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CONTAMINATION OF FUNGI WITH RADIONUCLIDES AFTER ACCIDENT ON CHERNOBYL NPP

N.E. Zarubina
Institute for NUCLEAR research NASU, Kiev, Ukraine
Corresponding author: natalie.zarubina@mail.ru

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Abstract
Impact of the accident on Chernobyl Nuclear Power Plant on pollution of fungi within the 30-km alienation zone and within the Kiev region has been studied. Fungi accumulate practically all radionuclides produced by the accident. Dynamics of the accumulation of ^{137}Cs by fungi has two phases. Main factors that produce significant impact on the specific activity of ^{137}Cs in fungi are: levels of soil contamination by this radionuclide, ecological group of the mushroom species and depth of mycelium in soil. Variations of ^{137}Cs content during vegetation period have been observed.

Keywords
accident, Chernobyl NPP, fungi, radionuclides

1.0 Introduction

The majority of palisade fungi that have big fruit body are classified as higher fungi (macromicetes). Species which were investigated in this research belong to the following ecological groups: saprotrophes, xylotrophes, symbiotrophes. *Lycoperdon perlatum Pers*. belongs to saprotrophes; *Fistulina hepatica Schaeff.: Fr*., *Armillariella melea (Vahl: Fr.) P. Karst*.) are xylotrophes.

Such well-known and widely spread species as: *Boletus edulis Bull*., *Russula xerampelina var. erythropus Pelt*., *Lactarius turpis (Weinm.) Fr., Lactarius deliciosus (L.: Fr.) Fr., Xerocomus badius (Fr.) Kuhn. ex Gilb*., *Suillus luteus (L.: Fr.) S.F.Gray* are obligate symbiotrophes. *Paxillus involutus (Batsch: Fr.) Fr*. is a facultative representative of symbiotrophs that can become a litter's saprotroph depending on certain factors during its growth [1].

For fungi, the predominant way of obtaining radioactive nuclides is absorption with roots from the ground layer where the major part of mycelium is located. Coefficients of correlation between the specific activity of ^{137}Cs in fungal fruit bodies and in the soil layer where mycelium of a species is localized, are described with such values: for *S. luteus* - +0.95, for *B. edulis* - + 0.93 [2]. Most of the fungi - symbiotrophes have their mycelium localized in the subsurface layer of soil, 0-5 sm (practically in the ground litter): *S. luteus*, *X. badius*, *Xerocomus chrysenteron (Bull.: St-Am.) Quel* and others.; mycelium of *B. edulis* and *Sarcodon imbricatus (Fr.) Karst*. have the main part of mycelium at the depth of 5 sm [3, 4]. According to the published sources [5] and to our research data [6], the specific activity of ^{137}Cs in mycelium and in fruit bodies is practically equal.

Our studies were carried out within the territory of the 30-km alienation zone of the Chernobyl NPP and Kyiv region outside the 30-km zone, in edatopes A1 (dry pine forest) and A2 (fresh pine forest). The names of testing grounds mentioned in the paper correspond to the names of the nearest settlements.

2.0 Main results

After the Chernobyl NPP accident, almost all kinds of radionuclides detectable by gamma-spectroscopy have been observed in fungi. Samples of *B. edulis* collected in June 1986 at the Tolokun testing ground (Kyiv oblast, 60km to the south-west of the NPP) were found to contain 39±17 Bq ^{137}Cs, 115±45 Bq ^{131}I and 229±37Bq of $^{140}Ba/^{140}La$ per kilogram of fresh

Table 1. Specific activity of accident-related radionuclides in fungi (1986, Tolokun testing ground, fresh weight).

Month	Species	Specific activity (Bq/kg)							
		^{137}Cs	^{134}Cs	^{106}Ru	^{103}Ru	^{95}Zr	^{95}Nb	^{141}Ce	^{144}Ce
July	***B. edulis***	50±10	45±10	-	45±15	35±15	40±15	-	10±5
	R. xerampelina	210±35	95±10	100±10	-	120±20	190±20	85±10	-
August	***B. edulis***	115±15	45±10	35±10	-	15±10	25±10	-	-
	S. luteus	770±85	370±45	290±45	180±35	-	565±80	-	-
September	***B. edulis***	430±40	185±30	-	-	-	-	-	55±20
	S. luteus	805±70	340±40	-	135±20	75±10	470±55	330±30	110±15

weight. In subsequent months, radioactive iodine, barium and lanthanum were not detected any more due to the short half-lives of these isotopes. Fungi collected in July 1986 at the same testing ground contained ^{103}Ru, ^{106}Ru, ^{141}Ce, ^{144}Ce, ^{95}Nb, ^{95}Zr, ^{137}Cs and ^{134}Cs. Table 1 presents the specific activity of radionuclides in fungi in July-September 1986. In September 1986, isotopes of Cesium — ^{137}Cs and ^{134}Cs — begin to make a significant (up to 30%) contribution to the total activity of accident-related radionuclides in fungi. In 1987 and 1988 the contribution of relatively short-lived ^{103}Ru, ^{106}Ru, ^{141}Ce, ^{144}Ce, ^{95}Nb, ^{95}Zr to the total radioactivity in fungi greatly declined, on average to 10%.

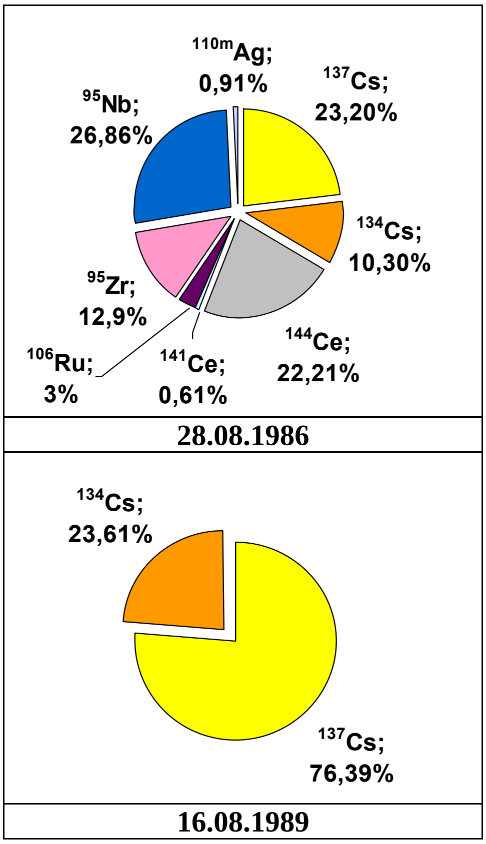

Figure 1. The contribution of different radionuclides to activity of *S. luteus* (testing ground “Stayki”, 150 km to the south-west of the ChNPP).

From 1989 to 2000 almost 100% of radioactivity in fungi has been due to ^{137}Cs and ^{134}Cs (Fig. 1), and from 2001 to the present (2010) no isotopes except ^{137}Cs were of any importance. For the duration of the study (1986-2010) specific activity of ^{90}Sr in higher fungi has been up to 3 orders of magnitude smaller than that of ^{137}Cs.

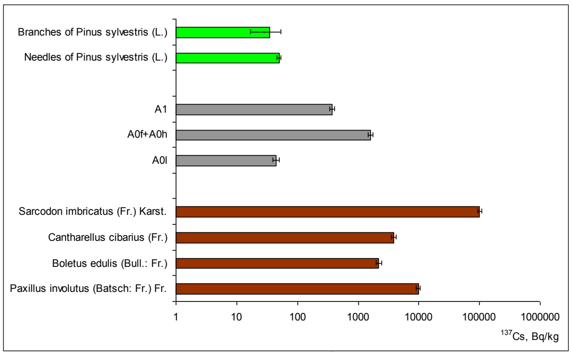

Figure 2. Specific activity of ^{137}Cs in fruit bodies of fungi, various layers of soil and in vegetation on testing ground “Paryshev”, 2013, Bq/kg of dry weight.

Table 2. Specific activity of ^{137}Cs in fruit bodies of *X. badius*, collected at various testing grounds between 15 and 25 October 2008 (fresh weight)

Testing grounds	Specific activity (Bq/kg)
«Yanov»	975000 ± 50000
«Lelev»	27000 ± 1500
«Paryshev»	5000 ± 400
«Sukholuchie»	4000 ± 300
«Dytiatky»	1100 ± 100
«Zagaltsi»	900 ± 60
«Rzhyschiv»	600 ± 60
«Staiky»	500 ± 50
«Lebedivka»	300 ± 20
«Chernigov»	200 ± 20

Till now fruit bodies of fungi are the maximum accumulators of cesium in forest ecosystems (Fig. 2).

Soil contamination by ^{137}Cs is one of the principal abiotic influences on the accumulation of this radionuclide by fungi. Specific activities of ^{137}Cs in mushrooms vary from several hundred to several million Bq per kilogram of fresh weight (according to [7], specific activity of ^{137}Cs in dry fruit bodies is 10 times higher than in fresh ones). Due to the spotted pattern of radioactive contamination, specific activity of ^{137}Cs can be higher in fruit bodies of fungi collected outside alienation zone than in those collected within it (Table 2).

In contrast to other members of forest ecosystems, accumulation of ^{137}Cs by macromycetes proceeded in two stages. The first stage began in 1986; its duration varied for mushrooms in different ecological groups. This stage was characterized by year-on-year increase in specific activity of ^{137}Cs in mushrooms. In the second stage, specific activity of this radionuclide in mushrooms has been declining (Fig. 3).

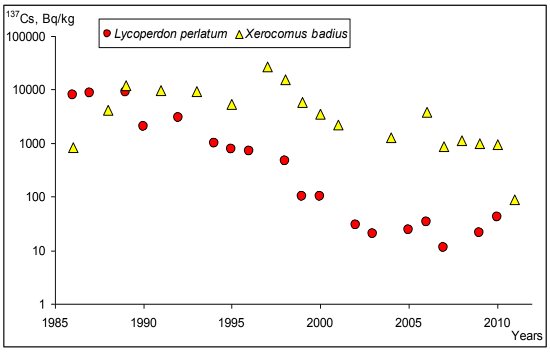

Figure 3. The dynamics of specific activity of ^{137}Cs in representatives of various ecological groups of fungi.

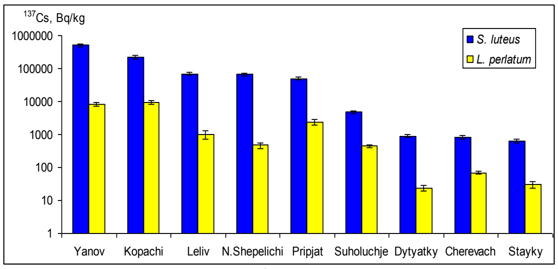

Figure 4. Content of ^{137}Cs in *S. Luteus* (symbiotrophes fungi) and *L. perlatum* (saprotrophes fungi) at various testing grounds, 2001, Bq/kg fresh weight.

Because of this difference in dynamics, several years post-accident, saprotrophes and xylotrophes macromycetes (*Lycoperdon* spp., *Macrolepiota* spp., *Agaricus* spp., *A. Melea*, *F. hepatica* etc.) have been accumulating much smaller quantities of ^{137}Cs than symbiotrophic fungi (*B. edulis*, *X. badius*, *Suillus* spp., *Xerocomus* spp., *Russula* spp., *Tricholoma* spp., *Lactarius* spp. etc.) (Fig. 4).

Symbioticity may be the reason for the elevated specific activity of ^{137}Cs in symbiotrophic fungi compared to saprotrophic and xylotrophic species. Transpiration and root pressure of mycotrophic plants probably cause much greater quantities of water with dissolved microelements to be pumped into symbiotrophes' mycelium. As part of the fungal organism's functioning, significant quantities of ^{137}Cs, a water-soluble element, can be taken up into symbiotrophes' mycelium with water and accumulate in the organism. That is, the quantity of ^{137}Cs taken up by symbiotrophes can be much greater than in saprotrophes and xylotrophes (cf. Figs. 3 and 4).

Specific activity of ^{137}Cs in mushrooms belonging to one ecological group - symbiotrophes - vary significantly (10 times and more) for mushrooms collected at the same test ground. Main factor which leads to these variations is the depth localization of the main part of mycelium of each species in soil. Among mushrooms – symbiotrophes, *B. edulis*, accumulates the lowest amount of this radionuclide. Characteristic feature of this species is deep (over 5 cm) localization of mycelium in the soil (Fig. 5).

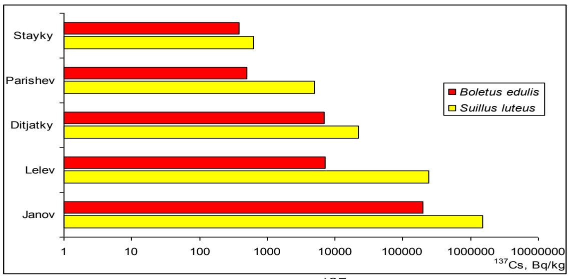

Figure 5. Specific activity of ^{137}Cs in fungi- symbiotrophes with different depth of localization of mycelium in the soil in 1997, Bq/kg fresh weight.

Dynamics of accumulation of ^{137}Cs by facultative representatives of ecological group of symbiotrophes also has its peculiarities. Of those species of symbiotrophes which were included into this research, *P. involutus* belongs to facultative symbiotrophes. This species was characterized by the highest levels of ^{137}Cs during first 10-15 years after the accident. As with other species of mushrooms, accumulation of ^{137}Cs by *P. involutus* has two specific stages (Fig. 6). At the second stage, the levels of specific activity of this radionuclide in *P.*

involutus decreased faster than in obligate symbiotrophes. Due to this, in the last years on the majority of test grounds specific activity of ^{137}Cs in this species is lower than in obligate symbiotrophes.

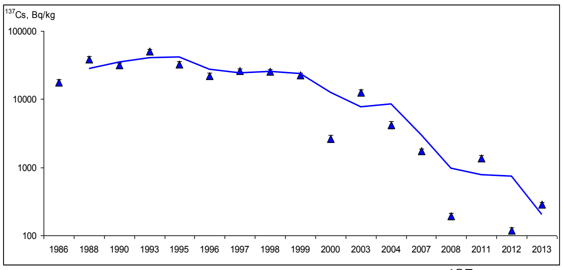

Fig. 6. Dynamics of specific activity of ^{137}Cs in *P. involutus* at "Dytiatky" testing ground, Bq/kg fresh weight.

Investigations held it the period between 2006 and 2012 showed that the content of ^{137}Cs in mushrooms is not a constant value but that it is variable during the vegetation period. Seasonal dynamic of ^{137}Cs in mushrooms was studied for those species whose fruiting periods have a maximal length. Depending on the month when fruit bodies appear, in mushrooms of the same species on the same test area figures can vary fivefold, or show even a greater dispersion
We must say that no gradual growth of the ^{137}Cs specific activity levels in fruit bodies has been observed within the period since the beginning of the vegetation till November. On the contrary, seasonal dynamic of the ^{137}Cs specific activity in mushrooms is complex and jump-like (Fig. 7).

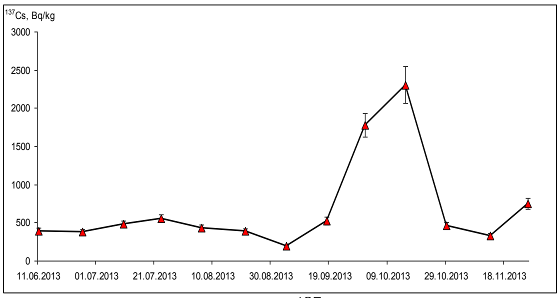

Fig. 7. Specific activity of ^{137}Cs in *C. cibarius* during vegetation period, testing ground "Paryshev", Bq/kg fresh weight

Abundant rainfalls perecede the growing of fruit bodies of macromycete fungi. In most cases, selecting sample fruit bodies for investigation, it is possible to select fruit bodies of other species simultaneously. But decrease and increase in ^{137}Cs specific activity levels do not coincide for different species of fungi throughout the vegetation season.

Research of impact of weather conditions (precipitation amount, air temperature) on ^{137}Cs content's magnitude in fruit bodies of fungi is conducted. Correlation factors, determination factors between specific activity ^{137}Cs in mushrooms and quantity of deposits (mm) and the maximum temperature of air (^{0}C) are calculated. At calculations the decrease of the content of ^{137}Cs in mushrooms at the expense of disintegration of this isotope has been considered. Authentic dependence of specific activity ^{137}Cs in fruit bodies of the studied species of mushrooms from quantity of deposits and air temperature has not been established.

3.0 Summary

Until the present moment (2013) fruit bodies of higher fungi exceed all species of the forest ecosystems in their tendency to accumulate such biologically significant and long-lived isotope as ^{137}Cs.

Ever since 1989 till now ^{137}Cs has contributed most significantly to the specific activity of higher fungi (^{90}Sr is accumulated in much smaller quantities). A large number of biotic and non-biotic factors impact its level in fungi: level of ^{137}Cs contamination of soil, ecological group of the specific fungi, depth of mycelium etc.

Results of research held in 2006 – 2013 show that there is one more factor that defines levels of ^{137}Cs specific activity. These are processes in a fungal body during the vegetatin season. As a result of their impact, during the vegetation period fivefold and even greater disperse of ^{137}Cs specific activity is observed.

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