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V. P. Krasnov[1], T. V. Kurbet[1], Z. M. Shelest[1], O. L. Boiko[2], O. V. Zborovska[3]

[1] *Zhytomyr State Technological University, Zhytomyr*
[2] *G. N. Vysotsky Kyiv Forest Research Station of Research Institute of Forestry and Forest Melioration, Liutezh, Kyiv region*
[3] *G. M. Vysotsky Poliskiy Branch of Ukrainian Research Institute of Forestry and Forest Melioration, Dovzhyk, Zhytomyr*

^{137}Cs DISTRIBUTION IN THE WOOD OF SCOTS PINE RADIAL GROWTH IN THE FORESTS OF UKRAINIAN POLISSIA

This research was conducted in regards to the distribution of ^{137}Cs in the radial growth of pine forests within the humid pine forests of the Polissia, Ukraine. To set the value patterns we used radionuclide specific activity of 5-year rings that were formed before and after the accident. Based on the quantitative assessment of the modern distribution of ^{137}Cs in pine wood it showed much higher levels of radionuclide in the peripheral annual rings. This analysis was marked by very significant values that were found in the forests formed after the accident at Chernobyl. The latter can be explained as the movement of radionuclide from the wood formed after the accident and radioactive contamination of forest ecosystems due to global fallout.

Keywords: radionuclides, radioactive contamination of wood, radionuclide specific activity, annual rings.

Introduction

The accident at Chernobyl Nuclear Power Plant radically changed the state of radiation in the forests of Polissia, Ukraine. This in turn, led to the need to review the existing ideas on the use of all forest resources and, in particular, wood recourses directly in areas contaminated with radionuclides. Some of the territories have introduced a ban or limit to use the wood. Over time, the level of radioactive contamination of forests and forest ecosystem components, including those used by people, declined. This, in turn, allowed the researchers to recommend the industry to restore the forest in certain areas. However, the exploitation of wood species has a problematic character because a significant number of radionuclides accumulated and continues to accumulate in the wood. These circumstances require continued monitoring levels of radioactive contamination.

In the 1950's and 1960's, researchers were interested in the distribution of radionuclides in the tissues and organs of tree species [1, 2]. They concluded that the tissues and organs can be positioned in the following row according to the content of ^{137}Cs in them: needles (leaves) > branch > bark > wood. The researchers noted that the differences between the indicator values (specific activity of a radionuclide) in that row reached 10 - 100 times.

After the Chernobyl accident, new research results obtained by Ukrainian scientists were similar to the mentioned above [3]. At the same time, they found out that in different periods since the Chernobyl accident certain tissues and organs of tree species occupied different places in the above noted series (row) of radioactive contamination. The researchers explained these circumstances by peculiarities of radioactive contamination of forest ecosystems and subsequent migration of radionuclides in them, and further, by the structure of the trees and functions of certain organs.

In Ukraine, for the first time researchers studied the distribution of ^{137}Cs in pine annual rings [3]. These studies were conducted in 8 years after the Chernobyl accident. It should be noted that this type of research was very complex and because of technical difficulties the research was discontinued. At that time, it was found out that the highest specific activity of radionuclide was observed in radial growth between 1992 and 1994. At the same time, the researchers noted the presence of ^{137}Cs in forest growth from 1956 - 1958, which is approximately 37 % of the growth that was in between the years 1992 - 1994. The latter was explained by diffusion of radionuclide from the outside of post Chernobyl annual increments of radial rings. In the following years, similar research was periodically conducted in Ukraine [4, 5]. The research data showed the increase of ^{137}Cs specific activity in peripheral annual rings of scots pine. It should be noted that this type of research has not been conducted for more than 10 years. At the same time, these data results are informative from the point of view of the processes taking place in forest ecosystems, besides; they are useful in the practice of wood industry.

In Belarus, similar research was conducted in several stages during the first 7 - 15 years after the Chernobyl accident [6, 7]. Researchers indicated that ^{137}Cs specific activity in peripheral annual rings differs by 2.5 times from that in the middle of the trunk.

Objects and methods

The aim of the research was to study current ^{137}Cs radial distribution in the wood of scots pine trunk formed before and after the Chernobyl accident. Research was conducted in 2011 and 2015 on permanent sample plots № 15 (PSP-15) in the SE "Luhiny LH" (Povchansk forestry) in the north of Zhytomyr region.

Characteristics of permanent sample plots PSP-15 (2011): radioactive soil contamination density of 195 ± 11 kBq/m^2. This sample plot with 65-year pine plantation demonstrates following characteristics: composition – 10 C, completeness – 0.9, average height – 24.0 m, type of forest conditions - wet subor (B_3). Herb-shrub layer (projective cover – 60 %) consists of Vaccinium myrtillus L., Vaccinium vitids-idaea L., Calluna vulgaris (L.) Hull.),Vaccinium uliginosum L., Ledum palustre L., Molinia caerulea L., Equisetum sylvaticum L., Melampyrum pratense L. Moss layer of projective covering 90 % of Dicranum polysetum Sw., Pleurotsiya Schreber (Pleurozium schreberi). Association – blueberry-green moss pine forest.

Soil is sod-middle-podzolic, sandy, on water-ice deposits. Litter has a thickness of up to 10 cm. Soil mineral part has the following horizons: humus-alluvial horizon is dark grey with a thickness of 10 - 12 cm; alluvial horizon is almost white and sandy with a thickness of 8 - 10 cm; illuvial - brown, loamy, with a thickness of 6 - 8 cm. The parent rock occurred at the depth of 80 - 85 cm.

Permanent sample plots (measuring 100 × 100 m) were laid down as a standard method [8]. Researchers made a list of trees to determine the average size – the diameter and height. Subsequently, on this PSP researchers selected 3 pine trees, the size of which met the average parameters. Selected trees were cut and at the bottom of the trunk (komel) the rings of wood (5 cm thick) were cut at a height of 1.3 meters and height of 0.5 to 0.75 of the trunk. The wood was selected from these rings by years. Since the removal of rings by using existing cutting tools is quite difficult, wood selection was carried out over the period of 5 years. Thus, the wood samples were obtained using radial growth periods (years): 2010 - 2006, 2005 - 2001, 2000 - 1996, 1995 - 1991, 1990 - 1986, 1985 - 1981, 1980 - 1976, 1975 - 1971, 1970 - 1966, 1965 - 1961. In 2015, three pine trunks of average size were selected to take samples of wood at the height of 1.3 m from the soil surface using a Pressler drill. Selected samples of the annual forest growth for the period of 2015 - 2010 were taken for the following spectrometric studies.

The density of soil radiation contamination was detected by taking 5 samples from soil under each of the selected trees. Soil samples were taken from the depth of 10 cm with a 5-cm-diameter bore. Composite sample was formed of 5 selected samples by envelope method (1 ×1m).

Selected sample were dried in oven at 105° C and subsequently were chopped and analyzed using spectrum analyzer "СЕГ-005-АКП" and scintillation detectors "БДЕГ-20-Р1" and "БДЕГ-20-Р2". Average total error of ^{137}Cs specific activity was about ± 9 % (confidence level – 0.95).

Results and discussion

The results helped to determine certain patterns in the specific activity of ^{137}Cs in annual tree rings of pine for the 5-year period (Table 1). A marked increase in this indicator since the Chernobyl accident to the 2010 - 2006 and then it's following reduction was observed. Thus, the value of the specific activity of ^{137}Cs in the wood accumulated in the year 1990 - 1986 was about 1144 ± 13.9 Bq/kg (data are obtained at the bottom of the trunk); and accumulated during the 2010 - 2006: 1825 ± 22.6 Bq/kg, which is 1.6 times higher. At the same time, the value of the indicator during 20 years after the accident changed in a small range: from 1144 ± 13.9 Bq/kg to 1283 ± ± 37.6 Bq/kg. It either increased or decreased slightly over the 5-year periods of study. These fluctuations can be explained by weather conditions observed in the growing seasons of specific years. For the annual rings that were formed during the 2010 - 2006, there was a significant increase in ^{137}Cs specific activity. It was confirmed by the data obtained at different trunk heights. This can be explained by several factors: weather conditions of the periods during which this wood was formed; cyclical migration of ^{137}Cs in forest ecosystems.

A significant decrease in ^{137}Cs specific activity in wood formed in 2015 - 2011's was observed compared to the previous period. Thus, in 2015 - 2011 at a height of 1.3 m from the soil surface, specific activity of radionuclide in tree wood was about 1305 ± 32.6 Bq/kg, and in 2006 - 2010 the wood was of 2021 ± 114.2 Bq/kg.

At the same time, we have seen quite significant values of the radionuclide specific activity in trees formed before the Chernobyl accident. The indicator for wood during the period of 1985 - 1981 was not much different; it was 99.3 % from that we have observed over the period 1986 - 2001 years. In general, in the wood that was formed 25 years before the accident, there is a gradual decrease in radionuclide specific activity from the trunk periphery to its center; wood formed in the period of 1985 - 1981years showed the following indicator 1136 ± ± 37.3 Bq/kg, and in 1965 - 1961 – 698 ± 4.0 Bq/kg (decreased by 1.6 times). The difference between the value of ^{137}Cs specific activity in wood of 2010 - 2006 (1825 ± 22.6 Bq/kg) and 1965 - 1961 (698 ± ± 4,0 Bq/kg) is higher by 2.6 times.

It was noted that there was a significant contamination of wood formed before the accident at Chernobyl NPP. This can be explained by two factors: the migration of radionuclide to the pine during the global contamination of forest ecosystems by radionuclide after the testing of nuclear weapons (wood was analyzed for 25 years before the Chernobyl accident), and their partial migration from the wood formed after the accident at Chernobyl nuclear power plant. It is known that in the pine trunk there is some migration of substances from the outside timber to the inside along the medullary rays [9].

Table 1. **^{137}Cs specific activity in radial growth of pine wood at different trunk heights, Bq/kg**

Radial growth for years	^{137}Cs specific activity in wood at the height of the trunk (P), m			
	0.1 m	1.3 m	0.5 H	0.75 H
2015 - 2011	-	1305 ± 33	-	-
2010 - 2006	1825 ± 23	2021 ± 114	1722 ± 13	1724 ± 103
2005 - 2001	1157 ± 30	1140 ± 44	1195 ± 97	1164 ± 109
2000 - 1996	1262 ± 58	1123 ± 35	1275 ± 108	1182 ± 56
1995 - 1991	1283 ± 38	1174 ± 45	1237 ± 23	-
1990 - 1986	1144 ± 14	1130 ± 57	1150 ± 78	-
1985 - 1981	1136 ± 37	1140 ± 48	-	-
1980 - 1976	1193 ± 53	1005 ± 55	-	-
1975 - 1971	1222 ± 43	643 ± 29	-	-
1970 - 1966	677 ± 2	651 ± 31	-	-
1965 - 1961	698 ± 4	-	-	-

The above materials were obtained in the lowest (the thickest) part of pine trunks where the number of selected annual rings was in maximum (50 years). This allowed researchers to establish a relationship between ^{137}Cs specific activity in periodic radial growth of wood and the number of years from the period of 2006 - 2011 to 1961 - 1965 (Fig. 1). Correlation between these parameters satisfactorily approximated by a linear equation is authentic, close and inversely proportional (r = -0.79).

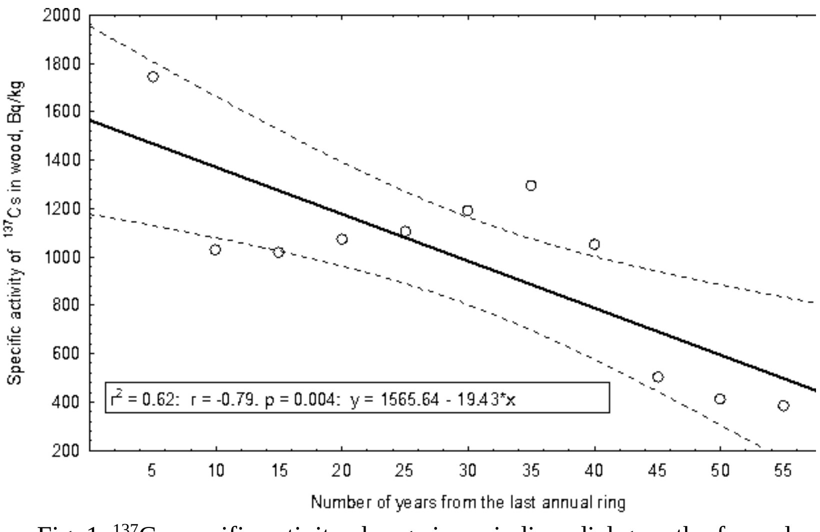

Fig. 1. ^{137}Cs specific activity change in periodic radial growth of wood from 1961 (5 years) to 2010 (55 years) in the butt part of the wood trunk.

Studies conducted in 2015 revealed that the value of ^{137}Cs specific activity in wood (at a height of 1.3 m from the soil surface) that was formed during the 2010 - 2015 was lower (by 1.6 times) of that of trees formed for the previous 5 years. These materials may prove the reduced intensity of radionuclide penetration to trees. This conclusion may be confirmed by analyzing the timber wood over the next 5 years, or at the present, after analysis of wood taken for each given year. It should be noted that the researchers' forecast models show that a slowdown of radionuclide penetration into tree species should have commenced about 10 years ago [10].

This data clarifies some methodological issues as for the comparing radioactive contamination of wood by using the indicator of the radionuclide specific activity in it. This indicator is used for radiation control of wood products and in the practice of

Radioecology of forest ecosystems.

In the case of radiation control, a selection of wood is usually carried out in the thickest part of the trunk through its cross section using a chainsaw. At the same time, tree sawdust from the surface is collected and studied. Thus, the wood contains sample formed both before and after the accident. In our case, (65-year plantations) samples from the butt part of the wood trunk consist of the wood formed before (25 years) and after (25 years) accident. In the first sample, the average specific activity of ^{137}Cs is (according to our data) 985 Bq/kg, and in the second - 1334 Bq/kg. Thus, any object that is made wholly or in part using the central part of the trunk will contain the amount of ^{137}Cs specific activity much lower than that produced from the peripheral part. Something similar occurs in the study of wood at half the height of the trunk - the average value of the index amounted to 1316 Bq/kg. It is higher from such a central part of the trunk – 985 Bq/kg. This analysis allows us to recommend a detailed study of forestry products and forestry areas at the stage of allotment and felling.

Along with the study of ^{137}Cs in periodic radial growth of pine wood, we investigated the relative magnitude of the radionuclide in the bark (Fig. 2). It was found that the specific activity of ^{137}Cs in the bark is much higher than this indicator in wood. Thus, in the bottom of the trunk it comprised around 4767.0 ± 527.6 Bq/kg, half the height of the trunk – 3574,0 ± 194.1 Bq/kg, and at 0.75 % of the height of the trunk – 4145.0 ± 148.3 Bq/kg. It is known [10] that the current contamination of the bark generally can be explained both by surface pollution during migration of radionuclide to forest ecosystems in 1986 (the outer layer of the bark) and the migration of radionuclide through roots in the subsequent period (the inside of the bark). Somewhat higher levels of ^{137}Cs specific activity in the bark of the bottom of the trunk can be explained by the migration of radionuclide that fell on the trunk in 1986 to its lower part via rainwater.

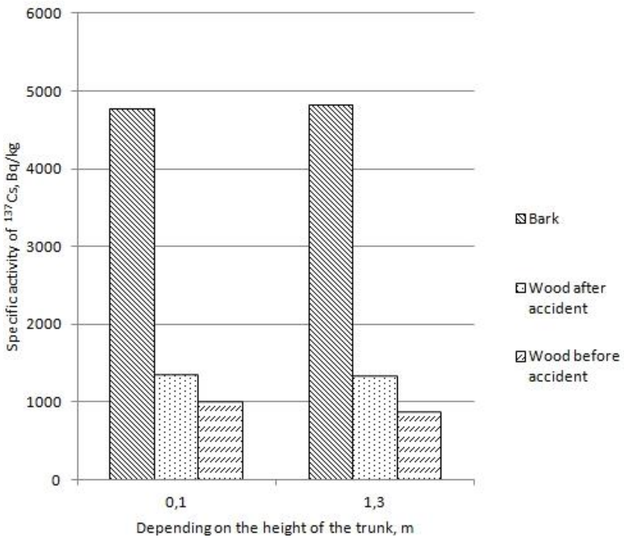

Fig. 2. ^{137}Cs average specific activity in the bark and the wood, formed before and after the accident in the butt part of the trunk of pine (at a height of 0.1 and 1.3 m from the soil surface).

These materials also have practical value, because higher levels of radioactive contamination of bark complicate the use of wood bark. The specific activity of ^{137}Cs in the wood bark exceeds its value for wood formed after the accident by 3.6 times, and for wood created before the accident – by 4.8 times. It can be recommended to the forestry production that wood processed from the contaminated areas should be subsequently processed with the removal of the bark. Thus, our studies have shown that the manufactured middle part of log (a bar) has significantly lower levels of radionuclide (Table 2). The specific activity of ^{137}Cs in bars (682 Bq/kg) is 3.3 times lower than the one in the bark and the wood slab (2219 Bq/kg).

Table 2. **^{137}Cs specific activity in different parts of the trunk of pine in the manufacture of wood**

Parts of the trunk, type of product	Statistics number distribution of specific activity of ^{137}Cs, Bq/kg				
	average value (M)	average value error (m)	standard deviation (σ)	variability coefficient (V), %	experiment accuracy (P), %
Slab*, bark	2219	51	889	4,0	2,3
Slab, wood	922	17	29	3,2	1,8
Slab, wood with bark	1279	76	131	10,3	5,9
Bar	682	7	12	1,7	1,0

N o t e: 1. Slab* - the outside of the trunk (cut), consisting of wood and bark. 2. Parameters of normal distribution, repeatability is threefold.

Conclusions

1. There is a decrease in the specific activity of ^{137}Cs in pine wood on the periphery of the trunk (in 2010) to its center (1961) and the fluctuation of this indicator in different periods since the accident. Marked fluctuations can be explained by weather conditions and the period during which the timber

was formed and cyclical migration of radionuclide in forest ecosystem.

2. Differences in the value of specific activity of ^{137}Cs in wood used from various parts of the trunk of trees (diameter and height) can be as high as 20 - 25 % requiring a revision of some regulations in the method of radiation control of forest products.

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В. П. Краснов[1], Т. В. Курбет[1], З. М. Шелест[1], О. Л. Бойко[2], О. В. Зборовська[3]

[1] Житомирський державний технологічний університет, Житомир
[2] Київська лісова науково-дослідна станція Українського науково-дослідного інституту лісового господарства і агролісомеліорації ім. Г. М. Висоцького, Лютеж, Київська область
[3] Поліський філіал Українського науково-дослідного інституту лісового господарства і агролісомеліорації ім. Г. М. Висоцького, Довжик, Житомир

РОЗПОДІЛ ^{137}Cs У ДЕРЕВИНІ РАДІАЛЬНИХ ПРИРОСТІВ СОСНИ ЗВИЧАЙНОЇ У ЛІСАХ ПОЛІССЯ УКРАЇНИ

Проведено дослідження щодо розподілу ^{137}Cs у деревині радіальних приростів сосни звичайної у вологих суборах лісів Полісся України. Для встановлення закономірностей використовувалась величина питомої активності радіонукліда в 5-річних кільцях, що утворились до і після аварії на ЧАЕС. На основі кількісної оцінки сучасного розподілу ^{137}Cs у деревині сосни звичайної показано значно більші рівні вмісту радіонукліда в периферійних річних кільцях. Відзначено досить суттєві величини показника, що вивчався, у деревині, утвореної до аварії на ЧАЕС. Останнє може пояснюватись як переміщенням радіонукліда з деревини, утвореної після аварії на ЧАЕС, так і радіоактивним забрудненням лісових екосистем унаслідок глобальних випадінь.

Ключові слова: радіонукліди, радіоактивне забруднення деревини, питома активність радіонукліда, річні кільця.

В. П. Краснов[1], Т. В. Курбет[1], З. М. Шелест[1], А. Л. Бойко[2], О. В. Зборовская[3]

[1] Житомирский государственный технологический университет, Житомир
[2] Киевская лесная научно-исследовательская станция Украинского научно-исследовательского института лесного хозяйства и агролесомелиорации им. Г. Н. Висоцкого, Лютеж, Киевская область
[3] Полесский филиал Украинского научно-исследовательского института лесного хозяйства и агролесомелиорации им. Г. Н. Висоцкого, Довжик, Житомир

РАСПРЕДЕЛЕНИЕ ^{137}Cs В ДРЕВЕСИНЕ РАДИАЛЬНЫХ ПРИРОСТОВ СОСНЫ ОБЫКНОВЕННОЙ В ЛЕСАХ ПОЛЕСЬЯ УКРАИНЫ

Проведено изучение распределения ^{137}Cs в древесине радиальных приростов сосны обыкновенной во влажных суборях лесов Полесья Украины. Для установления закономерностей использовалась величина удельной активности радионуклида в 5-летних годовых кольцах, которые образовались до и после аварии на ЧАЭС. На основе количественной оценки современного распределения ^{137}Cs в древесине сосны обыкновенной отмечены значительно большие уровни содержания радионуклида в периферийных годичных кольцах. Отмечены довольно существенные величины изучаемого показателя в древесине, образованной до аварии на ЧАЭС. Последнее может объясняться как некоторым перемещением радионуклида из древесины, образованной в последние годы, так и радиоактивным загрязнением лесных экосистем вследствие глобальных выпадений.

Ключевые слова: радионуклиды, радиоактивное загрязнение древесины, удельная активность радионуклида, годичные кольца.

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