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Outdoor ^{222}Rn behaviour in different areas of Slovakia

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Abstract. Radon activity concentration (RAC) in the outdoor atmosphere was monitored in four localities of Slovakia. The distance between the localities were up to 130 km. The localities had a diverse orography, ranging from flatland to hilly terrain. A significant influence of orography and ^{226}Ra and ^{222}Rn content in soil on diurnal time series of RAC was found. A simple approach of determining radon exhalation rate from soil based on the increase of RAC from daily minima to maxima and removal characteristic of radon is presented. A linear dependency between radon exhalation rate from the soil and RAC in the soil gas at a depth of 0.8 m was found for sandy soils.

Key words: radon • activity concentration • exhalation rate • orography

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Introduction

^{226}Ra in soil is the main source of atmospheric ^{222}Rn. Part of ^{222}Rn produced by the alpha decay of ^{226}Ra escapes from the soil grains into the soil gas. It is then transported mostly by diffusion into the outdoor atmosphere.

In the surface layer of the atmosphere, the concentration of radon is not stable. It depends on the exhalation rate of radon from the soil, intensity of solar radiation, wind speed and other meteorological factors [1, 2]. Regularity of time series of some meteorological parameters (intensity of solar radiation, atmospheric temperature) influences the time series of radon activity concentration (RAC) in the atmosphere. RAC exhibits daily and seasonal variations. In general, radon reacts sensitively to temporal changes of meteorological parameters and is therefore considered a suitable indicator of vertical exchange processes in the atmosphere [3].

Measurements of radon in the atmosphere provide not only the information about the state of the atmosphere but also allow evaluating the radiation exposure of the population. A great interest in radon during the past decades is also related to its utilization as a tracer for tracing the emission rates of some atmospheric pollutants [4, 5].

From the facts mentioned above, it follows that average radon concentration in the atmosphere and the shape of radon time series depends on the locality of the measurement. The orography of a locality affects the regional and local weather, which is characterized by the sum of all weather constituents and atmospheric effects at a certain place and time (especially temperature, cloudiness, solar radiation, wind speed, wind direction and the like) [6]. These parameters have a major influence on radon behaviour in the atmosphere. This was confirmed by the measurements carried out by various authors who showed that radon time series are different in urban, suburban and rural environments [7, 8].

This paper deals mostly with the study of the influence of a place of the measurement on atmospheric radon concentration in four areas of Slovakia. The orography of the localities is diverse, ranging from flatland to hilly terrain. The localities are located up to 130 km away from each other. Based on the typical shape of radon time series in the outdoor atmosphere during a 24-h period, radon exhalation rate from soil was estimated.

Measurement areas

The first locality was the campus of the Faculty of Mathematics, Physics and Informatics, Comenius University (FMPI CU) in Bratislava (Lat: 48°9'4" N; Lon: 17°4'14" E; 170 m a.s.l.) on a hill above Karlova Ves borough. The sampling place was located on an open grassy surface and situated about 3 km north-west from the downtown. Incoming solar radiation was not shielded by any terrain obstacles. ^{226}Ra concentration in the soil was 33 Bq·kg^{-1}. The soil on the campus was predominantly of clay-sandy type.

The second sampling place was situated in the area of the Slovak Metrology Institute (SMI) in Bratislava and is about 3 km to the west of the FMPI CU campus (Lat: 48°10'03" N; Lon: 17°02'36" E; 237 m a.s.l.). The SMI is situated in a basin and is shielded by hills, which protect the area from northern and western winds that are predominant in Bratislava. The soil in this area was predominantly of clay-sandy type. ^{226}Ra concentration in the soil was 28 Bq·kg^{-1}.

The third sampling area was located near the city of Jaslovské Bohunice in the vicinity of a nuclear power plant (Lat: 48°29'9" N, Lon: 17°39'55" E; 160 m a.s l.) and was about 55 km to the north-east of Bratislava. The locality was characterized by a rural, agricultural surrounding and flat terrain. The soil was predominantly of sand-loamy type, with ^{226}Ra concentration of about 37 Bq·kg^{-1}.

The fourth sampling place was situated in the town of Nováky (Lat: 48°43'4" N; Lon: 18°32'43" E; 245 m a.s.l.), a city in central Slovakia, about 130 km north-east of Bratislava. This town lies in the middle of the Upper Nitra valley and is surrounded by mountains. The measurement device was located on the city's outskirts, not far away from the underground coal mines. The soil was predominantly of loam-sandy type, with ^{226}Ra concentration of about 43 Bq·kg^{-1}.

The soil of the localities falls into the category of fine-grained soils that are moderately permeable [9]. In the FMPI CU area, the measurements of in-depth profiles of soil humidity were also carried out. During summer, the soil humidity (water content in a unit weight of soil) decreased with increasing depth, starting at 16% near the surface and decreasing to 4% at a depth of 0.25 m. At an even greater depth, the humidity remained approximately at 4%. During the winter and spring months, the soil humidity decreased from 25% at the surface to 5% at a depth of 1.2 m. For this humidity range, radon emanation coefficient remained practically constant: 13.5% for clay-sandy soils and 10% for sand-loamy soils.

Measurement methods

On the campus of FMPI CU in Bratislava, a large-volume cylindrical scintillation chamber (LSCH) with a sensitive volume of 4.5 l was used for ^{222}Rn measurements [10]. On the grounds of SMI in Bratislava and Nováky, Lucas-type scintillation chambers with sensitive volume of 1 L were employed (1LSCH). The chambers operated in a flow-through regime with a flow rate of 0.5 l·min^{-1}. The registered count rates were recorded and automatically stored on a computer's hard-drive at 30 min intervals. Subsequently, RACs at to 2-h intervals were calculated from the count rates using the Ward-Borak method [11]. The measurements near Jaslovské Bohunice were carried out by the AMS-02 continuous air monitoring system, which uses a silicone detector for the measurement of ^{222}Rn decay products [12]. The system provides the data about equilibrium equivalent concentration (EEC) every 30 min. In all the localities, air for sampling was collected from a height of 1.5 m above ground. For the measurement uncertainty of 30%, the detection limit is 1 Bq·m^{-3} for LSCH, 2 Bq·m^{-3} for 1LSCH and 0.2 Bq·m^{-3} for AMS-02. The detection system allows measuring the RAC in the outdoor atmosphere with the uncertainty lower than 30 for 80% of radon data.

Results and discussion

On the FMPI CU campus, radon has been continually monitored since 1991 [13]. In the remaining three localities, the measurements were carried out in the following time periods: Jaslovské Bohunice – February to October 2005 [14], Nováky – May 2007 to July 2008 [15], and SMI Bratislava – February 2003 to October 2004 [16]. The RAC measured in these three localities were compared with the reference values of RAC measured on the FMPI CU campus.

As can be seen in Fig. 1, short-term changes of outdoor RAC in all the three localities exhibit a similar pattern. Usually, the high or low RACs occur approximately at the same time as in the reference locality (FMPI CU). This was a consequence of similar meteorological conditions over the major part of Slovakia during the period of radon activity monitoring (there was a similar intensity of solar radiation, cloudiness and wind speed). For example, the significant decrease in RAC in FMPI CU and Nováky during 19–23.10.2010 was caused by an increased wind speed of up to 8 m·s^{-1} in both localities. Moreover, the correlation coefficients between RAC on the campus of FMPI CU Bratislava and

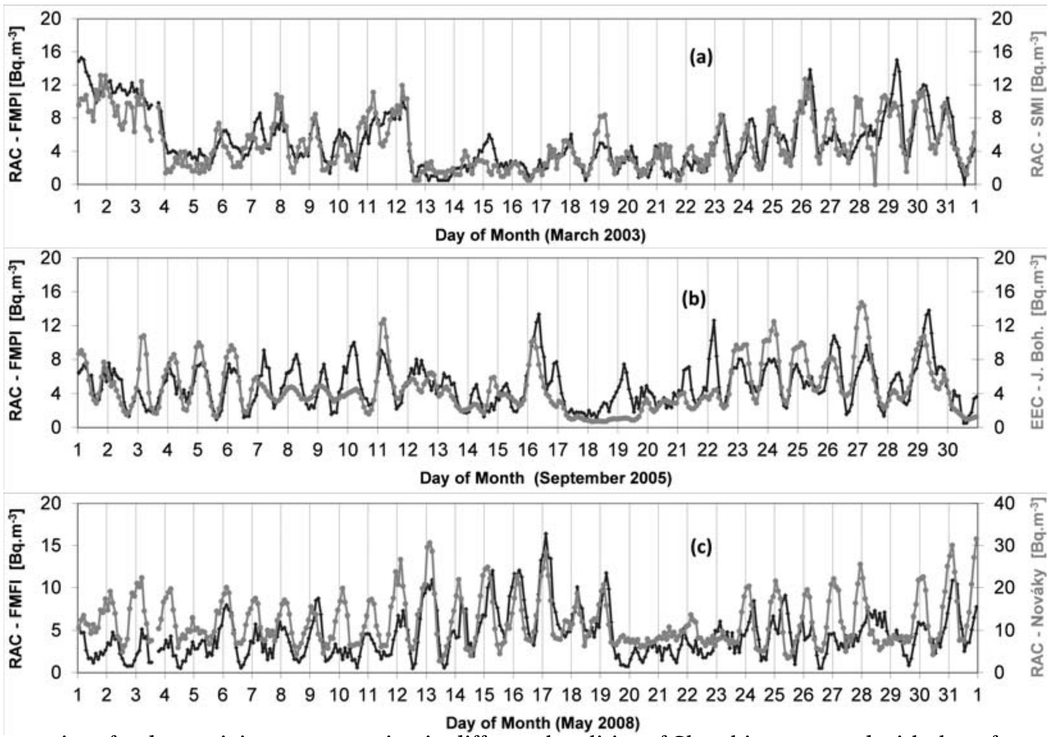

Fig. 1. Time series of radon activity concentration in different localities of Slovakia compared with the reference locality on the campus of Faculty of Mathematics, Physics and Informatics, Comenius University (FMPI CU).

other localities were quite high (R = 0.82 for SMI Bratislava, R = 0.64 for Jaslovské Bohunice, R = 0.55 for Nováky).

RAC measurements in SMI

The simultaneous measurements of RAC in the SMI and FMPI CU areas were realized during the years 2003 and 2004. Figure 2 shows composite diurnal cycles of ^{222}Rn activity concentration in the FMPI CU and SMI areas for two months of the year 2003. The amplitudes of diurnal time series are similar in both localities, 3.5 Bq·m^{-3} in June and 2 Bq·m^{-3} in March.

However, a notable time shift (up to 5 h) in daily minimum and maximum RAC was observed between the locality of FMPI and SMI (Fig. 2).

This effect was connected to the fact that the measurement area on the grounds of SMI was exposed to solar radiation only until 3 p.m. in summer and 12 a.m. in winter due to shielding from the west by nearby hills. This led to an earlier decrease of the intensity of vertical exchange processes in the air of SMI, resulting in an earlier increase of RAC, always a couple of hours earlier than a similar increase observed in the FMPI CU campus. This effect is particularly well visible during the summer months, when the influence of solar radiation on the time series of RAC is more significant, than during winter.

The measurements show that the average monthly values of RAC in the SMI area are usually higher (by 21–40%), mainly in the period from May to August, than RAC measured in FMPI CU area (Table 1). However, from February to April 2003, the RACs were practically at the same level in both localities. During the 11 months of radon monitoring in 2003, the average RAC values of 5.4 and 6.1 Bq·m^{-3} were obtained for FMPI CU and SMI air, respectively.

In the SMI area, maximum values of RAC were observed during summer, as opposed to winter maxima observed in the area of FMPI CU. In the SMI area, this summer maximum was a consequence of relatively high RAC during the day as well as the night (higher than RAC in the FMPI CU area).

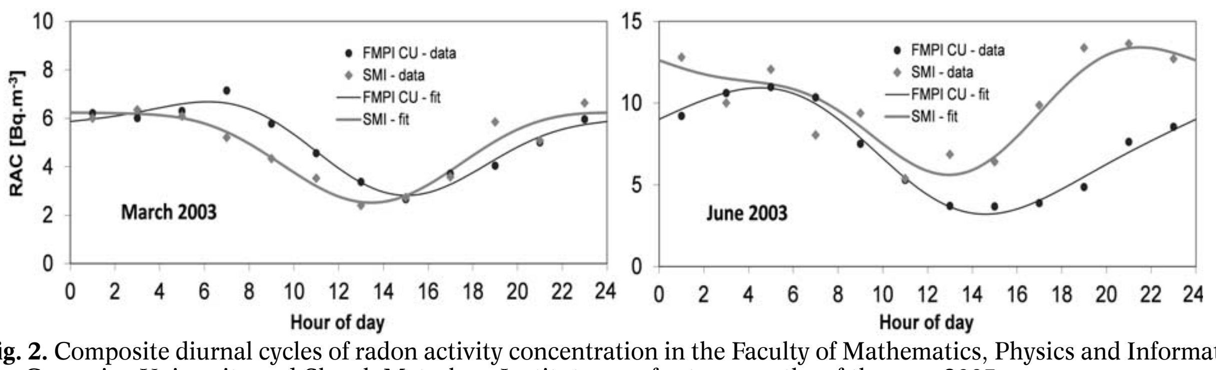

Fig. 2. Composite diurnal cycles of radon activity concentration in the Faculty of Mathematics, Physics and Informatics, Comenius University and Slovak Metrology Institute area for two months of the year 2003.

Table 1. Mean monthly values and standard deviations of radon activity concentration obtained in FMPI CU and SMI, Bratislava

Month and year	FMPI CU [Bq·m^{-3}]	SMI [Bq·m^{-3}]
February 2003	5.6 ± 3.2	4.7 ± 3.6
March 2003	5.1 ± 3.6	4.8 ± 3.7
April 2003	4.0 ± 2.5	4.3 ± 3.8
May 2003	5.4 ± 3.2	6.7 ± 5.1
June 2003	6.3 ± 3.2	8.9 ± 5.5
July 2003	5.4 ± 3.2	6.8 ± 4.7
August 2003	5.4 ± 4.3	6.5 ± 6.0
September 2003	4.2 ± 3.4	4.8 ± 5.8
October 2003	5.6 ± 2.8	6.6 ± 5.0
November 2003	6.5 ± 3.4	7.3 ± 3.9
July 2004	3.8 ± 2.6	5.1 ± 4.1
August 2004	4.5 ± 3.4	6.8 ± 4.6
September 2004	3.5 ± 3.2	6.4 ± 4.4
October 2004	5.7 ± 3.3	7.3 ± 4.2

FMPI CU, Faculty of Mathematics, Physics and Informatics, Comenius University; SMI, Slovak Metrology Institute.

RAC measurements in Jaslovské Bohunice

Simultaneous measurements of RAC in FMPI CU in Bratislava and EEC in Jaslovské Bohunice were realized for 5 months of the year 2005. Correlation coefficient *R* between all EEC and RAC data is at the level of 0.65. Composite diurnal cycles of RAC in FMPI CU and EEC in Jaslovské Bohunice are depicted in Fig. 3.

Figure 3 shows that the mean diurnal radon time series observed in the two localities are similar but slightly shifted apart. This shift is particularly well visible during the summer months (approximately 2 h). Also, the minima of daily radon courses during the summer months are more expanded in Jaslovské Bohunice than in Bratislava.

The amplitudes of mean daily time series of RAC and EEC are lowest during winter (in February, the RAC is 1.1 Bq·m^{-3} and EEC is 0.7 Bq·m^{-3}) and highest during summer and autumn: 2.3 Bq·m^{-3} and 2.1 Bq·m^{-3}, respectively.

Table 2. Mean monthly values and standard deviations of radon activity concentration and equilibrium equivalent concentration measured in FMPI CU and Jaslovské Bohunice

Month and year	FMPI CU [Bq·m^{-3}]	Jasl. Boh. [Bq·m^{-3}]
February 2005	5.2 ± 3.6	3.0 ± 3.2
April 2005	3.5 ± 2.2	2.9 ± 1.7
June 2005	3.6 ± 2.7	2.9 ± 2.2
September 2005	4.9 ± 3.1	4.7 ± 2.5
October 2005	5.8 ± 3.3	5.6 ± 2.5

FMPI CU, Faculty of Mathematics, Physics and Informatics, Comenius University; Jasl. Boh., Jaslovské Bohunice.

In the locality of Jaslovské Bohunice, lower monthly average values of EEC were found in April and June than in October (Table 2). RAC in the area of FMPI CU followed a similar pattern. During the 5 months of radon monitoring in 2005, the average RAC values of 4.6 Bq·m^{-3} and 5.4 Bq·m^{-3} were obtained for FMPI CU and Jaslovské Bohunice, respectively. For the conversion from EEC to RAC in Jaslovské Bohunice, the equilibrium factor of 0.7 was used [17].

These results imply that turbulent mixing of air in the atmosphere of both localities is very similar. A slight, approximately 2 h, shift of data is probably caused by an earlier incidence of solar radiation on the measurement area in Jaslovské Bohunice.

RAC measurements in Nováky

Radon was also continuously monitored in the atmosphere of Nováky and Bratislava from May 2007 to July 2008 [15]. In total, about 5300 of radon concentration data were obtained from each locality.

Average diurnal cycles of RAC for two months in both localities are shown in Fig. 4. Diurnal RAC cycles in both localities have the shape of a wave, with the maximum in the early morning and minimum in

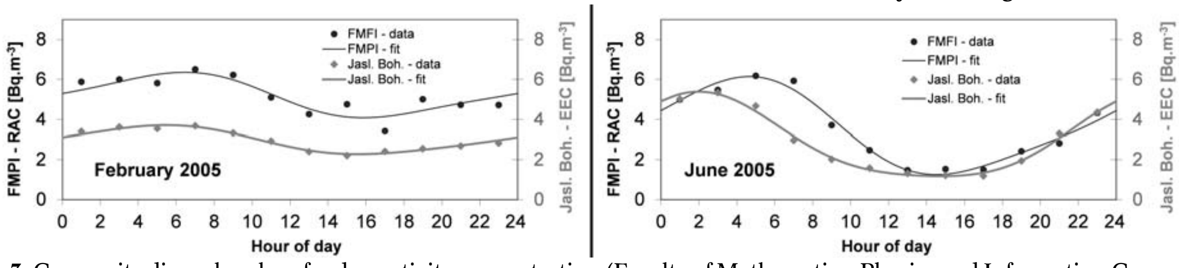

Fig. 3. Composite diurnal cycles of radon activity concentration (Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava) and equilibrium equivalent concentration (Jaslovské Bohunice) for two months of the year 2005.

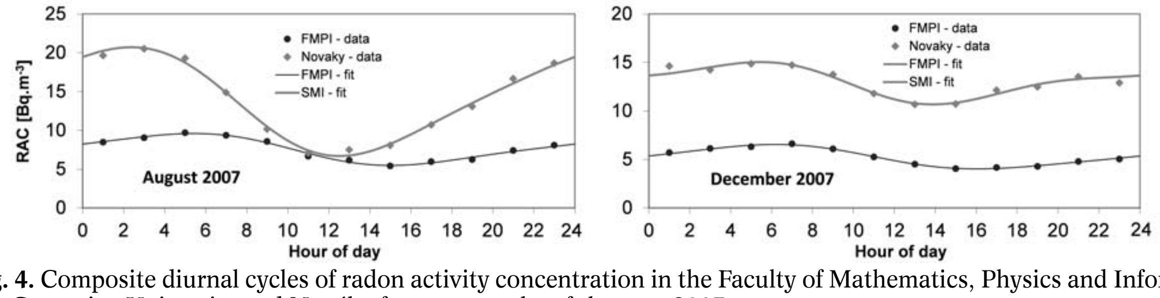

Fig. 4. Composite diurnal cycles of radon activity concentration in the Faculty of Mathematics, Physics and Informatics, Comenius University and Nováky for two months of the year 2007.

Table 3. Mean monthly values and standard deviations of radon activity concentration measured in FMPI CU and Nováky

Month and year	FMPI [Bq·m^{-3}]	Nováky [Bq·m^{-3}]
May 2007	5.3 ± 2.9	12.0 ± 8.5
June 2007	5.1 ± 3.3	11.5 ± 8.1
July 2007	5.8 ± 3.9	–
August 2007	7.3 ± 3.4	13.8 ± 8.3
September 2007	6.4 ± 3.4	11.7 ± 7.7
October 2007	8.0 ± 3.9	14.4 ± 8.8
November 2007	6.5 ± 3.6	11.0 ± 6.0
December 2007	5.6 ± 4.2	13.2 ± 5.7
January 2008	5.7 ± 3.8	11.6 ± 5.3
February 2008	6.3 ± 4.0	11.6 ± 6.6
March 2008	5.1 ± 3.8	12.8 ± 5.1
April 2008	3.9 ± 3.3	9.1 ± 5.4
May 2008	4.7 ± 3.5	12.1 ± 7.2
June 2008	5.8 ± 3.9	13.6 ± 8.6
July 2008	4.0 ± 3.1	11.5 ± 6.8

FMPI CU, Faculty of Mathematics, Physics and Informatics, Comenius University.

the late afternoon. However, diurnal cycles of RAC in Bratislava lag 2–3 h behind the ones observed in Nováky. This effect is likely caused by an earlier disintegration of nocturnal atmospheric inversion layer by solar radiation in Nováky as well as by longer duration of solar irradiation in Bratislava measurement area. The correlation coefficient between the mean daily courses of RAC in Bratislava shifted 2 h forward and the mean daily courses of RAC in Nováky was very high ($R^2 \sim 0.98$). During the summer months, high amplitudes of daily radon concentrations were found in Nováky (~6.5 Bq·m^{-3}) as well as Bratislava (~2 Bq·m^{-3}). Low amplitudes are typical for winter months (Nováky: ~1.6 Bq·m^{-3}; Bratislava: ~0.8 Bq·m^{-3}).

In the locality of Nováky, just like on the campus of FMPI CU, the highest average monthly values of RAC were found in October and the lowest ones in April (Table 3). The correlation between average monthly RACs in both localities is quite high ($R^2 \sim 0.78$) and seasonal changes in average monthly RAC in both localities exhibit a similar pattern. This can be ascribed to similar temporal changes of meteorological parameters over the whole midwest region of Slovakia, resulting in similar exchange processes in the air of both localities. Average RAC in the outdoor atmosphere of Nováky obtained during 14 consecutive months was more than twice as high as average RAC in the outdoor atmosphere of Bratislava (Nováky: 12.1 Bq·m^{-3}; FMPI CU: 5.7 Bq·m^{-3}). The higher RAC in Nováky was likely caused by an increased radon exhalation rate from the soil in this area.

Calculation of radon exhalation rate from outdoor RAC measurements

The following ratio appears to be a suitable characteristic for comparing radon data obtained in different localities:

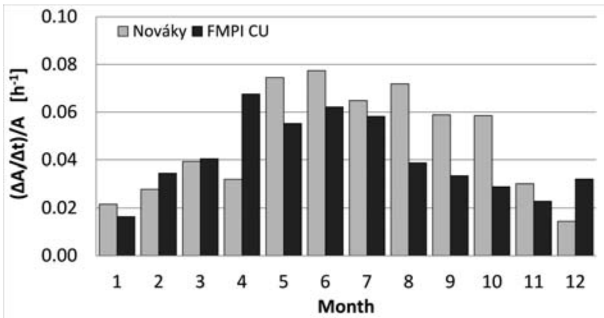

Fig. 5. Seasonal variation of λ_R in Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava and Nováky.

$$\lambda_R = \left(\frac{\Delta A}{\Delta t}\right)\Big/ A \quad (1)$$

where ΔA is the difference between the maximum and minimum RAC values in radon diurnal cycle, Δt is the duration of the increase of RAC from its minimum to its maximum and A is the average daily RAC.

According to Minato [18], λ_R represents the so-called removal characteristic, which is a measure of removal of radon from the surface layer of the atmosphere due to radioactive decay and variable wind speed. The course of λ_R for Nováky and FMPI is similar, with maximum during the summer and minimum during the winter months (Fig. 5). The coefficient of correlation between the courses is on the level of $R = 0.50$. Average value of the ratio λ_R(Nováky)/λ_R(FMPI) during the summer months is 1.21, which indicates that Bratislava atmosphere is about 20% more stable than the atmosphere in Nováky.

Under the assumption that radon is uniformly distributed in a box of height h_e during the stable nocturnal periods, the $\Delta A/\Delta t$ ratio in Eq. (1) can be expressed in the following form [19]:

$$\frac{\Delta A}{\Delta t} = \frac{E_S}{h_e} \quad (2)$$

where E_S is the radon exhalation rate from soil and h_e is the so-called equivalent mixing height (EMH). EMH differs from the nocturnal stable layer thickness. EMH is a parameter characterizing the intensity of vertical nocturnal diffusion in the atmosphere [20, 21].

Similar to $(\Delta A/\Delta t)/A$, the $\Delta A/\Delta t$ ratio in both localities reaches the maximum during the summer and minimum during the winter months. The correlation between the monthly $\Delta A/\Delta t$ values is relatively high ($R = 0.74$). Average value of $[(\Delta A/\Delta t)_{\text{Nováky}}]/[(\Delta A/\Delta t)_{\text{FMPI}}]$ ratio in summer months is 2.55. This means that the average value of ratio

$$\frac{(E_S / h_e)_{\text{Novaky}}}{(E_S / h_e)_{\text{FMPI}}} \quad (3)$$

in summer months is also 2.55.

Based on the mentioned assumptions, it is possible to estimate radon exhalation rate from the soil in Nováky if one knows radon exhalation rate at FMPI CU campus and the ratio between h_e in FMPI CU and h_e in Nováky. During the summer months,

Table 4. Basic radiation characteristics of soil and radon characteristics of the outdoor atmosphere during the summer months in various localities of Slovakia. $A_m(^{226}Ra)$ is the specific activity of ^{226}Ra in soil [22] and $A_v(^{222}Rn)$ is the radon activity concentration in the soil air at a depth of 0.8 m [22]. The meaning of the remaining symbols is described in the text

Locality	A_m ^{226}Ra [Bq·kg^{-1}]	A_v ^{222}Rn [kBq·m^{-3}]	A [Bq·m^{-3}]	ΔA [Bq·m^{-3}]	Δt [h]	$\Delta A/\Delta t = E_s/h_e$ [Bq·m^{-3}·h^{-1}]	$(\Delta A/\Delta t)/A = \lambda_R$ [h^{-1}]	E_S [mBq·m^{-2}·s^{-1}]
FMPI CU (BA)	32.9 ± 5.6	8.7 ± 3.8	5.0 ± 0.1	5.1 ± 0.3	14 ± 0.5	0.36 ± 0.02	0.073 ± 0.005	15.0 ± 1.8
Nováky	43.0 ± 4.0	27.3 ± 7.6	10.5 ± 0.2	13.0 ± 0.7	14 ± 0.5	0.93 ± 0.06	0.088 ± 0.006	46.4 ± 2.6
SMI (BA)	28.4 ± 5.1	11.0 ± 4.1	7.0 ± 0.1	6.5 ± 0.3	13 ± 0.5	0.50 ± 0.03	0.071 ± 0.005	20.2 ± 2.6
Jaslovské Bohunice	37.4 ± 7.4	14.5 ± 7.0	5.4 ± 0.1	5.8 ± 0.3	12 ± 0.8	0.48 ± 0.04	0.090 ± 0.008	24.4 ± 2.9

BA, Bratislava; FMPI CU, Faculty of Mathematics, Physics and Informatics, Comenius University; SMI, Slovak Metrology Institute.

direct measurements of radon flux in the FMPI CU campus give the average value of $E_S = (15.0 \pm 1.8)$ mBq·m^{-2}·s^{-1}.

From the ratio λ_R(Nováky)/λ_R(FMPI), it is possible to estimate that h_e(Nováky) ≈ 1.21 h_e(FMPI). Then from Eq. (3) one can obtain radon exhalation rate from the soil of Nováky $E_S = (46.4 \pm 2.6)$ mBq·m^{-2}·s^{-1}.

This value is in very good agreement with the direct measurement of radon exhalation rate in Nováky $E_S = (44.2 \pm 1.5)$ mBq·m^{-2}·s^{-1}. This relatively high E_S explains high values of outdoor RAC in Nováky.

A summary of radiation characteristics of soil and radon characteristics in the outdoor atmosphere for all localities is given in Table 4. Specific activities of ^{226}Ra and ^{222}Rn activity concentrations in soil were taken from the Map server of the State Geological Institute of Dionýz Štúr in Bratislava [22].

In each locality, the measurements of these parameters were also carried out by the authors of this paper. The values of specific activities of ^{226}Ra and ^{222}Rn activity concentrations represent arithmetic means of several measurements in each locality (consisting of 3 to 12 measurements), and the uncertainties represent their respective standard deviations. For each locality, radon characteristics of the outdoor atmosphere were calculated from average diurnal cycles of RAC obtained during the month of June. This month was chosen because, during summer, the surface layer of the soil is not affected by cold and humidity as much as during other seasons of the year. Hence, the relationship between radon exhalation rate and radiation characteristics of the soil should be more pronounced [23].

From Table 4 for Jaslovské Bohunice locality it follows that $[(\Delta A/\Delta t)_{\mathrm{J.Bohunice}}]/[(\Delta A/\Delta t)_{\mathrm{FMPI}}] = 1.33$ and λ_R(J.Bohunice)/λ_R(FMPI) = 1.23, which suggests that the intensity of vertical removal of radon in Jaslovské Bohunice is 23% higher than FMPI CU. In a similar fashion, for SMI area one obtains $[(\Delta A/\Delta t)_{\mathrm{SMI}}]/[(\Delta A/\Delta t)_{\mathrm{FMPI}}] = 1.37$ and λ_R(SMI)/λ_R(FMPI) = 0.98, which indicates that stability of the atmosphere in the SMI area during the night is approximately the same as the atmospheric stability in the locality of FMPI CU.

From the mentioned ratios it is possible to obtain, just as in the case of Nováky, the exhalation rate of radon from the soil of Jaslovské Bohunice $E_S = (24.4 \pm 2.9)$ mBq·m^{-2}·s^{-1} and the exhalation rate of radon from the soil of SMI $E_S = (20.2 \pm 2.6)$ mBq·m^{-2}·s^{-1}. Direct measurement of radon exhalation rate by a closed chamber method in Jaslovské Bohunice gave $E_S = (26.6 \pm 1.3)$ mBq·m^{-2}·s^{-1}, which is in a good agreement with the E_S for Jaslovské Bohunice stated above.

The correlation between obtained radon exhalation rates E_S and RAC in the soil air at a depth of 0.8 m is better ($R^2 = 0.99$) than the correlation between radon exhalation rates and specific activity of ^{226}Ra in the soil ($R^2 = 0.72$). The relation between E_S and soil RAC is linear and can be described by the following equation: E_S [mBq·m^{-2}·s^{-1}] = 1.66 $A_{v(222\mathrm{Rn})}$ [kBq·m^{-3}] + 0.95. The calculated E_S values lie within the range of the E_S values obtained from direct measurements published in [23].

In general, radon exhalation rate from the soil exhibits diurnal and seasonal variations. Usually, the lowest values of E_S are found during the winter months and the highest during the summer. A linear relationship between radon exhalation rate and outdoor temperature was found by Mazur and Kozak [23] for the temperature range from –5 to +25°C. It could be assumed that the exhalation rates obtained by us for individual localities based on summer measurements of outdoor radon are approximately twice as high as the yearly average. Szegvary *et al.* [24] gave the exhalation rates for moderately permeable soils in Hungary, ranging from 6.4 to 30 $mBq\cdot m^{-2}\cdot s^{-1}$, with the regional mean value of 16.6 $mBq\cdot m^{-2}\cdot s^{-1}$. The exhalation rates obtained by us lie within this range with the exception of the locality of Nováky. However, our values of E_S should be more representative than the ones obtained by a closed chamber method.

Conclusion

RAC in the surface layer of the atmosphere was continually monitored in four Slovak localities. The localities have a diverse orography ranging from flatland to hilly terrain and are up to 130 km apart. Similar diurnal patterns of RAC were found between the reference locality (FMPI campus in Bratislava) and the remaining three localities; a significant change in meteorological parameters like wind speed or temperature caused a corresponding significant change in RAC in all localities. These results imply that the turbulent mixing of air in the atmosphere of the localities is very similar. However, diurnal cycles of radon as well as average RAC values were affected by the orography of the locality and by ^{226}Ra and ^{222}Rn content in the soil. The influence of orography was particularly well visible in the area of SMI Bratislava where, due to specific solar irradiation conditions, the increase in RAC during the summer months was observed as early as 12 a.m., and the maximum of diurnal cycle occurred as early as 11 p.m. The influence of soil radioactivity was best visible in Nováky, where average yearly RAC was 2.2 times higher than average yearly RAC in the campus of FMPI CU, Bratislava due to high ^{226}Ra and ^{222}Rn content in the soil.

It was demonstrated that, by utilizing $\Delta A/\Delta t$ and λ_R ratios for different localities, it is possible to estimate radon exhalation rate from the soil in a given locality if the exhalation rate for at least one locality is known. On the basis of conducted analyses, the relation between radon exhalation rate and RAC in the soil air at a depth of 0.8 m was found.

The results presented in this paper show that if radon data are to be representative for a larger area, adequate attention should also be paid to the choice of orography of the locality as well as to the radiation characteristics of the soil.

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