**Purpose.** We continue our retrospective investigations of radioactive contamination of wild mushrooms from Ukrainian Polesie. The aim of the current study is an assessment of radioactive contamination of wild mushrooms from some locations of Chernihiv Polesie in 1991-2021.

**Methodology.** A study of radiocaesium activity in 66 wild mushroom species (edible, inedible, conditionally edible, poisonous) (from 2 to 25 fruitbodies per sample) and soils (0-5 cm of upper mineral layer, taken by the envelope method) from 14 locations of Chernihiv Polesie was carried out with γ-spectrometry (Ge-detector Canberra GLX 4019, USA). In some mushrooms, $^{90}\text{Sr}$ activity was determined radiochemically on the basis of $^{90}\text{Y}$ accumulation according to the standard method.

**Scientific novelty.** The results of γ-spectrometric studies of the activity of radiocaesium in 66 species of wild mushrooms from the localities of Chernihiv Polesie over a 30-year period are given, the coefficients reflecting the bioaccumulation activity of each species counted, the hyperaccumulator species of radiocaesium are determined, and the potential annual equivalent doses for adults are calculated under the conditions of consumption of some valuable culinary-medicinal mushrooms ($B.\text{edulis}$, $C. \text{cibarius}$, $I. \text{badia}$, $Suillus$ spp, $T. \text{equestre}$).

**Conclusions.** Activity levels of $^{137}\text{Cs}$ in wild mushrooms of Chernihiv Polesie varied over the years 1991-2021 depending on the mushroom species, its ecological affiliation, radioecological situation at the sampling sites, showing a certain tendency to decrease over time. Hyper-accumulative properties in relation to $^{137}\text{Cs}$ are demonstrated by $Cortinarius$, $Sarcodon$, $Paralepista$, $Tricholoma$, $Lactarius$, $Suillus$ spp. Widely distributed on the territory of Ukrainian Polesie – $I. \text{badia}$, $P. \text{involutus}$ and $L. \text{rufus}$, remain representative bioindicators of radiocaesium contamination. A potential calculated annual effective doses due to the mushrooms consumption by adults, considering only the effect of the $^{137}\text{Cs}$, reached a high values in $Suillus$ spp., $T. \text{equestre}$, and $I. \text{badia}$ – 0.041, 0.035 and 0.025 mSv, respectively, which indicates a relatively insignificant dose load when consuming mushrooms in these localities compared to other localities of Ukrainian Polesie that have higher levels of soil contamination with radionuclides. However, radiation monitoring can still be recommended during mushroom procurement and mass collections.

**Key words:** $^{137}\text{Cs}$, $^{90}\text{Sr}$, accumulation, mushrooms, bioindication
Introduction

Deterioration of the quality of the environment as a result of numerous man-made impacts (radiation and toxic emissions, growth of industrial waste and transport load, war actions, disturbance of natural landscapes) requires constant monitoring. A wide range of biological objects is involved for biotesting and bioindication of the state of the environment, among which some species of mushrooms are recognized as accumulative indicators, in particular radionuclides and heavy metals (Haselwandter et al., 1988; Fraiture et al., 1990; Wasser, Grodzinskaya, 1993; Grodzinskaya et al., 1995, 2003; 2011; 2012; Wasser et al., 1995; Baeza, Guillen, 2007; Kalač, 2012; 2019; Falandysz, Borovička, 2013; Grodzynska, 2017; Ernst, 2022). The forests of Ukrainian Polesie suffered the most as a result of the Chornobyl disaster, which reduced their resource and economic value and led to the fact that for more than three decades they are a constant source of radiation danger for the population (Landin, 2013). It is known that wild berries and mushrooms pose a special danger in the formation of a dose of internal radiation under the conditions of their consumption. Despite the rather extensive published results on the radioactive contamination of mushrooms, this topic continues to be of interest after the Chornobyl and the Fukushima accidents, due to the high accumulative capacity of mushrooms, in connection with the estimation of the long-term consequences and the danger of mushroom consumption (Guillen & Baeza, 2014; Nakashima et al., 2015; Orita et al., 2018; Komatsu et al., 2019; Grodzinskaya et al., 2022; Saniewski et al., 2022; Gabriel et al., 2023).

Materials and methods

Samples of whole fruitbodies of wild mushrooms and average soil samples (0-5 cm of upper mineral layer, taken by the envelope method) were collected in 14 locations of Chernihiv region of Ukraine. The sampling sites were approximately 25 × 25 m in size. Levels of soil contamination were determined both by the results of our field measurements and General dosimetry classification data (https://docs.google.com/presentation/d/15AxieLuqKiv5N5IAMrPfdetEUUfz8HUVf6wN1CryzvQ/htmlpreview?usp=gmail_thread) (Table 1).

Mushrooms (2 to 25 complete fruitbodies per species) were carefully cleaned from plant and soil debris, dried at 60°C, ground to a fine dispersion, dried again at 80°C during 24 hours, then placed in polyethylene bags with a zip lock. The same procedure was used for the soil samples. We used gamma-spectrometry (Ge-detector Canberra GLX 4019, USA) to determine radocaesium activity in fruitbodies of 66 mushroom species (Table 2). The currently valid names of mushrooms including authors are listed according to Index Fungorum (www.indexfungorum.org), and edibility of the species is indicated according to World of mushrooms of Ukraine (http://gribi.net.ua).
Table 1

List of locations and levels of soil surface contamination with $^{137}$Cs and $^{90}$Sr in Chernihiv region of Ukraine

<table>
<thead>
<tr>
<th>Location</th>
<th>The average levels of soil surface contamination, kBq/m$^2$ (recalculation for 2021)</th>
<th>Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$^{137}$Cs $^{90}$Sr</td>
<td></td>
</tr>
<tr>
<td>Nizhyn district</td>
<td></td>
<td></td>
</tr>
<tr>
<td>City of Bobrovytsia</td>
<td>5.0 1.7</td>
<td>50°45'18&quot;N /31°25'49&quot;E</td>
</tr>
<tr>
<td>Vil. Kobyzhcha</td>
<td>4.9 1.6</td>
<td>50°51'04&quot;N /31°27'31&quot;E</td>
</tr>
<tr>
<td>Snovs’k district</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vil. Kuchynivka</td>
<td>2.4 1.6</td>
<td>51°42'01&quot;N /31°53'51&quot;E</td>
</tr>
<tr>
<td>Kozelets’ district</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vil. Evvynka</td>
<td>7.8 2.0</td>
<td>50°50'06&quot;N /30°50'05&quot;E</td>
</tr>
<tr>
<td>Settl. Desna</td>
<td>17 3.9</td>
<td>50°55'28&quot;N /30°44'31&quot;E</td>
</tr>
<tr>
<td>Vil. Karpylivka</td>
<td>14 3.9</td>
<td>51°00'53&quot;N /30°45'30&quot;E</td>
</tr>
<tr>
<td>Vil. Krehayiv</td>
<td>8.7 2.0</td>
<td>50°48'52&quot;N /30°48'22&quot;E</td>
</tr>
<tr>
<td>Vil. Loshakova Guta</td>
<td>17.0 8.8</td>
<td>51°02'23&quot;N /30°39'12&quot;E</td>
</tr>
<tr>
<td>Regional landscape park Mizhirchyns’kyi</td>
<td>12.0 2.1</td>
<td>51°10'21&quot;N /30°47'26&quot;E</td>
</tr>
<tr>
<td>Vil. Nadynivka</td>
<td>3.9 1.0</td>
<td>51°12'19&quot;N /31°04'14&quot;E</td>
</tr>
<tr>
<td>Vil. Pavlivka</td>
<td>2.0 0.9</td>
<td>51°28'39&quot;N /31°12'17&quot;E</td>
</tr>
<tr>
<td>Vil. Sokolivka</td>
<td>7.8 1.0</td>
<td>51°08'59&quot;N /30°53'40&quot;E</td>
</tr>
<tr>
<td>Vil. Syrai</td>
<td>6.8 1.0</td>
<td>50°49'11&quot;N /30°02'09&quot;E</td>
</tr>
<tr>
<td>Chernihiv district</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vil. Smolyn</td>
<td>7.8 1.6</td>
<td>51°16'31&quot;N /30°57'26&quot;E</td>
</tr>
</tbody>
</table>

Table 2

List of studied species and their edibility

<table>
<thead>
<tr>
<th>Species, authors*</th>
<th>Edibility**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Agaricus campestris L.</td>
<td>Edible</td>
</tr>
<tr>
<td>Amanita citrina Pers.</td>
<td>Poisonous</td>
</tr>
<tr>
<td>A. muscaria (L.) Lam.</td>
<td>Poisonous</td>
</tr>
<tr>
<td>A. panterina (DC.) Krombh.</td>
<td>Poisonous</td>
</tr>
<tr>
<td>A. rubescens Pers.</td>
<td>Edible</td>
</tr>
<tr>
<td>Ampullolotocybe clavipes (Pers.) Redhead, Lutzoni, Moncalvo &amp; Vilgalys</td>
<td>Edible</td>
</tr>
<tr>
<td>Armillaria mellea (Vahl) P. Kumm.</td>
<td>Edible</td>
</tr>
<tr>
<td>Boletus edulis Bull.</td>
<td>Edible</td>
</tr>
<tr>
<td>Cantharellus cibarius Fr.</td>
<td>Edible</td>
</tr>
<tr>
<td>Chlorophyllum rhacodes (Vittad.) Vellinga</td>
<td>Edible</td>
</tr>
<tr>
<td>Clitocybe nebularis (Batsch) P. Kumm.</td>
<td>Edible</td>
</tr>
<tr>
<td>Coltricia perennis (L.) Murrill</td>
<td>Inedible</td>
</tr>
<tr>
<td>Cortinarius caperatus (Pers.) Fr.</td>
<td>Edible</td>
</tr>
<tr>
<td>C. malcorius Fr.</td>
<td>Its edibility is not known</td>
</tr>
<tr>
<td>C. praestans (Cordier) Gillet</td>
<td>Edible</td>
</tr>
<tr>
<td>C. varius (Schaeff.) Fr.</td>
<td>Conditionally edible</td>
</tr>
<tr>
<td>C. semisanguineus (Fr.) Gillet</td>
<td>Poisonous</td>
</tr>
<tr>
<td>C. trivialis J.E. Lange</td>
<td>Inedible</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Продовження табл. 2</strong></td>
<td></td>
</tr>
<tr>
<td>C. decipiens (Pers.) Zawadzki</td>
<td>Inedible</td>
</tr>
<tr>
<td>Hortiboletus rubellus (Krombh.) Simonini, Vizzini &amp; Gelardi</td>
<td>Edible</td>
</tr>
<tr>
<td>Hygrophoropsis aurantia (Wulfen) Maire</td>
<td>Inedible</td>
</tr>
<tr>
<td>Hypholoma capitata (Fr.) P.Kumm.</td>
<td>Edible</td>
</tr>
<tr>
<td>H. fasciculare (Huds.) P. Kumm.</td>
<td>Poisonous</td>
</tr>
<tr>
<td>Fistulina hepatica (Schaff.) With.</td>
<td>Edible</td>
</tr>
<tr>
<td>Formitopsis betulina (Bull.) B.K. Cui, M.L. Han &amp; Y.C. Dai</td>
<td>Inedible</td>
</tr>
<tr>
<td>Imeliera badia (Fr.) Vizzini</td>
<td>Edible</td>
</tr>
<tr>
<td>Inundulicybe gibba (Pers.) Harmaja</td>
<td>Edible</td>
</tr>
<tr>
<td>Lactarius belus (Fr.) Fr.</td>
<td>Inedible</td>
</tr>
<tr>
<td>L. rufus (Scop.) Fr.</td>
<td>Conditionally edible</td>
</tr>
<tr>
<td>L. turpis (Weinm.) Fr.</td>
<td>Conditionally edible</td>
</tr>
<tr>
<td>Lactifluus volemus (Fr.)Kuntze</td>
<td>Conditionally edible</td>
</tr>
<tr>
<td>Lecitnum aurantiacum (Bull.) Gray</td>
<td>Edible</td>
</tr>
<tr>
<td>L. sechum (Bull.) Gray</td>
<td>Edible</td>
</tr>
<tr>
<td>Lyophyllum perlatum Pers.</td>
<td>Edible</td>
</tr>
<tr>
<td>Macrocybe proera (Scop.) Singer</td>
<td>Edible</td>
</tr>
<tr>
<td>Marasmius orades (Bolton) Fr.</td>
<td>Edible</td>
</tr>
<tr>
<td>Paralepista gilva (Pers.) Raithelh.</td>
<td>Poisonous</td>
</tr>
<tr>
<td>Paxillus involutus (Batsch) Fr.</td>
<td>Poisonous</td>
</tr>
<tr>
<td>Pseudoliticyphe cyathiformis (Bull.) Singer</td>
<td>Edible</td>
</tr>
<tr>
<td>Rhodocollybia butyracea (Bull.) Lennox</td>
<td>Edible</td>
</tr>
<tr>
<td>R. maculata (Alb.&amp;Schwein.) Singer</td>
<td>Inedible</td>
</tr>
<tr>
<td>Russula aeruginea Lindblad ex Fr.</td>
<td>Edible</td>
</tr>
<tr>
<td>R. amethystina Quél.</td>
<td>Edible</td>
</tr>
<tr>
<td>R. cyanocantha (Schaff.) Fr.</td>
<td>Edible</td>
</tr>
<tr>
<td>R. delia Fr.</td>
<td>Edible</td>
</tr>
<tr>
<td>R. emetica (Shaeff.) Pers.</td>
<td>Inedible</td>
</tr>
<tr>
<td>R. foetens Pers.</td>
<td>Conditionally edible</td>
</tr>
<tr>
<td>R. fragilis Fr.</td>
<td>Conditionally edible</td>
</tr>
<tr>
<td>R. ochrolena Fr.</td>
<td>Edible</td>
</tr>
<tr>
<td>R. paludosa Britzelm.</td>
<td>Edible</td>
</tr>
<tr>
<td>R. roseipes Secr. ex Bres.</td>
<td>Edible</td>
</tr>
<tr>
<td>R. vescia Fr.</td>
<td>Edible</td>
</tr>
<tr>
<td>R. violeipes Quél.</td>
<td>Edible</td>
</tr>
<tr>
<td>R. xerampelina (Schaeff.) Fr.</td>
<td>Edible</td>
</tr>
<tr>
<td>Sarodon imbriatus (L.) P. Karst.</td>
<td>Edible</td>
</tr>
<tr>
<td>Suillus bovinus (L.) Roussel</td>
<td>Edible</td>
</tr>
<tr>
<td>S. granulatus (L.) Roussel</td>
<td>Edible</td>
</tr>
<tr>
<td>S. luteus (L.) Roussel</td>
<td>Edible</td>
</tr>
<tr>
<td>Thelephora terrestris Ehrh. ex Fr.</td>
<td>Inedible</td>
</tr>
<tr>
<td>Tricholoma equestre (L.) P. Kumm</td>
<td>Edible</td>
</tr>
<tr>
<td>T. fulvum (DC.) Bigeard &amp; H. Guill.</td>
<td>Edible</td>
</tr>
<tr>
<td>T. portentosum (Fr.) Quél.</td>
<td>Edible</td>
</tr>
<tr>
<td>T. saponaceum (Fr.) P.Kumm.</td>
<td>Inedible</td>
</tr>
<tr>
<td>Tricholomopsis rutilans (Schaeff.) Singer</td>
<td>Conditionally edible</td>
</tr>
<tr>
<td>Tyophyllus felleus (Bull.) P.Karst.</td>
<td>Inedible</td>
</tr>
<tr>
<td>Xerocomellus chrysenteron (Bull.) Šutara</td>
<td>Edible</td>
</tr>
</tbody>
</table>
The measurement time of the sample ranged from 6 to 36 hours. The measurement error of $^{137}$Cs was usually less than 10 %. In some mushroom samples, the activity of $^{90}$Sr was determined with the radiochemical method on the basis of $^{90}$Y accumulation according to the standard method. To assess the intensity of radionuclide accumulation by fruiting bodies, we calculated BAF – bioaccumulation factor (or coefficient of accumulation), which is equal to the ratio of the activity of the radionuclide in the mushroom fruitbody to its activity in the soil of the relevant habitat. For estimation of the potential risk to human health, the possible average dose of internal irradiation was calculated according to the formula:

$$H_{int} = c \times d_{int} \times e \times k,$$

where $H_{int}$ – dose of internal irradiation; $c$ – the specific activity of $^{137}$Cs, Bq/kg of crude weight; $d_{int}$ – coefficient to calculate the consumption of mushrooms by an adult $(1.3 \times 10^{-5}$ mSv/Bq for $^{137}$Cs); $e$ – estimated volume of annual consumption of mushrooms, kg (5 kg per person per year); $k$ – the coefficient of culinary processing $(0.5)$ (Grodzinskaya et al. 2022).

Results and discussion

Chernihiv Polesie is a low-lying, undulating plain. The general flatness of the territory is broken by the valleys of the Dnieper, Desna, and Snov rivers. The climate is moderately continental, with an average of 500-610 mm of precipitation per year. There are many lakes and marshes in the river valleys. The area of swamps is 4.5 % of the territory of Chernihiv Polesie. Sod-podzolic, marshy, gray forest soils are common. Forest coverage of the territory is about 25 %. The largest forest areas are kept on forestry sites, it is impossible to recommended the picking and harvesting of mushrooms due to continued potential risk of acquiring significant internal radiation doses due the uncontrolled consumption of wild mushrooms, particularly in the case of $I. badia$ and $Suillus$ spp., in these cases the corresponding effective doses reached 0.130 and 0.239 mSv/y taking into account only a contribution of $^{137}$Cs (Gabriel et al., 2023).

In previous years, some data on radioactive contamination of wild mushrooms in the Chernihiv region were published (Wasser, Grodzinskaya, 1993; Grodzinskaya et al., 2013). In 1991 the highest value of radiocaesium $(^{134}$Cs+$^{137}$Cs) was determined in symbiotroph $R. maculata$, the lowest – in humus saprotroph $A. campestris$, in which $^{134}$Cs was not found, as in the soil sample from this location. In 1999, samples of symbiotroph $A. muscaria$ (with BAF up to 174) still contained some amount of $^{134}$Cs, while this radionuclide was not found in soil samples from three localities of Kozelets’ district (Table 3).

In mushrooms and soils samples in 2001 $^{134}$Cs was not detected. In the vicinity of the vil. Kuchynivka, symbiotrophs $P. involutus$, $C. cibarius$, and $S. lutes$ were high contaminated with $^{137}$Cs, and respectively their coefficients of bioaccumulation (BAFs) were – 5.15, 3.85, and 2.73 (Table 3). Given that the maximum permissible level (PL) for dry mushrooms in Ukraine is 2.5 kBq/kg dry mass, it can be noted, that over 90 % of samples from this locality in 2001 exceeded this level (The Ministry of Health of Ukraine, 2006). In 2002, in the samples collected in the vicinity of the city of Bobrovytsya, the activity of radiocaesium was below the PL.
### Table 3

**134Cs and 137Cs-activity in mushrooms (kBq/kg dry mass) from Bobrovytsia (1991) and Kozelets’ (1999) districts**

<table>
<thead>
<tr>
<th>Species, soil</th>
<th>134Cs</th>
<th>137Cs</th>
<th>BAF for 137Cs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>near vil. Kobyzhcha</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Agaricus campestris</em></td>
<td>-</td>
<td>7</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Hypholoma capnoides</strong></td>
<td>0.234</td>
<td>1.155</td>
<td>16.50</td>
</tr>
<tr>
<td><strong>Rhodocollybia butyraceae</strong></td>
<td>0.237</td>
<td>1.364</td>
<td>19.49</td>
</tr>
<tr>
<td><strong>Rhodocollybia maculata</strong></td>
<td>0.646</td>
<td>3.306</td>
<td>47.23</td>
</tr>
<tr>
<td><strong>Tricholomopsis rutilans</strong></td>
<td>0.226</td>
<td>1.154</td>
<td>16.49</td>
</tr>
<tr>
<td>Soil</td>
<td>BDL*</td>
<td>0.070</td>
<td></td>
</tr>
<tr>
<td><strong>near vil. Evmynka</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Amanita muscaria</em></td>
<td>0.100</td>
<td>1.740</td>
<td>174.0</td>
</tr>
<tr>
<td>Soil</td>
<td>BDL</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td><strong>Near vil. Krehaiv</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Amanita muscaria</em></td>
<td>0.080</td>
<td>0.800</td>
<td>4.211</td>
</tr>
<tr>
<td>Soil</td>
<td>BDL</td>
<td>0.190</td>
<td></td>
</tr>
<tr>
<td><strong>Near vil. Desna</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Infundulicybe gibba</em></td>
<td>BDL</td>
<td>0.150</td>
<td>0.225</td>
</tr>
<tr>
<td>Soil</td>
<td>BDL</td>
<td>0.667</td>
<td></td>
</tr>
</tbody>
</table>

Note: *BDL – below detection limit

### Table 4

**137Cs-activity in (kBq/kg d.m.) in mushrooms from Snovs’k and Nizhyn districts in 2001 and 2002**

<table>
<thead>
<tr>
<th>Species, soil</th>
<th>137Cs</th>
<th>BAF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>near vil. Kuchynivka</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Amanita muscaria</em></td>
<td>1.694</td>
<td>0.636</td>
</tr>
<tr>
<td><em>Amanita rubescens</em></td>
<td>3.703</td>
<td>1.390</td>
</tr>
<tr>
<td><em>Boletus edulis</em></td>
<td>3.162</td>
<td>1.187</td>
</tr>
<tr>
<td><em>Cantharellus cibarius</em></td>
<td>10.26</td>
<td>3.851</td>
</tr>
<tr>
<td><em>Imelera badia</em></td>
<td>6.413</td>
<td>2.407</td>
</tr>
<tr>
<td><em>Lactarius helvus</em></td>
<td>3.725</td>
<td>1.398</td>
</tr>
<tr>
<td><em>Paxillus involutus</em></td>
<td>13.71</td>
<td>5.146</td>
</tr>
<tr>
<td><em>Russula ochroleuca</em></td>
<td>4.959</td>
<td>1.861</td>
</tr>
<tr>
<td><em>Russula serampelina</em></td>
<td>5.010</td>
<td>1.881</td>
</tr>
<tr>
<td><em>Suillus luteus</em></td>
<td>7.269</td>
<td>2.729</td>
</tr>
<tr>
<td><em>Tricholoma equestre</em></td>
<td>3.214</td>
<td>1.206</td>
</tr>
<tr>
<td>Soil</td>
<td>2.664</td>
<td></td>
</tr>
<tr>
<td><strong>near city of Bobrovytsya</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Amanita muscaria</em></td>
<td>0.071</td>
<td>0.670</td>
</tr>
<tr>
<td><em>Amanita pantherina</em></td>
<td>0.054</td>
<td>0.509</td>
</tr>
<tr>
<td><em>Suillus luteus</em></td>
<td>0.287</td>
<td>2.708</td>
</tr>
<tr>
<td>Soil</td>
<td>0.106</td>
<td></td>
</tr>
</tbody>
</table>

60
In 2005, the highest $^{137}$Cs-activity in mushroom samples from Kozelets district found in *S. luteus* – 12.29 (BAF – 42.84) from location near vil. Sokolivka, and in 2006 – in *B. edulis* (near vil. Nadynivka) – 11.25 kBq/kg dm (BAF-52.06) (Table 5). Since 2007, the collection of mushroom samples has been carried out in the localition on the border of the Kozelets’ and Chernihiv districts, near the village of Smolyn, due to the sufficient occurrence of species. In 2007 from this location the highest $^{137}$Cs-activities and BAFs detected in *L. rufus* – 125.0 kBq/kg d.m. (BAF – 33.48), *C. trivialis* – 61.49 (BAF – 304.4), *S. imbricatus* – 59.07 (77.32), and in 2008 – in *S. imbricatus* – 33.47 Bq/kg dm. (BAF-157.9). In 2007 and 2008, in general, 75.61 % and 31.25 % of mushrooms samples from location near Smolyn, respectively, exceeded the PL.

### Table 5

<table>
<thead>
<tr>
<th>Species, soil</th>
<th>$^{137}$Cs (kBq/kg d.m.)</th>
<th>BAF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2005</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>near vil. Sokolivka</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Amanita muscaria</em></td>
<td>1.125</td>
<td>3.920</td>
</tr>
<tr>
<td><em>Leccinum aurantiacum</em></td>
<td>0.544</td>
<td>1.895</td>
</tr>
<tr>
<td><em>Russula xerampelina</em></td>
<td>0.115</td>
<td>0.401</td>
</tr>
<tr>
<td><em>Suillus luteus</em></td>
<td>12.29</td>
<td>42.82</td>
</tr>
<tr>
<td>Soil</td>
<td>0.287</td>
<td></td>
</tr>
<tr>
<td><strong>2006</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>near vil. Nadynivka</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Boletus edulis</em></td>
<td>11.25</td>
<td>52.06</td>
</tr>
<tr>
<td>Soil</td>
<td>0.216</td>
<td></td>
</tr>
<tr>
<td><em>Boletus edulis</em></td>
<td>8.818</td>
<td>54.10</td>
</tr>
<tr>
<td>Soil</td>
<td>0.163</td>
<td></td>
</tr>
<tr>
<td><strong>2007</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>near v. Syrai</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Clitocybe nebularis</em></td>
<td>0.101</td>
<td>1.507</td>
</tr>
<tr>
<td><em>Lycoperdon perlatum</em></td>
<td>0.231</td>
<td>3.448</td>
</tr>
<tr>
<td>Soil</td>
<td>0.067</td>
<td></td>
</tr>
<tr>
<td>near vil. Smolyn</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Amanita citrina</em></td>
<td>2.225</td>
<td>0.596</td>
</tr>
<tr>
<td><em>Hygrophoropsis aurantiaca</em></td>
<td>5.248</td>
<td>1.405</td>
</tr>
<tr>
<td><em>Imichia badia</em></td>
<td>25.49</td>
<td>6.826</td>
</tr>
<tr>
<td><em>Lactarius rufus</em></td>
<td>125.0</td>
<td>33.48</td>
</tr>
<tr>
<td><em>Macrolepiota procera</em></td>
<td>0.116</td>
<td>0.031</td>
</tr>
<tr>
<td><em>Paxillus involutus</em></td>
<td>38.45</td>
<td>10.30</td>
</tr>
<tr>
<td><em>Pseudoclitocybe cyathiformis</em></td>
<td>6.493</td>
<td>1.739</td>
</tr>
<tr>
<td><em>Russula emetica</em></td>
<td>11.67</td>
<td>3.125</td>
</tr>
<tr>
<td><em>Russula fragilis</em></td>
<td>3.802</td>
<td>1.018</td>
</tr>
<tr>
<td><em>Russula xerampelina</em></td>
<td>6.656</td>
<td>1.783</td>
</tr>
<tr>
<td><em>Russula xerampelina</em></td>
<td>9.970</td>
<td>2.670</td>
</tr>
<tr>
<td>Soil</td>
<td>3.734</td>
<td></td>
</tr>
<tr>
<td><em>Amanita citrina</em></td>
<td>3.779</td>
<td>4.895</td>
</tr>
<tr>
<td><em>Amanita muscaria</em></td>
<td>1.046</td>
<td>1.355</td>
</tr>
<tr>
<td><em>Boletus edulis</em></td>
<td>4.038</td>
<td>5.231</td>
</tr>
<tr>
<td><em>Hypholoma fasciulare</em></td>
<td>1.817</td>
<td>2.354</td>
</tr>
<tr>
<td><em>Cortinarius cibarius</em></td>
<td>2.364</td>
<td>3.062</td>
</tr>
<tr>
<td><em>Cortinarius trivialis</em></td>
<td>34.38</td>
<td>44.53</td>
</tr>
<tr>
<td><em>Cortinarius varius</em></td>
<td>28.91</td>
<td>37.45</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Imleria badia</td>
<td>20.09</td>
<td>26.02</td>
</tr>
<tr>
<td>Soil</td>
<td>0.772</td>
<td></td>
</tr>
<tr>
<td>Lactarius rufus</td>
<td>37.58</td>
<td>49.19</td>
</tr>
<tr>
<td>Paxillus involutus</td>
<td>38.29</td>
<td>50.12</td>
</tr>
<tr>
<td>Sarcodon imbricatus</td>
<td>59.07</td>
<td>77.32</td>
</tr>
<tr>
<td>Suillus bovinus</td>
<td>11.08</td>
<td>14.50</td>
</tr>
<tr>
<td>Suillus luteus</td>
<td>3.622</td>
<td>4.741</td>
</tr>
<tr>
<td>Tricholoma equestre</td>
<td>3.710</td>
<td>4.856</td>
</tr>
<tr>
<td>Tricholoma portentosum</td>
<td>9.102</td>
<td>11.91</td>
</tr>
<tr>
<td>Tylopillus felleus</td>
<td>16.48</td>
<td>21.57</td>
</tr>
<tr>
<td>Soil</td>
<td>0.764</td>
<td></td>
</tr>
<tr>
<td>Amanita muscaria</td>
<td>1.221</td>
<td>6.045</td>
</tr>
<tr>
<td>Amanita rubescens</td>
<td>7.492</td>
<td>37.09</td>
</tr>
<tr>
<td>Amanita rubescens</td>
<td>2.089</td>
<td>10.34</td>
</tr>
<tr>
<td>Cortinarius semisanguineus</td>
<td>23.27</td>
<td>115.2</td>
</tr>
<tr>
<td>Cortinarius trivialis</td>
<td>61.49</td>
<td>304.4</td>
</tr>
<tr>
<td>Hygrophoropsis aurantiaca</td>
<td>4.208</td>
<td>20.83</td>
</tr>
<tr>
<td>Hypholoma fasciculare</td>
<td>3.971</td>
<td>19.66</td>
</tr>
<tr>
<td>Imleria badia</td>
<td>15.94</td>
<td>78.91</td>
</tr>
<tr>
<td>Lactarius rufus</td>
<td>3.512</td>
<td>17.39</td>
</tr>
<tr>
<td>Paxillus involutus</td>
<td>29.12</td>
<td>144.2</td>
</tr>
<tr>
<td>Russula xerampelina</td>
<td>0.844</td>
<td>4.178</td>
</tr>
<tr>
<td>Russula xerampelina</td>
<td>9.970</td>
<td>49.36</td>
</tr>
<tr>
<td>Soil</td>
<td>0.202</td>
<td></td>
</tr>
<tr>
<td>2008 near vil. Smolyn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amanita muscaria</td>
<td>5.140</td>
<td>24.25</td>
</tr>
<tr>
<td>Boletus edulis</td>
<td>0.500</td>
<td>2.358</td>
</tr>
<tr>
<td>Hygrophoropsis aurantiaca</td>
<td>0.746</td>
<td>3.519</td>
</tr>
<tr>
<td>Hypholoma fasciculare</td>
<td>0.272</td>
<td>1.283</td>
</tr>
<tr>
<td>Imleria badia</td>
<td>3.054</td>
<td>14.41</td>
</tr>
<tr>
<td>Lactarius rufus</td>
<td>1.800</td>
<td>8.491</td>
</tr>
<tr>
<td>Lactarius turpis</td>
<td>1.023</td>
<td>4.825</td>
</tr>
<tr>
<td>Macrolepiota procera</td>
<td>0.707</td>
<td>3.335</td>
</tr>
<tr>
<td>Paxillus involutus</td>
<td>7.423</td>
<td>35.01</td>
</tr>
<tr>
<td>Russula aeruginea</td>
<td>0.142</td>
<td>0.670</td>
</tr>
<tr>
<td>Russula delica</td>
<td>1.437</td>
<td>6.778</td>
</tr>
<tr>
<td>Russula amethystina</td>
<td>0.137</td>
<td>0.646</td>
</tr>
<tr>
<td>Sarcodon imbricatus</td>
<td>33.47</td>
<td>157.9</td>
</tr>
<tr>
<td>Suillus luteus</td>
<td>6.533</td>
<td>30.82</td>
</tr>
<tr>
<td>Tricholoma portentosum</td>
<td>0.927</td>
<td>4.373</td>
</tr>
<tr>
<td>Tricholomopsis rufulans</td>
<td>0.893</td>
<td>4.212</td>
</tr>
<tr>
<td>Soil</td>
<td>0.212</td>
<td></td>
</tr>
<tr>
<td>Regional landscape park «Mizhrichynskyi»</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amanita muscaria</td>
<td>0.257</td>
<td>0.704</td>
</tr>
<tr>
<td>Amanita pantherina</td>
<td>0.576</td>
<td>1.578</td>
</tr>
<tr>
<td>Amanita rubescens</td>
<td>0.772</td>
<td>2.115</td>
</tr>
<tr>
<td>Ampulloclitocybe clavipes</td>
<td>0.218</td>
<td>0.597</td>
</tr>
<tr>
<td>Cortinarius malicorus</td>
<td>30.33</td>
<td>83.10</td>
</tr>
<tr>
<td>Hypholoma fasciculare</td>
<td>5.670</td>
<td>15.53</td>
</tr>
<tr>
<td>Imleria badia</td>
<td>8.238</td>
<td>22.57</td>
</tr>
<tr>
<td>Imleria badia</td>
<td>6.390</td>
<td>17.51</td>
</tr>
<tr>
<td>Lactarius belvis</td>
<td>49.03</td>
<td>134.3</td>
</tr>
<tr>
<td>Marasmius oreades</td>
<td>1.952</td>
<td>5.348</td>
</tr>
<tr>
<td>Suillus luteus</td>
<td>1.398</td>
<td>3.830</td>
</tr>
<tr>
<td>Tricholoma portentosum</td>
<td>8.207</td>
<td>22.48</td>
</tr>
<tr>
<td>Tricholoma saponaceum</td>
<td>1.500</td>
<td>4.110</td>
</tr>
</tbody>
</table>
In 2010, the highest level of contamination with radiocesium was also found in the symbiotrophs *C. praestans* – up to 246.0 kBq/kg dm (BAF – up to 708.0) (near the village of Karpylivka), *Paralepista gilva* – 68.0 (BAF – 283.3), *A. rubescens* – up to 50.0 (BAF up to 173.0), in *L. helvus* up to 48.0 (BAF-141.6). It should be noted a high level of radiocesium activity variability in the same species from the same location – for example, the level in *I. badia* differed by 2.56 times, *A. rubescens* differed by 9.63, and *M. procera* to 27.14 times.

**Table 6**

<table>
<thead>
<tr>
<th>Species, soil</th>
<th>$^{137}$Cs (kBq/kg d.m.)</th>
<th>BAF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>near vil. Karpylivka</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Amanita citrina</em></td>
<td>0.562</td>
<td>2.342</td>
</tr>
<tr>
<td><em>Amanita pantherina</em></td>
<td>0.069</td>
<td>0.288</td>
</tr>
<tr>
<td><em>Amanita rubescens</em></td>
<td>5.192</td>
<td>21.63</td>
</tr>
<tr>
<td><em>Armillariella mellea</em></td>
<td>0.524</td>
<td>2.193</td>
</tr>
<tr>
<td><em>Boletus edulis</em></td>
<td>0.208</td>
<td>0.867</td>
</tr>
<tr>
<td><em>Infundibulicybe gibba</em></td>
<td>0.138</td>
<td>0.575</td>
</tr>
<tr>
<td><em>Fomitopsis betulina</em></td>
<td>0.040</td>
<td>0.167</td>
</tr>
<tr>
<td><em>Imleria badia</em></td>
<td>6.012</td>
<td>25.05</td>
</tr>
<tr>
<td><em>Lactarius tuepis</em></td>
<td>3.213</td>
<td>13.39</td>
</tr>
<tr>
<td><em>Lactifluus volemus</em></td>
<td>10.45</td>
<td>43.54</td>
</tr>
<tr>
<td><em>Macrolepiota procera</em></td>
<td>0.073</td>
<td>0.304</td>
</tr>
<tr>
<td><em>Paralepista gilva</em></td>
<td>68.00</td>
<td>283.3</td>
</tr>
<tr>
<td><em>Paxillus involutus</em></td>
<td>20.03</td>
<td>83.46</td>
</tr>
<tr>
<td><em>Russula cyanocantha</em></td>
<td>2.554</td>
<td>10.64</td>
</tr>
<tr>
<td><em>Russula vesca</em></td>
<td>1.925</td>
<td>8.020</td>
</tr>
<tr>
<td><em>Russula xerampelina</em></td>
<td>3.040</td>
<td>12.67</td>
</tr>
<tr>
<td><em>Suillus granulatus</em></td>
<td>1.108</td>
<td>4.617</td>
</tr>
<tr>
<td><em>Suillus luteus</em></td>
<td>10.65</td>
<td>44.38</td>
</tr>
<tr>
<td><em>Tricholomopsis rutilans</em></td>
<td>2.708</td>
<td>11.28</td>
</tr>
<tr>
<td><em>Tricholoma fulvum</em></td>
<td>0.906</td>
<td>3.775</td>
</tr>
<tr>
<td>Soil</td>
<td>0.240</td>
<td></td>
</tr>
<tr>
<td><em>Chlorophyllum rhacodes</em></td>
<td>0.324</td>
<td>0.956</td>
</tr>
<tr>
<td><em>Cortinarius praestans</em></td>
<td>240.0</td>
<td>708.0</td>
</tr>
<tr>
<td><em>Hypholoma fasciculare</em></td>
<td>0.059</td>
<td>0.174</td>
</tr>
<tr>
<td><em>Lactarius helvus</em></td>
<td>48.00</td>
<td>141.6</td>
</tr>
<tr>
<td><em>Macrolepiota procera</em></td>
<td>1.981</td>
<td>5.844</td>
</tr>
<tr>
<td><em>Russula aeruginea</em></td>
<td>0.901</td>
<td>2.658</td>
</tr>
<tr>
<td><em>Tricholoma equestre</em></td>
<td>3.428</td>
<td>10.11</td>
</tr>
<tr>
<td><em>Tricholoma fulvum</em></td>
<td>2.621</td>
<td>7.732</td>
</tr>
</tbody>
</table>
Due to the very high variability in the levels of radiocaesium contamination of mushrooms, observed even in the samples of one species from the same location, we calculated the geometric mean value. For all mushroom samples collected in 2005-2010, the geometric mean of $^{137}$Cs activity amounted to 2.766 kBq/kg dm. The geometric means of $^{137}$Cs activity differed significantly in some group of species – in *Amanita* spp. it was 1.180 kBq/kg dm (from 0.199 in *A. pantherina* to 5.004 kBq/kg dm in *A. rubescens*); in *Russula* spp. – 2.306 kBq/kg dm (from 0.137 in *R. amethystina* to 11.67 in *R. emetica*); in *Tricholomataceae* – 2.994 (from 0.496 in *T. rutilans* to 68.00 in *P. gigas*). In *Boletales* species, this value was 3.359 kBq/kg dm (from 0.052 in *H. rubescens* to 16.48 kBq/kg dm in *T. felleus*); in *Lactarius* spp. – 9.741 (from 3.731 in *L. turpis* to 49.03 in *L. bekus*); in *Cortinarius* spp. the geometrical mean was the highest – 49.85 kBq/kg dm (of 23.27 in *C. semisanguineus* to 187.2 in *C. praestans*).

D. Holiaka et al. (2020) confirmed significantly higher $^{90}$Sr mobility in elements of forest ecosystems than $^{137}$Cs. They noted a gradual further increase in the share of these radio nuclides in the aboveground biomass components (up to 0.9 %·year$^{-1}$ from the total activity in forest ecosystems) owing to the increase of organic matter stocks. On the one hand, this indicates the continuing danger of an additional source of contamination for mushrooms, on the other hand, the need for long-term radiation monitoring of all components of the biota.

Determination of $^{90}$Sr activity in some samples of mushrooms from a location near the village of Karpylivka showed a significant level of contamination – of 0.099 for *A. muscaria* to 7.900 kBq/dm for *A. rubescens*. Considering that the maximum permissible level for dry mushrooms of this radionuclide, adopted in Ukraine, is 0.250 kBq/kg, in this case we are talking about quite serious contamination with radiostrontium (Table 7). The $^{137}$Cs/$^{90}$Sr ratio in the studied samples ranged from 1.626 (*A. muscaria*) to 63.48 (*C. praestans*). For most mushroom species from the Zelenopolyansky forestry, this ratio was at the level of 10-10$^2$ (Gabriel et al., 2023).
**Table 7**

<table>
<thead>
<tr>
<th>Species</th>
<th>$^{90}$Sr</th>
<th>BAF</th>
<th>$^{137}$Cs/$^{90}$Sr</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Amanita muscaria</em></td>
<td>0.099</td>
<td>0.031</td>
<td>1.626</td>
</tr>
<tr>
<td><em>Amanita rubescens</em></td>
<td>7.900</td>
<td>2.469</td>
<td>6.329</td>
</tr>
<tr>
<td><em>Cantharellus cibarius</em></td>
<td>0.400</td>
<td>0.125</td>
<td>22.00</td>
</tr>
<tr>
<td><em>Cortinarius praestans</em></td>
<td>2.300</td>
<td>0.719</td>
<td>63.48</td>
</tr>
<tr>
<td><em>Imleria badia</em></td>
<td>2.800</td>
<td>0.875</td>
<td>5.500</td>
</tr>
<tr>
<td><em>Lactarius turpis</em></td>
<td>1.200</td>
<td>0.375</td>
<td>13.17</td>
</tr>
<tr>
<td><em>Russula cyanocantha</em></td>
<td>3.400</td>
<td>1.063</td>
<td>13.24</td>
</tr>
<tr>
<td><em>Russula vesca</em></td>
<td>4.000</td>
<td>1.250</td>
<td>7.750</td>
</tr>
<tr>
<td><em>Russula xerampelina</em></td>
<td>1.200</td>
<td>0.375</td>
<td>4.500</td>
</tr>
<tr>
<td><em>Suillus luteus</em></td>
<td>3.000</td>
<td>0.938</td>
<td>4.300</td>
</tr>
<tr>
<td>Soil</td>
<td>3.200</td>
<td></td>
<td>1.438</td>
</tr>
</tbody>
</table>

**Table 8**

$^{137}$Cs-activity in (kBq/kg d.m.) in mushrooms from Kozelets’ and Chernihiv districts in 2018, 2020 and 2021

<table>
<thead>
<tr>
<th>Species, soil</th>
<th>$^{137}$Cs</th>
<th>BAF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2018 near vil. Smolyn</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Canthartellus cibarius</em></td>
<td>0.677</td>
<td>2.943</td>
</tr>
<tr>
<td><em>Coltricia perennis</em></td>
<td>0.303</td>
<td>1.317</td>
</tr>
<tr>
<td><em>Hypholoma fasciculare</em></td>
<td>0.589</td>
<td>2.561</td>
</tr>
<tr>
<td><em>Imleria badia</em></td>
<td>3.761</td>
<td>16.35</td>
</tr>
<tr>
<td><em>Tylopilus fellens</em></td>
<td>1.996</td>
<td>8.678</td>
</tr>
<tr>
<td>Soil</td>
<td>0.230</td>
<td></td>
</tr>
<tr>
<td><em>Amanita pantherina</em></td>
<td>0.143</td>
<td>0.917</td>
</tr>
<tr>
<td><em>Amanita rubescens</em></td>
<td>0.829</td>
<td>5.314</td>
</tr>
<tr>
<td><em>Fistulina hepatica</em></td>
<td>0.460</td>
<td>2.949</td>
</tr>
<tr>
<td><em>Hypholoma fasciculare</em></td>
<td>0.269</td>
<td>1.724</td>
</tr>
<tr>
<td><em>Imleria badia</em></td>
<td>3.363</td>
<td>21.56</td>
</tr>
<tr>
<td><em>Lactarius scabrum</em></td>
<td>0.931</td>
<td>5.968</td>
</tr>
<tr>
<td><em>Russula foetens</em></td>
<td>0.843</td>
<td>5.404</td>
</tr>
<tr>
<td><em>Russula vesca</em></td>
<td>0.146</td>
<td>0.936</td>
</tr>
<tr>
<td><em>Telephora terrestris</em></td>
<td>0.280</td>
<td>1.795</td>
</tr>
<tr>
<td><em>Tylopilus fellens</em></td>
<td>0.791</td>
<td>5.071</td>
</tr>
<tr>
<td>Soil</td>
<td>0.156</td>
<td></td>
</tr>
<tr>
<td><em>Imleria badia</em></td>
<td>0.135</td>
<td>4.500</td>
</tr>
<tr>
<td><em>Russula vesca</em></td>
<td>0.041</td>
<td>1.367</td>
</tr>
<tr>
<td><em>Suillus granulatus</em></td>
<td>0.179</td>
<td>5.967</td>
</tr>
<tr>
<td>Soil</td>
<td>0.030</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Amanita citrina</em></td>
<td>0.999</td>
<td>1.986</td>
</tr>
<tr>
<td><em>Amanita muscaria</em></td>
<td>0.474</td>
<td>0.942</td>
</tr>
<tr>
<td><em>Amanita pantherina</em></td>
<td>0.310</td>
<td>0.616</td>
</tr>
<tr>
<td><em>Cortinarius caperatus</em></td>
<td>1.546</td>
<td>3.073</td>
</tr>
<tr>
<td><em>Cortinarius malacorae</em></td>
<td>13.66</td>
<td>27.16</td>
</tr>
<tr>
<td><em>Cortinarius trivialis</em></td>
<td>2.687</td>
<td>5.345</td>
</tr>
<tr>
<td><em>Hypholoma fasciculare</em></td>
<td>0.779</td>
<td>1.549</td>
</tr>
<tr>
<td><em>Hygrophoropsis aurantia</em></td>
<td>0.719</td>
<td>1.429</td>
</tr>
<tr>
<td><em>Hygrophoropsis aurantia</em></td>
<td>2.050</td>
<td>4.076</td>
</tr>
<tr>
<td><em>Lactarius rufus</em></td>
<td>2.030</td>
<td>4.036</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>----</td>
<td>-------</td>
<td>--------</td>
</tr>
<tr>
<td>Paxillus involutus</td>
<td>2.325</td>
<td>4.622</td>
</tr>
<tr>
<td>Russula amethystina</td>
<td>0.991</td>
<td>1.970</td>
</tr>
<tr>
<td>Russula serpapelina</td>
<td>0.381</td>
<td>0.757</td>
</tr>
<tr>
<td>Suillus bovinus</td>
<td>1.873</td>
<td>3.724</td>
</tr>
<tr>
<td>Soil</td>
<td>0.503</td>
<td></td>
</tr>
<tr>
<td>Amanita muscaria</td>
<td>0.682</td>
<td>3.187</td>
</tr>
<tr>
<td>Cantharellus cibarius</td>
<td>2.254</td>
<td>10.53</td>
</tr>
<tr>
<td>Chlorophyllum rhacodes</td>
<td>0.113</td>
<td>0.528</td>
</tr>
<tr>
<td>Cortinarius malicorus</td>
<td>10.84</td>
<td>50.65</td>
</tr>
<tr>
<td>Cortinarius praestans</td>
<td>11.45</td>
<td>53.50</td>
</tr>
<tr>
<td>Imelria badia</td>
<td>7.682</td>
<td>35.90</td>
</tr>
<tr>
<td>Lactarius rufus</td>
<td>5.080</td>
<td>23.74</td>
</tr>
<tr>
<td>Russula cyanocantha</td>
<td>2.974</td>
<td>13.90</td>
</tr>
<tr>
<td>Russula paludosa</td>
<td>0.578</td>
<td>2.701</td>
</tr>
<tr>
<td>Russula xerampelina</td>
<td>0.116</td>
<td>0.542</td>
</tr>
<tr>
<td>Soil</td>
<td>0.214</td>
<td></td>
</tr>
<tr>
<td>Amanita muscaria</td>
<td>0.553</td>
<td>3.435</td>
</tr>
<tr>
<td>Cantharellus cibarius</td>
<td>1.885</td>
<td>11.71</td>
</tr>
<tr>
<td>Cortinarius caperatus</td>
<td>4.742</td>
<td>29.45</td>
</tr>
<tr>
<td>Cortinarius decipiens</td>
<td>11.42</td>
<td>70.93</td>
</tr>
<tr>
<td>Cortinarius malicorus</td>
<td>24.96</td>
<td>155.0</td>
</tr>
<tr>
<td>Hygrophoropsis aurantia</td>
<td>1.497</td>
<td>9.298</td>
</tr>
<tr>
<td>Imelria badia</td>
<td>2.259</td>
<td>14.03</td>
</tr>
<tr>
<td>Lactarius rufus</td>
<td>2.708</td>
<td>16.82</td>
</tr>
<tr>
<td>Lycoperdon perlatum</td>
<td>0.133</td>
<td>0.826</td>
</tr>
<tr>
<td>Paxillus involutus</td>
<td>2.540</td>
<td>15.78</td>
</tr>
<tr>
<td>Russula amethystina</td>
<td>1.562</td>
<td>9.702</td>
</tr>
<tr>
<td>Russula roxipes</td>
<td>0.413</td>
<td>2.565</td>
</tr>
<tr>
<td>Russula paludosa</td>
<td>1.906</td>
<td>11.84</td>
</tr>
<tr>
<td>Sarcodon imbricatus</td>
<td>10.84</td>
<td>67.33</td>
</tr>
<tr>
<td>Suillus bovinus</td>
<td>1.957</td>
<td>12.16</td>
</tr>
<tr>
<td>Suillus granulatus</td>
<td>12.73</td>
<td>79.07</td>
</tr>
<tr>
<td>Tricholoma equestre</td>
<td>10.85</td>
<td>67.39</td>
</tr>
<tr>
<td>Tricholoma fulvum</td>
<td>3.259</td>
<td>20.24</td>
</tr>
<tr>
<td>Soil</td>
<td>0.161</td>
<td></td>
</tr>
</tbody>
</table>

2021
near vil. Smolyn

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amanita citrina</td>
<td>1.028</td>
<td>5.439</td>
<td></td>
</tr>
<tr>
<td>Amanita muscaria</td>
<td>0.416</td>
<td>2.201</td>
<td></td>
</tr>
<tr>
<td>Cantharellus cibarius</td>
<td>0.587</td>
<td>3.106</td>
<td></td>
</tr>
<tr>
<td>Fistulina hepatica</td>
<td>0.151</td>
<td>0.799</td>
<td></td>
</tr>
<tr>
<td>Hygrophoropsis aurantia</td>
<td>1.354</td>
<td>7.164</td>
<td></td>
</tr>
<tr>
<td>Imelria badia</td>
<td>1.760</td>
<td>9.312</td>
<td></td>
</tr>
<tr>
<td>Lactarius rufus</td>
<td>3.869</td>
<td>20.47</td>
<td></td>
</tr>
<tr>
<td>Lactarius turpis</td>
<td>2.210</td>
<td>11.69</td>
<td></td>
</tr>
<tr>
<td>Macrolepista procera</td>
<td>0.032</td>
<td>0.169</td>
<td></td>
</tr>
<tr>
<td>Russula aeruginea</td>
<td>0.618</td>
<td>3.270</td>
<td></td>
</tr>
<tr>
<td>Russula xerampelina</td>
<td>0.265</td>
<td>1.402</td>
<td></td>
</tr>
<tr>
<td>Sarcodon imbricatus</td>
<td>16.49</td>
<td>87.25</td>
<td></td>
</tr>
<tr>
<td>Suillus bovinus</td>
<td>2.019</td>
<td>10.68</td>
<td></td>
</tr>
<tr>
<td>Suillus granulatus</td>
<td>3.890</td>
<td>20.58</td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>0.189</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amanita pantherina</td>
<td>0.682</td>
<td>2.890</td>
<td></td>
</tr>
<tr>
<td>Amanita rubescens</td>
<td>1.903</td>
<td>8.064</td>
<td></td>
</tr>
<tr>
<td>Cantharellus cibarius</td>
<td>0.426</td>
<td>1.805</td>
<td></td>
</tr>
<tr>
<td>Coltricia perennis</td>
<td>0.216</td>
<td>0.915</td>
<td></td>
</tr>
<tr>
<td>Cortinarius caperatus</td>
<td>6.140</td>
<td>26.02</td>
<td></td>
</tr>
<tr>
<td>Cortinarius malicorus</td>
<td>12.46</td>
<td>52.80</td>
<td></td>
</tr>
</tbody>
</table>
Продовження табл. 8

<table>
<thead>
<tr>
<th></th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortinarius praestans</td>
<td>2.062</td>
<td>8.742</td>
</tr>
<tr>
<td>Cortinarius trivialis</td>
<td>10.39</td>
<td>44.03</td>
</tr>
<tr>
<td>Hygrocybe aurantia</td>
<td>0.914</td>
<td>3.873</td>
</tr>
<tr>
<td>Imeliera badia</td>
<td>3.049</td>
<td>12.92</td>
</tr>
<tr>
<td>Lactarius rufus</td>
<td>3.211</td>
<td>13.61</td>
</tr>
<tr>
<td>Lactarius scabrum</td>
<td>0.842</td>
<td>3.568</td>
</tr>
<tr>
<td>Paxillus involutus</td>
<td>2.715</td>
<td>11.50</td>
</tr>
<tr>
<td>Pseudoclitocybe cyathiformis</td>
<td>0.248</td>
<td>1.051</td>
</tr>
<tr>
<td>Russula cyanoxantha</td>
<td>2.467</td>
<td>10.45</td>
</tr>
<tr>
<td>Russula emetica</td>
<td>0.851</td>
<td>3.606</td>
</tr>
<tr>
<td>Russula foetens</td>
<td>0.695</td>
<td>2.945</td>
</tr>
<tr>
<td>Russula xerampelina</td>
<td>0.180</td>
<td>0.763</td>
</tr>
<tr>
<td>Suillus bovinus</td>
<td>1.164</td>
<td>4.932</td>
</tr>
<tr>
<td>Tricholoma fulvum</td>
<td>9.452</td>
<td>40.05</td>
</tr>
<tr>
<td>Tylopilus felleus</td>
<td>0.813</td>
<td>3.445</td>
</tr>
<tr>
<td>Soil</td>
<td>0.236</td>
<td></td>
</tr>
<tr>
<td>Amanita muscaria</td>
<td>1.249</td>
<td>6.123</td>
</tr>
<tr>
<td>Cortinarius decipiens</td>
<td>15.51</td>
<td>76.03</td>
</tr>
<tr>
<td>Cortinarius malicorus</td>
<td>28.97</td>
<td>142.0</td>
</tr>
<tr>
<td>Cortinarius praestans</td>
<td>8.613</td>
<td>42.22</td>
</tr>
<tr>
<td>Hygrocybe aurantia</td>
<td>1.693</td>
<td>8.299</td>
</tr>
<tr>
<td>Imeliera badia</td>
<td>2.916</td>
<td>14.29</td>
</tr>
<tr>
<td>Lactarius rufus</td>
<td>3.590</td>
<td>17.60</td>
</tr>
<tr>
<td>Lycoperdon perlatum</td>
<td>0.075</td>
<td>0.368</td>
</tr>
<tr>
<td>Paxillus involutus</td>
<td>6.521</td>
<td>31.97</td>
</tr>
<tr>
<td>Russula xerampelina</td>
<td>1.430</td>
<td>7.010</td>
</tr>
<tr>
<td>Sarodan imbricatus</td>
<td>9.942</td>
<td>48.74</td>
</tr>
<tr>
<td>Suillus bovinus</td>
<td>1.634</td>
<td>8.010</td>
</tr>
<tr>
<td>Suillus granulatus</td>
<td>11.48</td>
<td>56.27</td>
</tr>
<tr>
<td>Tricholoma equestre</td>
<td>9.636</td>
<td>47.24</td>
</tr>
<tr>
<td>Tricholoma fulvum</td>
<td>3.007</td>
<td>14.74</td>
</tr>
<tr>
<td>Soil</td>
<td>0.204</td>
<td></td>
</tr>
<tr>
<td>Amanita citrina</td>
<td>0.976</td>
<td>14.35</td>
</tr>
<tr>
<td>Amanita rubescens</td>
<td>1.124</td>
<td>16.53</td>
</tr>
<tr>
<td>Armillaria mellea</td>
<td>BDL*</td>
<td></td>
</tr>
<tr>
<td>Boletus edulis</td>
<td>0.189</td>
<td>2.779</td>
</tr>
<tr>
<td>Cantharellus cibarius</td>
<td>0.296</td>
<td>4.353</td>
</tr>
<tr>
<td>Cortinarius praestans</td>
<td>8.046</td>
<td>118.3</td>
</tr>
<tr>
<td>Fomitopsis betulina</td>
<td>0.083</td>
<td>1.221</td>
</tr>
<tr>
<td>Lycoperdon perlatum</td>
<td>BDL</td>
<td></td>
</tr>
<tr>
<td>Macrolepiota procera</td>
<td>0.140</td>
<td>2.056</td>
</tr>
<tr>
<td>Paralepiota gilva</td>
<td>11.81</td>
<td>173.7</td>
</tr>
<tr>
<td>Russula xerampelina</td>
<td>1.038</td>
<td>15.26</td>
</tr>
<tr>
<td>Russula vesca</td>
<td>1.687</td>
<td>24.81</td>
</tr>
<tr>
<td>Russula xerampelina</td>
<td>0.654</td>
<td>9.618</td>
</tr>
<tr>
<td>Suillus latens</td>
<td>12.49</td>
<td>183.7</td>
</tr>
<tr>
<td>Tricholoma fulvum</td>
<td>16.52</td>
<td>242.9</td>
</tr>
<tr>
<td>Tricholomopsis rutilans</td>
<td>0.542</td>
<td>7.971</td>
</tr>
<tr>
<td>Soil</td>
<td>0.068</td>
<td></td>
</tr>
<tr>
<td>Amanita muscaria</td>
<td>2.043</td>
<td>0.706</td>
</tr>
<tr>
<td>Russula vesca</td>
<td>14.11</td>
<td>4.879</td>
</tr>
<tr>
<td>Tricholoma fulvum</td>
<td>28.40</td>
<td>9.820</td>
</tr>
<tr>
<td>Xerocomellus chryxenteron</td>
<td>3.016</td>
<td>1.043</td>
</tr>
<tr>
<td>Soil</td>
<td>2.892</td>
<td></td>
</tr>
</tbody>
</table>

Note: *BDL – below detection limit
The geometric mean of radiocaesium activity in the studied mushrooms for the period 2018-2021 amounted to 1.434 kBq/kg dm (from the minimum value – BDL in A. mellea to the maximum – 16.79 kBq/kg dm in C. malicorus). At the same time, the geometric mean values in groups of species differed significantly: in Russula spp. – 0.635 kBq/kg dm (from 0.345 in R. vesca to 1.967 in R. cyanoxantha); in Amanita spp. – 0.737 (from 0.312 in A. pantherina up to 1.210 in A. rubescens); in Boletales spp. – 1.905 Bq/kg dm (from 0.189 in B. edulis up to 12.490 in S. luteus); in Lactarius spp. – 2.502 kBq/kg dm (of 0.863 in L. turpis to 2.987 in L. rufus); Tricholomataceae spp. – 4.910 (from 0.542 in T. rutilans to 11.81 in P. gilva); in Cortinarius spp. – 8.278 Bq/kg dm (from 4.437 in C. caperatus to 16.79 in C. malicorus). Previously, increased levels of radiocaesium were also determined in Cortinariaceae spp. (Haselwandter et al., 1988; Yoshida, Muramatsu, 1994; Grodzinskaya et al., 2003, 2011; Zalewska et al., 2016; Falandysz et al., 2019; Gabriel et al., 2023).

Significant differences in the levels of contamination of the same species are noted not only at different locations but also within the same sampling site, which is obviously associated with the extremely heterogenous nature of contamination, the depth of mycelium in the soil, and microclimatic conditions. Considering the variability in the levels of accumulation of radiocaesium by different species in different habitats, the BAF value is important for the assessment of the total accumulative ability of mushroom species (Table 9).

Table 9

<table>
<thead>
<tr>
<th>Species*</th>
<th>BAFs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. campestris, H. rubellus, A. mellea, I. giba, L. perlatum, F. betulina, A. clavipes, M. proceru, Ch. rhacodes, A. pantherina</td>
<td>0.1 – 1.0</td>
</tr>
<tr>
<td>R. cyanoxantha, T. fulvum, P. involutus, L. helvus, C. varius, L. volvens, R. maculata, C. trivialis</td>
<td>20.1 – 50.0</td>
</tr>
<tr>
<td>C. malicorus, C. decepiens, S. imbricatum, C. praestans</td>
<td>50.1 – 100.0</td>
</tr>
<tr>
<td>C. semisanguineus, P. gilva</td>
<td>&gt; 100</td>
</tr>
</tbody>
</table>

Note: * The species in the first column are arranged in order of increasing BAFs

Summarizing data on the intensity of radiocaesium accumulation during the research period (1991-2021) showed that among the species with an average and high level of accumulation are only mycorrhizal species. Hyper-accumulative properties in relation to radiocaesium are demonstrated by Cortinarius, Saxodond, Paralepista, Tricholoma, Lactarius, Suillus spp. Recommended by us earlier (Grodzinskaya et al., 2003, 2011, 2013), common on the territory of Ukrainian Polesie – I. badia (= B. badia), P. involutus and L. rufus, stably throughout the entire post-Chernobyl period serve as representative bioindicators of radiocaesium contamination.

The potential risk of radioactivity to human health is expressed as the equivalent dose in mSv per year. Based on the obtained data, we calculated the potential average dose of internal irradiation considering only the part connected with 137Cs by consumption of some popular culinary-medicinal species in 2020-2021, taking the average annual consumption of an adult inhabitant of Chernihiv Polesie (5 kg of fresh mushrooms) and a culinary processing coefficient of 0.5 (Table 10).
Potential annual doses of internal radiation (mSv/y) due to consumption of Boletus edulis, Imleria badia, C.cibarius, Suillus spp, T.equestre by adults from monitoring localities (near the villages of Smolyn and Karpylivka)

<table>
<thead>
<tr>
<th>Species</th>
<th>Min $^{137}$Cs activity (kBq/kg dry mass)</th>
<th>Min Dose (mSv/y)</th>
<th>Max $^{137}$Cs activity (kBq/kg dry mass)</th>
<th>Max Dose (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boletus edulis</td>
<td>189</td>
<td>0.0006</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Imleria badia</td>
<td>2259</td>
<td>0.0073</td>
<td>7682</td>
<td>0.0250</td>
</tr>
<tr>
<td>Cantharellus cibarius</td>
<td>296</td>
<td>0.0010</td>
<td>2254</td>
<td>0.0073</td>
</tr>
<tr>
<td>Suillus spp</td>
<td>1164</td>
<td>0.0038</td>
<td>12730</td>
<td>0.0414</td>
</tr>
<tr>
<td>Tricholoma equestre</td>
<td>9636</td>
<td>0.0313</td>
<td>10850</td>
<td>0.0353</td>
</tr>
</tbody>
</table>

In 2020-2021, the potential annual equivalent dose reached maximum values in Suillus spp., Tricholoma equestre and I. badia, in which it reached, respectively, 4.1, 3.5 and 2.5 % of the annual dose (1 mSv).

Conclusions

Activity levels of $^{137}$Cs in wild mushrooms of Chernihiv Polesie varied over the years 1991-2021 depending on the mushroom species, its ecological affiliation, radioecological situation at the sampling sites, showing a certain tendency to decrease over time.

Hyper-accumulative properties in relation to $^{137}$Cs are demonstrated by Cortinarius, Sarcodon, Paralepista, Tricholoma, Lactarius, Suillus spp. Widely distributed on the territory of Ukrainian Polesie – I. badia, P. involutus and L. rufus, remain representative bioindicators of radiocaesium contamination.

A potential calculated annual effective doses due to the mushrooms consumption by adults, considering only the effect of the $^{137}$Cs, reached a high values in Suillus spp., T. equestre, and I. badia – 0.041, 0.035 and 0.025 mSv, respectively, which indicates a relatively insignificant dose load when consuming mushrooms in these localities compared to other localities of Ukrainian Polesie that have higher levels of soil contamination with radionuclides.

However, radiation control can still be recommended during mushroom procurement and mass collections because of the persistent spotty and uneven nature of contamination of the territory of Chernihiv Polesie.

References


69


Information about the authors:

Grodzynska G. [in Ukrainian: Гродзинська Г.] ¹, Senior Researcher, PhD in Biol. Sc., email: a.grodzinskaya@gmail.com
ORCID – 0000-0002-5128-8695         Researcher ID – AAF-3287-2020         Scopus-Author ID – 6506163276
Department of Phytoecology, Institute for Evolutionary Ecology, National Academy of Sciences of Ukraine
Acad. Lebedeva St.37, Kyiv, 03143, Ukraine

Nebesnyi V. [in Ukrainian: Небесний В.] ², Researcher, email: nebvit@gmail.com
Department of Phytoecology, Institute for Evolutionary Ecology, National Academy of Sciences of Ukraine
Acad. Lebedeva St.37, Kyiv, 03143, Ukraine

Teslenko I. [in Ukrainian: Тесленко І.] ³, Lead Engineer, email: igor3654@ukr.net
ORCID – 0000-0002-4184-4774
Department of Phytoecology, Institute for Evolutionary Ecology, National Academy of Sciences of Ukraine
Acad. Lebedeva St.37, Kyiv, 03143, Ukraine

¹Study design, data collection, statistical analysis, manuscript preparation.
²Data collection, statistical analysis, manuscript preparation.
³Data collection, statistical analysis, manuscript preparation.