SKB TECHNICAL REPORT 90-35

Dose conversion factors for major nuclides within high level waste

Ulla Bergström, Sture Nordlinder

Studsvik Nuclear

November 1990

SVENSK KÄRNBRÄNSLEHANTERING AB

SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

BOX 5864 S-102 48 STOCKHOLM

TEL 08-665 28 00 TELEX 13108 SKB S
TELEFAX 08-661 57 19

DOSE CONVERSION FACTORS FOR MAJOR NUCLIDES WITHIN HIGH LEVEL WASTE

Ulla Bergström, Sture Nordlinder

Studsvik Nuclear

November 1990

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

Information on SKB technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17), 1982 (TR 82-28), 1983 (TR 83-77), 1984 (TR 85-01), 1985 (TR 85-20), 1986 (TR 86-31), 1987 (TR 87-33), 1988 (TR 88-32) and 1989 (TR 89-40) is available through SKB.

DOSE CONVERSION FACTORS FOR MAJOR NUCLIDES WITHIN HIGH LEVEL WASTE

Ulla Bergström, Sture Nordlinder

STUDSVIK NUCLEAR

November 1990

STUDSVIK NUCLEAR

STUDSVIK/NS-90/138

1990-11-28

Ulla Bergström
Sture Nordlinder

DOSE CONVERSION FACTORS FOR MAJOR NUCLIDES WITHIN HIGH LEVEL WASTE

Approved by

ABSTRACT

Individual doses to critical groups from a continuous unit release of nuclides to a standard biosphere were calculated. The selection of nuclides for this study was based on experience of their importance from a radiological point of view. The standard biosphere consisted of a well and a lake with adjacent farming-land. It was assumed that 1 % of the activity reached the well directly, while the remaining fraction was directly diluted into the lake water. Ten exposure pathways for activity from the well and the lake water to man were considered. The ecosystem was assumed to be similar to present conditions in Sweden. This was also the case concerning diet and living habits. In addition the doses from naturally occurring nuclides in the uranium decay chains were calculated, based on natural levels in water and soil. The calculations were carried out with the BIOPATH and PRISM codes. The latter code was used to obtain the uncertainty in the results due to the uncertainty in the input parameter values.

TABLE OF CONTENTS

1 INTRODUCTION

The individual doses from unit releases of long-lived radioactive nuclides contained within a deep geological repository were calculated and are reported in /Bergström et al, 1990/. The doses were calculated for a so called standard biosphere which constituted of a well and lake with adjacent farming-land. Current habits and metabolic conditions of human beings were assumed. Adults and five year old children were considered, respectively. The calculations were carried out with the emphasis to study the importance of uncertainties in the input parameter values. Discussion of the results from these uncertainty analyses are going to be published /Bergström et al, 1991/. One major contribution to the uncertainty in the results was the dilution volume for the nuclides in the groundwater. This dilution was studied by varying reservoir volumes as well as varying the fraction of activity reaching the water in the well. For some radionuclides additional calculations were carried out for a fixed fraction of the nuclides reaching the well /Bergström et al, 1991/.

In this summary report conversion factors between unit releases and doses to adults are presented for most nuclides appearing in considerable amounts in high level waste. In addition some nuclides are handled which also belong to the natural decay chain of uranium. For these nuclides doses are also calculated based upon natural occurring concentrations of them in water and soil.

In the release case the calculations are carried out with a basic assumption that a fraction of 1 % of each nuclide reaches the well directly. All other assumptions are likewise those reported in /Bergström et al, 1990/. A brief description of the model used, the exposure pathways considered and the used values of the input parameters are given in the report, for a more detailed description, see /Bergström et al, 1990/.

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

2 NUCLIDES

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

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

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

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

References

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

3 METHODOLOGY

The calculations were performed assuming a continuous leakage of 1 Bq per year of each nuclide in soluble form to the biosphere during a period of 500 years. Of the leakage 1 % was assumed to enter the well water directly while the remaining fraction leaked directly to the lake water. No delay or reduction of activity by accumulation in the interphase geosphere and biosphere was considered. With the objective to simulate the exposure, a seven compartment model of the studied biosphere was designed, see Figure 1 where also masses are given and flows of activity are described by arrows. The BIOPATH-code was used for solving the differential equations and calculating the doses. For the nuclides belonging to the natural occurring uranium decay chain doses were calculated for the same exposure pathways based upon the concentrations given in Table 3-1. These are based upon a brief literature survey, see Tables A.1 and A.2, and represent average background values.

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

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

Table 3-1 Nuclides assessed in the natural uranium decay chains. Mean concentration and ranges as logtrianguarly distributed extracted from /UNSCEAR 1988; Bowen, 1979; Yengar, 1990; Sundblad et al, 1985; Landström et al, 1986; Hallstadius et al, 1984; Eriksson et al, 1981 Kulich et al, 1988/.

Nuclide	Soil (Bq/kg)		Water (mBq/l)	
	Mean	Range	Mean	Range
U-238	50	10 - 100	10	1 - 100
U-234	50	10 - 100	10	1 - 100
Th-230	50	10 - 10	10	1 - 100
Ra-226	80	10 - 200	10	1 - 100
Po-210	100	10 - 1000	10	1 - 100
Pb-210	100	10 - 1000	10	1 - 100
U-235	2	0.1 - 10	0.5	0.05 - 5
Pa-231	2	0.1 - 10	0.5	0.05 - 5
Ac-227	2	0.1 - 10	0.5	0.05 - 5
Ra-223	2	0.1 - 10	0.5	0.05 - 5

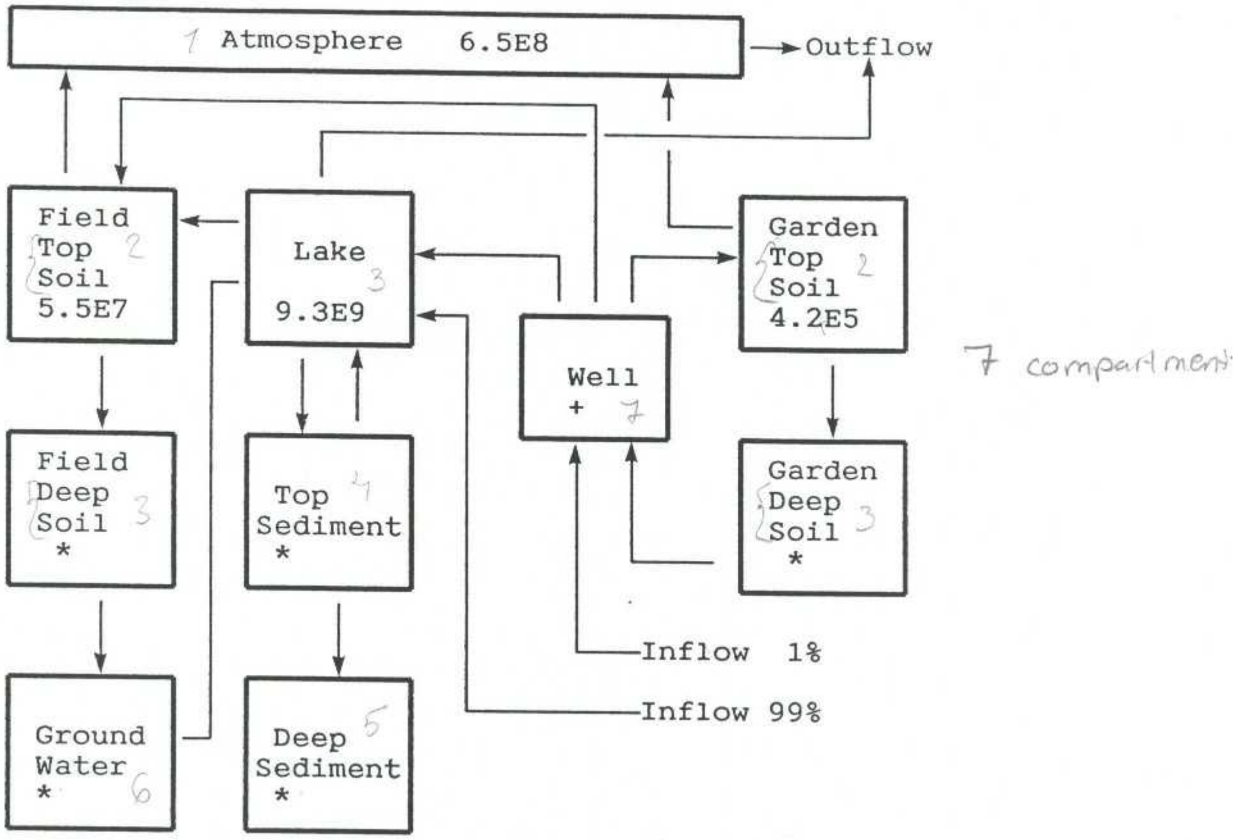

Figure 3-1 The structure of the compartment model with masses (kg).

* Not of importance for the results.

\+ The volume is varied within the calculations.

For the naturally occurring radionuclides the garden plot and field had the same background levels. This was also assumed concerning the levels in ground and lake water.

The pathways for ingestion of nuclides are via different types of food and drinking water. The intake of soil is also included. This latter pathway is valid via e.g. consuming unwashed vegetables. This intake is adopted to 10 g/y mainly from the garden plot.

Earlier calculations of the doses from these long-lived nuclides showed that the internal exposure dominates the exposure for the nuclides considered.

The only external exposure considered is from ground. This represents staying on the fields and the garden plots. The dose factors used are taken from /Svensson, 1979/ with assumption of homogenous distribution of the activity in soil.

The following pathways were considered:

- Water
- Milk
- Meat
- Vegetables
- Root vegetables (potatoes)
- Cereals
- Fish
- Soil
- External exposure from ground

The pathways considered and the compartments they emanate from are shown in Figure 3-2.

All biological uptake parameters such as root-uptake factors, bioaccumulation factors to fish and steady state factors giving the concentration in milk and meat from continuous intake are shown in Appendix A, Tables A.4 to A.6. The values used are based upon a literature survey carried out and reported in /Bergström et al, 1990/. The Tables A.4 to A.6 also show references for those nuclides not studied in that report.

Consumption data used are given in Appendix A. Table A.7.

In Tables A.4 to A.6 references are also given for the values used for those nuclides not handled in the earlier report.

In addition, som more nuclides are treated which whose references are given the tables.

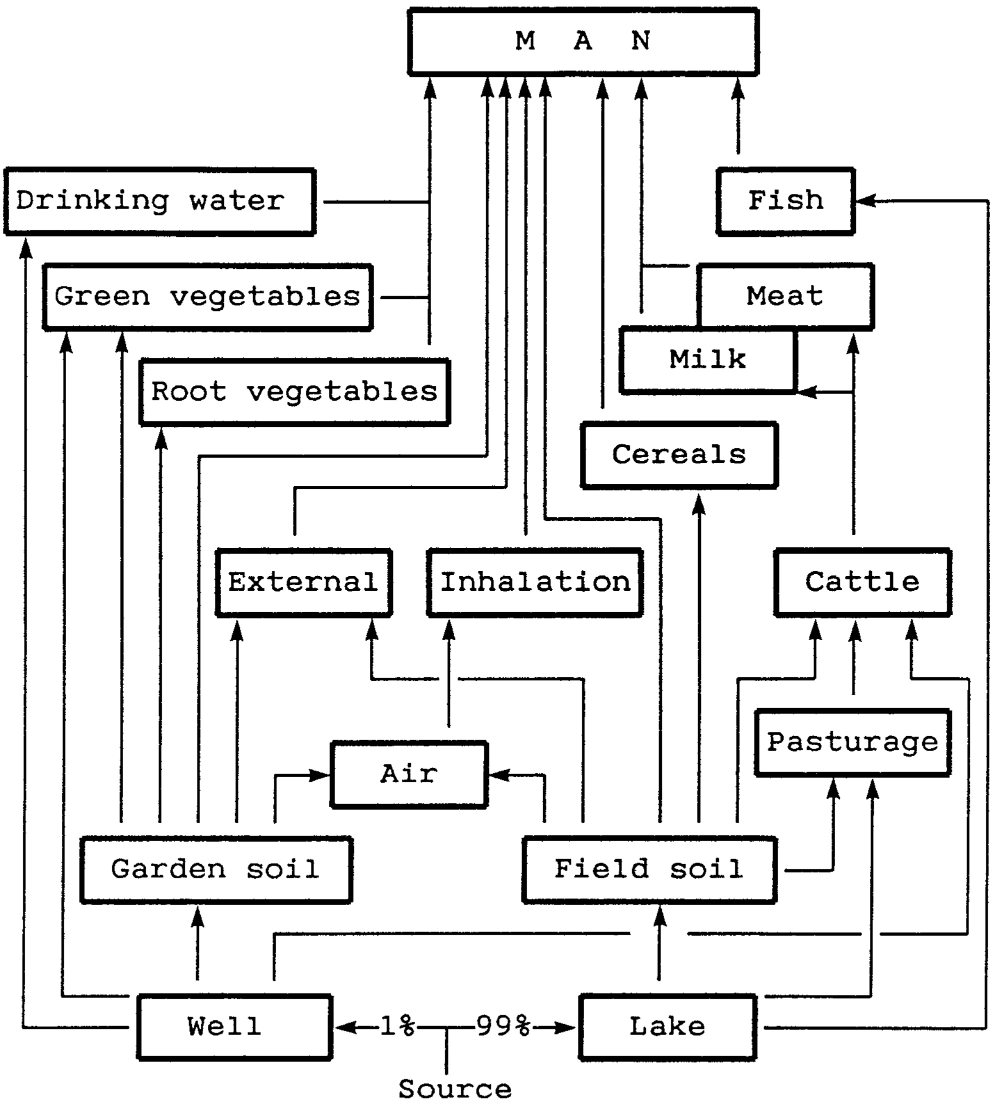

Figure 3-2 Exposure pathways for the critical group.

4 RESULTS

Results, as arithmetic mean values of the total dose are presented in Table 4-1. All these results do not consider any contributions from daughter nuclides. Such contributions were studied for Zr-93, Th-229 and Th-230, because of experience from earlier calculations /Bergström, 1989/. The daughter products studied are Nb-93m, Ra-225 and Ra-226 respectively. These contributions were only notable for Zr-93 and Th-229. Including them the conversion factors would increase with 7 and 36 percent, respectively.

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

Dominant pathway is drinking water for most nuclides, see Table 4-2. The fraction of activity reaching the well is constant in these calculations. That implies that the estimated ranges of uncertainty are quite small, see Table 4-1.

In Table 4-3 the annual doses from the naturally occurring nuclides are given as well as the doses given in UNSCEAR 88 for respective nuclide. The percentual contribution to the dose via different pathways are shown in Table 4-4. There are differences between the "release" case and the natural case concerning the dominant exposure pathways. This is due to the steady-state conditions the natural case reflects. The relation between the concentration of the nuclides in well water compared to soil and lake water is different in the two cases. The concentration in the well water is relatively higher in the "release" case which results in drinking of this as dominant exposure pathway.

Table 4-1 Individual doses from unit releases to adults arithmetic mean and ranges corresponding to 2.5 and 97.5 percentiles (Sv/Bq).

Nuclide	Arithm mean	Ranges
C-14	1.3E-14	(0.6 - 2.3)E-14
Se-79	6.3E-14	(1.6 - 37)E-14
Sr-90	2.2E-13	(1.4 - 4.1)E-13
Zr-93	2.5E-15	(1.6 - 4.3)E-15
Tc-99	1.7E-15	(1.2 - 2.5)E-15
Sn-126	3.7E-14	(2.2 - 7.6)E-14
I-129	5.4E-13	(3.1 - 13)E-13
Cs-135	3.9E-14	(1.2 - 17)E-14
Cs-137	2.4E-13	(0.7 - 9.9)E-13
Pb-210	6.7E-12	(4.6 - 9.9)E-12
Po-210	8.1E-13	(6.1 - 11)E-13
Ra-223	3.5E-14	(2.3 - 6.6)E-14
Ra-225	9.2E-14	(6.1 - 17)E-14
Ra-226	1.8E-12	(1.1 - 3.4)E-12
Ac-227	1.7E-11	(1.1 - 2.4)E-11
Th-229	4.4E-12	(3.1 - 6.6)E-12
Th-230	7.5E-13	(4.9 - 12)E-13
Pa-231	1.0E-10	(0.6 - 1.5)E-10
U-233	1.6E-12	(1.1 - 2.5)E-12
U-234	1.6E-12	(1.0 - 2.4)E-12
U-235	1.5E-12	(1.0 - 2.3)E-12
U-236	1.5E-12	(1.1 - 2.3)E-12
U-238	1.4E-12	(1.0 - 2.2)E-12
Np-237	2.2E-12	(1.4 - 3.3)E-12
Pu-239	4.3E-12	(3.1 - 6.1)E-12
Pu-240	4.3E-12	(2.9 - 6.2)E-12
Pu-241	7.9E-14	(5.7 - 11)E-14
Pu-242	3.9E-12	(2.6 - 5.6)E-12
Am-241	4.2E-12	(2.8 - 6.8)E-12

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

Nuclide	Drinking water	Milk	Meat	Vege-tables	Potatoes	Fish
C-14	18 (1)	8 (6)	3 (-)	3 (4)	- (-)	68 (91)
Se-79	15 (-)	1 (-)	- (-)	19 (18)	49 (80)	15 (1)
Sr-90	60 (11)	2 (-)	- (-)	29 (72)	7 (15)	1 (-)
Zr-93	63 (14)	- (-)	22 (75)	13 (10)	- (-)	1 (-)
Tc-99	81 (57)	- (-)	1 (-)	15 (41)	1 (1)	1 (1)
Sn-126	50 (8)	5 (1)	1 (-)	16 (35)	11 (39)	17 (16)
I-129	46 (4)	21 (20)	1 (-)	17 (58)	4 (12)	9 (3)
Cs-135	19 (-)	5 (-)	5 (-)	6 (-)	5 (-)	60 (99)
Cs-137	20 (-)	5 (-)	6 (-)	4 (-)	1 (-)	64(100)
Pb-210	77 (47)	1 (-)	- (-)	14 (43)	- (-)	9 (10)
Po-210	81 (58)	- (-)	1 (2)	16 (40)	- (-)	2 (-)
Ra-223	69 (8)	15 (83)	- (-)	12 (8)	- (-)	4 (1)
Ra-225	69 (8)	15 (82)	- (-)	12 (8)	- (-)	3 (1)
Ra-226	67 (4)	16 (84)	- (-)	14 (6)	3 (5)	1 (-)
Ac-227	82 (59)	- (-)	- (-)	15 (36)	- (-)	3 (5)
Th-229	80 (49)	- (-)	- (-)	16 (46)	3 (5)	- (-)
Th-230	80 (45)	- (-)	- (-)	16 (48)	3 (7)	- (-)
Pa-231	82 (51)	- (-)	1 (-)	15 (46)	1 (3)	- (-)
U-233	76 (51)	1 (-)	8 (16)	14 (33)	- (-)	1 (1)
U-234	76 (48)	1 (-)	8 (20)	14 (31)	- (-)	1 (-)
U-235	76 (48)	1 (-)	8 (20)	14 (31)	- (-)	1 (-)
U-236	76 (49)	1 (-)	8 (21)	14 (30)	- (-)	1 (-)
U-238	76 (51)	1 (-)	8 (16)	14 (32)	- (-)	1 (1)
Np-237	81 (54)	- (-)	1 (-)	15 (41)	2 (4)	1 (1)
Pu-239	85 (62)	- (-)	- (-)	15 (38)	- (-)	- (-)
Pu-240	84 (56)	- (-)	- (-)	15 (43)	- (-)	- (-)
Pu-241	85 (62)	- (-)	- (-)	15 (38)	- (-)	- (-)
Pu-242	84 (56)	- (-)	- (-)	15 (43)	- (-)	- (-)
Am-241	79 (39)	- (-)	- (-)	17 (55)	- (1)	3 (5)

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

Nuclide	Arithmetric	Ranges	UNSCEAR 88
U-238	7.3E-5	(0.5 - 31)E-5	5E-6
U-234	8.4E-5	(1 - 39)E-5	
Th-230	8.4E-6	(1 - 35)E-6	7E-6
Ra-226	1.3E-4	(0.1 - 7.2)E-4	7E-6
Po-210	2.8E-5	(0.4 - 9.6)E-5	1.2E-4
Pb-210	5.3E-4	(0.5 - 23)E-4	
U-235	3.3E-6	(0.3 - 17)E-6	
Pa-231	4.3E-5	(0.5 - 15)E-5	
Ac-227	2.6E-5	(0.2 - 13)E-5	
Ra-223	1.7E-6	(0.2 - 7)E-6	

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

Nuclide	Water	Milk	Meat	Vege-tables	Potatoe	Cereals	Fish
U-238	3 (-)	1 (-)	7 (5)	2 (1)	2 (2)	72 (88)	13 (3)
U-234	3 (-)	- (-)	7 (3)	2 (1)	2 (1)	72 (93)	13 (1)
Th-230	17 (15)	- (-)	1 (1)	11 (8)	11 (5)	3 (2)	5 (72)
Ra-226	2 (-)	40 (74)	1 (-)	12 (6)	17 (9)	19 (9)	9 (1)
Po-210	17 (16)	2 (1)	12 (7)	7 (7)	6 (5)	7 (6)	44 (56)
Pb-210	2 (-)	1 (1)	- (-)	4 (4)	11 (9)	58 (77)	22 (7)
U-235	4 (1)	1 (-)	7 (6)	2 (1)	2 (1)	69 (85)	15 (4)
Pa-231	23 (15)	- (-)	2 (1)	6 (6)	7 (7)	32 (30)	27 (41)
Ac-227	7 (2)	- (-)	- (-)	10 (1)	1 (-)	- (-)	81 (97)
Ra-23	4 (1)	26 (33)	1 (1)	13 (14)	19 (26)	19 (21)	17 (5)

REFERENCES

BERGSTRÖM, U, EDLUND, O, EVANS, S and RÖJDER, B
BIOPATH - A computer code for calculation of the turnover of nuclides in the biosphere and the resulting dose to man.
Studsvik Report (STUDSVIK/NW-82/261).

BERGSTRÖM, U and NORDLINDER, S
Individual radiation doses from unit releases of long lived radionuclides
SKB TR 90-09.

BERGSTRÖM, U and NORDLINDER, S
Individual doses from releases of Co-60, Sr-90, Cs-137 and Pu-239 to the lake Trobbofjärden.
Studsvik Report (STUDSVIK/NS-90/40) 1990.

BERGSTRÖM, U and NORDLINDER, S
SKB-WP-Cave Project.
Individual doses from unit releases of activations and fission products in spent fuel, well and lake scenarios.
SKB Tecn Note 88-16.

BERGSTRÖM, U and NORDLINDER, S
Uncertainties related to dose assessments for high level waste disposal.
Draft, To be published 1991.

BOWEN, H J M
Environmental Chemistry of the Elements.
Academic press, London, 1979. ISBN 0-12-120450-2.

ERIKSSON, Å and FREDRIKSSON, L
Naturlig radioaktivitet i mark och grödor. "Natural radioactivity in soil and craps" (in Swedish).
Sveriges Lantbruksuniversitet SLU-IRB-52, Uppsala 1981.
ISBN 91-576-1067-3.

GARDNER, R H, RÖJDER, B and BERGSTRÖM, U
PRISM: A systematic method for determining the effect of parameter uncertainties on model predictions.
Studsvik Report (STUDSVIK/NW-83/555).

HALLSTADIUS, L, HEDVALL, R, HOLM, E and PETTERSSON, H
Naturlig radioaktivitet kring två svenska uranmineraliseringar. En omgivningsradiologisk studie vid Lilljuthatten och Pleutajokk Institutionen för radiofysik, Lunds universitet, Februari 1984.

ICRP30
International Commission on Radiological Protection.
Limits for intake of radionuclides by workers.
ICRP Publication no 30, Part 1-3.

ICRP48
International Commission on Radiological Protection: The metabolism of Plutonium and related elements.
ICRP Publication no 48 1986.

ICRP56
Age-dependent doses to members of the public from intake of radionuclides, Part 1.
International Commission on Radiological Protection.
Annals of the ICRP.

International Atomic Energy Agency.
Generic Models and Parameters for assessing the environmental transfer of radionuclides from routine releases.
Exposure of critical groups.
Safety Series No. 57, 1982.

JOHANSSON, L
Oral intake of radionuclides in the population. A review of biological factors of relevance for assessment of absorbed dose at long term waste storage.
National Defence Research Institute.
KBS TR 82-14, Oct 1982.

JOHANSSON, L
Oralt intag av vissa radionuklider.
"Oral intake of certain radionuclides".
SKB Technical Note AR 84-38, 1984.

KULICH, J, MÖRE, H and SWEDJEMARK, G A
Radon och radium i hushållsvatten. "Radon and radium in drinking water".
SSI Rapport 88-11.

LANDSTRÖM, O and SUNDBLAD, B
Migration of thorium, uranium, radium and Cs-137 in till soils and their uptake in organic matter and peat.
SKB Technical Report 86-24, Stockholm, 1986.

SUNDBLAD, B, LANDSTRÖM, O and AXELSSON, R
Concentration and distribution of natural radionuclides at Klipperåsen and Bjulebo, Sweden.
SKB Technical Report 85-09, Stockholm, 1985.

SVENSSON, L
Dose conversion factor for external photon radiation.
FOA Rapport (C 400060-A3) 1979.

UNSCEAR 1988
Source, Effects and Risks of Ionizing Radiation.
United Nations Scientific Committee on the Effects of Atomic Radiation 1988.
Report to the General Assembly, with annexes.
United Nations, New York, 1988. ISBN 92-1-142143-8.

YENGAR, M A R
The natural distribution of radium.
The environmental behaviour of radium, volume 1, Technical Reports Series No. 310, IAEA 1991, Vienna.
ISBN 92-0125090.8

Appendix A.1

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

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

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

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

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

** Ground-water from private wells.

Table A-3

Some general input parameter values.

Parameter	B.E.	Type of distr*	Min	Max
Annual demand of water for man (m^3)	50	T	30	70
Annual demand of water for the live-stock (m^3)	230	T	200	260
Irrigation of the garden plot (l/m^2 year)	150	T	30	300
Irrigation of agri-cultural land (l/m^2 year)	150	T	30	300
Daily consumption of foodstuff for cattle (kg d w)	14	T	12	16
Daily consumption of soil when grazing (kg)	0.3	T	0.1	0.5
Residence time of water in the lake (year)	0.75	T	0.6	0.9
Turnover time of groundwater (year)	5	T	1	10
Area of garden plot (m^2)	1000	C		
Area of agri-cultural land (m^2)	130000	C		

* T = Triangular distribution.
C = Constant.

Appendix A.3

Table A-4

Root uptake factors for several types of nutrients (Bq/kg f w nutrient per Bq/kg d w soil).

Element	Distribution*	Pasturage (dw/dw)	Ranges or geom st dev	Cereals	Ranges or geom st dev	Vegetables	Ranges or geom st dev	Root vegetables	Ranges or geom st dev	
Se	LT	6.5	5E-1 - 7E1	1.5	1E-1 - 8E1	6.5	5E-1 - 6E1	1.3E1	1 - 1E2	
Sr	LT	3.2	1 - 7	1.4	0.5 - 3	5E-1	0.2 - 1.0	1.5-1	8E-2 - 0.3	(Bergström, 1990)
Zr**	LT	8E-4	1E-4 - 1E-2	2E-4	1E-5 - 1E-3	2E-4	1E-5 - 1E-3	2E-4	1E-5 - 1E-3	(Bergström, 1988)
Tc	LT	1.0	1E-1 - 1E1	9E-1	1E-1 - 1E1	2E-1	1E-2 - 1.0	1E-1	1E-2 - 1.0	
Sn	LT	1E-1	1E-2 - 1.0	4E-1	1E-2 - 1.0	6E-2	1E-2 - 1.0	5E-2	1E-2 - 1.0	
I	LN	6E-1	4.0	1E-1	4.0	3E-2	4.0	1E-2	4.0	
Cs	LN	5E-2	2.4	1E-2	1.8	2E-2	1.9	2E-2	1.9	
Pb	LT	2E-2	1E-3 - 1E-1	2E-2	1E-3 - 1E-1	2E-3	1E-4 - 1E-2	4E-3	1E-3 - 1E-2	
Po**	LT	4E-3	4E-4 - 4E-2	2E-4	2E-5 - 2E-3	2E-4	2E-5 - 2E-3	2E-4	2E-5 - 2E-3	(IAEA, 1982)
Ra	LN	5E-2	2.5	1E-2	2.5	1E-2	2.5	1E-2	2.5	
Ac	LT	5E-4	3E-5 - 7E-3	4E-4	1E-5 - 1E-3	4E-3	2E-4 - 8E-2	5E-5	2E-5 - 1E-2	
Th	LT	1E-2	1E-3 - 1E-1	7E-4	1E-4 - 1E-3	2E-3	1E-4 - 1E-2	2E-3	1E-4 - 1E-2	
Pa	LT	3E-3	3E-4 - 3E-2	3E-3	3E-4 - 3E-2	3E-4	3E-5 - 3E-3	6E-4	6E-5 - 6E-3	
U	LT	1E-2	1E-3 - 1E-1	4E-2	4E-3 - 4E-1	1E-3	1E-4 - 1E-2	1E-3	1E-4 - 1E-2	
Np	LT	1E-1	1E-2 - 1	1E-2	1E-3 - 1E-1	3E-3	5E-4 - 2E-1	3E-3	5E-4 - 2E-1	
Pu	LT	1E-3	7E-5 - 1E-2	1E-4	1E-6 - 1E-2	2E-5	1E-7 - 4E-4	5E-5	2E-7 - 1E-3	
Am***	LT	5E-4	3E-5 - 7E-3	4E-4	1E-5 - 1E-3	4E-3	2E-4 - 8E-2	5E-5	2E-5 - 1E-2	

* LT = Logtriangular distribution.
LN = Lognormal distribution.

** Assumed ranges.

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

Table A-5

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

Element	Best estimate	Type of distr*	Geom st dev	Ranges	References
C	4600	T		3000-6000	
Se	2000	T		500 - 5000	
Sr	5	T		1 - 20	(Bergström, 1990)
Zr**	60	T		10 - 100	(Bergström, 1988)
Tc	15	T		1 - 50	
Sn	3000	T		1000 - 6000	
I	200	T		10 - 500	
Cs	5000	LN	3.8		
Pb	100	T		50 - 200	
Po**	50	T		10 - 100	(IAEA, 1982)
Ra	50	T		10 - 100	
Ac	100	T		10 - 1000	
Th	30	T		1 - 100	
Pa	10	T		1 - 100	
U	50	T		10 - 100	
Np	50	T		1 - 100	
Pu	5	T		1 - 50	
Am***	100	T		10 - 1000	

* T = Triangular distribution.
LN = Lognormal distribution.

** Estimated ranges.

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

Table A-6

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

Element	Milk (day/l)	Ranges or geom st dev	Meat (day/kg)	Ranges or geom st dev	References
C	1E-2	1E-3 - 1E-1	3E-2	1E-3 - 1E-1	
Se	3E-3	1E-3 - 1E-2	9E-4	1E-4 - 1E-2	
Sr	8E-4	4E-4 - 3E-3	6E-4	7E-5 - 1E-3	(Bergström, 1990)
Zr**	5E-6	5E-7 - 5E-5	3E-2	3E-3 - 3E-1	(Bergström, 1988)
Tc	1E-4	1E-5 - 1E-3	2E-3	1E-4 - 1E-2	
Sn	3E-3	1E-3 - 1E-2	1E-3	1E-4 - 1E-2	
I*	1E-2	1.6	2E-3	2.1	
Cs*	8E-3	1.6	3E-2	2.1	
Pb	3E-4	2E-5 - 2E-3	4E-4	4E-5 - 4E-3	
Po**	1E-4	1E-5 - 1E-3	3E-3	1E-4 - 1E-2	(IAEA, 1982)
Ra*	3E-3	3.9	7E-4	1.2	
Ac	3E-7	3E-8 - 3E-6	1E-5	1E-6 - 1E-4	
Th	5E-6	1E-7 - 1E-4	7E-4	1E-4 - 1E-3	
Pa	5E-5	1E-6 - 1E-4	3E-3	2E-6 - 5E-3	
U	2E-4	2E-5 - 2E-3	1E-2	1E-3 - 1E-1	
Np	5E-6	1E-6 - 1E-4	3E-3	2E-4 - 5E-3	
Pu	1E-7	2E-8 - 3E-7	2E-6	1E-7 - 2E-5	
Am***	3E-7	3E-8 - 3E-6	1E-5	1E-6 - 1E-4	

* Lognormal distribution.

** Estimated ranges.

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

Table A-7

Consumption and habit data, triangular distribution.

	Best estimate	Min	Max
Individuals			
Inhalation (m^3/y)	8000	7000	9000
Drinking water (l/y)	600	450	750
Milk (l/y)	200	20	400
Meat (kg/y)	55	5	100
Green vegetables (kg/y)	40	5	100
Cereals (kg/y)	80	5	150
Root-fruits (kg/y)	70	5	150
Fish (kg/y)	30	5	100
Soil (kg/y)	0.01	0.001	0.1
Exposure time, garden plot (h/y)	200	100	400
Exposure time, fields (h/y)	200	100	400
Being outdoors (h/y)	1000	500	1500
Filtration factor, building	0.3	0.1	0.5

List of SKB reports

Annual Reports

1977-78
TR 121
KBS Technical Reports 1 – 120
Summaries
Stockholm, May 1979

1979
TR 79-28
The KBS Annual Report 1979
KBS Technical Reports 79-01 – 79-27
Summaries
Stockholm, March 1980

1980
TR 80-26
The KBS Annual Report 1980
KBS Technical Reports 80-01 – 80-25
Summaries
Stockholm, March 1981

1981
TR 81-17
The KBS Annual Report 1981
KBS Technical Reports 81-01 – 81-16
Summaries
Stockholm, April 1982

1982
TR 82-28
The KBS Annual Report 1982
KBS Technical Reports 82-01 – 82-27
Summaries
Stockholm, July 1983

1983
TR 83-77
The KBS Annual Report 1983
KBS Technical Reports 83-01 – 83-76
Summaries
Stockholm, June 1984

1984
TR 85-01
Annual Research and Development Report 1984
Including Summaries of Technical Reports Issued during 1984. (Technical Reports 84-01 – 84-19)
Stockholm, June 1985

1985
TR 85-20
Annual Research and Development Report 1985
Including Summaries of Technical Reports Issued during 1985. (Technical Reports 85-01 – 85-19)
Stockholm, May 1986

1986
TR 86-31
SKB Annual Report 1986
Including Summaries of Technical Reports Issued during 1986
Stockholm, May 1987

1987
TR 87-33
SKB Annual Report 1987
Including Summaries of Technical Reports Issued during 1987
Stockholm, May 1988

1988
TR 88-32
SKB Annual Report 1988
Including Summaries of Technical Reports Issued during 1988
Stockholm, May 1989

1989
TR 89-40
SKB Annual Report 1989
Including Summaries of Technical Reports Issued during 1989
Stockholm, May 1990

Technical Reports
List of SKB Technical Reports 1990

TR 90-01
FARF31 –
A far field radionuclide migration code for use with the PROPER package
Sven Norman[1], Nils Kjellbert[2]
[1]Starprog AB
[2]SKB AB
January 1990

TR 90-02
Source terms, isolation and radiological consequences of carbon-14 waste in the Swedish SFR repository
Rolf Hesböl, Ignasi Puigdomenech, Sverker Evans
Studsvik Nuclear
January 1990

TR 90-03
Uncertainties in repository performance from spatial variability of hydraulic conductivities –
Statistical estimation and stochastic simulation using PROPER
Lars Lovius[1], Sven Norman[1], Nils Kjellbert[2]
[1]Starprog AB
[2]SKB AB
February 1990

TR 90-04
Examination of the surface deposit on an irradiated PWR fuel specimen subjected to corrosion in deionized water
R. S. Forsyth, U-B. Eklund, O. Mattsson, D. Schrire
Studsvik Nuclear
March 1990

TR 90-05
Potential effects of bacteria on radionuclide transport from a Swedish high level nuclear waste repository
Karsten Pedersen
University of Gothenburg, Department of General and Marine Microbiology, Gothenburg
January 1990

TR 90-06
Transport of actinides and Tc through a bentonite backfill containing small quantities of iron, copper or minerals in inert atmosphere
Yngve Albinsson, Birgit Sätmark,
Ingemar Engkvist, W. Johansson
Department of Nuclear Chemistry,
Chalmers University of Technology, Gothenburg
April 1990

TR 90-07
Examination of reaction products on the surface of UO_2 fuel exposed to reactor coolant water during power operation
R. S. Forsyth, T. J. Jonsson, O. Mattsson
Studsvik Nuclear
March 1990

TR 90-08
Radiolytically induced oxidative dissolution of spent nuclear fuel
Lars Werme[1], Patrik Sellin[1], Roy Forsyth[2]
[1]Swedish Nuclear Fuel and waste Management Co (SKB)
[2]Studsvik Nuclear
May 1990

TR 90-09
Individual radiation doses from unit releases of long lived radionuclides
Ulla Bergström, Sture Nordlinder
Studsvik Nuclear
April 1990

TR 90-10
Outline of regional geology, mineralogy and geochemistry, Poços de Caldas, Minas Gerais, Brazil
H. D. Schorscher[1], M. E. Shea[2]
[1]University of Sao Paulo
[2]Battelle, Chicago
December 1990

TR 90-11
Mineralogy, petrology and geochemistry of the Poços de Caldas analogue study sites, Minas Gerais, Brazil
I: Osamu Utsumi uranium mine
N. Waber[1], H. D. Schorscher[2], A. B. MacKenzie[3], T. Peters[1]
[1]University of Bern
[2]University of Sao Paulo
[3]Scottish Universities Research & Reactor Centre (SURRC), Glasgow
December 1990

TR 90-12
Mineralogy, petrology and geochemistry of the Poços de Caldas analogue study sites, Minas Gerais, Brazil
II: Morro do Ferro
N. Waber
University of Bern
December 1990

TR 90-13
Isotopic geochemical characterisation of selected nepheline syenites and phonolites from the Poços de Caldas alkaline complex, Minas Gerais, Brazil
M. E. Shea
Battelle, Chicago
December 1990

TR 90-14
Geomorphological and hydrogeological features of the Poços de Caldas caldera, and the Osamu Utsumi mine and Morro do Ferro analogue study sites, Brazil
D. C. Holmes[1], A. E. Pitty[2], R. Noy[1]
[1]British Geological Survey, Keyworth
[2]INTERRA/ECL, Leicestershire, UK
December 1990

TR 90-15
Chemical and isotopic composition of groundwaters and their seasonal variability at the Osamu Utsumi and Morro do Ferro analogue study sites, Poços de Caldas, Brazil
D. K. Nordstrom[1], J. A. T. Smellie[2], M. Wolf[3]
[1]US Geological Survey, Menlo Park
[2]Conterra AB, Uppsala
[3]Gesellschaft für Strahlen- und Umweltforschung (GSF), Munich
December 1990

TR 90-16
Natural radionuclide and stable element studies of rock samples from the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil
A. B. MacKenzie[1], P. Linsalata[2], N. Miekeley[3], J. K. Osmond[4], D. B. Curtis[5]
[1]Scottish Universities Research & Reactor Centre (SURRC), Glasgow
[2]New York Medical Centre
[3]Catholic University of Rio de Janeiro (PUC)
[4]Florida State University
[5]Los Alamos National Laboratory
December 1990

TR 90-17
Natural series nuclide and rare earth element geochemistry of waters from the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil
N. Miekeley[1], O. Coutinho de Jesus[1], C-L Porto da Silveira[1], P. Linsalata[2], J. N. Andrews[3], J. K. Osmond[4]
[1]Catholic University of Rio de Janeiro (PUC)
[2]New York Medical Centre
[3]University of Bath
[4]Florida State University
December 1990

TR 90-18
Chemical and physical characterisation of suspended particles and colloids in waters from the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil
N. Miekeley[1], O. Coutinho de Jesus[1], C-L Porto da Silveira[1], C. Degueldre[2]
[1]Catholic University of Rio de Janeiro (PUC)
[2]PSI, Villingen, Switzerland
December 1990

TR 90-19
Microbiological analysis at the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil
J. West[1], A. Vialta[2], I. G. McKinley[3]
[1]British Geological Survey, Keyworth
[2]Uranio do Brasil, Poços de Caldas
[3]NAGRA, Baden, Switzerland
December 1990

TR 90-20
Testing of geochemical models in the Poços de Caldas analogue study
J. Bruno[1], J. E. Cross[2], J. Eikenberg[3], I. G. McKinley[4], D. Read[5], A. Sandino[1], P. Sellin[6]
[1]Royal Institute of Technology (KTH), Stockholm
[2]AERE, Harwell, UK
[3]PSI, Villingen, Switzerland
[4]NAGRA, Baden, Switzerland
[5]Atkins, ES, Epsom, UK
[6]Swedish Nuclear and Waste Management Co (SKB), Stockholm
December 1990

TR 90-21
Testing models of redox front migration and geochemistry at the Osamu Utsumi mine and Morro do Ferro analogue sites, Poços de Caldas, Brazil
J. Cross[1], A. Haworth[1], P. C. Lichtner[2], A. B. MacKenzi[3], L. Moreno[4], I. Neretnieks[4], D. K. Nordstrom[5], D. Read[6], L. Romero[4], S. M. Sharland[1], C. J. Tweed[1]
[1]AERE, Harwell, UK
[2]University of Bern
[3]Scottish Universities Research & Reactor Centre (SURRC), Glasgow
[4]Royal Institute of Technology (KTH), Stockholm
[5]US Geological Survey, Menlo Park
[6]Atkins ES, Epsom, UK
December 1990

TR 90-22
Near-field high temperature transport: Evidence from the genesis of the Osamu Utsumi uranium mine analogue site, Poços de Caldas, Brazil
L. M. Cathles[1], M. E. Shea[2]
[1]University of Cornell, New York
[2]Battelle, Chicago
December 1990

TR 90-23
Geochemical modelling of water-rock interactions at the Osamu Utsumi mine and Morro do Ferro analogue sites, Poços de Caldas, Brazil
D. K. Nordstrom[1], I. Puigdomenech[2], R. H. McNutt[3]
[1]US Geological Survey, Menlo Park
[2]Studsvik Nuclear, Sweden
[3]McMaster University, Ontario, Canada
December 1990

TR 90-24
The Poços de Caldas Project: Summary and implications for radioactive waste management
N. A. Chapman[1], I. G. McKinley[2], M. E. Shea[3], J. A. T. Smellie[4]
[1]INTERRA/ECL, Leicestershire, UK
[2]NAGRA, Baden, Switzerland
[3]Battelle, Chicago
[4]Conterra AB, Uppsala

TR 90-25
Kinetics of UO_2(s) dissolution reducing conditions: numerical modelling
I. Puigdomenech[1], I. Casas[2], J. Bruno[3]
[1]Studsvik AB, Nyköping, Sweden
[2]Department of Chemical Engineering, E.T.S.E.I.B. (U.P.C.), Barcelona, Spain
[3]Department of Inorganic Chemistry, The Royal Institute of Technology, Stockholm, Sweden
May 1990

TR 90-26
The effect from the number of cells, pH and lanthanide concentration on the sorption of promethium on gramnegative bacterium (Shewanella Putrefaciens)
Karsten Pedersen[1], Yngve Albinsson[2]
[1]University of Göteborg, Department of General and Marine Microbiology, Gothenburg, Sweden
[2]Chalmers University of Technology, Department of Nuclear Chemistry, Gothenburg, Sweden
June 1990

TR 90-27
Isolation and characterization of humics from natural waters
B. Allard[1], I. Arsenie[1], H. Borén[1], J. Ephraim[1], G. Gårdhammar[2], C. Pettersson[1]
[1]Department of Water and Environmental Studies, Linköping University, Linköping, Sweden
[2]Department of Chemistry, Linköping University, Linköping, Sweden
May 1990

TR 90-28
Complex forming properties of natural organic acids. Part 2. Complexes with iron and calcium
James H. Ephraim[1], Andrew S. Mathuthu[2], Jacob A. Marinsky[3]
[1]Department of Water in Environment and Society, Linköping University, Linköping, Sweden
[2]Chemistry department, University of Zimbabwe, Harare, Zimbabwe
[3]Chemistry Department, State University of New York at Buffalo, Buffalo, NY, USA
July 1990

TR 90-29
Characterization of humic substances from deep groundwaters in granitic bedrock in Sweden
C. Pettersson, J. Ephraim, B. Allard, H. Borén
Department of Water and Environmental Studies, Linköping University, Linköping, Sweden
June 1990

TR 90-30
The earthquakes of the Baltic shield
Ragnar Slunga
Swedish National Defence Research Institute
June 1990

TR 90-31
Near-field performance of the advanced cold process canister
Lars Werme
Swedish Nuclear Fuel and Waste Management Co (SKB)
September 1990

TR 90-32
Radioclide transport paths in the nearfield – a KBS-3 concept study
Roland Pusch
Clay Technology AB and Lund University of Technology
July 1990

TR 90-33
PLAN 90
Costs for management of the radioactive waste from nuclear power production
Swedish Nuclear Fuel and Waste Management Co (SKB)
June 1990

TR 90-34
GEOTAB: User's guide – Version 1.8.2
Ergodata
October 1990