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BIOACCUMULATION OF RADIONUCLIDES IN LICHENS AND MOSSES

Die Bioakkumulation von Radionukliden in Flechten und Moosen

by

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Key words: Lichens, mosses, bioaccumulation, radionuclides, dynamics, bioindication.

Schlagwörter: Flechten, Moose, Bioakkumulation, Radionukliden, Dynamik, Bioindikation.

Summary: Many-years dynamics of ^{90}Sr and ^{137}Cs content in moss-lichen vegetation has been studied. During 15-year period of the observations, ^{90}Sr concentration in plants was shown to be practically constant. ^{137}Cs content in lichens and mosses demonstrated 20-40-fold increase caused by Chernobyl's radioactive fallout. The dynamics of a process of purification of lichens and mosses from cesium's radionuclides has been ascertained. The possibility of making use of moss-lichen vegetation as biological indicator of global radioactive fallout as well as for the purpose of long-term radioecological monitoring has been stated.

Zusammenfassung: Es wurde die mehrjährige Dynamik des ^{90}Sr und ^{137}Cs Gehaltes in der Moos- und Flechtenvegetation untersucht. Es konnte gezeigt werden, daß die ^{90}Sr Konzentration in den Pflanzen während einer Untersuchungsperiode von 15 Jahren praktisch konstant blieb. Der ^{137}Cs Gehalt in Flechten und Moosen stieg um das 20-40 fache, bedingt durch den radioaktiven Fallout von Tschernobyl. Es wurde die Dynamik eines Reinigungsprozesses der Flechten und Moose von Cs-Radionukliden ermittelt. Die Verwendbarkeit der Flechten-Moos-Vegetation, sowohl als Bioindikator für globalen radioaktiven Ausfall, als auch für radioökologisches Langzeitmonitoring, wurde nachgewesen.

Introduction

Lichens and mosses are of obvious interest with respect to bioindication of environmental radioactive contamination. A complex of structural and functional features inherent to those plants ensures their increased accumulative capacities.

Recently, especially after the Chernobyl's accident, the increased radioactivity of lichens and mosses has attracted attention of numerous explorers (for example SEAWARD et al., 1988; NIFONTOVA, ALEKSASHENKO, 1992; HOFFMAN et al., 1995). At the same time, the specificity of the processes of accumulation and stability of radionuclides fixation by those plants have been studied extremely scanty; especially few data concerning the dynamics of radionuclides content in moss-lichen vegetation are available (TUOMINEN, YAAKKOLA, 1975; NIFONTOVA, 1995a).

Generalizing of the results of long-term investigations into lichens and mosses radioactivity in the Middle Urals makes it possible to estimate changes in ^{90}Sr and ^{137}Cs content in those plants in due course.

Methods

During 15 years, the materials were being collected within a territory with 60-km radius around the city of Ekaterinburg (the central part of the Middle Urals). The most widely distributed lichen and moss species have been chosen for studies. The plants were being collected in sample plots in birch-pine forests (with herbs and grasses in ground layer) not having been exposed to local radioactive contamination. The thalli of *Hypogymnia physodes* have been collected from the birch and pine trunks together with the bark sampling. As the substrata for epigeal lichens and mosses, the soil samples (from the upper 0-5-cm layer) have been taken. Sampling technique, primary data processing as well as the methods of gamma-spectrometric and radiochemical analyses have been published, in detail, earlier (NIFONTOVA, 1995b).

Results

Maximum ^{90}Sr concentration in the thalli of epiphytic lichen, *Hypogymnia physodes*, doesn't exceed 510 Bq/kg of dry mass; for ground moss-lichen vegetation, it doesn't exceed 240 Bq/kg (Table 1). The lower nuclide's content is characteristic of the substrata of those plants (tree bark, soil) where ^{90}Sr concentration ranges from 60 to 160 Bq/kg.

Judging by data given in Table 1, ^{90}Sr content in plants and substrata varied around the average values during 15-year period of observations. Two by two comparisons (on the year basis) of ^{90}Sr concentrations both in the plants and substrata demonstrate the criteria of significance of differences being lower

Table 1: The dynamics of ^{90}Sr concentration in moss-lichen vegetation and in substrata, Bq/kg of dry mass (± S.E.)

Years of observations	*Hypogymnia physodes*	Tree bark	Ground moss-lichen vegetation	Soil (0-5 cm layer)
1978	350 ± 50	60 ± 10	*	120 ± 40
1980	290 ± 20	160 ± 50	200 ± 30	120 ± 20
1981	370 ± 30	*	210 ± 40	*
1982	290 ± 30	90 ± 30	240 ± 60	110 ± 20
1983	*	*	150 ± 30	90 ± 10
1985	500 ± 100	100 ± 30	180 ± 30	120 ± 20
1986	510 ± 140	80 ± 30	140 ± 30	120 ± 10
1987	250 ± 40	60 ± 20	110 ± 20	110 ± 10
1988	380 ± 50	100 ± 10	140 ± 30	160 ± 10
1990	*	*	130 ± 40	120 ± 20
1991	*	70 ± 20	170 ± 20	60 ± 20
1992	180 ± 40	*	130 ± 30	*
1994	*	*	200 ± 30	110 ± 30
1995	260 ± 50	130 ± 40	110 ± 30	*

* radionuclide's content wasn't determined

than standard values. A slight tendency towards a gradual decrease in radionuclide's content in plants in due course is being observed.

During the same period of the time, ^{137}Cs content in moss-lichen vegetation changed essentially (Table 2). In the first half of the eighties, maximum ^{137}Cs concentration in the thalli of *Hypogymnia physodes* didn't exceed 750 Bq/kg, and 570 Bq/kg in the ground moss-lichen vegetation. There are considerably lesser nuclide's quantities in substrata, and ^{137}Cs concentrations in tree bark and in the soil range from 60 to 240 Bq/kg. Inasmuch as ^{137}Cs content in lichens and mosses exceeds that of ^{90}Sr, the ratio between those radionuclides in the plants varies from 1.4 to 4.0 units. Up to the middle of the eighties, ^{137}Cs content both in the plants and substrata changed insignificantly, and recorded differences aren't statistically reliable.

In 1986, due to Chernobyl's radioactive fallout, there was recorded a considerable increase in cesium's radionuclides content in moss-lichen vegetation of the Middle Urals. The nuclides concentration (the overall ^{134}Cs and ^{137}Cs activity was determined) in lichens and mosses has increased by 20-40-fold. In individual plant species, a considerable variability in cesium's radionuclides bioaccumulation is observed. So, in lichens and mosses of different taxa, 137Cs concentration varies from 5-6 kBq/kg (*Cladina stellaris, C.*

rangiferina) to 22-28 kBq/kg *(Atrichum undulatum, Plagiomnium rostratum)*. Table 1 shows that ^{90}Sr content in the plants remained practically constant.

Table 2: The dynamics of ^{137}Cs content in moss-lichen vegetation and in substrata, Bq/kg of dry mass (± S.E.)

Years of observations	*Hypogymnia physodes*	Tree bark	Ground moss-lichen vegetation	Soil (0-5 cm layer)
1978	480 ± 50	60 ± 10	*	*
1980	500 ± 60	100 ± 20	430 ± 50	180 ± 40
1981	750 ± 60	120 ± 10	280 ± 40	100 ± 20
1982	500 ± 60	60 ± 10	430 ± 40	190 ± 20
1983	*	*	420 ± 30	170 ± 20
1985	560 ± 60	120 ± 20	390 ± 40	180 ± 30
1986	12620 ± 720	1510 ± 300	11350 ± 1000	540 ± 30
1987	9000 ± 400	1120 ± 100	7570 ± 700	1100 ± 100
1988	8620 ± 650	910 ± 160	5270 ± 500	930 ± 70
1990	*	*	2700 ± 300	290 ± 20
1991	*		2890 ± 300	230 ± 40
1992	4140 ± 200	*	2140 ± 400	*
1994	*	*	470 ± 60	160 ± 60
1995	570 ± 30	210 ± 30	490 ± 60	*

* radionuclide's content wasn't determined

An analysis of the isotopic ratios ^{137}Cs: ^{90}Sr confirms the data obtained: the ratio between those radionuclides drifts up to 16-26 units in lichens and 23-75 units in mosses at the expense of increasing portion of cesium's radionuclides.

In tree bark and superficial soil layer, ^{137}Cs content has increased as well, and nuclides concentration has risen up to 0.5-1.5 kBq/kg (Table 2). It should be noted that ^{137}Cs concentration in the herbaceous vegetation of the Middle Urals has increased by one order of values (NIFONTOVA, KULIKOV, 1990).

Beginning from 1987, a decrease in radioactivity of moss-lichen vegetation takes place. The slowest purification from cesium's radionuclides is characteristic of the thalli of ephiphytic lichen, *Hypogymnia physodes*. For the first two years after radioactive contamination, its thalli lose up to 30% of ^{137}Cs; in subsequent two years, 30% are being lost additionally, and the initial level of nuclide's concentration (1985) in the plants is being attained for nine years. During this period of time, 37 Cs content in tree bark decreases by 80% (Table 2).

In ground moss-lichen vegetation, ^{137}Cs content decreases by 50% during the first two years after radioactive fallout. Nuclide's concentration in the plants falls to initial values for seven years. In herbaceous vegetation of the Middle Urals, cesium's radionuclides concentration has lowered to the initial levels for three years (NIFONTOVA, KULIKOV, 1990).

Discussion

The main source of radioactive contamination of lichens and mosses is aerial fallout; a level of content of radioactive substances in it predetermines, to a considerable extent, a presence of ^{90}Sr and ^{137}Cs in moss-lichen vegetation. The input of certain quantities of those radionuclides into lichens and mosses from substrata (wood, slash, soil) is possible however similar sources of radioactive contamination aren't of great importance.

During the period of the seventies-eighties, a decrease (as compared to maximum values recorded in 1962-1965) in the levels of radioactive contamination of global atmospheric fallout and stabilization of them have been revealed (BOLTNEVA et al., 1977). As a result of Chernobyl's accident (1986), a sharp increase in cesium's radionuclides content in atmospheric air happened, and the meteorological conditions during the accident facilitated dispersion of radioactive fallout for a long way off in north-western, north-eastern and southern directions from Chernobyl's NPS (IZRAEL' et al., 1990). "Eastern" trace of distribution of radioactive aerial masses had the following route: Chernobyl's NPS - Penza - Ekaterinburg - Tyumen'; at a distance of 2.4 thousand km, the levels of radioactive contamination up to 0.2 Ci/km^2 were recorded. An increase in cesium's radionuclides content in atmospheric fallout has resulted in rising of the nuclides levels in soil-vegetational cover within a territory of the Middle Urals. The data on ^{137}Cs contents in lichens, mosses and substrata given in Table 2 testify it. Similar increase in ^{137}Cs concentrations has been recorded for lichens and mosses from the territories belonging to north-western train of Chernobyl's fallout within Baltic and West-European countries.

Beginning from 1987, radioactivity of global atmospheric fallout decreases, and, during three years, practically attains the levels preceeding Chernobyl's accident (ZYKOVA, VORONINA, 1993). From the same time, a gradual decrease in cesium's radionuclides content in moss-lichen vegetation of the Middle Urals begins (Table 2).

Purification of the lichens and mosses from radioactive substances is known to be a result of leaching of radionuclides with atmospheric precipitation, trampling and grazing, and physical disintegration of radionuclides. The rate of purification characterized by the effective ecological period of half-purification, $T_{1/2eff.}$ (TROITSKAYA et al., 1971), serves as the radioecological parameter that makes it possible to record the dynamics of radionuclides content in lichens and mosses. The data on duration of ecological effective period of half-purification are contradictory: for arctic lichens, $T_{1/2eff.}$ was being determined over the range from three to thirteen years (MARTIN, KORANDA, 1971; TROITSKAYA et al., 1971).

According to our calculations, the average values for ecological effective period of ^{137}Cs half-purification comprise four years for the epiphytic lichen, *Hypogymnia physodes*, and two years for epigeal lichens and mosses. Similar results concerning the rate of purification from cesium's radionuclides have been obtained for lichens of Western Europe (HEINRICHE et al., 1994; BARTOK et al., 1996). It should be taken into account that $^{134}Cs/^{137}Cs$ ratio for Chernobyl's radioactive fallout equalled 0.55 (April, 1986), and the period of physical half-disintegration for ^{134}Cs comprised 2.08 year.

Thus, basing upon our study of the dynamics of ^{90}Sr and ^{137}Cs content in lichens and mosses, we have ascertained, as a matter of record, that accumulation of radionuclides by those plants was being determined, to a considerable extent, by the levels of radioactivity of global atmospheric fallout. By all this, an increased ^{90}Sr and ^{137}Cs concentrating capacity was typical of mosses and lichens in comparison with herbaceous and arborescent vegetation. The process of purification of moss-lichen vegetation from radioactive contamination proceeds for a rather long time, and a gradient of decrease in nuclides concentration shortens in due course.

The materials presented here give evidence of the effectiveness of making use of moss-lichen vegetation as the indicator of radioactive contamination of soil-vegetational cover. As the most adequate for radioecological indication, an epiphytic lichen, *Hypogymnia physodes*, might be suggested thanks to its wide distribution. Significant individual differences in accumulating capacity have been ascertained for epigeal lichens and mosses. Therefore, not individual species but moss-lichen cover on the whole should be used for indication. As the long period of purification from radioactive contamination is characteristic of lichens and mosses, the moss-lichen vegetation might be an apt object for a long-term radioecological environmental monitoring.

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