ACTIVE AND PASSIVE RADON CONCENTRATION MEASUREMENTS AND FIRST-STEP MAPPING IN SCHOOLS OF BANJA LUKA, REPUBLIC OF SRPSKA*

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Radon concentration measurements were performed in all 25 primary schools in Banja Luka city, the capital of Republic of Srpska, during 2011 and 2012, using both active RAD7 continual radon measuring instruments and CR-39 passive (commercially known as Gamma) detectors. The two complimentary methods were employed not only to obtain annual averages, but also to study the dynamics of radon concentration changes during the week. For each school, average and temporal variations of radon concentrations were analysed, taking into consideration local geology, building materials and meteorological conditions. The influence of forced ventilation, caused by frequent opening of doors and windows during working hours, with typical dawn and weekend peaks is evident in most but not all schools. Elevated levels of radon concentration (>400 Bq m^{-3}) were found in a few schools using both methods. Although high correlation factor of 0.8 between passive and active methods was found, still short-time (one-week) measurements cannot be used for annual estimation of radon activity but only as a screening one. Thus, the conclusion concerns only long time measurements as valid indicator of annual radon activity.

Key words: Indoor air, radon, primary schools, RAD7, Banja Luka city, Republic of Srpska, active detectors, passive detectors.

1. INTRODUCTION

To obtain a representative distribution of radon concentration and plan appropriate actions within countries, many national radon programmes have been

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started since 1970, particularly in Europe. North America and some Asian countries [1], [2], [3]. Designing and performing a survey on indoor radon concentration in Republic of Srpska (Figures 1 and 2) which may be considered representative of population exposure, became possible for the first time as a research activity in 2011. Primary schools in Banja Luka city were chosen as representative for measurements due to their city location correlation with the number of inhabitants [4], [5]. The assumption is that every community has approximately the same percentage of children within the population. Since children are the most sensitive members of the human society and they spend relatively long time in schools, we adopted as principle that the level of radiation accepted in the schools should be the same as in the dwellings. Most of Banja Luka city belongs to the Vrbas river basin (Figure 1). The river Vrbas flows through the middle of the city (Figure 2).

Fig. 1 – Schematic map of Republic of Srpska.

The central part of the city lies at an altitude of about 163 m and is surrounded by tertiary (Paleogene) hills. Quaternary deposits of clay, silica sand and gravel represent a transition from valley to mountain terrain. The city area can be divided into four parts such as follows: flat bottom valleys (where most of the schools are located), alluvial terraces, hills that surround the valley and of the entire mountains range the Dinaric Alps in the south (Figure 2). The area massif (400–1338 m above sea level) in the southern part of the city is built from limestone and dolomite formations. In the year 1969, two devastating earthquakes (6.0 and 6.4 on the Richter scale) damaged many buildings in Banja Luka. The city was developing downstream, and most settlements were built after World War II and after the earthquake in 1969 spreading out itself towards the hills surrounding Banja Luka.

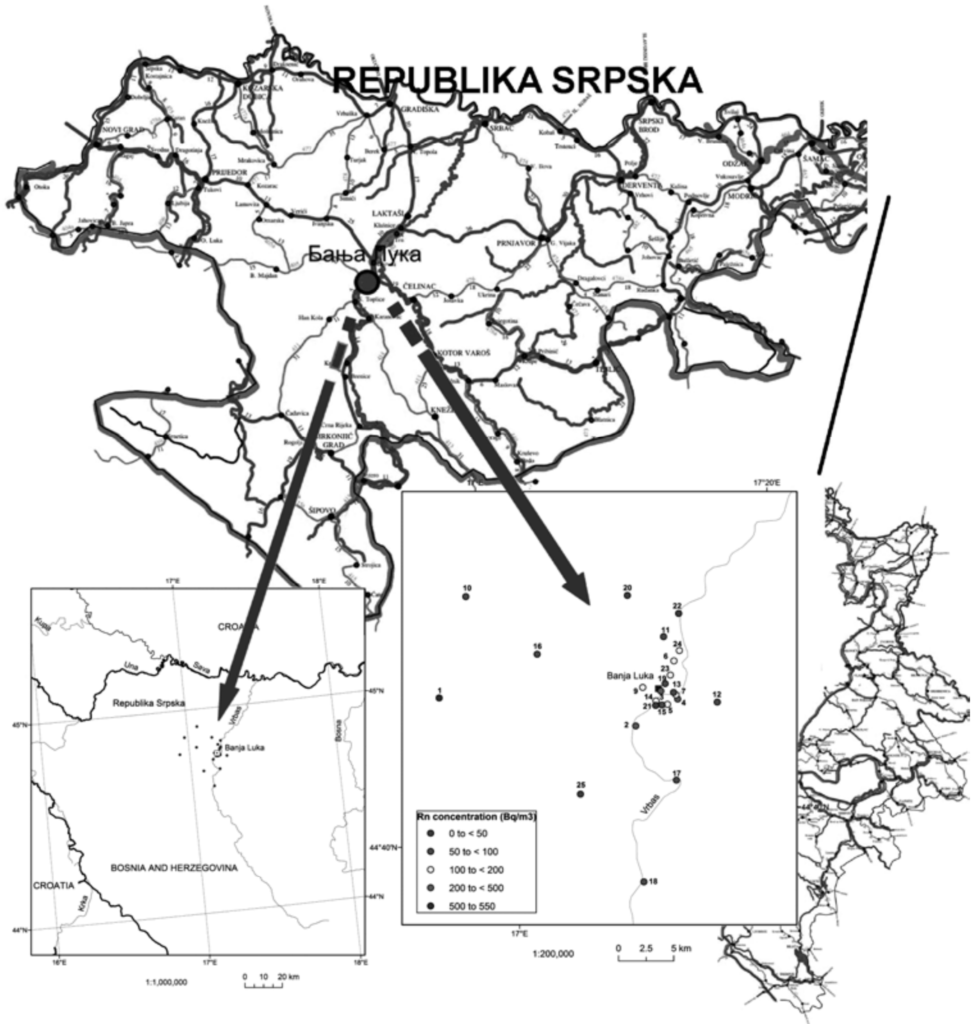

Fig. 2 – Geographical map of Republic of Srpska with location of schools sampled in Banja Luka city area marked in Table 1 (figure down left) and Radon concentration in schools sampled in Banja Luka city area (figure down right).

2. INSTRUMENTATION

The RAD7 continual radon measuring instrument from Durridge Company, USA, was used for active measurements. RAD7 is equipped with the semiconductor α-detector and works on the principle of the converting energy of α-particles directly into electrical signals. This enables determination of isotopes that are the products of radiation (^{218}Po, ^{214}Po), so that radon can be distinguished from its daughters and noise signal. The measuring range is between 4 and 750000 Bq m^{-3} [6]. The internal acquisition provides storage for up to 1000 radon concentration measurements. After passing through a dry stick to lower the relative humidity to below 10%, the sampled air enters an interaction chamber; the air-flow is 1 l/min. For passive sampling we used CR-39 track detectors (Gamma) made by Landauer Nordic, Sweden. For each school, the passive detectors were exposed continuously for one year in order to get an annual average and compare it with weekly averages obtained by the active method. Most of the schools measured (Figure 3) were built between 1950 and 1980, except for Ćirilo i Metodije in 1913, Dositej Obradović in 1799 and Branislav Nušić in 1897. The building materials were mostly bricks with concrete foundations while some schools were made from concrete blocks. The Jovan Jovanović Zmaj school is the only one that was built using metal plates and hence poorly insulated. CR-39 detectors and RAD7 equipment were placed side-by-side mostly in teacher's rooms which are considered as the most instrument-safe place, regarding children's curiosity. The locations of the investigated schools with the corresponding levels of their indoor radon concentrations are shown in Figure 3. By active method, the measurements were carried out in 23 schools between May 2011 and March 2012, on ground floor, while air was sampled 0.5 m above the ground. Data sampling was set at 2 hours by 84 times, *i.e.* one week. The relative humidity of the air sampled inside the instrument was below 10% during all the measurements, while temperatures ranged between 17 ^{o}C and 25 ^{o}C. The CR-39 detectors were exposed from April 2011 to May 2011 in 25 schools in the Banja Luka city area.

3. MEASUREMENT RESULTS

Table 1 shows the name of the school and its location, the results of annual radon concentration by CR-39, active 7-day, working days and weekend average concentrations, month and year of active measurements, school altitude and building materials. As can be seen from Figures 3 and 4, there was no significant increase in radon concentration over the weekend. Although, the most obvious example of radon exhalation behaviour was in Mladen Stojanović school (Figure 3), where radon reached daily maximum over 500 Bq/m^3, every day at 10 a.m. and minimum between 2 and 4 p.m. Sudden radon concentration decrease is visible at about 7 a.m., when classrooms are opened for cleaning and entry of pupils. Those minimum are less severe during the weekends when lowering of radon concentration maximum, caused by temperature inversion in dawn [7], which is governed by outdoor decreasing of the radon concentration. Similar radon concentration changes are already obtained [8]. During weekends the highest values, above 700 and 500 Bq m^{-3}, were reached after 24 hours. The average radon concentration using 7 days active sampling was 101 Bq m^{-3}, while the annual concentration obtained by passive sampling was 134 Bq m^{-3}. Different behaviours of radon exhalation dynamics basically depend on the schools' geographical position, construction material, meteorology and working time *i.e.* forced ventilation. Those changes are shown in Figures 3 and 4. Shaded areas represent the extended weekends, starting on Friday at 19 p.m. when the school is empty and finishing on Monday at 6 a.m. when the school becomes populated again. Figure 3 presents time variation of radon concentration in four schools with the highest radon concentration: Mladen Stojanović, Branislav Nušić, Ivo Andrić and Branko Radičević.

Table 1

Radon concentrations using passive method, weekly, weekend and working days average, building material and altitude of the schools in Banja Luka city area

No	Name of the School / Location	Passive method (CR-39) [Bq/m^3]	Average 7 days value [Bq/m^3]	Month and year of active meas.	Average working days value [Bq/m^3]	Average weekend value [Bq/m^3]	Building material ***	Altitude [m]
1.	Mladen Stojanović, Majdan	550	42	09 .2011	325	550	B & C	290
2.	Branislav Nušić, Toplice*	340	160	06. 2011	160	160	C	185
3.	Ivo Andrić, Centar**	327	401	07. 2011	235	640	B	210
4.	Branko Radičević, Starčevica**	314	120	05. 2011	50	240	C	239
5.	Petar Petrović Njegoš, Mejdan	120	59	09. 2011	59	59	C	215
6.	Ivan Goran Kovačić, Budžak**	130	50	10. 2011	40	50	old B	195
7.	Vuk Karadžić, Borik	126	51	08. 2011	58	42	B	211
8.	Milutin Bojić, Potkozarje	85	67	10. 2011	64	73	B	290
9.	Sveti Savo, Lauš*,**	101	160	08. 2011	150	160	B & C	240
10.	Cirilo i Metodije, Piskavica	63	n/a	08.2011	n/a	n/a	old B	186
11.	Đura Jakšić, Šaragovac	75	41	10. 2011	49	28	B	218

Table 1 (continued)

12.	Stanko Rakita, Vrbanja	80	35	09. 2011	35	35	B & C	211
13.	Branko Čopić, Borik	75	112	01. 2012.	112	114	B	206
14.	Jovan Cvijić, Centar	131	n/a	07. 2011	n/a	n/a	B	211
15.	Dositej Obradović, Mejdan	75	42	09. 2011	36	47	B	221
16.	Miroslav Antić, Bistrica	71	77	11. 2011	73	82	B	236
17.	Milan Rakić, Karanovac	69	51	12. 2011	67	37	C& B	169
18.	Vojislav Ilić, Krupa	65	84	12. 2011	45	127	C	212
19.	Georgije S. Rakovski, N.Varoš	60	40	07. 2011	30	n/a	C	215
20.	Desanka Maksimović, Dragočaj	50	42	10. 2011	45	45	B	167
21.	Zmaj J. Jovanović, Hisete***	50	30	08.2011	25	30	M & C	213
22.	Jovan Dučić, Zalužani	47	30	06.2011	30	40	B	200
23.	Aleksa Šantić, Malta**	142	119	02. 2012	129	102	the oldest B	211
24.	Bora Stanković, Budžak	103	60	10. 2011	30	n/a	B	199
25.	Petar Kočič, Han Kola	40	119	11. 2011	129	102	C	526

**Measurements were made during vacation ** Basement under ground floor with measurement*
**** - B – brick, C – concrete, M - metal plates*

The schools Mladen Stojanović and Ivo Andrić showed radon concentrations over 400 Bq m^{-3} by both active and passive methods. The schools Branislav Nušić and Branko Radičević showed concentrations over 300 Bq m^{-3} by passive method, while the active method gave concentrations only half those values (Figure 3). The school Ivo Andrić with extremely high concentrations is located 200 m away from the school Branko Radičević where high radon concentration is obtained only from the passive method. The higher radon concentration obtained by the active method than by the passive in Ivo Andrić school can be explained by the time when active measurements were made, *i.e.* summer vacation when forced ventilation rarely occurs. As can be seen, working-day levels were about 40 to 60% lower on the average, so the overall inhalation rate of children is lower than the weekly average but still above the recommended level.

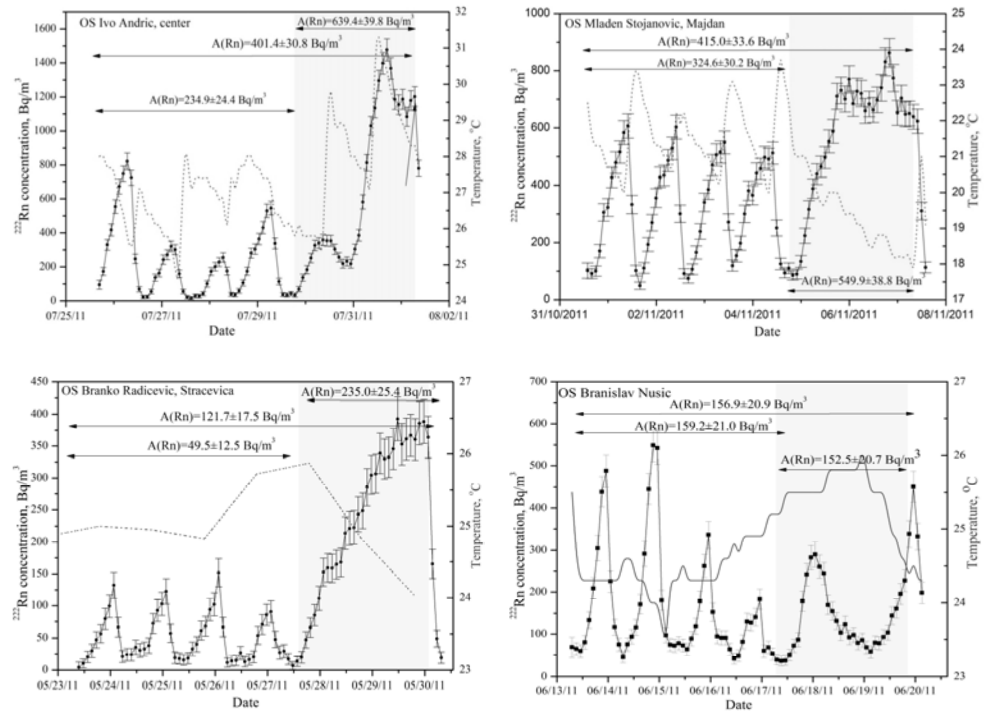

Fig. 3 – Examples of high radon concentrations measured in schools of Banja Luka city.

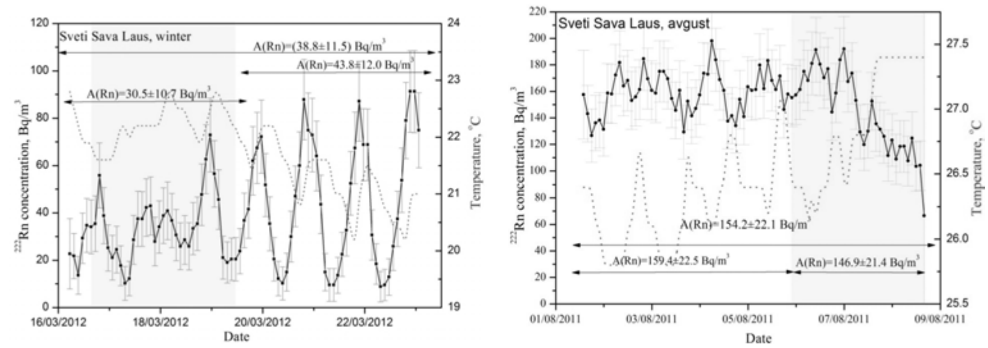

Fig. 4 – School Sveti Sava in summer during holidays and in winter.

In Figure 4, seasonal radon concentration differences during summer and winter are shown. Typical day/night minimum/maximum concentration distribution was different due to school holidays in July/August. During the winter high day-night radon concentration differences arise from forced ventilation during the day when doors and windows are frequently opened. Obvious opposite phase of temperature and radon concentration can be observed in all schools with clearly distinguished peaks. The correlation coefficient between concentrations for passive and active methods for all schools measured was 0.86, which gives a coefficient of determination (a measure of how good a predictor might be constructed from the modelled values) of 0.74. When using a seasonal variability adjustment factor developed for radon concentrations in homes by [9], an approximate correlation factor of 0.83 is obtained (Figure 5).

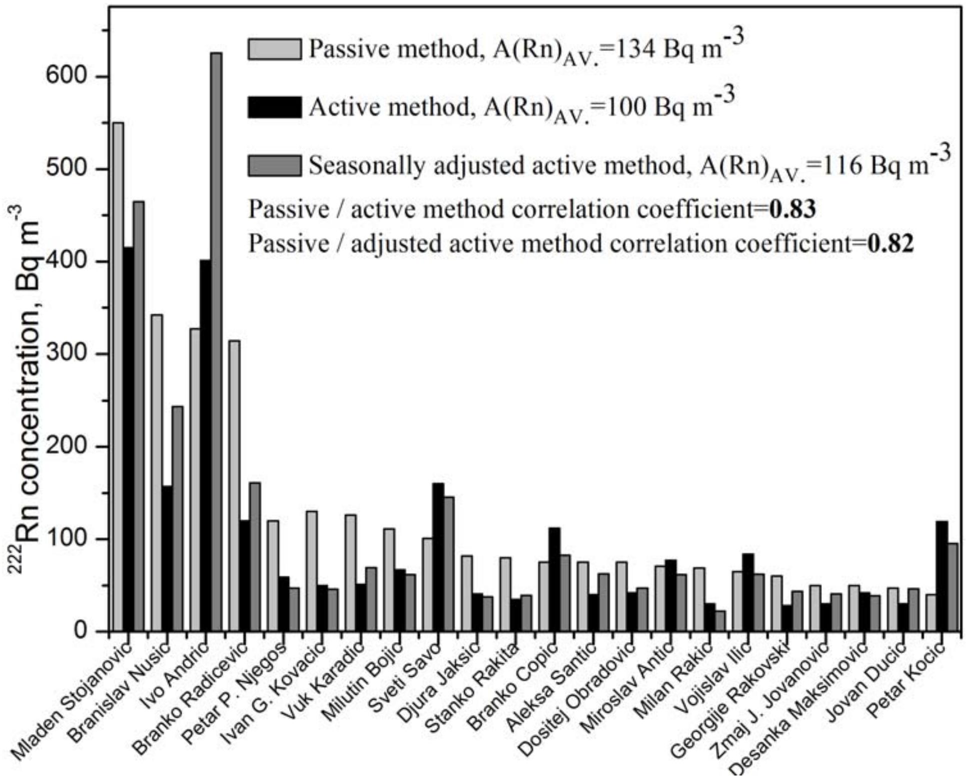

Fig. 5 – Comparison of passive and active methods.

4. CONCLUSION

According to the passive method for radon concentration measurements, 4 of the 25 schools sampled in the Banja Luka city area have concentrations higher than 300 Bq m^{-3}, so they need remediation. Continual (active) short-term measurements are an excellent way of analyzing the dynamics of the radon concentration changes and also for assessing doses received over the time when children are staying in school. Although the correlation coefficient between active and passive measurements is high, substantial errors can be made. This can be seen for example in the Branislav Nušić and Branko Radičević schools, where annual average is more than twice the weekly average. Such high discrepancies cannot be explained only by seasonal differences but also by local meteorology and variations of the ventilation conditions and air exchange between rooms and the outdoor. No particular correlation of radon concentration with building materials is observed, except in the case of the Jovan Jovanović Zmaj school where the positive consequences of poor insulation are very low radon concentrations. Values of radon concentration during the weekend could be very high, so ventilation is recommended before the beginning of the lectures on Mondays. All this can lead to the conclusion that only long time measurements are valid indicators of annual radon activity.

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