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Individual doses from radionuclides released to the Baltic coast

Ulla Bergström, Sture Nordlinder

Studsvik AB

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SVENSK KÄRNBRÄNSLEHANTERING AB
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO
BOX 5864 S-102 48 STOCKHOLM
TEL 08-665 28 00 TELEX 13108 SKB S
TELEFAX 08-661 57 19

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ABSTRACT

Individual doses to critical groups from a continuous unit release of nuclides from high-level waste to a coast area were calculated. The selection of nuclides for this study was based on experience of their importance from a radiological point of view. The coastal area should be representative for average conditions along the Swedish Baltic coast. The coastal area was simulated in the model by compartments for water and sediment, respectively. Six exposure pathways for activity from the water and sediment reservoirs were considered. The ecosystem was assumed to be similar to present conditions in Sweden. This was also the case concerning diet and living habits. In addition, the doses from naturally occurring nuclides in the uranium decay chains were calculated, based on natural levels. The calculations were carried out with the BIOPATH and PRISM codes. The latter code was used to obtain the uncertainty in the results due to the uncertainty in the input parameter values.

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1 INTRODUCTION

Nuclides in a repository for high-level waste may due to different processes reach biosphere by transport with ground water. Doses to critical groups from unit releases during 500 years to a fresh water environment were calculated and are reported in /Bergström et al, 1990/. However, the groundwater may instead leak into marine recipients, especially if a potential site for a repository is located at the coast. Dose conversion factors for such a scenario are given in this report. It is assumed that the recipient is somewhere along the Swedish east coast implying a brackish water recipient. Current habits and metabolic conditions of human beings were assumed. In this summary report the conversion factors between unit releases and doses to adults are presented for most nuclides appearing in considerable amounts in high level waste. In addition some nuclides are handled which also belong to the natural decay chain of uranium. For these nuclides doses are also calculated based upon natural occurring concentrations in water and soil.

A brief description of the model used, the exposure pathway considered and the used values of the input parameters are given.

The code BIOPATH /Bergström et al, 1982/ was used for calculations of the turnover of radionuclides in the biosphere and the code system PRISM /Gardner et al, 1983/ for obtaining the ranges of the uncertainty due to the uncertainty and variability in input parameter values.

2 NUCLIDES

Conversion factors were calculated for all radiologically important nuclides contained in high level waste. In addition factors were calculated for those nuclides belonging to the decay-chain of natural uranium but not appearing substantially in high level waste. Contributions from daughter nuclides were considered if they contributed significantly to the total dose. This is the case if the daughter nuclides are so long-lived that a considerable amount can be generated during the time studied. The nuclides treated, half-times and dose factors are shown in Table 2-1. The internal dose factors are the sum of weighted committed organ dose equivalents according to ICRP-standards.

Table 2-1 Nuclides assessed, half-lives and dose factors (Sv/Bq).

Nuclide	Half-life (years)	Inhalation	Ingestion
C-14	5.7E3	5.6E-10 1)	5.6E-10 1)
Se-79	6.4E4	2.4E-9 2)	2.3E-9 2)
Sr-90	2.9E1	6.0E-8 1)	3.5E-8 1)
Zr-93	1.5E6	8.6E-8 2)	4.2E-10 2)
Nb-93m	13.6	7.7E-9	1.4E-10
Tc-99	2.1E5	2.0E-9 2)	3.4E-10 2)
Sn-126	1.0E5	2.3E-8 2)	4.7E-9 2)
I-129	1.6E7	4.0E-8 1)	6.4E-8 1)
Cs-135	2.3E6	1.2E-9 2)	1.9E-9 2)
Cs-137	3.0E1	8.6E-9 1)	1.3E-8 1)
Pb-210	2.2E1	3.4E-6 2)	1.4E-6 2)
Po-210	1.4E2	2.2E-6 2)	5.0E-7 4)
Ra-223	1.1E1*	2.0E-6 2)	1.5E-7 2)
Ra-225	1.5E1*	2.0E-6 2)	3.1E-7 2)
Ra-226	1.6E3	2.1E-6 2)	3.1E-7 2)
Ac-227	2.2E1	1.8E-3 2)	3.8E-6 2)
Th-229	7.3E3	5.7E-4 2)	9.4E-7 2)
Th-230	7.7E4	8.6E-5 2)	1.6E-7 4)
Pa-231	3.2E4	3.4E-4 2)	2.2E-5 3)
U-233	1.6E5	3.6E-5 2)	3.1E-7**
U-234	2.5E4	3.6E-5 2)	3.0E-7**
U-235	7.0E8	3.3E-5 2)	2.8E-7 4)
U-236	2.3E7	3.4E-5 2)	2.9E-7**
U-238	4.5E9	3.2E-5 2)	2.7E-7 4)
Np-237	2.1E6	5.5E-5 1)	4.5E-7 1)
Pu-239	2.4E4	1.2E-4 1)	9.7E-7 1)
Pu-240	6.5E3	1.2E-4***	9.7E-7***
Pu-241	1.4E1	2.3E-6 1)	1.9E-8 1)
Pu-242	3.8E5	1.1E-4***	8.8E-7***
Am-241	4.3E2	1.1E-4 1)	8.9E-7 1)

* Given in days.
** Based upon values for U-235 and U-238 given in Johansson, 1984.
*** Based upon values for Pu-239 and Pu-241 given in ICRP56.

References

1) ICRP56
2) ICRP30
3) Johansson, 1982
4) Johansson, 1984

3 METHODOLOGY

With the objective to simulate the doses to critical group, a two compartment model of the studied biosphere was designed, see Figure 1, where the flows of activity considered are described by arrows. The volume chosen for the water compartment is representitive for east coast conditions and are based upon studies for calculating reference releases for the Swedish nuclear power plants /Sundblad et al, 1983/. The volume used is 2.10^7 m^3 varying between $2 \cdot 10^6$ to $2 \cdot 10^8$ m^3.

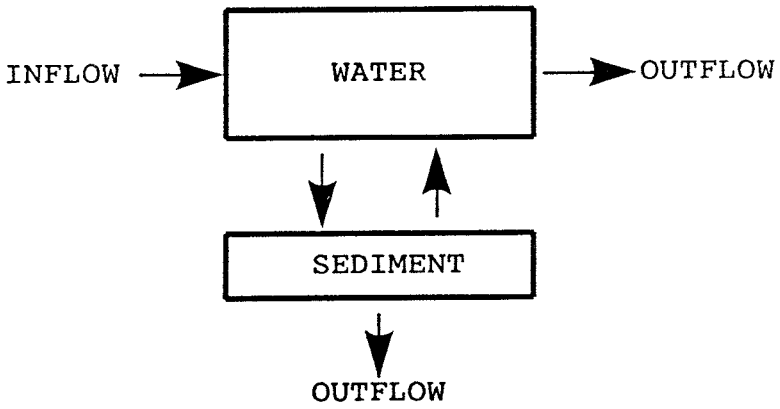

Figure 3-1 Structure of the compartment model.

The nuclides are transferred between the three reservoirs mainly due to turnover of water with streams, transfer from the water to the sediment and resuspension from sediments back to the water and by transfer to deeper situated sediments. The water was deemed to be exchanged in 10 days, leading to a rate constant of 36.5 per year. Rate constants for describing the transfer from water to the sediments were obtained from the following expression:

$$K_{ws} = \frac{K_d \cdot S}{h(1+K_d \cdot SS)}$$

where

K_{ws} = rate constant water to sediment (y^{-1})
S = mass sedimentation rate (kg/m^2 year)
K_d = distribution factor (m^3/kg)
h = depth of the water column (m)
SS = suspended matter (kg/m^3)

The values used with ranges are given in Appendix A.

Transfer to deeper situted sediments was modelled similarily for all nuclides. This is because it was assumed that the major process for this was the annual growth of sediments. Of course there are other processes such as diffusion and bioturbation which redistribute activity within the sediments. However as these processes mostly occur at the upper ten centimeters, which is the assumed height of this compartment, they are a part of the compartmental structure. Values with ranges are given in Appendix A table A-3.

The west and east coast in Sweden have different characteristics. The east coast is along the Baltic Sea which has brackish water while the water of the west coast has a higher content of salt. The choice of location was based upon a summary calculation in order to represent a recipient which should not underestimate the potential doses. If only comparing turn-over rates of water and uptake factors to fish, a location at the east coast would give rise to higher doses than at the west coast. This is because the velocity of the streams is higher at the west coast and the uptake in fish for most nuclides decreases when the salt content in the water increases. However if considering exposure from consumption of algea and shell-fish which is only possible to catch for consumption in the more salt water at the west coast the reverse may be true. Strict comparison of dilution volumes, bioaccumulation factors to fish, marine plants and shell-fish showed that for 11 of the total amount of 27 nuclides the doses could be higher for a west coast location compared to an east coast location. No consideration about the eventual leakage rates of the different nuclides were considered when making this judgement. As a basic assumption we assumed that the coastal area considered is situated along the Swedish east-coast. At this coast it is also possible that other pathways may cause exposure to man than these only related directly to marine products. This is due to cows grazing at the shore-lines where they also may consume brackish water. At the west-coast this does not occur.

In addition overflows and land rise may cause that near-shore fields may be contaminated by the nuclides from the water mass. These processes are for simplicity considered in the model by assuming conservatively that 10 % of the concentration of the nuclides in the sediments are valid for the near-shore fields.

As mentioned earlier, nuclides released to brackish water bodies may lead to internal exposure to man by accumulation in fish flesh. Additionally, if near-shore fields are used for grazing, these can be contaminated due to the processes described above leading to transfer of activity to milk and meat. These foodstuffs may also be contaminated by the animals consumption of brackish water.

Man can also be exposed externally by bathing and sunbathing. These external pathways are considered and it was conservatively assumed that the concentration of the nuclides in the sediments was applicable for the contamination of beaches. Measurements along beaches near to releases of cooling water containing activity from a research reactor did not show any increased levels of activity /Personal communication with S Lampe/. However, in these calculations the releases occur during a period long enogh for the landrise to cause former sediments to become beaches.

Another possible external exposure pathway is handling of contaminated fishing-tackle. However, it is not deemed that any commercial fishing would occur at the local water recipient. Additionally, most of the nuclides treated have low γ-energies. This in combination with the great uncertainty coupled to how this pathway should be described has implied that that pathway has not been taken into account.

Finally, it can not be excluded that the nuclides may be transferred to the air causing exposure by inhalation. The transfer to air is supposed to occur by seaspray.

No Swedish data were found for the transport of nuclides with seaspray. Because of that data from a British study was used /Klos et al, 1989/, however for a main coast. The seaspray enhancement factor is 10 (varying from 3 - 50) for Pb, Po, Ra, Ac, Thm, Pa, U, Np, Pu and Am. For all other nuclides it is 2 (varying from 1 to 3). The seaspray enhancement factor is defined as the ratio of the concentration of a nuclide in seaspray to that of the nuclide in bulk, unfiltered, seawater.

According to the above, the pathways considered in these calculations are:

- consumption of fish
- consumption of milk
- consumption of meat
- inhalation
- bathing
- sunbathing

The calculations were performed assuming a continuous leakage of 1 Bq per year of each nuclide in soluble form to a brackish water recipient during a period of 500 years. No delay or reduction of activity by retardation by sorption in the sediment before reaching the water compartment was considered.

For the nuclides belonging to the natural occurring uranium decay chain doses were calculated for the same exposure pathways but based upon the concentrations of those given in Table 3-1. These concentrations of the nuclides are mostly estimated from natural levels in fresh and sea

water, because of lack of data for the Baltic sea. However, measurements of uranium in the estaurine mixing zone of the Mississipi River /Ivanovich et al, 1982/ were used when estimating a probable average value for the uranium isotopes.

The ranges used cover the fresh and sea water, respectively. The flux of Po-210 to surface water is caused by decay of Rn-222. For example, in the upper 10 cm of a sediment core from Chesapeake Bay, the observed levels were between 70 to 130 Bq/kg which is in agreement with our used best estimate value, cf Table 3-1.

The brief literature survey performed for obtaining the background values of these nuclides is summarized in Appendix A, Tables A-1 to A-2.

The BIOPATH-code was used for solving the differential equations and calculating the doses.

The uncertainty in the results due to the uncertainty in input parameter values was examined with the PRISM-system. Some general data of interest are given in Appendix A, Table A-3.

The uncertainty analyses were carried out for each nuclide. All parameter values with the exception of dose conversion factors were varied.

Table 3-1 Concentration of naturally occurring radionuclides in sediment and water for dose calculations.

Nuclide	Sediment (Bq/kg)		Water (mBq/l)	
	Best estimate	Ranges	Best estimate	Ranges
U-238	10	1 - 100	15	1 - 40
U-234	10	1 - 100	15	1 - 40
Th-230	50	10 - 10	0.015	0.01 - 0.02
Ra-226	80	10 - 200	3	1 - 6
Po-210	100	10 - 1000	1	0.5 - 2
Pb-210	100	10 - 1000	0.2	0.1 - 0.5
U-235	3.5	1 - 10	0.05	0.01 - 2.0
Pa-231	3.5	0.1 - 10	0.05	0.01 - 0.09
Ac-227	3.5	0.1 - 10	0.05	0.01 - 0.09
Ra-223	3.5	0.1 - 10	0.05	0.01 - 0.09

All biological parameters such as root-uptake factors, bioaccumulation factors to fish and steady state factors giving the concentration in milk and meat from continuous intake are shown in Appendix A, Tables A-4 to A-6. It was not possible, however, to find bioaccumulation factors to fish for brackish conditions for all nuclides. For such nuclides factors for fresh-water were used.

The external dose-conversion factors used are given in Appendix A, Table A-8.

4 RESULTS

Results, as arithmetic mean values of the total dose are presented in Table 4-1. All these results do not consider any contributions from daughter nuclides. Such contributions were studied for Zr-93, Th-229 and Th-230, because of experience from earlier calculations /Bergström, 1989/. The daughter products studied are Nb-93m, Ra-225 and Ra-226 respectively. These contributions were only notable for Th-229 and Th-230. Including them the conversion factors would increase with 100 and 13 percent, respectively.

The percentual contributions to the total dose from dominant exposure pathways are given in Table 4-2. The percentual contribution to the total uncertainty from the respective exposure pathway is given within brackets.

Dominant pathway is consumption of fish for all nuclides, see Table 4-2.

In Table 4-3 the annual doses from the naturally occurring nuclides are given. The percentual contribution to the dose via different pathways is shown in Table 4-4.

Table 4-1 Individual doses to critical group from unit releases. Arithmetic mean and ranges corresponding to 2.5 and 97.5 percentiles (Sv/year).

Nuclide	Arithmetic mean	Ranges
C-14	3.5E-17	(0.5 - 17)E-17
Se-79	2.9E-16	(0.4 - 13)E-16
Sr-90	8.2E-18	(0.8 - 3.5)E-18
Zr-93	5.9E-19	(0.7 - 27)E-19
Tc-99	1.8E-19	(0.2 - 8)E-19
Sn-126	3.8E-16	(0.5 - 17)E-16
I-129	4.1E-16	(0.4 - 23)E-16
Cs-135	1.1E-17	(0.1 - 5.4)E-17
Cs-137	6.1E-17	(0.6 - 13)E-16
Pb-210	3.8E-15	(0.6 - 17)E-15
Po-210	4.2E-16	(0.2 - 20)E-16
Ra-223	1.3E-16	(0.2 - 6)E-16
Ra-225	2.9E-16	(0.3 - 13)E-16
Ra-226	7.2E-16	(0.5 - 37)E-16
Ac-227	3.3E-14	(0.3 - 16)E-14
Th-229	9.8E-16	(0.9 - 45)E-16
Th-230	1.7E-16	(0.1 - 7.7)E-16
Pa-231	2.0E-14	(0.1 - 9)E-14
U-233	4.3E-16	(0.5 - 20)E-16
U-234	4.2E-16	(0.5 - 19)E-16
U-235	4.0E-16	(0.4 - 18)E-16
U-236	4.1E-16	(0.5 - 19)E-16
U-238	3.8E-16	(0.4 - 17)E-16
Np-237	5.9E-16	(0.6 - 26)E-16
Pu-239	4.2E-16	(0.2 - 20)E-16
Pu-240	4.2E-16	(0.2 - 20)E-16
Pu-241	7.9E-18	(0.5 - 38)E-18
Pu-242	3.7E-16	(0.2 - 18)E-16
Am-241	7.8E-16	(0.4 - 37)E-16

Table 4-2 Percentual contribution from dominant exposure pathways to the total dose and, within brackets, to the uncertainty.

Nuclide	Fish	Milk	Meat	Beach	Inhalation
C-14	100 (100)				
Se-79	85 (90)	13 (9)	1 (1)		
Sr-90	88 (99)	11 (25)	1 (1)		
Zr-92	95 (97)		5 (3)		
Tc-99	96 (99)	1	3 (1)		
Sn-126	96 (99)	3 (1)			
I-129	86 (89)	13 (11)	1		
Cs-135	67 (68)	16 (17)	16 (15)		
Cs-137	83 (89)	15 (4)	16 (3)	5 (4)	
Pb-210	100 (100)				
Po-210	99 (100)				
Ra-233	97 (97)	3 (3)			
Ra-225	97 (97)	3 (3)			
Ra-226	53 (14)	45 (86)	1		
Ac-117	100 (100)				
Th-229	95 (97)		2 (1)		2 (1)
Th-230	96 (98)		2		2 (1)
Pa-231	94 (98)		6 (2)		
U-233	89 (93)		10 (7)		
U-234	89 (93)		10 (7)		
U-235	88 (92)	1	10 (6)	1	
U-236	89 (93)	1	10 (6)		
U-238	89 (93)	1	10 (6)		
Np-237	89 (94)		10 (5)		
Pu-239	99 (99)				1 (1)
Pu-240	99 (99)				1 (1)
Pu-241	99 (99)				1 (1)
Pu-242	99 (99)				1 (1)
Am-241	99 (100)				

Table 4-3 Individual annual doses to adults from naturally occurring uranium and daughter nuclides in soil and water, arithmetric mean and ranges corresponding to 2.5 and 97.5 percentiles (Sv/y).

Nuclide	Arithmetric	Ranges
U-238	1.8E-5	(0.5 - 3.7)E-5
U-234	2.0E-5	(0.6 - 4.1)E-5
Th-230	5.6E-8	(0.6 - 30)E-8
Ra-226	5.3E-5	(0.2 - 1)E-5
Po-210	3.5E-6	(0.3 - 18)E-6
Pb-210	1.8E-5	(0.2 - 7)E-5
U-235	7.9E-7	(0.7 - 26)E-7
Pa-231	3.1E-6	(0.4 - 7.8)E-6
Ac-227	3.5E-6	(0.4 - 10)E-6
Ra-223	1.0E-6	(0.03 - 7)E-6

Table 4-4 Percentual contribution from dominant exposure pathways to the total dose and within brackets, to the uncertainty for naturally occurring uranium nuclide and decay products.

Nuclide	Fish	Milk	Meat
U-238	87 (81)	1 (1)	12 (18)
U-234	86 (81)	1 (1)	12 (18)
Th-230	9 (6)	6 (-)	84 (94)
Ra-226	5 (-)	92 (100)	3 (-)
Po-210	31 (2)	14 (20)	54 (78)
Pb-210	12 (-)	61 (84)	25 (15)
U-235	65 (44)	2 (3)	33 (54)
Pa-231	64 (53)	1 (1)	35 (42)
Ac-227	100 (100)		
Ra-223	4 (1)	26 (33)	1 (1)

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Appendix A-1

Table A-1a Natural radionuclides in soil (Bq/kg).

Nuclide	Sundblad	Bowen	Eriksson		UNSCEAR	Hallstadius	Landström
			Mean	St dev			
U-238	21-220	24 (8-110)	70	57	25	3-29	6-434
U-234		26 (9-120)	77	61	25		
Th-230	100	100 (3700-16000)*	62	107	25		
Ra-226	39-120	(30 (7-180)	82	96		15-34	40-295
Po-210		8-220					
Pb-210		75-6300*				20 (12-1000)	

* From one abnormal soil containing 750-3000 Bq U-238/kg.

Table A-1b Natural radionuclides in Baltic sediment (Bq/kg).

Nuclide	Sundblad, 1991
U-238	10 (1 - 20)
U-234	10 (1 - 20)
U-235	4 (1 - 10)

Appendix A-2

Table A-2a Natural radionuclides in fresh water (mBq/l).

Nuclide	Bowen	UNSCEAR	Hallstadius	Sundblad	Kulich	Landström
U-238	4.8	25 (0.1 - 50)	0.3 - 47	5 - 36		0.5
U-234	5.2		0.4 - 80			0.5
Th-230	-					
Ra-226	4 - 400	22 (7 - 1800)	0.7 - 20	1 - 29	2 - 2455*	
Po-210	0.5 - 2.6					
Pb-210	3 - 8		2 - 24			

* Ground-water from private wells.

Table A-2b Natural radionuclides in sea water (mBq/l).

Nuclide	Bowen	Iyengar	Iyengar*
U-238	41		
U-235	1.8		
U-234	44		
Th-230	0.015		
Ra-226	3.3	0.7 - 3.7	appr 3 (1.11 - 5.55)
Pa-231	$\leq$ 0.09		
Ra-223	-		
Po-210	0.93		
Pb-210	0.17		

* Brackish water.

Table A-3

Some general input parameter values.

Parameter	B.E.	Type of distr*	Min	Max
Daily demand of water for the live-stock (l/day)	90	T	75	110
Daily consumption of foodstuff for cattle (kg d w/day)	14	T	12	16
Residence time of water in the release box (days)	7	T	3.5	11.5
Mass sedimentation rate (kg/m² year)	0.3	T	0.1	0.5
Suspended matter (kg/m³)	1E-3	T	5E-4	2E-3
Depth of water	9	T	7	11
Volume of water (m³)	2E7	T	2E6	2E8
Sediment density (kg/m³)	1.6E3	T	1.4E3	1.8E3
Sediment depth (m)	0.1	T	0.08	0.12
Resuspension fraction	0.5	T	0.05	0.9

* T = Triangular distribution.
C = Constant.

Table A-4

Distribution coefficients (m^3/kg), sediment brackish water, log-triangularly distributed.

Element	Best estimate	Min	Max	Ref
C	0.001	0.0001	0.01	5
Se	5	1	10	1
Sr	0.1	0.01	1.0	6
Zr	50	5	500	1
Nb	10	1	100	1
Tc	0.1	0.01	1	1
Sn	50	10	100	1
I	0.3	0.1	1	1
Cs	10	1	100	1
Pb	0.05	0.01	0.1	2
Po	5	1	25	7
Ra	10	1	100	3
Ac	10	1	100	2
Th	100	10	1000	4
Pa	100	10	1000	4
U	10	1	100	4
Np	10	1	100	1
Pu	100	10	1000	1
Am	10	1	100	1

Ref
1) Coughtrey et al, 1985
2) Bergström et al, 1985
3) Bergström et al, 1984
4) Bergström et al, 1983
5) Bergström et al, 1987
6) Bergström et al, 1990
7) IAEA Safety Series No. 57

Table A-5

Root uptake factors for pasturage (Bq/kg d w pasturage per Bq/kg d w soil).

Element	Distribution*	Pasturage (dw/dw)	Ranges or geom st dev	Ref
Se	LT	6.5	5E-1 - 7E1	1
Sr	LT	3.2	1 - 7	2
Zr**	LT	5E-3	1E-4 - 1E-2	3
Nb	LT	4E-2	4E-3 - 4E-1	4
Tc	LT	1.0	1E-1 - 1E1	1
Sn	LT	1E-1	1E-2 - 1.0	1
I	LN	6E-1	4.0	1
Cs	LN	5E-2	2.4	1
Pb	LT	2E-2	1E-3 - 1E-1	1
Po**	LT	2E-4	2E-5 - 2E-3	3
Ra	LN	5E-2	2.5	1
Ac	LT	5E-4	3E-5 - 7E-3	1
Th	LT	1E-2	1E-3 - 1E-1	1
Pa	LT	3E-3	3E-4 - 3E-2	1
U	LT	1E-2	1E-3 - 1E-1	1
Np	LT	1E-1	1E-2 - 1	1
Pu	LT	1E-3	7E-5 - 1E-2	1
Am***	LT	5E-4	3E-5 - 7E-3	

* LT = Logtriangular distribution.
LN = Lognormal distribution.

** Assumed ranges.

*** Same as for Ac-227, see Bergström 1990.

1 Bergström et al, 1991, I
2 Bergström et al, 1990, II
3 IAEA, Safety Series No. 57
4 Bergström et al, 1989

Table A-6

Bioaccumulation factors to fish (Bq/kg f w muscle per Bq/l), triangularly distributed.

Element	Best estimate	Geom st dev	Ranges	References
C	4600		3000 - 6000	1
Se	4000		2000 - 8000	2
Sr	5		1 - 20	3
Zr*	60		10 - 100	3
Nb	10		1 - 100	2
Tc	15		1 - 50	1
Sn	3000		1000 - 6000	1
I	200		10 - 500	1
Cs	200		50 - 600	3
Pb	100		50 - 200	1
Po*	50		10 - 100	4
Ra	50		10 - 100	1
Ac	100		10 - 1000	1
Th	30		1 - 100	1
Pa	10		1 - 100	1
U	50		10 - 100	1
Np	50		1 - 100	1
Pu	5		1 - 50	1
Am**	100		10 - 1000	

* Estimated ranges.

** Same as for Ac-227, see Bergström, 1990.

1 Bergström et al, 1990

2 Caughtrey et al, 1985

3 Neumann, 1985

4 IAEA Safety Series No. 57

Appendix A.7

Table A-7

Distribution factors for transfer to milk and meat, logtriangularly distributed.

Element	Milk (day/l)	Ranges or geom st dev	Meat (day/kg)	Ranges or geom st dev	References
C	1E-2	5E-3 - 2E-2	3E-2	1E-2 - 6E-2	1
Se	3E-3	1E-3 - 1E-2	9E-4	1E-4 - 1E-2	1
Sr	8E-4	4E-4 - 3E-3	6E-4	7E-5 - 1E-3	2
Zr**	5E-6	5E-7 - 5E-5	3E-2	3E-3 - 3E-1	3
Nb	3.5E-3	1E-4 - 1E-2	3E-7	2E-8 - 3E-6	4
Tc	1E-4	1E-5 - 1E-3	2E-3	1E-4 - 1E-2	1
Sn	3E-3	1E-3 - 1E-2	1E-3	1E-4 - 1E-2	1
I*	1E-2	1.6	2E-3	2.1	1
Cs*	8E-3	1.6	3E-2	2.1	1
Pb	3E-4	2E-5 - 2E-3	4E-4	4E-5 - 4E-3	1
Po**	1E-4	1E-5 - 1E-3	3E-3	1E-4 - 1E-2	5
Ra*	3E-3	3.9	7E-4	1.2	1
Ac	3E-7	3E-8 - 3E-6	1E-5	1E-6 - 1E-4	1
Th	5E-6	1E-7 - 1E-4	7E-4	1E-4 - 1E-3	1
Pa	5E-5	1E-6 - 1E-4	3E-3	2E-6 - 5E-3	1
U	2E-4	2E-5 - 2E-3	1E-2	1E-3 - 1E-1	1
Np	5E-6	1E-6 - 1E-4	3E-3	2E-4 - 5E-3	1
Pu	1E-7	2E-8 - 3E-7	2E-6	1E-7 - 2E-5	1
Am***	3E-7	3E-8 - 3E-6	1E-5	1E-6 - 1E-4	

* Lognormal distribution.

** Estimated ranges.

*** Same as for Ac-227, see Bergström, 1990.

1 Bergström et al, 1990 I
2 Bergström et al, 1991 II
3 NUREG 77
4 Bergström et al, 1989
5 IAEA Safety Series No. 57

Table A-8

Consumption and habit data, triangular distribution.

	Best estimate	Min	Max
Individuals			
Inhalation (m^3/y)	2920	2000	4000
Milk (l/y)	200	20	400
Meat (kg/y)	55	5	100
Fish (kg/y)	50	25	75
Exposure time, bathing (h/y)	20	10	40
Exposure time, sun-bathing (h/y)	100	50	150

Table A-9

External dose conversion factors for staying on beaches, and bathing /Svensson, 1979 and Kocher, 1989, respectively/.

Nuclide	Beach (Sv/h per Bq/m²)	Bathing (Sv/h per Bq/l)
C-14	-	-
Se-79	-	-
Sr-90	-	-
Zr-93	-	-
Tc-99		-
Sn-126	5.4E-14	3.31E-11
I-129	5.58E-15	1.48E-11
Cs-135	-	-
Cs-137	9.04E-13	3.4E-10
Pb-210	1.24E-15	2.67E-12
Po-210	1.7E-17	4.88E-15
Ra-223	1.62E-13	7.73E-11
Ra-225	5.36E-14	8.06E-12
Ra-226	1.11E-14	3.86E-12
Ac-227	1.44E-16	1.03E-13
Th-229	3.71E-14	5.75E-11
Th-230	5.46E-16	7.03E-12
Pa-231	3.25E-14	2.16E-11
U-233	1.1E-15	6.52E-13
U-234	6.62E-16	8.71E-13
U-235	1.97E-13	8.78E-11
U-236		7.88E-13
U-238	2.55E-17	6.95E-13
Np-237	3.32E-14	1.97E-11
Pu-239	5.9E-17	3.89E-13
Pu-240	1.5E-17	9.08E-13
Pu-241	-	-
Pu-242	-	7.17E-13
Am-241	2.0E-14	1.56E-11

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[1]Enviromental Services, Studsvik Nuclear, Nyköping, Sweden
[2]MBT Tecnologia Ambiental, CENT, Cerdanyola, Spain
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[1]SGAB, Luleå
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[2]KTH, Dpt. of Inorganic Chemistry, Stockholm, Sweden
[3]VTT, Tech. Res. Center of Finland, Espoo, Finland
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[1]Tyréns
[2]Clay Technology AB
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