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Uptake and transfer factors of ^{137}Cs by mushrooms*

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Summary. The ^{137}Cs content of 118 species (668 samples) of higher fungi collected in the period from August 1984 to October 1989 at three different locations in Styria, Austria, was determined by gamma-spectrometry. The Cs-content of most mushrooms has been increasing since September 1986. In order to find out which factors determine the ^{137}Cs-contamination of mushrooms and the transfer-value soil to mushroom, the concentration of total and plant-available radiocesium in soils as well as the pH-value, the content of humus, clay, silt, sand, exchangeable cations, the composition of the clay minerals, and the particle size distribution of the soils of two different locations were examined. The higher the ^{137}Cs contamination of the soil, the thicker the layer of humus and the higher the content of humus, the lower the pH-value, and the lower the amount of essential cations, especially of K^+, the higher the amount of ^{137}Cs plant-available will be. Therefore, the contamination of the mushrooms in the coniferous forest of Koralpenblick (1000 m) is higher than in the mixed forest at the Rosenberg around Graz at approx. 500 m height. Of 26 different species of mushrooms measured at both sites, only 61% show the highest TF-values soil to mushrooms also at the Koralpenblick. In the spruce forest at Koralpenblick there are many species of mushrooms with high ^{137}Cs-contamination which were not found at the Rosenberg. However, the properties of the species to which a mushroom belongs are more important than environmental conditions and soil properties. The transfer values of ^{40}K stay within narrow bounds, whereas those of ^{137}Cs differ widely.

Introduction

Aboveground nuclear tests gave rise to large amounts of radioactive fallout.

Radioactive contamination culminated in 1964. Due to the long half-lifes of ^{137}Cs and ^{90}Sr, the cumulative deposition decreased to just below 80% of the highest values until 1986. In the mid 1960s, certain species of mushrooms were found to accumulate radionuclides, especially ^{137}Cs (Grüter 1967, 1971;

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Kiefer and Maushart 1965; Rohleder 1967). Different species of mushrooms take up varying amounts of ^{137}Cs (Grüter 1967, 1971; Haselwandter 1977, 1978; Eckl et al. 1986, Gerzabek et al. 1988). Comprehensive studies on the content of naturally occurring cesium in higher fungi were persued by Seeger and Schweinshaut (1981). The reactor accident of Chernobyl drew the public's attention again to man-made radioactivity in mushrooms. A series of papers (Nimis et al. 1986; Elstner et al. 1987, 1989; Heinrich 1987; Rantavaara 1987; Rückert and Diehl 1987; Seeger 1987; Mascanzoni 1988; Teherani 1988; Byrne 1988; Gerzabek et al. 1988; Gratza and Seitz 1988, 1989; Henrich et al. 1988; Heinrich et al. 1989a, b; Bem et al. 1990, Rückert et al. 1990) dealt with this subject.

This paper reports on the results of measurements carried out on mushrooms in Styria over four vegetation periods. Furthermore, the transfer factors soil to mushroom and soil properties have been studied in depth.

Material and methods

The ^{137}Cs radioactivity of mushroom samples collected at three different locations in Styria were measured by means of a NaJ-crystal-detector (LKB) or a Ge(Li)-detector. Soil samples were taken from the sampling sites to allow determination of ^{137}Cs transfer factors. The ^{137}Cs transfer factors were calculated as: TF = Bq ^{137}Cs (fresh weight): Bq ^{137}Cs/kg soil (dry weight).

For measurement of samples with the NaJ-detector small plastic tubes were used, for the Ge(Li)-detector a one litre Marinelli-cup. For most of the samples, the flesh of the cup, the gills (spore-bearing hymenium) and the stalk were measured separately. The mean of these three values is taken as total concentration of the mushrooms. It is assumed that the various parts of the mushrooms contribute equally to the total weight, what of course is not the case for every species.

The soil samples were examined at the Institut für Mineralogie und Technische Geologie of the Technische Universität Graz. The particle size distribution was determined by sieving, sedimentation and centrifugation. X-ray spectrometry of <2 mm fraction was carried out according to Ahamer et al. (1989). The analyses of the contents of humus, clay, silt, sand, and of the exchangeable cations were done according to Blum et al. (1986), ÖNORM L 1061, and ÖNORM L 1081. The cation contents were measured with the help of a plasma emission spectrometer (Perkin Elmer Plasma II). Samples of the soil next to every mushroom fruit body were used for pH-determination. PH-value was measured according to ÖNORM L 1083. For determination of the plant available ^{137}Cs, soil samples were suspended in 1 n NH_4Cl and shaken for 24 h. After removal of the pellet by centrifugation the solution was adjusted to pH 3 with HCl and measured for 30 min.

The location Rosenberg is a mixed forest with *Fagus sylvatica*, *Quercus petraea*, *Castanea sativa*, *Carpinus betulus*, and *Pinus sylvestris* at a height of about 500 m northeast of Graz. Another collection site is around Herkhütte (800 m) with a mixed forest composed of *Picea abies*, *Pinus sylvestris*, *Larix decidua*, *Fagus sylvatica*. The forests around Koralpenblick (1000 m) are composed of *Picea abies*, *Abies alba*, and occasionally *Fagus sylvatica*. The two last-mentioned sites are only a few kilometres apart, located in a highly contaminated area between Deutschlandsberg and the so-called Weinebene in the

Table 1. Total ^{137}Cs in Bq/kg d.w. and plant-available ^{137}Cs in Bq/kg d.w. and in percent of the total cesium of soil samples from Rosenberg (15. 10. 1989) and from Koralpenblick (27. 10. 1989)

Dept in cm	^{137}Cs total	^{137}Cs plant-available	in %
Rosenberg:			
0–1	4478	137	3
1–2	4714	196	4.2
2–3	3715	39	1
3–4	1022	31	3
5–6	258	1	0.4
Koralpenblick:			
litter	2542	419	16.5
0–1	9260	1671	18
1–2	4260	1153	27
2–3	1570	528	34
3–4	836	198	23.7
4–7	105	10	9.5
7–10	34	12	35

Koralpen. The samples taken before Chernobyl were collected at some locations about 70 km west of Graz. Species determination was carried out after Cetto (1980a, b, 1983, 1984) and Michael et al. (1983a, b, 1985, 1986).

Results

Contamination of soils after Chernobyl

^{137}Cs-values of decreasing soil depth from a mixed forest of Rosenberg (15. 10. 1989) and from a coniferous forest of Koralpenblick (27. 10. 1989) were compared (Table 1). Table 1 also shows the values of plant-available ^{137}Cs in Bq/kg soil and in % of total cesium. Up to a depth of 3 cm, the soil sample collected at Rosenberg shows almost equal ^{137}Cs-contamination. At a depth of 4 to 7 cm, only 1% of the activity measured in the first cm was found in the soil of Koralpenblick, the activity was highest in the first cm and decreased rapidly with increasing depth. The high amount of ^{137}Cs-activity in the first cm is probably due to subsequent supply of ^{137}Cs through dropped needles and leaching of ^{137}Cs from needles and bark. At the location Rosenberg, most of the activity reached the soil after defoliation in fall 1986. As a whole, the soil sample of Rosenberg contained less total ^{137}Cs than that of Koralpenblick. This also applies to the plant-available ^{137}Cs content. Plant-availability was determined by methods applicable to higher plants. However, most mushrooms show a clearly greater Cs-uptake than higher plants.

Following, the soil properties are examined more closely to explain which parameters contribute to the varying availability of radiocesium (Table 2). The supply with essential cations is higher in the soil of the mixed forest at Rosenberg, than in the one of Koralpenblick. The K^+-content is approximately two times

Table 2. PH, exchangeable cations, content of humus, clay, silt, and sand in soils of Rosenberg and Koralpenblick. Mineral content and amorphous remainder in percent, in the fraction <2 μm

Location	*Rosenberg*		*Koralpenblick*	
horizon	A	B	A	B
$pH(CaCl_2)$	4.2	3.3–3.5	2.8	3.1
mval/100 g of soil				
K	1.8	0.6	1	0.4
Na	0.08	0.06	0.12	0.07
Ca	39.7	6.3	3.4	0.4
Mg	6.2	2.2	2.2	0.7
Cations	47.7	9.1	6.3	1.6
CEC*	20.7	9.2	12.3	8.6
Humus content %	14.2	4.4	28.7	11.5
Content in %	A+B	A+B		
Clay (<2 μm)	16.5	20.2		
Silt (2–63 μm)	26.8	54		
Sand (>64 μm)	56.7	25.7		
Horizon	A	B	A	B
Amorphous fraction	89	83	88	80
Quartz	4	5	7	7
Plagioklase	1	1.2	–	1
Calcite	2	0.2	0.2	0.2
Montmorillonite	0.2	0.5	0.3	0.4
Muscovite+illite	3	3.3	4	4
Chlorite	1	2.3	1	1
Kaolinite	–	5.2	0.4	7
Sum of four Clay minerals	4.2	11.3	5.7	12

* Cation Exchange Capacity ($\sum H^+, K^+, Na^+, Ca^{++}, Mg^{++}$)

higher, the Mg^{++}-content three times, and the content of Ca^{++} is nearly 12 times higher at Rosenberg than at Koralpenblick. Whereas in many experiments the content of magnesium had nearly no effect on the K-uptake by the plants and on the Cs-availability (Gerzabek et al. 1989), potassium acts sometimes as competitor for the cesium-uptake (Jackson et al. 1965). Weak, but significant correlations with Cs-uptake were also found by Boikat et al. (1985) for total potassium. The thicker layer and the higher content of humus, the lower pH-value, the lower amount of essential cations, especially of K^+, lead to a higher contamination of the mushrooms in the forest of Koralpenblick. On the other hand the lower amount of sand and the higher content of clay and silt are said to lead to the contrary effect.

X-ray diffraction was employed to determine the mineral composition of both soils (Table 2). The A and B horizons of soils from Rosenberg and Koralpenblick show similar contents of various minerals and of the four clay minerals with high affinity to Cs. Montmorillonite and muscovite influence the TF-values more than chlorite and kaolinite. Muscovite possesses a stronger resorption capacity of cesium than montmorillonite.

An important role in Cs-uptake by plants is attributed to the amount of small particle size fraction (Boikat et al. 1985). According to Ahamer et al. (1989),

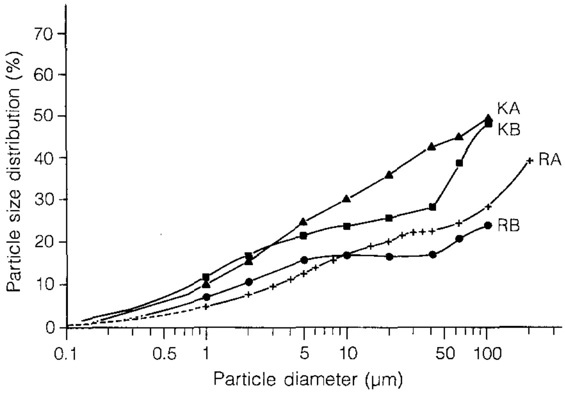

Fig. 1. Particle size distribution in A and B horizons of soils from Koralpenblick (K) and Rosenberg (R), plotted as integral curve

more than 50% of ^{137}Cs are bound by particles smaller than 2 mm, 90% by particles smaller than 20 mm. In the A and B horizons of Koralpenblick, particle size fraction ranging from 0.5 to 20 mm is slightly higher than in the horizons of Rosenberg (Fig. 1).

^{137}Cs-contents of mushrooms before Chernobyl

Even before Chernobyl mushrooms contained varying amounts of radionuclides as a result of aboveground nuclear weapon tests. The highest value of 28 samples collected 70 km west of Graz before Chernobyl (August to September 1984) showed *Paxillus involutus* with 2141 Bq/kg d.w., corresponding to approx. 190 Bq/kg f.w. Since the forest soil of this region showed 48 Bq in August 1984, the transfer value (TF) is 3.9. The values of *Suillus grevillei* were 333 Bq/kg d.w., 28 Bq/kg f.w., TF = 0.58; that of *Lactarius rufus* were 266, 26, TF = 0.5.

^{137}Cs-radioactivity of mushrooms after Chernobyl

The impact of the reactor accident of Chernobyl on the ^{137}Cs-values of mushrooms is demonstrated by measurement of various kinds of mushrooms collected at three locations. The collection sites Koralpenblick and Herkhütte are only a few kilometres apart, but Koralpenblick lies higher and is slightly more contaminated. The ^{137}Cs-activity of soil can vary widely within one forest because of the umbrella effect of trees. In 1989, soil samples from up to 10 cm depth next to every mushroom collected at Herkhütte and Koralpenblick were taken. However, the transfer factors are based on the average values of soil contaminations, because a sample of soil taken immediately next a mushroom must not represent the contamination of the soil layer on which the main part of the mycelium grows. The values were 832 ± 317 Bq/kg d.w. at Rosenberg (10 measurements), 2307 ± 1687 at Herkhütte (26 measurements) and 3196 ± 3933 at Koralpenblick (23 measurements).

Different species of mushrooms show varying degrees of ^{137}Cs-contamination. This also applies to different species of the same genus; e.g.

some species of *Lactarius (L. glyciosmus, L. pergamenus, L. piperatus, L. vellereus* and *L. volemus)* show low levels of contamination, whereas other like *L. blennius, L. camphoratus, L. chrysorrheus, L. cilicioides, L. lignyotus, L. necator, L. porninsis, L. rufus, L. torminosus* and *L. trivialis* are highly contaminated. Many species *of Russula*, among them most edible species, are hardly contaminated. *Russula emetica* shows high Cs-values. According to Eckl et al. (1986), however, this was already the case before Chernobyl. The genus *Boletus* was found to have lower values. Only some samples of *Boletus edulis* showed a higher degree of contamination. While *Leccinum scabrum* and *L. testaceoscabrum* had mostly low Cs-values in 1986, an increase in contamination was noticed in the following years. Most of the species of *Suillus (S. bovinus, granulatus, grevillei, luteus, variegatus)* examined were found to be 3 times more contaminated than the various species of *Boletus (B. edulis, erythropus, pinicola)*. Even higher Cs-values were measured in different *Xerocomus* species. Already since the 1960s, *Xerocomus badius*, a popular edible mushroom, has been known to be highly contaminated. However, other species of *Xerocomus (X. chrysenteron)* have still higher Cs-values. Low values were found in all saprotrophic mushrooms, such as *Agaricus arvensis, A. langei, A. silvaticus, Coprinus atramentarius, C. comatus, Lycoperdon perlatum* and *Macrolepiota procera*. The EC limit of 600 Bq/kg was exceeded by 13.5% of the samples of the mushrooms at the Rosenberg and by 56.7% at Herkhütte/Koralpenblick.

Highly contaminated mushrooms from highly contaminated soils have sometimes lower transfer factors than hardly contaminated mushrooms from soils with low Cs-concentration. This is partly due to the fact that most ^{137}Cs is often contained in the top cm of soil and is therefore not available to some mushrooms.

^{137}Cs-transfer of mushrooms from Rosenberg

73.8% of the collected species from Rosenberg showed TF values (the classification is based on the mean TF value of all measurements; the below limits have been assumed in an arbitrary manner); between

0–0.25 (73.8%): *2 (measurements) Agaricus arvensis 0.12, 4 Amanita citrina 0.1, 7 A. muscaria 0.04, 3 A. pantherina 0.11, 8 A. rubescens 0.03, 1 A. strobiliformis 0.05, 3 Armillariella mellea 0.05, 11 Boletus edulis 0.2, 12 Cantharellus cibarius 0.06, 1 Clavaria fennica 0.07, 2 Coprinus atramentarius 0.02, 6 C. comatus 0.08, 2 Hygrocybe conica 0.1, 2 Lactarius badiosanguineus 0.22, 2 L. glyciosmus 0.07, 1 L. mitissimus 0.09, 5 L. piperatus 0.13, 4 L. vellereus 0.03, 8 L. volemus 0.06, 6 Leccinum testaceoscabrum 0.19, 4 Lycoperdon perlatum 0.22, 10 Macrolepiota procera 0.05, 2 Paxillus atrotomentosus 0.08, 2 Piptoporus betulinus 0.12, 1 Ramaria rufescens 0.05, 3 Russula aeruginea 0.1, 2 R. atropurpurea 0.14, 2 R. azurea 0.14, 8 R. cyanoxantha 0.04, 3 R. delica 0.02, 8 R. foetens 0.05, 4 R. integra 0.02, 3 R. mairei 0.02, 5 R. nigricans 0.07, 3 R. obscura 0.04, 2 R. ochroleuca 0.25, 4 R. olivacea 0.05, 2 R. pectinata 0.07, 9 R. vesca 0.03, 6 R. virescens 0.03, 2 R. xerampelina 0.04, 1 Sparassis crispa 0.12, 1 S. laminosa 0. 3 Tricholoma saponaceum 0.04, 9 Xerocomus subtomentosus 0.16.*

0.26–0.5 (9.8%): *6 Clitocybe nebularis 0.34, 1 Hydnum repandum 0.34, 18 Leccinum scabrum 0.48, 2 Russula chlaroflava 0.31, 6 Scleroderma vulgare 0.32, 3 Xerocomus badius 0.29.*

0.51–1.0 (8.2%): *2 Clitocybe gibba 0.75, 2 Cortinarius sebaceus 1.0, 4 Suillus grevillei 0.84, 3 Xerocomus spadiceus 0.69, 7 X. chrysenteron 1.0.*
1.01–2 (4.9%): *6 Suillus bovinus 1.6, 3 S. granulatus 1.4, 5 S. variegatus 1.1.*
2.01–4 (3.3%): *5 Lactarius chrysorrheus 3.6, 2 Tylopilus felleus 3.3.*

^{137}Cs-transfer of mushrooms from Herkhütte/Koralpenblick

0.0–0.25 (44.3%): *3 Agaricus langei 0.003, 3 A. silvaticus 0.02, 1 Albatrellus confluens 0.03, A. ovinus 0.09, 2 Amanita fulva 0.02, 3 A. gemmata 0.01, 3 A. pantherina 0.02, 12 A. rubescens 0.2, 2 A. spissa 0.0, 21 Boletus edulis 0.1, 10 B. erythropus 0.19, 2 B. pinicola 0.09, 1 Bovista nigrescens 0.09, 3 Gomphidius glutinosus 0.2, 3 Hygrophorus pratensis 0.15, 2 Lactarius deliciosus 0.15, 2 L. pergamenus 0.07, 8 Leccinum scabrum 0.03, 7 Leccinum testaceoscabrum 0.07, 6 Lyophyllum fumosum 0.03, 4 Macrolepiota procera 0.02, 1 Phaeolus schweinitzii 0.02, 2 Ramaria aurea 0.1, 1 R. mairei 0.05, 1 R. rufescens 0.06, 2 Russula cyanoxantha 0.1, 3 R. heterophylla 0.02, 3 R. integra 0.007, 3 R. olivacea 0.01, 3 R. paludosa 0.04, 6 R. puellaris 0.05, 2 R. vesca 0.1, 3 R. vinosa 0.17, 4 Tricholoma caligatum 0.02, 3 Xerocomus subtomentosus 0.12.*
0.26–0.5 (11.4%): *4 Amanita muscaria 0.29, 8 Amanita vaginata 0.5, 3 Cortinarius suillus 0.26, 3 Lactarius vellereus 0.48, 5 Russula foetens 0.5, 7 R. ochroleuca 0.28, 3 R. pseudointegra 0.48, 2 Sarcodon imbricatum 0.35, 3 Suillus bovinus 0.3, 5 S. grevillei 0.45.*
0.51–1.0 (13.9%): *13 Cantharellus cibarius 0.7, 2 Cortinarius glaucopus 0.77, 3 C. rufoalbus 0.56, 3 C. lignyotus 1.0, 2 Paxillus atrotomentosus 0.55, 2 Pseudoclitocybe cyathiformis 0.66, 1 Ramaria flava 0.53, 4 Russula aeruginea 0.6, 3 R. nigricans 0.65, 3 Suillus granulatus 0.7, 3 S. variegatus 0.9, 2 Xerocomus armeniacus 0.8.*
1.01–2 (13.9%): *3 Amanita lividopallescens 1.1, Cortinarius limonius 1.7, 3 Lactarius necator 1.8, 3 L. rufus 1.3, 3 L. torminosus 1.73, 3 Russula emetica 1.09, 3 Russula sanguinea 1.8, 2 Suillus luteus 1.86, 8 Tylopilus felleus 1.45, 10 Xerocomus badius 1.61, 21 X. spadiceus 1.2.*
2.01–4 (8.9%): *3 Cortinarius integerrimus 2.03, 2 Lactarius camphoratus 3.7, 2 L. cilicioides 2.8, 3 L. helvus 2.4, 2 L. porninsis 2.9, 8 Paxillus involutus 3.09, Scleroderma verrucosum 2.08.*
4 (7.6%): *6 Hydnum repandum 5.05, 3 Lactarius blennius 4.6, 3 L. trivialis 7.2, 17 Rozites caperata 5.14, 3 Xerocomus chrysenteron 4.5, 2 X. parasiticus 4.5.*

Many species of mushrooms with high transfer values were found in the acid soil at Herkhütte/Koralpenblick, but not at Rosenberg.

Table 3 shows on which collection site the TF value of a given species is the highest. Of 26 different species of mushrooms which were collected on both sites 61.5% show the highest TF (mean)-values in the forest at Koralpenblick. In this case it was surprising that 75% of the tube bearing fungi at Rosenberg possess the highest TF-values, whereas at the Koralpenblick this is valid for 92% of the gill-bearing mushrooms.

Transfer factors of potassium

The dried soil of Koralpenblick has a ^{40}K-activity of 230 Bq/kg corresponding to 13.5 g ^{39}KCl/kg d.w. The ^{40}K-content of the mushrooms examined ranges

Table 3. Location with the highest TF-value of a distinct species (+)

	R	K		R	K
Amanita muscaria	0.04	0.29+	*Russula integra*	0.02	0.48+
Amanita rubescens	0.03	0.2+	*Russula nigricans*	0.07	0.65+
Boletus edulis[a]	0.2+	0.1	*Russula ochroleuca*	0.25	0.28+
Cantharellus cibarius	0.06	0.7+	*Russula vesca*	0.03	0.1+
Hydnum repandum[a]	0.34	5.05+	*Suillus bovinus*[a]	1.6+	0.3
Lactarius vellereus	0.03	0.48+	*Suillus granulatus*[a]	1.4+	0.7
Leccinum scabrum[a]	0.48+	0.03	*Suillus grevillei*[a]	0.84+	0.45
L. testaceoscabrum[a]	0.19+	0.07	*Suillus variegatus*[a]	1.1+	0.9
Macrolepiota procera	0.05+	0.02	*Tylopilus felleus*[a]	3.3+	1.45
Paxillus atrotomentosus	0.08	0.55+	*Xerocomus badius*[a]	0.29	1.61+
Russula aeruginea	0.1	0.6+	*Xerocomus chrysenteron*[a]	1.0	4.5+
Russula cyanoxantha	0.04	0.1+	*Xerocomus spadiceus*[a]	0.69	1.2+
Russula foetens	0.05	0.5+	*Xerocomus subtomentosus*[a]	0.16+	0.12

[a] Tube-bearing mushroom R, Rosenberg, K, Koralpenblick

Table 4. ^{40}K and ^{137}Cs in Bq and g per kg f.w. and transfer factors of different mushrooms

	Bq ^{40}K	g ^{39}KCl	Bq ^{137}Cs	10^{-10} g ^{137}Cs	TF ^{40}K	TF ^{137}Cs
Boletus edulis	104	6.1	236	0.65	0.17	0.07
Gomphidius glutinosus	104	6.1	468	1.39	0.17	0.15
Rozites caperata	96	5.6	10226	28.1	0.16	3.2
Russula integra	163	9.6	16	0.04	0.27	0.005
Suillus luteus	122	7.2	5962	16.4	0.2	1.87
Xerocomus badius	129	7.6	5649	15.5	0.22	1.77

from 96 to 163 Bq/kg d.w., corresponding to a ^{39}KCl-content ranging from 5.6 to 9.6 g/kg d.w. The average ^{137}Cs-activity of mushrooms from the same soil was 3190 Bq/kg d.w. Since 1 Bq corresponds to $0.275 \cdot 10^{-12}$ g ^{137}Cs, the upper soil layers of Koralpenblick contain $8.8 \cdot 10^{-10}$ g ^{137}Cs/kg d.w. The natural Cs-concentration ranges from 0.3 to 26 mg Cs/kg d.w. soil (Kabata Pendias and Pendias 1984). Assuming an average ^{133}Cs-value of 20 mg/kg d.w., the ^{39}KCl-content of soil is 675 times higher than that of the naturally occurring isotop ^{133}Cs.

Table 4 compares transfer factors of ^{40}K with those of ^{137}Cs of different mushrooms. The transfer values of ^{40}K keep within narrow bounds, whereas those of ^{137}Cs vary widely, depending on the species. Eckl et al. (1986) made the same observations. In all mushrooms except *Xerocomus badius* examined by Elstner et al. (1987), the ^{40}K-activity was generally higher than that of ^{137}Cs. The authors concluded that the analysed mushrooms (except *Xerocomus badius*) do not actively take up Cs from soil, in contrast to K.

Many of the analysed mushrooms in these study have higher transfer factors for ^{137}Cs than for ^{40}K. This suggests that in 1986 a large part of radiocesium was not available for the mycelia. Since the content of total potassium ($^{39}K + ^{40}K$) exceeds that of total Cs ($^{133}Cs + ^{137}Cs$) by far, it seems doubtful whether a direct comparison of transfer factors is appropriate at all.

Discussion

The mushrooms collected at the coniferous forest showed the highest values of contamination. This is in line with the findings by Gerzabek et al. 1988, who observed a decrease in Cs-content in the order: coniferous forest > deciduous forest > meadows. Also according to Johnson and Nayfield (1970), mushrooms at forest locations show the highest values of Cs-concentration, mushrooms at meadows the lowest. The contamination of a mushroom is determined by the local radionuclide contaminations, which in its turn depends on the general weather situation, amount of rainfall, direction of the wind, exposure and inclination; the location and especially the species properties. The locations are characterised by various biotopes (coniferous, deciduous, mixed forest, meadow), substrates (soil, living or dead wood) and different soil properties (pH-value, ion content, humus content, cation saturation and clay mineral content).

The coniferous forest examined in this study is located highest of all locations. This led to high contamination by clouds coming from Chernobyl. While there is only a very small difference in clay mineral content and percentage of amorphous fraction, the soil of Koralpenblick is by 1.2 pH-units more acid than that of Rosenberg. This may contribute considerably to the high amount of ^{137}Cs plant-available in coniferous forest soils as compared to mixed forests. Eckl et al. (1986) also point out the high transfer factors of mushrooms at acid locations. The solubility and mobility of ^{137}Cs increases with decreasing pH-value because the ^{137}Cs-ions bound by clay minerals can be exchanged for hydrogen ions.

Saprotrophic mushrooms have generally lower transfer values than symbiotic ones. This suggests that there is not just ^{137}Cs-transfer soil to mushrooms but also tree to mushrooms. This holds true especially for the Chernobyl incident where the leaves and needles of trees were contaminated directly. It is thinkable that not only carbohydrates but also radiocesium was delivered to the mycelia via the phloem of the trees.

The different symbiotic mushrooms species of the same tree have frequently different ^{137}Cs transfer factors. This may be partly due to the fact that soil samples from near-by locations can be contaminated to a different extent as a result of the umbrella effect of trees. Underneath dense spruce trees there are spots which receive very little rainfall, even during long periods of rain and therefore contain little ^{137}Cs. Holter (1990) showed that acidification often occurs in the soil surrounding the trunk of a beech. Mushrooms which can tolerate protons and released Al-ions grow in this area.

Aumann et al. (1989) suggest that the high concentration of ^{137}Cs in *Xerocomus badius* may be due to substances with special Cs-affinity in the head skin. The following example demonstrates that Cs-attraction caused by an attraction sink leads to increased Cs-uptake from the soil. The ^{137}Cs values of *Scleroderma vulgare* infected with *Xerocomus parasiticus* are 2.6 times higher than the values in non-infected *Scleroderma vulgare* of the same mycelium, even though *Xerocomus parasiticus* extracts ^{137}Cs from its host. *Xerocomus parasiticus* has values

2.3 times higher than the parasited *Scleroderma*, the peridium of which is more contaminated than the interior situated gleba. Due to infection with the parasitic mushroom the transfer factor soil to *Scleroderma* increases from 0.2 to 0.64. Maybe this can be explained by the fact that the fruiting body of *Scleroderma* contains the hyphae of *Xerocomus* which possess high ^{137}Cs values. *Xerocomus parasiticus* thus shows a transfer factor of 1.39.

Even more important than the existence of Cs-binding substances in the mushrooms is the affinity of Cs-transporting carriers in the plasmamembrane of the hyphae to this alkali metal (Rothstein 1965).

In line with the findings by Eckl et al. (1986), our studies showed that independent of the substrate, the ^{40}K-content lies within a narrow range, whereas the ^{137}Cs-content shows marked fluctuations.

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