Radiocesium in fungi: Accumulation pattern in the Kiev district of Ukraine including the Chernobyl zone*

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Fungal fruitbodies of 41 different species were collected in the Ukraine at various distances from Chernobyl, and their Cs-137 as well as their Cs-134 content was determined by gamma-spectrometry. The accumulation pattern is compared with the contamination level of the region where the samples were taken. The maximum radiocesium content (4,049,300 Bq.kg^{-1}/dry weight) was found in the basidiomycete *Gomphidius glutinosus* collected in Starye Shepelichy close to the city of Chernobyl.

Keywords: Cs-137, Cs-134, gamma-spectrometry, Basidiomycetes, Ascomycetes.

In the 30-km-zone arround Chernobyl Cs-137 soil surface contamination reached a level exceeding 1480 GBq.km^{-2}. Typical for the Chernobyl derived contamination is its inhomogenous distribution leading to spots with more than several hundreds of GBq.km^{-2} even outside the 30-km-zone (Grodzinsky, 1991). The Polessye region in Northern Ukraine is characterised by mixed forests. During a four year period after the Chernobyl accident, litter was the major radionuclide depot in the forest biogeocenosis of the Ukrainian Polessye (Tikhomirov & al., 1990).

Fungi are important components of any forest biogeocenosis and in a number of studies carried out before the Chernobyl accident fungi have been shown to accumulate radiocesium (see, e.g., Grüter, 1971; Haselwandter, 1978). Afterwards, the level of contamination of fungal fruitbodies increased (Gans, 1986; 1987; Guillite & al., 1986; Haselwandter & al., 1988; Teherani, 1988; Battiston & al., 1989; Haselwandter & Berreck, 1989; Bem & al., 1990; Wasser & al., 1991).

* This paper is dedicated to Professor M. Moser on the occasion of his seventieth birthday.

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Because fungi appear to accumulate radiocesium in a species-specific manner, they can be used as bioindicators for the contamination of the environment (Haselwandter & al., 1988). For the present study, fungal fruitbodies were collected at a number of Ukrainian locations differing in the distance from Chernobyl and in the level of radioactive contamination. The radiocesium content of the fungal fruitbodies was analysed by gamma-spectrometry. The accumulation pattern obtained for the fungal fruitbodies was compared with the contamination level of the region where the samples were taken.

Materials and methods

Samples representing 41 different species of basidio- and ascomycetous fungi were collected in 1992 in the Kiev region including the 30 km zone around Chernobyl (Fig. 1, Tab. 1). The fungal fruitbodies were dried at 40–50 °C before they were ground to a fine powder. Subsequently, the samples were dried at 80 °C for 24 h prior to their transfer into plastic tubes in which they were subjected to gamma-spectrometry. The samples were analysed using an automatic gamma sample-changer („Compugamma 1282-002“, LKB, Wallac Oy, SF-20101

Tab. 1. – Sampling sites in the Kiev district.

Site	District	Location
1	Kiev city	Teremki
2		Feofania
3		Chkalov st.
4		Tymyryazevskaya st.
5		Schevtchenko av.
6		K.Libknecht st.
7		Zabolothny st.
8		Pobedy av.
9		Hydropark
10		Vasilkovskaya st.
11		Tereshchenkovskaya st.
12	„	Vernadsky av.
13	Kiev	Belaya Tzerkov
14	Obuchov	Kontcha Zaspa
15	„	Kozin
16	Kievo–Svyatoshin	Petropavlovskaya Borshchagovka
17	„	Irpen
18	Makarov	Jasnogorodka
19	Vyshgorod	Vodogon
20	„	Lebedevka
21	Boryspol	Bortnitchi
22	Vasilkov	Maljutyanka
23	Borodyanka	Poroskoten
24		Klavdievo–Tarasovo

Site	District	Location
25	Brovary	Puchovka
26		Letki
Chernobyl zone		
27	Prypyat	Prypyat city
28		Starye Shepelichy
29		between Starye Shepelichy and Buryakovka
30		Buryakovka
31		Kopachi
32		Paryshev
33		Chernobyl city
34		Janov
35		Staraya Krasnitza

Turku, Finland) at the Department of Microbiology in Innsbruck, or with the multichannel gamma-analyser AFORA LP 4900 B at the Nuclear Research Institute of the Ukraine in Kiev.

Results and discussion

A high degree of variation in the radiocesium content of the fungal fruitbodies was observed (Tab. 2). Fungal species differ in their potential to accumulate radionuclides such as Cs-137 (see, e.g., Haselwandter & Berreck, 1994; Shcheglov & al., 1989; Fedorov & al., 1989), but even within one species, the radiocesium content of fungal fruitbodies varies. This is shown, for example, by *Amanita muscaria* collected at site 27, where the Cs-137 content ranged from 3.5 to 1,023 $KBq.kg^{-1}$ dry weight depending on the fruitbody examined.

In general, the radiocesium content increases with increasing contamination of the sampling sites (Tab. 2, Fig. 2). Most of the samples taken from an area which received less than $3,7.10^{7}$ $KBq.km^{-2}$ contained Cs-134 below the detection limit, and Cs-137 at a level of several hundreds of $Bq.kg^{-1}$ dry weight at the most. Exceptions are *Lactarius helvus* and *Suillus luteus* with a Cs-137 content in excess of 33,5 and 4,3 $KBq.kg^{-1}$, respectively. Sampling site 22 had apparently received a higher level of radioactive Chernobyl-derived contamination than assumed previously and expressed in Fig. 1, because not only the Cs-137 but also the Cs-134 content was high. Hence, this finding might be used to re-evaluate the potential of fungi as bioindicators of radioactive contamination of the environment. A similar approach was taken previously in a study of fungal fruitbodies sampled in Finland, in which the radiocesium content showed a good correlation with that of the sampling sites (Berreck & al., 1992).

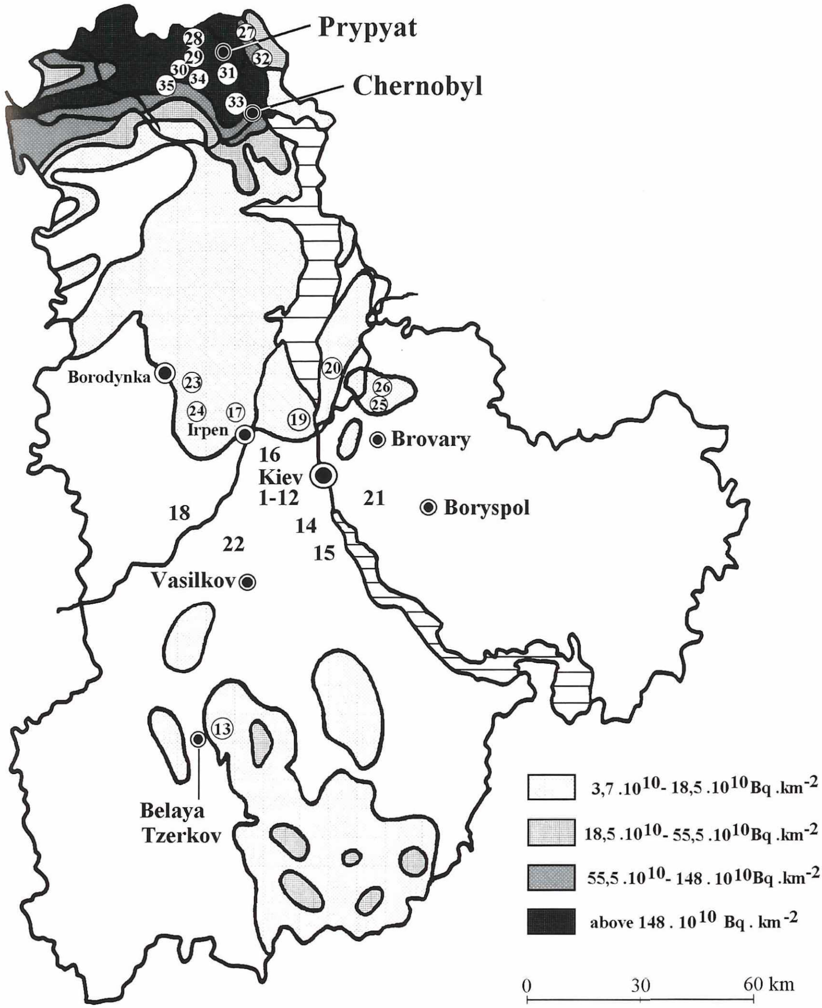

Fig. 1. – Cs-137 contamination of the Kiev region of the Ukraine. Sampling sites are listed in Tab. 1.

Even within a species, however, both the Cs-137 and Cs-134 content increased with increasing soil surface contamination. This is demonstrated for *S. luteus* sampled from locations differing in the surface contamination from less than 37 to more than 1480 GBq.km^{-2} (Fig. 2). Close to Chernobyl, *S. luteus* fruitbodies were more heavily contaminated than at the other sites.

As expected, the radiocesium content of fungal fruitbodies generally reached its highest level within the 30 km zone surrounding the Chernobyl power station, where the surface contamination was

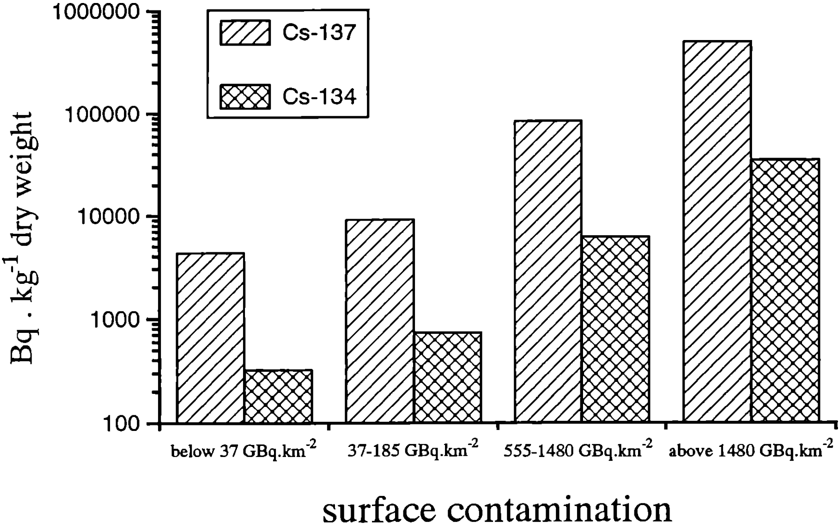

Fig. 2. – Mean Cs-137 and Cs-134 content of *Suillus luteus* fruitbodies collected 1992 in the Ukraine in regions with different soil surface contamination.

higher than 1,480 GBq.km^{-2} (Tab. 2). The samples did not only contain significant amounts of Cs-134 but also of Cs-137. The maximum content of both Cs-137 and Cs-134 detected so far in fungal fruitbodies was 4,049.3 KBq.kg^{-1} dry weight in *Gomphidius glutinosus*. Even outside the 30 km zone many fungal samples exceeded the highest acceptable radiocesium concentration for vegetables, if the level of 6 KBq.kg^{-1} of Cs-137/dry weight is adopted (Haselwandter & Berreck, 1989). The results of this investigation have practical implications, because a high number of the fungal species listed in Tab. 1 are generally considered to be edible. Fungi with a radioactivity higher than 6 KBq.kg^{-1} dry weight should not be considered suitable for human consumption. The content of long-lived radionuclides remains at approximately the same level for a long period of time. This has been shown for fungal fruitbodies collected in Western Europe (Berreck & Haselwandter, 1989) and in the Chernobyl zone (Nifontova & Aleksashenko, 1992).

Nifontova & Aleksashenko (1992) observed that in mushrooms, lichens and mosses sampled within an 18 km zone, the Sr-90 concentration increased by one to two orders of magnitude, and that of Cs-134 and Cs-137 by two to three orders of magnitude. Even 26 to 27 months after the accident, the radionuclide content in the 9 studied species varied broadly. The Sr-90 content ranged from 1.8 KBq.kg^{-1}

Tab. 2. – Radiocesium content of fungal fruitbodies collected 1992 in the Kiev region of the Ukraine. N: number of fruitbodies per collection; bdl: below dedection limit.

Site	Species	N	Date	Cs–137 Bq/kg dw	Cs–134 Bq/kg dw	Cs–137/ Cs–134
surface contamination: below 3.7×10^{10} Bq.km^{-2}						
1	*Ptychoverpa bohemica*	7	27.05.92	41	bdl	
1	*Entoloma clypeatum*	3	10.06.92	bdl	bdl	–
2	*Gyromitra esculenta*	4	27.05.92	87	bdl	
2	*Hypholoma fasciculare*	9	05.10.92	303	bdl	
2	*Lyophyllum connatum*	3	27.05.92	46	bdl	
2	*Melanoleuca brevipes*	8	27.05.92	bdl	bdl	
3	*Agaricus bitorquis*	8	05.06.92	bdl	bdl	
3	*A. vaporarius*	1	10.09.92	160	bdl	
3	*Calocybe gambosa*	7	25.05.92	bdl	bdl	
3	*Polyporus squamosus*	3	05.09.92	50	bdl	
3	*Macrolepiota procera*	3	08.09.92	40	bdl	
4	*Agaricus vaporarius*	4	10.06.92	bdl	bdl	
5	*A. arvensis*	6	05.06.92	102	bdl	
5	*Polyporus squamosus*	2	05.06.92	bdl	bdl	
6	*Agaricus xanthodermus*	6	15.06.92	bdl	bdl	
7	*A. xanthodermus*	3	15.09.92	40	bdl	
7	*Fistulina hepatica*	1	15.09.92	92	bdl	
8	*Polyporus squamosus*	8	10.09.92	bdl	bdl	
9	*Laetiporus sulfureus*	1	06.10.92	308	bdl	
10	*Paxillus involutus*	1	05.10.92	187	bdl	
11	*Scleroderma verrucosum*	5	16.09.92	bdl	bdl	
12	*Entoloma clypeatum*	5	05.06.92	bdl	bdl	
13	*Agaricus campester*	4	30.09.92	91	bdl	
13	*Pluteus atricapillus*	6	30.09.92	148	bdl	
14	*Lentinus cyathiformis*	3	25.05.92	150	bdl	
14	*Coprinus micaceus*	8	25.05.92	138	bdl	
14	*Calvatia utriformis*	2	21.05.92	210	bdl	
14	*Pholiota destruens*	1	10.09.92	310	bdl	
15	*Volvariella speciosa*	1	08.06.92	80	bdl	
16	*Paxillus atrotomentosus*	1	15.09.92	273	bdl	
18	*Fistulina hepatica*	1	15.09.92	291	70	4.2
21	*Lentinus lepideus*	1	28.08.92	150	bdl	
22	*Lactarius deliciosus*	4	15.10.92	247	bdl	
22	*L. helvus*	2	15.10.92	33562	2464	13.6
22	*Calvatia utriformis*	2	15.10.92	106	bdl	
22	*Suillus luteus*	9	15.10.92	4353	325	13.4
surface contamination: 3.7×10^{10} – 18.5×10^{10} Bq.km^{-2}						
17	*Agrocybe dura*	4	05.06.92	110	bdl	
19	*Boletus edulis*	1	08.09.92	841	86	9.8
19	*Suillus luteus*	5	08.09.92	9206	736	12.5
20	*Mutinus caninus*	5	20.09.92	322	33	9.6
23	*Piptoporus betulinus*	6	15.09.92	2382	268	8.9
23	*Hypholoma sublateritium*	8	15.09.92	4598	328	14.0
23	*Tricholomopsis rutilans*	1	15.09.92	14100	1010	14.0
24	*Piptoporus betulinus*	5	15.09.92	1897	128	14.8

Site	Species	N	Date	Cs–137 Bq/kg dw	Cs–134 Bq/kg dw	Cs–137/ Cs–134
25	*Laetiporus sulfureus*	1	10.06.92	bdl	bdl	
26	*L. sulfureus*	2	18.06.92	70	bdl	
surface contamination: 55.5•10^10 – 148•10^10 Bq . km^-2						
27	*Coprinus comatus*	6	05.10.92	5329	617	8.7
27	*Amanita muscaria*	4	05.10.92	3581	389	9.2
27	*A. muscaria*	5	05.10.92	16990	1415	12.0
27	*A. muscaria*	2	23.09.92	1023078	72200	14.2
27	*Marasmius oreades*	3	05.10.92	3594	368	9.8
27	*Suillus luteus*	3	05.10.92	83485	6100	13.7
27	*Macrolepiota rhacodes*	3	05.10.92	20854	1804	11.6
32	*Lentinus lepideus*	3	23.09.92	279928	19416	14.4
surface contamination: above 148•10^10 Bq.km^-2						
28	*Boletus edulis*	2	03.10.92	155303	13412	11.7
28	*Gomphidius glutinosus*	4	03.10.92	3775000	274336	13.8
29	*Amanita muscaria*	2	03.10.92	346509	22832	15.1
30	*Suillus luteus*	2	01.10.92	512784	33754	15.1
30	*S. luteus*	1	01.10.92	947400	68900	13.7
30	*Amanita rubescens*	2	01.10.92	92285	5077	18.2
31	*Marasmius oreades*	3	05.10.92	9139	837	10.9
33	*Coprinus comatus*	4	05.10.92	1459	146	10.0
34	*Amanita muscaria*	4	10.10.92	341410	27030	12.6
34	*A. pantherina*	3	10.10.92	48654	4740	10.3
34	*Paxillus involutus*	1	10.10.92	115947	8860	13.1
34	*S. luteus*	6	10.10.92	10718	816	13.1
34	*Macrolepiota rhacodes*	3	10.10.92	39954	3581	11.2
35	*Marasmius oreades*	2	01.10.92	256040	18078	14.2

dry wt. (*Lycoperdon* sp.) to 93.6 KBq kg^{-1} dry wt. (*Coltricia perennis*), and that of Cs-137 + Cs-134 between 25.9 KBq kg^{-1} dry wt. (*Leccinum aurantiacum*) and 889.3 KBq kg^{-1} dry wt. (*Leccinum scabrum*).

There are indications that ectomycorrhizal fungi may accumulate more radiocesium than saprophytic and parasitic fungi (Wasser & al., 1992; Wasser & Grodzinskaya, 1993; Smith & al., 1993). Because the diversity of ectomycorrhizal fungi is high in coniferous forests, a screening of a larger number of ectomycorrhizal species is required before a reliable evaluation of their potential to accumulate radiocesium is made.

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