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N.Ye. Zarubina, https://orcid.org/0000-0003-1630-7667

Institute for Nuclear Research of the NAS of Ukraine, Kyiv
E-mail: nataliia.zarubina@gmail.com, zarubina@kinr.kiev.ua

^{137}Cs circulation in forest ecosystems on the territory of the Chornobyl exclusion zone (Plant)

Presented by Academician of the NAS of Ukraine V.I. Slisenko

Seasonal changes in the content of ^{137}Cs in plants of the forest ecosystems on the territory of the Chornobyl exclusion zone have been studied. Samples were selected from 2013 till 2015 once per two weeks. The studied objects were one- and two-year-old needles and branches of the Scots pine (P. sylvestris). The ^{137}Cs content was measured by the gamma spectrometry. In the needles and branches of P. sylvestris, the maximum values of ^{137}Cs concentration are noted in the summer. The minimum values of ^{137}Cs content in the studied organs of P. sylvestris are characteristic of the autumn-winter period. Probably, the annual fluctuations in the content of this radionuclide in various organs of the studied plants are a consequence of the existence of the constant circulation of ^{137}Cs in the forest ecosystems, as a result of which this radionuclide not only gets from the soil into P. sylvestris, but is also excreted from its living tissues.

Keywords: *^{137}Cs, circulation, Chornobyl NPP, plant, forest ecosystems.*

Studies of the dynamics and redistribution of ^{137}Cs along the vertical profile of soils, forest layers, fungi, and other objects indicate a gradual decrease in the levels of the specific activity of this radionuclide in various objects of the forest ecosystems over time after the accident. The results of studies of the seasonal dynamics of the ^{137}Cs content are not so unambiguous and often contain contradictory data.

In [1], it was indicated that there is an internal cycle of the annual seasonal redistribution of ^{137}Cs between the aboveground and underground phytomasses on the territory of the Ukrainian Polissia. By the beginning of the growing season in May, the content of this radionuclide in the aboveground phytomass is lower than in June. By the end of the growing season, ^{137}Cs is transferred from the aboveground part of the mosses to the underground one.

Studies [2] carried out during the growing season on the territory of Ukrainian Polissia made it possible to assert that the contents of ^{137}Cs in plants of different species (blueberry, lingonberry, male fern, and bracken) are subject to seasonal changes characteristic of each species and physiological features associated with them.

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In [3], it was indicated that, in blueberries on the territory of the Ukrainian Polissia, the maximum content of ^{137}Cs was found in the ground phytomass during the period of mass fruiting in July. It was also noticed that beginning from March, the specific activity of this radionuclide in the terrestrial phytomass almost steadily increases. After the berries ripen, there is an intensive outflow of ^{137}Cs from the aboveground phytomass to the rhizomes till October-November.

In fungi-macromycetes of the forest ecosystems on the territory of the Ukrainian Polissia, the seasonal dynamics of the ^{137}Cs content was recorded — the maximum levels of specific activity of this radionuclide are registered in their fruit bodies in October, the minimum levels are found in June [4].

The authors of [5] determined that the levels of the specific activity of ^{137}Cs in the aboveground phytomass of the forest ecosystems in winter increases by 10 times compared to that of May. In [6], it is indicated that the seasonal dynamics of ^{137}Cs accumulation in the growth of Scots pine (a pollution indicating organ of the standing timber as a whole) is characterized by an almost unidirectional change in the ^{137}Cs concentration downward from spring to autumn.

In [7], seasonal changes in the assimilation apparatus of the Scots pine are taken into consideration. The author showed that sharp decreases in the ^{137}Cs concentration (by 2-3 times) from spring to autumn are characteristic of physiologically active needles of the current year. The stabilization begins around September. The same patterns were observed for two-year-old needles. But, at the same time, no clearly marked changes in the content of this radionuclide in two- and three-year-old needles are observed during the growing season.

The aim of the work was to study the seasonal variations in the content of ^{137}Cs in various objects of the forest ecosystems during the calendar year at a remote stage of the development of the accidental situation. The changes in the concentration of this radionuclide in the plant (Scotch pine) of the forest ecosystems in the exclusion zone of the Chornobyl nuclear power plant are discussed in. what follows.

Materials and methods. *Sampling sites.* We studied the ^{137}Cs circulation in different organs of the Scotch pine on the territory of the exclusion zone of Chornobyl NPP (ChNPP). The sampling sites are located at different distances and directions from Chornobyl NPP (Fig. 1).

The sampling sites within the Chornobyl exclusion zone are located at the following coordinates: Dytiatky (30°07'21.83"E, 51°07'13.37"N), Paryshiv (51°17'57.54"E, 30°18'17.43"N), Leliv (30°09'36.63"E, 51°19'19.74"N).

The sampling was carried out during 3 years between 2013 and 2015.

The size of the sampling sites is approximately 10 m by 10 m. The soil at the sampling sites belong to the sod-podzolic type. The Scots pine (*Pinus sylvestris* L.) prevails among the wood vegetation on the territory of the studied sampling sites.

Sampling of organs of P. sylvestris. Samples were taken once every two weeks.

The objects of research were one- and two-year needles and branches of *P. sylvestris.*

P. sylvestris was used as the main research object for several reasons:

- this species is the predominant species of the forested areas on the territory of the Chornobyl exclusion zone — 91565.0 hectares (pine forests occupy almost 60 % of the forested area) [8];
- sampling of photosynthesis' organs of this plant species is available throughout the year;
- the ability to carry out the simultaneous sampling of needles and branches of different ages.

Fig. 1. The sampling sites within the Chornobyl exclusion zone: *1* — Leliv; *2* — Paryshiv; *3* — Dytiatky

To study the dynamics of the ^{137}Cs content, samples of branches with needles were taken using a pruner without felling a tree. Each sampling was taken from 7 out of the specified 15 model trees. The sample consisted of 15 annual and 15 two-year-old branches with needles.

Under laboratory conditions, the needles were separated from the branches, and the resulting 4 samples (one- and two-year-old needles and branches) were dried separately at room temperature for 1-1.5 months.

The obtained samples after the drying were ground using a laboratory mill and placed in disposable calibrated plastic dishes for the following gamma-spectrometric studies [9].

Radiometry. ^{137}Cs specific activity measurements were performed employing a CANBERRA gamma-spectrometric unit based on the coaxial high-purity HPGe semiconductor detector, model GC6020.

The detection unit was covered with 100-mm lead protection allowing effective measurements of samples with comparatively low radionuclide specific activity.

The measurement time was from 600 to 14,400 seconds depending on the specific activity of radionuclides. The measurement errors of this series of samples did not exceed 10 % and, as a rule, were within the limits of 3-5 % of the radionuclide activity.

When carrying on the research of the content of radiocaesium (^{137}Cs with a half-life of about 30 years in this work) in the same object, it is necessary to exclude the influence of the physical decay of this element in it. The recalculation of the results was carried out on the "zero" date of the event (for 1986/04/26) according to the formula of radioactive decay. The data obtained in this way excluded the influence of that part of the radionuclide that had decayed on the date of each specific sampling. In the study, the values of ^{137}Cs activity concentrations in different organs of *P. sylvestris* are shown, being recalculated using the radioactive decay formula.

In this article, the ^{137}Cs specific activity in samples (dry weight) is given in Bq/kg.

Results and discussion. As a result of the studies, it was found that the content of ^{137}Cs in annual needles is, on average, higher than in other studied organs of *P. sylvestris* at all sampling sites. The lowest levels of specific activity of ^{137}Cs are characteristic of 2-year-old branches. An exception is the Paryshiv sampling site, where the content of ^{137}Cs in this organ is slightly higher than in 2-year-old needles (Table 1).

Needles and branches show seasonal changes in ^{137}Cs specific activity levels, unlike soil (Fig. 2-4). The maximum content of this radionuclide is typical of annual needles and branches from the beginning of the growing season (from May till autumn). By the end of the growing season, the concentration of ^{137}Cs in young needles and branches in some years decreases by almost an order of magnitude smaller. Increases in the levels of specific activity of ^{137}Cs during the season of vegetation in needles and branches are observed during the second year of their lives, which correlate well with similar changes in the content of this radionuclide in annual needles and branches (Table 2).

An increase in the levels of the specific activity of ^{137}Cs is observed with the onset of the intensive growth of young needles and branches. During this period, the plant requires significantly larger amounts of nutrients and water. Additional amounts of radionuclide may come with water, which leads to an increase in the content of ^{137}Cs in growing needles and branches. The pine is an obligate mycotroph. Probably, the indicated additional intake of ^{137}Cs into the plant during the period of intensive growth of young branches and needles is associated not only with its intake in the dissolved form with water, but is also the result of the existing symbiosis: an additional amount of ^{137}Cs can come from the long-term depot of this radionuclide — mushroom mycelium at the high pumping of water through the Gartig network into the root system of the plant and further into the growing organs.

The annual decrease in the ^{137}Cs content in all the studied organs of *P. sylvestris* by autumn may indicate the existence of the circulation of this radionuclide in forest ecosystems in the soil–plant chain. Thus, ^{137}Cs enters into the soil not only with litter, but also its outflow from living plant tissues can occur. The literature indicates that potassium constantly circulates in plants [9]. It can be assumed that cesium, being a chemical analog of potassium, can also constantly circulate in the plant.

Peaks and drops in the specific activity of ^{137}Cs in different organs of *P. sylvestris*, not related in time to the growing season, can be caused by short-term changes in weather conditions. The latter can cause the drying out or moistening of the forest litter, which is reflected in changes in the number of soil microflora and active mycelium of fungi, as well as in the intensity of their vital

Table 1. **Average contents of ^{137}Cs in various organs of *P. sylvestris* on the territory of sampling sites from 2013 till 2015, Bq/kg dry weight**

Organ	Leliv	Paryshiv	Dytiatky
1st needles	811 ± 587	194 ± 160	1292 ± 582
1st branches	531 ± 418	142 ± 103	871 ± 580
2nd needles	280 ± 184	75 ± 49	464 ± 190
2nd branches	258 ± 142	80 ± 41	374 ± 165

Table 2. **Spearman correlation coefficients between the contents of ^{137}Cs in different organs of *P. sylvetsris* on the territory of sampling sites**

Organ	Leliv	Paryshiv	Dytiatky
1st needles – 1st branches	0.888	0.852	0.828
1st needles – 2nd needles	0.821	0.661	0.762
1st needles – 2nd branches	0.807	0.665	0.653
1st branches – 2nd needles	0.736	0.642	0.620
1st branches – 2nd branches	0.782	0.777	0.705
2nd needles – 2nd branches	0.847	0.681	0.680

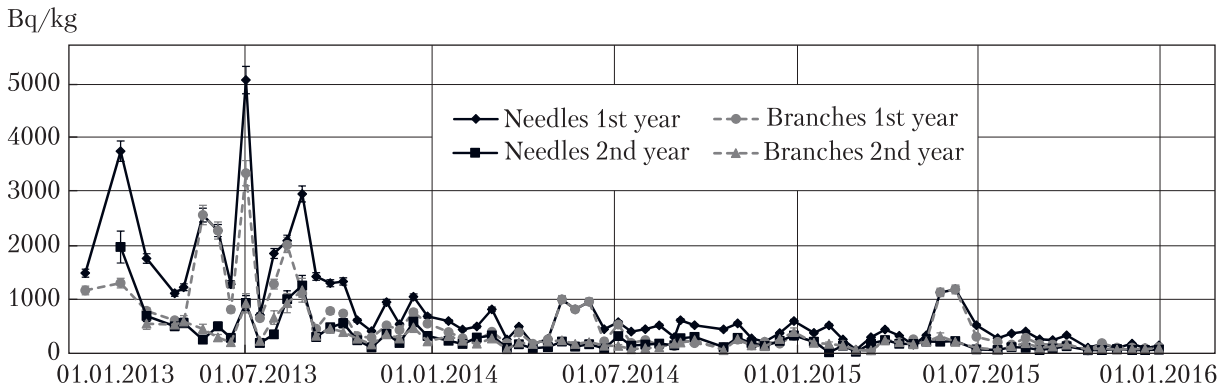

Fig. 2. Specific activity of ^{137}Cs in different organs of *P. sylvestris*, sampling site Leliv, Bq/kg dry weight

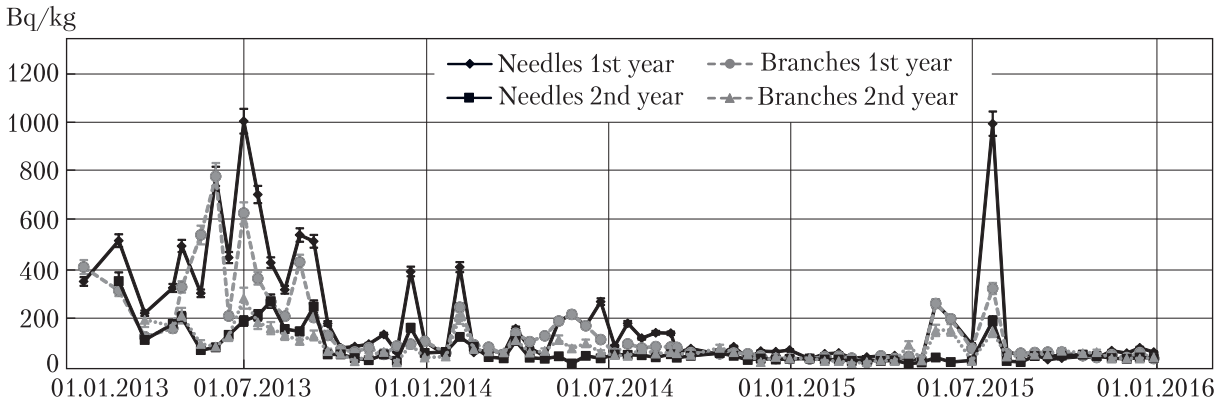

Fig. 3. Specific activity of ^{137}Cs in different organs of *P. sylvestris*, sampling site Paryshiv, Bq/kg dry weight

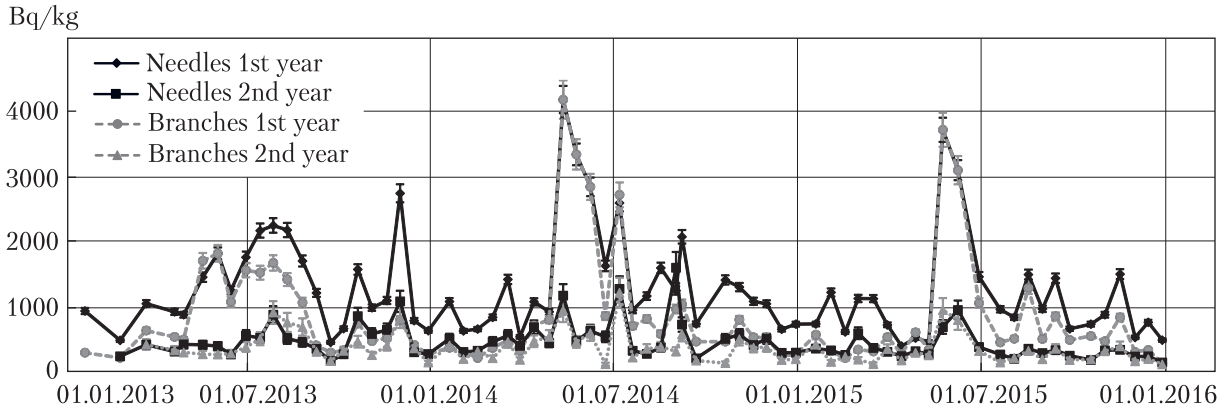

Fig. 4. Specific activity of ^{137}Cs in different organs of *P. sylvestris*, sampling site Dytiatky, Bq/kg dry weight

activity. This, in turn, can lead to abrupt changes in the value of the specific activity of ^{137}Cs in various organs of the Scots pine [10].

As a result of the executed studies, an abnormally high content of ^{137}Cs in the pine needles and branches at the Dytiatky sampling site was detected (see Fig. 4 and Table 1). The relatively low content of this radionuclide in the soil of this sampling site cannot be the cause for the noticed phenomenon [11]. The specific activity of ^{137}Cs in the pine organs at this sampling site is approximately 1.5 times higher than at the Leliv sampling site (10-km zone) and 2 times higher than at the Paryshiv sampling site. The high content of ^{137}Cs in the needles and branches may be due to the structural features of the forest litter at this sampling site. The thickness of the litter at the Dytiatky sampling site differs significantly from the thickness of the litter at other sampling sites. If, at the Leliv and Paryshiv sampling sites, the average thickness of the soil layer $A_0f + A_0h$ is 7 cm, at the Dytiatky sampling site, it is only 1.5 cm. The low volume of the litter layer contains a smaller amount of soil biota and fungi, which are a barrier to the entry of ^{137}Cs into the plant. This, probably, leads to the relatively high ^{137}Cs content in the pine needles and branches at the Dytiatky sampling site.

Conclusions. The levels of the specific activity of ^{137}Cs in needles and branches of *P. sylvestris* vary depending on the season. This process occurs almost simultaneously for one- and two-year-old branches and needles. The maximum values of the ^{137}Cs content in the studied organs of *P. sylvestris* are observed in summer. From the beginning of autumn till the end of the year, slight spikes in the values of the ^{137}Cs content are observed against the general background of low concentrations of this radionuclide.

Based on the data obtained, it can be argued that the ^{137}Cs content in the needles and branches of the Scots pine is not a constant value, but is subjected to seasonal changes. The redistribution of this radionuclide in forest ecosystems has a complex multidirectional character. Probably, in forest ecosystems, there is a constant circulation of ^{137}Cs in the soil-plant chain.

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Н.Є. Зарубіна, https://orcid.org/0000-0003-1630-7667

Інститут ядерних досліджень НАН України, Київ

E-mail: nataliia.zarubina@gmail.com, zarubina@kinr.kiev.ua

ЦИРКУЛЯЦІЯ ^{137}Cs У ЛІСОВИХ ЕКОСИСТЕМАХ НА ТЕРИТОРІЇ ЧОРНОБИЛЬСЬКОЇ ЗОНИ ВІДЧУЖЕННЯ (РОСЛИНА)

Досліджено сезонні зміни вмісту ^{137}Cs у рослинах лісових екосистем на території Чорнобильської зони відчуження. Зразки відбиралися у 2013, 2014 та 2015 рр. із періодичністю один раз на два тижні. Досліджено одно- та дворічні хвоя і пагони сосни звичайної (*P. sylvestris*). Вміст ^{137}Cs визначено за допомогою методів гамма-спектрометрії. У хвої та пагонах *P. sylvestris* максимальні концентрації цього радіонукліда відмічено влітку. Мінімальні значення питомої активності ^{137}Cs у досліджених органах сосни звичайної є характерними для осені та зими. Ймовірно, щорічні коливання вмісту цього радіонукліда в різних органах *P. sylvestris* є наслідком існування постійного кругообігу ^{137}Cs у лісових екосистемах, під час якого цей радіонуклід не тільки потрапляє з ґрунту до рослини, але й виводиться з її живих тканин.

Ключові слова: ^{137}Cs, циркуляція, Чорнобильська АЕС, рослина, лісові екосистеми.