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DOSE AND DOSE COMMITMENT CALCULATIONS FROM GROUNDWATERBORNE RADIOACTIVE ELEMENTS RELEASED FROM A REPOSITORY FOR SPENT NUCLEAR FUEL

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ABSTRACT

The turnover of radioactive matter entering the biosphere with groundwater has been studied with regard to exposure and doses to critical groups and populations. Two main recipients, a well and a lake, have been considered for the inflow of groundwaterborne nuclides.

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 treatment of the model is based upon compartment theory with first order kinetics and also includes products in decay chains.

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.

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1 INTRODUCTION

An important question concerning the final storage of radioactive waste in the bedrock is how individuals and populations of humans will be exposed in time and space to the radioactive material which may reach the biosphere from contaminated groundwater. The transport of materials by groundwater is generally a very slow process. The substances which are transported with the groundwater move slower than the water because they interact chemically and physically with their environments (e.g. sorption to materials in the bedrock). After sufficiently long periods of time, however, 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 use estimates of the long-range turnover of radioactive elements in various ecosystems to predict doses which may result from contaminated groundwater reaching the biosphere.

Two main types of recipients for the radioactive elements reaching the biosphere are discussed here:

- inflow of groundwater into a well, and

- inflow of groundwater into a lake and its downstream lake system.

Calculations of the dose burden are carried out by 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 (e.g. groundwater, upper and deeper soil, sediment and surface water) which differ significantly in their turnover rates of various radionuclides.

The mathematical models make it possible to consider the decay of a parent nuclide, during its circulation in the biosphere, to radioactive daughter nuclides.

The model is also designed to describe important reservoir 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 model calculations include estimates of:

- dose to the critical group (the limited number of individuals living in the vicinity of the release point) and

- dose to the general population (the collective dose, which can refer to the exposure of a portion or the entire global population).

Radiation doses are given in the form of annual doses from one year's exposure. 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 for some releases.

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 methods are based on compartment theory with first-order kinetics (1). The cycling and content of radioactive matter in different ecosystems are, therefore, described by a system of first-order linear differential equations with constant transfer coefficients and a number of physically 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,
- all atoms, molecules or other elementary units have 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

$$\dot{Y}_M(t) = K_M Y_M(t) + Q_M(t) - \lambda_M Y_M(t)$$

for parent nuclides

$$\dot{Y}_{D_n}(t) = K_{D_n} Y_{D_n}(t) + \lambda_{D_n} Y_{D_{n-1}}(t) - \lambda_{D_n} Y_{D_n}(t) + Q_n(t)$$

for daughter nuclides

where n = 1-9

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 matrices K (year^{-1}) and Q (t) (activity year^{-1}) describe the transfer rates between the reservoirs and production or release within the reservoir, respectively. The vector of decay constants is

$\lambda_{D_n} = \lambda_m = \ell n2/T_{1/2}$, where $T_{1/2}$ is the

physical half-life of the isotope m.

Solutions of the equation system and calculations of Y (t) for "parent" and "daughter" are provided by the computer program BIOPATH (1).

2.2 Primary recipients

Groundwater passing through the repository and reaching the surface of the earth constitutes the path of inflow for the radioactive elements.

Regardless of the ecosystem considered, two main recipients for inflow to the biosphere have been studied, namely a well and a lake. Another possible primary recipient has also been treated, namely a peat-bog for the dominant nuclides from the dose burden view.

2.3 Model structure

The model of the biosphere is divided into four different subsystems:

- local
- regional
- intermediate
- global zone

Sometimes the regional area can include the local area.

The regional area is fully described in a following chapter for some different recipient areas.

The turnover processes are largely controlled by the interchange of three zones, such as regional, intermediate, and global zone.

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

- study extreme exposure situations within limited areas;

- increase the realism of the dispersal pattern described by the model, 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 intermediate zone.

Within the subsystem, 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, and
- available information on dispersal mechanisms.

2.4 Reservoir sizes

When the primary recipient constitutes of a well, it is of the same size for all recipient areas considered. The annual volume for the dilution of the nuclides is 500 000 m^3. That value is based upon closer studies of the groundwater flow for a well and the proportion of water comming from the repository in relation to the total amount of water available for dilution (23, 24). Besides the groundwater reservoir there is one soil reservoir included in the local area for the well case.

Reservoir sizes, intermediate and global areas

The reservoirs which are designed for the intermediate and global zones are the same as previously used, see ref (16). However, one exception is that the sediments are illustrated by the use of two reservoirs instead of previously one. That has been done in order to make it possible to simulate the sediment partly acting as a sink.

The sites of the reservoirs for the intermediary and global zones which are general, despite the choice of recipient area, are shown in Appendix A, Table A2.

Turnover processes

In short terms the following turnover processes are generally used in the model:

- water turnover
- irrigation
- sedimentation
- turnover in the sediments
- migration in soil
- turnover of groundwater
- resuspension
- deposition
- seaspray

More detailed information about the turnover processes is available in reference (16).

3 EXPOSURE SITUATIONS

3.1 Exposure pathways

When the radionuclides are transported through the different reservoirs in the model, the activity can reach man via different paths of exposure.

The internal exposure occurs through inhalation, intake of food-stuffs and drinking water, while the external exposure included originates from activity in water or material accumulated in ground or sediment. This leads to irradiation from bathing, out-door stay, activities on the beaches of lakes or seas, handling of fishing tackle which has come into contact with the bottom sediments.

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 which leads to contemporary contamination of the surfaces of vegetation
- uptake via the food chain of grass-meat, grass-milk and grain-egg
- consumption of soil when grazing
- uptake in fish or other marine food-stuffs from surrounding water

Certain feed-backs in some of the studied ecosystems reinforce the flow of radioactivity along certain paths of exposure.

In the main case alternative, pasture and crops are irrigated with water from the lake.

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.

The different primary recipients, well or lake, lead to different paths of exposure for the main case. The paths of exposure dealt with in the main alternative are:

Path of exposure	Primary recipient[a)]
Inhalation	L
Drinking water	W, L
Milk	W[b)], L
Meat	W[b)], L
Green vegetables	W, L
Cereals	L
Root vegetables	L
Eggs	W, L
Fish	W, L
Land	L
Beach	W, L
Bathing	W, L
Fishing	W, L

a) W (well), L (lake).

b) In this case the only pathway considered is the animals consumption of drinking water.

For the other candidate sites the pathways are described in chapter 5.

In the well alternative man is exposed both to the activity which is drawn up with water from the well, as well as to the activity reaching the lake by taking the annual amount fish for consumption from the contaminated lake.

The final repository will be placed in rock with low water flow and the potential formations are surrounded by geometrically well-defined fracture zones. See further reference (25).

The low permeability of the rock and the fracture zones in the candidate sites investigated render them unsuitable for wells with large water extractions. Only wells for single-family households or summer homes could reasonably be drilled in such areas. Typical water extraction for those wells are in the range of 1.5-6 m^3/d and the depths are normally down to about 60 m. Following no irrigation of agricultural products like pasturage and cereals could be relevant for the well-alternative.

When a lake is primary recipient the whole spectrum of terrestrial exposure pathways normally used in the BIOPATH-program is represented.

The activity in the lake water and the sediments exposes the critical group. For that reason the drinking water both for man and cattle is taken from the lake.

3.3 Exposure of populations

The exposure to the regional populations depends on the appearance of the recipient areas studied.

The yield values for surface water as well as for farming land in different parts of Sweden are used as a basis for calculation of the regional collective doses. Typical yield values for fish in lakes are about 7 kg per 10 000 m^2 (1 hectare) while the corresponding for flowing water is about 20-40 kg/hectare (4).

The exposure pathways of the Baltic zone naturally originates from the activity in lake and sediment. The internal exposure from consumption of fish is based upon reported yield values for the Baltic Sea, which at present is about $9 \cdot 10^5$ tons. Of that amount about two thirds are considered to be for direct human consumption. No corrections are made for the decrease in the amounts taken for consumption due to the disappearances before and under the preparations before eating. It is possible that in the future, some kind of so called marine farming could be expected. This has implied that also other marine food-stuff like crustacea plants or algea are included in the dose calculations.

Those different species of marine food-stuffs, except for fish, have been lumped together called "marine plants". Thereby the production is assumed to be $2 \cdot 10^5$ ton, a fairly high amount but chosen in order not to underestimate the predicted doses.

For the global area, the world population has been assumed to be exposed by all the previously mentioned pathways. Diet composition and annual amounts of the food-stuffs are summarized in Appendix B. The values are based upon values given in reference (2). Also for the global population the use of marine food-stuffs other than fish is included and treated in the same manner as for the Baltic population. The world population in the calculations consists of 10^{10} individuals, with a starting value of $6 \cdot 10^9$ individuals in the year 2000. Thereafter the growth will take place exponentially at a rate of 2 % per year and will stop at $1 \cdot 10^{10}$ individuals.

3.4 Uptake in food chains

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

Symbols:

U_i = Uptake of a particular nuclide in food-stuff i. Given in Bq per unit of food (kg, litre or piece).

F_i = Distribution factor for a given nuclide for food-stuff i. Given in day per unit of food (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),
s soil (kg).

C_j = Concentration of a certain nuclide in reservoir j. Given in Bq 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 pathway 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, food-stuff (dry weight) and soil for animal in dominant transport links (l/day, kg/day).

DEP = deposition (m per day).

γ = mass interception factor (m^2 per kg).

IRR = irrigation (ℓm^{-2} day^{-1}).

R = average residence time on vegetation = 20 days.

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

The following equations are used for each nuclide to estimate the uptake in the different foods:

Uptake in milk and meat

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

- Root uptake to pasturage;
- Deposition on pasturage;
- Drinking water;
- Intake of soil during grazing.

Thus,

U_m (in Ci per litre) =

$$F_m\ (MC_p \times E_p + MC_s) \times C_s + MC_l \times C_l + \gamma \times DEP \times C_a \times R \times MC_p),$$

and

U_k (in Ci per kg) =

$$F_K\ (MC_p \times E_p + MC_s) \times C_s + MC_l \times C_l + \gamma \times DEP \times C_a \times R \times MC_p).$$

Uptake in green vegetables

The concentration of radioactive elements in green vegetables, U_v, originates from two sources: the uptake of radioactivity via the root system, and deposition directly on the surfaces of the leaves.

Thus,

U_v (in Ci per kg) =

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

The concentration factor, C_s, between soil and plant is specific for each individual nuclide.

Uptake in grain and root vegetables

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

Thus,

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

and

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

Uptake in eggs

The radioactivity in eggs, U_e, comes from feeding the hens with contaminated grain and drinking water.
Thus,
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, U_f, takes place through the inflow of contaminated groundwater into the lake and the feedback of radioactivity from the runoff area and the bottom sediments.

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

3.5 External exposure

Exposure from ground

The dose conversion factors for exposure from radioactivity in the soil and on beaches are taken from reference (8).

Exposure in connection with bathing

The exposure from bathing is received by the use of factors derived by Kocher (9).

Exposure from fishing tackle

The whole-body dose from 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.

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

where

N = Bq of the nuclide per kg of fishing tackle times the number of particles, or photons, per disintegration.

A = fraction of energy absorbed per cm of 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 (19). For β-radiation, 100 % absorption within 1 cm thick tissue, as above, has been assumed.

$5.75 \cdot 10^{-7}$ = unit conversion factor for $MeVs^{-1}$ to Sv^{-1}.

4 RADIATION DOSES

The radioactive elements which enter the biosphere via the groundwater can expose man to ionizing radiation from radioactive decay of nuclides by either external irradiation of the body, or internal irradiation by consumption of contaminated food or water.

The magnitude of the radiation dose to different organs through internal irradiation is dependent upon, among other things, how the nuclide enters the body. Important factors affecting the final dose are the substances in which 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 particleborne activity in the respired air can be absorbed by the blood through the lungs, or remain in the lungs, or be transferred to the intestinal tract. In recognition of such factors, the radiation protection authorities have chosen to assess dose on the basis of the solubility or "transportability" of the element and the paths of intake, i.e. by inhalation, consumption of drinking water, or food (3, 5, 6).

4.1 Dose factors

After the intake of radioactive substances, several tissues can be exposed. The doses to these tissues can then be recalculated to a total whole-body dose according to ICRP publ no 26.

The values given by ICRP derive from adults with contemporary standard of several age dependence factors. ICRP has, however, indicated that because of lack of better information, these values might be used for children. The age-dependence nature of absorbed dose, and dose equivalent, is summarized in the following section (3).

Children and new-borne

Ionizing gamma radiation with an energy greater than 10 KeV located in one tissue will be strong enough to also irradiate other tissues. For small children the radiation will reach more tissues than in adults. This will result in an increased absorbed dose in these tissues.

On the other hand, children's consumption of food stuffs and water is less than adults and, at the same time, children's metabolism is faster. This means that the active nuclides will be eliminated faster than for adults. Thus, the increase in the absorbed dose by children is, to some extent, compensated for by increased metabolism.

If nuclides are taken early in life, the expected longer life-time for children must be considered when calculating the dose equivalent commitment. For nuclides with both long biological and physical half-time it is usually not enough to integrate only to 50 years. Instead, an integration to 70 years ought to be used.

For technetium-99 and iodine-129 one can expect significant differences in the dose equivalent commitment depending on differences in body size. The body size effect can be roughly estimated as a factor of 10 for an infant compared to an adult. For radium and certain actinides the body size has a limited influence on the dose equivalent commitment. However, the greater uptake by GIT for some actinides is an important factor.

The dose factor used in the calculations are based upon the revision of dose factors performed (3), with 70 years integration time. For those nuclides not included in the revision the values from ICRP has been used.

The dose factors are shown in Appendix C.

4.2 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 time point after inflow to the biopshere has begun.

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 (5).

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.

5 RECIPIENT AREAS

The regional zone of the model is used for describing the ecosystems in the recipient areas.

There are, at present, five areas in Sweden which are closely studied as potential places for a repository. Detailed descriptions of each recipient area are available (4). The recipient areas considered are separated from each other by distances of about 1 000 km. These large distances imply that differences exist between them concerning climate, hydrology, vegetation etc.

Natural changes in the ecosystems of each area can be expected with time. Thus, the use of the different recipient areas is of interest to see how the exposure to man can vary with the ecosystems involved, regardless of the specific geographic situation. The recipient areas will be presented below.

5.1 Fjällveden

Fjällveden is situated in the south of Sweden and surrounded by farm-land and large lake system.

The primary recipient is supposed to be a little lake, the Morpa lake, which is drained to the Lidsjön-Långhalsen lakes. These lakes are drained by Nyköpingsån, which flows into Nyköpingsfjärden before reaching the Baltic. The model system used is shown in Figure 1.

In Appendix A the sizes of the reservoirs are shown.

Turnover processes

The model assumes that processes affecting the turnover of nuclides in all water reservoirs are the same, namely outflow and sedimentation. Nuclides may move from the sediments back into the water or be transported in the opposite direction to deeper sediments, which act as a sink.

Only from the Lidsjön-Långhalsen area is lake water used for irrigation of farms. The upper soil reservoir is thus continuously supplied with nuclides, while migration into the soil transports the activity away. Nuclides in the upper soil are exchanged with the atmosphere by resuspension and deposition.

The nuclides of the upper soil layer (the root zone or ploughed layer) are transported through deeper soils by leaching before reaching the groundwater reservoir. The groundwater reservoir drains into the lake.

Exposure pathways

Besides the "well" case, man may be exposed by movement of nuclides in the system through the following pathways.

Area	
The Morpa lake	Water, consumption of fish, meat and milk. The latter by the animals drinking contaminated water.
Lidsjön-Långhalsen	Water, consumption of fish and all terrestrial pathways.
Nyköpingsfjärden	Consumption of marine food stuffs.

5.2 Gideå

The Gideå area is situated in the middle of Sweden. The use of land for agricultural purposes is much smaller than the Fjällveden area. Arable land is about 6 % of the total area, compared with 34 % for the potential site situated further south.

This means that for this region the possibility of using contaminated water for irrigation is not considered.

The primary recipient for the groundwater-borne nuclides is the section of the Gideå river, one of the two main water courses in the area, which is impounded by a dam.

Another possible recipient is Gideån itself, which flows into a coastal part of the Baltic. The model system is quite simple compared to the previous areas and is shown in Figure 2. The sizes of the reservoirs are summarized in Appendix A.

Turnover processes

The Gideå recipient area represents only the turnover processes directly coupled to the surface water system, namely turnover of water and sedimentation. Sedimentation does not occur in the river because the flow of water is high and a lot of material can be carried in suspension. In other water reservoirs there are exchanges between water and sediments. As mentioned earlier, the deeper sediment layers act as a sink.

Exposure pathways

The lack of transport from water to surrounding land reduces the number of exposure pathways significantly. Activity in the Gideå dam impoundment can expose man to contaminated water or fish. Some cattle can also take water from the impoundment, which leads to possible exposure from consumption of contaminated milk and meat. The only exposure pathway from the Gide river, is by consumption of contaminated fish.

Finally, as the nuclides are transported to the coast, they can reach man via consumption of marine food stuffs.

5.3 Kamlunge-kölen

The Kamlunge-kölen is the farthest north of all potential sites, and much like the earlier treated Gideå area. The area with a water dividing range has two recipient areas. Stor-Lappträsket has, however, been chosen to be the best representative for the primary recipient, because here, two fracture zones encounter each other. At present there are some other small lakes in the district, but vegetation growth will probably cover them in the near future.

Stor-Lappträsket drains into the Kalix river, which is the next recipient. This is a river with many smooth reaches of water interrupted by rapids of different length.

The lake system is composed of one water reservoir with two underlying sediment reservoirs. The river is represented by one water and one sedimentation reservoir.

Outside the river's mouth there is a coastal water reservoir with two underlying sediment reservoirs.

The model system is shown in Figure 3. and in Appendix A the sizes of the reservoirs are given.

Turnover processes

The Kamlunge-kölen represents the same type of reservoir system and transfer processes as the Gideå area. The radionuclides are exchanged between water and sediment as well as transported away by the water movement.

Deeper situated sediments represented as sediment 2 in the figure behave like a sink for some part of the nuclides. Only one sediment layer is included for the Kalix river because in this river sediments seldom occur. At the river mouth finer material can be deposited followed by deep erosion can also take place.

Exposure pathways

The exposure pathways considered are the same as for the Gideå area, namely:

Area	
Stor-Lappträsket	Consumption of water, fish, milk and meat. The latter by animals drinking contaminated water.
The Kalix river	Consumption of fish.
Coastal area	Consumption of marine food stuffs.

5.4 Finnsjön

Earlier calculations of the doses from leakage of groundwaterborne nuclides have been performed with the BIOPATH code and reservoir systems similar to this area. For comparison, some calculations have been done using this model system. For detailed description of the choice of reservoirs, and turnover processes, reference is made to (16). The masses of the reservoirs are also included in appendix and the model system is presented in Figure 4.

The exposure pathways are for the well alternative the same as used in the other areas. The lake alternative has the whole spectrum of exposure pathways used normally in the BIOPATH code.

5.5 Doses for unit releases

For these recipient areas mentioned above, doses have been calculated for unit releases of some nuclides. These results are shown in Table 1 for critical group for the lake alternative and in Table 2 for the collective doses.

6 DISPERSAL SCENARIOS FOR UNREPROCESSED URANIUM FUEL

A number of different dispersal scenarios have been studied within the project (7). Some of the source strengths obtained in this manner have then been used as a basis for dose calculations for the two inflow alternatives.

In Appendix A the different dispersal scenarios are presented. The release scenarios are based upon

- different migration distances
- water flow
- chemical conditions

Dissolved material as well as sorption on colloidal matter are treated.

The life time of the canisters is supposed to be uniform distributed from 10^5 years to 10^6 years. The case of some defective canisters leaching directly after 100 years is also treated.

7 MAIN CASE (SCENARIO A)

7.1 Ecosystem

The main calculations have been performed within an ecosystem based upon the Fjällveden area. This has been done in order not to underestimate the doses and to consider all the exposure pathways which, by experience from earlier work, have shown to be important.

The Morpa lake in the Fjällveden area has an extremely low turnover time for the water, only 30 liters per second.

The model system for the main calculation cases is shown in Figure 5 and the masses of the volumes are presented in Appendix A.

The water in the Morpa lake is supposed to be used for irrigation.

The farming land is receiving about 150 mm of water anually. The size of the reservoir is arbitrarily chosen and shown in Appendix A. For calculation of the individual dose the size of the reservoir is not of any importance, it is only the supplied volume per area unit which is decisive for the doses.

After the Morpa lake there is further surface water system before the water and the nuclides are reaching the Baltic. This system is represented in the figure. However, the reservoirs are of minor importance for both the calculation of the turnover of the activity as well as for the doses received. Of the total released activity only about 1-8 percent, depending on the nuclide, is recovered in this area.

7.2 Transfer coefficients

The nuclides are exchanged between the reservoirs according to the processes described earlier.

In Appendix A Table 4 and Table 5 the transfer coefficients used are shown. These are, as earlier mentioned, derived mostly from reference (2). For the nuclide zirconium which is not included in that revision, the transfer coefficients used are derived in the same manner, outgoing from K_d-values for soil and sediment respectively.

The nuclide plutonium is supposed to behave very similar to protactinium in these aspects. Therefors the same set of transfer coefficients as for protactinium is used.

The transfer coefficient describing the transfer from upper sediment to deeper situated sediment is derived outgoing from the annual growth of the sediments.

7.3 Exposure pathways

This main ecosystem has been chosen so that all exposure pathways, which experience has shown to be of importance for calculation of individual doses, are included. They are presented in the first part of this report but are for completeness repeated.

The paths of exposure dealt with in this main alternative are:

Path of exposure	Primary recipient[a)]
Inhalation	L
Drinking water	W, L
Milk	W[b)], L
Meat	W[b)], L
Green vegetables	W, L
Cereals	L
Root vegetables	L
Eggs	W, L
Fish	W, L
Land	L
Beach	W, L
Bathing	W, L
Fishing	W, L

a) W (well), L (lake).

b) In this case the only pathway considered is the animals consumption of drinking water.

8 DOSE FOR DIFFERENT RELEASE SCENARIOS OF INFLOW TO THE BIOSPHERE

For this main ecosystem doses to critical group and populations have been performed for continuous leakage of 1 Bq per year as well as for the release scenarios described in chapter 6. These so called conversion factors between release from the geosphere of 1 Bq per year and resulting dose to critical group and population are shown in Table 3.

In this Table 3 there are also conversion factors for some fission products like selen-79 and tin-126. Those factors are derived through BIOPATH-calculations.

However, as the dose contributions from those nuclides are of minor importance, the transfer coefficients used are not explicitly shown in the Appendix.

The transfer coefficients are based upon the K_d-values found in the literature (17) and are 10^{-2} and $9 \cdot 10^{-4}$ for selen and tin, respectively.

The biological uptake factors are taken from reference (18). Tin-126 has a high concentration factor water-fish, 3 000, why the individual dose is the same for the well and the lake case.

Complete BIOPATH calculations have been performed for the scenario A, which corresponds to the central case in the main report and for release case F.

The results of those calculations are shown in the Figures 6 a-d and 7 a-d respectively, as well as in tables 4, 5 and 10.

Tables 4 and 5 illustrate the maximum dose burden to the critical group, the contributions from the three predominant paths of exposure and the maximum annual collective dose for the two inflow alternatives well and lake for the central case.

The results for the other release scenarios, see Appendix A, are mostly received outgoing from the conversion factors from the unit releases.

This direct linearity between release and dose is valid for most of the nuclides studied and the discrepancies which may occur are surely within a factor of two. However, for the collective dose this method can be questionable. The maximum collective dose is dependent, among other things, upon how the source term varies in time. For example, the time point for the equilibrium values received from the unit release can be later in time than the duration of the release.

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

For most of the release scenarios the dominant nuclides from dose burden view are iodine-129, radium-226 and neptunium-237.

For the release scenario K corresponding to initial defective canister and colloidal transport doses to critical group in the well case have been calculated for several nuclides. For those nuclides which are not run through the BIOPATH-code, the doses are received only for the exposure through drinking water. Dose factors used are taken from ICRP publ no 30.

8.1 Individual dose - well

In Table 4 the dominant exposure pathways are shown for the well case. For most nuclides drinking water constitutes the crucial paths of exposure. Only for zirconium and cesium the fish pathway is the predominant route of exposure, because of the high concentration factor for fish relative to water.

8.2 Primary recipient - lake

The aquatic pathways for the lake are the dominant causes of exposure. The proportion that drinking water contributes to the total dose is however somewhat lower but the corresponding pathway for fish has increased. Naturally, this depends on the larger dispersion volume which is available for the lake. The exposure from inhalation is the dominate pathway for thorium and plutonium.

8.3 Collective doses

The consumption of fish and other marine foodstuffs totally dominates the collective doses for all nuclides. The distribution of the maximum collective dose in the subsystems of the model is shown in Table 15. As can be seen from the table, the largest contributions emanate from the global or the intermediate zones. In the central case it is iodine-129 which gives the highest contribution to the collective doses. The accumulated collective doses shown in Figure 6 d and 7 d for the release scenarios A and F amount highest to about 10^6 manSv.

This value could be compared with the irradiation caused from natural background which, during the same time period, should be about 10^{17} manSv for the same size of global populations.

9 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.

9.1 Model design and paths of exposure

The components of the compartment model have been designed on the basis of previous radioecological models (20, 21, 22). 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 (21, 22).

The 14 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.

9.2 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% (1).

9.3 Variations in exchange between the reservoirs in the ecosystems

There can be a wide range of reported values for the transfer coefficients which describe the exchange of nuclides between different reservoirs in the ecosystems. The basic philosophy of most studies has been to choose values which do not underestimate the doses to man. However, it has been shown that for individual dose calculations the exact values for the volumes and turnover of the primary compartments (e.g. well or lake) are important.

The primary compartment is chosen so that the available volume for dispersion will not be underestimated. The turnover of water in the lake is very slow. The doses for the "lake" alternative is, therefore, nearly inversely proportional to the volume and the turnover rate. Thus, a halved turnover time gives a corresponding decrease in the dose.

For those nuclides where fish or drinking water do not constitute important paths of exposure, the dose burden to critical group would increase more or less proportionately to the irrigation intensity.

The transfer to the sediments from the water in the lake is also of importance for the calculated doses. Nuclides like thorium, protactinium and plutonium are considered to rapidly move from the water to the sediment. If sedimentation does not occur the doses from these nuclides would be increased by a factor of about five for calculated doses in the "lake" alternative. For iodine, which is one of the dominant nuclides from dose burden, the transfer to the sediment is considered to be low. Consequently, using even lower values would not affect the doses at all, but naturally higher transfer coefficients would reduce the doses.

For the collective doses a more effective transfer to the sediments would reduce the doses as well as lower leakage rates from the sediments would do.

9.4 Variations in diet composition and uptake through food chains

The critical group shall represent a few individuals who, owing to their diet and living habits, receive relatively higher doses than average. With this purpose, a typical diet was composed for the critical groups. For most nuclides, water, fish, milk and meat are the dominant paths of exposure in the inland alternative. Water consumption can not reasonably be increased above the assumed 440 l/yr. If the consumption of freshwater fish (30 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.

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 food-stuffs 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, because 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 of most foods are usually removed during processing and are not consumed by humans. Approximately half of the total fish catch consists of industrial fish used for animal feed and fertilizer. In this case, the entire fish is used. These 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 results in natural variations in the concentration factor. In the case of Cs-135 and the inland alternative, the dose can vary in relation to the nominal value by a factor of 5 in either direction. A concentration factor of 10-100 has been reported for Ra-226 in freshwater fish (2). A concentration factor for Ra-226 in freshwater fish of 25 has been used in the calculations.

The uptake of nuclides from soil by plants can vary widely, depending upon such factors as the species of plant and soil condition. These factors have been reviewed in reference (2) where variation intervals are given. The values chosen in the calculations are, in general, the geometric mean values of the parameters and are shown in Appendix B, Table B.2. The dose obtained using those estimates has been compared with the results from an uncertainty analysis using the Monte Carlo method. That has been done for the milk pathway for the nuclide radium-226. The Monte Carlo simulations of the BIOPATH model takes into account the mutual dependence of the constituent parameters to as great extent as possible. In this manner it has been possible to approximate the contributions of different parameters to the total uncertainty.

The calculations for radium-226, via the milk pathway, include parameters which, by experience, have been shown to be important for dose calculations. The calculations have been performed for a case with irrigation of pastures. The results for a case with constant concentration of nuclides in the water:

Parameter	Contribution to the uncertainty %
Distribution factor	ca 60
Irrigation intensity	" 10
Migration from the root zone	" 10
Dose factor	" 10

If, on the other hand, the concentration of nuclides in water is not constant but varies within a range of 100, the results are:

Parameter	Contribution to the uncertainty %
Activity level in the water	ca 30
Distribution factor	" 30
Irrigation intensity	" 5
Migration from rootzone	" 5
Dose factor	" 5

Comparison of the frequency distribution obtained by the Monte Carlo simulation of the BIOPATH model estimates the probability of 60-65 % of underestimating the actual dose by setting the parameters at their nominal value.

The dominating exposure pathway for the population is consumption of marine food-stuffs such as algea and crustacea. If that pathway is only considered for a more limited group of individuals this would significantly reduce the collective doses.

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

The description of the different recipient areas is based upon contemporary conditions. The local ecosystems can undergo considerable changes during the millions of year it will take the nuclides to reach the surface water. It ought to be the conditions at that time which serve as a point of departure for the evaluations of the turnover in the biosphere and the resulting dose to man. The design of the model makes it possible to analyse some of the probable changes, but assumptions concerning conditions in the future will, of necessity, be associated with large uncertainties.

External conditions can be expected to be changed as a function of variations in the climate. Changes in the climate directly affect the water balance as well as the land use. Periodically we have had ice ages and it is probable that others will follow. However, one can expect that after the ice has melted, vegetation, animals and human beings will return. Also the main topographical features of the landscape will probably remain the same.

There are, however, changes in the landscape of much shorter periods. Entrophication of lakes seems to have accelerated over the past decades due to the increased use of fertilizers in farming. Increased pollution, due to combustion of fossil fuels and other industrial releases, also causes the "death" of significant portions of life in lakes.

The drying-up of lakes implies that lake sediments can be used for agricultural purposes. Many nuclides are supposed to deposit and accumulate in the sediments with time and will, consequently, reach vegetation and human beings. However, calculations show that the exposure from agricultural products will be of the same order of magnitude as those obtained from drinking water or fish.

Another possible change in the recipient areas, now existing or going to be created, is that the outflow from the repository will be directly towards a peat area. This peat could be exploited for different purposes and human beings subsequently exposed if:

- peat land is converted to agricultural land,
- peat is used as a soil conditioner,
- peat is used for combustion.

Using the peat for combustion would not result in a significant increase in doses due to a rather large area. Of those cases, the lowest doses will be expected from combustion.

Calculations have been performed for some dominant nuclides for the case where peat is used for agricultural purposes. The following assumptions have been used:

- the peat will accumulate all the amount of the nuclides leaking out at their maximum leakage rate for 10000 years,
- 10 % of the soil is peat,
- the area of the peat bog is 1 km^2,
- leakage from the soil occurs with the transfer rate used in the previous calculations, se Appendix A.

The results are shown in Table 16 for the release scenario A (central case) and, as can be seen, the doses are somewhat higher than those obtained from the earlier calculations.

The acidification process of lakes from fossil fuel combustion can cause increased mobility in the soil and uptake to vegetation. This would not have a great affect on the individual doses as the dominating exposure pathways originate from the activity level in the water. An increased mobility in soil can raise the collective doses.

Excluding the environmental conditions there can be changes in the dietary habits. The paths of exposure which are now covered by the model are based upon present conditions except for the intermediate and global populations. There is a search for other sources of nutrition from the sea depending on the overexploitation of traditional fish populations. This have been taken into account in some extent by including the "marin plant" as an exposure pathway.

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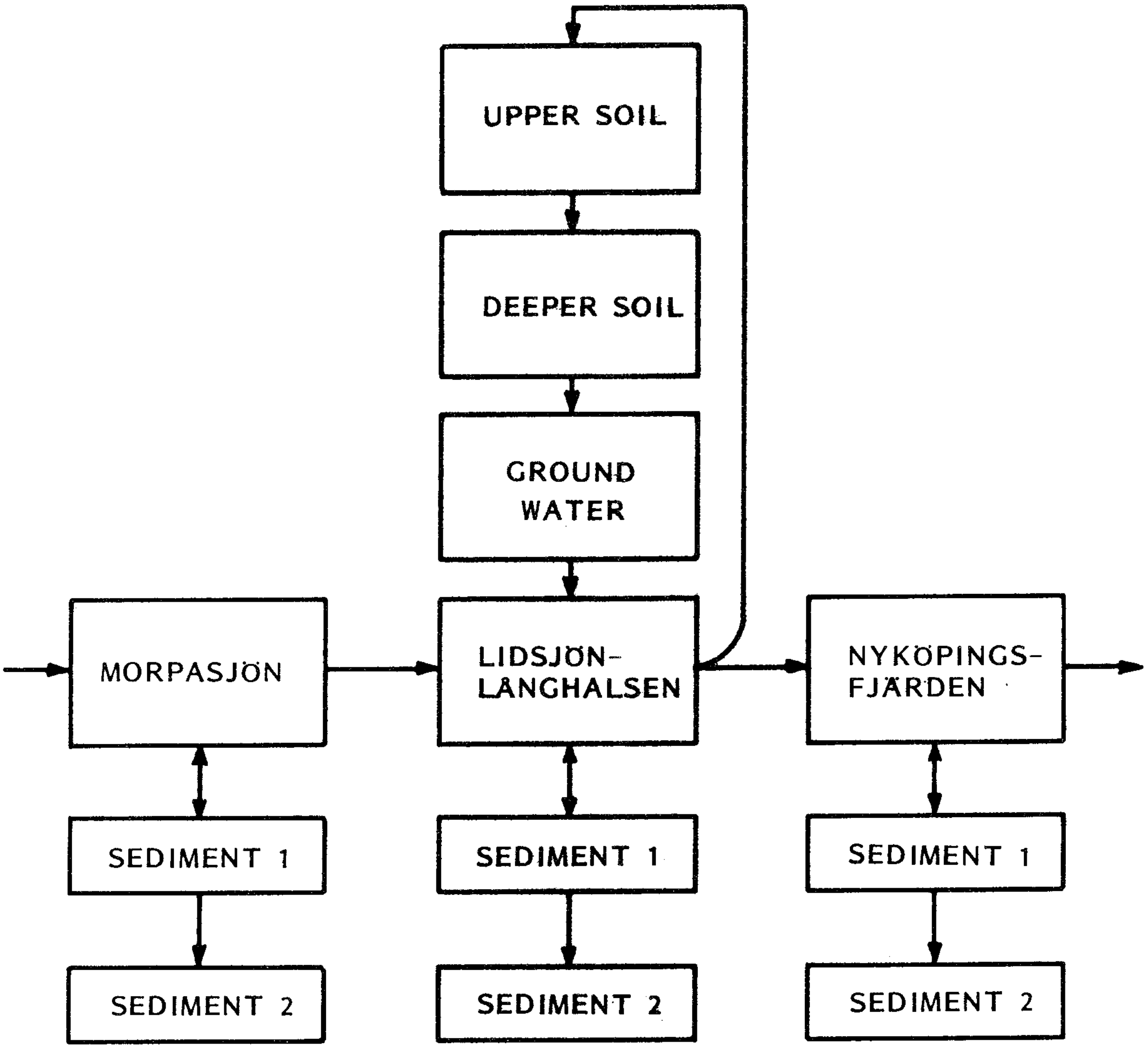


FIGURE 1 MODEL SYSTEM FOR THE FJÄLLVEDEN AREA

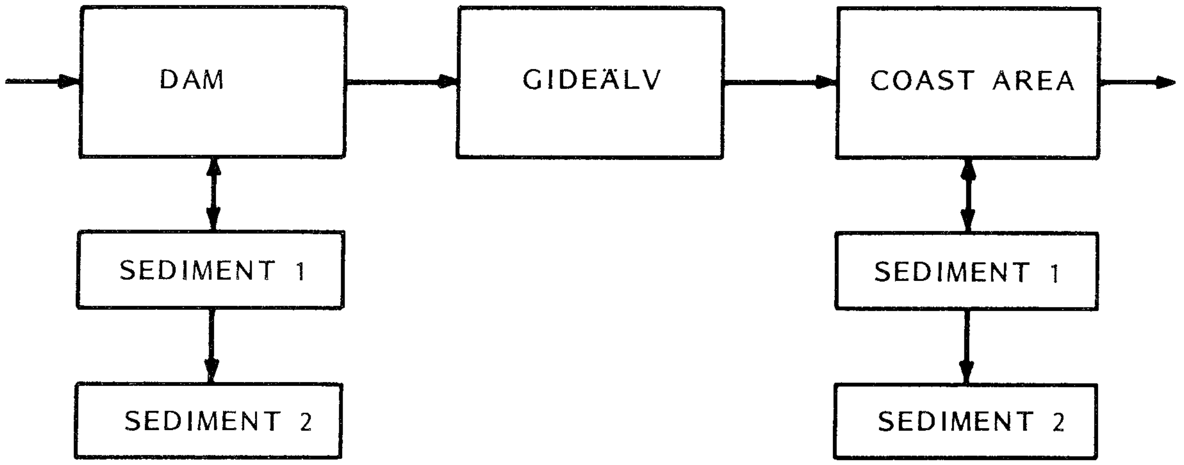


FIGURE 2 MODEL SYSTEM FOR THE GIDEÅ AREA

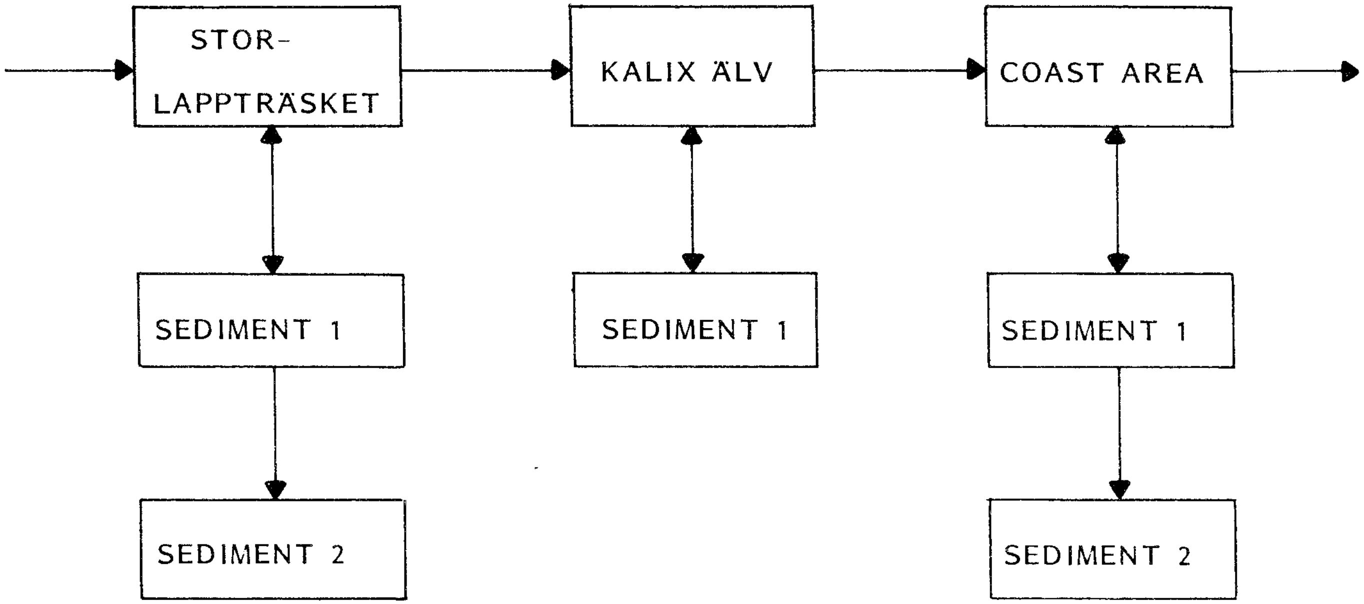


FIGURE 3 MODEL SYSTEM FOR THE KAMLUNGEKÖLEN AREA

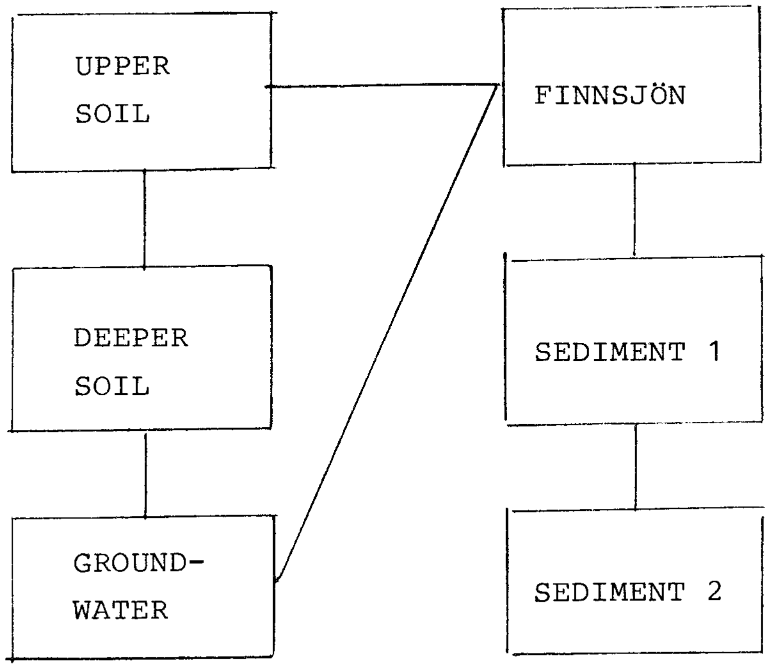
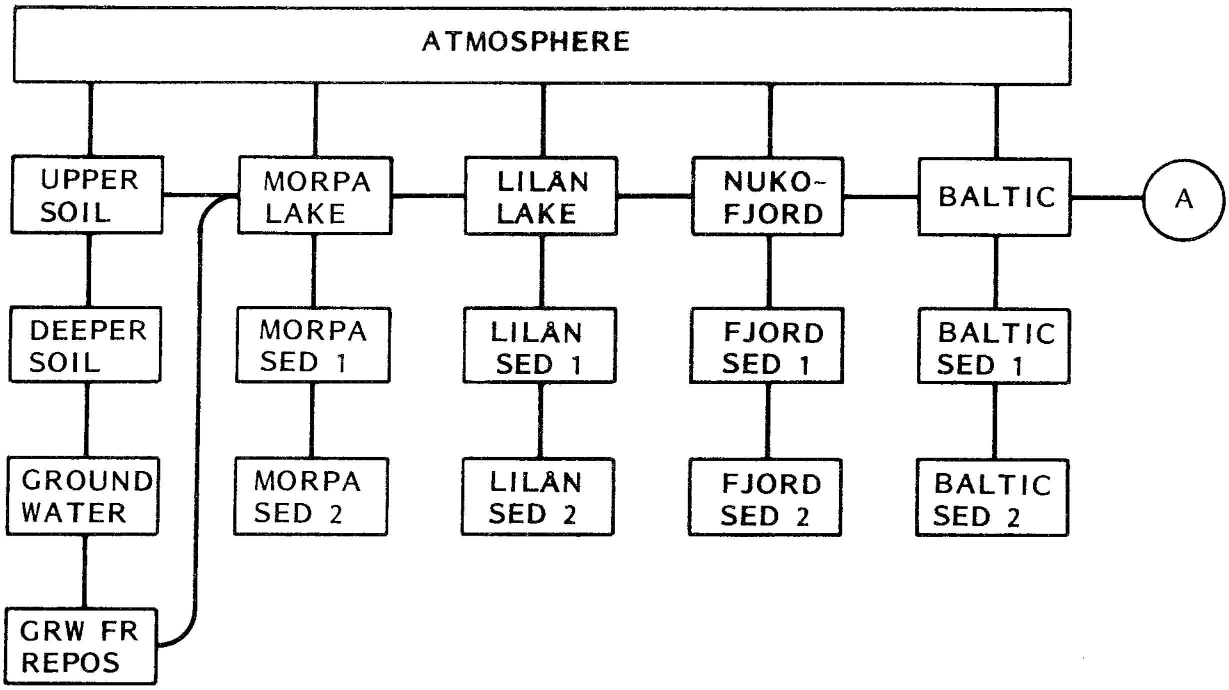


FIGURE 4 MODEL SYSTEM FOR THE FINNSJÖN AREA



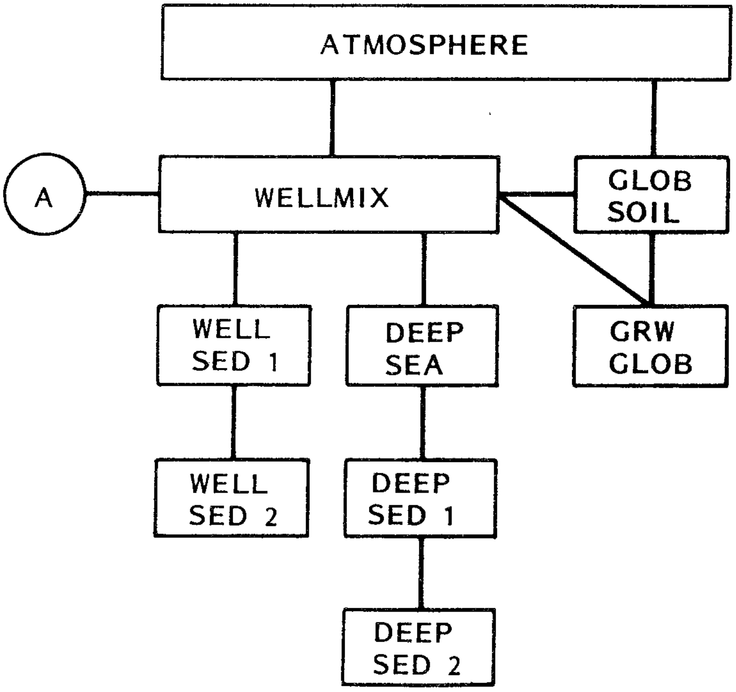


FIGURE 5 MODEL SYSTEM FOR THE MAIN CASE

Figure 6a Individual doses, well case , release scenario A (central case)

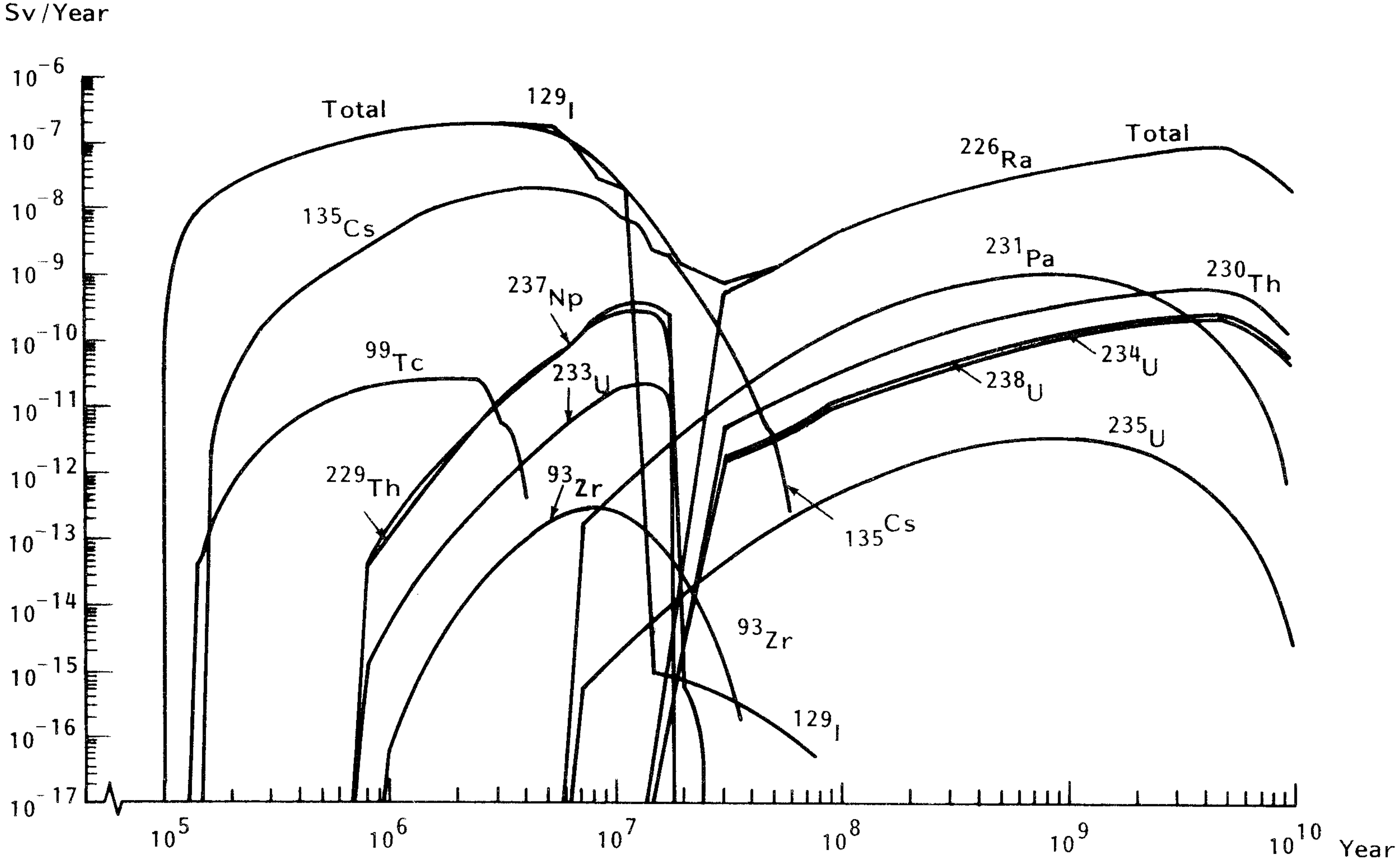


Figure 6b Individual doses, lake case, release scenario A (central case)

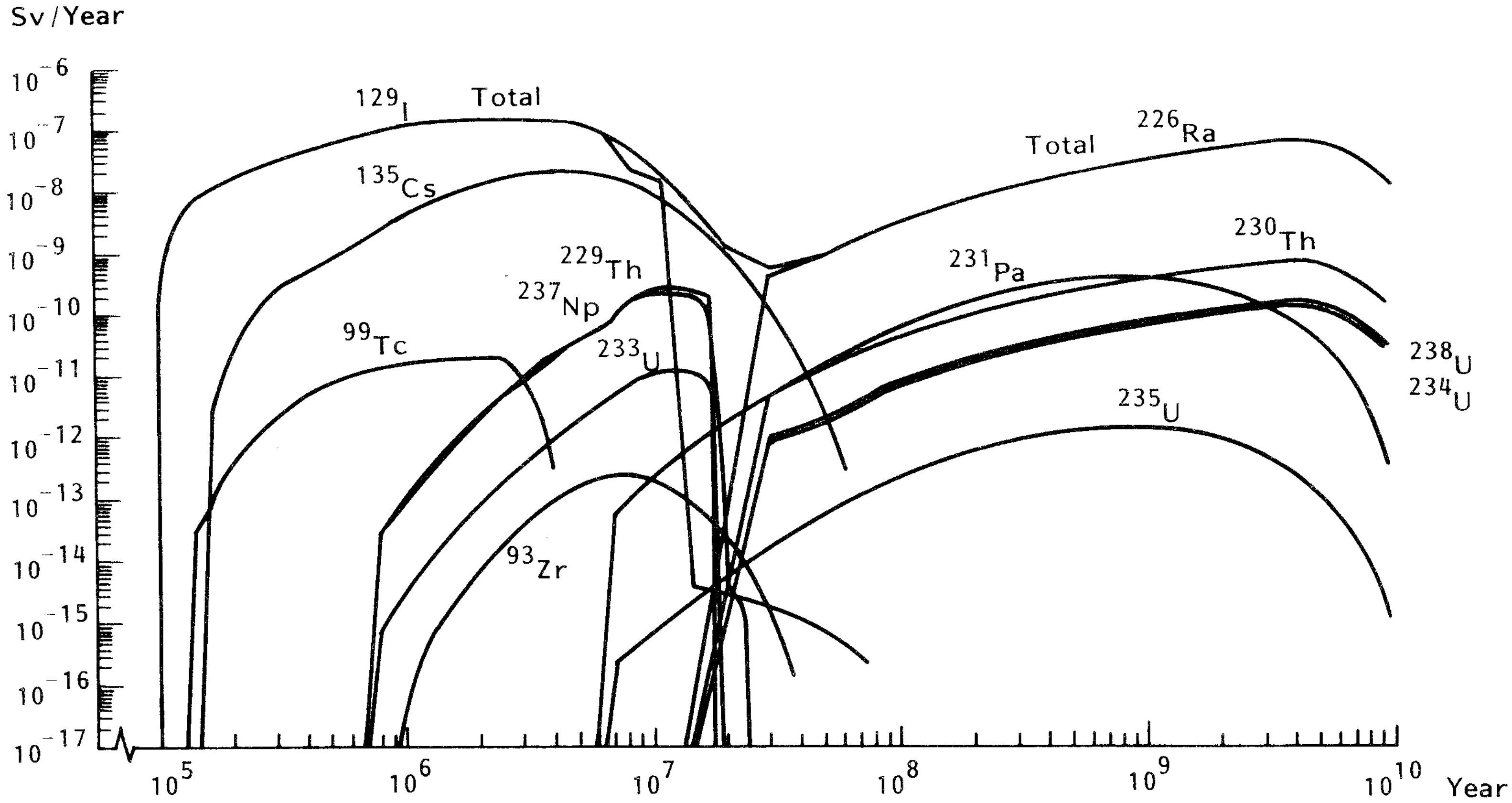


Figure 6c Collective doses, release scenario A (central case)

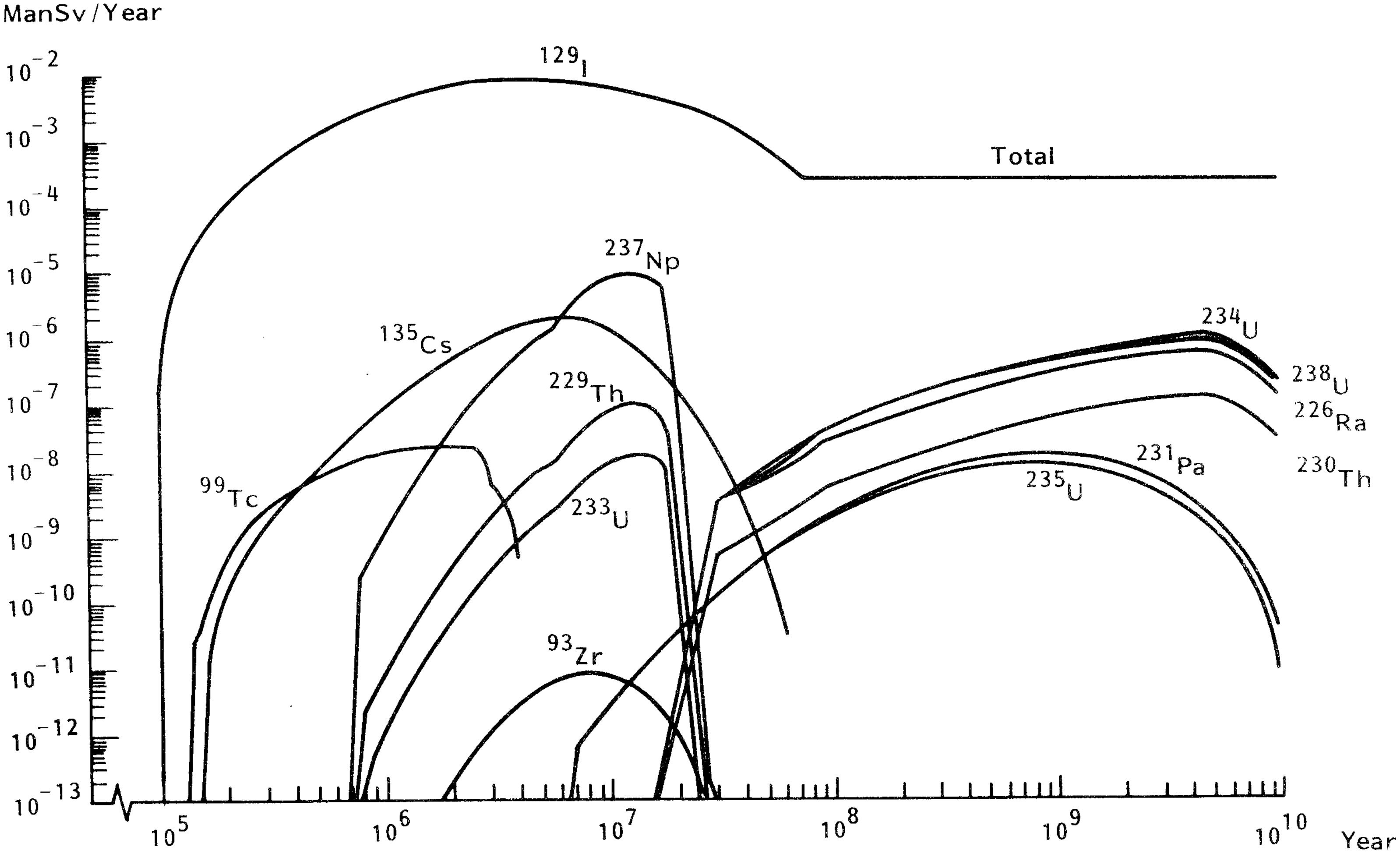


Figure 6d Collective accumulated dose, release scenario A (central case)

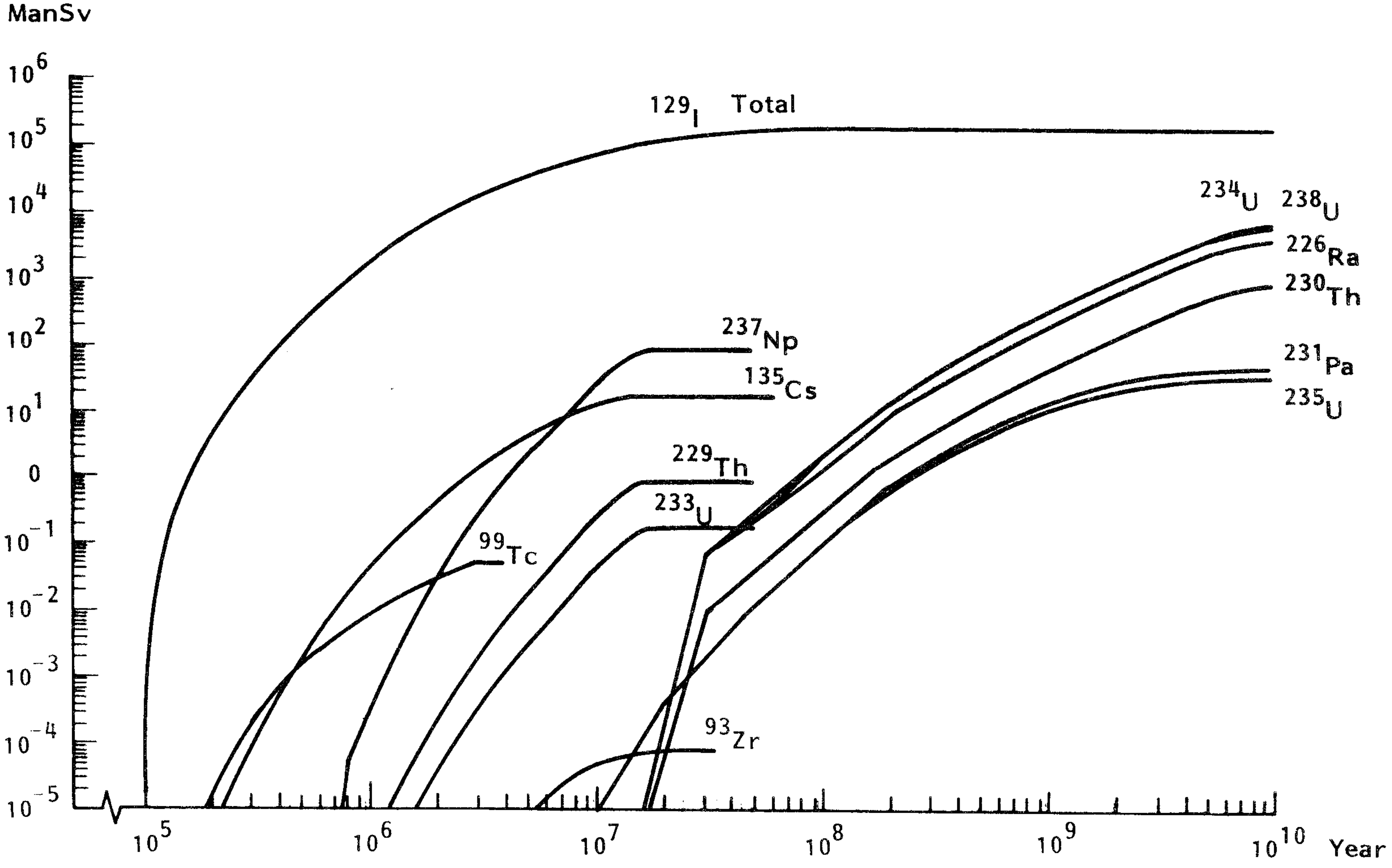


Figure 7a Individual doses, well case, release scenario F

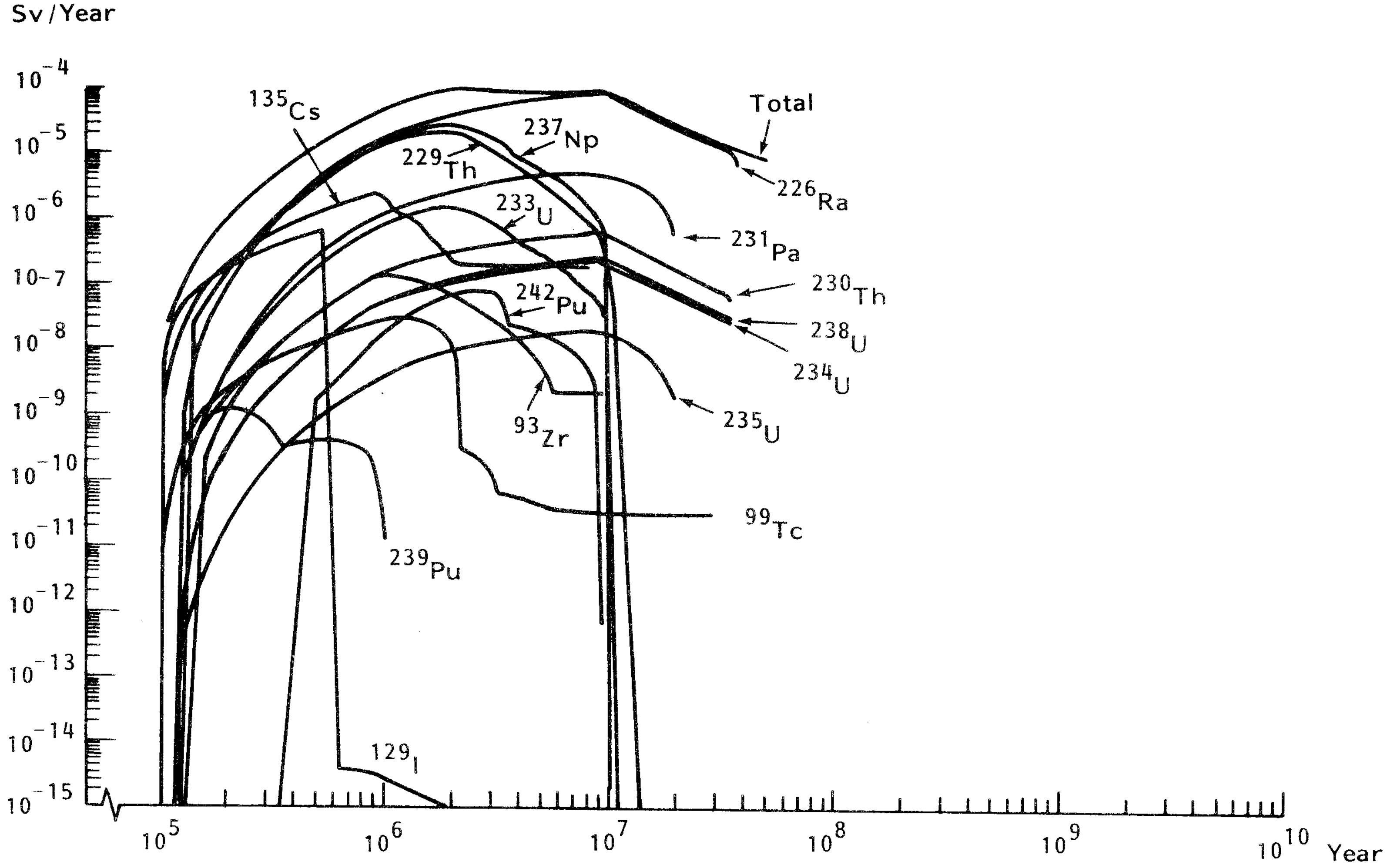


Figure 7b Individual doses, lake case, release scenario F (central case)

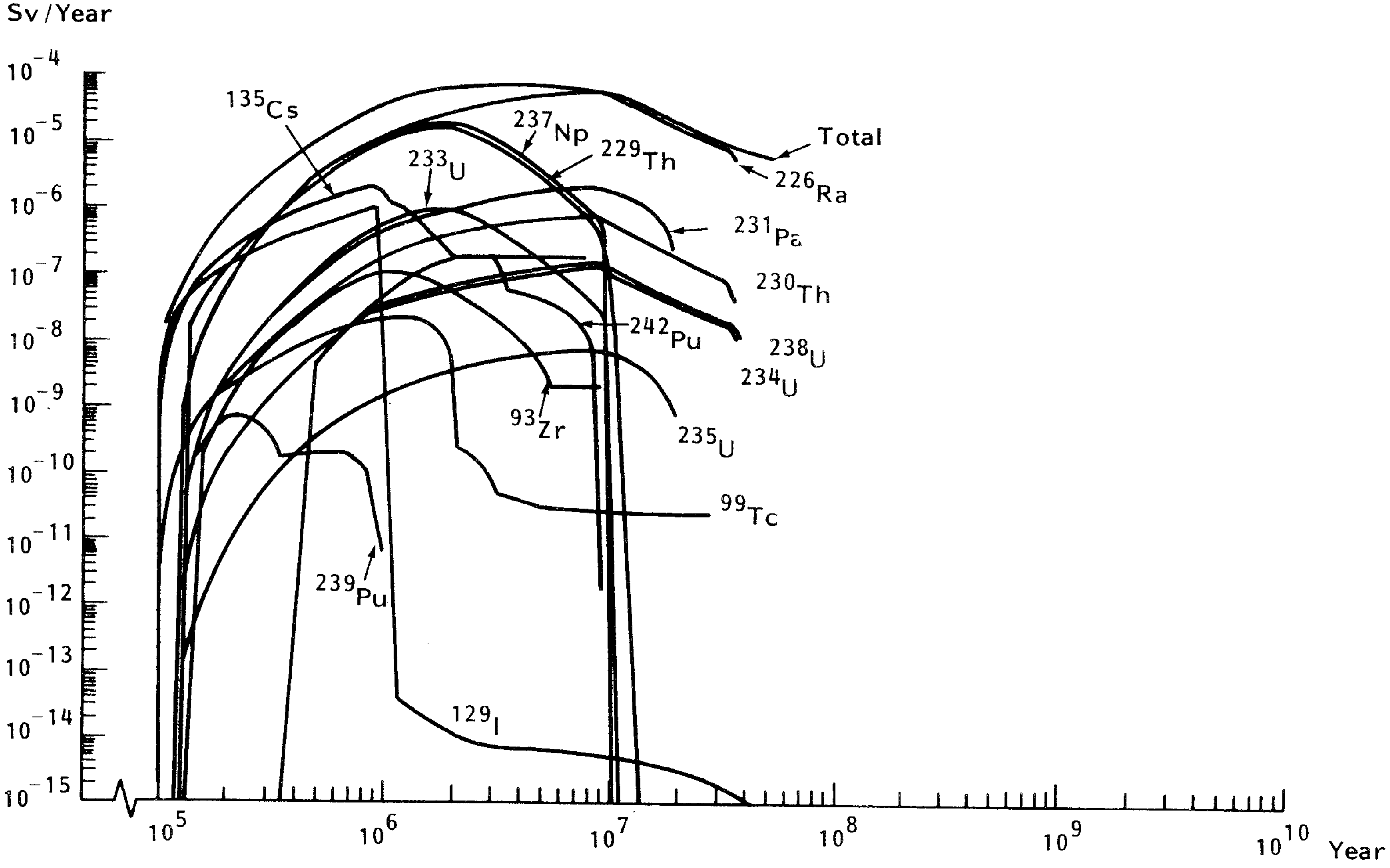


Figure 7c Collective doses, release scenario F

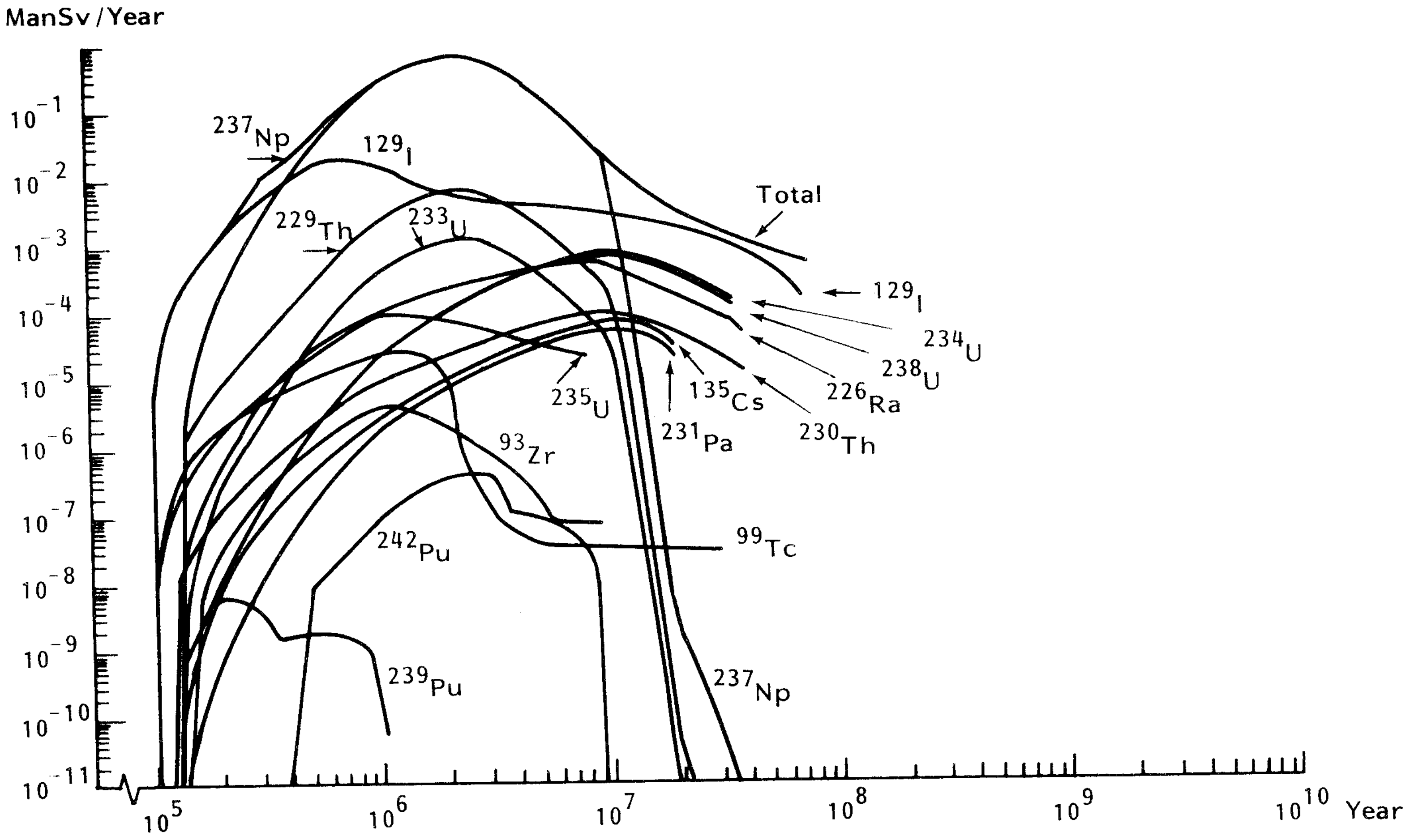


Figure 7d Collective accumulated dose, release scenario F

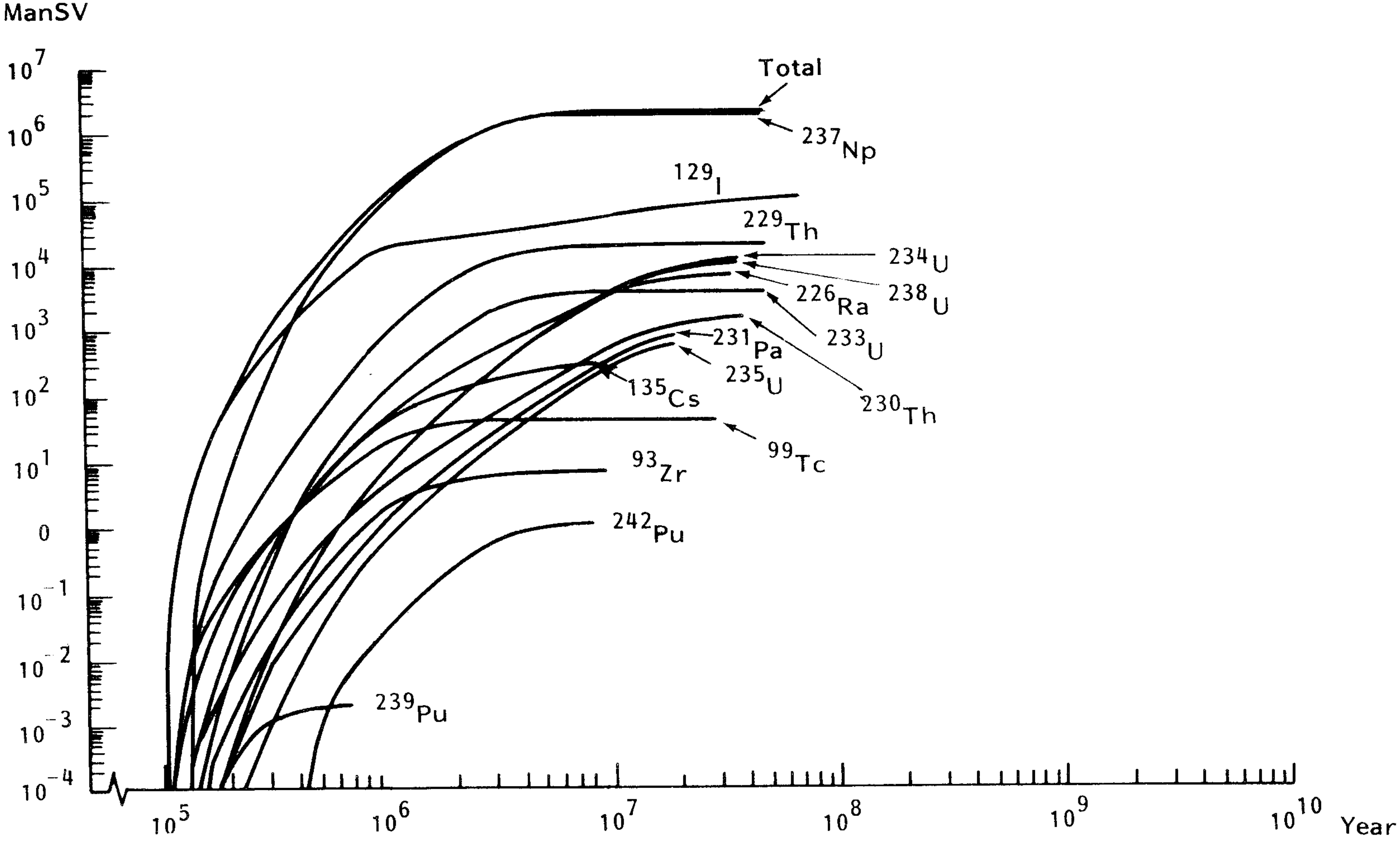


Table 1

Individual doses (Sv/year), lake alternative for different recipient areas, continuous leakage of 1 Bq/year

Nuclide	Finnsjön	Fjällveden	Gideå	Kamlunge
Zr-93	$1.3\cdot10^{-16}$			
Tc-99	$2.0\cdot10^{-17}$	$5.3\cdot10^{-16}$	$3.3\cdot10^{-19}$	$9.2\cdot10^{-17}$
I-129		$1.2\cdot10^{-13}$		$2.1\cdot10^{-14}$
Cs-135		$4.8\cdot10^{-14}$	$7.0\cdot10^{-17}$	
Ra-226	$3.1\cdot10^{-14}$	$8.0\cdot10^{-13}$	$8.0\cdot10^{-16}$	
U-233		$3.5\cdot10^{-14}$		$8.1\cdot10^{-15}$
Th-229		$2.8\cdot10^{-13}$	$7.7\cdot10^{-16}$	$1.9\cdot10^{-13}$
U-234	$7.3\cdot10^{-16}$	$3.4\cdot10^{-14}$	$9.7\cdot10^{-18}$	$8.0\cdot10^{-15}$
Th-230	$1.1\cdot10^{-15}$	$5.0\cdot10^{-14}$	$1.3\cdot10^{-16}$	
U-235		$3.4\cdot10^{-14}$		$7.7\cdot10^{-15}$
Pa-231	$2.6\cdot10^{-13}$	$3.8\cdot10^{-12}$	$6.0\cdot10^{-15}$	
U-236		$3.3\cdot10^{-14}$		$7.5\cdot10^{-15}$
U-238		$3.1\cdot10^{-14}$		$7.1\cdot10^{-15}$
Pu-239				$9.3\cdot10^{-15}$
Pu-242	$7.1\cdot10^{-16}$	$1.4\cdot10^{-14}$		$9.0\cdot10^{-15}$
Np-237	$1.4\cdot10^{-14}$	$9.0\cdot10^{-13}$	$3.3\cdot10^{-16}$	$1.6\cdot10^{-13}$

Table 2

Collective doses (man Sv/year), for different recipient areas, continuous leakage of 1 Bq/year

Nuclide	Finnsjön	Fjällveden	Gideå	Kamlunge
Zr-93	$1.4\cdot10^{-13}$			
Tc-99	$5.9\cdot10^{-13}$	$1.4\cdot10^{-13}$	$5.9\cdot10^{-13}$	$5.9\cdot10^{-13}$
I-129		$1.4\cdot10^{-8}$		$1.4\cdot10^{-8}$
Cs-135	$3.9\cdot10^{-12}$	$1.9\cdot10^{-12}$	$1.5\cdot10^{-13}$	
Ra-226	$1.2\cdot10^{-11}$		$1.5\cdot10^{-12}$	
U-233		$1.9\cdot10^{-11}$		$2.7\cdot10^{-11}$
Th-229		$3.0\cdot10^{-11}$	$2.2\cdot10^{-10}$	$1.8\cdot10^{-10}$
U-234	$3.4\cdot10^{-11}$	$1.9\cdot10^{-11}$	$4.9\cdot10^{-13}$	$4.0\cdot10^{-11}$
Th-230	$1.1\cdot10^{-11}$	$7.9\cdot10^{-12}$	$5.4\cdot10^{-11}$	$4.5\cdot10^{-11}$
U-235				$3.6\cdot10^{-10}$
Pa-231	$3.7\cdot10^{-10}$	$3.2\cdot10^{-11}$	$1.8\cdot10^{-10}$	$1.5\cdot10^{-10}$
U-236		$2.3\cdot10^{-10}$		$3.3\cdot10^{-10}$
U-238				$3.3\cdot10^{-10}$
Pu-239				$2.3\cdot10^{-12}$
Pu-242	$7.2\cdot10^{-13}$	$4.7\cdot10^{-13}$		$2.5\cdot10^{-12}$
Np-237	$2.8\cdot10^{-8}$	$2.5\cdot10^{-10}$	$2.7\cdot10^{-10}$	$3.0\cdot10^{-8}$

Table 3

Conversion factors between releases from the geosphere and dose via well and lake, continuous release of 1 Bq/year

	Individual dose dose (Sv/year)		Collective dose (man Sv/year)
Nuclide	Well	Lake	
Se-79	$5.4 \cdot 10^{-14}$	$1.2 \cdot 10^{-13}$	---
Zr-93	$3.4 \cdot 10^{-15}$	$3.8 \cdot 10^{-15}$	$1.0 \cdot 10^{-13}$
Tc-99	$7.3 \cdot 10^{-16}$	$5.5 \cdot 10^{-16}$	$6.0 \cdot 10^{-13}$
Sn-126	$3.3 \cdot 10^{-13}$	$3.3 \cdot 10^{-13}$	---
I-129	$1.7 \cdot 10^{-13}$	$1.6 \cdot 10^{-13}$	$1.4 \cdot 10^{-8}$
Cs-135	$5.0 \cdot 10^{-14}$	$5.0 \cdot 10^{-14}$	$1.9 \cdot 10^{-12}$
Ra-226	$6.1 \cdot 10^{-13}$	$4.0 \cdot 10^{-13}$	$3.3 \cdot 10^{-12}$
Th-229	$1.1 \cdot 10^{-12}$	$7.0 \cdot 10^{-13}$	$2.9 \cdot 10^{-11}$
Th-230	$1.9 \cdot 10^{-13}$	$1.9 \cdot 10^{-13}$	$7.9 \cdot 10^{-12}$
Pa-231	$2.2 \cdot 10^{-11}$	$1.2 \cdot 10^{-11}$	$3.3 \cdot 10^{-11}$
U-233	$7.8 \cdot 10^{-14}$	$4.9 \cdot 10^{-14}$	$1.9 \cdot 10^{-11}$
U-234	$7.8 \cdot 10^{-14}$	$4.9 \cdot 10^{-14}$	$2.0 \cdot 10^{-11}$
U-235	$8.0 \cdot 10^{-14}$	$3.3 \cdot 10^{-14}$	$2.6 \cdot 10^{-10}$
U-236	$7.3 \cdot 10^{-14}$	$4.5 \cdot 10^{-14}$	$2.3 \cdot 10^{-10}$
U-238	$6.9 \cdot 10^{-14}$	$4.3 \cdot 10^{-14}$	$2.4 \cdot 10^{-10}$
Np-237	$1.6 \cdot 10^{-12}$	$1.1 \cdot 10^{-12}$	$4.0 \cdot 10^{-8}$
Pu-239	$6.5 \cdot 10^{-13}$	$2.6 \cdot 10^{-13}$	$5.0 \cdot 10^{-13}$
Pu-242	$1.2 \cdot 10^{-13}$	$2.1 \cdot 10^{-13}$	$4.7 \cdot 10^{-13}$

Table 4

Annual individual and collective doses with dominant pathways of exposure at the time of maximum burden for release scenario A (central case). Well case

	Max ind annual dose (Sv/year)	Dominant pathways of exposure 1	%	2	%	3	%	Max coll annual dose (man Sv/year)
Zr-93	$3.0 \cdot 10^{-13}$	fish	84	water	11	meat	4	$8.9 \cdot 10^{-12}$
Tc-99	$2.9 \cdot 10^{-11}$	fish	54	water	44	milk	2	$2.5 \cdot 10^{-8}$
I-129	$1.9 \cdot 10^{-7}$	water	48	fish	34	milk	13	$1.0 \cdot 10^{-2}$
Cs-135	$2.2 \cdot 10^{-8}$	fish	94	water	3	meat	1	$1.8 \cdot 10^{-6}$
Ra-226	$1.0 \cdot 10^{-7}$	water	54	fish	32	vege	12	$6.4 \cdot 10^{-7}$
Th-229	$3.0 \cdot 10^{-10}$	water	75	fish	17	vege	5	$8.4 \cdot 10^{-8}$
Th-230	$7.4 \cdot 10^{-10}$	water	71	fish	17	vege	12	$1.4 \cdot 10^{-7}$
Pa-231	$1.2 \cdot 10^{-9}$	water	83	vege	7	fish	7	$1.8 \cdot 10^{-8}$
U-233	$2.2 \cdot 10^{-11}$	water	80	fish	10	meat	9	$1.8 \cdot 10^{-8}$
U-234	$3.0 \cdot 10^{-10}$	water	80	fish	10	meat	9	$1.1 \cdot 10^{-6}$
U-235	$4.1 \cdot 10^{-12}$	water	73	fish	9	ground	9	$1.4 \cdot 10^{-8}$
U-236	$7.4 \cdot 10^{-13}$	water	80	fish	10	meat	9	$2.5 \cdot 10^{-9}$
U-238	$2.7 \cdot 10^{-10}$	water	80	fish	10	meat	9	$1.0 \cdot 10^{-6}$
Np-237	$3.9 \cdot 10^{-10}$	water	71	fish	24	vege	3	$9.2 \cdot 10^{-6}$

Table 5

Annual individual and collective doses with dominant pathways of exposure at the time of maximum burden for release scenario A (central case), lake case

	Max ind annual dose	Dominant pathways of exposure						Max coll annual dose
	(Sv/year)		%		%		%	(man Sv/year)
Zr-93	$3.0 \cdot 10^{-13}$	fish	75	meat	13	water	4	$8.9 \cdot 10^{-12}$
Tc-99	$2.2 \cdot 10^{-11}$	fish	68	water	29	milk	1	$2.5 \cdot 10^{-8}$
I-129	$1.4 \cdot 10^{-7}$	fish	46	water	33	milk	15	$1.0 \cdot 10^{-2}$
Cs-135	$2.2 \cdot 10^{-8}$	fish	95	meat	3	milk	2	$1.8 \cdot 10^{-6}$
Ra-226	$7.4 \cdot 10^{-8}$	fish	44	water	26	cereal	13	$6.4 \cdot 10^{-7}$
Th-229	$2.3 \cdot 10^{-10}$	inhal	57	fish	22	water	11	$8.4 \cdot 10^{-8}$
Th-230	$8.4 \cdot 10^{-10}$	inhal	64	fish	15	water	7	$1.4 \cdot 10^{-7}$
Pa-231	$4.4 \cdot 10^{-10}$	cereal	50	water	32	meat	18	$1.8 \cdot 10^{-8}$
U-233	$1.2 \cdot 10^{-11}$	water	50	inhal	18	fish	17	$1.8 \cdot 10^{-8}$
U-234	$1.8 \cdot 10^{-10}$	water	50	inhal	18	fish	17	$1.1 \cdot 10^{-6}$
U-235	$1.6 \cdot 10^{-12}$	water	50	inhal	18	fish	17	$1.4 \cdot 10^{-8}$
U-236	$3.3 \cdot 10^{-13}$	water	50	inhal	18	fish	17	$2.5 \cdot 10^{-9}$
U-238	$1.6 \cdot 10^{-10}$	water	50	inhal	18	fish	17	$1.0 \cdot 10^{-6}$
Np-237	$3 \quad \cdot 10^{-10}$	water	47	fish	32	root vege	11	$9.2 \cdot 10^{-6}$

Table 6

Maximum individual doses (Sv/year) for critical group, release scenario B

Nuclide	Well	Lake
Ni-59	$2.5\cdot10^{-18}$	$2.5\cdot10^{-18}$
Zr-93	$7.5\cdot10^{-17}$	$8.4\cdot10^{-17}$
Tc-99	$6.8\cdot10^{-12}$	$6.6\cdot10^{-12}$
I-129	$6.0\cdot10^{-11}$	$1.1\cdot10^{-8}$
Cs-135	$6.0\cdot10^{-12}$	$1.2\cdot10^{-9}$
Ra-226	$2.6\cdot10^{-11}$	$1.7\cdot10^{-11}$
Th-229	$6.6\cdot10^{-14}$	$4.2\cdot10^{-14}$
Th-230	$1.7\cdot10^{-13}$	$1.7\cdot10^{-13}$
U-233	$4.7\cdot10^{-15}$	$2.9\cdot10^{-15}$
U-234	$7.0\cdot10^{-14}$	$4.4\cdot10^{-14}$
U-235	$8.8\cdot10^{-16}$	$3.6\cdot10^{-16}$
Pa-231	$2.4\cdot10^{-13}$	$1.1\cdot10^{-13}$
U-238	$6.2\cdot10^{-14}$	$3.9\cdot10^{-14}$
Np-237	$9.6\cdot10^{-14}$	$6.6\cdot10^{-14}$

Table 7

Maximum individual doses (Sv/year) for critical group, release scenario C

Nuclide	Well	Lake
Tc-99	$1.9 \cdot 10^{-8}$	$1.4 \cdot 10^{-8}$
I-129	$1.9 \cdot 10^{-7}$	$1.8 \cdot 10^{-7}$
Cs-135	$2.2 \cdot 10^{-8}$	$2.2 \cdot 10^{-8}$
Ra-226	$2.6 \cdot 10^{-7}$	$1.7 \cdot 10^{-7}$
Th-230	$1.6 \cdot 10^{-9}$	$1.6 \cdot 10^{-9}$
Pa-231	$1.5 \cdot 10^{-8}$	$6.6 \cdot 10^{-9}$
U-233	$6.2 \cdot 10^{-7}$	$3.9 \cdot 10^{-7}$
U-234	$3.4 \cdot 10^{-7}$	$2.1 \cdot 10^{-7}$
U-235	$2.6 \cdot 10^{-8}$	$1.1 \cdot 10^{-8}$
U-236	$3.1 \cdot 10^{-7}$	$1.9 \cdot 10^{-7}$
U-238	$3.0 \cdot 10^{-7}$	$1.9 \cdot 10^{-7}$
Np-237	$1.2 \cdot 10^{-5}$	$8.2 \cdot 10^{-6}$

Table 8

Maximum individual doses (Sv/year) for critical group, release scenario D

Nuclide	Well	Lake
Zr-93	$4.2 \cdot 10^{-10}$	$4.7 \cdot 10^{-10}$
Tc-99	$1.6 \cdot 10^{-13}$	$1.2 \cdot 10^{-13}$
Cs-135	$1.8 \cdot 10^{-11}$	$1.8 \cdot 10^{-11}$
Ra-226	$9.7 \cdot 10^{-7}$	$6.3 \cdot 10^{-7}$
Th-229	$1.1 \cdot 10^{-8}$	$7.1 \cdot 10^{-9}$
Th-230	$8.1 \cdot 10^{-9}$	$8.1 \cdot 10^{-9}$
Pa-231	$6.8 \cdot 10^{-6}$	$3.1 \cdot 10^{-6}$
U-233	$2.1 \cdot 10^{-11}$	$1.3 \cdot 10^{-11}$
U-234	$2.7 \cdot 10^{-11}$	$1.7 \cdot 10^{-11}$
U-236	$4.8 \cdot 10^{-12}$	$3.0 \cdot 10^{-12}$
U-238	$4.2 \cdot 10^{-12}$	$2.6 \cdot 10^{-12}$
Np-237	$5.5 \cdot 10^{-8}$	$3.8 \cdot 10^{-8}$
Pu-239	$8.6 \cdot 10^{-11}$	$3.5 \cdot 10^{-11}$
Pu-242	$1.1 \cdot 10^{-9}$	$1.9 \cdot 10^{-9}$

Table 9

Maximal individual and collective doses, release scenario F

	Individual dose (Sv/year)		Collective dose (man Sv/year)
Nuclide	Well	Lake	
Zr-93	$1.4 \cdot 10^{-7}$	$1.3 \cdot 10^{-7}$	$4.1 \cdot 10^{-6}$
Tc-99	$3.1 \cdot 10^{-8}$	$2.6 \cdot 10^{-8}$	$2.7 \cdot 10^{-5}$
I-129	$7.3 \cdot 10^{-7}$	$6.4 \cdot 10^{-7}$	$1.7 \cdot 10^{-2}$
Cs-135	$2.4 \cdot 10^{-6}$	$2.4 \cdot 10^{-6}$	$9.1 \cdot 10^{-5}$
Ra-226	$9.2 \cdot 10^{-5}$	$6.6 \cdot 10^{-5}$	$5.6 \cdot 10^{-4}$
Th-229	$2.2 \cdot 10^{-5}$	$1.7 \cdot 10^{-5}$	$6.2 \cdot 10^{-3}$
Th-230	$6.5 \cdot 10^{-7}$	$7.3 \cdot 10^{-7}$	$1.0 \cdot 10^{-4}$
Pa-231	$5.7 \cdot 10^{-6}$	$2.2 \cdot 10^{-6}$	$7.0 \cdot 10^{-5}$
U-233	$1.6 \cdot 10^{-6}$	$9.7 \cdot 10^{-7}$	$1.2 \cdot 10^{-3}$
U-234	$2.7 \cdot 10^{-7}$	$1.6 \cdot 10^{-7}$	$7.9 \cdot 10^{-4}$
U-235	$2.1 \cdot 10^{-8}$	$8.4 \cdot 10^{-9}$	$5.5 \cdot 10^{-5}$
U-236	$1.7 \cdot 10^{-7}$	$1.1 \cdot 10^{-7}$	$4.7 \cdot 10^{-4}$
U-238	$2.4 \cdot 10^{-7}$	$1.4 \cdot 10^{-7}$	$7.0 \cdot 10^{-4}$
Np-237	$2.9 \cdot 10^{-5}$	$2.2 \cdot 10^{-5}$	$6.2 \cdot 10^{-1}$
Pu-239	$2.0 \cdot 10^{-9}$	$9.7 \cdot 10^{-10}$	$7.9 \cdot 10^{-9}$
Pu-242	$7.8 \cdot 10^{-8}$	$2.0 \cdot 10^{-7}$	$3.9 \cdot 10^{-7}$

Table 10

Maximum individual doses (Sv/year) for critical group, release scenario G

Nuclide	Well	Lake
Zr-93	$1.4 \cdot 10^{-7}$	$1.6 \cdot 10^{-7}$
Tc-99	$1.7 \cdot 10^{-6}$	$1.3 \cdot 10^{-6}$
I-129	$1.5 \cdot 10^{-6}$	$1.4 \cdot 10^{-6}$
Cs-135	$2.9 \cdot 10^{-6}$	$2.9 \cdot 10^{-6}$
Ra-226	$1.7 \cdot 10^{-5}$	$1.1 \cdot 10^{-5}$
Th-229	$6.3 \cdot 10^{-7}$	$4.0 \cdot 10^{-7}$
Th-230	$1.1 \cdot 10^{-7}$	$1.1 \cdot 10^{-7}$
Pa-231	$5.4 \cdot 10^{-7}$	$2.5 \cdot 10^{-7}$
U-233	$2.2 \cdot 10^{-5}$	$1.4 \cdot 10^{-5}$
U-234	$2.2 \cdot 10^{-5}$	$1.4 \cdot 10^{-5}$
U-235	$4.6 \cdot 10^{-7}$	$1.9 \cdot 10^{-7}$
U-236	$5.5 \cdot 10^{-6}$	$3.4 \cdot 10^{-6}$
U-238	$4.9 \cdot 10^{-6}$	$3.0 \cdot 10^{-6}$
Np-237	$3.9 \cdot 10^{-4}$	$2.7 \cdot 10^{-4}$
Pu-239	$1.2 \cdot 10^{-8}$	$4.9 \cdot 10^{-9}$
Pu242	$5.8 \cdot 10^{-8}$	$1.0 \cdot 10^{-7}$

Table 11

Maximum individual doses (Sv/year) for critical group, release scenario H

Nuclide	Well	Lake
Zr-93	$3.3 \cdot 10^{-9}$	$3.7 \cdot 10^{-9}$
Tc-99	$1.5 \cdot 10^{-13}$	$1.1 \cdot 10^{-13}$
Cs-135	$2.7 \cdot 10^{-11}$	$2.7 \cdot 10^{-11}$
Ra-226	$5.8 \cdot 10^{-6}$	$3.8 \cdot 10^{-6}$
Th-229	$1.7 \cdot 10^{-8}$	$1.1 \cdot 10^{-8}$
Th-230	$7.5 \cdot 10^{-10}$	$7.5 \cdot 10^{-10}$
Pa-231	$6.3 \cdot 10^{-6}$	$2.9 \cdot 10^{-6}$
U-233	$2.5 \cdot 10^{-9}$	$1.6 \cdot 10^{-9}$
U-234	$9.5 \cdot 10^{-9}$	$6.0 \cdot 10^{-9}$
U-235	$1.2 \cdot 10^{-10}$	$5.1 \cdot 10^{-11}$
U-236	$1.7 \cdot 10^{-9}$	$1.0 \cdot 10^{-9}$
U-238	$1.4 \cdot 10^{-9}$	$8.7 \cdot 10^{-10}$
Np-237	$5.5 \cdot 10^{-7}$	$3.8 \cdot 10^{-7}$
Pu-239	$6.4 \cdot 10^{-8}$	$2.6 \cdot 10^{-8}$
Pu-242	$2.4 \cdot 10^{-9}$	$4.2 \cdot 10^{-9}$

Table 12

Maximum individual doses (Sv/year) for critical group, release scenario I

Nuclide	Well	Lake
Zr-93	$7.3\cdot10^{-10}$	$8.2\cdot10^{-10}$
Tc-99	$3.2\cdot10^{-10}$	$2.4\cdot10^{-10}$
I-129	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$
Cs-135	$1.2\cdot10^{-7}$	$1.2\cdot10^{-7}$
Ra-226	$6.2\cdot10^{-8}$	$4.0\cdot10^{-8}$
Th-229	---	---
Th-230	$4.2\cdot10^{-10}$	$4.2\cdot10^{-10}$
Pa-231	$1.9\cdot10^{-9}$	$1.1\cdot10^{-9}$
U-233	$8.9\cdot10^{-9}$	$5.6\cdot10^{-9}$
U-234	$1.7\cdot10^{-10}$	$1.1\cdot10^{-10}$
U-235	$7.0\cdot10^{-12}$	$2.9\cdot10^{-12}$
U-236	$1.6\cdot10^{-11}$	$9.9\cdot10^{-12}$
U-238	$1.5\cdot10^{-10}$	$9.5\cdot10^{-11}$
Np-237	$1.8\cdot10^{-7}$	$1.3\cdot10^{-7}$

Table 13

Maximum individual doses (Sv/year) for critical group, release scenario J

Nuclide	Well	Lake
Zr-93	$7.3\cdot10^{-10}$	$8.2\cdot10^{-10}$
Tc-99	$7.8\cdot10^{-9}$	$5.9\cdot10^{-9}$
I-129	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$
Cs-135	$1.2\cdot10^{-7}$	$1.2\cdot10^{-7}$
Ra-226	$6.2\cdot10^{-7}$	$4.0\cdot10^{-7}$
Th-229	$3.9\cdot10^{-8}$	$2.5\cdot10^{-8}$
Th-230	$3.9\cdot10^{-9}$	$3.9\cdot10^{-9}$
Pa-231	$1.8\cdot10^{-8}$	$8.4\cdot10^{-9}$
U-233	$1.2\cdot10^{-6}$	$7.8\cdot10^{-7}$
U-234	$7.9\cdot10^{-7}$	$5.0\cdot10^{-7}$
U-235	$3.4\cdot10^{-8}$	$1.4\cdot10^{-8}$
U-236	$3.9\cdot10^{-7}$	$2.4\cdot10^{-7}$
U-238	$3.9\cdot10^{-7}$	$2.5\cdot10^{-7}$
Np-237	$2.5\cdot10^{-5}$	$1.7\cdot10^{-5}$
Pu-239	---	---
Pu-242	$4.6\cdot10^{-10}$	$8.1\cdot10^{-10}$

Table 14

Maximum individual dose (Sv/year) for the well alternative, release scenario K

Nuclide	Well
Ni-59	$3.5 \cdot 10^{-16}$
Ni-63	$6.5 \cdot 10^{-14}$
Zr-93	$1.6 \cdot 10^{-13}$
Nb-94	$1.8 \cdot 10^{-14}$
Tc-99	$1.2 \cdot 10^{-17}$
Cs-135	$6.2 \cdot 10^{-15}$
Cs-137	$1.2 \cdot 10^{-9}$
Sm-151	$2.5 \cdot 10^{-9}$
Eu-154	$6.0 \cdot 10^{-11}$
Ra-226	$1.7 \cdot 10^{-9}$
Th-229	$2.5 \cdot 10^{-12}$
Th-230	$1.1 \cdot 10^{-13}$
Pa-231	$1.5 \cdot 10^{-9}$
U-233	$2.2 \cdot 10^{-15}$
U-234	$1.0 \cdot 10^{-14}$
U-235	$1.0 \cdot 10^{-16}$
U-236	$1.5 \cdot 10^{-15}$
U-238	$1.2 \cdot 10^{-15}$
Pu-238	$1.5 \cdot 10^{-11}$
Pu-239	$1.2 \cdot 10^{-11}$
Pu-240	$4.2 \cdot 10^{-12}$
Pu-242	$1.7 \cdot 10^{-13}$
Np-237	$1.3 \cdot 10^{-11}$
Sr-90	$1.0 \cdot 10^{-10}$
Am-241	$1.4 \cdot 10^{-7}$
Am-242m	$2.1 \cdot 10^{-10}$
Am-243	$9.0 \cdot 10^{-10}$
Cm-245	$7.0 \cdot 10^{-12}$
Cm-246	$5.1 \cdot 10^{-13}$

Table 15

Distribution of maximum collective annual dose

Nuclide	Region	Baltic Sea	Global
Zr-93	4	82	12
TC-99	2	49	49
I-29			100
CS-135		4	96
Ra-226	22	53	25
Th-230	2	22	76
Pa-231	3	7	90
U-233			100
U-234			100
U-235			100
U-236			100
U-238			100
Np-237		1	99
Pu-239	11	65	24
Pu-242	11	65	25

Table 16

Maximum individual dose (Sv/year), peat - bog recipient and release scenario A.

Nuclide	Dose
Ra-226	$2 \cdot 10^{-7}$
Th-229	$5 \cdot 10^{-10}$
Pa-231	$9 \cdot 10^{-10}$
Np-237	$5 \cdot 10^{-10}$

APPENDIX A

Input data for calculation of the activity concentration.

CONTENTS

Table A.1

Release scenarios

Case	U_o	D	Red	Ox	Colloidal particles	Comments
A	0.1	100	$1 \cdot 10^{-5}$			All canisters
B	0.1	100	$1 \cdot 10^{-5}$			Initially defective canister
C	0.1	100		$3.6 \cdot 10^{-1}$		All canisters
D	0.1	100			x	"-
F	1	50	$1 \cdot 10^{-3}$			"-
G	1	50		$9.5 \cdot 10^{-1}$		"-
H	1	50	$1 \cdot 10^{-3}$		x	"-
I	0.3	5	$1 \cdot 10^{-5}$			"-
J	0.3	5			$3.6 \cdot 10^{-1}$	"-
K	0.1	100	$1 \cdot 10^{-5}$		x	Initially defective canister

The symbols used are the following:

U_o = water flux in the undisturbed rock (l/m2 year)
D = migration distance (m)
Red = reducing conditions
Ox = oxidizing conditions

In the column for reducing and oxidizing conditions respectively the solubility used for uranium in g/l is written.

In the comment column the expression all canisters means the uniform decay of canisters from 10^5 to 10^6 years. The first scenarios is the central calculation case according to the main report.

Cases B, C and D also correspond to scenarios B, C and D respectively in reference (25).

Scenario E in (25) correspond to case A with a peat-bog recipient.

Table A:2 Reservoir sizes (kg) - site independent

RESERVOIR	NAME	MASS
16	REG ATM	$4.8 \cdot 10^{14}$
17	BALTIC	$2.2 \cdot 10^{16}$
18	BALTIC SED 1	$3.7 \cdot 10^{13}$
19	BALTIC SED 2	---
20	GLOBATM	$4.4 \cdot 10^{18}$
21	WELLMIX	$2.0 \cdot 10^{19}$
22	WELLSED 1	$2.0 \cdot 10^{15}$
23	WELLSED 2	---
24	DEEP SEA	$1.4 \cdot 10^{21}$
25	DEEP SED 1	$3.6 \cdot 10^{16}$
26	DEEP SED 2	---
27	GLOBSOIL	$1.1 \cdot 10^{17}$
28	GRWGLOB	$6.0 \cdot 10^{18}$

Table A3 Reservoir Sizes (kg) - Regional areas, Site Dependent

	Fjällveden		Finnsjön		Gideå		Kamlunge	
Reservoir	Name	Mass kg	Name	Mass kg	Name	Mass kg	Nam	Mass kg
3	MORPALAKE	$3.2 \cdot 10^9$	REGSOIL 1		DAM	$2.3 \cdot 10^9$	LAPPTRASK	$3.3 \cdot 10^9$
4	MORPASED1	$4.8 \cdot 10^7$	REGSOIL2		DAMSED1	$5.4 \cdot 10^7$	LAPPSED1	$4.8 \cdot 10^9$
5	MORPASED2		GRW REG	$5.0 \cdot 10^9$	DAMSED2		LAPPSED2	
6	LILÅNLAKE	$3.8 \cdot 10^{11}$	LAKE	$8.6 \cdot 10^9$	GIDERIV	$6.0 \cdot 10^8$	KALIXRIV	$1.5 \cdot 10^{10}$
7	LILÅNSED1	$4.7 \cdot 10^9$	LAKESED1	$6.5 \cdot 10^8$	COASTAREA	$4.3 \cdot 10^{10}$	KALRIVSED	$9.6 \cdot 10^9$
8	LILÅNSED2		LAKESED2		COASTSED1	$4.2 \cdot 10^8$	COASTAREA	$3.6 \cdot 10^{11}$
9	REGSOILUP	$3.9 \cdot 10^7$			COASTSED2		COASTSED1	$7.7 \cdot 10^{10}$
10	REGSOILDE	$2.7 \cdot 10^8$					COASTED2	
11	GRWREG	$9.4 \cdot 10^7$						
12	NYKOFJORD	$1.9 \cdot 10^{10}$						
13	NYKOSED1	$1.1 \cdot 10^9$						
14	NYKOSED2							

Table A4 Transfer Coefficients (turnover/year) - Site Independent

TRANSFER											
FROM	TO	IR	TC	I	CS	RA	TH	PA	U	NP	PU
REG ATM	BALTIC	$9.5\cdot10^{1}$	$9.5\cdot10^{1}$	$9.5\cdot10^{1}$	$9.5\cdot10^{1}$	$9.5\cdot10^{1}$	$9.5\cdot10^{1}$	$9.5\cdot10^{1}$	$9.5\cdot10^{1}$	$9.5\cdot10^{1}$	$9.5\cdot10^{1}$
REG ATM	GLOBATM	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$	$1.5\cdot10^{2}$
BALTIC	BALTIC SED1	$8.3\cdot10^{-2}$	$1.6\cdot10^{-4}$	$1.6\cdot10^{-4}$	$1.2\cdot10^{-3}$	$8.0\cdot10^{-1}$	5.8	5.8	$8.3\cdot10^{-3}$	$8.3\cdot10^{-3}$	5.8
BALTIC	WELLMIX	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10-2$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$	$4.3\cdot10^{-2}$
BALTIC SED1	BALTIC	$5.0\cdot10^{-3}$	$5.0\cdot10^{-4}$	$4.8\cdot10^{-4}$	$1.0\cdot10^{-4}$	$4.8\cdot10^{-3}$	$1.2\cdot10^{-2}$	$1.2\cdot10^{-2}$	$5.0\cdot10^{-4}$	$5.0\cdot10^{-4}$	$1.2\cdot10^{-2}$
BALTIC SED1	BALTIC SED2	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10$
GLOB ATM	REG ATM	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.6\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10-2$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$
GLOB ATM	WELLMIX	$3.5\cdot10^{1}$	$3.5\cdot10^{1}$	$2.1\cdot10^{1}$	$3.5\cdot10^{1}$	$3.5\cdot10^{1}$	$3.5\cdot10^{1}$	$3.5\cdot10^{1}$	$3.5\cdot10^{1}$	$3.5\cdot10^{1}$	$3.5\cdot10^{1}$
GLOB ATM	GLOB SOIL	$1.7\cdot10^{1}$	$1.7\cdot10^{1}$	1.1	$1.7\cdot10^{1}$	$1.7\cdot10^{1}$	$1.7\cdot10^{1}$	$1.7\cdot10^{1}$	$1.7\cdot10^{1}$	$1.7\cdot10^{1}$	$1.7\cdot10^{1}$
WELLMIX	GLOBATM	0	0	$1.4\cdot10^{-3}$	0	0	0	0	0	0	0
WELLMIX	WELL SED2	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-5}$	$5.0\cdot10^{-5}$	$3.0\cdot10^{-3}$	$3.3\cdot10^{-1}$	$3.3\cdot10^{-1}$	$5.0\cdot10^{-5}$	$5.0\cdot10^{-4}$	$3.3\cdot10^{-1}$
WELLMIX	DEEP SEA	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$	$1.1\cdot10^{-1}$
WELLMIX	GLOBSOIL	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$
WELLSED1	WELLMIX	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$6.6\cdot10^{-5}$	$6.6\cdot10^{-5}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$6.6\cdot10^{-5}$
WELLSED1	WELLSED2	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$
DEEP SEA	WELLMIX	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	$8.0\cdot10^{-4}$
DEEP SEA	DEEP SED1	$2.5\cdot10^{-3}$	$2.5\cdot10^{-4}$	$2.2\cdot10^{-6}$	$1.7\cdot10^{-6}$	$2.5\cdot10^{-4}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$2.5\cdot10^{-7}$	$2.5\cdot10^{-7}$	$1.0\cdot10^{-2}$
DEEP SED1	DEEP SEA	$1.0\cdot10^{-6}$	$1.0\cdot10^{-6}$	$2.0\cdot10^{-7}$	$1.0\cdot10^{-6}$	$1.0\cdot10-6$	$1.0\cdot10^{-6}$	$1.0\cdot10^{-6}$	$1.0\cdot10^{-6}$	$1.0\cdot10^{-6}$	$1.0\cdot10^{-6}$
DEEP SED1	DEEP SED2	$1.0\cdot10^{-6}$	$1.0\cdot10^{-6}$	0	$1.0\cdot10^{-6}$	$1.0\cdot10^{-6}$	$1.0\cdot10-6$	$1.0\cdot10^{-6}$	$1.0\cdot10^{-6}$	$1.0\cdot10^{-6}$	$1.0\cdot10^{-6}$
GLOBSOIL	GLOB ATM	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10-5$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$
GLOB SOIL	WELLMIX	$4.4\cdot10^{-5}$	$2.2\cdot10^{-1}$	$1.9\cdot10^{-4}$	$8.8\cdot10^{-4}$	$3.7\cdot10^{-4}$	$2.0\cdot10^{-5}$	$2.0\cdot10^{-5}$	$6.6\cdot10^{-4}$	$6.6\cdot10^{-4}$	$2.0\cdot10^{-5}$
GLOB SOIL	GRW GLOB	$3.8\cdot10^{-5}$	$1.9\cdot10^{-1}$	$3.6\cdot10^{-5}$	$7.6\cdot10^{-4}$	$3.2\cdot10^{-4}$	$1.7\cdot10^{-5}$	$1.7\cdot10^{-5}$	$5.7\cdot10^{-4}$	$5.7\cdot10^{-4}$	$1.7\cdot10^{-5}$
GRW GLOB	WELLMIX	$1.7\cdot10^{-8}$	$9.0\cdot10^{-5}$	$1.1\cdot10^{-3}$	$3.4\cdot10^{-7}$	$1.4\cdot10^{-7}$	$7.7\cdot10^{-9}$	$7.7\cdot10^{-9}$	$2.5\cdot10^{-7}$	$2.5\cdot10^{-7}$	$7.7\cdot10^{-9}$
GRW GLOB	GLOBSOIL	$2.9\cdot10^{-7}$	$1.5\cdot10^{-3}$	0	$5.8\cdot10^{-6}$	$2.4\cdot10^{-6}$	$1.3\cdot10^{-7}$	$1.3\cdot10^{-7}$	$4.3\cdot10^{-6}$	$4.3\cdot10^{-6}$	$1.3\cdot10^{-7}$

Table A5 - Transfer Coefficients (turnover/year), Main Case - Site Dependent

TRANSFER											
FROM	TO	ZR	TC	I	CS	RA	TH	PA	U	NP	PU
GRW	SOIL	$2.4\cdot10^{-4}$	$2.4\cdot10^{-4}$	$2.4\cdot10^{-4}$	$2.4\cdot10^{-4}$	$2.4\cdot10^{-4}$	$2.4\cdot10^{-4}$	$2.4\cdot10^{-4}$	$2.4\cdot10^{-4}$	$2.4\cdot10^{-4}$	$2.4\cdot10^{-4}$
GRW	MORPA	2	2	2	2	2	2	2	2	2	2
SOIL	MORPA	$1.0\cdot10^{-4}$	$6.0\cdot10^{-1}$	$1.0\cdot10^{-2}$	$2.1\cdot10^{-3}$	$8.8\cdot10^{-4}$	$5.3\cdot10^{-5}$	$5.3\cdot10^{-5}$	$1.6\cdot10^{-3}$	$1.6\cdot10^{-3}$	$5.3\cdot10^{-5}$
MORPA	MORPA SED1	1.8	$3.7\cdot10^{-2}$	$3.0\cdot10^{-2}$	$4.0\cdot10^{-1}$	1.8	$1.4\cdot10^{1}$	$1.4\cdot10^{1}$	1.8	$2.2\cdot10^{-1}$	$1.4\cdot10^{1}$
MORPA	LIDS-LÅNG	$3.0\cdot10^{-1}$	$3.0\cdot10^{-1}$	$3.0\cdot10^{-1}$	$3.0\cdot10^{-1}$	$3.0\cdot10^{-1}$	$3.0\cdot10^{-1}$	$3.0\cdot10^{-1}$	$3.0\cdot10^{-1}$	$3.0\cdot10-1$	$3.0\cdot10^{-1}$
MORPA SED1	MORPA	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.3\cdot10^{-3}$	$1.1\cdot10^{-3}$	$1.6\cdot10^{-2}$	$1.3\cdot10^{-2}$	$1.3\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.3\cdot10^{-2}$
MORPA SED1	MORPA SED2	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10$
SOILUP	SOLIDE	$1.0\cdot10^{-4}$	$3.0\cdot10^{-1}$	$1.0\cdot10^{-2}$	$2.1\cdot10^{-3}$	$8.8\cdot10^{-4}$	$5.3\cdot10^{-5}$	$5.3\cdot10^{-5}$	$1.6\cdot10^{-3}$	$1.6\cdot10^{-3}$	$5.3\cdot10^{-5}$
SOILUP	ATMF	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$
LIDS-LÅNGH	L-L SED1	1.5	$3.0\cdot10^{-2}$	$3.0\cdot10^{-2}$	$4.0\cdot10^{-1}$	2.8	$1.4\cdot10^{1}$	$1.4\cdot10^{1}$	1.5	$1.8\cdot10^{-1}$	$1.4\cdot10^{1}$
MORPA	SOILUP	$4.4\cdot10^{-3}$	$4.4\cdot10^{-3}$	$4.4\cdot10^{-3}$	$4.4\cdot10^{-3}$	$4.4\cdot10^{-3}$	$4.4\cdot10^{-3}$	$4.4\cdot10^{-3}$	$4.4\cdot10^{-3}$	$4.4\cdot10^{-3}$	$4.4\cdot10^{-3}$
LIDS-LÅNGH	NYK FJORD	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
L-L SED1	LIDS-LÅNGH	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.3\cdot10^{-3}$	$1.4\cdot10^{-2}$	$1.3\cdot10^{-2}$	$1.3\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.3\cdot10^{-2}$
L-L SED1	L-L SED2	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$
SOILDE	GRUNDV	$7.9\cdot10^{-6}$	$4.0\cdot10^{-2}$	$2.5\cdot10^{-4}$	$1.6\cdot10^{-4}$	$6.7\cdot10^{-5}$	$4.0\cdot10^{-6}$	$4.0\cdot10^{-6}$	$1.2\cdot10^{-4}$	$1.2\cdot10^{-4}$	$4.0\cdot10^{-6}$
GRW	LIDS-LÅNGH	$2.0\cdot10^{-5}$	$2.0\cdot10^{-1}$	$2.0\cdot10^{-1}$	$4.0\cdot10^{-4}$	$1.7\cdot10^{-4}$	$9.1\cdot10^{-6}$	$9.1\cdot10^{-6}$	$3.0\cdot10^{-4}$	$2.9\cdot10^{-4}$	$9.1\cdot10^{-6}$
NYK FJORD	N-F SED1	7.3	$1.5\cdot10^{-1}$	$1.5\cdot10^{-1}$	$4.0\cdot10^{-1}$	$1.4\cdot10^{1}$	$5.8\cdot10^{1}$	$5.8\cdot10^{1}$	7.3	$8.9\cdot10^{-1}$	$5.8\cdot10^{1}$
NYK FJORD	BALTIC	$4.6\cdot10^{1}$	$4.6\cdot10^{1}$	$4.6\cdot10^{1}$	$4.6\cdot10^{1}$	$4.6\cdot10^{1}$	$4.6\cdot10^{1}$	$4.6\cdot10^{1}$	$4.6\cdot10^{1}$	$4.6\cdot10^{1}$	$4.6\cdot10^{1}$
N-F SED1	NYK FJORD	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$2.7\cdot10^{-4}$	$1.4\cdot10^{-2}$	$1.2\cdot10^{-2}$	$1.2\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.2\cdot10^{-2}$
N-F SED1	N-F SED2	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10-3$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$
REG ATM	MORPA	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10-4$
REG ATM	LIDS-LÅNGH	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$
REG ATM	SOILUP	$3.7\cdot10^{-4}$	$3.7\cdot10^{-4}$	$3.7\cdot10^{-4}$	$3.7\cdot10^{-4}$	$3.7\cdot10^{-4}$	$3.7\cdot10^{-4}$	$3.7\cdot10^{-4}$	$3.7\cdot10^{-4}$	$3.7\cdot10^{-4}$	$3.7\cdot10^{-4}$
REG ATM	NYK FJORD	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$	$2.5\cdot10^{-3}$

Table A6 Transfer Coefficients (turnover/year), Finnsjon - Site Dependent

TRANSFER											
FROM	TO	ZR	TC	I	CS	RA	TH	PA	U	NP	PU
GRW	LOCSOIL	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	1.0·10-2	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$
GRW	LAKE	2	2	2	2	2	2	2	2	2	2
LOCSOIL	GRW REG	$1.0\cdot10^{-4}$	$6.0\cdot10^{-1}$	$1.0\cdot10^{-2}$	$2.1\cdot10^{-3}$	$8.8\cdot10^{-4}$	$5.3\cdot10^{-5}$	$5.3\cdot10^{-5}$	$1.6\cdot10^{-3}$	$1.6\cdot10^{-3}$	$5.3\cdot10^{-5}$
REGSOIL 1	REGSOIL 2	$1.0\cdot10^{-4}$	$6.0\cdot10^{-1}$	$1.0\cdot10^{-2}$	$2.1\$10^{-3}$	$8.8\cdot10^{-4}$	$5.3\cdot10^{-5}$	$5.3\cdot10^{-5}$	$1.6\cdot10^{-3}$	$1.6\cdot10^{-3}$	$5.3\cdot10^{-5}$
REGSOIL 1	REG ATM	$1.0\cdot10^{-5}$	1.0·10-5	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$
REGSOIL 2	GRW REG	$7.9\cdot10^{-6}$	$4.0\cdot10^{-2}$	$2.5\cdot10^{-4}$	$1.6\cdot10^{-4}$	$6.7\cdot10^{-5}$	$4.0\cdot10^{-6}$	$4.0\cdot10^{-6}$	$1.2\cdot10^{-4}$	$1.2\cdot10^{-4}$	$4.0\cdot10^{-6}$
GRW REG	LAKE	$2.0\cdot10^{-5}$	$1.0\cdot10^{-1}$	$2.0\cdot10^{-1}$	$4.0\cdot10^{-4}$	$1.7\cdot10^{-4}$	$9.1\cdot10^{-6}$	$9.1\cdot10^{-6}$	$3.0\cdot10^{-4}$	$3.0\cdot10^{-4}$	$9.1\cdot10^{-6}$
LAKE	REGSOIL 1	$5.8\cdot10^{-2}$	$5.8\cdot10^{-2}$	$5.8\cdot10^{-2}$	$5.8\cdot10^{-2}$	$5.8\cdot10^{-2}$	$5.8\cdot10^{-2}$	$5.8\cdot10^{-2}$	$5.8\cdot10^{-2}$	$5.8\cdot10^{-2}$	$5.8\cdot10^{-2}$
LAKE	LAKE SED1	7.3	$3.0\cdot10^{-2}$	$3.0\cdot10^{-2}$	$4.0\cdot10^{-1}$	7.3	$7.0\cdot10^{1}$	$7.0\cdot10^{1}$	7.3	7.3	$7.0\cdot10^{1}$
LAKE	BALTIC	3	3	3	3	3	3	3	3	3	3
LAKE SED1	LAKE	$1.5\cdot10^{-2}$	$3.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-2}$	$4.7\cdot10^{-3}$	$4.7\cdot10^{-3}$	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$4.7\cdot10^{-3}$
LAKE SED2	LAKE SED2	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-}$
REG ATM	REG SOIL	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$
REG ATM	LAKE	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$	$1.3\cdot10^{-3}$

Table A7 Transfer Coefficients (turnover/year), Gidea - Site Dependent

TRANSFER											
FROM	TO	ZR	TC	I	CS	RA	TH	PA	U	NP	PU
GRW	LOCSOIL		$1.0\cdot10^{-2}$		$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$
GRW	DAM		2		2	2	2	2	2	2	2
LOCSOIL	DAM		$6.0\cdot10^{-1}$		$2.2\cdot10^{-3}$	$8.8\cdot10^{-4}$	$5.3\cdot10^{-5}$	$5.3\cdot10^{-5}$	$1.6\cdot10^{-3}$	$1.6\cdot10^{-3}$	$5.3\cdot10^{-5}$
DAM	DAM SED1		$3.0\cdot10^{-2}$		$4.0\cdot10^{-1}$	2.9	$4.6\cdot10^{1}$	$4.6\cdot10^{1}$	2.9	2.9	$4.6\cdot10^{1}$
DAM	GIDERIV		$4.6\cdot10^{2}$		$4.6\cdot10^{2}$	$4.6\cdot10^{2}$	$4.6\cdot10^{2}$	$4.6\cdot10^{2}$	$4.6\cdot10^{2}$	$4.6\cdot10^{2}$	$4.6\cdot10^{2}$
DAM SED1	DAM		$1.0\cdot10^{-2}$		$1.0\cdot10^{-4}$	$1.5\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.0\cdot10^{-2}$
DAM SED1	DAM SED2		$1.0\cdot10^{-3}$		$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$
GIDERIV	COASTAREA		$1.8\cdot10^{3}$		$1.8\cdot10^{3}$	$1.8\cdot10^{3}$	$1.8\cdot10^{3}$	$1.8\cdot10^{3}$	$1.8\cdot10^{3}$	$1.8\cdot10^{3}$	$1.8\cdot10^{3}$
COAST AREA	COAST SED1		$2.0\cdot10^{-3}$		$4.0\cdot10^{-1}$	1.6	5.5	5.5	1.6	1.6	5.5
COAST AREA	BALTIC		$4.1\cdot10^{1}$		$4.1\cdot10^{1}$	$4.1\cdot10^{1}$	$4.1\cdot10^{1}$	$4.1\cdot10^{1}$	$4.1\cdot10^{1}$	$4.1\cdot10^{1}$	$4.1\cdot10^{1}$
COAST SED1	COAST AREA		$1.0\cdot10^{-4}$		$1.0\cdot10^{-4}$	$1.5\cdot10^{-2}$	$4.9\cdot10^{-3}$	$4.9\cdot10^{-3}$	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$4.9\cdot10^{-3}$
COAST SED1	COAST SED2		$1.0\cdot10^{-4}$		$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$

Table A8 Transfer Coefficients (turnover/year), Kamlunge - Site Dependent

TRANSFER												
FROM	TO	ZR	TC	I	CS	RA	TH	PA	U	NP	PU
GRW	LOCSOIL		$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$		$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$
GRW	LAPPTRASK		2	2		2	2	2	2	2	2
LOCSOIL	LAPPTRASK		$1.0\cdot10^{-2}$	$1.0\cdot10^{-2}$		$8.8\cdot10^{-4}$	$5.3\cdot10^{-4}$	$5.3\cdot10^{-5}$	$1.6\cdot10^{-3}$	$1.6\cdot10^{-3}$	$5.3\cdot10^{-5}$
LAPPTRASK	LAPP SED1		$4.0\cdot10^{-2}$	$3.0\cdot10^{-2}$		1.8	$1.4\cdot10^{1}$	$1.4\cdot10^{1}$	1.8	$2.2\cdot10^{-1}$	$1.4\cdot10^{1}$
LAPPTRASK	KALIX RIV		5.8	5.8		5.8	5.8	5.8	5.8	5.8	5.8
LAPP SED1	LAPPTRASK		$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$		$1.5\cdot10^{-2}$	$1.2\cdot10^{-2}$	$1.2\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.2\cdot10^{-2}$
LAPP SED1	LAPP SED2		$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$		$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$
KALIX RIV	KAL RIV SED		$1.5\cdot10^{-1}$	$1.5\cdot10^{-1}$		7.3	$5.8\cdot10^{1}$	$5.8\cdot10^{1}$	7.3	$8.8\cdot10^{-1}$	$5.8\cdot10^{1}$
KALIX RIV	COAST AREA		$3.6\cdot10^{2}$	$3.6\cdot10^{2}$		$3.6\cdot10^{2}$	$3.6\cdot10^{2}$	$3.6\cdot10^{2}$	$3.6\cdot10^{2}$	$3.6\cdot10^{2}$	$3.6\cdot10^{2}$
KAL RIV SED	KALIX RIV		$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$		$1.5\cdot10^{-2}$	$1.2\cdot10^{-2}$	$1.2\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.2\cdot10^{-2}$
COAST AREA	COAST SED1		$5.0\cdot10^{-2}$	$5.0\cdot10^{2}$		2.4	$1.9\cdot10^{1}$	$1.9\cdot10^{1}$	2.4	$2.9\cdot10^{-1}$	$1.9\cdot10^{1}$
COAST AREA	BALTIC		$3.6\cdot10^{1}$	$3.6\cdot10^{1}$		$3.6\cdot10^{1}$	$3.6\cdot10^{1}$	$3.6\cdot10^{1}$	$3.6\cdot10^{1}$	$3.6\cdot10^{1}$	$3.6\cdot10^{1}$
COAST SED1	COAST AREA		$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$		$1.5\cdot10^{-2}$	$1.2\cdot10^{-2}$	$1.2\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.5\cdot10^{-2}$	$1.2\cdot10^{-2}$
COAST SED1	COAST SED2		$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$		$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$

APPENDIX B

INPUT DATA FOR CALCULATION OF ACTIVITY INTAKE

Contents

- Table B.1: Diet composition and annual consumption for critical group and population.
- Table B.2: Concentration and distribution factors for transfer of radioactive nuclides from different reservoirs in the ecosystem to the food chains.
- Table B.3: Other input data for exposure via animal and vegetable food stuffs.

Table B.1 Diet composition and annual consumption for critical group and population

		Well alternative	Lake alternative	Regional alternative	Global alternative
Inhalation	m^3	$9.4 \cdot 10^3$	$9.4 \cdot 10^3$	$9.4 \cdot 10^3$	$9.4 \cdot 10^3$
Drinking water	l	$4.4 \cdot 10^2$	$4.4 \cdot 10^2$	$4.4 \cdot 10^2$	$4.4 \cdot 10^2$
Milk	kg	$1.9 \cdot 10^2$	$1.9 \cdot 10^2$	$1.9 \cdot 10^2$	$9.0 \cdot 10^1$
Meat	kg	$5.5 \cdot 10^1$	$5.5 \cdot 10^1$	$5.5 \cdot 10^1$	$2.5 \cdot 10^1$
Green vegetables	kg	$2.5 \cdot 10^1$	$2.5 \cdot 10^1$	$2.5 \cdot 10^1$	$9.0 \cdot 10^1$
Grain	kg		$7.5 \cdot 10^1$	$7.5 \cdot 10^1$	$1.2 \cdot 10^2$
Root vegetables and potatoes	kg		$7.5 \cdot 10^1$	$7.5 \cdot 10^1$	$8.0 \cdot 10^1$
Fish	kg	$3.0 \cdot 10^1$	$3 \cdot 10^1$	$3.0 \cdot 10^1$	$1.0 \cdot 10^1$
Eggs	pc	$2.0 \cdot 10^2$	$2 \cdot 10^2$	$2.0 \cdot 10^2$	$5.4 \cdot 10^1$
Marine plants					$1.0 \cdot 10^1$

Tabel B.2 Concentration and distribution factors for transfer of activity from different reservoirs to food chains

	Concentration factors*)								
Element	Pasturage	Grain	Green vegetables	Root vegetables	Fish fresh w.	Fish brackishw	Fish sea water	Marine plants brackish water	Marine plants sea water
Zr	$1.1\cdot10^{-3}$	$1.7\cdot10^{-4}$	$1.7\cdot10^{-4}$	$1.7\cdot10^{-4}$	$3.0\cdot10^{2}$	$3.0\cdot10^{2}$	$1.0\cdot10^{2}$	$5.0\cdot10^{2}$	$5.0\cdot10^{2}$
Tc	1.0	$9.0\cdot10^{-1}$	$1.0\cdot10^{-1}$	$2.0\cdot10^{-1}$	$3.5\cdot10^{1}$	$3.0\cdot10^{1}$	$1.0\cdot10^{1}$	$4.0\cdot10^{3}$	$4.0\cdot10^{3}$
I	$8.0\cdot10^{-2}$	$2.0\cdot10^{-3}$	$5.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$2.0\cdot10^{1}$	$2.0\cdot10^{1}$	$2.0\cdot10^{1}$	$4\cdot10^{3}$	$4\cdot10^{3}$
Cs	$1.0\cdot10^{-1}$	$1.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$2.0\cdot10^{-2}$	$1.3\cdot10^{3}$	$2.0\cdot10^{2}$	$1.0\cdot10^{1}$	$1.5\cdot10^{2}$	$2\cdot10^{1}$
Ra	$2.0\cdot10^{-2}$	$1.0\cdot10^{-2}$	$7.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	$2.5\cdot10^{1}$	$1.0\cdot10^{1}$	$1.0\cdot10^{1}$	$1.0\cdot10^{2}$	$1.0\cdot10^{2}$
Th	$6.0\cdot10^{-3}$	$6.9\cdot10^{-4}$	$5.0\cdot10^{-4}$	$1.0\cdot10^{-3}$	$3.0\cdot10^{1}$	$3.0\cdot10^{1}$	$3.0\cdot10^{3}$	$3.0\cdot10^{3}$	$3.0\cdot10^{3}$
Pa	$3.0\cdot10^{-3}$	$3.0\cdot10^{-3}$	$3.0\cdot10^{-4}$	$6.0\cdot10^{-4}$	$1.0\cdot10^{1}$	$1.0\cdot10^{1}$	$1.0\cdot10^{2}$	$5.0\cdot10^{1}$	$5.0\cdot10^{1}$
U	$4.0\cdot10^{-3}$	$1.2\cdot10^{-3}$	$4.0\cdot10^{-4}$	$8.0\cdot10^{-4}$	5.0	5.0	1.0	$5.0\cdot10^{1}$	$5.0\cdot10^{1}$
Np	$3.0\cdot10^{-2}$	$4.0\cdot10^{-4}$	$3.0\cdot10^{-3}$	$6.0\cdot10^{-3}$	$1.0\cdot10^{1}$	$1.0\cdot10^{1}$	$1.0\cdot10^{1}$	$2.0\cdot10^{3}$	$2.0\cdot10^{3}$
Pu	$6.7\cdot10^{-4}$	$1.0\cdot10^{-6}$	$1.0\cdot10^{-4}$	$1.0\cdot10^{-3}$	3.5	8.0	3.5	$1.8\cdot10^{2}$	$1.0\cdot10^{3}$

*) Bq/kg in food stuffs per
Bq/kg in the reservoir, for plants given as dry weight values of the vegetation, otherwise fresh weight
References 2, 10, 11, 12, 13, 14

	Distribution factors		
Element	milk d/kg d/kg	meat d/kg	eggs d/pc
Zr	$5.0\cdot10^{-6}$	$3.4\cdot10^{-2}$	$6.0\cdot10^{-5}$
Tc	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$9.0\cdot10^{-4}$
I	$7.0\cdot10^{-3}$	$8.0\cdot10^{-3}$	$3.0\cdot10^{-2}$
Cs	$7.0\cdot10^{-3}$	$3.0\cdot10^{-2}$	$2.0\cdot10^{-2}$
Ra	$3.0\cdot10^{-3}$	$7.0\cdot10^{-4}$	$1.0\cdot10^{-6}$
Th	$5.0\cdot10^{-6}$	$7.0\cdot10^{-4}$	$1.0\cdot10^{-4}$
Pa	$5.0\cdot10^{-6}$	$3.0\cdot10^{-3}$	$1.0\cdot10^{-4}$
U	$2.0\cdot10^{-4}$	$1.0\cdot10^{-2}$	$1.0\cdot10^{-4}$
Np	$5.0\cdot10^{-6}$	$3.0\cdot10^{-3}$	$1.0\cdot10^{-4}$
Pu	$1.0\cdot10^{-7}$	$1.0\cdot10^{-6}$	$1.0\cdot10^{-4}$

Table B.3 Daily consumption of water and food for live stock, Mc_i

	Mc_w (l/day)	Mc_p (kg/day)
Cow	$9 \cdot 10^1$	$1.6 \cdot 10^1$ *)
Hens	$2.5 \cdot 10^{-1}$	$1.1 \cdot 10^{-1}$

*) Dry weight

Daily consumption of soil in connection with grazing 0.3 kg

Mass interception fraction, pasturage γ_p = 1.8 m^2/kg

Mass interception fraction, vegetables $\gamma_w = 3.6 \cdot 10^{-1}$ m^2/kg

Irrigation, IRR = $4 \cdot 10^{-4}$ $l \cdot m^2$ day

Deposition rate for transfer from atmosphere to soil, DEP = 259 m/day.

APPENDIX C

DOSE FACTORS

Contents

Table C.1 Dose factors (Sv/Bq) for intake via food, water and respiration of some important nuclides

Nuclide	Inhalation	Ingestion
Se-79	$2.4 \cdot 10^{-9}$	$2.3 \cdot 10^{-9}$
Zr-93	$8.6 \cdot 10^{-9}$	$4.2 \cdot 10^{-10}$
Tc-99	$2.0 \cdot 10^{-9}$	$3.4 \cdot 10^{-10}$
Sn-126	$2.3 \cdot 10^{-8}$	$4.7 \cdot 10^{-9}$
I-129	$4.7 \cdot 10^{-8}$	$9.8 \cdot 10^{-8}$
Cs-135	$1.2 \cdot 10^{-9}$	$1.9 \cdot 10^{-9}$
Ra-226	$2.6 \cdot 10^{-6}$	$3.3 \cdot 10^{-7}$
Th-229	$5.7 \cdot 10^{-4}$	$9.4 \cdot 10^{-7}$
Th-230	$8.6 \cdot 10^{-5}$	$1.6 \cdot 10^{-7}$
Pa-231	$3.4 \cdot 10^{-4}$	$2.2 \cdot 10^{-5}$
U-233	$3.6 \cdot 10^{-5}$	$7.2 \cdot 10^{-8}$
U-234	$3.6 \cdot 10^{-5}$	$7.1 \cdot 10^{-8}$
U-236	$3.4 \cdot 10^{-5}$	$6.7 \cdot 10^{-8}$
U-238	$3.2 \cdot 10^{-5}$	$6.3 \cdot 10^{-8}$
Np-237	$1.3 \cdot 10^{-4}$	$1.2 \cdot 10^{-6}$
Pu-239	$1.4 \cdot 10^{-4}$	$7.0 \cdot 10^{-7}$
Pu-242	$1.3 \cdot 10^{-4}$	$1.1 \cdot 10^{-7}$

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