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MEASUREMENTS OF OUTDOOR RADON CONCENTRATION OVER 24-HOUR PERIODS IN DIFFERENT SETTLEMENTS IN BULGARIA

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Abstract: *This work presents the results of continuous radon measurements in open atmosphere, including measurements of air humidity, temperature, pressure and gamma dose rate, in 11 different settlements of Bulgaria. Using AlphaGuard equipment, measurements were made in mountain, spas, plain, sea level and uranium mining environments in the summer period, in series of 10-min intervals over 24 hours., . The analysis of results showed different daily variation among the outdoor radon measurements in different measuring sites. The outdoor radon concentrations ranged from 22 Bq.m⁻³ (city in lowland) to 180 Bq.m⁻³ (uranium mining site Eleshnica). Outdoor radon levels were found to be increasing during the night by a factor of 1.5 (in 9 locations), factor 2 (location at sea level) and factor 1 (location in the plain). The relation between outdoor radon concentrations and meteorological factors as well with gamma dose rate was observed.*

Key words: *outdoor radon, AlphaGuard, temperature, humidity*

1. INTRODUCTION

Radon (^{222}Rn) is a colorless, odorless and tasteless radioactive gas. It is chemically inert and the heaviest noble gas. Sometimes it can be a significant source of the radioactivity in the atmospheric boundary layer. It is created in the soil due the radioactive decay of radium (^{226}Ra) and then is exhalated from the ground into the atmosphere transported mainly by turbulent diffusion or convection (1). A typical outdoor radon concentration, according to UNSCEAR, is 10 Bqm^{-3} (2).

The concentration of radon in the outdoor air depends mainly on soil characteristics such as concentration of radium porosity and permeability gas and meteorological parameters.

The influence of meteorological parameters on outdoor radon concentration is related mainly to temperature gradient, humidity and barometric pressure

Temporal variability of ^{222}Rn in the air above the ground level in relation to meteorological elements (air pressure, day and night air temperature, wind velocity, precipitation and snow cover) and vertical mixing processes in the atmosphere is already documented in previous research (1, 3, 4, 5).

Accumulation of data concerning the fluctuations of outdoor radioactivity in the lower atmosphere provides important hints in the process of preliminary indication of the behavior of indoor radon. The present study gave the results of simultaneous continuous outdoor radon concentration. humidity, temperature pressure and gamma dose rate measurements in 11 settlements, located in various geographical and climate settings in Bulgaria.

2. METHODS

Simultaneous measurements of radon concentration, temperature, pressure and humidity in outdoor air were performed with AlphaGuard PQ 2000 radon monitors (Genitron, Germany). The values were registered for 10-min intervals over approximately a 24-hours period. On the same locations, the gamma dose rate (μSvh⁻¹) was measured at the height of 1m above the ground using a Gamma Detector (RADOS RDS 110). The values of gamma dose rate are registered in 5-min intervals. The average value of 12–15 records is taken as a final result for one location.

Measurements took place in 11 villages in Bulgaria during the summer period (Fig. 1), distributed as follows: mountains (4 locations), spas (3 locations), plain (1 location), sea level (1 location) and former uranium mining sites (2 locations).

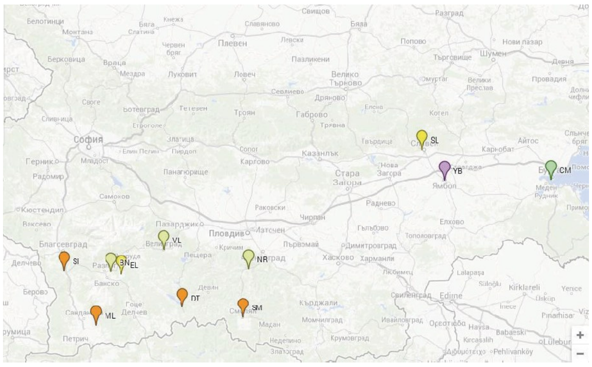

Fig. 1 Location of measurement sites

Variability of outdoor radon concentrations against background weather conditions is a subject of attention and analysis. The focus is on comparison between the radon levels recorded at separate hours (day/night) in mountainous sites (marked in orange on the map), spa sites (in light green), uranium mining sites (yellow points), sites by the seaside and in the plain (green and violet points on the map).

3. RESULTS

The results of gamma dose rate D (μSvh⁻¹) measured in all 11 locations are presented in Table 1. Table 2 shows results of arithmetic mean (AM) of outdoor radon concentration (Bqm⁻³) and standard deviation (SD), temperature (°C), humidity (%) and atmospheric pressure (mbar) measured in the same locations, where the codes are as in Table 1.

The results of gamma dose rate ranged from 0.10 to 0.20 μSvh ¹, measured in plain and spa sites respectively.

The arithmetic mean of radon concentrations varied from 22 to 180 Bqm⁻³. The obtained range in this survey is wider than radon concentration range 3.7 to 41.0 Bqm⁻³ reported for Slovenia (6), Difference between the outdoor ^{222}Rn concentrations measured in mountain (AM=34 Bqm⁻³), spa (AM=44 Bqm⁻³) and sites located in the plain (22 Bqm⁻³), is obvious. Radon variations recorded in mountain and in the plain sites can be related to their specific geological settings as well high radon in spa indicating radon-rich mineral water. Furthermore, the maximum concentration of radon was measured in settlements, located in vicinity of former uranium mining sites (Eleshnica and Sliven). The evidence confirms initial observation that uranium mining activities increased background radiation. High value of outdoor radon concentration is in agreement to high previously measured values of indoor radon concentration (AM 675 Bqm⁻³) in Eleshnica (7).

Table 1. Gamma dose rate measurements in 11 locations

Code	Village	Sites	Dates	D [μSvh⁻¹]
BN	Banja	spa	06.08.13	0.17
NR	Narechen	spa	18.07.12	0.20
VL	Velingrad	spa	10.09.13	0.14
CM	Cherno-morec	sea level	04.07.13	0.11
DT	Dospat	mountain	01.08.12	0.17
SI	Simitli	mountain	10.05.13	0.12
ML	Melnik	mountain	05.06.13	0.14
SM	Smolian	mountain	08.07.13	0.11
YB	Yambol	plain	30.09.13	0.10
SL	Sliven	uranium	08.05.12	0.12
EL	Eleshnica	uranium	25.07.12	0.18

Table 2. Measurements of outdoor radon concentration, temperature, humidity, pressure in the same locations

Code	AM [Bqm⁻³]	SD	Tempera ture [°C]	Humidi ty [%]	Pressu re [mbar]
BN	49	3	23	72	927
NR	42	3	21	35	953
VL	42	3	17	99	930
CM	33	2	23	75	1014
DT	27	2	20	67	876
SI	35	2	22	72	977
ML	36	2	15	67	972
SM	38	2	18	78	899
YB	22	1	11	69	1004
SL	77	5	23	52	974
EL	180	9	19	46	921

The results of outdoor radon measurements during the “day” (defined as 7 am - 8 pm) and during the “night” (8 pm - 7 am) together with the respective temperatures are presented in Table 3. The ratio K=Rn(night)/Rn(day) is calculated and also shown in Table 3.

Inversion of the outdoor radon concentration due to temperature in the morning is already noticed (8, 9). The morning peak of radon concentration corresponds to the higher values, which were recorded in the "night" results. This peculiarity is linked to the initial hour of "daily" measurements (7 am). The morning peak is noticed during the earlier hours.

Table 3. Measurements of day and night temperature, radon concentration and calculated ratio K

Code	Rn Bqm-3 Day	t° Day	Rn Bqm-3 Night	t° Night	K
BN	25	27	68	19	2.72
NR	35	24	47	18	1.34
VL	33	19	50	14	1.52
CM	22	25	47	20	2.14
DT	24	23	33	17	1.38
SI	26	29	42	15	1.62
ML	30	16	42	13	1.40
SM	32	20	46	16	1.44
YB	21	11	21	11	1.00
SL	57	29	89	16	1.56
EL	134	22	201	16	1.50

Outdoor radon levels increase during the "night" by a factor of 1.5 (in 9 locations), factor 2 (at the sea level) and factor 1 (in the plain). Daily outdoor radon concentrations show less variability in the plain in comparison to sites in mountains or by sea. The minimum and maximum values encountered in the variation differ by a factor less than a factor of about 3 found in Thrace, in the city of Xanthi in North-eastern Greece (8).

Scatter plots of outdoor radon concentration versus gamma dose rate, temperature and humidity in natural logarithmic form are presented in Figs. 2-4.

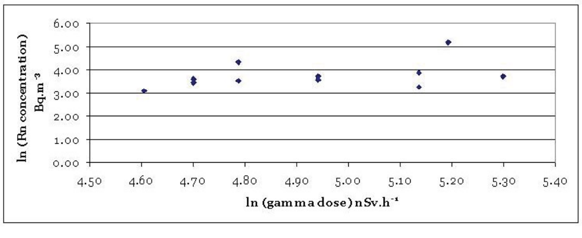

Fig. 2. Outdoor radon concentration versus gamma dose rate

From Fig. 2 we can se that a higher level of radon concentration does not coincide with higher a gamma dose rate in all cases. The radon concentration values increase with increasing temperature and decreasing humidity (Figs. 3 and 4). A similar trend is observed in the survey in North-eastern Greece (8).

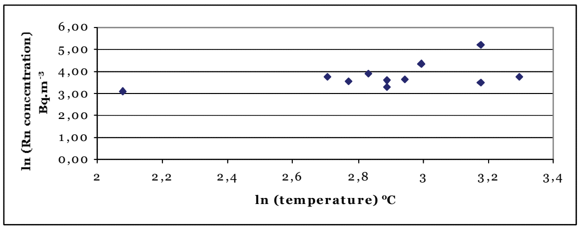

Fig. 3. Outdoor Rn concentration and temperature

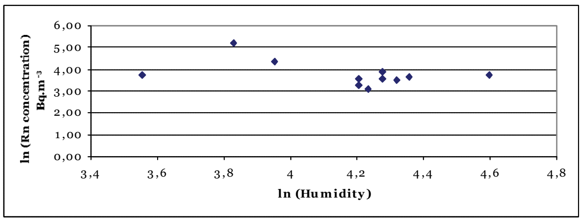

Fig. 4. Outdoor Rn concentration and humidity

Linear regression analyses of this data set were performed at 95% significance level. The results show no significant correlation between outdoor radon concentration and gamma dose rate ($p=0.203$). Correlations between outdoor radon concentration and temperature ($p=0.106$) as well humidity ($p=0.568$) were not significant from the statistical point of view.

4. CONCLUSION

The paper provides an overview of results of short-term averages of outdoor radon concentration in relation to temperature, humidity and pressure in air, as well as gamma dose rate, measured in various settlements in Bulgaria. A correlation of outdoor radon concentration to meteorological parameters was not confirmed statistically. In order to get accurate average values for several regions in Bulgaria, measurements with passive detectors will be carried out continuously during the year. The measurements will provide an insight into local and general factors, affecting the changes in outdoor radon concentrations, in respect to the planned indoor measurement.

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