SKBF KBS TEKNISK RAPPORT 81-03

Analysis of the importance for the doses of varying parameters in the biopath-program

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Studsvik Energiteknik AB, 1981-03-06

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ANALYSIS OF THE IMPORTANCE FOR THE DOSES OF VARYING PARAMETERS IN THE BIOPATH-PROGRAM

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This report concerns a study which was conducted for the KBS project. The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the client.

A list of other reports published in this series during 1981, is attached at the end of this report. Information on KBS technical reports from 1977-1978 (TR 121), 1979 (TR 79-28) and 1980 (TR 80-26) is available through SKBF/KBS.

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STUDSVIK/NW-81/20

1981-03-06

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KBS 16.35

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ABSTRACT

The doses to individuals and populations from water-borne nuclides leaked from a repository have been calculated earlier using the computer program BIOPATH. The turnover of nuclides in the biosphere is thereby simulated by the application of compartment theory. For the dominant nuclides in the disposal an analysis of the importance of varying parameters has been done, to decide how strongly uncertainties in data will affect resulting doses. The essential part has been the transfer coefficients but also the uptake in the food-chains has been studied. The purpose of the study has also been to make proposals for forthcoming efforts to improve the basis for such calculations. The study shows the great importance of the surface water-soil-groundwater-drinking water system for the dose. Thereby the most important question is the solubility of the nuclides in the different water reservoirs.

Performed within a joint research program in co-operation with SKBF/KBS.

Approved by

Lars Ramberg

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1. BACKGROUND

Within the KBS project "Final disposal of high level waste" calculations of the dose to man have been made using the computer program BIOPATH (1). In the program a simulation is included of the dynamic exchange of radionuclides in the biosphere. That is done by the application of compartment theory.

The reliability of the calculated doses depends on the structure of the model, exposure pathways, approximations and uncertainties in the data used. When there has been a range in the data used, the policy has been to use those values which give a higher dose burden.

To decide how strongly uncertainties in data will affect resulting doses, a variation analysis concerning important parameters in BIOPATH has been performed. This has been done for dominant nuclides from the point of view of the dose burden, and as a complement to earlier analyses.

2. PURPOSE OF THIS STUDY

The aim of this study has been first of all to study what influence variations in important parameters will have on the results of the dose calculations for dominant nuclides in the disposal of high level waste according to the KBS concept (4).The project also aims to make proposals for forthcoming efforts and developments to improve the basis for such calculations.

3. ASSUMPTIONS

3.1 Nuclides and source strengths

The study has been restricted to dominant nuclides as indicated by earlier calculations. However, new data have become available for the uptake of certain nuclides, such as neptunium and protactinium, in the human body. This has resulted increased interest in these nuclides. The following nuclides and decay chains are therefore supposed significant:

I-129
Cs-135
Ra-226
Pa-231
Np-237
Th-230/Ra-226
U-234/Ra-226
U-235/Pa-231

The inflow of activity to the recipient area is taken to be 10^{-6} Ci annum for 10^{6} years. For longlived nuclides with low mobility in soil the maximum radiation doses will occur very late, or equilibrium will perhaps not quite be reached in soil. The doses might then be a little higher than the radiation doses from the calculated release pattern, if the actual releases last for a shorter time.

3.2 Dose factors

In this study the most recent values published by ICRP for weighted committed dose equivalent per unit activity intake have been used (5). For those nuclides not listed in ICRP-30 values have been taken from NRPB (6). In Table 1 the dose factors used previously are compared with those used in this study.

3.3 Release alternative

The inland alternative has been studied, that means that the recipient for the groundwater borne nuclides is a lake. The study has been concentrated to the regional doses, as they are directly dependent on the ecological processes that are described by the transfer coefficients used. The doses to the critical group via a well are mainly dependent on the initial dilution volume and the amount of water used for irrigation. In that case only the change of irrigation rate has been studied.

3.4 Reference values

In Figure 1 the model system which has been used is shown. The variation analysis and the comparisons in this report are based on reference values. These reference values have been obtained from the set of transfer, concentration and distribution coefficients used in (3) and continuous leakage rates of 10^{-6} Ci annum for 10^{6} years. The diet and living habits are the same as in (3).

4. VARIATION OF TRANSFER COEFFICIENTS

The transfer coefficients which are of the greatest importance for the dose calculation, and therefore are of interest to study, are those related to the following processes:

- surface water → Baltic Sea
- surface water → soil
- turnover of soil and ground water
- soil → surface water
- water → sediment
- soil → ground water

These have been chosen as they are important for the exposure pathways which dominate the intake of activity to man. Previous discussion of the models (3) accuracy has also been used as a tool to estimate the important process.

4.1 Turnover of water in the lake

The time for the turnover of water in the lake is taken to be 0.25 - 0.3 and 1 - 2 years for the simulation of lower and higher residence times respectively for the nuclides in the reservoir. The reference value is 0.5 year. In (7) a more careful analysis of the turnover of water in Finnsjön has resulted in a residence time of 0.6 year.

4.2 Irrigation

Use of irrigation in farming depends on a number of factors such as type of harvest, species of soil and climate. Garden products, pasture and potatoes are considered to be sufficiently lucrative to irrigate. The mean value which necessitates a contribution by irrigation, if the year is dry, has been estimated to be about 100 - 150 mm (10). At present about 5 percent of farming land in Sweden is irrigated but an increase to about 10 % has been considered be lucrative (10). The reference value for transfer from the lake to the adjacent farming land is 0.02 $year^{-1}$ based upon 10 % of the land within the drainage area of the lake being irrigated once a year with 35 mm of water.

If the Finnsjö area is concerned, the value used in the calculations is considered to be too high because the area consists mainly of nonarable land.

However, if the recipient is situated in typical farming land with the present intensity of irrigation in Sweden the reference value could be considered to be relevant. Increased irrigation (to 10 % of farming land) in the future would result in a three times higher transfer from the lake to the adjacent farming land. That means a probable range for the transfer of 0.01 - 0.06 $year^{-1}$.

4.3 Turnover of soil and ground water and infiltration

As the turnover of ground water and the infiltration in the soil are connected processes, they are discussed together in this section. To investigate the importance of the residence time in the ground water reservoir the transfers from there have been altered by a factor five up and down to simulate higher and lower turnover times respectively for the different nuclides.

Infiltration of water from the soil reservoir to the water reservoir has in the reference calculations been supposed to be 0.1 year. Multiplication with the k_d factors for the different nuclides gives the total transfer rates.

Another way of treating the important transfer to the ground water from the soil is the following: a so-called sponge model is used for the water blance, which means that the zone of soil water must be saturated before any addition to the ground water can be expected; nor is there surface water run-off. Then if a water blance is made for the system the following relationship is valid

$$Q = P - E$$

where

Q = runoff
P = precipitation
E = evapotranspiration

In this case the potential formation of groundwater in a year is about the same as the runoff during the year. By "potential ground water formation" is meant the maximal part of the precipitation that can possibly form groundwater.

In the following table the mean values (in mm) of the above mentioned parameters (9) are summarized for different areas in Sweden.

Area	Q	E	P
Halland	440	545	985
Gotland	175	485	660
Södermanland	205	475	680
Västmanland	305	485	790
Uppland	215	470	690
Norther Jämtland	750	170	920
Norther Lappland, except the mountain region	350	245	595
Norther Lappland, including the mountain region	685	190	825

Different types of soils have different field capacities, that is the capacity to retain water after drainage. Typical values for different soils are shown in the table below.

Type of soil	Field capacity mm
Moraine	65 - 140
Sand	40
Sand with gravel	15 - 25
Fine sand	120 - 130
Sandy fine gravel	10 - 20
Fine gravel	2 - 4
Gravel	2
Peat	200

The variations are considerable. Farming land is the main part of clay soils, such as moraine clay. That should in Uppland, for example (where Finnsjön is situated) imply a transfer rate of 2 - 3 $year^{-1}$. On the other hand the derived value 2 - 3 $year^{-1}$, is valid for the superficial ground water, and our reference value is a mean value including both the superficial and the deeper ground water. The behavior of water in soil and ground is a very complicated process and strongly dependen on the conditions in the area. That change can also be seen as a variation in the volume of water in the ground.

4.4 Sedimentation

If there were intervals in the transfer to sediment from the water represented in (3), the upper and/or the lower value have been considered in the variation analysis.

Otherwise the reference values have been altered by a factor of five or for some nuclides they have been completely changed in order to investigate the importance of their variation.

5. RESULTS OF THE VARIATION OF TRANSFER COEFFICIENTS

The resulting doses when the transfer coefficients are varied are shown in Tables 4 - 11. Figure 2 is a graphic summary in a lin-log plot of almost all the variations of transfer coefficients considered in this study. The relative changes of the doses compared to the reference case for the nuclides studied are graphicly presented in detail below, where short explanations over the results are given as well.

5.1 Iodine-129

In the reference case the exposure to man is dominated by the consumption of meat (57 %), milk (22 %), and fish (20 %).

The turnover of water in the lake

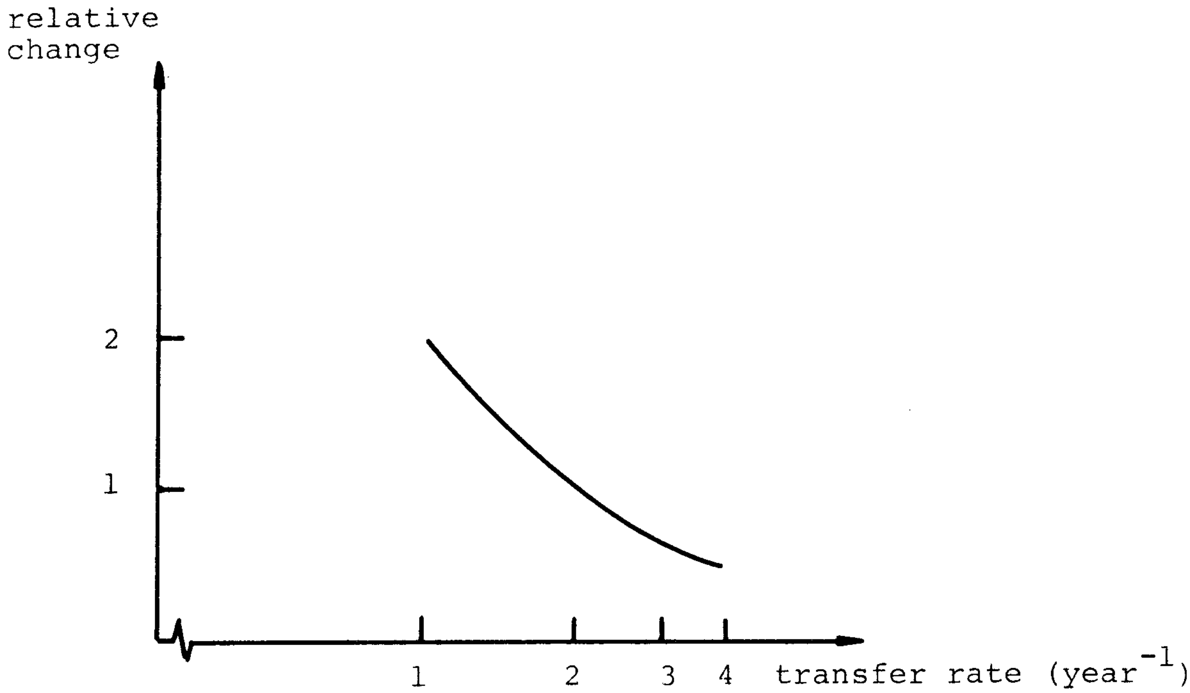

Figure 3

The relative changes of the dose from iodine-129 when the turnover rate of water in the lake is varied. The reference value is 2 year^{-1}.

The doses from the terrestrial pathways, which are the dominating ones, are received by cattle consuming water. Therefore the doses are inversely proportional to the turnover time of water in the lake.

Irrigation

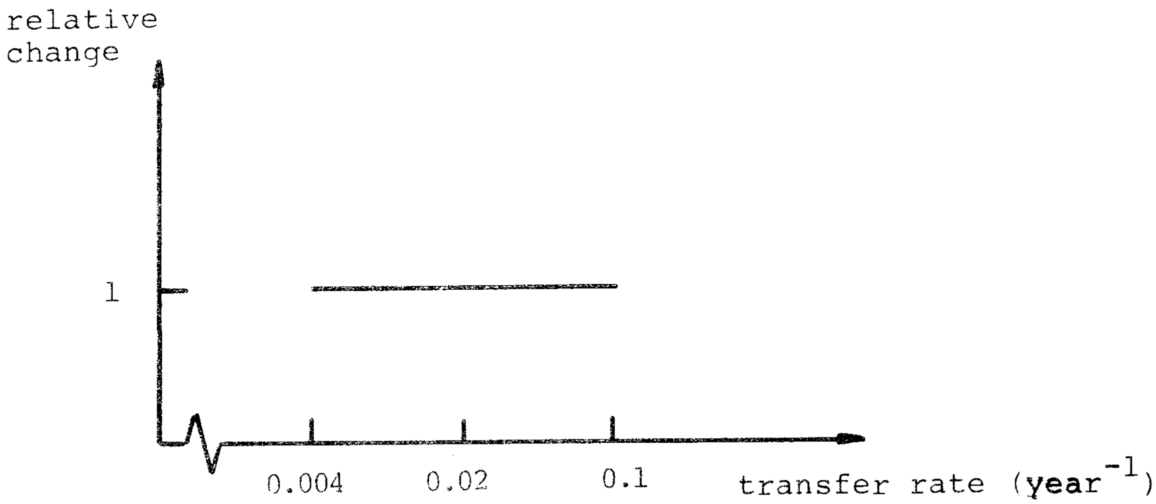

Figure 4

The relative changes of the dose from iodine-129 when the irrigation rate is varied. The reference value is 0.02 year^{-1}.

Changing the rate of irrigation does not affect the results at all as the contamination level of the nuclide in the lake water is the dominant factor for the doses.

Soil and groundwater turnover

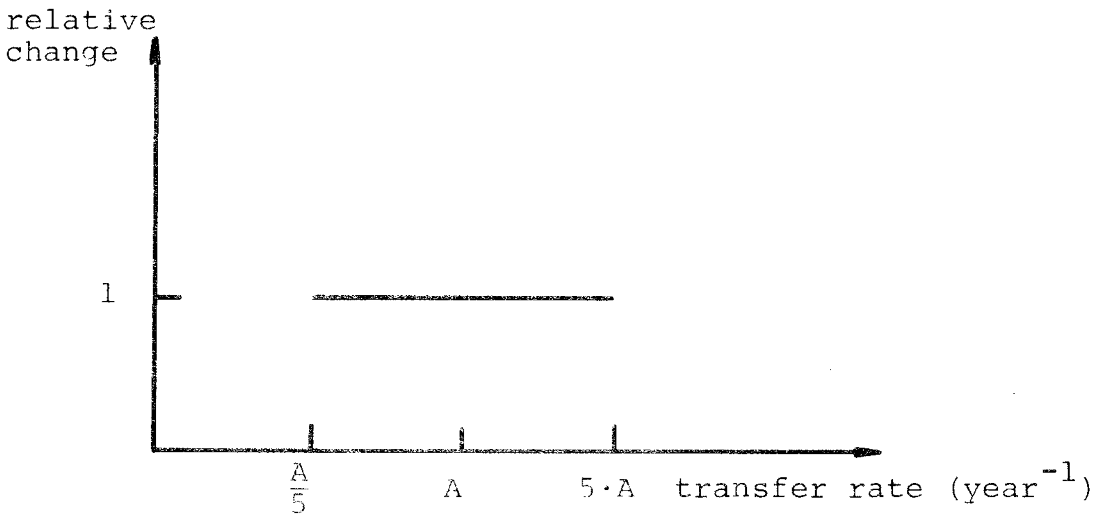

Figure 5

The relative changes of the dose from iodine-129 when the turnover time of the nuclide in the soil and groundwater is varied. The reference values A are

groundwater → surface water 0.2 year^{-1}
groundwater → soil 0.1 year^{-1}

As for the case of varying transfer based upon irrigation, the influence of the resulting dose is totally negligible

5.2 Cesium-135

The radiation dose from cesium is strongly dominated by fish consumption. In the reference case that exposure pathway constitutes up to about 91 % of the total dose, followed by the exposure from drinking water.

The turnover of water in the lake

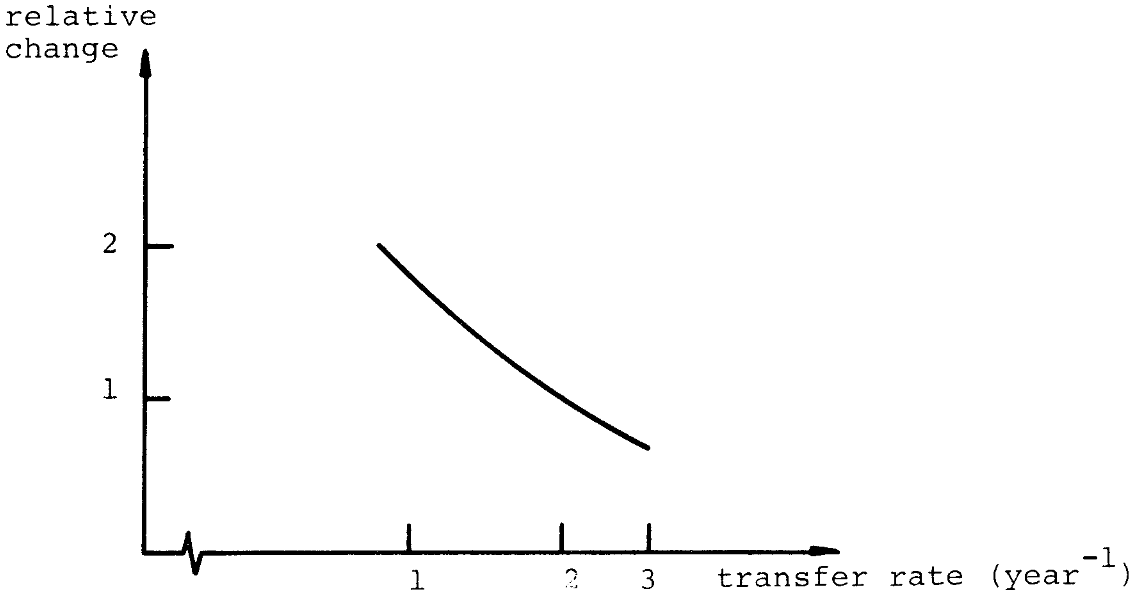

Figure 6

The relative changes of the dose from cesium-135 when the turnover rate of water in the lake is varied. The reference value is 2 year^{-1}.

As the exposure pathway due to fish consumption is so dominating, the doses are almost inversely proportional to the change of turnover time of the water in the lake. The turnover time determines the concentration of the activity in the lake, and accordingly the uptake in fish.

Irrigation

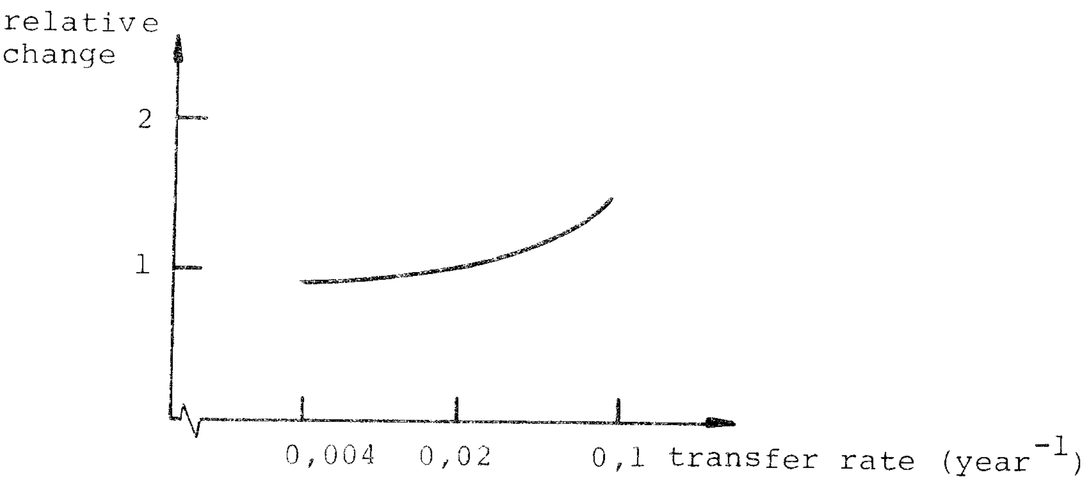

Figure 7

The relative changes of the dose from cesium-135 when different intensities of irrigation from the lake to the surrounding farming land are used. The reference value is 0.02 year^{-1}.

Increased irrigation causes higher concentration levels in the soil and ground water reservoirs. That implies that the exposure by drinking water will increase correspondingly. But as the exposure due to the consumption of fish is so dominant the total radiation dose is only slightly affected.

Sedimentation

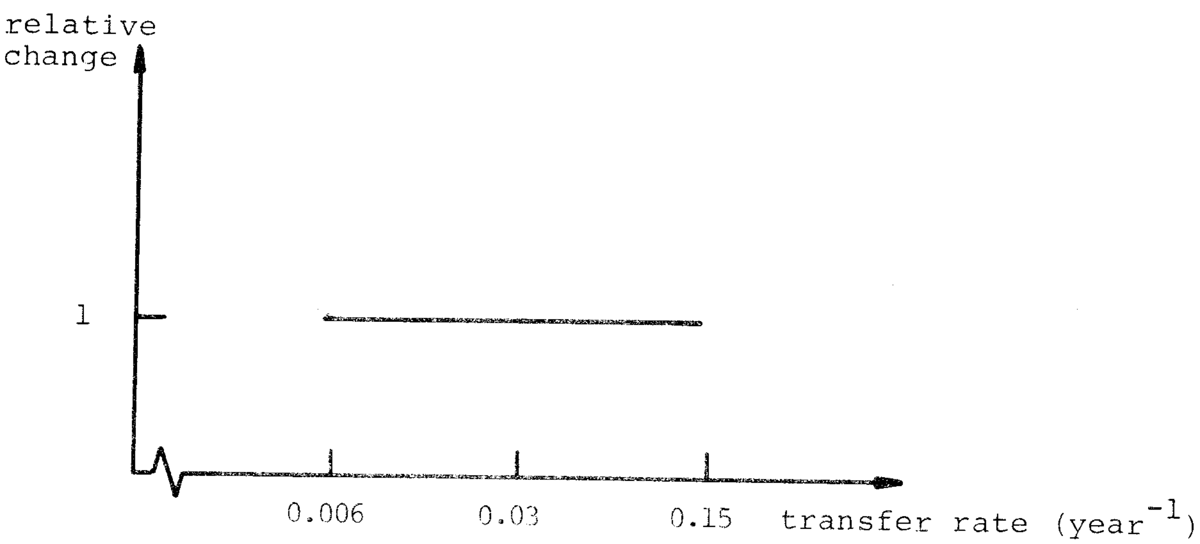

Figure 8

The relative changes of the dose from cesium-135 when different sedimentation rates in the lake are used. The reference value is 0.03 year^{-1}.

The importance of the transfer of cesium to the sediments from the water reservoir was studied by decreasing and increasing the reference value by a factor five. These variations do not affect the results because the turnover of water in the lake determines the activity level in the water for cesium, which is known to be fairly soluble. Here can be mentioned that a special study of the cesium-137 turnover in a lake (13) indicated that a fraction of 0.37 was sedimenting. But for that particular lake the turnover of the water was low. Naturally the concentration levels in the sediment will change according to different sedimentation rates, and that has significance if the food chain over bottom living worms to fish is considered. Further it is of importance for the possible drying up of the lake in the future and the use of the sediments as farming land.

5.3 Radium-226

In the reference case the maximum regional dose is dominated by the exposure through drinking water 64 %. The exposure from the consumption of fish and milk contribute 33 % and 2 % respectively.

The turnover of water in the lake

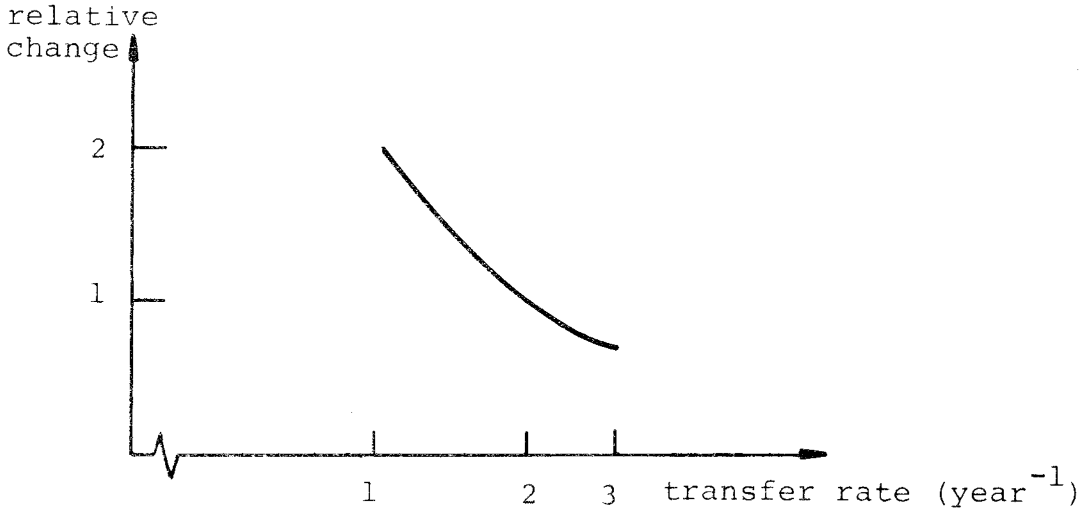

Figure 9

The relative changes of the dose from radium-226 when different turnover rates of water in the lake are used. The reference value is 2 year^{-1}.

As the activity level in the lake is decisive for the radiation dose from radium-226, change in the turnover time for the water in the lake gives corresponding changes in the dose.

Irrigation

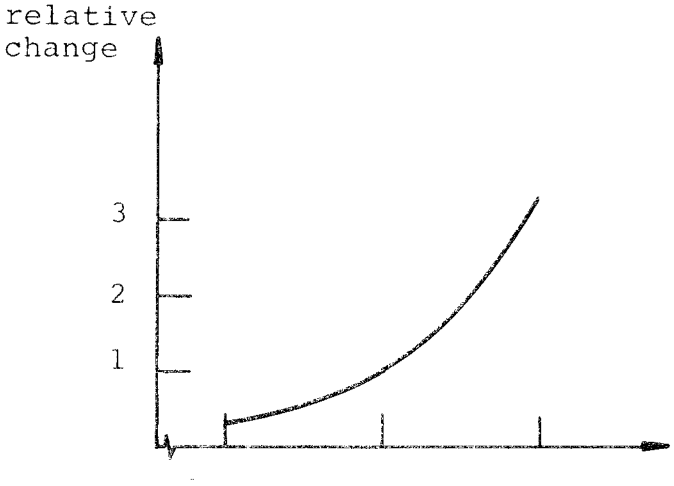

Figure 10

The relative changes of the dose from radium-226 when different irrigation intensities from the lake to the surrounding farming land are used. The reference value is 0.02 year^{-1}.

As the changes of the irrigation only influence that fraction of the total dose which is received by the activity in the groundwater, the changes in the dose is not directly proportional to the change in irrigation.

Soil and ground water turnover

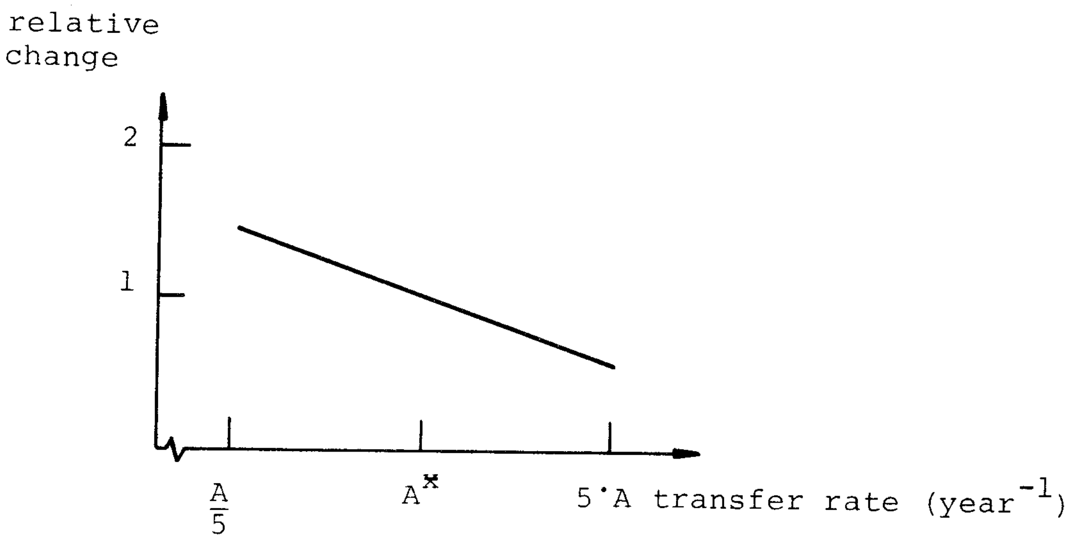

Figure 11

The relative changes of the dose from radium-226 when different rates for the turnover of the nuclide in the groundwater are used. The reference values (A) are:

ground water → soil = $2 \cdot 10^{-4}$ year^{-1}
ground water → surface water = $4 \cdot 10^{-4}$ year^{-1}

The change of turnover time for soil and groundwater gives changes in the fraction of the dose received through the consumption of ground water. However, the physical half-life of radium compensates the build-up of activity which otherwise would be expected when the residence time gets longer.

Soil to ground water

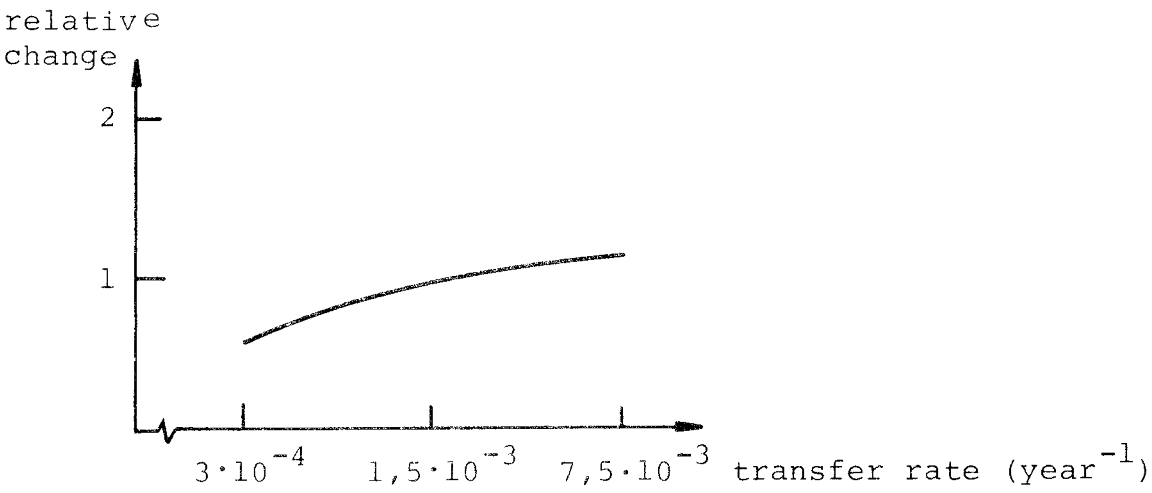

Figure 12

The relative changes of the dose from radium-226 when different infiltration rates in the regional soil reservoir are used. The reference value is $1.5 \cdot 10^{-3}$ $year^{-1}$.

When the rate of infiltration to the soil reservoir is decreased by using a lower transfer coefficient, and the physical half-life is relatively short, a smaller amount of activity is brought to the groundwater reservoir. The activity level in the soil reservoir will be increased, but as the dominant terrestrial exposure pathways (milk, meat) depend on the cattle intake of activity via drinking water, taken from the lake that does not affect the dose. More rapid transport to the ground water reservoir will give an increment of the fraction of the dose received via groundwater.

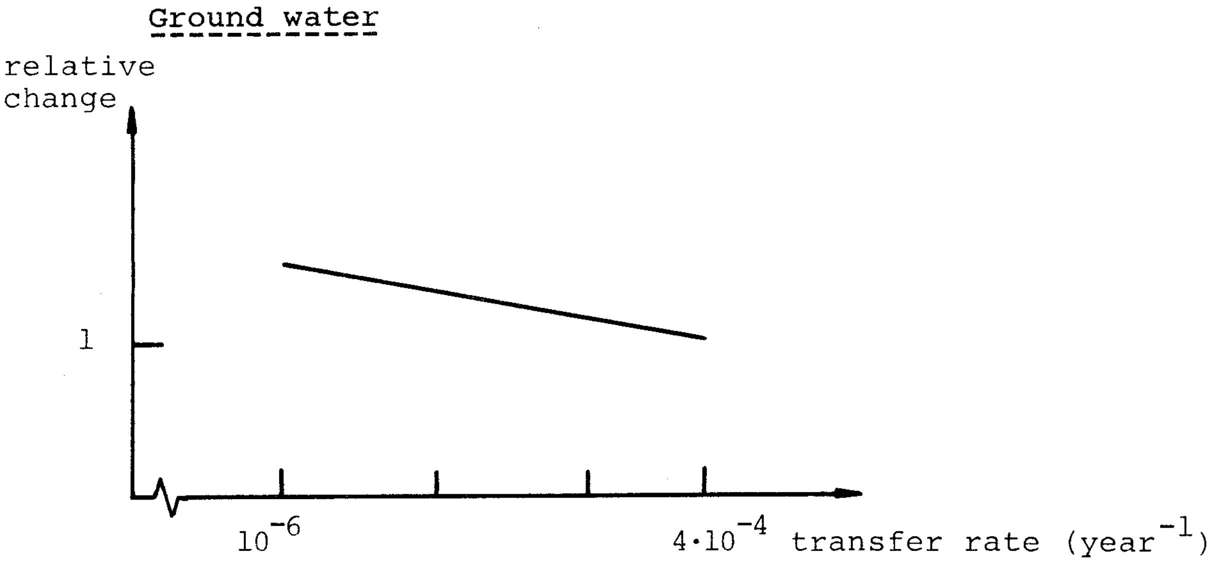

Figure 13
The relatice change of the dose from radium-226 when the transfer from the groundwater to the surfacewater is $1.0 \cdot 10^{-6}$ $year^{-1}$. The reference value is $4 \cdot 10^{-4}$ $year^{-1}$.

The transfer rate from the ground water to the lake, has in the reference case been taken to be $4 \cdot 10^{-4}$ $year^{-1}$. A much lower value $1 \cdot 10^{-6}$ $year^{-1}$ is quoted in (7). When the lower value is used the dose will increase by a factor 1.5, depending on the exposure via drinking water. The change is relatively small compared to the difference in transfer rates, and that depends on the physical half-life, that is relatively short and compensates the build-up in the reservoir.

5.4 Protactinium-231

In the reference case for protactinium the regional dose is almost completely dominated by the drinking water (96 %), followed by exposure from the consumption of fish (4 %).

The turnover of water in the lake

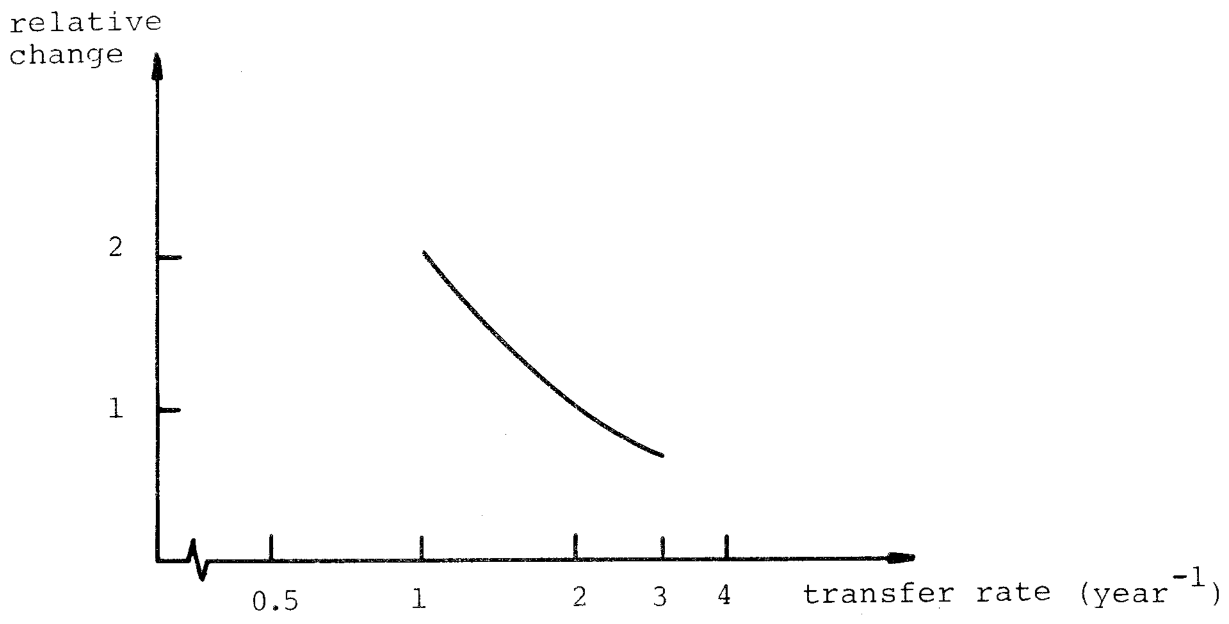

Figure 14

The relative changes of the dose from protactinium-231 when the turnover rates of water in lake are varied. The reference value is 2 year^{-1}.

Changes in the turnover time give corresponding changes in the dose.

Irrigation

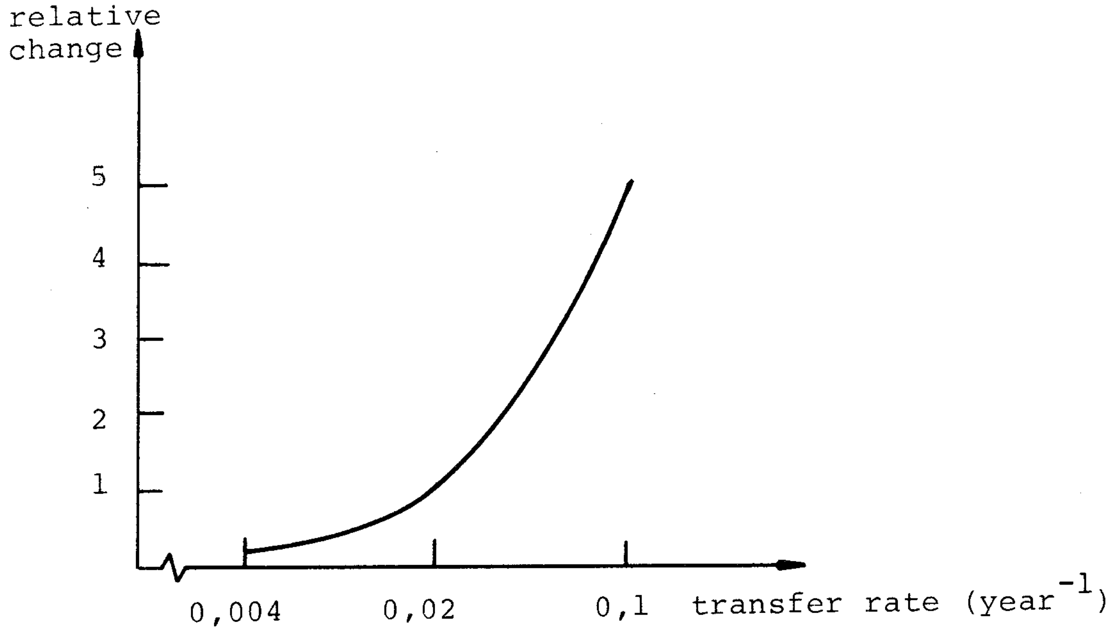

Figure 15

The relative changes of the dose from protactinium-231 when different intensities of irrigation from the lake are used. The reference value is 0.02 year^{-1}.

As the dose is so strongly dominated by the exposure via drinking water, the changes are almost directly proportional.

Soil and ground water turnover

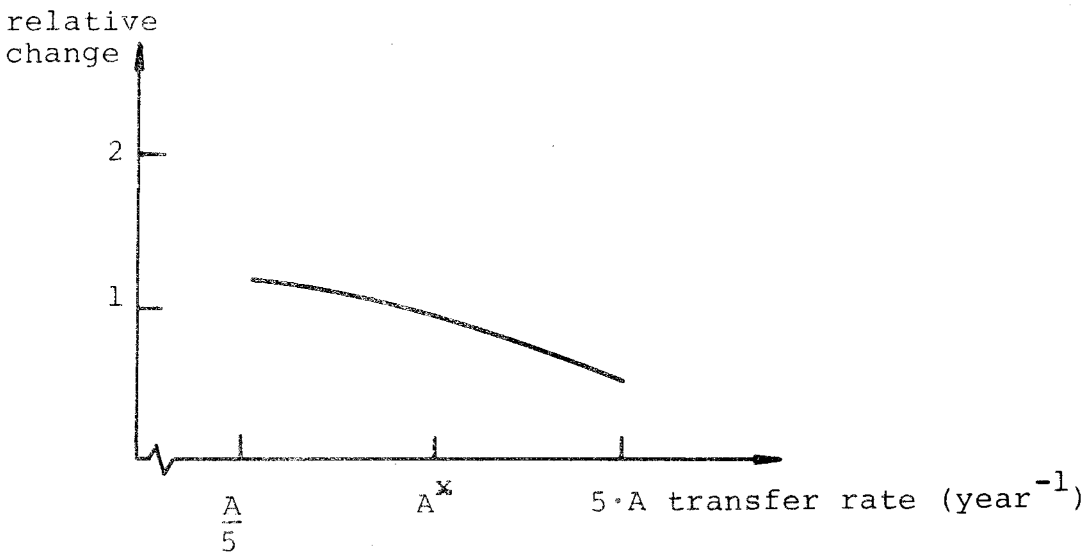

Figure 16

The relative changes of the dose from protactinium-231 when different rates for the turnover of the nuclide in soil and groundwater are used.
The reference values (A) are:
ground water → soil = $6 \cdot 10^{-6}$ year^{-1}
ground water → surface water = $1.2 \cdot 10^{-6}$ year^{-1}

The increment and decrement of the turnover time for ground water by a factor five from the reference value has rather little influence on the dose. The reference value based upon the retention factor is so low that in the actual range the physical half-life is of major importance for determining the activity level in the groundwater reservoir.

Soil → ground water

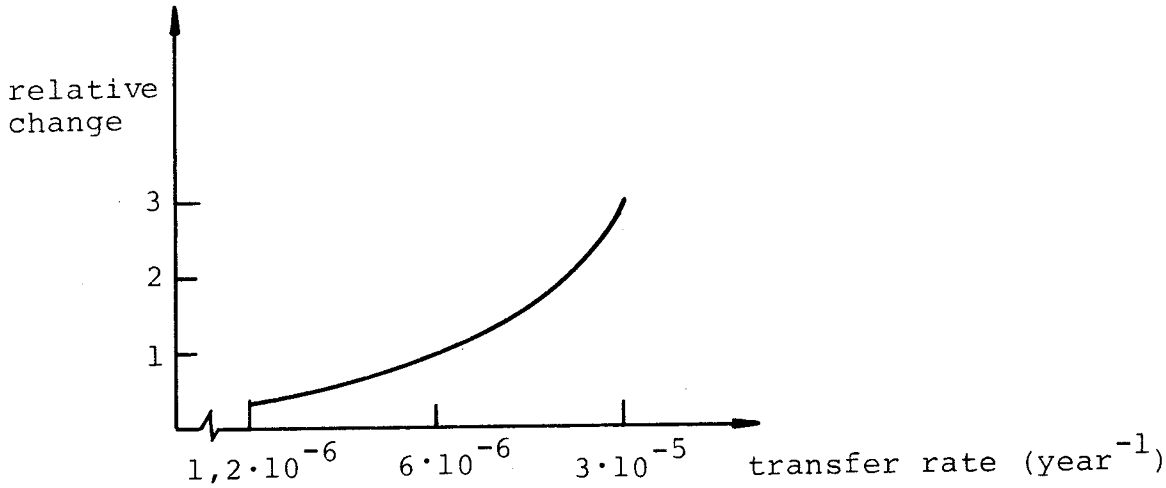

Figure 17

The relative changes of the dose from protactinium-231 when different infiltration rates in the soil reservoir are used. The reference value is $6 \cdot 10^{-6}$ $year^{-1}$.

With increased retention in soil the doses will decrease as, less of the activity before decay will be brought to the groundwater reservoir which is dominant from the point of wiew of exposure. If the infiltration is faster than in the reference case the dose will increase but not be directly proportional, dependent on the physical half-life.

Water to sediment

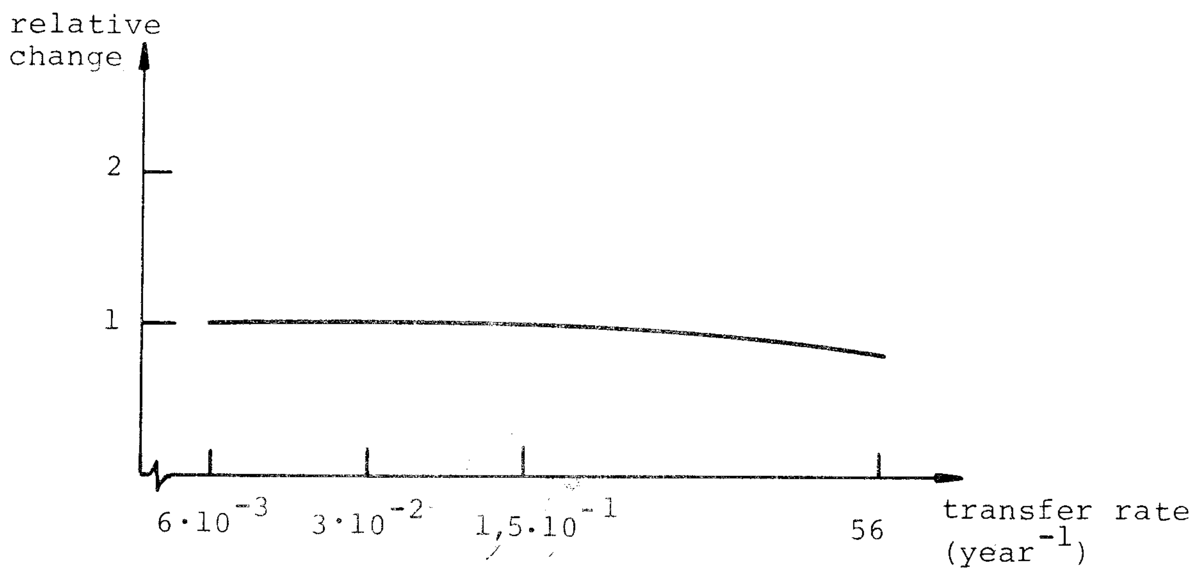

Figure 18

The relative changes of the dose from protactinium-231 when the sedimentation rate in the lake is varied. The reference value is 0.03 $year^{-1}$.

The importance of the sedimentation has been studied by varying the reference value by a factor five and also by using the high transfer coefficient which is applicable in the model for the different sedimentation rates of the particles. That value is 56 $year^{-1}$. As can be seen from figure 18 the influence on the doses is very small. As mentioned earlier, with low sedimentation rates the concentration of activity in the lake is determined by the turnover of water in the lake. When the transfer to the sediment is high there is another important parameter, namely the leakage from the sediment back to the water. For protactinium this transfer is assumed to be 10^{-3} $year^{-1}$. When using the higher sedimentation rate there will be a considerable leakage back, and the equilibrium will be reached later, but at a level not much lower than in the reference case. Therefore the doses will be slightly changed.

5.5 Neptunium-237

Exposure from neptunium is dominated by drinking water (56 %) and the consumption of fish (43 %) in the reference case.

The turnover time of the water in the lake

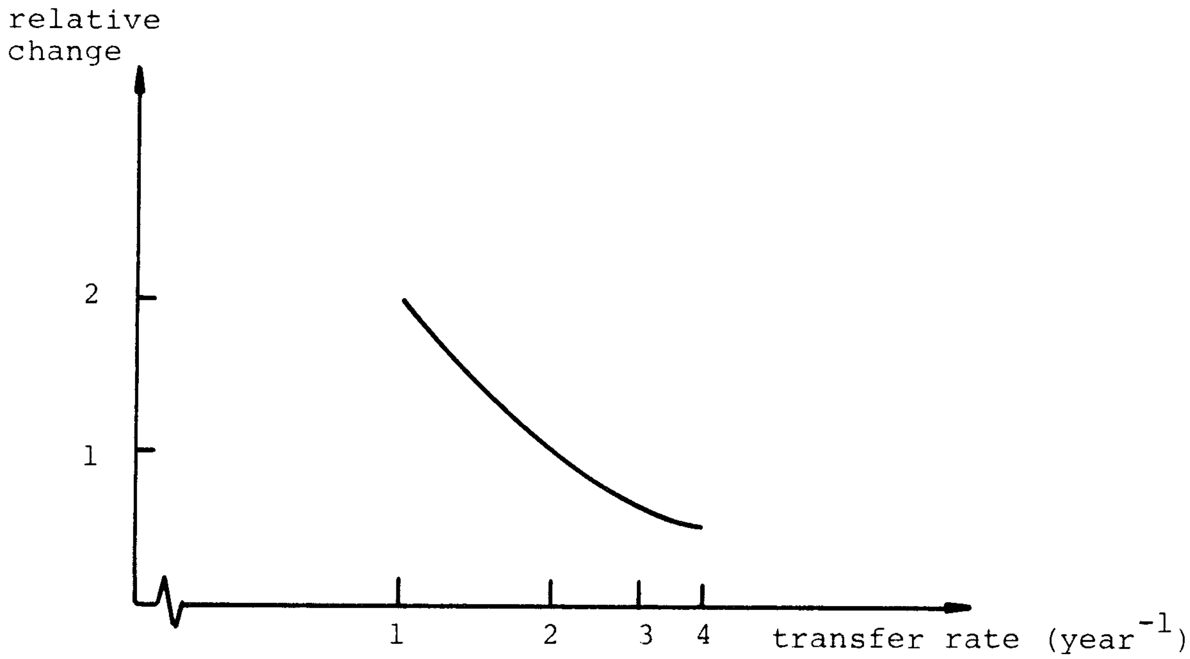

Figure 19

The relative changes of the dose from neptunium-237 when different turnover rates of the water in the lake are used. The reference value is 2 year^{-1}.

The dose is inversely proportional to the turnover time as the drinking water and the consumption of fish dominate the exposure.

Irrigation

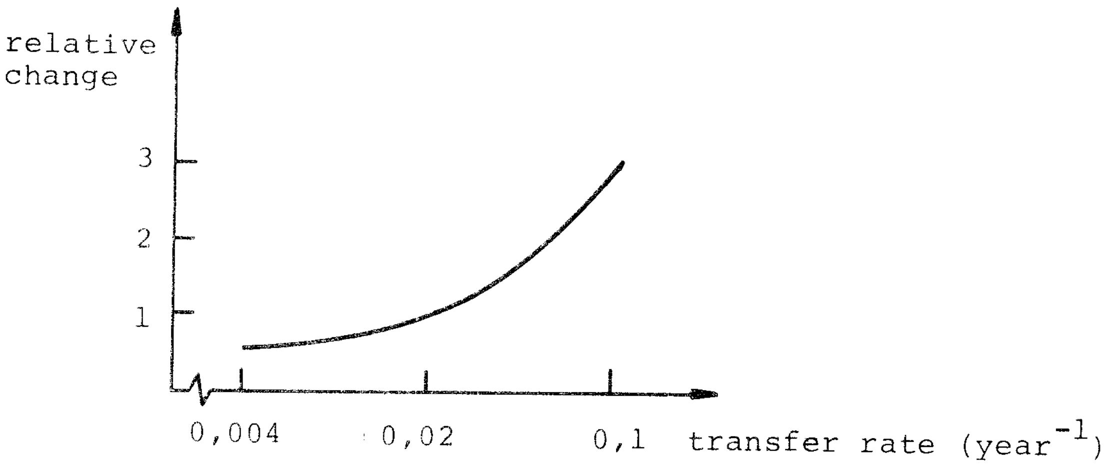

Figure 20

The relative changes of the dose from neptunium-237 when different irrigation intensities from the lake are used. The reference value is 0.02 $year^{-1}$.

As the changes of the irrigation rates only influence that fraction of the total dose which is received by the activity in the groundwater, the changes in the dose is not directly proportional to the change in irrigation.

Soil and ground water turnover

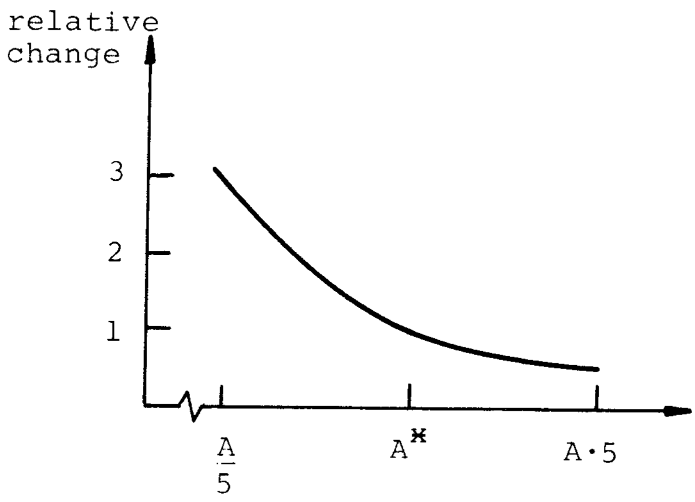

Figure 21

The relative changes of the dose from neptunium-237 when the turnover time of the nuclide in soil and groundwater is varied. The reference values (A) are:
ground water → soil = $1 \cdot 10^{-3}$ $year^{-1}$
ground water → surface water = $2 \cdot 10^{-3}$ $year^{-1}$

As the turnover of the water in the ground only affects that part of the dose which is received through the consumption of drinking water the changes of dose will be as in Fig 21.

5.6 Thorium-230/Radium-226

This decay chain has been studied by contemporaneous changes of the different transfer coefficients. In the reference case the exposure from thorium is dominated almost entirely by drinking water (99 %).

The consumption of fish contributes with 1 %. For radium the dose is dominated by drinking water (67 %), consumption of fish (30 %) and milk (2 %).

The turnover of water in the lake

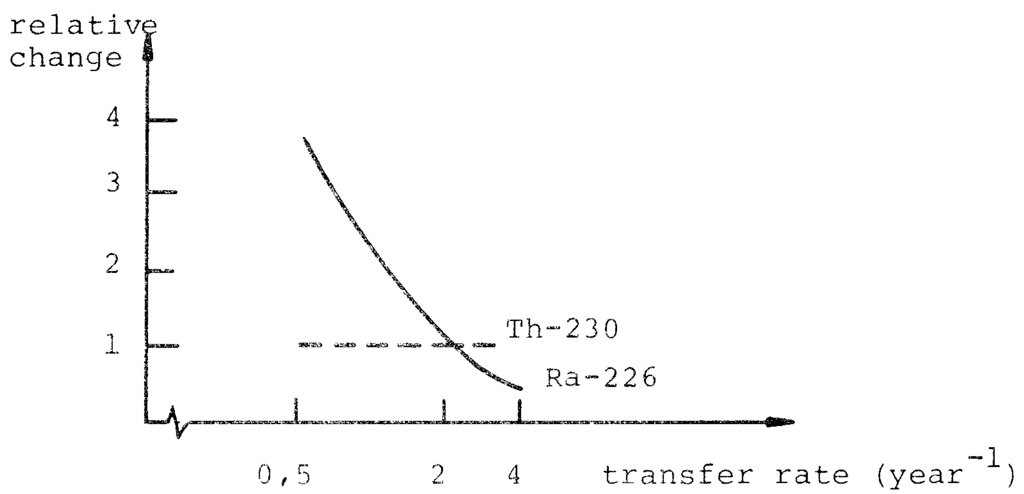

Figure 22

The relative changes of the doses from thorium-230 and its daughter nuclide radium-226 when different turnover rates of the water in the lake are used. The reference value is 2 year^{-1}.

There is no change in the dose from thorium when relatively high or low turnover times are used for the water in the lake. This depends on the large transfer to the sediment and the very low leakage back to the water reservoir, which determine the level of activity in the lake for thorium. The concentration of radium in the lake is, however, determined by the residence time of the water in the lake and correspondingly the doses are almost proportional to the changes in the turnover of the water.

Irrigation

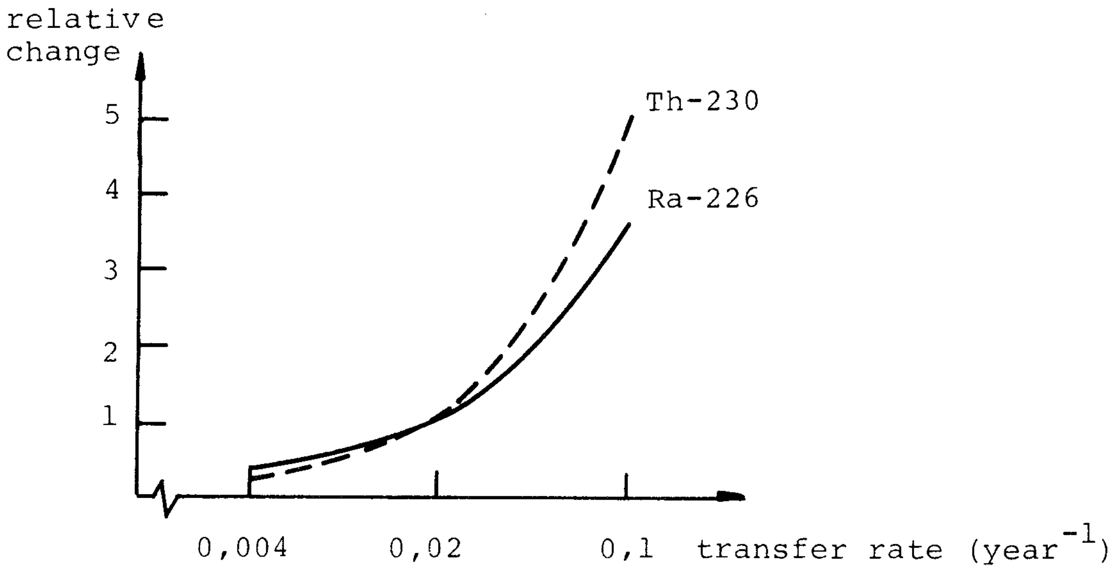

Figure 23

The relative changes of the doses from thorium-230 and its daughter nuclide radium-226 when the rate of irrigation from the lake to the surrounding farming land is varied. The reference value is 0.02 year^{-1}.

As almost the entire dose from thorium originates from drinking water, the doses are directly proportional to the rate of irrigation. For radium only the dose received from drinking water is influenced which is why the dose changes are smaller for that nuclide.

Soil and ground water turnover

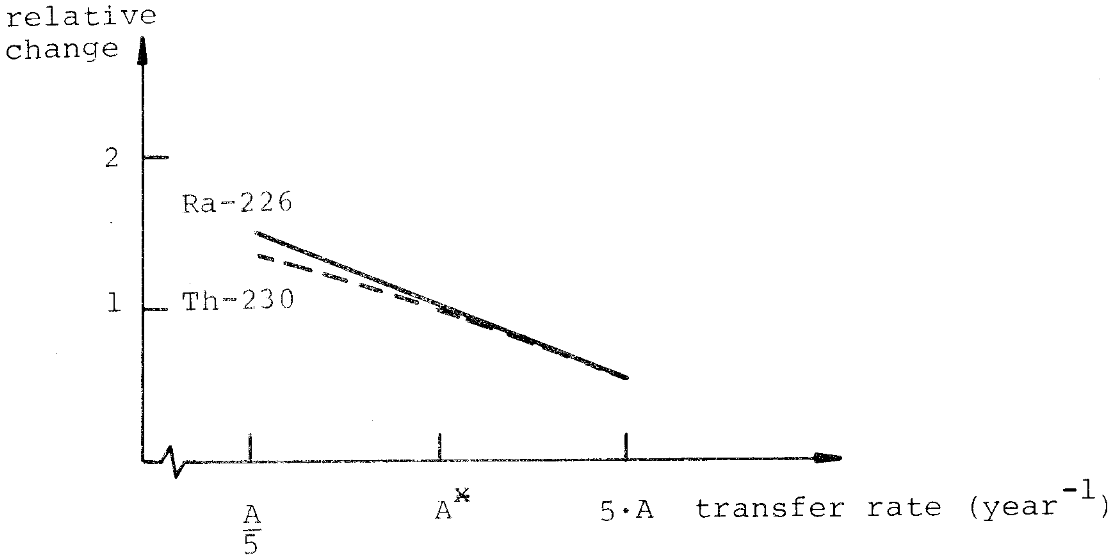

Figure 24

The relative changes of the doses from thorium-230 and its daughter nuclide radium-226 when the turnover rate of the the nuclides in the soil and groundwater is varied. The reference values (A) in year^{-1} are:

	Th-230	Ra-226
ground water → soil	$2\cdot10^{-6}$	$2\cdot10^{-4}$
ground water → surface water	$4\cdot10^{-6}$	$4\cdot10^{-4}$

For both nuclides the doses will be halved if the turnover time is increased by a factor five. The relatively small influence depends on the physical half-life which is fairly short compared to the turnover times in the reservoir for the nuclides.

For longer residence times the doses will increase a little. The small change depends again on the physical half-life of the nuclides.

5.7 Uranium-234/Radium-226

The decay chain U-234 → Th-230 → Ra-226 has been studied by the simplified decay chain U-234 → Ra-226.

Contemporaneous changes of the different transfers have been carried out. Uranium causes doses, mainly through the drinking water, (62 %), and consumption of fish (38 %). For the daughter product radium the dominating exposure pathway is drinking water (100 %).

The turnover of water in the lake

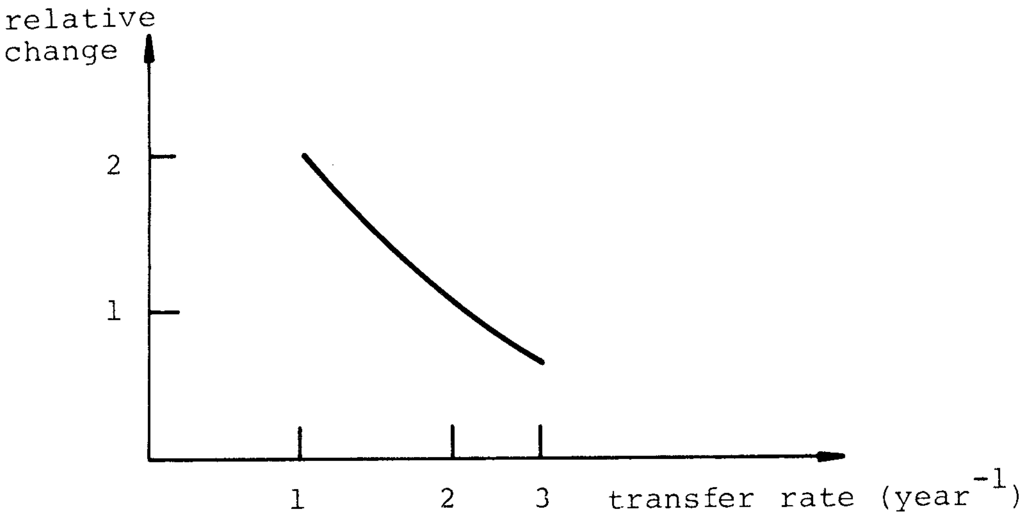

Figure 25

The relative changes of the dose from uranium-234 and its daughter nuclide radium-226 when the turnover rate of the water in the lake is varied. The reference value is 2 year^{-1}.

For both nuclides the curve in figure 24 describes the changes in dose when the outflow from the lake is altered. The proportionality depends on the dominating exposure paths: the consumption of water and fish. These are directly proportional to the concentration in the lake, which for these nuclides is determined by the turnover of the water in the lake.

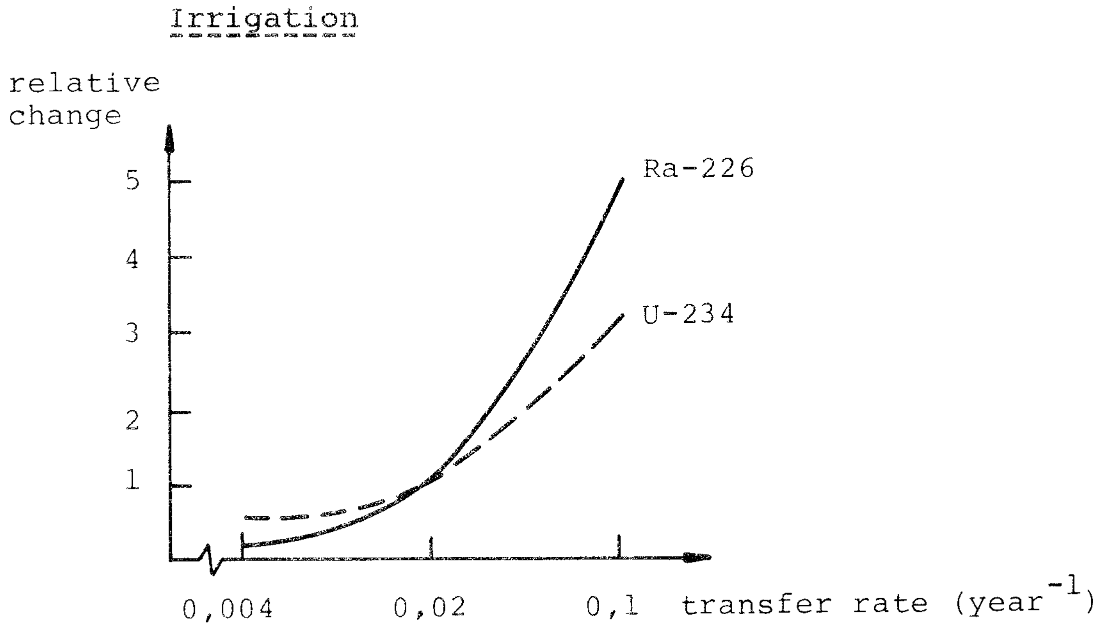

Figure 26

The relative changes of the dose from uranium-234 and its daughter nuclide radium-226 when the rate of irrigation in the regional zone is varied. Reference value is 0.02 year^{-1}.

As the irrigation influences the contamination of the groundwater directly, the fraction of the dose which is received from drinking water is increased proportionally. For radium it is the dominating exposure path, so the doses are directly proportional to the turnover of the water in the lake.

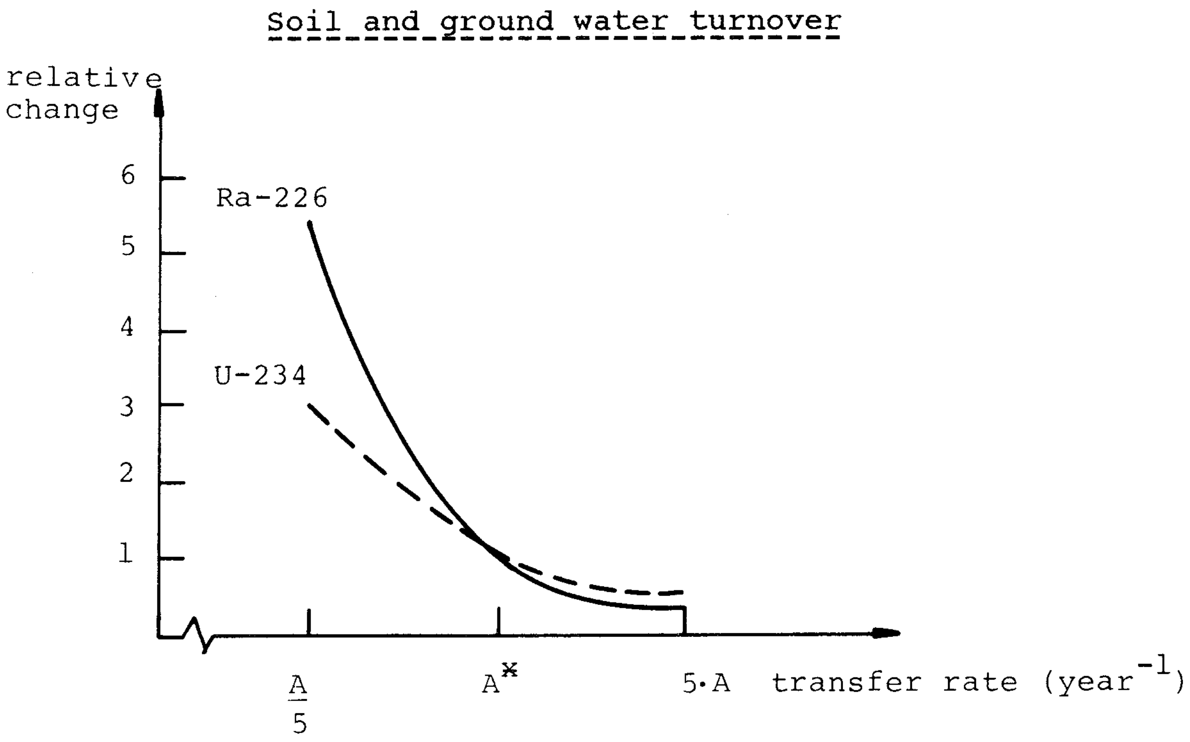

Figure 27

The relative changes of the dose from uranium-234 and its daughter product radium-226 when the turnover of the nuclides in soil and groundwater is varied. The reference values (A) are, in $year^{-1}$:

	U-234	Ra-226
ground water → soil	$1 \cdot 10^{-4}$	$2 \cdot 10^{-4}$
ground water → surface water	$1 \cdot 10^{-3}$	$4 \cdot 10^{-4}$

The dose originating from the groundwater for uranium will increase proportionally with the change of the turnover time. For radium the importance is quite clear as 100 % of the dose is obtained from the groundwater and the decreament of the turnover time for uranium-234 gives corresponding increament of the activity level in the ground water reservoir. That implies an increased dose up to about 5.4 times the reference value for radium-226.

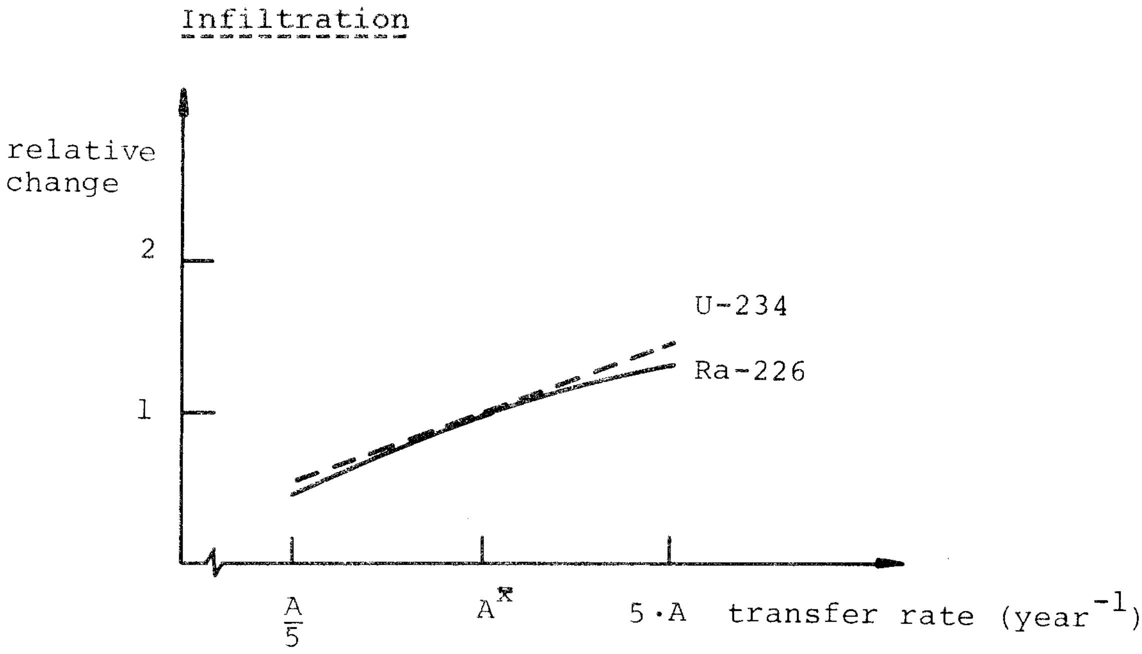

Figure 28

The relative changes of the doses from uranium-234 and its daughter product radium-226 when the rate of the infiltration in the soil reservoir is varied. The reference values (A) are $1 \cdot 10^{-3}$ year^{-1} and $4.5 \cdot 10^{-3}$ year^{-1} for uranium and radium respectively.

When the infiltration rate in the soil is increased the doses will be higher. The change is however relatively small. The doses will decrease correspondingly if a lower mobility of the nuclides in the soil is assumed.

Sedimentation

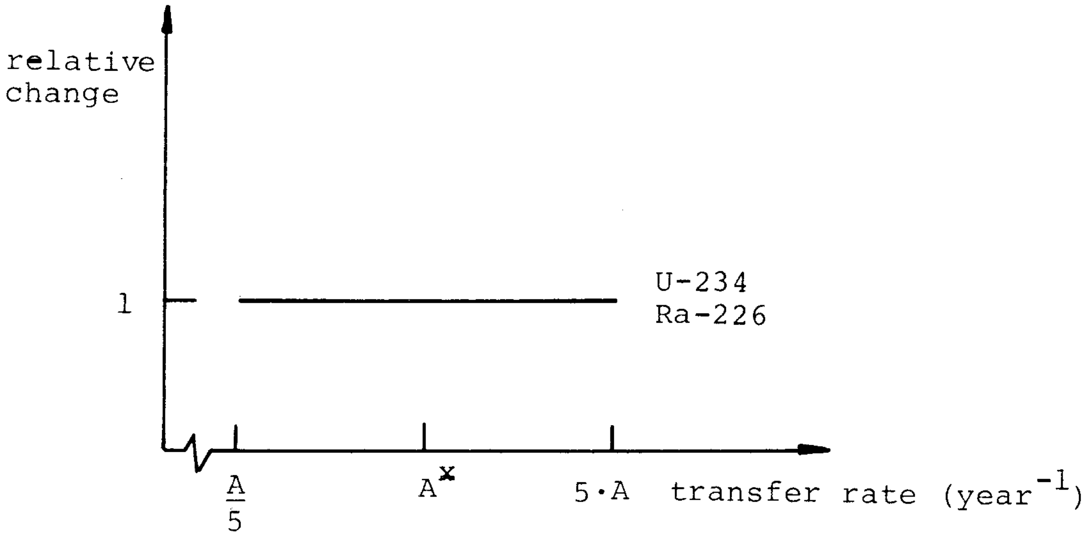

Figure 29

The relative changes of the doses from uranium-234 and its daughter product radium-226 when the transfer rate from the water to the sediment in the lake is varied. The reference values (A) are 56 $year^{-1}$ and $5 \cdot 10^{-3}$ $year^{-1}$ for uranium and radium respectively.

These changes do not affect the dose at all as the turnover of the water in the lake determines the level of the concentration for the nuclides.

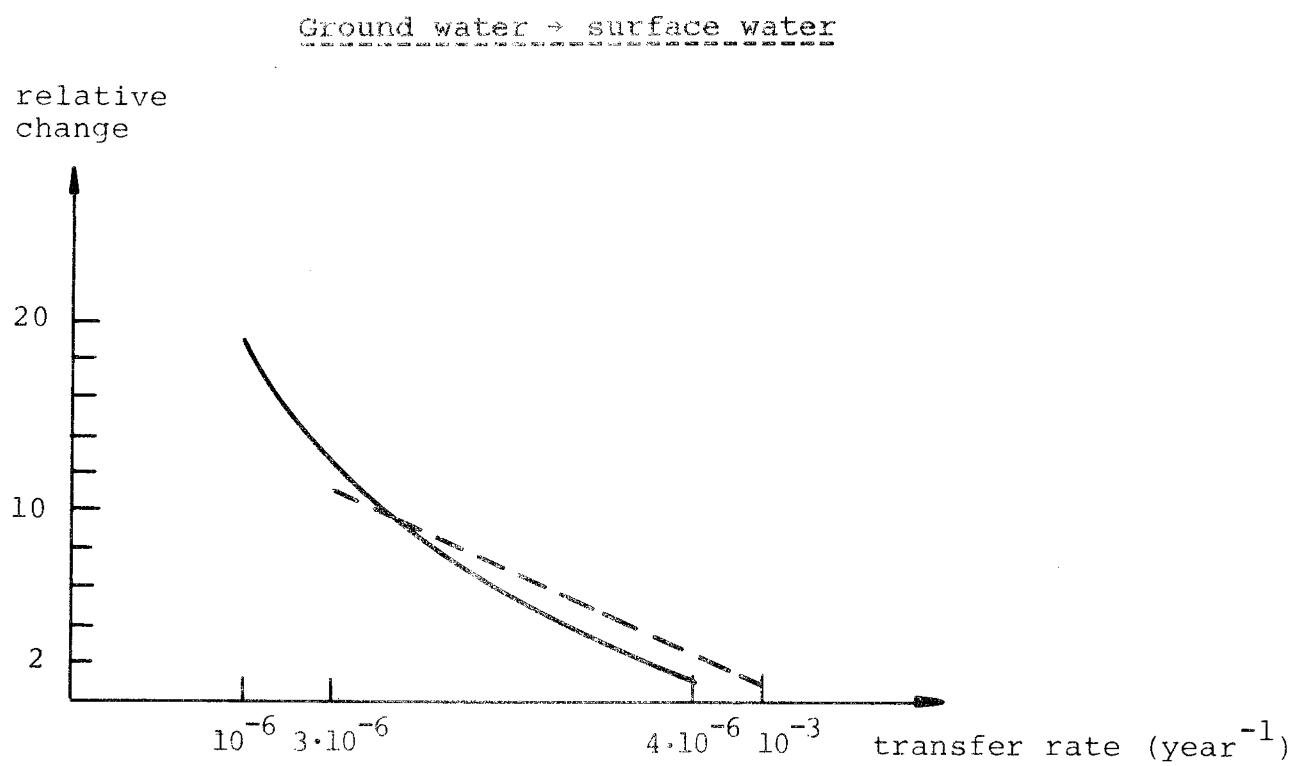

Figure 30

The relative changes of the doses for uranium-234 and radium-226 when the transfer rate from the groundwater to the surface water is changed. The reference values are 10^{-3} year^{-1} and $4 \cdot 10^{-4}$ year^{-4} for uranium-234 and radium-226 respectively.

A study of uranium and radium in soil and water has given the values $3 \cdot 10^{-6}$ year^{-1} and 10^{-6} year^{-1} (7). If those values are used the dose from uranium will increase by a factor of 11, and for radium this implies as much as an increase of 19 times the dose. This is because of the much higher concentration which can be built up in the groundwater reservoir if the transfer rates to the lake are so low.

5.8 Uranium-235/Protactinium-231

This decay chain has not been calculated in the earlier KBS-calculations, but the great importance of protactinium for the total dose, in particular as new information become available concerning the biological uptake to man has indicated the significance of studying that chain. In the reference case the dose for uranium-235 is dominated by drinking water (63 %) and the consumption of fish (38 %). For protactinium the dose is dominated by drinking water (100 %). As for the other decay chains contemperaneous change of the different transfer coefficients have been made.

The turnover of water in the lake

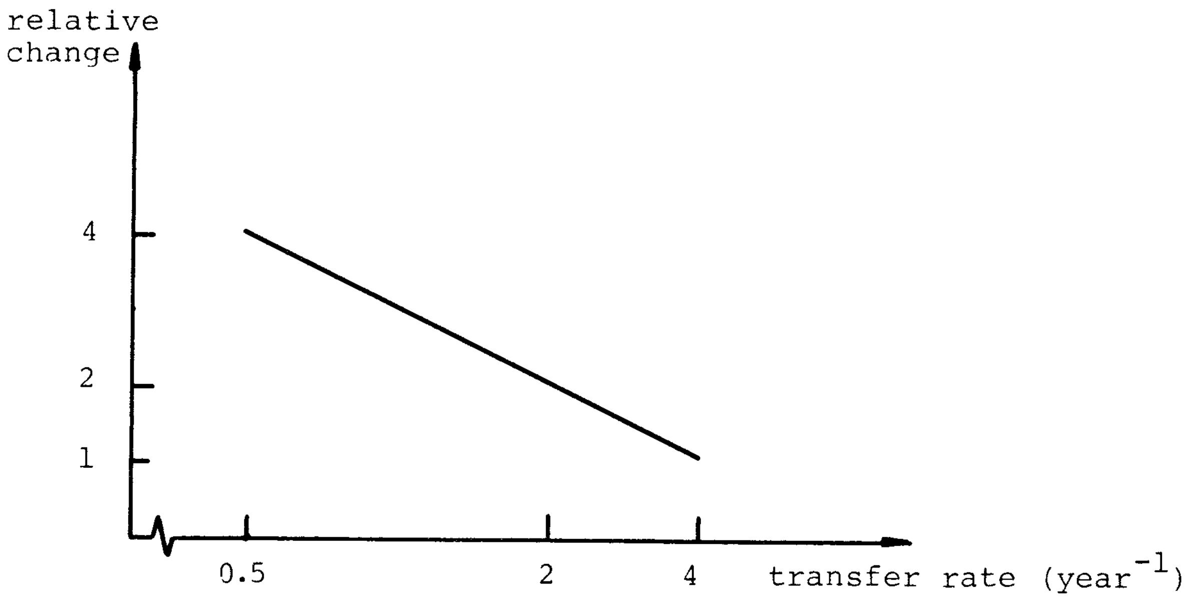

Figure 31

The relative changes of the doses from uranium-235 and its daughter nuclide protactinium-231 when the turnover rate of the water in the lake is varied. The reference value is 2 year^{-1}.

The doses for both nuclides are proportional to the turnover time of the lake as the dominatant exposure pathways are drinking water and fish.

Irrigation

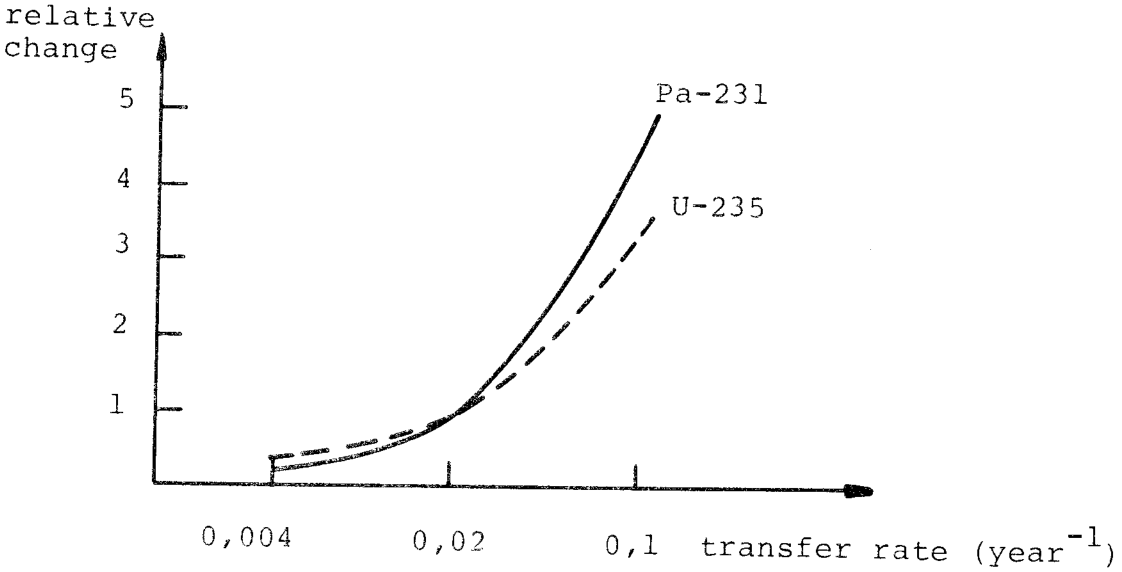

Figure 32

The relative changes of the doses from uranium-235 and its daughter nuclide protactinium-231 when the rate of irrigation from the lake is varied. The reference value is 0.02 year^{-1}.

As irrigation only affects the fraction of the dose received by the ground water, the changes of dose when different irrigation rates are simulated is smaller for uranium than for protactinium.

6. THE WELL ALTERNATIVE

In the earlier studies the irrigation from a well to the local area has been set to 60 m^3 water per year. Intensified irrigation has been simulated, the local area $2.5 \cdot 10^4$ m^2 has been irrigated with 100 mm water per year. In Table 12 the relative changes of the individual doses compared to the reference case for the different nuclides are shown. The importance of the irrigation varies for the different nuclides. Radium generated by the decay of thorium is not affected at all as the exposure in the well alternative is dominated completely by the consumption of fish from the near by lake. For all decay products except protactinium the dose will be higher in the regional area even for an extremely high irrigation. This is because the present version of the model does not include the decay of the mother nuclide in the local area and also there is no reservoir for the nuclides after migration in to the soil, as is the case in the regional area. For protactinium the large change depends on the terrestrial exposure pathways, vegetables, rootfruits and grain. Even if a fairly small amount of protactinium generated by the dacay of uranium-235 in the groundwater reservoir is brought into the local area, the nuclide is considered to be so imobile that the concentration in the soilreservoir will increase considerably.

7. VARIATION IN UPTAKE THROUGH FOOD CHAINS

The uptake and distribution of nuclides in food-stuffs is a very important factor in calculations of the total internal dose to critical groups and populations. Uncertainties about those, especially for uptake in fish have a direct effect on the total dose-burden. There are natural variations in the biological uptake of nuclides in vegetation and biota. The values used for uptake and distribution in food-stuffs are shown in Table 3 for the reference case, where even intervals for the factors found in the literature are given.

If the upper limit of the values are used in the calculations, or when there is no variation in the values, the reference values have been increased by a factor of 10.

In Tables 13 and 14 the relative changes compared to the reference case are given for the well and for the lake cases respectively.

The changes are smaller in the lake alternative because of the dominance of drinking water.

If the factors are decreased to the same extent the doses will decrease. The relative changes are shown in Table 15.

8. VARIATION OF ANIMAL DIETS

The reference value for animal consumption of water has been set to 30 l per day. This value is probably too low, a report of analysis of factors for dose calculations (10) has given ranges between 60 and about 100 l per day for cattle. The higher value corresponds to the grazing period. Therefore a mean value of 75 litres per day seems reasonable. The importance of that factor is, however, relatively low as the exposure pathways via milk and meat are often of minor importance, except for (the nuclide) iodine. Besides, in the well case where those pathways are of greater interest compared to the lake case, the dominant of exposure pathway is by the direct surface contamination of the pasturage.

9. CHOICE OF CRITICAL GROUP

The change of transfer coefficients influences the doses as previously seen, but changes of certain transfer coefficients can also cause other individuals to be exposed more than in the reference case. That means for example that for radium-226, generated by the decay of thorium-230 in the biosphere, with a low irrigation rate, the concentration of the nuclide in the lake will be higher than in the ground water reservoir, so the critical group in that case consists of those who are using the lake for their water instead of the ground water. Independent of the model for the activity concentration there will be changes in the dose burden resulting from the choice of critical group, diet and living habits.

10. DOSE FACTORS

Uncertainties in the dose factors directly affect the resulting doses. The dose are proportional to the absorption of the nuclide from the gastrointestinal tract. This uptake can vary with the solubility of the compounds. As example a quotation from ICRP 30 is included below, for the neptunium nuclide.

Experiments on rats indicate that the fractional absorption of neptunium from the gastrointestinal tract is about 0.01 when it is administrated as the nitrate. However, the tractional absorption of trace quantities of the element may be a factor of ten lower as may be the fractional absorption of neptunium incorporated in food.

11. FURTHER DEVELOPMENT

This study has indicated the great importance of the dose to individuals from the lake → soil → groundwater system. To obtain a better basis for the dose calculations three different areas for further development can be identified.

11.1 The model

The present model does not include the decay of a mother nuclide to an active daughter in the local ecosystem, which is a weakness in the program for the well case.

The direct contamination by retention of contaminated water on the pasturages ought also to be included in the calculations of doses from the regional zone. For the local area it is the most important transfer for exposure from the consumption of milk and meat.

The model system in the regional area could be increased by two compartments namely 2 soils and 2 groundwater reservoirs.

Division of soil into 2 reservoirs should be done to simulate an upper layer (the plough layer) and a deeper soil reservoir.

In the present model there is only one reservoir which simulates the soil and groundwater. This is fairly rough, especially as the movement of water in the ground is a very complex process. Two reservoirs might therefore be used to simulate the different turnover times of water.

11.2 Transfer coefficients

There are obvious uncertainties concerning the behaviour of nuclides in the soil reservoir. The species of soil vary with different chemistry and waterfield capacities. As farming land is the most interesting receiver of released nuclides from dose burden point of view, it would be very useful to study the migration of the dominant nuclides in respresentative soils. As this also depends on the water balance in the area a more precise water balance and capacity to retain water should be studied for the contaminated area considered.

11.3 Input data for dose calculations

As earlier shown the dominant exposure pathways have been drinking water and consumption of fish. But in the well alternative considered or with a more developed model the uptake of nuclides to plants or to animals can be of greater importance. New information is continously being presented and the factors used ought to be updated. Here it can be mentioned that the nuclide technetium has been shown to be much more readily taken up plants than was thought previosly (12). The dose factor for neptunium has been changed considerably by the much higher uptake to man. This nuclide seems to be much more available to the biosphere and from work at The Swedish University of Agricultural Sciences the uptake has been shown to be about the same as for cesium; about $2.5\text{-}10^{-2}\text{-}0.5$ (Ci/kg plant per Ci/kg soil) (8).

Concerning the calculation of the collective doses; it is probably better to study the potential yield of products from regional area than a particular population density. For example, the amount of fish taken up from the lake has in the earlier calculations been overestimated. A lucrative yield of fish in Swedish lakes is considered to be about 7 kg fish per $10^4 m^2$ lake area.

If the Finnsjö is considered to this should imply about $3.5 \cdot 10^3$ kg fish used for consumption compared with the value $60 \cdot 10^3$ kg in this report.

Furthermore an overestimation of the doses can be discussed. The model assumes that the nuclides in the soil and ground are delayed compared to water but remain in solution. The adsorption to clay particles and incorporation in onpanic complexes is thus not considered. In reality however a high proportion of the nuclides are perhaps not dissolved and not available in drinking water. Studies of equilibrium constants for these radionuclides in representative soil-water systems are therefore nessessary.

Also the uptake of radionuclides by vegetation from the soil is dependent on the soil properties. Field experiments on some of the most typical soils used for agriculture in Sweden to give a set of transfere coefficients instead of only one may improve this part of the model.

12. SUMMARY

A variation analysis of parameters in the BIOPATH-model has been done for dominant nuclides from the point of view of the doses. That has been done to decide how strongly uncertainties in data will affect the doses and make proposals for forthcoming efforts.

The following nuclides and decay chains have been studied.

I-129
Cs-135
Ra-226
Pa-231
Np-237
Th-230/Ra-226
U-234/Ra-226
U-235/Pa-231

The inflow of the nuclides is taken to be 10^{-6} Ci annum for 10^{6} years. The dosefactors used are the most recent values published by ICRP for weighted commited dose equivalent per unit activity intake (5). When the transfer coefficients were varied the regional maximum doses were studied.

All done variations have been compared with so called reference values, which are the doses received by the same set of indata as in (3). Most varied transfer coefficients are those related to following processes.

- surface water → Baltic sea
- surface water → soil
- turnover of soil and groundwater
- soil → surface water
- water → sediment
- soil → groundwater

The values used for the transfercoefficients are often the referencevalues altered by a factor fice up and down or extreme values. The later have been chosen for the turnover of the water in the lake and for the irrigation. For the wellalternative an intensified irrigation has been studied. Also the uptake through the foodchains has been investigated by used of extreme values.

For most nuclides studied the dominating exposure pathway is by the drinkingwater, followed by the consumption of fish. Thereafter the terrestial paths milk and meat follow.

Figure 2 is a graphic summary in a lin-log plot of almost all the variations of transfercoefficients in this study. The importance of the done variations are somewhat different for the nuclieds. But for all nuclides the rate of the turnover of water in the lake is almost inversely proportional to the dose. The tendency for the transfer related to the irrigation is also quite clear. Increased irrigation interrisly causes increased doses.

The turnover of the nuclides in the soil and groundwater influences the doses in the same way but how much is specific for the nuclides, depending among other factors on their physical half-lives. The variation in sedimentation rates seems to be rather insignificant. The intensified irrigation in the well alternative resulted naturally in increased doses, specific for each nuclide. The relative inreases were in the ranger 6-40, highest for protactinium-231 generated by the decay of uranium-235.

The use of extreme values for uptake in the food-chains for the well and for the lake case affects the doses in the well case somewhat more than in the lake case. That is because the dominance of the exposure from the drinking water in the lake case. Also the change of animal diets can affect the doses a little. The choice of critical group is an important factor for prognosing the exposure to man. That is the question of primary recipients, well or lake.

This study confirms the importance of equilibrium constants for the soil-water system because the drinking-water is the most important exposure pathway. Also the factors for uptake in the food-chains ought to be updated.

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Table 1

Dose factors for intake with food or water (rem/Ci)

	According to KBS-100	According to ICRP-30
I-129	3.4E 5	2.7E 5
Cs-135	7.3E 3	7.0E 3
Ra-226	2.8E 6	1.1E 6
Th-230	3.4E 5	5.4E 5
Pa-231	6.6E 5	1.7E 8*
U-234	1.1E 5	2.6E 5
U-235	1.1E 5	2.5E 5
Np-237	2.0E 5	3.9E 7

* From NRPB 82 (6)

Table 2

Reference data for the transfer coefficients (turnover/year) for the exchange of nuclides within the regional reservoir system

	I	Cs	Ra	Th	Pa	U	Np
Groundwater 1 → surface water	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Groundwater 2 → soil	1.0E-1	1.0E-4	2.0E-4	2.0E-6	6.0E-6	1.0E-4	1.0E-3
Groundwater 2 → surface water	2.0E-1	2.0E-4	4.0E-4	4.0E-6	1.2E-6	1.0E-3	2.0E-3
Soil → groundwater 2	1.0E-1	1.0E-3	1.5E-3	3.5E-3	6.0E-6	1.0E-3	4.0E-3
Soil → reg atmosphere	1.0E-2	1.1E-7	1.1E-7	1.9E-7	1.1E-7	1.1E-7	1.1E-7
Soil → surface water	2.0E-1	1.2E-6	1.8E-4	3.0E-6	1.2E-6	1.2E-3	1.2E-3
Reg atmosphere → soil	1.2E-3	4.5E-1	4.5E-1	4.5E-1	4.5E-1	4.5E-1	4.5E-1
Reg atmosphere → surface water	6.7E-6	2.5E-3	2.5E-3	2.5E-3	2.5E-3	2.5E-3	2.5E-3
Reg atmosphere → Baltic	5.0E-1	1.9E 2	1.9E 2	1.9E 2	1.9E 2	1.9E 2	1.9E 2
Reg atmosphere → global atmosphere	1.5E 2	1.5E 2	1.5E 2	1.5E 2	1.5E 2	1.5E 2	1.5E 2
Surface water → soil	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2
Surface water → reg atmosphere	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2
Surface water → reg atmosphere	1.3E-2	0	0	0	0	0	0
Surface water → sediment	7.0E-2	3.0E-2	5.0E-3	5.6E 1	3.0E-2	5.6E 1	5.6E 1
Surface water → Baltic	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Sediment → surface water	1.2E 1	1.0E-3	3.1E-4	3.0E-6	1.0E-3	1.2	1.2

Table 3

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

Nuclide	ENRICHMENT FACTORS** Plant-soil	Cereals-soil	G veg-soil	R veg-soil	Fish-lake	Fish-brackish w	Fish-sea water	DISTRIBUTION FACTORS Day/l milk-grass	day/kg meat-grass	day/pc egg-feed
I-129	$2x10^{-2}$				1-225 15	20	20	10^{-2}	$9x10^{-2}$	$3x10^{-2}$
Cs-135	$3x10^{-3}$-7*** $3x10^{-3}$	$3x10^{-3}$-1 $3x10^{-3}$	10^{-3}-5 $1x10^{-3}$	$3x10^{-3}$ $3.3x10^{-2}$	500-$1.2x10^{4}$ $2x10^{3}$	500	5-240 40	$7x10^{-3}$	$4x10^{-2}$	$2x10^{-2}$
Ra-226	$3x10^{-4}$-$8x10^{-4}$ $3x10^{-4}$		10^{-4}-$3x10^{-4}$ $3x10^{-4}$		1-50 15	50	50	$8x10^{-3}$ $4.5x10^{-4}$	$9x10^{-4}$-$1.5x10^{-2}$ $9x10^{-4}$	10^{-6}
Th-230	$4x10^{-3}$				30	40	40-10^{4} 40	$5x10^{-6}$	$5x10^{-3}$	10^{-4}
Pa-231	$2.5x10^{-3}$				11	11	10	$5x10^{-6}$	$5x10^{-3}$	10^{-4}
U-all	$2.5x10^{-3}$				2-10	10	10	$5x10^{-4}$	$5x10^{-3}$	10^{-4}
Np-237	$2.5x10^{-3}$				10	10	10	$5x10^{-6}$	10^{-2}	10^{-4}

* When enrichment factors for ceveals, green vegetables and root vegetables are not available the value for plant-soil has been used.

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

** $3 \cdot 10^{-3}$-7 refers to the spread in values with the typical value given underneath. The typical value is the input value for the reference case.

Table 4

Annual individual and collective doses for I-129 at different transfer rates. Continous leakage of 10^{-6} Ci/year

Transfer	Numerical value	Max ind annual dose well case (rem/year)	Max reg ind annual dose lake case (rem/year)	Max collective annual dose (manrem/year)
Reference		4.4E-7	4.7E-9	1.6E-1
6 → 8	4	4.4E-7	2.4E-9	1.6E-1
6 → 8	1	4.8E-7	9.4E-9	1.6E-1
6 → 4	0.1	4.5E-7	4.7E-9	1.6E-1
6 → 4	4.0E-3	4.5E-7	4.7E-9	1.6E-1
2 → 4	0.5	4.5E-7	4.7E-9	1.6E-1
2 → 6	1.0			
2 → 4	0.02	4.5E-7	4.7E-9	1.6E-1
2 → 6	0.04			
local irrigation	2.5E-6	1.1E-5	4.7E-9	1.6E-1

Table 5

Annual individual and collective doses for Cs-135 at different transfer rates. Continous leakage of 10^{-6} Ci/year

Transfer	Numerical value	Max ind annual dose well case (rem/year)	Max reg ind annual dose lake case (rem/year)	Max collective annual dose (manrem/year)
Reference		2.1E-8	1.5E-8	5.7E-5
6 → 8	3.0	1.7E-8	1.0E-8	4.5E-5
6 → 8	1.0	3.5E-8	3.1E-8	9.5E-5
6 → 4	4.0E-3	2.2E-8	1.4E-8	5.5E-5
6 → 4	0.1	2.2E-8	2.1E-8	7.0E-5
6 → 7	6.0E-3	2.2E-8	1.5E-8	5.7E-5
6 → 7	0.15	2.2E-8	1.5E-8	6.1E-5
local irrigation	2.5E 6	1.7E-7	1.5E-8	5.7E-5

Table 6

Annual individual and collective doses for Ra-226 at different transfer rates. Continous leakage of 10^{-6} Ci/year

Transfer	Numerical value	Max ind annual dose well case (rem/year)	Max reg ind annual dose lake case (rem/year)	Max collective annual dose (manrem/year)
Reference		8.2E-7	5.1E-8	1.7E-4
6 → 8	3.0	8.2E-7	3.4E-8	1.2E-4
6 → 8	1.0	8.2E-7	1.0E-7	3.3E-4
6 → 4	4.0E-3	8.2E-7	1.8E-8	1.1E-4
6 → 4	0.1	8.2E-7	1.8E-7	4.7E-4
2 → 4 2 → 6	1.0E-3 2.0E-3	8.2E-7	2.9E-8	1.2E-4
2 → 4 2 → 6	4.0E-5 8.0E-5	8.2E-7	7.5E-8	2.3E-4
4 → 2	3.0E-4	8.1E-7	3.1E-8	1.3E-4
4 → 2	7.5E-3	8.2E-7	6.3E-8	2.0E-4
2 → 6	1.0E-6	8.2E-7	7.5E-8	2.4E-4
local irrigation	2.5E6	2.1E-6	5.1E-8	1.7E-4

Table 7

Annual individual and collective doses for Pa-231 at different transfer rates. Continous leakage of 10^{-6} Ci/year

Transfer	Numerical value	Max ind annual dose well case (rem/year)	Max reg ind annual dose lake case (rem/year)	Max collective annual dose (manrem/year)
Reference		1.0E-4	5.1E-5	1.3E-1
6 → 8	3.0	1.0E-4	3.3E-5	8.9E-2
6 → 8	1.0	1.0E-4	1.0E-4	2.5E-1
6 → 4	4.0E-3	1.0E-4	1.2E-5	3.6E-2
6 → 4	0.1	1.0E-4	2.4E-4	5.9E-1
2 → 4 2 → 6	1.2E-6 2.4E-7	1.0E-4	2.8E-5	7.4E-2
2 → 4 2 → 6	3.0E-5 6.0E-6	1.0E-4	6.1E-5	1.5E-1
4 → 2	3.0E-5	9.4E-5	1.4E-4	3.6E-1
4 → 2	1.2E-6	1.1E-4	1.4E-5	4.1E-2
6 → 7	6.0E-3	1.0E-4	5.1E-5	1.3E-1
6 → 7	1.5E-1	1.0E-4	5.1E-5	1.3E-1
6 → 7	56	1.0E-4	4.1E-5	3.6E-1
local irrigation	2.5E 6	1.2E-3	5.1E-5	1.3E-1

Table 8

Annual individual and collective doses for Np-237 at different transfer rates. Continous leakage of 10^{-6} Ci/year

Transfer	Numerical value	Max ind annual dose well case (rem/year)	Max reg ind annual dose lake case (rem/year)	Max collective annual dose (manrem/year)
Reference		2.1E-5	9.5E-7	2.0E-2
6 → 8	4.0	2.2E-5	4.6E-7	1.8E-2
6 → 8	3.0	2.2E-5	6.2E-7	1.8E-2
6 → 8	1.0	2.2E-5	1.8E-6	2.2E-2
6 → 4	0.004	2.1E-5	5.1E-7	1.8E-2
6 → 4	0.1	2.1E-5	3.0E-6	2.4E-2
2 → 4 2 → 6	5.0E-3 1.0E-2	2.1E-5	5.1E-7	1.8E-2
2 → 4 2 → 6	2.0E-4 4.0E-4	2.1E-5	3.0E-6	2.4E-2

Table 9

Annual individual and collective doses for Th-230 and its daughter Ra-226 at different transfer rates. Continous leakage of 10^{-6} Ci/year

Transfer	Numerical value	Max ind annual dose well case (rem/year)	Max reg ind annual dose lake case (rem/year)	Max coll annual dose (manrem/year)	Transfer	Numerical value	Max ind annual dose well case (rem/year)	Max reg ind annual dose lake case (rem/year)	Max coll annual dose (manrem/year)
Reference		2.7E-7	7.3E-8	1.7E-4	Base		3.1E-7	1.1E-6	3.9E-3
6 → 8	4.0	2.7E-7	6.9E-8	1.5E-4	6 → 8	4.0	1.5E-7	5.5E-7	2.4E-3
6 → 8	0.5	2.7E-7	7.4E-8	1.7E-4	6 → 8	0.5	1.2E-6	3.9E-6	1.3E-2
6 → 4	4.0E-3	2.7E-7	1.5E-8	3.6E-5	6 → 4	4.0E-3	3.1E-7	4.7E-7	2.7E-3
6 → 4	0.1	2.7E-7	3.6E-7	8.5E-4	6 → 4	0.1	3.1E-7	3.8E-6	9.4E-3
2 → 4 2 → 6	1.0E-5 2.0E-5	2.7E-7	3.3E-8	7.9E-5	2 → 4 2 → 6	1.0E-3 2.0E-3	3.1E-7	5.5E-7	2.9E-3
2 → 4 2 → 6	4.0E-7 8.0E-7	2.7E-7	9.5E-8	1.7E-4	2 → 4 2 → 6	4.0E-5 8.0E-5	3.1E-7	1.6E-6	5.5E-3
local irrigation	2.5E 6	1.4E-6	7.3E-8	1.7E-4	local irrigation	2.5E 6	3.2E-7	1.1E-6	3.9E-3

Table 10

Annual individual and collective doses for U-234 and its daughter nuclide Ra-226 at different transfer rates.
Continous leakage of 10^{-6} Ci/year

Transfer	Numerical value	Max ind annual dose well case (rem/year)	Max reg ind annual dose lake case (rem/year)	Max coll annual dose (manrem/year)	Transfer	Numerical value	Max ind annual dose well case (rem/year)	Max reg ind annual dose lake case (rem/year)	Max coll annual dose (manrem/year)
Reference		1.4E-7	7.1E-9	6.6E-5	Base		2.9E-10	1.6E-8	2.0E-4
6 → 8	3.0	1.4E-7	4.7E-9	6.1E-5	6 → 8	3.0	2.3E-10	1.0E-8	1.9E-4
6 → 8	1.0	1.4E-7	1.4E-8	8.5E-5	6 → 8	1.0	5.8E-10	3.3E-8	2.5E-4
6 → 4	4.0E-3	1.4E-7	3.5E-9	5.9E-5	6 → 4	4.0E-3	2.7E-10	3.3E-9	1.7E-4
6 → 4	0.1	1.4E-7	2.6E-8	1.0E-4	6 → 4	0.1	3.9E-10	8.2E-8	3.6E-4
2 → 4 2 → 6	5.0E-4 5.0E-3	1.4E-7	3.6E-9	5.9E-5	2 → 4 2 → 6	1.0E-3 2.0E-3	2.9E-10	3.1E-9	1.7E-4
2 → 4 2 → 6	2.0E-5 2.0E-4	1.4E-7	2.4E-8	1.0E-4	2 → 4 2 → 6	4.0E-5 8.0E-5	2.9E-10	8.6E-8	3.7E-4
4 → 2	5.0E-3	1.4E-7	1.1E-8	7.5E-5	4 → 2	7.5E-3	2.8E-10	2.1E-8	2.2E-4
4 → 2	2.0E-4	1.4E-7	4.0E-9	5.9E-5	4 → 2	3.0E-4	3.5E-10	7.4E-9	1.8E-4
6 → 7	11.2	1.4E-7	7.1E-9	6.8E-5	6 → 7	1.0E-3	2.3E-10	1.6E-8	2.0E-4
6 → 7	280	1.4E-7	7.1 E-9	6.6E-5	6 → 7	2.5E-2	5.8E-10	1.7E-8	2.1E-4
2 → 6	3.0E-6	1.4E-7	7.1E-8	2.3E-4	2→ 6	1.0E-6	2.9E-10	3.0E-7	9.0E-4
local irrigation	2.5E 6	8.7E-7	8.0E-9	6.6E-5	local irrigation	2.5E 6	3.3E-9	1.6E-8	2.0E-4

Table 11

Annual individual and collective doses for U-235 and its daughter Pa-231 at different transfer rates.
Continous leakage of 10^{-6} Ci/year

Transfer	Numerical value	Max ind annual dose well case (rem/year)	Max reg ind annual dose lake case (rem/year)	Max coll annual dose (manrem/year)	Transfer	Numerical value	Max ind annual dose well case (rem/year)	Max reg ind annual dose lake case (rem/year)	Max coll annual dose (manrem/year)
Base		1.4E-7	6.8E-9	1.5E-4	Base		1.5E-7	1.9E-6	1.2E-1
6 → 8	4.0	1.4E-7	3.4E-9	1.4E-4	6 → 8	4.0	1.5E-7	9.7E-7	1.2E-1
6 → 8	0.5	1.4E-7	2.7E-8	2.1E-4	6 → 8	0.5	1.7E-7	8.0E-6	1.4E-1
6 → 4	4·E-3	1.4E-7	2.7E-9	1.4E-4	6 → 4	4E-3	1.5E-7	3.9E-7	1.2E-1
6 → 4	0.1	1.4E-7	2.5E-8	1.9E-4	6 → 4	0.1	1.5E-7	9.7E-6	1.4E-4
local irrigation	2.5E 6	8.4E-7	6.8E-9	1.5E-4	local irrigation	2.5E 6	6.4E-6	1.9E-6	1.2E-1

Table 12

Relative changes of the individual doses in the well case when an intensified irrigation is assumed

Nuclide	Relative change
I-129	25
Cs-135	8
Ra-226	14
Ra-226*	1
Ra-226**	11
Th-230	6
Pa-231	12
Pa-231***	40
U-234	6
U-235	6

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

** Refers to the Ra-226 which is generated by the decay of U-234 in the biosphere.

*** Refers to the Pa-231 which is generated by the decay of U-235 in the biosphere.

Table 13

Relative changes of the individual dose in the well case by use of extreme factors

Nuclide	Relative change
I-129	3
Cs-135	13
Ra-226	4.5
Ra-226*	3
Ra-226**	4
Th-230	2
Pa-231	3
Pa-231***	12
Np-237	3
U-234	2
U-235	2

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

** Refers to the Ra-226 which is generated by the decay of U-234 in the biosphere.

*** Refers to the Pa-231 which is generated by the decay of U-235 in the biosphere.

Table 14

Relative changes of the dose burden received from the regional area by use of extreme concentration and distribution factors

Nuclide	Relative change
I-129	10
Cs-135	6
Ra-226	2
Ra-226*	2
Ra-226**	1
Pa-231	1.4
Pa-231***	1
U-234	4
U-235	4
Np-237	5

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

** Refers to the Ra-226 which is generated by the decay of U-234 in the biosphere.

*** Refers to the Pa-231 which is generated by the decay of U-235 in the biosphere.

Table 15

Relative changes of the dose burden to critical group when the concentration and distribution factors are decreased

	Relative change	
Nuclide	Well case	Lake case
I-129	0.3	0.1
Cs-135	0.3	0.2
Ra-226	0.6	0.6
Ra-226*	0.7	0
Ra-226**	1.0	0.4
Th-230	1.0	0.9
Pa-231	0.8	1.0
Pa-231***	1	0.1
U-234	0.7	0.8
U-235	0.7	0.8
Np-237	0.6	0.8

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

** Refers to the Ra-226 which is generated by the decay of U-234 in the biosphere.

*** Refers to the Pa-231 which is generated by the decay of U-235 in the biosphere.

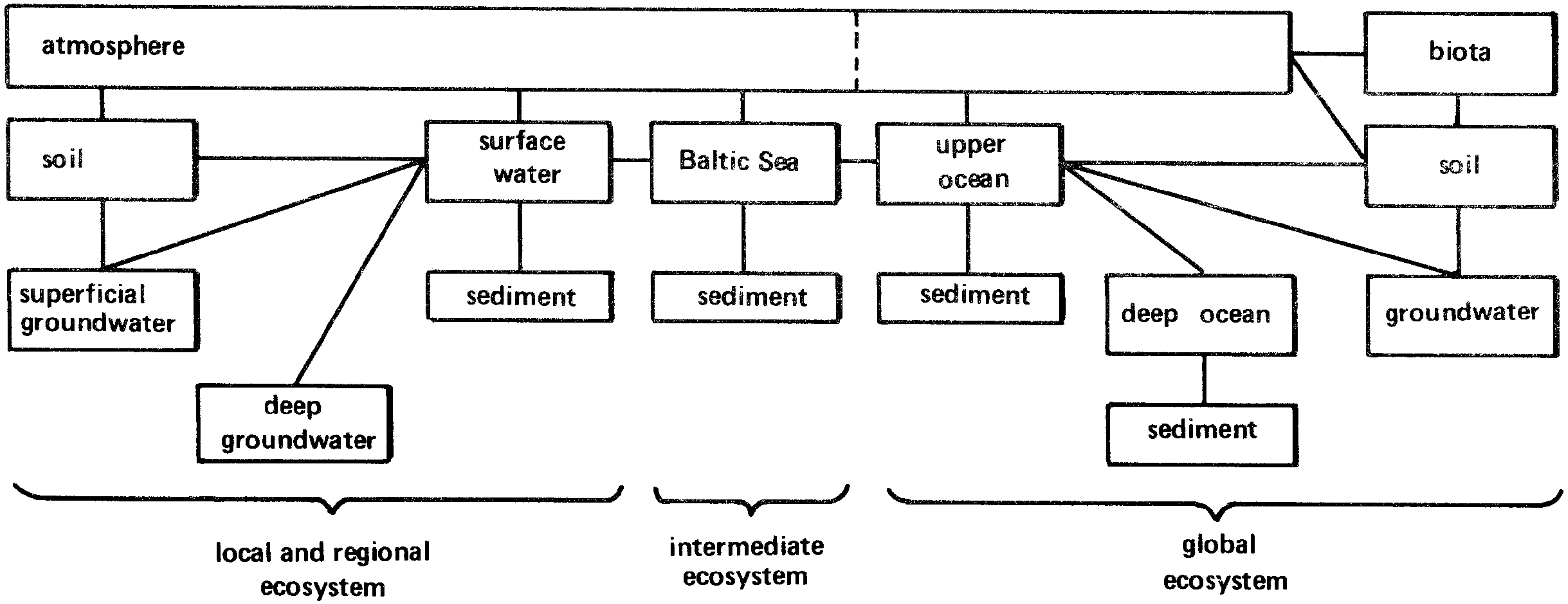

Figure 1. Reservoirs for the different ecosystems

Figure 2

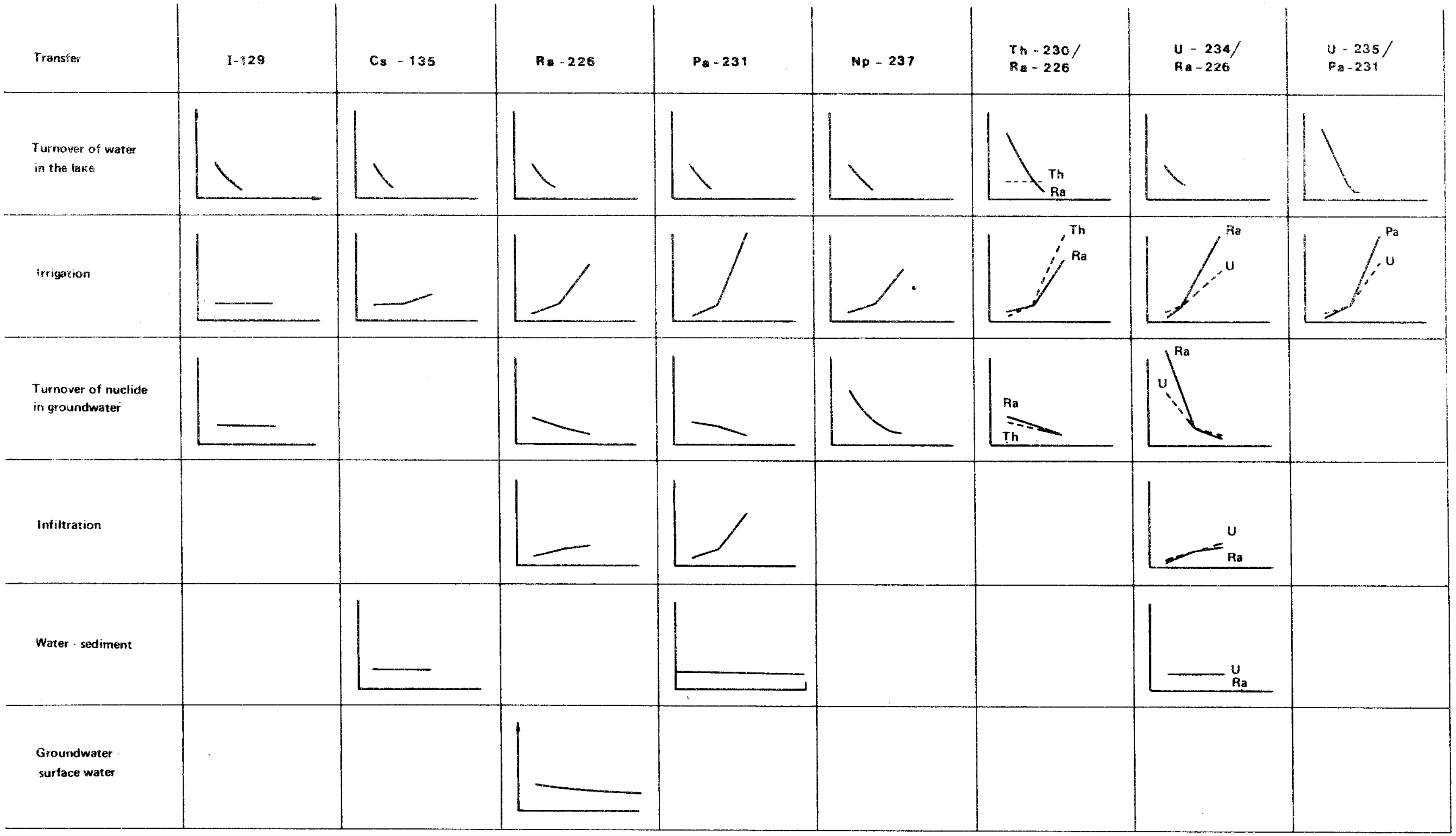

Figure 2. Relative importance* of changed transfer coefficients for the studied nuclides

* For details see specific figures for each nuclide and transfer in the text

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