VARIATIONS OF Rn-222 CONCENTRATION IN THE BRATISLAVA AIR

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INTRODUCTION

^{222}Rn is produced by alpha decay of ^{226}Ra in soil. A small fraction of totally produced ^{222}Rn escapes from soil particles into soil air. Then ^{222}Rn is transported predominantly by molecular diffusion into outdoor atmosphere. The radon concentration in the outdoor atmosphere is not stable. It varies irregularly depending on meteorological conditions. However, there were found out regular daily and seasonal variations of ^{222}Rn concentration in outdoor atmosphere. These variations were measured in numerous works and results are summarized f.e. in work of Gesell (1). A simple model described the annual variations of ^{222}Rn concentration was published by Minato (2). A mathematical analysis of daily course of ^{222}Rn concentration in outdoor atmosphere was realized by Garzon et al. (3).

Some results of our study of ^{222}Rn variations in outdoor atmosphere of Bratislava are shown in this report.

METHODS

The ^{222}Rn concentration in the outdoor atmosphere has been studied at our department since 1987. Up until the end of 1991 the method of measurement of radon concentration in the outdoor atmosphere was as follows. Radon was concentrated from the air volume of 10 *l* on an active carbon and after its transfer radon was measured by means of the scintillation chamber of Lucas-type (4). A sampling was realized every morning at 9 o'clock in the hight of 1,5 m above the ground surface. Since Februar of 1991, radon in the outdoor atmosphere has been monitored continueously by a large volume scintillation chamber which volume is 4,5 *l* (4).

RESULTS

We obtained about 80 000 data of ^{222}Rn concentration (February 1991 - August 1995) by continual monitoring of radon in the outdoor atmosphere of Bratislava. This large number of data with great variability have to be processed statistically to reveal some regularities. Table 1. gives the arithmetic means of ^{222}Rn concentrations averaged throughout the years 1991-1995.

Table 1. ^{222}Rn concentrations [Bq.m^{-3}] - years 1991 - 1995.

Hour	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
00.00 - 02.00	7,22	6,01	4,99	4,57	5,97	6,36	7,85	9,01	8,01	8,6	6,62	6,77	6,83
02.00 - 04.00	7,68	6,23	5,61	5,15	6,66	6,54	8,89	10,29	8,35	8,39	6,71	6,93	7,28
04.00 - 06.00	7,91	6,51	5,54	5,27	6,58	7,18	9,13	9,89	9,22	8,87	6,87	6,96	7,49
06.00 - 08.00	7,88	6,41	5,41	5,57	5,88	6,39	8,74	9,91	8,43	8,63	7,55	7,87	7,39
08.00 - 10.00	7,39	6,27	5,25	4,02	4,73	4,85	5,87	7,09	7,04	7,99	6,14	7,13	6,15
10.00 - 12.00	6,82	5,81	3,74	3,32	3,51	3,65	4,65	5,67	5,41	6,42	6,72	6,94	5,22
12.00 - 14.00	6,31	5,12	3,75	2,98	3,25	2,97	3,77	3,76	4,26	5,87	6,24	6,29	4,55
14.00 - 16.00	6,85	4,99	3,51	2,62	3,11	3,01	3,71	4,05	4,13	5,26	6,01	6,57	4,48
16.00 - 18.00	6,67	5,27	3,89	2,89	3,42	2,84	3,52	3,88	4,55	6,06	6,57	6,41	4,67
18.00 - 20.00	7,17	5,54	4,07	3,35	4,27	3,72	4,96	5,54	5,59	6,83	6,52	7,03	5,38
20.00 - 22.00	6,85	5,74	4,21	4,05	4,95	4,99	6,51	6,77	6,41	7,65	6,69	6,51	5,94
22.00 - 24.00	7,21	6,05	5,03	4,22	5,28	5,31	6,84	7,62	7,01	8,18	6,79	6,44	6,33
Mean	7,16	5,83	4,58	4,01	4,79	4,82	6,19	6,96	6,53	7,41	6,62	6,82	5,98

The results averaged in this way enable us to demonstrate the average daily courses of ^{222}Rn concentration for individual months and average annual courses for various time intervals.

The average daily course of ^{222}Rn concentration calculated on the basis of all measurements reaches a maximum between 4 and 6 a.m. and a minimum between 2 and 4 p.m. The ^{222}Rn concentration reaches its average daily value at 9: 30 a.m. and at 9 o'clock in the evening.The ratio of the maximum and minimum values in the average daily course of ^{222}Rn concentration amounts to 1.67. The daily variations of the ^{222}Rn cocentration are ascribed to variations of atmospheric stability and vertical mixing (5).

The average annual course of ^{222}Rn concentration calculated on the basis of continual measurements during the years 1991 - 95 reaches the maximum value in October and the minimum value in April. Further we can see in Table 1, that the average annual course of ^{222}Rn concentration calculated from all the data is in good agreement with the average annual course of ^{222}Rn concentration calculated on the basis of measurements made between 8 and 10 p.m.

Nearly five years lasting continual monitoring of the ^{222}Rn concentration in the outdoor atmosphere enables us to make an analysis of mean daily waves for different months of the year. According to Garzon et al. (3), the average daily course of the ^{222}Rn concentration in the outdoor atmosphere can be expressed by the following equation :

$$\frac{C(t)}{\bar{C}} = 1 + A_1\cos\left(\frac{2\pi}{24}t+\Phi_1\right) + A_2\cos\left(\frac{2\pi}{12}t+\Phi_2\right) \tag{1}$$

where C(t) is the average ^{222}Rn concentration at the time t, $\bar{C}$ is the monthly average of the ^{222}Rn concentration, A_1 is the first harmonic amplitude, A_2 is the second harmonic amplitude, Φ_1 is the first harmonic phase, and Φ_2 is the second harmonic phase.

In this equation, the first harmonic term describes the turbulent dispersion process originated by solar heating. The second harmonic term describes the influence of the diurnal instability interval varying with the season. The values of the parameters in Eq.(1) are summarized in Table 2. They were obtained by the Fourier's analysis of the average daily courses of the ^{222}Rn concentrations.

Table 2. Results of Fourier analysis of the mean daily waves.

Month	A_1	A_2	A_1/A_2	Φ_1	Φ_2
1	0,08	0,04	1,87	298,2	173,3
2	0,11	0,04	2,78	295,9	117,5
3	0,22	0,05	4,75	302,8	162,4
4	0,32	0,08	4,16	303,6	158,5
5	0,36	0,06	5,58	315,7	186,6
6	0,43	0,06	7,69	309,4	174,2
7	0,45	0,08	5,91	309,9	175,2
8	0,46	0,07	6,93	306,7	167,4
9	0,35	0,08	4,74	305,9	156,7
10	0,22	0,06	3,75	312,5	116,3
11	0,05	0,03	1,49	307,3	142,4
12	0,06	0,05	1,23	263,1	145,7
Mean	0,26	0,06	4,24	302,6	156,4

Further we were looking for correlations between Φ_2 and the hourly difference between the sunrise and the sunset ΔH, and for correlations between A_1 and the intensity of solar radiation, so as it was done in Ref.(3). We determined the followed expression for Φ_2 and A_1 :

$$\Phi_2 = (34,8 \pm 23,3) + (9,2 \pm 1,7)\Delta H \tag{2}$$

where ΔH was calculated for the 15 th day of each month and taken as the monthly average value,

$$A_1 = (-0,053 \pm 0,024) + (0,00069 \pm 0,00005)Q \tag{3}$$

where the global solar radiation Q was calculated according to an equation published in (6), for the 15 th day in a month at 12 a.m. of the local time.

The phase Φ_1 of the first harmonic term is practically constant for all the months and its average value is equal to (302,6°±13,6°).

The amplitude A_2 of the second harmonic term shows only small variations during the year. Therefore we did not search for any correlation for A_2 and we calculated an average value :

$$A_2 = 0,056 \pm 0,015$$

CONCLUSION

In Table 3., there are compared the results of analysis of our measurements with results of analysis done by Garzon et al. (3) for data from various places in the world .

Table 3. The values of Φ_1 , Φ_2 and A_2 for the monthly mean waves at various places in the world.

	Φ_1	Φ_2		A_2
		$\Phi_2 = a_2 + b_2 \Delta H$	r^2	
Oviedo	276,8±3,7	-116,3+19,5ΔH	0,94	from 0,05 to 0,1
Socorro	278,2±9,7	-155,7+23,1ΔH	0,75	
Toulouse	276,4±8,4	12,1+10,6ΔH	0,98	
Brazaville	271,4±10,7	-1494+133,7ΔH	0,41	
Bratislava	302,6±13,6	34,8+9,2ΔH	0,90	0,056±0,015

The amplitudes and phases of the harmonic terms determined by Fourier's analysis of mean daily courses for different months have the same behaviour as those from Oviedo (3). The amplitude A_1 of the first harmonic term is well correlated with the global solar radiation fallen down on the Earth's surface.

The phase Φ_1 is constant and its value found out for Bratislava is about 10 % higher than its average value given in Ref.(3).

The expression of Φ_2 determined by us approaches mostly to the relation that is valid for data from Toulouse. The average value of the amplitude A_2 is between 0,05 and 0,1. This is in the range of the values found out also for the other places.

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