E18-2005-113

G. Ganbold*, Sh. Gerbish*, S. F. Gundorina,
M. V. Frontasyeva, T. M. Ostrovnaya,
S. S. Pavlov, Ts. Tsendeekhuu*

ATMOSPHERIC DEPOSITION OF TRACE ELEMENTS AROUND ULAN-BATOR CITY STUDIED BY MOSS AND LICHEN BIOMONITORING TECHNIQUE AND INAA

* National University of Mongolia, Ulan-Bator, Mongolia

Ганболд Г. и др. E18-2005-113

Изучение атмосферных выпадений некоторых элементов в окрестностях Улан-Батора с использованием биомониторов (мхов, лишайников) и ИНАА

Впервые для определения загрязнения воздуха в городе Улан-Батор — столице Монголии были использованы биомониторы (мхи и лишайники). Инструментальный нейтронно-активационный анализ (ИНАА) на ИБР-2 позволил определить концентрации 35 элементов в биомониторах. Методом ИНАА с использованием тепловых, резонансных нейтронов были проанализированы образцы мхов, лишайников, собранных со склонов горы, находящейся на расстоянии 10–15 км к югу от Улан-Батора. Для изучения атмосферных выпадений были использованы мхи *Rhytidium rugosum*, *Thuidium abietinum*, *Entodon concinnus* и лишайники *Cladonia stellaris*, *Parmelia separata*. В результате изучения данных образцов показано, что выбранные типы мха могут быть использованы в качестве биомониторов атмосферных выпадений в окрестностях города Улан-Батор. Полученные результаты сравниваются с данными атмосферных выпадений в некоторых европейских государствах.

Работа выполнена в Лаборатории нейтронной физики им. И. М. Франка ОИЯИ и Центре ядерных исследований Монгольского государственного университета.

Сообщение Объединенного института ядерных исследований. Дубна, 2005

Ganbold G. et al. E18-2005-113

Atmospheric Deposition of Trace Elements Around Ulan-Bator City Studied by Moss and Lichen Biomonitoring Technique and INAA

For the first time the moss and lichen biomonitoring technique has been applied to air pollution in Mongolia (Ulan-Bator, the capital city). INAA at the IBR-2 reactor has made it possible to determine the content of 35 elements in moss and lichen biomonitors. Samples collected at sites located 10–15 km from the center of Ulan-Bator were analyzed by Instrumental Neutron Activation Analysis (INAA) using epithermal neutrons. The mosses (*Rhytidium rugosum*, *Thuidium abietinum*, *Entodon concinnus*) and lichens (*Cladonia stellaris*, *Parmelia separata*) were used to study the atmospheric deposition of trace elements. It was shown that the suggested types of mosses could be used as suitable biomonitors to estimate the concentration levels of heavy metals and trace elements in Ulan-Bator atmospheric deposition. The results are compared to the data of atmospheric deposition of some European countries.

The investigation has been performed at the Frank Laboratory of Neutron Physics, JINR, and Nuclear Research Center of National University of Mongolia.

Communication of the Joint Institute for Nuclear Research. Dubna, 2005

INTRODUCTION

Ongoing concern about atmospheric pollutants underlies the efforts to establish a control program in many countries. In practice, controlling (anthropogenic) air pollutants is a very complex problem: sources and emissions have to be identified, analytical methods have to be evaluated, risks have to be assessed, critical emissions have to be controlled, and economical aspects have to be integrated. Many countries in the world determine the levels of trace elements in the atmosphere by using suitable biomonitors such as lichens and mosses [1–4]. Biomonitoring is an important tool for assessing the atmospheric pollution and in monitoring the dynamic behavior of environmental changes.

This study is the first attempt to evaluate levels of atmospheric deposition of heavy metals and some trace elements near Ulan-Bator, a city with a 1-million population, using specific types of lichen and moss biomonitors growing in the arid climate of Mongolia.

1. EXPERIMENTAL PROCEDURE

The methods used in this study are based on the Scandinavian recommendations [1] adapted to the local environmental conditions as described below. INAA at FLNP, JINR, is widely used for air-pollution study in Central Russia, Eastern Europe, and Balkans [5–8].

1.1. The Study Area. Ulan-Bator is the only industrial and cultural center in Mongolia, with a population of over one million. The city is located in the valley of Tool river, and is bordered by massive mountains south (Bogd Khan), east (Bayan Zurkh), north (Chingeltei) and west (Songino Khairkhan). Main sources of air pollution are:

— three power plants using brown coal as a fuel during the year;

— around 100 local heating systems also using brown coal in winter;

— over 90 thousand the yurtas and houses heated by coal during winter (6 months);

— vehicle combustion exhausts (70 000 cars, 3 500 taxis and 2 500 buses).

1.2. Sampling, Collection and Preparation of Samples. The sampling procedure was similar to that used in European project «Atmospheric heavy metals deposition in Northern Europe 1990, 1995, 2000» [1]. The name, date and some geographical data and sampling points are shown as red crosses in physical map of Mongolia (Fig. 1) and given in Table 1. Two samples of lichen

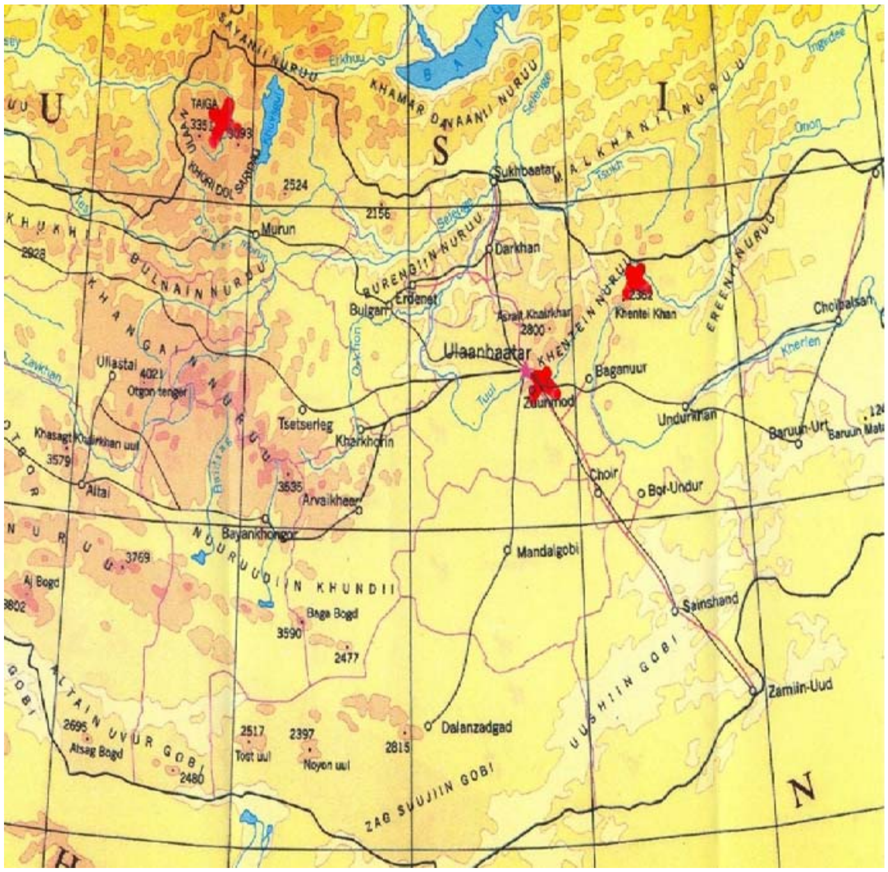

Fig. 1. Physical map of Mongolia. The sample-collection places are shown by red crosses

(*Cladonia stellaris*) were collected from the north site of Mongolia: Ulaan Taiga of Ulaan Uul somon (Khubsugul aimak) on 2001 and 2002. These are located 900 km to the north-west of Ulan-Bator. Another sample was collected from Burkhan Khaldun Uul (Khentei aimak, Khan Khentei mountain protected area) located 260 km to the north-east of Ulan-Bator in 2001. All of these samples were used as reference background or clean samples.

Table 1. Name of biomonitors, sampling places, date and some geographical data

No.	Type of biomonitors	Sampling place	Sampling date	Altitude, m	Latitude by GPS	Longitude by GPS
1.	Lichen, *Cladonia stellaris*	Khubsugul, Ulaan Uul, Ulaan Taiga	July 05, 2001	2200	45°51′	97°98′
2	Lichen, *Cladonia stellaris*	Khubsugul, Ulaan Uul, Ulaan Taiga	July 07, 2002	2412	45°51′	89°98′
3	Lichen, *Cladonia stellaris*	Khentei, Umundelger, Burkhan Khaldun Uul	August 20, 2001	1741	48°44′	109°02′
4	Lichen, *Cladonia stellaris*	Ulan-Bator, Bogd Khan Uul, Bogini Am	May 26, 2002	1610	47°51′	106°53′
5	Lichen, *Parmelia separata*	Ulan-Bator, Bogd Khan Uul, Zaisani Am	May 26, 2002	1610	47°51′	106°56′
6	Moss, *Rhytidium rugosum*	Ulan-Bator, Bogd Khan Uul, Zaisani Am	May 26, 2002	1610	47°51′	106°53′
7	Moss, *Thuidium abietinum*	Ulan-Bator, Bogd Khan Uul, Bogini Am	May 26, 2002	1610	47°51′	106°53′
8	Moss, *Entodon concinnus*	Ulan-Bator, Bogd Khan Uul, Zaisani Am	May 26, 2002	1610	47°51′	106°53′

Two species of lichens [*Cladonia stellaris* (Fig. 2) and *Parmelia separata* (Fig. 3)] and three species of mosses [*Rhytidium rugosum* (Fig. 4), *Thuidium abietinum* (Fig. 5) and *Entodon concinnus* (Fig. 6)] were collected during the May of 2002 from 6 points in northern Bogd Khan Uul (protected area) in a 40 × 40 m area, located 10–15 km from the center of Ulan-Bator. Sampling and sample handling were performed using polyethylene gloves, and samples were stored in paper bags.

Fig. 2. Lichen *Cladonia stellaris* collected from Burkhan Khaldun Uul (Khentei aimak, Umundelger somon), 2001

Fig. 3. Lichen *Parmelia separata* collected from Bogd Khan Uul, 2002

Fig. 4. Moss *Rhytidium rugosum* collected from Bogd Khan Uul, 2002

Fig. 5. Moss *Thuidium abietinum* collected from Bogd Khan Uul, 2002

The lichen and moss samples were cleaned from all dead parts and attached litter, and only the green and green-brown shoots were analyzed, after 24 hours of drying at 40° C. Samples were not subjected to washing. For long-term irradiation using epithermal neutrons, lichen and moss samples of about 300 mg were packed in aluminum cups. For short-term irradiation (conventional NAA) samples of about 300 mg were heat-sealed in polyethylene foil bags.

1.3. Analysis (Instrumental Neutron Activation Analysis). Neutron activation analysis was performed at the Frank Laboratory of Neutron Physics, JINR, Dubna. Most elements were determined by ENAA with detection limits within the range of 0.01–10 g/g. The samples were irradiated in channels of the fast pulsed reactor IBR-2, the flux parameters of neutron at irradiation channels: the thermal neutron flux density of 1.1E + 12 $n/cm^2 \cdot s$ and fast neutron density of 1.4E + 12 $n/cm^2 \cdot s$ [4–6]. For the neutron flux density measurement, gold foil was used [6]. Two kinds of analyses was performed: long irradiation (for 100 h) in channel (Ch1) was used to determine elements associated with long-lived radio-nuclides (As, Cd, Ba, Br, Ce, Cs, Eu, Fe, Ni, La, Rb, Sb, Sc, Se, Sm, Th, U, Zn) and short irradiation (for 20 min) in channel (Ch2) was used for short-lived radio-nuclides (Al, Ca, Cl, I, K, Na, Mg, Mn, V, Cu).

Gamma-ray spectra were recorded 4–5 times using gamma spectrometer with HP Ge detectors. Cooling times of 5 and 10 min are chosen after decay periods following the short irradiation, and 5, 13, and 20 days following the long irradiation. The elements were determined by INAA shown in Tables 2–3. The lichen and moss, which were collected from Bogd Khan Uul, are presented in Figs. 2–6. The results of INAA of lichen, which were collected from Khubsugul (Ulaan Uul), are shown in Table 4. The comparison results of lichen samples Nos. 1 and 2, which were collected from Khubsugul (Ulaan Uul), are shown in Table 4 more reliably.

2. DISCUSSION AND CONCLUSIONS

• We concluded that lichens (*Cladonia stellaris* and *Parmelia separata*) and mosses (*Rhytidium rugosum*, *Thuidium abietinum* and *Entodon concinnus*) shown in Table 1 and collected from Bogd Khan Uul are more suitable and useful biological indicators for air-pollution control of the capital city of Ulan-Bator, Mongolia.

• The Nuclear Analytical (INAA) Technique has a sensitivity and an accuracy for the monitoring measurement of heavy metals and trace elements better than biological indicators. Results are shown in Tables 2 and 3.

• From Table 4, the result's reproducibility of INAA for lichen *Cladonia stellaris* from the clean area of Ulaan Taiga, Khubsugul, 900 km from Ulan-Bator collected in 2001 and 2002 is quite acceptable. It can be seen that the

Fig. 6. Moss *Entodon concinnus* collected from Bogd Khan Uul, 2002

ratio of results Nos. 1 and 2 has the value around 1 and the difference of values 9.46 %.

• From Table 2, the results of INAA lichen samples collected from clean area of Ulaan Taiga, Khubsugul aimak, (Nos. 1 and 2, mean data) and Burkhan Khaldun Uul, Khentei aimak, (No. 3) 900 and 260 km from Ulan-Bator respectively, and Bogd Khan Uul located 10–15 km to the south of the centre of Ulan-Bator (Nos. 4 and 5), and their mean data. Table 5, a shows the ratio of mean contents of elements in lichen samples collected from clean areas and polluted areas. From these data we concluded that ration element contents are: Na, Mg — 5.5; iron group Sc, Cr, Ti, V, Mn, Fe, Co and Ni — from 3.1 to 6.8; toxic elements such as Se — 1.6 and As — 6.1; Ca — 50; U — 16 and Br — 10.

• In Table 5, b, the ratios of mean content elements in lichen samples collected from clean areas (Khubsugul, Ulaan Taiga) and Khentei, Burkhan Khaldun Uul, are shown. From these data, we can conclude that ratios of element contents such as Na — 3.1; Mg — 1.5; iron group Sc, Cr, Ti, V, Mn, Fe, Co and Ni are from 1.4 to 2.6; toxic elements such as Se, Hg — 0.3 — 0.5 and As — 1.4; Ca — 3.8; Th, U — 1.9 and Br — 2.1. It means that Burkhan Khaldun Uul, Khentei aimak, has the influence of air pollution of Ulan-Bator city.

• The ratio of content elements in polluted moss and lichen are shown in Table 6. From these data we can conclude that moss is a more effective indicator than lichen.

• Comparison results are shown in Table 7 and the polluted level of Ulan-Bator aerosols is the same as in some European countries such as Serbia, Bulgaria and Poland.

Table 2. Concentration of elements (mg/kg; $\Delta X, \%$) in lichen samples

Element	Mean data Khubsugul, Ulaan Taiga	Khentei, Burkhan Khaldun Uul (No. 3)	Bogd Khan Uul, Bogini Am (No. 4)	Bogd Khan Uul, Zaisani Am (No. 5)	Mean data of lichens from Bogd Khan Uul
Na	196.5 (10)	612 (10)	1140 (10)	1220 (10)	1180 (10)
Mg	466.5 (29)	697 (29)	1740 (29)	3220 (29)	2480(29)
Al	1251 (20)	1210 (20)	2390 (20)	8780 (20)	5585 (20)
Cl	1.69 (26)	4.18 (26)	9.66 (26)	6.26 (26)	7.96 (26)
K	2103 (23)	1930 (23)	2250 (23)	5280 (23)	3765 (23)
Sc	0.238 (13)	0.519 (13)	0.616 (13)	1.98 (13)	1.298 (13)
Ca	78.2 (33)	295 (33)	827 (33)	6660 (33)	3743 (33)
Cr	1.3 (23)	3.5 (23)	4.2 (23)	9.7 (23)	7.0 (23)
Ti	50.0 (43)	75.8 (43)	99 (43)	551 (43)	325 (43)
V	3.68 (20)	ND	ND	14.2 (20)	14.2 (20)
Mn	25.7 (6)	66.4 (6)	176 (6)	130 (6)	153 (6)
Fe	519 (5)	1220 (5)	2190 (5)	4940 (5)	3565 (5)
Co	0.28 (12)	0.58 (12)	0.79 (12)	2.21 (12)	1.5 (12)
Ni	0.85 (26)	1.20 (26)	2.23 (26)	3.13 (26)	2.68 (26)
Zn	12.9 (5)	19.4 (5)	31.8 (5)	30.1 (5)	30.9 (5)
Se	0.11 (25)	0.04 (25)	0.05 (25)	0.30 (25)	0.17 (25)
As	0.35 (6)	0.49 (6)	0.59 (6)	3.70 (6)	2.14 (6)
Br	0.55 (25)	1.16 (25)	2.21 (25)	8.44 (25)	5.3 (25)
Sr	5.96 (14)	26.3 (7)	37.0 (7)	64.6 (7)	50.8 (7)
Rb	5.74 (9)	4.88 (9)	5.33 (9)	10.8 (9)	8.06 (9)
Zr	1.69 (49)	4.47 (24)	7.15 (15)	22.8 (15)	14.97 (15)
Nb	0.16 (50)	0.35 (29)	0.52 (24)	1.94 (24)	1.23 (24)
Sb	0.048 (17)	0.063 (17)	0.103 (14)	0.301 (14)	0.202 (14)
Ba	8.45 (12)	32.1 (9)	41.8 (9)	54.2 (9)	48.0 (9)
Cs	0.45 (13)	0.26 (13)	0.33 (13)	1.04 (13)	0.68 (13)
Ta	0.016 (25)	0.033 (25)	0.036 (25)	0.110 (25)	0.073 (25)
La	0.69 (7)	1.21 (7)	1.32 (7)	9.20 (7)	5.26 (7)
Ce	1.2 (15)	2.8 (13)	4.0 (12)	23.6 (12)	13.8 (12)
Nd	ND	1.50 (52)	ND	6.96 (29)	6.96 (29)
Eu	ND	ND	0.071 (33)	0.393 (30)	0.232 (32)
Sm	0.13 (7)	0.217 (7)	0.289 (7)	1.81 (7)	1.05 (7)
Tb	0.014 (34)	0.170 (34)	0.024 (34)	0.172 (34)	0.098 (34)
Dy	0.075 (43)	0.126 (42)	3.89 (38)	1.06 (38)	2.47 (38)
Tm	ND	0.022 (19)	0.041 (20)	0.117 (11)	0.079 (15)
Hf	0.064 (12)	0.125 (9)	0.178 (9)	0.523 (9)	0.35 (9)
W	0.51 (11)	1.32 (11)	0.81 (11)	5.16 (11)	2.98 (11)
Au	0.002 (6)	0.003 (7)	0.022 (6)	0.004 (6)	0.013 (4)
Hg	0.006 (40)	0.003 (33)	0.027 (36)	0.014 (36)	0.020 (36)
Th	0.20 (10)	0.32 (10)	0.44 (10)	2.55 (10)	1.49 (10)
U	0.13 (15)	0.25 (15)	0.68 (14)	3.45 (14)	2.07 (14)

Note: ND — nondetected.

Table 3. Concentration of elements (mg/kg; $\Delta X, \%$) in moss samples

Element	Bogd Khan Uul, Zaisani Am (No. 6)	Bogd Khan Uul, Bogini Am (No. 7)	Bogd Khan Uul, Zaisani Am (No. 8)	Mean data of mosses	Range of content in mosses
Na	1590 (10)	1380 (10)	1120 (10)	1363 (10)	1120–1590
Mg	5460 (28)	5420 (28)	4970 (28)	5283 (28)	4970–5460
Al	9430 (20)	10800 (20)	7120 (20)	9117 (20)	7120–10800
Cl	6.23 (26)	5.07 (26)	7.84 (26)	6.38 (26)	5.07–7.84
K	1040 (23)	1130 (23)	1180 (23)	1117 (23)	1040–1180
Sc	2.13 (13)	2.01 (13)	1.42 (13)	1.85 (13)	1.42–2.13
Ca	1830 (33)	2060 (33)	1330 (33)	1740 (33)	1330–2060
Cr	12.70 (23)	8.10 (23)	8.76 (23)	9.85 (23)	78.1–12.7
Ti	458 (42)	746 (42)	493 (42)	566 (42)	458–746
V	13.4 (20)	18.0 (20)	10.5 (20)	14.0 (20)	10.5–18.0
Mn	232 (6)	289 (6)	256 (6)	259 (6)	232–289
Fe	6400 (3)	5810 (3)	4370 (3)	5527 (3)	4370–6400
Co	3.18 (10)	3.01 (10)	2.12 (10)	2.77 (10)	2.12–3.18
Ni	3.98 (21)	3.82 (21)	3.48 (21)	3.76 (21)	3.48–3.98
Zn	36.3 (5)	38.4 (5)	33.2 (5)	36.0 (5)	33.32–38.4
Cu	ND	ND	66.0 (28)	66.0 (28)	10–66
Se	0.18 (22)	0.19 (22)	0.16 (22)	0.17 (22)	0.16–0.19
As	3.68 (6)	3.66 (6)	2.30 (6)	3.21 (6)	2.30–3.68
Br	2.55 (25)	3.75 (25)	2.40 (25)	2.90 (25)	2.40–3.75
Sr	112.0 (6)	98 (6)	80.3 (6)	97 (6)	80–112
Rb	13.4 (9)	13.1 (9)	10.0 (9)	12.2 (9)	10.0–13.4
Zr	28.6 (10)	23.5 (10)	18.5 (10)	23.5 (10)	18.5–28.6
Nb	2.11 (22)	1.94 (22)	1.51 (22)	1.85 (22)	1.51–2.11
Sb	0.336 (13)	0.398 (13)	0.273 (13)	0.336 (13)	0.273–0.398
Ba	135 (8)	126 (8)	117 (8)	126 (8)	117–135
Cs	1.27 (13)	1.20 (13)	0.89 (13)	1.12 (13)	0.89–1.27
Ta	0.158 (25)	0.137 (25)	0.120 (25)	0.138 (25)	0.120–0.158
La	6.14 (7)	6.19 (7)	4.14 (7)	5.49 (7)	4.14–6.19
Ce	19.5 (12)	18.2 (12)	13.0 (12)	16.9 (12)	13.0–19.5
Nd	5.78 (32)	5.07 (32)	2.56 (32)	4.47 (32)	2.56–5.78
Eu	0.20 (28)	0.20 (28)	0.18 (28)	0.19 (28)	0.18–0.20
Sm	1.07 (7)	1.20 (7)	0.85 (7)	1.04 (7)	0.85–1.20
Tb	0.124 (33)	0.120 (33)	0.080 (33)	0.108 (33)	0.080–0.124
Dy	0.84 (39)	0.79 (39)	0.75 (39)	0.79 (39)	0.75–0.84
Tm	0.136 (7)	0.123 (8)	0.084 (9)	0.114 (9)	0.084–0.136
Hf	0.71 (8)	0.61 (8)	0.48 (9)	0.60 (8)	0.48–0.71
W	3.99 (11)	3.69 (11)	1.95 (11)	3.20 (11)	1.95–3.99
Au	0.008 (8)	0.008 (8)	0.007 (8)	0.008 (8)	0.007–0.008
Hg	0.072 (32)	0.060 (31)	0.052 (32)	0.061 (32)	0.052–0.072
Th	2.71 (10)	2.50 (10)	1.73 (10)	2.55 (10)	1.73–2.71
U	4.27 (14)	3.99 (14)	2.34 (14)	3.53 (14)	2.34–4.27

Table 4. Content of elements (mg/kg; $\Delta X, \%$); concentration ratio and mean content of elements in lichen sample Nos. 1 and 2, collected from Ulaan Taiga, Khubsugul

Element	Lichen sample No. 1	Lichen sample No. 2	Ratio of contents	Mean data of lichens Nos. 1 and 2
11 Na	196 (10)	197 (10)	0.99	196.5 (10)
12 Mg	471 (29)	462 (29)	1.02	466.5 (29)
13 Al	1530 (20)	972 (20)	1.57	1251 (20)
17 Cl	1.89 (26)	1.49 (26)	1.27	1.69 (26)
19 K	3610 (23)	2700 (23)	1.34	2103 (23)
20 Ca	90.1 (33)	66.3 (33)	1.36	78.2 (33)
21 Sc	0.231 (14)	0.245 (14)	0.94	0.238 (14)
22 Ti	47.4 (46)	52.7 (46)	0.90	50.05 (46)
23 V	2.69 (20)	4.67 (20)	0.57	3.68 (20)
24 Cr	1.42 (30)	1.27 (30)	1.12	1.34 (30)
25 Mn	25.8 (6)	25.7 (6)	1.00	25.7 (6)
26 Fe	522 (5)	516 (5)	1.01	519 (5)
27 Co	0.28 (14)	0.28 (14)	1.00	0.28 (14)
28 Ni	0.80 (26)	0.91 (26)	0.88	0.85 (26)
30 Zn	14.1 (5)	11.7 (5)	1.20	12.9 (5)
33 As	0.34 (6)	0.36 (6)	0.94	0.35 (6)
34 Se	0.13 (26)	0.09 (26)	1.44	0.11 (26)
35 Br	0.64 (25)	0.47 (25)	1.36	0.55 (25)
37 Rb	6.20 (9)	5.28 (9)	1.17	5.74 (9)
38 Sr	5.40 (14)	6.53 (14)	0.83	5.96 (14)
40 Zr	1.66 (52)	1.73 (52)	0.96	1.69 (52)
41 Nb	0.17 (50)	0.15 (50)	1.13	0.16 (50)
51 Sb	0.065 (15)	0.031 (15)	2.1	0.048 (15)
55 Cs	0.49 (13)	0.41 (13)	1.19	0.45 (13)
56 Ba	9.35 (12)	7.56 (12)	1.24	8.45 (12)
57 La	0.67 (7)	0.71 (7)	0.94	0.69 (7)
58 Ce	1.62 (14)	1.62 (14)	1.00	1.62 (14)
62 Sm	0.15 (7)	0.12 (7)	1.25	0.13 (7)
65 Tb	0.012 (34)	0.016 (34)	0.75	0.014 (34)
66 Dy	0.074 (44)	0.076 (44)	0.97	0.075 (44)
72 Hf	0.07 (12)	0.058 (12)	1.20	0.064 (12)
73 Ta	0.016 (25)	0.016 (25)	1.00	0.016 (25)
74 W	0.643 (11)	0.387 (11)	1.66	0.515 (11)
79 Au	0.002 (6)	0.003 (6)	0.67	0.0025 (6)
90 Th	0.193 (11)	0.212 (11)	0.91	0.202 (11)
92 U	0.133 (15)	0.127 (15)	1.11	0.13 (15)

Table 5, a. Ratio contents of elements (mg/kg; $\Delta X, \%$) in clean and polluted lichen samples

Element	Mean data (mg/kg) of lichens Nos. 1 and 2 from Ulaan Taiga, Khubsugul	Mean data (mg/kg) of lichens from Bogd Khan, Ulan-Bator	Ratio contents of elements in clean and polluted lichens
Na	196.5 (10)	1180 (10)	6.0
Mg	466.5 (29)	2480 (29)	5.3
Al	1251 (20)	5585 (20)	4.5
Cl	1.69 (26)	7.96 (26)	4.7
K	2103 (23)	3765 (23)	1.8
Sc	0.238 (14)	1.298 (14)	5.4
Ca	78.2 (33)	3743 (33)	47.8
Cr	1.34 (30)	7.0 (23)	5.2
Ti	50.0 (44)	325 (42)	6.5
V	3.68 (20)	14.2 (20)	3.8
Mn	25.75 (6)	153 (6)	5.9
Fe	519 (5)	3565 (4)	6.8
Co	0.28 (14)	1.5 (11)	5.3
Ni	0.85 (26)	2.68 (25)	3.1
Zn	12.9 (5)	30.95 (4)	2.4
Se	0.11 (25)	0.175 (23)	1.6
As	0.35 (6)	2.14 (6)	6.1
Br	0.55 (25)	5.3 (25)	9.6
Sr	5.96 (14)	50.8 (7)	8.5
Rb	5.74 (9)	8.06 (9)	1.4
Zr	1.69 (49)	14.97 (15)	8.8
Nb	0.16 (50)	1.23 (24)	7.7
Sb	0.048 (16)	0.202 (14)	4.2
Ba	8.45 (12)	48 (9)	5.7
Cs	0.45 (13)	0.68 (13)	1.5
Ta	0.016 (25)	0.073 (25)	4.5
La	0.69 (7)	5.26 (7)	7.6
Ce	1.62 (15)	13.8 (12)	8.5
Nd	ND	6.96 (29)	—
Eu	ND	0.232 (32)	—
Sm	0.13 (7)	1.05 (7)	8.1
Tb	0.014 (34)	0.098 (33)	7.0
Dy	0.075 (43)	2.47 (38)	32.9
Tm	ND	0.079 (15)	—
Hf	0.064 (12)	0.35 (9)	5.5
W	0.515 (11)	2.98 (11)	5.8
Au	0.0025 (6)	0.013 (4)	5.2
Hg	0.006 (40)	0.02 (36)	3.3
Th	0.202 (11)	1.49 (10)	7.4
U	0.13 (15)	2.07 (14)	15.9

Table 5, *b*. Concentration of elements (mg/kg; ΔX, %) in lichen samples

Element	Khubsugul, Ulaan Taiga (mean data)	Khentei, Burkhan Khaldun Uul (No. 3)	Ratio contents of elements in clean and polluted lichens
Na	196.5 (10)	612 (10)	3.1
Mg	466.5 (29)	697 (29)	1.5
Al	1251 (20)	1210 (20)	0.9
Cl	1.69 (26)	4.18 (26)	2.5
K	2103 (23)	1930 (23)	0.9
Sc	0.238 (14)	0.519 (13)	2.2
Ca	78.2 (33)	295 (33)	3.8
Cr	1.34 (30)	3.49 (29)	2.6
Ti	50.0 (44)	75.8 (44)	1.5
V	3.68 (20)	ND	—
Mn	25.75 (6)	66.4 (5)	2.6
Fe	519 (5)	1220 (5)	2.3
Co	0.28 (14)	0.58 (12)	2.1
Ni	0.85 (26)	1.20 (31)	1.4
Zn	12.9 (5)	19.4 (5)	1.5
Se	0.11 (25)	0.04 (28)	0.3
As	0.35 (6)	0.49 (6)	1.4
Br	0.55 (25)	1.16 (25)	2.1
Sr	5.96 (14)	26.3 (7)	4.3
Rb	5.74 (9)	4.88 (9)	0.8
Zr	1.69 (49)	4.47 (24)	2.6
Nb	0.16 (50)	0.35 (29)	2.2
Sb	0.048 (16)	0.063 (17)	1.3
Ba	8.45 (12)	32.1 (9)	0.4
Cs	0.45 (13)	0.26 (13)	0.6
Ta	0.016 (25)	0.033 (13)	2.0
La	0.69 (7)	1.21 (7)	1.7
Ce	1.62 (15)	2.82 (13)	1.7
Nd	ND	1.50 (52)	—
Sm	0.13 (7)	0.22 (7)	1.6
Tb	0.014 (34)	0.170 (34)	12.1
Dy	0.075 (43)	0.126 (42)	1.7
Tm	ND	0.022 (19)	—
Hf	0.064 (12)	0.125 (9)	1.9
W	0.515 (11)	1.32 (11)	2.6
Au	0.0025 (6)	0.003 (7)	1.5
Hg	0.006 (40)	0.003 (33)	0.5
Th	0.202 (11)	0.317 (10)	1.5
U	0.13 (15)	0.25 (15)	1.9

Table 6. Ratio contents of elements (mg/kg; ΔX %) in polluted lichen and moss samples

Element	Mean data of lichen samples from Bogd Khan Uul	Mean data of moss samples from Bogd Khan Uul	Ratio contents of elements in lichen and moss samples
Na	1180 (10)	1363 (10)	1.15
Mg	2480 (28)	5283 (28)	2.13
Al	5585 (20)	9117 (20)	1.63
Cl	7.96 (26)	6.38 (26)	0.80
K	3765 (23)	1117 (23)	0.3
Sc	1.298 (13)	1.85 (13)	1.4
Ca	3743 (33)	1740 (33)	0.46
Cr	7.0 (23)	9.85 (23)	1.4
Ti	325 (42)	566 (42)	1.7
V	14.2 (19)	13.97 (19)	1.0
Mn	153 (6)	259 (6)	1.7
Fe	3565 (4)	5527 (3)	1.5
Co	1.5 (11)	2.77 (11)	1.8
Ni	2.68 (25)	3.76 (21)	1.4
Zn	30.95 (4)	35.97 (5)	1.16
Cu	ND	66.0 (28)	—
Se	0.17 (23)	0.17 (22)	1.0
As	2.14 (6)	3.21 (6)	1.5
Br	5.3 (25)	2.9 (25)	0.5
Sr	50.8 (7)	97 (6)	1.9
Rb	8.06 (9)	12.17 (9)	1.5
Zr	14.97 (15)	23.5 (10)	1.57
Nb	1.23 (24)	1.85 (22)	1.5
Sb	0.202 (14)	0.336 (13)	1.7
Ba	48 (9)	126 (8)	2.6
Cs	0.68 (13)	1.12 (13)	1.6
Ta	0.073 (25)	0.138 (25)	1.9
La	5.26 (7)	5.49 (7)	1.0
Ce	13.8 (12)	16.9 (12)	1.2
Nd	6.96 (29)	4.47 (29)	0.6
Eu	0.232 (32)	0.19 (28)	0.8
Sm	1.05 (7)	1.04 (7)	1.0
Tb	0.098 (33)	0.108 (33)	1.1
Dy	2.47 (38)	0.79 (38)	0.3
Tm	0.079 (15)	0.114 (9)	1.4
Hf	0.35 (9)	0.60 (9)	1.7
W	2.98 (11)	3.20 (11)	1.1
Au	0.013 (4)	0.008 (8)	0.6
Hg	0.02 (36)	0.061 (33)	3.0
Th	1.49 (10)	2.55 (10)	1.7
U	2.07 (14)	3.53 (14)	1.7

Table 7. Elemental concentrations (mg/kg) in moss samples collected near Ulan-Bator, Mongolia, and data of some European countries for comparison

Element	Mongolia Ulan-Bator	($N = 8$)	Russia (South. Urals)	($N = 56$)	Serbia	($N = 92$)	Bosnia	($N = 23$)
	Median	Range	Median	Range	Median	Range	Median	Range
Na	1363	1120–1590	346	104–1304	694	178–2440	360	91–1100
Mg	5283	4970–5460	3096	1188–15400	2780	1100–8130	2670	1040–9520
Al	9117	7120–10800	2300	810–8877	6800	1280–22090	6270	2305–20740
Cl	6.38	5.07–7.84	250	55–1114	256	105–1030	344	156–715
K	1117	1040–1180	6954	3011–13260	5090	2710–11750	4820	1950–6820
Ca	1740	1330–2060	3972	1720–13800	7720	2890–18120	10310	5323–34330
Sc	1.578	1.42–2.13	0.53	0.10–1.78	1.31	0.27–4.13	0.47	0.13–1.37
Ti	565.7	458–746			71	11–297	57	14–222
V	13.97	10.5–18.0	7	2.0–28.8	11	2.85–39	11	2.89–34
Cr	9.85	8.1–12.7	11	1.5–194.3	6.51	1.14–22	5.09	0.94–19
Mn	259	231–289	285	59–1402	217	30–2340	503	38–1770
Fe	5527	4370–6400	1689	335–20730	3110	720–9230	1600	439–4750
Co	2.77	2.12–3.18	0.57	0.14–2.75	8.24	1.42–39	1.09	0.18–7
Ni	3.7	3.48–3.98	3.2	0.41–93.9	6.73	1.96–26	7.14	0.92–25
Cu	66		22	3.4–200	94	6.31–3140	22	10.0–67.0
Zn	35.97	33.2–38.4	58	15–304	44	14–415	25	10.0–57
As	3.21	2.30–3.68	1.57	0.37–9.68	3.35	0.46–61	1.12	0.31–3.7
Se	0.177	0.16–0.19	0.29	0.02—2.21	0.39	0.046–10	0.09	0.035–0.18
Br	2.9	2.40–3.75	4.3	0.09–25.40	5.75	1.83–18	4.31	1.99–8.1
Rb	12.17	10.0–13.4	10	2.8–38.6	13	3.0–47	9	3.0–19
Sr	96.67	80.3–112.0			22	6.8–95	14	5.8–32
Mo					0.85	0.12–23	0.97	0.26–3
Ag			0.09	0.01–0.47	0.078	0.012–1.5	0.052	0.015–0.076
Sb	0.336	0.27–0.40	0.5	0.08–3.46	0.52	0.13–7	0.25	0.068–1.5
Cs	1.12	0.89–1.27	0.21	0.03–0.61	0.76	0.11-18.2	0.39	0.079–2.5
Ba	126	117–135	43	6–129	39	13–130	41	8.0–90
La	5.49	4.14–6.19	1.3	0.37–12.58	4.66	1.09–13	3.11	0.82–8
Ce	16.9	13.0–19.5	2.7	0.53–18.10	9.2	1.84–28	3.31	0.87–12
Eu	0.194	0.18–0.20			0.08	0.02–0.48	0.17	0.019–0.48
Tb	0.122	0.08–0.12	0.024	0.004–0.171	0.11	0.02–0.36	0.13	0.041–0.31
Hf	0.6	0.48–0.71	0.21	0.02–1.78	0.78	0.15–2.6	1.06	0.29–3.8
Ta	0.138	0.12–0.16	0.029	0.004–0.108	0.11	0.024–0.29	0.13	0.04–0.36
W	3.21	1.95–3.99	0.23	0.05–1.27	1.34	0.19–3.3	0.21	0.03–0.52
Au	0.008	0.007–0.008	0.006	0.002–0.086	0.0041	0.00029–0.087	0.0057	0.0017 –0.017
Hg	0.061	0.052–0.072			0.55	0.056–2.7	0.53	0.047–4.9
Th	2.313	1.73–2.71	0.29	0.05–2.42	0.82	0.18–2.4	0.38	0.11–1.5
U	3.53	2.34–4.27	0.19	0.05–4.60	0.32	0.08–1.03	0.21	0.05–0.61

Note: N — number of analyzed samples

Table 7 (continued)

Element	Romania ($N = 70$) (Transilvania)		Bulgaria ($N = 103$) (West and South)		Poland ($N = 86$) (Copper Basin)		Norway ($N = 464$) Moss survey 2000	
	Median	Range	Median	Range	Median	Range	Median	Range
Na	902	192–4330	523	155–5573	152	74–302		
Mg	2850	480–6840	2026	748–12500	1694	800–6480	1543	645–3678
Al	5545	830–23000	3843	1111–46350	815	237–2590	350	97–10970
Cl	370	160–1300	161	59–1180	226	123–537		
K	7770	4770–19980	5764	3274–20490	5000	515–8708		
Ca	5770	1250–23500	7283	2266–19650	2230	1190–12800	3120	1379 –22512
Sc	0.94	0.21–6.13	0.65	0.2–6.4	0.15	0.03-0.63		
Ti							31	10–414
V	8.7	1.9–32	8.4	2.2–112.6	2.5	1.14–8.13	1.35	0.28–22.6
Cr	13.8	2.7–52	3.2	0.5–26.9	1.43	0.80–3.16	0.69	0.058–259
Mn	265	27–1470	251	32–986	222	70–896	333	28–5415
Fe	3290	815–21340	2314	692–14700	357	147–845	362	99–11216
Co	1.41	0.32–7.0	1.08	0.23–10.6	0.26	0.11–1.48	0.17	0.014–2.6
Ni	5.4	0.6–32	4.1	0.5–18.6	1.83	0.09-3.55	1.1	0.057–72.1
Cu	68	18–810			20	7.3–2040	32	1.7–52.7
Zn	135	39–2950	41	19–379	45	31–110	32	9.7–661
As	2.2	0.59–45.1	1	0.3–59.0	0.61	0.25–6.04	0.135	0.0023 –2.63
Se	0.36	0.08–5.01	0.24	0.01–1.18	0.33	0.22–0.77		
Br	8.6	2.03–20.9	3.6	1.1–11.6	1.38	0.89–2.85		
Rb	15	5.8–135	12	3.0–69	22.4	2.0–45.5	9.9	1.2–50.77
Sr	37.4	1.8–290	25	7–106	12.4	0.69–339	11.5	2–74.2
Mo	0.65	0.13–10	0.99	0.16–3.36	0.29	0.05–2.42	0.108	0.0087 –2.42
Ag	0.13	0.03–4.54			0.09	0.04–1.7	0.021	0.0017 –0.27
Sb	0.88	0.16–51	0.23	0.07–20.2	0.25	0.16–0.79	0.056	0.001–0.46
Cs	0.51	0.12–3.4	0.4	0.1–2.96	0.416	0.16–1.3	0.129	0.01–2.06
Ba	101	20–658	68	17–517	10.30	5.5–79.2	19.2	4.3–217
La	2.4	0.4–15.2	2.9	0.8–23.7	0.5	0.14–1.61	0.28	0.049–9
Ce	6.1	0.9–42.5			1.1	0.24–3.74	0.54	0.098–17.6
Eu							0.01	<0.0003 –0.24
Tb	0.07	0.01–0.42	0.068	0.016–0.610	0.01	0.003–0.09	0.005	<0.0001 –0.16
Hf	0.56	0.12–4.66	0.46	0.11–4.78	0.09	0.01–0.58	0.006	0.001–0.16
Ta	0.1	0.01–0.66	0.076	0.018–0.563	0.02	0.004–0.13	<0.0005	<0.0005 –0.14
W	1.02	0.12–8.74	0.193	0.03–1.39	0.19	0.02–0.67	0.04	0.002–0.89
Au	0.025	0.003–0.114	0.004	0.0009–0.0465	0.003	0.001–0.015		
Hg								
Th	0.81	0.21–4.16	0.56	0.11–4.53	0.13	0.08–0.45	0.054	<0.0002 –1.7
U	0.28	0.04–1.36	0.2	0.03–1.87	0.08	0.02–0.99	0.017	<0.0004 –0.37

Acknowledgements. We would like to thank DS Ts. Tsegmid and PhD O. Enkhtuya (Institute of Botanics of Academy of Sciences, Mongolia) for the identification of types of lichen and moss samples.

REFERENCES

1. *Ruhhling A., Steinnes E.* Atmospheric heavy metal deposition in Europe 1995–1996. Nordic Council of Ministers, NORD 1998:15, 1998.

2. *Steinnes E.* A critical evaluation of the use of naturally growing moss to monitor the deposition of atmospheric metals // Sci. Total Envir. 1995. V. 160/161. P. 24.

3. *Jeran Z., Jacimovic R.* Radionuclides and heavy metals in environment. Netherlands: Kluwer Academic Publishers. 2001. P. 171–178.

4. *Rahn K. A.* A graphical technique for distinguishing plant material and soil from atmospheric deposition in biomonitors. IAEA-TECDOC-1152, IAEA, June 2000.

5. *Ermakova E. V., Frontasyeva M. V., Steinnes E.* Air-pollution studies in Central Russia (Tula Region) using the moss biomonitoring technique, INAA and AAS // Journal of Radioanalytical and Nuclear Chemistry. 2004. V. 259, No. 1. P. 51–58.

6. *Frontasyeva M. V. et al.* Atmospheric deposition of heavy metals in northern Serbia and Bosnia-Herzegovina studied by the moss biomonitoring, neutron activation analysis and GIS technology // Journal of Radioanalytical and Nuclear Chemistry. 2004. V. 259, No. 1. P. 141–147.

7. *Culikov O. A. et al.* Atmospheric deposition of heavy metals around the lead and copper-zinc smelters in Baia Mare, Romania, studied by the moss biomonitoring technique, neutron activation analysis and flame absorption spectrometry // Journal of Radioanalytical and Nuclear Chemistry. 2002. V. 254, No. 1. P. 109–115.

8. *Grodzinska K. et al.* Trace element contamination in industrial regions of Poland studied by moss monitoring // Environmental Monitoring and Assessment. 2003. V. 87, No. 3. P. 255–270.

9. *Frontasyeva M. V. et al.* Heavy metal atmospheric deposition study in the South Ural Mountains // Journal of Radioanalytical and Nuclear Chemistry. 2004. V. 259, No. 1. P. 19–26.

Received on July 20, 2005.

Редактор *Н. С. Скокова*

Подписано в печать 07.10.2005.
Формат 60 × 90/16. Бумага офсетная. Печать офсетная.
Усл. печ. л. 1,0. Уч.-изд. л. 1,36. Тираж 270 экз. Заказ № 55056.

Издательский отдел Объединенного института ядерных исследований
141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6.
E-mail: publish@pds.jinr.ru
www.jinr.ru/publish/