R-02-28

Nuclide documentation

Element specific parameter values used in the biospheric models of the safety assessments SR 97 and SAFE

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May 2002

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ISSN 1402-3091
SKB Rapport R-02-28

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Abstract

In this report the element and nuclide specific parameter values used in the biospheric models of the safety assessments SR 97 and SAFE are presented. The references used are presented and where necessary the process of estimation of data is described. The parameters treated in this report are distribution coefficients in soil, organic soil and suspended matter in freshwater and brackish water, root uptake factors for pasturage, cereals, root crops and vegetables, bioaccumulation factors for freshwater fish, brackish water fish, freshwater invertebrates and marine water plants, transfer coefficients for transfer to milk and meat, translocation factors and dose coefficients for external exposure, ingestion (age-dependent values) and inhalation (age-dependent values). The radionuclides treated are those which could be of interest in the two safety assessments. Physical data such as half-lives and type of decay are also presented.

Sammanfattning

I den här rapporten presenteras alla ämnes- och nuklidspecifika parametervärden som använts i säkerhetsanalyserna SR 97 och SAFE. Använda referenser presenteras och där så är relevant beskrivs också urvalsprocessen vid bestämning av data. De parametrar som omfattas är följande: fördelningskoefficienter for jord, organisk jord och suspenderat material i söt- respektive brackvatten, rotupptagsfaktorer för betesgräs, spannmål, rotupptag och grönsaker, bioackumulationsfaktorer för sötvattens och brackvattenfisk, sötvattensevertebrater och marina vattenväxter, transferkoefficienter för överföring till mjölk och kött, translokationsfaktorer samt doskoefficienter för extern exponering, intag (åldersberoende data) och inhalation (åldersberoende data). Radionukliderna som inkluderats är sådana som ansågs kunna vara av intresse i de två säkerhetsanalyserna. Fysikaliska data så som halveringstider och sönderfallstyp finns också presenterade.

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1 Introduction

The aim of this study was to gather element and nuclide specific data on the behaviour of radionuclides in the biosphere which are used in dose assessments. The elements studied in this report are those which could be of interest in two earlier safety assessments performed by SKB; SR 97 (for a deep repository of spent nuclear fuel) and SAFE (for the final repository for radioactive operational waste, SFR). The biospheric part of these safety assessments is handled in Bergström *et al* (1999) and Karlsson *et al* (2001), respectively. Basic physical data and dose coefficients have also been included in this report. The aim was also to perform a quality control of the data used and to document the source references. The age-dependent dose coefficients presented here have not been used in these two safety assessments but are presented anyway. Some changes of data have been performed which is clearly marked in the tables.

In Chapter 2 data are sorted according to element with rising atomic number. In Appendix the same data are presented but as tables with different parameters.

The parameters which are handled in this report are presented in the table below.

Parameters treated in this report

Distribution coefficients in:	soil organic soil suspended matter in freshwater suspended matter in brackish water
Root uptake factors for:	pasturage cereals root crops vegetables
Bioaccumulation factors for:	freshwater fish brackish water fish freshwater invertebrates marine waterplants
Transfer coefficients to:	milk meat
Translocation factors	
Dose coefficients for:	external exposure (ground) ingestion (age-dependent values) inhalation (age-dependent values)

2 Elements and nuclides

Data concerning the occurrence of the elements and if they are essential and/or toxic to biota as well as where they tend to accumulate are taken from two sources; Bowen (1979) and Emsley (1989). Information about stable isotopes has been taken from Emsley (1989). The radioactive isotopes found in ICRP 38 (1983) for each element have been listed and the isotopes which are further handled in this report are written in bold letters. The half-lives of the isotopes were taken from Firestone et al (1999). Some of those differ from the half-lives used in SR 97 which is marked in the tables. Dose coefficients for oral intake and inhalation presented in this report are taken from EU (1996) and these have been used in the SAFE study. In SR 97 these data were taken from ICRP (1996) and some data are different which is also marked in the tables. The dose coefficients for inhalation are sometimes given as more than one value to compensate for different speed of the passage through the lungs. In SR 97 these coefficients were taken from ICRP (1996) which recommends that values for medium rate passage through lungs should be used. In SAFE the values were taken from EU (1996) and the highest dose coefficient of that for different passage through the lungs has been used as is prescribed by the authorities. Dose coefficients for external exposure were estimated from Svensson (1979), i.e. the values given in (rad/h)/(Ci/m^3) were converted to (Sv/h)/(Bq/m^3) and multiplied with the nuclide specific organ correction factor for total body.

In the dose assessments performed for SR 97 and the SAFE study external exposure from other emitters than gamma-emitting nuclides has not been considered. External exposure does also occur from beta emitting nuclides if they e.g. are attached to the skin. The exposure is so low anyway that this has been neglected.

In the model system used most parameters are assigned statistical distributions and ranges from which random values are generated. Often, information on real type of distribution for a specific parameter is lacking because of scarcity of data. In these cases the parameters have been given triangular (for narrow ranges) or log-triangular distributions (for ranges over orders of magnitudes), as is recommended by IAEA (1995). Log-triangular distributions are also used for parameters with askewed distributions.

When information about appropriate ranges has been missing minimum and maximum values ten times lower and higher than the best estimate have been used. Values for bioaccumulation factors in brackish water (valid for the Baltic Sea) have not been possible to find for all radionuclides. In these cases values for freshwater have been used. When different values for marine environments and freshwater have been found the highest value has been used. Most often the values for freshwater are higher than those for marine environments since the amount of other elements conquering for uptake is much smaller in freshwater.

The values for translocation (transfer of radionuclides from vegetation surfaces to edible parts) can be quantified in two ways; either as activity concentration in edible parts at harvest per activity retained on 1 m^2 of foliage at the time of deposition ([Bq/kg]/[Bq/m^2]) or as activity in edible parts of 1 m^2 at harvest per activity retained on 1 m^2 of foliage at the time of deposition ([Bq/m^2]/[Bq/m^2]). The later is often expressed as percent. Assuming a vegetation density of 1 kg/m^2 (based on values for different kinds of crops in Sweden (Jordbruksverket & SCB, 1999) these two kind of values are comparable.

A general statement is that radionuclides with short half-lives are less well documented than the long-lived ones as they are of less importance when estimating long-term risk from radioactive waste.

In SR 97 ecosystem specific dose conversion factors (EDFs) for each nuclide considered were presented for the following ecosystems: well, lake, running waters, coast, agricultural land and mire. These factors (expressed in Sv/Bq) can be multiplied with the source terms (in Bq/year) to get the dose rates (in Sv/year). In Bergström *et al* (1999) the importance of different exposure pathways for different nuclides were analysed for all ecosystems and these data have been the base for the discussion about exposure pathways which can be found in the summary section for each element in this report.

2.1 Hydrogen

2.1.1 Physical properties

Occurrence	In atmosphere: 0.53 ppm (volume). Constituent of water, sedimentary and igneous rocks, organic deposits and biota. Essential to all organisms.
Stable isotopes (natural abundance)	H-1 (99.985 %), H-2 (0.015 %)
Radioactive isotopes (half-life)	**H-3 (12.26 years)**
Decay chains:	${}^{3}_{1}H \rightarrow {}^{3}_{2}He$ (stable)

2.1.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3]).

	B.E.	Distr	Low	High	Reference
Soil	–	–	–	–	*
Organic soil	–	–	–	–	*
Suspended matter					
lakes	–	–	–	–	*
brackish water	1E-3	LT	5E-5	1E-2	IAEA, 1985

* Hydrogen does not sorb to particle matter to a large extent and therefore no effort has been put on finding K_d-values since they are missing in e.g. IAEA (1994).

2.1.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil]).

	B.E.	Distr	Low	High	Reference
Pasturage*	5E+1	LT	2E+1	8E+1	***
Cereals**	5E+1	LT	2E+1	8E+1	***
Root crops**	1E+1	T	5E+0	2E+1	***
Vegetables**	1E+1	T	5E+0	2E+1	***

* Dry weight.

** Wet weight.

*** Calculated considering the same concentration of tritium in water in plant as in soil water.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	1E+0	LT	5E-1	2E+0	IAEA, 1994*
Baltic fish	1E+0	LT	5E-1	2E+0	**
Freshwater invertebrates	1E+0	LT	5E-1	2E+0	Thompson *et al*, 1972*
Marine water plants	1E+0	LT	5E-1	2E+0	Thompson *et al*, 1972*

* Accumulation of tritium from water seems not very probable as the element is a constituent of water, instead a somewhat lower uptake of tritium compared to ordinary water may occur as the molecular of tritium is somewhat heavier. This fact has not been considered anyway and the range is set so that it fits in the probabilistic calculations used, i.e. a range given is set so that the value used in the calculations do not differ much from the best estimate given.

** A best estimate of 1 L/kg was recommended in Bergström & Nordlinder (1992) based on Strand *et al* (1976) and Blaylock & Frank (1979).

2.1.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/[Bq daily intake]) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2.0E-2	LT	1.0E-2	3.0E-2	*
Meat (day/kg)	1.0E-2	LT	5.0E-3	2.0E-2	**

* Van den Hoek *et al* (1979) has studied the metabolism of tritium in cattle. The studies showed that secretion of H-3 to milk was 0.016 (average value). This value has been rounded off and a narrow range has been used since tritium is a constituent of water and therefore the variation is considered not to be so large.

** In Bergström *et al* (1991) a model for calculation of dose from tritium was set up. The transfer coefficients used were taken from Neil (1991). A transfer coefficient from vegetation to meat of 0.2 kg/kg grass was used. In SR 97 and SAFE another model approach was used with a transfer coefficient to meat related to the cow's consumption of cereals and grass (not the whole amount of vegetation present in the area as in the former study). With a consumption rate about 20 kg/day (5 kg grass and 12 kg cereals per day in SR 97 and 8.5 kg grass and 11 kg cereals per day in SAFE) and a transfer coefficient of 0.01 day/kg this matches the transfer coefficient from vegetation to meat given by Neil (1991). The range used in SR 97 ($1 \cdot 10^{-3}$–$1 \cdot 10^{-1}$) has been decreased in SAFE. In accordance to other data a narrow range has been used since tritium is a constituent of water and therefore the variation is considered not to be so large.

2.1.5 Translocation

Element specific translocation factor from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Tritium with its short half-life has never been a radionuclide in focus in safety assessments for repositories of nuclear waste so not much effort has been placed on finding data for this nuclide. Translocation should not be of significant importance for this nuclide as it is part of water which, generally said, passes through the vegetation from roots and out through the leaves. A small portion of the water used by vegetation may be taken up from vegetation surfaces but it should not be actively transported to edible parts to a large extent. Anyway, since data are lacking a best estimate of 10 % has been used as for many other elements for which other data have not been found. A rather wide range has been used, as the uncertainty is high. The translocated part should therefore be overestimated which is a conservative approach.

2.1.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
H-3	β	12	0	1.8E-11	2.6E-10*

* The value used in SR 97 is 4.5E-11.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
H-3	6.4E-11	4.8E-11	3.1E-11	2.3E-11	1.8E-11

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
H-3	1.2E-09	1.0E-09	6.3E-10	3.8E-10	2.8E-10

2.1.7 Summary

As a constituent of water, hydrogen is present within almost all kind of environments and in all organisms. Two stable isotopes occur of which H-1 is the most abundant. The only radioactive isotope is tritium (H-3) which has a relatively short half-life (12 years) and because of this tritium has not been an important nuclide in safety assessments for repositories for nuclear fuel or waste. As part of water or hydrogen gas tritium do not sorb to solid matter in soils, sediments or peat to any larger extent. The root uptake in crops is, of course, significant and the transfer to milk and meat in cattle is also of importance. In aquatic organisms do no accumulation to speak of occur. Because of weak β-radiation the dose coefficients for ingestion and inhalation are relatively low and no significant external exposure occur, as it is a beta radiating nuclide. The conclusion is that exposure from tritium is very low in all kinds of ecosystem (coast, lake, mire, agricultural land, well, running waters). The dominant exposure pathway anyway is in the well model of course consumption of water. The dominating pathway in the lake, coastal and running waters models is consumption of milk. In the agricultural land and mire models are consumption of cereals and milk the most important exposure pathways.

2.2 Beryllium

2.2.1 Physical properties

Occurrence	In earth crust 2 ppm, seawater $5 \cdot 10^{-5}$ ppm, small amounts in biota. Accumulates in mammal bone, very toxic to mammals.
Stable isotopes (natural abundance)	Be-9 (100 %)
Radioactive isotopes (half-life)	Be-7 (53.1 days), **Be-10 ($1.51 \cdot 10^6$ years)***
Decay chains:	${}^{10}_{4}\text{Be} \rightarrow {}^{10}_{5}\text{B}$ (stable)

* The half-life used in SR 97 is 1 600 000 years.

2.2.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E+0	LT	1E-1	1E+1	IAEA, 1994
Organic soil	3E+0	LT	3E-1	3E+1	IAEA, 1994
Suspended matter					
lakes	1E+0	LT	1E-1	1E+1	Estimated*
brackish water	1E+0	LT	1E-1	1E+1	Estimated*

* Since no values were found in the literature an estimation was performed. Assuming that beryllium behaves like the elements in the same column in the periodic table the K_d-values for strontium and radium were compared and a value for beryllium was estimated from those. This may be questioned as e g Hägg (1979) states that the first element in each serie of the periodic table behaves somewhat different than the rest of the elements in the serie. As Be was not considered in the SAFE study no effort has been placed on finding better data.

2.2.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E-2	LT	1E-3	1E-1	Davis *et al*, 1993
Cereals**	3E-3	LT	3E-4	3E-2	Davis *et al*, 1993
Root crops**	3E-3	LT	3E-4	3E-2	Davis *et al*, 1993
Vegetables**	3E-3	LT	3E-4	3E-2	Davis *et al*, 1993

* Dry weight. ** Wet weight.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	1E+2	LT	1E+1	1E+3	IAEA, 1994
Baltic fish	2E+2	LT	2E+1	2E+3	NCRP, 1996*
Freshwater invertebrates	1E+1	LT	1E+0	1E+2	Thompson *et al*, 1972
Marine water plants	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

* The value presented for marine fish is used as it is higher than that for freshwater fish (100 L/kg).

2.2.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	9.0E-07	LT	9.0E-8	9.0E-6	Davis *et al*, 1993
Meat (day/kg)	1.0E-3	LT	1.0E-4	1.0E-2	Davis *et al*, 1993

2.2.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
4E-3	T	1E-3	6E-2	*

* Beryllium has never been a radionuclide in focus in safety assessments for repositories of nuclear waste so not much effort has been placed on finding data for this nuclide. In SR 97 (Bergström *et al*, 1999) a best estimate of 0.1 was used (range 0.02-0.3). Data from IAEA (1994) shows lower values, the value for a time period between contamination and harvest of 40 days (which is most relevant for our models) is 0.004 and the highest value (that for a time period of 20 days) is 0.06. Based on this the values has been changed and the values used in the SAFE study (Karlsson *et al*, 2001) is presented in this table.

2.2.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Be-10	β	1 150 000	0	1.1E-9	3.5E-8*

* The value used in SR 97 was 9.6E-9 Sv/Bq.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Be-10	1.4E-8	8.0E-9	4.1E-9	2.4E-9	1.4E-9

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Be-10	9.9E-8	9.1E-8	6.1E-8	4.2E-8	3.7E-8

2.2.7 Summary

Beryllium occurs in small amounts in the biosphere. It is known to accumulate in mammal bone and is very toxic to mammals. One stable isotope occurs and several radioactive ones. The radioisotope of interest for repositories for nuclear fuel and waste is Be-10 which has a half-life of $1.51 \cdot 10^6$ years. The root uptake is relatively low whereas the sorption to solid matter in soil, sediments and peat is intermediate compared to other elements in this study. The transfer to milk is very low whereas that to meat is intermediate (1,000 times higher than to milk). Also accumulation to aquatic organisms is of intermediate level, lowest for freshwater invertebrates and highest for marine water plants. Because of weak β-radiation the dose coefficients for ingestion and inhalation are relatively low and no significant external exposure occur, as it is a beta radiating nuclide. In conclusion exposure from radioactive beryllium is low from all kinds of ecosystem (coast, lake, mire, agricultural land, well, running waters). The dominant exposure pathway in the well model is consumption of water whereas consumption of fish is the most important exposure pathway in the lake, coastal and running waters models. In the agricultural land model consumption of cereals and root crops are the dominating exposure pathways whereas consumption of vegetables, cereals and root crops are the most important pathways for dose in the mire model.

2.3 Carbon

2.3.1 Physical properties

Occurrence	In atmosphere: CO_2 335 ppm (volume), CH_4 1.7 ppm (volume), CO up to 0.02 ppm (volume), earth crust 180 ppm, sea water 28 ppm. Basis of all life (part of DNA). Accumulates in all organisms, essential to all organisms.
Stable isotopes (natural abundance)	C-12 (98.90 %), C-13 (1.10 %)
Radioactive isotopes (half-life)	C-11 (20.4 minutes), **C-14 (5 730 years)**
Decay chains:	${}^{14}_{6}C \rightarrow {}^{14}_{7}N$ (stable)

2.3.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E-3	LT	4E-4	1E-2	*
Organic soil	7E-2	LT	7E-3	7E-1	Davis *et al*, 1993
Suspended matter					
lakes	1E-3	LT	1E-4	1E-2	Bergström & Nordlinder, 1990a**
brackish water	1E-3	LT	1E-4	1E-2	Estimated from McKinley & Scholtis, 1992

* The best estimate and range was defined in Bergström & Nordlinder (1990a) but the minimum value given in the reference has been increased somewhat (before 1E-4). The increase in minimum value has been done by mistake. As the values are very low and the increase is very small too, this change has no influence on the results. The best estimate is originally from Andersson *et al* (1982).

** The best estimate and range are defined in Bergström & Nordlinder (1990a). As no other data were available the same values as for soil was used.

2.3.3 Uptake in biota

No **root uptake** of carbon is considered in the models. Carbon is taken up in vegetation as carbon dioxide gas by special cleavages called stomata. These are located on the green parts of the vegetation especially on leaves.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	5E+4	LT	5E+3	5.1E+4	IAEA, 1994*
Baltic fish	2E+3	T	1.8E+3	3E+3	**
Freshwater invertebrates	9E+3	LT	9E+2	1E+4	Thompson *et al*, 1972
Marine water plants	2E+3	LT	2E+2	1E+4	Thompson *et al*, 1972

* According to experience from an international model comparison study (BIOMOVS, 1996) the range used in SR 97 (Bergström *et al*, 1999), 1 000-60 000 l/kg has been altered (the range given in IAEA, 1995 has been used) in SAFE (Karlsson *et al*, 2001). As the maximum value can not be the same as the best estimate in the model system used, a value of 5 100 l/kg has been used instead of 5 000 l/kg.

** Based on the carbon content in fresh fish and the levels in surrounding water a bioaccumulation factor of about 2 400 l/kg is gained for the Baltic Sea (calculated from carbon amounts given in Hesböl *et al* (1990). The factor is about 1 800 l/kg for the Swedish West coast. A best estimate of 2 000 l/kg has therefore been used.

2.3.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	1.0E-2	LT	5.0E-3	2.0E-2	*
Meat (day/kg)	3.0E-2	LT	1.5E-2	6.0E-2	*

* The best estimates are taken from Bergström & Puigdomenech (1987) with reference to unpublished results by Bergström & Hoffman. The results have not been published but the value used is in accordance with that used by Davis *et al* (1993); $1.5 \cdot 10^{-2}$ day/l for milk and $6.4 \cdot 10^{-2}$ day/kg for meat. Values for carbon are based on the amounts of the stable element in different medium and organisms and as that content do not vary very much for cattle and grass respectively a rather narrow range has been used. The range used for meat in SR 97 ($1 \cdot 10^{-3}$ day/l – $1 \cdot 10^{-1}$ day/l) has been decreased in accordance to this.

2.3.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* No data were found for carbon so an estimation had to be performed. Translocation should not be of significant importance for this nuclide as carbon is fixed from the gas form found in the atmosphere and the part contributed from irrigation water should be a very small part. Anyway, since data are lacking a best estimate of 10 % has been used as for many other elements for which data have not been found. A rather wide range has been used, as the uncertainty is high. The translocated part should therefore be overestimated which is a conservative approach. This process is of importance only in the well model. In the lake model, where irrigation is also implemented, the exposure via consumption of fish is so important that exposure via irrigated crop is not visible in the results.

2.3.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
C-14	β	5 730	0	5.8E-10	5.8E-9*

* The value used in SR 97 is 2.0E-9

Dose coefficients for oral intake for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
C-14	1.4E-09	1.6E-09	9.9E-10	8.0E-10	5.7E-10

Dose coefficients for inhalation for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
C-14	1.9E-08	1.7E-08	1.1E-08	7.4E-09	6.4E-09

2.3.7 Summary

As carbon is the essential part of all living organisms it occurs in all kinds of ecosystems in large amounts. Carbon accumulates in all organisms and is also essential to all organisms. Two stable isotopes occur (C-12 and C-13) and several radioactive ones. The radioactive isotope of interest for dose assessments concerning repositories for nuclear fuel and waste is C-14 with a half-life of 5 730 years. As vegetation mainly fixes the carbon they need from carbon dioxide in the atmosphere no root uptake has been considered in the models. The sorption to solid matter in soils, sediments and peat are very low. The transfer to milk and meat in cattle is high and the uptake in aquatic organisms is high. Because of weak β-radiation the dose coefficients for ingestion and inhalation are low and no significant external exposure occurs, as it is a beta radiating nuclide. In conclusion exposure from radioactive carbon is high in aquatic models (lake, coastal and running waters models) but low in agricultural land, mire and well models. The dominating exposure pathway in the well model is consumption of water whereas consumption of fish is the most important pathway in the lake, running water and coastal models (more than 90 % of the dose comes from this exposure pathway). In the agricultural land and mire models the contribution from consumption of milk and meat dominate the exposure. This foodstuff has been contaminated by the cattle's consumption of contaminated soil only, since no root uptake of carbon is considered in the models.

2.4 Chlorine

2.4.1 Physical properties

Occurrence	In earth crust 126 ppm, sea water 19 000 ppm. Accumulates e.g. in halophytic plants. Essential to all organisms as Cl^-. Highly toxic as Cl_2, ClO^- and ClO_3^-.
Stable isotopes (natural abundance)	Cl-35 (75.77 %), Cl-37 (24.23 %)
Radioactive isotopes (half-life)	**Cl-36 (3.01·10^5 years)**, Cl-38 (37.2 minutes), Cl-39 (55.6 minutes)
Decay chains:	${}^{36}_{17}Cl \rightarrow {}^{36}_{16}S$ (stable) (1.9%) ${}^{36}_{17}Cl \rightarrow {}^{36}_{18}Ar$ (stable) (98.1%)

2.4.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m³])

	B.E.	Distr	Low	High	Reference
Soil	1E-3	LT	1E-4	1E-2	Estimated from McKinley & Scholtis, 1992
Organic soil	1E-2	LT	1E-3	1E-1	*
Suspended matter					
lakes	1E+0	LT	1E-1	1E+1	McKinley & Scholtis, 1992
brackish water	1E-3	LT	1E-4	1E-2	IAEA, 1985

* No value was found in IAEA (1994) so an estimation was performed. Assuming that chlorine behaves like iodine in reducing environments (pers. comm. P-O Aronsson, Ringhals NPP 2001-10-22) a K_d-value close to that used for iodine has been used.

2.4.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	3E+1	T	1E+1	1E+2	Coughtrey *et al*, 1985***
Cereals**	3E+1	T	9E+0	9E+1	Coughtrey *et al*, 1985***
Root crops**	6E+0	T	2E+0	2E+1	Coughtrey *et al*, 1985***
Vegetables**	3E+0	T	1E+0	1E+1	Coughtrey *et al*, 1985***

* Dry weight.

** Wet weight.

*** Coughtrey *et al* (1995) recommend a best estimate between 25 and 50 for “natural vegetation, pasturage herbage, edible vegetables and cereal grain”. A value of 30 has been used for pasturage and this value has been converted into wet weight for cereals, root crops and vegetables assuming water contents of 10, 80 and 90 %, respectively.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	5E+1	LT	1E+1	1E+2	Coughtrey *et al*, 1983
Baltic fish	1E+0	LT	1E-1	1E+1	Coughtrey *et al*, 1985*
Freshwater invertebrates	1E+2	LT	1E+1	1E+3	Thompson *et al*, 1972
Marine water plants	1E-1	LT	1E-2	1E+0	Thompson *et al*, 1972

* The value for marine fish has been used since the behaviour of chlorine in that kind of environment is more similar to that in brackish water than the behaviour in freshwater environonments.

2.4.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	1.7E-2	T	1.5E-2	2.0E-2	IAEA, 1994
Meat (day/kg)	2.0E-2	LT	1.0E-2	4.0E-2	IAEA, 1994

2.4.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* In lack of data a best estimate of 10 % has been used as for many other elements for which data have not been found. A rather wide range has been used, as the uncertainty is high. As chlorine is a bioavailable element (e.g. high root uptake) this values are put on a rather reasonable level.

2.4.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Cl-36	β	301,000	0	9.3E-10	7.3E-9

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Cl-36	9.8E-9	6.3E-9	3.2E-9	1.9E-9	1.2E-9

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Cl-36	3.1E-8	2.6E-8	1.5E-8	1.0E-8	8.8E-9

2.4.7 Summary

Chlorine is an important part of sea water and is also essential to all organisms so it occurs in all kind of ecosystems. Certain kind of organisms such as e.g. halophytic plants accumulates chlorine. Some forms of chlorine (Cl_2, ClO^- and ClO_3^-) are highly toxic. Two stable isotopes occur; Cl-35 (most common) and Cl-37 and several radioactive ones. The radioactive isotope of interest for dose assessments concerning repositories for nuclear fuel and waste is Cl-36 with a half-life of 301,000 years. The root uptake is very high whereas sorption to solid matter in soils, sediments and peat is very low. The transfer to milk and meat in cattle is high whereas accumulation in aquatic organisms does not occur to any significant extent. Because of weak β-radiation the dose coefficients for ingestion and inhalation are low and no significant external exposure occurs. In conclusion exposure from radioactive chlorine is low in the aquatic models (lake, coastal and running waters models) and the well model and intermediate in the agricultural land and mire models. The dominating exposure pathway in the well model is consumption of root crops followed by consumption of water. Consumption of milk is the most important pathway for the lake, coastal and running waters models whereas consumption of cereals and milk dominate the exposure in the agricultural land and mire models.

2.5 Iron

2.5.1 Physical properties

Occurrence	In: earth crust 62 000 ppm, sea water 0.01 ppm. Essential to all organisms. Accumulates in reed blood cells, fish liver, certain bacteria and lichens.
Stable isotopes (natural abundance)	Fe-54 (5.8 %), Fe-56 (91.7 %), Fe-57 (2.2 %), Fe-58 (0.3 %)
Radioactive isotopes (half-life)	Fe-52 (8.3 hours), **Fe-55 (2.7 years)**, Fe-59 (44.5 days), Fe-60 ($1.5 \cdot 10^5$ years)
Decay chains:	${}^{55}_{26}\mathrm{Fe} \rightarrow {}^{55}_{25}\mathrm{Mn}$ (stable)

2.5.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E+1	LT	1E+0	1E+2	Estimated from Coughtrey *et al*, 1985
Organic soil	5E+0	LT	5E-1	5E+1	IAEA, 1994
Suspended matter					
lakes	5E+0	LT	1E+0	1E+1	IAEA, 1994
brackish water	5E+4	LT	3E+1	3E+5	IAEA, 1985*

* The K_d-values for fresh and brackish waters differ very much. As Fe-55 has a short half-life it has not been of interest in any of the safety assessments performed by the authors and therefore no effort has been placed on checking this data more thoroughly.

2.5.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	3E-3	LT	3E-4	3E-2	USNRC, 1977***
Cereals**	7E-4	LT	7E-5	7E-3	USNRC, 1977***
Root crops**	7E-4	LT	7E-5	7E-3	USNRC, 1977***
Vegetables**	7E-4	LT	7E-5	7E-3	USNRC, 1977***

* Dry weight.

** Wet weight.

*** A plant to soil factor of 6.6E-4 was found for Fe in USNRC (1977). This value has been used, for pasturage the value has been converted into dry weight.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	2E+2	LT	5E+1	2E+3	IAEA, 1994
Baltic fish	6E+2	LT	5E+2	1E+4	Coughtrey *et al*, 1985*
Freshwater invertebrates	3E+3	LT	3E+2	3E+4	Thompson *et al*, 1972
Marine water plants	5E+4	LT	5E+2	1E+5	Thompson *et al*, 1972

* Values for marine fish.

2.5.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	1.2E-3	LT	1.2E-4	1.2E-2	USNRC, 1977*
Meat (day/kg)	2E-2	LT	2E-3	5E-2	IAEA, 1994

* In IAEA (1994) a much lower value (3.0E-5) is presented as “expected value”. The higher transfer coefficient from USNRC (1977) has been chosen in order to be conservative.

2.5.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
2E-1	T	1E-1	3E-1	Coughtrey *et al*, 1985

2.5.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Fe-55	EC	2.7	0	3.3E-10	7.7E-10

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Fe-55	7.6E-09	2.4E-09	1.7E-09	1.1E-09	7.7E-10

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Fe-55	4.2E-09	3.2E-09	2.2E-09	1.4E-09	9.4E-10

2.5.7 Summary

Iron is essential to all organisms and it accumulates in reed blood cells, fish liver, certain bacteria and lichens. Four stable isotopes occur; Fe-54, Fe-56 (more than 90 %), Fe-57 and Fe-58 and a number of radioactive ones. The only radioactive isotope which may be of interest for dose assessments concerning repositories for nuclear fuel and waste is Fe-55 which has a relatively short half-life (3 years) and because of this it has not been an important nuclide in earlier safety assessments. Root uptake is low whereas sorption to solid matter in soils, sediments and peat is very high. The transfer to milk and meat in cattle is rather high and accumulation in aquatic organisms is also high (medium for freshwater fish and very high for freshwater crustacean and marine water plants). The dose coefficients of Fe-55 for ingestion and inhalation are low and no external exposure occurs as it disintegrates with electronic capture. Fe-55 was not considered in SR 97 and the SAFE study so no discussion about important exposure pathways is presented here.

2.6 Cobalt

2.6.1 Physical properties

Occurrence	In : earth crust 29 ppm, sea water 0.0005 ppm. Essential trace element (vitamin B_{12}) for all organisms except for perhaps green algae and seed plants. Carcinogenic.
Stable isotopes (natural abundance)	Co-59 (100 %)
Radioactive isotopes (half-life)	Co-55 (17.5 hours), Co-56 (77.3 days), Co-57 (271.8 days), Co-58m (9.15 hours), Co-58 (70.9 days), Co-60m (10.5 minutes), **Co-60 (5.3 years)**, Co-61 (1.7 hours), Co-62m (13.9 minutes)
Decay chains:	$^{60}_{27}\mathrm{Co} \rightarrow ^{60}_{28}\mathrm{Ni}$ (stable)

2.6.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E+0	LT	1E-2	2E+1	IAEA, 1994
Organic soil	1E+0	LT	5E-2	2E+1	IAEA, 1994
Suspended matter					
lakes	5E+0	LT	1E+0	7E+1	IAEA, 1994
brackish water	1E+2	LT	1E+0	2E+2	*

* The best estimate and range are defined in Bergström & Nordlinder (1993). The K_d-values used in that study have been extracted from Coughtrey *et al* (1985), Puigdoménech & Bergström (1995) and McKinley and Scholtis (1992).

2.6.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E-1	LT	1E-2	1E+0	***
Cereals**	1E-1	LT	1E-2	1E+0	***
Root crops**	1E-2	LT	1E-3	1E-1	***
Vegetables**	1E-2	LT	1E-3	1E-1	***

* Dry weight.

** Wet weight.

*** The number of studies concerning cobalt is limited. Data given in IAEA (1994) and Ng *et al* (1982) is of the same magnitude. The data used is extracted from these publications.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	3E+2	LT	1E+1	4E+2	IAEA, 1994*
Baltic fish	3E+2	LT	3E+1	5E+2	**
Freshwater invertebrates	2E+2	LT	2E+1	2E+3	Thompson *et al*, 1972
Marine water plants	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

* The range given in IAEA (1994) has been extended somewhat.

** In Bergström & Nordlinder (1992) a best estimate of 300 l/kg and a range of 20–400 l/kg is recommended for brackish water fish. In Coughtrey & Thorne (1983) a value of 3 l/kg is recommended for fish flesh whereas Poston & Klopfer (1986) recommends much higher values (100 l/kg for marine environments and 330 l/kg for freshwater fish when water quality is unknown). Because of this uncertainty the range has been altered somewhat, i.e. the minimum and maximum values has both been increased.

2.6.4 Metabolism

Transfer coefficients to cow milk and cow meat (Bq/l/Bq daily intake) and (Bq/kg wet weight/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	3.0E-4	LT	6.0E-5	1.0E-2	IAEA, 1994
Meat (day/kg)	1.0E-2	LT	4.0E-5	7.0E-2	IAEA, 1994

2.6.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
2E-1	T	1E-1	3E-1	*

* The best estimate and range are taken from Bergström *et al* (1999) which refers to Coughtrey *et al* (1985). The latter presents a value of up to 15 % and that has been rounded up to 0.2. IAEA (1994) presents values which vary between 0.007-0.05. In order to be conservative these lower values have not been used. The range has been set as for many other elements for which data are lacking.

2.6.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m³)	Ingestion Sv/Bq	Inhalation Sv/Bq
Co-60	β,γ	5.3	2.8E-13	3.4E-9	3.1E-8*

* The value used in SR 97 is 1.0E-8

Dose coefficients for oral intake for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Co-60	5.4E-08	2.7E-08	1.7E-08	1.1E-08	7.9E-09

Dose coefficients for inhalation for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Co-60	9.2E-08	8.6E-08	5.9E-08	4.0E-08	3.4E-08

2.6.7 Summary

Cobalt is essential as a trace element (vitamin B_{12}) for most (if not all) organisms. In seems to be carcinogenic in larger amounts. There is only one stable isotope in nature, Co-59 whereas several radioactive isotopes occur. The only radioactive isotope which may be of interest for dose assessments concerning repositories for nuclear fuel and waste is Co-60 which has a relatively short half-life (5 years) and because of this it has not been an important nuclide in earlier safety assessments. The root uptake is intermediate compared to other elements in this study whereas sorption to solid matter in soils, sediments and peat is high. Transfer to milk is intermediate compared to other elements in this study whereas transfer to meat in cattle is high. Accumulation to aquatic organisms occurs and is intermediate (freshwater and brackish water fish, freshwater crustaceans) to high (marine water plants). The dose coefficients for ingestion and inhalation are of the same magnitude as e.g. Ag-108m and Sn-126 but not as high as those for the actinides. It has a relatively high dose coefficient for external exposure because of the rather high gamma energy. In conclusion exposure from radioactive cobalt is medium to low for the models used (lake, coastal, running waters, agricultural land, mire, well). The dominating exposure pathway in the well model is consumption of water whereas consumption of fish is the most important pathway in the lake, coastal and running waters models. In the agricultural land and mire models consumption of cereals contribute most to the exposure.

2.7 Nickel

2.7.1 Physical properties

Occurrence	In: earth crust 99 ppm, sea water 0.0005 ppm. Essential to some microbes and plants and all vertebrates. Carcinogenic.
Stable isotopes (natural abundance)	Ni-58 (68.27 %), Ni-60 (26.10 %), Ni-61 (1.13 %), Ni-62 (3.59 %), Ni-64 (0.91 %)
Radioactive isotopes (half-life)	Ni-56 (6.1 days), Ni-57 (35.6 hours), **Ni-59 ($7.6 \cdot 10^4$ years)**, **Ni-63 (100.1 years)***, Ni-65 (2.5 hours), Ni-66 (54.6 hours)
Decay chains:	${}^{59}_{28}Ni \rightarrow {}^{59}_{27}Co$ (stable) ${}^{63}_{28}Ni \rightarrow {}^{63}_{29}Cu$ (stable)

* The half-live used for Ni-59 and Ni-63 in SR 97 are 75 000 and 96 years, respectively

2.7.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	5E-1	LT	5E-2	5E+0	IAEA, 1994
Organic soil	1E+0	LT	2E-1	7E+0	IAEA, 1994
Suspended matter					
lakes	1E+1	LT	1E+0	1E+2	McKinley & Scholtis, 1992
brackish water	1E+1	LT	1E+0	1E+2	McKinley & Scholtis, 1992

2.7.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	2E-1	LT	2E-2	2E+0	IAEA, 1994
Cereals**	3E-2	LT	3E-3	3E-1	IAEA, 1994
Root crops**	4E-2	LT	4E-3	4E-1	IAEA, 1994***
Vegetables**	2E-2	LT	2E-3	2E-1	IAEA, 1994***

* Dry weight.

** Wet weight.

*** No values for root crops or vegetables were given in IAEA (1994) so the value for pasturage (in dry weight) was converted into wet weight considering a water content of 80% in root crops and 90% in vegetables.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	1E+2	LT	1E+1	1E+3	IAEA, 1994
Baltic fish	3E+2	LT	3E+1	5E+2	*
Freshwater invertebrates	1E+2	LT	1E+1	1E+3	Thompson *et al*, 1972
Marine water plants	3E+2	LT	3E+1	3E+3	Thompson *et al*, 1972

* The best estimate and range are recommended in Bergström & Nordlinder (1992). The accumulation of nickel in muscles of marine animals is limited (Coughtrey & Thorne, 1983). Due to the small amount of data for nickel these authors recommend data for cobalt to be used instead. The low uptake has also been confirmed by Tjaelve *et al* (1988).

2.7.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2.0E-2	LT	2.0E-3	5.0E-2	IAEA, 1994*
Meat (day/kg)	5.0E-3	LT	5.0E-4	5.0E-2	IAEA, 1994*

* The value given for milk in IAEA (1994) has been rounded off.

2.7.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-2	T	5E-3	4E-2	*

* Data are scarce but according to Coughtrey *et al* (1985) it is assumed that very little nickel is transferred to edible parts. Therefore a low value has been used.

2.7.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Ni-59	β	76 000	0	6.3E-11	4.4E-10*
Ni-63	β	100.1	0	1.5E-10	1.3E-09*

* The value used for Ni-59 in SR 97 is 1.3E-10 Sv/Bq. For Ni-63 a value of 4.8E-10 Sv/Bq was used.

Dose coefficients for oral intake for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Ni-59	6.4E-10	3.4E-10	1.9E-10	1.1E-10	7.3E-11
Ni-63	1.6E-09	8.4E-10	4.6E-10	2.8E-10	1.8E-10

Dose coefficients for inhalation for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1 –2**	**2 – 7**	**7 – 12**	**12 – 17**
Ni-59	1.7E-9	1.5E-9	9.5E-10	5.9E-10	4.6E-10
Ni-63	4.8E-09	4.3E-09	2.7E-09	1.7E-09	1.3E-09

2.7.7 Summary

Nickel is essential to all vertebrates and also to some microbes and plants. It is carcinogenic in high amounts. Five stable isotopes occur in the environment; Ni-58 (most abundant), Ni-60 (about 25%), Ni-61, Ni-62 and Ni-64. The only radioactive isotopes which may be of interest for dose assessments concerning repositories for nuclear fuel and waste are Ni-59 (76,000 years) and Ni-63 (100 years). The root uptake is very high in pasturage but low in cereals, root crops and vegetables. Sorption to solid matter in soils, sediments and peat is rather high. The transfer to milk and meat in cattle is also high, somewhat lower to meat though. Accumulation in aquatic organisms is intermediate compared to the other radionuclides in this study. Because of weak β-radiation the dose coefficients for ingestion and inhalation are low, those for Ni-63 are two to three times higher than for Ni-59. No significant external exposure occurs as the nuclides are beta radiating nuclides. In conclusion the exposure from these two radioactive nickel isotopes are low in all models used (lake, coastal, running waters, agricultural land, mire, well). In the agricultural land model the exposure from Ni-59 are about 200 times higher per released becquerel than for Ni-63. In this model the radionuclides reach the biosphere as contaminated groundwater which migrates upward to the top soil layer of a field where exposure to humans occur. As Ni-63 has a shorter half-life than Ni-59 a larger amount of the nuclides disintegrate before they reach the top soil and therefore the exposure from this nuclide is lower. The dominating exposure pathway in the well model is for Ni-59 consumption of root crops but for Ni-63 consumption of water. This is due to the shorter half-life of the latter, which do not accumulate in soil to the same extent as Ni-59. As a consequence the water becomes more important for this nuclides. In a shorter time perspective (than 10,000 years) the importance of water for exposure from Ni-59 is high in the beginning and decreases as the amount of nuclides in soil increases. Consumption of fish and milk are the most important exposure pathways for both nuclides in the lake, coastal and running waters models whereas consumption of milk, followed by consumption of root crops and cereals are the pathways which contribute most to dose in the agricultural land and mire models.

2.8 Selenium

2.8.1 Physical properties

Occurrence	In: earth crust 0.05 ppm, sea water 0.004 ppm. Essential to some plants and microbes and all vertebrates. Carcinogenic, teratogenic.
Stable isotopes (natural abundance)	Se-74 (0.9 %), Se-76 (9.0 %), Se-77 (7.6 %), Se-78 (23.5 %), Se-80 (49.6 %), Se-82 (9.4 %)
Radioactive isotopes (half-life)	Se-70 (41 minutes), Se-73m (39.8 minutes), Se-73 (7.15 hours), Se-75 (119.8 days), **Se-79 (1.13·10^6 years)**, Se-81m (57.3 minutes), Se-81 (18.5 minutes), Se-83 (22.3 minutes)
Decay chains:	$^{79}_{34}\text{Se} \rightarrow ^{79}_{35}\text{Br}$ (stable)

2.8.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E-2	LT	1E-3	1E-1	Extracted from Coughtrey *et al*, 1985
Organic soil	2E+0	LT	2E-1	2E+1	IAEA, 1994
Suspended matter					
lakes	5E+0	LT	1E+0	1E+1	Coughtrey *et al*, 1985
brackish water	5E+0	LT	1E+0	1E+1	Coughtrey *et al*, 1985

2.8.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	2E+1	LT	1E+0	3E+1	Estimated fromCoughtrey *et al*, 1985***
Cereals**	2E+1	LT	9E-1	3E+1	Estimated from Coughtrey *et al*, 1985***
Root crops**	4E+0	LT	2E-1	6E+0	Estimated from Coughtrey *et al*, 1985***
Vegetables**	2E+0	LT	1E-1	3E+0	Estimated from Coughtrey *et al*, 1985***

* Dry weight.
** Wet weight.
*** In Coughtrey *et al* (1985) a range of ~2 → 66 is presented for "pasturage herbage". A best estimate of 20 has been used and this value has been converted into wet weight for cereals, root crops and vegetables (assuming water contents of 10, 80 and 90%, respectively).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	2E+3	LT	5E+2	5E+3	Extracted from Coughtrey *et al*, 1983
Baltic fish	4E+3	LT	2E+3	8E+3	Extracted from Coughtrey *et al*, 1983
Freshwater invertebrates	2E+2	LT	2E+1	2E+3	Thompson *et al*, 1972
Marine water plants	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

2.8.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	4.0E-3	LT	4.0E-4	4.0E-2	Davis *et al*, 1993
Meat (day/kg)	1.5E-2	LT	1.0E-4	2.0E-2	Davis *et al*, 1993

2.8.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* According to Coughtrey *et al* (1985) selenium is effectively translocated; the foliar absorption is about 30% and of this 20% is found in the roots. This gives a value of 0.06 (0.3*0.2) which is rounded off to 0.1. In cereals as much as 70% of the above-ground burden is said to be found in grain at harvest. This seems to be a very high value and a maximum value of 30% has been used as for many elements for which data are lacking.

2.8.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m³)	Ingestion Sv/Bq	Inhalation Sv/Bq
Se-79	β	1,130 000	0	2.9E-9	6.8E-9*

* The value used in SR 97 is 2.6E-9

Dose coefficients for oral intake for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Se-79	4.1E-8	2.8E-8	1.9E-8	1.4E-8	4.1E-9

Dose coefficients for inhalation for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Se-79	2.3E-8	2.0E-8	1.3E-8	8.7E-9	7.6E-9

2.8.7 Summary

Selenium is essential to all vertebrates as a trace element and it is also needed by some plants and microbes. In large amounts it has been shown to be carcinogenic as well as teratogenic. Six stable isotopes occur in the environment; Se-74, Se-76, Se-77, Se-78 (about 25%), Se-80 (about 50%) and Se-82. Several radioactive isotopes occur but the only one which may be of interest for dose assessments concerning repositories for nuclear fuel and waste. This is Se-79 which has a half-life of 1 130,000 years. The root uptake of selenium is very high and sorption to solid matter in soils is very low whereas sorption in sediments and peat is high. This combination of properties (high root uptake and high sorption) leads to a very high potential for exposure in the mire model. No specific root uptake factors for the mire model has been used instead the same as for agricultural soil was adopted. As root uptake and sorption to solid matters are inversely proportional to each other this simplification may result in overestimated exposure as the sorption properties varies between soil and peat. Transfer to milk is intermediate compared to the other nuclides in this study whereas transfer to meat is rather high. Accumulation in aquatic organisms is high. Because of weak β-radiation the dose coefficients for ingestion and inhalation are low and no significant external exposure occurs as it is a beta radiating nuclide. In conclusion the exposure from Se-79 is very high in the mire model, high in the agricultural land and coastal models and intermediate in the lake, running waters and well models. The dominant exposure pathway in the well model is consumption of root crops whereas consumption of fish is the most important exposure pathway in the lake, coastal and running waters models. Consumption of cereals dominates the contribution to dose in the agricultural land and mire models.

2.9 Strontium

2.9.1 Physical properties

Occurrence	In: earth's crust 384 ppm, sea water 8 ppm. Possibly essential to mammals. Accumulates in vertebrate bone (mimics calcium), by some protozoan and all brown algae.
Stable isotopes (natural abundance)	Sr-84 (0.56 %), Sr-86 (9.86 %), Sr-87 (7.0 %), Sr-88 (82.58 %)
Radioactive isotopes (half-life)	Sr-80 (106.3 minutes), Sr-81 (22.3 minutes), Sr-82 (25.6 days), Sr-83 (32.4 hours), Sr-85m (67.6 minutes), Sr-85 (64.8 days), Sr-87m (2.8 hours), Sr-89 (50.5 days), **Sr-90 (28.8 years)**, Sr-91 (9.6 hours), Sr-92 (2.7 hours)
Decay chains:	${}^{90}_{38}\text{Sr} \rightarrow {}^{90}_{39}\text{Y} \rightarrow {}^{90}_{40}\text{Zr}$ (stable)

2.9.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m³])

	B.E.	Distr	Low	High	Reference
Soil	1E-2	LT	1E-3	1E-1	IAEA, 1994
Organic soil	2E-1	LT	4E-3	6E+0	IAEA, 1994
Suspended matter					
lakes	1E+0	LT	1E-1	1E+1	IAEA, 1994
brackish water	1E-1	LT	1E-2	1E+0	*

* The best estimate is derived from Bergström & Nordlinder (1990b) who treat lake water. It is most possible that this study has used the K_d-value for fresh water used in Bergström & Puigdomenech (1987) (0.1 m^3/kg). This value is originally extracted from Kenna (1980). Coughtrey *et al* (1985) imply a lower value for marine sediments (0.1 m^3/kg) than for freshwater sediments (1 m^3/kg). There is no information about the behaviour of strontium in brackish waters. Because of the short half-life of strontium it has not been in focus in earlier safety assessments and therefore checking data has not been a priority.

2.9.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E+0	LT	4E-1	3E+0	IAEA, 1994
Cereals**	2E-1	LT	2E-2	1E+0	IAEA, 1994
Root crops**	6E-2	LT	1E-2	3E-1	IAEA, 1994
Vegetables**	3E-1	LT	3E-2	3E+0	IAEA, 1994

* Dry weight.

** Wet weight.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	6E+1	LT	1E+0	1E+3	IAEA, 1994
Baltic fish	3E+1	LT	1E+0	1E+2	*
Freshwater invertebrates	1E+2	LT	1E+1	1E+3	Thompson *et al*, 1972
Marine water plants	1E+1	LT	1E+0	1E+2	Thompson *et al*, 1972

* The value is taken from Bergström & Nordlinder (1992). This study recommends a best estimate of 30 l/kg for brackish waters based on recommendations in Patzer (1976) of bioaccumulation factors of 3–10 l/kg for fresh water fish and 0.9–0 l/kg for marine fish. The range given here is set to include these two ranges.

2.9.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2.8E-3	LT	1.0E-3	3.0E-3	IAEA, 1994
Meat (day/kg)	8.0E-3	LT	3.0E-4	1.0E-2	IAEA, 1994*

* The maximum value given in IAEA (1994); $8{\cdot}10^{-3}$ day/kg has been rounded off to $1.0{\cdot}10^{-2}$ day/kg.

2.9.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
4E-1	T	1E-1	7E-1	Coughtrey *et al*, 1995*

* In SR 97 (Bergström *et al*, 1999) IAEA (1994) was given as reference but the values presented there is much lower. The right reference is instead Coughtrey *et al* (1985) which presents translocation factors of 70% for root vegetables (30–70%) and 0.5–13% for cereals. To include this large interval a rather wide range has been used, 0.1–0.7, the arithmetic mean value has been used as best estimate. Lower values (about 2%) in accordance with those in IAEA (1994) is presented by Aarkrog (1994), but in order to be conservative the higher values from Coughtrey *et al* (1985) have been used.

2.9.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m³)	Ingestion Sv/Bq	Inhalation Sv/Bq
Sr-90	β	29	0	2.8E-8	1.6E-07*

* The value used in SR 97 is 3.6E-8

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Sr-90	2.3E-07	7.3E-08	4.7E-08	6.0E-08	8.0E-08

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Sr-90	4.2E-07	4.0E-07	2.7E-07	1.8E-07	1.6E-07

2.9.7 Summary

Strontium mimics calcium and accumulates in vertebrate bone. It is also accumulated by some protozoan and all brown algae. Four stable isotopes occur in the environment; Sr-84, Sr-86, Sr-87, Sr-88 of which the latter dominates totally. Several radioactive isotopes occur but the only one which may be of interest for dose assessments concerning repositories for nuclear fuel and waste. This is Sr-90 which has a half-life of about 30 years. The root uptake of strontium is rather large in pasturage, cereals and vegetables but lower in root crops. Sorption to solid matter varies with matrix, from low sorption in soil to rather high in lake sediments. The transfer to milk and meat in cattle is rather high. Accumulation in aquatic organisms is rather low, highest for freshwater crustaceans. Because of rather strong β-radiation the dose coefficients for ingestion and inhalation are rather high whereas significant external exposure do not occur. In conclusion the exposure from Sr-90 is high in the well model but lower in the other models (lake, coastal, running waters, agricultural land, mire). The dominating exposure pathway is consumption of water followed by consumption of root crops (due to a significant translocation). Consumption of fish is the most important exposure pathway in the lake, coastal and running waters models. In the agricultural land and mire models the dominating exposure pathways are consumption of cereals and vegetables. In the agricultural land model both are of the same importance whereas consumption of vegetables contributes more to dose than consumption of cereals in the mire model.

2.10 Zirconium

2.10.1 Physical parameters

Occurrence	In: earth crust 162 ppm, sea water $2.6 \cdot 10^{-5}$ ppm. Non-essential. Carcinogenic
Stable isotopes (natural abundance)	Zr-90 (51.45 %), Zr-91 (11.32 %), Zr-92 (17.19 %), Zr-94 (17.28 %), Zr-96 (2.76 %)
Radioactive isotopes (half-life)	Zr-86 (16.5 hours), Zr-88 (83.4 days), Zr-89 (78.4 hours), **Zr-93 ($1.53 \cdot 10^{6}$ years)**, Zr-95 (64.0 days), Zr-97 (16.9 hours)
Decay chains:	${}^{93}_{40}\mathrm{Zr} \rightarrow {}^{93}_{41}\mathrm{Nb}$ (stable)

2.10.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E+0	LT	1E-1	1E+1	IAEA, 1994
Organic soil	7E+0	LT	7E-1	7E+1	IAEA, 1994
Suspended matter					
lakes	1E+0	LT	1E-1	1E+1	IAEA, 1994
brackish water	5E+1	LT	5E+0	5E+2	Coughtrey *et al*, 1985*

* Value for marine sediments.

2.10.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E-3	LT	1E-4	1E-2	IAEA, 1994***
Cereals**	9E-4	LT	9E-5	9E-3	IAEA, 1994***
Root crops**	2E-4	LT	2E-5	2E-3	IAEA, 1994***
Vegetables**	1E-4	LT	1E-5	1E-3	IAEA, 1994***

* Dry weight.

** Wet weight.

*** In IAEA (1994) one unspecified value is given. This value has been used for pasturage. For cereals, root crops and vegetables the value has been converted into wet weight (assuming 10% water in cereals, 80% in root crops and 90% in vegetables).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	2E+2	LT	3E+0	3E+2	estimated from IAEA, 1994
Baltic fish	1E+2	LT	1E+1	2E+2	*
Freshwater invertebrates	7E+0	LT	7E-1	7E+1	Thompson *et al*, 1972
Marine water plants	2E+3	LT	2E+2	1E+4	Thompson *et al*, 1972

* The best estimate and range are taken from Bergström & Nordlinder (1992) which refers to Coughtrey & Thorne (1983). In the latter a bioaccumulation factor of 200 l/kg for whole fish and muscle for long-time exposure is recommended whereas a factor of 10 is recommended for muscle concerning short-time exposure. These two values has been used at minimum and maximum values.

2.10.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	6.0E-7	LT	6.0E-8	6.0E-6	IAEA, 1994*
Meat (day/kg)	1.0E-6	LT	1.0E-7	1.0E-5	IAEA, 1994**

* The value given for milk in IAEA (1994) has been rounded off. No ranges are given in the reference.

** In Bergström *et al* (1999) a maximum value of 1E-2 has been used. This is in the same order of magnitude as the value used in Davies *et al* (1994). As the same (low) value was presented in NCRP (1996) this extremely high value was ignored and a lower maximum value was used in SAFE (Karlsson *et al,* 2001).

2.10.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* In SR 97 (Bergström *et al*, 1999) a range of 0.05–0.2 (best estimate 0.1) was used referring to Bergström *et al* (1991) which refers to Coughtrey *et al* (1985). In the latter no data are presented, and therefore the same range as is set for other elements where data are missing, has been used in the SAFE study (Karlsson *et al*, 2001). The best estimate has not been changed as it is the same as that used for other elements lacking further information. A rather wide range has been used as the uncertainty is high.

2.10.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Zr-93	β	1 530 000	0	1.1E-9	2.5E-8*

* The value used in SR 97 is 1.0E-8.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Zr-93	1.2E-9	7.6E-10	5.1E-10	5.8E-10	8.6E-10

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Zr-93	7.0E-9	6.4E-9	5.3E-9	9.7E-9	1.8E-8

2.10.7 Summary

Zirconium is a non-essential element which is carcinogenic. Five stable isotopes occur in the environment; Zr-90, Zr-91, Zr-92, Zr-94 and Zr-96 of which the first is the most abundant. Several radioactive isotopes occur but the only one which may be of interest for dose assessments concerning repositories for nuclear fuel and waste is Zr-93 which has a half-life of 1,530,000 years. Root uptake as well as transfer to milk and meat in cattle are very low whereas sorption to solid matter in soils, sediments and peat is high. Accumulation in aquatic organisms varies, from low in freshwater crustaceans to high in marine water plants. The dose coefficients for ingestion and inhalation are of the same order of magnitude as e.g. Ag-108m and Sn-126 but not as high as those for the actinides. No external exposure occurs as it is a beta radiating nuclide. In conclusion the exposure from

Zr-93 is low in all models (lake, coastal, running waters, agricultural land, mire, well). The dominating exposure pathways in the well model are consumption of water and inhalation of dust which are of equal importance. Consumption of fish is the dominating pathway in the lake, coastal and running waters models. In the agricultural land and mire models consumption of cereals and inhalation of dust are the most important exposure pathways, in the agricultural land model these two are of equal importance whereas inhalation contributes somewhat more to the dose in the mire model.

2.11 Niobium

2.11.1 Physical parameters

Occurrence	In: earth crust 20 ppm, seawater $1 \cdot 10^{-5}$ ppm. Non-essential. Moderately toxic
Stable isotopes (natural abundance)	Nb-93 (100%)
Radioactive isotopes (half-life)	Nb-88 (14.5 minutes), Nb-89 (1.9 hours), Nb-90 (14.6 hours), **Nb-93m (16.1 years)**, **Nb-94 ($2.0 \cdot 10^4$ years)**, Nb-95m (86.6 hours), Nb-95 (35.0 days), Nb-96 (23.4 hours), Nb-97m (52.7 seconds), Nb-97 (72.1 minutes), Nb-98 (51.3 minutes)
Decay chains:	${}^{93m}_{41}Nb \rightarrow {}^{93}_{41}Nb(stable)$ ${}^{94}_{41}Nb \rightarrow {}^{94}_{42}Mo\ (stable)$

2.11.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m³])

	B.E.	Distr	Low	High	Reference
Soil	5E-1	LT	5E-2	5E+0	IAEA, 1994
Organic soil	2E+0	LT	2E-1	2E+1	IAEA, 1994
Suspended matter					
lakes	1E+1	LT	1E+0	1E+2	McKinley & Scholtis, 1992
brackish water	1E+1	LT	1E+0	1E+2	Coughtrey *et al*, 1985

2.11.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	5E-3	LT	5E-4	5E-2	Davis *et al*, 1993
Cereals**	4E-3	LT	4E-4	4E-2	Davis *et al*, 1993
Root crops**	1E-3	LT	1E-4	1E-2	Davis *et al*, 1993
Vegetables**	5E-4	LT	5E-5	5E-3	Davis *et al*, 1993

* Dry weight.

** Wet weight.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	3E+2	LT	1E+2	3E+4	IAEA, 1994
Baltic fish	1E+2	LT	1E+1	5E+2	*
Freshwater invertebrates	1E+2	LT	1E+1	1E+3	Thompson *et al*, 1972
Marine water plants	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

* The best estimate and range are taken from Bergström & Nordlinder (1992). The bioaccumulation factor presented in Thompson *et al* (1972) is 30,000 l/kg which is considerably higher than what has been found by others (ScottRussel, 1966 and Ancellin *et al*, 1979). The latter has measured factors between 1 and 30 in in-situ studies and between 110 and 260 in experiments. Freeke (1967) used a factor of 100 in his calculations and this value has also been used here.

2.11.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	4.0E-7	LT	1.0E-7	4.0E-6	IAEA, 1994*
Meat (day/kg)	3.0E-7	LT	3.0E-8	1.0E-2	IAEA, 1994

* The value given for milk in IAEA (1994) has been rounded off.

2.11.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
2E-1	T	1E-1	3E-1	*

* The best estimate and range are taken from Bergström *et al* (1991) which refers to Coughtrey *et al* (1985). In the latter a translocation for root crops and non root vegetables of 10 to 15% is presented. This has conservatively been rounded to 0.2. For cereals translocation up to 0.45 is presented which seems to be an unreasonable high value. The maximum value has been set to 0.3 instead as is used for elements for which data are lacking.

2.11.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Nb-93m	γ	16.1	5.5E-17	1.2E-10	1.8E-9
Nb-94	β, γ	20 000	1.6E-13	1.7E-9	4.9E-8*

* The value used in SR 97 is 1.5E-9

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Nb-93m	1.5E-9	9.1E-10	4.6E-10	2.7E-10	1.5E-10
Nb-94	1.5E-08	9.7E-09	5.3E-09	3.4E-09	2.1E-09

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Nb-93m	7.4E-9	6.5E-9	4.0E-9	2.5E-9	1.9E-9
Nb-94	1.2E-07	1.2E-07	8.3E-08	5.8E-08	5.2E-08

2.11.7 Summary

Niobium is a non-essential element which is moderately toxic. One stable isotope occurs, Nb-93, but a number of radioactive isotopes. The two isotopes which may be of interest for dose assessments concerning repositories for nuclear fuel and waste are Nb-93m and Nb-94 with half-lives of 16 and 20,000 years respectively. Root uptake and transfer of niobium to milk and meat in cattle are very low whereas sorption to solid matter in soils, sediments and peat is high. Accumulation in aquatic organisms is intermediate compared to the other elements in this study but high for marine water plants. The dose coefficients for ingestion and inhalation are rather high for Nb-94 and about ten times lower for Nb-93m. Due to differences in gamma radiation the dose coefficient for external exposure in high for Nb-94 but low for Nb-93m. In conclusion the exposure from Nb-94 is intermediate to low for all models (lake, coastal, running waters, agricultural land, mire, well) used in SR 97. Nb-93m was not considered in SR 97 but in SAFE. The dominating exposure pathway for Nb-93m in the well model is consumption of water followed by consumption of root crops. In the lake and coastal models consumption of fish is the most important pathway. Consumption of cereals is the dominating contributor to dose in the agricultural land and mire models. External exposure is the dominating exposure pathway for Nb-94 in the well, agricultural land and mire models whereas consumption of fish is the dominant contributor to dose in the lake and coastal models.

2.12 Molybdenum

2.12.1 Physical properties

Occurrence	In: earth crust 1.2 ppm, seawater 0.01 ppm. Essential to all organisms. Moderately toxic, teratogenic.
Stable isotopes (natural abundance)	Mo-92 (14.84 %), Mo-94 (9.25 %), Mo-95 (15.92 %), Mo-96 (16.68 %), Mo-97 (9.55 %), Mo-98 (24.13 %), Mo-100 (9.63 %)
Radioactive isotopes (half-life)	Mo-90 (5.6 hours), Mo-93m (6.9 hours), **Mo-93 ($4.0 \cdot 10^3$ years)***, Mo-99 (65.9 hours), Mo-101 (14.6 minutes)
Decay chains:	${}^{93}_{42}\text{Mo} \rightarrow {}^{93}_{41}\text{Nb}$ (stable)

* The half-life used in SR 97 is 3 500 years

2.12.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E-1	LT	1E-2	1E+0	IAEA, 1994
Organic soil	3E-2	LT	3E-3	3E-1	IAEA, 1994
Suspended matter					
lakes	1E-3	LT	1E-4	1E-2	*
brackish water	1E-3	LT	1E-4	1E-2	*

* The best estimate is taken from Aggeryd & Bergström (1990). In that report the same K_d-values were used for sediments as for soil. The value is originally from Jiskra (1985) which refers to Inoue & Morisawa (1974). The same value has been used for freshwater and brackish water.

2.12.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	8E-1	LT	8E-2	8E+0	IAEA, 1994***
Cereals**	7E-1	LT	7E-2	7E+0	IAEA, 1994***
Root crops**	2E-1	LT	2E-2	2E+0	IAEA, 1994***
Vegetables**	8E-2	LT	8E-3	8E-1	IAEA, 1994***

* Dry weight.

** Wet weight.

*** In IAEA (1994) one unspecified value is given. This value has been used for pasturage. For cereals, root crops and vegetables the value has been converted into wet weight (assuming 10% water in cereals, 80% in root crops and 90% in vegetables).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	1E+1	LT	1E+0	1E+2	IAEA, 1994
Baltic fish	1E+1	LT	1E+0	5E+1	*
Freshwater invertebrates	1E+1	LT	1E+0	1E+2	Thompson *et al*, 1972**
Marine water plants	1E+1	LT	1E+0	1E+2	Thompson *et al*, 1972**

* The best estimate and range are taken from Bergström & Nordlinder (1992) which refers to Short *et al* (1971).

** In Bergström *et al* (1999) triangular distributions were wrongly written in the table for these two bioaccumulation factors. Log-triangular distributions have been used.

2.12.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2.0E-3	LT	2.0E-4	2.0E-2	IAEA, 1994*
Meat (day/kg)	1.0E-3	LT	1.0E-4	1.0E-2	IAEA, 1994*

* In SR 97 a mix-up between the values for milk and meat has been done, i.e. the value for milk given IAEA (1994) has been used for meat and vice versa. This has been corrected in the SAFE study.

2.12.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* According to Coughtrey *et al* (1985) a tentative value could be 10 % to roots. This value has been used as a best estimate. The range has been set as for many elements for which data have not been found. A rather wide range has been used as the uncertainty is high.

2.12.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Mo-93	EC	4 000	0	3.1E-9	2.3E-09*

* The value used in SR 97 is 5.9E-10.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Mo-93	7.9E-9	6.9E-9	5.0E-9	4.0E-9	3.4E-9

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1 –2**	**2 – 7**	**7 – 12**	**12 – 17**
Mo-93	6.0E-9	5.8E-9	4.0E-9	2.8E-9	2.4E-9

2.12.7 Summary

Molybdenum is essential to all organisms as a trace element. It is moderately toxic and also teratogenic in high concentrations. A number of isotopes occur, stable as well as radioactive. The stable ones are Mo-92, Mo-94, Mo-95, Mo-96, Mo-97, Mo-98 and Mo-100 of which Mo-98 is the most abundant. The only radioactive isotope which is of interest for dose assessments concerning repositories for nuclear fuel and waste is Mo-93 which has a half-life of 4 000 years. Sorption to solid matter is low in sediments and peat but somewhat higher in soils. The root uptake of molybdenum is rather high in pasturage, cereals and root crops but lower in vegetables. The transfer to milk and meat in cattle are rather high whereas accumulation in aquatic organisms is low. The dose coefficients for ingestion and inhalation are low and no significant external exposure occurs as it disintegrates with electron capture. In conclusion the exposure from Mo-93 is high in the agricultural land model but intermediate to low for all the others (lake, coastal, running waters, mire, well). The dominating exposure pathway in the well model is consumption of root crops followed by consumption of water. Consumption of cereals is the most important pathway in the lake, running waters, agricultural land and mire models whereas consumption of fish and milk contribute most to dose in the coastal model.

2.13 Technetium

2.13.1 Physical properties

Occurrence	In: earth crust 0.0007 ppm, seawater 0 ppm. Non-essential.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Tc-93m (43.5 minutes), Tc-93 (2.75 hours), Tc-94m (52.0 minutes), Tc-94 (293 minutes), Tc-95m (61 days), Tc-95 (20.0 hours), Tc-96m (51.5 minutes), Tc-96 (4.28 days), Tc-97m (90.1 days), Tc-97 ($2.6 \cdot 10^6$ years), Tc-98 ($4.2 \cdot 10^6$ years), Tc-99m (6.0 hours), **Tc-99 ($2.11 \cdot 10^5$ years)***, Tc-101 (14.2 minutes), Tc-104 (18.3 minutes)
Decay chains:	${}^{99}_{43}Tc \rightarrow {}^{99}_{44}Ru$ (stable)

* The half-life used in SR 97 is 213 000 years

2.13.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	5E-3	LT	1E-3	1E-2	Estimated from Hoffman & Baes, 1979*
Organic soil	2E-3	LT	4E-5	6E-2	IAEA, 1994
Suspended matter					
lakes	1E-1	LT	1E-2	1E+0	Coughtrey *et al*, 1985
brackish water	1E-1	LT	1E-2	1E+0	Coughtrey *et al*, 1985

* The observed range given in Hoffman & Baes (1979) is 0.007–2.8 l/kg. The best estimate given here is found in the upper part of this range and the range is shifted according to this to give a conservative value since root uptake in crops is calculated from the part of radionuclides in soil sorbed to the soil particles.

2.13.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	8E+0	LT	8E-1	8E+1	IAEA, 1994
Cereals**	6E-1	LT	6E-2	3E+0	IAEA, 1994***
Root crops**	5E-2	LT	5E-3	5E-1	IAEA, 1994***
Vegetables**	2E+1	LT	1E-1	8E+1	Extracted from IAEA, 1994***

* Dry weight.

** Wet weight.

*** For cereals, root crops and vegetables the value from IAEA (1994) has been converted into wet weight (assuming 10% water in cereals, 80% in root crops and 90% in vegetables). For vegetables the highest value was not chosen i.a. because technetium is known to age in soil so that the root uptake decrease with time (Eriksson, 1981).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	2E+1	LT	2E+0	8E+1	IAEA, 1994
Baltic fish	3E+1	LT	1E+0	1E+2	*
Freshwater invertebrates	5E+0	LT	5E-1	5E+1	Thompson *et al*, 1972
Marine water plants	4E+3	LT	4E+2	1E+4	Thompson *et al*, 1972

* The best estimate and range are taken from Bergström & Nordlinder (1992) based on the following information; Blaylock & Frank (1982) measured bioaccumulation factors from 11 to 121 l/kg for different fish species in a small pond. Laboratory experiments with marine fish show lower factors, about 2 l/kg (Masson *et al*, 1989). Pentreath measured an average value of 11 l/kg (Pentreath, 1981) whereas Verthé *et al* (1986) measured a bioaccumulation factor of 0.2 l/kg in marine environment for *Serranus cabrilla*. As is said in Beasley & Loez (1986) the uptake of technetium is considered to be low in fish.

2.13.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2.0E-5	LT	1.0E-5	1.0E-3	IAEA, 1994*
Meat (day/kg)	1.0E-4	LT	1.0E-5	1.0E-3	IAEA, 1994

* The value given for milk in IAEA (1994) has been rounded off. The range given has been increased somewhat.

2.13.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
5E-3	T	4E-3	6E-3	*

* The best estimate and range are taken from Bergström *et al* (1991) which refers to Coughtrey *et al* (1985). According to the latter only 0.5% is translocated to edible parts as it is primarily translocated to leaves. By mistake a value of 50% (0.5) has been used instead. As technetium is a bioavailable element (e.g. high root uptake factor) it is not unlikely that also the translocation factor should have a high value. Therefore this mistake has passed by unnoticed and the hundred times to high value was used in SR 97 (Bergström *et al*, 1999) as well as in the SAFE study (Karlsson *et al*, 2001).

2.13.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Tc-99	β	211 000	0	6.4E-10	1.3E-8*

* The value used in SR 97 is 4.0E-9 Sv/Bq.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Tc-99	1.0E-08	4.8E-09	2.3E-09	1.3E-09	8.2E-10

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Tc-99	4.1E-08	3.7E-08	2.4E-08	1.7E-08	1.5E-08

2.13.7 Summary

Any stable isotope of technetium does not occur and it is not essential to organisms. A large number of radioactive isotopes exists, the only one which is of interest for dose assessments concerning repositories for nuclear fuel and waste is Tc-99 which has a half-life of 211,000 years. The root uptake of technetium varies, from intermediate compared to the other elements in this study for vegetables to very high for uptake in pasturage. Sorption to solid matter is low in lake and Baltic Sea sediments and very low in soils and peat. Transfer to milk and meat in cattle is very low and also accumulation in aquatic organisms, except for marine water plants which accumulates technetium to a large extent. The dose coefficients for ingestion and inhalation are low and no external exposure occurs as it is a beta radiating nuclide. In conclusion the exposure from Tc-99 is low in all models (lake, coastal, running waters, agricultural land, mire, well). The dominating exposure pathway in the well model is consumption of vegetables followed by consumption of water and root crops. In the lake and running waters models a number of exposure pathways are of importance. Most contribution to dose comes from consumption of vegetables whereas consumption of cereals, root crops water and fish are of the same importance. The dominating exposure pathway in the coastal model is consumption of fish whereas consumption of vegetables is most important in the agricultural land and mire models.

2.14 Ruthenium

2.14.1 Physical properties

Occurrence	In: earth crust 0.0001 ppm, seawater <1·10^{-10} ppm. None-essential. RuO_4 is highly toxic to mammals.
Stable isotopes (natural abundance)	Ru-96 (5.52 %), Ru-98 (1.88 %), Ru-99 (12.7 %), Ru-100 (12.6 %), Ru-101 (17.0 %), Ru-102 (31.6 %), Ru-104 (18.7 %)
Radioactive isotopes (half-life)	Ru-94 (51.8 minutes), Ru-97 (2.9 days), Ru-103 (39.3 days), Ru-105 (4.4 hours), **Ru-106 (373.6 days)**
Decay chains:	${}^{106}_{44}Ru \rightarrow {}^{106}_{45}Rh \rightarrow {}^{106}_{46}Pd$ (stable)

2.14.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E-1	LT	3E-3	1E+0	IAEA, 1994
Organic soil	7E+1	LT	4E+1	1E+2	IAEA, 1994
Suspended matter					
lakes	1E-1	LT	1E-2	1E+0	NCRP, 1996
brackish water	1E+0	LT	1E-1	1E+1	IAEA, 1985

2.14.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	9E-2	LT	9E-3	9E-1	IAEA, 1982***
Cereals**	8E-3	LT	8E-4	8E-2	IAEA, 1982***
Root crops**	8E-3	LT	8E-4	8E-2	IAEA, 1982***
Vegetables**	8E-3	LT	8E-4	8E-2	IAEA, 1982***

* Dry weight.

** Wet weight.

*** That uptake of ruthenium to vegetation in general is low is also evident in Ng (1982).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	1E+1	LT	5E-1	2E+2	IAEA, 1994*
Baltic fish	1E+1	LT	1E+0	1E+2	**
Freshwater invertebrates	3E+2	LT	3E+1	3E+3	Thompson *et al*, 1972
Marine water plants	2E+3	LT	2E+2	2E+4	Thompson *et al*, 1972

* In IAEA (1994) an expected value of 10 l/kg with a range of 20–200 is presented. As the minimum value can not be the same as the best estimate in the model system used, a somewhat lower value has been used.

** The best estimate and range are taken from Bergström & Nordlinder (1992). Coughtrey & Thorne (1983) recommends bioaccumulation factors between 10 and 100 l/kg for whole fish whereas the values for muscle are about 100 times lower (Pentreath, 1977). Considerably higher values, average 70 and 170 l/kg for Ru-106 and Ru-103 respectively, have been measured in muscles from fish from Donau (Herrmann *et al*, 1975). In order not to underestimate the uptake a best estimate of 10 is recommended for brackish water.

2.14.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	3.3E-6	LT	1.0E-7	2.0E-5	IAEA, 1994
Meat (day/kg)	5.0E-2	LT	1.0E-4	4.0E-1	IAEA, 1994*

* The best estimate is the value presented for “beef” in IAEA (1994). The range has been estimated from the same reference; a range of 1E-2–4E-1 is presented for veal meat whereas the presented range for beef is 1E-4–5E-2. As the behaviour of this radionuclide is not very well known (it has not been an important nuclide in earlier dose assessments) the range has been set to include also the larger values for veal meat in order not to underestimate the dose to humans.

2.14.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
2E-2	T	2E-3	5E-2	IAEA, 1994*

* According to the data presented in IAEA (1994) the translocation factor decreases with increasing time between contamination and harvest. The highest value is here used as the maximum value whereas the value presented for a time period of 60 days between contamination and harvest is used as the minimum value. The value for a time period of 40 days (most relevant for the model used) is used as best estimate. According to Coughtrey *et al* (1985) the translocation for ruthenium in cereals is less than 0.01%. These data have not been considered though, in order not to underestimate the exposure to man.

2.14.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m³)	Ingestion Sv/Bq	Inhalation Sv/Bq
Ru-106	β	1	2.0E-14	7.0E-9	6.6E-8

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Ru-106	8.4E-08	4.9E-08	2.5E-08	1.5E-08	8.6E-09

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Ru-106	2.6E-07	2.3E-07	1.4E-07	9.1E-08	7.1E-08

2.14.7 Summary

Ruthenium is a none-essential element. The chemical form RuO_4 is highly toxic to mammals. Ruthenium occurs in a number of forms, stable as well as radioactive. The stable forms are Ru-96, Ru-98, Ru-99, Ru-100, Ru-101, Ru-102 and Ru-104 of which Ru-102 is the most abundant. The radioactive isotope which may be of interest for dose assessments concerning repositories for nuclear fuel and waste is Ru-106 which has a half-life of 374 days. The root uptake of ruthenium is rather low. Sorption to solid matter are intermediate compared to the other elements in this study for soils and lake sediments and high for Baltic Sea sediments and peat. Transfer to milk is very low whereas transfer to meat is high. Accumulation in aquatic organisms is high for marine water plants and intermediate for freshwater fish and crustaceans and brackish water fish. Due to rather high emission energies the dose coefficients for ingestion, inhalation and external exposure are rather high for Ru-106. Ru-106 was not considered in SR 97 and the SAFE study so no discussion about important exposure pathways is presented here.

2.15 Palladium

2.15.1 Physical properties

Occurrence	In: earth crust 0.015 ppm, seawater <1·10^{-10} ppm. Non-essential. Very toxic to fungi.
Stable isotopes (natural abundance)	Pd-102 (1.02 %), Pd-104 (11.14 %), Pd-105 (22.33 %), Pd-106 (27.33 %), Pd-108 (26.46 %), Pd-110 (11.72 %)
Radioactive isotopes (half-life)	Pd-100 (3.6 days), Pd-101 (8.5 hours), Pd-103 (17.0 days), **Pd-107 (6.5·10^6 years)**, Pd-109 (13.7 hours)
Decay chains:	$^{107}_{46}\text{Pd} \rightarrow ^{107}_{47}\text{Ag}$ (stable)

2.15.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	2E-1	LT	2E-2	2E+0	IAEA, 1994
Organic soil	7E-1	LT	7E-2	7E+0	IAEA, 1994
Suspended matter					
lakes	2E+0	LT	2E-1	2E+1	Estimated from McKinley & Scholtis, 1992
brackish water	1E+1	LT	1E+0	1E+2	Estimated from McKinley & Scholtis, 1992

2.15.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	2E-1	LT	2E-2	2E+0	***
Cereals**	3E-2	LT	3E-3	3E-1	***
Root crops**	4E-2	LT	4E-3	4E-1	***
Vegetables**	2E-2	LT	2E-3	2E-1	***

* Dry weight.

** Wet weight.

*** Due to lack of data the same values as for nickel has been used, as recommended in Bergström *et al* (1985) referring to Grogan (1985b). Pt is considered to be a better analogue for Pd (Moody, 1982) but no data were available for this element either.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	1E+2	LT	1E+1	1E+3	*
Baltic fish	1E+1	LT	1E+0	1E+2	NCRP, 1996
Freshwater invertebrates	3E+2	LT	3E+1	3E+3	Thompson *et al*, 1972
Marine water plants	2E+3	LT	2E+2	1E+4	Thompson *et al*, 1972

* Due to lack of data the same values as for nickel has been used, as recommended in Bergström *et al* (1985) referring to Grogan (1985b). That study concerns root uptake but a similar behaviour between palladium and nickel can also be expected in aquatic environments. Pt is considered to be a better analogue for Pd (Moody, 1982) but no data were available for this element either.

2.15.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	1.0E-3	LT	1.0E-4	1.0E-2	*
Meat (day/kg)	1.0E-3	LT	1.0E-4	1.0E-2	*

* The amount of data concerning the metabolism of palladium is not large, e.g. no values are found in IAEA (1994). The values given in NCRP (1996) and those used in Davis *et al* (1993) differ very much. For milk a value of $1{\cdot}10^{-4}$ day/L is presented by NCRP and $1{\cdot}10^{-2}$ day/L is used by Davis *et al*. The values for meat are $2{\cdot}10^{-4}$ day/kg (NCRP) and $4{\cdot}10^{-3}$ day/kg (Davis *et al*). The values used here are set to include these ranges.

2.15.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Since data are lacking a best estimate of 10% has been used as for many other elements for which data have not been found. A rather wide range has been used, as the uncertainty is high.

2.15.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Pd-107	β	6 500 000	0	3.7E-11	5.9E-10*

* The value used in SR 97 is 8.5E-11.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Pd-107	4.4E-10	2.8E-10	1.4E-10	8.1E-11	4.6E-11

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Pd-107	2.2E-9	2.0E-9	1.3E-9	7.8E-10	6.2E-10

2.15.7 Summary

Palladium is a non-essential element which is very toxic to fungi. It exists in a large number of stable as well as radioactive isotopes. The stable ones are Pd-102, Pd-104, Pd-105, Pd-106, Pd-108 and Pd-110 of which Pd-106 and Pd-108 are the most abundant. The radioactive isotope which is of interest for dose assessments concerning repositories for nuclear fuel and waste is Pd-107 which has a half-life of 6 500 000 years. The root uptake of palladium is rather low, somewhat higher in pasturage. Sorption to solid matter in soils, sediments and peat is intermediately compared to the other elements in this study whereas the transfer to milk and meat in cattle is rather high. Accumulation in aquatic organisms varies, from low for freshwater and brackish water fish to high for marine water plants. Because of weak β-radiation the dose coefficients for ingestion and inhalation are rather low and no significant external exposure occurs. In conclusion the exposure from Pd-107 is very low for all models (lake, coastal, running waters, agricultural land, well). The dominating exposure pathways for the well model are consumption of root crops and water (about the same importance). Consumption of fish is the most important pathway for the lake, coastal and running waters models. In the agricultural land and mire models consumption of root crops and cereals and also to some extent consumption of vegetables are the most important exposure pathways.

2.16 Silver

2.16.1 Physical properties

Occurrence	In: earth crust 0.08 ppm, seawater 0.0003 ppm. Non-essential. Toxic to lower organisms but not animals. Suspected carcinogen.
Stable isotopes (natural abundance)	Ag-107 (51.83 %), Ag-109 (48.17 %)
Radioactive isotopes (half-life)	Ag-102 (12.9 minutes), Ag-103 (65.7 minutes), Ag-104m (33.5 minutes), Ag-104 (69.2 minutes), Ag-105 (41.3 days), Ag-106m (8.3 days), Ag-106 (24.0 minutes), **Ag-108m (418 years)***, Ag-108 (2.4 minutes), Ag-110m (249.8 days), Ag-110 (24.6 seconds), Ag-111 (7.5 days), Ag-112 (3.1 hours), Ag-115 (20.0 minutes)
Decay chains:	$^{108m}_{47}Ag \rightarrow ^{108}_{46}Pd$ (stable) 91.1% $^{108m}_{47}Ag \rightarrow ^{108}_{47}Ag$ 8.9% $\rightarrow ^{108}_{48}Cd$ (stable) 97.65% $^{108m}_{47}Ag \rightarrow ^{108}_{47}Ag$ 8.9% $\rightarrow ^{108}_{46}Pd$ (stable) 2.35%

* The half-life used in SR 97 is 127 years

2.16.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E-1	LT	1E-2	1E+0	IAEA, 1994
Organic soil	2E+1	LT	2E+0	9E+1	IAEA, 1994
Suspended matter					
lakes	2E+0	LT	2E-1	2E+1	McKinley & Scholtis, 1992
brackish water	1E+0	LT	1E-1	1E+1	*

* The best estimate and range are defined in Bergström & Nordlinder (1993). The K_d-values in that study were extracted from Coughtrey *et al* (1985), Puigdomenech & Bergström (1995) and McKinley & Scholtis (1992).

2.16.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	5E-1	LT	5E-2	4E+0	***
Cereals**	4E-1	LT	4E-2	3E+0	***
Root crops**	2E-1	LT	2E-2	1E+0	***
Vegetables**	1E-1	LT	1E-2	8E-1	***

* Dry weight.

** Wet weight.

*** The best estimates and ranges are defined in Bergström *et al* (1991). Silver is found in about the same concentrations in vegetation as in soil (Coughtrey *et al*, 1985, Bowen, 1979). Very high concentrations have been found in flour though. In Coughtrey *et al* (1985) is a general value of 1.0 kg/kg recommended which is said to be a conservative value. This value is also recommended by IAEA (1982). Considering this it is recommended in Bergström *et al* (1991) to use a value of 0.5 kg/kg as best estimate for pasturage. For other crops this value is converted to wet weight. As a value of 1 kg/kg is said to be conservative a maximum value four times that value is used. The minimum value used is ten times lower than the best estimate.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	5E+0	LT	2E-1	1E+1	IAEA, 1994
Baltic fish	5E+2	LT	1E+2	1E+3	*
Freshwater invertebrates	8E+2	LT	8E+1	8E+3	Thompson *et al*, 1972
Marine water plants	2E+2	LT	2E+1	2E+3	Thompson *et al*, 1972

* The best estimate and range are taken from Bergström & Nordlinder (1992) which refer to Coughtrey & Thorne (1983). The value for freshwater in Coughtrey & Thorne (1983) has been used.

2.16.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	5.0E-5	LT	5.0E-6	5.0E-4	IAEA, 1994
Meat (day/kg)	3.0E-3	LT	2.0E-3	6.0E-3	IAEA, 1994

2.16.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Since data are lacking a best estimate of 10% has been used as for many other elements for which data have not been found. A rather wide range has been used, as the uncertainty is high.

2.16.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Ag-108m	γ	418	1.6E-13	2.3E-9	3.7E-8*

* In SR 97 is value of 7.4E-9 was used.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Ag-108m	2.1E-8	1.1E-8	6.5E-9	4.3E-9	2.8E-9

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Ag-108m	8.9E-8	8.7E-8	6.2E-8	4.4E-8	3.9E-8

2.16.7 Summary

Silver is toxic to lower organisms but not to animals. Two stable isotopes occur; Ag-107 and Ag-109 which are of about the same abundance. The radioactive isotope which is of interest for dose assessments concerning repositories for nuclear fuel and waste is Ag-108m which has a half-life of 420 years. The root uptake of silver is rather high and sorption to solid matter is also high, in peat very high. This combination of properties (high root uptake and high sorption) leads to a very high potential for exposure in the mire model. Transfer to milk and meat in cattle is low whereas accumulation in aquatic biota varies from low in freshwater fish to rather high in brackish water fish and freshwater crustaceans. The dose coefficients for ingestion and inhalation are of the same magnitude as e.g. Zr-93 and Sn-126 but not as high as those for the actinides. The dose coefficient for external exposure is high due to strong gamma-radiation. In conclusion the exposure from Ag-108m is intermediate to low for the models used (lake, coastal, running waters, agricultural land, mire, well). The dominating exposure pathways in the well model are consumption of water and root crops. In the lake and running waters models used in SR 97 the most important pathway is consumption of shellfish. This exposure pathway was not included in the lake model used in the SAFE study, instead external exposure is the most dominant exposure pathway followed by consumption of root crops. In the coastal model consumption of fish dominates the contribution to dose totally. In the agricultural land and mire models is consumption of cereals the most important exposure pathway.

2.17 Cadmium

2.17.1 Physical properties

Occurrence	In: earth crust 0.16 ppm, seawater 0.0001 ppm. Accumulates in mammal kidney. Toxic, carcinogenic, teratogenic
Stable isotopes (natural abundance)	Cd-106 (1.25 %), Cd-108 (0.89 %), Cd-110 (12.51 %), Cd-111 (12.81 %), Cd-112 (24.13 %), Cd-113 (12.22 %), Cd-114 (28.72 %), Cd-116 (7.47 %)
Radioactive isotopes (half-life)	Cd-104 (57.7 minutes), Cd-107 (6.5 hours), Cd-109 (462.6 days), **Cd-113m (14.1 years)**, Cd-113 ($7.7 \cdot 10^{15}$ years), Cd-115m (44.6 days), Cd-115 (53.5 hours), Cd-117m (3.4 hours), Cd-117 (2.5 hours)
Decay chains:	${}^{113m}_{48}Cd \rightarrow {}^{113}_{49}In$ (stable)

2.17.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E-1	LT	2E-3	3E+0	IAEA, 1994
Organic soil	8E-1	LT	8E-3	8E+1	IAEA, 1994
Suspended matter					
lakes	1E-1	LT	1E-2	1E+0	NCRP, 1996
brackish water	5E+0	LT	1E+0	1E+2	IAEA, 1985

2.17.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	**Distr**	**Low**	**High**	**Reference**
Pasturage*	5E+0	LT	5E-1	5E+1	NCRP, 1996***
Cereals**	5E+0	LT	5E-1	5E+1	NCRP, 1996***
Root crops**	1E+0	LT	1E-1	1E+1	NCRP, 1996***
Vegetables**	5E-1	LT	5E-2	5E+0	NCRP, 1996

* Dry weight.

** Wet weight.

*** The value for fresh vegetables has been used for pasturage, cereals and root crops. This conversion was based on the following water contents in crop: 10% water in cereals and pasturage, 80% in root crops and 90% in vegetables.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	2E+1	LT	2E+0	2E+2	Coughtrey & Thorne, 1983
Baltic fish	2E+2	LT	2E+1	2E+3	Coughtrey & Thorne, 1983
Freshwater invertebrates	2E+3	LT	2E+2	2E+4	Thompson *et al*, 1972
Marine water plants	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

2.17.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	**Distr**	**Low**	**High**	**Reference**
Milk (day/l)	1E-4	LT	1E-5	1E-3	Coughtrey *et al*, 1985*
Meat (day/kg)	4E-4	LT	4E-5	4E-3	IAEA, 1994

* An equilibrium forage-to-milk transfer coefficient of 1E-4 day/l is suggested in Coughtrey *et al* (1985). It is also stated that this value is larger than suggested by available experimental results and may require modification. To use a conservative approach this value is used.

2.17.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	**Distr**	**Low**	**High**	**Reference**
2E-2	T	6E-5	5E-2	IAEA, 1994

2.17.6 Nuclide specific parameters

Cd-113m

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Cd-113m	β	14.1	0	2.3E-8	1.1E-7

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Cd-113m	1.2E-7	5.6E-8	3.9E-8	2.9E-8	2.4E-8

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Cd-113m	3.0E-7	2.7E-7	1.8E-7	1.3E-7	1.1E-7

2.17.7 Summary

Cadmium accumulates in mammal kidney. It is toxic, carcinogenic and teratogenic. A number of isotopes occur; Cd-106, Cd-108, Cd-110, Cd-111, Cd-112, Cd-113, Cd-114 and Cd-116 of which Cd- 112 and Cd-114 are the most abundant. The radioactive isotope which may be of interest for dose assessments concerning repositories for nuclear fuel and waste is Cd-113m which has a half-life of 14 years. The root uptake of cadmium is high. Sorption to solid matter is intermediate compared to the other elements in this study for soils, peat and freshwater sediments but higher in brackish water sediments. Transfer to milk and meat in cattle is low whereas accumulation in aquatic organisms is intermediate (freshwater and brackish water fish) and rather high for freshwater crustaceans and marine water plants. Because of the rather strong beta-radiation the dose coefficients for ingestion and inhalation are rather high whereas significant external exposure do not occur. Cd-113m was not considered in SR 97 and the SAFE study it was only considered in the coastal model. Consumption of fish is the dominating exposure pathway in the coastal model.

2.18 Tin

2.18.1 Physical properties

Occurrence	In: earth crust 2.1 ppm, seawater 0.003 ppm. Probably essential to vertebrates (trace element). Organotins used as biocids. Carcinogenic.
Stable isotopes (natural abundance)	Sn-112 (1.0 %), Sn-114 (0.7 %), Sn-115 (0.4 %), Sn-116 (14.7 %), Sn-117 (7.7 %), Sn-118 (24.3 %), Sn-119 (8.6 %), Sn-120 (32.4 %), Sn-122 (4.6 %), Sn-124 (5.6 %)
Radioactive isotopes (half-life)	Sn-110 (4.1 hours), Sn-111 (35.3 minutes), Sn-113 (115.1 days), Sn-117m (13.6 days), Sn-119m (293.1 days), Sn-121m (55 years), Sn-121 (27.1 hours), Sn-123m (40.1 minutes), Sn-123 (129.2 days), Sn-125 (9.6 days), **Sn-126 ($1 \cdot 10^5$ years)**, Sn-127 (2.1 hours), Sn-128 (59.1 minutes)
Decay chains:	${}^{126}_{50}Sn \rightarrow {}^{126}_{51}Sb \rightarrow {}^{126}_{52}Te$ (stable)

2.18.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E-1	LT	5E-2	5E-1	*
Organic soil	2E+0	LT	2E-1	2E+1	IAEA, 1994
Suspended matter					
lakes	5E+1	LT	1E+1	1E+2	Coughtrey *et al*, 1985
brackish water	5E+1	LT	1E+1	1E+2	Coughtrey *et al*, 1985**

* Tin is assumed to be analogous with Pb for which data originally was taken from Jiskra (1985). This study refers to Wuschke *et al* (1981).

** Values for freshwater are used.

2.18.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E-1	LT	1E-2	2E+0	***
Cereals**	4E-1	LT	1E-2	1E+0	***
Root crops**	6E-2	LT	1E-2	1E+0	***
Vegetables**	5E-2	LT	1E-2	1E+0	***

* Dry weight.

** Wet weight.

*** The root uptake factors for tin was updated in Bergström *et al* (1985) as justified by data in Coughtrey *et al* (1983). In the later a value of about 1 kg/kg is recommended but a value of 0.1 was used. This mistake has not been corrected so a too low value has been used also in SR 97 (Bergström *et al*, 1999) and SAFE (Karlsson *et al*, 2001).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	3E+3	LT	3E+2	3E+4	IAEA, 1994
Baltic fish	1E+3	LT	1E+2	1E+4	*
Freshwater invertebrates	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972
Marine water plants	1E+2	LT	1E+1	1E+3	Thompson *et al*, 1972

* A value of 100 l/kg is recommended in Bergström & Nordlinder (1992) which is said to be in accordance to the recommendation given in Coughtrey *et al* (1983). A value of 1 000 l/kg is given in Coughtrey *et al* (1983) anyway and therefore this value has been used in SAFE (Karlsson *et al*, 2001) whereas a value of 100 was used in SR 97 (Bergström *et al*, 1999).

2.18.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	1.0E-3	LT	1.0E-4	1.0E-2	NCRP, 1996*
Meat (day/kg)	1.0E-2	LT	1.0E-3	1.0E-1	NCRP, 1996*

* In SR 97 transfer coefficients of $3{\cdot}10^{-3}$ day/l ($1{\cdot}10^{-3}$–$1{\cdot}10^{-2}$ day/l) and $3{\cdot}10^{-3}$ day/kg ($3{\cdot}10^{-4}$ - $3{\cdot}10^{-2}$ day/kg) were used to milk and meat, respectively, with reference to Bergström & Nordlinder (1990a). The value given for meat in that study is somewhat lower though ($1{\cdot}10^{-3}$ day/kg) and the reference given is Bergström *et al* (1985). In the latter the values are $1.2{\cdot}10^{-3}$ day/l for milk and $2.5{\cdot}10^{-3}$ day/kg for meat. These values are said to be used in Bergström (1983) but tin is not treated in that report. Data for tin is not very common as it is a radionuclide of minor importance for dose from repositories or nuclear power plants. The values used in the SAFE study (see this table) are taken from NCRP (1996) where no ranges are given. In Davis *et al* (1993) the following values were used for tin; $1.2{\cdot}10^{-3}$ day/l for milk (in accordance to the value used here) and $8{\cdot}10^{-2}$ day/kg for meat (higher than the best estimate used here but in the same order of magnitude as the maximum value). As that study used only one value for each parameter this must be conservative in order not to underestimate the dose to humans.

2.18.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Since data are lacking a best estimate of 10 % has been used as for many other elements for which data have not been found. A rather wide range has been used as the uncertainty is high.

2.18.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m³)	Ingestion Sv/Bq	Inhalation Sv/Bq
Sn-126	β, γ	100 000	3.0E-15	4.7E-9	2.8E-8

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Sn-126	5.0E-8	3.0E-8	1.6E-8	9.8E-9	5.9E-9

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Sn-126	1.2E-7	1.0E-7	6.2E-8	4.1E-8	3.3E-8

2.18.7 Summary

Tin is probably essential to vertebrates as a trace element. Organic compounds containing tin is used as biocids. In large amounts tin are carcinogenic. A large number of stable isotopes occur in the environment; Sn-112, Sn-114, Sn-115, Sn-116, Sn-117, Sn-118, Sn-119, Sn-120, Sn-122 and Sn-124 of which Sn-120 and Sn-118 are the must abundant. The radioactive isotope which is of interest for dose assessments concerning repositories for nuclear fuel and waste is Sn-126 which has a half-life of 100 000 years. The root uptake is intermediate compared to other elements in this study. The sorption to solid matter is high in sediments and peat and somewhat lower in soils. The transfer to meat is high whereas transfer to milk is somewhat lower but still high. Accumulation in fish (freshwater as well as brackish water) and freshwater crustaceans are high whereas accumulation in marine water plants is somewhat lower. The dose coefficients for ingestion and inhalation are of the same order of magnitude as e.g. Zr-93 and Ag-108m but not as high as those for the actinides. The dose coefficient for external exposure is intermediate compared to the other radionuclides in this study. In conclusion the exposure from Sn-126 is high in the lake, running waters and agricultural land models and intermediate in the coastal, mire and well models. The dominating exposure pathway for the well model is consumption of root crops followed by consumption of water and vegetables. In the lake, coastal and running waters models consumption of fish dominates the distribution to dose totally. Consumption of cereals followed by consumption of root crops and vegetables are the most important exposure pathways in the agricultural land and mire models.

2.19 Iodine

2.19.1 Physical properties

Occurrence	In: earth crust 0.46 ppm, seawater 0.05 ppm. Essential to i.a. vertebrates. Accumulates in mammal thyroid. I_2 vapour harmful.
Stable isotopes (natural abundance)	I-127 (100 %)
Radioactive isotopes (half-life)	I-120m (53 minutes), I-120 (81.0 minutes), I-121 (2.1 hours), I-122 (3.6 minutes), I-123 (13.3 hours), I-124 (4.2 days), I-125 (59.4 days), I-126 (13.1 days), I-128 (25.0 minutes), **I-129 (1.57·10^{7} years)**, I-130 (12.4 hours), I-131 (8.0 days), I-132m (1.4 hours), I-132 (2.3 hours), I-133 (20.8 hours), I-134 (52.5 minutes), I-135 (6.6 hours)
Decay chains:	${}^{129}_{53}I \rightarrow {}^{129}_{54}Xe$ (stable)

2.19.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	3E-1	LT	1E-1	1E+0	*
Organic soil	3E-2	LT	3E-3	3E-1	IAEA, 1994
Suspended matter					
lakes	3E-1	LT	1E-1	1E+0	Coughtrey *et al*, 1985
brackish water	3E-1	LT	1E-1	1E+0	Coughtrey *et al*, 1985**

* The best estimate has been calculated from a transfer rate used in Bergström & Wilkens (1983). The transfer rate was extracted from Kantelo *et al* (1981).

** Values for fresh water are used.

2.19.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	**Distr**	**Low**	**High**	**Reference**
Pasturage*	6E-1	LT	6E-2	6E+0	Deitermann *et al*, 1989
Cereals**	1E-1	LT	1E-2	1E+0	Robens *et al*, 1988
Root crops**	1E-2	LT	1E-3	1E+0	Robens *et al*, 1988
Vegetables**	3E-2	LT	3E-3	3E-1	Robens *et al*, 1988

* Dry weight.

** Wet weight.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	**Distr**	**Low**	**High**	**Reference**
Freshwater fish	2E+2	LT	1E+1	5E+2	Poston & Klopfer, 1986*
Baltic fish	3E+1	LT	1E+1	1E+2	**
Freshwater invertebrates	5E+0	LT	5E-1	5E+1	Thompson *et al*, 1972
Marine water plants	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

* The value recommended for piscivorous fish in Poston & Klopfer (1986) has been used although an even higher value was reported for omnivorous and planktivorous fishes (500). However, the most common fishes consumed by humans belong to piscivorous species. The range used includes the values recommended for marine fish (10 l/kg) and fresh water omnivorous and planktivorous species (500 l/kg) in Poston & Klopfer (1986). In Bergström *et al* (1999) a maximum value of 600 l/kg has been used by mistake. The maximum value in Karlsson *et al* (2001) is 500 l/kg.

** The best estimate and range are taken from Bergström & Nordlinder (1992). A best estimate of 30 is given for freshwater fish in Coughtrey *et al* (1983).

2.19.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	1.0E-2	LT	1.0E-3	4.0E-2	IAEA, 1994
Meat (day/kg)	4.0E-2	LT	7.0E-3	5.0E-2	IAEA, 1994

2.19.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	5E-2	2E-1	*

* The best estimate and range are taken from Bergström *et al* (1991) which refers to Coughtrey *et al* (1983). Here it is reported that a fractional transfer to edible parts of 1 was used by Palms *et al* (1975). It is also stated that there is little evidence of such high translocation and that Hotson *et al* (1980) assumed a value of 0.1 for root vegetables, green vegetables, fruit and cereal grain. The same value was used by the Clark *et al* (1979) for root vegetables and grain. A value of 0.1 has therefore been chosen also here. As data were found for this element a somewhat narrower range was adopted than for elements for which no data were found. This may be questioned as it means that the maximum value is lower.

2.19.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
I-129	β	15 700 000	3.4E-16	1.1E-7	3.6E-8*

* In SR 97 a value of 1.5E-8 Sv/Bq was used.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
I-129	1.8E-07	2.2E-07	1.7E-07	1.9E-07	1.4E-07

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
I-129	7.2E-08	8.6E-08	6.1E-08	6.7E-08	4.6E-08

2.19.7 Summary

Iodine is essential to i.a. vertebrates. It accumulates in mammal thyroid. I_2 vapour is harmful. Only one stable isotope occurs (I-127) but a number of radioactive ones. The radioactive isotope which is of interest for dose assessments concerning repositories for nuclear fuel and waste is I-129 which has a half-life of 15,700,000 years. The root uptake of iodine is rather high in pasturage and cereals and somewhat lower for root crops and vegetables. Sorption to solid matter is intermediate for soil and suspended matter in fresh and brackish water but lower in peat. The transfer to milk and meat is high. Accumulation is high in marine water plants, intermediate for fish (freshwater as well as brackish water) and low in freshwater crustaceans. Due to the strong β-radiation the dose coefficient for ingestion is high, in the same magnitude as those for the actinides. Also the dose coefficient for inhalation is rather high but not as those for the actinides. The dose coefficient for external exposure is intermediate compared to the other radionuclides in this study. In conclusion the exposure from I-129 is intermediate in the mire model but high in the other models (lake, coastal, running waters, agricultural land, well). The dominating exposure pathway in the well model is consumption of root crops followed by consumption of water and vegetables. In the lake, running waters and coastal models consumption of fish, milk and meat are important pathways, in the two former they are of about equal importance whereas consumption of milk are most important in the coastal model. In the agricultural land and mire models consumption of milk and cereals are the most important exposure pathways followed by consumption of meat.

2.20 Cesium

2.20.1 Physical properties

Occurrence	In: earth crust 2.6 ppm, seawater 0.0005 ppm. Mimics potassium and accumulates in muscle. None-essential. Non-toxic.
Stable isotopes (natural abundance)	Cs-133 (100 %)
Radioactive isotopes (half-life)	Cs-125 (45 minutes), Cs-126 (1.6 minutes), Cs-127 (6.3 hours), Cs-128 (3.7 minutes), Cs-129 (32.1 hours), Cs-130 (29.2 minutes), Cs-131 (9.7 days), Cs-132 (6.5 days), Cs-134m (2.9 hours), **Cs-134 (2 years)**, Cs-135m (53 minutes), **Cs-135 (2.3·10^{6} years)**, Cs-136 (13.2 days), **Cs-137 (30 years)**, Cs-138 (33.4 minutes)
Decay chains:	${}^{134}_{55}Cs \rightarrow {}^{134}_{56}Ba$ (stable) ${}^{135}_{55}Cs \rightarrow {}^{135}_{56}Ba$ (stable) ${}^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba$ (stable)

2.20.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E+0	LT	1E-1	1E+1	Coughtrey *et al*, 1985
Organic soil	3E-1	LT	1E-1	3E+0	IAEA, 1994*
Suspended matter					
lakes	1E+1	LT	1E+0	1E+2	Coughtrey *et al*, 1985
brackish water	1E+1	LT	1E+0	1E+2	Coughtrey *et al*, 1985**

* The range given in the reference has not been used, instead a minimum values ten times lower and a maximum value ten times higher than the best estimate has been used.

** Values for freshwater are used.

2.20.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	2E-1	LT	2E-2	2E+0	IAEA, 1994
Cereals**	2E-2	LT	2E-3	2E-1	IAEA, 1994
Root crops**	2E-2	LT	2E-3	2E-1	IAEA, 1994
Vegetables**	2E-2	LT	2E-3	2E-1	IAEA, 1994

* Dry weight.

** Wet weight.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	1E+4	LT	5E+3	2E+4	*
Baltic fish	2E+2	LT	1E+2	5E+2	**
Freshwater invertebrates	1E+2	LT	1E+1	1E+3	Thompson *et al*, 1972
Marine water plants	5E+1	LT	5E+0	5E+2	Thompson *et al*, 1972

* Value valid for oligotrophic freshwater. In Bergström & Nordlinder (1990a) a value of 5,000 l/kg is used based on a number of studies. Kohlemainen *et al* (1968) gives bioaccumulation factors in the range of 200–2,000 l/kg for piscivorous fish in eutrophic (nutrient rich) lake systems and Neumann (1985) gives a generic value of 200 l/kg. Vanderploeg *et al* (1975) gives the transfer at steady state as a function of the potassium concentration in water; 15,000/[K] for piscivorous fish. Studies of the Chernobyl fallout in the same type of lakes give a value of about 5 000 l/kg for species used as food (Bergström & Nordlinder, 1989). In Bergström *et al* (1999) a best estimate of 10,000 l/kg was used instead for eutrophic lakes (with low potassium content). The value is higher than that for oligotrophic lakes in accordance to the function set up by Vanderploeg *et al* (1975).

** The best estimate and range are taken from Bergström & Nordlinder (1992). This study refers to Evans (1985 and 1991) and Grimås (1991) for a bioaccumulation factor of about 200 l/kg for fish from the Baltic Sea.

2.20.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	8.0E-3	LT	1.0E-3	3.0E-2	IAEA, 1994
Meat (day/kg)	5.0E-2	LT	1.0E-2	6.0E-2	IAEA, 1994*

* The best estimate and range are those presented for beef. For veal meat values about one order of magnitude higher are given in IAEA (1994) but that has not been considered since veal meat is a small part of the diet. Young animals also eat much less than older ones and therefore it is not reasonable to think that the concentration of radionuclides in veal meat will be higher than in "ordinary" beef meat.

2.20.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
2E-1	T	1E-2	3E-1	IAEA, 1994*

* In IAEA (1994) values for translocation are given for various times between deposition and harvest. Conservatively biased values for wheat and rye were selected and used for both kind of vegetation (cereals and root crops). The maximum value (0.3) is the same as that given for root vegetables in Coughtrey *et al* (1985).

2.20.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m³)	Ingestion Sv/Bq	Inhalation Sv/Bq
Cs-134	β	2	0	1.9E-8	2.0E-8
Cs-135	β	2 300 000	0	2.0E-9	8.6E-9*
Cs-137	β, γ	30	5.6E-14	1.3E-8	3.9E-8*

* The value used for Cs-135 in SR 97 was 3.1E-9 Sv/Bq. For Cs-137 a value of 9.7E-9 Sv/Bq was used.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Cs-134	2.6E-8	1.6E-8	1.3E-8	1.4E-8	1.9E-8
Cs-135	4.1E-9	2.3E-9	1.7E-9	1.7E-9	2.0E-9
Cs-137	2.1E-8	1.2E-8	9.6E-9	1.0E-8	1.3E-8

Dose coefficients for inhalation for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Cs-134	7.0E-08	6.3E-08	4.1E-08	2.8E-08	2.3E-08
Cs-135	2.7E-8	2.4E-8	1.6E-8	1.1E-8	9.5E-8
Cs-137	1.1E-07	1.0E-07	7.0E-08	4.8E-08	4.2E-08

2.20.7 Summary

Cesium is known to mimic potassium and accumulates in bone. It is strongly sorbed in clay. Cesium is none-essential and non-toxic. Only one stable isotope occurs in the environment (Cs-133) but the radioactive ones are numerous. The radioactive isotopes which are of interest for dose assessments concerning repositories for nuclear fuel and waste are Cs-134, Cs-135 and Cs-137 which have a half-lives of 2, 2,300,000 and 30 years, respectively. The root uptake of cesium is intermediate compared to the other elements is this study. Uptake in pasturage is somewhat higher. The sorption to solid matter is high in soils and sediments but lower in peat. Transfer to milk and meat in cattle is high. Accumulation in freshwater fish is very high in oligotrophic (nutrient poor) lakes and somewhat lower but still high for eutrophic (nutrient rich) lakes. Accumulation in brackish water fish and freshwater crustaceans are somewhat lower and for marine water plants the accumulation of cesium is low. Due to strong β-radiation the dose coefficients for ingestion are high for Cs-134 and Cs-137, for Cs-137 it is about ten times lower. The dose coefficients for inhalation are rather low. Of these three radioisotopes Cs-137 is the only one with significant gamma disintegration and the dose coefficient for external exposure is rather high. Cs-134 was not considered in SR 97 and the SAFE study so no discussion about important exposure pathways for this radionuclide is presented here. The exposure from Cs-135 is high in the lake and running waters models but intermediate in the coastal, agricultural land, mire and well models. For Cs-137 the exposure is generally somewhat higher than for Cs-135 with the exception of the agricultural land model. In the latter accumulation is an important process for log-time exposure and the amounts of Cs-135 in the top soil layer becomes higher than that of Cs-137, because of its longer half-life. For Cs-135 consumption of root crops is the dominating exposure pathway followed by consumption of water and vegetables in the well model. For Cs-137 consumption of water is most important. The difference between the two isotopes is mainly the importance of the half-life for accumulation in soils. For the lake, coastal and running waters models consumption of fish is the exposure pathway which totally dominate the contribution to dose. In the coastal model consumption of milk and meat are also of some importance. In the agricultural land and mire models consumption of meat and milk are the most important exposure pathways followed by consumption of cereals and root crops. Consumption of vegetables is also of some importance in the mire model.

2.21 Promethium

2.21.1 Physical properties

Occurrence	In: earth crust traces in uranium ores, seawater 0 ppm. Non-essential. Accumulates in mammalian bone and liver.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Pm-141 (20.9 minutes), Pm-142 (40.5 seconds), Pm-143 (265 days), Pm-144 (363 days), Pm-145 (17.7 years), Pm-146 (5.5 years), **Pm-147 (2.6 years)**, Pm-148m (41.3 days), Pm-148 (5.4 days), Pm-149 (53.1 hours), Pm-150 (2.7 hours), Pm-151 (28 hours)
Decay chains:	${}^{147}_{61}Pm \rightarrow {}^{147}_{62}Sm \rightarrow {}^{143}_{60}Nd$ (stable)

2.21.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	2E+2	LT	2E+1	2E+3	NCRP, 1996
Organic soil	1E+0	LT	5E-1	3E+0	*
Suspended matter					
lakes	5E+0	LT	1E+0	1E+1	IAEA, 1994
brackish water	1E+3	LT	5E+1	1.1E+3	IAEA, 1985**

* No value was found in IAEA (1994) so an estimation was performed. Assuming that promethium behaves like the elements in the same column in the periodic table the same K_d-value as is used for neptunium was chosen.

** The K_d-values for fresh and brackish waters differ very much. As Pm-147 has a short half-life it has not been of interest in any of the safety assessments performed by the authors and therefore no effort has been placed on checking this data more thoroughly. As the maximum value cannot be the same as the best estimate in the model system used, a value of 1,100 m^3/kg has been used instead of 1 000 which is given in the reference.

2.21.3 Uptake in biota

Root-uptake factors (transfer factors) (Bq/kg/Bq dry weight soil)

	B.E.	Distr	Low	High	Reference
Pasturage*	4E-2	LT	4E-3	4E-1	IAEA, 1982***
Cereals**	2E-3	LT	2E-4	2E-2	IAEA, 1982***
Root crops**	2E-3	LT	2E-4	2E-2	IAEA, 1982***
Vegetables**	2E-3	LT	2E-4	2E-2	IAEA, 1982***

* Dry weight.

** Wet weight.

*** The values used as best estimates are found in IAEA (1982). Here it is said that in lack of data values for Ce have been used. The minimum and maximum values of the ranges are ten times lower and higher respectively of the best estimate.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	3E+1	LT	1E+1	2E+2	IAEA, 1994
Baltic fish	1E+2	LT	1E+1	1E+3	NCRP, 1996
Freshwater invertebrates	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972
Marine water plants	5E+3	LT	5E+2	5E+4	Thompson *et al*, 1972

2.21.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2E-5	LT	2E-6	2E-4	IAEA, 1982
Meat (day/kg)	2E-3	LT	2E-4	2E-2	IAEA, 1982*

* In absence of data of promethium the transfer coefficient in IAEA (1982) is based on data for Ce.

2.21.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Since data are lacking a best estimate of 10 % has been used as for many other elements for which data have not been found. A rather wide range has been used as the uncertainty is high.

2.21.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Pm-147	β	2.6	0	2.6E-10	5.0E-9

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Pm-147	3.6E-9	1.9E-9	9.6E-10	5.7E-10	3.2E-10

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2 –7**	**7–12**	**12–17**
Pm-147	2.1E-8	1.8E-8	1.1E-8	7.0E-9	5.8E-9

2.21.7 Summary

No stable isotope of promethium occurs in the environment. The radioactive isotopes can be found as traces in uranium ores. The element is non-essential and accumulates in mammalian bone and liver. The radioactive isotope which may be of interest for dose assessments concerning repositories for nuclear fuel and waste is Pm-147 which has a half-life of 3 years. The root uptake of promethium is low whereas sorption to solid matter in soils, suspended matter and peat is high. Transfer to meat is high whereas transfer to milk is low (thousand times lower). Accumulation is rather low in fish (freshwater as well as brackish) whereas it is high in freshwater crustaceans and marine water plants. Due to low β-radiation the dose coefficients for ingestion and inhalation are rather low and no significant external exposure occurs as it is a beta radiating nuclide. Pm-147 was not considered in SR 97 and the SAFE study so no discussion about important exposure pathways is presented here.

2.22 Samarium

2.22.1 Physical properties

Occurrence	In: earth crust 7.0 ppm, seawater $2 \cdot 10^{-7}$ ppm. Non-essential. Low toxicity.
Stable isotopes (natural abundance)	Sm-144 (3.1 %), Sm-147 (15.1 %), Sm-148 (11.3 %), Sm-149 (13.9 %), Sm-150 (7.4 %), Sm-152 (26.6 %), Sm-154 (22.6 %)
Radioactive isotopes (half-life)	Sm-141m (22.6 minutes), Sm-141 (10.2 minutes), Sm-142 (72.5 minutes), Sm-145 (340 days), Sm-146 ($1.03 \cdot 10^{8}$ years), Sm-147 ($1.06 \cdot 10^{11}$ years), **Sm-151 (90 years)**, Sm-153 (46.3 hours), Sm-155 (22.3 minutes), Sm-156 (9.4 hours)
Decay chains:	${}^{151}_{62}\text{Sm} \rightarrow {}^{151}_{63}\text{Eu}$ (stable)

2.22.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E+0	LT	1E-1	1E+1	IAEA, 1994
Organic soil	3E+0	LT	3E-1	3E+1	IAEA, 1994
Suspended matter					
lakes	5E+0	LT	5E-1	5E+1	McKinley & Scholtis, 1992
brackish water	1E+2	LT	1E+1	1E+3	Estimated from McKinley & Scholtis, 1992

2.22.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E-2	LT	1E-3	1E-1	***
Cereals**	1E-4	LT	1E-5	1E-3	***
Root crops**	4E-5	LT	4E-6	4E-4	***
Vegetables**	3E-3	LT	3E-4	3E-2	***

* Dry weight.

** Wet weight.

*** The best estimates are taken from Aggeryd & Bergström (1990) who refer to Baker *et al* (1976), Miller *et al* (1980) and Coughtrey & Thorne (1983).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	3E+1	LT	3E+0	3E+2	USNRC, 1977*
Baltic fish	3E+1	LT	3E+0	3E+2	USNRC, 1977**
Freshwater invertebrates	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972
Marine water plants	5E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

* The value has been rounded off.

** In USNRC (1977) the same value (25 l/kg) is given for freshwater and marine fish. The value has been rounded off.

2.22.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2.0E-5	LT	2.0E-6	2.0E-4	Miller *et al*, 1980
Meat (day/kg)	5.0E-3	LT	5.0E-4	5.0E-2	Baker *et al*, 1976

2.22.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Since data are lacking a best estimate of 10 % has been used as for many other elements for which data have not been found. A rather wide range has been used as the uncertainty is high.

2.22.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Sm-151	β	90	4.6E-18	9.8E-11	4.0E-9

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Sm-151	1.5E-9	6.4E-10	3.3E-10	2.0E-10	1.2E-10

Dose coefficients for inhalation for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Sm-151	1.1E-8	1.0E-8	6.7E-9	4.5E-9	4.0E-9

2.22.7 Summary

Samarium is a non-essential element with low toxicity. A number of stable isotopes occur in the environment; Sm-144, Sm-147, Sm-148, Sm-149, Sm-150, Sm-152 and Sm-154 of which the two latest are the most abundant. The radioactive isotope which are of interest for dose assessments concerning repositories for nuclear fuel and waste is Sm-151 which has a half-life of 90 years. The root uptake of samarium is very low, in pasturage somewhat higher but still low. The sorption to solid matter in soils, sediments and peat is high. The transfer to meat is rather high whereas transfer to milk is low (hundred times lower). Accumulation is rather low in fish (freshwater as well as brackish) but high in freshwater crustaceans and marine water plants. Due to weak β-radiation the dose coefficients for ingestion, inhalation and external exposure are low. In conclusion the exposure from Sm-151 is very low in all models (lake, coastal, running waters, agricultural land, mire, well). The dominating exposure pathway in the well model is consumption of water. In the lake and running waters models used in SR 97 consumption of shellfish is the most important exposure pathway. This pathway was not included in the lake model used in the SAFE study, in this model consumption of fish is totally dominating the contribution to dose. This is also true for the coastal model. In the agricultural land and mire models inhalation is the most important exposure pathway.

2.23 Europium

2.23.1 Physical properties

Occurrence	In: earth crust 2.1 ppm, seawater $4 \cdot 10^{-8}$ ppm. None-essential. Low toxicity.
Stable isotopes (natural abundance)	Eu-151 (47.8 %), Eu-153 (52.2 %)
Radioactive isotopes (half-life)	Eu-145 (5.9 days), Eu-146 (4.6 days), Eu-147 (24.1 days), Eu-148 (54.5 days), Eu-149 (93.1 days), Eu-150 (12.8 hours), Eu-150 (36.9 years), Eu-152m (9.3 hours), **Eu-152 (13.5 years)**, **Eu-154 (8.6 years)**, **Eu-155 (4.8 years)**, Eu-156 (15.2 days), Eu-157 (15.2 hours), Eu-158 (45.9 minutes)
Decay chains:	$^{152}_{63}\text{Eu} \rightarrow ^{152}_{62}\text{Sm}$ (stable) 72.1% $^{152}_{63}\text{Eu} \rightarrow ^{152}_{64}\text{Gd} \rightarrow ^{148}_{62}\text{Sm}$ (stable) 27.9% $^{154}_{63}\text{Eu} \rightarrow ^{154}_{64}\text{Gd}$ (stable) 99.98% $^{154}_{63}\text{Eu} \rightarrow ^{154}_{62}\text{Sm}$ (stable) 0.02% $^{155}_{63}\text{Eu} \rightarrow ^{155}_{64}\text{Gd}$ (stable)

2.23.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	2E+2	LT	2E+1	2E+3	NCRP, 1996*
Organic soil	1E+0	LT	5E-2	2E+1	**
Suspended matter					
lakes	5E-1	LT	5E-2	5E+0	IAEA, 1994
brackish water	1E+1	LT	1E+0	1E+2	Estimated***

* The K_d-values presented in NCRP (1996) are generally very high. As no other information has been found for europium this high value (240 m^3/kg) has been rounded off and used.

** Data are lacking for this uncommon element and as Eu-152, Eu-154 and Eu-155 have short half-lives it has not been of interest in any of the safety assessments performed by the authors and therefore no effort has been placed on finding data. The values for other lanthanides vary. The highest value (for Ce) is 2,000 m^3/kg. As the nuclides have short half-lives they are important for dose to humans in a short time perspective, which makes accumulation in sediments an unimportant process. To be conservative a relatively low K_d-value has been used so that a larger fraction is available for exposure to man. The relation between K_d i lakes and brackisk water is set to be the same as for Sm.

*** Data are lacking for this uncommon element and the values for other lanthanides varies. The highest value (for Ce) is 2,000 m^3/kg. Since Eu has a short half-life it is important for dose to humans in a short time perspective and to use a conservative approach a rather low K_d-value has been chosen so that a larger amount should be available for exposure to humans during the coastal stage.

2.23.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E-2	LT	1E-3	1E-1	***
Cereals**	2E-4	LT	2E-5	2E-3	***
Root crops**	6E-5	LT	6E-6	6E-4	***
Vegetables**	3E-3	LT	3E-4	3E-2	***

* Dry weight.

** Wet weight.

*** The best estimates are taken from Aggeryd & Bergström (1990) who refer to Baker *et al* (1976), Miller *et al* (1980) and Coughtrey & Thorne (1983).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	5E+1	LT	1E+1	2E+2	IAEA, 1994
Baltic fish	1E+2	LT	1E+1	1E+3	NCRP, 1996
Freshwater invertebrates	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972
Marine water plants	5E+3	LT	5E+2	5E+4	Thompson *et al*, 1972

2.23.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2.0E-5	LT	2.0E-6	2.0E-4	Miller *et al*, 1980
Meat (day/kg)	6.0E-3	LT	6.0E-4	6.0E-2	Miller *et al*, 1980

2.23.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
2E-2	T	1E-2	3E-2	*

* The best estimate and range are taken from Bergström *et al* (1991) who write that the values for translocation factors are estimated from chemically similar elements with no further specification. The element is not specifically bioavailable (e.g. root uptake and bioaccumulation factors are low) and therefore it is reasonable to use low values also for the translocation factor.

2.23.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Eu-152	β, EC	14	1.5E-13	1.4E-9	4.2E-8
Eu-154	β, EC	8.6	1.3E-13	2.0E-9	5.3E-8
Eu-155	β	4.8	3.9E-15	3.2E-10	6.9E-9

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Eu-152	1.6E-8	7.4E-9	4.1E-9	2.6E-9	1.7E-9
Eu-154	2.5E-08	1.2E-08	6.5E-09	4.1E-09	2.5E-09
Eu-155	4.3E-9	2.2E-9	1.1E-9	6.8E-10	4.0E-10

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1 –2	2 – 7	7 – 12	12 – 17
Eu-152	1.1E-7	1.0E-7	7.0E-8*	4.9E-8	4.4E-8
Eu-154	1.6E-07	1.5E-07	9.7E-08	6.5E-08	5.6E-08
Eu-155	2.6E-8	2.3E-8	1.4E-8	9.2E-9	7.6E-9

* In EU (1996) the value $7.0 \cdot 10^{-4}$ Sv/Bq is presented but this has to be a misprint. The most reasonable value to use is instead that presented in this table.

2.23.7 Summary

Europium is a none-essential element with low toxicity. Two stable isotopes occur in the environment; Eu-151 and Eu-153 which are of about the same abundance. A large number of radioactive isotopes occur. The ones which are of interest for dose assessments concerning repositories for nuclear fuel and waste are Eu-152, Eu-154 and Eu-155 which have half-lives of 14, 9 and 5 years, respectively. The root uptake of europium is very low, somewhat higher in pasturage but still low. The sorption to solid matter in soils, sediments and peat is rather high. Transfer to meat is rather high whereas transfer to milk is lower (about one hundred times). Accumulation in fish (freshwater as well as brackish) is intermediate compared to the other elements in this study whereas accumulation in freshwater crustaceans and marine water plants is high. The dose coefficients are similar for Eu-152 and Eu-154 whereas those for Eu-155 are lower. Due to strong β-radiation the dose coefficients for ingestion and inhalation for the former ones are rather high but not as those for the actinides. The dose coefficients for external exposure are high. For Eu-155 the dose coefficients for ingestion and inhalation are about ten times lower than for Eu-152 and Eu-154 and the dose coefficient for external exposure is about hundred times lower. No radioisotopes of europium were considered in SR 97. In the SAFE study Eu-152 and Eu-154 was considered in the coastal model but they were of no importance at all.

2.24 Holmium

2.24.1 Physical properties

Occurrence	In: earth crust 1.3 ppm, seawater $8 \cdot 10^{-8}$ ppm. None-essential. Low toxicity.
Stable isotopes (natural abundance)	Ho-165 (100 %)
Radioactive isotopes (half-life)	Ho-155 (48 minutes), Ho-157 (12.6 minutes), Ho-159 (33.1 minutes), Ho-161 (2.5 hours), Ho-162m (68 minutes), Ho-162 (15 minutes), Ho-164m (37.5 minutes), Ho-164 (29 minutes), **Ho-166m (1 200 years)**, Ho-166 (26.8 hours), Ho-167 (3.1 hours)
Decay chains:	${}^{166m}_{67}\mathrm{Ho} \rightarrow {}^{166}_{68}\mathrm{Er}$ (stable)

2.24.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E+0	LT	1E-1	1E+1	IAEA, 1994
Organic soil	3E+0	LT	3E-1	3E+1	IAEA, 1994
Suspended matter					
lakes	3E-1	LT	3E-2	3E+0	*
brackish water	1E-1	LT	1E-2	1E+0	*

* These values were presented in Bergström *et al* (1999) with reference to McKinley & Scholtis (1992). In the latter no values are presented for Ho, instead the values from the row below (values for I) have been read by mistake. Comparing these values with those for e.g. Sm (another lanthanide) they are very low. Uptake in biota is low which also indicates rather strong sorption properties. In future studies higher values (e.g. those used for Sm) should be used for K_d-values in freshwater and brackish water. For the results in SR 97 (Bergström *et al*, 1999) and SAFE (Karlsson *et al*, 2001) this mistake makes the calculations of exposure to man more conservative as a larger fraction of the released amounts is available for uptake in aquatic biota. Because of the relatively short half-life, accumulation of Ho in sediments is of no importance in the SAFE study.

2.24.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E-3	LT	1E-4	1E-2	***
Cereals**	1E-4	LT	1E-5	1E-3	***
Root crops**	9E-5	LT	9E-6	9E-4	***
Vegetables**	3E-3	LT	3E-4	3E-2	***

* Dry weight.

** Wet weight.

*** The best estimates are taken from Aggeryd & Bergström (1990) who refer to Baker *et al* (1976) and Coughtrey & Thorne (1983). The value for pasturage was given for lanthanides in general.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	3E+1	LT	3E+0	3E+2	USNRC, 1977*
Baltic fish	3E+1	LT	3E+0	3E+2	USNRC, 1977**
Freshwater invertebrates	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972
Marine water plants	5E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

* The value has been rounded off.

** In USNRC (1977) the same value (25 l/kg) is given for freshwater and marine fish. The value has been rounded off.

2.24.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2.5E-6	LT	3.0E-7	3.0E-5	Baker *et al*, 1976
Meat (day/kg)	5.0E-3	LT	5.0E-4	5.0E-2	Baker *et al*, 1976

2.24.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Since data are lacking a best estimate of 10 % has been used as for many other elements for which data have not been found. A rather wide range has been used as the uncertainty is high.

2.24.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Ho-166m	γ	1 200	1.6E-13	2.0E-9	1.2E-7

Dose coefficients for oral intake for various age groups (Sv/Bq)

	Age (Years)				
Isotope	<1	1–2	2–7	7–12	12–17
Ho-166m	2.6E-8	9.3E-9	5.3E-9	3.5E-9	2.4E-9

Dose coefficients for inhalation for various age groups (Sv/Bq)

	Age (Years)				
Isotope	<1	1–2	2–7	7–12	12–17
Ho-166m	2.6E-7	2.5E-7	1.8E-7	1.3E-7	1.2E-7

2.24.7 Summary

Holmium is a none-essential element with low toxicity. One stable isotope (Ho-165) occurs in the environment and a number of radioactive ones. The radioactive isotope of interest for dose assessments concerning repositories for nuclear fuel and waste is Ho-166m which has a half-life of 1 200 years. The root uptake of holmium is very low. Instead the sorption to solid matter in soils, suspended matter and peat is rather high. The transfer to meat is rather high whereas transfer to milk is low (about thousand times lower). The accumulation in fish (freshwater as well as brackish) is low whereas accumulation in freshwater crustaceans and marine water plants is high. Due to strong β-radiation the dose coefficients for ingestion and inhalation are rather high but not as those for the actinides. The dose coefficient for external exposure is high. In conclusion the exposure from Ho-166m is intermediate to low in the models (lake, coastal, running waters, agricultural land, mire, well). The dominating exposure pathway in the well model is external exposure. In the lake and running waters models used in SR 97 consumption of shellfish is the most important contributor to dose followed by external exposure and consumption of fish. Consumption of shellfish was not included in the lake model used in the SAFE study, instead external exposure is the most important pathway. In the coastal model consumption of fish is the dominating exposure pathway whereas external exposure is most important in the agricultural land and mire models. In the latter inhalation is also of some importance.

2.25 Lead

2.25.1 Physical properties

Occurrence	In: earth crust 13 ppm, seawater 0.003 ppm. Non-essential. Accumulates in mammalian bone. Toxic, teratogenic, carcinogenic.
Stable isotopes (natural abundance)	Pb-204 (1.4 %), Pb-206 (24.1 %), Pb-207 (22.1 %), Pb-208 (52.3 %)
Radioactive isotopes (half-life)	Pb-195m (16 minutes), Pb-198 (2.4 hours), Pb-199 (90 minutes), Pb-200 (21.5 hours), Pb-201 (9.3 hours), Pb-202m (4 hours), Pb-202 (52 500 years), Pb-203 (51.9 hours), Pb-205 ($1.53 \cdot 10^7$ years), **Pb-210 (22.3 years)**, Pb-211 (36.1 minutes), Pb-212 (10.6 hours), Pb-214 (26.8 minutes)
Decay chains:	${}^{210}_{82}Pb \rightarrow {}^{210}_{83}Bi \rightarrow {}^{210}_{84}Po \rightarrow {}^{206}_{82}Pb$ (stable)

2.25.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m³])

	B.E.	Distr	Low	High	Reference
Soil	1E-1	LT	1E-2	1E+0	*
Organic soil	2E+1	LT	8E+0	6E+1	IAEA, 1994
Suspended matter					
lakes	5E-2	LT	1E-2	1E-1	**
brackish water	5E-2	LT	1E-2	1E-1	***

* The value is taken from Jiskra (1985) which refers to Pinner & Hill (1982) and Wuschke *et al* (1981).

** The best estimate is in Bergström *et al* (1985) chosen within the range given in Jiskra (1985). The referred range (0.01-0.1 m^3/kg) is taken from Wuschke *et al* (1981).

*** The same value as for freshwater is used.

2.25.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E-3	LT	1E-4	1E-2	IAEA, 1994***
Cereals**	4E-3	LT	4E-4	4E-2	IAEA, 1994****
Root crops**	4E-3	LT	4E-4	4E-2	IAEA, 1994****
Vegetables**	1E-3	LT	1E-4	1E-2	IAEA, 1994****

* Dry weight.

** Wet weight.

*** A best estimate of 0.01 m^3/kg (minimum 0.001 and maximum 0.1 m^3/kg) has been used in SR 97 by mistake. The value given in IAEA (1994) is 0.001 m^3/kg and the values in this table were used in SAFE.

**** For cereals, root crops and vegetables the values given in IAEA, 1994 has been converted into wet weight (assuming 10% water in cereals, 80% in root crops and 90% in vegetables).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	**Distr**	**Low**	**High**	**Reference**
Freshwater fish	3E+2	T	1E+2	4E+2	IAEA, 1994*
Baltic fish	1E+2	LT	5E+1	2E+2	Thompson *et al*, 1972**
Freshwater invertebrates	1E+2	LT	1E+1	1E+3	Thompson *et al*, 1972
Marine water plants	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

* The somewhat higher maximum value has been used since the value presented in IAEA (1994) is the same as the best estimate which is not accepted by the model system used. Since the range is very narrow a triangular distribution has been used in SAFE (Karlsson *et al*, 2001) whereas a log-triangular distribution was used in SR 97 (Bergström *et al*, 1999).

** The value presented for freshwater fish has been used.

2.25.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	**Distr**	**Low**	**High**	**Reference**
Milk (day/l)	3.0E-4	LT	2.0E-5	2.0E-3	*
Meat (day/kg)	4.0E-4	LT	1.0E-4	7.0E-4	IAEA, 1994

* The best estimate and range is taken from Bergström & Nordlinder (1990a) which refers to a DRAFT from IAEA. In the resulting report (IAEA, 1994) no transfer coefficients for lead to milk are presented. The same value is used in Davis *et al* (1993) and is also found in Ng *et al* (1977).

2.25.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
3E-2	T	1E-2	1E-1	IAEA, 1994*

* The value presented for a time period of 40 days between contamination and harvest (most relevant for the models used) has been used as a best estimate. As values are missing for the time period where maximum values are presented for other elements in the table a somewhat higher value than that given for a time period of 0 days (0.05) has been used as maximum value. The minimum value has been set to fit with the other values.

2.25.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Pb-210	β	22.3	7.2E-17	6.9E-7	5.6E-6*

* In SR 97 a value of 1.1E-6 Sv/Bq was used.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1 –2	2 – 7	7 – 12	12 – 17
Pb-210	8.4E-06	3.6E-06	2.2E-06	1.9E-06	1.9E-06

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1 –2	2 – 7	7 – 12	12 – 17
Pb-210	1.8E-05	1.8E-05	1.1E-05	7.2E-06	5.9E-06

2.25.7 Summary

Lead is a non-essential element which accumulates in mammalian bone. It is toxic in large amounts and is known to be teratogenic as well as carcinogenic. Four stable isotopes occur in the environment; Pb-204, Pb-206, Pb-207 and Pb-208 of which the latter is the most abundant. Root uptake of lead is rather low. The radioactive isotope which may be of interest for dose assessments concerning repositories for nuclear fuel and waste is Pb-210 which has a half-life of 22 years. The sorption to solid matter varies from low in sediments to high in peat. The transfer to milk and meat is rather low. Accumulation in aquatic organisms is intermediate (freshwater fish and crustaceans, brackish water fish) to high (marine water plants). The dose coefficients for ingestion, inhalation and external exposure are all high. In conclusion the exposure from Pb-210 is high in the lake, coastal, running waters and well models but intermediate in the agricultural land and mire models. The dominating exposure pathway in the well model is consumption of water whereas consumption of fish is the main contributor to dose in the lake, coastal and running waters models. Consumption of cereals and root crops are the most important exposure pathways in the agricultural land and mire models.

2.26 Polonium

2.26.1 Physical properties

Occurrence	In: earth crust $3 \cdot 10^{-10}$ ppm, seawater 0 ppm. None-essential. Accumulates in mammalian bone and hair. Very toxic to mammals.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Po-203 (36.7 minutes), Po-205 (1.7 hours), Po-207 (5.8 hours), **Po-210 (138.4 days)**, Po-211 (0.5 seconds), Po-212 (0.3 microsec), Po-213 (4.2 microsec), Po-214 (164 microsec), Po-215 (1.8 msec), Po-216 (0.15 sec), Po-218 (3.1 minutes)
Decay chains:	${}^{210}_{84}Po \rightarrow {}^{206}_{82}Pb$ (stable)

2.26.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	5E-1	LT	5E-2	3E+0	IAEA, 1994
Organic soil	7E+0	LT	7E-1	7E+2	IAEA, 1994
Suspended matter					
lakes	1E+1	LT	1E+0	1E+2	NCRP, 1996
brackish water	2E+4	LT	1E+2	5E+4	IAEA, 1985*

* The K_d-values for fresh and brackish waters differ very much. As Po-210 has a short half-life it has not been of interest in any of the safety assessments performed by the authors and therefore no effort has been placed on checking this data more thoroughly.

2.26.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	5E-2	LT	5E-3	5E-1	IAEA, 1994***
Cereals**	1E-3	LT	1E-4	1E-2	IAEA, 1994***
Root crops**	4E-3	LT	4E-4	4E-2	IAEA, 1994***
Vegetables**	1E-3	LT	1E-4	1E-2	IAEA, 1994***

* Dry weight.

** Wet weight.

*** The values presented in IAEA (1994) have been divided with two to correct for aerial contamination as recommended.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	5E+1	LT	5E+0	5E+2	IAEA, 1994
Baltic fish	2E+3	LT	2E+2	2E+4	NCRP, 1996
Freshwater invertebrates	2E+4	LT	2E+3	2E+5	Thompson *et al*, 1972
Marine water plants	2E+3	LT	2E+2	2E+4	Thompson *et al*, 1972

2.26.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	3.4E-4	LT	3.4E-5	3.4E-3	IAEA, 1994
Meat (day/kg)	5.0E-3	LT	6.0E-4	5.1E-3	IAEA, 1994*

* As the maximum value can not be the same as the best estimate in the model system used, a value of 5.1E-3 has been used instead of 5E-3 which is presented in the reference.

2.26.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	5E-2	2E-1	*

* The best estimate and range are taken from Bergström *et al* (1991) which writes that the values for translocation factors are estimated from chemically similar elements with no further specification.

2.26.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Po-210	α	0.4	0	1.2E-6	4.3E-6

Dose coefficients for oral intake for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Po-210	2.6E-05	8.8E-06	4.4E-06	2.6E-06	1.6E-06

Dose coefficients for inhalation for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Po-210	1.8E-05	1.4E-05	8.6E-06	5.9E-06	5.1E-06

2.26.7 Summary

Polonium is a none-essential element which accumulates in mammalian bone and hair. It is very toxic to mammals. No stable isotope exists but some radioactive ones. The radioactive isotope which may be of interest for dose assessments concerning repositories for nuclear fuel and waste is Po-210 which has a half-life of 240 days. Root uptake of polonium is rather low. The sorption to solid matter in solids, sediments and peat is high. Transfer to meat is rather high and transfer to milk somewhat lower (about ten times lower). Accumulation is high in brackish water fish, freshwater crustaceans and marine water plants but intermediate compared to the other elements in this study in freshwater fish. Due to the strong α-radiation the dose coefficient for ingestion is very high and also the dose coefficient for inhalation is high. No significant external exposure occurs. Po-210 was not considered in SR 97 and the SAFE study so no discussion about important exposure pathways is presented here.

2.27 Radon

2.27.1 Physical properties

Occurrence	Atmosphere trace. In: earth crust $1.7 \cdot 10^{-10}$ ppm, seawater $9 \cdot 10^{-15}$ ppm. None-essential. Highly toxic to mammals.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Rn-218 (35 msec), Rn-219 (3.9 seconds), Rn-220 (55.6 seconds), **Rn-222 (3.8 days)**
Radioactive mother nuclide (half-life)	Ra-226 (1 600 years) → Rn-222

Decay chains:

$^{222}_{86}Rn \rightarrow ^{218}_{84}Po \rightarrow ^{214}_{82}Pb$ (99.98%) $\rightarrow ^{214}_{83}Bi \rightarrow ^{214}_{84}Po \rightarrow ^{210}_{82}Pb \rightarrow ^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb$ (stable)

$^{222}_{86}Rn \rightarrow ^{218}_{84}Po \rightarrow ^{218}_{85}At$ (0.02%) $\rightarrow ^{214}_{83}Bi \rightarrow ^{214}_{84}Po \rightarrow ^{210}_{82}Pb \rightarrow ^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb$ (stable)

2.27.2 Sorption properties

Sorption of radon in soils, sediments or peat is not considered because it is a gas.

2.27.3 Uptake in biota

Uptake and accumulation of radon in biota is not considered because it is a gas.

2.27.4 Metabolism

Transfer of radon to milk and meat in cattle has not been considered since it is a gas.

2.27.5 Translocation

Translocation of radon in vegetation has not been considered since it is a gas.

2.27.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Rn-222	α	0.01	–*	–*	1.6E-8**

* As radon is an alfa emitting gas inhalation is the only kind of exposure which is relevant.

** During many years a factor of 0.037 mSv per year per Bq/m^3 was used in the Nordic countries based on an UNSCEAR report from 1982 (UNSCEAR, 1982). Some epidemiological studies has been performed to study the risk with radon and from those ICRP has calculated a factor of 0.021 [mSv/year]/[Bq/m^3] (ICRP, 1993). This is the one which should be used today (Nils Hagberg, SSI, pers. comm. 2001-04-11). This factor has been transformed into Sv/Bq using the following assumptions; the time spent within the house is 8.76 hours per day and an equilibrium factor of 0.4 is used (Nils Hagberg, SSI, pers. comm. 2001-04-11). The inhalation rate is 1 m^3 per hour (ICRP, 1974).

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Rn-222	–*	–*	–*	–*	–*

* As radon is an alfa emitting gas, intake is not of interest.

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Rn-222	–*	–*	–*	–*	–*

* No age specific data have been found.

2.27.7 Summary

Radon is a radioactive gas which appears as trace in the atmosphere. It is none-essential. No stable isotopes occur but some radioactive ones. Rn-222 is produced from radium and is common in Swedish groundwater. It escapes quickly from water to air. High levels in water may therefore lead to high levels in indoor air. Radon in indoor air may also descend from construction material containing radium. As radon is a gas no root uptake or uptake in aquatic organisms occurs as well as sorption to solid matter. The only kind of exposure of interest is exposure through inhalation. Due to the rather strong α-radiation the dose coefficient for inhalation is rather high but not as those for the actinides.

2.28 Radium

2.28.1 Physical properties

Occurrence	In: earth crust 10^{-6} ppm, seawater $3 \cdot 10^{-11}$ ppm. Non-essential. Accumulates in mammalian bone.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Ra-222 (38.0 seconds), Ra-223 (11.4 days), Ra-224 (3.7 days), Ra-225 (14.9 days), **Ra-226 (1 600 years)**, Ra-227 (42.2 minutes), Ra-228 (5.75 years)
Radioactive mother nuclide (half-life)	Th-230 (75 380 years) → Ra-226

Decay chains:

$$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn \rightarrow ^{218}_{84}Po \rightarrow ^{214}_{82}Pb \text{ (99.98\%)} \rightarrow ^{214}_{83}Bi \rightarrow ^{214}_{84}Po \rightarrow ^{210}_{82}Pb \rightarrow ^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb \ (stable)$$

$$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn \rightarrow ^{218}_{84}Po \rightarrow ^{218}_{85}At \text{ (0.02\%)} \rightarrow ^{214}_{83}Bi \rightarrow ^{214}_{84}Po \rightarrow ^{210}_{82}Pb \rightarrow ^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb \ (stable)$$

2.28.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	5E-1	LT	1E-2	1E+0	*
Organic soil	2E+0	LT	2E-1	2E+1	IAEA, 1994
Suspended matter					
lakes	1E+1	LT	1E+0	1E+2	**
brackish water	1E+1	LT	1E+0	1E+2	**

* The best estimate and range was defined in Bergström & Nordlinder (1990a) who refer to Bergström *et al* (1984). The range used in Bergström *et al* (1984) is based on three references; Sheppard (1980), Andersson & Allard (1983) and Andersson *et al* (1983).

** The best estimate and range was defined in Bergström *et al* (1984). The minimum value of 0.5 m^3/kg has been rounded off to 1 m^3/kg. Very few data on distribution coefficients for radium are available in the literature. Some data for concentrations in water and sediments in Lake Hornborgarsjön and River Flian, Sweden (Agnedal, 1967) may be interpreted as distribution coefficients in the range of 1-10 m^3/kg. The same ratio seems to exist for river sediments and water from northern Sweden (Ek *et al*, 1982). For French river sediments a distribution coefficient of about 1.9 m^3/kg has been reported (Rancon, 1978). Higher values (up to 200 m^3/kg) have also been reported (Bergström & Wilkens, 1983 and Holm, 1981). The same value has been used for freshwater and brackish water.

2.28.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	8E-2	LT	2E-2	4E-1	IAEA, 1994***
Cereals**	1E-3	LT	2E-4	5E-3	IAEA, 1994***
Root crops**	4E-3	LT	4E-4	2E-2	IAEA, 1994***
Vegetables	5E-3	LT	3E-4	1E-1	IAEA, 1994***

* Dry weight.

** Wet weight.

*** The ranges used in SR 97 (low ten times lower than best estimate, maximum ten times higher than best estimate) has been changed to those presented in IAEA (1994). The values used for cereals, root crops and vegetables in SR 97 (0.07, 0.002 and 0.05 respectively) were referred to IAEA (1994) but did not match those given so they were corrected and the values presented here is those used in the SAFE study. The values for cereals, root crops and vegetables were converted to be valid for wet weight (10% water in cereals, 80% in root crops and 90% in vegetables).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	5E+1	LT	1E+1	2E+2	IAEA, 1994
Baltic fish	5E+1	LT	1E+1	1E+2	Poston & Klopfer, 1986*
Freshwater invertebrates	3E+2	LT	3E+1	3E+3	Thompson *et al*, 1972
Marine water plants	1E+2	LT	1E+1	1E+3	Thompson *et al*, 1972

* The range is estimated from the freshwater values for undisturbed environments in Agnedal (1982) (7–230 l/kg). The studies referred to in this study are de Bortoli & Gaglione (1972), Schüttelkopf & Kiefer (1979 and 1980) and Wahlgren *et al* (1976).

2.28.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	1.3E-3	LT	1.0E-4	2.0E-3	IAEA, 1994*
Meat (day/kg)	9.0E-4	LT	5.0E-4	5.0E-3	IAEA, 1994

* The range given in IAEA (1994) has been extended somewhat.

2.28.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Since data are lacking a best estimate of 10% has been used as for many other elements for which data have not been found. A rather wide range has been used as the uncertainty is high.

2.28.6 Nuclide specific parameters

Ra-226

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Ra-226	α	1 600	6.0E-16	2.8E-7	9.5E-6*

* In SR 97 a value of 3.5E-6 Sv/Bq was used.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Ra-226	4.7E-06	9.6E-07	6.2E-07	8.0E-07	1.5E-06

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1 –2**	**2 – 7**	**7 – 12**	**12 – 17**
Ra-226	3.4E-05	2.9E-05	1.9E-05	1.2E-05	1.0E-05

2.28.7 Summary

Radium does not occur as a stable isotope in the environment. When it decays the radioactive gas radon is formed (see previous section). Radium is a non-essential element which accumulates in mammalian bone. The radioactive isotope which may be of interest for dose assessments concerning repositories for nuclear fuel and waste is Ra-226 which has a half-life of 1 600 years. The root uptake of radium is rather low whereas sorption to solid matter in soils, sediments and peat is high. Transfer to milk and meat is rather high. Accumulation in aquatic organisms is rather low. Due to strong α-radiation the dose coefficients for ingestion and inhalation are high whereas the coefficient for external exposure is low. In conclusion the exposure from Ra-226 is high in all models (lake, coastal, running waters, agricultural land, mire, well). Ra-226 was considered in SR 97 but not in the SAFE study. The dominating exposure pathway in the well model is consumption of water followed by consumption of vegetables. In the lake and running waters models consumption of fish and shellfish are the most important pathways. Consumption of fish is the dominant exposure pathway in the coastal model whereas consumption of cereals, followed by consumption of root crops is the most important in the agricultural land and mire models.

2.29 Actinium

2.29.1 Physical properties

Occurrence	Only traces in uranium ores. None-essential. Accumulates in liver and bone.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Ac-223 (2.1 minutes), Ac-224 (2.8 hours), Ac-225 (10.0 days), Ac-226 (29.4 hours), **Ac-227 (21.8 years)**, Ac-228 (6.2 hours)
Radioactive mother nuclide (half-life)	Pa-231 (32 760 years) → Ac-227

Decay chains:

$${}^{227}_{89}Ac \rightarrow {}^{227}_{90}Th\ (98.6\%) \rightarrow {}^{223}_{88}Ra \rightarrow {}^{219}_{86}Rn \rightarrow {}^{215}_{84}Po \rightarrow {}^{211}_{82}Pb \rightarrow {}^{211}_{83}Bi \rightarrow {}^{207}_{81}Tl\ (99.72\%) \rightarrow {}^{207}_{82}Pb\ (stable)$$

$${}^{227}_{89}Ac \rightarrow {}^{223}_{87}Fr\ (1.4\%) \rightarrow {}^{223}_{88}Ra \rightarrow {}^{219}_{86}Rn \rightarrow {}^{215}_{84}Po \rightarrow {}^{211}_{82}Pb \rightarrow {}^{211}_{83}Bi \rightarrow {}^{207}_{81}Tl\ (99.72\%) \rightarrow {}^{207}_{82}Pb\ (stable)$$

$${}^{227}_{89}Ac \rightarrow {}^{223}_{87}Fr\ (1.4\%) \rightarrow {}^{223}_{88}Ra \rightarrow {}^{219}_{86}Rn \rightarrow {}^{215}_{84}Po \rightarrow {}^{211}_{82}Pb \rightarrow {}^{211}_{83}Bi \rightarrow {}^{211}_{84}Po\ (0.28\%) \rightarrow {}^{207}_{82}Pb\ (stable)$$

2.29.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E+0	LT	1E-1	1E+1	*
Organic soil	5E+0	LT	5E-1	5E+1	IAEA, 1994
Suspended matter					
lakes	1E+1	LT	1E+0	1E+2	**
brackish water	1E+1	LT	1E+0	1E+2	**

* The range and best estimate was defined in Bergström & Nordlinder (1990a) who refer to Bergström *et al* (1985). In that study this value is used and referred to Jiskra (1985). In this report a value of 0.1 m^3/kg is used based on a range of 0.1–1 m^3/kg (Wuschke *et al*, 1981) and a value of 3 m^3/kg (Pinner & Hill, 1982). In order not to underestimate the sorbed fraction a value of 1 m^3/kg has been used.

** The range and best estimate was defined in Bergström & Nordlinder (1990a) which refers to Bergström *et al* (1985). No reference is given in Bergström *et al* (1985) but in the discussion actinium is said to show large similarity with actinides and the values are of the same order as the K_d-values used for americium.

2.29.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	5E-4	LT	3E-5	7E-3	***
Cereals**	4E-4	LT	1E-5	1E-3	***
Root crops**	5E-5	LT	2E-5	1E-2	***
Vegetables	4E-3	LT	2E-4	8E-2	***

* Dry weight.

** Wet weight.

*** These values are given in Bergström & Nordlinder (1990a). Due to absence of data for actinium, data for americium were used as these two elements are chemically similar. The best estimates and ranges are said to be estimated from a DRAFT from IAEA (IAEA, 1994). The ranges used are those recommended by Frissel & Koster (1989).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	1E+2	LT	1E+1	2E+2	*
Baltic fish	1E+2	LT	1E+1	2E+2	*
Freshwater invertebrates	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972
Marine water plants	5E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

* Thompson *et al* (1972) recommends a bioaccumulation factor of 25 l/kg for fish whereas Poston & Klopfer (1986) recommend a value of 100. As actinium concentrate in bone this value may be too high. A value of 100 l/kg has been used anyway in order to be conservative. In Bergström & Nordlinder (1990a) a range of 10–1,000 l/kg was used. The maximum value has been lowered to 200 as actinium tends to accumulate in bone. The best estimate of 100 is also, as said earlier, considered conservative. In Bergström *et al* (1999) a maximum value of 1,000 l/kg was used for Baltic fish but this has been lowered to 200 in Karlsson *et al* (2001).

2.29.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2.0E-6	LT	2.0E-7	2.0E-5	NCRP, 1996*
Meat (day/kg)	2.0E-5	LT	2.0E-6	2.0E-4	NCRP, 1996*

* In SR 97 transfer coefficients of $3{\cdot}10^{-7}$ day/l ($3{\cdot}10^{-8}$–$3{\cdot}10^{-6}$ day/l) and $1{\cdot}10^{-5}$ day/kg ($1{\cdot}10^{-6}$–$1{\cdot}10^{-4}$ day/kg) was used to milk and meat, respectively, with reference to Bergström & Nordlinder (1990a). In that report no references are given but it seems reasonable that values for americium (with similar chemical behaviour) has been a base when these values were set up. As values for actinium was found in NCRP (1996) these has been used in the SAFE study (see this table). The actinium values are higher than those used earlier and in accordance to those used in Davis *et al* (1993); $2.0{\cdot}10^{-5}$ day/l for milk and $2.5{\cdot}10^{-5}$ day/kg for meat. As that study used only one value for each parameter this must be conservative in order not to underestimate the dose to humans.

2.29.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Since data are lacking a best estimate of 10 % has been used as for many other elements for which data have not been found. A rather wide range has been used as the uncertainty is high.

2.29.6 Nuclide specific parameters

Ac-227

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m³)	Ingestion Sv/Bq	Inhalation Sv/Bq
Ac-227	α	21.8	0	1.1E-6	5.5E-4*

* In SR 97 a value of 2.2E-4 Sv/Bq was used.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Ac-227	3.3E-05	3.1E-06	2.2E-06	1.5E-06	1.2E-06

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	<1	1–2	2–7	7–12	12–17
Ac-227	1.7E-03	1.6E-03	1.0E-03	7.2E-04	5.6E-04

2.29.7 Summary

No stable isotope of actinium occurs but some radioactive ones are present as traces in uranium ores. It is a none-essential element which accumulates in liver and bone. The radioactive isotope which may be of interest for dose assessments concerning repositories for nuclear fuel and waste is Ac-227 which has a half-life of 22 years. The root uptake of actinium is low whereas sorption to solid matter in soils, sediments and peat is high. Transfer to milk and meat is low. Accumulation in aquatic organisms varies, from intermediate compared to the other elements in this study in fish (freshwater as well as brackish) to high in freshwater crustaceans and marine water plants. Due to the strong α-radiation the dose coefficients for ingestion and inhalation are very high whereas significant external exposure do not occur. In conclusion the exposure from Ac-227 is high in the lake, coastal, running waters and well model and low in the agricultural land and mire models. Ac-227 was considered in SR 97 but not in the SAFE study. The dominating exposure pathway in the well model is consumption of water. In the lake and running waters models the most important exposure pathway is consumption of shellfish followed by consumption of fish. In the coastal model consumption of fish is totally dominant whereas inhalation of dust is the most important exposure pathway in the agricultural land and mire models.

2.30 Thorium

2.30.1 Physical properties

Occurrence	In: earth crust 8.1 ppm, seawater 0.0007 ppm. None-essential. Accumulates in mammalian bone. Low toxicity.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Th-226 (30.6 minutes), Th-227 (18.7 days), Th-228 (1.9 years), **Th-229 (7 340 years)**, **Th-230 (75 380 years)***, Th-231 (25.5 hours), **Th-232 ($1.405 \cdot 10^{10}$ years)**, Th-234 (24.1 days)
Radioactive mother nuclide (half-life)	U-233 (159 200 years) → Th-229 U-234 (245 500 years) → Th-230 U-236 ($2.342 \cdot 10^{7}$ years) → Th-232

Decay chains:

$^{229}_{90}Th \rightarrow ^{225}_{88}Ra \rightarrow ^{225}_{89}Ac \rightarrow ^{221}_{87}Fr \rightarrow ^{217}_{85}At \rightarrow ^{213}_{83}Bi \rightarrow ^{213}_{84}Po$ (97.8%) $\rightarrow ^{209}_{82}Pb \rightarrow ^{209}_{83}Bi$ (stable)

$^{229}_{90}Th \rightarrow ^{225}_{88}Ra \rightarrow ^{225}_{89}Ac \rightarrow ^{221}_{87}Fr \rightarrow ^{217}_{85}At \rightarrow ^{213}_{83}Bi \rightarrow ^{209}_{81}Tl$ (2.2%) $\rightarrow ^{209}_{82}Pb \rightarrow ^{209}_{83}Bi$ (stable)

$^{230}_{90}Th \rightarrow ^{226}_{88}Ra \rightarrow ^{222}_{86}Rn \rightarrow ^{218}_{84}Po \rightarrow ^{214}_{82}Pb$ (99.98%) $\rightarrow ^{214}_{83}Bi \rightarrow ^{214}_{84}Po \rightarrow ^{210}_{82}Pb \rightarrow ^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb$ (stable)

$^{230}_{90}Th \rightarrow ^{226}_{88}Ra \rightarrow ^{222}_{86}Rn \rightarrow ^{218}_{84}Po \rightarrow ^{218}_{85}At$ (0.02%) $\rightarrow ^{214}_{83}Bi \rightarrow ^{214}_{84}Po \rightarrow ^{210}_{82}Pb \rightarrow ^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb$ (stable)

$^{232}_{90}Th \rightarrow ^{228}_{88}Ra \rightarrow ^{228}_{89}Ac \rightarrow ^{228}_{90}Th \rightarrow ^{224}_{88}Ra \rightarrow ^{220}_{86}Rn \rightarrow ^{216}_{84}Po \rightarrow ^{212}_{82}Pb \rightarrow ^{212}_{83}Bi \rightarrow ^{208}_{81}Tl$ (35.9%) $\rightarrow ^{208}_{82}Pb$ (stable)

$^{232}_{90}Th \rightarrow ^{228}_{88}Ra \rightarrow ^{228}_{89}Ac \rightarrow ^{228}_{90}Th \rightarrow ^{224}_{88}Ra \rightarrow ^{220}_{86}Rn \rightarrow ^{216}_{84}Po \rightarrow ^{212}_{82}Pb \rightarrow ^{212}_{83}Bi \rightarrow ^{212}_{84}Po$ (64.1%) $\rightarrow ^{208}_{82}Pb$ (stable)

* The half-life used in SR 97 is 77 000 years

2.30.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E+1	LT	1E+0	1E+2	*
Organic soil	9E+1	LT	9E+0	9E+2	IAEA, 1994**
Suspended matter					
lakes	1E+2	LT	1E+1	1E+3	Wahlgren & Orlandini, 1982
brackish water	1E+2	LT	1E+1	1E+3	Wahlgren & Orlandini, 1982***

* The value is taken from Jiskra (1985) who refers to Ames & Rai (1978), Dahlman *et al* (1976) and Parker & Grant (1979).

** A very wide range is given in the reference (9E-2–9E-5 m^3/kg). This has been decreased to the range set when information is missing i.e. minimum ten times lower than best estimate and maximum ten times higher.

*** In lack of data the same values as for fresh water has been used.

2.30.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E-2	LT	1E-3	1E-1	IAEA, 1994
Cereals**	1E-2	LT	1E-3	1E-1	IAEA, 1994***
Root crops**	1E-5	LT	1E-6	1E-4	IAEA, 1994
Vegetables**	2E-4	LT	2E-5	2E-3	IAEA, 1994

* Dry weight.

** Wet weight.

*** The value for pasturage (in dry weight) has been converted into fresh weight considering a water content of 10% for cereals.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	1E+2	LT	3E+1	1E+3	IAEA, 1994*
Baltic fish	3E+1	LT	1E+0	1E+2	**
Freshwater invertebrates	5E+2	LT	5E+1	5E+3	Thompson *et al*, 1972
Marine water plants	3E+3	LT	3E+2	3E+4	Thompson *et al*, 1972***

* The range given in IAEA (1994), 30–10,000 l/kg has been decreased somewhat (maximum 1,000 l/kg) as thorium tends to accumulate in bone and so high values as 10,000 is than not reasonable for accumulation in fish flesh.

** The best estimate and range are defined in Bergström & Nordlinder (1990a). The best estimate is taken from USNRC (1977) and IAEA (1982) (value for freshwater fish). Much higher values are recommended by Poston & Klopfer (1986); 1,000 l/kg for freshwater fish and 600 l/kg for marine species. The high values have not been selected since it seems questionable for a bone-seeking nuclide. No ranges were given in USNRC (1977) or IAEA (1982) and the range presented in Bergström & Nordlinder (1990a) is not motivated.

*** In SR 97 (Bergström *et al*, 1999) a maximum value of 10,000 l/kg was used. No motivation to this somewhat different choice of value was given and in SAFE (Karlsson *et al*, 2001) a maximum value of 30,000 l/kg has been used in accordance to how the maximum value has been chosen for other elements when no range is found in the literature.

2.30.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	5.0E-6	LT	1.0E-7	1.0E-4	IAEA, 1982*
Meat (day/kg)	6.0E-6	LT	6.0E-7	6.0E-5	Davis *et al*, 1993

* The value given in IAEA (1982) is said to be derived from human data by Ng *et al* (1977).

2.30.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Since data are lacking a best estimate of 10% has been used as for many other elements for which other data have not been found. A rather wide range has been used as the uncertainty is high.

2.30.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Th-229	α	7 340	2.0E-15	4.9E-7	2.4E-4*
Th-230	α	75 380	3.5E-17	2.1E-7	1.0E-4*
Th-232	α	14 050 000 000	1.5E-17	2.3E-7	1.1E-4*

* In SR 97 a value of 1.1E-4 Sv/Bq was used for Th-229. For Th-230 a value of 4.3E-5 Sv/Bq was used. The value used for Th-232 was 4.5E-5 Sv/Bq.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Th-229	1.1E-05	1.0E-06	7.8E-07	6.2E-07	5.3E-07
Th-230	4.1E-06	4.1E-09	3.1E-07	2.4E-07	2.2E-07
Th-232	4.6E-06	4.5E-07	3.5E-07	2.9E-07	2.5E-07

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1 –2**	**2 – 7**	**7 – 12**	**12 – 17**
Th-229	5.4E-04	5.1E-04	3.6E-04	2.9E-04	2.4E-04
Th-230	2.1E-04	2.0E-04	1.4E-04	1.1E-04	9.9E-05
Th-232	2.3E-04	2.2E-04	1.6E-04	1.3E-04	1.2E-04

2.30.7 Summary

No stable isotope exists for thorium but some radioactive ones. It is a none-essential element which accumulates in mammalian bone. The toxicity is low. The radioactive isotopes which are of interest for dose assessments concerning repositories for nuclear fuel and waste are Th-229, Th-230 and Th-232 which have half-lives of 7 340, 75 380 and 14 050 000 000 years, respectively. The root uptake of thorium is intermediate for pasturage and cereals and low for vegetables and root crops. The sorption to solid matter in soils, sediments and peat is high whereas transfer to milk and meat is low. The accumulation in aquatic organisms varies, from intermediate compared to the other elements in this study to high (marine water plants). Due to the strong α-radiations the dose coefficients for ingestion and inhalation are very high for all three nuclides whereas the dose coefficients for external exposure are intermediate (Th-229) to low. In conclusion the exposure from all three thorium isotopes (Th-229, Th-230 and Th-232) is high in all models (lake, coastal, running waters, agricultural land, mire and well). The dominating exposure pathway for those nuclides in the well model is inhalation of dust followed by consumption of water. In the lake, coastal and running waters models consumption of fish is the most important pathway. In the agricultural land and mire models do inhalation and consumption of cereals dominate the contribution to exposure, in the former model these two pathways are of the same importance whereas inhalation are of larger importance than consumption of cereals in the mire model.

2.31 Protactinium

2.31.1 Physical properties

Occurrence	Trace in uranium ores. Seawater $2 \cdot 10^{-12}$ ppm. None-essential. Accumulates in mammalian bone.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Pa-227 (38.3 minutes), Pa-228 (22 hours), Pa-230 (17.4 days), **Pa-231 (32 760 years)**, Pa-232 (1.3 days), Pa-233 (27 days), Pa-234m (1.2 minutes), Pa-234 (6.7 hours)
Radioactive mother nuclide (half-life)	Th-231 (25.5 hours) → Pa-231

Decay chains:

$^{231}_{91}Pa \rightarrow ^{227}_{89}Ac \rightarrow ^{227}_{90}Th$ (98.6%) $\rightarrow ^{223}_{88}Ra \rightarrow ^{219}_{86}Rn \rightarrow ^{215}_{84}Po \rightarrow ^{211}_{82}Pb \rightarrow ^{211}_{83}Bi \rightarrow ^{207}_{81}Tl$ (99.72%) $\rightarrow ^{207}_{82}Pb$ (stable)

$^{231}_{91}Pa \rightarrow ^{227}_{89}Ac \rightarrow ^{223}_{87}Fr$ (1.4%) $\rightarrow ^{223}_{88}Ra \rightarrow ^{219}_{86}Rn \rightarrow ^{215}_{84}Po \rightarrow ^{211}_{82}Pb \rightarrow ^{211}_{83}Bi \rightarrow ^{207}_{81}Tl$ (99.72%) $\rightarrow ^{207}_{82}Pb$ (stable)

$^{231}_{91}Pa \rightarrow ^{227}_{89}Ac \rightarrow ^{223}_{87}Fr$ (1.4%) $\rightarrow ^{223}_{88}Ra \rightarrow ^{219}_{86}Rn \rightarrow ^{215}_{84}Po \rightarrow ^{211}_{82}Pb \rightarrow ^{211}_{83}Bi \rightarrow ^{211}_{84}Po$ (0.28%) $\rightarrow ^{207}_{82}Pb$ (stable)

2.31.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E+1	LT	1E+0	1E+2	*
Organic soil	7E+0	LT	7E-1	7E+1	IAEA, 1994
Suspended matter					
lakes	1E+2	LT	1E+1	1E+3	*
brackish water	1E+2	LT	1E+1	1E+3	*

* Protactinium seems to behave like thorium in aquatic environments (Riley & Skirrow, 1975), and studies of the geochemical behaviour seem to confirm these results. The same distribution coefficients as for thorium have therefore been used.

2.31.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	3E-3	LT	3E-4	3E-2	***
Cereals**	3E-3	LT	3E-4	3E-2	***
Root crops**	6E-4	LT	6E-5	6E-3	***
Vegetables	3E-4	LT	3E-5	3E-3	***

* Dry weight.

** Wet weight.

*** Data concerning the root uptake of protactinium are sparse. In Bergström & Wilkens (1983) a factor of 0.003 m^3/kg was chosen with reference to Gera (1976), IAEA (1982) and Miller *et al* (1980). This value was converted to be valid for wet weight for cereals, root crops and vegetables (10% water in cereals, 80% in root crops and 90% in vegetables).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	1E+1	LT	1E+0	1E+2	IAEA, 1982
Baltic fish	1E+1	LT	1E+0	1E+2	IAEA, 1982*
Freshwater invertebrates	1E+2	LT	1E+1	1E+3	Thompson *et al*, 1972
Marine water plants	6E+0	LT	6E-1	6E+1	Thompson *et al*, 1972

* The value for freshwater fish has been used.

2.31.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	5.0E-5	LT	1.0E-6	1.0E-4	Ng, 1982
Meat (day/kg)	1.0E-5	LT	1.0E-6	1.0E-4	Davis *et al*, 1993

2.31.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Since data are lacking a best estimate of 10% has been used as for many other elements for which data have not been found. A rather wide range has been used as the uncertainty is high.

2.31.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Pa-231	α	32 760	1.8E-15	7.1E-7	1.4E-4

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Pa-231	1.3E-05	1.3E-06	1.1E-06	9.2E-07	8.0E-07

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Pa-231	2.2E-04	2.3E-04	1.9E-04	1.5E-04	1.5E-04

2.31.7 Summary

No stable isotope of protactinium occurs in the environment. Radioactive ones occur as trace in uranium ores. The element is none-essential and accumulates in mammalian bone. The radioactive isotope which may be of interest for dose assessments concerning repositories for nuclear fuel and waste is Pa-231 which has a half-life of 33,000 years. The root uptake of palladium is low whereas sorption to solid matter in soils, sediments and peat is high. Transfer to milk and meat is low which is also the case with accumulation in aquatic organisms. Due to the strong α-radiation the dose coefficients for ingestion and inhalation are high whereas that for external exposure is intermediate compared to the other nuclides in this study. In conclusion the exposure from Pa-231 is high in all models (lake, coastal, running waters, agricultural land, mire, well). The dominating exposure pathway in the well, agricultural land and mire models is inhalation of dust. This is also the most important exposure pathway in the lake and running waters models followed by consumption of water and fish. In the coastal model consumption of fish is the dominating exposure pathway.

2.32 Uranium

2.32.1 Physical properties

Occurrence	In: earth crust 2.3 ppm, seawater 0.003 ppm. None-essential. Toxic.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	U-230 (20.8 days), U-231 (4 days), **U-232 (68.9 years)**, **U-233 (159 200 years)***, **U-234 (245 500 years)***, **U-235 (7.038·10^8 years)**, **U-236 (2.342·10^7 years)**, U-237 (6.8 days), **U-238 (4.468·10^9 years)***, U-239 (23.4 minutes), U-240 (14.1 hours)
Radioactive mother nuclide (half-life)	Pu-238 (87.7 years) → U-234 Pu-239 (24 110 years) → U-235 Pu-240 (6 563 years) → U-236 Pu-242 (372 300 years) → U-238

Decay chains:

$$^{232}_{92}U \to ^{228}_{90}Th \to ^{224}_{88}Ra \to ^{220}_{86}Rn \to ^{216}_{84}Po \to ^{212}_{82}Pb \to ^{212}_{83}Bi \to ^{212}_{84}Po \text{ (64.07\%)} \to ^{208}_{82}Pb \text{ (stable)}$$
$$^{232}_{92}U \to ^{228}_{90}Th \to ^{224}_{88}Ra \to ^{220}_{86}Rn \to ^{216}_{84}Po \to ^{212}_{82}Pb \to ^{212}_{83}Bi \to ^{208}_{81}Tl \text{ (35.93\%)} \to ^{208}_{82}Pb \text{ (stable)}$$

$$^{233}_{92}U \to ^{229}_{90}Th \to ^{225}_{88}Ra \to ^{225}_{89}Ac \to ^{221}_{87}Fr \to ^{217}_{85}At \to ^{213}_{83}Bi \to ^{213}_{84}Po \text{ (97.84\%)} \to ^{209}_{82}Pb \to ^{209}_{83}Bi \text{ (stable)}$$
$$^{233}_{92}U \to ^{229}_{90}Th \to ^{225}_{88}Ra \to ^{225}_{89}Ac \to ^{221}_{87}Fr \to ^{217}_{85}At \to ^{213}_{83}Bi \to ^{209}_{81}Tl \text{ (2.16\%)} \to ^{209}_{82}Pb \to ^{209}_{83}Bi \text{ (stable)}$$

$$^{234}_{92}U \to ^{230}_{90}Th \to ^{226}_{88}Ra \to ^{222}_{86}Rn \to ^{218}_{84}Po \to ^{214}_{82}Pb \text{ (99.98\%)} \to ^{214}_{83}Bi \to ^{214}_{84}Po \to ^{210}_{82}Pb \to ^{210}_{83}Bi \to$$
$$\to ^{210}_{84}Po \to ^{206}_{82}Pb \text{ (stable)}$$
$$^{234}_{92}U \to ^{230}_{90}Th \to ^{226}_{88}Ra \to ^{222}_{86}Rn \to ^{218}_{84}Po \to ^{218}_{85}At \text{ (0.02\%)} \to ^{214}_{83}Bi \to ^{214}_{84}Po \to ^{210}_{82}Pb \to ^{210}_{83}Bi \to$$
$$\to ^{210}_{84}Po \to ^{206}_{82}Pb \text{ (stable)}$$

$$^{235}_{92}U \to ^{231}_{90}Th \to ^{231}_{91}Pa \to ^{227}_{89}Ac \to ^{227}_{90}Th \text{ (98.62\%)} \to ^{223}_{88}Ra \to ^{219}_{86}Rn \to ^{215}_{84}Po \to ^{211}_{82}Pb \to ^{211}_{83}Bi \to$$
$$\to ^{207}_{81}Tl \text{ (99.72\%)} \to ^{207}_{82}Pb \text{ (stable)}$$
$$^{235}_{92}U \to ^{231}_{90}Th \to ^{231}_{91}Pa \to ^{227}_{89}Ac \to ^{223}_{87}Fr \text{ (1.38\%)} \to ^{223}_{88}Ra \to ^{219}_{86}Rn \to ^{215}_{84}Po \to ^{211}_{82}Pb \to ^{211}_{83}Bi \to$$
$$\to ^{207}_{81}Tl \text{ (99.72\%)} \to ^{207}_{82}Pb \text{ (stable)}$$
$$^{235}_{92}U \to ^{231}_{90}Th \to ^{231}_{91}Pa \to ^{227}_{89}Ac \to ^{223}_{87}Fr \text{ (1.38\%)} \to ^{223}_{88}Ra \to ^{219}_{86}Rn \to ^{215}_{84}Po \to ^{211}_{82}Pb \to ^{211}_{83}Bi \to$$
$$\to ^{211}_{84}Po \text{ (0.28\%)} \to ^{207}_{82}Pb \text{ (stable)}$$

$$^{236}_{92}U \to ^{232}_{90}Th \to ^{228}_{88}Ra \to ^{228}_{89}Ac \to ^{228}_{90}Th \to ^{224}_{88}Ra \to ^{220}_{86}Rn \to ^{216}_{84}Po \to ^{212}_{82}Pb \to ^{212}_{83}Bi \to ^{212}_{84}Po \text{ (64.07\%)} \to$$
$$\to ^{208}_{82}Pb \text{ (stable)}$$
$$^{236}_{92}U \to ^{232}_{90}Th \to ^{228}_{88}Ra \to ^{228}_{89}Ac \to ^{228}_{90}Th \to ^{224}_{88}Ra \to ^{220}_{86}Rn \to ^{216}_{84}Po \to ^{212}_{82}Pb \to ^{212}_{83}Bi \to ^{208}_{81}Tl \text{ (35.93\%)} \to$$
$$\to ^{208}_{82}Pb \text{ (stable)}$$

$$^{238}_{92}U \to ^{234}_{90}Th \to ^{234}_{91}Pa \to ^{234}_{92}U \to ^{230}_{90}Th \to ^{226}_{88}Ra \to ^{222}_{86}Rn \to ^{218}_{84}Po \to ^{214}_{82}Pb \text{ (99.98\%)} \to ^{214}_{83}Bi \to ^{214}_{84}Po \to$$
$$\to ^{210}_{82}Pb \to ^{210}_{83}Bi \to ^{210}_{84}Po \to ^{206}_{82}Pb \text{ (stable)}$$
$$^{238}_{92}U \to ^{234}_{90}Th \to ^{234}_{91}Pa \to ^{234}_{92}U \to ^{230}_{90}Th \to ^{226}_{88}Ra \to ^{222}_{86}Rn \to ^{218}_{84}Po \to ^{218}_{85}At \text{ (0.02\%)} \to ^{214}_{83}Bi \to ^{214}_{84}Po \to$$
$$\to ^{210}_{82}Pb \to ^{210}_{83}Bi \to ^{210}_{84}Po \to ^{206}_{82}Pb \text{ (stable)}$$

* The half-live used for U-233 and U-234 in SR 97 are 158,500 and 244,500 years respectively.

2.32.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E-1	LT	1E-2	1E+0	*
Organic soil	4E-1	LT	3E-3	4E+0	IAEA, 1994**
Suspended matter					
lakes	1E+1	LT	1E+0	1E+2	***
brackish water	1E+1	LT	1E+0	1E+2	****

* In Grogan (1985a) this value was used with reference to Jiskra (1985) which refers to Parker & Grant (1979) and Dahlman *et al* (1976).

** A very wide range is given in the reference; 3E-3–6E1. This has been decreased to the range set when information is missing, i.e. minimum ten times lower than best estimate and maximum ten times higher.

*** A distribution coefficient in lakes in northern Sweden of 43 m^3/kg (mean value) was reported by Holm (1981) and a range of 0.2–250 m^3/kg was given in Bergström & Wilkens (1983). A value of 10 m^3/kg has been extracted from this information.

**** The values for fresh waters have been used.

2.32.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	2E-2	LT	2E-3	2E-1	IAEA, 1994
Cereals**	1E-3	LT	1E-4	1E-2	IAEA, 1994***
Root crops**	3E-3	LT	3E-4	3E-2	IAEA, 1994***
Vegetables	1E-3	LT	1E-4	1E-2	IAEA, 1994***

* Dry weight.

** Wet weight.

*** The value for pastureage has been converted into wet weight (10% water in cereals, 80% in root crops and 90% in vegetables).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	1E+1	LT	2E+0	5E+1	IAEA, 1994
Baltic fish	5E+1	LT	1E+1	1E+2	*
Freshwater invertebrates	1E+2	LT	1E+1	1E+3	Thompson *et al*, 1972
Marine water plants	7E+1	LT	7E+0	7E+2	Thompson *et al*, 1972

* The best estimate and range is defined in Bergström & Nordlinder (1990a). The best estimate is the value recommended for freshwater fish muscle in Poston & Klopfer (1986). In Hoffman (1988) factors mostly less than one are obtained but the higher value was chosen in order to be conservative.

2.32.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	4.0E-4	LT	7.0E-5	6.0E-4	IAEA, 1994*
Meat (day/kg)	3.0E-4	LT	3.0E-5	3.0E-3	IAEA, 1994

* The values given in IAEA (1994) have been rounded off.

2.32.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	1E-2	3E-1	*

* Since data are lacking a best estimate of 10% has been used as for many other elements for which data have not been found. A rather wide range has been used as the uncertainty is high.

2.32.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
U-232	α	68.9	1.6E-17	3.3E-7	3.7E-5
U-233	α	159 200	5.9E-17	5.1E-8	9.6E-6*
U-234	α	245 500	3.1E-17	4.9E-8	9.4E-6*
U-235	α	703 800 000	1.1E-14	4.7E-8	8.5E-6*
U-236	α	23 415 000	0	4.7E-8	8.7E-6*
U-238	α	4 468 000 000	0	4.5E-8	8.0E-6*

* In SR 97 a value of 3.6E-6 Sv/Bq was used for U-233. A value of 3.5E-6 Sv/Bq was used for U-234 and the value for U-235 was 3.1E-6 Sv/Bq. For U-236 a value of 3.2E-6 Sv/Bq was used and the value for U-238 was 2.9E-6 Sv/Bq.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
U-232	2.5E-6	8.2E-7	5.8E-7	5.7E-7	6.4E-7
U-233	3.8E-07	1.4E-07	9.2E-08	7.8E-08	7.8E-08
U-234	3.7E-07	1.3E-07	8.8E-08	7.4E-08	7.4E-08
U-235	3.5E-07	1.3E-07	8.5E-08	7.1E-08	7.0E-08
U-236	3.5E-07	1.3E-07	8.4E-08	7.0E-08	7.0E-08
U-238	3.4E-07	1.2E-07	8.0E-08	6.8E-08	6.7E-08

Dose coefficients for inhalation for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
U-232	1.0E-4	9.7E-5	6.6E-5	4.3E-5	3.8E-5
U-233	3.4E-05	3.0E-05	1.9E-05	1.2E-05	1.1E-05
U-234	3.3E-05	2.9E-05	1.9E-05	1.2E-05	1.0E-05
U-235	3.0E-05	2.6E-05	1.7E-05	1.1E-05	9.2E-06
U-236	3.1E-05	2.7E-05	1.8E-05	1.1E-05	9.5E-06
U-238	2.9E-05	2.5E-05	1.6E-05	1.0E-05	8.7E-06

2.32.7 Summary

No stable isotope of uranium occurs in the environment but several radioactive ones. The element is none-essential and toxic. The radioactive isotopes which may be of interest for dose assessments concerning repositories for nuclear fuel and waste are U-232 (with a half-life of 69 years), U-233 (159,000 years), U-234 (245,000 years), U-235 (704,000,000 years), U-236 (23,000,000 years) and U-238 (4,500,000,000 years). Uranium is no bioavailable element. The root uptake of uranium is rather low whereas the sorption to solid matter in soils, sediments and peat is rather high. Transfer to milk and meat are low which is also true for the accumulation in aquatic organisms. The dose coefficients for ingestion and inhalation are rather similar for all six nuclides, and rather high. The dose coefficients for external exposure differ though. No significant external exposure occurs from U-236 and U-238. The highest coefficient is that of U-235 whereas the dose coefficients for U-232, U-233 and U-234 are low. U-232 was not considered in SR 97 or in the SAFE study. In conclusion the exposure from the other five uranium isotopes is rather high in the well model and intermediate in the other models (lake, coastal, running waters, agricultural land, mire). The dominating exposure pathway in the well model is consumption of water followed by inhalation of dust and consumption of root crops. In the agricultural land and mire models inhalation is the most important exposure pathway followed by consumption of root crops. Consumption of fish is dominating the contribution to dose in the coastal, lake and running waters models, in the two latter models consumption of fish and shellfish (the latter only in the models used in SR 97) are also of importance.

2.33 Neptunium

2.33.1 Physical properties

Occurrence	Traces in uranium minerals, seawater 0 ppm. None-essential. Accumulates in mammalian bone.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Np-232 (14.7 minutes), Np-233 (36.2 minutes), Np-234 (4.4 days), Np-235 (396.1 days), Np-236 (154 000 years), **Np-237 (2.144·10^6 years)**, Np-238 (2.1 days), Np-239 (2.4 days), Np-240m (7.2 minutes), Np-240 (61.9 minutes)
Radioactive mother nuclide (half-life)	Am-241 (432.2 years) → Np-237

Decay chains:

$$^{237}_{93}Np \rightarrow ^{233}_{91}Pa \rightarrow ^{233}_{92}U \rightarrow ^{229}_{90}Th \rightarrow ^{225}_{88}Ra \rightarrow ^{225}_{89}Ac \rightarrow ^{221}_{87}Fr \rightarrow ^{217}_{85}At \rightarrow ^{213}_{83}Bi \rightarrow ^{213}_{84}Po \text{ (97.84\%)} \rightarrow$$
$$\rightarrow ^{209}_{82}Pb \rightarrow ^{209}_{83}Bi\ (stable)$$
$$^{237}_{93}Np \rightarrow ^{233}_{91}Pa \rightarrow ^{233}_{92}U \rightarrow ^{229}_{90}Th \rightarrow ^{225}_{88}Ra \rightarrow ^{225}_{89}Ac \rightarrow ^{221}_{87}Fr \rightarrow ^{217}_{85}At \rightarrow ^{213}_{83}Bi \rightarrow ^{209}_{81}Tl \text{ (2.16\%)} \rightarrow$$
$$\rightarrow ^{209}_{82}Pb \rightarrow ^{209}_{83}Bi\ (stable)$$

2.33.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E-1	LT	1E-2	1E+0	*
Organic soil	1E+0	LT	5E-1	3E+0	IAEA, 1994
Suspended matter					
lakes	1E+1	LT	1E+0	1E+2	Coughtrey *et al*, 1985**
brackish water	1E+1	LT	1E+0	1E+2	Coughtrey *et al*, 1985

* According to Thompson (1982) the distribution coefficient for neptunium was about ten times lower than for uranium. In order not to underestimate the accumulation of neptunium in soils the same distribution coefficient as for uranium has been used.

** In lack of data for fresh water values for marine water are used.

2.33.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	7E-2	LT	7E-3	7E-1	IAEA, 1994
Cereals**	2E-3	LT	2E-4	2E-2	IAEA, 1994***
Root crops**	2E-3	LT	2E-4	2E-2	estimated from IAEA, 1994***
Vegetables	4E-3	LT	4E-4	4E-2	IAEA, 1994***

* Dry weight.

** Wet weight.

*** The value has been converted into wet weight (10% water in cereals, 80% in root crops and 90% in vegetables). For cereals a very wide range is given in IAEA (1994); 2E-5 – 7E-2. This has been decreased to the range set when information is missing, i.e. minimum ten times lower than best estimate and maximum ten times higher.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	5E+1	LT	1E+1	3E+3	Poston & Klopfer, 1986*
Baltic fish	5E+1	LT	1E+1	3E+3	**
Freshwater invertebrates	4E+2	LT	4E+1	4E+3	Thompson *et al*, 1972
Marine water plants	6E+0	LT	6E-1	6E+1	Thompson *et al*, 1972

* The best estimate is the value recommended for piscivorous fish for freshwater and marine species in Poston & Klopfer (1986). The range is taken from IAEA (1994).

** In Bergström *et al* (1999) a best estimate of 10 and a range of 1–100 l/kg was used. The values were taken from Bergström & Nordlinder (1992) but the considerations made in that study is valid for a short-lived neptunium isotope (Np-239) and the rather low value of 10 should not be used for Np-239. Instead the same value as for freshwater fish has been used in the SAFE study.

2.33.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	5.0E-6	LT	5.0E-7	5.0E-5	IAEA, 1994
Meat (day/kg)	1.0E-3	LT	1.0E-4	1.0E-2	*

** In SR 97 the value used for meat was $1 \cdot 10^{-4}$ day/kg ($1 \cdot 10^{-5}$–$1 \cdot 10^{-3}$ day/kg) referring to Coughtrey *et al* (1984). This reference is not correct. In IAEA (1994) as well as NCRP (1996) a value of $1 \cdot 10^{-3}$ is given and this value has been used in the SAFE study. The range has been adjusted to this value.

2.33.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
1E-1	T	5E-2	2E-1	*

* Since data are lacking a best estimate of 10% has been used as for many other elements for which data have not been found. A rather wide range has been used as the uncertainty is high.

2.33.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Np-237	α	2 144 000	1.8E-15	1.1E-7	5.0E-5*

* In SR 97 a value of 2.3E-5 Sv/Bq was used.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Np-237	3.8E-07	1.4E-07	9.2E-08	7.8E-08	7.8E-08

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Np-237	9.8E-05	9.3E-05	6.0E-05	5.0E-05	4.7E-05

2.33.7 Summary

No stable isotope of neptunium occurs in the environment but some radioactive ones are found as traces in uranium minerals. The element is none-essential and accumulates in mammalian bone. The radioactive isotope of interest for dose assessments concerning repositories for nuclear fuel and waste is Np-237 which has a half-life of 2,100,000 years. The root uptake of neptunium is rather low whereas sorption to solid matter in soils, sediments and peat is rather high. Transfer to meat is rather high whereas transfer to milk is low (two hundred times lower). Accumulation in aquatic organisms is low except for in freshwater crustacean. Due to the strong α-radiation the dose coefficients for ingestion and inhalation are high whereas the coefficient for external exposure is intermediate compared to the other radionuclides in this study. In conclusion the exposure from Np-237 is high in all models (lake, coastal, running waters, agricultural land, mire, well). The dominating exposure pathway in the well model is consumption of water followed by inhalation of dust. The latter pathway is the most important in the agricultural land and mire models. In the lake, coastal and running waters models consumption of fish is the dominating exposure pathway.

2.34 Plutonium

2.34.1 Physical properties

Occurrence	Traces in uranium ores, seawater 0 ppm. None-essential. Very toxic to mammals.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Pu-234 (8.8 hours), Pu-235 (25.3 minutes), Pu-236 (2.9 years), Pu-237 (45.2 days), **Pu-238 (87.7 years)**, **Pu-239 (24 110 years)***, **Pu-240 (6 563 years)***, **Pu-241 (14.4 years)**, **Pu-242 (372 300 years)***, Pu-243 (5.0 hours), **Pu-244 ($8.08 \cdot 10^7$ years)**, Pu-245 (10.5 hours), Pu-246 (10.8 days)
Radioactive mother nuclide (half-life)	Cm-243 (29.1 years) → Pu-239 Cm-244 (18.1 years) → Pu-240

Decay chains:

$^{238}_{94}Pu \rightarrow ^{234}_{92}U \rightarrow ^{230}_{90}Th \rightarrow ^{226}_{88}Ra \rightarrow ^{222}_{86}Rn \rightarrow ^{218}_{84}Po \rightarrow ^{214}_{82}Pb$ (99.98%) $\rightarrow ^{214}_{83}Bi \rightarrow ^{214}_{84}Po \rightarrow ^{210}_{82}Pb \rightarrow$
$\rightarrow ^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb$ (stable)
$^{238}_{94}Pu \rightarrow ^{234}_{92}U \rightarrow ^{230}_{90}Th \rightarrow ^{226}_{88}Ra \rightarrow ^{222}_{86}Rn \rightarrow ^{218}_{84}Po \rightarrow ^{218}_{85}At$ (0.02%) $\rightarrow ^{214}_{83}Bi \rightarrow ^{214}_{84}Po \rightarrow ^{210}_{82}Pb \rightarrow$
$\rightarrow ^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb$ (stable)

$^{239}_{94}Pu \rightarrow ^{235}_{92}U \rightarrow ^{231}_{90}Th \rightarrow ^{231}_{91}Pa \rightarrow ^{227}_{89}Ac \rightarrow ^{227}_{90}Th$ (98.62%) $\rightarrow ^{223}_{88}Ra \rightarrow ^{219}_{86}Rn \rightarrow ^{215}_{84}Po \rightarrow ^{211}_{82}Pb \rightarrow$
$\rightarrow ^{211}_{83}Bi \rightarrow ^{207}_{81}Tl$ (99.72%) $\rightarrow ^{207}_{82}Pb$ (stable)
$^{239}_{94}Pu \rightarrow ^{235}_{92}U \rightarrow ^{231}_{90}Th \rightarrow ^{231}_{91}Pa \rightarrow ^{227}_{89}Ac \rightarrow ^{223}_{87}Fr$ (1.38%) $\rightarrow ^{223}_{88}Ra \rightarrow ^{219}_{86}Rn \rightarrow ^{215}_{84}Po \rightarrow ^{211}_{82}Pb \rightarrow$
$\rightarrow ^{211}_{83}Bi \rightarrow ^{207}_{81}Tl$ (99.72%) $\rightarrow ^{207}_{82}Pb$ (stable)
$^{239}_{94}Pu \rightarrow ^{235}_{92}U \rightarrow ^{231}_{90}Th \rightarrow ^{231}_{91}Pa \rightarrow ^{227}_{89}Ac \rightarrow ^{223}_{87}Fr$ (1.38%) $\rightarrow ^{223}_{88}Ra \rightarrow ^{219}_{86}Rn \rightarrow ^{215}_{84}Po \rightarrow ^{211}_{82}Pb \rightarrow$
$\rightarrow ^{211}_{83}Bi \rightarrow ^{211}_{84}Po$ (0.28%) $\rightarrow ^{207}_{82}Pb$ (stable)

$^{240}_{94}Pu \rightarrow ^{236}_{92}U \rightarrow ^{232}_{90}Th \rightarrow ^{228}_{88}Ra \rightarrow ^{228}_{89}Ac \rightarrow ^{228}_{90}Th \rightarrow ^{224}_{88}Ra \rightarrow ^{220}_{86}Rn \rightarrow ^{216}_{84}Po \rightarrow ^{212}_{82}Pb \rightarrow ^{212}_{83}Bi \rightarrow$
$\rightarrow ^{212}_{84}Po$ (64.07%) $\rightarrow ^{208}_{82}Pb$ (stable)
$^{240}_{94}Pu \rightarrow ^{236}_{92}U \rightarrow ^{232}_{90}Th \rightarrow ^{228}_{88}Ra \rightarrow ^{228}_{89}Ac \rightarrow ^{228}_{90}Th \rightarrow ^{224}_{88}Ra \rightarrow ^{220}_{86}Rn \rightarrow ^{216}_{84}Po \rightarrow ^{212}_{82}Pb \rightarrow ^{212}_{83}Bi \rightarrow$
$\rightarrow ^{208}_{81}Tl$ (35.93%) $\rightarrow ^{208}_{82}Pb$ (stable)

$^{241}_{94}Pu \rightarrow ^{241}_{95}Am \rightarrow ^{237}_{93}Np \rightarrow ^{233}_{91}Pa \rightarrow ^{233}_{92}U \rightarrow ^{229}_{90}Th \rightarrow ^{225}_{88}Ra \rightarrow ^{225}_{89}Ac \rightarrow ^{221}_{87}Fr \rightarrow ^{217}_{85}At \rightarrow ^{213}_{83}Bi \rightarrow$
$\rightarrow ^{213}_{84}Po$ (97.84%) $\rightarrow ^{209}_{82}Pb \rightarrow ^{209}_{83}Bi$ (stable)
$^{241}_{94}Pu \rightarrow ^{241}_{95}Am \rightarrow ^{237}_{93}Np \rightarrow ^{233}_{91}Pa \rightarrow ^{233}_{92}U \rightarrow ^{229}_{90}Th \rightarrow ^{225}_{88}Ra \rightarrow ^{225}_{89}Ac \rightarrow ^{221}_{87}Fr \rightarrow ^{217}_{85}At \rightarrow ^{213}_{83}Bi \rightarrow$
$\rightarrow ^{209}_{81}Tl$ (2.16%) $\rightarrow ^{209}_{82}Pb \rightarrow ^{209}_{83}Bi$ (stable)

$^{242}_{94}Pu \rightarrow ^{238}_{92}U \rightarrow ^{234}_{90}Th \rightarrow ^{234}_{91}Pa \rightarrow ^{234}_{92}U \rightarrow ^{230}_{90}Th \rightarrow ^{226}_{88}Ra \rightarrow ^{222}_{86}Rn \rightarrow ^{218}_{84}Po \rightarrow ^{214}_{82}Pb$ (99.98%) $\rightarrow$
$\rightarrow ^{214}_{83}Bi \rightarrow ^{214}_{84}Po \rightarrow ^{210}_{82}Pb \rightarrow ^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb$ (stable)
$^{242}_{94}Pu \rightarrow ^{238}_{92}U \rightarrow ^{234}_{90}Th \rightarrow ^{234}_{91}Pa \rightarrow ^{234}_{92}U \rightarrow ^{230}_{90}Th \rightarrow ^{226}_{88}Ra \rightarrow ^{222}_{86}Rn \rightarrow ^{218}_{84}Po \rightarrow ^{218}_{85}At$ (0.02%) $\rightarrow$
$\rightarrow ^{214}_{83}Bi \rightarrow ^{214}_{84}Po \rightarrow ^{210}_{82}Pb \rightarrow ^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb$ (stable)

$^{244}_{94}Pu \rightarrow ^{240}_{92}U \rightarrow ^{240}_{93}Np \rightarrow ^{240}_{94}Pu \rightarrow ^{236}_{92}U \rightarrow ^{232}_{90}Th \rightarrow ^{228}_{88}Ra \rightarrow ^{228}_{89}Ac \rightarrow ^{228}_{90}Th \rightarrow ^{224}_{88}Ra \rightarrow ^{220}_{86}Rn \rightarrow$
$\rightarrow ^{216}_{84}Po \rightarrow ^{212}_{82}Pb \rightarrow ^{212}_{83}Bi \rightarrow ^{212}_{84}Po$ (64.07%) $\rightarrow ^{208}_{82}Pb$ (stable)
$^{244}_{94}Pu \rightarrow ^{240}_{92}U \rightarrow ^{240}_{93}Np \rightarrow ^{240}_{94}Pu \rightarrow ^{236}_{92}U \rightarrow ^{232}_{90}Th \rightarrow ^{228}_{88}Ra \rightarrow ^{228}_{89}Ac \rightarrow ^{228}_{90}Th \rightarrow ^{224}_{88}Ra \rightarrow ^{220}_{86}Rn \rightarrow$
$\rightarrow ^{216}_{84}Po \rightarrow ^{212}_{82}Pb \rightarrow ^{212}_{83}Bi \rightarrow ^{208}_{81}Tl$ (35.93%) $\rightarrow ^{208}_{82}Pb$ (stable)

* The half-live used for Pu-239, Pu-240 and Pu-242 in SR 97 are 24,065, 6,537 and 376,300 years respectively.

2.34.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	5E+0	LT	1E-1	1E+1	Coughtrey *et al*, 1985*
Organic soil	2E+0	LT	2E-1	2E+1	IAEA, 1994**
Suspended matter					
lakes	1E+2	LT	1E+1	1E+3	Coughtrey *et al*, 1985
brackish water	1E+2	LT	1E+1	1E+3	Coughtrey *et al*, 1985***

* This reference is given in Sundblad *et al* (1988) but a value of 5 m^3/kg is found in Coughtrey *et al* (1985). In SR 97 a value of 50 m^3/kg (minimum 1 and maximum 100 m^3/kg) has been used whereas the values in the table were used in SAFE.

** The range given in the reference has not been used, instead a minimum values ten times lower and a maximum value ten times higher than the best estimate has been used.

*** The values for freshwater have been used.

2.34.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	4E-4	LT	5E-5	7E-1	estimated from IAEA, 1994
Cereals**	7E-6	LT	7E-7	7E-5	IAEA, 1994***
Root crops**	3E-5	LT	3E-6	3E-4	IAEA, 1994***
Vegetables	2E-5	LT	2E-6	2E-4	estimated from IAEA, 1994***

* Dry weight.

** Wet weight.

*** The value has been converted into wet weight (10% water in cereals, 80% in root crops and 90% in vegetables).

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	3E+1	LT	4E+0	3E+2	IAEA, 1994
Baltic fish	3E+1	LT	5E+0	5E+1	*
Freshwater invertebrates	1E+2	LT	1E+1	1E+3	Thompson *et al*, 1972
Marine water plants	3E+2	LT	3E+1	3E+3	Thompson *et al*, 1972

* The range and best estimate is defined in Bergström & Nordlinder (1992). Bioaccumulation factors between 0.9 and 550 l/kg have been recorded from the Marshall Islands (Noshkin *et al*, 1981) whereas factors for freshwater fish have been reported from i.a. Vanderborght (1985). Also here the variation was large; from 0.04 l/kg up to above 200. According to Eyman & Trabalka (1980) the factor decreases with increasing position in the food web. They recommend a factor of 250 for bottom dwelling fishes, a factor of 25 for plankton feeding species and a factor of 5 for piscivorous species. It is mainly piscivorous species which are consumed by humans, but to be conservative a best estimate of 30 has been used.

2.34.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	1.0E-6	LT	3.0E-9	3.0E-6	IAEA, 1994*
Meat (day/kg)	1.0E-5	LT	2.0E-7	2.0E-4	IAEA, 1994

* The values in IAEA (1994) have been rounded off.

2.34.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
2E-2	T	1E-2	3E-2	*

* The range and best estimate is taken from Bergström *et al* (1999) which refers to Coughtrey *et al* (1985). In the latter a range of 0.2%-about 2% is presented. A value of 2% has been chosen as a best estimate in order not to underestimate this process. The values are low in accordance with the fact that actinides are not specifically bioavailable elements (low root uptake factors).

2.34.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m³)	Ingestion Sv/Bq	Inhalation Sv/Bq
Pu-238	α	88	1.3E-17	2.3E-7	1.1E-4*
Pu-239	α	24 110	6.6E-18	2.5E-7	1.2E-4*
Pu-240	α	6 563	0	2.5E-7	1.2E-4*
Pu-241	α, β	14.4	0	4.8E-9	2.3E-6
Pu-242	α	372 300	0	2.4E-7	1.1E-4*
Pu-244	α	80 800 000	1.8E-15	2.4E-7	1.1E-4

* In SR 97 a value of 4.6E-5 Sv/Bq was used for Pu-238. For Pu-239 and Pu-240 a value of 5.0E-5 Sv/Bq was used. The values used for Pu-242 was 4.8E-5 Sv/Bq.

Dose coefficients for oral intake for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Pu-238	3.5E-07	1.3E-07	8.5E-08	7.1E-08	7.0E-08
Pu-239	3.5E-07	1.3E-07	8.4E-08	7.0E-08	7.0E-08
Pu-240	3.4E-07	1.2E-07	8.0E-08	6.8E-08	6.7E-08
Pu-241	5.6E-08	5.7E-09	5.5E-09	5.1E-09	4.8E-09
Pu-242	4.0E-06	4.0E-07	3.2E-07	2.6E-07	2.3E-07
Pu-244	4.0E-6	4.1E-7	3.2E-7	2.6E-7	2.3E-7

Dose coefficients for inhalation for various age groups (Sv/Bq)

Isotope	Age (Years) <1	1–2	2–7	7–12	12–17
Pu-238	2.0E-04	1.9E-04	1.4E-04	1.1E-04	1.0E-04
Pu-239	2.1E-04	2.0E-04	1.5E-04	1.2E-04	1.1E-04
Pu-240	2.1E-04	2.0E-04	1.5E-04	1.2E-04	1.1E-04
Pu-241	2.8E-06	2.9E-06	2.6E-06	2.4E-06	2.2E-06
Pu-242	2.0E-04	1.9E-04	1.4E-04	1.2E-04	1.1E-04
Pu-244	2.0E-4	1.9E-4	1.4E-4	1.2E-4	1.1E-4

2.34.7 Summary

No stable isotopes of plutonium occur in the environment but radioactive ones can be found as traces in uranium ores. The element is non-essential and very toxic to mammals. The radioactive isotopes of interest for dose assessments concerning repositories for nuclear fuel and waste are Pu-238 (with a half-life of 88 years), Pu-239 (24,000 years), Pu-240 (6,500 years), Pu-241 (14 years), Pu-242 (380 000 years) and Pu-244 (81,000,000 years). Plutonium is not a bioavailable element. Root uptake of plutonium is very low whereas sorption to solid matter in soils, sediments and peat is very high. Transfer to milk and meat as well as accumulation in aquatic organisms is low. Due to the strong α-radiations the dose coefficients for ingestion and inhalation are high for these radionuclides except for Pu-241 for which the coefficients are lower (dose coefficient for ingestion about hundred times lower and that for inhalation about ten times lower). Significant external exposure occurs from Pu-238, Pu-239 and Pu-244. The dose coefficients for external exposure are intermediate (Pu-244) to low (Pu-238, Pu-239) compared to the other radionuclides in this study. Pu-241 was not considered in SR 97 or in the SAFE study. In conclusion the exposure from the other five plutonium radionuclides is high in all models (lake, coastal, running waters, agricultural land, mire, well) except for the exposure from Pu-238 in the agricultural land model which is low. This is due to the relatively short half-life of this nuclide, because of this the amounts which reaches the top soil layer where exposure is possible is smaller than for the other plutonium isotopes. The dominating exposure pathway in the well model is for Pu-238 consumption of water whereas for the other inhalation is the most important pathway. The difference is due to the short half-life of Pu-238 which makes accumulation in soil less important than for the other nuclides. In the lake and running waters models consumption of fish is the most important contributor to dose for all five nuclides, in the lake model this exposure pathway is followed by consumption of water whereas inhalation of dust is the second most important pathway for the other nuclides. In the coastal model consumption of fish is the dominating exposure pathway for all five nuclides whereas inhalation is the only exposure pathway of importance for all nuclides in the agricultural land and mire models.

2.35 Americium

2.35.1 Physical properties

Occurrence	Accumulates in mammalian bone.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Am-237 (73.0 minutes), Am-238 (98 minutes), Am-239 (11.9 hours), Am-240 (50.8 hours), **Am-241 (432.2 years)**, **Am-242m (141 years)**, Am-242 (16.0 hours), **Am-243 (7 370 years)***, Am-244m (26 minutes), Am-244 (10.1 hours), Am-245 (2.1 hours), Am-246m (25.0 minutes), Am-246 (39 minutes)
Radioactive mother nuclide (half-life)	Pu-241 (14.4 years) → Am-241

Decay chains:

${}^{241}_{95}\mathrm{Am} \to {}^{237}_{93}\mathrm{Np} \to {}^{233}_{91}\mathrm{Pa} \to {}^{233}_{92}\mathrm{U} \to {}^{229}_{90}\mathrm{Th} \to {}^{225}_{88}\mathrm{Ra} \to {}^{225}_{89}\mathrm{Ac} \to {}^{221}_{87}\mathrm{Fr} \to {}^{217}_{85}\mathrm{At} \to {}^{213}_{83}\mathrm{Bi} \to$
$\to {}^{213}_{84}\mathrm{Po}\ (97.84\%) \to {}^{209}_{82}\mathrm{Pb} \to {}^{209}_{83}\mathrm{Bi}$ (stable)

${}^{241}_{95}\mathrm{Am} \to {}^{237}_{93}\mathrm{Np} \to {}^{233}_{91}\mathrm{Pa} \to {}^{233}_{92}\mathrm{U} \to {}^{229}_{90}\mathrm{Th} \to {}^{225}_{88}\mathrm{Ra} \to {}^{225}_{89}\mathrm{Ac} \to {}^{221}_{87}\mathrm{Fr} \to {}^{217}_{85}\mathrm{At} \to {}^{213}_{83}\mathrm{Bi} \to$
$\to {}^{209}_{81}\mathrm{Tl}\ (2.16\%) \to {}^{209}_{82}\mathrm{Pb} \to {}^{209}_{83}\mathrm{Bi}$ (stable)

${}^{242m}_{95}\mathrm{Am} \to {}^{242}_{95}\mathrm{Am}\ (99.5\%) \to {}^{242}_{94}\mathrm{Pu}\ (17.3\%) \to {}^{238}_{92}\mathrm{U} \to {}^{234}_{90}\mathrm{Th} \to {}^{234}_{91}\mathrm{Pa} \to {}^{234}_{92}\mathrm{U} \to {}^{230}_{90}\mathrm{Th} \to {}^{226}_{88}\mathrm{Ra} \to$
$\to {}^{222}_{86}\mathrm{Rn} \to {}^{218}_{84}\mathrm{Po} \to {}^{214}_{82}\mathrm{Pb}\ (99.98\%) \to {}^{214}_{83}\mathrm{Bi} \to {}^{214}_{84}\mathrm{Po} \to {}^{210}_{82}\mathrm{Pb} \to {}^{210}_{83}\mathrm{Bi} \to {}^{210}_{84}\mathrm{Po} \to {}^{206}_{82}\mathrm{Pb}$ (stable)

${}^{242m}_{95}\mathrm{Am} \to {}^{238}_{93}\mathrm{Np}\ (0.5\%) \to {}^{238}_{94}\mathrm{Pu} \to {}^{234}_{92}\mathrm{U} \to {}^{230}_{90}\mathrm{Th} \to {}^{226}_{88}\mathrm{Ra} \to {}^{222}_{86}\mathrm{Rn} \to {}^{218}_{84}\mathrm{Po} \to {}^{214}_{82}\mathrm{Pb}\ (99.98\%) \to$
$\to {}^{214}_{83}\mathrm{Bi} \to {}^{214}_{84}\mathrm{Po} \to {}^{210}_{82}\mathrm{Pb} \to {}^{210}_{83}\mathrm{Bi} \to {}^{210}_{84}\mathrm{Po} \to {}^{206}_{82}\mathrm{Pb}$ (stable)

${}^{242m}_{95}\mathrm{Am} \to {}^{242}_{95}\mathrm{Am}\ (99.5\%) \to {}^{242}_{96}\mathrm{Cm}\ (82.7\%) \to {}^{238}_{94}\mathrm{Pu} \to {}^{234}_{92}\mathrm{U} \to {}^{230}_{90}\mathrm{Th} \to {}^{226}_{88}\mathrm{Ra} \to {}^{222}_{86}\mathrm{Rn} \to {}^{218}_{84}\mathrm{Po} \to$
$\to {}^{214}_{82}\mathrm{Pb}\ (99.98\%) \to {}^{214}_{83}\mathrm{Bi} \to {}^{214}_{84}\mathrm{Po} \to {}^{210}_{82}\mathrm{Pb} \to {}^{210}_{83}\mathrm{Bi} \to {}^{210}_{84}\mathrm{Po} \to {}^{206}_{82}\mathrm{Pb}$ (stable)

${}^{242m}_{95}\mathrm{Am} \to {}^{242}_{95}\mathrm{Am}\ (99.5\%) \to {}^{242}_{94}\mathrm{Pu}\ (17.3\%) \to {}^{238}_{92}\mathrm{U} \to {}^{234}_{90}\mathrm{Th} \to {}^{234}_{91}\mathrm{Pa} \to {}^{234}_{92}\mathrm{U} \to {}^{230}_{90}\mathrm{Th} \to {}^{226}_{88}\mathrm{Ra} \to$
$\to {}^{222}_{86}\mathrm{Rn} \to {}^{218}_{84}\mathrm{Po} \to {}^{218}_{85}\mathrm{At}\ (0.02\%) \to {}^{214}_{83}\mathrm{Bi} \to {}^{214}_{84}\mathrm{Po} \to {}^{210}_{82}\mathrm{Pb} \to {}^{210}_{83}\mathrm{Bi} \to {}^{210}_{84}\mathrm{Po} \to {}^{206}_{82}\mathrm{Pb}$ (stable)

${}^{242m}_{95}\mathrm{Am} \to {}^{238}_{93}\mathrm{Np}\ (0.5\%) \to {}^{238}_{94}\mathrm{Pu} \to {}^{234}_{92}\mathrm{U} \to {}^{230}_{90}\mathrm{Th} \to {}^{226}_{88}\mathrm{Ra} \to {}^{222}_{86}\mathrm{Rn} \to {}^{218}_{84}\mathrm{Po} \to {}^{218}_{85}\mathrm{At}\ (0.02\%) \to$
$\to {}^{214}_{83}\mathrm{Bi} \to {}^{214}_{84}\mathrm{Po} \to {}^{210}_{82}\mathrm{Pb} \to {}^{210}_{83}\mathrm{Bi} \to {}^{210}_{84}\mathrm{Po} \to {}^{206}_{82}\mathrm{Pb}$ (stable)

${}^{243}_{95}\mathrm{Am} \to {}^{239}_{93}\mathrm{Np} \to {}^{239}_{94}\mathrm{Pu} \to {}^{235}_{92}\mathrm{U} \to {}^{231}_{90}\mathrm{Th} \to {}^{231}_{91}\mathrm{Pa} \to {}^{227}_{89}\mathrm{Ac} \to {}^{227}_{90}\mathrm{Th}\ (98.62\%) \to {}^{223}_{88}\mathrm{Ra} \to {}^{219}_{86}\mathrm{Rn} \to$
$\to {}^{215}_{84}\mathrm{Po} \to {}^{211}_{82}\mathrm{Pb} \to {}^{211}_{83}\mathrm{Bi} \to {}^{207}_{81}\mathrm{Tl}\ (99.72\%) \to {}^{207}_{82}\mathrm{Pb}$ (stable)

${}^{243}_{95}\mathrm{Am} \to {}^{239}_{93}\mathrm{Np} \to {}^{239}_{94}\mathrm{Pu} \to {}^{235}_{92}\mathrm{U} \to {}^{231}_{90}\mathrm{Th} \to {}^{231}_{91}\mathrm{Pa} \to {}^{227}_{89}\mathrm{Ac} \to {}^{223}_{87}\mathrm{Fr}\ (1.38\%) \to {}^{223}_{88}\mathrm{Ra} \to {}^{219}_{86}\mathrm{Rn} \to$
$\to {}^{215}_{84}\mathrm{Po} \to {}^{211}_{82}\mathrm{Pb} \to {}^{211}_{83}\mathrm{Bi} \to {}^{207}_{81}\mathrm{Tl}\ (99.72\%) \to {}^{207}_{82}\mathrm{Pb}$ (stable)

${}^{243}_{95}\mathrm{Am} \to {}^{239}_{93}\mathrm{Np} \to {}^{239}_{94}\mathrm{Pu} \to {}^{235}_{92}\mathrm{U} \to {}^{231}_{90}\mathrm{Th} \to {}^{231}_{91}\mathrm{Pa} \to {}^{227}_{89}\mathrm{Ac} \to {}^{223}_{87}\mathrm{Fr}\ (1.38\%) \to {}^{223}_{88}\mathrm{Ra} \to {}^{219}_{86}\mathrm{Rn} \to$
$\to {}^{215}_{84}\mathrm{Po} \to {}^{211}_{82}\mathrm{Pb} \to {}^{211}_{83}\mathrm{Bi} \to {}^{211}_{84}\mathrm{Po}\ (0.28\%) \to {}^{207}_{82}\mathrm{Pb}$ (stable)

* The half-live used for Am-242m and Am-243 in SR 97 are 152 and 7 380 years respectively.

2.35.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	2E+0	LT	2E-1	2E+1	IAEA, 1994*
Organic soil	1E+2	LT	1E+1	1E+3	IAEA, 1994*
Suspended matter					
lakes	5E+0	LT	5E-1	5E+1	IAEA, 1994*
brackish water	1E+1	LT	1E+0	1E+2	Coughtrey *et al*, 1985**

* The range given in the reference has not been used, instead a minimum values ten times lower and a maximum value ten times higher than the best estimate has been used.

** A lower value has been used as best estimate and the range has been decreased.

2.35.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E-3	LT	5E-4	2E-1	IAEA, 1994
Cereals**	2E-5	LT	2E-6	2E-4	IAEA, 1994***
Root crops**	4E-5	LT	4E-6	4E-4	IAEA, 1994***
Vegetables	7E-5	LT	7E-6	7E-4	IAEA, 1994***

* Dry weight.

** Wet weight.

*** The value has been converted into wet weight (10% water in cereals, 80% in root crops and 90% in vegetables). The ranges for cereals and root crops given in IAEA (1994) have been decreased.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	3E+1	LT	1E+1	3E+2	IAEA, 1994*
Baltic fish	1E+2	LT	1E+1	2E+2	**
Freshwater invertebrates	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972
Marine water plants	5E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

* The range given in IAEA (1994) has been increased somewhat.

** The range and best estimate is defined in Bergström & Nordlinder (1992). The available amount of data concerning bioaccumulation in americium is scarce. Poston & Klopfer (1986) recommend a value of 100 l/kg for freshwater fish. In the same reference values of bio-accumulation factors depending on the trophic level of the fish is also presented; 2,500 l/kg for bottom dwelling fish, 250 for plankton feeding species and 50 for piscivorous species. It is mainly piscivorous species which are consumed by humans, and in order not to underestimate the uptake in fish, a best estimate of 100 has been used.

2.35.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2.0E-6	LT	4.0E-7	2.0E-5	IAEA, 1994*
Meat (day/kg)	4.0E-5	LT	4.0E-6	1.0E-4	IAEA, 1994**

* The values given in IAEA (1994) have been rounded off.

** The value for "beef" has been used. An expected value of $1 \cdot 10^{-3}$ day/kg is given for veal meat in IAEA (1994) but that has not been considered since veal meat is a small part of the diet. Young animals also eat much less than older ones and therefore it is not reasonable to think that the concentration of radionuclides in veal meat will be higher than in "ordinary" beef meat.

2.35.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m²])

B.E.	Distr	Low	High	Reference
1E-2	T	5E-3	2E-2	Coughtrey *et al*, 1985*

* As an actinide americium is not specifically bioavailable (low root uptake factors) and therefore a low translocation factor is used. Coughtrey *et al* (1985) present factors of 2% for non-root vegetables, 1% for root vegetables, 3% for cereals and 2.5% for fruit. The recommended best estimate should not be greater than 1%, anyway. A best estimate of 0.01 has therefore been used and the range set rather narrow as the values in Coughtrey *et al* (1985) imply.

2.35.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m³)	Ingestion Sv/Bq	Inhalation Sv/Bq
Am-241	α	432	1.1E-15	2.0E-7	9.6E-5*
Am-242m	α	141	1.5E-17	1.9E-7	9.2E-5*
Am-243	α	7 370	2.9E-15	2.0E-7	9.6E-5*

* In SR 97 a value of 4.2E-5 was used for Am-241. For Am-242m a value of 3.7E-5 Sv/Bq was used and the value used for Am-243 was 4.1E-5 Sv/Bq.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Am-241	3.7E-06	3.7E-07	2.7E-07	2.2E-07	2.0E-07
Am-242m	3.1E-6	3.0E-7	2.3E-7	2.0E-7	1.9E-7
Am-243	3.6E-06	3.7E-07	2.7E-07	2.2E-07	2.0E-07

Dose coefficients for inhalation for various age groups (Sv/Bq)

	Age (Years)				
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Am-241	1.8E-04	1.8E-04	1.2E-04	1.0E-04	9.2E-05
Am-242m	1.6E-4	1.5E-4	1.1E-4	9.4E-5	8.8E-5
Am-243	1.8E-04	1.7E-04	1.2E-04	1.0E-04	9.1E-05

2.35.7 Summary

No stable isotopes occur of americium in the environment. The element accumulates in mammalian bone. The radioactive isotopes of interest for dose assessments concerning repositories for nuclear fuel and waste are Am-241 (with a half-life of 430 years), Am-242m (150 years) and Am-243 (7 000 years). Root uptake of americium is low whereas sorption to solid matter in soils, sediments and peat is high. Transfer to milk and meat is very low whereas accumulation in aquatic organisms varies. The accumulation in freshwater fish is low whereas accumulation in brackish water fish is somewhat higher. Accumulation in freshwater crustaceans and marine water plants is high. Due to the strong α-radiation the dose coefficients for ingestion and inhalation are high whereas the coefficient for external exposure is intermediate compared to the other radionuclides in this study. In conclusion the exposure from all three americium radionuclides is high in the lake, coastal, running waters and well models. In the agricultural land and mire models the exposure differs somewhat between the different americium isotopes. In both models the exposure from Am-243 is high whereas that of Am-241 is ten (mire) to forty times lower and that of Am-242m is about thirty (mire) to 400 times lower. The dominating exposure pathway in the well model is consumption of water followed by inhalation for Am-241 and Am-242m whereas the opposite order is valid for Am-243. In the agricultural land and mire models inhalation is the dominating exposure pathway for all three nuclides. For the lake and running waters models consumption of shellfish, followed by consumption of fish, is the most important pathway.

2.36 Curium

2.36.1 Physical properties

Occurrence	Accumulates in mammalian bone.
Stable isotopes (natural abundance)	–
Radioactive isotopes (half-life)	Cm-238 (2.4 hours), Cm-240 (27 days), Cm-241 (32.8 days), Cm-242 (162.8 days), **Cm-243 (29.1 years)**, **Cm-244 (18.1 years)**, **Cm-245 (8 500 years)**, **Cm-246 (4 730 years)**, Cm-247 ($1.56 \cdot 10^7$ years), Cm-248 (340 000 years), Cm-249 (64.2 minutes), Cm-250 (9 000 years)

Decay chains:

${}^{243}_{96}\mathrm{Cm}\to{}^{239}_{94}\mathrm{Pu}\ (99.8\%)\to{}^{235}_{92}\mathrm{U}\to{}^{231}_{90}\mathrm{Th}\to{}^{231}_{91}\mathrm{Pa}\to{}^{227}_{89}\mathrm{Ac}\to{}^{227}_{90}\mathrm{Th}\ (98.62\%)\to{}^{223}_{88}\mathrm{Ra}\to{}^{219}_{86}\mathrm{Rn}\to$
$\to{}^{215}_{84}\mathrm{Po}\to{}^{211}_{82}\mathrm{Pb}\to{}^{211}_{83}\mathrm{Bi}\to{}^{207}_{81}\mathrm{Tl}\ (99.72\%)\to{}^{207}_{82}\mathrm{Pb}$ (stable)
${}^{243}_{96}\mathrm{Cm}\to{}^{243}_{95}\mathrm{Am}\ (0.24\%)\to{}^{239}_{93}\mathrm{Np}\to{}^{239}_{94}\mathrm{Pu}\to{}^{235}_{92}\mathrm{U}\to{}^{231}_{90}\mathrm{Th}\to{}^{231}_{91}\mathrm{Pa}\to{}^{227}_{89}\mathrm{Ac}\to{}^{227}_{90}\mathrm{Th}\ (98.62\%)\to$
$\to{}^{223}_{88}\mathrm{Ra}\to{}^{219}_{86}\mathrm{Rn}\to{}^{215}_{84}\mathrm{Po}\to{}^{211}_{82}\mathrm{Pb}\to{}^{211}_{83}\mathrm{Bi}\to{}^{207}_{81}\mathrm{Tl}\ (99.72\%)\to{}^{207}_{82}\mathrm{Pb}$ (stable)
${}^{243}_{96}\mathrm{Cm}\to{}^{239}_{94}\mathrm{Pu}\ (99.8\%)\to{}^{235}_{92}\mathrm{U}\to{}^{231}_{90}\mathrm{Th}\to{}^{231}_{91}\mathrm{Pa}\to{}^{227}_{89}\mathrm{Ac}\to{}^{223}_{87}\mathrm{Fr}\ (1.38\%)\to{}^{223}_{88}\mathrm{Ra}\to{}^{219}_{86}\mathrm{Rn}\to$
$\to{}^{215}_{84}\mathrm{Po}\to{}^{211}_{82}\mathrm{Pb}\to{}^{211}_{83}\mathrm{Bi}\to{}^{207}_{81}\mathrm{Tl}\ (99.72\%)\to{}^{207}_{82}\mathrm{Pb}$ (stable)
${}^{243}_{96}\mathrm{Cm}\to{}^{239}_{94}\mathrm{Pu}\ {*}(99.8\%)\to{}^{235}_{92}\mathrm{U}\to{}^{231}_{90}\mathrm{Th}\to{}^{231}_{91}\mathrm{Pa}\to{}^{227}_{89}\mathrm{Ac}\to{}^{223}_{87}\mathrm{Fr}\ (1.38\%)\to{}^{223}_{88}\mathrm{Ra}\to{}^{219}_{86}\mathrm{Rn}\to$
$\to{}^{215}_{84}\mathrm{Po}\to{}^{211}_{82}\mathrm{Pb}\to{}^{211}_{83}\mathrm{Bi}\to{}^{210}_{84}\mathrm{Po}\ (0.28\%)\to{}^{207}_{82}\mathrm{Pb}$ (stable)
${}^{243}_{96}\mathrm{Cm}\to{}^{243}_{95}\mathrm{Am}\ (0.24\%)\to{}^{245}_{96}\mathrm{Cm}\to{}^{241}_{94}\mathrm{Pu}\to{}^{241}_{95}\mathrm{Am}\to{}^{237}_{93}\mathrm{Np}\to{}^{233}_{91}\mathrm{Pa}\to{}^{233}_{92}\mathrm{U}\to{}^{229}_{90}\mathrm{Th}\to{}^{225}_{88}\mathrm{Ra}\to$
$\to{}^{225}_{89}\mathrm{Ac}\to{}^{221}_{87}\mathrm{Fr}\to{}^{217}_{85}\mathrm{At}\to{}^{213}_{83}\mathrm{Bi}\to{}^{209}_{81}\mathrm{Tl}\ (2.16\%)\to{}^{209}_{82}\mathrm{Pb}\to{}^{209}_{83}\mathrm{Bi}$ (stable)
${}^{243}_{96}\mathrm{Cm}\to{}^{243}_{95}\mathrm{Am}\ (0.24\%)\to{}^{239}_{93}\mathrm{Np}\to{}^{239}_{94}\mathrm{Pu}\to{}^{235}_{92}\mathrm{U}\to{}^{231}_{90}\mathrm{Th}\to{}^{231}_{91}\mathrm{Pa}\to{}^{227}_{89}\mathrm{Ac}\to{}^{223}_{87}\mathrm{Fr}\ (1.38\%)\to$
$\to{}^{223}_{88}\mathrm{Ra}\to{}^{219}_{86}\mathrm{Rn}\to{}^{215}_{84}\mathrm{Po}\to{}^{211}_{82}\mathrm{Pb}\to{}^{211}_{83}\mathrm{Bi}\to{}^{207}_{81}\mathrm{Tl}\ (99.72\%)\to{}^{207}_{82}\mathrm{Pb}$ (stable)
${}^{243}_{96}\mathrm{Cm}\to{}^{243}_{95}\mathrm{Am}\ (0.24\%)\to{}^{239}_{93}\mathrm{Np}\to{}^{239}_{94}\mathrm{Pu}\to{}^{235}_{92}\mathrm{U}\to{}^{231}_{90}\mathrm{Th}\to{}^{231}_{91}\mathrm{Pa}\to{}^{227}_{89}\mathrm{Ac}\to{}^{223}_{87}\mathrm{Fr}\ (1.38\%)\to$
$\to{}^{223}_{88}\mathrm{Ra}\to{}^{219}_{86}\mathrm{Rn}\to{}^{215}_{84}\mathrm{Po}\to{}^{211}_{82}\mathrm{Pb}\to{}^{211}_{83}\mathrm{Bi}\to{}^{211}_{84}\mathrm{Po}\ (0.28\%)\to{}^{207}_{82}\mathrm{Pb}$ (stable)

${}^{244}_{96}\mathrm{Cm}\to{}^{240}_{94}\mathrm{Pu}\to{}^{236}_{92}\mathrm{U}\to{}^{232}_{90}\mathrm{Th}\to{}^{228}_{88}\mathrm{Ra}\to{}^{228}_{89}\mathrm{Ac}\to{}^{228}_{90}\mathrm{Th}\to{}^{224}_{88}\mathrm{Ra}\to{}^{220}_{86}\mathrm{Rn}\to{}^{216}_{84}\mathrm{Po}\to{}^{212}_{82}\mathrm{Pb}\to$
$\to{}^{212}_{83}\mathrm{Bi}\to{}^{212}_{84}\mathrm{Po}\ (64.07\%)\to{}^{208}_{82}\mathrm{Pb}$ (stable)
${}^{244}_{96}\mathrm{Cm}\to{}^{240}_{94}\mathrm{Pu}\to{}^{236}_{92}\mathrm{U}\to{}^{232}_{90}\mathrm{Th}\to{}^{228}_{88}\mathrm{Ra}\to{}^{228}_{89}\mathrm{Ac}\to{}^{228}_{90}\mathrm{Th}\to{}^{224}_{88}\mathrm{Ra}\to{}^{220}_{86}\mathrm{Rn}\to{}^{216}_{84}\mathrm{Po}\to{}^{212}_{82}\mathrm{Pb}\to$
$\to{}^{212}_{83}\mathrm{Bi}\to{}^{208}_{81}\mathrm{Tl}\ (35.93\%)\to{}^{208}_{82}\mathrm{Pb}$ (stable)

${}^{245}_{96}\mathrm{Cm}\to{}^{241}_{94}\mathrm{Pu}\to{}^{241}_{95}\mathrm{Am}\to{}^{237}_{93}\mathrm{Np}\to{}^{233}_{91}\mathrm{Pa}\to{}^{233}_{92}\mathrm{U}\to{}^{229}_{90}\mathrm{Th}\to{}^{225}_{88}\mathrm{Ra}\to{}^{225}_{89}\mathrm{Ac}\to{}^{221}_{87}\mathrm{Fr}\to{}^{217}_{85}\mathrm{At}\to$
$\to{}^{213}_{83}\mathrm{Bi}\to{}^{213}_{84}\mathrm{Po}\ (97.84\%)\to{}^{209}_{82}\mathrm{Pb}\to{}^{209}_{83}\mathrm{Bi}$ (stable)
${}^{245}_{96}\mathrm{Cm}\to{}^{241}_{94}\mathrm{Pu}\to{}^{241}_{95}\mathrm{Am}\to{}^{237}_{93}\mathrm{Np}\to{}^{233}_{91}\mathrm{Pa}\to{}^{233}_{92}\mathrm{U}\to{}^{229}_{90}\mathrm{Th}\to{}^{225}_{88}\mathrm{Ra}\to{}^{225}_{89}\mathrm{Ac}\to{}^{221}_{87}\mathrm{Fr}\to{}^{217}_{85}\mathrm{At}\to$
$\to{}^{213}_{83}\mathrm{Bi}\to{}^{209}_{81}\mathrm{Tl}\ (2.16\%)\to{}^{209}_{82}\mathrm{Pb}\to{}^{209}_{83}\mathrm{Bi}$ (stable)

${}^{246}_{96}\mathrm{Cm}\to{}^{242}_{94}\mathrm{Pu}\to{}^{238}_{92}\mathrm{U}\to{}^{234}_{90}\mathrm{Th}\to{}^{234}_{91}\mathrm{Pa}\to{}^{234}_{92}\mathrm{U}\to{}^{230}_{90}\mathrm{Th}\to{}^{226}_{88}\mathrm{Ra}\to{}^{222}_{86}\mathrm{Rn}\to{}^{218}_{84}\mathrm{Po}\to$
$\to{}^{214}_{82}\mathrm{Pb}\ (99.98\%)\to{}^{214}_{83}\mathrm{Bi}\to{}^{214}_{84}\mathrm{Po}\to{}^{210}_{82}\mathrm{Pb}\to{}^{210}_{83}\mathrm{Bi}\to{}^{210}_{84}\mathrm{Po}\to{}^{206}_{82}\mathrm{Pb}$ (stable)
${}^{246}_{96}\mathrm{Cm}\to{}^{242}_{94}\mathrm{Pu}\to{}^{238}_{92}\mathrm{U}\to{}^{234}_{90}\mathrm{Th}\to{}^{234}_{91}\mathrm{Pa}\to{}^{234}_{92}\mathrm{U}\to{}^{230}_{90}\mathrm{Th}\to{}^{226}_{88}\mathrm{Ra}\to{}^{222}_{86}\mathrm{Rn}\to{}^{218}_{84}\mathrm{Po}\to$
$\to{}^{218}_{85}\mathrm{At}\ (0.02\%)\to{}^{214}_{83}\mathrm{Bi}\to{}^{214}_{84}\mathrm{Po}\to{}^{210}_{82}\mathrm{Pb}\to{}^{210}_{83}\mathrm{Bi}\to{}^{210}_{84}\mathrm{Po}\to{}^{206}_{82}\mathrm{Pb}$ (stable)

2.36.2 Sorption properties

Distribution coefficients (K_d), concentration in solid matter/concentration in solution ([Bq/kg dry weight]/[Bq/m^3])

	B.E.	Distr	Low	High	Reference
Soil	1E+1	LT	1E+0	1E+2	IAEA, 1994
Organic soil	1E+1	LT	1E+0	1E+2	IAEA, 1994
Suspended matter					
lakes	5E+0	LT	1E-1	7E+1	IAEA, 1994*
brackish water	1E+3	LT	1E+1	2E+3	**

* The range given in the reference has been decreased.

** Best estimate and range defined in Bergström & Nordlinder (1993). The K_d-values in that study was extracted from Coughtrey *et al* (1985), Puigdomenech & Bergström (1995) and McKinley & Scholtis (1992).

2.36.3 Uptake in biota

Root-uptake factors (transfer factors) ([Bq/kg]/[Bq/kg dry or wet weight soil])

	B.E.	Distr	Low	High	Reference
Pasturage*	1E-3	LT	1E-4	4E-3	IAEA, 1994***
Cereals**	2E-5	LT	1E-6	3E-4	IAEA, 1994***
Root crops**	3E-5	LT	2E-6	5E-4	IAEA, 1994***
Vegetables	8E-5	LT	8E-6	8E-4	IAEA, 1994****

* Dry weight.

** Wet weight.

*** For cereals, root crops and vegetables the value has been converted into wet weight (10% water in cereals, 80% in root crops and 90% in vegetables). The range given for pasturage in IAEA (1994) has been increased somewhat.

**** In SR 97 a best estimate of $2 \cdot 10^{-4}$ kg/kg ($2 \cdot 10^{-5}$–$2 \cdot 10^{-3}$ kg/kg) was used (Bergström *et al*, 1999) with reference to IAEA (1994). This value must have been incorrectly read from the table since the value given for mixed green vegetables are $7.7 \cdot 10^{-4}$ kg/kg which, converted into wet weight (90% water) and rounded off gives a value of $8 \cdot 10^{-5}$ kg/kg. The latter value has been used in the SAFE study (Karlsson *et al*, 2001) and the range has been adjusted to this value.

Bioaccumulation factor ([Bq/kg wet weight]/[Bq/l])

	B.E.	Distr	Low	High	Reference
Freshwater fish	3E+1	LT	1E+1	3E+2	IAEA, 1994*
Baltic fish	5E+1	LT	1E+1	3E+2	**
Freshwater invertebrates	1E+3	LT	1E+2	1E+4	Thompson *et al*, 1972
Marine water plants	5E+3	LT	1E+2	1E+4	Thompson *et al*, 1972

* The range given in IAEA (1994) has been increased somewhat.

** The best estimate and range is defined in Bergström & Nordlinder (1992). The amount of data concerning bioaccumulation of curium is scarce. Eyman & Trabalka (1980) recommends bioaccumulation factors related to the trophic level of the fish species; 50 l/kg for piscivorous fishes and 250 for plankton feeding species. As it is mainly piscivorous species which are consumed by humans a best estimate of 50 has been used.

2.36.4 Metabolism

Transfer coefficients to cow milk and cow meat ([Bq/l]/Bq daily intake) and ([Bq/kg wet weight]/Bq daily intake), respectively

	B.E.	Distr	Low	High	Reference
Milk (day/l)	2.0E-5	LT	2.0E-6	2.0E-4	IAEA, 1982*
Meat (day/kg)	2.0E-5	LT	2.0E-6	2.0E-4	IAEA, 1982**

* The value given in IAEA (1982) is based on the assumption that curium behaves chemically similar to $CeCl_3$.

** The value given in IAEA (1982) is, in absence of relevant data, based on the value for americium.

2.36.5 Translocation

Element specific translocation factors from surface to edible parts of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2])

B.E.	Distr	Low	High	Reference
2E-2	T	1E-2	3E-2	*

* In lack of data the same values as for plutonium is used.

2.36.6 Nuclide specific parameters

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Cm-243	α, EC	29.1	1.0E-14	1.5E-7	6.9E-5
Cm-244	α	18	0	1.2E-7	5.7E-5*
Cm-245	α	8 500	3.2E-15	2.1E-7	9.9E-5*
Cm-246	α	4 730	0	2.1E-7	9.8E-5*

* The value used for Cm-244 in SR 97 was 2.7E-5 Sv/Bq. For Cm-245 and Cm-246 a value of 4.2E-5 Sv/Bq was used.

Dose coefficients for oral intake for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Cm-243	3.2E-06	3.3E-07	2.2E-07	1.6E-07	1.4E-07
Cm-244	2.9E-06	2.9E-07	1.9E-07	1.4E-07	1.2E-07
Cm-245	3.7E-6	3.7E-7	2.8E-7	2.3E-7	2.1E-7
Cm-246	3.7E-6	3.7E-7	2.8E-7	2.2E-7	2.1E-7

Dose coefficients for inhalation for various age groups (Sv/Bq)

			Age (Years)		
Isotope	**<1**	**1–2**	**2–7**	**7–12**	**12–17**
Cm-243	1.6E-04	1.5E-04	9.5E-05	7.3E-05	6.5E-05
Cm-244	1.5E-04	1.3E-04	8.3E-05	6.1E-05	5.3E-05
Cm-245	1.9E-4	1.8E-4	1.2E-4	1.0E-4	9.4E-5
Cm-246	1.9E-4	1.8E-4	1.2E-4	1.0E-4	9.4E-5

2.36.7 Summary

No stable isotopes occur of curium in the environment. The element accumulates in mammalian bone. The radioactive isotopes of interest for dose assessments concerning repositories for nuclear fuel and waste are Cm-243 (with a half-life of 29 years), Cm-244 (18 years), Cm-245 (8,500 years) and Cm-246 (4,700 years). Root uptake of curium is very low whereas sorption to solid matter in soils, sediments and peat is very high. The transfer to milk and meat is low which is also the case for accumulation in fish (freshwater as well as brackish water). The accumulation in freshwater crustaceans and marine water plants is high. The dose coefficients for ingestion and inhalation are very similar for all four curium isotopes, they are all high. Significant external exposure occurs from Cm-243 and Cm-245. The dose coefficient for external exposure is high for Cm-243 and about ten times lower for Cm-245. Cm-243 was not considered in SR 97 or in the SAFE study. In conclusion the exposure from the other three curium isotopes is high in all models (lake, coastal, running waters, agricultural land, mire, well) with the exception of Cm-244 in the agricultural land and mire model. The exposure from Cm-244 in the agricultural land model is very low whereas the exposure in the mire model is intermediate. This is due to the relatively short half-life of this nuclide, because of this the amounts which reaches the top soil layer where exposure is possible is smaller than for the other curium isotopes. The dominating exposure pathway for Cm-244 in the well model is consumption of water whereas inhalation of dust, followed by consumption of water is most important for Cm-245 and Cm-246. In the agricultural land and mire models inhalation is the dominating contributor to dose for all three radionuclides. In the lake and running waters models used in SR 97 consumption of shellfish, followed by consumption of fish, is the most important exposure pathway. In the coastal model consumption of fish is the dominating exposure pathway.

3 Summary

The aim of this report is to compile (in one single document) element and nuclide specific data which are used when modelling transport and uptake of radionuclides within and between different ecosystems. The parameter values used in earlier safety assessments for repositories for radioactive waste are more or less well documented and the information is scattered in many documents. Effort has been placed on checking data and also on the documentation of references. Some mistakes have been found and corrected.

The search backwards for the initial references often lead to some kind of “compilation documents”. Some of these contain detailed discussions about different sources (e.g. Coughtrey and co-workers) whereas others present values mainly as tables, sometimes with short notes (e.g. IAEA and NCRP). These documents have been used as “endpoints” for information and no investigation about their references has been performed.

As mentioned earlier, data for short-lived radionuclides has been of lower priority, in this document as well as in earlier safety assessments. This is because these nuclides are not of interest in the long time perspective of most safety assessments for repositories for radioactive waste. Some of the radionuclides may not even reach the biosphere before they have decayed.

The parameter values are given a range which should represent the natural variability of the parameter and also include the uncertainty in knowledge. Generally, relatively wide ranges were used, i.e. when information is lacking a minimum value ten times lower than the best estimate has been used, and together with a maximum value ten times higher than the best estimate the range stretches over two orders of magnitude. It may seem very wide but for some parameters this range should be even wider. The values has been defined using a conservative approach, i.e. the range of the parameter values has been chosen in the upper part of the “true” interval.

The amount of data varies very much between different parameters but most of all between different elements. For some elements best estimates and ranges are presented in the literature whereas for other a single value has been found somewhere. For some elements no data at all has been found and then an estimation has been done often by using values for a chemical analogue.

Data concerning bioaccumulation or distribution coefficients to suspended matter in brackish environments are very scarce and if information from both fresh and marine waters were available the highest value has been chosen. For bioaccumulation factors this is a conservative approach. For sorption to suspended matter it depends on i.a. the focus of the model if the approach is conservative or not. A high value for sorption means that a smaller fraction of the radionuclides are available for uptake in aquatic biota and thus for exposure through intake of this foodstuff, but if the water turnover is rapid, as in the SAFE study, this has little, if any, importance at all. Instead it may be more interesting to look at how much of the radionuclides that is accumulated in the sediments which is later assumed to be used as agricultural land. The later is of course only interesting if the radionuclides are so long-lived that they are still present in the sediment/soil at the time point when it is ploughed and cultivated.

What do we learn from this compilation of data? We can clearly see that the amount of information differ between different elements and also between parameters. The half-lives of radionuclides are known physical facts and are the least uncertain parameters in this compilation. The dose coefficients are also, for sure, connected with uncertainties but since no information about uncertainties or variations is present these have been treated as constant values. Translocation (from vegetation surfaces to edible parts of vegetation) is the one single parameter for which very little data has been found. Only for bioavailable nuclides some data has been found. Comparing a translocation value of 0.1 (which means that 10% of the deposited radionuclides is found in the edible parts) with the root uptake factors used which are several orders of magnitude lower it is clearly seen that this parameter are of importance for the results (for some nuclides) in dose calculations. No thorough investigation of the values used for root crops has been performed, the values used are to a much larger extent than for e.g. the values for bioaccumulation factors for fish based on tabulated values.

For one single element a lot of data is available. This element is, of course, cesium which is present within almost all ecosystems in Sweden as a result of the nuclear bomb test during the 60ties and the Chernobyl accident 1986. All the data found has lead to that mathematical expressions has been set up to calculate e.g. uptake in fish depending on environmental conditions such as potassium content in water. This reduces the uncertainties in parameter values as well as in results. This kind of expression has also been set up for strontium but is not available for other elements.

In the future SKB will move the focus from generic models to more site specific ones. In this perspective it may be argued that models using general parameters such as those used here should be replaced by models which go into more detail in important processes for the turnover of matter and radionuclides in each specific ecosystem. As the number of radionuclides which may be of interest is rather large this can not be done without large resources and perhaps this should be performed only for a few, important elements. Our proposal is instead that resources should, in first place, be concentrated on a few nuclides which are of importance for dose to humans and the nuclides which has been of most interest in the two latest safety assessments by SKB (SR 97 and SAFE) is C-14, Cl-36, Ni-59, Se-79, Mo-93, I-129 and Ra-226. Cs-135 is also of interest but the necessity to improve the data for this nuclide is not that urgent as for the others (see above).

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Parameter Values

LT = Logtriangular distribution.
T = Triangular distribution.

Table A-1 Element specific root uptake factors for pasturage (which represents both grass and fodder ([Bq/kg d.w. grass]/[Bq/kg d.w. soil]).

	Pasturage (dry veg/dry soil)			
Element	**B.E**	**Distr**	**Low**	**High**
H	5E+1	LT	2E+1	8E+1
Be	1E-2	LT	1E-3	1E-1
C	–	–	–	–
Cl	3E+1	T	1E+1	1E+2
Fe	3E-3	LT	3E-4	3E-2
Co	1E-1	LT	1E-2	1E+0
Ni	2E-1	LT	2E-2	2E+0
Se	2E+1	LT	1E+0	3E+1
Sr	1E+0	LT	4E-1	3E+0
Zr	1E-3	LT	1E-4	1E-2
Nb	5E-3	LT	5E-4	5E-2
Mo	8E-1	LT	8E-2	8E+0
Tc	8E+0	LT	8E-1	8E+1
Ru	9E-2	LT	9E-3	9E-1
Pd	2E-1	LT	2E-2	2E+0
Ag	5E-1	LT	5E-2	4E+0
Cd	5E+0	LT	5E-1	5E+1
Sn	1E-1	LT	1E-2	2E+0
I	6E-1	LT	6E-2	6E+0
Cs	2E-1	LT	2E-2	2E+0
Pm	4E-2	LT	4E-3	4E-1
Sm	1E-2	LT	1E-3	1E-1
Eu	1E-2	LT	1E-3	1E-1
Ho	1E-3	LT	1E-4	1E-2
Pb	1E-3	LT	1E-4	1E-2
Po	5E-2	LT	5E-3	5E-1
Rn	–	–	–	–
Ra	8E-2	LT	2E-2	4E-1

Table A-1 (cont'd)

	Pasturage (dry veg/dry soil)			
Element	**B.E**	**Distr**	**Low**	**High**
Ac	5E-4	LT	3E-5	7E-3
Th	1E-2	LT	1E-3	1E-1
Pa	3E-3	LT	3E-4	3E-2
U	2E-2	LT	2E-3	2E-1
Np	7E-2	LT	7E-3	7E-1
Pu	4E-4	LT	5E-5	7E-1
Am	1E-3	LT	5E-4	2E-1
Cm	1E-3	LT	1E-4	4E-3

Table A-2 Element specific root uptake factors for cereals ([Bq/kg w.w. cereals]/[Bq/kg d.w. soil]).

	Cereals (grain/dry soil)			
Element	**B.E**	**Distr**	**Low**	**High**
H	5E+1	LT	2E+1	8E+1
Be	3E-3	LT	3E-4	3E-2
C	–	–	–	–
Cl	3E+1	T	9E+0	9E+1
Fe	7E-4	LT	7E-5	7E-3
Co	1E-1	LT	1E-2	1E+0
Ni	3E-2	LT	3E-3	3E-1
Se	2E+1	LT	9E-1	3E+1
Sr	2E-1	LT	2E-2	1E+0
Zr	9E-4	LT	9E-5	9E-3
Nb	4E-3	LT	4E-4	4E-2
Mo	7E-1	LT	7E-2	7E+0
Tc	6E-1	LT	6E-2	3E+0
Ru	8E-3	LT	8E-4	8E-2
Pd	3E-2	LT	3E-3	3E-1
Ag	4E-1	LT	4E-2	3E+0
Cd	5E+0	LT	5E-1	5E+1
Sn	4E-1	LT	1E-2	1E+0
I	1E-1	LT	1E-2	1E+0
Cs	2E-2	LT	2E-3	2E-1
Pm	2E-3	LT	2E-4	2E-2
Sm	1E-4	LT	1E-5	1E-3
Eu	2E-4	LT	2E-5	2E-3
Ho	1E-4	LT	1E-5	1E-3
Pb	4E-3	LT	4E-4	4E-2
Po	1E-3	LT	1E-4	1E-2
Rn	–	–	–	–
Ra	1E-3	LT	2E-4	5E-3
Ac	4E-4	LT	1E-5	1E-3
Th	1E-2	LT	1E-3	1E-1
Pa	3E-3	LT	3E-4	3E-2
U	1E-3	LT	1E-4	1E-2
Np	2E-3	LT	2E-4	2E-2
Pu	7E-6	LT	7E-7	7E-5
Am	2E-5	LT	2E-6	2E-4
Cm	2E-5	LT	1E-6	3E-4

Table A-3 Element specific root uptake factors for root crops ([Bq/kg w.w. root crop]/[Bq/kg d.w. soil]).

	Root crops (fresh veg/dry soil)			
Element	**B.E**	**Distr**	**Low**	**High**
H	1E+1	T	5E+0	2E+1
Be	3E-3	LT	3E-4	3E-2
C	–		–	–
Cl	6E+0	T	2E+0	2E+1
Fe	7E-4	LT	7E-5	7E-3
Co	1E-2	LT	1E-3	1E-1
Ni	4E-2	LT	4E-3	4E-1
Se	4E+0	LT	2E-1	6E+0
Sr	6E-2	LT	1E-2	3E-1
Zr	2E-4	LT	2E-5	2E-3
Nb	1E-3	LT	1E-4	1E-2
Mo	2E-1	LT	2E-2	2E+0
Tc	5E-2	LT	5E-3	5E-1
Ru	8E-3	LT	8E-4	8E-2
Pd	4E-2	LT	4E-3	4E-1
Ag	2E-1	LT	2E-2	1E+0
Cd	1E+0	LT	1E-1	1E+1
Sn	6E-2	LT	1E-2	1E+0
I	1E-2	LT	1E-3	1E+0
Cs	2E-2	LT	2E-3	2E-1
Pm	2E-3	LT	2E-4	2E-2
Sm	4E-5	LT	4E-6	4E-4
Eu	6E-5	LT	6E-6	6E-4
Ho	9E-5	LT	9E-6	9E-4
Pb	4E-3	LT	4E-4	4E-2
Po	4E-3	LT	4E-4	4E-2
Rn	–	–	–	–
Ra	4E-3	LT	4E-4	2E-2
Ac	5E-5	LT	2E-5	1E-2
Th	1E-5	LT	1E-6	1E-4
Pa	6E-4	LT	6E-5	6E-3
U	3E-3	LT	3E-4	3E-2
Np	2E-3	LT	2E-4	2E-2
Pu	3E-5	LT	3E-6	3E-4
Am	4E-5	LT	4E-6	4E-4
Cm	3E-5	LT	2E-6	5E-4

Table A-4 Element specific root uptake factors for vegetables ([Bq/kg w.w. vegetable]/[Bq/kg d.w. soil]).

	Vegetables (fresh veg/dry soil)			
Element	**B.E**	**Distr**	**Low**	**High**
H	1E+1	T	5E+0	2E+1
Be	3E-3	LT	3E-4	3E-2
C	–		–	–
Cl	3E+0	T	1E+0	1E+1
Fe	7E-4	LT	7E-5	7E-3
Co	1E-2	LT	1E-3	1E-1
Ni	2E-2	LT	2E-3	2E-1
Se	2E+0	LT	1E-1	3E+0
Sr	3E-1	LT	3E-2	3E+0
Zr	1E-4	LT	1E-5	1E-3
Nb	5E-4	LT	5E-5	5E-3
Mo	8E-2	LT	8E-3	8E-1
Tc	2E+1	LT	1E-1	8E+1
Ru	8E-3	LT	8E-4	8E-2
Pd	2E-2	LT	2E-3	2E-1
Ag	1E-1	LT	1E-2	8E-1
Cd	5E-1	LT	5E-2	5E+0
Sn	5E-2	LT	1E-2	1E+0
I	3E-2	LT	3E-3	3E-1
Cs	2E-2	LT	2E-3	2E-1
Pm	2E-3	LT	2E-4	2E-2
Sm	3E-3	LT	3E-4	3E-2
Eu	3E-3	LT	3E-4	3E-2
Ho	3E-3	LT	3E-4	3E-2
Pb	1E-3	LT	1E-4	1E-2
Po	1E-3	LT	1E-4	1E-2
Rn	–	–	–	–
Ra	5E-3	LT	3E-4	1E-1
Ac	4E-3	LT	2E-4	8E-2
Th	2E-4	LT	2E-5	2E-3
Pa	3E-4	LT	3E-5	3E-3
U	1E-3	LT	1E-4	1E-2
Np	4E-3	LT	4E-4	4E-2
Pu	2E-5	LT	2E-6	2E-4
Am	7E-5	LT	7E-6	7E-4
Cm	8E-5	LT	8E-6	8E-4

Table A-5 Element specific translocation factors from surface to edible part of cereals and root crops ([Bq/kg w.w.]/[Bq/m^2]), triangularly distributed.

	Translocation factors (m^2/kg)		
Element	**B.E**	**Min**	**Max**
H	1E-1	1E-2	3E-1
Be	4E-3	1E-3	6E-2
C	1E-1	1E-2	3E-1
Cl	1E-1	1E-2	3E-1
Fe	2E-1	1E-1	3E-1
Co	2E-1	1E-1	3E-1
Ni	1E-2	5E-3	4E-2
Se	1E-1	1E-2	3E-1
Sr	4E-1	1E-1	7E-1
Zr	1E-1	1E-2	3E-1
Nb	2E-1	1E-1	3E-1
Mo	1E-1	1E-2	3E-1
Tc	5E-3	4E-3	6E-3
Ru	2E-2	2E-3	5E-2
Pd	1E-1	1E-2	3E-1
Ag	1E-1	1E-2	3E-1
Cd	2E-2	6E-5	5E-2
Sn	1E-1	1E-2	3E-1
I	1E-1	5E-2	2E-1
Cs	2E-1	1E-1	3E-1
Pm	1E-1	1E-2	3E-1
Sm	1E-1	1E-2	3E-1
Eu	2E-2	1E-2	3E-2
Ho	1E-1	1E-2	3E-1
Pb	3E-2	1E-2	1E-1
Po	1E-1	5E-2	2E-1
Rn	–	–	–
Ra	1E-1	1E-2	3E-1
Ac	1E-1	1E-2	3E-1
Th	1E-1	1E-2	3E-1
Pa	1E-1	1E-2	3E-1
U	1E-1	1E-2	3E-1
Np	1E-1	5E-2	2E-1
Pu	2E-2	1E-2	3E-2
Am	1E-2	5E-3	2E-2
Cm	2E-2	1E-2	3E-2

Table A-6 Element specific distribution coefficients (K_d) for soil, concentration in solid matter/concentration in solution ([Bq/kg d.w.]/[Bq/m^3]).

	K_d Soil (m^3/kg)			
Element	**B.E**	**Distr**	**Low**	**High**
H	–	–	–	–
Be	1E+0	LT	1E-1	1E+1
C	1E-3	LT	4E-4	1E-2
Cl	1E-3	LT	1E-4	1E-2
Fe	1E+1	LT	1E+0	1E+2
Co	1E+0	LT	1E-2	2E+1
Ni	5E-1	LT	5E-2	5E+0
Se	1E-2	LT	1E-3	1E-1
Sr	1E-2	LT	1E-3	1E-1
Zr	1E+0	LT	1E-1	1E+1
Nb	5E-1	LT	5E-3	5E+0
Mo	1E-1	LT	1E-2	1E+0
Tc	5E-3	LT	1E-3	1E-2
Ru	1E-1	LT	3E-3	1E+0
Pd	2E-1	LT	2E-2	2E+0
Ag	1E-1	LT	1E-2	1E+0
Cd	1E-1	LT	2E-3	3E+0
Sn	1E-1	LT	5E-2	5E-1
I	3E-1	LT	1E-1	1E+0
Cs	1E+0	LT	1E-1	1E+1
Pm	2E+2	LT	2E+1	2E+3
Sm	1E+0	LT	1E-1	1E+1
Eu	2E+2	LT	2E+1	2E+3
Ho	1E+0	LT	1E-1	1E+1
Pb	1E-1	LT	1E-2	1E+0
Po	5E-1	LT	5E-2	3E+0
Rn	–	–	–	–
Ra	5E-1	LT	1E-2	1E+0
Ac	1E+0	LT	1E-1	1E+1
Th	1E+1	LT	1E+0	1E+2
Pa	1E+1	LT	1E+0	1E+2
U	1E-1	LT	1E-2	1E+0
Np	1E-1	LT	1E-2	1E+0
Pu	5E+0	LT	1E-1	1E+1
Am	2E+0	LT	2E-1	2E+1
Cm	1E+1	LT	1E+0	1E+2

Table A-7 Element specific distribution coefficients (K_d) for peat (organic soil), concentration in solid matter/concentration in solution ([Bq/kg d.w.]/[Bq/m^3]).

K_d Peat (m^3/kg)				
Element	**B.E**	**Distr**	**Low**	**High**
H	–	–	–	–
Be	3E+0	LT	3E-1	3E+1
C	7E-2	LT	7E-3	7E-1
Cl	1E-2	LT	1E-3	1E-1
Fe	5E+0	LT	5E-1	5E+1
Co	1E+0	LT	5E-2	2E+1
Ni	1E+0	LT	2E-1	7E+0
Se	2E+0	LT	2E-1	2E+1
Sr	2E-1	LT	4E-3	6E+0
Zr	7E+0	LT	7E-1	7E+1
Nb	2E+0	LT	2E-1	2E+1
Mo	3E-2	LT	3E-3	3E-1
Tc	2E-3	LT	4E-5	6E-2
Ru	7E+1	LT	4E+1	1E+2
Pd	7E-1	LT	7E-2	7E+0
Ag	2E+1	LT	2E+0	9E+1
Cd	8E-1	LT	8E-3	8E+1
Sn	2E+0	LT	2E-1	2E+1
I	3E-2	LT	3E-3	3E-1
Cs	3E-1	LT	1E-1	3E+0
Pm	1E+0	LT	5E-1	3E+0
Sm	3E+0	LT	3E-1	3E+1
Eu	1E+0	LT	5E-2	2E+1
Ho	3E+0	LT	3E-1	3E+1
Pb	2E+1	LT	8E+0	6E+1
Po	7E+0	LT	7E-1	7E+2
Rn	–	–	–	–
Ra	2E+0	LT	2E-1	2E+1
Ac	5E+0	LT	5E-1	5E+1
Th	9E+1	LT	9E+0	9E+2
Pa	7E+0	LT	7E-1	7E+1
U	4E-1	LT	3E-3	4E+0
Np	1E+0	LT	5E-1	3E+0
Pu	2E+0	LT	2E-1	2E+1
Am	1E+2	LT	1E+1	1E+3
Cm	1E+1	LT	1E+0	1E+2

Table A-8 Element specific distribution coefficients (K_d) for suspended matter in lakes, concentration in solid matter/concentration in solution ([Bq/kg d.w.]/[Bq/m^3]).

K_d Lake sediment (m^3/kg)				
Element	**B.E**	**Distr**	**Low**	**High**
H	–	–	–	–
Be	1E+0	LT	1E-1	1E+1
C	1E-3	LT	1E-4	1E-2
Cl	1E+0	LT	1E-1	1E+1
Fe	5E+0	LT	1E+0	1E+1
Co	5E+0	LT	1E+0	7E+1
Ni	1E+1	LT	1E+0	1E+2
Se	5E+0	LT	1E+0	1E+1
Sr	1E+0	LT	1E-1	1E+1
Zr	1E+0	LT	1E-1	1E+1
Nb	1E+1	LT	1E+0	1E+2
Mo	1E-3	LT	1E-4	1E-2
Tc	1E-1	LT	1E-2	1E+0
Ru	1E-1	LT	1E-2	1E+0
Pd	2E+0	LT	2E-1	2E+1
Ag	2E+0	LT	2E-1	2E+1
Cd	1E-1	LT	1E-2	1E+0
Sn	5E+1	LT	1E+1	1E+2
I	3E-1	LT	1E-1	1E+0
Cs	1E+1	LT	1E+0	1E+2
Pm	5E+0	LT	1E+0	1E+1
Sm	5E+0	LT	5E-1	5E+1
Eu	5E-1	LT	5E-2	5E+0
Ho	3E-1	LT	3E-2	3E+0
Pb	5E-2	LT	1E-2	1E-1
Po	1E+1	LT	1E+0	1E+2
Rn	–	–	–	–
Ra	1E+1	LT	1E+0	1E+2
Ac	1E+1	LT	1E+0	1E+2
Th	1E+2	LT	1E+1	1E+3
Pa	1E+2	LT	1E+1	1E+3
U	1E+1	LT	1E+0	1E+2
Np	1E+1	LT	1E+0	1E+2
Pu	1E+2	LT	1E+1	1E+3
Am	5E+0	LT	5E-1	5E+1
Cm	5E+0	LT	1E-1	7E+1

Table A-9 Element specific distribution coefficients (K_d) for suspended matter in brackish waters, concentration in solid matter/concentration in solution ([Bq/kg d.w.]/[Bq/m^3]).

	K_d Baltic Sea sediment (m^3/kg)			
Element	**B.E**	**Distr**	**Low**	**High**
H	1E-3	LT	5E-5	1E-2
Be	1E+0	LT	1E-1	1E+1
C	1E-3	LT	1E-4	1E-2
Cl	1E-3	LT	1E-4	1E-2
Fe	5E+4	LT	3E+1	3E+5
Co	1E+2	LT	1E+0	2E+2
Ni	1E+1	LT	1E+0	1E+2
Se	5E+0	LT	1E+0	1E+1
Sr	1E-1	LT	1E-2	1E+0
Zr	5E+1	LT	5E+0	5E+2
Nb	1E+1	LT	1E+0	1E+2
Mo	1E-3	LT	1E-4	1E-2
Tc	1E-1	LT	1E-2	1E+0
Ru	1E+0	LT	1E-1	1E+1
Pd	1E+1	LT	1E+0	1E+2
Ag	1E+0	LT	1E-1	1E+1
Cd	5E+0	LT	1E+0	1E+2
Sn	5E+1	LT	1E+1	1E+2
I	3E-1	LT	1E-1	1E+0
Cs	1E+1	LT	1E+0	1E+2
Pm	1E+3	LT	5E+1	1.1E+3
Sm	1E+2	LT	1E+1	1E+3
Eu	1E+1	LT	1E+0	1E+2
Ho	1E-1	LT	1E-2	1E+0
Pb	5E-2	LT	1E-2	1E-1
Po	2E+4	LT	1E+2	5E+4
Rn	–	–	–	–
Ra	1E+1	LT	1E+0	1E+2
Ac	1E+1	LT	1E+0	1E+2
Th	1E+2	LT	1E+1	1E+3
Pa	1E+2	LT	1E+1	1E+3
U	1E+1	LT	1E+0	1E+2
Np	1E+1	LT	1E+0	1E+2
Pu	1E+2	LT	1E+1	1E+3
Am	1E+1	LT	1E+0	1E+2
Cm	1E+3	LT	1E+1	2E+3

Table A-10 Element specific transfer coefficients to cow milk from daily intake ([Bq/l]/[Bq intake/day]).

	F-milk (day/l)			
Element	**B.E**	**Distr**	**Low**	**High**
H	2E-2	LT	1E-2	3E-2
Be	9E-7	LT	9E-8	9E-6
C	1E-2	LT	5E-3	2E-2
Cl	1.7E-2	T	1.5E-2	2E-2
Fe	1.2E-3	LT	1.2E-4	1.2E-2
Co	3E-4	LT	6E-5	1E-2
Ni	2E-2	LT	2E-3	5E-2
Se	4E-3	LT	4E-4	4E-2
Sr	2.8E-3	LT	1E-3	3E-3
Zr	6E-7	LT	6E-8	6E-6
Nb	4E-7	LT	1E-7	4E-6
Mo	2E-3	LT	2E-4	2E-2
Tc	2E-5	LT	1E-5	1E-3
Ru	3.3E-6	LT	1E-7	2E-5
Pd	1E-3	LT	1E-4	1E-2
Ag	5E-5	LT	5E-6	5E-4
Cd	1E-4	LT	1E-5	1E-3
Sn	1E-3	LT	1E-4	1E-2
I	1E-2	LT	1E-3	4E-2
Cs	8E-3	LT	1E-3	3E-2
Pm	2E-5	LT	2E-6	2E-4
Sm	2E-5	LT	2E-6	2E-4
Eu	2E-5	LT	2E-6	2E-4
Ho	2.5E-6	LT	3E-7	3E-5
Pb	3E-4	LT	2E-5	2E-3
Po	3.4E-4	LT	3.4E-5	3.4E-3
Rn	–	–	–	–
Ra	1.3E-3	LT	1E-4	2E-3
Ac	2E-6	LT	2E-7	2E-5
Th	5E-6	LT	1E-7	1E-4
Pa	5E-5	LT	1E-6	1E-4
U	4E-4	LT	7E-5	6E-4
Np	5E-6	LT	5E-7	5E-5
Pu	1E-6	LT	3E-9	3E-6
Am	2E-6	LT	4E-7	2E-5
Cm	2E-5	LT	2E-6	2E-4

Table A-11 Element specific transfer coefficients to cow meat from daily intake ([Bq/kg d.w.]/[Bq intake/day]).

	F-meat (day/kg)			
Element	**B.E**	**Distr**	**Low**	**High**
H	1E-2	LT	5E-3	2E-2
Be	1E-3	LT	1E-4	1E-2
C	3E-2	LT	1.5E-2	6E-2
Cl	2E-2	LT	1E-2	4E-2
Fe	2E-2	LT	2E-3	5E-2
Co	1E-2	LT	4E-5	7E-2
Ni	5E-3	LT	5E-4	5E-2
Se	1.5E-2	LT	1E-4	2E-2
Sr	8E-3	LT	3E-4	1E-2
Zr	1E-6	LT	1E-7	1E-5
Nb	3E-7	LT	3E-8	1E-2
Mo	1E-3	LT	1E-4	1E-2
Tc	1E-4	LT	1E-5	1E-3
Ru	5E-2	LT	1E-4	4E-1
Pd	1E-3	LT	1E-4	1E-2
Ag	3E-3	LT	2E-3	6E-3
Cd	4E-4	LT	4E-5	4E-3
Sn	1E-2	LT	1E-3	1E-1
I	4E-2	LT	7E-3	5E-2
Cs	5E-2	LT	1E-2	6E-2
Pm	2E-3	LT	2E-4	2E-2
Sm	5E-3	LT	5E-4	5E-2
Eu	6E-3	LT	6E-4	6E-2
Ho	5E-3	LT	5E-4	5E-2
Pb	4E-4	LT	1E-4	7E-4
Po	5E-3	LT	6E-4	5.1E-3
Rn	–	–	–	–
Ra	9E-4	LT	5E-4	5E-3
Ac	2E-5	LT	2E-6	2E-4
Th	6E-6	LT	6E-7	6E-5
Pa	1E-5	LT	1E-6	1E-4
U	3E-4	LT	3E-5	3E-3
Np	1E-3	LT	1E-4	1E-2
Pu	1E-5	LT	2E-7	2E-4
Am	4E-5	LT	4E-6	1E-4
Cm	2E-5	LT	2E-6	2E-4

Table A-12 Element specific bioaccumulation factors to fish in freshwater ([Bq/kg w.w.]/[Bq/l]).

	BAF freshwater fish (l/kg w.w.)			
Element	**B.E**	**Distr**	**Low**	**High**
H	1E+0	LT	5E-1	2E+0
Be	1E+2	LT	1E+1	1E+3
C	5E+4	LT	5E+3	5.1E+4
Cl	5E+1	LT	1E+1	1E+2
Fe	2E+2	LT	5E+1	2E+3
Co	3E+2	LT	1E+1	4E+2
Ni	1E+2	LT	1E+1	1E+3
Se	2E+3	LT	5E+2	5E+3
Sr	6E+1	LT	1E+0	1E+3
Zr	2E+2	LT	3E+0	3E+2
Nb	3E+2	LT	1E+2	3E+4
Mo	1E+1	LT	1E+0	1E+2
Tc	2E+1	LT	2E+0	8E+1
Ru	1E+1	LT	1E+1	2E+2
Pd	1E+2	LT	1E+1	1E+3
Ag	5E+0	LT	2E-1	1E+1
Cd	2E+1	LT	2E+0	2E+2
Sn	3E+3	LT	3E+2	3E+4
I	2E+2	LT	1E+1	5E+2
Cs	1E+4	LT	5E+3	2E+4
Pm	3E+1	LT	1E+1	2E+2
Sm	3E+1	LT	3E+0	3E+2
Eu	5E+1	LT	1E+1	2E+2
Ho	3E+1	LT	3E+0	3E+2
Pb	3E+2	LT	1E+2	4E+2
Po	5E+1	LT	5E+0	5E+2
Rn	–	–	–	–
Ra	5E+1	LT	1E+1	2E+2
Ac	1E+2	LT	1E+1	2E+2
Th	1E+2	LT	3E+1	1E+3
Pa	1E+1	LT	1E+0	1E+2
U	1E+1	LT	2E+0	5E+1
Np	5E+1	LT	1E+1	3E+3
Pu	3E+1	LT	4E+0	3E+2
Am	3E+1	LT	1E+1	3E+2
Cm	3E+1	LT	1E+1	3E+2

Table A-13 Element specific bioaccumulation factors for fish to be used in the coast modules ([Bq/kg w.w.]/[Bq/l]).

BAF brackish water fish (l/kg w.w.)				
Element	**B.E**	**Distr**	**Low**	**High**
H	1E+0	LT	5E-1	2E+0
Be	2E+2	LT	2E+1	2E+3
C	2E+3	LT	1.8E+3	3E+3
Cl	1E+0	LT	1E-1	1E+1
Fe	6E+2	LT	5E+2	1E+4
Co	3E+2	LT	3E+1	5E+2
Ni	3E+2	LT	3E+1	5E+2
Se	4E+3	LT	2E+3	8E+3
Sr	3E+1	LT	1E+0	1E+2
Zr	1E+2	LT	1E+1	2E+2
Nb	1E+2	LT	1E+1	5E+2
Mo	1E+1	LT	1E+0	5E+1
Tc	3E+1	LT	1E+0	1E+2
Ru	1E+1	LT	1E+0	1E+2
Pd	1E+1	LT	1E+0	1E+2
Ag	5E+2	LT	1E+2	1E+3
Cd	2E+2	LT	2E+1	2E+3
Sn	1E+3	LT	1E+2	1E+4
I	3E+1	LT	1E+1	1E+2
Cs	2E+2	LT	1E+2	5E+2
Pm	1E+2	LT	1E+1	1E+3
Sm	3E+1	LT	3E+0	3E+2
Eu	1E+2	LT	1E+1	1E+3
Ho	3E+1	LT	3E+0	3E+2
Pb	1E+2	LT	5E+1	2E+2
Po	2E+3	LT	2E+2	2E+4
Rn	–	–	–	–
Ra	5E+1	LT	1E+1	1E+2
Ac	1E+2	LT	1E+1	2E+2
Th	3E+1	LT	1E+0	1E+2
Pa	1E+1	LT	1E+0	1E+2
U	5E+1	LT	1E+1	1E+2
Np	5E+1	LT	1E+1	3E+3
Pu	3E+1	LT	5E+0	5E+1
Am	1E+2	LT	1E+1	2E+2
Cm	5E+1	LT	1E+1	3E+2

Table A-14 Element specific bioaccumulation factors for freshwater crustaceans and for marine waters plants* ([Bq/kg w.w.]/[Bq/l]).

	Freshwater crustacean (l/kg w.w.)				Marine waterplants (l/kg w.w.)			
Element	**B.E**	**Distr**	**Low**	**High**	**B.E**	**Distr**	**Low**	**High**
H	1E+0	LT	5E-1	2E+0	1E+0	LT	5E-1	2E+0
Be	1E+1	LT	1E+0	1E+2	1E+3	LT	1E+2	1E+4
C	9E+3	LT	9E+2	1E+4	2E+3	LT	2E+2	1E+4
Cl	1E+2	LT	1E+1	1E+3	1E-1	LT	1E-2	1E+0
Fe	3E+3	LT	3E+2	3E+4	5E+4	LT	5E+2	1E+5
Co	2E+2	LT	2E+1	2E+3	1E+3	LT	1E+2	1E+4
Ni	1E+2	LT	1E+1	1E+3	3E+2	LT	3E+1	3E+3
Se	2E+2	LT	2E+1	2E+3	1E+3	LT	1E+2	1E+4
Sr	1E+2	LT	1E+1	1E+3	1E+1	LT	1E+0	1E+2
Zr	7E+0	LT	7E-1	7E+1	2E+3	LT	2E+2	1E+4
Nb	1E+2	LT	1E+1	1E+3	1E+3	LT	1E+2	1E+4
Mo	1E+1	LT	1E+0	1E+2	1E+1	LT	1E+0	1E+2
Tc	5E+0	LT	5E-1	5E+1	4E+3	LT	4E+2	1E+4
Ru	3E+2	LT	3E+1	3E+3	2E+3	LT	2E+2	2E+4
Pd	3E+2	LT	3E+1	3E+3	2E+3	LT	2E+2	1E+4
Ag	8E+2	LT	8E+1	8E+3	2E+2	LT	2E+1	2E+3
Cd	2E+3	LT	2E+2	2E+4	1E+3	LT	1E+2	1E+4
Sn	1E+3	LT	1E+2	1E+4	1E+2	LT	1E+1	1E+3
I	5E+0	LT	5E-1	5E+1	1E+3	LT	1E+2	1E+4
Cs	1E+2	LT	1E+1	1E+3	5E+1	LT	5E+0	5E+2
Pm	1E+3	LT	1E+2	1E+4	5E+3	LT	5E+2	5E+4
Sm	1E+3	LT	1E+2	1E+4	5E+3	LT	1E+2	1E+4
Eu	1E+3	LT	1E+2	1E+4	5E+3	LT	5E+2	5E+4
Ho	1E+3	LT	1E+2	1E+4	5E+3	LT	1E+2	1E+4
Pb	1E+2	LT	1E+1	1E+3	1E+3	LT	1E+2	1E+4
Po	2E+4	LT	2E+3	2E+5	2E+3	LT	2E+2	2E+4
Rn	–	–	–	–	–	–	–	–
Ra	3E+2	LT	3E+1	3E+3	1E+2	LT	1E+1	1E+3
Ac	1E+3	LT	1E+2	1E+4	5E+3	LT	1E+2	1E+4
Th	5E+2	LT	5E+1	5E+3	3E+3	LT	3E+2	3E+4
Pa	1E+2	LT	1E+1	1E+3	6E+0	LT	6E-1	6E+1
U	1E+2	LT	1E+1	1E+3	7E+1	LT	7E+0	7E+2
Np	4E+2	LT	4E+1	4E+3	6E+0	LT	6E-1	6E+1
Pu	1E+2	LT	1E+1	1E+3	3E+2	LT	3E+1	3E+3
Am	1E+3	LT	1E+2	1E+4	5E+3	LT	1E+2	1E+4
Cm	1E+3	LT	1E+2	1E+4	5E+3	LT	1E+2	1E+4

Table A-15 Nuclide specific parameters; half-live (Firestone et al, 1999), dose coefficients for adults (ingestion and inhalation from EU (1996) and external exposure from Svensson (1979)).

Nuclide	Type of dominating decay	Half-life Year	External exposure $(Sv/h)/(Bq/m^3)$	Ingestion Sv/Bq	Inhalation Sv/Bq
H-3	β	12	0	1.8E-11	2.6E-10
Be-10	β	1 150 000	0	1.1E-9	3.5E-8
C-14	β	5 730	0	5.8E-10	5.8E-9
Cl-36	β	301 000	0	9.3E-10	7.3E-9
Fe-55	EC	2.7	0	3.3E-10	7.7E-10
Co-60	β, γ	5.3	2.8E-13	3.4E-9	3.1E-8
Ni-59	β	76 000	0	6.3E-11	4.4E-10
Ni-63	β	100.1	0	1.5E-10	1.3E-9
Se-79	β	1 130 000	0	2.9E-9	6.8E-9
Sr-90	β	29	0	2.8E-8	1.6E-7
Zr-93	β	1 530 000	0	1.1E-9	2.5E-8
Nb-93m	γ	16	5.5E-17	1.2E-10	1.8E-9
Nb-94	β, γ	20 000	1.6E-13	1.7E-9	4.9E-8
Mo-93	EC	4 000	0	3.1E-9	2.3E-9
Tc-99	β	211 000	0	6.4E-10	1.3E-8
Ru-106	β	1	2.0E-14	7.0E-9	6.6E-8
Pd-107	β	6 500 000	0	3.7E-11	5.9E-10
Ag-108m	γ	418	1.6E-13	2.3E-9	3.7E-8
Cd-113m	β	14.1	0	2.3E-8	1.1E-7
Sn-126	β, γ	100 000	3.0E-15	4.7E-9	2.8E-8
I-129	β	15 700 000	3.4E-16	1.1E-7	3.6E-8
Cs-134	β	2	0	1.9E-8	2.0E-8
Cs-135	β	2 300 000	0	2.0E-9	8.6E-9
Cs-137	β, γ	30	5.6E-14	1.3E-8	3.9E-8
Pm-147	β	2.6	0	2.6E-10	5.0E-9
Sm-151	β	90	4.6E-18	9.8E-11	4.0E-9
Eu-152	β, EC	14	1.5E-13	1.4E-9	4.2E-8
Eu-154	β, EC	8.6	1.3E-13	2.0E-9	5.3E-8
Eu-155	β	4.8	3.9E-15	3.2E-10	6.9E-9
Ho-166m	γ	1 200	1.6E-13	2.0E-9	1.2E-7
Pb-210	β	22.3	7.2E-17	6.9E-7	5.6E-6
Po-210	α	0.4	0	1.2E-6	4.3E-6
Rn-222	α	0.01	0	0	1.6E-8
Ra-226	α	1 600	6.0E-16	2.8E-7	9.5E-6
Ac-227	α	21.8	0	1.1E-6	5.5E-4
Th-229	α	7 340	2.0E-15	4.9E-7	2.4E-4
Th-230	α	75 380	3.5E-17	2.1E-7	1.0E-4
Th-232	α	14 050 000 000	1.5E-17	2.3E-7	1.1E-4
Pa-231	α	32 760	1.8E-15	7.1E-7	1.4E-4
U-232	α	69	1.6E-17	3.3E-7	3.7E-5
U-233	α	159 200	5.9E-17	5.1E-8	9.6E-6
U-234	α	245 500	3.1E-17	4.9E-8	9.4E-6
U-235	α	703 800 000	1.1E-14	4.7E-8	8.5E-6
U-236	α	23 415 000	0	4.7E-8	8.7E-6
U-238	α	4 468 000 000	0	4.5E-8	8.0E-6
Np-237	α	2 144 000	1.8E-15	1.1E-7	5.0E-5

Table A-15 (cont'd)

Nuclide	Type of dominating decay	Half-life Year	External exposure (Sv/h)/(Bq/m^3)	Ingestion Sv/Bq	Inhalation Sv/Bq
Pu-238	α	88	1.3E-17	2.3E-7	1.1E-4
Pu-239	α	24 110	6.6E-18	2.5E-7	1.2E-4
Pu-240	α	6 563	0	2.5E-7	1.2E-4
Pu-241	α, β	14.4	0	4.8E-9	2.3E-6
Pu-242	α	372 300	0	2.4E-7	1.1E-4
Pu-244	α	80 800 000	1.8E-15	2.4E-7	1.1E-4
Am-241	α	432	1.1E-15	2.0E-7	9.6E-5
Am-242m	α	141	1.5E-17	1.9E-7	9.2E-5
Am-243	α	7 370	2.9E-15	2.0E-7	9.6E-5
Cm-243	α, EC	29.1	1.0E-14	1.5E-7	6.9E-5
Cm-244	α	18	0	1.2E-7	5.7E-5
Cm-245	α	8 500	3.2E-15	2.1E-7	9.9E-5
Cm-246	α	4 730	0	2.1E-7	9.8E-5