RADON MEASUREMENT IN SCHOOLS AND KINDERGARTENS (KREMIKOVTSI MUNICIPALITY, BULGARIA)*

DANIEL VUCHKOV[1], KREMENA IVANOVA[1], ZDENKA STOJANOVSKA[2], BISTRA KUNOVSKA[1], VIKTOR BADULIN[1]

[1]National Center of Radiobiology and Radiation Protection - Sofia, Bulgaria, E-mail: k.ivanova@ncrrp.org
[2]Faculty of Medical Sciences, Goce Delcev, University of Stip, FYR of Macedonia, E-mail: stojanovskazdenka@gmail.com

Received November 15, 2012

Indoor radon concentration was measured in all schools (n = 9) and kindergartens (n = 7) of Kremikovtsi district, Bulgaria, using passive integrating electret detectors. The study was based on two successive: short and long term set measurements. In first phase, the short term detectors were deployed in all frequently occupied rooms in ground floor. The exposure was during the summer vacation (2011) under close condition with 10 days duration. From the results of short term measurement we have found that the radon concentration in 4 schools and 5 kindergartens were above the recommended National level of 300 Bq m^{-3} for existing buildings. In order to confirm the initial short-term measurement long-term measurements for the period from September 2011 to April 2012, in the same buildings of schools and kindergartens were performed under normal functional conditions (second phase). Comparing the results obtained from the short-term measurements under close conditions with the results of long-term measurement, we found that measured values were in correlation (R = 0.817).

Key words: Radon concentration, Long-term measurement, Short-term measurements, Schools, Kindergartens.

1. INTRODUCTION

Exposure to natural radioactive sources is due mostly to radon approximately 50% [1]. Radon is colorless, odorless, and tasteless. It is recognized as a second factor causing lung cancer after smoking [2]. Radon comes indoors by: soil gas - due to pressure difference between the building and its foundations in soil, over: micro pores in the floor, cavities in the interior walls, structural connections, cracks in walls, drains, communication pipes, construction materials, drinking water. Because of high occupancy time for children in schools and kindergarten and

* Paper presented at the First East European Radon Symposium – FERAS 2012, September 2–5, 2012, Cluj-Napoca, Romania.

because of their higher sensitivity to radon exposure than adults, the evaluation of indoor radon in these buildings is more than important.

In this work, we present results obtained from radon concentration survey in schools and kindergartens of the Kremikovtsi municipality in Bulgaria. The comparison of the results obtained by using two different short and long term measurements is reported.

2. MATERIALS AND METHODS

The investigated area of Kremikovtsi (Figure 1) is located to the northeast of the capital town Sofia, Bulgaria and it is located close to the sites associated with former uranium mining and milling industry.

The study on the concentration of radon in premises of kindergartens and schools was conducted on in two phases: short term measurement and long term measurement. Short term measurements in all occupied premises were carried out during the summer vacation under closed conditions during August – September 2011. Depending on the result above than or approximately equal to limit for radon concentration in existing buildings of 300 Bq m^{-3} according to Bulgarian national legislation, was planned next phase of the study. Long term detectors in kindergartens and schools were exposed only in the 29 previously measured classrooms on the ground floors in period from September 2011 to April 2012. Results of five detectors were lost during the survey. Number of buildings and premises in the first phase and classrooms are given in the Table 1.

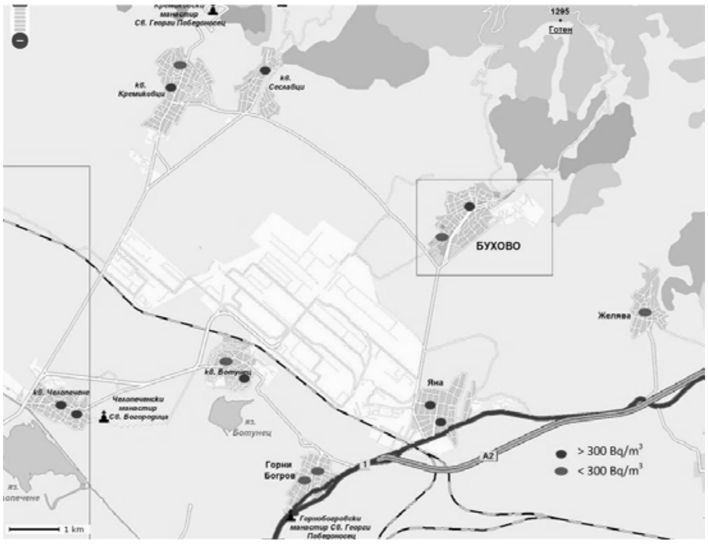

Fig. 1 – Map of Kremikovtsi area with measured buildings.

The study on the concentration of radon in premises of kindergartens and schools was conducted on in two phases: short term measurement and long term measurement. Short term measurements in all occupied premises were carried out during the summer vacation under closed conditions during August–September 2011. Depending on the result above than or approximately equal to limit for radon concentration in existing buildings of 300 Bq m^{-3} according to Bulgarian national legislation, was planned next phase of the study. Long term detectors in kindergartens and schools were exposed only in the 29 previously measured classrooms on the ground floors in period from September 2011 to April 2012. Results of five detectors were lost during the survey. Number of buildings and premises in the first phase and classrooms are given in the Table 1.

Table 1

Numbers of measured buildings and premises/classrooms

Type of measurement	Tape of building	Number of buildings	Number of premises/classrooms
Short-term	School	9	57
	Kindergarten	7	41
Long-term	School	4	12
	Kindergarten	5	12

The measurements were carried out with Electret ionization chambers (EICs) passive integrating detectors. Radon gas diffuses into the chamber by passive diffusion through a filtered inlet. Radiation emitted by radon and its decay products formed inside the chamber ionizes the air within the chamber volume. The negative ions are collected by the positive electret located at the bottom of the chamber. The discharge of the electret over a known time interval is a measure of time-integrated ionization during the interval and proportional to the radon concentration. The electret discharge in volts was measured using a noncontact battery-operated electret reader. This value, time exposure and calibration factor yields the radon concentration in Bq m^{-3}. Linear correlation between CF and the electrets voltage over a range of 150 V to 750 V, was used to develop calibration factors for appropriate time exposure (Equation 1):

$$CF = A + B \cdot \frac{(I + F)}{2}, \quad (1)$$

where A and B are constants for a particular configuration, and I and F are the initial and final electret voltages.

The gamma background radiation was measured with the portable gamma dose rate meter in order to apllied background correction on results for radon concentration calculation.

Three main sources of uncertainties influent the assessment of radon concentration: The first associated with the system component imperfections, which includes uncertainty in chamber volumes, electret thickness and other component parameters. The second is in the electret voltage reading and calculate using Equation 2.

$$u_v = \frac{100 \cdot 1.4}{(I-F)}\%, \tag{2}$$

where I and F are the initial and final electret voltages and 1.4 volts is the uncertainty of the two readings difference which is the square root of the sum of the squares of the two 1 volt errors. The third source is due to uncertainty in the gamma background.

Typical at a concentration of 150 Bq m^{-3} short-term EICs are designed to measure radon for 2 to 15 days and the long-term EICs measure radon over 3 to 12 months [2].

For the purpose of evaluation of precision and accuracy of the measurement method the duplicate measurements were used. The duplicate measurement have made concurrently and in the same location. When the average value of couple detectors was <100 Bq m^{-3} these results were not included in the succeeding evaluation. In case of average value greater or equal to 100 Bq m^{-3} the calculation of the relative percentage difference between detectors was estimated, using the following equation:

$$RPD = \frac{|A_1 - A_2|}{M} 100\%, \tag{3}$$

where A_1 and A_2 are the measured results of the duplicate detector, and M is the average value between them. The results were considered to be acceptable if RPD <20%. In our study the estimated average relative difference for all 15 duplicate measurements was 5%, therefore the results was considered to be acceptable.

3. RESULTS AND DISCUSSION

The summary statistic with relevant parameters of the log-normal distribution of radon concentration measured in first phase is reported in Table 2. Data ranged between 32 and 1305 Bq m^{-3}, with arithmetic mean of 339 Bq m^{-3} (SD: 315 Bq m^{-3}) and geometric mean of 220 Bq m^{-3} (GSD: 2.59).

Table 2
Summary statistic of indoor radon concentration in all 16 schools and kindergarten buildings of Kremikovtsi district (short term measurements)

	C_{Rn} (Bq m^{-3})
No. of monitored premises	98
Minimum	32
Median	196
Maximum	1305
Arithmetic mean	339
Estimated standard deviation	315
Standard-error	32
Geometric mean	220
Geometric standard deviation	2.59
Distribution	Log-normal

The minimum and maximum radon concentrations measured for each building in first phase and its arithmetic mean values are shown in Figure 2.

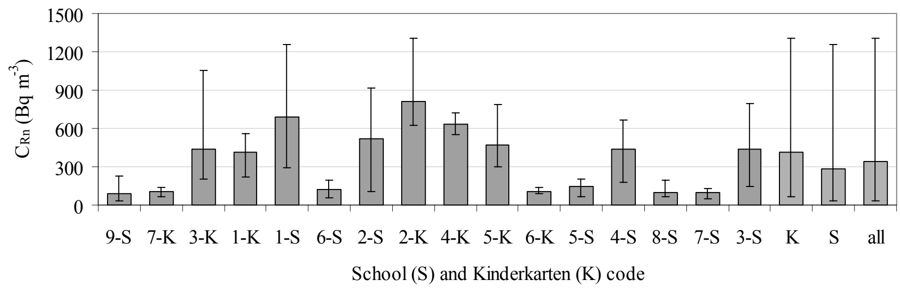

Fig. 2 – Arithmetic mean of indoor radon concentrations obtained in first phase: short-term measurements in Kremikovtsi schols and kindergartens (first phase measurements). Bars present min and max values.

It can be seen from the figure that the radon concentration above recommended level of 300 Bq m^{-3} were obtained in 9 of the 16 school buildings and kindergartens in Kremikovtsi region in Sofia-city district. High values can be attributed to different factors: mainly of the bedrock geology as well building characteristics and ventilation regime. Anyway, the highest value of indoor radon concentration (1305 Bq m^{-3}) was measured in kindergarten (2-K), in an old building with poor ventilation. In general, if we compare the results of indoor radon concentration measurements in all schools and kindergarten, we find out that values for kindergarten are higher than values for schools. That may have two reasons. The first is related to presence of basement and number of floors in schools buildings, which is generally higher than in kindergarten. The kindergartens were mainly old ground floor buildings without basement and foundations, factors which allow radon gas to emanate easily from underlying soil into the indoor areas. The second reason could be found in the lower ventilation rate of the kindergarten due to keeping closed windows longer than in schools. Moreover, on elevated radon concentration in renovated building (schools and kindergarten) also may result from the renovated buildings were wood frames of the windows has been replaced by a new type PVC windows. This type of windows save energy but results reduced ventilation rates, leading to increased indoor radon concentration.

The arithmetic mean values of indoor radon concentration in schools (AM = 287 Bq m^{-3}) and kindergarten (AM = 411 Bq m^{-3}) of Kremikovtsi based on short-term measurements are comparable with the results from the other countries. The indoor radon concentration in Slovenian school (AM = 480 Bq m^{-3}) was higher than that found in this study [3]. In schools in Greece (AM = 149 Bq m^{-3}) and in Neapolitan area, Italy (AM = 144 Bq m^{-3}), the concentration were lower [4-5]. In addition, AM of indoor radon in kindergarten of Kremikovtsi (AM = 896 Bq m^{-3}) is higher than value reported for Slovenian kindergartens (AM = 411 Bq m^{-3}), [3].

In order to insure reliable values of radon concentration, long-term measurements in 24 classrooms of 9 buildings with radon concentration exceeding reference levels of 300 Bq m^{-3}, were conducted. The long term detectors were exposed along a period of six months, in identical classrooms on identical position to that of short-term measurements, under normal functional conditions. The summary statistics is presented on Table 3. As well as short term measurements, the long term measurements were log normally distributed with GM=542 Bq m^{-3} and GSD= 2.06.

Table 3

Summary statistics of long-term measurements in 4 schools and 5 kindergartens.

	C_{Rn} (Bq m^{-3})
No. of monitored classrooms	24
Minimum	104
Median	463
Maximum	1761
Mean	694
Estimated standard deviation	504
Standard-error	103
Geometric mean	542
Geometric standard deviation	2.06
Distribution	Log-normal

The minimum and maximum radon concentrations measured for each building in second phase and appropriate arithmetic mean values are shown in Figure 3. When we compared the results of arithmetic mean radon concentration obtained by long term and short term measurements, we find that: concentrations higher than 300 Bq m^{-3} have been measured in all buildings; the maximum value in 2-K kindergarten was measured in both methods.

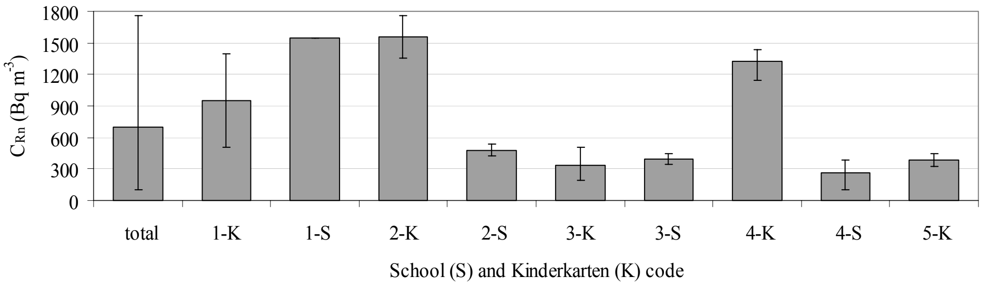

Fig. 3 – Results of short- and log-term measurements in kindergartens and schools.

In order to clarify relationship between short and long term measurements a linear regression model was used. The ln transformed radon concentration obtained in long term measurements was plotted *versus* ln transformed radon concentration measured by the short-term method as shown in Figure 4. The error bars in individual measurements are also shown in the same figure. The results show a significant correlation between the two set measurements (LR, $p < 0.0001$). The linear correlation coefficient was found to be $R = 0.817$. The obtained coefficient of determination $R^2 = 0.668$ indicates that there is linear correlation between the short-term measurements and the long-term measurements.

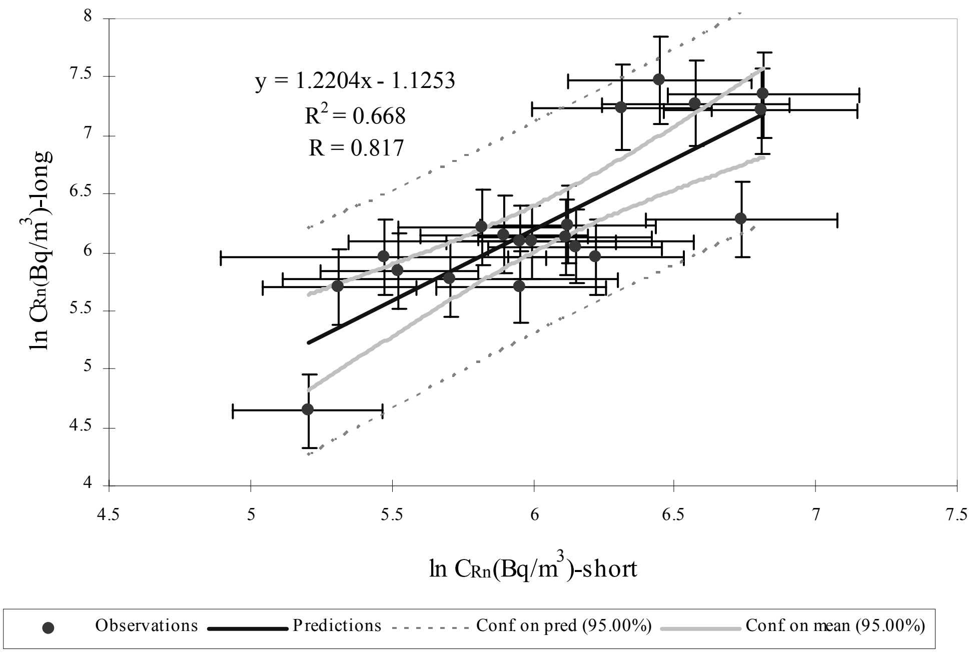

Fig. 4 – Linear regression between short-term and long-term measurements.

4. CONCLUSIONS

First comparative study of the short- and long-term indoor radon measurements in Kremikovtsi was carried out using passive techniques. The obtained results from both data sets for schools and kindergartens were higher than those reported in some other investigation and confirmed our expectation for high radon concentration mainly due to location close to uranium mining and milling sites. Higher radon concentrations were observed in kindergartens than in schools because of different building characteristics. Moreover, the comparison between the measurements performed by short and long term detectors, confirms the reliability of the short term measurements as a cheaper and faster methods. Long term measurements should be extended to a larger area with measurements in dwellings in order to identify possible radon prone area as well estimate public exposure.

Acknowledgements. The authors wish to thank colleagues from Executive Environment Agency (Sofia), for their support and collaboration on implementation of the survey.

REFERENCES

1. UNSCEAR Volume I, Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effect of Atomic Radiation 2008, United Nations, New York, (2010).
2. Handbook on indoor radon: a public health perspective. Hajo Zeeb and Ferid Shannoun, eds. WHO Press. World Health Organization, Geneva, 2009
3. J. Vaupotic, N. Kávási. Preliminary study of thoron and radon levels in various indoor environments in Slovenia. Radiation Protection Dosimetry 141(4), 383–385 (2010).
4. A. Clouvas, S. Xanthos, G. Takoudis, Indoor radon levels in Greek schools. J Environ Radioact. 2011 Sep;102(9):881-5.
5. G. Venoso, F. De Cicco, B. Flores, L. Gialanella, M. Pugliese, V. Roca, C. Sabbarese, Radon concentrations in schools of the Neapolitan area, Radiation measurements 44(1), 127–130 (2009).