RADIONUCLIDE TRANSFER OF SR, CS, CO, AND MN TO PLANTS GROWN ON SOILS WITH DIFFERENT PHYSICAL AND CHEMICAL PROPERTIES AND FROM DIFFERENT SITES AT ESCHWEILER, GORLEBEN, BIBLIS, AND STADE, F.R.G.

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In the vicinity of nuclear facilities, the soil types used agriculturally differ widely with respect to their physical and chemical properties. These soil properties, especially pH, clay and organic carbon content, and exchangeable calcium, influence the availability of radionuclides deposited on the soil, and subsequently also the soil-plant radionuclide transfer. Results from literature /1/2/3/ and from own lysimeter experiments /4/5/ show a considerable variation of the radionuclide transfer, mainly due to the different soil properties. To evaluate this variation for Sr-85, Cs-137, Co-60, and Mn-54 within one site and between several sites, a pot experiment with different soils from four different sites in the Federal Republic of Germany was conducted.

EXPERIMENTAL PROCEDURE

In this experiment 12 different soils (Ap-horizon) representing peaty, clayey, loamy, and sandy types were used: one soil each from the region of Eschweiler (soil No. 1.1) and from the future storage facility site at Gorleben (soil No. 2.1) and 6 and 4 soils, respectively, from the nuclear power station sites at Biblis (soils No. 3.1 - 3.6) and Stade (soils No. 4.1 - 4.4). These soils are differing widely with respect to their physical and chemical properties. The characterization of the soils and their major physical and chemical properties are presented in table 1.

The radionuclides, carrier-free Sr-85, Cs-137, Co-60, and Mn-54 in chloride form, were mixed into the soil uniformly. The radioactivity per kg of soil amounted to 206 KBq for Sr-85, 470 KBq for Cs-137, 394 KBq for Co-60, and 180 KBq for Mn-54. The contaminated soils were filled into dubble wall experimental pots: 8 kg per pot and 8 replicates per soil type. The soils were fertilized with a complex fertilizer (10 % N, 10 % P_2O_5, 17 % K_2O, 2 % MgO) before cultivation of each crop at a rate of 1 g/kg. Soil humidity was controlled at least three times per week and regulated at 50 % of maximum water capacitiy.

The experiment was conducted in a cold green house. The following plants were grown in a 2 years crop rotation: Spring wheat, lettuce, potatoes, and beans (phaseolus vulgaris). The crops were harvested being ready for consumption, dryed and ground. Aliquots of this plant material were measured in a well type Ge(Li)-detector. The results presented as radioactivity concentration (Bq/g dry plant material) were computed statistically. The significance of differences was checked using t-test.

RESULTS AND DISCUSSION

Normally, the transfer factor is used to indicate the entrance of radionuclides from soils via plants into food chains. However, transfer factors based on results from pot experiments generally do not deliver realistic values to estimate the irradiation of man due to ingestion /6/. Therefore, the magnitude of radionuclide transfer from soil to plants is reported as radioactivity concentration measured in distinct plant parts and presented as Bq/g dry plant material. In spring wheat grain and potatoe tubers a lower radioactivity concentration was measured for Sr-85, Cs-137, Co-60, and Mn-54 than in lettuce (Table 2-4). Considering the radioactivity amount applied per kg of dry soil, the lowest concentration was found for Co-60. For the other radionuclides increasing values were registered in the range Cs-137 - Mn-54 - Sr-85.

Table 1: Origin, characterization, and major physical and chemical properties of the soils (Ap horizon)

Soil No.	Origin and site		Characterization	Clay <2 µm %	Silt 2-60 µm %
1.1	Eschweiler (NRW)		Typic hapludalf	12.0	82.6
2.1	Gorleben		Plaggeptic haplohumod	2.6	5.1
3.1	Rhein, km 453,	Biblis	Mollic udifluvent	13.3	25.2
3.2	Griesheim,	"	Alfic udipsamment	6.4	10.4
3.3	Weilerhof,	"	Typic eutrochrept	24.4	22.5
3.4	Wattenheim,	"	Aquic hapludoll	17.1	26.3
3.5	St. Stephan,	"	Lithic udipsamment	3.4	8.5
3.6	Nuclear power Stn.,	"	Typic haplaquoll	17.6	20.7
4.1	Schloß Agathenburg,	Stade	Histic humaquept	0.7	22.7
4.2	Barnkrug,	"	Aquic udifluvent	19.8	60.2
4.3	Hammah,	"	Plaggeptic udipsamment	8.6	20.0
4.4	Brobergen,	"	Plaggeptic haplohumod	2.4	1.9

Soil No.	Fine sand 60-200 µm %	Med./coarse sand 200-2000 µm %	Total C %	pH($CaCl_2$)	Exchange capacity meq/100 g of soil	Ca^{++} meq/100 g of soil	K^+ meq/100 g of soil
1.1	4.0	1.4	1.4	6.2	11.2	11.8	0.8
2.1	32.1	60.2	1.1	4.7	6.2	0.8	0.2
3.1	23.9	37.6	1.4	7.5	15.7	12.2	0.7
3.2	70.9	12.2	0.8	6.7	6.8	5.6	0.5
3.3	42.5	10.6	1.3	7.4	14.3	12.3	0.9
3.4	23.1	33.5	1.1	7.4	11.9	10.1	0.8
3.5	74.1	14.1	0.4	7.6	3.3	2.0	0.3
3.6	19.5	42.2	1.1	7.4	13.2	8.7	1.3
4.1	25.0	47.7	14.7	5.2	66.2	55.0	0.3
4.2	19.0	1.0	2.5	7.2	17.6	15.3	0.1
4.3	36.6	34.9	2.1	4.1	10.0	1.7	0.2
4.4	19.2	76.5	2.7	4.3	6.6	2.6	0.1

The mean values for the radioactivity in the edible plant parts computed from 8 replicates of one soil show a low variation with one exception (Co-60 in lettuce, Table 2-4). However, a partly considerable variation can be observed between the radioactivity concentrations in plants from different soils of one site. For Sr-85 and Cs-137 this variation is in the same order at the sites of Biblis and Stade, but for Co-60 and Mn-54 the variation is considerably higher in plants grown on soils from the site of Stade. Probably this is due to the wide variation of the physical and chemical soil properties (Table 1).

Between the different sites, for Sr-85, the radioactivity concentration in plants shows only a low variation, whereas for the other radionuclides increasing differences in the range Co-60 - Mn-54 - Cs-137 are determined (Table 2-4). Comparing all radioactivity concentrations of one radionuclide determined in edible plant parts produced on 12 different soils from 4 different sites, considerable differences can be registered reaching factors of 9-15 for Sr-85, 36-122 for Mn-54, 23-233 for Co-60, and 119-507 for Cs-137. For all radionuclides differences amounting a factor of 2 or more are significant (P = 1 %) or highly significant (P = 0,1 %).

Table 2: Transfer of Sr-85, Cs-137, Co-60, and Mn-54 from soils with different physical and chemical properties to spring wheat grain

Soil No.	Dry matter %	Bq/g plant dry matter											
		Sr-85			Cs-137			Co-60			Mn-54		
		x̄		s	x̄		s	x̄		s	x̄		s
1.1	94.0	23.6	±	1.64	2.86	±	0.27	1.04	±	0.11	109	±	8.99
2.1	95.2	43.2	±	8.22	104	±	7.61	56.0	±	10.2	1613	±	125
3.1	94.1	13.0	±	0.83	9.42	±	0.60	0.42	±	0.04	35.1	±	4.01
3.2	93.9	35.5	±	4.64	3.32	±	0.28	1.43	±	0.20	62.5	±	4.75
3.3	94.5	9.33	±	0.95	0.46	±	0.07	1.15	±	0.32	37.7	±	5.90
3.4	93.0	10.4	±	0.62	1.12	±	0.13	2.65	±	0.16	53.6	±	5.63
3.5	95.5	31.0	±	5.47	4.72	±	0.37	3.53	±	0.32	79.9	±	9.25
3.6	94.5	4.98	±	0.73	1.13	±	0.11	1.51	±	0.24	62.1	±	8.65
4.1	95.7	12.0	±	1.65	97.6	±	7.60	1.03	±	0.19	156	±	16.3
4.2	97.1	10.7	±	1.34	47.7	±	2.89	0.24	±	0.03	17.6	±	1.23
4.3	96.9	37.9	±	3.19	14.6	±	1.33	18.8	±	5.07	399	±	34.3
4.4	96.5	45.2	±	5.14	233	±	11.1	7.32	±	1.84	970	±	60.5

Table 3: Transfer of Sr-85, Cs-137, Co-60, and Mn-54 from soils with different physical and chemical properties to lettuce

Soil No.	Dry matter %	Bq/g plant dry matter											
		Sr-85			Cs-137			Co-60			Mn-54		
		x̄		s	x̄		s	x̄		s	x̄		s
1.1	5.58	792	±	109	40.1	±	11.9	6.38	±	1.65	137	±	12.0
2.1	6.01	2399	±	115	549	±	73.2	241	±	39.3	2251	±	332
3.1	4.40	498	±	27.8	76.6	±	6.27	7.61	±	0.82	33.6	±	4.60
3.2	5.65	951	±	121	38.2	±	6.55	15.2	±	4.20	113	±	16.7
3.3	5.43	378	±	46.3	6.75	±	1.39	5.13	±	0.77	28.2	±	3.72
3.4	5.14	708	±	67.3	24.3	±	7.35	14.1	±	3.02	79.6	±	9.76
3.5	5.68	1054	±	119	56.5	±	5.71	34.5	±	12.2	128	±	20.8
3.6	4.76	156	±	9.97	13.7	±	1.84	10.1	±	1.32	55.4	±	5.10
4.1	5.38	313	±	33.7	142	±	23.0	12.4	±	3.18	235	±	33.3
4.2	5.32	336	±	24.4	251	±	46.0	5.04	±	0.93	18.4	±	1.87
4.3	5.76	1601	±	249	130	±	12.3	50.0	±	7.85	597	±	158
4.4	4.71	1828	±	248	802	±	140	93.3	±	16.6	1970	±	314

The highest radioactivity concentrations for all radionuclides investigated are measured in crops grown on sandy soils with low pH values, low clay and exchangeable calcium content and low exchange capacity (soils No. 2.1, 4.4, 4.3, Table 2-4). In crops from soils with high pH values, high contents of clay and exchangeable calcium, and high exchange capacity low radioactivity concentrations are found (soils No. 3.3, 3.4, 3.6, 4.2, Table 2-4), as it is also observed in crops grown on a peaty soil with high content of organic carbon, low clay but high exchangeable calcium content and exchange capacity (soil No. 4.1, Table 2-4). As a fourth crop beans (phaseolus vulgaris) are grown on these soils. These results will be presented in the poster.

Table 4: Transfer of Sr-85, Cs-137, Co-60, and Mn-54 from soils with different physical and chemical properties to potatoe tubers

Soil No.	Dry matter %	Bq/g plant dry matter Sr-85 $\bar{x}$	s	Cs-137 $\bar{x}$	s	Co-60 $\bar{x}$	s	Mn-54 $\bar{x}$	s
1.1	21.4			9.66 ±	0.91	6.55 ±	0.63	9.50 ±	1.04
2.1	21.3			148 ±	19.1	74.0 ±	9.78	96.8 ±	11.1
3.1	22.6			11.4 ±	1.33	8.84 ±	1.20	5.33 ±	0.39
3.2	21.5			14.5 ±	0.96	11.4 ±	1.22	7.73 ±	0.77
3.3	21.4	not		2.89 ±	0.36	7.68 ±	1.43	4.15 ±	0.78
3.4	22.0	detectable		8.58 ±	1.20	11.7 ±	1.36	5.38 ±	0.86
3.5	22.6	due to decay		15.8 ±	1.22	16.5 ±	2.54	11.5 ±	1.86
3.6	23.2			4.11 ±	0.69	6.24 ±	1.04	3.47 ±	0.73
4.1	22.5			23.3 ±	2.84	5.55 ±	0.56	10.1 ±	0.46
4.2	20.9			37.6 ±	5.91	3.26 ±	0.31	2.72 ±	0.20
4.3	20.8			43.2 ±	4.38	32.7 ±	4.25	35.1 ±	2.35
4.4	20.8			358 ±	40.7	54.3 ±	5.91	67.6 ±	8.41

CONCLUSIONS

According to these results the availability of radionuclides for plant roots in the soil is variing in dependence on pH, clay, calcium, and organic carbon content,and exchange capacity. In all crops the highest variation can be observed for Cs-137, and a lower variability for the other radionuclides decreasing in the range Co-60 - Mn-54 - Sr-85. Furthermore, the results of this experiment indicate, that within one nuclear facility site and between two different sites the possible variation for the radionuclide transfer from soil to plant might amount one order of magnitude each due to the different soil properties. In addition there is a variation of one order of magnitude caused by the plant species. These findings are in accordance with results from literature /1/2/.

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