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MEASUREMENT OF RADON CONCENTRATION IN KINDERGARTENS AND SCHOOLS IN NIŠ, SERBIA[†]

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Abstract. *In this study, the activity concentration of radon, ^{222}Rn, in kindergartens and schools in the town of Niš, Serbia, was explored. The method of active charcoal was applied. The measurements were carried out by gamma – spectrometry with HPGe detector. The results belong to the range of 15 Bq/m^3 – 256 Bq/m^3, with an average value of 59.7 Bq/m^3 and a standard deviation of 25.3 Bq/m^3. It was shown that data are distributed according to the log-normal distribution, and that is no correlation between indoor ^{222}Rn concentrations and the activity concentrations of radium, ^{226}Ra, in the soil.*

Key words: *Radon concentration, active charcoal, gamma - spectrometry*

1. INTRODUCTION

Radon (^{222}Rn) is a radioactive, noble gas (half-life $T_{1/2}$ = 3.825 d) and has been discovered, together with its two isotopes (^{220}Rn, $T_{1/2}$ = 55.6 s and ^{219}Rn, $T_{1/2}$ = 3.96 s) in 1900. ^{222}Rn is a decay product of radium (^{226}Ra), therefore the presence of radon in indoor air is due to the radium contents in the ground. Since building materials originate from the rocks' material, which could contain a certain amount of radium, they could be a considerable source of radon in indoor air. Soil gas radon can enter into the buildings through cracks by pressure-driven mechanism and by diffusion. The relatively long half-life allows it enough time to transport and homogenous mixing in a room (UNSCEAR, 2006).

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The radiation of radon is the largest source of dose which an individual from the general population receives (1.15 mSv), among the other natural sources of radiation (total 2.4 mSv) (UNSCEAR, 2006). Radon presents a certain health hazard due to its short-lived progenies (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po) that may deposit within the lung. Namely, when radon is inhaled, some of its decay products, attached and nonattached to the aerosols, tend to stick to the epithelial tissue and deposit in the lungs and irradiate cells in the respiratory tract. Therefore, the ICRP (International Committee for Radiological Protection) recommendations emphasized the importance of controlling radon exposure in dwellings and workplaces arising from existing exposure situations (ICRP, 2007). Very extensive measurement programs have been conducted and have formed the basis for implementing measures to reduced indoor radon concentrations (UNSCEAR, 2008). Some European countries established national guidelines for ^{222}Rn of 200 Bq/m^3 for both existing houses and new construction. A number of countries, as well as Serbia, determined 400 Bq/m^3 as the upper limit for existing houses and 200 Bq/m^3 for new construction (Off. Gazette, 2018).

There are studies that have showed that children are more susceptible to radiation exposure than adults even for low doses received (Bem, 2013). So, many research projects worldwide concerned the radon in kindergartens and schools (Durick et al., 1997, Gaidolfi et al. 1998, Maged 2006, Synnot et al., 2006, Rahman et al., 2009, Obed et al., 2011, Trevisi et al. 2012, Bem et al., 2013, Vuchkov et al. 2013, Branco et al., 2016). Few investigations deal with radon measurements in kindergartens and schools in some regions of Serbia (Žunić et al., 2010, Stajić et al., 2015). Since there were no such investigations in the region of the town of Niš (43º19'15" N, 21º53'45"E, 201 m above the sea level), which is an economic, cultural and educational center of southeastern Serbia, in which vicinity is Niška Banja where very high radon concentrations have been measured (Manić et al., 2006, Nikolov et al., 2012), in this work the measurements of radon concentrations in kindergartens and schools in Niš were done.

2. METHOD

The indoor radon activity concentration has been measured in 30 kindergartens and schools in the town of Niš during the winter-spring season. Radon concentrations in air were determined by the active charcoal canisters method, according to the standard EPA procedure (EPA, 1987).

Measurements were performed by gamma – spectrometry with Canberra HPGe detector calibrated in the energy range 40 keV – 3000 keV, with relative efficiency 26% and FWHM = 1.8 at 1332 keV (^{60}Co), using the software Genie 2000, Canberra, USA. Calibration was performed by a standard radionuclide source of ^{226}Ra in 10 cm C-S canister (NIST – 679, US), with the relative expanded uncertainty 3.3 %. The estimated combined standard uncertainty of the method was 10% at a 95% confidence level.

The concentration of ^{222}Rn was determined by the photopeaks of its gamma-emitting progenies ^{214}Pb (295 keV and 351 keV) and ^{214}Bi (609 keV). So, the measurements were carried out 3 hours after closing the canisters, when the radioactive equilibrium between radon and its progenies has been reached. Further, the ^{222}Rn concentration was calculated using a program with the input quantities (EPA, 1987):

- The total number of counts in the range of 270 keV – 720 keV, for measurements before opening and after closing canister, in CPM (counts per minute);
- The efficiency of counting of gamma detector for specified range in CPM /Bq;
- The time from the middle of indoor exposure of the activated charcoal to the start of measurement on the gamma spectrometer;
- The masses of canister before and after exposure.

3. Results and Discussion

The results of the measurements of indoor radon for 20 kindergartens and 10 elementary schools in the city of Niš are presented in Table 1. For each measurement site, two or three canisters were used and the result is the mean of obtained values.

The corresponding annual effective doses *E* (mSv) are also given in the table. They are calculated by the equation:

$$E = C\,(^{222}\mathrm{Rn}) \cdot F \cdot O \cdot DCF\ ,$$

where: C (^{222}Rn) is concentration activity of ^{222}Rn in Bq/m^3, F is equilibrium factor indoors (F = 0.4), O is indoor occupancy (O = 7000 h) and DCF is the dose conversion factor, DCF = 9 nSv/(Bq h m^{-3}) (UNSCEAR, 2000).

Table 1 The radon concentrations in kindergartens and schools in Niš, C (^{222}Rn) (Bq/m^3), corresponding effective doses, E (mSv), and activity concentrations of radium, A (^{226}Ra) (Bq/kg), (Manic et al., 2019) in soils from the yards of kindergartens and schools in Niš

Serial number	The name and address of kindergarten or school	C (^{222}Rn) (Bq/m^3)	E (mSv)	A (^{226}Ra) (Bq/kg)
	Kindergartens			
1.	"Maslačak", Sokolska b.b.	46	1.16	18
2.	"Cvrčak", Bulevar Nemanjića b.b.	52	1.31	35
3.	"Biser", Školska česma b.b.	34	0.857	95
4.	"Plavi Čuperak", Boško Buha b.b.	34	0.857	31
5.	"Slavuj", Dr Milutina Ivkovića b.b.	52	1.31	20
6.	"Bubamara", Kosovke devojke 1	35	0.882	25
7.	"Bambi", Bulevar Nemanjića b.b.	30	0.756	28
8.	"Crvenkapa", Mokranjčeva b.b.	15	0.378	36
9.	"Kolibri", Dragiše Mišovića 2	33	0.832	23
10.	"Petar Pan", Đerdapska b.b.	70	1.76	29
11.	"Palčić", Đerdapska b.b.	19	0.479	28
12.	"Karađorđe", Prosvetina 1	34	0.857	18
13.	"Zvončići", Romanijska b.b.	20	0.504	37
14.	"Pinokio", Sestara Baković 17	52	1.31	17
15.	"Vilin grad", Timočka b.b.	52	1.31	17
16.	"Bajka", Salvadora Aljendea b.b.	17	0.428	17
17.	"Neven", Katićeva b.b.	42	1.06	18
18.	"Pepeljuga", Marina Držića 48	32	0.806	21
19.	"Svitac", Ratka Jovića b.b.	28	0.706	24
20.	"Leptirić", Južnomoravskih brigada b.b.	36	0.907	24

Table 1 (continued)

Serial number	The name and address of kindergarten or school	C (^{222}Rn) (Bq/m^3)	E (mSv)	A (^{226}Ra) (Bq/kg)
	Elementary schools			
1.	"Branko Miljković", Ljubomira Nikolića 3	63	1.59	14
2.	"Miroslav Antić", Knjaževačka 156	34	0.857	22
3.	"Vuk Karadžić", Beogradska 2	86	2.17	18
4.	"Kralj Petar prvi", Vojvode Putnika 1	43	1.08	18
5.	"Stefan Nemanja", Kosovke devojke b.b.	160	4.03	23
6.	"Bubanjski heroji", Bubanjskih heroja b.b.	131	3.30	19
7.	"Sveti Sava", Garsije Lorke b.b.	81	2.04	22
8.	"Učitelj Tasa", Rajićeva 34	118	2.97	20
9.	"Bubanj", Bubanjskih heroja 3	256	6.45	20
10.	"Čegar", Školska b.b.	85	2.14	20

It can be seen from the table that the minimum concentration of ^{222}Rn, 15 Bq/m^3, with the corresponding effective dose of 0.378 mSv, was measured in kindergarten "Crvenkapa", Mokranjčeva b.b. The maximum of ^{222}Rn concentration, 256 Bq/m^3, with an effective dose of 6.45 mSv, was found in elementary school "Bubanj", Bubanjskih heroja 3. The average value of ^{222}Rn concentration is 59.7 Bq/m^3 (E = 1.50 mSv) and standard deviation is 25.3 Bq/m^3 (0.638 mSv).

Worldwide indoor radon concentrations vary widely from a few Bq/m^3 to more than $7 \cdot 10^4$ Bq/m^3 in high background areas (UNSCEAR, 2006). The average values for individual countries range from 9 to 184 Bq/m^3, and UNSCEAR 2000 Report deduced a value of 40 Bq/m^3 for the arithmetic mean. So, the average value of indoor radon concentration obtained in this study is about 50 % higher from the average value worldwide. However, since higher ^{222}Rn concentrations occur in the autumn or early winter and lower in the summer, the values measured in this work are probably higher than the yearly means.

Figure 1 presents a probability density distribution of measured concentrations of radon. In order to explore whether the data can be fitted by a log-normal distribution, the Kolmogorov – Smirnov test was applied.

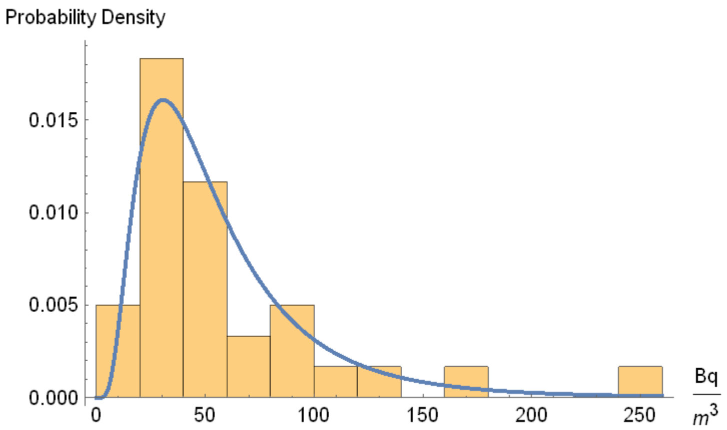

Fig. 1 Probability density distribution of indoor ^{222}Rn concentration (Bq/m^3)

Obtained test statistic value is $D = 0.138$. This is lower than critical value, determined from Kolmogorov - Smirnov distribution table, $D_{30}(0.05) = 0.242$. Also, the probability value, i.e. the *p*-value, $p = 0.149$, is larger than the significance level of 0.05. It indicates that the null hypothesis that the data are distributed according to the log-normal distribution cannot be rejected at the 5 percent level based on the Kolmogorov – Smirnov test.

Since ^{222}Rn is the direct product of ^{226}Ra decay, in this study the correlation between measured indoor radon concentrations and the activity concentrations of ^{226}Ra in the soils in the yards of kindergartens and schools (presented in Table 1), determined earlier (Manić et al., 2019), were explored. The radon measurement results versus corresponding activity concentrations of radium are presented in the form of a scatter plot in Figure 2. Obviously, these two datasets are not linearly dependent. The value of Pearson's correlation coefficient (Wackerly, 1996) which represents the degree of linear dependence of two physical quantities, with a range of values from -1 to 1 is: $\rho = -0.196$. This means that the data are low correlated, and moreover, they are negatively correlated. The obtained negative correlation can be explained by the fact that in addition to the content of the radium in the soil, a large number of factors affect the concentration of indoor radon: soil permeability and moisture, building materials used in the construction, meteorological conditions, ventilation, type of heating, etc. (UNSCEAR, 2008, Gulan, 2017), but probably the most important factor is the content of ^{226}Ra in deeper layers of the ground.

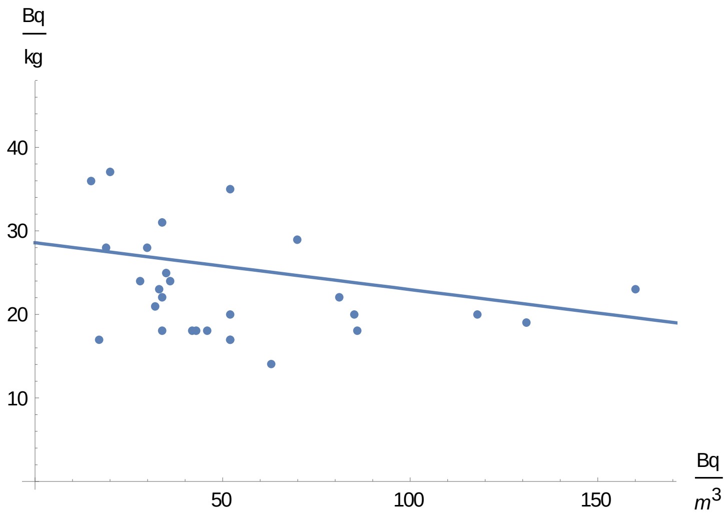

Fig. 2 The scatter plot of indoor ^{222}Rn concentrations (Bq/m^3) and the activity concentrations of ^{226}Ra (Bq/kg) in a soil

4. Conclusion

Almost all values of radon concentration in kindergartens and schools in Niš are below the limit of 200 Bq/m^3. Only one measurement result is above that limit, but under the limit of 400 Bq/m^3 for existing houses. The data follows a log-normal distribution. There is no correlation between indoor ^{222}Rn concentrations and the activity concentration of

^{226}Ra in the surface soil. In order to control the irradiation of the population, further research of radon concentration, which would extend to the whole town, not just to kindergartens and schools, can be recommended.

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MERENJE KONCENTRACIJE RADONA U OBDANIŠTIMA I ŠKOLAMA U NIŠU, SRBIJA

U radu je ispitivana koncentracija radona, ^{222}Rn, u obdaništima i školama u Nišu. Korišćen je metod aktivnog uglja. Merenja su obavljena pomoću gama – spektrometrije sa HPGe detektorom. Rezultati se nalaze u opsegu 15 Bq/m^3 – 256 Bq/m^3, a srednja vrednost iznosi 59,7 Bq/m^3, dok je standardna devijacija 25,3 Bq/m^3. Pokazano je da podaci slede log–normalnu raspodelu, kao i da nema korelacije između koncentracije ^{222}Rn i koncentracije aktivnosti ^{226}Ra u površinskom sloju tla.

Ključne reči: *Koncentracija radona, aktivni ugalj, gama-spektrometrija*