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REPORT**

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Biosphere data base revision

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BIOSPHERE DATA BASE REVISION

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This report concerns a study which was conducted for SKB. 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 1986 is attached at the end of this report. Information on KBS technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17), 1982 (TR 82-28), 1983 (TR 83-77), 1984 (TR 85-01) and 1985 (TR 85-20) is available through SKB.

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1 INTRODUCTION

The turnover of long-lived radionuclides in the biosphere has previously been modelled and the exposure to man calculated (BER83:2). The nuclides were long-lived actinides and fission products leaking from a deep rock repository for spent nuclear fuel. The data base for these calculations (BER83:1) has been updated in the present work and in addition a number of nuclides that were not included in the earlier work have been treated. Some of the nuclides treated here are not long-lived enough to be expected to leak into the biosphere from a repository for spent fuel. These nuclides may however leak from more shallow repositories for low- and intermediate-level waste.

The doses, to critical group individuals and to populations, obtained from continuous unit releases to the biosphere under certain decided conditions have been calculated and called conversion factors. This report gives conversion factors for most of the nuclides appearing in spent fuel.

The model in this case consists of several compartments (27). Some are naturally of more importance than others for the calculation of the doses to critical groups. These compartments are the surface water and the upper soil reservoir, while in the global area it is only the well-mixed sea reservoir. Accordingly efforts have been concentrated onto the surface water and the upper soil reservoir and they are explicitly given in the Appendix for the nuclides calculated.

2 ECOSYSTEM AND EXPOSURE SITUATIONS

2.1 Model

The mathematical methods are based on compartment theory with first-order kinetics (BER82). 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 $Q(t)$ ($\text{activity year}^{-1}$) describe the transfer rates between the

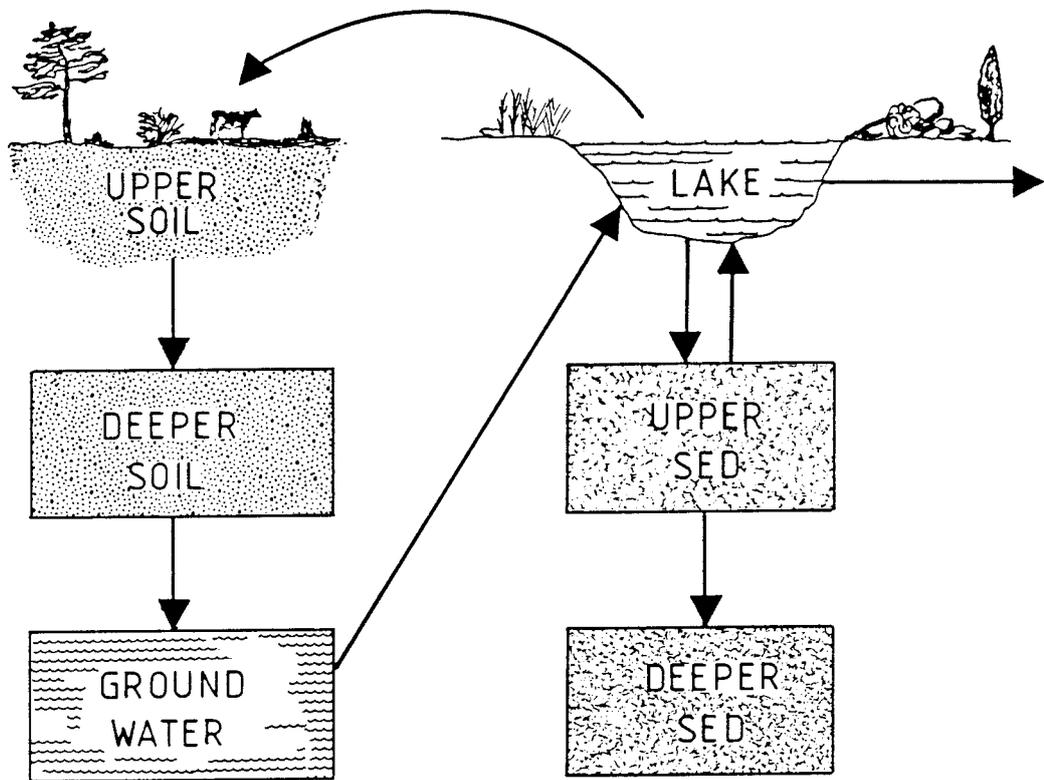


Fig.1 Model system used

reservoirs and production or release within the reservoir, respectively. The vector of decay

constants is

$\lambda_{D_n} = \lambda_m = \ln 2 / t_{1/2}$, 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 code BIOPATH (BER82).

The model is divided into four different subsystems to simulate the increased dispersion from the source out to the whole area. The subsystems describe the following areas:

- local
- regional
- intermediate
- global

Primary recipients for the groundwater borne nuclides are either groundwater supporting a well or a lake. The well case consists simply of one reservoir, in Figure 1, the model system for the lake case is shown.

The exposure pathways considered are shown below as well as the characteristics of the most important reservoirs for determining the dose to critical groups.

Primary Recipients:

	Well	Lake
Volume (m ³)	$2.5 \cdot 10^5$	$3.2 \cdot 10^6$
Turnover time (years)	0.5	3

Exposure Pathways:	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 consumption of drinking water by animals. The water in the lake is used for the irrigation of neighbouring farmland. However, the water in the well is only assumed to be sufficient for the irrigation of vegetables.

2.2 Transfer coefficients and uptake in food-chains

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

Symbols:

- U_i = Uptake of one particular nuclide in food-stuff i . Given in Bq per unit (kg, litre or piece).
- F_i = Distribution factor for a given nuclide for food-stuff i . Given in day per unit (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 a 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.

for p the values used are given as (dry weight vegetation/dry weight soil) in all other cases the wet weights are used.

- MC_i = Daily consumption of water, food-stuff (dry weight) and soil for animal in dominant transport links (l/day, kg/day).
 DEP = deposition rate (m per day).
 γ = mass interception factor (m^2 per kg).
 IRR = irrigation ($l m^{-2} day^{-1}$).
 R = average residence time on vegetation = 20 days.

The values for the quantities MC_i , DEP; γ and IRR which were used are summarized below.

<u>Parameter</u>	<u>Value</u>
MC_w (cow)	90 l/day
MC_p (cow)	16 kg/day
MC_s (cow)	0.3 kg/day
γ_p	1.8 m^2/kg
ω	$3.6 \cdot 10^{-1} m^2/kg$
IRR	0.15 $l/m^2 \cdot day$
DEP	259 m/day

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

2.2.1 Uptake in milk and meat

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

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

Thus,

U_m (in Bq per litre) =

$$F_m \left((MC_p \cdot E_p + MC_s) \cdot C_s + MC_1 \cdot C_1 + \gamma \cdot DEP \cdot C_a \cdot R \cdot MC_p \right),$$

and

U_k (in Bq per kg) =

$$F_K \left((MC_p \cdot E_p + MC_s) \cdot C_s + MC_1 \cdot C_1 + \gamma \cdot DEP \cdot C_a \cdot R \cdot MC_p \right),$$

2.2.2 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 to deposition direct onto the surfaces of the leaves.

Thus,

U_v (in Bq per kg) =

$$E_v \cdot C_s + \gamma \cdot R \cdot COV_v^{-1} (IRR \cdot C_1 + DEP \cdot C_a)$$

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

2.2.3 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,

$$U_g \text{ (in Bq per kg)} = E_g \cdot C_s,$$

and

$$U_r \text{ (in Bq per kg)} = E_r \cdot C_s$$

2.2.4 Uptake in eggs

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

Thus, U_e (in Bq/per egg) =

$$F_e (MC_g \cdot E_g \cdot C_s + MC_l \cdot C_w)$$

2.2.5 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,

$$U_f \text{ (in Bq per kg)} = E_f \cdot C_f$$

2.3 External exposure

Earlier performed calculations have shown that external exposure is of minor importance compared with internal exposure.

The only external exposure pathway of any interest has been irradiation from contaminated ground. Accordingly, this is the only pathway considered in this report. The dose conversion factors for exposure from radioactivity in the soil and on beaches are taken from reference (SVE79).

3 NUCLIDES AND DATA

This report is an updating of the data used for nuclides previously treated in (BER83:2) as well as a renewed calculation of conversion factors for several fission products and some actinides.

However, there are several nuclides which were treated earlier and for which no new data were found which could justify updating the old.

These are:

Zirconium-93
Technetium-99
Cesium-135
Radium-226
Thorium-229
Thorium-230
Protactinium-231

Accordingly, these nuclides are not treated here at all, and only the conversion factors are given in Table 4 for comparison.

For all uranium isotopes the only new information available concerns the dose factor (the effective weighted dose equivalent). The actual exposure situation, chronic exposure over a long period of time where exposure is mostly caused by contaminated food, will lead to a higher uptake by blood from the gastro-intestinal tract (JOH84). In chapter 4, Table 5 the dose factors for uranium used are shown. The integration time is also changed to 70 years in (JOH84) while ICRP uses 50 years. However, this is of marginal importance.

For selenium-79, tin-126, iodine-129, neptunium-137, plutonium-239 and plutonium-242 the new data considered are provided below.

The following "new" nuclides are treated:

Carbon-14
 Nickel-59
 Strontium-90
 Molybdenum-93
 Niobium-93 and 94
 Palladium-107
 Cesium-137
 Lead-210
 Actinium-227
 Plutonium-241
 Curium-245

The data for those nuclides are also given below. Each element is briefly described concerning chemical properties, solution chemistry and uptake in food chains.

The nuclide-dependent transfer coefficients describing migration in soil and transfer to the sediments are given in Appendix 1.

3.1 Carbon-14

3.1.1 Chemical properties - Solution chemistry

Since carbon is one of the most abundant elements in the biosphere, the behaviour of trace C-14 will therefore be similar to the macro component, since the isotopic effect probably is very small. A release of C-14 into groundwater, lake- or seawater will probably be mainly as HC-14O_3^- , since hydrogen carbonate is the most

common carbon species in deep groundwaters. Some of the C-14 may, however, be in the form of C-14H₄ (methane) or more complicated organic components including simple microorganisms.

The released C-14 may enter the global carbon cycle where carbon dioxide and carbon monoxide are found in the atmosphere, and various forms of dissolved organic carbon in biota and in surface waters (including decomposition products like humic substances). In soil and rocks carbonate is present both in dissolved (bicarbonate, organic) and solid (carbonate minerals) form.

The solution chemistry of C-14 will therefore depend on the species formed and upon whether or not it is incorporated into biological material. The physical and chemical reactions involving C-14 are also numerous. Apart from the quite well-known inorganic specification reactions, there will be reactions with the dissolved organic compounds in water like oxidation/reduction, complexation sorption, precipitation and volatilisation (CAR 72, BOH 81).

3.1.2 Transfer coefficients and uptake in food-chains

The transport paths in the environment for C-14 will differ somewhat from those of metal ions.

There is no root uptake of carbon species in plants, the uptake occurs from the atmosphere via photosynthesis.

The existence of an equilibrium between dissolved carbon species in surface waters and atmospheric carbon dioxide is an example of a

Transfer coefficients for the biosphere transport may be derived from data for the cycling of stable carbon. These transfer coefficients describe the exchange when there is a steady state in the carbon cycle.

In Appendix 1, the formula used for deriving transfer coefficients describing migration in soil and transfer from water to sediment are given.

Regarding uptake in food-stuffs, the only exposure pathway of interest is by consumption of fish. Regarding the above the concentration factors used are:

Type of water

Fresh	4.6E3
Brackish	4.6E3
Salt	1.6E3

3.2 Nickel-59 and nickel-63

3.2.1 Chemical properties - Solution chemistry

The predominating valence state of Ni in water solution is +2 and it forms strong inorganic complexes with sulfide, hydroxide and carbonate. Hydrolysis and carbonate complexation will lead to a low mobility at neutral pH. Fulvic acids also form strong complexes with Ni. At moderate fulvic acid concentrations these complexes are unstable at pH 8-9 while soluble complexes are formed at higher fulvic acid concentrations (MO084).

The hydrolysis and complex formation implies a high degree of binding of Ni to suspended matter in natural waters. This has also been shown for some cases although when the concentration of suspended matter and pH is low, the particle-bound fraction may be as low as 10 - 15 % (MOO84)

3.2.2 Transfer coefficients and uptake in food-chains

The data on Ni in the biosphere are limited and mainly based on the behaviour of the stable element.

In aquatic systems Coughtrey et al (COU83) reports the following concentration factors.

Sediment/water	1.E4
Fish/water	1.E2

The NRC Regulatory Guide (NRC77) also recommends fish/water concentration factors of 10^2 both for fresh and salt water.

The NRC also recommends a soil-factor for vegetation/soil of $1.9E-2$ (w.w.). The distribution factor used for milk is $6.7E-3$ d/l and for meat $5.3E-2$ d/kg.

The transfer coefficients for soil and sediment compartments have been estimated according to the method described in Appendix 1. The following distribution coefficients have been used.

	<u>Fresh</u>	<u>Brackish</u>	<u>Sea</u>
Sediment/water	10	10	10
Soil/water	5.E-3		

3.3 Selenium-79

For selenium the only changes to earlier used values are:

- an increase in the uptake of selenium in fresh-water fish
- a decrease in the excretion of selenium in milk

The new values are 2000 and 4.E-3 d/l respectively (COU83).

3.4 Strontium-90

3.4.1 Chemical properties - Solution chemistry

The solution chemistry of Sr is very similar to that of Ca. Of trace Sr there is often a competition with macro amounts of Ca e.g. in ion exchange reactions. These metals have only one valence state in water solution (+2) and do not form any strong complexes under conditions prevailing in groundwater. At high pH, carbonate complexes may be formed.

No data for natural organic compound complexes with Sr have been found in literature, but the strength of fulvic acid - Ca - complexes is quite low compared to other metals (SCH70).

A considerable solubility and mobility of Sr is therefore to be expected.

3.4.2 Transfer coefficients and uptake in food-chains

For soils and sediments the methods described in Appendix 1 have been used to estimate the transfer coefficients.

For plants, a decreasing uptake with increasing content of organic matter has been observed. From Coughtrey et al (COU83) following values are found and those have also been used:

Plant/soil:

general	0.017 - 100 (w.w)
pasturage	3.2 (0.5 - 20) (d.w)
hay	0.72 (w.w)
cereal	1.67 (d.w)
root veg.	0.75 (d.w)
leafy veg.	2.5 (dw)

Distribution factor for excretion in milk:
5.E-4 - 3.8E-3 d/l

NRC regulatory guide recommends (NRC77)

Plant/soil	1.7E-2 (w.w)
milk	8.0E-4 d/l
meat	6.0E-4 d/kg

The uptake in fish is calculated by use of the following values found in (NEU85)

Fish fresh w	20
" marine	5

The same value has been used for brackish as for freshwater.

Approximately the same values are recommended from NRC (NRC77).

3.5 Molybdenum-93

3.5.1 Chemical properties - Solution chemistry

Although Mo may have valence states between -II and +VI, Mo in a water solution exists predominantly as the tetra valent molydate an ion MoO_4^{2-} . This ion has also been found in seawater (COU 83). The complexing at natural water pH is small and like other anions, the sorption to particulates under these conditions is small. The sorption may be expected to increase with decreasing pH as in the case of I^- (Cf ALL80).

3.5.2 Transfer coefficients and uptake in food chains

There are not many reported data on biosphere transfer factors for Mo.

Coughtrey et al (COU83) have in their literature survey found the following:

Plants/soil	0.5 (d.w)
Milk	8.0E-2d/l (poor data)
Sediment/water	300
Fish/water	10-200

NRC regulatory guide (NRC77) recommends the following which also have been used.

Vegetation/soil	0.12 (w.w)
Milk	7.5E-3 d/l
Meat	8.0E-3 d/kg
Fish/water fresh	10
" salt	10

The data used for deriving the migration in soil as well as the exchange between water and sediment are shown in Appendix 1.

3.6 Niobium-93 and -94

3.6.1 Chemical properties - Solution chemistry

The possible valence states of Niobium in a water solution are +3 and +5 but the concentration of free niobate ions is extremely low. There are several metal niobates that have very low solubilities and in natural waters the Ca-niobate would limit the solubility to 4 - 50 µg/l depending on the calcium concentration. In alkaline solutions there is a tendency of polymerisation of niobium species, forming large molecular weight aggregates.

The low solubility of niobium in water solutions makes laboratory studies, even of trace concentrations, difficult. There are organic complex formers like citrate and tartrate that may keep niobium in solution and these are used e.g. in preparing Nb radionuclide stock solutions.

3.6.2 Transfer coefficients and uptake in food-chains

The low solubility of niobium has two effects:

- long residence time in soil and sediment
- difficult to assess transfer coefficients

Coughtrey et al (COU83) have found some data in the literature:

Vegetation/soil	0.1 (w.w)
Cereals/soil	0.01
Sediment/water	10^5
Fish	10 - 100

No Nb was detected in goat milk in an experiment.

The uptake of Nb in vegetation appears to be higher than zirconium uptake, which can be worth a remark as Nb in many cases are supposed to behave like Zr.

The NRC regulatory guide (NCR77) recommends the following values:

Vegetation/soil	9.4E-3
Milk	2.5E-3 d/l
Meat	0.28 d/kg
Fish/water fresh	30 000
" salt	30 000

The values from Coughtrey have been used for the terrestrial environment while the concentration factor fish/water used is 100 and is taken from (NEU85). This value is used for all types of water.

3.7 Palladium-107

3.7.1 Chemical properties - Solution chemistry

Palladium belongs to Group VIII in the periodic table. The second and third triads of this group (ruthenium, rhodium, palladium, osmium, iridium and platinum) have many properties in common, and are frequently referred to as the platinum group. Their properties differ somewhat from those of the elements in the first triad i.e. iron, cobalt and nickel. Pd(II), as well as Pt(II), have a small radius and rarely forms uncomplexed cations. Pd may also have the valence state (+VI) although +2 would be expected in a water solution (HES60).

3.7.2 Transfer coefficients and uptake in food-chains

No data for Pd has been found in the literature. Neither has any data been found for Pt which may be expected to behave quite like Pd.

Grogan (GRO85) has used the same values as for Ni in the NAGRA safety analysis. The same data as for Ni have also been used here.

3.8 Tin-126

3.8.1 Chemical properties - Solution chemistry

Tin belongs to the same group in the periodic table as Pb, and the possible valence states are (+II) and (+IV).

3.8.2 Transfer coefficients and uptake in food-chains

Tin has been treated in the previous safety analysis (BER83:2). New data in the compilation by Coughtrey et al (COU83) justifies a revision of some of the data earlier used. Higher uptake factors than previously used for plant/soil have been observed. In order not to underestimate the contributions from Sn-126 to the total dose, the following values have been adopted:

	<u>KBS3</u>	<u>New</u>
Pasturage	1.3E-2	1.0E-1
Grain	3.0E-3	3.6E-1
Green veg	2.5E-2	4.6E-2
Root veg	2.5E-2	6.0E-2

No other data have been changed.

3.9 Iodine-129

3.9.1 Transfer coefficients and uptake in food-chains

Iodine has been treated earlier (BER83:1, BER83:2). Some new data for uptake in plants, included in the literature survey by Coughtrey et al (COU83) have been considered. They are:

<u>Factor</u>	<u>KBS-3</u>	<u>New value</u>
Pasturage/soil	8.0E-2	2.0E-2
Grain/soil	2.0E-3	2.0E-1
Green veg /soil	5.0E-3	2.0E-1
Root veg/soil	1.0E-3	2.0E-1

No other data have been changed.

3.10 Cesium-135 and -137

Cs-135 was included in the previous study (BER83:1, BER83:2) and no data that justifies changes in the previously used values have been found. The same data base has been used for cesium-137.

3.11 Lead-210

3.11.1 Chemical properties - Solution chemistry

There are a number of sparingly soluble lead salts that may be formed in natural waters e.g sulfate, phosphate and halide. In reducing the environment PbS(s) with very low solubility may also be formed.

Hydrolysis also plays an important role in the environmental chemistry of lead. In natural water with a pH above 6.5 the predominating species will be $\text{Pb}(\text{OH})_3^-$ (MO084) This ion will determine the sorption properties of lead and it's behaviour will resemble that of actinides forming anionic hydrolysis products.

3.11.2 Transfer Coefficients and uptake in food-chains

Lead radioisotopes in nature have not been studied to any great extent. The NRC regulatory guide does not have any recommendations for lead.

Ng (in Nuclear safety 23, 1982 (NG82)), however, has recommendations for the distribution coefficients for milk and meat. They are:

Milk $2.6E-4$ d/l

Meat $4.E-4$ d/kg

In the NAGRA safety study (JIS85) the concentration factors for fish/water have been set to the same value as that used for Ba namely 100. For plant uptake NAGRA has used values from Schüttelkopt and Kiefer, i.e.

Pasture/soil	$4.5E-3$
Cereals/soil	$1.7E-2$
Leaf vegetables/soil	$1.8E-3$
Root vegetable/soil	$2.7E-3$

They are all given in fresh weight plant/dry weight soil.

Consequently NAGRA values have been used in this report.

3.12 Actinium-227

3.12.1 Chemical properties - Solution chemistry

Actinium is the first member of the actinide group and has only one valence state + III. Ac-227 occurs in nature and decays by a weak β -decay. (KAT57). Actinides in the same valence state usually show large similarities as regards solution chemistry and sorption on solids.

Actinium has been prepared in very small amounts and the number of studies of Ac-chemistry are

few. The similarity between the various trivalent actinides as well as their similarity to trivalent lanthanides is large and analogies may be drawn.

Like La(III), Ac forms low solubility hydroxides fluorides, oxalates, carbonates and phosphates. Although very little investigation has been done on the sorption of Ac it may therefore be expected to behave quite similarly to e.g. Am(III). Am sorbs strongly to solids in groundwater at environmental pH (ALL83) due to hydrolysis.

3.12.2 Transfer coefficients and uptake in food-chains

There seems to be no data concerning uptake in vegetation or fish available for actinium. The data used has then been that for americium, due to the chemical similarity between these elements. For transfer coefficients, see Appendix 1.

The uptake of americium in clover has been studied at The Swedish University of Agricultural Sciences at Ultuna (ERI81). In the lysimeter experiments performed the soil factor varied from $3E-5$ up to $1.4E-3$. In the literature many reports propose $2.5E-4$ for the plant/soil factor.

In this work the following values have been used:

pasturage/soil	1.E-3
cereals/soil	1.E-5
green vegetables/soil	1.E-3
root vegetables/soil	1.E-3
milk	2.5E-5 d/l
meat	1.E-2 d/kg
fish/fresh water	25
" /brackish water	25
" /salt water	25

3.13 Plutonium-239, -241 and -242

3.13.1 Chemical properties - Solution chemistry

The solution chemistry of Pu has been quite thoroughly investigated both in laboratory studies and in studies of fallout plutonium in the environment.

Plutonium in natural waters may have the oxidation states +III, +IV, +V and \pm VI although the IV state seems to dominate, under oxidizing conditions (ALL84).

At the redox potential of 0.3 - 0.8 V, which may be expected in surface waters, tetravalent Pu as $\text{Pu}(\text{OH})_4$ is the dominant soluble species.

At very high potentials e.g in the presence of strong oxidizing agents or at very high carbonate concentrations, pentavalent carbonates ($\text{PuO}_2(\text{CO}_3)_3^{5-}$ and $\text{PuO}_2(\text{CO}_3)_2^{3-}$) may dominate.

For Pu a solubility minimum may be expected at pH 7 - 8 and Eh 0.4 - 0.8 V. The change from

tetra- to pentavalent state that may occur in natural water gives an enhanced mobility (total solubility) and a reduced sorption compared to the tetravalent state.

The presence of organics (e.g humic substances) may in some cases give a reduction, possibly to Pu(III) (ALL84).

3.13.2 Transfer coefficients and uptake in food-chains

Plutonium has been treated previously (BER83:2). Since then a large literature survey on plutonium in the geosphere and biosphere has been published (COU84). Most recent data correlate well with the earlier data but some changes have been made:

	<u>KBS 3</u>	<u>New value</u>
Pasturage/soil	6.2E-4	9.0E-3
Grain/soil	1.0E-4	3.0E-5
Green veg/soil	1.0E-4	6.0E-5
Fish, saltwater	3.5	29

3.14 Curium-245

3.14.1 Solution Chemistry

The solution chemistry of Curium has not been studied to a large extent, since this element is produced in quite small quantities (in g-quantities only Cm-242 and Cm-244).

Curium occurs in only one valence state (+III) and may therefore be expected to show many chemical similarities with americium. A large fraction of the Cm present in natural waters is associated with particulates probably in the

form of hydrolysis products of Am and the soluble fraction has been attributed to carbonate or organic complexes (COU84).

3.14.2 Transfer coefficients and uptake in food-chains

Some data on the biosphere transfer of curium have been reported (COU84).

For uptake in crops and plants the range of values is very large and Coughthrey et al have compiled a summary of geometric means and ranges of values e.g:

Pasturage etc	4.8E-4	(4.4E-5 to 4.9E-2)	9 obs
Cereal	1.9E-5	(4.7E-8 to 4.8E-3)	27 "
Tomato	6.1E-5	(2.1E-6 to 2.0E-4)	7 "
Leguminous crops	3.2E-3	(1.8E-8 to 4.4)	46 "

No data for fruit, leafy vegetables and root crops has been found. There seems however to be a large similarity between the uptake of Cm and Am. Where no data has been found for Cm the corresponding values for Am have been employed.

For the transfer to milk, Ng has suggested $2E-5$ d/l which is similar to other lanthanides. McKellan et al have studied the excretion to the milk of sheep following intravenous injection. The integration gave an equilibrium forage to milk transfer factor of $1.3E-5$ d/l (COU84).

The concentration factor fish/water used:

fresh	30
brackish	25
marine	10

3.15 Comprehension of biological data

In the two tables below the biological values used in the calculations are shown.

Table 1

Element	Distribution factors	
	milk d/l	meat d/kg
Ni	6.7E-3	5.3E-2
Sr	5E-4	6E-4
Mo	7.5E-3	8.0E-3
Nb	2.5E-3	2.8E-1
Pd	6.7E-3	5.3E-3
Sn	1.2E-3	2.5E-3
I	7.0E-3	8.0E-3
Pb	2.6E-4	4.0E-4
Ac	2.5E-5	1.0E-2
Pu	1.0E-7	1.0E-6
Cm	2.5E-5	1.0E-2

Table 2 Concentration and distribution factors for transfer of activity from different reservoirs to food chains

Element	Concentration factors ^{*)}						
	Pasturage	Grain	Green vegetables	Root vegetables	Fish fresh w.	Fish brackishw	Fish sea water
Ni-59	9.5E-2	1.9E-2	1.9E-2	1.9E-2	1.0E2	1.0E2	1.0E2
Ni-63	9.5E-2	1.9E-2	1.9E-2	1.9E-2			
Se-79	6.5	1.5	13	6.5	2.0E3	4.0E3	4.0E3
Sr-90	3.2	1.4	0.5	0.15	20	20	5
Mo-93	0.6	0.12	0.12	0.12	10	10	10
Zr-93	8.5E-4	1.7E-4	1.7E-4	1.7E-4			
Nb-95	4.7E-2	9.4E-3	9.4E-3	9.4E-3	1.0E2	1.0E2	1.0E2
Tc-99	1.0	9.0E-1	1.0E-1	2.0E-1			
Pd-107	1.9E-2	5.0E-3	5.0E-3	5.0E-3	1.0E2	1.0E2	1.0E2
Sn-126	1.0E-1	3.6E-1	4.6E-2	6.0E-2	3.0E3	3.0E3	3.0E3
I-129	2.0E-2	2.0E-1	2.0E-1	2.0E-1			
Pb-210	4.5E-3	1.7E-2	1.8E-3	2.7E-3	3.0E2	3.0E2	3.0E2
Ac-227	1.0E-3	1.0E-5	1.0E-3	1.0E-3	25	2.5	2.5
Pu-239	9.0E-3	3.0E-5	6.0E-5	1.0E-3	3.5	8	29
Cm-242	4.8E-4	1.9E-5	3.2E-3	3.2E-3	30	25	10

*) Bq/kg in food stuffs per Bq/kg in the reservoir, for plants given as dry weight values of the vegetation, otherwise fresh weight.

4 DOSE FACTORS

The dose factors used in these calculations are the weighted committed dose equivalents according to ICRP publ. no 26 (ICRP26).

In ICRP 30 the weighted committed dose equivalent can be obtained for all nuclides. However, some nuclides have been reviewed by Johansson (JOH84). The dose factors used in that calculations are based upon the revision of dose factors performed (JOH84), with 70 years integration time. For those nuclides not included in the revision the values from ICRP have been used.

The dose factors used for getting the conversion factors are shown in Table 5.

Table 3

Dose factors (Sv/Bq) for intake via inhalation and ingestion.

	Inhalation	Ingestion
C-14	5.7E-10	5.7E-10
Ni-59	3.6E-10	5.4E-11
Ni-63	8.4E-10	1.5E-10
Se-79	2.4E-9	2.3E-9
Sr-90	3.4E-7	3.6E-8
Zr-93	8.6E-8	4.2E-10
Mo-93	7.6E-9	3.5E-10
Nb-93m	7.7E-9	1.4E-10
Nb-94	9.0E-8	1.4E-9
Tc-99	2.0E-9	3.4E-10
Pd-107	3.4E-9	3.7E-11
Sn-126	2.3E-8	4.7E-9
I-129	4.7E-8	9.8E-8
Cs-135	1.2E-9	1.9E-9
Cs-137	8.7E-9	1.4E-8
Pb-210	3.4E-6	1.4E-6
Ra-226	2.1E-6	3.3E-7
Ac-227	1.8E-3	4.1E-6
Th-229	5.7E-4	9.4E-7
Th-230	8.6E-5	1.6E-7
Pa-231	3.4E-4	2.2E-5
U-233	3.6E-5	3.1E-7
U-234	3.6E-5	3.0E-7
U-235	3.3E-5	2.8E-7
U-236	3.4E-5	2.9E-7
U-238	3.2E-5	2.7E-7
Np-237	1.3E-4	1.2E-6
Pu-239	1.4E-4	7.0E-7
Pu-241	2.8E-6	2.4E-9
Pu-242	1.3E-4	1.1E-7
Cm-245	1.5E-5	7.5E-7

5 RESULTS AND DISCUSSION

In Table 4, the conversion factors for all nuclides calculated now or previously are given. The leakage is assumed to be a continuous 1 Bq per year. The equilibrium condition is obtained within a few hundred years, however in most cases a relative equilibrium (up to about 90 %) is very quickly obtained.

The doses obtained from the calculations are dominated by the exposure through consumption of fish or water, see Table 5. The only exception is Nb-94. The dominance of the above mentioned pathways agree well with earlier calculations.

In spite of all the factors which can influence the results, it is obvious that the doses are directly proportional to the volume and turnover time used for the water recipients.

Assuming the model used gives a fair description of reality, the uncertainty coupled to the choice of input parameter values can be investigated by use of statistical methods.

One error propagation method named PRISM has been previously used in connection with the BIOPATH-code to determine the dominating contributors to the uncertainty for the continuous release of Cs-137 and Ra-226 to a fresh-water system.

For cesium with a high bioaccumulation factor to fish, the uncertainty was naturally dominated by that accumulation factor while for radium it was dominated by the buildup in soil.

More details regarding the type of lake could then decrease the uncertainty for cesium. It is an example of how the type of ecosystem considered in the calculations can affect the results.

The transfer coefficients used to describe the exchange of the element between the reservoirs are in many cases very difficult to obtain.

However, when the dominating exposure pathways are those associated with the recipient's well or lake it is basically the coefficients coupled to the turnover of water which are sensitive to the results.

Accordingly the use of different consumption values mean a corresponding change in the results.

Another important detail can be mentioned, namely the lack of relevant data for describing the direct retention and turnover time on the surface vegetation of nuclides brought there by the irrigation water.

Table 4

Conversion factors from the release of 1 Bq/year to dose via a well or a lake.

	Individual dose (SvBq/year)		Collective dose manSv/year
	Well	Lake	
C-14	8.8E-14	8.7E-14	2.5E-12
Ni-59	1.0E-16	5.6E-17	6.8E-15
Ni-63	2.4E-16	9.7E-17	6.7E-16
Se-79	2.0E-13	2.3E-13	8.8E-12
Sr-90	6.1E-14	5.3E-13	5.2E-13
Mo-93	5.3E-16	3.2E-16	6.8E-14
Zr-93	3.4E-15	3.8E-15	1.0E-13
Nb-93m	2.4E-16	8.6E-17	1.1E-15
Nb-94	1.3E-12	1.9E-13	3.5E-13
Tc-99	7.3E-16	5.5E-16	6.0E-13
Pd-107	7.6E-17	4.0E-17	9.3E-15
Sn-126	3.3E-13	3.8E-13	6.9E-12
I-129	2.1E-13	2.5E-13	5.8E-9
Cs-135	5.0E-14	5.0E-14	1.9E-12
Cs-137	2.6E-13	2.4E-13	6.6E-13
Pb-210	1.3E-11	1.2E-11	2.0E-10
Ra-226	6.1E-13	4.0E-13	3.3E-12
Ac-227	4.5E-12	8.9E-13	1.6E-10
Th-229	1.1E-12	7.0E-13	2.9E-11
Th-230	1.9E-13	1.9E-13	7.9E-12
Pa-231	2.2E-11	1.2E-11	3.3E-11
U-233	3.4E-13	1.8E-13	8.1E-11
U-234	3.3E-13	1.7E-13	1.1E-10
U-235	3.2E-13	1.6E-13	2.3E-10
U-236	3.2E-13	1.7E-13	2.4E-10
U-238	3.0E-13	1.6E-13	2.2E-10
Np-237	1.5E-12	1.5E-12	3.1E-8
Pu-239	6.4E-13	3.2E-13	2.6E-12
Pu-241	2.1E-15	2.2E-16	6.0E-15
Pu-242	1.0E-13	2.6E-13	5.1E-13
Cm-245	9.5E-13	3.2E-13	4.1E-10

Table 5

Dominant Pathways of exposure at the time of equilibrium in the biosphere (numbers give the dose percentage)

Well

C-14	Fish 93
Ni-59	Fish 47, drinking-water 46, milk 6
Ni-63	Fish 34, drinking-water 53, milk 7
Sr-90 ^a	Fish 31, drinking-water 52, vegetables 16,
Re-93	Fish 20, drinking-water 58, milk 17
Nb-93m	Fish 29, drinking-water 50, meat 16
Nb-94	Ground 99
Pd-107	Fish 43, drinking-water, milk 11
Cs-137	Fish 91, drinking-water 5, meat 2
Pb-210	Fish 90, drinking-water 10
Ac-227	Fish 12, drinking-water 79, meat 9
Pu-241	Fish 2, drinking-water 98,
Cm-245	Fish 21, drinking-water 69, meat 8

Lake

C-14	Fish 95
Ni-59	Fish 86, drinking-water 12, milk 12
Ni-63	Fish 84, drinking-water 12, milk 2
Sr-90 ^a	Fish 36, drinking-water 25, cereals 17 root-fruits 18
Re-93	Fish 33, drinking-water 48, meat 14
Nb-93m	Fish 82, drinking-water 12, meat 4
Nb-94	Ground 95, meat 2
Pd-107	Fish 84, drinking-water 12, milk 3
Cs-137	Fish 98, drinking-water 1
Pb-210	Fish 95, drinking-water 5
Ac-227	Fish 60, drinking-water 35, meat 4
Pu-241	Fish 19, drinking-water 79,
Cm-245	Fish 61, drinking-water 30, meat 5

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TRANSFER COEFFICIENTS FOR SOILS AND SEDIMENTS

Transfer coefficients describing the transport from water to sediment and the migration in the soil and groundwater of nuclides are normally not possible to be found directly in literature. These transfer coefficients have been estimated from physico-chemical data on sorption, water and particulate transport etc in the same way as used in (BER83:1). A brief description of the methods is given below.

Water-sediment

For obtaining the transfer coefficient describing the transport of radionuclides from water to sediment, the following equation has been used:

$$K_{ws} = K_d \cdot S \cdot h_m \cdot (1 + K_d \cdot SS)^{-1}$$

where

K_{ws} = transfer coefficient water-sediment y^{-1}

K_d = distribution coefficient water sediment =
concentration in solid/concentration in
liquid m^3/kg

S = sediment growth rate $kg/m^2, y$

h_m = depth m

SS = concentration of suspended matter in the
water kg/m^3

The following nuclide-independent data have been used:

	Lake	Brackish Sea water	
$S \quad kg/m^2, y$	1.5	0.5	0.01
$h_m \quad m$	10	60	100
$SS \quad kg/m^3$	$3 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-4}$

The following nuclide-dependent distribution coefficients have been used:

Nuclide	Lake	Ref	Brackish	Ref	Sea	Ref
C-14	0.001	ALL80	0.001	ALL80	0.001	ALL80
Ni	10	COU83	10	COU83	10	COU83
Sr	0.1	COU83	0.05	COU83	0.01	COU83
Mo	0.001	JIS85	0.001	JIS85	0.001	
Nb	10		10		10	
Pd	10		10		10	
Sn	0.05		0.05		0.05	
Pb	0.05*	JIS85	0.05	JIS85	0.05	
Ac	10		10		10	
Cm	10	COU84	10	COU84	10	COU84

* Chosen within the range given of JIS85

Nb For most of the nuclides sorption data has been found only for one or two of the types of water discussed. The extrapolations for other conditions have been made using the knowledge of the sorption mechanisms involved and their sensitivity to changes in ionic strength. Cf the main text of this report and also (AND82).

The transfer coefficients are summarized in Table 1.

Soils

The transfer coefficient describing the leakage from soil compartment was obtained from :

$$K_s = \frac{U_w \cdot R}{h} = \frac{U}{h} \frac{w}{1 + K_d \cdot S_p} \frac{(1-\epsilon)}{\epsilon}^{-1}$$

K_s = transfer coefficient [y^{-1}]

U_w = water velocity through compartment [m/y]

h = depth of compartment [m]

R = retention factor = nuclide velocity/water velocity

ϵ = porosity of soil [m^3/m^3]

K_d = distribution coefficient [m^3/kg]

S_p = density of soil particles [kg/m^3]

The following nuclide independent data have been used:

$U_w = 3$ m/y upper 0.3 m

$h = 0.3$ m

$\frac{1-\epsilon}{\epsilon} \cdot S_p = 10^4$ (kg/m^3)

($S_p = 2.5 \cdot 10^3$ kg/m^3 , $\epsilon = 0.2$)

The following distribution coefficients have been used:

Nuclide	K_d	Ref
C	0.001	AND82
Ni	0.005	AND83
Sr	0.1	AND83
Mo	0.001	JIS85
Nb	10	AND79
Pd	0.005	Anal. with Ni
Sn	0.1	Anal. with Pb
Pb	0.1	JIS85
Ac	1.0	JIS85
Cm	0.5	SCH70

Table 1

Transfer coefficients used

Nuclide	From upper soil to deeper soil	Fresh water sediment	Brackish water sediment	Marine w. sediment
C-14	$9.1 \cdot 10^{-1}$	$1.5 \cdot 10^{-4}$	$8.3 \cdot 10^{-6}$	$1.0 \cdot 10^{-7}$
Ni	$2.0 \cdot 10^{-1}$	1.5	$8.3 \cdot 10^{-2}$	$1.0 \cdot 10^{-3}$
Sr	$1.0 \cdot 10^{-2}$	$1.5 \cdot 10^{-2}$	$4.2 \cdot 10^{-4}$	$1.0 \cdot 10^{-6}$
Mo	$9.1 \cdot 10^{-1}$	$1.5 \cdot 10^{-4}$	$8.3 \cdot 10^{-6}$	$1.0 \cdot 10^{-7}$
Nb	$1.0 \cdot 10^{-4}$	1.5	$8.3 \cdot 10^{-2}$	$1.0 \cdot 10^{-3}$
Pd	$2.0 \cdot 10^{-1}$	1.5	$8.3 \cdot 10^{-2}$	$1.0 \cdot 10^{-3}$
Sn	$2.0 \cdot 10^{-2}$	$7.5 \cdot 10^{-3}$	$4.2 \cdot 10^{-4}$	$5.0 \cdot 10^{-6}$
I	$9.1 \cdot 10^{-1}$	$1.5 \cdot 10^{-2}$	$4.2 \cdot 10^{-4}$	$1.0 \cdot 10^{-6}$
Pb	$2.0 \cdot 10^{-2}$	$7.5 \cdot 10^{-3}$	$4.2 \cdot 10^{-4}$	$5.0 \cdot 10^{-6}$
Ac	$1.0 \cdot 10^{-3}$	1.5	$8.3 \cdot 10^{-2}$	$1.0 \cdot 10^{-3}$
Th	$1.0 \cdot 10^{-4}$	1.5	$8.3 \cdot 10^{-2}$	$1.0 \cdot 10^{-3}$
Pa	$1.0 \cdot 10^{-3}$	1.5	$8.3 \cdot 10^{-3}$	$1.0 \cdot 10^{-4}$
Pu	$2.0 \cdot 10^{-5}$	1.5	$8.3 \cdot 10^{-2}$	$1.0 \cdot 10^{-3}$
Cm	$2.0 \cdot 10^{-3}$	1.5	$8.3 \cdot 10^{-2}$	$1.0 \cdot 10^{-3}$

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TR 86-01

I: An analogue validation study of natural radionuclide migration in crystalline rock using uranium-series disequilibrium studies

II: A comparison of neutron activation and alpha spectroscopy analyses of thorium in crystalline rocks

JAT Smellie, Swedish Geological Co, A B MacKenzie and RD Scott, Scottish Universities Research

Reactor Centre

February 1986

TR 86-02

Formation and transport of americium pseudocolloids in aqueous systems

U Olofsson

Chalmers University of Technology, Gothenburg, Sweden

B Allard

University of Linköping, Sweden

March 26, 1986

TR 86-03

Redox chemistry of deep groundwaters in Sweden

D Kirk Nordstrom

US Geological Survey, Menlo Park, USA

Ignasi Puigdomenech

Royal Institute of Technology, Stockholm, Sweden

April 1, 1986

TR 86-04

Hydrogen production in alpha-irradiated bentonite

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TR 86-05

Preliminary investigations of fracture zones in the Brändan area, Finnsjön study site

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February 1986

TR 86-06

Geological and tectonical description of the Klipperås study site

Andrzej Olkiewicz
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Swedish Geological Company
Uppsala, June 1986

TR 86-07

Geophysical investigations at the Klipperås study site

Stefan Sehlstedt
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Swedish Geological Company
Luleå, July 1986

TR 86-08

Hydrogeological investigations at the Klipperås study site

Bengt Gentschein
Swedish Geological Company
Uppsala, June 1986

TR 86-09

Geophysical laboratory investigations on core samples from the Klipperås study site

Leif Stenberg
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Luleå, July 1986

TR 86-10

Fissure fillings from the Klipperås study site

Eva-Lena Tullborg
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Göteborg, June 1986

TR 86-11

Hydraulic fracturing rock stress measurements in borehole Gi-1, Gideå Study Site, Sweden

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April 1986

TR 86-12

PLAN 86— Costs for management of the radioactive waste from nuclear power production

Swedish Nuclear Fuel and Waste Management Co
June 1986

TR 86-13

Radionuclide transport in fast channels in crystalline rock

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TR 86-14

Migration of fission products and actinides in compacted bentonite

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