Environment Protection Engineering

Vol. 7 1981 No. 1

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MOSSES AS BIOINDICATORS OF ATMOSPHERIC BERYLLIUM

In contrast to recreational areas the industrial ones, especially those under the influence of dusts and gases emitted from power stations, are characterized by relatively high content of beryllium in the atmosphere. This fact is manifested by beryllium bioaccumulation in mosses *Hypnum cupressiforme*, *Hylocomium splendens*, *Polytrichum juniperinum*, and *Polytrichum commune*. These mosses satisfy the criteria required for chemical bioindicators. The mosses examined differ in beryllium concentration in ashes which depends on the amount of dust precipitation, beryllium concentration in meteorological precipitation, sum of annual meteorological precipitations, and beryllium concentration in soil.

1. INTRODUCTION

There are some plants in which contents of different elements are higher than usual, due to the presence of large amounts of those elements in the habitat. Such plants may indicate the presence of a given element (of natural or anthropogenic origin) in soil or atmosphere. When the element is of anthropogenic origin its migration is accelerated, most frequently in a cyclic way. Human activity influences the course of thermodynamic processes in ecosystems and changes the differences of chemical potential which, eventually, determines the migration rate and direction of a great number of elements, e. g. beryllium, germanium, selenium. Both the rate and direction of beryllium migration in natural environment may be to some extent stimulated by the ability of plants to cumulate selectively some elements.

In the areas characterized by an abnormal content of beryllium in soil, it is cumulated in higher or lower degree by the separate plant species. Higher plants display a relatively high ability to cumulate beryllium. According to KOWALEWSKI [4], at the concentration of beryllium in soil and infiltrating water amounting from 2 to $3 \times 10^{-4}\%$ the roots of different plant species, not precisely determined by the author, contain 0.01–0.06% of beryllium. Tobaco leaves, depending upon the species, contain 0.015–0.075 μg of beryllium/g [3].

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The above-mentioned ability of plants to cumulate beryllium is responsible for the so--called "natural dispersion". Some species of *Bryophyta* and roots of conifers may be also used as beryllium bioindicators.

2. METHODS

To justify statistically the conclusions obtained the indispensable number of moss samples had to be determined first of all. To this end it has been hypothetically assumed that there exists a correlation between the content of beryllium im mosses and its concentration in monthly precipitation rates.

Basing on the formula for the significance of the given correlation the samllest number n of samples was established for the given correlation r assuming that the given interdependence is significant from natural science view-point if and only if the number of samples $t > 3$:

$$t = \frac{1}{2} \ln \frac{1+r}{1-r} \cdot \sqrt{n-3}.$$

In the case considered such a number of samples has been recognized as indispensable which would correspond to the coefficient of correlation equal to 0.5 [2].

Our assumptions and procedure had been justified by the following conclusions obtained in the former investigations [5]:

1. concentrations of beryllium in atmospheric precipitation water decrease with the increasing precipitation rate,

2. the relation between beryllium content in atmospheric precipitations water y and its salinity x is described by the regression equation of the type of $y = a \cdot x^b$.

The size of the samples being analyzed was corrected according to the suggestions by GREGORY [2], using the formula

$$n = (S/d)^2,$$

where:

S — standard deviation,

d — standard error — 2.5%.

The collected samples of moss, dried at the temperature of 105° ±1°C, were subject to flameless combustion and ashed in a muffle furnace at 400°C.

In the samples examined beryllium was determined spectrographically by means of a spectrograph of the average dispersion Q–24 (produced by Carl Zeiss, Jena), as well as by the method of atomic absorption, using AA–5 analyzer, type Varian-Techtron.

Detectability of beryllium by spectrographic method amounted to 0.01 μg/g. The separate results obtained by photometry method, at the wavelength of 312.5 nm, differend by 8% with respect to the mean from six measurements.

Sensitivity of atomic absorption method amounted to 0.17 μg/ml, and its detectability 0.002 μg/ml. Beryllium was determined at the wavelength of 234.9 nm, using reducing flame composed of acetylene and nitrous oxide.

In the atomic absorption method individual results differed by about 10% with respect to the mean value from six measurements. The values determined by spectrographic method differed by 3% to 20%.

3. RESULTS AND DISCUSSION

From the areas affected by industrial pollutants the following species have been collected: *Hypnum cupressiforme*, *Hylocomium splendens*, *Polytrichum juniperinum*, and *Polytrichum commune*. The contents of beryllium in the separate species varied from 10 to 102 μg/g of ashes. Results presented in tab. 1 show a high ability of mosses to beryl-

Table 1

Beryllium concentrations in mosses collected in different localities of the Katowice district

Stężenie berylu w mchach zebranych w różnych miejscowościach województwa katowickiego

Sampling site	Moss species	Beryllium concentration μg/g	Beryllium precipitation μg/m²/month	Beryllium concentration in atmospheric precipitations μg/dm³	Beryllium concentration in soil μg/g
Katowice	*Hypnum cupressiforme*	44.8	140.8	38.7	11.3
	Hylocomium splendens	10.5			
Katowice	*Polytrichum juniperinum*	72.0	157.4	33.4	16.2
Katowice	*Polytrichum commune*	38.5	132.8	26.0	11.6
Chorzów	*Hylocomium splendens*	66.0	151.4	47.5	22.6
	Hypnum cupressifororme	98.0			
Bytom	*Hypnum cupressiforme*	85.0	137.8	20.0	13.0
	Hylocomium splendens	59.0			
	Hypnum cupressiforme	102.0			
Rybnik	*Hypnum cupressiforme*	81.0	144.8	33.8	10.8
Zabrze	*Polytrichum commune*	72.0	157.8	49.0	17.5
	Hypnum cupressiforme	62.3			
Knurów	*Hypnum cupressiforme*	72.0	160.0	32.0	20.0
Gliwice	*Hypnum cupressiforme*	70.0	160.4	30.8	10.7
Mikołów	*Polytrichum commune*	36.9	150.8	26.9	13.0
Szczyrk	*Polytrichum juniperinum*	60.5	37.8	21.4	
	Polytrichum commune	60.0			
Wisła	*Polytrichum commune*	33.5	111.0	27.0	16.0
Ustroń	*Polytrichum juniperinum*	31.5	120.0	25.0	14.0
Wapienica	*Polytrichum commune*	35.0	132.0	50.9	8.2
Międzybrodzie	*Hypnum cupressiforme*	50.0	127.2	32.0	7.5
Ruda Śląska	*Polytrichum commune*	51.0	144.5	36.0	23.0

lium cumulation. Higher concentrations of this element in mosses have been observed in habitats affected by meteorological or atmospheric precipitations (dry precipitation + meteorological precipitation).

The average content of beryllium in some species of mosses indicates that the beryllium concentrations characteristic of the given species of moss differ depending on the content of this element in the habitat.

In the particular species the concentration of beryllium ranged within 21–63 µg/g (*Polytrichum commune*), 29–78 µg/g (*Polytrichun juniperinum*), 23–112 µg/g (*Hypnum cupressiforme*), and 7.2–40.0 µg/g (*Hylocomium splendens*). Thus, *Hypnum cupressiforme* should be recognized as the best bioindicator of beryllium. In the vicinity of power stations that produce energy from the combustion of coal, the concentration of beryllium was always very high of order of 100 µg/g of ashes, in contrast to recreational areas where it was of order of 35 µg/g of ashes. The above-mentioned observations have been confirmed by the quotients of beryllium concentrations in mosees and rain water (*a*) or in soil (*b*) (tab. 2). The values of quotients of beryllium concentrations in mosses referred

Table 2

Percentage of meteorological precipitations and soil in the loadings of some moss species with beryllium (in µg/g of ashes)

Udział opadów meteorologicznych oraz gleby w obciążeniu niektórych gatunków mchów berylem (w µg/g popiołu)

Sampling site		*Polytrichum commune*	*Polytrichum juniperinum*	*Hypnum cupressiforme*	*Hylocomium splendens*
Katowice	a*	2.2	1.2	2.0	0.38
	b**	4.5	4.0	4.0	0.90
Chorzów	a	1.3	2.0	2.5	1.4
	b	2.4	4.9	6.9	2.99
Łaziska	a	2.8	1.9	1.3	—
	b	4.4	4.7	3.5	—
Szczyrk	a	1.3	2.4	1.2	—
	b	2.4	5.3	3.2	—
Wisła	a	0.79	0.8	2.2	1.3
	b	2.4	2.05	5.2	1.6
Wapienica	a	0.68	—	2.1	2.1
	b	4.24	—	1.3	1.4

* a — meteorological precipitations,
** b — soil.

to soil were higher than those referred to rain, while those referred to rain were higher under conditions of industrial pollution of the atmosphere. The detailed observations of the species examined have shown that the average cumulation coefficient equals 20–65.

The usefulness of mosses as bioindicators is also confirmed by the histograms presented in figs. 1 and 2, where the average beryllium contents in mosses within industrial and recreational areas have been marked for comparative reasons.

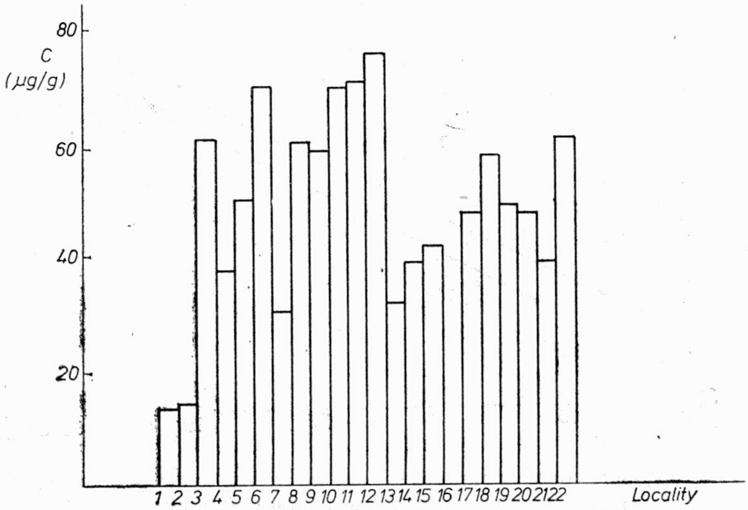

Fig. 1. Comparison of beryllium concentrations (*C*) in mosses sampled in some localities of industrial areas

Rys. 1. Porównanie zawartości berylu (*C*) w mchach pobranych w niektórych miejscowościach na terenach przemysłowych

1 — Starganiec, 2 — Panewniki, 3 — Blachownia, *4* — Mikołów, *5* — Sosnowiec, *6* — Łaziska, *7* — Paniowy, *8* — Katowice, *9* — Zabrze, *10* — Gliwice, *11* — Ruda Śląska, *12* — Bytom, *13* — Siewierz, *14* — Wojkowice, *15* — Łagisza, *16* — Sarnów, *17* — Paprocany, *18* — Rybnik, *19* — Leszczyny, *20* — Knurów, *21* — Jastrzębie, *22* — Chorzów

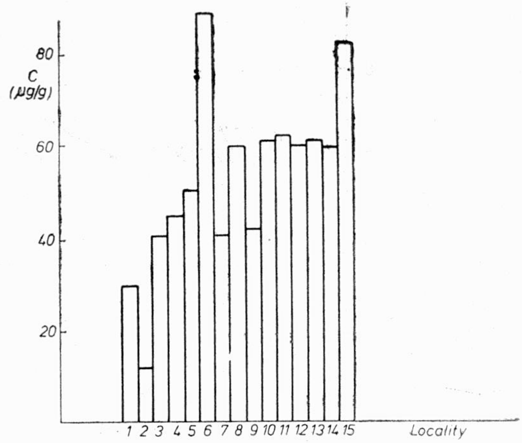

Fig. 2. Comparison of beryllium concentrations (*C* in mosses sampled in some localities of recreationa areas

Rys. 2 . Porównanie zawartości berylu (*C*) w mchach pobranych w niektórych miejscowościach na terenach rekreacyjnych

1 — Wapiennica, 2 — Istebna, 3 — Jeleśnia, *4* — Jaszowiec, *5* — Wisła Oaza, *6* — Szczyrk, *7* — Wisła Malinka, *8* — Równica, *9* — Wapiennica, *10* — Czaniec, *11* — Tresna, *12* — Porąbka, *13* — Brenna, *14* — Goczałkowice, *15* — Korbielów

The average concentration of beryllium in mosses depends on its concentration in soil (fig. 3), amounts of dusts precipitated (fig. 4), beryllium concentration in meteorological precipitation (fig. 5), and annual sum of meteorological precipitation rates (fig. 6). The above-mentioned parameters are strongly correlated. The respective correlation coefficients r range within 0.7–0.8, except for the dependence of beryllium content in mosses on the sums of annual meteorological precipitations on the industrialized areas whe-

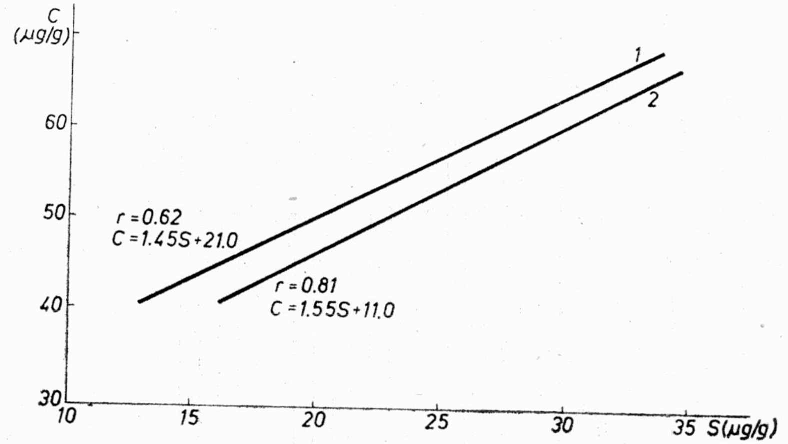

Fig. 3. Changes of beryllium concentrations (C) in mosses growing on recreational (1) and industrial (2) areas depending on beryllium concentration (S) in soil

Rys. 3. Zmiana zawartości berylu (C) w mchach na terenach rekreacyjnych (1) i przemysłowych (2) w zależności od zawartości berylu (S) w glebie

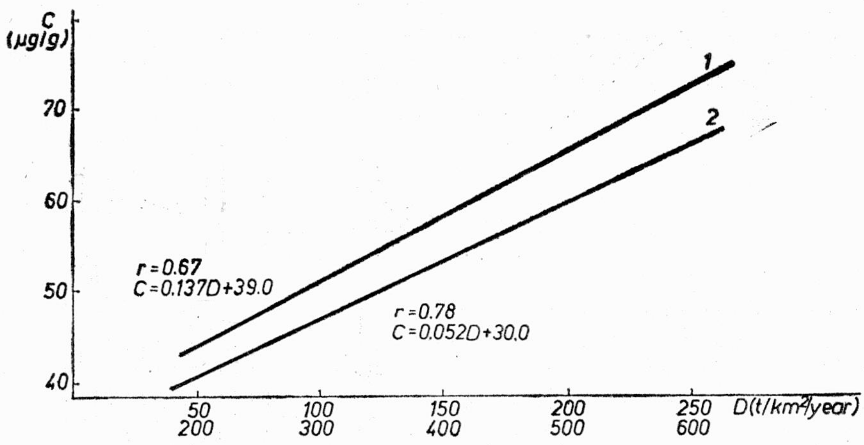

Fig. 4. Changes of beryllium concentrations (C) in mosses growing on recreational (1) and industrial (2) areas depending on amounts of dust precipitations (D)

Rys. 4. Zmianaz awartości berylu (C) w mchach na terenach rekreacyjnych (1) i przemysłowych (2) w zależności od ilości opadów pyłu (D)

re $r = 0.29$. All the dependences are described by the regression equations of the type $y = ax+b$ given in tab. 3. Free terms are interpreted as the minimal quantity of beryllium in a sample, where the change in its concentration is decided by the remaining parameters, e. g. from the comparison of figs. 3, 4, and 5 it follows that soil did not contain this element at all, however, samples of moss will contain beryllium, since free term in

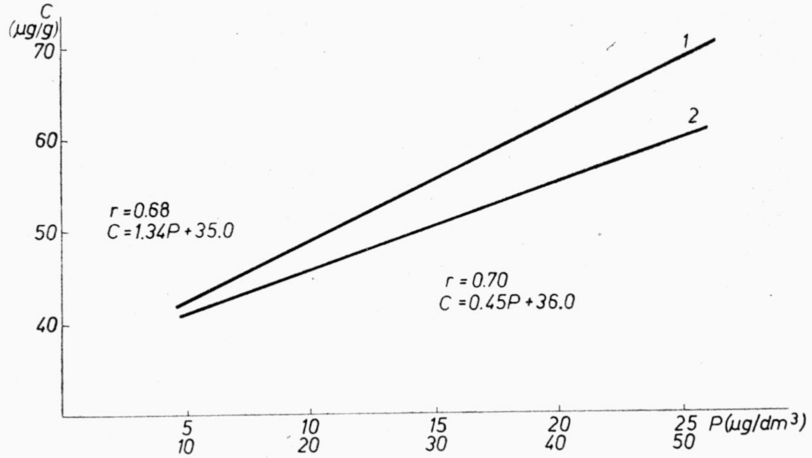

Fig. 5. Changes of beryllium concentrations (C) in mosses growing on recreational (*1*) and industrial (*2*) areas depending on beryllium content in atmospheric precipitations (*P*)

Rys. 5. Zmiana zawartości berylu (C) w mchach na terenach rekreacyjnych (*1*) i przemysłowych (*2*) w zależności od zawartości berylu w opadach atmosferycznych (*P*)

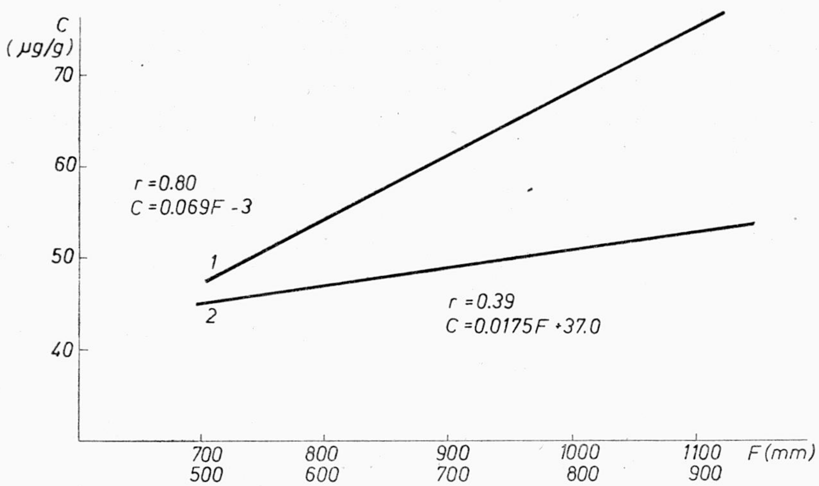

Fig. 6. Changes of beryllium concentrations (C) in mosses growing on recreational (*1*) and industrial (*2*) areas depending on amount of meteorological precipitations (F)

Rys. 6. Zmiana zawartości berylu (C) w mchach na terenach rekreacyjnych (*1*) i przemysłowych (*2*) w zależności od ilości opadów meteorologicznych (F)

Table 3

The influence of the selected factors on the beryllium content (C) in mosses
Wpływ wybranych czynników na zawartość berylu (C) w mchach

Parameter	Equation of regression	Coefficient of correlation r	Standard deviation
Beryllium content S in soil	$C_a^* = 1.45S+21.0$	0.62	3.4
$\mu g/g$	$C_b^{**} = 1.55S+11.0$	0.81	3.3
Amount of dust precipitations D	$C_a = 0.137D+39.0$	0.67	3.6
$t/km^2 \cdot yr$	$C_b = 0.52D+30.0$	0.78	3.9
Beryllium content P in atmospheric precipitations	$C_a = 1.34P+35.0$	0.68	3.7
$\mu g/dm^3$	$C_b = 0.45P+36.0$	0.70	3.9
Annual amount of meteorological precipitations F	$C_a = 0.069F-3$	0.80	3.4
mm	$C_b = 0.017F+37$	0.29	3.7

*a — recreational areas,
**b — intustrial areas.

the equation of regression, expressing the dependence on the amount of dust or on the beryllium content in meteorological precipitations is greater than the free term for soil.

Physiological constitution of the mosses examined prefers the influence of the two factors discussed. It should be added that the influence of beryllium content in soil takes place via secondary dusting of soil.

The effect of sums of annual meteorological prepitation rates on beryllium content is not univocal. The increment in beryllium content would be caused only by the annual sum of meteorological precipitations of order of 400 mm, and it is known that in Silesian Beskid it is, as a rule, much higher. On the industrialized areas the changes in beryllium concentration depending on the annual sum of meteorological precipitations are characterized by a great dispersion of the results and a small — about 5 $\mu g/g$ — increment in beryllium content falling to the difference of meteorological precipitations amounting to 400 mm. This fact is confirmed by a relatively low value of the correlation coefficient $r = 0.29$.

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BIOINDYKACJA BERYLU W POWIETRZU ATMOSFERYCZNYM Z WYKORZYSTANIEM MCHÓW

W przeciwieństwie do rekreacyjnych tereny przemysłowe, zwłaszcza te w zasięgu imisji pyłów i gazów z elektrowni, charakteryzuje względnie duże skażenie powietrza atmosferycznego berylem. Odzwierciedla się to w biokumulacji berylu w mchach *Hypnum cupressiforme*, *Hylocomium splendens*, *Polytrichum juniperinum* i *Polytrichum commune*. Spełniają one kryteria stawiane bioindykatorom skażeń chemicznych. Rozpatrywane mchy różnią się zawartością berylu w popiele. Zawartość ta zależy od wielkości opadu pyłów, stężenia berylu w opadach meteorologicznych, sumy rocznych opadów meteorologicznych i od stężenia berylu w glebie.

BIOINDIKATION VON BERYLLIUM IN DER LUFT DURCH MOOSE

Im Gegensatz zum Erholungsgelände, sind Industrieflächen auf enorme Staub- und Gasimissionen aus Kraftwerken ausgesetzt. Sie charakterisieren sich u.a. durch hohe Kontamination der Luft durch Beryllium. Das spiegelt sich wider in der Anhäufung des Berylliums in den folgenden Moosarten: *Hypnum cupressiforme*, *Hylocomium splendens*, *Polytrichum juniperinum* und *Polytrichum commune*, die den Bioindikator-Kriterien durch chemische Kontaminanten voll entsprechen. Die Gehalte von Beryllium im Glührückstand der angeführten Moosarten differierten wesentlich voneinander. Diese Gehalte hängen von der Staubmenge, der Konzentration des Berylliums im Niederschlag, vom Jahresniederschlag und von der Konzentration des Berylliums im Boden ab.

БИОИНДИКАЦИЯ БЕРИЛЛИЯ В АТМОСФЕРНОМ ВОЗДУХЕ

Промышленные территории, в отличие от рекреационных территорий, в частности те, которые находятся в пределах имиссии пыли и газов с электростанций, характеризуются сравнительно большим загрязнением атмосферного воздуха бериллием. Это отображается в биокумуляции бериллия в мхах *Hypnum cupressiforme*, *Hylocomium splendens*, *Polytrichum juniperinum* и *Polytrichum commune*. Они удовлетворяют критериям, предьявляемым к биоиндикаторам химических заражений. Рассматриваемые мхи отличаются по содержанию бериллия в золе. Это содержание зависит от величины выпадания пыли, концентрации бериллия в метеорологических осадках, суммы годичных метеорологических осадков и от концентрации бериллия в почве.