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DETERMINATION OF THE MONTHLY VARIATION OF RADON ACTIVITY CONCENTRATION IN SOIL

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ABSTRACT. The aim of this study was to assess the monthly variation of radon concentration in soil. Besides the radon concentration in soil, the measured parameters were soil permeability, air temperature, pressure, humidity and wind speed. The measurements were conducted for seven months, from December to June. For the soil permeability measurements RadonJok device was used and for determination of radon activity concentration in the soil it was used the Luk-3C device, equipped with scintillation cells. The highest radon concentration was measured in June (48 kBq m^{-3}). Due to precipitations, on the soil surface a water film was created and as a result the radon could not diffuse into the atmosphere. Because of high permeability, a lower radon concentration was measured on April, which was 17 kBq m^{-3}. The permeability favored radon diffusion which decreased its quantity in soil. The highest radon potential was determined to be in June. The lowest was determined to be in April, when the soil permeability was at its highest value. The radon index was medium for January to May and high for June.

Key words: *radon in soil, monthly variation, radon potential, radon index.*

INTRODUCTION

Radon (Rn-222) is one of the most studied elements at this moment and, as a result of epidemiological studies; it was classified as the second cause of lung cancer, after smoking (WHO, 2009). Radon is colorless; it has no smell or taste.

Radon is highly mobile and cannot be fixed by chemical reactions. Since radon sources continuously emit this gas, systematic measurements are required to determine areas with increased radon potential (Niță et al., 2010). The resulting products from the disintegration of Rn-222 are attached to aerosol particles. Lungs inhalation of these particles causes an increase in internal exposure of the human body and may result in a higher incidence of lung cancer (Mikšová & Barnet, 2002).

Radon migration from the place of formation to atmosphere, water and houses, depends on certain factors such as soil porosity and humidity, pressure and temperature difference between two environments (soil, atmosphere and water).

The radon exhalation from the soil involves two processes: the emission and the transportation of radon through diffusion and convection (Alharbi et al., 2006). The two processes are affected by several factors including soil properties such as moisture, porosity, permeability and soil grain (Tauner, 1964).

MATERIALS AND METHODS

The determination of radon activity concentration in soil

The measurements of radon activity concentration in soil were performed with the LUK-3C device, shown in figure 1. The device is based on scattering detection technique through Lucas cells. The method for determining the concentration of radon activity is detailed by Cosma et al., 2013.

Fig. 1. *LUK-3C device*

The determination of the radon potential in soil

In order to determine the radon potential in soil, both radon activity concentration and soil permeability measurements are necessary. Soil permeability is very important in the process of transporting the gas through the soil. This largely influences radon flow or exhalation and, in the present case, it was determined with the help of Radon Jok device (figure 2). The base of soil permeability determination is Darcy equation (I):

$$Q = F \cdot \left(\frac{k}{\mu}\right) \cdot \Delta p \qquad \text{(I)}$$

Q – the air flow through the extraction tube ($m^3 \cdot s^{-1}$), **F** – extraction tube shape factor (m), **k** – soil permeability (m^2), **μ** - dynamic air viscosity (Pa·s), **Δp** – pressure difference between the soil surface and the active soil area (Pa).

For the calculation of the shape factor (**F**) of the probe from equation (I), the following relation is used (II):

$$F = \frac{2 \cdot \pi \cdot L}{\ln \{2 \cdot L \cdot [\frac{(4 \cdot D - L)}{(4 \cdot D + L)}]^{1/2} / d\}} \qquad \text{(II)}$$

L – the active surface length (m), **d** – the diameter of the active surface (m), **D** – the depth of the extraction tube (m).
The determination of soil permeability is calculated according to the equation (III) (Radon Jok manual):

$$k = \frac{V \cdot \mu}{F \cdot \Delta p \cdot t} \quad \text{(III)}$$

V – volume of the expandable cell of Radon Jok device (2 · 10-3 m3), μ - dynamic air viscosity (Pa·s), at 10ºC, μ = 1,75 · 10-5, F – extraction tube shape factor (m), t – the time in which the cell is expanded to maximum (s).Δp – pressure difference between the soil surface and the active soil area (Pa).

The upper detection limit of the Radon Jok device is 1.8 x 10 -11 m2, and it does not have a lower limit (Mikšová & Barnet, 2002). The upper part of the Radon Jok device is equipped with an expandable air cell with a volume of 2 x 10-3 m3. On the upper part, the air cell is equipped with a tap connected to the air extraction probe from the soil. On the lower part of the cell there is a calibrated metal rod equipped at the end of it with the weights needed to expand the air cell filled with air extracted from the soil. With the help of these two weights the pressure difference is determined. The pressure difference is 2160 Pa when using a single weight and 3750 Pa when using both weights, in order to determine soil permeability. The lower part of the device is equipped with a tripod so that the device will stand in a straight position for proper use. Once the tap is open, the Radon Jok begins measuring the time required to fill the expandable cell. The resulting time is the time (t) from equation (III).

Radon Potential is calculated according to the equation (IV) (Neznal, et al., 2004):

$$R.P. = \frac{3th\ quartile\ from\ Radon\ Activity\ Concentration - 1}{-\log(3th\ quartile\ from\ soil\ permeability) - 10} \quad \text{(IV)}$$

Radon Index is ***LOW*** for Radon Potential (R.P.) <10, ***MEDIUM*** for 10 ≤ R.P. < 35 and ***HIGH*** for R.P. ≥ 35.

Fig. 2. *Radon Jok device.*

RESULTS AND DISCUSSIONS

In order to evaluate the monthly variation of radon activity concentration in soil, a set of measurements was made during a period of six months (December - June) within the Faculty of Environmental Sciences and Engineering yard. In this study, it was taken into account the meteorological conditions (air temperature, atmospheric pressure, relative humidity and wind speed), soil permeability and radon activity concentration in five points on an area of 10 m^2 in order to observe the spatial distribution of radon activity.

Table 1 presents the meteorological situation during the determination of the radon activity concentrations in the selected points, and also the concentration values of radon activity in soil. In December the maximum concentration was 45.5 kBq m^{-3} and the minimum concentration was 24.8 kBq m^{-3}. In January, the radon concentration in soil was lower than in December. In February, the highest average of radon activity concentrations from the entire study was obtained (35.2 kBq m^{-3}). Low concentrations of radon activity were recorded in April and in two measuring points the concentrations could not be determined. The main cause was the high soil moisture concentration. Soil permeability was determined since February, when soil moisture was reduced.

Table 1. *The activity of radon in the soil on a period of six months*

Months	***T (ºC)***	***P (mb)***	***H (%)***	***Wind speed (m s^{-1})***	***Soil perm. (m^2)***	*Radon Concentration **(kBq m^{-3})***				
						Measuring points				
						1	**2**	**3**	**4**	**5**
December	2.2	952.4	85	0.4	-	26.6	27.6	45.5	24.8	30.8
January	10.1	958.9	99	3.6	-	20.4	26.1	27.0	22.1	24.6
February	14.1	950.7	45	2	$2.23 \cdot 10^{-12}$	29.0	40.9	43.2	32.8	29.9
March	10.5	954.2	42	2	$6.23 \cdot 10^{-12}$	10.1	22.0	32.2	35.2	22.6
April	14.2	976.7	35	4.0	$9.42 \cdot 10^{-12}$	-	-	20.4	16.7	12.7
May	20.3	971.3	50	0.5	$6.38 \cdot 10^{-12}$	10.0	11.9	42.1	29.2	20.3
June	23.3	967.5	50	1.5	$5.25 \cdot 10^{-12}$	43.8	42.3	52.2	46.4	53.7

T – Temperature; **P** – atmospheric pressure; **H** – relative humidity; **Soil perm.** – Soil permeability.

The Spearman correlation coefficient shown a good negative correlation between the radon activity concentration in soil and atmospheric pressure (r = -0.83), respectively a moderate correlation with wind velocity (r = -0.75).

Table 1 and figure 3 show the evolution of the radon activity concentrations in soil during this study, respectively the atmospheric pressure. The explanation of the high radon concentration in soil on the cold period is that in the three months (December, January and February), the precipitation is often short-lived, maintaining the soil pores saturated with water making the radon unable to pass through the pores so that the radon concentration increases. In the warm season, the soil moisture is reduced, the pores of the soil are devoid of water and radon diffuses and reaches the atmosphere, lowering the concentration of radon in the soil (Taipale and Winqvist 1985; Cosma and Jurcuț, 1996).

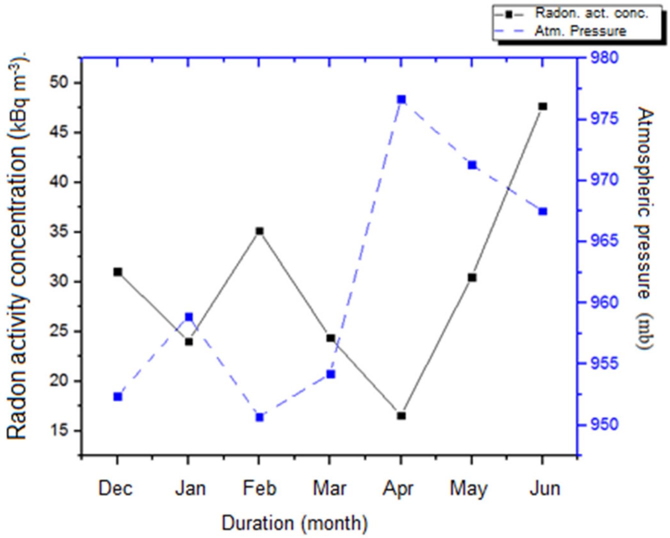

Fig. 3. *The variation of radon activity concentration in soil and atmospheric pressure for the monitored period.*

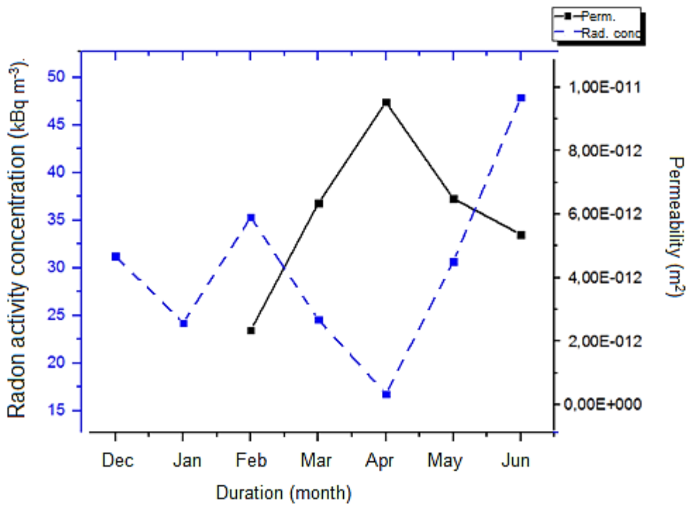

Fig. 4. *Variation of soil permeability and soil radon concentration for the monitored period.*

Figure 4 shows the permeability of the soil and the concentration of radon activity in the soil for the study period. Analyzing this graph, it can be observed that radon concentration variation depends on soil permeability. For example, in April, when soil permeability is increased, radon activity in soil was at its lowest concentration of 16.58 kBq m^{-3}. In January and February, when the soil permeability is low, the concentration of radon activity in the soil was at its highest concentration 35.15 kBq m^{-3}.

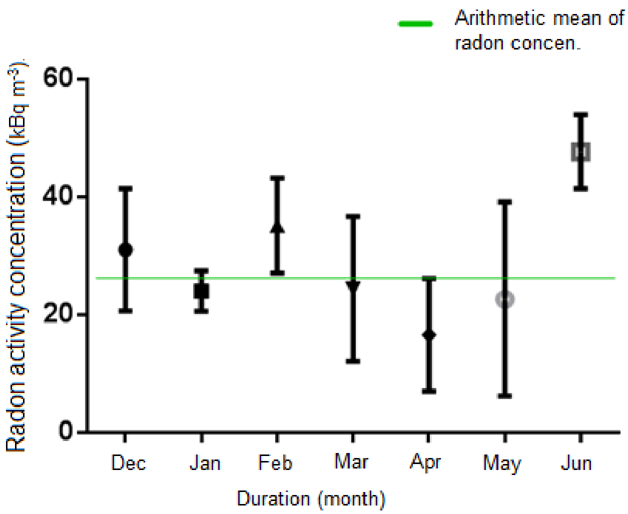

Fig. 5. *Arithmetic mean of radon concentration with confidence interval of 95%*

Figure 5 shows the concentration of radon activity with a confidence interval of 95%. It can be noticed that, except for June, all 95% confidence intervals contain the average of all measurements. The arithmetic mean obtained in June can be considered an outlier because the measurements took place under different conditions (heavy rainfall). Therefore, in case of determining the radon activity concentration in soil, it is recommended to carry out measurements at several points and to determine the 95% confidence interval, along with the recommendation not to perform measurements in periods of heavy rainfall.

Table 2. *The radon potential (R.P) and the radon index (R.I) determined in soil calculated with radon activity concentration and soil permeability*

Month	*D* ***(m)***	*Rn Conc.* ***(kBq m^{-3})***	*K* ***(m^2)***	*R.P.*	*R.I.*
December	0.8	31.1	-	-	-
January	0.8	24.0	-	-	-
February	0.8	35.2	$2.23 \cdot 10^{-12}$	24	MEDIUM
March	0.6	24.4	$6.23 \cdot 10^{-12}$	26	MEDIUM
April	0.8	16.6	$9.42 \cdot 10^{-12}$	18	MEDIUM
May	0.8	30.5	$6.38 \cdot 10^{-12}$	31	MEDIUM
June	0.8	47.7	$5.25 \cdot 10^{-12}$	43	HIGH

Table 2 shows the highest radon potential which was determined in June and the lowest in April, when the soil permeability was highest. The radon index was medium from February to May and high in June. Although variations in radon concentration in soil are high (16.58 – 47.7 kBq m^{-3}), from the perspective of radon index, with the exception of June, the same category (Medium) was found. As such, it is recommended that, along with radon concentration in soil, the soil permeability to be also calculated, in order to assess the radon potential and radon index which are essential for the identification of “hot” areas in terms of radon activity concentration.

CONCLUSIONS

This paper aimed primarily to assessing the variation of radon activity concentration in soil. In addition, weather conditions were taken into account when determining the concentration (air temperature, atmospheric pressure, air humidity and wind speed). The meteorological information is available on the web site of the National Meteorological Administration (*www.meteoromania.ro*).

The highest average concentration of radon activity in soil was determined in June (47.7 kBq m^{-3}), due to the abundant rainfall creating a water film through which radon could not diffuse, thus accumulating in the soil. In April, when the lowest concentration of radon activity was recorded, soil permeability was at it’s the highest throughout the study.

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