MODELING OF THE TRANSFER OF IODINE AND CESIUM VIA THE GRASS-COW-MILK PATHWAY AFTER THE CHERNOBYL ACCIDENT

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ABSTRACT

More than 60 data sets of time dependent activities of iodine and cesium in grass and milk measured after the Chernobyl accident are evaluated using the concepts of linear compartmental theory. The transfer kinetics can be described by models including two (^{131}I) or three (^{137}Cs) compartments. Calculated weathering half lives and equilibrium transfer coefficients into milk are in the range of values reported in reviews of experimental data based on observations of atomic weapons fallout and on laboratory experiments.

INTRODUCTION

After the Chernobyl accident many measurements of time dependent activities of iodine and cesium isotopes in grass and milk samples were performed. Based on the analysis of 62 datasets [1–15], both the structure of compartmental models which adequately describe the kinetics of the transport of ^{131}I and ^{137}Cs via the gras-cow-milk pathway and numerical values of radioecological parameters are presented in this paper.

CALCULATIONAL METHODOLOGY

From datasets including nuclide concentrations in the milk of single animals both the structures of *minimal* compartmental models which adequately describe the measured transfer kinetics and numerical values of the associated transfer rates were calculated using the concepts of linear compartmental theory [16]. Additionally, equilibrium transfer coefficients grass → milk were calculated. As averaged milk samples do not represent the transfer kinetics of the individual animals [16], for these data sets only equilibrium transfer coefficients could be determined.

RESULTS AND DISCUSSION

Results of the analyses are given in Tab. 1, structures of the minimal compartmental models are shown in Fig. 1. For both nuclides feeding experiments established the existence of a long-term storage compartment [17] which in a part of the datasets of Tab. 1 is not observed. Explanations could be (a) experiments of too short duration, (b) difficulties to resolve processes with numerically small transfer rates from data scattering (especially in the case of experiments with constant nuclide intake), (c) problems to fit experimental data to sums of more than three exponentials [18].
Mean values of weathering half-lives - 5.9 ± 0.7 d (^{131}I) and 9.5 ± 0.9 d (^{137}Cs) - are in good agreement with data given in a previous review [19].
The range of equilibrium transfer coefficients given in Tab. 1 agrees well with nuclear weapons fallout data [20], but their mean values of $(3.8 \pm 0.5) \cdot 10^{-3}$ d/ℓ (^{131}I) and of $(3.4 \pm 0.3) \cdot 10^{-3}$ d/ℓ (^{137}Cs) are lower.

Tab. 1 : Minimal compartmental models, weathering half-lives, $t^{w}_{1/2}$, and equilibrium transfer coefficients, TF, of the data sets analysed

Data-set no.	Site	Nuclide	Model structure [a]	$t^{w}_{1/2}$ [d]	TF [10^{-3} d/ℓ]	
1	Geel	^{131}I	(1)	8.4 ± 0.5	1.1 ± 0.1	ref. 1
2	Uenzen	^{131}I	(3)	5.7 ± 0.8	3.8 ± 0.4	ref. 12
3	Uppsala	^{131}I	(1)	18.8 ± 9.2	6.4 ± 1.2	ref. 3
4	Uppsala	^{131}I	(1)	18.8 ± 9.2	4.7 ± 0.8	ref. 3
5	Uppsala	^{131}I	(1)	18.8 ± 9.2	3.5 ± 0.6	ref. 3
6	Uppsala	^{131}I	(1)	18.8 ± 9.2	4.8 ± 0.9	ref. 3
7	Uppsala	^{131}I	(1)	18.8 ± 9.2	5.0 ± 0.8	ref. 3
8	Uppsala	^{131}I	(1)	18.8 ± 9.2	4.5 ± 0.8	ref. 3
9	Uppsala	^{131}I	(1)	18.8 ± 9.2	5.1 ± 0.9	ref. 3
10	Uppsala	^{131}I	(1)	18.8 ± 9.2	5.2 ± 0.8	ref. 3
11	Neuherberg	^{131}I	(1)	- [b]	8.2 ± 0.8	ref. 3
12	Neuherberg	^{131}I	(1)	- [b]	5.9 ± 0.5	ref. 3
13	Neuherberg	^{131}I	(1)	- [b]	8.4 ± 0.7	ref. 9
14	Geel	^{137}Cs	(2a),(2b) [d]	25.5 ± 10 [c]	1.8 ± 0.1	ref. 1
15	Uenzen	^{137}Cs	(3)	9.7 ± 1.1	7.0 ± 0.8	ref. 12
16	Uppsala	^{137}Cs	(1)	20.7 ± 4.3	1.9 ± 0.1	ref. 3
17	Uppsala	^{137}Cs	(1)	20.7 ± 4.3	2.0 ± 0.1	ref. 3
18	Uppsala	^{137}Cs	(1)	20.7 ± 4.3	1.8 ± 0.1	ref. 3
19	Uppsala	^{137}Cs	(1)	20.7 ± 4.3	1.3 ± 0.1	ref. 3
20	Uppsala	^{137}Cs	(1)	20.7 ± 4.3	1.6 ± 0.1	ref. 3
21	Uppsala	^{137}Cs	(1)	20.7 ± 4.3	1.6 ± 0.1	ref. 3
22	Uppsala	^{137}Cs	(3)	20.7 ± 4.3	2.5 ± 1.7	ref. 3
23	Uppsala	^{137}Cs	(1)	20.7 ± 4.3	1.7 ± 0.1	ref. 3
24	Uppsala	^{137}Cs	(3)	20.7 ± 4.3	2.5 ± 0.9	ref. 3
25	Uppsala	^{137}Cs	(3)	20.7 ± 4.3	1.9 ± 0.2	ref. 3
26	Uppsala	^{137}Cs	(1)	24 ± 11	6.5 ± 1.0	ref. 3
27	Uppsala	^{137}Cs	(1),(3) [d]	24 ± 11	7.4 ± 1.1	ref. 3
28	Uppsala	^{137}Cs	(1)	24 ± 11	7.2 ± 0.9	ref. 3
29	Uppsala	^{137}Cs	(1)	24 ± 11	6.4 ± 1.0	ref. 3
30	Uppsala	^{137}Cs	(1)	24 ± 11	6.1 ± 0.8	ref. 3
31	Uppsala	^{137}Cs	(1),(3) [d]	24 ± 11	7.9 ± 3.9	ref. 3
32	Uppsala	^{137}Cs	(1)	24 ± 11	7.6 ± 1.1	ref. 3
33	Uppsala	^{137}Cs	(1)	24 ± 11	8.6 ± 1.1	ref. 3
34	Uppsala	^{137}Cs	(1)	24 ± 11	6.5 ± 1.3	ref. 3
35	Uppsala	^{137}Cs	(1)	24 ± 11	6.3 ± 0.8	ref. 3
36	Grangeneuve	^{137}Cs	- [e]	- [b]	6.3 ± 1.4	ref. 7
37	Grangeneuve	^{137}Cs	- [e]	- [b]	3.2 ± 0.5	ref. 7
38	Neuherberg	^{137}Cs	(3)	- [b]	- [f]	ref. 9
39	Neuherberg	^{137}Cs	(3)	- [b]	4.1 ± 1.1	ref. 9
40	Neuherberg	^{137}Cs	(3)	- [b]	3.0 ± 0.2	ref. 9
41	Saclay	^{137}Cs	(3)	- [b]	10.7 ± 1.1	ref. 4

(continued on next page)

Tab. 1 : (continued)

Data-set no.	Site	Nuclide	Model structure [(a)]	$t^{w}_{1/2}$ [d]	TF [10^{-3} d/ℓ]	
42	Saclay	^{137}Cs	(3)	- [(b)]	10.0 ± 1.0	ref. 4
43	Trawsgoed	^{137}Cs	(3)	- [(b)]	4.6 ± 0.1	ref. 5
44	Trawsgoed	^{137}Cs	(3)	- [(b)]	6.4 ± 1.4	ref. 5
45	Chester	^{131}I	- [(g)]	7.5 ± 1.1	1.2 ± 0.2	ref. 2
46	Tranvik	^{131}I	- [(g)]	4.5 ± 1.1	1.4 ± 0.2	ref. 1
47	Berlin	^{131}I	- [(g)]	8.7 ± 1.1 [(h)]	6.5 ± 0.3	ref. 1
48	Tokai	^{131}I	- [(g)]	12.2 ± 5.6	4.3 ± 0.5	ref. 1
49	Mariensee	^{131}I	- [(g)]	13.3 ± 4.8	2.2 ± 0.3	ref. 10
50	Bonn	^{131}I	- [(g)]	9.8 ± 1.6	4.6 ± 1.1	ref. 11
51	Russy	^{131}I	- [(g)]	4.5 ± 1.0	3.5 ± 0.9	ref. 8
52	Guschelmuth	^{131}I	- [(g)]	3.6 ± 0.2	2.0 ± 0.4	ref. 8
53	Cumbria	^{131}I	- [(g)]	6.8 ± 1.7	2.7 ± 0.1	ref. 6
54	Faulensee	^{131}I	- [(g)]	5.8 ± 0.7 [(k)]	2.6 ± 0.3	ref. 13
55	Tranvik	^{137}Cs	- [(g)]	8.7 ± 1.3	8.6 ± 1.2	ref. 1
56	Berlin	^{137}Cs	- [(g)]	8.7 ± 1.2 [(h)]	8.3 ± 0.7 [(i)]	ref. 1
57	Mariensee	^{137}Cs	- [(g)]	11.2 ± 1.0 [(j)]	3.0 ± 0.4	ref. 10
58	Bonn	^{137}Cs	- [(g)]	16.6 ± 4.3 [(c)]	3.1 ± 0.7	ref. 11
59	Cumbria	^{137}Cs	- [(g)]	7.1 ± 0.5	4.8 ± 0.2	ref. 6
60	Faulensee	^{137}Cs	- [(g)]	12.9 ± 2.2 [(k)]	3.5 ± 0.3	ref. 13
61	Petten	^{137}Cs	- [(g)]	- [(b)]	2.9 ± 0.8	ref. 14
62	Petten	^{131}I	- [(g)]	- [(b)]	8.5 ± 6.2	ref. 15

[(a)] see Figure 1
[(b)] experiments using fodder with constant activity concentrations
[(c)] mean half-live assuming model (2a)
[(d)] based on the Akaike information criterion [21], no decision is possible between the two model candidates
[(e)] model identification not possible as animal had incorporated Cs prior to the feeding experiment
[(f)] statistical uncertainty of 3-compartment-model > 100 %
[(g)] model identification not possible as milk samples were mixed from various cows [16]
[(h)] mean of the pasture vegetations used as feed
[(i)] milk data until day 37 taken into account
[(j)] grass data until day 45 taken into account
[(k)] 1st cut

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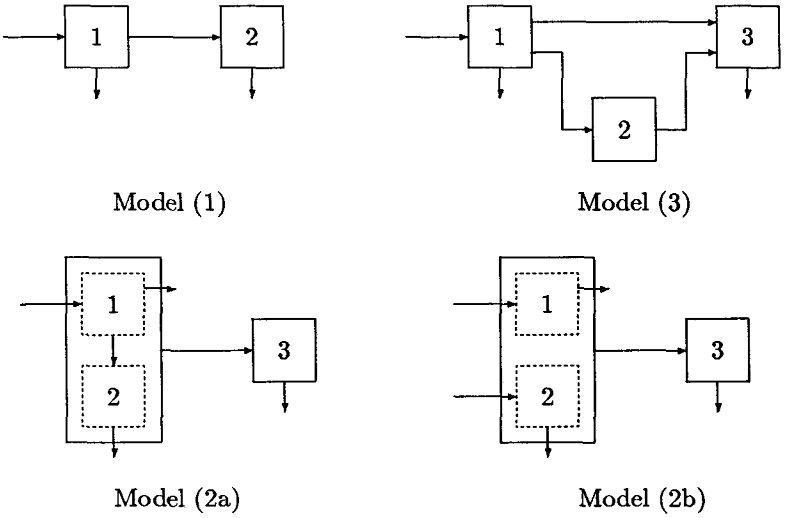

Fig. 1 : Structures of compartmental systems compatible with the experimental data

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