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The data on <sup>137</sup>Cs distribution in sod-podzol forest soils of Ukrainian Polissia contaminated by radionuclides after Chernobyl accident are presented. Researches were conducted on the permanent sample areas in wet bory and sugrudy in 2000 and in 2012 years. It is proved that <sup>137</sup>Cs migration from the forest litter to the soil mineral part occurred comparatively quickly. It can be explained by a thin layer and a high mineralization of the forest litter in wet sugrudy. Nevertheless, wet bory are characterized by more intensive radionuclide migration to the deeper layers of the soil mineral part. Such regularity can be explained by a small amount of humus and fine-dispersed particles as well as higher soil acidity in wet bory.

*Keywords:* radionuclides, soil radiation contamination, radionuclide specific activity, forest plantations, sod-podzol soils.

**Introduction**

It is known that radionuclides aerial migration into forest ecosystems occurred as a result of Chernobyl accident. It is considered that 60 - 90 % of radioactive fallout was absorbed by tree crowns depending on the tree species, the age of the tree and the condition of forest plantations. After that, the radionuclides migration and redistribution among the components of forest biogeocenosis began. By the end of the vegetative period of 1986 almost 95 % of radionuclides migrated from the tree crowns to the forest litter surface [4].

After Chernobyl accident many scientists from Ukraine [1, 3], Belarus [2], Russia [7] and some other Western European countries [9, 10] studied <sup>137</sup>Cs distribution in forest soils. The majority of the research on this topic were conducted in the period of 10 – 15 years after Chernobyl accident. However, the behavior of <sup>137</sup>Cs in soil is very complicated. It is dynamic process in time and in space. The peculiarities of <sup>137</sup>Cs behavior influences on the amount of radioactive contamination of the components of forest ecosystems; it also influences on the directions and the intensity of the radionuclide following migration in trophic chain, as well as the isotope penetration into human body. These research issues are still topical. Nevertheless, just few reports on radionuclides distribution in forest soils have appeared for the last decade [8]. There has been no investigation of these processes for a long period of time.

**Materials and methods**

The investigations were conducted on the permanent sample areas (PSA) in forest massifs of SE “Lugyny F” in 2000 and in 2012 years. PSA-68 is located in wet bory (A<sub>3</sub>) and PSA-88 is located in wet

sugrudy (C<sub>3</sub>). The study areas are characterized by equal humidity and different soil trophicity. Bory have poor soil condition; sugrudy have comparatively rich soil conditions. Wet bory are characterized by pine forest plantations. The Oak (*Quercus robur* L.) with insignificant number of pine (*Pinus sylvestris* L.) prevail in sugrudy. The plantations on these sample areas are of the same age and planting density.

PSA-68 has sod-medium podzol sandy soil located on water-glacial sediments. The forest litter is of 15cm there. PSA-88 is characterized by comparatively rich type of sod-medium podzol sabulous soil located on fluvioglacial sediments. The forest litter on this area is of 3 cm. In 2012, the average value of soil radiation contamination density on PSA-68 was  $342 \pm 26$  kBq/m<sup>2</sup> and  $421 \pm 19$  kBq/m<sup>2</sup> on PSA-88.

Thus, permanent sample areas differ in some characteristic factors such as: soil conditions; composition of forest plantations; diversity of species and their spread in undergrowth and understory, as well as in herbaceous layer; forest litter density. But, the soil radiation contamination density on these sample areas does not differ much.

Sample areas with the territory of 100 × 100 m were laid out according to the generally accepted technique [5]. There were dugged out 3 soil profiles within a sample area. The examination of horizons was done there. Soil samples were collected from each 2 cm thick layer starting from the soil top. Soil sampling was performed with a sample selector in the form of rectangle scoop (500 cm<sup>2</sup> (25 × 20 cm). Selected samples were dried under the temperature of 105°C in thermostats. After that, they were mixed and studied using spectrum analyzer “СЕГ-005-АКП” and scintillation detectors “БДЕГ-20-Р1” and “БДЕГ-20-Р2”.

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## Results and discussion

In 2000, investigations of soil from sample area laid out in wet bory showed that 69.03 % of the total  $^{137}\text{Cs}$  content was concentrated in the forest litter and 30.97 % was concentrated in the mineral soil part (Table 1). Radionuclides distribution in different layers of the forest litter was also uneven. The major part of  $^{137}\text{Cs}$  (48.75 % of the total content in the soil) was concentrated in the lower decayed (humified) layer. It should be mentioned that the forest litter on this sample area is very dense. It consists mainly of organic remains of pine (*Pinus sylvestris* L.) (needles, bark, branches, strobiles). These remains contain numerous organic substances (e.g.: lignin, which is difficult to hydrolyze; gums, essences, waxes, etc.). Such substances have a high acidity. All these factors slow down the humification of organic remains. The decay of organic abscission

under the influence of chemicals, humidity and temperature occurs simultaneously with the biological destruction. Bacteriological action of some substances from abscission of coniferous species causes mineralization of the forest litter, predominantly, under the action of fungi [6]. It slows down the decay of organic substances and causes its accumulation. Thus, it could be mentioned, that the major part of  $^{137}\text{Cs}$  moved to the decayed layer of the wet bory forest litter during 14 years after Chernobyl accident. Taking into account the density of the forest litter (about 15 cm), the rate of this process can be calculated. Thus, the rate of  $^{137}\text{Cs}$  transition into the forest litter is about 1cm per year. The results of the investigation show that during this period the considerable part of the radionuclide migrated to the soil mineral layer, mainly to the 0 - 4 cm layer of the humus-alluvial horizon.

Table 1.  $^{137}\text{Cs}$  radiation contamination density (kBq/m<sup>2</sup>) in soil layers in different types of forest conditions (2000 and 2012)

Soil layer	Wet bory – A <sub>3</sub>				Wet sugrudy – C <sub>3</sub>			
	2000		2012		2000		2012	
	$^{137}\text{Cs}$ radiation contamination density in soil layers				$^{137}\text{Cs}$ radiation contamination density in soil layers			
	kBq/m <sup>2</sup>	%	kBq/m <sup>2</sup>	%	kBq/m <sup>2</sup>	%	kBq/m <sup>2</sup>	%
<i>Forest litter</i>	445.26	69.03	42.49	12.41	242.62	34.73	7.17	1.70
A <sub>0l</sub> not decayed	1.04	0.16	0.50	0.15	0.62	0.09	0.16	0.04
A <sub>0f</sub> half decayed	129.80	20.12	27.04	7.90	11.84	1.69	1.80	0.43
A <sub>0h</sub> decayed	314.42	48.75	14.95	4.36	230.16	32.95	5.21	1.23
<i>Soil mineral layers</i>	199.74	30.97	299.77	87.59	455.92	65.27	414.76	98.30
0 - 2	118.72	18.40	146.08	42.68	258.36	36.99	197.45	46.79
2 - 4	23.00	3.57	56.95	16.64	96.96	13.88	129.52	30.70
4 - 6	8.44	1.31	22.95	6.71	54.86	7.85	41.63	9.86
6 - 8	6.64	1.03	15.50	4.53	22.52	3.22	22.13	5.25
8 - 10	5.90	0.91	12.15	3.55	9.72	1.39	7.06	1.67
10 - 12	3.66	0.57	10.64	3.11	5.42	0.78	4.85	1.15
12 - 14	3.98	0.62	9.81	2.87	3.22	0.47	1.68	0.40
14 - 16	5.52	0.86	6.42	1.88	1.46	0.21	2.10	0.50
16 - 18	4.60	0.71	4.14	1.21	0.80	0.11	1.60	0.38
18 - 20	4.96	0.77	3.25	0.95	0.60	0.09	1.40	0.33
20 - 22	3.60	0.56	2.24	0.65	0.50	0.07	1.11	0.26
22 - 24	3.44	0.53	3.57	1.04	0.44	0.06	1.43	0.34
24 - 26	2.88	0.45	2.34	0.68	0.40	0.06	1.30	0.31
26 - 28	2.60	0.40	2.21	0.65	0.36	0.05	0.91	0.22
28 - 30	1.80	0.28	1.52	0.44	0.30	0.04	0.59	0.14
<i>Total</i>	645.00	100.00	342.26	100.00	698.54	100.00	421.93	100.0

Other regularities in the process of <sup>137</sup>Cs disintegration were observed in wet sugrudy in 2000. Forest litter contained just 34.73 % from the total radionuclide content in soil. The mineral part of soil contained the rest of the radionuclide activity. Considerably high radionuclide migration was observed in the mineral part of soil down to the depth of 8 cm. The oak (*Quercus robur L.*) prevails in the composition of forest plantations on this sample area. Abscission of the oak and of other tree species and shrubs, as well as the remains of herbs, mineralize quickly enough. It lasts for 1 - 1.5 year [6]. At the same time, pine (*Pinus sylvestris L.*) abscission slows down the process of humification and mineralization of organic remains. In this way forest litter of 3 cm thick forms. The structure of the forest litter in sugrudy is similar to the forest litter formed in wet bory. More intensive mineralization of organic matter causes the radionuclides transition to the deeper soil layers.

Reselection of samples was performed in 2012. The investigation results show that considerable radionuclides transition from the forest litter to the soil mineral part occurred on both sample areas during 12 years.

Thus, the density of <sup>137</sup>Cs radiation contamination of the forest litter in wet bory declined to 12.41 % (or by 5.6 times). Notwithstanding the considerable radionuclides transition down through the soil profile, the forest litter in bory still contains a large amount of <sup>137</sup>Cs. More considerable radionuclide transition occurred in wet sugrudy. In such conditions the density of <sup>137</sup>Cs radiation contamination of the forest litter declined to 1.7 % (or by 20.4 times) of the total in the soil. Now, soil radiation contamination in wet sugrudy is calculated by radionuclide content in soil mineral part.

Thus, gradual decrease of the forest litter radiation contamination occurred in 2000 and in 2012 (Figs. 1 and 2). This process can be explained both by the vertical <sup>137</sup>Cs migration into the soil mineral part and by the decline of <sup>137</sup>Cs content in the abscission. The decline of the radionuclides penetration into plants is explained by the radioactive disintegration of isotopes, which allocate in the organic and nonorganic parts of the soil as well as by the establishing of the dynamic balance of <sup>137</sup>Cs in a biotic component of the forest biogeocenosis [4].

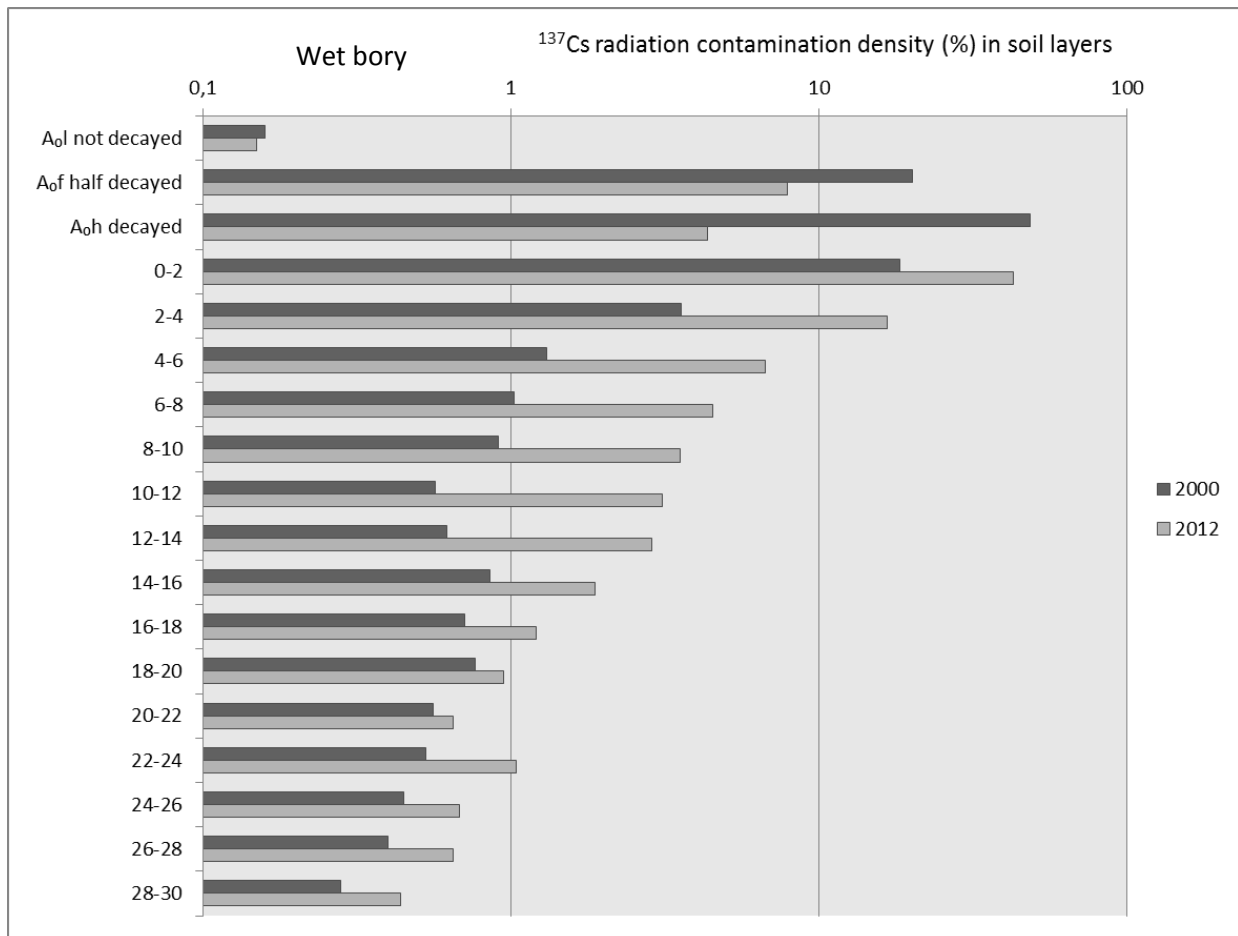


Fig. 1. The vertical distribution of the ratio of <sup>137</sup>Cs radiation contamination density (kBq/m<sup>2</sup>) in soil layers in wet bory (2000 and 2012).

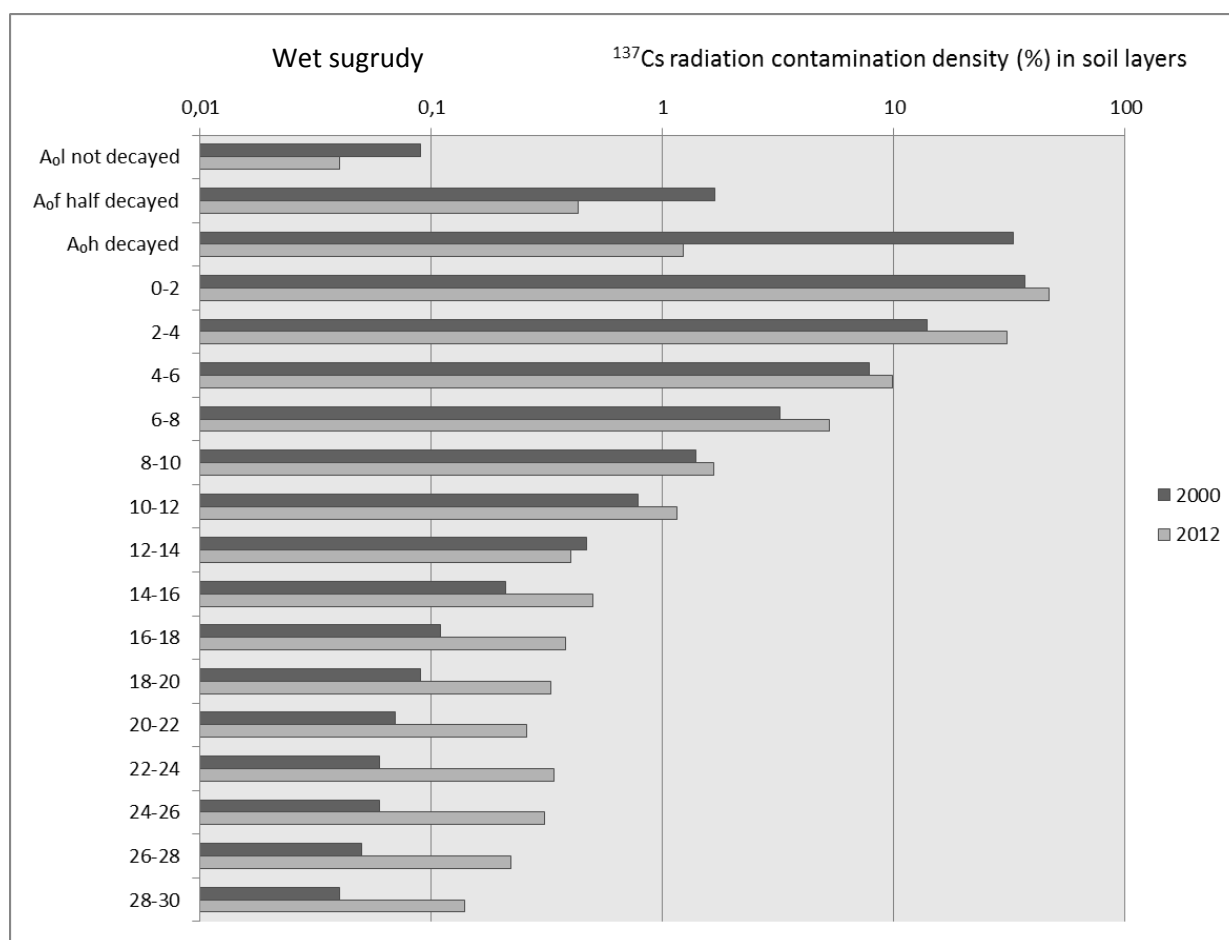


Fig. 2 The vertical distribution of the ratio of  $^{137}\text{Cs}$  radiation contamination density ( $\text{kBq/m}^2$ ) in soil layers in wet sugrudy (2000 and 2012).

Investigation results show that  $^{137}\text{Cs}$  transition to the soil mineral part occurred more quickly in wet sugrudy than in wet bory. The process of the radionuclides vertical migration slowed down with the lapse of time.  $^{137}\text{Cs}$  migration in the mineral part of the soil profile in bory differs from that in subory. Thus, more than 1 % of the radionuclide activity in wet bory soil was observed in the depth of 8 cm in 2000; in 2012, the same radionuclide activity in soil was observed in the depth of 24 cm. Wet sugrudy were observed to have 1 % of the radionuclide activity in the depth of 10 and 12 cm respectively. Such regularity appears when analyzing in-depth distribution of  $^{137}\text{Cs}$  activity in the soil mineral part (Table 2). In 2000,  $^{137}\text{Cs}$  content in bory sandy soil was about 25.22 % in the layer of 0 - 10 cm; in 2012,  $^{137}\text{Cs}$  content in this layer was about 74.11 %. Thus, the activity increased by 2.9 times. Similar increase was observed in the layer of 0 - 20 cm. In 2000, the radionuclide content in sandy-loam sugrudy was about 63.33 % in the layer of 0 - 10 cm; in 2012 this index was about 94.27 %. The activity increase by 1.5 times was observed in the layer of 0 - 20 cm. When compared rich soil conditions of sugrudy with poor soil conditions of bory, it can be

seen that today, the major part of  $^{137}\text{Cs}$  activity is concentrated in sugrudy in the layers of the soil mineral part with the thickness of 10 and 20 cm. Thus, in wet bory, 10 cm soil layer contained 74.11 % of the total radionuclide activity in soil; in wet sugrudy this index was about 94.27 %. Depending on the type of forest conditions, a 20 cm thick layer contained 84.13 and 97.03 %. Today, soil mineral part is a source of radionuclide penetration into plants.

Mentioned peculiarities are explained by a higher content of organic matter and fine-grained particles of soil in wet sugrudy, as well as by higher soil acidity in wet bory [6]. Consequently, in wet sugrudy after  $^{137}\text{Cs}$  transition from the forest litter to the soil mineral part it fixes strongly in the upper layers of the humus-alluvial horizon. The thickness of this horizon in wet sugrudy is about 20 cm. The data show that 94.27 % of  $^{137}\text{Cs}$  activity in soil was concentrated in 10 cm layer even in 2012. Only 2.97 % of this radionuclide activity migrated outside the humus-alluvial horizon. The thickness of the humus-alluvial horizon is about 10 cm in wet bory. Thus, in 2012, this soil horizon contained 74.11 % of  $^{137}\text{Cs}$  activity in soil (2000 – 25.22 % of the activity).

Considerable part of the radionuclide, that is 25.89 %, migrated to the alluvial horizon. It causes more intensive radionuclide migration to the deeper

soil layers. It is known that practically, the alluvial horizon does not contain humus and fine-grained particles.

**Table 2. The ratio of <sup>137</sup>Cs (%) activity in soil mineral part layers of different density in wet bory and sugrudy (2000 and 2012)**

Layers of soil mineral part. cm	Wet bory		Wet sugrudy	
	2000	2012	2000	2012
0 - 2	18.40	42.68	36.99	46.79
0 - 4	21.97	59.32	50.87	77.49
0 - 6	23.28	66.03	58.72	87.35
0 - 8	24.31	70.56	61.94	92.60
0 - 10	25.22	74.11	63.33	94.27
0 - 12	25.79	77.22	64.11	95.42
0 - 14	26.41	80.09	64.58	95.82
0 - 16	27.27	81.97	64.79	96.32
0 - 18	27.98	83.18	64.90	96.70
0 - 20	28.75	84.13	64.99	97.03

### Summary

1. During the period of the observation (in 2000 and in 2012) the considerable redistribution of the total <sup>137</sup>Cs activity between the forest litter and the soil mineral part occurred. The density of <sup>137</sup>Cs radioactive contamination of the forest litter in poor soil conditions of wet bory reduced by 5.6 times. And the density of <sup>137</sup>Cs radioactive contamination in

comparatively rich conditions of wet sugrudy reduced by 20.4 times.

2. More intensive <sup>137</sup>Cs vertical migration was observed in poor sandy soils of wet bory during 2000 - 2012 compared to comparatively rich sandy-loam soils of wet sugrudy. However, a higher percentage of <sup>137</sup>Cs activity is concentrated in 10 - 20 cm layer of the soil mineral part in more rich conditions of sugrudy, compared to poor bory conditions.

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### **ПЕРЕРОЗПОДІЛ <sup>137</sup>Cs У ГРУНТАХ ВОЛОГИХ БОРІВ І СУГРУДІВ ЛІСІВ ПОЛІССЯ УКРАЇНИ У ЧАСІ**

Наведено матеріали щодо розподілу <sup>137</sup>Cs у дерново-підзолистих ґрунтах лісів Полісся України, забруднених радіонуклідами після аварії на ЧАЕС. Дослідження проводились у 2000 і 2012 р. на постійних пробних площах, закладених у вологих борах і сугрудах. Показано, що у вологих сугрудах переміщення <sup>137</sup>Cs з лісової підстилки до мінеральної частини ґрунту відбулося в коротший період. Пояснюється це меншою потужністю і більш інтенсивною мінералізацією лісової підстилки у вологих сугрудах. У вологих борах з часом відзначається більш інтенсивне переміщення радіонукліда у глибші шари мінеральної частини ґрунту. Відзначена закономірність пояснюється, імовірно, меншим вмістом гумусу та дрібнодисперсних часток і вищою кислотністю ґрунту у вологих борах.

*Ключові слова:* радіонукліди, радіоактивне забруднення ґрунту, питома активність радіонукліда, лісові насадження, дерново-підзолисті ґрунти.

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### **ПЕРЕРАСПРЕДЕЛЕНИЕ <sup>137</sup>Cs В ПОЧВАХ ВЛАЖНЫХ БОРОВ И СУГРУДОВ ЛЕСОВ ПОЛЕСЬЯ УКРАИНЫ ВО ВРЕМЕНИ**

Приведены материалы по распределению <sup>137</sup>Cs в дерново-подзолистых почвах лесов Полесья Украины, загрязненных радионуклидами после аварии на ЧАЭС. Исследования проводились в 2000 и 2012 г. на постоянных пробных площадях, заложенных во влажных борах и сугрудах. Показано, что во влажных сугрудах перемещение <sup>137</sup>Cs из лесной подстилки в минеральную часть почвы произошло быстрее. Объясняется это меньшей мощностью и большей интенсивностью минерализации лесной подстилки во влажных сугрудах. Во влажных борах со временем отмечается более интенсивное перемещение радионуклида в более глубокие слои минеральной части почвы. Отмеченная закономерность объясняется, вероятно, меньшим содержанием гумуса и мелкодисперсных частиц и более высокой кислотностью почвы во влажных борах.

*Ключевые слова:* радионуклиды, радиоактивное загрязнение почвы, удельная активность радионуклидов, лесные насаждения, дерново-подзолистые почвы.

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