E+00	2,48E+00	2,48E+00	1,60E+01	3,36E+01	1,51E+00	2,71E+00	2,54E+00	6,69E-02	3,64E-04	3,64E-01	8,42E-03
^{129}I	2,39E+01	2,12E+01	8,50E+00	3,48E+00	3,51E+00	2,27E+01	9,41E+00	7,11E-01	3,19E+00	2,01E+00	1,35E+00	8,53E-05	3,24E-05	2,13E-03
^{40}K	1,65E+01	1,64E+01	6,14E+00	2,55E+00	2,86E+00	1,57E+01	3,34E+01	1,53E+00	2,57E+00	2,39E+00	7,00E-02	1,20E-04	8,23E-02	2,90E-03
^{93}Mo	2,11E+01	2,92E+01	8,24E+00	4,96E+00	3,46E+00	2,05E+01	9,91E+00	7,68E-01	1,12E+00	5,87E-01	2,56E-01	5,63E-03	1,01E-03	3,80E-02
^{94}Nb	8,68E+00	8,26E+00	3,13E+00	1,30E+00	1,38E+00	8,26E+00	3,66E+00	2,73E-01	1,97E-02	2,11E-05	1,19E-04	2,41E-01	6,47E+01	6,83E-02
^{59}Ni	2,14E+01	2,23E+01	7,97E+00	8,16E+00	4,75E+00	2,04E+01	1,41E+00	2,12E-01	1,12E+01	2,14E+00	3,14E-02	6,82E-02	0,00E+00	7,97E-02
^{63}Ni	2,39E+01	2,23E+01	8,61E+00	5,27E+00	4,08E+00	2,28E+01	1,14E+00	1,24E-01	9,83E+00	1,84E+00	3,25E-02	3,02E-02	0,00E+00	2,84E-02
^{237}Np	2,84E+01	2,50E+01	1,01E+01	4,13E+00	4,17E+00	2,69E+01	1,13E+00	8,89E-02	3,99E-03	2,23E-02	3,71E-03	1,86E-01	1,18E-02	7,33E-03
^{231}Pa	8,57E+00	2,26E+01	4,43E+00	2,23E+00	4,00E+00	8,85E+00	6,79E+00	4,28E-01	1,44E-02	3,23E-01	1,55E-03	4,06E+01	1,69E-01	9,03E-01
^{202}Pb	2,42E+01	2,30E+01	1,06E+01	3,72E+00	3,66E+00	2,29E+01	1,01E+01	9,51E-01	1,54E-01	7,28E-02	3,66E-01	2,53E-02	2,40E-05	1,65E-01
^{210}Pb	2,55E+01	2,25E+01	9,10E+00	3,70E+00	3,72E+00	2,41E+01	1,00E+01	7,65E-01	1,05E-01	4,76E-02	3,67E-01	1,62E-03	1,74E-05	9,20E-03
^{107}Pd	1,71E+01	3,04E+01	8,93E+00	4,29E+00	7,55E+00	1,76E+01	1,09E+01	6,35E-01	2,18E+00	1,81E-01	8,98E-04	2,92E-01	0,00E+00	1,50E-01
^{238}Pu	2,81E+01	2,48E+01	9,97E+00	4,08E+00	4,11E+00	2,68E+01	1,11E+00	8,40E-02	1,26E-03	6,02E-04	6,62E-04	9,75E-01	3,56E-06	3,98E-02
^{239}Pu	2,47E+01	2,18E+01	8,75E+00	3,59E+00	3,62E+00	2,37E+01	1,03E+00	8,25E-02	1,71E-03	8,48E-04	5,82E-04	1,22E+01	9,27E-05	5,00E-01
^{240}Pu	2,51E+01	2,21E+01	8,88E+00	3,64E+00	3,67E+00	2,40E+01	1,03E+00	8,27E-02	1,70E-03	8,38E-04	5,91E-04	1,10E+01	3,56E-05	4,49E-01
^{241}Pu	2,85E+01	2,51E+01	1,01E+01	4,13E+00	4,16E+00	2,70E+01	1,12E+00	8,47E-02	1,19E-03	5,65E-04	6,69E-04	1,60E-01	4,39E-06	6,96E-03
^{242}Pu	2,47E+01	2,17E+01	8,70E+00	3,57E+00	3,59E+00	2,35E+01	1,02E+00	8,26E-02	1,72E-03	8,52E-04	5,78E-04	1,27E+01	3,79E-05	5,21E-01
^{244}Pu	2,40E+01	2,11E+01	8,50E+00	3,48E+00	3,50E+00	2,30E+01	9,99E-01	8,05E-02	1,68E-03	8,32E-04	5,64E-04	1,22E+01	2,71E+00	5,09E-01
^{226}Ra	1,54E+01	2,15E+01	1,85E+01	3,30E+00	3,74E+00	1,49E+01	1,00E+01	2,24E+00	1,76E+00	2,84E+00	1,53E-01	1,57E+00	1,84E+00	2,13E+00

	DW	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	SOIL_ING
^{79}Se	4,78E+00	5,87E+00	1,85E+00	9,89E-01	1,52E+00	4,75E+00	3,81E+00	1,59E-01	1,58E+00	7,44E+01	4,13E-01	4,78E-04	9,55E-06	1,03E-02
^{126}Sn	1,32E+01	1,72E+01	5,11E+00	2,13E+00	2,54E+00	1,27E+01	9,22E+00	6,28E-01	5,63E-01	1,23E+00	2,29E-01	6,24E-02	3,51E+01	9,11E-02
^{90}Sr	2,05E+01	1,87E+01	7,44E+00	3,11E+00	3,40E+00	1,95E+01	2,56E+00	1,81E-01	3,56E-03	1,35E+00	1,10E-05	2,22E+01	0,00E+00	9,20E-01
^{99}Tc	2,65E+01	2,38E+01	1,38E+01	3,88E+00	4,52E+00	2,53E+01	5,96E-01	2,14E-01	2,45E-01	4,32E-03	1,05E+00	4,03E-04	1,57E-05	5,27E-04
^{229}Th	2,29E+01	2,17E+01	9,49E+00	3,35E+00	3,88E+00	2,17E+01	1,74E+00	1,86E-01	6,94E-03	4,12E-02	2,89E-02	1,43E+01	2,43E-01	5,74E-01
^{230}Th	2,20E+01	2,11E+01	9,37E+00	3,23E+00	3,84E+00	2,09E+01	1,85E+00	2,03E-01	7,07E-03	4,19E-02	2,80E-02	1,68E+01	5,99E-04	6,69E-01
^{232}Th	2,39E+01	2,29E+01	1,02E+01	3,49E+00	4,19E+00	2,26E+01	2,03E+00	2,25E-01	7,72E-03	4,59E-02	3,04E-02	7,77E+00	1,89E+00	7,43E-01
^{232}U	2,81E+01	2,48E+01	1,02E+01	4,07E+00	4,12E+00	2,66E+01	1,21E+00	8,79E-02	3,82E-01	1,45E-01	2,43E-01	3,23E-01	8,87E-02	2,46E-02
^{233}U	2,74E+01	2,46E+01	1,04E+01	3,99E+00	4,08E+00	2,60E+01	1,47E+00	9,71E-02	3,98E-01	1,52E-01	2,39E-01	7,59E-01	3,84E-04	8,76E-02
^{234}U	2,76E+01	2,47E+01	1,05E+01	4,01E+00	4,10E+00	2,61E+01	1,47E+00	9,77E-02	3,99E-01	1,52E-01	2,40E-01	7,71E-01	1,09E-04	8,85E-02
^{235}U	2,74E+01	2,46E+01	1,05E+01	3,99E+00	4,09E+00	2,60E+01	1,46E+00	9,76E-02	3,98E-01	1,52E-01	2,39E-01	7,06E-01	2,26E-01	8,82E-02
^{236}U	2,75E+01	2,47E+01	1,05E+01	3,99E+00	4,09E+00	2,60E+01	1,47E+00	9,76E-02	3,98E-01	1,53E-01	2,40E-01	7,34E-01	5,86E-05	8,81E-02
^{238}U	2,74E+01	2,46E+01	1,05E+01	3,98E+00	4,08E+00	2,60E+01	1,46E+00	9,69E-02	3,98E-01	1,52E-01	2,39E-01	6,47E-01	4,37E-02	8,77E-02
^{93}Zr	2,20E+01	1,94E+01	7,82E+00	3,19E+00	3,24E+00	2,09E+01	2,16E+01	1,63E+00	6,57E-03	3,82E-03	2,31E-04	4,07E-02	3,55E-04	3,43E-02

Table E-4: Relative contributions of the different pathways to the dose (%) for the river receptor for an adult considering Mediterranean climate

	DW	FISH	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	EX_SED	SOIL_ING
^{227}Ac	3,41E+00	6,48E+00	2,72E+01	1,09E+01	4,45E+00	4,52E+00	2,91E+01	1,21E+01	9,14E-01	2,57E-03	6,11E-02	4,03E-03	6,52E-01	3,09E-03	1,06E-01	1,13E-02
^{108m}Ag	3,41E-01	8,53E-01	8,75E-01	3,26E-01	1,36E-01	1,46E-01	8,75E-01	1,83E+00	1,36E-01	4,18E-02	5,03E-02	3,68E-03	6,09E-03	2,14E+00	9,24E+01	3,10E-03
^{241}Am	3,69E+00	6,97E+00	2,92E+01	1,17E+01	4,81E+00	4,83E+00	3,15E+01	1,32E+00	1,10E-01	4,81E-03	3,98E-02	2,51E-03	5,64E+00	7,19E-03	2,12E-01	2,20E-01
^{242m}Am	3,82E+00	7,23E+00	3,03E+01	1,21E+01	4,97E+00	5,01E+00	3,26E+01	1,35E+00	1,06E-01	4,12E-03	3,34E-02	2,60E-03	2,03E+00	4,34E-03	3,54E-01	8,02E-02
^{243}Am	2,72E+00	5,17E+00	2,17E+01	8,76E+00	3,58E+00	3,60E+00	2,32E+01	1,05E+00	1,28E-01	6,64E-03	5,69E-02	1,86E-03	2,49E+01	7,11E-01	3,47E+00	9,95E-01
^{10}Be	2,53E+01	3,92E+01	6,67E+00	3,69E+00	1,64E+00	1,88E+00	1,28E+01	4,75E+00	3,28E-01	3,63E-03	2,84E-01	2,70E-02	4,09E-01	7,36E-01	1,19E+00	9,08E-01
^{14}C	2,23E+00	9,78E+01	1,07E-01	3,22E-03	2,16E-03	7,66E-03	1,78E-03	1,92E-02	1,05E-03	3,22E-02	2,82E-02	5,49E-03	7,99E-06	8,86E-08	1,63E-04	5,26E-06
^{41}Ca	4,29E+01	1,48E+01	5,64E+00	2,89E+00	1,90E+00	1,44E+00	1,18E+01	8,81E+00	9,44E-01	8,21E+00	3,33E-01	9,72E-02	1,98E-05	0,00E+00	0,00E+00	2,79E-03
^{36}Cl	2,26E+01	9,54E+00	7,72E+00	2,24E+00	8,58E-01	3,87E-01	4,14E+00	1,27E+01	1,45E+00	2,82E+01	9,01E+00	9,97E-01	6,36E-05	1,35E-03	9,17E-05	5,70E-04
^{244}Cm	1,01E+01	1,28E+01	2,68E+01	1,08E+01	4,41E+00	4,45E+00	2,89E+01	1,20E+00	9,03E-02	4,36E-03	3,25E-03	1,19E-03	2,59E-01	1,23E-06	9,48E-05	9,41E-03
^{245}Cm	7,72E+00	9,76E+00	2,05E+01	8,25E+00	3,40E+00	3,82E+00	2,20E+01	9,58E-01	9,61E-02	7,98E-03	6,36E-03	9,10E-04	2,22E+01	2,32E-01	1,78E-01	9,06E-01
^{246}Cm	8,10E+00	1,02E+01	2,14E+01	8,63E+00	3,55E+00	3,93E+00	2,31E+01	9,97E-01	9,58E-02	7,83E-03	6,21E-03	9,54E-04	1,92E+01	5,46E-05	5,05E-05	7,83E-01
^{248}Cm	7,21E+00	9,12E+00	1,91E+01	7,71E+00	3,18E+00	3,71E+00	2,05E+01	9,12E-01	9,89E-02	8,24E-03	6,56E-03	8,50E-04	2,73E+01	1,64E-05	9,27E-06	1,14E+00
^{135}Cs	4,36E+00	5,15E+01	8,76E+00	3,61E+00	1,28E+00	1,19E+00	6,02E+00	1,78E+01	7,14E-01	2,40E+00	2,38E+00	3,41E-02	3,50E-03	2,34E-04	1,41E-03	8,30E-02
^{137}Cs	4,16E+00	4,91E+01	5,26E+00	2,12E+00	8,60E-01	8,60E-01	5,54E+00	1,16E+01	5,24E-01	9,38E-01	8,79E-01	2,32E-02	1,26E-04	1,26E-01	1,77E+01	2,91E-03
^{129}I	4,04E+01	3,41E+01	3,19E+00	6,30E-01	7,65E-01	2,85E-01	6,80E+00	8,05E+00	8,35E-01	3,12E+00	1,36E+00	6,85E-01	6,80E-06	1,13E-04	5,30E-04	1,47E-03
^{40}K	5,06E+00	5,96E+01	1,02E+00	5,00E-01	2,33E-01	2,81E-01	1,93E+00	7,28E+00	4,57E-01	6,32E-01	4,18E-01	1,04E-02	2,44E-06	7,24E-02	2,24E+01	5,08E-04

	DW	FISH	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	EX_SED	SOIL_ING
^{93}Mo	4,87E+01	8,36E-01	1,12E+01	4,00E+00	2,83E+00	1,87E+00	1,46E+01	1,24E+01	1,32E+00	1,35E+00	5,24E-01	2,23E-01	6,57E-04	5,09E-03	3,85E-02	3,83E-02
^{94}Nb	6,14E+00	1,04E+01	5,89E+00	2,23E+00	9,26E-01	9,80E-01	5,89E+00	2,61E+00	1,95E-01	1,40E-02	1,50E-05	8,51E-05	1,72E-01	4,61E+01	1,83E+01	4,87E-02
^{59}Ni	2,83E+01	3,34E+01	6,08E+00	2,79E+00	3,71E+00	2,30E+00	1,08E+01	1,32E+00	2,73E-01	9,32E+00	1,35E+00	2,38E-02	5,95E-03	0,00E+00	0,00E+00	6,01E-02
^{63}Ni	1,51E+01	1,78E+01	1,97E+01	7,59E+00	4,65E+00	3,59E+00	2,01E+01	1,01E+00	1,09E-01	8,66E+00	1,62E+00	2,87E-02	2,66E-02	0,00E+00	0,00E+00	2,50E-02
^{237}Np	6,07E+01	5,21E+00	7,73E+00	4,00E+00	1,88E+00	1,81E+00	1,67E+01	1,25E+00	1,34E-01	5,17E-03	2,03E-02	2,87E-03	1,91E-02	5,26E-02	8,48E-01	6,50E-03
^{231}Pa	2,04E+01	3,79E+00	1,81E+01	4,93E+00	2,50E+00	6,16E+00	1,23E+01	1,64E+01	1,42E+00	1,78E-02	3,72E-01	1,12E-02	9,13E+00	1,65E+00	9,95E-01	1,75E+00
^{202}Pb	4,46E+01	1,12E+01	7,35E+00	5,03E+00	1,75E+00	1,67E+00	1,45E+01	1,14E+01	1,46E+00	1,55E-01	5,46E-02	3,88E-01	2,64E-03	1,09E-04	6,62E-05	1,49E-01
^{210}Pb	1,20E+01	5,91E+00	2,49E+01	1,01E+01	4,09E+00	4,11E+00	2,66E+01	1,10E+01	8,45E-01	1,15E-01	5,25E-02	4,05E-01	1,79E-03	1,92E-05	8,51E-03	1,02E-02
^{107}Pd	2,64E+01	4,45E+00	1,51E+01	6,47E+00	3,09E+00	7,44E+00	1,57E+01	1,71E+01	1,36E+00	2,47E+00	1,67E-01	1,16E-03	4,23E-02	0,00E+00	0,00E+00	1,88E-01
^{238}Pu	1,14E+01	8,68E-01	3,02E+01	1,22E+01	4,97E+00	5,01E+00	3,27E+01	1,35E+00	1,02E-01	1,54E-03	7,34E-04	8,07E-04	1,19E+00	4,34E-06	4,60E-04	4,85E-02
^{239}Pu	9,79E+00	7,43E-01	2,59E+01	1,04E+01	4,27E+00	4,30E+00	2,81E+01	1,22E+00	9,81E-02	2,04E-03	1,01E-03	6,92E-04	1,45E+01	1,10E-04	8,63E-04	5,94E-01
^{240}Pu	9,97E+00	7,56E-01	2,63E+01	1,06E+01	4,34E+00	4,37E+00	2,86E+01	1,23E+00	9,85E-02	2,02E-03	9,98E-04	7,04E-04	1,31E+01	4,24E-05	3,74E-04	5,35E-01
^{241}Pu	1,16E+01	8,75E-01	3,05E+01	1,23E+01	5,02E+00	5,06E+00	3,28E+01	1,36E+00	1,03E-01	1,45E-03	6,87E-04	8,14E-04	1,94E-01	5,33E-06	2,52E-03	8,46E-03
^{242}Pu	9,74E+00	7,37E-01	2,58E+01	1,03E+01	4,23E+00	4,26E+00	2,79E+01	1,21E+00	9,80E-02	2,04E-03	1,01E-03	6,86E-04	1,51E+01	4,50E-05	3,36E-04	6,18E-01
^{244}Pu	7,64E+00	5,79E-01	2,02E+01	8,11E+00	3,32E+00	3,35E+00	2,20E+01	9,53E-01	7,69E-02	1,60E-03	7,95E-04	5,39E-04	1,16E+01	2,58E+00	1,93E+01	4,86E-01
^{226}Ra	1,37E+01	6,05E+00	2,01E+01	1,72E+01	3,07E+00	3,48E+00	1,38E+01	9,34E+00	2,08E+00	1,63E+00	2,64E+00	1,42E-01	1,46E+00	1,72E+00	1,63E+00	1,98E+00
^{79}Se	1,06E+01	1,83E+01	2,03E+00	8,22E-01	5,07E-01	1,02E+00	3,10E+00	4,37E+00	2,49E-01	1,60E+00	5,70E+01	3,41E-01	5,08E-05	4,43E-05	8,58E-05	9,44E-03
^{126}Sn	8,38E-01	1,70E+01	2,69E-01	1,01E-01	4,64E-02	6,22E-02	3,67E-01	4,75E-01	4,42E-02	2,80E-02	4,46E-02	1,01E-02	2,98E-04	7,30E+00	7,34E+01	3,74E-03
^{90}Sr	1,00E+01	4,63E+00	2,01E+01	7,99E+00	3,34E+00	3,65E+00	2,10E+01	2,75E+00	1,94E-01	3,82E-03	1,45E+00	1,18E-05	2,38E+01	0,00E+00	0,00E+00	9,88E-01
^{99}Tc	5,71E+01	7,21E+00	7,27E+00	6,97E+00	1,76E+00	2,21E+00	1,55E+01	6,51E-01	3,20E-01	2,48E-01	3,28E-03	7,92E-01	4,10E-05	6,95E-05	1,47E-04	4,62E-04
^{229}Th	1,09E+01	1,46E+01	2,05E+01	8,99E+00	3,17E+00	3,68E+00	2,06E+01	1,65E+00	1,76E-01	6,57E-03	3,90E-02	2,74E-02	1,35E+01	2,30E-01	1,30E+00	5,43E-01
^{230}Th	1,06E+01	1,43E+01	2,03E+01	9,04E+00	3,11E+00	3,70E+00	2,02E+01	1,78E+00	1,96E-01	6,82E-03	4,04E-02	2,70E-02	1,62E+01	5,78E-04	2,69E-03	6,45E-01
^{232}Th	2,02E+01	2,73E+01	5,60E+00	3,63E+00	1,24E+00	1,63E+00	1,09E+01	1,74E+00	2,64E-01	4,85E-03	2,25E-02	4,91E-02	6,22E-01	6,53E+00	1,99E+01	5,11E-01
^{232}U	2,68E+01	4,70E-01	2,46E+01	1,01E+01	4,04E+00	4,09E+00	2,64E+01	1,20E+00	8,72E-02	3,79E-01	1,44E-01	2,41E-01	3,21E-01	8,80E-02	1,16E+00	2,44E-02
^{233}U	2,65E+01	4,65E-01	2,48E+01	1,05E+01	4,01E+00	4,11E+00	2,62E+01	1,48E+00	9,78E-02	4,01E-01	1,53E-01	2,41E-01	7,65E-01	3,87E-04	1,49E-03	8,82E-02
^{234}U	6,19E+01	1,08E+00	8,20E+00	4,72E+00	1,96E+00	1,94E+00	1,73E+01	1,74E+00	1,58E-01	5,20E-01	1,41E-01	2,33E-01	8,48E-02	5,20E-04	1,34E-03	8,38E-02
^{235}U	5,95E+01	1,04E+00	7,89E+00	4,55E+00	1,88E+00	1,87E+00	1,67E+01	1,67E+00	1,52E-01	5,00E-01	1,35E-01	2,24E-01	7,50E-02	1,04E+00	2,68E+00	8,06E-02
^{236}U	6,19E+01	1,08E+00	8,20E+00	4,72E+00	1,95E+00	1,95E+00	1,73E+01	1,74E+00	1,58E-01	5,21E-01	1,41E-01	2,33E-01	8,09E-02	2,81E-04	7,21E-04	8,38E-02
^{238}U	6,15E+01	1,08E+00	8,14E+00	4,70E+00	1,95E+00	1,94E+00	1,72E+01	1,73E+00	1,57E-01	5,17E-01	1,40E-01	2,31E-01	7,10E-02	2,08E-01	5,34E-01	8,32E-02
^{93}Zr	2,56E+01	4,14E+01	3,84E+00	1,99E+00	9,32E-01	9,08E-01	8,29E+00	1,53E+01	1,58E+00	5,33E-03	2,18E-03	1,24E-04	2,67E-03	1,02E-03	2,48E-02	1,95E-02

Table E-5: Relative contributions of the different pathways to the dose (%) for the wetland receptor for an adult considering Mediterranean climate

	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	SOIL_ING
^{227}Ac	3,03E+01	1,04E+00	8,52E-01	2,25E+00	5,71E-01	5,57E+00	3,49E-01	6,21E-02	0,00E+00	3,06E-03	5,62E+01	2,67E-01	9,80E-01
^{108m}Ag	6,04E+00	6,91E-03	1,01E-01	4,47E-01	1,40E-02	1,11E+00	9,94E-03	2,01E+00	0,00E+00	1,77E-02	2,48E-01	8,73E+01	1,26E-01
^{241}Am	5,73E-01	2,08E-01	7,72E-02	2,98E-02	8,13E-02	2,98E-01	1,95E-01	7,52E-02	0,00E+00	3,35E-05	9,39E+01	1,20E-01	3,65E+00
^{242m}Am	5,83E-01	2,12E-01	7,85E-02	3,03E-02	8,26E-02	3,03E-01	1,98E-01	7,64E-02	0,00E+00	3,41E-05	9,38E+01	2,00E-01	3,71E+00
^{243}Am	5,77E-01	2,09E-01	7,76E-02	3,00E-02	8,17E-02	3,00E-01	1,96E-01	7,56E-02	0,00E+00	3,37E-05	9,15E+01	2,62E+00	3,67E+00
^{10}Be	3,89E+01	6,05E+00	2,99E+00	4,49E+00	2,02E+00	1,96E+01	6,81E-01	6,21E-02	6,39E+00	8,92E-01	3,57E+00	6,45E+00	7,94E+00
^{14}C	5,17E+01	1,51E+00	1,03E+00	3,60E+00	8,35E-01	8,90E+00	4,79E-01	1,57E+01	1,37E+01	2,67E+00	4,88E-04	5,40E-06	2,56E-03
^{41}Ca	3,24E+01	2,47E+00	2,76E+01	5,14E+00	1,31E+00	2,62E+00	8,37E-01	2,54E+01	1,62E+00	3,70E-01	6,49E-04	0,00E+00	9,14E-02
^{36}Cl	1,53E+01	9,40E-01	3,21E-01	1,16E-01	1,71E-01	3,23E+00	2,83E-01	5,81E+01	2,05E+01	1,27E+00	3,21E-05	6,87E-04	2,89E-04
^{244}Cm	4,18E-01	1,30E-01	1,38E-01	1,52E+00	9,72E-02	1,79E-01	1,01E-01	9,36E-02	0,00E+00	1,27E-05	9,43E+01	4,48E-04	3,42E+00
^{245}Cm	4,60E-01	1,44E-01	1,52E-01	1,68E+00	1,07E-01	1,97E-01	1,11E-01	1,03E-01	0,00E+00	1,40E-05	9,24E+01	9,69E-01	3,76E+00
^{246}Cm	4,64E-01	1,45E-01	1,54E-01	1,69E+00	1,08E-01	1,99E-01	1,12E-01	1,04E-01	0,00E+00	1,41E-05	9,32E+01	2,65E-04	3,80E+00
^{248}Cm	4,77E-01	1,49E-01	1,57E-01	1,74E+00	1,11E-01	2,04E-01	1,14E-01	1,07E-01	0,00E+00	1,45E-05	9,29E+01	5,59E-05	3,89E+00
^{135}Cs	2,75E+01	4,39E+00	1,39E+00	9,99E-01	7,09E-01	2,06E+01	5,99E-01	2,13E+01	0,00E+00	8,34E-02	1,28E-02	8,57E-04	3,03E-01
^{137}Cs	2,43E+01	3,88E+00	1,23E+00	8,83E-01	6,26E-01	1,82E+01	5,29E-01	1,89E+01	0,00E+00	7,38E-02	1,16E-02	1,16E+01	2,68E-01
^{129}I	5,76E+01	4,16E+00	8,65E-01	1,73E+00	1,75E+00	3,21E+00	7,02E-01	1,27E+01	8,98E+00	7,96E+00	1,40E-03	2,32E-02	3,01E-01
^{40}K	5,20E+01	3,12E+00	1,97E+00	5,20E+00	1,33E+00	1,29E+01	8,06E-01	8,46E+00	8,72E+00	2,62E-01	1,74E-04	5,15E+00	3,63E-02
^{93}Mo	7,70E+01	2,07E+00	5,92E+00	1,10E+00	1,56E+00	4,99E+00	4,47E-01	3,62E+00	2,04E+00	1,02E+00	2,10E-03	1,63E-02	1,23E-01
^{94}Nb	1,98E+00	6,76E-02	5,54E-02	1,47E-01	3,73E-02	3,63E-01	2,27E-02	3,79E-02	0,00E+00	2,00E-05	3,60E-01	9,67E+01	1,02E-01
^{59}Ni	2,29E+01	9,72E-01	1,46E+01	4,43E+00	4,04E-01	1,64E+00	4,26E-01	4,52E+01	9,18E+00	1,13E-01	2,35E-02	0,00E+00	2,38E-01
^{63}Ni	2,14E+01	9,11E-01	1,36E+01	4,15E+00	3,79E-01	1,54E+00	4,00E-01	4,76E+01	0,00E+00	2,16E-02	2,36E-01	0,00E+00	2,23E-01
^{237}Np	3,66E+01	1,22E+01	2,63E+00	3,87E+00	3,06E+00	6,72E+00	1,75E+00	9,40E-02	5,86E-01	9,65E-02	7,93E+00	2,18E+01	2,70E+00
^{231}Pa	6,37E+01	2,18E+00	1,78E+00	4,71E+00	1,20E+00	1,17E+01	7,29E-01	7,89E-02	1,88E+00	5,11E-02	8,81E+00	1,59E+00	1,70E+00
^{202}Pb	4,84E+01	2,20E+01	2,61E+00	1,50E+00	1,53E-01	8,16E+00	2,88E+00	2,33E+00	1,18E+00	8,53E+00	3,71E-02	1,53E-03	2,09E+00
^{210}Pb	5,23E+01	2,37E+01	2,82E+00	1,61E+00	1,65E-01	8,80E+00	3,11E+00	2,56E+00	0,00E+00	5,82E-01	3,97E-01	4,27E-03	2,25E+00
^{107}Pd	6,04E+01	4,22E+00	3,06E+00	8,07E+00	2,06E+00	1,28E+01	6,47E-01	7,86E+00	6,79E-01	4,17E-03	5,92E-02	0,00E+00	2,62E-01
^{238}Pu	2,00E-01	3,08E-02	1,20E-02	1,41E-02	1,34E+00	4,07E-01	6,94E-02	3,12E-02	0,00E+00	3,63E-06	9,41E+01	3,43E-04	3,84E+00
^{239}Pu	2,00E-01	3,09E-02	1,20E-02	1,41E-02	1,34E+00	4,08E-01	6,94E-02	3,13E-02	0,00E+00	3,64E-06	9,41E+01	7,14E-04	3,85E+00
^{240}Pu	2,00E-01	3,09E-02	1,20E-02	1,41E-02	1,34E+00	4,08E-01	6,94E-02	3,13E-02	0,00E+00	3,64E-06	9,41E+01	3,05E-04	3,85E+00
^{241}Pu	2,13E-01	3,27E-02	1,28E-02	1,50E-02	1,42E+00	4,33E-01	7,39E-02	3,32E-02	0,00E+00	3,87E-06	9,36E+01	2,57E-03	4,09E+00
^{242}Pu	2,00E-01	3,08E-02	1,20E-02	1,41E-02	1,33E+00	4,07E-01	6,93E-02	3,12E-02	0,00E+00	3,64E-06	9,40E+01	2,79E-04	3,84E+00
^{244}Pu	1,69E-01	2,60E-02	1,01E-02	1,19E-02	1,13E+00	3,43E-01	5,85E-02	2,63E-02	0,00E+00	3,07E-06	7,74E+01	1,72E+01	3,24E+00
^{226}Ra	3,52E+01	2,15E+01	2,03E+00	2,70E+00	4,41E-01	7,60E+00	3,39E+00	5,52E+00	0,00E+00	4,29E-01	3,11E+00	3,66E+00	4,21E+00

	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	SOIL_ING
^{79}Se	3,09E+00	1,10E-01	2,35E-01	6,20E-01	1,58E-01	1,54E+00	1,38E-02	1,84E+00	9,20E+01	3,82E-01	4,56E-05	3,98E-05	8,48E-03
^{126}Sn	6,44E+00	1,89E-01	1,08E-01	2,85E-01	7,26E-02	7,06E-01	2,06E-02	2,40E-01	5,68E-01	2,51E-01	3,72E-03	9,09E+01	4,68E-02
^{90}Sr	4,46E+00	5,49E-01	4,49E-01	1,19E+00	3,02E-01	2,95E+00	1,85E-01	4,07E-02	0,00E+00	1,81E-06	7,09E+01	0,00E+00	2,95E+00
^{99}Tc	1,56E+01	6,13E+01	6,16E-01	1,00E+01	2,54E+00	1,22E+00	2,80E+00	4,90E+00	9,27E-02	7,66E-01	7,73E-04	1,31E-03	8,72E-03
^{229}Th	1,57E+01	5,38E+00	1,47E-01	2,33E+00	9,89E-02	3,83E+00	5,41E-01	8,53E-02	0,00E+00	1,46E-02	6,75E+01	1,15E+00	2,71E+00
^{230}Th	1,58E+01	5,40E+00	1,48E-01	2,34E+00	9,94E-02	3,87E+00	5,45E-01	8,62E-02	0,00E+00	1,47E-02	6,80E+01	2,44E-03	2,72E+00
^{232}Th	2,24E+01	7,69E+00	2,10E-01	3,33E+00	1,42E-01	5,50E+00	7,76E-01	6,25E-02	3,89E-01	1,23E+00	4,69E+00	4,95E+01	3,86E+00
^{232}U	2,52E+01	1,52E+01	3,53E-01	1,87E+00	5,56E-01	9,26E+00	3,87E-01	6,00E+00	0,00E+00	1,68E-01	2,85E+01	7,80E+00	2,16E+00
^{233}U	3,05E+01	1,85E+01	4,29E-01	2,26E+00	6,74E-01	1,12E+01	4,67E-01	7,27E+00	0,00E+00	2,04E-01	2,28E+01	1,15E-02	2,62E+00
^{234}U	3,81E+01	2,30E+01	5,33E-01	2,82E+00	8,37E-01	1,40E+01	5,83E-01	4,25E+00	1,79E+00	7,65E+00	3,31E+00	2,04E-02	3,26E+00
^{235}U	2,68E+01	1,62E+01	3,74E-01	1,98E+00	5,90E-01	9,82E+00	4,10E-01	2,98E+00	1,26E+00	5,39E+00	2,13E+00	2,98E+01	2,29E+00
^{236}U	3,80E+01	2,30E+01	5,33E-01	2,82E+00	8,39E-01	1,40E+01	5,82E-01	4,27E+00	1,79E+00	7,67E+00	3,17E+00	1,10E-02	3,29E+00
^{238}U	3,53E+01	2,14E+01	4,94E-01	2,62E+00	7,79E-01	1,30E+01	5,40E-01	3,95E+00	1,66E+00	7,12E+00	2,59E+00	7,61E+00	3,04E+00
^{93}Zr	4,64E+01	9,02E+00	3,32E-01	8,22E+00	5,09E-01	1,51E+01	2,04E+00	3,72E-01	2,39E-01	4,08E-02	2,03E+00	7,71E-01	1,49E+01

Table E-6: Relative contributions of the different pathways to the dose (%) for the well receptor for an adult considering boreal climate

	DW	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	SOIL_ING
^{227}Ac	8,10E+01	0,00E+00	5,00E+00	0,00E+00	0,00E+00	0,00E+00	1,28E+01	9,64E-01	2,74E-03	4,07E-02	2,25E-03	9,45E-02	2,23E-03	5,32E-03
^{108m}Ag	3,88E+01	0,00E+00	2,39E+00	0,00E+00	0,00E+00	0,00E+00	3,10E+01	2,29E+00	4,38E-01	3,17E-01	3,12E-02	1,41E-02	2,48E+01	2,32E-02
^{241}Am	9,19E+01	0,00E+00	5,68E+00	0,00E+00	0,00E+00	0,00E+00	1,46E+00	1,23E-01	4,73E-03	2,41E-02	1,48E-03	8,63E-01	5,48E-03	1,09E-01
^{242m}Am	9,25E+01	0,00E+00	5,70E+00	0,00E+00	0,00E+00	0,00E+00	1,46E+00	1,14E-01	4,75E-03	2,43E-02	1,49E-03	3,00E-01	3,20E-03	3,84E-02
^{243}Am	8,65E+01	0,00E+00	5,41E+00	0,00E+00	0,00E+00	0,00E+00	1,48E+00	1,80E-01	4,44E-03	2,27E-02	1,39E-03	4,81E+00	6,90E-01	6,26E-01
^{10}Be	8,45E+01	0,00E+00	6,48E+00	0,00E+00	0,00E+00	0,00E+00	6,80E+00	3,43E-01	3,46E-03	2,03E-01	7,63E-03	8,64E-01	1,78E-01	7,18E-01
^{14}C	9,95E+01	0,00E+00	6,20E-02	0,00E+00	0,00E+00	0,00E+00	3,66E-01	1,97E-02	0,00E+00	0,00E+00	0,00E+00	5,45E-05	4,83E-07	9,37E-05
^{41}Ca	7,18E+01	0,00E+00	4,54E+00	0,00E+00	0,00E+00	0,00E+00	1,14E+01	8,92E-01	1,08E+01	3,93E-01	9,44E-02	3,78E-05	0,00E+00	2,00E-03
^{36}Cl	5,07E+01	0,00E+00	7,36E+00	0,00E+00	0,00E+00	0,00E+00	2,25E+01	1,87E+00	1,37E+01	2,77E+00	8,00E-01	1,66E-04	4,06E-04	5,58E-04
^{244}Cm	9,27E+01	0,00E+00	5,71E+00	0,00E+00	0,00E+00	0,00E+00	1,46E+00	1,10E-01	6,39E-03	3,03E-03	7,70E-04	4,32E-02	1,03E-06	5,09E-03
^{245}Cm	8,76E+01	0,00E+00	5,43E+00	0,00E+00	0,00E+00	0,00E+00	1,45E+00	1,45E-01	6,05E-03	2,86E-03	7,29E-04	4,59E+00	2,41E-01	6,05E-01
^{246}Cm	8,86E+01	0,00E+00	5,49E+00	0,00E+00	0,00E+00	0,00E+00	1,45E+00	1,39E-01	6,11E-03	2,90E-03	7,37E-04	3,83E+00	5,44E-05	5,06E-01
^{248}Cm	8,63E+01	0,00E+00	5,39E+00	0,00E+00	0,00E+00	0,00E+00	1,45E+00	1,58E-01	5,95E-03	2,83E-03	7,17E-04	5,97E+00	1,80E-05	8,10E-01
^{135}Cs	4,04E+01	0,00E+00	5,80E+00	0,00E+00	0,00E+00	0,00E+00	4,73E+01	1,89E+00	2,83E+00	1,68E+00	3,35E-02	1,27E-03	4,26E-04	9,75E-02
^{137}Cs	4,96E+01	0,00E+00	3,20E+00	0,00E+00	0,00E+00	0,00E+00	3,96E+01	1,78E+00	3,48E+00	2,06E+00	4,12E-02	5,91E-05	2,94E-01	4,40E-03
^{129}I	7,50E+01	0,00E+00	4,66E+00	0,00E+00	0,00E+00	0,00E+00	1,18E+01	8,94E-01	4,86E+00	1,96E+00	8,94E-01	1,46E-05	2,80E-05	1,19E-03
^{40}K	4,92E+01	0,00E+00	3,35E+00	0,00E+00	0,00E+00	0,00E+00	4,00E+01	1,83E+00	3,47E+00	2,04E+00	4,09E-02	1,98E-05	6,75E-02	1,54E-03

	DW	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	SOIL_ING
^{93}Mo	7,66E+01	0,00E+00	5,68E+00	0,00E+00	0,00E+00	0,00E+00	1,44E+01	1,12E+00	1,37E+00	4,42E-01	1,43E-01	1,12E-03	1,00E-03	2,46E-02
^{94}Nb	3,03E+01	0,00E+00	1,93E+00	0,00E+00	0,00E+00	0,00E+00	5,12E+00	3,81E-01	2,60E-02	1,73E-05	8,42E-05	4,64E-02	6,21E+01	4,25E-02
^{59}Ni	7,90E+01	0,00E+00	5,37E+00	0,00E+00	0,00E+00	0,00E+00	2,10E+00	3,13E-01	1,17E+01	1,36E+00	2,20E-02	1,38E-02	0,00E+00	5,23E-02
^{63}Ni	7,97E+01	0,00E+00	5,09E+00	0,00E+00	0,00E+00	0,00E+00	1,53E+00	1,65E-01	1,19E+01	1,38E+00	2,22E-02	5,52E-03	0,00E+00	1,69E-02
^{237}Np	9,26E+01	0,00E+00	5,75E+00	0,00E+00	0,00E+00	0,00E+00	1,47E+00	1,16E-01	6,26E-03	2,22E-02	2,56E-03	3,33E-02	1,06E-02	4,25E-03
^{231}Pa	5,75E+01	0,00E+00	6,77E+00	0,00E+00	0,00E+00	0,00E+00	1,82E+01	1,15E+00	2,95E-03	1,06E-02	6,53E-04	1,50E+01	3,11E-01	1,08E+00
^{202}Pb	7,81E+01	0,00E+00	7,13E+00	0,00E+00	0,00E+00	0,00E+00	1,31E+01	1,23E+00	1,48E-01	4,27E-02	2,37E-01	4,48E-03	2,13E-05	9,47E-02
^{210}Pb	8,08E+01	0,00E+00	5,10E+00	0,00E+00	0,00E+00	0,00E+00	1,27E+01	9,71E-01	1,53E-01	4,41E-02	2,46E-01	2,83E-04	1,52E-05	5,19E-03
^{107}Pd	7,06E+01	0,00E+00	8,47E+00	0,00E+00	0,00E+00	0,00E+00	1,80E+01	1,05E+00	1,57E+00	7,74E-02	4,65E-04	6,62E-02	0,00E+00	1,10E-01
^{238}Pu	9,23E+01	0,00E+00	5,68E+00	0,00E+00	0,00E+00	0,00E+00	1,46E+00	1,10E-01	1,87E-03	5,68E-04	4,62E-04	1,75E-01	3,21E-06	2,32E-02
^{239}Pu	9,02E+01	0,00E+00	5,54E+00	0,00E+00	0,00E+00	0,00E+00	1,50E+00	1,21E-01	1,83E-03	5,54E-04	4,50E-04	2,45E+00	9,26E-05	3,24E-01
^{240}Pu	9,02E+01	0,00E+00	5,54E+00	0,00E+00	0,00E+00	0,00E+00	1,49E+00	1,19E-01	1,83E-03	5,54E-04	4,50E-04	2,17E+00	3,51E-05	2,87E-01
^{241}Pu	9,27E+01	0,00E+00	5,72E+00	0,00E+00	0,00E+00	0,00E+00	1,46E+00	1,10E-01	1,88E-03	5,67E-04	4,62E-04	2,86E-02	3,91E-06	4,02E-03
^{242}Pu	9,03E+01	0,00E+00	5,56E+00	0,00E+00	0,00E+00	0,00E+00	1,50E+00	1,21E-01	1,83E-03	5,51E-04	4,49E-04	2,56E+00	3,81E-05	3,39E-01
^{244}Pu	8,72E+01	0,00E+00	5,37E+00	0,00E+00	0,00E+00	0,00E+00	1,45E+00	1,17E-01	1,77E-03	5,37E-04	4,36E-04	2,43E+00	2,70E+00	3,30E-01
^{226}Ra	5,70E+01	0,00E+00	2,02E+01	0,00E+00	0,00E+00	0,00E+00	1,49E+01	3,32E+00	3,76E-01	8,71E-02	4,42E-02	7,40E-01	1,87E+00	1,41E+00
^{79}Se	2,41E+01	0,00E+00	1,77E+00	0,00E+00	0,00E+00	0,00E+00	7,71E+00	3,22E-01	2,22E+00	6,35E+01	3,49E-01	1,33E-04	1,33E-05	9,23E-03
^{126}Sn	4,67E+01	0,00E+00	3,41E+00	0,00E+00	0,00E+00	0,00E+00	1,30E+01	8,88E-01	6,95E-01	9,40E-01	1,29E-01	1,21E-02	3,41E+01	5,71E-02
^{90}Sr	8,40E+01	0,00E+00	5,47E+00	0,00E+00	0,00E+00	0,00E+00	4,19E+00	2,95E-01	2,84E-03	6,42E-01	9,30E-06	4,98E+00	0,00E+00	6,72E-01
^{99}Tc	8,75E+01	0,00E+00	1,05E+01	0,00E+00	0,00E+00	0,00E+00	7,88E-01	2,83E-01	2,49E-01	2,68E-03	7,29E-01	7,32E-05	1,43E-05	3,10E-04
^{229}Th	8,64E+01	0,00E+00	7,11E+00	0,00E+00	0,00E+00	0,00E+00	2,62E+00	2,82E-01	5,84E-03	2,07E-02	2,20E-02	2,95E+00	2,51E-01	3,83E-01
^{230}Th	8,56E+01	0,00E+00	7,40E+00	0,00E+00	0,00E+00	0,00E+00	2,87E+00	3,17E-01	5,75E-03	2,05E-02	2,18E-02	3,57E+00	6,41E-04	4,61E-01
^{232}Th	8,54E+01	0,00E+00	7,45E+00	0,00E+00	0,00E+00	0,00E+00	2,91E+00	3,22E-01	5,77E-03	2,05E-02	2,18E-02	1,53E+00	1,85E+00	4,72E-01
^{232}U	9,13E+01	0,00E+00	5,85E+00	0,00E+00	0,00E+00	0,00E+00	1,58E+00	1,14E-01	5,80E-01	1,40E-01	1,67E-01	5,77E-02	7,90E-02	1,42E-02
^{233}U	6,33E+01	8,09E+00	4,66E+00	1,93E+00	1,93E+00	1,71E+01	1,72E+00	1,56E-01	5,14E-01	1,39E-01	2,29E-01	8,26E-02	1,82E-03	8,26E-02
^{234}U	9,05E+01	0,00E+00	6,42E+00	0,00E+00	0,00E+00	0,00E+00	1,93E+00	1,28E-01	5,74E-01	1,38E-01	1,65E-01	1,39E-01	9,82E-05	5,14E-02
^{235}U	9,02E+01	0,00E+00	6,40E+00	0,00E+00	0,00E+00	0,00E+00	1,93E+00	1,28E-01	5,73E-01	1,38E-01	1,65E-01	1,27E-01	2,04E-01	5,13E-02
^{236}U	9,06E+01	0,00E+00	6,41E+00	0,00E+00	0,00E+00	0,00E+00	1,94E+00	1,29E-01	5,76E-01	1,38E-01	1,66E-01	1,33E-01	5,31E-05	5,16E-02
^{238}U	9,04E+01	0,00E+00	6,42E+00	0,00E+00	0,00E+00	0,00E+00	1,93E+00	1,28E-01	5,74E-01	1,38E-01	1,65E-01	1,17E-01	3,96E-02	5,15E-02
^{93}Zr	6,75E+01	0,00E+00	4,18E+00	0,00E+00	0,00E+00	0,00E+00	2,65E+01	2,00E+00	9,40E-03	3,47E-03	1,50E-04	6,85E-03	2,99E-04	1,87E-02

Table E-7: Relative contributions of the different pathways to the dose (%) for the river receptor for an adult considering boreal climate

	DW	FISH	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	EX_SED	SOIL_ING
^{227}Ac	1,98E+01	3,77E+01	0,00E+00	1,10E+01	0,00E+00	0,00E+00	0,00E+00	2,83E+01	2,12E+00	6,03E-03	8,98E-02	4,95E-03	2,08E-01	4,91E-03	8,42E-01	1,17E-02
^{108m}Ag	2,65E-01	6,62E-01	0,00E+00	4,39E-02	0,00E+00	0,00E+00	0,00E+00	5,70E-01	4,22E-02	8,06E-03	5,82E-03	5,74E-04	2,60E-04	4,56E-01	9,79E+01	4,26E-04
^{241}Am	2,65E+01	5,01E+01	0,00E+00	1,47E+01	0,00E+00	0,00E+00	0,00E+00	3,78E+00	3,17E-01	1,22E-02	6,24E-02	3,83E-03	2,23E+00	1,42E-02	2,08E+00	2,81E-01
^{242m}Am	2,66E+01	5,03E+01	0,00E+00	1,47E+01	0,00E+00	0,00E+00	0,00E+00	3,77E+00	2,95E-01	1,23E-02	6,27E-02	3,85E-03	7,74E-01	8,26E-03	3,38E+00	9,92E-02
^{243}Am	1,66E+01	3,15E+01	0,00E+00	9,35E+00	0,00E+00	0,00E+00	0,00E+00	2,56E+00	3,11E-01	7,68E-03	3,92E-02	2,41E-03	8,31E+00	1,19E+00	2,90E+01	1,08E+00
^{10}Be	3,41E+01	5,29E+01	0,00E+00	4,81E+00	0,00E+00	0,00E+00	0,00E+00	5,05E+00	2,55E-01	2,57E-03	1,51E-01	5,67E-03	6,43E-01	1,33E-01	1,60E+00	5,34E-01
^{14}C	2,23E+00	9,78E+01	0,00E+00	1,45E-03	0,00E+00	0,00E+00	0,00E+00	8,53E-03	4,58E-04	0,00E+00	0,00E+00	0,00E+00	1,27E-06	1,13E-08	1,63E-04	2,18E-06
^{41}Ca	5,73E+01	1,97E+01	0,00E+00	3,71E+00	0,00E+00	0,00E+00	0,00E+00	9,29E+00	7,28E-01	8,79E+00	3,21E-01	7,70E-02	3,08E-05	0,00E+00	0,00E+00	1,63E-03
^{36}Cl	4,20E+01	1,77E+01	0,00E+00	6,10E+00	0,00E+00	0,00E+00	0,00E+00	1,87E+01	1,55E+00	1,13E+01	2,29E+00	6,63E-01	1,37E-04	3,36E-04	1,70E-04	4,62E-04
^{244}Cm	3,99E+01	5,05E+01	0,00E+00	7,39E+00	0,00E+00	0,00E+00	0,00E+00	1,89E+00	1,43E-01	8,27E-03	3,93E-03	9,97E-04	5,60E-02	1,33E-06	5,11E-04	6,59E-03
^{245}Cm	3,68E+01	4,65E+01	0,00E+00	6,86E+00	0,00E+00	0,00E+00	0,00E+00	1,83E+00	1,83E-01	7,64E-03	3,62E-03	9,21E-04	5,80E+00	3,04E-01	1,16E+00	7,64E-01
^{246}Cm	3,76E+01	4,75E+01	0,00E+00	7,01E+00	0,00E+00	0,00E+00	0,00E+00	1,85E+00	1,78E-01	7,81E-03	3,70E-03	9,42E-04	4,89E+00	6,95E-05	3,21E-04	6,47E-01
^{248}Cm	3,65E+01	4,61E+01	0,00E+00	6,83E+00	0,00E+00	0,00E+00	0,00E+00	1,84E+00	2,01E-01	7,55E-03	3,59E-03	9,09E-04	7,57E+00	2,28E-05	6,43E-05	1,03E+00
^{135}Cs	6,73E+00	7,95E+01	0,00E+00	1,35E+00	0,00E+00	0,00E+00	0,00E+00	1,10E+01	4,40E-01	6,60E-01	3,92E-01	7,82E-03	2,97E-04	9,94E-05	2,97E-03	2,28E-02
^{137}Cs	4,99E+00	5,88E+01	0,00E+00	4,51E-01	0,00E+00	0,00E+00	0,00E+00	5,58E+00	2,51E-01	4,91E-01	2,90E-01	5,81E-03	8,32E-06	4,14E-02	2,91E+01	6,20E-04
^{129}I	4,59E+01	3,88E+01	0,00E+00	2,86E+00	0,00E+00	0,00E+00	0,00E+00	7,22E+00	5,48E-01	2,98E+00	1,20E+00	5,48E-01	8,98E-06	1,72E-05	6,02E-04	7,27E-04
^{40}K	5,36E+00	6,32E+01	0,00E+00	5,10E-01	0,00E+00	0,00E+00	0,00E+00	6,09E+00	2,78E-01	5,28E-01	3,11E-01	6,23E-03	3,01E-06	1,03E-02	2,37E+01	2,35E-04
^{93}Mo	7,43E+01	1,28E+00	0,00E+00	5,91E+00	0,00E+00	0,00E+00	0,00E+00	1,50E+01	1,16E+00	1,42E+00	4,59E-01	1,48E-01	1,17E-03	1,04E-03	5,88E-02	2,56E-02
^{94}Nb	1,10E+01	1,87E+01	0,00E+00	7,05E-01	0,00E+00	0,00E+00	0,00E+00	1,87E+00	1,39E-01	9,47E-03	6,29E-06	3,07E-05	1,69E-02	2,27E+01	4,48E+01	1,55E-02
^{59}Ni	3,92E+01	4,63E+01	0,00E+00	3,73E+00	0,00E+00	0,00E+00	0,00E+00	1,46E+00	2,18E-01	8,15E+00	9,47E-01	1,53E-02	9,61E-03	0,00E+00	0,00E+00	3,63E-02
^{63}Ni	3,95E+01	4,65E+01	0,00E+00	3,51E+00	0,00E+00	0,00E+00	0,00E+00	1,06E+00	1,14E-01	8,20E+00	9,55E-01	1,53E-02	3,81E-03	0,00E+00	0,00E+00	1,17E-02
^{237}Np	8,47E+01	7,27E+00	0,00E+00	5,36E+00	0,00E+00	0,00E+00	0,00E+00	1,37E+00	1,08E-01	5,84E-03	2,07E-02	2,39E-03	3,11E-02	9,84E-03	1,18E+00	3,96E-03
^{231}Pa	3,69E+01	6,84E+00	0,00E+00	8,69E+00	0,00E+00	0,00E+00	0,00E+00	2,34E+01	1,48E+00	3,79E-03	1,35E-02	8,39E-04	1,93E+01	3,99E-01	1,80E+00	1,38E+00
^{202}Pb	6,29E+01	1,58E+01	0,00E+00	6,89E+00	0,00E+00	0,00E+00	0,00E+00	1,27E+01	1,19E+00	1,43E-01	4,12E-02	2,29E-01	4,33E-03	2,06E-05	9,32E-05	9,15E-02
^{210}Pb	4,88E+01	2,39E+01	0,00E+00	7,18E+00	0,00E+00	0,00E+00	0,00E+00	1,79E+01	1,37E+00	2,15E-01	6,22E-02	3,47E-01	3,98E-04	2,14E-05	4,72E-02	7,32E-03
^{107}Pd	5,00E+01	8,42E+00	0,00E+00	1,20E+01	0,00E+00	0,00E+00	0,00E+00	2,55E+01	1,49E+00	2,22E+00	1,10E-01	6,58E-04	9,38E-02	0,00E+00	0,00E+00	1,55E-01
^{238}Pu	7,58E+01	5,75E+00	0,00E+00	1,40E+01	0,00E+00	0,00E+00	0,00E+00	3,59E+00	2,72E-01	4,61E-03	1,40E-03	1,14E-03	4,31E-01	7,89E-06	4,17E-03	5,71E-02
^{239}Pu	7,10E+01	5,39E+00	0,00E+00	1,31E+01	0,00E+00	0,00E+00	0,00E+00	3,53E+00	2,85E-01	4,32E-03	1,31E-03	1,06E-03	5,78E+00	2,19E-04	8,56E-03	7,65E-01
^{240}Pu	7,16E+01	5,43E+00	0,00E+00	1,32E+01	0,00E+00	0,00E+00	0,00E+00	3,54E+00	2,83E-01	4,36E-03	1,32E-03	1,07E-03	5,16E+00	8,36E-05	3,69E-03	6,83E-01
^{241}Pu	7,61E+01	5,76E+00	0,00E+00	1,41E+01	0,00E+00	0,00E+00	0,00E+00	3,58E+00	2,70E-01	4,62E-03	1,39E-03	1,14E-03	7,03E-02	9,61E-06	2,27E-02	9,87E-03
^{242}Pu	7,09E+01	5,37E+00	0,00E+00	1,31E+01	0,00E+00	0,00E+00	0,00E+00	3,54E+00	2,85E-01	4,31E-03	1,30E-03	1,06E-03	6,04E+00	8,98E-05	3,35E-03	7,99E-01
^{244}Pu	2,02E+01	1,53E+00	0,00E+00	3,72E+00	0,00E+00	0,00E+00	0,00E+00	1,01E+00	8,12E-02	1,23E-03	3,72E-04	3,02E-04	1,68E+00	1,87E+00	6,96E+01	2,28E-01
^{226}Ra	4,17E+01	1,85E+01	0,00E+00	1,56E+01	0,00E+00	0,00E+00	0,00E+00	1,14E+01	2,55E+00	2,89E-01	6,70E-02	3,40E-02	5,69E-01	1,44E+00	6,82E+00	1,08E+00

	DW	FISH	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	EX_SED	SOIL_ING
^{79}Se	1,69E+01	2,90E+01	0,00E+00	1,26E+00	0,00E+00	0,00E+00	0,00E+00	5,48E+00	2,29E-01	1,58E+00	4,52E+01	2,48E-01	9,44E-05	9,44E-06	1,36E-04	6,56E-03
^{126}Sn	9,03E-01	1,83E+01	0,00E+00	1,05E-01	0,00E+00	0,00E+00	0,00E+00	4,03E-01	2,75E-02	2,15E-02	2,91E-02	3,99E-03	3,74E-04	1,05E+00	7,91E+01	1,77E-03
^{90}Sr	5,29E+01	2,45E+01	0,00E+00	7,58E+00	0,00E+00	0,00E+00	0,00E+00	5,81E+00	4,10E-01	3,94E-03	8,90E-01	1,29E-05	6,90E+00	0,00E+00	0,00E+00	9,32E-01
^{99}Tc	7,88E+01	9,95E+00	0,00E+00	9,41E+00	0,00E+00	0,00E+00	0,00E+00	7,09E-01	2,54E-01	2,24E-01	2,41E-03	6,56E-01	6,59E-05	1,28E-05	2,02E-04	2,79E-04
^{229}Th	3,54E+01	4,76E+01	0,00E+00	5,82E+00	0,00E+00	0,00E+00	0,00E+00	2,15E+00	2,30E-01	4,78E-03	1,69E-02	1,80E-02	2,41E+00	2,05E-01	5,82E+00	3,13E-01
^{230}Th	3,72E+01	5,00E+01	0,00E+00	6,44E+00	0,00E+00	0,00E+00	0,00E+00	2,50E+00	2,75E-01	5,00E-03	1,78E-02	1,89E-02	3,11E+00	5,58E-04	1,29E-02	4,01E-01
^{232}Th	2,73E+01	3,68E+01	0,00E+00	4,76E+00	0,00E+00	0,00E+00	0,00E+00	1,86E+00	2,06E-01	3,69E-03	1,31E-02	1,39E-02	9,79E-01	1,18E+00	2,69E+01	3,01E-01
^{232}U	8,52E+01	1,49E+00	0,00E+00	5,67E+00	0,00E+00	0,00E+00	0,00E+00	1,53E+00	1,10E-01	5,62E-01	1,35E-01	1,62E-01	5,60E-02	7,66E-02	5,04E+00	1,38E-02
^{233}U	6,18E+01	1,08E+00	8,20E+00	4,73E+00	1,95E+00	1,95E+00	1,73E+01	1,75E+00	1,58E-01	5,21E-01	1,41E-01	2,33E-01	8,37E-02	1,85E-03	4,74E-03	8,37E-02
^{234}U	8,87E+01	1,55E+00	0,00E+00	6,55E+00	0,00E+00	0,00E+00	0,00E+00	1,97E+00	1,31E-01	5,86E-01	1,41E-01	1,69E-01	1,42E-01	1,00E-04	1,92E-03	5,24E-02
^{235}U	8,52E+01	1,49E+00	0,00E+00	6,28E+00	0,00E+00	0,00E+00	0,00E+00	1,89E+00	1,26E-01	5,62E-01	1,35E-01	1,62E-01	1,25E-01	2,01E-01	3,84E+00	5,04E-02
^{236}U	8,88E+01	1,55E+00	0,00E+00	6,53E+00	0,00E+00	0,00E+00	0,00E+00	1,97E+00	1,31E-01	5,87E-01	1,41E-01	1,69E-01	1,35E-01	5,41E-05	1,03E-03	5,25E-02
^{238}U	8,82E+01	1,54E+00	0,00E+00	6,50E+00	0,00E+00	0,00E+00	0,00E+00	1,96E+00	1,30E-01	5,81E-01	1,40E-01	1,68E-01	1,19E-01	4,01E-02	7,66E-01	5,22E-02
^{93}Zr	3,12E+01	5,04E+01	0,00E+00	2,32E+00	0,00E+00	0,00E+00	0,00E+00	1,47E+01	1,11E+00	5,21E-03	1,92E-03	8,33E-05	3,80E-03	1,66E-04	3,01E-02	1,04E-02

Table E-8: Relative contributions of the different pathways to the dose (%) for the wetland receptor for an adult considering boreal climate

	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	SOIL_ING
^{227}Ac	4,97E+01	1,70E+00	1,40E+00	3,68E+00	9,35E-01	9,11E+00	5,71E-01	9,68E-02	2,52E+00	7,17E-03	2,84E+01	6,73E-01	1,60E+00
^{108m}Ag	4,12E+00	4,71E-03	6,91E-02	3,05E-01	9,53E-03	7,56E-01	6,78E-03	1,10E+00	1,40E+00	1,72E-02	5,24E-02	9,21E+01	8,58E-02
^{241}Am	1,66E+00	6,03E-01	2,24E-01	8,65E-02	2,36E-01	8,65E-01	5,64E-01	6,60E-02	5,89E-01	1,39E-04	8,40E+01	5,35E-01	1,06E+01
^{242m}Am	1,68E+00	6,10E-01	2,26E-01	8,74E-02	2,38E-01	8,74E-01	5,70E-01	6,67E-02	5,95E-01	1,40E-04	8,35E+01	8,90E-01	1,07E+01
^{243}Am	1,53E+00	5,54E-01	2,06E-01	7,95E-02	2,17E-01	7,95E-01	5,19E-01	6,07E-02	5,42E-01	1,27E-04	7,50E+01	1,07E+01	9,73E+00
^{10}Be	3,93E+01	6,11E+00	3,02E+00	4,54E+00	2,04E+00	1,98E+01	6,88E-01	4,70E-02	4,84E+00	1,85E-02	9,64E+00	2,00E+00	8,02E+00
^{14}C	5,17E+01	1,51E+00	1,03E+00	3,60E+00	8,35E-01	8,90E+00	4,79E-01	1,57E+01	1,37E+01	2,67E+00	1,87E-04	1,65E-06	2,56E-03
^{41}Ca	3,33E+01	2,53E+00	2,82E+01	5,27E+00	1,34E+00	2,69E+00	8,58E-01	2,38E+01	1,52E+00	2,28E-01	1,77E-03	0,00E+00	9,37E-02
^{36}Cl	1,61E+01	9,86E-01	3,37E-01	1,22E-01	1,80E-01	3,38E+00	2,97E-01	5,69E+01	2,01E+01	1,32E+00	9,02E-05	2,20E-04	3,03E-04
^{244}Cm	1,19E+00	3,72E-01	3,94E-01	4,34E+00	2,77E-01	5,09E-01	2,87E-01	7,86E-02	6,55E-02	5,17E-05	8,28E+01	1,97E-03	9,74E+00
^{245}Cm	1,25E+00	3,92E-01	4,15E-01	4,58E+00	2,92E-01	5,37E-01	3,02E-01	8,29E-02	6,89E-02	5,46E-05	7,77E+01	4,08E+00	1,03E+01
^{246}Cm	1,31E+00	4,09E-01	4,33E-01	4,78E+00	3,05E-01	5,60E-01	3,15E-01	8,65E-02	7,19E-02	5,69E-05	8,11E+01	1,15E-03	1,07E+01
^{248}Cm	1,34E+00	4,17E-01	4,42E-01	4,88E+00	3,11E-01	5,72E-01	3,21E-01	8,83E-02	7,35E-02	5,80E-05	8,06E+01	2,42E-04	1,09E+01
^{135}Cs	3,13E+01	5,00E+00	1,59E+00	1,14E+00	8,06E-01	2,34E+01	6,82E-01	1,75E+01	1,82E+01	1,36E-01	4,49E-03	1,51E-03	3,45E-01
^{137}Cs	2,55E+01	4,06E+00	1,29E+00	9,24E-01	6,55E-01	1,90E+01	5,54E-01	1,43E+01	1,47E+01	1,10E-01	3,75E-03	1,87E+01	2,80E-01
^{129}I	6,18E+01	4,47E+00	9,30E-01	1,86E+00	1,88E+00	3,45E+00	7,54E-01	1,20E+01	8,46E+00	3,85E+00	4,00E-03	7,63E-03	3,24E-01
^{40}K	5,46E+01	3,28E+00	2,07E+00	5,46E+00	1,39E+00	1,36E+01	8,47E-01	8,19E+00	8,47E+00	2,37E-01	4,86E-04	1,67E+00	3,81E-02

	CEREAL	LEAFYV	LEGU	FRUIT	NLVEG	TUB	ROOT	MILK	MEAT	EGGS	INHAL	EX_SOIL	SOIL_ING
^{93}Mo	7,76E+01	2,09E+00	5,97E+00	1,10E+00	1,57E+00	5,03E+00	4,50E-01	3,31E+00	1,88E+00	7,51E-01	5,66E-03	5,06E-03	1,24E-01
^{94}Nb	1,30E+00	4,44E-02	3,64E-02	9,61E-02	2,45E-02	2,38E-01	1,49E-02	8,90E-03	1,04E-05	1,87E-05	7,27E-02	9,81E+01	6,69E-02
^{59}Ni	2,41E+01	1,02E+00	1,54E+01	4,66E+00	4,25E-01	1,73E+00	4,49E-01	4,31E+01	8,76E+00	3,48E-02	6,61E-02	0,00E+00	2,51E-01
^{63}Ni	2,41E+01	1,02E+00	1,53E+01	4,66E+00	4,26E-01	1,73E+00	4,50E-01	4,31E+01	8,76E+00	3,47E-02	8,22E-02	0,00E+00	2,50E-01
^{237}Np	3,74E+01	1,24E+01	2,69E+00	3,95E+00	3,13E+00	6,86E+00	1,79E+00	8,32E-02	5,18E-01	5,40E-03	2,16E+01	6,84E+00	2,76E+00
^{231}Pa	5,62E+01	1,92E+00	1,57E+00	4,15E+00	1,06E+00	1,03E+01	6,43E-01	6,29E-02	1,51E+00	5,79E-03	2,07E+01	4,32E-01	1,50E+00
^{202}Pb	5,28E+01	2,40E+01	2,84E+00	1,63E+00	1,67E-01	8,89E+00	3,15E+00	2,22E+00	1,12E+00	8,39E-01	1,08E-01	5,13E-04	2,28E+00
^{210}Pb	5,27E+01	2,39E+01	2,83E+00	1,62E+00	1,66E-01	8,85E+00	3,13E+00	2,21E+00	1,11E+00	8,34E-01	1,24E-01	6,62E-03	2,27E+00
^{107}Pd	6,08E+01	4,25E+00	3,08E+00	8,13E+00	2,07E+00	1,29E+01	6,51E-01	7,18E+00	6,21E-01	2,08E-03	1,59E-01	0,00E+00	2,63E-01
^{238}Pu	5,73E-01	8,81E-02	3,43E-02	4,03E-02	3,82E+00	1,16E+00	1,99E-01	2,69E-02	1,42E-02	1,49E-05	8,30E+01	1,52E-03	1,10E+01
^{239}Pu	5,71E-01	8,82E-02	3,43E-02	4,04E-02	3,82E+00	1,16E+00	1,98E-01	2,69E-02	1,42E-02	1,49E-05	8,30E+01	3,16E-03	1,10E+01
^{240}Pu	5,71E-01	8,82E-02	3,43E-02	4,04E-02	3,82E+00	1,16E+00	1,98E-01	2,69E-02	1,42E-02	1,49E-05	8,30E+01	1,35E-03	1,10E+01
^{241}Pu	6,03E-01	9,28E-02	3,62E-02	4,25E-02	4,03E+00	1,23E+00	2,10E-01	2,84E-02	1,50E-02	1,57E-05	8,21E+01	1,13E-02	1,16E+01
^{242}Pu	5,73E-01	8,83E-02	3,44E-02	4,04E-02	3,81E+00	1,17E+00	1,99E-01	2,69E-02	1,42E-02	1,49E-05	8,31E+01	1,23E-03	1,10E+01
^{244}Pu	3,05E-01	4,68E-02	1,82E-02	2,15E-02	2,03E+00	6,18E-01	1,05E-01	1,43E-02	7,55E-03	7,91E-06	4,30E+01	4,79E+01	5,83E+00
^{226}Ra	3,67E+01	2,22E+01	2,10E+00	2,79E+00	4,58E-01	7,86E+00	3,52E+00	4,69E+00	6,82E+00	6,34E-01	2,30E+00	5,81E+00	4,36E+00
^{79}Se	3,35E+00	1,19E-01	2,55E-01	6,73E-01	1,72E-01	1,67E+00	1,50E-02	1,84E+00	9,18E+01	2,51E-01	1,32E-04	1,32E-05	9,20E-03
^{126}Sn	1,77E+01	5,17E-01	2,96E-01	7,80E-01	1,99E-01	1,94E+00	5,66E-02	5,46E-01	1,29E+00	2,55E-01	2,72E-02	7,66E+01	1,28E-01
^{90}Sr	1,12E+01	1,37E+00	1,12E+00	2,97E+00	7,56E-01	7,38E+00	4,62E-01	3,16E-02	1,25E+01	6,44E-06	5,47E+01	0,00E+00	7,38E+00
^{99}Tc	1,57E+01	6,19E+01	6,21E-01	1,01E+01	2,56E+00	1,23E+00	2,82E+00	4,62E+00	8,71E-02	6,83E-01	2,08E-03	4,06E-04	8,81E-03
^{229}Th	2,93E+01	1,00E+01	2,74E-01	4,35E+00	1,85E-01	7,16E+00	1,01E+00	6,39E-02	4,00E-01	3,89E-02	3,89E+01	3,31E+00	5,05E+00
^{230}Th	3,02E+01	1,03E+01	2,82E-01	4,48E+00	1,90E-01	7,40E+00	1,04E+00	6,61E-02	4,11E-01	4,02E-02	4,03E+01	7,21E-03	5,20E+00
^{232}Th	3,11E+01	1,07E+01	2,92E-01	4,62E+00	1,96E-01	7,62E+00	1,08E+00	6,83E-02	4,23E-01	4,15E-02	1,74E+01	2,11E+01	5,36E+00
^{232}U	3,19E+01	1,93E+01	4,46E-01	2,36E+00	7,03E-01	1,17E+01	4,89E-01	2,71E+00	1,14E+00	3,05E-01	1,11E+01	1,52E+01	2,73E+00
^{233}U	3,79E+01	2,30E+01	5,33E-01	2,81E+00	8,38E-01	1,40E+01	5,81E-01	4,24E+00	1,79E+00	7,67E+00	3,26E+00	7,21E-02	3,26E+00
^{234}U	3,94E+01	2,38E+01	5,51E-01	2,91E+00	8,66E-01	1,44E+01	6,03E-01	3,34E+00	1,41E+00	3,74E-01	9,14E+00	6,46E-03	3,37E+00
^{235}U	3,49E+01	2,11E+01	4,88E-01	2,58E+00	7,69E-01	1,28E+01	5,35E-01	2,97E+00	1,25E+00	3,33E-01	7,43E+00	1,19E+01	2,99E+00
^{236}U	3,94E+01	2,38E+01	5,52E-01	2,92E+00	8,69E-01	1,45E+01	6,03E-01	3,34E+00	1,41E+00	3,76E-01	8,75E+00	3,49E-03	3,40E+00
^{238}U	3,89E+01	2,35E+01	5,43E-01	2,89E+00	8,57E-01	1,43E+01	5,94E-01	3,31E+00	1,39E+00	3,69E-01	7,60E+00	2,56E+00	3,34E+00
^{93}Zr	4,53E+01	8,79E+00	3,24E-01	8,02E+00	4,96E-01	1,47E+01	1,99E+00	2,68E-01	1,72E-01	5,25E-04	5,28E+00	2,30E-01	1,45E+01

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