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Dose and dose commitment from groundwater-borne radioactive elements in the final storage of spent nuclear fuel

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AB Atomenergi 1979-02-02

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SUMMARY

The turnover of radioactive matter entering the biosphere with the groundwater has been studied with regard to exposure and doses for critical groups and populations.

The main alternatives considered for the inflow of radioactive effluents to the biosphere are:

- inflow in a valley containing a well and to a nearby lake
- inflow to a freshwater lake and to the downstream lake system
- inflow in a coastal region of the Baltic Sea

Mathematical models of a set of coupled ecosystems on regional, intermediate and global levels have been used for calculations of doses. The intermediate system refers to the Baltic Sea.

The mathematical analysis, based on first order kinetics for the exchange of matter in a system according to compartment principles, also includes products in decay chains, i.e. daughter nuclides generated by decay of nuclides during ecological cycling.

The time-dependent exposures have been studied for certain long-lived nuclides of radiological interest in waste from disposed fuel. Dose and dose commitment have been calculated for different episodes for inflow to the biosphere. The source strength is equal to the inflow at the boundary between geosphere and biosphere calculated by use of a geospheric model.

1. INTRODUCTION

An important question in connection with the final storage of radioactive waste in the bedrock is how the population will be exposed in time and in space to the radioactive material which can reach the biosphere with the groundwater. The transport of groundwater-borne material is generally a very slow process. It can take tens of thousands of years for groundwater originating from precipitation to reach the ground surface once again after a cycle extending down to a depth of several hundred metres. The substances which are transported with the groundwater are generally greatly retarded in relation to the movements of the water by interaction with the environment, such as sorption to materials in the bedrock. After sufficiently long periods of time, however, stable substances from all depths which have been exposed to circulating groundwater can reach the biosphere and thereby also man.

The purpose of this work is to estimate radiation doses which result from radioactive elements reaching the biosphere by predicting the long-range turnover of various radioactive elements in various ecosystems.

The main types of inflow of radioactive elements to the biosphere discussed here are:

- inflow both to a valley which may contain a well and to a nearby lake
- inflow to a lake and its downstream lake system
- inflow to a coastal region of the Baltic Sea

Calculations of the dose burden are carried out using mathematical models of interconnected ecosystems on regional, intermediary and global levels. The intermediary system refers to the Baltic Sea.

The ecosystems have been divided into a number of reservoirs, for example, groundwater, soil, sediment and surface water, which significantly influence the turnover of various radionuclides.

The mathematical analysis also makes it possible to take into consideration the decay of a parent nuclide during its circulation in the biosphere, generating a radioactive daughter nuclide.

The model is designed to describe important turnover and exposure mechanisms and to permit assessments based on radiological concepts defined by international and Swedish radiation protection authorities for radiation doses to individuals and populations.

The results of the calculations include:

- dose to critical group consisting of a limited number of individuals living in the vicinity of the release point
- dose to population - the collective dose - which can refer to the exposure of portions or all of the global population

Radiation doses are given in the form of dose rates, annual doses. The accumulated dose during a certain limited or unlimited period of time - the dose commitment - following a given release of radioactivity to the biosphere is also calculated.

2. MODELS OF ECOSYSTEMS

2.1 Mathematical model

A model system has been developed for simulating the dynamic exchange of radionuclides in the biosphere. The mathematical treatment of the model is based on compartment theory with first-order kinetics (42). The cycling and content of radioactive matter in different ecosystems is therefore described by a system of first-order linear differential equations with constant transfer coefficient and a number of physically well-defined areas or volumes. The premises are that:

- the outflow for reservoir "j" is dependent solely upon the quantity Y_j of the radionuclide
- the reservoir is instantaneously well-mixed
- each atom, molecule or other elementary unit has the same probability of leaving the reservoir

The relationship between the amounts of activity in the reservoir system is expressed mathematically in vector form by

$$\dot{Y}_M(t) = K_M Y_M(t) + Q_M(t) - \lambda_M Y_M(t) \quad \text{for parent nuclides}$$

$$\dot{Y}_D(t) = K_D Y_D(t) + \lambda_D Y_M(t) - \lambda_D Y_D(t) \quad \text{for daughter nuclides}$$

The vectors Y and $\dot{Y}$ refer to activity and activity changes per unit time in the system's different reservoirs at time t. The coefficient matrix K ($year^{-1}$) and Q (t) (activity $year^{-1}$) describes the transfer rates between the reservoirs and production or release within the reservoir, respectively. For the daughter activity, the source strength within each reservoir is a function of the quantity of parent nuclide within the reservoir. The decay constant $\lambda = \ell n2/T_{1/2}$, where $T_{1/2}$ is the physical half-life.

Solutions of the equation system and calculations of Y (t) for "parent" and "daughter" have been carried out with a computer program named BIOPATH (43).

2.2 Interfaces between geosphere and biosphere

The groundwater which flows from the repository to a recipient at the surface of the earth constitutes a path of inflow for the radioactive nuclides. According to the hydrological investigations which have been carried out at a possible repository site, there is a groundwater divide there. The model is therefore designed to take into account different paths of inflow to the biosphere at the same time. Three main cases for inflow to the biosphere have been studied (Figure 1).

Alt. 1. The inflow of groundwater-borne material is divided equally between a valley containing a well and a nearby lake.

Alt. 2. The inflow is divided equally between a nearby lake and its downstream lake system.

Alt. 3. The inflow occurs into a coastal zone of the Baltic Sea.

Thus, three dispersal alternatives have been studied. The first concerns dispersal via well and lake to the local and regional areas and the second dispersal via lake and the downstream lake system. The third concerns dispersal through groundwater runoff directly to the Baltic Sea.

A computer program called GETOUT (29) has been used for the calculations of the nuclide transport from the final repository to the overlying biosphere and the results define the source strengths for BIOPATH.

2.3 Model structure

The model of the biosphere is divided into three subsystems of progressively increasing size referring to a regional (R), an intermediary (I) and a global (G) zone. The regional area also includes a local area immediately around the point of inlow from the repository to the biosphere.

The turnover processes are largely controlled by the exhange between these three zones.

The subdivision of the model system into several zones makes it possible to:

- study extreme exposure situations in limited ecosystems.
- increase the realism of the dispersal pattern described by the model by considering gradual dispersal on an ever-increasing scale as well as feedback between different zones.
- apply the model adequately to Swedish conditions by choosing the Baltic Sea as an intermediary zone.

Within the subsystems, the reservoirs have been designed to provide a representative average picture of the flow of radioactivity in the ecosystem. The number and structure of subreservoirs represent a compromise between:

- a sufficiently differentiated system in order to encompass all important reservoirs and paths of exposure
- simplicity of design in order to facilitate uncertainty analysis and comparison of model predictions with measurements of turnover and elemental balance in nature or calculations using other models
- available information on dispersal mechanisms

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2.4 Reservoir sizes

The local ecosystems are different in the inland and coast alternatives. In the inland (alternatives 1 and 2), the local area consists of 6 acres of farmland of the same qualitative makeup and with the same turnover rates for the nuclides as in the regional area.

In the Baltic Sea alternative, the local and regional areas coincide. The area consists of 1 km^3 of brackish water and underlying sediment within a 2 km wide and 30 km long coastal belt.

Figure 2 illustrates the division of the regional, intermediary and global zones into reservoirs. The regional ecosystem in the inland alternatives consists of 900 km^2 of farmland. This size is representative for a central Swedish agricultural region. The shallowest soil zone in the region is considered to have an average depth of 2 fm. Groundwater 2 includes all soil water and groundwater down to a depth of 2 metres and is not, in contrast to groundwater 1, a primary recipient for the activity.

The average period of turnover for this water is assumed to be 3 years. There is hydrological equilibrium within a precipitation area so that runoff is equal to precipitation.

The primary surface water recipient within the region is a specified lake with an area of 5 km^2. The average depth of the lake is assumed to be 2.5 m, which gives a volume of $1.25 \cdot 10^7$ m^3. The area of the sediment layer is the same as for the lake, i.e. 5 km^2. An upper 10 cm deep sediment layer is assumed to participate actively in the processes of exchange with overlying water.

The Baltic Sea system consists of the Baltic Sea, with a surface area of $3.7 \cdot 10^5$ km^2 and an average depth of 60 m. The sediment reservoir is the sediment layer at the bottom of the Baltic Sea. The atmosphere above the regional and Baltic Sea area is the troposheric air volume up to an altitude of 1 km.

The global ecosystem embraces the following 7 reservoirs which are considered to be important for the dispersal and turnover of long-lived nuclides in particular.

The oceans are divided into two reservoirs, since mixing and exchange in the seas decrease rapidly with increasing depth.

The surface sea consists of the upper water layer down to a depth of about 100 m. The deep sea basin is below the surface sea. These two reservoirs are in direct connection with the respective sediment reservoir. The uppermost sediment reservoir encircles the continents and amounts to about 4% of the total sediment area.

The soil reservoir consists of the upper ground layer on top of the continents down to a depth of 0.5 m. The groundwater reservoir, which transports the nuclides to the surface water and back to the soil reservoir, is in connection with the soil reservoir. The biota reservoir consists of the terrestrial short- and long--lived primary producers, i.e. vegetation which has a short life cycle of up to a few years and vegetation with a life extending over several decades. The biota is important for the turnover of carbon, iodine and technetium in particular.

The masses of the different reservoirs are presented in Table A.1.

2.5 Turnover processes

The turnover of radioactive elements takes place in relation to the movement of certain carriers in different media. Through irrigation as well as dry and wet deposition, the ground is continuously supplied with radioactive substances, while resuspension, leaching and runoff are responsible for a transport in the opposite direction to the atmosphere, groundwater and lake water. In the lake, the activity settles out and is resuspended while at the same time it is carried to the Baltic Sea through water turnover. Exchange of activity between water and sediment occurs there as well. The Baltic Sea is connected via Öresund and The Belts with the global sea area. Exchange takes place between the global atmosphere and the sea by means of evaporation, precipitation and aerosol formation. Radioactive elements are recirculated in the global land area by means of resuspension, leaching and runoff.

The structure of the model permits the recirculation of radioactive elements between different parts of the reservoir system.

The exchange of radionuclides between the reservoirs is described by transfer coefficients which give turnover per unit time. Water balance calculations and hydrological information concerning water turnover on a regional and global scale are used in cases where groundwater and surface water are carriers. With this as a basis and with the aid of distribution coefficients determined by the mobility of the nuclide in relation to that of water, nuclide-specific coefficients for transfer between soil and water are obtained.

Studies of fallout radioactivity from nuclear weapons tests have provided information on the dispersal and deposition of various nuclides in various media. Leaking storage facilities and releases have also contributed to information on how elements migrate in soil and water (9, 13, 19, 22, 28). The distribution of the equivalent stable isotopes of the radioactive elements or of chemically analogous elements in the different reservoirs, as well as experimental data from field and laboratory studies, have also been used in the calculations (13, 17, 18, 23, 26).

8 The transfer parameters with derivations are reported in Appendix B.

3. EXPOSURE SITUATIONS

3.1 Exposure pathways

When the radioactive nuclides are exchanged between the different reservoirs in the model, they can reach man via different paths of exposure (Figure 3). Internal exposure via inhalation, food and drinking water and external exposure from material deposited in the ground have been shown by experience to be of particular importance. Bathing, presence on beaches where radioactive material has accumulated and handling fishing tackle which has come into contact with bottom sediments constitute such possible paths of exposure. Internal exposure from food can take place via a number of links in the ecological transport chain such as uptake in crops via root uptake, direct deposition on vegetation, uptake in fish via water and uptake via the food chain of grass-meat, grass-milk and grain-eggs.

Certain feedbacks in the ecosystems reinforce the flow of radioactivity along certain paths of exposure. In the local and regional areas, pastures and crops are irrigated, which leads to contamination of the groundwater. For mobile nuclides such as C-14, the exchange between water, atmosphere and soil is important, particularly in the coast alternative. In this case, there is also a dose burden via the land-based paths of exposure.

3.2 Exposure of critical group

According to the radiological definition, the critical group shall consist of a limited number of individuals who can receive higher doses than average. It is assumed that the same group is critical with regard to the activity which reaches both the well and the lake in the first inflow alternative.

The different paths of dispersal, inland and coast, lead to different paths of exposure. The ones which have been dealt with for the different alternatives of well, lake and Baltic Sea are:

Path of exposure	Inflow alternative [a]
Soil - grain	W, L
Soil - green vegetables	W, L
Soil - root vegetables	W, L
Soil - grass	W, L
Grass - milk	W, L
Grass - meat	W, L
Grain - eggs	W, L
Drinking water	W, L
Water - fish (fresh and salt water fish, respectively)	W, L, B
Land (external exposure)	W, L
Beach activities (external exposure)	L, B
Bathing (external exposure)	L, B
Fishing (external exposure)	L, B

a) W (well), L (lake), B (Baltic Sea)

Radioactive matter enters the local ecosystem in the inland alternative via irrigation. The radioactive elements accumulate in the upper 0.5 m of the soil and are gradually distributed in the environment via groundwater and surface water runoff. Exposure has been calculated with regard to these factors.

Thus, in the well alternative, man is exposed both to the activity which is drawn up with water from the well and to the activity which reaches the lake and leads to contamination of fish.

When the lake is the primary recipient, exposure in the local area takes place via activity in the lake water and the sediments. An indirect path is provided by wells in contact with groundwater outside the primary recipient for activity from the repository, but located in that part of the region where activity is supplied via irrigation from the lake. In some cases, this path has been found to be at least as important as the one where the well comes directly into contact with groundwater from the repository.

In the Baltic Sea case, the land-based paths of exposure can generally be disregarded; exposure here takes place via water and sediment. The concentration of radioactive elements in the bottom sediments also describes the contamination of shores. Certain elements such as C-14 are transferred rapidly from the water to the air reservoir and are then transferred on a relatively large scale to the land nearby. For such situations, the dose to the individual in the region via agricultural products has been added to the dose burden on the critical group.

3.3 Exposures of populations

The exposure pathways in the regional ecosystem are the same as in the local system. However, the average exposure of individuals in the region differs quantitively from that in the local system.

In the regional agricultural area of 30 x 30 km^2, the surface water includes a specified lake. Water from the lake is used for irrigation within the region to an extent which corresponds to the statistical average for central Sweden. On the basis of the size of the lake, (5 km^2 surface area), this means that 60 km^2 of the region's 900 km^2 are assumed to be irrigated directly with water from the lake. In Sweden, lakes make up approximately 8% of the surface area of the country. On the basis of a mean density of 20 persons per km^2 (38), the regional population in the inland alternative consists of 18 000 individuals. Of these, 1 200 individuals eat fish from the lake.

The population in the coastal region is the same as for the inland alternative; 1 200 individuals take their fish from the Baltic coastal zone.

The size of the population which is exposed in the intermediary area is calculated on the basis of fish consumption. The total yield of fish for human consumption from the Baltic Sea is approximately 200 million kg per year (24). With an average consumption of 20 kg per year and individual, the affected population is 10 million persons. With regard to external exposure, the situation

for the population in the Baltic Sea area is assumed to be qualitatively identical to that in the coastal zone in the local and regional systems.

The same paths of exposure have been assumed for the world population as for the regional area. Diet composition for the global population is reported in Appendix C. Dietary habits are simplified by necessity, for example fish is the only food taken from the sea. The analysis of variation in Chapter 6 reports the changes in the result which can occur if another utilization of the food resources of the sea is assumed.

6.10^9 individuals is the starting value for the global population in the year 2000. Growth thereafter will take place exponentially at a rate of 2% per year and will stop at $1 \cdot 10^{10}$ individuals. Of the world population, it is assumed that 1% lives in coastal regions with an exposure situation similar to that in the Baltic Sea area.

For the remaining 99%, the exposure situation is qualitatively similar to that in the regional agricultural area. Tables showing the different times for external exposure and the size of the populations in the different areas follow below.

Exposure times (h/year) for the external paths of exposure, by area:

Area	Local		Regional		Baltic Sea	Global	
	Lake alt.	Coast alt.	Inland	Coast alt.		Coast	Inland
Bathing	30	30	30	30	30	30	
Beach	90	90	90	90	90	90	
Fishing tackle	30	1 000	30	30	10	10	
Ground	8 760		8 760				8 760

Population sizes for the different paths of exposure and areas:

Paths of exposure	Region		Baltic Sea	Global
	Inland alt.	Coast alt.		
Inhalation and consumption of terrestrial foodstuffs	1.8×10^4	1.8×10^4		1×10^{10}
Fish consumption	1.2×10^3	1.2×10^3	1×10^7	1×10^{10}
External exposure via bathing, beach activities and handling of fishing tackle	1.2×10^3	1.2×10^3	1×10^7	1×10^8
External exposure from the ground	1.8×10^4			1×10^{10}

3.4 Uptake in food chains

The uptake of radioactive elements in different foodstuffs via various paths of uptake has been calculated in the following manner:

Symbols:

U_i = Uptake of a certain nuclide in foodstuff i. Given in Ci per unit of foodstuff (kg, litre or piece).

F_i = Distribution factor for a given nuclide for foodstuff i. Given in day per unit of foodstuff (kg, litre or piece).

i =

m	milk (litres)
l	water consumption per animal (litres)
k	meat (kg)
v	green vegetables (kg)
g	grain (kg)
r	root vegetables (kg)
e	eggs (pcs)
f	fish (kg)
p	pasturage (kg)

C_j = concentration of a certain nuclide in reservoir j. Given in Ci per unit of reservoir.

j =

w	groundwater (litres)
a	air (kg)
l	lake water (litres)
s	soil (kg)

E_n = concentration factor for certain nuclide for uptake via n, where

n =

p	soil -> pasturage
v	soil -> green vegetables
g	soil -> grain
r	root -> root vegetables
f	water -> fish

MC_i = daily consumption of water and foodstuff for animal in dominant transport links (1/day, kg/day).

DEP = deposition (m per day).

COV_i = degree of coverage for green vegetables and pasturage (kg per m^2).

IRR = irrigation ($\ell m^{-2} day^{-1}$).

R = average residence time on vegetation = 29 days.

The retention of fallout on leaf surfaces is assumed to be 80%.

The values for the quantities F_i, E_n, MC_i, DEP, COV_i and IRR which were used are given in Appendix C, Table C.2 and Table C.3.

For each nuclide, the following equations are obtained for uptake in the different foodstuffs:

Uptake in milk and meat

Radioactive elements in meat and milk originate from uptake over the following ecological paths of transport:

- Root uptake to pasturage
- Deposition on pasturage
- Drinking water

U_m (in Ci per litre) =

$$F_m \left(Mc_p \times E_p \times C_s + Mc_l \times C_l + 0.8 \times DEP \times C_a \times R \times COV_p^{-1} \times Mc_p\right)$$

U_K (in Ci per kg) =

$$F_K \left(Mc_p \times E_p \times C_s + Mc_l \times C_l + 0.8 \times DEP \times C_a \times R \times COV_p^{-1} \times Mc_p\right)$$

Uptake in green vegetables:

The concentration of radioactive elements in green vegetables originates from two sources: the uptake of radioactivity via the root system and deposition directly on the surfaces of the leaves. The concentration factor between soil and plant is specific for each individual nuclide.

U_v (in Ci per kg) =

$$E_v \times C_s + 0.8 \times R \times COV_v^{-1} (IRR \times C_l + DEP \times C_a)$$

Uptake in Grain and Root Vegetables:

Uptake in grain and root vegetables is assumed to take place primarily through the root system.

U_g (in Ci per kg) = $E_g \times C_s$

U_r (in Ci per kg) = $E_r \times C_s$

Uptake in eggs:

The radioactivity in eggs comes from feeding the hens with contaminated grain and drinking water.

U_e (in Ci per egg) = F_e ($Mc_g \times E_g \times C_s + Mc_l \times C_w$)

Uptake in fish:

Uptake in fish takes place through the inflow of contaminated groundwater into the lake and the feedback of radioactivity from the runoff area and the bottom sediments.

U_f (in Ci per kg) = $E_f \times C_f$

3.5 External exposure

Exposure from ground:

The following formula has been used to calculate the external dose from radioactivity in the soil and on beaches, taken as an infinite surface source (65).

$$D = \frac{N}{4} \log \left(\frac{R^2}{d^2}+1\right) \cdot A \cdot E \cdot 5.75 \cdot 10^{-5} \cdot f \cdot t \cdot B \text{ rem year}^{-1}$$

where

N = number of particles or photons emitted each second per unit area of the source

R = radius of radiation source (10^3 cm in the calculations)

d = height above radiation source (100 cm in the calculations)

A = fraction of energy absorbed per cm tissue. In the case of β - radiation, it is assumed that all energy is absorbed in a 1 cm thick layer of tissue. Energy absorption from β -particles with a kinetic energy of less than 70 keV has not been taken into consideration owing to their extremely short ranges.

E = energy in MeV of particles or photons. A.E for γ -emitters has been obtained from a graph (54). For β-radiation, 100% absorption within 1 cm thick tissue as above has been assumed.

B = weighting factor for reduction of exposure due to limited particle range or attenuation.

f = portion of total number of disintegrations with higher energy than E, expressed in percent.

t = exposure time (hours per year)

$5.75 \cdot 10^{-5}$ = unit conversion factor for $MeVs^{-1}$ to $remh^{-1}$.

The kinetic energy of the β-particles is very low for the long-lived nuclides in question. The ranges are therefore very short, entailing a penetration of no more than 1 mm in soil or sediment (60). Only 1% of the radioactive material which is assumed to be homogeneously distributed in the upper 10 cm of the soil can therefore give rise to β-exposure above the surface of the ground. For a dose from β-particles, B = 0.01.

According to calculations (61), approximately 70% of the total dose from γ-radiation at a point 100 cm above the surface originates from disintegration in the uppermost 10 cm thick layer, provided the activity is homogeneously distributed to infinite depth. Self-absorption, assuming a homogeneous distribution of activity, is around 30% in a 10 cm thick layer of soil. The hypothesis in the dose calculation formula on the previous page that there is no attenuation in the soil reservoir thus involves an overestimate by 30% of the disintegrations in this layer, the upper 10 cm of the ground. This is nearly completely compensated for by the 30% of the total

exposure which originates from disintegrations at depths greater than 10 cm in the soil reservoir. The doses from beach activity (i.e. the sedimented material), when all activity is distributed as a surface source, thus gives an overestimate of around 30% for gamma doses compared with homogeneous mixture in a 10 cm surface layer.

Exposure in connection with bathing:

The following relations have been used for calculating skin doses via bathing.

$$D_\beta = 51.2 \cdot Q \cdot 0.33 \cdot E_m \cdot$$

$$\cdot f\left(1 - \frac{\sqrt{Z}}{50}\right)\left(1 + \frac{\sqrt{E_m}}{4}\right) \frac{0.5}{24} \cdot t \text{ rem year}^{-1}$$

Q = μ Ci of the nuclide per g water.

0.5 = factor which adjusts for the low kinetic energy and thereby relatively high absorption in water of the β-particles.

24 = number of hours per day.

$0.33 \cdot E_m$ = mean energy of β-particles from disintegration.

51.2 = unit conversion factor for disintegrations per day and μ Ci to rem per Mev.

Z = atomic number of nuclide.

$$D_\gamma = 51.2 \cdot Q \cdot E_m \cdot f \cdot \frac{1}{24} \cdot t \quad \text{rem year}^{-1}$$

A 4π geometry has been assumed, i.e. the submerged body is in the centre of a large sphere which is exposed isotrophically.

Exposure from fishing tackle:

The whole-body dose from the handling of contaminated fishing tackle has been assumed to derive from the activity in 10 kg of fishing tackle (wet weight) at a distance of 100 cm in the form of a point source. The following relation applies:

$$D_\gamma = \frac{N}{4\pi 100^2} \cdot A \cdot E \cdot 5.75 \cdot 10^{-2} \cdot t \quad \text{rem year}^{-1}$$

with symbols as above.

In this case, N = Ci of the nuclide per kg of fishing tackle times the number of particles or photons per disintegration.

8

4. DISPERSAL SCENARIOS FOR UNREPROCESSED URANIUM FUEL

A number of different dispersal scenarios have been studied within the project (64). Some of the source strengths obtained in this manner have then been used as a basis for dose calculations for all or one of the inflow alternatives. Following is a presentation of the different scenarios and a table of the retention factors in rock used in connection therewith. The two main cases described in the KBS report on unreprocessed spent nuclear fuel are described first. The dose results are presented and discussed in Chapter 5 for the main cases. For the other cases, dose calculations for the outflow alternatives considered in each case are reported in Appendix A in the following order.

1. All canisters have degraded after 100 000 years, leaching from the repository proceeds for 500 000 years, transit time for groundwater to the biosphere 3 000 years, retention factors as given in table, set c.

2. Degradation and leaching, see para. 1, transit time for groundwater to the biosphere 400 years, retention factors set b.

3. All canisters have degraded after 10 000 years, leaching from repository proceeds for 10 000 years, transit time for groundwater to biosphere 400 years with retention factors according to set a.

4. Same as para. 3, but with leaching period of 100 000 years.

5. Same as para. 3, but with leaching period of 1 000 000 years.

6. Concerned solely with gap activity in case where one canister breaks down immediately, leaching from canister proceeds for 1 000 years, otherwise as in para. 1.

7. All canisters have degraded after 3 000 years, otherwise as in para. 2.

Retention factors in rock, Ki

Element	Set a	Set b	Set c
Ni	-	-	6 100
Sr	51	120	1 500
Zr	8 000	4 800	61 000
Tc	1	1	950
I	1	1	1
Cs	800	1 200	4 000
Ce	80 000	19 000	200 000
Nd	25 000	3 000	200 000
Eu	50 000	30 000	200 000
Ra	670	1 200	48 000
Th	5 100	1 900	46 000
Pa	37	37	11 000
U	41	1 900	23 000
Np	1 100	2 800	5 700
Km	80 000	19 000	610 000
Cm	40 000	950	305 000

5. RADIATION DOSES

The radioactive elements which enter the biosphere via the groundwater expose man to ionizing radiation caused by radioactive decay both in the environment, leading to external irradiation, and in the body, leading to internal irradiation.

The size of the radiation dose to different organs through internal irradition is dependent upon, among other things, how the nuclide enters the body. Important factors are in which substances the radioactive nuclide is present, whether the activity is ingested with drinking water and food or inhaled and to what extent the airborne activity is carried by particles.

Portions of the particle-borne activity in the respiration air can be absorbed by the blood through the lungs or remain in the lungs or be tranferred to the intestinal tract. In recognition of such factors, the radiation protection authorities have chosen to assess doses on the basis of the solubility or "transportability" of the element and the paths of intake, i.e. inhalation or consumption of drinking water or food (3, 4, 8).

5.1 Dose factors

The dose factors which have been used in the calculations in this study and which describe how the intake of 1 Ci of a certain nuclide can be translated into radiation doses pertain to the soluble or transportable form which has been ingested with food and drinking water and the

insoluble or non-transportable form which is inhaled. The portion which is carried from the lungs to the intestinal tract is assumed to be transportable.

The dose factors for the whole-body dose calculated in accordance with previous recommendations of the International Commission on Radiological Protection ICRP (8), organ doses and the weighted whole-body dose in accordance with new regulations (4) are presented in Appendix D, Table D.2 for the nuclides in question.

The health effect (2) is dependent upon the radiation dose level and a number of other factors, including the range of the ionizing radiation in tissue, the ionization density, which tissue is exposed to irradiation and the time span over which the exposure takes place.

Thus, the biological effect of the absorbed dose may vary widely. However, if the dose is given in rem, as in these calculations, the relative biological impact of different types of radiation and exposure situations is taken into account.

Some organs are more sensitive to radiation and accumulate more of a given radioactive element than others. Moreover, the most sensitive organs vary for the different nuclides.

An attempt is made to take into account the combined effect of different doses to different organs on the human body by means of the so-called "whole-body" dose, which consists of weighted dose contributions from the radiologically most important organs in the body. The weighting factors (4) which have been used in the dose calculations, are presented in Appendix D.1. These weighting factors apply regardless of age and sex, and are relevant for an average dose burden in the population.

The weighted whole-body dose, D, can be calculated as follows:

$$D = \sum_{i=1}^{n} f_i R_i + \left(1 - \sum_{i=1}^{n} f_i\right) \times R_{tb}$$

f_i = weighting factor for organ i
R_i = dose factor (rem/Ci) for organ i
R_{tb} = dose factor, whole-body (rem/Ci)

The dose to individual organs is proportional to the biological turnover time of the nuclide in the organs. The annual intake of the long-lived nuclides changes extremely slowly. In most cases, an equilibrium situation is therefore attained where the total dose from a single year's intake is numerically equal to the annual dose in the case of continuous intake. With turnover times spanning several generations, where such a state of equilibrium is not attained during the lifetime of one person, the individual dose is calculated over a period of 50 years. This applies to bone doses for most of the heavy nuclides such as thorium, neptunium, plutonium and americium.

In judging the risks of genetic damage, the radiation doses to the gonads, i.e. the reproductive organs, are more relevant than the weighted whole-body dose. Dose factors for the gonads are given in Appendix D.2 for nuclides which can give a relatively heavy dose to these organs.

Of the radium which is absorbed by and remains in the body for more than a few days, most accumulates in the skeleton (54). When radium-226 decays, most of the decay energy is carried by α-particles with very short ranges. The cell tissue which covers the bones thereby receives the highest doses, making it a "critical organ" in relation to its dose limit (8, 55). The blood-forming organs in the bone marrow receive an average of one-tenth of the dose received by the bone-forming cells on the surface of the bone. The turnover of radium in the soft tissues of the body is rapid, so the doses there are only about 1/25th of those in the bones. It should therefore be expected that the whole-body dose will be lower than the dose for the critical organ. Only the oldest dose calculations from ICRP still include the whole-body dose of radium-226. At that time, however, knowledge concerning the metabolism of radium in the human body was relatively uncertain, which can be seen from the fact that the whole-body dose is of the same magnitude as the dose to bones later calculated by ICRP. In the case of radium-226, the use of the calculation principles in formula (2) above should therefore lead to a considerable overestimation of the dose. The calculations for this isotope have therefore been based on the dose to bones and bone marrow and the dose to soft tissues has been substituted for the whole-body dose.

5.2 Collective dose and dose commitment

The collective dose is the sum of the various doses to all individuals in a given population. Model studies of the radioactive elements which are cycled within and between different ecosystems make it possible to calculate the collective doses to three different populations: the regional population, the Baltic Sea area population and the global population outside of the Baltic Sea area.

Which of these populations is dominant with respect to collective dose will vary depending upon the nuclide and the time after inflow to the biosphere. The local population does not make a significant contribution to the collective dose.

If the individual or collective doses from a given radioactive release are integrated in time, the dose commitment for an unlimited future is obtained. The concept of dose commitment is intended to be used to estimate the long-term accumulation of doses from the radioactive releases of different years (4). For such extremely long-lived nuclides as those which can occur in the groundwater-borne material, the radiation protection authorities have, with regard to other phases of the nuclear fuel cycle, chosen to introduce the concept of accumulated dose over a period of 500 years in addition to dose commitment.

The gradual dispersal of radioactive material from the repository out into global circulation is a very slow process governed by carrier transport and ecological turnover, which is more or less specific for the different nuclides. In the case of sufficiently long-lived and mobile nuclides, the time for the maximum collective annual dose may in many cases not be attained for thousands of years after the outflow maximum has been reached.

Two different points of departure are possible in calculating the long-range collective doses:

- the maximum accumulated collective dose over a 500-year period from a certain final repository of average size

- the maximum collective annual dose from such a final repository multiplied by the maximum number of years for which it can be assumed that nuclear power generation by fission will proceed, i.e. 500 years

Since changes in dose rate take place very slowly, the accumulated dose for a 500-year period around the time of the maximum collective annual dose will be approximately equal to this annual dose multiplied by a factor of 500.

5.3 Doses for different scenarios for inflow to the biosphere

Doses to the critical group as well as annual and accumulated collective doses have been calculated for the groundwater-borne radioactive material which reaches the biosphere via the paths of inflow: well, lake and Baltic Sea coast.

Tables 2 and 3 illustrate the maximum dose burden to the critical group, the time of the maximum dose, the contributions form the three dominant paths of exposure and the maximum annual collective dose for the two main cases. Table 4 shows the percentage distribution of the collective annual dose in the inland and Baltic Sea alternatives.

In general, the maximum individual dose in the well alternative is greater than or equal to the corresponding dose in the lake alternative.

The collective doses are the same for the inland alternatives. The coast alternative gives markedly lower doses to the critical group and the population.

Different paths of exposure can be dominant, depending upon whether the nuclide is transported with the groundwater from the repository or is generated upon the decay of a long-lived parent nuclide which has already reached the biosphere.

The maximum dose to the critical group and the maximum collective annual dose to the population for a given nuclide are often obtained at different points in time. Moreover, the dose to the critical group is often heavily dependent upon the timetable for the inflow.

The term "secondary well" is used in the following comparison. It is used to refer to the wells which are situated in that part of the region which is irrigated from the lake.

Individual dose

Inland alternative

In the well alternative, drinking water consititutes the crucial path of exposure for most nuclides. Fish, however, is the most important source with respect to cesium, owing to the high concentration factor for fish relative to water.

Collective dose

Inland alternative

For the uranium isotopes as well as radium and cesium, the dominant contributions to the collective dose derive from fish consumption.

In the lake case, the exposure is generally dominated by drinking water consumption from secondary wells. This applies specially for those nuclides which are greatly retarded in relation to the movement of the water through the soil layer and their radioactive decay products. For the more mobile nuclides, food consumption dominates.

For thorium-230, plutonium and thorium-229, as daughter product to uranium-233, drinking water from secondary wells is the dominant path of exposure.

Coast alternative

In the Baltic coastal zone, exposure from fish consumption generally dominates. In the case of thorium-229, external irradiation from beach activities and fishing tackle dominate.

Coast alternative

In most cases, the collective doses derive from exposure via fish in the global area, the exceptions being the thorium isotopes and the mobile nuclides carbon-14, technetium-99 and iodine-129. In the case of thorium-229, external exposure via sediment in the coastal region and the Baltic Sea dominates.

In the case of mobile nuclides such as carbon-14, terrestrial foodstuffs also contribute significantly to the exposure. Carbon-14 is rapidly transferred from the water reservoir via the adjacent atmosphere and to neighbouring agricultural areas.

The mobile nuclides make the largest contributions via agricultural products in the global area.

6. ACCURACY OF THE MODEL PREDICTION

The reliability and precision of the calculated doses is dependent upon the structure of the model, the choice of exposure pathways, numerical approximations in the calculations and uncertainties in the utilized data.

6.1 Model design and paths of exposure

The components of the compartment model have been designed on the basis of previous radioecological models (5, 6, 7). These main components are the regional, intermediary and global ecosystems. The final model has been evolved by a process where reservoirs have successively been introduced in these main areas in order to allow testing of the significance of each single reservoir with regard to radiation doses to the critical group and population.

The radioactive nuclides are present at very low concentrations compared to the stable isotopes of the respective elements or chemically analogous carriers. The amount of radioactive matter present, e.g. in a water recipient, cannot affect the rate of transfer to adjacent reservoirs. Thus the assumption of first order kinetics (i.e. that the outflow from a reservoir "j" is dependent solely upon the amount of radioactivity in the reservoir) yields a very accurate description for most reservoirs.

The premise of instantaneous homogeneous mixture in the reservoirs can be assumed to be satisfactorily fulfilled in most cases. The different surface water and atmosphere reservoirs are examples of such ideal reservoirs. In

ecosystems, such ideal reservoirs are often connected to areas with concentration gradients, such as soil and sediment. Studies of fallout activity have shown that residence times for nuclides in soil and sediment vary with depth. In view of the long time spans involved, however, these reservoirs may be satisfactorily treated as if the activity were homogeneously distributed (6, 7, 56).

The 13 exposure pathways which have been included in the calculations cover the most important pathways for doses to man according to general radiological experience. Radioactive elements can reach man via his food by way of direct deposition on vegetation, root uptake or accumulation in animal products. The exposure paths also take into account internal and external doses originating from activity in the air, ground and water. The structure of the model also permits studies of future changes of diet composition. Such possible changes which could make other exposure pathways interesting are dealt with in sections 6.4 and 6.7.

6.2 Numerical approximation

The numerical method which is used in the model makes it possible to estimate the uncertainty which has been introduced by approximations in the iterative processes. Error analyses have shown that uncertainty stemming from numerical approximations is no more than 20% in calculated doses. In most cases, it is less than 5%.

6.3 Variations in exchange between the reservoirs in the ecosystems

Transfer parameters for the exchange between the reservoirs in the model are given for each nuclide in Appendix B, Tables B.4 and B.5, for the inland and Baltic Sea alternatives, respectively.

These coefficients have been derived from empirical and calculated data from the literature. In some cases, the span in the interval is large. In such cases, the values which give a higher dose burden with regard to both the critical group and populations have generally been used. If other values within the specified interval are chosen, the doses may deviate from the results.

In the inland alternative , the dose burden to the regional population is largely dependent upon the amount of irrigation and the rate of water turnover in the lake. This is especially true for those nuclides which are greatly retarded in relation to the water turnover and which thereby give the greatest dose contribution via drinking water from the regional area. The doses which are discussed below are, for all nuclides, the maximum doses in time to individuals or the population.

In the coast alternative, the dose burden to the critical group is determined primarily by the rate of water exchange in the coastal region.

The amount of irrigation has been assumed to be relatively high in this study, with 10% of the farming acreage being irrigated in comparison with the average value for Sweden of 3%. For those nuclides where fish or a primary well do not constitute important paths of exposure, the dose burden to the critical group and the regional population would increase more or less proportionately to the irrigation intensity.

This also applies to the dose burden to the critical group from nuclides such as the thorium isotopes and the daughter product Ra-226, for which the dominant path of exposure is drinking water from secondary wells. For the decay chain thorium-radium, an irrigation intensity approximately 4 times lower would reduce the individual and collective doses from thorium by a factor of 4. The contribution from the daughter product would decrease by a factor of about 2.

The dose contribution from the nuclides, especially Cs-135, whose dominant path of exposure is fish is inversely porportional to the water exchange rate.

The dose burden in the coast alternative is also inversely proportional to the water exchange rate. A more rapid water exchange within reasonable limits can reduce the doses by a factor of 3, while a poor rate of exchange can increase the doses by a corresponding factor.

In a sensitivity analysis concerning the rate of exchange for thorium between sediment and water, two situations have been studied. The one is based on the maximum transfer from sediment to water in the calculated interval, $3 \cdot 10^{-6}$-10^{-4} per year (see Appendix B), while the same feedback as for plutonium has been used in the other extreme case. When a transfer coefficient of 10^{-4} is used for Th-230 instead of that given in Table B.4 of Appendix B, the individual dose is increased 1.5 times in the well case and 7 times in the lake case. The collective dose is increased by a factor of 7. Only a slight change in the doses is obtained for the daughter product Ra-226.

Using the same feedback from sediment to water for thorium-229 as for plutonium results in a 1.2 times higher individual dose in the lake case and an equally great increase of the corresponding collective annual dose. The size of the dose contributions from the different paths of exposure, is, however, changed radically. The internal dose contributions to the critical group increases approximately 36 times while the external contributions lose their significance. The redistribution of the dominant paths of exposure explains the relatively small change in the final result.

The turnover time for groundwater in the region has been assumed to be 3 years. For thorium-230 with daughter product radium-226, a turnover rate which is three times faster reduces all doses by 30% except the individual dose for the parent nuclide in the well alternative.

A 25 times more rapid transport of plutonium from the soil reservoir to the surface water in the inland alternative reduces the collective dose by 30% while the dose to the critical group remains essentially the same. However, a very strong retardation in the soil reservoir for plutonium reduces all doses sharply, except for the doses to the critical group in the well case.

The dominant exposure pathway for cesium is fish. Although the sedimentation rate in the typical lake is relatively low, a 10 times higher sedimentation rate, which can occur in certain nutrient-rich lakes, does not deplete the concentration in the water sufficiently to cause any appreciable change in the dose burden.

6.4 Variations in diet composition and uptake through food chains

The critical group shall represent a few individuals who, owing to their diet and their living habits, receive relatively higher doses than average. With this purpose, a suitable diet has been composed for the critical groups in the inland and coast alternatives. For most nuclides, water, fish, milk and meat are the dominant paths of exposure in the inland alternative. Water consumption can hardly be increased above the assumed 440 l/yr. If the relatively high consumption of freshwater fish (50 kg/yr) were to be reduced by half, the dose from cesium-135 would be reduced nearly proportionately. However, the doses from thorium, americium, radium and uranium would be reduced by less than one-third.

Reasonable changes in the consumption of milk and meat have only a slight effect on the dose in the inland alternative.

The uptake of nuclides in food chains, which is expressed in the model by means of concentration factors, e.g. for uptake in fish from water or uptake in foodstuffs from soil, is a critical factor in determining the internal dose burden. Uncertainty here, especially in the concentration factors for uptake in fish, generally has a significant effect on the total dose burden, due to the fact that this path of exposure is so often of great importance.

Certain nuclides accumulate selectively in skeletal tissues in fish. Radium, thorium, uranium and plutonium are examples of such "bone-seeking" nuclides. The skeletal parts are removed for the most part during processing and are not used in food for human consumption. Approximately half of the total fish catch consists of industrial fish which are used for animal feed and fertilizer. In this case, the entire fish is utilized. Such indirect introductions into the food chains are assumed to be of less importance than direct use for human consumption.

Differences in the rate of turnover of elements in different freshwater ecosystems result in natural variations in the concentration factor (62). In the case of Cs-135, the dose can vary in relation to the given value by a factor of 5 in either direction in the inland alternative. In the literature (22, 30), a concentration factor

of 10 - 100 has been given for the concentration of Ra-226 in freshwater fish, while Swedish investigations (31) have given values of around 1 - 3. A concentration factor for Ra-226 in freshwater fish of 15 has been used in the calculations. In the lake case, the doses for Ra-226 can thus vary by a factor of approximately 7 in either direction.

The uptake of radioactivity from soil by plants varies widely, depending upon such factors as the species of plant and soil condition. The variation interval and the typcial values which have been chosen in the calculations are given in Table C.2. If extreme values for uptake factors are used, the dose burden to the critical group or the regional population is not appreciably altered, since the important paths of exposure via milk and meat depend primarily on the cow's consumption of well or lake water.

The increase in individual and collective doses resulting from the use of the upper limit of the concentration factors (see Table C.2) or, in the case of nuclides lacking variation intervals, from the multiplication of the values by a factor or 10, can be seen below.

	Relative increase of annual dose with the use of extreme concentration factors.	
	Individual	Collective
I 129	3	3
Cs 135	13	2
Ra 226	4	6
Th 229	2	1
Th 229*	1	1
Th 230	2	7
U 233	2	4
U 234	2	5
Ra 226	4	4

* Th-229 som dotterprodukt till U-233

The critical group which is exposed through the use of water from the primary groundwater recipient generally receives the highest doses. The estimate of the dilution of the activity which can leak out from the repository is necessarily rough. Detailed knowledge on the rate of groundwater turnover at different depths in the areas in question is lacking. The dilution is based solely on the amount of precipitation which falls on the surface above the repository. If groundwater from other areas also contributes to the dilution, the doses received by the critical group via drinking water and irrigation may be overestimated.

6.5 Daughter products in decay chains

In decay chains with radioactive daughter products, the distribution of the daughter product between parts of the biosphere depends to a certain extent on the turnover processes to which the parent nuclide is subjected. Uncertainties in the turnover of the parent nuclide can, in come cases, be amplified in the dose calculations for the daughter nuclide. In view of the relatively large dose contributions involved, the decay chain of uranium-234 - thorium-230 - radium-226 is of particular interest.

Thorium is dispersed slowly through soil in relation to its physical decay rate. Variations in the rate of exchange between soil and groundwater therefore have a relatively insignificant effect on the amount of thorium present in the soil. With the interface in an inland area, the amount of radium-226 to which the critical group and the

regional population is exposed therefore depends primarily on how rapidly uranium and radium are transported through the surface soil, since this greatly influences the radium levels both in the food chains and in the groundwater which can reach wells in the environment.

Current studies of the transport of uranium and its daughter products (59) indicate that uranium is leached considerably more rapidly through typical Swedish soils than has been assumed in previous studies on vitrified wastes. The field and laboratory studies which have been carried out with respect to strontium and radium (Table B.2) indicate that radium is dispersed considerably more slowly than strontium through soils under widely varying conditions. In previous studies, however, it has been assumed that radium is leached through the soil at the same rate as strontium.

In comparison with the previous calculations concerning vitrified waste, the new choice of transfer rates in the soil-groundwater system for uranium and radium results in a reduction of the exposure of the critical group and the regional population. In the inland alternative, the doses from radium intake are reduced by half with the new transfer coefficients.

6.6 Variations in population distribution

Changes in the regional population distribution can affect the calculated collective doses. This applies especially for the relatively short-lived or poorly soluble nuclides, for which the collective dose derives primarily from the regional exposure. The assumed distribution of 20 persons/km^2 is the average for Sweden (38). A possible future increase of the population density can only lead to a limited increase of the collective doses calculated for the different nuclides.

The yield of fish from the lake has been set at 60 000 kg/year, which is an overestimation. No increase in the collective dose due to an increase in the fish catch can be expected, in view of the limited supply of fish from the primary lake recipient.

In cases where an increase of the population occurs at the expense of the cultivated acreage and food is a critical path of exposure, an increased population density can hardly lead to any increase in the collective dose in the region.

The contribution to the regional collective dose due to irrigation will be proportional to that factor of the regional population which obtains its drinking water from wells which are reached by activity from the irrigation area as well as to the irrigation frequency.

6.7 The relevance of the model in a long-range perspective

The local ecosystems in particular can, over the time spans covered by the forecasts, undergo considerable changes which have significant effects on the exposure situation.

The design of the model permits an anaylsis of the consequences of important changes, such as the draining of the lake which constitutes the primary recipient for groundwater-borne activity from the repository. A gradual draining of e.g. the Baltic Sea can give rise to considerable exposure from the use of sediments in agriculture.

Many elements are deposited and accumulate in the sediments. In the case of the radionuclides which give the dominant internal dose to the critical group or collective dose to the population, draining does not lead to any increase in the annual doses, since cultivation of agricultural products on contaminated sediment gives a smaller dose contribution than that which is obtained through the consumption of fish. In the case of thorium-229, most of which accumulates in the sediments, however, the doses through external exposure can increase considerably in the Baltic Sea case.

The paths of exposure which are covered by the model are based on current dietary habits. Over a longer perspective, however, certain food resources, mainly marine ones, may be exploited to a greater extent and attain global importance.

Overexploitation of traditional fish populations has led to a search for other sources of nutrition from the sea. In addition to increased utilization of fish species which have formerly not been fished, there are large reserves in the form of squid and krill. Algae, especially those of macro-size, have been used in many countries as a food source for a long time.

Any forecast concerning possible future changes in human dietary habits which could lead to an altered dose pattern is, however, highly speculative and can only give a hint of the magnitude of such a change.

Potential catches of krill may suffice for an annual average consumption of 5 - 10 kg per individual for a population of 10^{10} individuals. Great technical difficulties are involved in catching these shrimps. There is little possibility of using plankton as a food source within the foreseeable future. However, the importance of macroalgae as a food source will increase.

It has been assumed that, with no changes in the amount of protein in the diet, 10 kg of meat products are replaced by 10 kg algae annually. The choice of algae has been determined by the fact that for almost all nuclides, the concentration factors for marine plants (28, 35) have been reported to be higher than those for fish or crustaceans. The results are listed in the following table

Nuclide	Concentration factor marine plants	Relative change in collective dose for the inland alternative
U-234	67	2
Pu-242	$1 \cdot 10^3$	3
U-233 U-235 U-236	67	3
I-129	$1 \cdot 10^4$	4
U-238	67	4
Zr-93	$2 \cdot 10^3$	4
Tc-99	$4 \cdot 10^3$	4
Cs-135	$2 \cdot 10^3$	5

The relatively small changes in spite of the considerable increase in concentration factors for some nuclides are due to the distribution of maximum collective dose between the different zones or the great importance of other exposure puthways.

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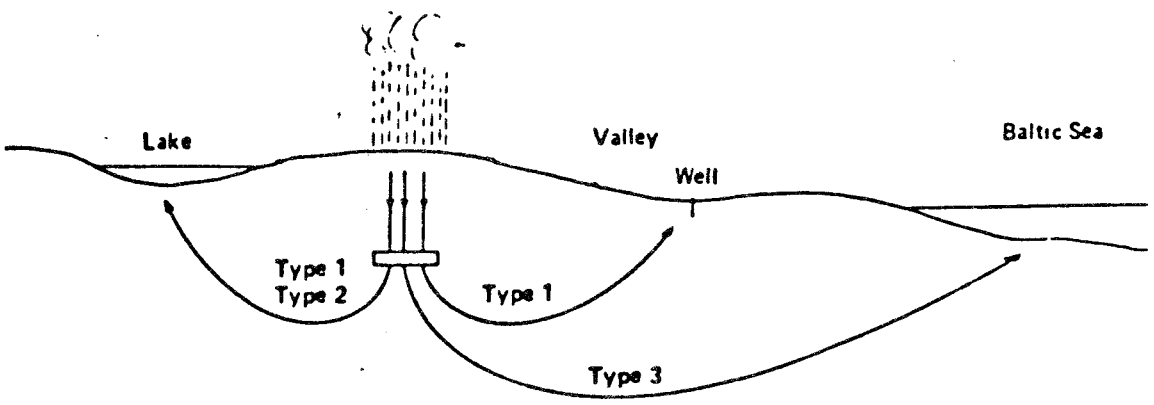

Figure 1 The three main paths of transport of radioactive substances to the biosphere.

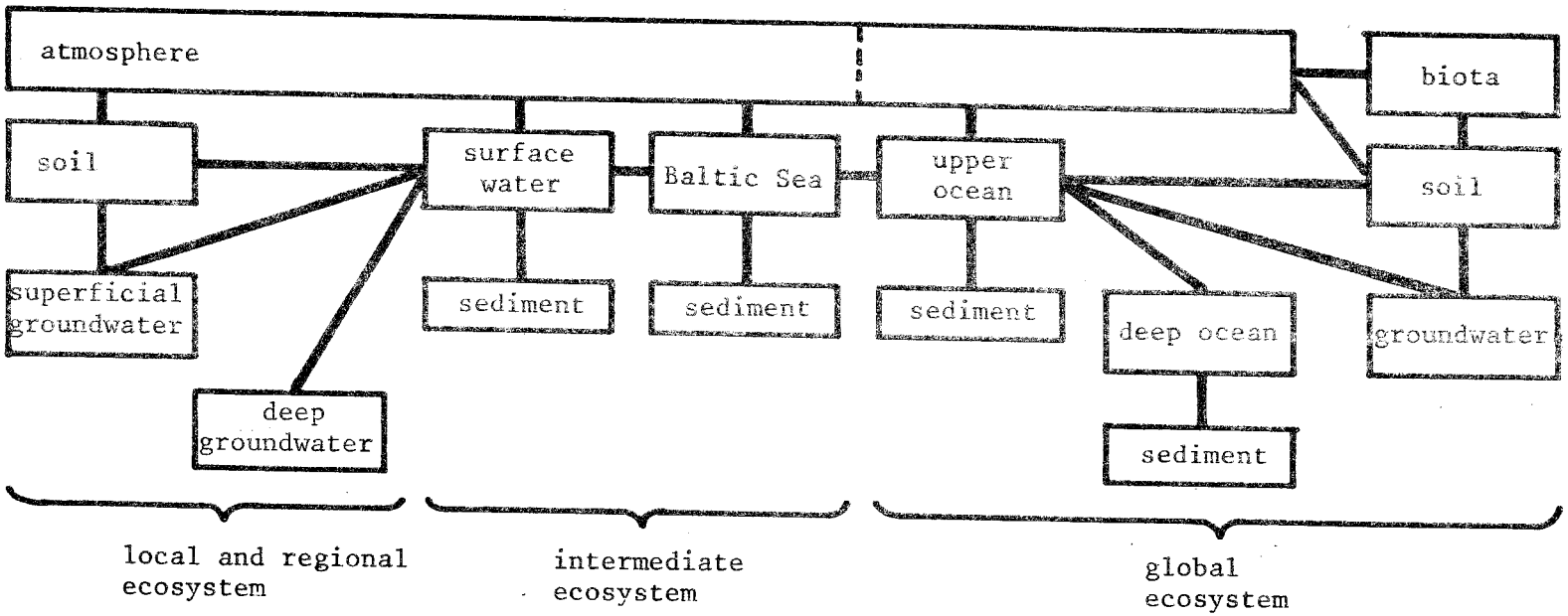

Figure 2. Reservoirs for the different ecosystems. The details of the local ecosystem are not shown in detail.

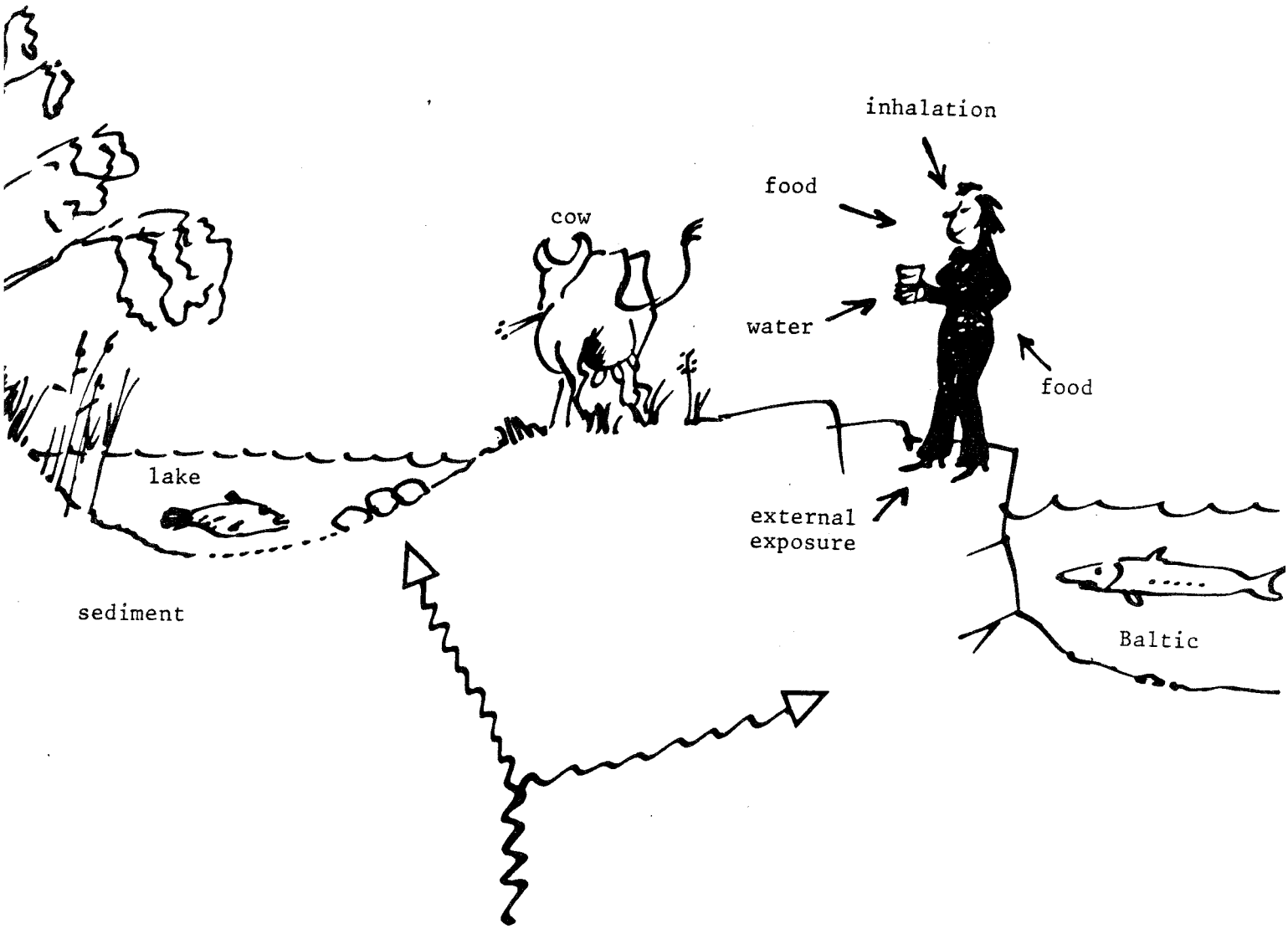

Figure 3 Pathways of human exposure in the ecosystem.

TABLES

Table 1

Areas and masses of the reservoir system

Masses and areas		Alt. 1 and 2	Alt. 3
Groundwater 1	kg	$2.5 \cdot 10^{8}$	$2.5 \cdot 10^{8}$
Groundwater 2	kg	$8.6 \cdot 10^{11}$	$8.6 \cdot 10^{11}$
Soil, regional	kg	$3.6 \cdot 10^{12}$	$3.6 \cdot 10^{12}$
Atmosphere, regional	kg	$4.8 \cdot 10^{14}$	$4.8 \cdot 10^{14}$
Surface water	kg	$1.25 \cdot 10^{10}$	$1.0 \cdot 10^{12}$
Sediment	dm^2	$5.0 \cdot 10^{8}$	$5.0 \cdot 10^{10}$
Baltic Sea	kg	$2.2 \cdot 10^{16}$	$2.2 \cdot 10^{16}$
Baltic Sea sediment	dm^2	$3.7 \cdot 10^{13}$	$3.7 \cdot 10^{13}$
Atmosphere, global	kg	$4.4 \cdot 10^{18}$	$4.4 \cdot 10^{18}$
Surface sea	kg	$2.0 \cdot 10^{19}$	$2.0 \cdot 10^{19}$
Deep sea	kg	$1.4 \cdot 10^{21}$	$1.4 \cdot 10^{21}$
Deep sea sediment	dm^2	$3.6 \cdot 10^{16}$	$3.6 \cdot 10^{16}$
Biota, global	kg	$1.8 \cdot 10^{15}$	$1.8 \cdot 10^{15}$
Soil, global	kg	$1.6 \cdot 10^{17}$	$1.6 \cdot 10^{17}$
Groundwater, global	kg	$6.0 \cdot 10^{19}$	$6.0 \cdot 10^{19}$
Surface sea sediment	dm^2	$2.0 \cdot 10^{15}$	$2.0 \cdot 10^{15}$

Table 2.a

Annual individual and collective doses with dominant pathways of exposure at the time of maximum burden for the outflow based on the main case (case 1 in chap.4) Well case.

Nuclide	Max ind. annual dose rem/yr	Time years	Dominant pathways of exposure 1	%	2	%	3	%	Max. coll. annual dose manrem/yr	Time years
C-14	5.2×10^{-10}	1.0×10^{5}	meat	64	fish	30	water	3	5.0×10^{-4}	1.1×10^{5}
Tc-99	8.2×10^{-9}	3.0×10^{6}	water	50	milk	46	fish	2	4.9×10^{-5}	3.2×10^{6}
I-129	4.2×10^{-4}	1.0×10^{5}	meat	52	water	26	milk	20	1.7×10^{1}	5.8×10^{5}
Cs-135	6.8×10^{-6}	1.2×10^{7}	fish	65	water	14	meat	13	1.5×10^{-2}	1.2×10^{7}
Ra-226[a]	5.2×10^{-3}	6.9×10^{7}	water	59	milk	36	fish	2	1.1×10^{0}	6.9×10^{7}
Ra-226[b]	4.4×10^{-3}	6.9×10^{7}	water	55	fish	23	milk	20	1.2×10^{1}	6.9×10^{7}
Ra-226[c]	2.4×10^{-4}	6.9×10^{7}	water	100	fish	3×10^{-1}	milk	2×10^{-1}	2.2×10^{0}	6.9×10^{7}
Th-230	2.3×10^{-4}	6.9×10^{7}	water	88	miat	10	gr vege	3	1.3×10^{-1}	6.9×10^{7}
Pa-231	3.9×10^{-4}	6.9×10^{7}	water	76	meat	9	gr vege	7	3.9×10^{-1}	6.9×10^{7}
U-234	3.3×10^{-5}	6.9×10^{7}	water	83	meat	9	milk	3	1.2×10^{-1}	6.9×10^{7}
U-235	2.6×10^{-5}	6.9×10^{7}	water	83	meat	9	milk	3	4.2×10^{-2}	1.1×10^{8}
U-236	5.7×10^{-5}	6.9×10^{7}	water	83	meat	9	milk	3	3.9×10^{-2}	6.9×10^{7}
U-238	3.2×10^{-4}	6.9×10^{7}	water	83	meat	9	milk	3	2.3×10^{-1}	7.2×10^{7}
Np-237	3.4×10^{-13}	7.0×10^{7}	water	78	meat	17	gr vege	2	8.0×10^{-12}	7.0×10^{7}

a) Refers to the Ra-226 which reaches the biosphere directly via the groundwater from the repository.
b) Refers to the Ra-226 which is generated by the dacay of Th 230 in the biosphere.
c) Refers to the Ra-226 which is generated by the decay chain U-234 -> Th-230 -> Ra-226 in the biosphere.

Table 2b. Annual individual and collective does with dominant pathway of exposure at the time of the maximum burden for the outflow based on the main case (case 1 in chap 4). Lake case.

Nuclide	Max ind. annual dose rem/yr	Time years	Dominant pathways of exposure 1	%	2	%	3	%	Max. coll. annual dose manrem/yr	Time years
C-14	1.7×10^{-10}	1.0×10^{5}	fish	91	meat	9	milk	3×10^{-1}	5.0×10^{-4}	1.1×10^{5}
Tc-99	3.3×10^{-10}	3.0×10^{6}	milk	55	fish	42	meat	1	4.9×10^{-5}	3.2×10^{6}
I-129	1.9×10^{-5}	1.0×10^{5}	meat	57	milk	22	fish	20	1.7×10^{1}	5.8×10^{5}
Cs-135	4.9×10^{-6}	1.2×10^{7}	fish	91	water	9	meat	9×10^{-1}	1.5×10^{-2}	1.2×10^{7}
Ra-226[a)]	4.3×10^{-4}	6.7×10^{7}	water	52	fish	24	milk	21	1.1×10^{0}	6.7×10^{7}
Ra-226[b)]	4.4×10^{-3}	6.9×10^{7}	water	55	fish	23	milk	20	1.2×10^{1}	6.9×10^{7}
Ra-226[c)]	2.4×10^{-4}	6.9×10^{7}	water	100	fish	3×10^{-1}	milk	2×10^{-1}	2.2×10^{0}	6.9×10^{7}
Th-230	4.6×10^{-5}	6.9×10^{7}	water	99	fish	1	meat	1×10^{-1}	1.3×10^{-1}	6.9×10^{7}
Pa-231	1.5×10^{-4}	6.9×10^{7}	water	93	fish	6	meat	1	3.9×10^{-1}	6.9×10^{7}
U-234	1.9×10^{-5}	6.9×10^{7}	water	57	fish	33	meat	8	1.2×10^{-1}	6.9×10^{7}
U-235	1.5×10^{-6}	6.9×10^{7}	water	57	fish	33	meat	8	4.2×10^{-2}	1.1×10^{8}
U-236	3.4×10^{-5}	6.9×10^{7}	water	57	fish	33	meat	8	3.9×10^{-2}	6.9×10^{7}
U-238	1.9×10^{-14}	6.9×10^{7}	water	57	fish	33	meat	8	2.3×10^{-1}	7.2×10^{7}
Np-237	1.5×10^{-14}	7.0×10^{7}	water	50	fish	29	meat	16	8.0×10^{-12}	7.0×10^{7}

Table 2c. Annual individual and collective doses with dominant pathways of exposure at the time of maximum burden for the outflow based on the main case (case 1 in chap.4). Baltic sea case.

Nuclide	Max ind. annual dose rem/yr	Time years	Dominant pathways of exposure 1	%	2	%	3	%	Max. coll. annual dose manrem/yr	Time years
C-14	3.1×10^{-12}	1.0×10^{5}	fish	98	meat	2	milk	5×10^{-2}	5.0×10^{-4}	1.1×10^{5}
Tc-99	1.0×10^{-12}	3.0×10^{6}	fish	99	milk	1	fish tac	2×10^{-1}	4.8×10^{-5}	3.3×10^{6}
I-129	1.0×10^{-7}	1.0×10^{5}	fish	100	meat	4×10^{-1}	milk	2×10^{-1}	1.7×10^{1}	6.1×10^{5}
Cs-135 a)	2.2×10^{-8}	1.2×10^{7}	fish	100	beach	1×10^{-1}	fish tac	4×10^{-2}	8.1×10^{-3}	1.3×10^{7}
Ra-226 b)	7.0×10^{-6}	6.7×10^{7}	fish	100	gr vege	7×10^{-3}	fish tac	2×10^{-3}	1.1×10^{-1}	6.7×10^{7}
Ra-226 c)	3.0×10^{-9}	6.9×10^{7}	fish	90	fish tac	9	beach	1	1.1×10^{0}	6.9×10^{7}
Th-230	7.3×10^{-7}	6.9×10^{7}	fish	98	fish tac	2	beach	5×10^{-1}	1.7×10^{0}	6.9×10^{7}
Pa-231	1.9×10^{-7}	6.9×10^{7}	fish	100	gr vege	9×10^{-3}			9.7×10^{-5}	6.9×10^{7}
U-234	1.1×10^{-7}	6.9×10^{7}	fish	100	gr vege	4×10^{-2}			2.0×10^{-2}	6.9×10^{7}
U-235	1.3×10^{-9}	6.9×10^{7}	fish	100	gr vege	4×10^{-2}			8.2×10^{-2}	6.9×10^{7}
U-236	9.9×10^{-8}	6.9×10^{7}	fish	91	fish tac	6		3	5.5×10^{-2}	1.0×10^{8}
U-238	2.2×10^{-7}	6.9×10^{7}	fish	100	gr vege	4×10^{-2}			3.9×10^{-2}	7.0×10^{7}
Np-237	1.2×10^{-16}	7.0×10^{7}	fish	100	gr vege	4×10^{-2}			2.3×10^{-1}	7.2×10^{7}
			fish	100	fish tac	2×10^{-1}		4×10^{-2}	1.3×10^{-14}	7.0×10^{7}

Table 3a. Annual individual and collective doses with dominant pathways of exposure at the time of maximum burden for the outflow based on the pessimistic case (case 2 in chap. 4). Well case.

Nuclide	Max ind. annual dose rem/yr	Time years	Dominant pathways of exposure 1	%	2	%	3	%	Max. coll. annual dose manrem/yr	Time years
C-14	6.8×10^{-10}	1.0×10^{5}	meat	64	fish	30	water	3	6.7×10^{-4}	1.1×10^{5}
Zr-93	3.4×10^{-6}	2.4×10^{6}	water	99	fish	2×10^{-1}	meat	3×10^{-2}	2.3×10^{-2}	2.5×10^{6}
Tc-99	9.9×10^{-5}	1.0×10^{5}	water	50	milk	46	fish	2	5.6×10^{-1}	3.9×10^{5}
I-129	4.2×10^{-4}	1.0×10^{5}	meat	52	water	26	milk	20	1.7×10^{1}	5.8×10^{5}
Cs-135	9.9×10^{-5}	5.9×10^{5}	fish	65	water	14	meat	13	2.0×10^{-1}	6.6×10^{5}
Ra-226 a)	3.4×10^{-2}	9.2×10^{5}	water	59	milk	36	fish	2	7.5×10^{0}	9.2×10^{5}
Ra-226 b)	2.5×10^{-2}	1.2×10^{6}	water	55	fish	23	milk	20	6.5×10^{1}	1.2×10^{6}
Ra-226 c)	4.1×10^{-4}	8.8×10^{5}	water	100	fish	3×10^{-1}	milk	2×10^{-1}	3.3×10^{0}	1.3×10^{6}
Th-229	1.3×10^{-2}	9.1×10^{5}	water	87	meat	10	gr vege	3	1.8×10^{1}	9.6×10^{5}
Th-229 d)	9.2×10^{-4}	1.1×10^{6}	water	100	beach	5×10^{-1}	fish tac	5×10^{-2}	9.1×10^{-1}	1.3×10^{6}
Th-230	1.4×10^{-3}	9.2×10^{5}	water	88	meat	10	gr vege	3	6.6×10^{-1}	1.2×10^{6}
Pa-231	2.9×10^{-3}	8.6×10^{5}	water	76	meat	9	gr vege	7	2.5×10^{0}	8.6×10^{5}
U-233	9.7×10^{-4}	9.2×10^{5}	water	83	meat	9	milk	3	3.1×10^{-1}	1.3×10^{6}
U-234	5.2×10^{-4}	8.8×10^{5}	water	80	meat	9	milk	3	1.9×10^{-1}	1.3×10^{6}
U-235	3.1×10^{-5}	9.0×10^{6}	water	83	meat	9	milk	3	1.8×10^{-2}	1.3×10^{6}
U-236	5.4×10^{-4}	1.0×10^{5}	water	83	meat	9	milk	3	3.0×10^{-1}	1.3×10^{6}
U-238	3.9×10^{-4}	9.4×10^{5}	water	83	meat	9	milk	3	1.9×10^{-1}	3.9×10^{6}
Np-237	1.6×10^{-3}	9.3×10^{6}	water	78	meat	17	gr vege	2	7.0×10^{-1}	1.4×10^{6}
Pu-242	5.6×10^{-4}	1.3×10^{6}	water	99	meat	2×10^{-1}	fish	2×10^{-1}	1.7×10^{0}	1.4×10^{6}

a) Refers to the Ra-226 which reaches the biosphere directly via the groundwater from the repository.
b) Refers to the Ra-226 which is generated by the decay of Th-230 in the biosphere.
c) Refers to the Ra-226 which is generated by the decay chain U-234 -> Th-230 -> Ra-226 in the biosphere.
d) Refers to the Th-229 which is generated by the decay of U-233 in the biosphere.

Table 3b. Annual individual and collective doses with dominant pathways of exposure at the time of maximum burden for the outflow based on the pessimistic case (case 2 in chap.4). Lake case.

Nuclide	Max ind. annual dose rem/yr	Time years	Dominant pathways of exposure 1	%	2	%	3	%	Max. coll. annual dose manrem/yr	Time years
C-14	2.3×10^{-10}	1.0×10^{5}	fish	91	meat	9	milk	3×10^{-1}	6.7×10^{-4}	1.1×10^{5}
Zr-93	3.4×10^{-6}	2.4×10^{6}	water	99	fish	2×10^{-1}	meat	3×10^{-2}	2.3×10^{-2}	2.5×10^{6}
Tc-99	3.6×10^{-5}	1.0×10^{5}	milk	55	fish	42	meat	1	5.6×10^{-1}	3.9×10^{5}
I-129	1.0×10^{-5}	1.0×10^{5}	meat	57	milk	22	fish	20	1.7×10^{1}	5.8×10^{5}
Cs-135 a)	7.2×10^{-3}	5.9×10^{5}	fish	91	water	9	meat	9×10^{-1}	1.9×10^{-1}	6.6×10^{5}
Ra-226 b)	2.8×10^{-2}	9.1×10^{6}	water	52	fish	24	milk	21	7.5×10^{0}	9.2×10^{5}
Ra-226 c)	2.5×10^{-4}	1.2×10^{5}	water	55	fish	23	milk	20	6.5×10^{1}	1.2×10^{5}
Th-229	4.1×10^{-3}	8.8×10^{5}	water	100	fish	3×10^{-1}	milk	2×10^{-1}	3.3×10^{0}	1.3×10^{6}
Th-229 d)	7.7×10^{-4}	9.1×10^{5}	beach	73	fish tac	21	water	4	1.8×10^{1}	9.6×10^{5}
Th-230	9.2×10^{-4}	1.1×10^{6}	water	100	beach	5×10^{-1}	fish tac	5×10^{-2}	9.1×10^{-1}	1.3×10^{6}
Pa-231	2.7×10^{-3}	9.2×10^{5}	water	99	fish	1	meat	1×10^{-1}	6.6×10^{-1}	1.2×10^{6}
U-233	1.1×10^{-5}	8.6×10^{5}	water	93	fish	6	meat	1	2.5×10^{0}	8.6×10^{5}
U-234	5.7×10^{-5}	9.2×10^{5}	water	56	fish	32	meat	8	3.1×10^{-1}	1.3×10^{5}
U-235	3.1×10^{-6}	8.9×10^{5}	water	57	fish	33	meat	8	1.8×10^{-1}	1.3×10^{6}
U-236	1.8×10^{-5}	9.0×10^{6}	water	57	fish	33	meat	8	1.8×10^{-2}	1.3×10^{6}
U-238	3.2×10^{-5}	1.0×10^{5}	water	57	fish	33	meat	8	3.0×10^{-1}	1.3×10^{6}
Np-237	2.3×10^{-5}	9.4×10^{5}	water	52	fish	33	meat	8	1.9×10^{-1}	3.9×10^{6}
Pu-242	8.7×10^{-5}	9.3×10^{5}	water	50	fish	29	meat	16	8.8×10^{-1}	1.4×10^{6}
	5.6×10^{-4}	1.3×10^{6}	water	99	meat	2×10^{-1}	fish	2×10^{-1}	1.7×10^{0}	1.4×10^{6}

Table 3c. Annual individual and collective doses with dominant pathways of exposure at the time of meximum burden for the outflow based on the pessimustic case (case 2, in chap. 4). Baltic sea case.

Nuclide	Max ind. annual dose rem/yr	Time years	Dominant pathways of exposure 1	%	2	%	3	%	Max. coll. annual dose manrem/yr	Time years
C-14	4.4×10^{-12}	1.0×10^{5}	fish	98	meat	2	milk	5×10^{-2}	9.2×10^{-4}	1.0×10^{5}
Zr-93	9.8×10^{-9}	2.1×10^{6}	fish	65	fish tac	26	beach	9	1.5×10^{-2}	2.5×10^{6}
Tc-99	2.3×10^{-8}	1.0×10^{5}	fish	99	milk	1	fish tac	2×10^{-1}	5.5×10^{-1}	3.9×10^{5}
I-129	1.0×10^{-7}	1.0×10^{5}	fish	100	meat	4×10^{-1}	milk	2×10^{-1}	1.7×10^{1}	5.9×10^{5}
Cs-135	3.2×10^{-5}	5.9×10^{5}	fish	100	beach	1×10^{-1}	fish tac	4×10^{-2}	4.5×10^{-2}	1.1×10^{6}
Ra-226[a]	4.6×10^{-4}	9.1×10^{5}	fish	100	gr vege	7×10^{-3}	fish tac	2×10^{-3}	7.5×10^{-1}	9.2×10^{5}
Ra-226[b]	1.6×10^{-8}	1.2×10^{6}	fish	90	fish tac	9	beach	1	6.4×10^{0}	1.2×10^{6}
Ra-226[c]	1.2×10^{-4}	8.7×10^{5}	fish	98	fish tac	2	beach	5×10^{-1}	2.6×10^{0}	1.4×10^{6}
Th-229	8.1×10^{-7}	9.6×10^{5}	fish tac	89	beach	10	fish	1	4.1×10^{-1}	9.5×10^{5}
Th-229[d]	2.0×10^{-6}	9.6×10^{5}	fish tac	90	beach	10	fish	1×10^{-3}	6.4×10^{-1}	1.4×10^{6}
Th-230	1.4×10^{-7}	9.2×10^{5}	fish	100	gr vege	9×10^{-3}			6.9×10^{-4}	9.2×10^{5}
Pa-231	7.4×10^{-7}	8.5×10^{5}	fish	100	gr vege	4×10^{-2}			1.3×10^{-1}	8.7×10^{5}
U-233	3.7×10^{-7}	9.2×10^{5}	fish	100	gr vege	4×10^{-2}			1.9×10^{-1}	1.4×10^{6}
U-234	2.0×10^{-8}	8.8×10^{5}	fish	100	gr vege	4×10^{-2}			1.2×10^{-1}	1.3×10^{6}
U-235	1.3×10^{-7}	9.0×10^{5}	fish	91	fish tac	6	beach	3	1.6×10^{-2}	2.7×10^{6}
U-236	1.8×10^{-7}	8.8×10^{5}	fish	100	gr vege	4×10^{-2}			2.4×10^{-1}	1.4×10^{6}
U-238	1.4×10^{-7}	8.8×10^{5}	fish	100	gr vege	4×10^{-2}			2.0×10^{-1}	3.2×10^{6}
Np-237	5.9×10^{-8}	9.3×10^{5}	fish	100	fish tac	2×10^{-1}	beach	4×10^{-2}	6.9×10^{-1}	1.4×10^{6}
Pu-242	$3.3 \times 10^{-}$	1.3×10^{6}	fish	100	water	1×10^{-6}			1.8×10^{-2}	1.7×10^{6}

Table 4a

Distribution of maximum collective annual dose in the inland alternative

Nuclide	Region	Baltic sea	Global
C-14	-	-	100
Zr-93	34		66
Tc-99	1		99
I-129	-	-	100
Cs-135	80	2	18
Ra-226[a)]	90	6	4
Ra-226[b)]	91	6	3
Ra-226[c)]	23	-	77
Th-229	100	-	-
Th-229[d)]	93	1	6
Th-230	100	-	-
Pa-231	99	-	1
U-233	41	1	58
U-234	33	1	66
U-235	-	-	100
U-236	-	-	100
U-238	-	-	100
Np-237	21	1	78
Pu-242	100	-	-

a) Refers to the Ra-226 which reaches the biosphere directly with the groundwater from the repository.

b) Refers to the Ra-226 which is generated by the decay of Th 230 in the biosphere.

c) Refers to the Ra-226 which is generated by the decay chain U-234 -> Th-230 ->Ra-226 in the biosphere.

d) Refers to the Th-229 which is generated by the decay of U-233 in the biosphere.

Table 4a

Distribution of maximum collectibe annual dose int the coast alternative

Nuclide	Region	Baltic sea	Global
C-14	-	-	100
Zr-93	-	-	100
Tc-99	-	-	100
I-129	-	-	100
Cs-135	-	8	92
Ra-226[a)]	2	62	36
Ra-226[b)]	1	63	36
Ra-226[c)]	-	-	100
Th-229	39	60	1
Th-229[d)]	-	11	89
Th-230	59	38	2
Pa-231	-	6	94
U-233	-	2	98
U-234	-	2	98
U-235	-	-	100
U-236	-	-	100
U-238	-	-	100
Np-237	-	-	100
Pu-242	-	-	100

APPENDIX A.1

APPENDIX A

RESULTS OF DISPERSAL SCENARIOS

Contents

- Tables A.1-5. a-b. Annual maximum individual and collective doses after inflow to primary recipient for cases 3-7 (see Chapter 4 Outflow from repository).

Table A.1 a

Maximum individual doses, D_{max}, in critical group and time for maxima, T_{max}, for case 3

Nuclide	Well:		Lake:		Baltic Sea:	
	D_{max} (rem/yr)	T_{max} (yr)	D_{max} (rem/yr)	T_{max} (yr)	D_{max} (rem/yr)	T_{max} (yr)
Zr 93	5.0×10^{-5}	3.2×10^{6}	5.0×10^{-5}	3.2×10^{6}	1.5×10^{-7}	3.2×10^{6}
I 129	2.1×10^{-2}	1.1×10^{4}	9.5×10^{-4}	1.1×10^{4}	5.1×10^{-6}	1.1×10^{4}
Cs 135	5.0×10^{-3}	3.4×10^{5}	3.7×10^{-3}	3.4×10^{5}	1.9×10^{-5}	3.4×10^{5}
Ra 226 (sum)	2.6×10^{-2}	3.7×10^{4}	1.2×10^{-2}	3.7×10^{4}	3.0×10^{-5}	3.8×10^{4}
Ra 226	2.1×10^{-2}	3.7×10^{4}	1.8×10^{-3}	3.8×10^{4}	2.8×10^{-5}	3.8×10^{4}
Th 230/Ra 226	1.8×10^{-3}	1.4×10^{5}	1.8×10^{-3}	1.4×10^{5}	1.0×10^{-5}	1.4×10^{5}
U 234/Ra 226	5.3×10^{-3}	3.6×10^{4}	1.1×10^{-2}	3.6×10^{4}	2.1×10^{-6}	3.2×10^{4}
Th 229 (sum)	7.1×10^{-3}	1.0×10^{5}	6.8×10^{-3}	1.0×10^{5}	2.4×10^{-5}	6.7×10^{4}
Th 229	7.7×10^{-4}	8.3×10^{4}	4.1×10^{-4}	8.3×10^{4}	2.4×10^{-5}	6.7×10^{4}
U 233/Th 229	6.6×10^{-3}	1.1×10^{5}	6.6×10^{-3}	1.1×10^{5}	8.9×10^{-7}	3.6×10^{4}
Th 230	1.8×10^{-4}	3.8×10^{4}	1.8×10^{-5}	3.8×10^{4}	1.7×10^{-7}	3.9×10^{4}
Pu 239	1.3×10^{-4}	4.3×10^{5}	8.2×10^{-6}	4.3×10^{5}	1.6×10^{-8}	4.3×10^{5}
U 233	7.3×10^{-3}	3.5×10^{4}	2.9×10^{-4}	3.5×10^{4}	2.7×10^{-6}	3.6×10^{4}
U 234	9.9×10^{-2}	2.3×10^{4}	3.8×10^{-3}	2.7×10^{4}	3.8×10^{-5}	2.7×10^{4}
U 235	1.3×10^{-3}	3.6×10^{4}	3.9×10^{-5}	3.6×10^{4}	2.4×10^{-6}	3.6×10^{4}
U 236	2.4×10^{-2}	3.6×10^{4}	9.4×10^{-4}	3.6×10^{4}	4.6×10^{-6}	3.6×10^{4}
U 238	1.9×10^{-2}	2.9×10^{4}	7.3×10^{-4}	3.6×10^{4}	7.3×10^{-6}	2.7×10^{4}
Np 237	1.2×10^{-1}	1.3×10^{5}	6.2×10^{-3}	1.3×10^{5}	4.3×10^{-5}	1.3×10^{5}
Pu 242	3.8×10^{-2}	4.4×10^{5}	3.3×10^{-2}	4.4×10^{5}	3.1×10^{-6}	4.4×10^{5}

Table A.1b

Maximum collective doses, D_{max}, and time for maxima, T_{max}, for case 3

Nuclide	Inland alternatives:		Baltic Sea:	
	D_{max} (manrem/yr)	T_{max} (yr)	D_{max} (manrem/yr)	T_{max} (yr)
Zr 93	$5.3 \cdot 10^{-2}$	$3.4 \cdot 10^{6}$	$1.3 \cdot 10^{-2}$	$3.2 \cdot 10^{6}$
I 129	$3.7 \cdot 10^{1}$	$1.1 \cdot 10^{4}$	$3.7 \cdot 10^{1}$	$2.0 \cdot 10^{4}$
Cs 135	$9.2 \cdot 10^{0}$	$3.4 \cdot 10^{5}$	$1.8 \cdot 10^{-1}$	$3.4 \cdot 10^{5}$
Ra 226	$2.2 \cdot 10^{2}$	$3.9 \cdot 10^{4}$	$1.4 \cdot 10^{2}$	$4.4 \cdot 10^{4}$
Th 229	$1.8 \cdot 10^{1}$	$1.2 \cdot 10^{5}$	$2.1 \cdot 10^{0}$	$1.4 \cdot 10^{5}$
Th 230	$4.3 \cdot 10^{-2}$	$1.4 \cdot 10^{5}$	$9.7 \cdot 10^{-5}$	$3.9 \cdot 10^{4}$
Pu 239	$1.5 \cdot 10^{-1}$	$4.4 \cdot 10^{5}$	$4.7 \cdot 10^{-4}$	$4.4 \cdot 10^{5}$
U 233	$1.1 \cdot 10^{0}$	$1.2 \cdot 10^{5}$	$4.7 \cdot 10^{-1}$	$1.3 \cdot 10^{5}$
U 234	$8.6 \cdot 10^{0}$	$3.6 \cdot 10^{4}$	$1.5 \cdot 10^{0}$	$3.6 \cdot 10^{4}$
U 235	$1.8 \cdot 10^{-1}$	$3.6 \cdot 10^{4}$	$8.5 \cdot 10^{-2}$	$2.8 \cdot 10^{7}$
U 236	$2.1 \cdot 10^{0}$	$3.6 \cdot 10^{4}$	$5.0 \cdot 10^{-1}$	$9.7 \cdot 10^{5}$
U 238	$1.7 \cdot 10^{0}$	$3.6 \cdot 10^{4}$	$3.0 \cdot 10^{-1}$	$3.6 \cdot 10^{4}$
Np 237	$1.6 \cdot 10^{1}$	$1.3 \cdot 10^{5}$	$1.2 \cdot 10^{0}$	$1.3 \cdot 10^{5}$
Pu 242	$5.7 \cdot 10^{1}$	$4.4 \cdot 10^{5}$	$2.9 \cdot 10^{-1}$	$5.4 \cdot 10^{5}$

Table A.2a

Maximum individual dosed, D_{max}, in critical group and time for maxima, T_{max}, for case 4

Nuclide	Well:		Lake:		Baltic Sea:	
	D_{max} (rem/yr)	T_{max} (yr)	D_{max} (rem/yr)	T_{max} (yr)	D_{max} (rem/yr)	T_{max} (yr)
Zr 93	not calculated		not calculated		2.8×10^{-8}	3.2×10^{6}
Tc 99					1.5×10^{-7}	1.1×10^{4}
I 129	2.1×10^{-3}	1.1×10^{4}	9.5×10^{-5}	1.1×10^{4}	5.1×10^{-7}	1.1×10^{4}
Cs 135	5.2×10^{-4}	3.5×10^{5}	3.8×10^{-4}	3.5×10^{5}	1.7×10^{-6}	3.4×10^{5}
Ra 226	1.0×10^{-2}*	1.2×10^{5}	1.2×10^{-3}*	1.2×10^{5}	1.4×10^{-5}	1.3×10^{5}
Th 230/Ra 226	not calculated		not calculated		8.8×10^{-6}	2.0×10^{5}
U 234/Ra 226					2.1×10^{-7}	3.1×10^{5}
Th 229 (sum)					2.1×10^{-5}	1.3×10^{5}
Th 229					2.1×10^{-5}	1.3×10^{5}
U 233/Th 229					8.0×10^{-7}	1.2×10^{5}
Th 230					1.1×10^{-7}	1.2×10^{5}
U 233					2.0×10^{-6}	1.2×10^{5}
U 234					3.7×10^{-6}	2.7×10^{4}
U 235					1.6×10^{-5}	1.1×10^{5}
U 236					9.1×10^{-7}	4.3×10^{4}
U 238					6.9×10^{-7}	2.8×10^{4}
Np 237					4.4×10^{-6}	1.4×10^{5}
Pu 239					1.6×10^{-9}	4.3×10^{5}
Pu 242					6.8×10^{-7}	4.5×10^{5}

* Refers to the Ra-226 which reaches the biosphere directly via the groundwater from the repository

Table A.2b

Maximum collective doses, D_{max}, and time for maxima, T_{max}, for case 4.

Nuclide	inland alternatives:		Baltic Sea:	
	D_{max} (manrem/yr)	T_{max} (yr)	D_{max} (manrem/yr)	T_{max} (yr)
Zr 93			$2.6 \cdot 10^{-3}$	$3.3 \cdot 10^{6}$
Tc 99			$3.7 \cdot 10^{-1}$	$2.9 \cdot 10^{5}$
I 129	$1.9 \cdot 10^{1}$	$1.9 \cdot 10^{4}$	$1.9 \cdot 10^{1}$	$9.6 \cdot 10^{5}$
Cs 135	$2.7 \cdot 10^{0}$	$3.9 \cdot 10^{5}$	$7.0 \cdot 10^{-2}$	$4.2 \cdot 10^{5}$
Ra 226	$2.7 \cdot 10^{0}$*	$1.3 \cdot 10^{5}$	$1.2 \cdot 10^{2}$	$1.3 \cdot 10^{5}$
Th 229			$2.2 \cdot 10^{0}$	$2.2 \cdot 10^{5}$
Th 230			$6.4 \cdot 10^{-5}$	$1.2 \cdot 10^{5}$
U 233			$4.4 \cdot 10^{-1}$	$2.1 \cdot 10^{5}$
U 234			$8.5 \cdot 10^{-1}$	$1.2 \cdot 10^{5}$
U 235			$9.3 \cdot 10^{-2}$	$1.3 \cdot 10^{5}$
U 236			$3.5 \cdot 10^{-1}$	$9.5 \cdot 10^{5}$
U 238			$2.4 \cdot 10^{-1}$	$4.1 \cdot 10^{7}$
Np 237			$1.2 \cdot 10^{0}$	$2.3 \cdot 10^{5}$
Pu 239			$6.4 \cdot 10^{-5}$	$4.6 \cdot 10^{5}$
Pu 242			$1.4 \cdot 10^{-1}$	$5.3 \cdot 10^{5}$

* Refer to the Ra-226 which reaches the biosphere directly via the groundwater from the repository.

Table A.3a

Maximum individual doses, D_{max}, in critical group and time for maxima, T_{max}, for case 5

Nuclide	Well:		Lake:		Baltic Sea:	
	D_{max} (rem/yr)	T_{max} (yr)	D_{max} (rem/yr)	T_{max} (yr)	D_{max} (rem/yr)	T_{max} (yr)
C 14	7.0×10^{-5}	1.2×10^{4}	1.6×10^{-5}	1.2×10^{4}	not calculated	
Zr 93	9.8×10^{-7}	3.2×10^{6}	9.8×10^{-7}	3.2×10^{6}	2.8×10^{-9}	3.2×10^{6}
I 129	2.1×10^{-4}	1.2×10^{4}	9.5×10^{-6}	1.2×10^{4}	5.1×10^{-8}	1.1×10^{4}
Cs 135	5.2×10^{-5}	3.4×10^{5}	3.8×10^{-5}	3.4×10^{5}	1.7×10^{-7}	3.4×10^{5}
Ra 226 (sum)	1.3×10^{-3}	2.0×10^{5}	9.1×10^{-4}	1.1×10^{5}	2.0×10^{-6}	3.6×10^{5}
Ra 226	1.2×10^{-3}	2.0×10^{5}	1.2×10^{-4}	2.0×10^{5}	1.7×10^{-6}	2.2×10^{5}
Th 230/Ra 226	2.7×10^{-4}	3.6×10^{5}	2.7×10^{-4}	3.6×10^{5}	1.9×10^{-6}	3.6×10^{5}
U 234/Ra 226	9.0×10^{-4}	1.1×10^{5}	9.0×10^{-4}	1.1×10^{5}	2.1×10^{-8}	3.4×10^{4}
Th 229 (sum)	4.9×10^{-4}	5.2×10^{5}	4.4×10^{-4}	5.0×10^{5}	3.6×10^{-6}	5.2×10^{5}
Th 229	9.6×10^{-5}	5.3×10^{5}	4.6×10^{-5}	5.3×10^{5}	3.5×10^{-6}	3.6×10^{5}
U 233/Th 229	4.0×10^{-4}	5.0×10^{5}	4.0×10^{-4}	5.0×10^{5}	1.3×10^{-7}	5.2×10^{5}
Th 230	1.5×10^{-5}	2.6×10^{5}	2.7×10^{-6}	2.6×10^{5}	1.3×10^{-8}	2.2×10^{5}
U 233	8.6×10^{-4}	6.5×10^{5}	3.4×10^{-5}	6.5×10^{5}	3.0×10^{-7}	5.7×10^{5}
U 234	9.8×10^{-4}	2.9×10^{4}	3.8×10^{-5}	2.9×10^{4}	3.7×10^{-7}	2.8×10^{4}
U 235	1.6×10^{-5}	1.1×10^{5}	8.0×10^{-7}	1.1×10^{5}	5.6×10^{-8}	9.9×10^{4}
U 236	2.5×10^{-4}	4.9×10^{4}	1.8×10^{-5}	4.9×10^{4}	9.3×10^{-8}	4.9×10^{4}
U 238	1.9×10^{-4}	9.7×10^{5}	1.3×10^{-5}	9.7×10^{5}	7.0×10^{-8}	2.9×10^{4}
Np 237	1.2×10^{-3}	1.5×10^{5}	6.5×10^{-5}	1.5×10^{5}	4.4×10^{-7}	1.4×10^{5}
Pu 239	1.3×10^{-6}	4.3×10^{5}	7.9×10^{-7}	4.3×10^{5}	1.3×10^{-8}	4.3×10^{5}
Pu 242	1.5×10^{-3}	5.4×10^{5}	1.5×10^{-3}	5.4×10^{5}	7.5×10^{-8}	4.4×10^{5}

Table A.3b

Maximum collective doses, D_{max}, and time for maxima, T_{max}, for case 5

Nuclide	Inland alternatives:		Baltic Sea:	
	D_{max} (manrem/yr)	T_{max} (yr)	D_{max} (manrem/yr)	T_{max} (yr)
C 14	$5.6 \cdot 10^{-2}$	$1.2 \cdot 10^{4}$		
Zr 93	$3.6 \cdot 10^{-4}$	$3.4 \cdot 10^{6}$	$8.2 \cdot 10^{-3}$	$4.2 \cdot 10^{6}$
I 129	$1.6 \cdot 10^{1}$	$9.6 \cdot 10^{5}$	$1.6 \cdot 10^{1}$	$9.6 \cdot 10^{5}$
Cs 135	$1.2 \cdot 10^{-1}$	$1.3 \cdot 10^{6}$	$1.4 \cdot 10^{-1}$	$1.3 \cdot 10^{6}$
Ra 226	$2.4 \cdot 10^{1}$	$4.4 \cdot 10^{5}$	$2.2 \cdot 10^{1}$	$4.5 \cdot 10^{5}$
Th 229	$1.8 \cdot 10^{0}$	$8.0 \cdot 10^{5}$	$8.0 \cdot 10^{-1}$	$9.5 \cdot 10^{5}$
Th 230	$6.1 \cdot 10^{-3}$	$3.4 \cdot 10^{5}$	$5.8 \cdot 10^{-6}$	$2.7 \cdot 10^{5}$
U 233	$2.5 \cdot 10^{-1}$	$8.0 \cdot 10^{5}$	$1.8 \cdot 10^{-1}$	$9.5 \cdot 10^{5}$
U 234	$2.3 \cdot 10^{-1}$	$2.9 \cdot 10^{5}$	$1.5 \cdot 10^{-1}$	$4.6 \cdot 10^{5}$
U 235	$1.9 \cdot 10^{-2}$	$9.6 \cdot 10^{5}$	$1.8 \cdot 10^{-2}$	$2.6 \cdot 10^{7}$
U 236	$2.7 \cdot 10^{-1}$	$9.6 \cdot 10^{5}$	$2.4 \cdot 10^{-1}$	$1.4 \cdot 10^{6}$
U 238	$1.9 \cdot 10^{-1}$	$4.4 \cdot 10^{7}$	$2.3 \cdot 10^{-1}$	$4.4 \cdot 10^{7}$
Np 237	$9.4 \cdot 10^{-1}$	$1.1 \cdot 10^{6}$	$8.5 \cdot 10^{-1}$	$1.1 \cdot 10^{6}$
Pu 239	$2.2 \cdot 10^{-3}$	$4.6 \cdot 10^{5}$	$8.6 \cdot 10^{-6}$	$4.5 \cdot 10^{5}$
Pu 242	$3.7 \cdot 10^{0}$	$5.5 \cdot 10^{5}$	$4.4 \cdot 10^{-2}$	$1.0 \cdot 10^{6}$

Appendix A.8

Table A.4.a

Maximum individual doses, E_{max}, in critical group at time for maxima, T_{max}, for case 6

Nuclid	Well: D_{max} (rem/yr)	T_{max} (yr)
C 14	1.5×10^{-8}	3.1×10^{3}
Tc 99	1.6×10^{-12}	2.9×10^{6}
I 129	2.9×10^{-6}	3.3×10^{3}
Cs 135	1.0×10^{-9}	1.2×10^{7}
Ra 226 (sum)	8.9×10^{-7}	6.9×10^{7}
Th 230	7.5×10^{-8}	8.0×10^{7}
Pa 231	7.4×10^{-8}	6.9×10^{7}
U 235	3.7×10^{-9}	6.9×10^{7}
U 236	8.8×10^{-9}	6.9×10^{7}
U 238	5.2×10^{-8}	6.9×10^{7}

Appendix A.9

Table A.4b

Maximum collective dose, D_{max}, and time for maxima, T_{max}, for case 6.

Nuclid	Well: D_{max} (manrem/yr)	T_{max} (yr)
C 14	7.8×10^{-3}	4.0×10^{3}
I 129	2.1×10^{-3}	4.0×10^{3}

Appendix A.10

Table A.5a

Maximum individual doses, D_{max}, in critical group at time for maxima, T_{max}, for case 7

Nuclide	Well: D_{max} (rem/yr)	T_{max} (yr)
C 14	2.6×10^{-4}	3.6×10^{3}
Zr 93	1.2×10^{-6}	2.0×10^{6}
Tc 99	1.4×10^{-4}	3.6×10^{3}
I 129	4.2×10^{-4}	3.7×10^{3}
Cs 135	1.0×10^{-4}	5.0×10^{5}
Ra 226 (sum)	3.0×10^{-2}	1.0×10^{6}
Ra 226	1.7×10^{-2}	8.2×10^{5}
Th 230/Ra 226	2.7×10^{-2}	1.0×10^{6}
U 234/Ra 225	4.2×10^{-4}	7.9×10^{5}
Th 229 (sum)	1.7×10^{-2}	8.7×10^{5}
Th 229	1.7×10^{-2}	8.7×10^{5}
U 233/Th 229	1.1×10^{-3}	9.5×10^{5}
Th 230	1.6×10^{-3}	8.2×10^{5}
U 233	1.1×10^{-3}	8.3×10^{5}
U 234	5.7×10^{-4}	7.8×10^{5}
U 235	3.1×10^{-5}	8.0×10^{5}
U 236	4.7×10^{-4}	7.8×10^{5}
U 238	3.6×10^{-4}	8.3×10^{5}
Np 237	1.9×10^{-3}	8.3×10^{5}
Pu 242	8.2×10^{-4}	1.3×10^{6}

Appendix A.11

Table A.5b

Maximum collective doses, D_{max}, and time for maxima, T_{max}, for case 7

Nuclide	Inland alternative: D_{max} (manrem/yr)	T_{max} (yr)
C 14	2.2×10^{2}	9.4×10^{3}
Zr 93	1.0×10^{-3}	2.0×10^{6}
Tc 99	7.8×10^{-1}	3.0×10^{5}
I 129	1.7×10^{1}	5.0×10^{5}
Cs 135	2.1×10^{-1}	9.5×10^{5}
Ra 226 (sum)	7.2×10^{1}	1.0×10^{6}
Ra 226	3.7×10^{0}	8.2×10^{5}
Th 230/Ra 226	7.1×10^{1}	1.0×10^{6}
U 234/Ra 226	3.5×10^{0}	1.2×10^{6}
Th 229 (sum)	2.1×10^{1}	8.7×10^{5}
Th 229	3.5×10^{0}	8.7×10^{5}
U 233/Th 229	2.1×10^{1}	1.2×10^{6}
Th 230	6.3×10^{-1}	1.0×10^{6}
U 233	3.6×10^{-1}	1.2×10^{6}
U 234	1.9×10^{-1}	1.2×10^{6}
U 235	1.6×10^{-2}	3.8×10^{6}
U 236	2.9×10^{-1}	1.6×10^{6}
U 238	2.0×10^{-1}	5.0×10^{6}
Np 237	9.7×10^{-1}	1.3×10^{6}
Pu 242	2.0×10^{0}	1.3×10^{6}

APPENDIX B

TRANSFER COEFFICIENTS

Contents

Appendix B.2

TRANSFER COEFFICIENTS

Transfer coefficients with water and air as carriers of activity are reported in Table B.1.

Table B.1	Year^{-1}
Groundwater 1 - surface water	2.0
Groundwater 2 - soil	$1.0 \cdot 10^{-1}$
Groundwater 2 - surface water	$2.0 \cdot 10^{-1}$
Soil - groundwater 2	$1.0 \cdot 10^{-1}$
Soil - atmosphere, reg.	$1.1 \cdot 10^{-7}$
Soil - surface water	$2.0 \cdot 10^{-1}$
Atmosphere - soil, reg.	$4.5 \cdot 10^{-1}$
Atmosphere - surface water	$2.5 \cdot 10^{-3}$
Atmosphere - surface sea, reg.	$1.9 \cdot 10^{2}$
Atmosphere - atmosphere, global	$1.5 \cdot 10^{2}$
Surface water - soil	$2.0 \cdot 10^{-2}$
Surface water - Baltic Sea	2.0
Baltic sea, reg. - Baltic Sea	10.0
Baltic Sea - surface sea, global	$4.3 \cdot 10^{-2}$
Atmosphere, global - Atmosphere reg.	$1.6 \cdot 10^{-2}$
Atmosphere - surface sea, global	$1.3 \cdot 10^{1}$
Atmosphere - soil, global	5.5
Surface sea - deep sea	$1.1 \cdot 10^{-1}$
Surface sea - soil, global	$1.7 \cdot 10^{-7}$
Deep sea - surface sea	$8.0 \cdot 10^{-4}$
Soil - atmosphere, global	$6.8 \cdot 10^{-5}$
Soil - surface sea, global	$4.6 \cdot 10^{-1}$
Soil - groundwater, global	$1.0 \cdot 10^{-1}$
Groundwater - surface sea, global	$1.0 \cdot 10^{-3}$
Groundwater - soil, global	$1.0 \cdot 10^{-3}$

Appendix B.3

Derivation of transfer coefficients for the general carrier system

Groundwater 1 - surface water

A rapid transfer of 2 $year^{-1}$ for entry into the biosphere from the groundwater recipient at the interface between the geosphere and the biosphere has been assumed for all nuclides.

Groundwater 2 - soil and groundwater 2 - surface water

The average turnover time for groundwater and soil water has been set at 3 years, which gives a transport rate of 0.3 $year^{-1}$. This transport has been distributed so that 1/3 of the transfer reaches the soil reservoir via root uptake and rising forces while the remaining 2/3 runs off to the surface water.

Soil - groundwater 2

14% of the total infiltration percolates down to the groundwater (30), which gives a transport rate of 1.10^{-1} $year^{-1}$.

Soil - surface water

Most of the water which is brought into the soil reservoir by precipitation is then carried away by evaporation, infiltration and surface water runoff. The latter is assumed to be 0.2 $year^{-1}$, which thus describes the transfer from soil to surface water.

Atmosphere - surface sea and surface water, regional and global

A deposition rate of $3 \cdot 10^{-3}$ m s^{-1} has been assumed for all nuclides except for I and T_2. The mean height of the regional atmosphere is $5 \cdot 10^{2}$ m and of the global $5 \cdot 10^{2}$ m. The transfers between the atmosphere and the respective areas are then:

regional $$\frac{3 \cdot 10^{-3} \cdot 3.15 \cdot 10^{7}}{5 \cdot 10^{2}} = 1.9 \cdot 10^{2} \text{ year}^{-1}$$

global $$\frac{0.71 \cdot 3 \cdot 10^{-3} \cdot 3.15 \cdot 10^{7}}{5 \cdot 10^{3}} = 1.3 \cdot 10^{1} \text{ year}^{-1}$$

The transfer between the atmosphere and the surface water is weighted in proportion to the surface area:

$$\frac{5}{3.8 \cdot 10^{5}} \cdot 1.9 \cdot 10^{2} = 2.5 \cdot 10^{-3} \text{ year}^{-1}$$

Atmosphere - soil, regional and global

The transfers are weighted in proportion to the areas of the reservoirs which are contiguous to the atmosphere. Experimental studies have given residence times for particles in the atmosphere of between 1 and 3 weeks (27).

regional $$\frac{9 \cdot 10^{2}}{3.8 \cdot 10^{5}} 1.9 \cdot 10^{2} = 4.5 \cdot 10^{-1} \text{ year}^{-1}$$

global $$\frac{0.29 \cdot 3 \cdot 10^{-3} \cdot 3.15 \cdot 10^{7}}{5 \cdot 10^{3}} = 5.5 \text{ year}^{-1}$$

Soil - atmosphere, regional and global

The resuspension of particle-borne activity is based on experimental analysis (22) and theoretical estimates of the feedback of radioactive elements to the atmosphere from the surface layer of the ground. A resuspension factor of 10^{-8} - 10^{-9} m^{-1} has been obtained for Pu (41). All nuclides except for I and Tc are considered to have the same resuspension factor. the soil is considered to have a surface density of 224 kg m^{-2} (10) and a volume density of $2.2 \cdot 10^{3}$ kg/m^{3}. At equilibrium, when the transfers via deposition are $4.2 \cdot 10^{-1}$ $year^{-1}$ for the region and 6.7 $year^{-1}$ for the global area, resuspension is:

regional $$\frac{4.2 \cdot 10^{-1} \cdot 224 \cdot 10^{-8} \cdot 500}{2 \cdot 2.2 \cdot 10^{3}} = 1.1 \cdot 10^{-7} \text{ year}^{-1}$$

global $$\frac{6.7 \cdot 224 \cdot 10^{-8} \cdot 5\,000}{0.5 \cdot 2.2 \cdot 10^{3}} = 6.8 \cdot 10^{-5} \text{ year}^{-1}$$

Atmosphere - atmosphere, global

This exchange varies between 100 and 200 $year^{-1}$. The typical value used in the model is 150 $year^{-1}$.

Surface water - soil

Of the region's 900 km^2, 60 km^2 is precipitation area to the lake. Of these 60 km^2, 10% are irrigated. The portion of the total cultivated acreage which is irrigated in Sweden is 3% (61). The quantity of water per irrigation episode, 35 mm m^{-2} (61), gives

$$35 \cdot 10^{-3} \cdot 6 \cdot 10^{6} = 2.1 \cdot 10^{5} \ m^3$$

which gives a transfer of

$$\frac{2.1 \cdot 10^{5}}{1.25 \cdot 10^{7}} = 2 \cdot 10^{-2} \ year^{-1}$$

Surface water - Baltic Sea

In Sweden, 7 - 8% of a precipitation area consists of lake area (38) and the annual runoff averages at 14 l s^{-1} km^{-2}. This gives an annual runoff volume for a lake with a surface area of 5 km^2 and a surrounding precipitation area of 60 km^2 of

$$60 \cdot 14 \cdot 3.15 \cdot 10^{7} = 2.6 \cdot 10^{7} \ m^3$$

With an average depth of 2.5 m, the volume of Finnsjö Lake is $1.25 \cdot 10^{7}$ m^3. The transfer between the lake and the Baltic Sea is then

$$\frac{2.6 \cdot 10^{7}}{1.25 \cdot 10^{7}} \approx 2 \ year^{-1}$$

Baltic Sea, regional - Baltic Sea

It is assumed that this volume is exchanged 10 times annually.

Baltic Sea - surface sea, global

940 km^3 of water flows annually out of the Baltic Sea through the Belts and Öresund (15). The Baltic Sea has a volume of 21 800 km^3 (15). The transfer coefficient is thus

$$\frac{940}{21800} = 4.3 \cdot 10^{-2} \text{ year}^{-1}$$

Atmosphere, global - atmosphere, regional

Since the transfer from the regional atmosphere to the global atmosphere has been assumed to be 150 $year^{-1}$, the mass balance gives a transfer of $1.6 \cdot 10^{-2}$ $year^{-1}$ in the opposite direction.

Surface sea - deep sea

The exchange between the surface sea and the deep sea has been obtained from a global model (5).

Surface sea - soil, global

$1.2 \cdot 10^9$ tons of salt enter the atmosphere above the sea annually. Of this quantity, it is assumed that 10% is deposited on land (27). There are approximately $3.5 \cdot 10^{-2} \cdot 2.10^{19} = 7 \cdot 10^{17}$ kg of salt in the surface sea. This gives a transfer of

$$\frac{120 \cdot 10^9}{7 \cdot 10^{17}} = 1.7 \cdot 10^{-7} \text{ year}^{-1}$$

Soil - groundwater, global

In the global system, the stationary volume of the soil water is $82 \cdot 10^3$ km^3 (30), which is equivalent to the

annual infiltration. 14% of the total infiltration percolates down to the groundwater storage (30), which gives a transfer of 0.1 year $^{-1}$.

Soil - surface sea, global

Runoff from the continents to the sea is estimated at $3.8 \cdot 10^4$ km^2 year^{-1} (30), which gives a transfer of

$$\frac{3.8 \cdot 10^4}{82 \cdot 10^3} = 4.6 \cdot 10^{-1} \text{ year}^{-1}$$

Groundwater - soil and surface sea, global

The active part of the groundwater has a volume of $4 \cdot 10^6$ km^3 (30). The outflow from this groundwater to surrounding surface sea and soil reservoirs has been assigned a value of $1 \cdot 10^{-3}$ year^{-1}.

The transfer of a given nuclide from soil water to groundwater and from groundwater to surface sea is determined by the product of this factor for water transport and the nuclide's k_d factor as given by Table B.2.

Derivation of nuclide-specific transfer coefficients

C-14

For C-14, a previous study (5) has been used for the global transfer coefficients. Regionally, C-14 transport follows the general carrier system (table B.1).

I-129

Transfer coefficients for iodine and technetium have been derived in part from information on the global annual iodine cycle (31, 32), i.e. assuming that technetium cycles in the biosphere in a similar manner to iodine.

Atmosphere - soil and surface water, regional and global

The iodine content of the atmosphere is $1 \cdot 10^{12}$ g and the annual deposition is $5 \cdot 10^{11}$ g. This gives a transfer coefficient of 0.5 $year^{-1}$, which is weighted in proportion to the areas of the reservoirs which are contiguous to the atmosphere.

Atmosphere - biota

25% of deposited iodine is retained on the vegetation. This gives a transfer of $4.2 \cdot 10^{-2}$ $year^{-1}$ from the atmosphere to the biota.

Surface water - atmosphere

Annual evaporation is $5 \cdot 10^{11}$ g. The total inventory of iodine in the surface sea reservoir amounts to $1 \cdot 10^{15}$g (31). The sea covers 2/3 of the surface of the earth. The transfer from the surface sea to the atmosphere can thus be written:

$$\frac{\frac{2}{3} \cdot 5 \cdot 10^{11}}{1 \cdot 10^{15}} \text{ year}^{-1} = 3.3 \cdot 10^{-4}$$

The transfer from the other water reservoirs - lake, coastal area or Baltic Sea - is obtained from the global

transfer with adjustment for the size of the reservoir in question in accordance with the following relationship:

$$K = \frac{100}{D} \cdot 3.3 \cdot 10^{-4} \text{ year}^{-1}$$

D = mean depth of the reservoir
100 = mean depth of the surface sea in metres

Global soil - atmosphere

Two different derivations have been used.

a) The concentrations of iodine in the soil water and in the hydrosphere are assumed to be equal. If one-third of the evaporation derives from the soil reservoir, the transfer can be written:

$$\frac{\frac{1}{3} \cdot 5 \cdot 10^{11}}{6 \cdot 10^{-5} \cdot 7.1 \cdot 10^{16}} \text{ year}^{-1} = 4 \cdot 10^{-2} \text{ year}^{-1}$$

where $6 \cdot 10^{-5}$ is the ratio of global soil water to the hydrosphere.

b) Rain water contains 0.2 - 5 ppm iodine (57). The mean value for rainfall on the continents (730 mm year^{-1}) gives a transport to the ground of 15 - 370 ppm cm^{-2} year^{-1}. The concentration of iodine in the soil is 1 - 5 ppm (44, 57). A 50 cm deep soil layer with a cross-sectional area of 1 cm^2 and an estimated density of 2.2 g/cm^3 contains 110 - 550 ppm iodine. Thus, the transfer for the stationary state can be written:

$$\frac{(15-370) \cdot 10^{-6}}{(110-550) \cdot 10^{-6}} \text{ year}^{-1}$$

The maximum interval is $3 \cdot 10^{-2}$ - 3.4 $year^{-1}$. Other transports of iodine away from the soil reservoir have not been taken into consideration. A value of $4 \cdot 10^{-2}$ has been used in this study.

Biota - atmosphere

The biological half-life for iodine in biota is 8 days (58) which gives a transfer of 50 $year^{-1}$ to describe the loss of iodine from the biota to the atmosphere.

Biota - soil

The loss of iodine from the biota to the soil is assumed to be proportionate to humus growth, i.e. inversely proportional to the average life of biota, which is 10 years, giving a transfer of $1 \cdot 10^{-1}$ $year^{-1}$.

Surface sea - soil

The annual transport of iodine to the continents from the surface sea through "sea spray" is $5 \cdot 10^{9}$ g (31). The transfer coefficient is thus

$$\frac{5 \cdot 10^{9}}{1 \cdot 10^{15}} = 5 \cdot 10^{-6} \ year^{-1}$$

Water - sediment

Iodine, which follows the movements of water in nature, has been assumed to have the same distribution as water between the surface water reservoir and the uppermost centimetres of the sediment reservoir.

The average water content of the uppermost sediment layer is around 75%. If the transfer coefficient from sediment to water is assumed to be 12 $year^{-1}$ and stationary states prevail, the transfer in the opposite direction can be written:

$$K = 12 \cdot \frac{M_s}{M_w},$$

where M_s and M_w are the quantities of water in the respective reservoirs.

CESIUM

Deep sea - deep sea sediment

According to (28), 1 - 2% of the fallout has reached the sediments in the deep sea. The rest is transported dissolved in water. In 1970, 1-2% of the cesium was present in sediment at a depth of 10^3-$4 \cdot 10^3$ metres.

The big contribution from fallout took place in the early 1960's. Assuming the transfer to be a continuous process which has led to an accumulation of 1-2% in the sediments over the past 10 years, the transfer is:

$$2 \cdot 10^{-3} \text{ year}^{-1}$$

A much lower transfer is obtained, however, if the transport is based on the average residence time for the stable nuclide in the global ocean.

The residence time for Cs in the deep sea is about 6.10^5 years (52), which gives a transfer rate of:

$$\frac{1}{6 \cdot 10^5} = 1.7 \cdot 10^{-6} \text{ year}^{-1}$$

The latter alternative, which has been chosen for the calculations, gives slightly higher doses than the former alternative.

Sediment - water

No back-leakage of cesium from the sediments has been detected thus far. Theoretical calculations of this feedback place it at an order of magnitude of around $1 \cdot 10^{-3}$ year^{-1} (6). This value has been used in the regional area, while a value of 10^{-4} has been used for the Baltic Sea and the global area.

Surface water - sediment

The sedimentation of cesium in the lake varies with the type of lake (53). A value of $3 \cdot 10^{-2}$ has been taken to be representative.

Baltic Sea water - Baltic Sea sediment

Previous studies (6) have arrived at a span of $(0.5\text{-}6) \cdot 10^{-2}$ year^{-1} for the transfer. A value of $5 \cdot 10^{-3}$ has been used in the calculations, since it gives a somewhat higher dose burden.

Soil - groundwater

According to (51), 20 - 50% of the quantity of Cs-137 from fallout has penetrated from the 0 - 5 cm layer down to 5 - 10 cm in 5 years.

This means that:

20 - 50% has a transport rate of 1 -2 cm/year
50 - 80% has a transport rate of < 1 cm/year.
If this is weighted over the soil profile, a rate of 0.2 - 1 cm/year is obtained.

Studies of 4 different soil types (51) have given a penetration of 0.5 - 1.5 cm in 6 years. These different studies thus indicate an interval of $5 \cdot 10^{-4}$ - $5 \cdot 10^{-3}$ $year^{-1}$, for the transfer in the regional area, where the depth of the soil reservoir is assumed to be 2 m. The value 10^{-3} $year^{-1}$ has been chosen for the calculations. The corresponding value for the global area is $4 \cdot 10^{-3}$ $year^{-1}$, since the thickness of the soil reservoir there has been taken to be 0.5 m.

THORIUM

Deep sea - deep sea sediment

According to (22), the residence time for thorium in the deep sea is 300 - 350 years. This gives a transfer coefficient of $3.3 \cdot 10^{-3}$ $year^{-1}$.

Deep sea sediment - deep sea

According to (52, 53), sea water contains 10^{-2} ppb while sediment contains 2.1 ppm thorium.

Since equilibrium prevails in the system, k_{out} can be written:

$$3.3 \cdot 10^{-3} \cdot \frac{1.4 \cdot 10^{13}}{10^{14}} \text{ year}^{-1} = 3.3 \cdot 10^{-4}$$

On the other hand, it can be assumed that the rate of leakage from sediment to water is of the same order of magnitude as the rate of leaching from the soil to the surface water reservoir. This would give $3 \cdot 10^{-6}$ year^{-1}.

Within the interval $3 \cdot 10^{-6} - 3.3 \cdot 10^{-4}$ year^{-1}, the value of $3 \cdot 10^{-6}$ year^{-1} has been chosen, since this value gives a higher dose burden for Th-229, which provides the largest dose contributions to the critical group and the population in comparison with other isotopes of thorium.

Sediment - surface water

The same value as above has been used.

PLUTONIUM

Soil - groundwater

Calculations of the transport of plutonium in soil vary widely from $4 \cdot 10^{-7}$ to $8 \cdot 10^{-1}$ m year^{-1}, based on different data in the literature (48, 49). When adjusted to agree with empirical data (50), diffusion calculations show that 40% of the content in a 1 cm layer is transferred per year to surrounding soil layers. This diffusion can be assumed to be equally great in the horizontal and vertical directions. If we consider a 2 m deep soil layer, only 20% of the plutonium present in the 1 cm interface is transferred to deeper regions. The transfer rate can thus be estimated to be:

$$\frac{1}{200} \cdot \frac{1}{2} \cdot 0.40 = 10^{-3} \text{ year}^{-1}.$$

Plutonium exhibits a similar distribution in sediment and soils (45).

Water - sediment

The transport of plutonium to the sediments is described by a model where plutonium is bound to particulate material with a varying sinking rate of descent, 70 - 210 m/year (19). With a mean sinking rate of 140 m $year^{-1}$ for particle-bound activity, transfer rates between surface water and surface sediment in the lake and Baltic sea reservoirs as well as global rates can be written:

$$\frac{140}{d} \text{ year}^{-1}$$

where d is the mean depth of the reservoir.

With regard to transfer between surface sea and surface sea sediment, the portion of the surface sea which is located above the coastal zone sediments must be taken into consideration. This portion is approximately 3.7% of the total volume (25). The transfer is thus:

$$3.7 \cdot 10^{-2} \cdot \frac{140}{60} \approx 8.6 \cdot 10^{-2} \text{ year}^{-1}$$

Soil - surface water

According to (40), $5 \cdot 10^{-2}$% of the total quantity of plutonium in the soil is transported annually via erosion from a precipitation area. If the k_d value for Pu is used in the water turnover data, however, $2 \cdot 10^{-5}$ $year^{-1}$ is obtained for the region and $3 \cdot 10^{-5}$ for the global area. The latter values have been

used in this study.

Sediment - water

Calculation of the distribution factor k_d for water - sediment has given values between $4 \cdot 10^4$ - $6 \cdot 10^7$ ml/g (47). According to this, the leakage is very small, which is confirmed by the studies which were carried out in connection with the Thule accident, where no significant change was measured in the integral activity level in the sediments (47). The precision in these calculations is estimated to exclude feedback rates higher than 10^{-2} year $^{-1}$.

According to (46), however, relatively large losses have been measured in coastal sediments. According to this reference, the feedback could be 0.43 year^{-1}. Within the interval 10^{-4} - 0.43 year^{-1}, 0.43 year^{-1} has been chosen for the Baltic sea area, since it gives a higher dose burden. For the lake and the regional part of the Baltic sea, this value has been scaled down in relation to the water depth.

For the deep sea sediments, where no significant change has been found, resuspension has been assumed to be 10^{-2} year^{-1}.

AMERICIUM

Soil - groundwater

Americium is transported in soil at a rate of $1 \cdot 10^{-3}$ - $6 \cdot 10^{-3}$ cm per mm precipitation (20), where the lower

value applies to acidic soils and the higher to basic. Average precipitation over the continents is 730 mm $year^{-1}$ (30), while evaporation is 470 mm $year^{-1}$ (30). This gives a transport rate in soil of 0.3 - 1.6 cm $year^{-1}$. The depth of the soil reservoir in the regional area, 2 m, gives a transfer coefficient of $1.5 \cdot 10^{-3}$ - $8 \cdot 10^{-3}$ $year^{-1}$. A value of $4 \cdot 10^{-3}$ $year^{-1}$ has been chosen as being representative.

The global soil reservoir, with a depth of 0.5 m, gives a transfer rate of $1.6 \cdot 10^{-2}$ $year^{-1}$.

URANIUM

Soil - water

Studies carried out at the Swedish College of Agriculture (59) have arrived at a transport rate for uranium through Swedish soils which is much faster than that for radium and thorium. Leaching has been around 1% for a 1-metre soil layer. A distribution coefficient of 10^{-3} has therefore been used for uranium in the calculations.

Transfer Coeffficients for the exchange between soil and water

The water transport rate and the distribution coefficient given in Table B.2 have been used in calculating the transfer coefficients between soil and water for the following nuclides and transfers:

	Pa	Zr	Cs	Ra	Th	I	Tc	Np	Pu	Am
Groundwater 2 - soil	x	x	x	x	x	x	x	x	x	x
Groundwater 2 - surface water	x	x	x	x	x	x	x	x	x	x
Soil - surface sea	x				x	x	x	x	x	x
Soil - groundwater, global	x	x		x	x	x	x	x		x
Groundwater - surface sea	x	x	x	x	x	x	x	x	x	x
Groundwater - soil	x	x	x	x	x	x	x	x	x	x

Table B-2

Distribution coefficients for "Western US desert subsoil.*"

Element	K^{-1}
H	1
Be	3 E - 3
C	1 E - 1
Na	2 E - 2
K	6 E - 3
Ca	1 E - 2
Fe	3 E - 4
Co	3 E - 3
Ni	3 E - 3
Se	1 E - 2
Rb	2 E - 3
Sr	1 E - 2
Y	1 E - 4
Zr	1 E - 4
Nb	1 E - 4
Mo	4 E - 2
Tc	1
Pd	9 E - 4
Cd	1 E - 4
Sn	9 E - 4
Sb	1 E - 2
I	1
Cs	1 E - 3
Pm	4 E - 4
Sm	4 E - 4
Eu	4 E - 4
Ho	4 E - 4
Tl	1 E - 1
Pb	6 E - 5
Bi	2 E - 2
Po	9 E - 3
Fr	1 E - 3
Ra	2 E - 3
Ac	2 E - 4
Th	2 E - 5
Pa	6 E - 5
U	7 E - 5
Np	1 E - 2
Pu	1 E - 4
Am	1 E - 4
Cm	3 E - 4
Bk	3 E - 4

* Source: Schneider - Platt, Editors, BNWL-1900, High-Level Waste Management Alternatives.

Soil - surface water

The transfers from soil to surface water regionally for the nuclides Cs, Ra, Zr, Th, U and globally for Th and U have been derived as follows.

Based on information on the mean concentration of the naturally occurring isotope in soil, fresh and sea water, the loss of nuclides from soil to surface water can be calculated as follows:

$$\frac{C_w \cdot F_w}{C_s \cdot V_s} \text{ year}^{-1}$$

where

C_w = the concentration of the stable nuclide in fresh or sea water

F_w = the annual water flow from the area

C_s = the concentration of the stable nuclide in soil

V_s = the volume of the soil reservoir

Where specific information is lacking concerning the behaviour of the nuclides in the sediment and water reservoirs, they have been compared with analagous elements which can be expected to behave similarly with respect to a given transport process. Table B.3 shows the elements and transfers where such a comparison has been utilized. The matrix elements indicate with which element the comparison is made in the different cases.

Table B.3

Transfer	Element							
	Zr	Tc	Ra	Th	U	Np	Am	Pa
Surface water - surface water sediment	Cs		Sr	Pu	Pu	Pu	Pu	Cs
Baltic sea - Baltic sea sediment		I		Pu	Pu	Pu	Pu	Cs
Baltic sea - Baltic sea		I	Sr		Pu	Pu		
Surface sea - surface sea sediment	Cs		Sr	Pu	Pu	Pu	Pu	Cs
Deep sea - deep sea sediment	Cs				Pu	Pu		Cs

Table 8.4 Transfer coefficients (turnover/year) for the exchange of nuclides within the regional, intermediate and global reservoir systems. Alternatives 1. well and 2. lake.

		C	Zr	Tc	I	Cs	Ra	Th	Pa	U	Np	Pu	Am
REGIONAL	Groundwater 1 - surface water	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	Groundwater 1 - soil	$1.0\cdot10^{-1}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-1}$	$1.0\cdot10^{-1}$	$1.0\cdot10^{-4}$	$2.0\cdot10^{-4}$	$2.0\cdot10^{-6}$	$6.0\cdot10^{-6}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$
	Groundwater 2 - surface water	$2.0\cdot10^{-1}$	$2.0\cdot10^{-5}$	$2.0\cdot10^{-1}$	$2.0\cdot10^{-1}$	$2.0\cdot10^{-4}$	$4.0\cdot10^{-4}$	$4.0\cdot10^{-6}$	$1.2\cdot10^{-6}$	$1.0\cdot10^{-3}$	$2.0\cdot10^{-3}$	$2.0\cdot10^{-5}$	$2.0\cdot10^{-5}$
	Soil - groundwater 2	$2.1\cdot10^{-1}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-1}$	$1.0\cdot10^{-1}$	$1.0\cdot10^{-3}$	$1.5\cdot10^{-3}$	$3.5\cdot10^{-3}$	$6.0\cdot10^{-6}$	$1.0\cdot10^{-3}$	$4.0\cdot10^{-3}$	$2.0\cdot10^{-3}$	$4.0\cdot10^{-3}$
	Soil - regional atmosphere	$1.0\cdot10^{-2}$	$1.1\cdot10^{-7}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$	$1.9\cdot10^{-7}$	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$
	Soil - surface water	$2.0\cdot10^{-1}$	$1.4\cdot10^{-6}$	$2.0\cdot10^{-1}$	$2.0\cdot10^{-1}$	$1.2\cdot10^{-6}$	$1.8\cdot10^{-4}$	$3.0\cdot10^{-6}$	$1.2\cdot10^{-6}$	$1.2\cdot10^{-3}$	$1.2\cdot10^{-3}$	$2.0\cdot10^{-5}$	$1.2\cdot10^{-3}$
	Regional atmosphere - soil	$1.2\cdot10^{-3}$	$4.5\cdot10^{-1}$	$1.2\cdot10^{-3}$	$1.2\cdot10^{-3}$	$4.5\cdot10^{-1}$	$4.5\cdot10^{-1}$	$4.5\cdot10^{-1}$	$4.5\cdot10^{-1}$	$4.5\cdot10^{-1}$	$4.5\cdot10^{-1}$	$4.5\cdot10^{-1}$	$4.5\cdot10^{-1}$
	Regional atmosphere - surface water	$6.7\cdot10^{-6}$	$2.5\cdot10^{-3}$	$6.7\cdot10^{-6}$	$6.7\cdot10^{-6}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$
	Regional atmosphere - Baltic Sea	$5.0\cdot10^{-1}$	$1.9\cdot10^{2}$	$5.0\cdot10^{-1}$	$5.0\cdot10^{-1}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$
	Regional atmosphere - global atmosphere	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$
	Surface water - soil	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$
	Surface water - regional atmosphere	$2.6\cdot10^{-3}$	0	$1.3\cdot10^{-2}$	$1.3\cdot10^{-2}$	0	0	0	0	0	0	0	0
	Surface water - sediment	$7.0\cdot10^{-2}$	$3.0\cdot10^{-2}$	$7.0\cdot10^{-2}$	$7.0\cdot10^{-2}$	$3.0\cdot10^{-2}$	$5.0\cdot10^{-3}$	$5.6\cdot10$	$3.0\cdot10^{-2}$	$5.6\cdot10$	$5.6\cdot10$	$5.6\cdot10$	$5.6\cdot10$
	Surface water - Baltic	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
INTERMEDIATE	Sediment - surface water	$1.2\cdot10^{1}$	$1.0\cdot10^{-3}$	$1.2\cdot10$	$1.2\cdot10$	$1.0\cdot10^{-3}$	$3.1\cdot10^{-4}$	$3.0\cdot10^{-6}$	$1.0\cdot10^{-3}$	1.2	1.2	1.2	4.0
	Baltic - regional atmosphere	$1.3\cdot10^{-4}$	0	$5.5\cdot10^{-4}$	$5.5\cdot10^{-4}$	0	0	0	0	0	0	0	0
	Baltic - Baltic sediment	$3\cdot10^{-3}$	$5.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	$5.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	2.3	$5.0\cdot10^{-3}$	2.3	2.3	2.3	2.3
	Baltic - upper ocean	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-3}$	$4.3\cdot10^{-2}$
	Baltic sediment - Baltic	$1.2\cdot10^{1}$	$1.0\cdot10^{-3}$	$1.2\cdot10$	$1.2\cdot10$	$1.0\cdot10^{-4}$	$3.1\cdot10^{-4}$	$3.0\cdot10^{-6}$	$1.0\cdot10^{-4}$	$4.3\cdot10^{-1}$	$4.3\cdot10^{-1}$	$4.3\cdot10^{-1}$	$4.3\cdot10^{-1}$
	Global atmosphere - regional atmosphere	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$
	Global atmosphere - upper ocean	$1.4\cdot10^{-1}$	$1.3\cdot10$	$3.3\cdot10^{-1}$	$3.3\cdot10^{-1}$	$1.3\cdot10$	$1.3\cdot10$	$1.3\cdot10$	$1.3\cdot10$	$1.3\cdot10$	$1.3\cdot10$	$1.3\cdot10$	$1.3\cdot10$
	Global atmosphere - Biota	$5\cdot10^{-2}$	0	$4.2\cdot10^{-2}$	$4.2\cdot10^{-2}$	0	0	0	0	0	0	0	0
	Global atmosphere - soil	$5.6\cdot10^{-2}$	5.5	$1.3\cdot10^{-1}$	$1.3\cdot10^{-1}$	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
	Upper ocean - global atmosphere	$1.9\cdot10^{-1}$	0	$3.3\cdot10^{-4}$	$3.3\cdot10^{-4}$	0	0	0	0	0	0	0	0
	Upper ocean - deep ocean	$8.0\cdot10^{-2}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$
	Upper ocean - soil	$5.0\cdot10^{-6}$	$1.7\cdot10^{-7}$	$5.0\cdot10^{-6}$	$5.0\cdot10^{-6}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$
	Upper ocean - upper sediment	$8.0\cdot10^{-2}$	$2.0\cdot10^{-4}$	$1.1\cdot10^{-4}$	$1.1\cdot10^{-4}$	$2.0\cdot10^{-4}$	$1.1\cdot10^{-4}$	$8.6\cdot10^{-2}$	$2.0\cdot10^{-4}$	$8.6\cdot10^{-2}$	$8.6\cdot10^{-2}$	$8.6\cdot10^{-2}$	$8.6\cdot10^{-2}$
GLOBAL	Deep ocean - upper ocean	$1.3\cdot10^{-3}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$
	Deep ocean - deep sediment	$3.3\cdot10^{-4}$	$1.7\cdot10^{-6}$	$4.5\cdot10^{-5}$	$4.5\cdot10^{-5}$	$1.7\cdot10^{-6}$	$1.0\cdot10^{-2}$	$3.3\cdot10^{-3}$	$1.7\cdot10^{-6}$	$5.0\cdot10^{-3}$	$5.0\cdot10^{-3}$	$5.0\cdot10^{-3}$	$5.0\cdot10^{-3}$
	Deep sediment - deep ocean	$1.2\cdot10^{1}$	$1.0\cdot10^{-3}$	$1.2\cdot10$	$1.2\cdot10$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-3}$	$3.0\cdot10^{-6}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$
	Biota - global atmosphere	$2.2\cdot10^{-2}$	0	$5.0\cdot10$	$5.0\cdot10$	0	0	0	0	0	0	0	0
	Biota - soil	$5.6\cdot10^{-2}$	0	$1.0\cdot10^{-1}$	$1.0\cdot10^{-1}$	0	0	0	0	0	0	0	0
	Soil - global atmosphere	$3.6\cdot10^{-2}$	$6.8\cdot10^{-5}$	$4.0\cdot10^{-2}$	$4.0\cdot10^{-2}$	$6.8\cdot10^{-5}$	$6.8\cdot10^{-5}$	$6.8\cdot10^{-5}$	$6.8\cdot10^{-5}$	$6.8\cdot10^{-5}$	$6.8\cdot10^{-5}$	$6.8\cdot10^{-5}$	$6.8\cdot10^{-5}$
	Soil - upper ocean	$3.1\cdot10^{-1}$	$1.4\cdot10^{-6}$	$3.2\cdot10^{-1}$	$3.2\cdot10^{-1}$	$2.5\cdot10^{-6}$	$5.0\cdot10^{-5}$	$8.0\cdot10^{-6}$	$2.5\cdot10^{-6}$	$1.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	$3.0\cdot10^{-5}$	$3.0\cdot10^{-5}$
	Soil - Biota	$6.0\cdot10^{-1}$	0	$6.0\cdot10^{-1}$	$6.0\cdot10^{-1}$	0	0	0	0	0	0	0	0
	Soil - groundwater	$1.4\cdot10^{-1}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-1}$	$1.0\cdot10^{-1}$	$4.0\cdot10^{-3}$	$2.0\cdot10^{-4}$	$2.0\cdot10^{-6}$	$6.0\cdot10^{-6}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$8.0\cdot10^{-3}$	$1.0\cdot10^{-5}$
	Groundwater - upper ocean	$1.0\cdot10^{-4}$	$1.0\cdot10^{-7}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-6}$	$2.6\cdot10^{-6}$	$2.0\cdot10^{-8}$	$6.0\cdot10^{-8}$	$1.0\cdot10^{-6}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-7}$	$1.0\cdot10^{-7}$
	Groundwater - soil	$1.0\cdot10^{-4}$	$1.0\cdot10^{-7}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-6}$	$2.0\cdot10^{-6}$	$2.0\cdot10^{-8}$	$6.0\cdot10^{-8}$	$1.0\cdot10^{-6}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-7}$	$1.0\cdot10^{-7}$
	Upper sediment - upper ocean	$1.2\cdot10^{-2}$	$1.0\cdot10^{-3}$	$1.2\cdot10$	$1.2\cdot10$	$1.0\cdot10^{-4}$	$3.1\cdot10^{-4}$	$3.0\cdot10^{-6}$	$1.0\cdot10^{-4}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$

Table B.5 Transfer coefficients (turnover/year) for the exchange of nuclides within the regional, intermediate and global reservoir systems. Alternative 3. Baltic.

		C	Zr	Tc	I	Cs	Ra	Th	Pa	U	Np	Pu	Am
REGIONAL	Groundwater 1 - surface water	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	Groundwater 1 - soil	$1.0\cdot10^{-1}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-1}$	$1.0\cdot10^{-1}$	$1.0\cdot10^{-4}$	$2.0\cdot10^{-4}$	$2.0\cdot10^{-6}$	$6.0\cdot10^{-6}$	$7.0\cdot10^{-6}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$
	Groundwater 2 - surface water	$2.0\cdot10^{-1}$	$2.0\cdot10^{-5}$	$2.0\cdot10^{-1}$	$2.0\cdot10^{-1}$	$2.0\cdot10^{-4}$	$4.0\cdot10^{-4}$	$4.0\cdot10^{-6}$	$2.0\cdot10^{-4}$	$1.4\cdot10^{-5}$	$2.0\cdot10^{-3}$	$2.0\cdot10^{-5}$	$2.0\cdot10^{-5}$
	Soil - groundwater 2	$1.0\cdot10^{-1}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-1}$	$1.0\cdot10^{-1}$	$1.0\cdot10^{-3}$	$7.0\cdot10^{-3}$	$3.5\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-5}$	$4.0\cdot10^{-3}$	$2.0\cdot10^{-3}$	$4.0\cdot10^{-3}$
	Soil - regional atmosphere	$1.0\cdot10^{-2}$	$1.6\cdot10^{-8}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.6\cdot10^{-8}$	$1.6\cdot10^{-8}$	$1.6\cdot10^{-8}$	$1.6\cdot10^{-8}$	$1.6\cdot10^{-8}$	$1.6\cdot10^{-8}$	$1.6\cdot10^{-8}$	$1.6\cdot10^{-8}$
	Soil - surface water	$2.0\cdot10^{-1}$	$1.4\cdot10^{-6}$	$2.0\cdot10^{-1}$	$2.0\cdot10^{-1}$	$1.2\cdot10^{-6}$	$1.8\cdot10^{-4}$	$3.0\cdot10^{-6}$	$1.2\cdot10^{-6}$	$1.2\cdot10^{-3}$	$1.2\cdot10^{-3}$	$2.0\cdot10^{-5}$	$1.2\cdot10^{-3}$
	Regional atmosphere - soil	$1.2\cdot10^{-3}$	$4.2\cdot10^{-1}$	$1.2\cdot10^{-3}$	$1.2\cdot10^{-3}$	$4.2\cdot10^{-1}$	$4.2\cdot10^{-1}$	$4.2\cdot10^{-1}$	$4.2\cdot10^{-1}$	$4.2\cdot10^{-1}$	$4.2\cdot10^{-1}$	$4.2\cdot10^{-1}$	$4.2\cdot10^{-1}$
	Regional atmosphere - surface water	$6.7\cdot10^{-6}$	$2.3\cdot10^{-1}$	$6.7\cdot10^{-5}$	$6.7\cdot10^{-5}$	$2.3\cdot10^{-1}$	$2.3\cdot10^{-1}$	$2.3\cdot10^{-1}$	$2.3\cdot10^{-1}$	$2.3\cdot10^{-1}$	$2.3\cdot10^{-1}$	$2.3\cdot10^{-1}$	$2.3\cdot10^{-1}$
	Regional atmosphere - Baltic Sea	$5.0\cdot10^{-1}$	$1.9\cdot10^{2}$	$5.0\cdot10^{-1}$	$5.0\cdot10^{-1}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$	$1.9\cdot10^{2}$
	Regional atmosphere - global atmosphere	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$
INTERMEDIATE	Surface water - regional atmosphere	$3.3\cdot10^{-4}$	0	$3.3\cdot10^{-4}$	$3.3\cdot10^{-4}$	0	0	0	0	0	0	0	0
	Surface water - sediment	$1.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$5.0\cdot10^{-3}$	6.9	$3.0\cdot10^{-2}$	6.9	6.9	6.9	6.9
	Surface water - Baltic	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	Sediment - surface water	$1.2\cdot10^{1}$	$1.0\cdot10^{-3}$	1.2·10	1.2·10	$1.0\cdot10^{-3}$	$3.1\cdot10^{-4}$	$1.7\cdot10^{-9}$	$1.0\cdot10^{-3}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$
	Baltic - regional atmosphere	$1.3\cdot10^{-4}$	J	$1.3\cdot10^{-4}$	$1.3\cdot10^{-4}$	0	0	0	0	0	0	0	0
	Baltic - Baltic sediment	$3\cdot10^{-3}$	$5.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	$5.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	2.3	$5.0\cdot10^{-2}$	2.3	2.3	2.3	2.3
	Baltic - upper ocean	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-3}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$
	Baltic sediment - Baltic	$1.2\cdot10^{1}$	$1.0\cdot10^{-3}$	1.2·10	1.2·10	$1.0\cdot10^{-4}$	$3.1\cdot10^{-4}$	$1.7\cdot10^{-9}$	$1.0\cdot10^{-4}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$
	Global atmosphere - regional atmosphere	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$
	Global atmosphere - upper ocean	$1.4\cdot10^{-1}$	1.3·10	$3.3\cdot10^{-1}$	$3.3\cdot10^{-1}$	1.3·10	1.3·10	1.3·10	1.3·10	1.3·10	1.3·10	1.3·10	1.3·10
	Global atmosphere - Biota	$5\cdot10^{-2}$	0	$4.\cdot10^{-2}$	$4.2\cdot10^{-2}$	0	0	0	0	0	0	0	0
	Global atmosphere - soil	$1.3\cdot10^{-1}$	6.7	$1.3\cdot10^{-1}$	$1.3\cdot10^{-1}$	6.7	6.7	6.7	5.5	6.7	6.7	6.7	6.7
	Upper ocean - global atmosphere	$1.9\cdot10^{-1}$	0	$6.6\cdot10^{-5}$	$6.6\cdot10^{-5}$	0	0	0	0	0	0	0	0
	Upper ocean - deep ocean	$8.0\cdot10^{-2}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$
	Upper ocean - soil	$5.0\cdot10^{-6}$	$1.7\cdot10^{-7}$	$5.0\cdot10^{-6}$	$5.0\cdot10^{-6}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$
	Upper ocean - upper sediment	$8.9\cdot10^{-4}$	$2.0\cdot10^{-4}$	$1.1\cdot10^{-4}$	$1.1\cdot10^{-4}$	$2.0\cdot10^{-4}$	$1.1\cdot10^{-4}$	$8.6\cdot10^{-2}$	$2.0\cdot10^{-4}$	$8.6\cdot10^{-2}$	$8.6\cdot10^{-2}$	$8.6\cdot10^{-2}$	$8.6\cdot10^{-2}$
	Deep ocean - upper ocean	$1.3\cdot10^{-3}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$
	Deep ocean - deep sediment	$3.3\cdot10^{-4}$	$1.7\cdot10^{-6}$	$4.5\cdot10^{-5}$	$4.5\cdot10^{-5}$	$1.7\cdot10^{-6}$	$3.0\cdot10^{-7}$	$3.3\cdot10^{-3}$	$1.7\cdot10^{-6}$	$5.0\cdot10^{-3}$	$5.0\cdot10^{-3}$	$5.0\cdot10^{-3}$	$5.0\cdot10^{-3}$
	Deep sediment - deep ocean	$1.2\cdot10^{1}$	$1.0\cdot10^{-3}$	1.2·10	1.2·10	$1.0\cdot10^{-4}$	$3.0\cdot10^{-4}$	$1.7\cdot10^{-9}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$
GLOBAL	Biota - global atmosphere	$2.2\cdot10^{-2}$	0	5.0·10	5.0·10	0	0	0	0	0	0	0	0
	Biota - soil	$5.6\cdot10^{-2}$	0	$1.0\cdot10^{-1}$	$1.0\cdot10^{-1}$	0	0	0	0	0	0	0	0
	Soil - global atmosphere	$3.6\cdot10^{-2}$	$2.5\cdot10^{-6}$	$4.0\cdot10^{-2}$	$4.0\cdot10^{-2}$	$2.5\cdot10^{-6}$	$2.5\cdot10^{-6}$	$2.5\cdot10^{-6}$	$2.5\cdot10^{-6}$	$2.5\cdot10^{-6}$	$2.5\cdot10^{-6}$	$2.5\cdot10^{-6}$	$2.5\cdot10^{-6}$
	Soil - upper ocean	$4.6\cdot10^{-2}$	$1.4\cdot10^{-6}$	$3.2\cdot10^{-1}$	$3.2\cdot10^{-1}$	$2.5\cdot10^{-6}$	$4.8\cdot10^{-6}$	$8.0\cdot10^{-6}$	$2.5\cdot10^{-6}$	$2.1\cdot10^{-5}$	$3.0\cdot10^{-3}$	$3.0\cdot10^{-5}$	$3.0\cdot10^{-5}$
	Soil - Biota	$6.0\cdot10^{-1}$	0	$6.0\cdot10^{-1}$	$6.0\cdot10^{-1}$	0	0	0	0	0	0	0	0
	Soil - groundwater	$1.4\cdot10^{-1}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-1}$	$1.0\cdot10^{-1}$	$1.0\cdot10^{-4}$	$2.0\cdot10^{-4}$	$2.0\cdot10^{-6}$	$6.0\cdot10^{-6}$	$7.0\cdot10^{-6}$	$1.0\cdot10^{-3}$	$8.0\cdot10^{-3}$	$1.0\cdot10^{-5}$
	Groundwater - upper ocean	$2.0\cdot10^{-4}$	$1.0\cdot10^{-7}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-6}$	$2.0\cdot10^{-6}$	$2.0\cdot10^{-8}$	$6.0\cdot10^{-8}$	$7.0\cdot10^{-8}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-7}$	$1.0\cdot10^{-7}$
	Groundwater - soil	$2.0\cdot10^{-4}$	$1.0\cdot10^{-7}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-6}$	$2.0\cdot10^{-6}$	$2.0\cdot10^{-8}$	$6.0\cdot10^{-8}$	$7.0\cdot10^{-8}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-7}$	$1.0\cdot10^{-7}$
	Upper sediment - upper ocean	$1.2\cdot10^{-2}$	$1.0\cdot10^{-3}$	1.2·10	1.2·10	$1.0\cdot10^{-4}$	$3.1\cdot10^{-4}$	$1.7\cdot10^{-9}$	$1.0\cdot10^{-4}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$	$5.6\cdot10^{-1}$

APPENDIX C

Appendix C.1 (4)

INPUT DATA FOR CALCULATION OF ACTIVITY INTAKE

Contents

- Table C.1: Diet composition and annual consumption for criticial group and population

- Table C.2: Concentration and distribution factors for transfer of radioactive nuclides from different reservoirs in the ecosystem to the food chains. The table shows the spread in calculated transfers and typical values which serve as input data in the dose calculations.

- Table C.3: Other input data for exposure via animal and vegetable foodstuffs.

Appendix C.2

Table C.1

Diet composition and annual consumption for critical group and population

		CRITICAL GROUP		POPULATION		
		Inland alt.	Baltic sea alt.	Region	Baltic sea	Global
Inhalation	m^3	9 400		9 400		9 400
Drinking water	l	440		440		440
Milk	l	183		183		130
Meat	kg	53		53		46
Green vegetables	kg	28		28		120
Grain	kg	58		58		120
Root vegetables	kg	83		83		82
Fish	kg	50	200	50	20	22
Eggs	st	220		220		220

Table C.2

Enrichment* and distribution factors for transfer of activity from different reservoirs to food chains

Nuclide	ENRICHMENT FACTORS **				DISTRIBUTION FACTORS					
	Plant-soil	Cereals-soil	G.veg. - soil	R.veg. - soil	Fish - lake	Fish - brackish w.	fish - sea water	day/l milk - grass	day/kg meat - grass	day/pc egg - feed
C-14	5.5				4.6×10^{3}	4.6×10^{3}	1.8×10^{3}	7.5×10^{-3}	1.0	1.0
Zr-93	1.7×10^{-4}				3	200	200	2.5×10^{-6}	10^{-3}	6×10^{-5}
Tc-99	2.5×10^{-1}				15	10	10	1.2×10^{-2}	9×10^{-4}	9×10^{-4}
I-129	2×10^{-2}				1-225	20	20	10^{-2}	9×10^{-2}	3×10^{-2}
					15					
Cs-135 o -139	3×10^{-3}-7***	3×10^{-3}-1	10^{-3}-5	3×10^{-3}	500-1.2×10^{4}	500	5-240	7×10^{-3}	4×10^{-2}	2×10^{-2}
	3×10^{-3}	3×10^{-3}	1×10^{-3}		2×10^{3}		40			
Ra-226	3×10^{-4}-8×10^{-4}		10^{-4}-3×10^{-4}		1-50	50	50	8×10^{-3}	9×10^{-4}-1.5×10^{-2}	10^{-6}
	3×10^{-4}		3×10^{-4}		15				9×10^{-4}	
Th-229 o -230	4×10^{-3}				30	40	40-10^{4}	5×10^{-6}	5×10^{-3}	10^{-4}
							40			
Pa-231	2.5×10^{-3}				11	11	10	5×10^{-6}	5×10^{-3}	10^{-4}
U-all	2.5×10^{-3}				2-10	10	10	5×10^{-4}	5×10^{-3}	10^{-4}
					10					
Np-237	2.5×10^{-3}				10	10	10	5×10^{-6}	10^{-2}	10^{-4}
Pu-all	2×10^{-4}-6×10^{-4}	4×10^{-8}-4×10^{-4}	10^{-7}-3×10^{-2}	1.8×10^{-2}	3.5	3.5	1-5	10^{-6}	10^{-2}	10^{-4}
	2×10^{-4}	4×10^{-4}	3×10^{-3}				3			
Am-240 o -243	2.5×10^{-4}	10^{-7}-10^{-2}	3×10^{-4}-3	3×10^{-2}	25	25	25	5×10^{-6}	10^{-2}	10^{-4}
		2.5×10^{-4}	3×10^{-2}							
Referenser:	(10,12,16,18, 20,21,22,36)	(10,11,12,16, 17,18,20,21, 23,36)	(10,11,16, 17,18,20,21, 22,23,36)	(10,11, 12,17,21)	(10,13,35, 37)	(35,39)	(22,28,35, 37)	(10,14,22)	(10,14,22)	(10)

* Wherever enrichment factors for cereals, green vegetables and root vegetables are lacking, the value for "plant - soil" is used.

** pCi/kg in foodstuffs per pCi/kg in the reservoir.

*** 3×10^{-3} -7 refers to the spread in values with typical value given underneath. The typical value is the input value for the dose calculations.

Appendix C.4

Table C.3

Daily consumption of water and food for livestock, Mc_i.

	Mc_w (l day^{-1})	Mc_b (kg day^{-1})	Mc (kg day^{-1})
Cow	3×10^{1}	3×10^{1}	
Chicken	1.8×10^{-1}		7×10^{-2}

Coverage for pasturage, $Cov_p = 3 \times 10^{-2}$ kg m^{-2}.

Coverage for green vegetables, $Cov_g = 1.5$ kg m^{-2}.

Irrigation, IRR = 4×10^{-4} l m^{-2} day^{-1}.

Deposition rate for transfer from atmosphere to soil, DEP = 259 m day^{-1}.

Appendix D.1

APPENDIX D

WEIGHTING AND DOSE FACTORS

Contents

Appendix D.2

Table D.1

Weighting factors for calculation of whole-body dose.

Organ or tissue	Weighting factor
Reproductive glands	0.25
Chest	0.15
Red bone marrow	0.12
Lung tissue	0.12
Thyroid gland	0.03
Bone tissue	0.03
Remaining organs (individual organs 1/5)	0.30
	1.00

Appendix D.3

Table D.2

Dose factors for intake with food, water and respiration air of 1 curie of some important nuclides.

	Whole-body dose*	Bone dose	Lung dose	Gonad dose	Thyroid dose	Weighted** whole-body dose
Dose via intake of food or water (rem/Ci)						
C-14	6.1×10^{2}	2.7×10^{3}				
Sr-90	9.1×10^{5}	1.1×10^{7}		2.0×10^{3}		9.9×10^{2}
Zr-93	9.1×10^{-1}					1.5×10^{6}
Tc-99	4.6×10^{1}	1.2×10^{2}	1.4×10^{1}	4.6×10^{1}		1.7×10^{2}
I-129	9.1×10^{3}			3.4×10^{3}	1.1×10^{7}	5.5×10^{2}
Cs-135	4.6×10^{3}	1.8×10^{4}	1.8×10^{3}	4.6×10^{3}		3.4×10^{5}
Cs-137	4.6×10^{4}	1.1×10^{5}	1.1×10^{4}	4.6×10^{4}		7.3×10^{3}
Ra-226	3.0×10^{7}	3.0×10^{6}				5.5×10^{4}
Th-229	6.1×10^{4}	1.5×10^{7}				2.8×10^{6}
Th-230	6.1×10^{4}	2.2×10^{6}				1.8×10^{6}
Pa-231	1.6×10^{5}	4.1×10^{6}				3.4×10^{5}
U-233	4.6×10^{4}	5.4×10^{5}				6.6×10^{5}
U-234	4.6×10^{4}	5.4×10^{5}				1.1×10^{5}
U-235	4.6×10^{4}	5.4×10^{5}				1.1×10^{5}
U-236	4.6×10^{4}	5.4×10^{5}				1.1×10^{5}
U-238	4.6×10^{4}	5.4×10^{5}				1.1×10^{5}
Np-227	4.6×10^{4}	1.2×10^{6}				1.1×10^{5}
Pu-239	1.8×10^{4}	1.1×10^{6}				2.0×10^{5}
Pu-240	1.8×10^{4}	1.1×10^{6}				1.6×10^{5}
Pu-242	1.8×10^{4}	1.1×10^{6}				1.6×10^{5}
Am-241	4.6×10^{4}	1.1×10^{6}				1.6×10^{5}
Am-243	4.6×10^{4}	1.1×10^{6}				2.2×10^{5}
						2.2×10^{5}

Cont.

Table D.2 cont.

	Whole-body Dose*	Bone dose	Lung dose	Gonad dose	Thyroid dose	Weighted** whole-body dose
	Dose via inhalation (rem/Ci)					
C-14	4.0×10^{2}	2.0×10^{3}				6.6×10^{2}
Sr-90	1.0×10^{6}	1.2×10^{7}		2.7×10^{3}		2.3×10^{6}
Zr-93	2.5×10^{3}	1.2×10^{5}				1.8×10^{4}
Tc-99	5.0×10^{1}	1.3×10^{2}	1.5×10^{1}	5.0×10^{1}		3.6×10^{2}
I-129	1.0×10^{4}			2.6×10^{3}	6.0×10^{6}	1.9×10^{5}
Cs-135	3.3×10^{3}	1.5×10^{4}	1.5×10^{3}	3.3×10^{3}		5.7×10^{3}
Cs-137	3.3×10^{4}	6.0×10^{4}	1.0×10^{4}	3.3×10^{4}		3.8×10^{4}
Ra-226	4.0×10^{7}	4.0×10^{6}	3.0×10^{8}			3.8×10^{6}
Th-229	1.0×10^{8}	4.0×10^{10}	3.2×10^{8}			4.9×10^{9}
Th-230	1.0×10^{8}	6.0×10^{9}				9.0×10^{8}
Pa-231	1.2×10^{9}	1.2×10^{10}				2.4×10^{9}
U-233	1.0×10^{6}	1.4×10^{7}				2.7×10^{6}
U-234	1.0×10^{6}	1.3×10^{7}				2.7×10^{6}
U-235	1.0×10^{6}	1.3×10^{7}				2.7×10^{6}
U-236	1.0×10^{6}	1.3×10^{7}				2.7×10^{6}
U-238	1.0×10^{6}	1.3×10^{7}				2.7×10^{6}
Np-237	1.0×10^{8}	3.0×10^{9}				5.0×10^{8}
Pu-239	2.0×10^{8}	6.0×10^{9}				9.5×10^{8}
Pu-240	2.0×10^{8}	6.0×10^{9}				9.5×10^{8}
Pu-242	2.0×10^{8}	6.0×10^{9}				9.5×10^{8}
Am-241	1.0×10^{8}	2.0×10^{9}				4.1×10^{8}
Am-243	1.0×10^{8}	2.0×10^{9}				4.1×10^{8}

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