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RETROSPECTIVE ASSESSMENT ON SCOTS PINE STANDS SITUATED FAR AND NEAR CHERNOBYL FALLOUT AREAS

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Abstract

The high radiosensitivity of woody plants and the large forest areas polluted by Chernobyl fallout demand assessment of radiation effect on the forest ecosystems components. This research aims to study the state of Scots pine (*Pinus sylvestris* L.) stands located in the far and near areas contaminated by Chernobyl fallout, and to assess the current dose loads on the structural elements of the trees 30 years after the Chernobyl Nuclear Power Plant (CNPP) accident. The study was conducted in radioactively contaminated Scots pine stands, which are the near and far areas,in the Chernobyl fallout areas. The experimental plots were established during the period from 1991 to 2006 inside Scots pine stands from the II–IV age classes. The retrospective assessment of dose loads of the Scots pine was conducted according to the data obtained on 13 experimental plots located in the far area of the Chernobyl fallout through the software RESRAD-BIOTA 1.5 (11/18/2009). The condition of pine stands in the near areas has significantly worsened since the accident, compared to their condition before the accident. The changes in the state of the pine stands after the accident were characterized by their strong weakening. Ambiguous trends were also observed in the stability of stands depending on the type of forest and land relief. In 1986, the radionuclide ^{134}Cs accounted for 25 % of the total amount of soil pollution by mixture (^{134}Cs + ^{137}Cs) in pine stands. However, in 1995, this amount decreased to 2.5 %. The state of the Scots pine stands after the accident were characterized by their strong weakening.

Key words: anthropogenic factor, dose loading, pine stands, radiation dose, stability, state of stands.

Introduction

Forest ecosystems are dynamic and natural formations, which cover a considerable portion of the land surface on our planet, and among others significantly affect the distribution and migration of radioactive materials in the biosphere at a global scale. In this framework, forests act as accumulators of radionuclides, preventing the migration of radioactive materials on the surface of the earth. During the Chernobyl accident, 60–90 % of radioactive fallout was accumulated in the tree layer due to the high retention capacity of the forest ecosystems (Sokolov et al. 1994).

Radiation effects in contaminated natural ecological systems depend on the radiosensitivity of the dominant species. Scots pine (*Pinus sylvestris* L.) and spruce (*Picea abies* L. Karst.) forests are sensitive to radiation, and their destruction can even occur under the influence of small doses of radiation, which although do not cause noticeable violations in phytocoenoses of other types, such as herbaceous vegetation (Tikhomirov and Aleksakhin 1971).

Depending on the size of the absorbed dose, woody plants can have various radiobiological effects. The primary reactions of a forest to radioactive effects generally depends on the radiation dose of its separated components. Decrease in radiation intensity mostly affects the radiation dose distribution of separate organs of woody plants or organisms. At the same time, the soil shielding from radiation reduces the radiation dose at a great extent. This condition can have a decisive impact on the survival of populations of irradiated organisms (Aleksakhin et al. 1970, Menshikov et al. 2019).

In terms of the importance of issues addressed by forest radioecology, issues relating to radioecological effects on humans are generally considered first. Nevertheless, the high radiosensitivity of woody plants and the large forest area polluted by Chernobyl fallout demand assessment of radiation effect on the forest ecosystems components.

Arkhipov et al. (1994) reported that by 1991 Scots pine trees had returned to ‘normal’ with no obvious morphological damage in stands in the low and medium (up to 10 Gy) dose regions, and a new plant community was developing in the severely damaged regions. However, in 1995 there was still evidence of cytogenetic damage in seedling roots of pines in two sites at Chernobyl of dose rates (approximately 0.25 and 27 mGy·h^{-1}) (Geraskin et al. 2003). It is not clear whether this was a result of the initial acute dose (10–20 Gy at the high dose site) or the ongoing chronic exposure, or a combination of the two. A reduction in mutation load with time and adaptation was observed in other studies (Abramov et al. 1995, Kovalchuk et al. 2004, Beresford et al. 2016). Abramov et al. (1995), Kovalchuk et al. (2004) and Beresford et al. (2016) found that mutation load was increased in the first two years after the accident but that ‘in areas with contamination up to 10 mR h^{-1} (approx. 100 mGy·h^{-1}) the mutation load decreased to control levels by 1990. In the areas with contamination up to 130 mR·h^{-1} (approx. 1300 mG·h^{-1}) the mutation load (still) exceeded the control by 4–8 times’.

This research aims to study the state of Scots pine stands, located in far and near sites contaminated by Chernobyl fallout 30 years after Chernobyl Nuclear Power Plant (CNPP) accident and to assess the current dose loads on the structural elements of the Scots pine trees.

Material and Methods

The study was conducted in Scots pine stands in radioactively contaminated the near (plots ‘Nt- Chernobyl near field fallout’ with the numbers from 1 to 6, up to 30 km from the CNPP) and far areas (plots ‘Ft-Chernobyl far field fallout’ with the numbers from 1 to 13, more than 30 km from the CNPP) located in the Chernobyl fallout areas (Fig. 1). The study was carried out in 2016–2017 (about 30 years after the CNPP accident).

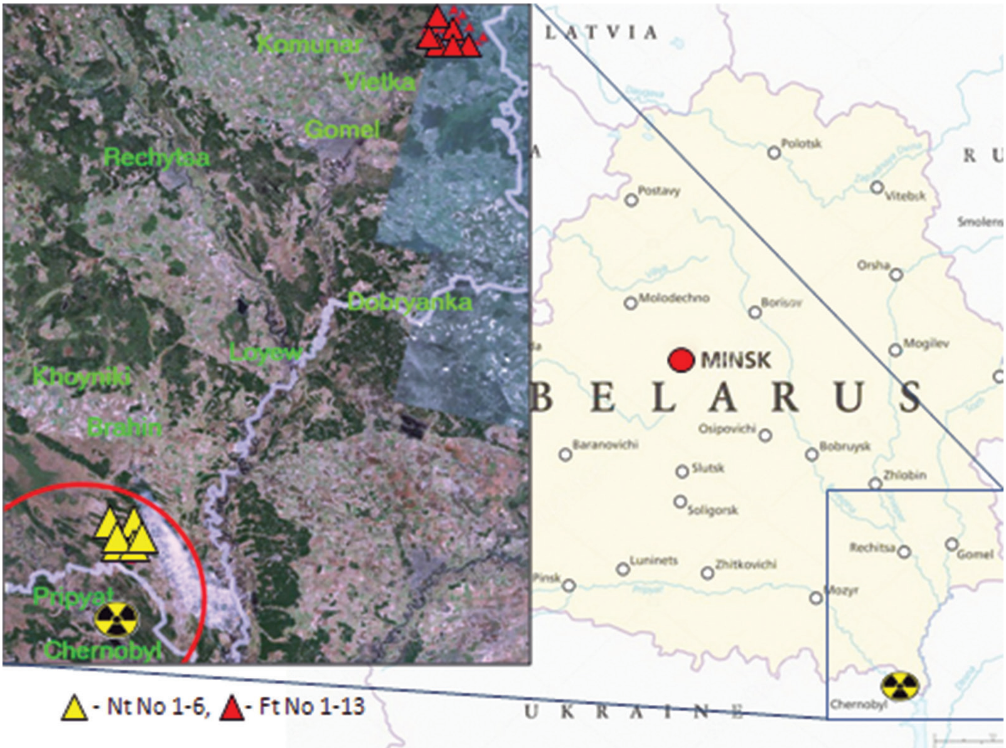

Fig. 1. Location of experimental.

Determination of soil contamination density and dose rate was carried out at all sites in the year when these samples were laid as well as studies conducted again in 2016 (Table 1).

The retrospective assessment of dose loads of the Scots pine was conducted according to the data obtained on 13 experimental plots (21 test areas) located in the far area of the Chernobyl fallout through the software RESRAD-BIOTA 1.5 (11/18/2009), developed at Argonne National Laboratory (USA) (ISCRS 2004).

The dynamics of the pollution density of ^{134}Cs and ^{137}Cs of the soil-litter complex, as well as their contribution to the formation of dose loads on trees in long-range pine stands were determined in the study area 1Ft located in the far area of the Chernobyl fallout, by modeling the data from 1991, which were obtained at the initial stage of laying the study area.

The dose rate (μSvh^{-1}) was determined at a height 1 m above ground and at ground level. The average daily and annual doses absorbed by the Scots pine stands in the far area of the Chernobyl fallout for the study period were 0.35 ±0.02 mGy per day and 0.13 ±0.01 Gy per year, respectively.

Forest inventory parameters (diameter at breast height, height, basal area, stand volume, stand density and site class) were determined for each experimental plot using standard techniques (Baginsky 1984, Zagreev et al. 1992, TKP 026-2006 (02080) 2006). The data obtained were compared with the data of these stands from the time of establishment of experimental plots (Ipatyev 2000, 2005).

Table 1. Characteristics of Scots pine stands in the experimental plots in the near and far areas located in the Chernobyl fallout.

Object number	Year of object bookmark	Age of a stand, years	Dose rate, μSvh^{-1}		Contamination density by ^{137}Cs, $Ci \cdot km^{-2}$*
			at a height of 1 m*	at ground level*	
Chernobyl far field fallout (Ft)					
1Ft	1991	80	2.58 / 0.84	3.18 / 1.05	41.50 / 27.3
2Ft	1993	91	1.30 / 0.89	1.67 / 1.12	23.14 / 20.3
3Ft	1994	91	1.47 / 0.96	1.85 / 1.26	34.76 / 29.4
4Ft	1994	72	1.47 / 0.92	1.82 / 1.07	27.67 / 20.6
5Ft	1996	50	1.04 / 0.83	1.22 / 0.91	17.66 / 13.4
6Ft	1996	65	1.50 / 1.24	1.74 / 1.39	34.73 / 27.4
7Ft	2002	54	0.67 / 0.68	1.12 / 0.75	10.59 / 15.4
8Ft	2006	70	0.89 / 1.02	1.13 / 1.12	23.23 / 16.7
9Ft	2006	60	0.91 / 1.15	1.26 / 1.23	28.44 / 23.0
10Ft	2006	45	0.81 / 0.70	1.08 / 0.88	20.00 / 16.8
11Ft	2008	33	0.98 / 0.75	1.18 / 0.88	18.51 / 16.9
12Ft	2008	88	1.11 / 0.94	1.39 / 1.14	21.19 / 23.5
13Ft	2008	33	1.45 / 1.15	1.70 / 1.44	26.53 / 36.7
Chernobyl near field fallout (Nt)					
1Nt	1993	79	12.35 /4.1	16.94 /4.9	206.80 /131.6
2Nt	1993	79	11.73 /4.7	14.89 /5.6	254.20 /169.4
3Nt	1997	63	11.80 /5.6	16.20 /7.9	241.40 /237.4
4Nt	1997	63	9.00 /4.8	11.20 /5.9	150.00 /143.7
5Nt	1997	63	6.50 /3.7	7.00 /4.3	129.60 /123.6
6Nt	1997	63	6.90 /3.5	8.40 /4.2	178.20 /79.2

Note: *numerator – data as of the year of the object bookmark; denominator – data as of 2016.

To assess the state of trees the ‘Scale of Categories of State of Coniferous Trees’ in standard TKP 026-2006 ‘Sustainable Forest Management. Sanitary Regulations in Forests of the Republic of Belarus’ was used, which was defined as follows:

I – Without signs of decline;

II – Weakened trees;

III – Strongly weakened ones;

IV – Tree dieback;

V – Dead wood of the current year;

VI – Dead wood of the last year (old).

The average category of the state of trees in stands was determined according to their average size by indices of state categories and percentage of trees in accordance with their referred categories.

The state of forest stands was evaluated according to the index of a sanitary state (Karpenko 1981, Alekseev 1990), which was calculated for each experimental plot according to the following equation (1):

$$In = \frac{\sum Ik \cdot n}{N}, \qquad (1)$$

where:

I_n – the index of a sanitary state of forest stands;

I_k – category of sanitary state (I–VI);

n – quantity of trees of this category of state;

N – quantity of trees on the experimental area.

Statistical analysis was performed using Statistica (version 9.0).

Results and Discussion

The sustainability indicators of the Scots pine in the approaching maturity stands of the IV age class on the experimental plots in the near and far field areas (Nt 1–6 and Ft 1–13) demonstrated that, in the specific zone, the sanitary state of pine stands considerably differed depending on the forest type. It was found that in the radiation zone the density of soil contamination with ^{137}Cs in pine forests varied from 15 to 35 Ci·km^{-2} (Ft 1–13). The bulk of the pine trees belonged to III and IV categories, while they were strongly weakened and were on dieback status (Table 2, Fig. 2).

Fig. 2. Pine stands in the far site of Chernobyl fallout with soil contamination density of ^{137}Cs 27.3 Ci·km^{-2}.

Table 2. The sanitary state of Scots pine stands in Ft and Nt areas of the Chernobyl fallout.

Object number	Type of forest	Age of a forest stand, years (2016)	Total trees, pieces / %	Category of a sanitary state of a forest stand						*In*
				I	II	III	IV	V	VI	
			Chernobyl far field fallout (Ft)							
1Ft	Pine mossy	92	75 / 100.0	1.1	51.4	18.6	6.1	5.6	17.2	3.2
2Ft	Pine mossy	80	184 / 100.0	0.0	11.6	38.1	22.6	0.5	27.3	3.9
3Ft	Pine mossy	92	73 / 100.0	0.0	6.3	69.1	7.4	1.1	16.2	3.5
4Ft	Pine mossy	50	45.25 / 100.0	0.0	0.0	42.1	22.1	3.4	32.4	4.3
5Ft	Pine mossy	65	18.50 / 100.0	0.0	0.0	25.8	28.8	3.4	42.0	4.6
6Ft	Pine mossy	72	84.33 / 100.0	0.0	1.9	58.3	7.0	1.2	31.7	4.0
7Ft	Pine mossy	33	88 / 100.0	0.0	0.0	76.1	11.4	4.5	8.0	3.4
8Ft	Pine mossy	88	102 / 100.0	0.0	0.0	76.5	8.8	0.0	14.7	3.5
9Ft	Pine mossy	33	52 / 100.0	0.0	0.0	73.1	7.7	5.8	13.5	3.6
10Ft	Pine mossy	70	161 / 100.0	0.0	0.0	65.8	14.3	-	19.9	3.7
11Ft	Pine mossy	54	101 / 100.0	0.0	1.0	60.4	11.9	5.0	21.8	3.9
12Ft	Pine bracken	72	234 / 100.0	0.0	4.7	56.9	13.7	1.7	23.1	3.8
13Ft	Pine mossy	45	248 / 100.0	0.0	0.0	44.0	25.8	2.8	27.4	4.1
			Chernobyl near field fallout (Nt)							
1Nt	Pine lichen	63	150 / 100.0	22.0	44.7	14.0	10.7	2.0	6.7	2.5
2Nt	Pine mossy	63	78 / 100.0	39.7	35.9	9.0	6.4	2.6	6.4	2.2
3Nt	Pine bilberry	63	90 /100.0	26.7	34.4	15.6	8.9	-	14.4	2.6
4Nt	Pine sedge	63	41 / 100.0	14.6	24.4	19.5	9.8	-	31.7	3.5
5Nt	Pine mossy	79	132 / 100.0	-	18.9	32.6	15.9	1.5	31.1	3.9
6Nt	Pine mossy	79	112 / 100.0	0.9	28.6	38.4	11.6	1.8	18.8	3.4

Before the Chernobyl accident, Belarusian forests were characterized by a high level of forest management. Thinning was carried out regularly, according to the established periods. As a result, trees of the lower structural levels were periodically withdrawn from the plantations. Consequently, most, especially the pine stands had elevated status indices (from 1.2 to 1.7) including those in the CNPP zone (Stepanchik 1996).

At present, the state of highly polluted ^{137}Cs pine stands has significantly deteriorated compared to the state of stands at the time of the accident. In specific,the average index of the sanitary state of stands from 3.2 raised to 4.6, which is 43.7 percentage higher. Forest stands in the far areas of the Chernobyl radioactive fallout were strongly weakened, especially stand of II–III classes of age that was not caused by a radiation factor, but it was due to the lack of economic activity. As a result of the long term absence of forest management activities in radionuclide-contaminated pine stands of all age groups, the proportion of healthy pine trees was lower, and the proportion of dying and dry pine trees is higher than in stands, 5 years after the accident at the CNPP. Most of this trend is expressed in young II class and middle-aged stands, which is fixed by high index of sanitary condition, which are, on average, 4.1, in pine stands; 61–80 years it is 3.3 (Potapenko et al. 2017).

To date, the state of pine stands polluted by ^{137}Cs in the first decades after the CNPP accident has been worsened significantly compared to the results of assessment of the state of pine stands at the first stages of their development after the accident. Moreover, the stands were strongly weakened, especially those in II–III age classes. During the absence of forestry management practices for 8–24 years, the pine stands of all age groups, polluted by radionuclides, were characterized by the predominance of strongly weakened stands. Most of these tendencies were observed in young growth II class and middle-aged forest stands, fixed by high indices of sanitary state, producing an average of 4.1. In 61-80-year-old stands, index of sanitary state decreased by 1.2 times and produced an average of 3.3 (Potapenko et al. 2017).

In pine stands growing in the areas with the density of soil pollution with ^{137}Cs ranged from 79 to 237 Ci·km^{-2}, the percentage of healthy pine trees of the I category of a sanitary state changed from 14.6 % to 39.7 %. At the same time, the greatest indicators of trees in this category were noted in mossy pine forests, which grew on a hill slope, whereas the smallest were observed in sedge pine forests at the foot of the hill (Table 2, Fig. 3).

Note that, in pine stands growing on the plain with soil pollution density contaminated with^{137}Cs ranging from 133 to 169 Ci·km^{-2}, this category of trees was practically absent.

The distribution of weakened trees of the category II in the stand was quite similar. The greatest percentage of trees in this category with ^{137}Cs soil pollution density ranging from 79 to 237 Ci·km^{-2} was noted in lichen pine forests at the top of hill, accounting for 44.7 %, while that in the mossy ones on a hill slope was 35.9 %.

In mossy pine forests growing on the flat area, the individual share of weakened trees of the Scots pine decreased by 1.3–1.9 times in comparison to mossy pine forests on the slope of the hill. In addition, the share of trees in categories III and IV of a sanitary state increased twice (Fig. 2). The smallest share of trees of these categories (9.0 % and 6.4 % respectively), were found in the mossy pine forest grow-

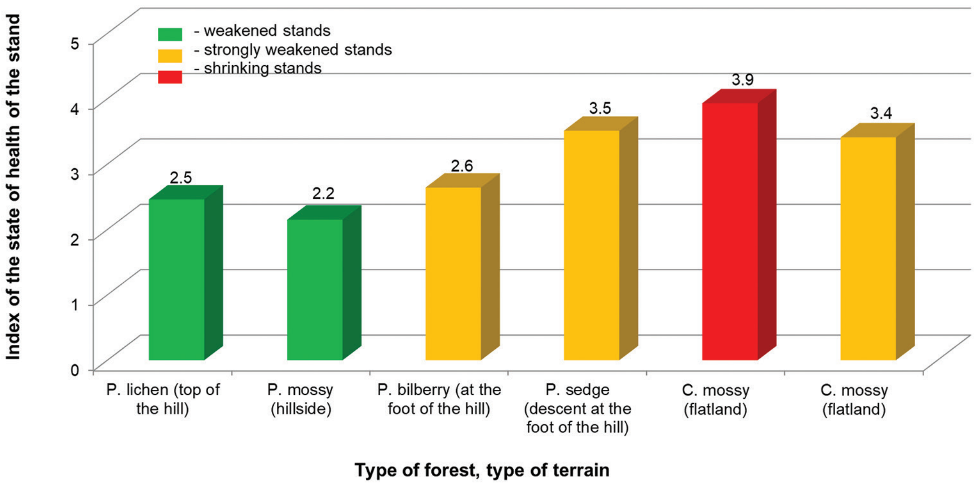

Fig. 3. Sanitary state of pine stands depending on the type of forest and the relief of the land in near field of the Chernobyl radioactive fallout.

ing in the middle part of the hill slope. At the same time, the greatest share of trees in categories V and VI was observed in the sedge pine forest at the foot of the hill and the mossy pine forest on the plain.

Our analysis of the sanitary state of Scots pine stands in the near field of the Chernobyl fallout showed ambiguous trends of their stability in various forests and relief.

In the initial period after the Chernobyl accident, the radionuclide composition of the radioactive fallout was characterized by the predominance of ^{137}Cs in the far trace, the half-life ($T_{1/2}$) of which was 30 years, as well as the presence of such radionuclides as: ^{131}I ($T_{1/2}$ – 8 days), ^{144}Ce ($T_{1/2}$ – 286 days) and ^{134}Cs ($T_{1/2}$ – 2.06 years). Of the above radionuclides in 1991, there were quite noticeable amounts of ^{137}Cs and ^{134}Cs, which was confirmed by studies Ipatiev (2000) (Fig. 4).

According to the established data, the content of ^{134}Cs and ^{137}Cs in the litter-soil complex was determined for the period 1987 to 1996, in which their relative dynamics in the territory of the far area was noted. Figure 4 shows that by 1996 the 134Cs content in the ^{134}Cs+^{137}Cs mixture had decreased to 1.5%. At the same time, ^{137}Cs prevailed in the soil-litter complex, the share of which was 98.5%. Similar results were obtained by other authors (Bulavik and Perevolotsky 1997).

It is well known that, in the year of the Chernobyl accident, the dose load on the biota was mainly determined by radioactive fallout. Subsequently, at the concentration of radionuclides in the upper soil layers, the dose loads on the vegetation components were caused both by internal irradiation (due to root consumption) and external (shielded by surface soil). Therefore, the main source of absorbed doses is the specific activity of radionuclides in the soil, which allows using RESRAD-BIOTA to assess the dose load on vegetation.

Based on the activity of radionuclides in the soil at the 1Ft site during screening in 1991, absorbed doses from ^{134}Cs and ^{137}Cs for the period 1987–1996 in pine plantations were estimated (Fig. 5).

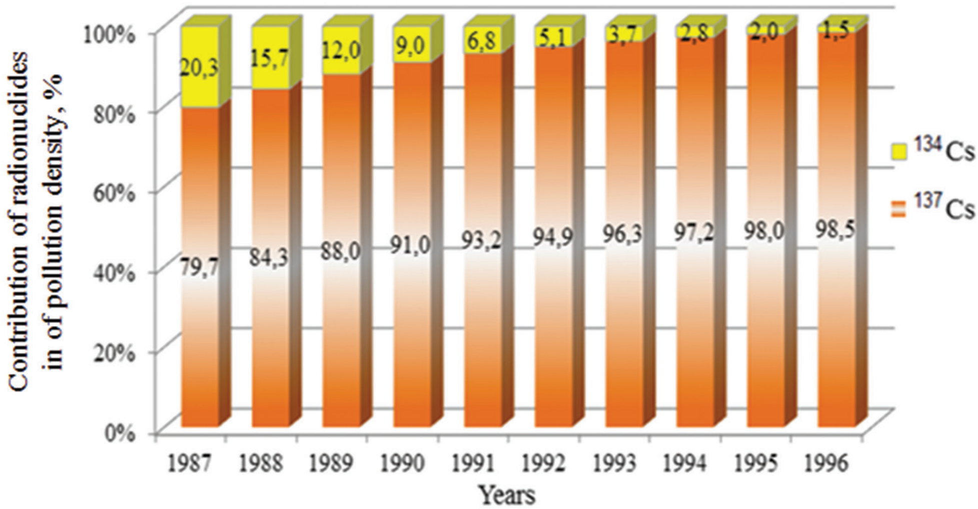

Fig. 4. Dynamics of pollution density of ^{134}Cs and ^{137}Cs of soil-litter complex in the long-range area of Chernobyl fallout over a 10-year period.

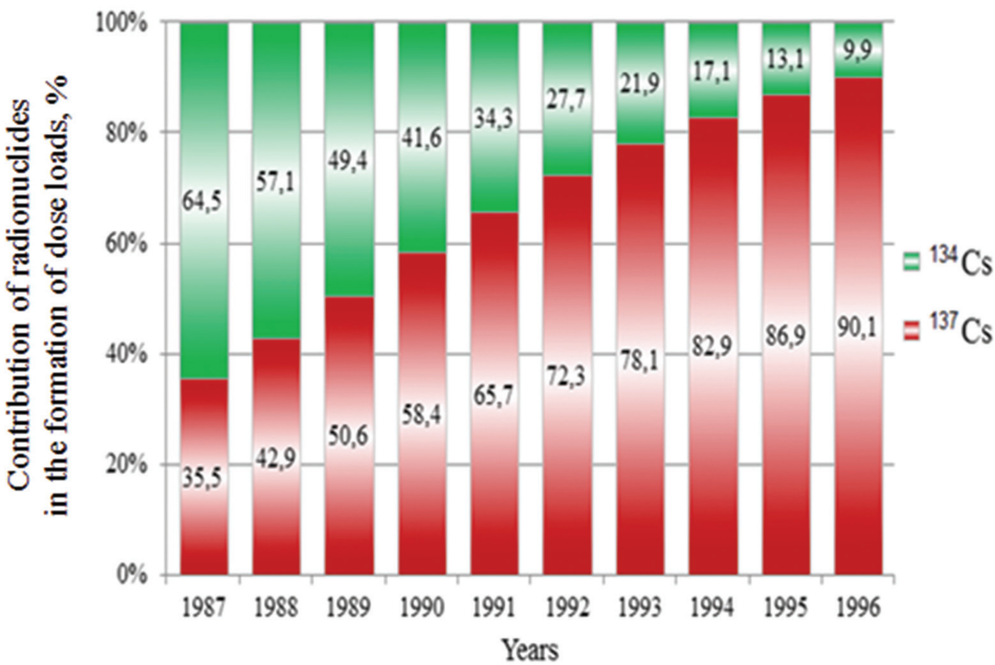

Fig. 5. Dynamics of contribution of ^{134}Cs and ^{137}Cs in the formation of dose loads of pine trees in pine stands in the long-range area of Chernobyl fallout over a 10-year period.

It was found that in 1987, despite the content of ^{134}Cs in the soil was 20.3 % of the mixture of ^{134}Cs + ^{137}Cs, the dose load on pine stands from ^{134}Cs was 1.8 times (64.5 %) higher compared to ^{137}Cs (35.5 %). This is due to the higher total photon energy at ^{134}Cs (1.55 MeV/decay), than ^{137}Cs (0,565) (Gusev and Belyaev 1991). Subsequently, by 1996, due to the radioactive decay of ^{134} Cs, the dose from this nuclide decreased by 6.5 times (to 9.9 %). Thus, after 1996, the main source of γ-radiation on pine trees was ^{137}Cs. The highest levels of radiation doses for tree layer from the mix ^{134}Cs+^{137}Cs identified during our evaluation fell on 1987. However, their size even at that time did not exceed 4.7 mGy per day (1.7 Gy per year) (Gusev and Belyaev 1991).

Using the results of periodic studies in pine phytocenoses (for 25 years), where the density of radionuclide contamination components of soil absorbing complex (moss, litter, soil layers) was determined, a retrospective assessment of radiation doses of structural elements of pine trees in the period from 1991 to 2016 was performed.

The calculation of dose load in the applied model was performed on the basis of data of the radionuclide content in the layers of the soil and covering complex. At the same time, the change in radiation doses can depend not only on the radionuclide disintegration process but also on the joint action of some other factors, which cannot be considered when sampling for identification of its impurity. These factors include the discrete nature of the Chernobyl radioactive fallout, the digging activity of wild animals and rodents that disturb the existing natural distribution of ^{137}Cs in the layers of the soil and covering complex, and the features and speed of migration of radionuclide in it. These factors modify distribution of ^{137}Cs on the layers of the soil and covering complex, as well asboth features and speed of radionuclide migration.

The assessment of dose loads on the tree layer, generative organs, and seedlings of the Scots pine at the experimental plots are given in Table 3. As seen from the table, in the studied pine stands, generally, the maximum and minimum dose loads in their structural elements showed the following: maximum: on the tree layer – 0.206 Gy per year, generative organs – 0.052 Gy per year, and seedlings – 0.065 Gy per year; minimum: on the tree layer – 0.068 Gy per year, generative organs – 0.017 Gy per year, and seedlings – 0.022 Gy per year.

The obtained results showed that dose loads of structural elements of pine stands on sites with the largest levels of pollution (32.7 and 36.1 Ci·km^{-2}) on the far in the Chernobyl areas did not exceed the amount for the tree layer of 0.21 Gy per year, which were 17.4 times lower than the dose of 3.7 Gy per year offered by the Publication 91 on behalf of the International Commission on Radiological Protection (ICRP 2004) as a dose of radiation that is safe for land plants.

On the basis of the carried out assessment of the radiation doses of pine plants in pine stands in the area of the Chernobyl far field fallout with a ^{137}Cs soil pollution density ranging from 15 to 36 Ci·km^{-2}, we can possibly conclude that morphological signs of radioactive pollution impact on pine trees cannot be revealed considering that the threshold level of pollution of the studied stands was significantly lower than the level at which they arise (3.7 Gy per year), since according to the Publication 91 ISCRS threshold level, safe for terrestrial plants in the studied plantings is significantly lower.

Table 3. Doses of radiation in structural elements of pine trees in the stands of the Chernobyl far areas at present.

Object number	The average dose, Gy per year*								
	Tree layer			Generative organs			Seedlings		
	M	min	max	M	min	max	M	min	max
1 (1Ft)	0.135	0.061	0.201	0.254	0.253	0.254	0.317	0.316	0.317
2 (1Ft)	0.136	0.125	0.146	0.253	0.253	0.254	0.316	0.315	0.318
3 (1Ft)	0.128	0.052	0.183	0.253	0.253	0.254	0.316	0.315	0.317
4 (1Ft)	0.106	0.070	0.150	0.254	0.254	0.254	0.317	0.317	0.317
5 (2Ft)	0.129	0.092	0.188	0.254	0.253	0.254	0.316	0.316	0.317
6 (2Ft)	0.188	0.118	0.284	0.253	0.253	0.254	0.317	0.315	0.318
7 (2Ft)	0.130	0.071	0.167	0.253	0.253	0.254	0.316	0.316	0.317
8 (3Ft)	0.171	0.092	0.291	0.254	0.253	0.254	0.316	0.315	0.317
9 (3Ft)	0.152	0.122	0.206	0.253	0.253	0.254	0.316	0.315	0.317
10 (4Ft)	0.068	0.038	0.092	0.196	0.025	0.254	0.316	0.316	0.317
11 (5Ft)	0.150	0.093	0.183	0.253	0.253	0.254	0.316	0.315	0.317
12 (6Ft)	0.128	0.103	0.155	0.254	0.253	0.254	0.316	0.315	0.318
13 (6Ft)	0.111	0.104	0.116	0.254	0.253	0.254	0.317	0.316	0.318
14 (6Ft)	0.107	0.087	0.127	0.254	0.253	0.254	0.317	0.316	0.317
15 (7Ft)	0.102	0.079	0.120	0.253	0.253	0.254	0.317	0.316	0.318
16 (8Ft)	0.139	0.127	0.158	0.253	0.253	0.253	0.316	0.315	0.316
17 (9Ft)	0.206	0.160	0.296	0.254	0.253	0.254	0.316	0.316	0.317
18 (10Ft)	0.094	0.080	0.103	0.254	0.253	0.254	0.317	0.316	0.317
19 (11Ft)	0.079	0.064	0.094	0.254	0.253	0.254	0.317	0.316	0.317
20 (12Ft)	0.129	0.112	0.154	0.253	0.253	0.254	0.317	0.317	0.318
21 (13Ft)	0.105	0.094	0.116	0.253	0.253	0.253	0.316	0.315	0.316

Note: * numerator – average.

Krivolutsky (2000) stated that forest and fruit trees in the 30-km CNPP zone were seriously damaged by pests. Within this zone accelerated development of new phytopathogenic forms, races with enhanced virulence, thus accelerated horizontal transfer of genes among different species of microorganisms became possible (Dmitriev et al. 2007). Those pathogens could be easily exported out of the contaminated areas. Therefore, the zone of 30-km CNPP may be an environmental hazard and the ecological processes within the zone need to be monitored attentively. To date, some living populations inhabiting the 30-km CNPP zone demonstrating high levels of mutagenesis (Golubev et al. 2005) and morphologic anomalies (Sorochinsky 2003), which can lead to a decline in adaptation and reproductive potential in organisms comprising the populations (Moller and Mousseau 2003). At the same time, an analysis of the patterns of the formation of biological effects in the zone exposed to radioactive contamination as a result of the Chernobyl accident, suggests that dose rates in the order of 0.1 mGy/day are able to cause significant increase in genetic effects in the most sensitive representatives of flora and fauna (Geras'kin et al. 2006, 2008). From this point of view, conifer trees are a unique object due to their high radio sensitivity. Indeed, experimental studies have shown that the frequency of cytogenetic disorders in the root meristem of seedlings of pine seeds from the most polluted areas exceeds the control level by two times (Geras'kin et al. 2007).

Conclusions

The sanitary condition of pine stands in near and far field sites of the Chernobyl fallout has significantly worsened 30 years after the accident when compared to initial estimations. These stands are characterized by their strong weakening. Ambiguous trends are also observed in the sustainability of stands depending on the forest type and land relief. The stands growing on the territory with the expressed difference of the moesorelief (from 5 to 15 m) in lichen, mossy, and bilberry types of forests were the most resistant among the studied pine stands of various forests in the near field sites of Chernobyl fallout. Among them, most resistant were the stands growing in the middle part of the hill slope.

In pine stands on the territory of the Chernobyl far field fallout for the 9-year period after the CNPP accident, the ^{134}Cs contribution in soil pollution density and the total radiation dose of pine trees in the ^{134}Cs + ^{137}Cs mixture decreased considerably due to disintegration of ^{134}Cs. The greatest dose load of the tree layer of the Scots pine from radionuclide was noted in 1991, i.e., ^{137}Cs of 1.0–1.7 mGy per day, and from a ^{134}Cs + ^{137}Cs mixture of 1.6–2.4 mGy per day.

The radiation doses of structural elements of the pine trees were influenced by the following factors: radionuclide disintegration, changes in its contents caused by the discrete nature of radioactive losses, digging activity of animals, and features of vertical migration of radionuclide. In this regard, the size of daily radiation doses at the tree layer of the pine for the 30-year period after the CNPP accident changed from 0.19 to 0.57 mGy per day. To date, in pine stands on the far field sites with ^{137}Cs soil pollution contamination ranging from 15 to 36 $Ci \cdot km^{-2}$, dose loads at the tree layer of the pine show a value of 0.07–0.21 Gy per year. This value was 17.4–52.1 times lower than the safe doses of radiation. At the same time, an analysis of the patterns of formation of biological effects in the zone exposed to radioactive contamination as a result of CNPP accident suggests that dose rates of the order of 0.1 mGy per day can induce a significant increase in genetic effects in the most sensitive representatives of flora and fauna (Geras'kin et al. 2007). From this point of view coniferous trees are a unique object due to their high radio sensitivity.

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