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GEOGRAPHY

Artificial Radionuclides in Edible Wild Mushrooms and Berries of the Murmansk Region

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The omnipresent dispersion of technogenic isotopes has significantly increased the risk of the population of the Russian Federation and several countries of Western Europe receiving additional doses of internal irradiation from the consumption of food products of forest origin. This fact is confirmed by investigations in regions polluted with anthropogenic radionuclides that demonstrate that some species of edible toadstool mushrooms and wild berries significantly exceed other components of forest biocenoses in their capability to accumulate artificial radionuclides; the transition coefficients for forest production are one order of magnitude greater than those of agricultural products. Although mushrooms and berries are not essential food products, they are actively consumed. As a result, people get not only the nutrients and vitamins but also additional amounts of technogenic isotopes and irradiation doses.

Atmospheric nuclear tests and the incident at the Chernobyl nuclear power station in 1986 influenced strongly the distribution of artificial radionuclides in the Arctic ecosystems [1]. The surface activity of radionuclides that precipitated over the Murmansk region, the northern territories of Norway (the Troms and Finnmark counties), and Finland (the Lapland region) as reported in 1985 varied in the range: 1.2–4.2 Bq/m^2 for ^{137}Cs and 0.8–2.6 for ^{90}Sr [2, 3]. In 1986, the maximum amounts of ^{137}Cs (up to 3.6 Bq/m^2) of Chernobyl origin precipitated on the Lapland territory in Finland [4]; in the Murmansk region and Northern Norway, this precipitation did not exceed 2.72 and 1.19 Bq/m^2, respectively [2, 5].

The objective of this work is determination of the modern radioactive pollution of edible and conventionally edible wild toadstool mushrooms and berries in the Murmansk region and estimates of the internal radiation doses of the population caused by the consumption of forest production.

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In order to attain this goal, samples of soils, lichens, and mass species of edible wild mushrooms and berries were collected in 2011–2012 on some sites on the territory of the Murmansk region (Fig. 1; Table 1):

site 1: vicinities of Dalniye Zelentsy settlement;

site 2: location of the road marker for 104 km on the road from Murmansk to Tumanny;

site 3: location of the road marker for 30 km on the road from Murmansk to Verkhnetulomskii;

site 4: vicinities of Liinahamari;

site 5: vicinities of the town of Apatity.

Sampling was performed in the regions most widely visited by the local population for collecting the forest production. All samples were taken at the points with topographic links to the terrain (Fig. 1).

The selected samples were cleaned, dried, ground, and weighed. The measurements of specific ^{137}Cs activity in the samples were performed using a certified γ-spectrometric setup manufactured by the Canberra Co. with a Germanium detector. Processing of spectra was performed using the Genie-2000 software. The measurements of ^{90}Sr were performed with a LS–6500 β-radiometer manufactured by Beckman Co. on the basis of the Cherenkov radiation with the preliminary radio-chemical concentration of daughter isotope ^{90}Y. The error of measurements did not exceed 30%. The specific activities of soil and lichens were reduced to the dry mass, and the activities of mushrooms and berries were reduced to the wet mass.

The total pollution levels on the investigated sites were estimated on the basis of the concentration of technogenic radionuclides in the soil and lichens (Table 2). The soil has an increased capability for accumulation of radionuclides, especially ^{137}Cs owing to irreversible fixation of it by individual soil components. On the basis of data in 2011–2012, the specific activity of ^{137}Cs in the upper layer (0–2 cm) of the soil varied within 11.6–113.0 Bq/kg. The soil at site 1 located at a distance of 130 km from Murmansk on the coast of the Barents Sea was maximally polluted with Cs. The least amounts of radionuclides were found in the soil at site 3. The amount of ^{90}Sr in the soil of the regions is significantly smaller than ^{137}Cs. The measured data confirm the relatively high total pollu-

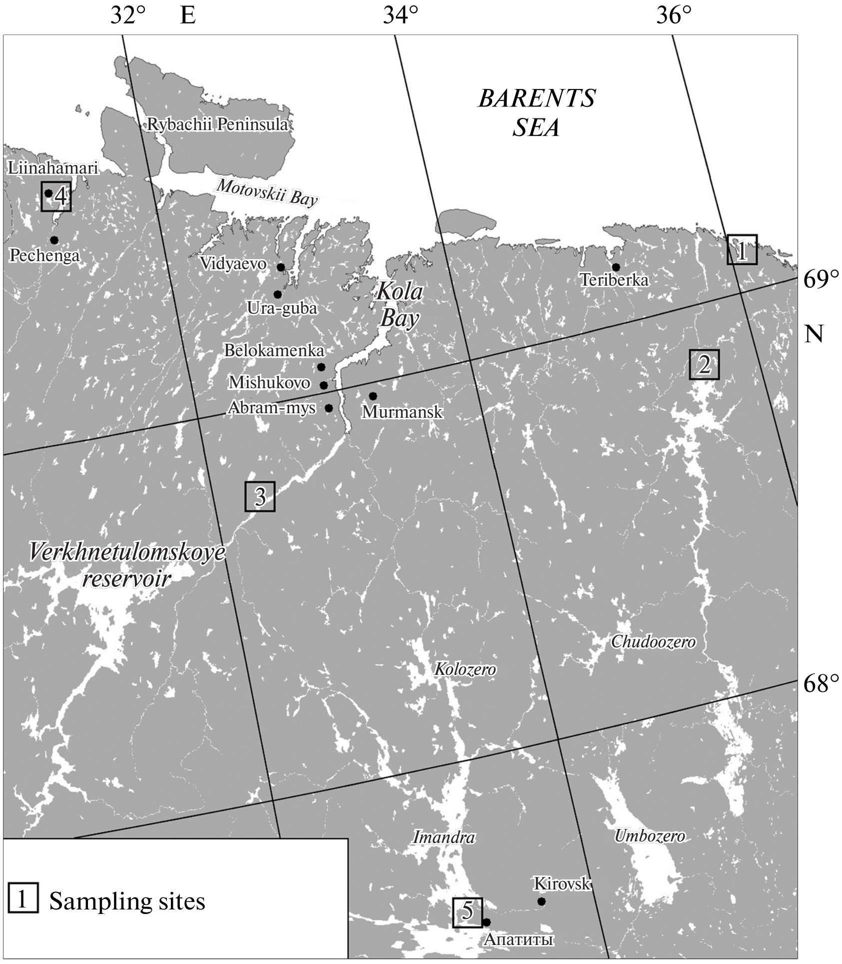

Fig. 1. Sample stations of the land environment and biota on the territory of the Murmansk region in 2011–2012.

tion of site 1 with radionuclides (17.6 Bq/kg of ^{90}Sr and 113.0 Bq/kg of ^{137}Sr) and lowest pollution of site 3.

Lichens accumulate isotopes contained in wet and dry atmospheric precipitations through the upper part of thalli. According to the modern general data [6], 150–400 Bq/kg of ^{137}Cs and 100–120 Bq/kg of ^{90}Sr are contained in the moss–lichen cover of the northern European part of Russia. Representatives of the family Cladoniaceae on the territory of the Murmansk region contained, on average, 22.6 ± 9.1 Bq/kg of ^{137}Cs and 3.2 ± 1.7 Bq/kg ^{90}Sr. The maximum concentrations were revealed at sites 1 and 5. In addition to ^{137}Cs, ^{134}Cs (1.9 Bq/kg) was found in the sample from *Cladonia stellaris* from site 5, which may provide evidence about the emission of this short-living isotope from the Kola nuclear power station located at a distance of a few tens of kilometers from the sampling place. The lichens sampled at site 3 were least polluted with Cs. In the modern samples of lichens, the activity of ^{137}Cs is several orders of magnitude smaller than in the 1990s. For example, in 1992, 231 Bq/kg of ^{137}Cs was contained in the lichens of the genus Cladonia and 180 Bq/kg in the lichens of the genus Cetraria [7].

Comparison of the results of γ-spectrometric analysis of mushrooms belonging to the families Boletaceae and Russulaceae revealed the wide variability of specific activities of ^{137}Cs in the representatives of one species from different regions and in the samples collected within one site. For example, the concentration of ^{137}Cs in the most popular and abundant edible mushroom *Leccinum versipelle* was 1.2–19.1 Bq/kg, in *Russula paludosa* it was 6.2–49.4 Bq/kg, and in *Paxillus involutus* the concentration varied from 25.7 to 50.1 Bq/kg. Increased concentrations of radionuclides were found in conventionally edible mushrooms *Cortinarius mucosis* and *Cortinarius caperatus* (21.8–45.9 Bq/kg). Averaging of the data of species belonging to specific families was performed to generalize the results (Table 2). Statistical analysis demonstrated that mushroom species belonging to the family Boletaceae accumulate ^{137}Cs in a linear dependence on the concentration of radionuclides in the upper soil layer

Table 1. List of investigated species of land biota

Family	Species, *n*—number of samples	Name
	Lichens	
Parmeliaceae	Cetraria islandica ($n = 3$)	Iceland moss
Cladoniaceae	Cladonia stellaris ($n = 7$)	Lichen cup stellaris
	Mushrooms	
Boletaceae	Leccinum versipelle ($n = 7$)	Orange bolete
	Sullius variegatus ($n = 1$)	Brown and yellow suillus
	Leccinum scabrum ($n = 5$)	Birch bolete
	Boletus subtomentosus ($n = 1$)	Brown and yellow bolet
Russulaceae	Russula paludosa ($n = 4$)	Swamp russula
	Lactarius torminosus ($n = 3$)	Woolly milkcap
	Lactarius rufus ($n = 1$)	Rufous Milkcap
Cortinariaceae	Cortinarius caperatus ($n = 1$)	Gypsy mushroom
	Cortinarius mucosus ($n = 1$)	Orange webcap
Paxillaceae	Paxillus involutus ($n = 2$)	Brown roll-rim
	Berries	
Ericaceae	Vaccinium uliginosum ($n = 2$)	Northern bilberry
	Vaccinium myrtillus ($n = 2$)	Blueberry
	Vaccinium vitis-idaea ($n = 3$)	Cowberry
	Empetrum nigrum ($n = 2$)	Black crowberry
Cornaceae	Cornus suecica ($n = 1$)	Bunchberry

Table 2. Specific activities of ^{137}Cs and ^{90}Sr (Bq/kg) in individual elements of forest ecosystems at different sites (1–5)

	1	2	3	4	5	Mean value
			^{137}Cs			
Soil	113.0	46.0	11.6	43.7	29.5	48.7 ± 38.5
Cladoniaceae	29.9	21.8	11.5	16.2	33.4	22.6 ± 9.1
Boletaceae	19.0	10.0	13.2	11.9	6.4	12.1 ± 4.6
Russulaceae	2.6	27.8	9.6	11.4	9.3	12.1 ± 9.4
Ericaceae	2.1			2.1	2.3	2.2 ± 0.1
			^{90}Sr			
Soil	17.6	6.8	2.9	11.2	8.3	9.4 ± 5.5
Cladoniaceae	1.8	4.1	2.1	5.7	2.3	3.2 ± 1.7
Boletaceae	0.14	0.1	0.7	0.5	1.6	0.6 ± 0.6
Russulaceae		0.4				
Ericaceae	1.2			2.6	1.1	1.6 ± 0.8

according to the relation $y = 0.0874x + 7.8216$ ($R^2 = 0.53$).

The specific activity of ^{90}Sr in all investigated mushroom species was lower than the activity of ^{137}Cs. The maximum concentrations of radionuclide in the mushrooms of the family Boletaceae were 2.4 Bq/kg in *Leccinum versipelle* found at site 5 near Apatity. A dependence of ^{90}Sr accumulation by the mushroom fruit body on the concentration of the radionuclide in the upper soil layer was not revealed.

In 1987–1992, the concentration of ^{137}Cs in the mushrooms of the Boletaceae family was 100–280 Bq/kg. This radionuclide was accumulated in the representatives of the Russulaceae family in amounts within 50–150 Bq/kg [7]. At the present time, pollution of wild mushrooms in the Murmansk region has decreased approximately by more than a factor of 10.

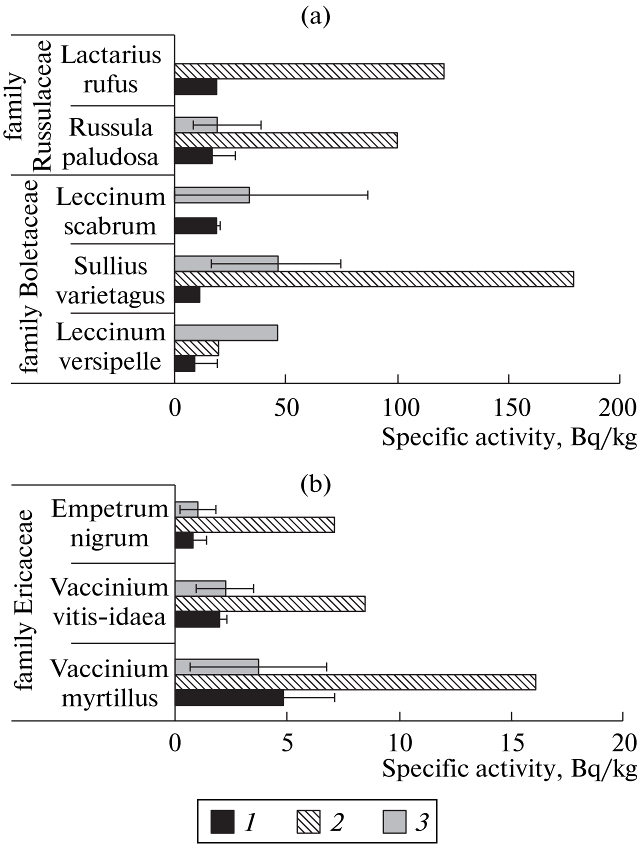

Fig. 2. Specific activity of ^{137}Cs in wild mushrooms (a) and berries (b) in the Murmansk region (*1*), Northern Finland (*2*), and Northern Norway (*3*).

The mean concentration of ^{137}Cs in the bush berries belonging to the Ericaceae family is 2.1 Bq/kg; the maximum specific activity of radionuclides (7.1 Bq/kg) was recorded in *Vaccinium myrtillus*. The concentration of ^{137}Cs in the berries decreased by a factor of four compared to the data in 1992 [7]. The specific activity of ^{90}Sr in the berries of all investigated species did not exceed 2.6 Bq/kg.

At present, the mean content of the main dose-forming radionuclides in mushrooms and berries of the Murmansk region is significantly smaller than the permissible levels accepted on the territory of the Russian Federation (in Bq/kg): 500 for ^{137}Cs and 50 for ^{90}Sr in mushrooms; 160 for ^{137}Cs and 60 for ^{90}Sr in berries [8].

Comparison of the modern accumulation levels of ^{137}Cs in edible wild mushrooms and berries of the Murmansk region with similar data obtained by Finnish [9] and Norwegian [10] colleagues (Fig. 2) demonstrated that mushrooms and berries from Northern Finland (Inari municipality) have greater pollution levels compared with similar species collected on the Kola Peninsula and in Northern Norway (Troms county).

The calculation of internal radiation doses of the population after consumption of wild berries and mushrooms has been carried out in practically all countries in which the population gathers and processes forest products. The approaches applied for estimating the doses are generally similar. However, some peculiarities of the methods (inclusion of different sets of nuclides for the dose calculation, application or nonapplication of the activity coefficient during culinary processing, etc.), and also the differences in the initial data (annual mean consumption of berries and mushrooms, concentration of radionuclides in the fruit bodies) lead to the fact that the radiation doses caused by consumption of mushrooms and berries calculated by different authors vary in wide limits and cannot be compared [11].

In this work, we estimated the human internal radiation dose from consuming the forest berries and mushrooms caused by anthropogenic radionuclides ^{137}Cs and ^{90}Sr [12]. In order to avoid indefiniteness induced by inexact statistical data based on the annual consumption of forest products, the calculations were made for conventional consumption: 1 kg per year. This value of conventional consumption agrees well with the available data of the Federal State Statistical Service for 2010 on the consumption of forest mushrooms by the population living in different regions: Murmansk region (0.9 kg/yr), Northern Norway (1.0 kg/yr) [10], Northern Finland (~0.7 kg/yr) [13]. Information about consumption of wild berries by the population is limited in the literature; in Russia statistical calculation of this parameter is not available.

Calculation of the annual internal radiation doses was performed according to the following formulas:

$$E_{\text{int}} = \sum_k (dk_k I_k),$$

where E_{int} is the internal radiation dose, mSv/yr; dk_k is the dose coefficient of radionuclide k consumption by the organism with food, $dk_{\text{Cs}} = 1.3 \times 10^{-5}$, $dk_{\text{Sr}} = 2.8 \times 10^{-5}$ mSv/Bq [12, 14];

$$I_k = \sum_p (C_{kp} V_p K_{kp}),$$

where I_k is the annual consumption of radionuclide k with food, Bq/yr; C_{kp} is specific activity of radionuclide k in food product p, Bq/kg; V_p is annual consumption of food product p, kg/yr; $V_p = 1$ kg/yr; K_{kp} is a coefficient decreasing the concentration of radionuclide k in prepared food product p due to its culinary processing, relative units.

The coefficient for ^{137}Cs and ^{90}Sr radionuclides equal to $K_p = 1.0$ is used for berries, and $K_p = 0.5$ is used for mushrooms.

It follows from Table 3 that currently the annual receipt of the ^{137}Cs and ^{90}Sr radionuclides by the organisms of the adult population in the Murmansk region due to the consumption of wild berries and

Table 3. Annual receipt and internal radiation doses of the adult population in the Murmansk region from ^{137}Cs and ^{90}Sr caused by consuming wild berries and mushrooms (V_p = 1 kg/yr)

Radionuclide	Berries of the Ericaceae family		Mushrooms of the Boletaceae family		Mushrooms of the Russulaceae family	
	I, Bq/yr	E_{int}, μSv/yr	I, Bq/yr	E_{int}, μSv/yr	I, Bq/yr	E_{int}, μSv/yr
^{137}Cs	2.20	0.03	6.050	0.079	6.050	0.079
^{90}Sr	1.60	0.05	0.300	0.008	0.200	0.008
^{137}Cs + ^{90}Sr	3.80	0.08	6.350	0.087	6.250	0.087

Table 4. Internal radiation doses from ^{137}Cs obtained by the adult population of the Murmansk region and northern regions of Finland and Norway, μSv/yr

Region	Berries		Mushrooms	
	Vaccinium vitis-idaea (cowberry)	Vaccinium myrtillus (blueberry)	Leccinum versipelle (orange bolete)	Russula paludosa (swamp russula)
Murmansk region	0.06	0.03	0.12	0.11
Northern Finland	0.21	0.11	0.26	0.65
Northern Norway	0.05	0.03	0.60	0.13

mushrooms and the radiation doses formed as a result of this are very low.

Consumption of 1 kg of mushrooms belonging to the Boletaceae family including valuable mushrooms from the point of view of culinary needs (birch bolete, orange bolete, and others) leads to an additional receipt of ^{137}Cs and ^{90}Sr in amounts not exceeding 6.5 Bq/yr and a dose load of approximately 0.09 μSv/yr. Receipt of each of these radionuclides is tens of thousand times lower than the limits of their receipt with food, which are approximately 7.7×10^4 and 1.3×10^4 Bq/yr for ^{137}Cs and ^{90}Sr, respectively [15]. The dose obtained during such a consumption is less than 0.01% of the safe annual dose of technogenic irradiation for the population set at a level of 1 μSv/yr [15].

Similar tendencies and regularities are found for mushrooms of the family Russulaceae and wild berries. Unlike the mushrooms, for which the main dose forming nuclide that forms approximately 85% of the dose is ^{137}Cs, the contribution of ^{90}Sr to the total dose of internal radiation caused by consumption of 1 kg of berries can be as high as 60%.

The calculation of internal radiation doses from ^{137}Cs caused by consumption of wild forest products in three northern regions was carried out with account for medium radiation activity in mushrooms and berries presented in Fig. 2 for conventional annual consumption by the population of 1 kg/yr (Table 4). Comparison of the doses demonstrated that the population of Northern Finland gets somewhat greater doses of technogenic radiation, which is explained by the increased pollution of the Finnish Laplandia territory after the accident at the Chernobyl nuclear power station.

The modern distribution of ^{137}Cs and ^{90}Sr in the components of the land ecosystem in the investigated regions of the Kola Peninsula, in general, reflects the global pollution level with long-living radionuclides characteristic of the northern part of the Russian European territory. Comparative analysis of the ^{137}Cs and ^{90}Sr concentrations in the samples of soil and land biota in the Murmansk region revealed a significant decrease in the pollution of forest products compared with the data of the 1990s. The specific activity of radionuclides in berries and mushrooms does not exceed the maximum permissible levels. The calculation of human internal radiation doses caused by consumption of wild berries and mushrooms demonstrated that from the point of view of radiation hygiene consumption of forest products is safe for the population of the Murmansk region and northern regions of Finland and Norway.

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