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The Radionuclides in Lichen Thalli in Chernobyl and East Urals Areas after Nuclear Accidents

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Summary

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The concentrations of all measured radionuclides in thalli of common sylvan lichen species at the contaminated areas of the Kyshtym on East Urals (1957) and Chernobyl (1986) accidents exceeds by hundreds and up to thousend times the concentrations known for lichens of these radionuclides from global fallout. For example for *Hypogymnia physodes* thalli Cs-137 concentration at distance 1.5 km from Chernobyl NPP was 5840 $Bq \cdot g^{-1}$ dw, for *Parmelia sulcata* – 14600 $Bq \cdot g^{-1}$, for *Cladina mitis* – 2700 $Bq \cdot g^{-1}$, and for pine bark – 1260 $Bq \cdot g^{-1}$.

Zusammenfassung

BIAZROV, L. G. 1994. Radionuklide in Flechtenlagern aus den Gebieten um Tschernobyl und des Ost-Urals nach Kernunglücken. – Phyton (Horn, Austria) 34 (1): 85–94. – Englisch mit deutscher Zusammenfassung.

In den als Folge der Kernunglücke verseuchten Gebiete von Kyshtym im Ost Ural (1957) und Tschernobyl (1986) ist die Aktivität aller gemessenen Radionuklide in Lagern von gewöhnlichen Waldflechten hundert bis tausend mal höher, als die für Flechten bekannten Konzentrationen aus dem globalen Fallout: z. B. betrug in einer Entfernung von 1,5 km von Tschernobyl KKW die Konzentration von Cs-137 5840 $Bq \cdot g^{-1}$ TG in Lagern von *Hypogymnia physodes,* 14600 $Bq \cdot g^{-1}$ bei *Parmelia sulcata,* 2700 $Bq \cdot g^{-1}$ bei *Cladina mitis* und in Rinden von Kiefern 1260 $Bq \cdot g^{-1}$.

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1. Introduction

The exploitation of nuclear energy for military and peaceful purposes has considerably increased the risks of higher doses of ionizing radiations being received by living organisms. This problem has received particular attention after the tragic accident in April 26, 1986, at the Chernobyl nuclear power plant (NPP) in the Ukrainian Polesye. Other large-scale accident, including the hushed up explosion of the deposit of nucelar wastes in Kyshtym in Eastern Urals in 1957 has also been investigated (NIKIPELOV & al. 1990).

As is also known in fungi, lichens are living accumulators of natural and man-made radionuclides and heavy metals (ECKL & al. 1986, TÜRK 1988, HEINRICH & al. 1989). Their concentrations, e. g. in the thalli of lichens, exceed by far the content of the same substances in various organs of vascular plants (BIAZROV & ADAMOVA 1990, ADAMOVA & BIAZROV 1991). As was revealed experimentally, these organisms are capable of retaining high dosages of ionizing radiation (1000 R/24h during 22 months) without detrimental effects (BRODO 1964).

The to accidents mentioned, resulted in considerable relase of fission products of the nuclear fuel into the atmosphere in Eastern Urals and in the Chernobyl region. The purpose of my studies dealing with the ecological consequences of the accidents conducted in 1987–1988 was: (1) the better understanding of the spatial distribution of a number of radionuclides in the thalli of different lichen species, and (2) elucidation of both general patterns and regional features of the accumulation of radionuclides in the thalli of lichens from these two nuclear accidents, that were far apart, both spatially and temporally.

2. Areas, Material and Methods

The plant material of the Chelyabinsk region (Kyshtym, Eastern Urals) between the lakes Bolshoi Kuyash and Kasli was collected in 1987, where in 1957 as a result of an explosion of highly-radioactive nuclear wastes, a plume of radioactive pollution somewhat over 100 km long and 10 km wide was formed (NIKIPELOV & al. 1990). In that area the radioactive trace started the level of radioactivity was between 2 and 4000 $Ci \cdot km^{-2}$ with Sr-90 being the prinicpal long-lived radionuclide. The samples from Ural were collected at 1 to 1.5 m above the soil surface from birch trunks in birch forest sites being 50–60 years old with herbs on the ground, differently affected by the release of nuclear waste: (1) highly contaminated sites being situated in the center the plume and close to the site of the explosion (the level of Sr-90 deposition in 1987 was estimated at 2 $Ci \cdot km^{-2}$), (2) less contaminated sites at the margin of the plume, several kilometers NE of site 1, with the Sr-90 deposition was 0.5 $Ci \cdot km^{-2}$, and (3) a low zone with a plot beyond the radioactive plume. If one takes into account the fact that over 30 years after the explosion the amount halved, and at the moment of the explosion the contribution of this radionuclide to total pollution was about 3% (NIKIPELOV & al. 1990), than the deposition on site 1 at 1957 was ca. 150 $Ci \cdot km^{-2}$.

The samples of lichens in the Ukrainian Polesye were taken in 1988 from the soil surface and from trunks of pine tree at the same height in 40–60 year old pine forests of the following sites adjacent of the Chernobyl NPP: A – ca. 1.5 km SW from the CNPP, B – ca. 7 km SW from the CNPP, C – ca. 12–13 km NW from the CNPP near the boundary of the Gomel region of the Byelrussia, D – ca. 19 km S from the CNPP, E –

ca. 37 km to the S of the CNPP, outside of the 30 km zone of population evacuation. In site E materials were collected in three adjoining similar forest habitats.

The thalli of lichens belong to the world's most-widely distributed plants. They are ground fruticose lichens *Cladina mitis* (Sandst.) Hale et W. Culb., *Cladonia crispata* (Ach.) Flot., *C. gracilis* (L.) Willd., epiphytic foliose lichens *Hypogymnia physodes* (L.) Nyl., *Parmelia sulcata* Tayl., and pine tree (*Pinus sylvestris* L.) bark.

At sampling sites thalli of lichens were thoroughly examined in their natural habitats to reveal anomalies in their development. Attention was paid to the colour of thallus, the character of frutification and other features which might imply injury.

The weight of each sample for measurements of the activity of radionuclides was ca. 25–50 g. The thalli were collected from several trees of the plot under study. To determine the relationship between the accumulation of the radionuclides and the age of thalli in site 1 (in Kyshtym) thalli under 20 mm in diameter, 21–40 mm in diameter and over 40 mm in diameter were collected separately. This division was based on measurements of the diameters of several hundred thalli directly in the forest (Table 1) and subsequent observations of the current annual increment of the representatives of the species. The determination of the linear increment of the thalli revealed that the average increment of the diameter of *Hypogymnia physodes* thalli in 1987–1989 was 2.0 mm · y^{-1}, while that of *Parmelia sulcata* was 2.3 mm · y^{-1}. But the differences between these values were not statistically significant, hence the growth rate of the representatives of the above species in this region can be regarded as similar. The thalli with diameters of less than 20 mm were found to be 8–10 years old, the of over having diameters of 21–40 mm were between 8–10 and 16–20 years old, and these with diameters of more than 40 mm were older than 16–20 years.

Table 1

Distribution (%) of the thalli of epiphytic lichens over the classes of their size (Kyshtym, site 1)

Species	Diameter of thallus, mm								Total number of thalli measured
	16–20	21–25	26–30	31–35	36–40	41–45	46–50	51–55	
Hypogymnia physodes	5	8	35	25	18	7	1	1	218
Parmelia sulcata	4	12	19	28	26	9	1	1	222

Plant samples were cleaned, dried at 110° C for 24 h, pulverized and filled in 70 cm^3 beakers for measurements. Measurement was performed by gamma spectrometry with a lithium drifted germanium crystal detector and a multichannel-analyser at the Laboratory of Research Stations on Urals (Antonenko & al. 1988).

3. Results and Discussion

The visual examination of lichens at the sampling sites did not reveal any direct impact on their development. The colour of thalli was normal for the representatives of each species, no spots were present, frutification of the *Cladoniaceae* was normal, apothecia were of normal brownish colour. Abundance of soredia on thalli of foliose lichens was also normal.

The results of the measurement of the radionuclides (Table 2 and 3) indicate that with increasing from the source of pollution the concentration of radionuclides in lichen thalli decreased. In the Kyshtym area among the samples collected for measurement, obviously there were no thalli of the same age as the explosion. By knowing the annual increment of these epiphytic lichens this is indicated by measurements of the diameters of several hundred of thalli (Table 1). Most of the thalli were aged 15–20 years, i. g. they appeared after the explosion. However, their thalli developed of the sites being studied (1 and 2) under conditions of an increased radiation background. Varying levels of radioactive contamination affected their accumulated by the thalli (Table 2). However, the accumulation of radionuclides by the thalli, judging from measurements of the activity in the thalli of different diameter (Table 2), was not directly related to the period increased radiation background. Certainly the thalli of the representatives of both species of over 40 mm in diameters exihibited a higher concentration of radionuclides compared with the thalli of lesser diameters. Still among the latter, the thalli with a diameter of less than 20 mm are distinguished by a high concentration of radionuclides as compared with the thalli of medium size which does not permit an unequivocal conclusion.

An absence of epiphytic lichens older than 30 years in site 1 (Kyshtym) is difficult to interpret, since the assumption of the possible mortality of lichens because of nuclear explosion is not supported both experimentally (BRODO 1964) and by observations in the area of the Chernobyl NPP, where

Table 2

Activity (Bq · g^{-1} dw) of radionuclides in the epiphytic lichen thalli of the different sizes clusters in the birch forests of the Eastern-Urals radioactive trace 30 years after the accident

Site*)	*Hypogymnia physodes*				*Parmelia sulcata*			
	Mean for thalli all sizes	D < 20 mm	D = 21–40 mm	D > 40 mm	mean for thalli all sizes	D < 20 mm	D = 21–40 mm	D > 40 mm
1	56.2	62.2	30.2	72.5	46.4	39.8	35.7	67.0
2	11.8	n. m.	n. m.	n. m.	11.5	n. m.	n. m.	n. m.
3	1.2	n. m.	n. m.	n. m.	0.7	n. m.	n. m.	n. m.

*) = explanation in text, page 3; n. m. = not measured

the lichens accumulated a very high level of radionuclides but no morphological damage of the thalli near the damaged reactor was revealed by direct observation.

Table 3

Concentrations (Bq · g^{-1} dw) of radionuclides in lichen thalli and bark of pine tree in the vicinity of the Chernobyl NPP (a collection of specimens was in July 1988, measurement was in January 1989)

Site*)	RN	*Hypogymnia physodes*	*Parmelia sulcata*	Bark of pine tree	*Cladina mitis*	*Cladonia crispata*	*Cladonia gracilis*
A	^{106}Ru	1700	3940	335	777	1260	593
	^{134}Cs	1140	2840	258	561	n. m.	1230
	^{137}Cs	5840	14600	1260	2700	n. m.	5960
	^{144}Ce	2400	6480	588	662	1830	981
B	^{106}Ru	1130	n. m.	355	747	10500	n. m.
	^{134}Cs	730	n. m.	257	570	n. m.	n. m.
	^{137}Cs	3600	n. m.	1210	2850	n. m.	n. m.
	^{144}Ce	1160	n. m.	684	988	2690	n. m.
C	^{106}Ru	183	n. m.	23	394	17	n. m.
	^{134}Cs	92	n. m.	24	263	n. m.	n. m.
	^{137}Cs	539	n. m.	107	1230	n. m.	n. m.
	^{144}Ce	184	n. m.	34	385	184	n. m.
D	^{106}Ru	49	n. m.	n. m.	43	n. m.	n. m.
	^{134}Cs	41	n. m.	n. m.	26	n. m.	n. m.
	^{137}Cs	200	n. m.	n. m.	118	n. m.	n. m.
	^{144}Ce	46	n. m.	n. m.	35	n. m.	n. m.
E**)	^{106}Ru	34–337	n. m.	86	19–20	16–39	n. m.
	^{134}Cs	12–150	n. m.	12	10–12	n. m.	n. m.
	^{137}Cs	71–792	n. m.	57	44–58	n. m.	n. m.
	^{144}Ce	20–223	n. m.	22	12–20	23–44	n. m.

*) = explanation in text, page 86; **) = the intervals of activity for three habitats; n. m. = not measured

The highest concentrations of the gamma-emitting radionuclides in the area of the Chernobyl NPP were recorded immediately near the place of the accident (Table 3). The lowest values of the activity of radionuclides were recorded in samples taken beyond the 30 km zone population evacuation (E). However there were also considerable fluctuations of the observed activities, (e. g. in thalli of *Hypogymnia physodes*), pointing to the uneven distrubution of the radioactive fallout. Measured radionuclides content and their correlation in lichen thalli correspond rather good with core inventory and estimate of radionuclides total release in damaged reactor of the CNPP (LEVI 1991).

Ru-106 is formed in the process of uranium fission, its halflife is 368 days (LEVI 1991). It was shown experimentally that vascular plants accumulate this radionuclide from soil solutions very small, especially in their above-ground parts (MAKHONINA & al. 1965). However, lichen thalli in the Chernobyl area manifest considerable activity of this radionuclide after the accident. Considering the decay of Ru-106 its concentration at that time was 6–7 times higher than values shown in the Table 3. Generally, a rather regular trend of decreasing Ru-106 from wrecked reactor was noted.

The lichens are known to accumulate large quantities of Cs-137 from global fallout. In the years when nuclear arms were tested mainly in the atmosphere the thalli of *Cladina* in the Russian Arctic contained about 2.6 $Bq \cdot g^{-1}$ of Cs-137 (ALEXAKHIN & RAVIKOVICH 1969). In the early 1980's in the area of the first commercial russian nuclear power plant (Beloyarsk, in the Central Urals) the acitivity of Cs-137 in thalli of *Hypogymnia physodes* was 0.3–0.75 $Bq \cdot g^{-1}$ and 0.1–0.25 $Bq \cdot g^{-1}$ in pine bark (NIFONTOVA & al. 1988). After the nuclear tests 1980 made in China, the activity of Cs-137 in thalli of *Cladina rangiferina* and *Cladonia furcata* in forests of Austria was 0.25 and 0.3 $Bq \cdot g^{-1}$, in thalli of *H. physodes,* 0.1–1.3 $Bq \cdot g^{-1}$ (ECKL & al. 1986). The isotopes Cs-134 and Cs-137 are formed in the process of fission of U and Pu, the latter isotope is considered to be most important in tissue doses and radiobiological consequences. The physical half-life of Cs-134 is 2.1 years, of Cs-137 one 30.0 years (LEVI 1991). Taking this into consideration, at the moment of the accident there was almost 2.5 times more Cs-134 around the Chernobyl NPP and if in 1000 days after the accident the ratio Cs-134/Cs-137 was about 0.2, it was about 0.5 during the first days after the accident. This ratio in thalli of lichens in Arctic in 1950's–1960's was about 0.002–0.004 (HANSON & al. 1967). The concentration of these isotopes regularly decreases in lichen thalli and pine bark with increasing distances from the accident site. As a rule, the activity of these radionuclides is higher in the epiphytic lichens than in thalli of the epigeal species and in pine bark, but among the epiphytic lichens the thalli of *Parmelia sulcata* near the damaged reactor of CNPP contained 2–2.5 times higher concentrations of radionuclides compared with *H. physodes* thalli (Table 3). In the Kyshtym area there were practically no differences in activity level between representatives of these two species belonging to different life form groups (GOLUBKOVA & BIAZROV 1989). The magnitude of the Cs-137 concentration in thalli of *H. physodes* outside of the 30-km zone of population evacuation in area CNPP (E) 1000 days after the accident was the same as in the Bavarian Forest and the Alps (FEIGE & al. 1990) or in forests of Austria in August 1986. In Austria the acitivity of this radionuclide in thalli of the same species was 33.5 $Bq \cdot g^{-1}$, and in spruce trunks 3.5 $Bq \cdot g^{-1}$. Before the Chernobyl accident in the same forests in Austria the concentration of Cs-137 in thalli of *H. physodes* was 0.07 $Bq \cdot g^{-1}$ (HOFMANN & al. 1988).

The last estimated radionuclide, Ce-144, is present in emissions of atomic power plants and of plants processing worked-out nuclear fuel. Ce-144 and its daugther product Pr-144 make up to 30% of all radioactivity after atomic bomb explosions. The halflife of Ce-144 is 284 days (LEVI 1991), thus it is recommended that values of the Table 3 for Ce-144 should be increased approximately 10–11 times for the estimation of the concentration level of this radionuclide in lichen thalli and pine bark shortly after the accident. With increasing distances from the place of explosion, the concentration of Ce-144 in lichen thalli and pine bark decreased. Background concentrations of this isotope universally common in air and fallout in lichens is comparatively low. Measurements after the tests of termonuclear arms in China in 1980 showed that the activity value of Ce-144 in different lichen species of the forests in Austria was 0.01–0.14 $Bq \cdot g^{-1}$ (ECKL & al. 1986).

If the ratios of concentrations of measured radionuclides were compared, only the Cs-134/Cs-137 ratio remained constant in the lichen thalli and in the pine bark, and at all sites (Table 4). The values of ratios

Table 4

The ratios of activity values of some radionuclides in thallus of lichens and in bark of pine tree in the Chernobyl area

Site*)		*Hypogymnia physodes*				*Cladina mitis*				Bark of pine tree			
	RN	Ru-106	Cs-134	Cs-137	Ce-144	Ru-106	Cs-134	Cs-137	Ce-144	Ru-106	Cs-134	Cs-137	Ce-144
A	Ru-106	W				W				W			
	Cs-134	1.5	W			1.4	W			1.3	W		
	Cs-137	0.3	0.2	W		0.3	0.2	W		0.3	0.2	W	
	Ce 144	0.7	0.5	2.4	W	1.2	0.8	4.0	W	0.6	0.4	2.1	W
B	Ru-106	W				W				W			
	Cs-134	1.5	W			1.3	W			1.4	W		
	Cs-137	0.3	0.2	W		0.3	0.2	W		0.3	0.2	W	
	Ce-144	1.0	0.6	3.1	W	0.8	0.6	2.9	W	0.5	0.4	1.8	W

(Table 4, Continuation)

Site*)	RN	*Hypogymnia physodes*				*Cladina mitis*				Bark of pine tree			
		Ru-106	Cs-134	Cs-137	Ce-144	Ru-106	Cs-134	Cs-137	Ce-144	Ru-106	Cs-134	Cs-137	Ce-144
C	Ru-106	W				W				W			
	Cs-134	2.0	W			1.5	W			1.0	W		
	Cs-137	0.3	0.2	W		0.3	0.2	W		0.2	0.2	W	
	Ce-144	1.0	0.5	2.9	W	1.0	0.7	3.2	W	0.7	0.7	3.1	W
D	Ru-106	W				W							
	Cs-134	1.2	W			1.6	W						
	Cs-137	0.3	0.2	W		0.4	0.2	W					
	Ce-144	1.1	0.9	4.3	W	1.2	0.7	3.4	W				
E	Ru-106	W				W				W			
	Cs-134	2.5	W			1.8	W			7.2	W		
	Cs-137	0.4	0.2	W		0.4	0.2	W		1.5	0.2	W	
	Ce-144	1.6	0.6	3.5	W	1.3	0.7	3.3	W	3.9	0.5	2.6	W

*) = explanation in text, page 86

of other radionuclides or of caesium to other radionuclides vary within wide limits. Generally a tendency is noted that on stations situated closer to the wrecked reactor, the ratio between concentrations of radionuclides in thalli of various lichen species and in pine bark vary less than for stations situated farther from the Chernobyl NPP. The farther from the accident the more ratios vary. Probably within the radius of 6–8 km from the accident, the fallout of products of nuclear fuel was more or less homogenous and rather dense. At greater distances the fallout of radioactive particles of nuclear fuel was influenced by atmospheric processes and by physical peculiarities of thrown out particles, their sedimentation was patchy and accumulation in lichens and in pine bark was heterogenous.

4. Conclusions

- Development of lichen thalli, appearing after the nuclear accident in Kyshtym, under condition of increased radiation background, contribute to higher accumulation of radionuclides by thalli;
- The concentrations of all measured radionuclides both in lichen thalli and in tree bark near nuclear accidents exceeds from hundreds to tens of thousands times the values known for lichens only affected by the global fallout prior to the accidents;
- The impact of rather high concentrations of radionuclides, even based on observations in 1987–1988 near the place of accident in Chernobyl NPP, did not cause any visually discernable anomalies in the development of lichen thalli. The observations are consistent with the data on high resistance of lichens to radioactive irradiation (BRODO 1964);
- At greater distances from the place of accidents, the concentrations of radionuclides in lichen thalli and tree bark decreased. Even outside the 30 km evacuation zone of Chernobyl NPP their concentration in lichen thalli surpassed the values prior to the accident by hundreds of times;
- The accident at the CNPP affected a wide area; this fact should be taken into considerations when interpreting observations of the global radionuclide fallout and their accumulation in organisms;
- The fallout of fission products from nuclear fuel was patchy. The heterogeneity was both quantitative and qualitative;
- The concentration of the studied radionuclides was much higher in lichen thalli than in pine bark; among lichens the activity of radionuclides was as rule higher in epiphytic lichens than in thalli of lichens from soil surface;
- My data indicate that, when certain standards for sampling are met, the concentration of radionuclides in the thalli of lichens is a fairly reliable index of relative differences between areas in terms of the level of radionuclide pollution and their qualitative composition. One can agree with opinion that lichens are silent chronists of nuclear accidents (FEIGE & al. 1990, SEAWARD 1992).

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