MEASUREMENTS OF RADON CONCENTRATION IN SOIL GAS OF URBAN AREAS, BULGARIA*

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These work present results of preliminary study of radon concentration in soil gas at 64 locations within 13 urban areas of Bulgaria using AlphaGuard equipment. The measuring period was from 2008 to 2012. The temperature and humidity has been measured as well, including the gamma dose rate. The radon concentration in soil gas was found to be log-normally distributed within the range from 3–97 kBq.m^{-3}, with arithmetic mean of 26 kBq.m^{-3}. The influence of the meteorological and geological factors in relation to radon measurements was examined. Correlation between radon in soil gas and gamma dose rate was also present.

Key words: radon, soil gas, gamma dose.

1. INTRODUCTION

Gaseous radioactive radon (^{222}Rn), decay product of the radium isotope ^{226}Ra is present in all types of soil and rock. Radium atoms decays in soil particles, the resulting atoms of radon entering to air filled pores and then transported by diffusion and advection through this space in order to exhale into the atmosphere [1]. Radon concentrations in soil gas within a few meters of the surface of the ground are clearly important in determining radon rates of entry into pore spaces and subsequently into the atmosphere and it's depend on the radium concentration in the bedrock and on the permeability of the soil [2].

The measurement of ^{222}Rn concentration in soil gas, in principle, can be used as a method of evaluating the potential for elevated indoor radon concentrations [3]. Radon-prone areas can be identified directly by using indoor measurements or indirectly using radon concentration in the soil, by previous established correlation with the indoor radon concentrations. For example, The United States of America

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developed its radon map based on a combination of indoor measurements, geological characteristics, aerial radioactivity, soil permeability and foundation type [4]. Another approach used in some countries, such as the Czech Republic [5] involves testing of individual building sites prior to construction to establish a radon index for the site. Surveys of the radon concentration in soil gas can be used to: determine the radon index of the building site; effectiveness of preventive and remedial measures; identify contaminants and relative concentrations; identify sources; indicate extent of contamination etc. For that reason, in the future, large scale investigation of radon concentration in soil gas is planned in Bulgaria. So, this preliminary study was carried out and we present results of radon concentration in soil gas as well gamma dose rate and its correlation in 13 urban areas of Bulgaria.

2. MATERIALS AND METHODS

The radon concentration in soil gas was measured with a specially designed soil gas unit connected the AlphaGuard PQ 2000 radon monitor. The scheme of the experimental setup is presented in Figure 1.

The soil gas unit consists of a drilling rod with an exchangeable drilling tip with air-lock which is closed by a rivet and capillary probe. By drilling rod a hole of 0.8 m deep was drilled. Afterwards, the drilling rod has to be drawn up 2–3 cm. The capillary probe was inserted into the drilling rod and pushed forward until a firm stroke was noticed. Herewith, the capillary probe penetrates the air-lock and pushes the rivet out of the tip of the probe. By this, the opening for sucking the air in becomes free. With the pump and radon progeny filters connected in series, soil gas was sucked out from the surrounding ground area through the capillary probe and pressed into the ionization chamber of the monitor. In order to determine only ^{222}Rn concentration, the ionization chamber was kept closed tightly after filling it with soil gas for about 10 min–time need thoron to decay.

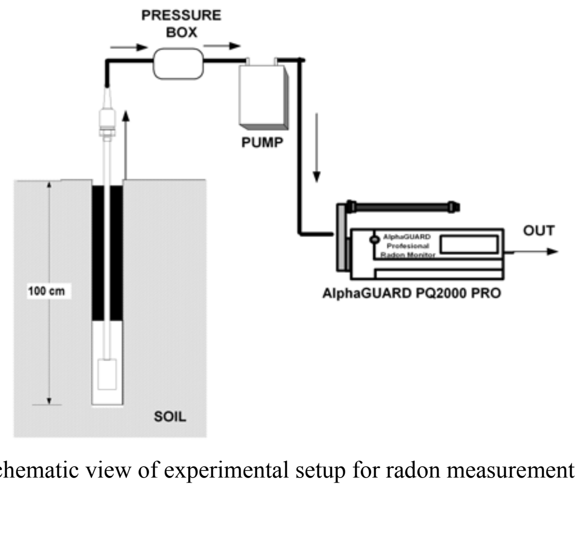

Fig. 1 – Schematic view of experimental setup for radon measurement in soil gas.

After initial growth, the concentration became stabilized. The average of the last few stabilized values was taken as the radon concentration in soil gas.

For the quality assurance of the radon monitor radon chamber with radium source was used. Evaluation of the results was done by estimation of the relative deviation using the follow equation:

$$\mathrm{Re}\,l(B) = \frac{A_r - A_A}{A_A} \cdot 100\% \quad (1)$$

where A_A is known activity in volume of radon chamber in Bq m^{-3}, A_r is measured activity in Bq m^{-3}.

According to the acceptance criteria, the results were considered “acceptable” when the relative deviation was <5 %, “warning” – <10% and “unacceptable” when the deviation was >10%.

Measurements were carried out in 13 urban areas in different time periods from 2008 to 2012. The site of the study in each area was approximately a 1000 m^2 in size. On site measurements were done in a center and each angle of the square during the one day. Soil gas was sampled at 50-80 cm depth. Global Positioning System (GPS) was used to determine geographical coordinates in center of the site. Because one measurement is missed, radon concentrations in soil gas were obtained for 64 locations. The basic information for each site of the study is presented, in Table 1.

Additionally, at the same sites, 51 gamma dose rate measurements were performed. A commercially available RADOS RDS 110 survey meter was used. A reading was taken in the air 1 m above ground level and the results of gamma dose rate were recorded in units of nSv.h^{-1}.

Table 1

Towns with GPS coordinates, period of measurements, gamma dose rate and tape of soil

Urban area	code	GPS	Period of measurements	Gamma dose rate [nSv h^{-1}]	Type of soil
Asenovgrad	AG	N 42°00’54” E 24°52’03”	Sept.2011	90-150	Clay and magma stone
Botevgrad	BG	N 42°54’40” E 23°48’16”	Aug.2008	130	Gravel and sand
Burgas	BS	N 42°48’00” E 27°24’36”	Febr.2010	150-170	Clay
Chernomorec	CM	N 42°27’12” E 27°35’37”	May 2011	160-240	Sand and humus
Eleshnica	EL	N 41°52’14” E 23°37’33”	Aug.2008	250	Granite and gneiss

Table 1 (continued)

Pernik	PK	N 42°36'22" E 23°07'00"	Sept.2010	130-160	Clay
Peshtera	PS	N 42°02'04" E 24°18'34"	Nov.2011	70-150	Granite
Plovdiv	PV	N 42°07'19" E 24°44'29"	May 2009	150-180	Sand
Sandanski	SA	N 41°33'01" E 23°16'14"	May 2011	110	Sand
Smolian	SM	N 41°34'22" E 24°42'50"	Aug.2010	160-220	Gravel
Sofia	SO	N 42°33'54" E 23°28'48"	Aug.2011	90-140	Clay
Stara Zagora	SZ	N 42°25'58" E 25°38'22"	May 2008	120-120	Large gravel with alloy of clay and sand
Varna	VA	N 43°12'05" E 27°54'16"	Nov.2011	80-120	Clay and sand

3. RESULTS AND DISCUSSION

The ranges and arithmetic mean values of radon concentration in soil gas, temperature, humidity and its arithmetic mean values for urban areas under investigation are given in Table 2. The frequency distribution of radon concentration in soil gas and gamma dose rate is illustrated in Figure 2. The measured values of radon concentration in soil gas were between 3 kBq m^{-3} and 97.3 kBq m^{-3}; mostly (86%) were below 50 kBq m^{-3}. The radon concentrations above 70 kBq m^{-3} were measured at seven locations. For comparison: the AM value of 26 kBq m^{-3} were lower than the average of 40.1 kBq.m^{-3} obtained at 70 location all over Slovenia [8] and lower than 75 kBq.m^{-3} for Austria [7].

Table 2

Radon concentration in soil gas

Code	No.	C(^{222}Ra) in soil gas [kBq m^{-3}]		Temperature [°C]		Humidity [%]	
		range	AM	range	AM	Range	AM
AG	5	11-18	14	28-31	29	31-41	37
BG	4	4-19	10	23-42	32	21-41	31
BS	5	3-50	21	15-22	19	45-59	51
CM	5	24-67	50	17-25	19	61-90	84
EL	5	12-97	52	23-31	26	41-80	55
PK	5	11-21	17	32-39	34	27-35	33
PS	5	22-49	30	30-39	35	14-18	16

Table 2 (continued)

PV	5	28-66	52	21-37	29	24-51	35
SA	5	13-40	22	-	-	-	-
SM	5	12-27	17	21-30	26	45-78	61
SO	5	23-41	34	32-39	36	20-41	31
SZ	5	4-5	4	-	-	26-34	29
VA	5	7-22	13	22-31	26	32-59	44
All	64	3-97	26	15-42	28	14-90	42

From the Table 2 we can see that the arithmetic mean values vary from area to area as well as from location to location within the same area caused by the complexity of the geology. The urban areas: Eleshnica (EL) and Plovdiv (PV) have the higher AM concentration of radon concentrations in soil gas and the lowest in Stara Zagora (SZ) area was found compared with other areas.

The arithmetic mean value of gamma dose rate 141 nSv.h^{-1} in the range 70–250 nSv h^{-1} and was higher than the average value obtained for the central part of Slovenia of 118 nSv h^{-1} [6].

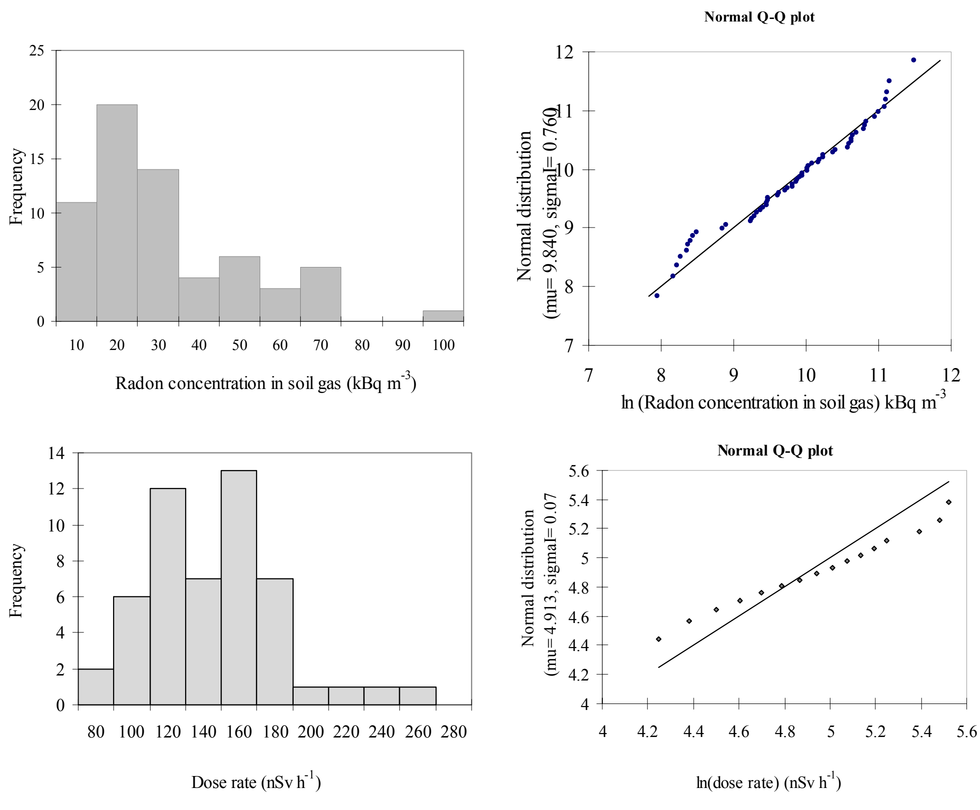

Fig. 2 – left: Frequency distributions of the radon concentration in soil gas (upper) and gamma dose rate (down). Right (upper and down): ln transformed data fitted with normal distributions.

Left graphs on the Figure 2 indicate that the distribution of radon concentration in soil gas and gamma dose rate are log normal distributed. The hypothesis for log – normality of measured data were tested using Kolmogorov-Smirnov test with error probability $p > 0.05$. The testing results presented in Table 3 have shown that: the distribution of radon concentration in soil gas, temperature, humidity and gamma doses rate follows a log normal distribution.

Table 3

Results of log-normal distribution test at 95% significance level

Variable	p - probability*
^{222}Radon	0.813
Temperature	0.235
Humidity	0.975
Gamma dose	0.525

* *when p>0.05 the difference between empirical and theoretical distributions is not significant*

In order to avoid influence of the extreme values, for correlation identification between measured quantities the ln transformed data were used.

Firstly we analyzed the influence of temperature and humidity, parameters responsible on temporal variation of radon in soil gas. Because the one site measurements were performed in one day, the null hypothesis for correlation between soil gas radon concentration and temperature, humidity were rejected at the level of significance $\alpha = 0.05$.

Furthermore, the significant correlation between radon concentration in soil gas and gamma dose rate was obtained. There was weak (Pearson coefficient $R = 0.302$ and Determination coefficient $R^2 = 0.0915$, $p = 0.033$) as shown in Figure 3. The similar correlation was reported by Ramolaa R.C. *et al.*, (2006) [9].

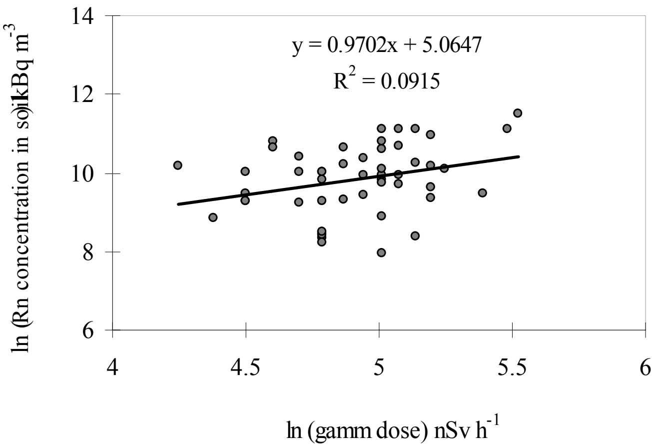

Fig. 3 – Correlation between radon concentration in soil gas and gamma dose rate.

Analysis performed on type of soil affected to radon concentration in soil gas and gamma dose rate an appeared to be significant. The mean ln transformed values of soil gas radon concentration and gamma dose rate grouped by different type of soil are presented in Figure 4. The higher geometric means of radon concentration in soil gas than the other for: sand & humus (47 kBq.m^{-3}), granite & gneiss (40 kBq m^{-3}), sand (32 kBq m^{-3}), and granite (29 kBq m^{-3}) were obtained. As expected, the high values in granite and granite & gneiss were found, which in general, is caused by high radium contents in granites. The high value in sound, because of its high permeability indicates on relationship between soil and bedrock radium content. In addition for humus we take explanation given in UNSCEAR, 2000 that radium transfers freely to vegetation and the emanation from soil organic matter is more effective than from soil minerals [2].

The highest 250 nSv h^{-1} and the lowest 97 nSv h^{-1} geometric mean of gamma dose rate were obtained for granite&gneiss and clay&sand respectively.

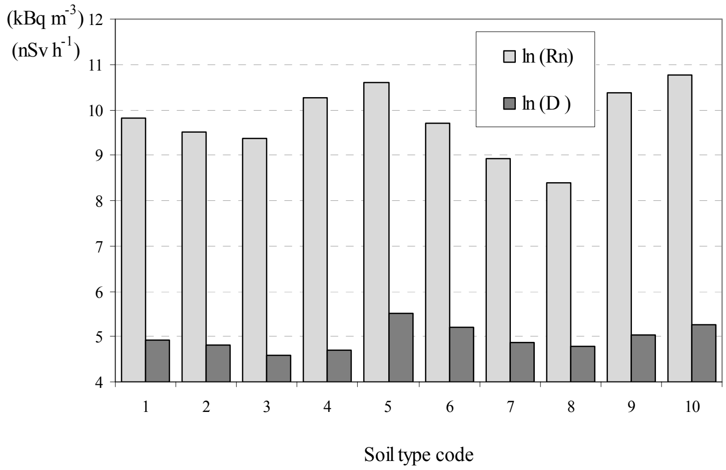

Fig. 4 – Mean values of radon concentration in soil gas and gamma dose rate in different soil type, coded: 1 - clay, 2 - clay & magma stone, 3 - clay & sand, 4 - granite, 5 - granite & gneiss, 6 - gravel, 7 - gravel & sand, 8 - large gravel with alloy of clay and sand, 9 - sand and 10 - sand & humus.

4. CONCLUSION

The preliminary survey of radon concentration in soil gas and gamma dose rate in different urban areas of Bulgaria was performed. A weakly positive correlation between radon in soil gas and gamma dose rate with a correlation coefficient (R) of 0.033 was obtained.

The fact that the measured radon concentration in soil gas in some urban areas is higher than other is due to the geology and, consequently high indoor radon can be expected. Further studies have to be carried out to confirm these results, measuring: indoor radon, ^{226}Ra in soil and radon in soil gas as well soil permeability.

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