Nagra
Nationale
Genossenschaft
für die Lagerung
radioaktiver Abfälle

Cédra
Société coopérative
nationale
pour l'entreposage
de déchets radioactifs

Cisra
Società cooperativa
nazionale
per l'immagazzinamento
di scorie radioattive

TECHNICAL REPORT 85-15

Database for Radionuclide Transport in the Biosphere:

Nuclide Specific and Geographic Data for Northern Switzerland

J. Jiskra

January 1985

Swiss Federal Institute for Reactor Research, Würenlingen

Parkstrasse 23 5401 Baden/Schweiz Telephon 056/20 55 11

Nagra
Nationale
Genossenschaft
für die Lagerung
radioaktiver Abfälle

Cédra
Société coopérative
nationale
pour l'entreposage
de déchets radioactifs

Cisra
Società cooperativa
nazionale
per l'immagazzinamento
di scorie radioattive

TECHNICAL REPORT 85-15

Database for Radionuclide Transport in the Biosphere:

Nuclide Specific and Geographic Data for Northern Switzerland

J. Jiskra

January 1985

Swiss Federal Institute for Reactor Research, Würenlingen

Parkstrasse 23 5401 Baden/Schweiz Telephon 056/20 55 11

Table of contents

Summary, Zusammenfassung, Resume

1. INTRODUCTION 1

2. NUCLIDE SPECIFIC PARAMETERS 4
2.1 Distribution coefficients soil-soilwater 4
2.2 Concentration ratios plant-soil 8
2.3 Concentration ratios for fish and distribution ratios for meat, milk and eggs 13
2.4 Dose conversion factors for ingestion 15

3. GEOGRAPHIC DATA 19
3.1 Dilution in groundwater 21
3.2 Evaluation of volumes of compartments and of flowrates between compartments 23

4. CONSUMPTION VALUES 33
4.1 Food consumption by man 33
4.2 Consumption by animals 36

5. POPULATION OF CRITICAL REGIONS 37

CONCLUSIONS 40

ACKNOWLEDGEMENTS 41

LITERATURE 42

Figures

Fig. 1 Example of compartmentalisation of the biosphere described in BIOPATH 2
Fig. 2 Areas in northern Switzerland selected for BIOPATH modelling 20
Fig. 3 Map of the Laufenburg region 26
Fig. 4 Scheme of compartments for Laufenburg 27
Fig. 5 Scheme of compartments for Wallbach 28
Fig. 6 Scheme of compartments for Zurzach 29
Fig. 7 Scheme of compartments for Schinznach 30
Fig. 8 Map of the Hellikon and Zuzgen region 31
Fig. 9 Scheme of compartments for Hellikon/Zuzgen 32

Tables

Table 1 Kd-values (soil-water) 6
Table 2 Correction factors Q for different Kd's 10
Table 3 Average water content of crops 11
Table 4 Concentration ratios plant-soil 12
Table 5 Concentration ratios for fish and distribution ratios for milk, meat and eggs 14
Table 6 Dose conversion factors for ingestion 16
Table 7 Flowrates and water-path specifications for the regions considered 22
Table 8 Annual consumption values for man 35
Table 9 Average daily consumption by cattle 36
Table 10 Average daily consumption by hen 37
Table 11 Annual yield of agricultural products 38
Table 12 Surface and population of region modelled 39

SUMMARY

The biosphere model is the final link in the chain of radionuclide transport models, used for radiation dose calculations from high-level waste repositories. This report presents the data needed for biosphere calculations and discusses them where necessary.

The first part is dedicated to the nuclide specific parameters like distribution coefficients (water - soil), concentration ratios (soil - plant) and distribution factors (for milk, meat, etc.) which are reported in the literature.

The second part contains the choice of regions, their division into compartments and the discussion of nutritional habits for man and animals. At the end a theoretical human population for each region is estimated based on the consumption rates and on the yield of agricultural products, assuming an autonomous nutrition.

ZUSAMMENFASSUNG

Im Rahmen der Sicherheitsanalysen für die Endlagerung von hochradioaktiven Abfällen bildet das Biosphärentransportmodell das letzte Glied in der Kette der Modelle.

Der vorliegende Bericht hat zum Zweck, die Daten, die für die Biosphärenmodellierung benötigt werden, als Uebersicht darzustellen, und dort, wo es nötig erscheint, detaillierter zu diskutieren.

Der erste Teil ist den nuklidspezifischen Parametern wie Verteilungskoeffizienten (Wasser - Boden), Verteilungsfaktoren (Boden - Pflanzen) und Konzentrationsfaktoren (für Milch, Fleisch, usw.), die aus der Literatur eruiert wurden, gewidmet.

Der zweite Teil befasst sich mit der Auswahl der Regionen, ihrer Einteilung in Kompartimente sowie mit den heutigen Verzehrgewohnheiten von Menschen und Tieren.

Abschliessend wird eine theoretische Bevölkerungsgrösse in der jeweiligen Region für den Fall einer autonomen Ernährung anhand der spezifischen Agrarfläche und der Verzehrmenge abgeschätzt.

RESUME

Dans le cadre de l'analyse de sécurité pour le stockage définitif des déchets hautement radioactifs le modèle de la biosphère constitue le dernier chaînon du transport des radionucléides. Le présent rapport a comme but de présenter les données nécessaires pour modeler la biosphère et de les discuter plus amplement si nécessaire.

La première partie est consacrée aux paramètres spécifiques aux nucléides, tirés de la littérature, tels que coefficients de distribution (eau - sol), quotients de concentration (plante - sol) et facteurs de distribution pour le lait et pour la viande.

La deuxième partie concerne le choix de régions, leur division en compartiments ainsi que les habitudes nutritionelles actuelles des populations humaine et animales.

Enfin on estime la population humaine théorique de chaque région sur la base des taux de consommation et du rendement agricole, en partant de l'hypothèse d'autarcie nutritionelle.

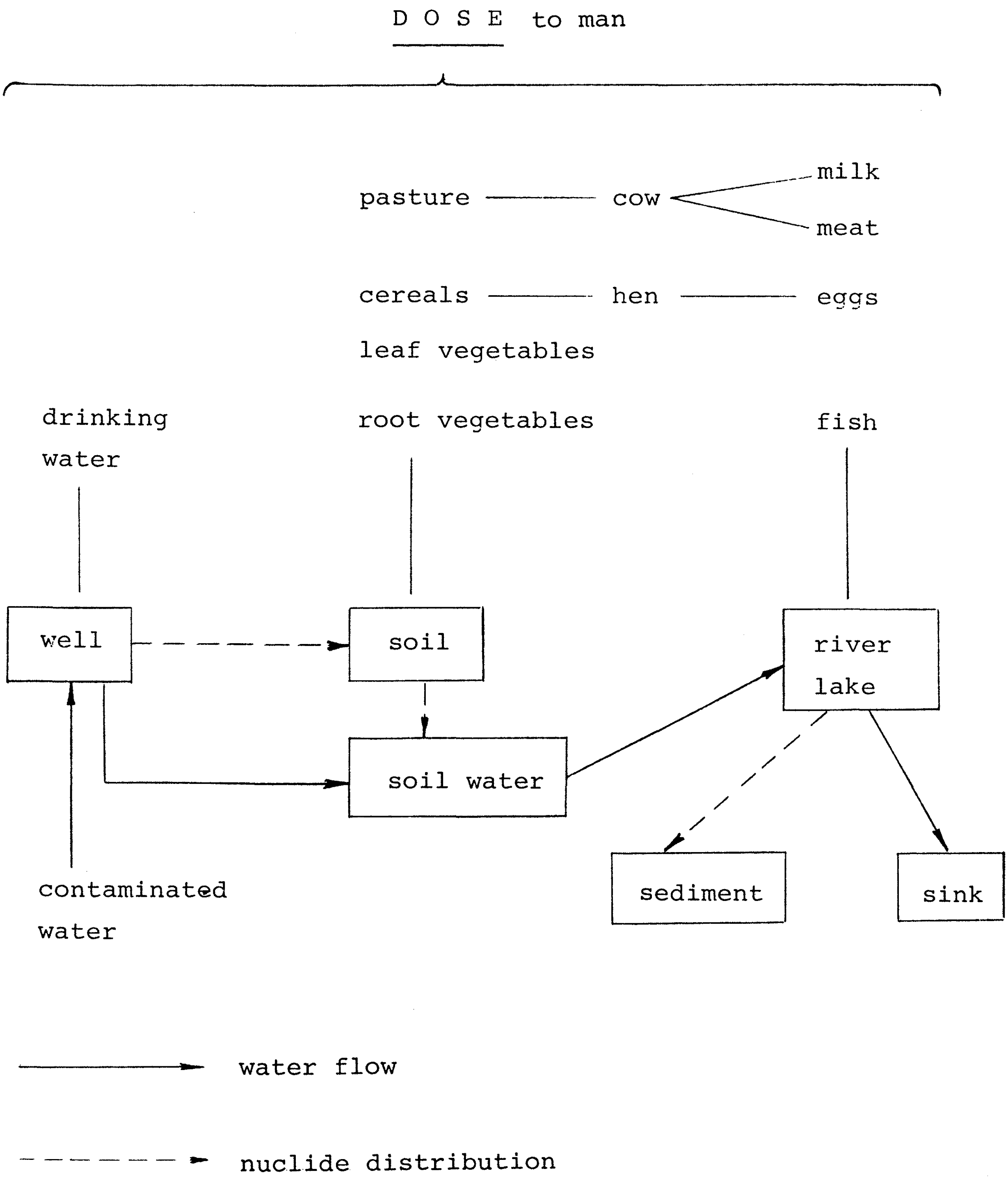
1. Introduction.

The biosphere transport model is the final link in the chain of models, used for dose calculations from high level waste repositories. The release of activity from the repository site, which is planned to be located deep in the crystalline rock in Switzerland (63) can be described by a large number of scenarios. The IAEA (64) listed a whole range of scenarios from direct exposure of the whole repository site as a consequence of an earthquake, to a release of radioactivity by spot-drilling into a repository cavern. Depending on the release scenario chosen, there are many different exposure pathways that lead to a dose to man, through external irradiation, ingestion of water and food and by inhalation.

For Switzerland, the release of radioactivity from the repository by intrusion of water and subsequent leaching is considered as a base scenario for safety analyses (63, 65) and results in the ingestion pathway being the most important.

For our biosphere modelling, the Swedish BIOPATH code (1) is used. For this code the region modelled is divided into compartments (well, groundwater, soil, soilwater, rivers, lakes, fluvial sediments). The nutritional chains are then attached to the appropriate compartments (fig. 1). Finally, average consumption values and dose conversion factors, allow the calculation of radiation doses to members of the population.

Fig. 1: Example of compartmentalisation of the biosphere described in BIOPATH.



The geosphere transport calculations show that the activity will reach the biosphere after several hundreds of thousands of years (66). The biosphere will by then have experienced many changes in climate, waterflow paths, vegetation and nutritional habits of its human population.

However, it seems reasonable to begin with a base case scenario, based on the present situation - the data set presented herein serves for this purpose - and to proceed further to other scenarios, in the sense of varying the climate, waterflow paths, vegetation and nutritional habits. Therefore, all data collected here attempt to describe the biosphere as it is today, as accurately as achievable. Future changes will be considered in some special scenarios and by varying parameter values. This will be described in another report.

2. Nuclide specific parameters.

2.1. Distribution coefficients soil-soilwater

The subdivision of soil into a solid phase and a water phase compartment allows the affinity of radionuclides to the solid phase to be considered for modelling (2). For simplicity, this affinity can be quantified by the distribution coefficient, Kd, defined in the following way:

$$Kd = \frac{\text{activity/kg soil}}{\text{activity/m soilwater}}$$

This implies a reversible distribution equilibrium, which is independent of time and concentration. These conditions are guaranteed only for very simple sorption systems of well defined homogeneous solid phase and small concentrations of the sorbate. When soil, with its complexity of mineral composition and size, organic contents and the variety of microorganisms, is to be considered, the use of Kd in a rigorous sense is obviously precluded, but as a first approximation, measured values of this parameter will be used to quantify partitioning between soil and solution phases.

Another uncertainty lies in the mineral composition of soils as well as in the effect of microorganisms. For instance, sorption measurements of Pu show a variation of Kd between .035 and 14 m^3/kg for different soils under the same measuring conditions (4). The effect of microorganisms was demonstrated for the case of I^- distribution on loamy sand (3), where under sterile conditions a Kd = .002 m^3/kg, for non-sterile conditions a Kd = .01 m^3/kg were measured.

Taking these facts into account, it seems reasonable to list the distribution coefficients with a precision of one order of magnitude for the purpose of BIOPATH calculations. Table 1 gives Kd-values to be used in BIOPATH together with recent values from the literature suitable for Swiss soils and climate (values for desert sand, for example, are not included). Where literature data were not available, values from similar biosphere studies were taken. If data for river and lake sediments could be found in the literature, they are also included in the table.

Table 1: Kd-values (soil-water) in m^3/kg. References are given in parenthesis.

Element	selected Kd value	Literature data
C	0,001	chalk(5): 0,0003 - 0,0006
		rocks(6): 0 - 10
Ca	0,1	Nevada soils(7): 0,03 - 1,4
Ni	0,01	(8): 0,08
Se	0,001	sea-minerals(9): 0,007
Rb	0,1	analogous to Cs
Sr	0,1	soils(10,11,12,13): 0,009 - 0,28
		parabraunerde, podsol(14): 0,04
Zr	0,01	braunerde(15): 0,02 - 0,04
		podsol(15): 0,003 - 0,024
Mo	0,001	Tokai soil(16): 0,005
Tc	0,001	braunerde(15): 0,0003
		podsol(15): 0,0003 - 0,0015
Pd	0,01	analogous to Ni
Sn	0,1	analogous to Pb
J	0,01	parabraunerde - podsol(14): 0,008 - 0,02
		braunerde - podsol(15): 0,003 - 0,03
Cs	0,1	soils(10,11,13): 0,2 - 1,1
		podsol - parabraunerde(14): 0,25 - 1,75
Ho	0,1	analogous to Eu: loam(17): 0,2 - 10
Pb	0,1	(8): 5

Element	selected Kd value	Literature data
Pb	0,1	(23): 0 - 0,1
Ra	0,1	Utah soil(18): 0,2 - 0,5
		tuff(18): 6,7
	0,1	river sediment(22): 0,07 - 0,37
Ac	0,1	(8): 3
		(23): 0,1 - 1
Th	10,0	silt clay(18): 2,7 - 10
		clay soils(19,12): 160 - 200
Pa	0,1	(8): 6
		(23): 1 - 10
U	0,1	clay soils(12,19): 0,2 - 4,4
	0,01	river sediment(18): 0,04
Np	0,01	clay soils(12,19): 0,0003 - 0,3
Pu	1,0	soils(4): 0,035 - 14
		clay soils(12,19): 20 - 300
	10,0	river sediment(20): 10 - 100
Am	0,1	soils(18): 0,08 - 10
		clay soils(12): 0,001 - 0,3
		clay(21): 0,3 - 2,3
Cm	0,1	loamy sand(18): 0,1
		silty loam(18): 0,7
		sand(18): 1,2 - 1,9
		clay loam(18): 71,0
Cf	0,1	analogous to Cm

2.2 Concentration ratios plant-soil

The model BIOPATH permits the calculation of nuclide uptake by plants from total soil only. When the soil is divided into a solid and a water compartment, two compartments must be taken into account for plant uptake. The calculational procedure is as follows:

The total activity is (to be rewritten afterwards, from here to table 2):

$$A(tot) = A(s) + A(l); \quad \frac{A(tot)}{V(tot)} = \frac{A(s)}{V(tot)} + \frac{A(l)}{V(tot)}, \qquad 1)$$

where A represents activity, V volume and M mass with subscripts (s) for solid and (l) for liquid phases.

Setting $\varepsilon = V(l)/V(tot)$ equation 1) becomes:

$$\frac{A(tot)}{V(tot)} = \frac{A(l)}{V(l)} . \varepsilon + \frac{A(s)}{V(s)} (1-\varepsilon) . \qquad 2)$$

The distribution coefficient is by definition:

$$Kd = \frac{A(s)\ V(l)}{M(s)\ A(l)}$$

Thus equation 2) can be written:

$$\frac{A(tot)}{V(tot)} = \frac{A(s)\ \varepsilon}{M(s)\ Kd} + \frac{A(s)}{V(s)} (1-\varepsilon) = \frac{A(s)}{M(s)} \left[\frac{\varepsilon}{Kd} + \rho_s (1-\varepsilon) \right] \qquad 3)$$

Using the expression:

$$M(tot) = M(l) + M(s) = V(tot) \quad [\rho_l \, \varepsilon \; + \rho_s \, (1-\varepsilon)]$$

V(tot) can be calculated and substituted in equation 3) giving:

$$\frac{A(tot)}{M(tot)} \left[\rho_l \varepsilon + \rho_s (1-\varepsilon)\right] = \frac{A(s)}{M(s)} \left[\frac{\varepsilon}{Kd} + \rho_s (1-\varepsilon)\right] \qquad 4)$$

The concentration ratio for plants is usualy determined (25) by the measurement of activity in the plant (dry weight) and activity in dry soil (dried in an oven at 105 °C). This means that soil water is evaporated before measurement and the total activity in soil given per unit weight of the solid phase. The concentration ratio CR is:

$$CR = \frac{A(plant)\ M(s)}{M(plant)\ A(tot)} ; \qquad \frac{A(plant)}{M(plant)} = CR \ \frac{A(tot)}{M(s)} \qquad 5)$$

From equation 4) A(tot)/M(s) can be calculated:

$$\frac{A(tot)}{M(s)} = \frac{A(s)}{M(s)} \left[1 + \frac{\varepsilon}{Kd \cdot \rho_s \cdot (1-\varepsilon)}\right] \qquad 6)$$

In the BIOPATH version utilized, the plants are attached to the solid phase compartment of the soil and the nuclide uptake is described by equation 7) which follows from equations 5) and 6).

$$\frac{A(plant)}{M(plant)} = CR \underbrace{\left[1 + \frac{\varepsilon}{Kd \cdot \rho_s \cdot (1-\varepsilon)}\right]}_{Q} \frac{A(s)}{M(s)} \qquad 7)$$

Q is called the correction factor which converts the concentration ratio from literature into the concentration ratio to be used in BIOPATH.

The average value for the density of solid components of soil is reported to be $2.65 \cdot 10^3$ kg/m^3 (24). Assuming an average water content in soil to be 30% ($\varepsilon = 0.3$) and an air content of 10%, the density ρ_s becomes $2.27 \cdot 10^3$ kg/m^3 and the correction factor Q, can be calculated for appropriate Kd-values.

Table 2: Correction factor Q for different Kd's

Kd(m^3/kg)	Q
0,0001	2,887
0,001	1,189
0,01	1,019
0,1	1,002
1,0	1,000
10,0	1,000

CR values reported in the literature are frequently given on a plant dry weight basis, however the BIOPATH model uses the CR on a wet weight basis. Table 3 lists the average water content of the crop types, used to convert dry weight into wet weight.

Table 3: Average water content of crops (26)

crop	water content (%)
pasture	75
cereals	11
leaf vegetables	90
root vegetables	85

In table 4 literature data for plant-soil concentration ratios compiled by H. Grogan (NTB 85-16) and the concentration factors to be used by BIOPATH, (CR" = CR.Q), are given.

Table 4: Concentration ratios plant-soil (fresh weight plant/dry weight soil; calculated from literature data; CR"= Q . CR(lit.))

element	pasture		cereals		leaf vegetables		root vegetables	
	CR(literature)	CR"	CR(literature)	CR"	CR(literature)	CR"	CR(literature)	CR"
Ca	(Sr):0,5	0,5	(Sr):0,12	0,12	(Sr):0,15	0,15	(Sr):0,14	0,14
Ni	(27):5e-2	5e-2	(27):4,2e-2	4,2e-2	(28,29):1,7e-2	1,7e-2	(28,29):1,6e-2	1,6e-2
Se	(34):0,25	0,30	(34):3,6e-2	4,3e-2	(34):3,5e-2	4,2e-2	(34):3,8e-2	4,5e-2
Rb	(34):7,5e-2	7,5e-2	(34):2,7e-1	2,7e-1	(34):3e-2	3e-2	(34):4,5e-2	4,5e-2
Sr	(26):0,58	0,58	(26):0,12	0,12	(26):0,15	0,15	(26):0,14	0,14
Zr	(30):2,0e-2	2,1e-2	(30):2,7e-2	2,7e-2	(30,31):3,4e-3	3,5e-3	(30):2,1e-3	2,1e-3
Mo	(26):1,1	1,3	(26):4,0	4,8	(26):0,5	0,6	(26):0,7	0,8
Tc	(32,33):2,5	3,0	(32,33):4,5	5,4	(32,33):1,0	1,2	(32,33):1,5	1,8
Pd	(Ni):5e-2	5e-2	(Ni):4,2e-2	4,2e-2	(Ni):1,7e-2	1,7e-2	(Ni):1,6e-2	1,6e-2
Sn	(34):0,1	0,1	(34):0,36	0,36	(34):4,6e-2	4,6e-2	(34):6e-2	6e-2
J	(34):0,1	0,1	(34):0,36	0,36	(26):1,9e-2	1,9e-2	(26):5,6e-3	5,6e-3
Cs	(26,35):2e-2	2e-2	(26,35):1,3e-2	1,3e-2	(26,35):1,3e-2	1,3e-2	(26,35):8e-3	8e-3
Pb	(42):4,5e-3	4,5e-3	(42):1,7e-2	1,7e-2	(42):1,8e-3	1,8e-3	(42):2,7e-3	2,7e-3
Ra	(40):4e-3	4e-3	(40):1,4e-2	1,4e-2	(40):1,6e-3	1,6e-3	(40):3e-3	3e-3
Ac	(41):5e-4	5e-4	(41):1,8e-4	1,8e-4	(41):2e-4	2e-4	(41):3e-4	3e-4
Th	(40):9,5e-4	9,5e-4	(40):7,1e-4	7,1e-4	(40):3,8e-4	3,8e-4	(40):5,7e-4	5,7e-4
Pa	(35,36):9,3e-3	9,4e-3	(26,36):1,7e-2	1,7e-2	(26,36):2,7e-2	2,7e-2	(36):6e-2	6e-2
U	(40):9,5e-4	9,5e-4	(40):1,3e-3	1,3e-3	(40):3,8e-4	3,8e-4	(40):5,7e-4	5,7e-4
Np	(35,36):9,3e-3	9,4e-3	(26,36):1,7e-2	1,7e-2	(26,36):2,7e-2	2,7e-2	(36):6e-2	6e-2
Pu	(35,36):3,8e-4	3,8e-4	(35,39):1,8e-3	1,8e-3	(38,39):1,4e-4	1,4e-4	(36,39):3e-4	3e-4
Am	(35,36):5e-4	5e-4	(35,36):2,2e-5	2,2e-5	(36):2e-4	2e-4	(36):3e-4	3e-4
Cm	(36):5e-4	5e-4	(36,37):1,1e-3	1,1e-3	(36):2e-4	2e-4	(36):3e-4	3e-4

2.3 Concentration ratios for fish and distribution ratios for meat, milk and eggs.

The literature values of interest are listed in table 5 together with references. In the case of elements for which no data can be found in the literature, values for chemicaly similar elements are used by analogy.

Distribution ratios for eggs are given in (day/piece) and related to egg content, that is egg white and yolk without shell. For calculations, the following numbers were used: egg weight: 58 gr, weight fraction of 89% for egg contents (43).

The listed ratios are defined in the following way:

CR(fish) = activity in 1 kg fish/activity in 1 kg water

DR(milk, meat, egg) = Fraction of the element ingested daily that is present in 1 kg of muscle, in 1 l milk or in 1 egg, respectively

Table 5: Concentration ratios for fish and distribution ratios for milk, meat(cattle) and eggs (reference between brackets)

element	CR(fish)	DR(milk) in d/l	DR(meat) in d/kg	DR(egg) in d/piece
Ca		(44): 1,1 e-2	(43): 1,6 e-3	(43): 2,3 e-2
Ni	(45): 100	(44): 1,0 e-3	(43): 2,0 e-3	(Co>Ni>Cu): 5,2 e-2
Se	(45): 200	(44): 4,0 e-3	(43): 0,32	(43): 0,48
Rb	(45): 2 e3	(44): 1,2 e-2	(43): 1,1 e-2	(~Cs): 1,1 e-2
Sr	(45): 30	(44): 1,4 e-3	(43): 8,1 e-4	(43): 1,6 e-2
Zr	(45): 200	(44): 3,0 e-5	(43): 2,0 e-2	(~Y): 1,0 e-4
Mo	(~Cr,Nb): 200	(44): 1,4 e-3	(43): 6,8 e-3	(43): 2,6 e-2
Tc	(45): 15	(45): 2,5 e-2	(43): 1,0 e-3	(43): 9,8 e-2
Pd	(~Ni): 100	(~Ni): 1,0 e-3	(~Ni): 2,0 e-3	(~Ni): 5,2 e-2
Sn	(45): 3 e3	(44): 1,2 e-3	(~Pb): 4 e-4	(~Pb): 4,6 e-2
J	(45): 50	(44): 9,9 e-3	(43): 3,6 e-3	(43): 1.5 e-1
Cs	(45): 1 e3	(44): 7,1 e-3	(43): 2,6 e-2	(43): 2,5 e-2
Pb	(~Ba): 100	(44): 2,6 e-4	(43): 4 e-4	(~Ba): 4,6 e-2
Ra	(46): 25	(44): 4 e-4	(43): 9 e-4	(~Ba): 4,6 e-2
Ac	(~La): 100	(45): 5 e-6	(45): 6 e-2	(~U,~Ra): 5 e-2
Th	(45): 30	(45): 5 e-6	(45): 2 e-4	(~U,~Ra): 5 e-2
Pa	(46): 10	(45): 5 e-6	(45): 8 e-2	(~U,~Ra): 5 e-2
U	(45): 2	(44): 3,7 e-4	(45): 3,4 e-4	(43): 5,1 e-2
Np	(45): 10	(45): 5 e-6	(43): 2 e-4	(~Am): 4,4 e-4
Pu	(45): 5	(44): 1 e-7	(43): 2 e-6	(43): 3,9 e-4
Am	(45): 25	(44): 4,1 e-7	(45): 2 e-4	(43): 4,4 e-4
Cm	(45): 25	(45): 5 e-6	(45): 2 e-4	(~Am): 4.4 e-4

~Nb: Nb is used as analog

2.4 Dose conversion factors for ingestion

Physical half-lifes (47) and dose conversion factors (DF) for ingestion given by ICRP 30 (48) are listed in table 6.

Short-lived daughters in decay series that are not considered separately in the biosphere calculations are assumed to be in equilibrium with their long-lived parent. This is reasonable only for nuclides with similar Kd values or half-lifes which are very short relative to biological turnover time-scales

Daughters dose conversion factors must also be taken into account and thus, in table 6, DF's of short-lived daughters are added to those of the long-lived parents and listed in the DF"ing column. For example:

$$\begin{aligned} DF''(Ra\text{-}226) &= DF(Ra\text{-}226) + DF(Pb\text{-}214) + DF(Bi\text{-}214) + \\ &\quad DF(Pb\text{-}210) + DF(Bi\text{-}210) + DF(Po\text{-}210) = \\ &= 2{,}2\ e\text{-}6\ Sv/Bq \text{ whereas} \\ DF(Ra\text{-}226) &= 3{,}1\ e\text{-}7\ Sv/Bq. \end{aligned}$$

Table 6: Dose conversion factors for ingestion

nuclide	half-life (a)	DFing. (Sv/Bq)	DFing. (rem/Ci)	DF"ing (rem/Ci)
1. activation products				
C-14	5730	5,7 e-10	2,1 e3	
Ca-41	1,4 e5	3,3 e-10	1,2 e3	
Ni-59	7,4 e4	5,4 e-11	2,0 e2	
Se-79	6,5 e4	2,3 e-9	8,5 e3	
Zr-93	1,53 e6	4,2 e-10	1,6 e3	2,1 e3
Mo-93	3,5 e3	3,5 e-10	1,3 e3	1,8 e3
2. fission products				
Rb-87	4,7 e10	1,3 e-9	4,8 e3	
Sr-90	29,12	3,6 e-8	1,3 e5	1,4 e5
Tc-99	2,13 e5	3,4 e-10	1,3 e3	
Pd-107	6,5 e6	3,7 e-11	1,4 e2	
Sn-126	1,0 e5	4,7 e-9	1,7 e4	2,7 e4
J-129	1,57 e7	7,4 e-8	2,7 e5	
Cs-135	2,3 e6	1,9 e-9	7,0 e3	
Ho-166m	1,2 e3	2,1 e-9	7,8 e3	
3. decay series				
3.1 4N				
Cm-248	3,39 e5	2,2 e-6	8,2 e6	
Pu-244	8,26 e7	1,1 e-7	4,1 e5	
Cm-244	18,11	3,0 e-7	1,1 e6	

nuclide	half-life (a)	DFing. (Sv/Bq)	DFing. (rem/Ci)	DF"ing. (rem/Ci)
Pu-240	6537	1,2 e-7	4,4 e5	
Np-236	1,15 e5	2,2 e-6	8,2 e6	
U-236	2,3415 e7	6,7 e-8	2,5 e5	
Th-232	1,405 e10	7,4 e-7	2,7 e6	
Pu-236	2,851	3,9 e-8	1,4 e5	
Ra-228	5,75	3,3 e-7	1,2 e6	
U-232	72	3,4 e-7	1,3 e6	
Th-228	1,9131	1,0 e-7	3,7 e5	7,4 e5
3.2 (4N+1)				
Cm-245	8500	6,1 e-7	2,3 e6	
Pu-241	14,4	2,4 e-9	8,9 e3	
Am-241	432,2	5,9 e-7	2,2 e6	
Np-237	2,14 e6	1,1 e-5	4,1 e7	
U-233	1,585 e5	7,2 e-8	2,7 e5	
Th-229	7340	9,4 e-7	3,5 e6	3,9 e6
3.3 (4N+2)				
Cm-250	6900			6,7 e2
Cf-250	13,08	2,7 e-7	1,0 e6	
Cm-246	4730	6,0 e-7	2,2 e6	
Am-242m	152	5,7 e-7	2,1 e6	2,2 e6
Pu-238	87,74	1,0 e-7	3,7 e5	
Pu-242	3,763 e5	1,1 e-7	4,1 e5	
U-238	4,468 e9	6,3 e-8	2,3 e5	2,5 e5

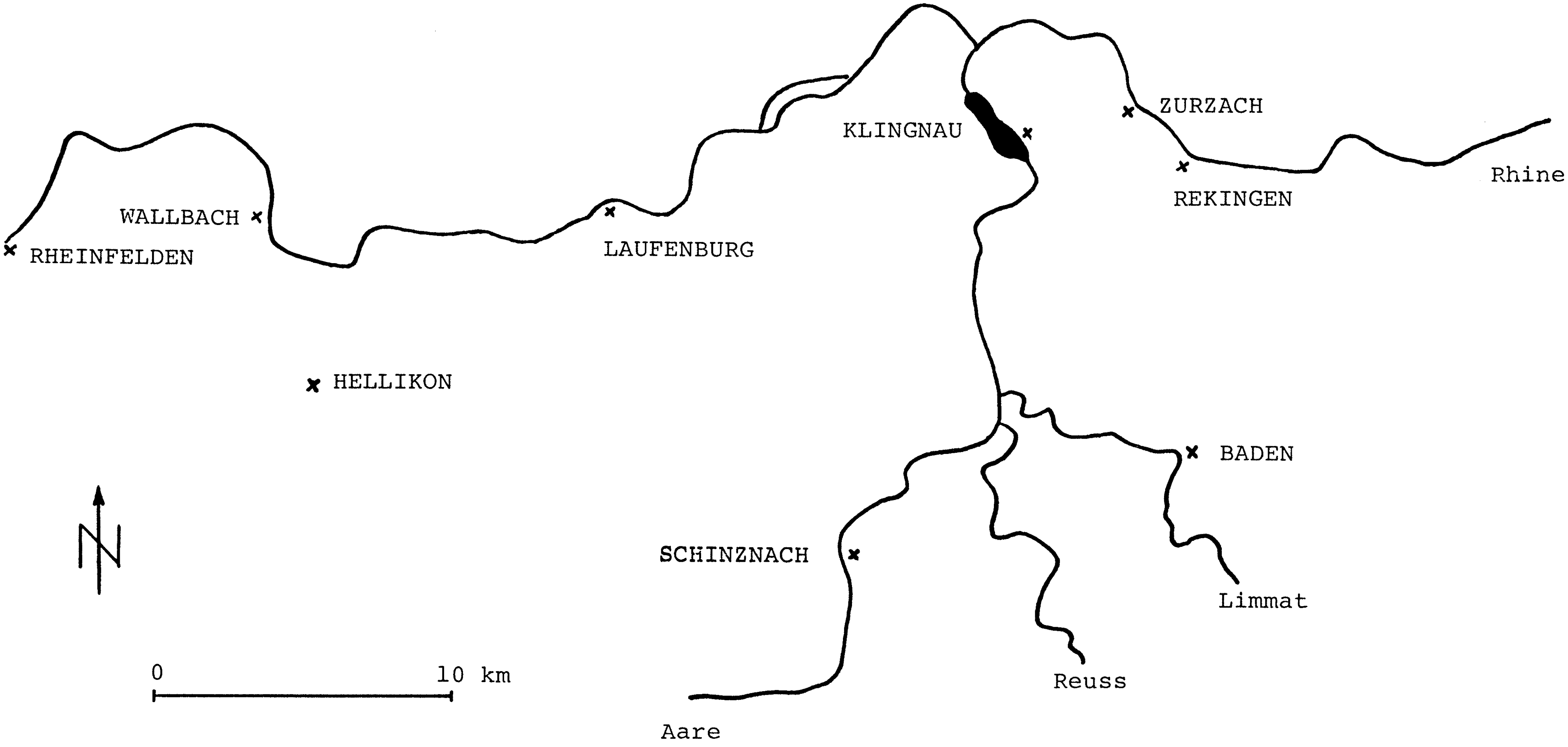
nuclide	half-life (a)	DFing. (Sv/Bq)	DFing. (rem/Ci)	DF"ing. (rem/Ci)
U-234	2,445 e5	7,1 e-8	2,6 e5	
Th-230	7,7 e4	1,5 e-7	5,6 e5	
Ra-226	1600	3,1 e-7	1,2 e6	8,2 e6
3.4 (4N+3)				
Cm-247	1,56 e7	5,6 e-7	2,1 e6	
Am-243	7380	5,9 e-7	2,2 e6	
Cm-243	28,5	3,9 e-7	1,4 e6	
Pu-239	24065	1,2 e-7	4,4 e5	
U-235	7,038 e8	6,8 e-8	2,5 e5	
Pa-231	3,276 e4	2,9 e-6	1,1 e7	
Ac-227	21,773	3,8 e-6	1,4 e7	1,5 e7

3. Geographic data and consumption values

In the base case scenario of the safety analyses for a high level waste repository in Switzerland, the activity is assumed to be transported by water, through granite, up to aquifers or sources of mineral water. A number of different geographical regions of potential contamination have been considered for the modelling, although the actual site of the repository was not yet defined when this study was carried out, and therefore the water pathways had to be estimated. This has been done in view of the time-scales involved before radioactivity is likely to enter the biosphere (10^5 - 10^7 years), during which the earth's surface might undergo significant changes.

Because it is unlikely that northern Switzerland will remain unchanged during this time period, a selected region serves as a model base of an area that might be contaminated when the leachate, after all dilutions and interactions in and with the geosphere, reaches the biosphere. For this purpose regions with groundwater streams, mineral sources or a well in the muschelkalk were chosen in the northern part of Switzerland (fig. 2). Aquifers in the gravel terrace are considered to be in the biosphere and are called groundwater streams.

Fig. 2: Areas in northern Switzerland selected for BIOPATH modelling (marked with x)



3.1. Dilution in the groundwater

With a known flowrate of the contaminated water coming out of the geosphere, the dilution is determined by the total waterflow in the groundwater stream or the source.

The most probable location where the contamination could enter the biosphere is a gravel bank along a river which forms a base scenario. Other scenarios are outflow into a mineral source, a well in the muschelkalk or straight into a river. Present flowrates for regions selected are listed together with the water-path specifications in table 7.

Table 7: Flowrates and water-path specifications for the regions considered.

region	flowrate(m^3/y)	specification	ref.
Laufenburg	5,5 e6	groundwater	***)
Wallbach	5,0 e6	groundwater	***)
Baden	7,0 e6	groundwater	(2)
	4,2 e5	mineral water	(49)
Klingnau	5,6 e7	groundwater	(2)
Zurzach	5,5 e6	groundwater	***)
	9,0 e5	mineral water	(49)
Schinznach	4,6 e6	groundwater	***)
	3,7 e5	mineral water	(49)
Hellikon	2,6 e5	well in the muschelkalk	(49)
Rekingen	1,4 e10	river Rhine*)	(50)
Rheinfelden	3,2 e10	river Rhine**)	(50)

*) average value between 1904 and 1979

**) average value between 1935 and 1979

***) calculated in this study

It should be noted, that the flowrates within the groundwater streams for the above mentioned regions are all of roughly the same order of magnitude. In order to be conservative the Laufenburg region which has the lowest dilution ($3,3.10^6$ m^3/y) in the groundwater will be chosen for the more detailed calculations.

However, the Hellikon region has the lowest dilution for any water source and would serve as a scenario for drilling a well into a contaminated aquifer in the muschelkalk.

3.2 Evaluation of volumes of compartments and of flowrates between the compartments.

Groundwater: The area of the appropriate groundwater stream, its depth and its slope can be derived from groundwater maps (49). The permeability of all groundwater streams considered herein is high (52), the hydraulic conductivity varying from 10^{-3} to 10^{-2} m/sec (52). For our calculations the average value 5.10^{-3} m/sec was used for the hydraulic conductivity. With these data the flowrate through the groundwater stream can be calculated by multiplying the average cross-section of the stream with its slope and the hydraulic conductivity.

Soil: The surface area of the soil layer corresponds to the surface area of the groundwater stream below, its depth is assumed to be 25 cm for agricultural purposes (53). For the BIOPATH modelling (2) the soil is divided into a solid phase compartment and into a soilwater compartment. It is assumed that the soil contains 10% air, 30% water and 60% solid material by volume. The mass density of the soil minerals is assumed to be 2,65.10^3 kg/m^3(24).

<u>Precipitation:</u> The annual precipitation is assumed to be 1'000 mm (that is 47 mm lower than the average value for Switzerland between 1901 and 1960), the evapotranspiration to be 500 mm (55,56). The precipitation surplus is only taken for the soil surface of the region modelled, and assumed to be 500 mm/y.

<u>Rivers, lakes:</u> Their surface areas can be calculated using groundwater maps (49), their depths are rough estimates. The flowrates are averages of all annual data available for the twentieth century (50).

<u>River and lake sediments:</u> The sediment layer being available for sorption is assumed to be 5 cm thick.

<u>Sink:</u> The sink has no influence on the transport calculation with BIOPATH. For all regions modelled, the nuclides flow into the river Rhine and thus the actual sink would be the Atlantic ocean. For the purpose of keeping the nuclide concentration in the sink low enough during the times considered (10^6 years), the sink volume is assumed to be six orders of magnitude higher than the annual flowrate of the Rhine, e.g. 10^{16} m^3.

<u>Connection of the compartments:</u> The flow of the originally contaminated water (groundwater or mineral water) does not necessarily describe the natural water path, instead pessimistic assumptions are made to ensure conservatism. In the case of a water source (mineral water source or a well in the muschelkalk), all water flows into the soilwater compartment and then into the groundwater. If the contamination leads from the geosphere straight into a groundwater compartment, then this groundwater is assumed to flow into soilwater, to get the highest activity achievable in the soilwater compartment used for plant uptake. In the soilwater compartment, the activity concentration is diluted by the precipitation surplus only.

The compartmental schemes are depicted on the following pages.

Fig. 3: Map of the Laufenburg region.

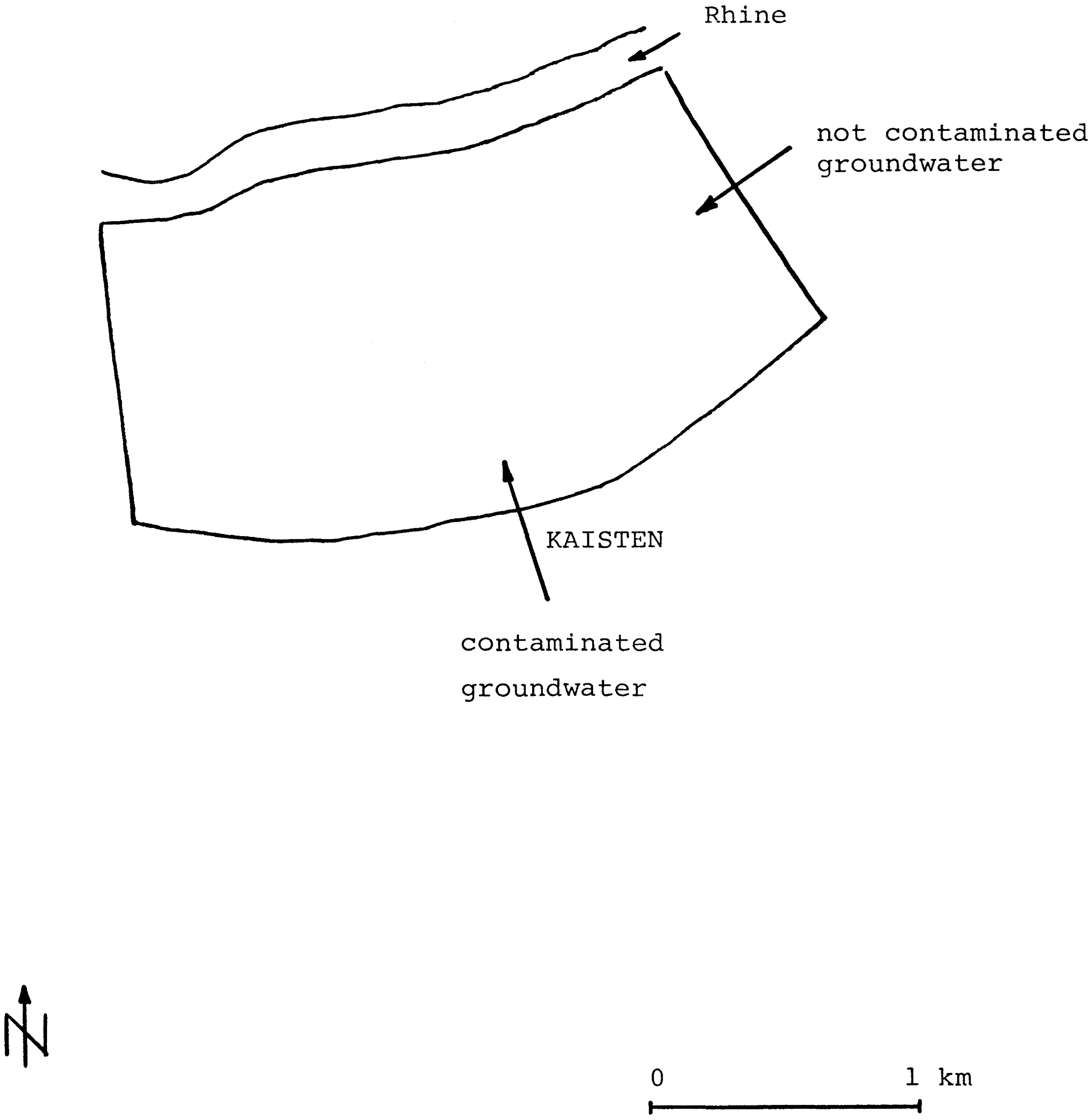


Fig. 4: Scheme of compartments for Laufenburg.

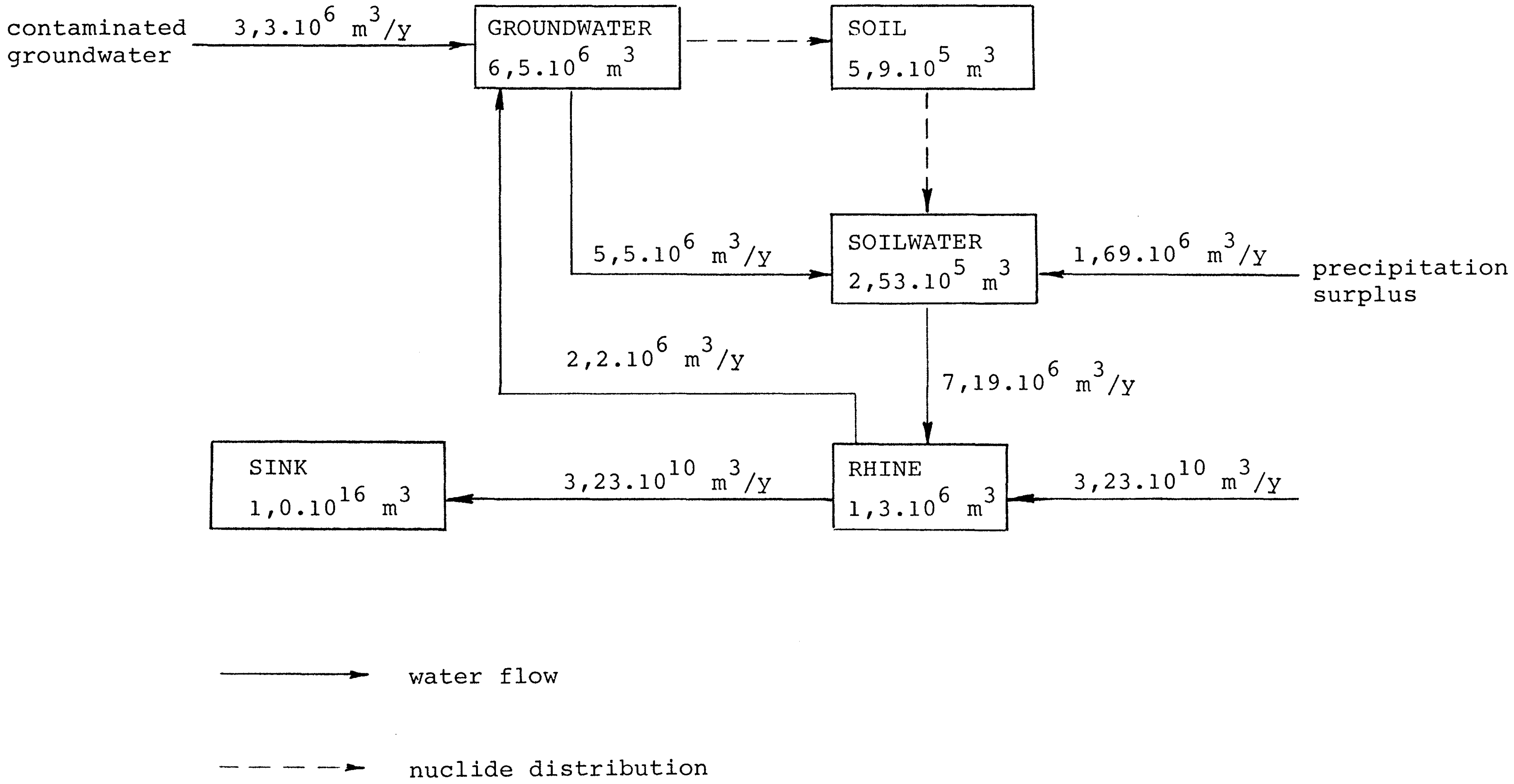


Fig. 5: Scheme of compartments for Wallbach.

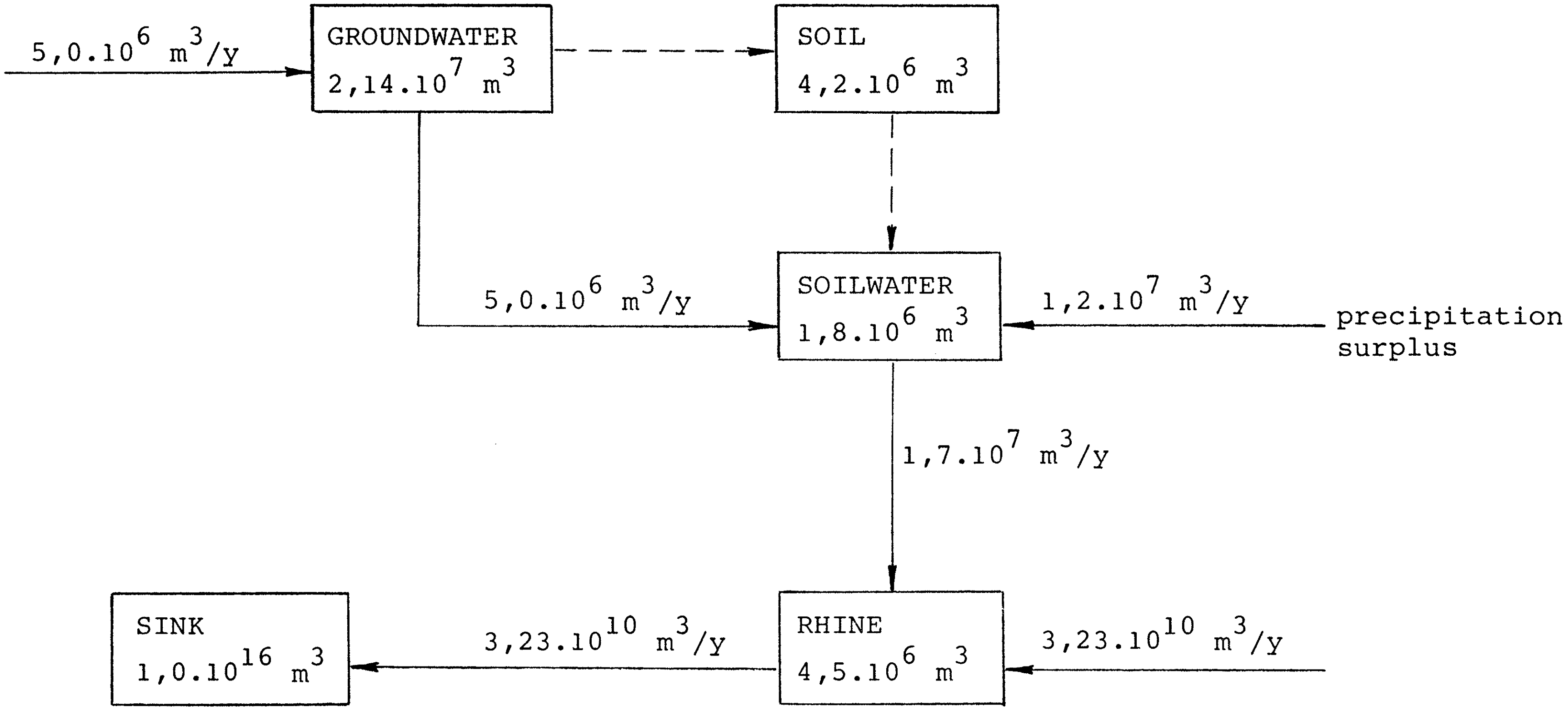


Fig. 6: Scheme of compartments for Zurzach.

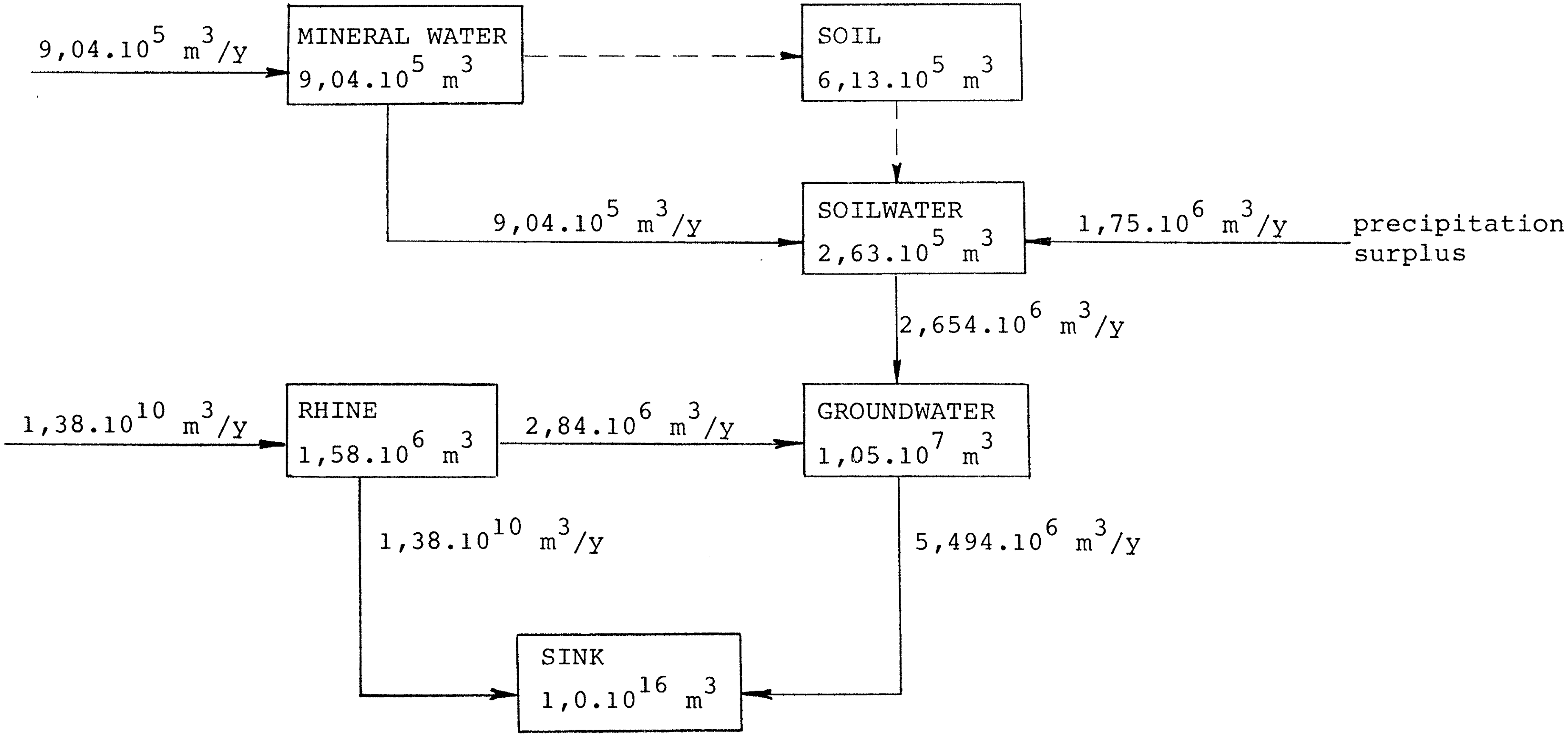


Fig. 7: Scheme of compartments for Schinznach.

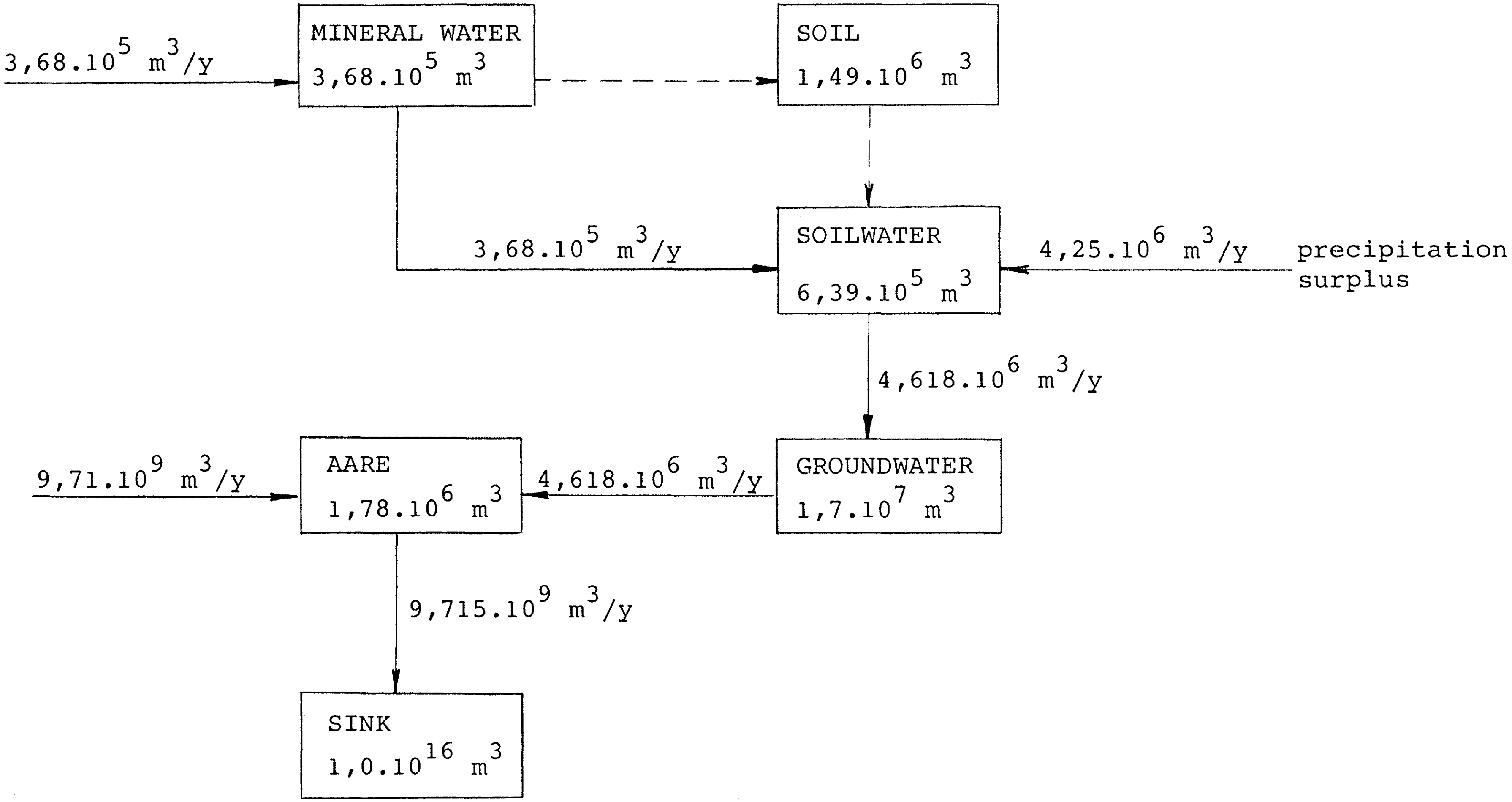


Fig. 8: Map of the Hellikon and Zuzgen region.

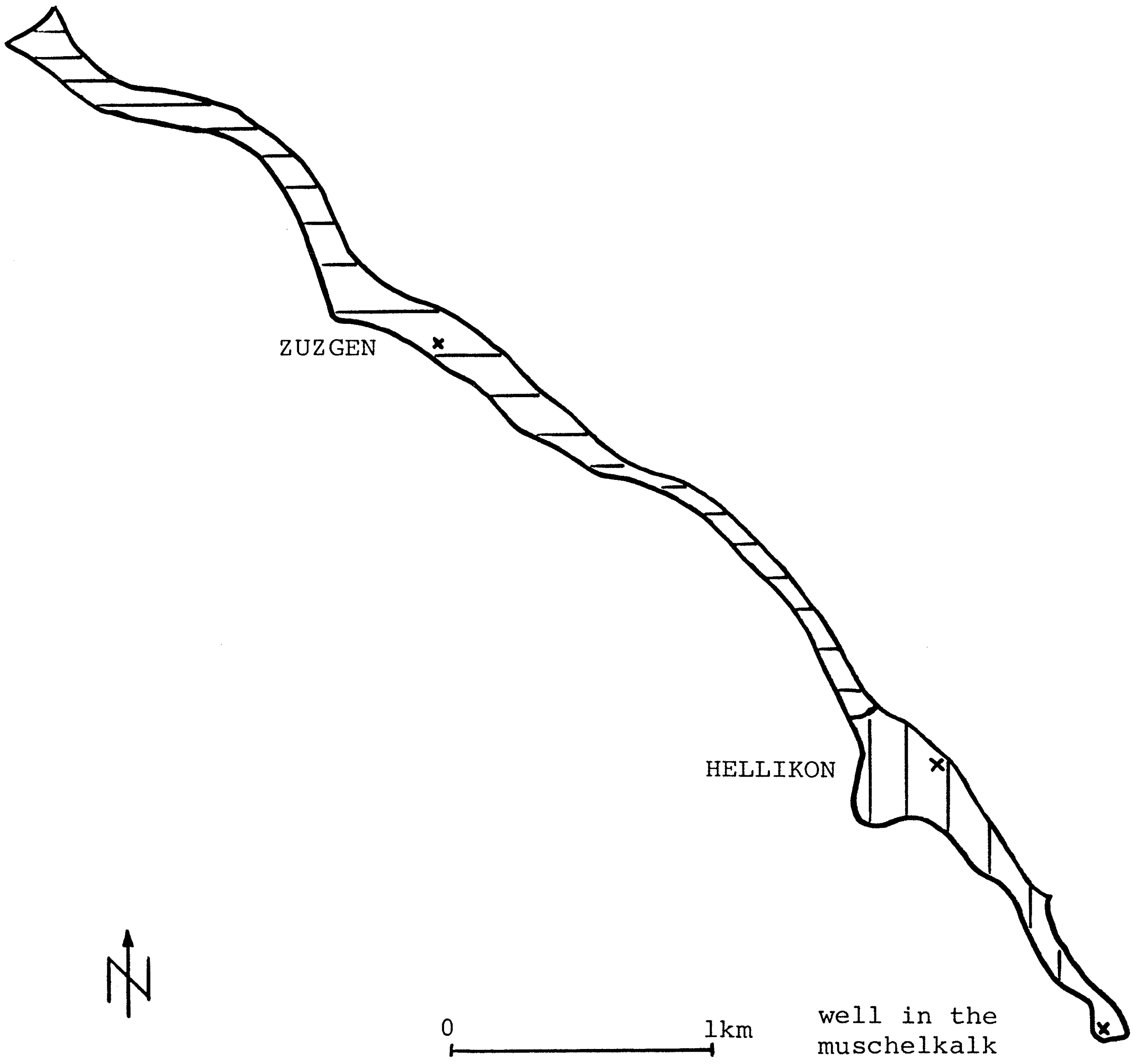
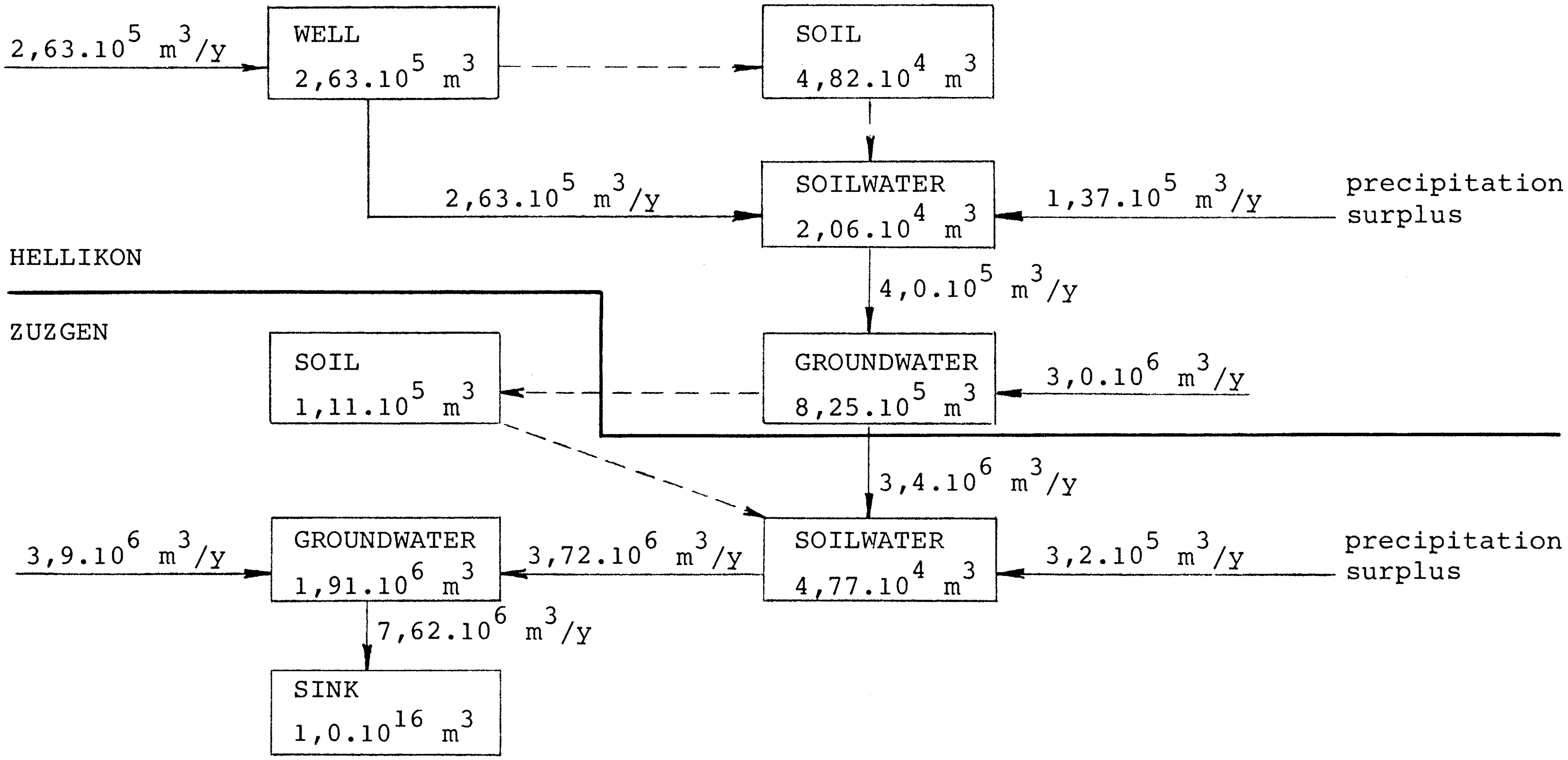


Fig. 9: Scheme of compartments for Hellikon/Zuzgen.



4. Consumption values

4.1. Food consumption by man

The consumption values have a significant influence on the final individual dose and therefore deserve a profound discussion. First of all it must be stressed that every region modelled is supposed to be completely autonomous with respect to all dietary products for the sake of conservatism. This means that the drinking water comes from the contaminated source, all plants are grown on the contaminated soil, the animals are fed with the contaminated fodder and grains and the fish live in the contaminated river or lake of the region. Because it is impossible to take all existing food products into account for the calculations, their number is reduced to the most important ones, i.e., drinking water, milk, meat (beef), leaf vegetables, root vegetables, cereals, fish and eggs for BIOPATH.

Nutritional habits are expressed in terms of statistical values and will vary on large time-scales. Therefore the numbers given in table 8 are averages applicable only to a large population as well as for present nutritional habits.

Two sets of consumption values are listed in table 8. The first is based on the statistical values for Switzerland (57), the second on the assumption of an average energy demand of 3'000 kcal per day and capita (58,59). For 3'000 kcal all food products not regarded in BIOPATH are added to the products which are available in the BIOPATH code, i.e., sugar and jam calories are recalculated for sugar-beet and added to root vegetables, plant oils to cereals etc. In the recalculations for sugar and oils it is assumed that concentrations of radionuclides do not change during refinement.

Also in table 8 the consumption rates for Switzerland are compared to those used in German (60), British (61) and Swedish (46) biosphere transport models. In this comparison the amount of drinking water might appear high. ICRP 23 mentions a total fluid intake of 1,95 litres per day for an adult man and 1,40 litres for an adult woman. We assumed conservatively 2 litres per day.

Table 8: Consumption values for man (per year).

	calorific (62)	Switzerland		Germany (60)	England (61)	Sweden (46)
		statistical (57)	3'000 kcal/d			
drinking water		730 lt	730 lt	440 lt		440 lt
milk	67 kcal/100 ml	165 lt	332 lt	110 kg	300 lt	190 lt
meat (beef)	174 kcal/100 g	85 kg	95 kg	75 kg	110 kg	55 kg
cereals	360 kcal/100 g	80 kg	145 kg	96 kg	130 kg	75 kg
leaf vegetables	20 kcal/100 g	60 kg	60 kg	21 kg	80 kg	25 kg
root vegetables	68 kcal/100 g	90 kg	231 kg	87 kg	120 kg	75 kg
eggs	83 kcal/100 g	200 pieces	200 pieces			200 pieces
fish		2 kg	2 kg	1,3 kg		30 kg

4.2. Consumption by animals

In the BIOPATH code only two livestock species (cattle and hen) and three animal products (milk, beef, eggs) appear in the nutritional chain. So the variety of meats (veal, pork, poultry, lamb etc.) is reduced to beef and the nuclide uptake described by cattle to represent the meat source. The variety of the feed is also reduced to fodder for cattle, and cereal for hen. It has been realized in recent experiments that soil ingestion by cattle can be of large significance and even become dominant over fodder and watering with respect to the uptake of radionuclides (67).

In table 9 and 10 the consumption values for BIOPATH are listed and compared to those used by foreign groups working on biosphere modelling.

Table 9: Average daily consumption by cattle.

	Switzerland(2)	England(61)	Sweden(46)
water	30 l	35-55 l	90 l
fodder (wet weight)	100 kg	60 kg	107 kg
soil (67)	1 kg		

Table 10: Average daily consumption by hen.

	Switzerland(2)	Sweden(46)
water	0,2 l	0,25 l
cereals (grains)	0,07 kg	0,11 kg

5. Population of critical regions

Finally, it is interesting to know the numbers of individuals that could live on the regions modelled. These numbers stress the conservatism of the assumption of an autonomous diet - the less people that live in the region, the more unrealistic the autonomous diet - as well as the importance of the critical region for collective dose.

The population is calculated from the average dietary values (table 8) and the yield of agricultural nutrition products (table 11).

The knowledge of the specific area for every nutrition product enables to estimate the consequences of changing dietary habits, e.g. the substitution of meat by grains.

One important 'product' not mentioned in table 11 is water. Apart from the two litres of drinking water about 600 litres - 460 from public water-supplies (68) plus 150 from private and industrial wells (69) - are used per day and capita in large agglomerations like Zurich. Two examples of water use for agricultural purpose that are delivered by precipitation in our climate can be mentioned (70): 300 to 600 lt/kg cereals (dry weight) and 600 to 800 lt/kg potatoes or fodder (dry weight).

Table 11: Annual yield of agricultural products.

product	yield(wet weight)	reference
cereals	4'000 kg/ha	(57),p. 38
potatoes	35'000 kg/ha	(57),p. 48
(for root vegetables)		
leaf vegetables	30'000 kg/ha	(57),p. 52
beef	250 kg/animal	(57),p. 84
milk	4'000 kg/cow	(57),p. 89
eggs	220 pc/hen	(57),p. 91
fodder	83'300 kg/ha	(70),p. 39

With the consumption values from table 8, one individual needs 0,446 ha (based on statistical average) or 0,587 ha (based on 3'000 kcal/day) for autonomous diet. With these data the population number of inhabitants which can be supported exclusively from the agricultural production of the regions listed in table 7 can be calculated.

Table 12: Surface and population of region modelled.

region	surface(ha)	number of inhabitants	
		statistical diet	3'000 kcal diet
Laufenburg	337,5	757	575
Wallbach	2'400	5'381	4'089
Baden	492	1'103	838
Klingnau	2'500	5'605	4'259
Zurzach	350	785	596
Schinznach	850	1'906	1'448
Hellikon	27,5	62	47
Zuzgen	15,9	36	27

Conclusions

The data sets presented in this report form a complete base for biosphere modelling of a 'critical' region in the northern part of Switzerland. Although the activity is assumed to enter the biosphere in some hundreds of thousands of years from now, the present geographical, hydrological and climatic situation is used for the base case scenario.

As a matter of fact no process involved in the nuclide transport through the biosphere can be described by one exact number because of natural variability and fluctuation of the system. Therefore all parameters used must be considered as indicative only.

Many data had to be deduced from experiments performed under conditions different from those in Switzerland, or even from other elements by reasons of analogy because of missing experimental data. In general reasonably conservative data are chosen in this report.

The influence of variations of geographical, climatic, agricultural and consumption parameters as well as the sensitivity of the model to nuclide specific data will be discussed in other reports.

Acknowledgements

The author would like to thank J. Hadermann, F. van Dorp, H. Grogan, I. McKinley and F. Roesel for helpful discussions and constructive criticism.

Literature

(1) Bergstroem U., Dose and Dose Commitment Calculations from Groundwaterborne Radioactive Elements Released from a Repository for Spent Nuclear Fuel, KBS-TR 83-49 (1983)

(2) Bundi A., Biosphaerentransport von Radionukliden - Untersuchungen anhand eines ausgewaehlten Beispiels, EIR-Bericht Nr. 503, (1983)

(3) Carlsen L., Bo P., Sorption of Radionuclides on Clay Materials, IAEA-SM-257/82, p. 97 (1982)

(4) Glover et al., Plutonium and Americium Behaviour in the Soil, Water Environment I.: Sorption of Plutonium and Americium by Soils, BNWL-2117, p. 224 (1976)

(5) Maennich K. O. et al., Dating of Groundwater with Tritium and C-14, Isotopes in Hydrology, Proc. of a Symposium, Vienna 14. - 18. Nov. 1966

(6) Anderson K. et al., Sorption Behaviour of Long-lived Radionuclides in Igneous Rocks, IAEA-SM-257/20, p. 111 (1982)

(7) Nork W. E. et al., Radioactivity in Water, Central Nevada Test Area, NVO-1229-175 (1971)

(8) Pinner A. V., Hill M. D., Radiological Protection Aspects of Shallow Land Burial of PWR Operating Wastes, NRPB-R138 (1982)

(9) Salter P. F. et al., Sorption of Selected Radionuclides on Secondary Minerals Associated with the Columbia River Basalts, RHO-BWI-LD-43, p. 9 (1981)

(10) Godse V. et al., Characterization of Trombey Soils for Disposal of Radioactive Wastes, Proc. Symposium on Disposal of Radioactive Wastes into the Ground, Vienna 1967

(11) Hajek B., Knoll K., Disposal Characteristics of Plutonium and Americium in a High Salt Waste,BMWL-CC-649 (1966)

(12) Parker F. L., Grant J. L., Chemical Migration of Radioactive Material in Soils, ANS-Meeting Atlanta, ANS/ED/TP-2, p. 54 (1979)

(13) Inoue Y., Prediction of Radionuclide Migration in Groundwater at the Japan Atomic Energy Research Institute, Proc. Symposium on Disposal of Radioactive Wastes into Ground, Vienna 1967

(14) Bachhuber H. et al., Ausbreitung von Radionukliden in oberflaechennahen Boeden, GSF-Bericht S-788, Institut fuer Strahlenschutz, Muenchen, p. 46 (1981)

(15) Albertsen M., Matthess G., Ausbreitung von Radionukliden in oberflaechennahen Boeden, PSE-Bericht Nr. 81/13 (1979)

(16) Inoue Y., Morisawa S., On the Selection of a Ground Disposal Site for Radioactive Wastes: An Approach to its Safety Evaluation, Health Physics 26, p. 52 (1974)

(17) Allard B. et al., Sorption av langlivade radionuklider i lera och berg, KBS-TR-55 (1977)

(18) Radionuclide Interactions with Soils and Rock Media, Vol. 1, Batelle 1978

(19) Dahlman R. et al., Biological Pathways and Chemical Behaviour of Plutonium and other Actinides in the Environment, San Francisco, 1976

(20) Sanchez et al., Distribution Coefficients for Plutonium and Americium on Particulates in Aquatic Environments, IAEA-SM-257/90 P, p. 188 (1982)

(21) Dosch R., Lynch A., Interaction of Radionuclides with Geomedia Associated with the Waste Isolation Pilot Plant Side in New Mexico, Sandia Laboratories, Albuquerque, SAND 78-0297 (1978)

(22) Mansfield A., Natural Radionuclides in Waters, their Occurence and Behaviour, Ph. D. Thesis, Institute of Chemical Technology, Prag 1977

(23) Wuschke D. M. et al., Environmental and Safety Assessment Studies for Nuclear Fuel Waste Management Vol. 3, Post Closure Assessment, Whiteshell Nuclear Research Establishment Pinawa, Manitoba (1981)

(24) Scheffer F., Schachtschabel P. et al., Lehrbuch der Bodenchemie, Enke Stuttgart, 11. Auflage, S. 129 (1982)

(25) Report on a Workshop on the Mesurement of Soils to Plant Transfer Factors for Radionuclides, Part I, EURATOM-ITAL, Wageningen, p. 11 (1982)

(26) Ng Y.C. et al., Soil-to-Plant Concentration Factors for Radiological Assessments, NUREG/CR-2975 (1982)

(27) Anderson A., Nilsson K.O., Influence on the Levels of Heavy Metals in Soil and Plant from Sewage-Studies used as Fertilizer, Swed. J. Agric. Res. 6, p. 151 (1976)

(28) Furr A.K. et al., Multielement Uptake by Vegetables and Mitlet Grown in Pots on Fly Ash Amended Soil, J. Agr. food Chem. 24, p. 885 (1976)

(29) Furr A.K. et al., Multielement Absorption by Crops grown in Pots on Municipal Sludge Amended Soils, J. Agr. food Chem. 24, p. 889 (1976)

(30) Sartor J.D. et al., Uptake of Radionuclides by Plants, AD-649009, Stanford Research Inst. Mento Park, CA, (1966)

(31) Boerngen J.G., Schachlette H.T., Chemical Analyses of Fruits, Vegetables and their Associated Soils from Areas of Commercial Production in the Conterminous United States, Open-file Report 80-84, U.S. Geological Survey (1980)

(32) Hoffman F.O. et al., Environmental Behaviour of Technetium in Soil and Vegetation, Implications for Radiological Assessment, Environ. Sci. Technol. 16, p. 214 (1982)

(33) Hoffman F.O. et al., Sampling of Technetium-99 in Vegetation and Soils in the Vicinity of Operating Gaseous Diffusion Facilities, ORNL/TM-7386, Oak Ridge National Laboratory, Oak Ridge TN, (1980)

(34) Coughtrey P.J., Thorne M.C., Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems, Vols. 1 - 3, A.A. Balkema Publishers, Rotterdam (1983)

(35) I.U.R. Report on a Workshop on the Measurement of Soils to Plant Transfer Factors for Radionuclides, Parts I + II, EURATOM-ITAL, 6700 AA, Wageningen (1982)

(36) Schreckhise R.G., Cline J.F., Comparative Uptake and Distribution of Plutonium, Americium, Curium and Neptunium in Four Plant Species, Health Physics 38, p. 817 (1980)

(37) Adriano et al., Plutonium, Curium and other Radionuclide Uptake by the Rice Plant from a Naturally Weathered Contaminated Soil, Soil Sci. 132, p. 83 (1981)

(38) White G.C. et al., Factors Affecting Radionuclide Availability to Vegetables grown at Los Alamos, J. Environ. Qual. 10, p. 294 (1981)

(39) Pimpl M., Schuettelkopf H., Transport of Plutonium, Americium and Curium from Soils into Plants by Root Uptake, Nucl. Safety 22, p. 214 (1981)

(40) Evans S., Eriksson A., Uranium, Thorium and Radium in Soil and Crops - Calculations of Transfer Factors, KBS/TR 83-73 (1983)

(41) Generic Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases - Exposures of Critical Groups, Safety Series No. 57, IAEA Vienna (1982)

(42) Schuettelkopf H., Kiefer H., Die Dosisexposition der Umgebungsbevoelkerung durch natuerliches und aus einer uranhaltigen Halde emittiertes Ra-226 und Pb-210, KfK 3282 (1982)

(43) Ng Y.C. et al., Transfer Coefficients for Assessing the dose from Radionuclides in Meat and Eggs, NUREG/CR-2976, (1982)

(44) Ng Y.C., A Review of Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products, Nucl. Safety 23, p. 57 (1982)

(45) General Principle of Calculations for the Radiation Exposure Resulting from Radioactive Effluents in Exhaust Air and in Surface Waters (Guideline under Sec. 45 of the Radiological Protection Ordinance), GRS Koeln, p. 62, 88 (1980)

(46) Bergstroem U., Dose and Dose Commitment Calculations from Groundwaterborne Radioactive Elements Released from a Repository for Spent Nuclear Fuel, KBS 83-49, Appendix B.2, B.3 (1983)

(47) Nuclear Data Sheet, according to Cumulated A-Index, 33(2), (1981)

(48) International Commision on Radiological Protection: Limits for Intake of Radionuclides by Workers, ICRP Publication No. 30, Parts 1 - 3.

(49) Grundwasserkarte des Kantons Aargau, Speich AG Zuerich 1981, Blatt Rheinfelden, Zurzach, Frick, Baden

(50) Hydrologisches Jahrbuch der Schweiz 1979

(51) Hydrogeologische Karte der Schweiz, Geographischer Verlag Bern 1972, Blatt Boezberg-Beromuenster.

(52) Hydrogeologische Karte der Schweiz, Erlaeuterungen, Schweizerische Geotechnische Kommission, Zuerich, p. 14 (1972)

(53) Scheffer F., Schachtschabel P. et al., Lehrbuch der Bodenkunde, 11. Auflage, Enke Stuttgart, p. 203 (1982)

(54) Bodman G.B., Coleman E.A., Soil. Sci. Soc. Amer. Proc. 8, p. 116 (1943)

(55) Atlas der Schweiz, Blatt 12: Klima und Wetter

(56) Die Verdunstung in der Schweiz, Beitraege zur Geologie der Schweiz - Hydrologie, Nr. 25, p. 64 (1978)

(57) Statistische Erhebungen und Schaetzungen ueber Landwirtschaft und Ernaehrung, 57. Jahrheft

(58) Forth W. et al., Pharmakologie und Toxikologie, B.I. - Wissenschaftsverlag Zuerich, 2. Auflage, p. 283 (1977)

(59) Klevers Kalorien-Joule Kompas, Graese und Unzer Verlag Muenchen, 13. Auflage, p. 6

(60) Deutsche Gesellschaft fuer Ernaehrung e. V., Ernaehrungsbericht 1976, Eigenverlag Frankfurt/M 1976

(61) Pinner A.V., Hill M.D., Radiological Protection Aspects of Shallow Land Burial of PWR Operating Wastes, NRPB-R 138, p. 72 (1982)

(62) Wandler R., Landenberger M., Ratschlaege zur Gewichtsreduktion mit Menueplan und Naehrwerttabellen, Verlag Schweizerische Vereinigung fuer Ernaehrung, Bern 1977

(63) Wege zum Nachweis der Sicherheit von Endlagern, NTB 83-03, p. 9f (1983)

(64) Safety Assessment for the Underground Disposal of Radioactive Wastes, IAEA Safety Series Nr. 56, Procedures and Data, Wien 1980

(65) Zurkinden A., Niederer U., Release Scenarios: Water Intrusion as a Normal Case, in: Radionuclide Release Scenarios for Geologic Repositories, Proc. NEA Workshop, Paris 8. - 12. September 1980, p. 143

(66) Hadermann J., Roesel F., NTB in preparation

(67) Zach R., Mayoh K.R., Soil Ingestion by Cattle: A Neglected Pathway, Health Physics 46, p. 426 - 431 (1884)

(68) Wasserversorgung Zuerich, 114. Geschaefts- und Untersuchungsbericht 1982, p. 29

(69) Skarda C., Wasserversorgung Zuerich, private communications

(70) Landwirtschaftliches Handbuechlein, Wirz Verlag Aarau, (1981)