SOME RESULTS OF A RADON SURVEY IN 207 SERBIAN SCHOOLS*

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In this paper the results of radon concentration measurements performed in 207 schools in 7 communities of Southern Serbia are presented. The annual radon concentration varied from 17 Bqm^{-3} to 428 Bq m^{-3} with a median value of 96 Bq m^{-3}. The arithmetic mean (AM) of the 207 annual averages was 118 Bq m^{-3} with a standard deviation (SD) of 78 Bq m^{-3}. The best distribution fitting of radon concentration by log-normal function was obtained. The log-normal parameters are the following: geometric mean (GM) = 97 Bq m^{-3}, geometric standard deviation (GSD) = 1.9. In addition, a spatial distribution of the indoor radon concentration over the investigated areas is observed.

Key words: indoor radon, primary schools, Southern Serbia, CR-39 detectors, radon map.

1. INTRODUCTION

Since many countries started to conduct their national programs on radon in dwellings around 1970, surveys using radon measurements in schools and kindergartens have also been performed in a number of countries throughout the world. In Europe, radon surveys have been carried out in schools in Slovenia [1], in Greece [2, 3], in Italy: the Salento peninsula in Southeast Italy [4], in Eastern Sicily [5], in the Neapolitan area [6], and in the province of Parma [7]. Out of all investigations in Europe, the highest number of schools included in a survey, more than 4.000, was achieved in Ireland [8]. In other parts of the world, the radon concentration in schools have also been investigated, such as in Jordan's capital Amman [9], and in Nigeria in the Oke-Ogun area [10].

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In Serbia, over the period 2008–2010, a systematic survey of radon concentration in schools was conducted, covering all primary schools in mainly rural communities of Southern Serbia (Figure 1). This paper deals with the results of field activities encompassing 207 primary schools over the 7 communities, within two districts [11]. The survey was carried out through an international collaboration between scientists from several institutes, namely, the Vinca Institute of Nuclear Sciences, Serbia (that initiated, coordinated and made field activities); the National Institute of Health, Rome, Italy; the Safety and Environment Department of Telecom-Italia; the German Federal Office for Radiation Protection; and the Joint Research Centre of the European Commission [12]. Aiming at further continuation of a systematic radon concentration survey in primary schools of Southern Serbia [11, 12], encompassing 207 new schools, the main goals of this work were: to evaluate radon exposure of children and teachers in these primary schools; to improve the knowledge of radon distribution in Serbia also by evaluating the extent to which primary schools can be considered acceptable "radon proxies of residential buildings" and potentially to contribute to the European Atlas of Natural Radiation.

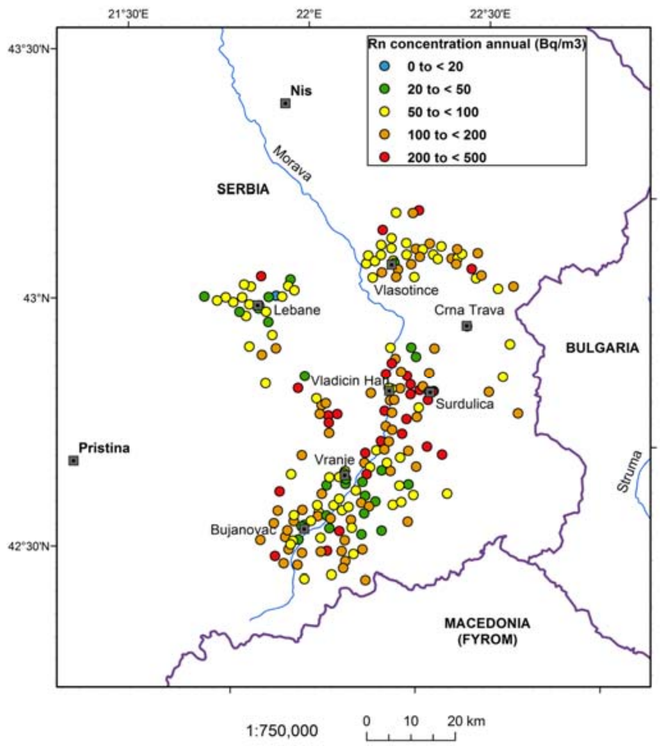

Fig. 1 – Spatial estimate of annual average radon concentration in 207 schools.

2. MATERIALS AND METHODS

In two (Lebane and Crna Trava) of the seven communities investigated, CR-39 detectors were exposed for one year. In the other five communities (Figure 1), the detectors were exposed in rooms side-by-side for two consecutive six-months periods, starting in March/May 2009 and ending in March/May 2010. The pairs of CR-39 detectors have been deployed in classrooms on ground floor, teacher's or director's rooms. For each school, GPS coordinates were recorded. The measurement points of the detectors were on shelves and cupboards mostly, or on the wall directly. After being etched, the detectors were analyzed using a fully automated image analysis (read-out) system, the Politrack one, operating with software Politrack version 4.1 (produced in Italy). System calibration was obtained in the radon chambers of the UK Health Protection Agency and the Italian National Metrology Ionising Radiation Institute (INMRI) [12]. For each school, the annual average radon concentration of the monitored rooms was calculated.

3. RESULTS AND DISCUSSION

Summary statistics of indoor radon measurements in schools are presented in Table 1. Out of the 207 schools under investigation, valid measurements were performed in 167 schools for the first six months period of exposure, and in 166 schools for the second one. In two communities with 38 schools total, the detectors were exposed for one 12 consecutive months.

Table 1

Descriptive statistics of indoor radon concentrations measured in: 1st six-months period, 2nd six-months period and one year (a single 12-months period). In the last column are the parameters of the annual average for measurements in all the 207 measured schools

Parameter	1st six-months period	2nd six-months period	12-months period	Annual average
No. of measurements	167	166	38	207
Minimum (Bq m^{-3})	17	29	17	17
Median (Bq m^{-3})	92	112	78	96
Maximum (Bq m^{-3})	363	492	303	428
Arithmetic mean (Bq m^{-3})	118	130	95	118
Standard deviation (Bq m^{-3})	81	83	72	78
Standard error (Bq m^{-3})	6	6	12	5
Geometric mean (Bq m^{-3})	94	108	76	97
Geometric standard deviation	2.0	1.9	1.9	1.9
Skewness	1.2	1.5	1.7	1.3
Kurtosis	0.7	2.7	2.0	1.4

The ratio between radon concentrations measured in the first and second periods was analyzed in order to obtain correction factors for schools where measurements have been carried out for only one six-months period. At the 95% level of significance, the decision was not to reject the null hypothesis. The ratio within the communities follows a normal distribution (Anderson-Darling Test at $p > 0.05$). The arithmetic mean values of the ratio of radon concentration both for the first and the second period for 5 communities are shown in Figure 2. If there were – for some reason – missing measurements and results in one of the periods, the annual radon concentration was estimated using the obtained ratio. For these schools, the values measured in the first (or second) period were divided (or multiplied) by the value (arithmetic mean) for the communities reported in Figure 2. The results of the annual mean radon concentration for a particular school was an arithmetic mean of the measurements performed in both periods.

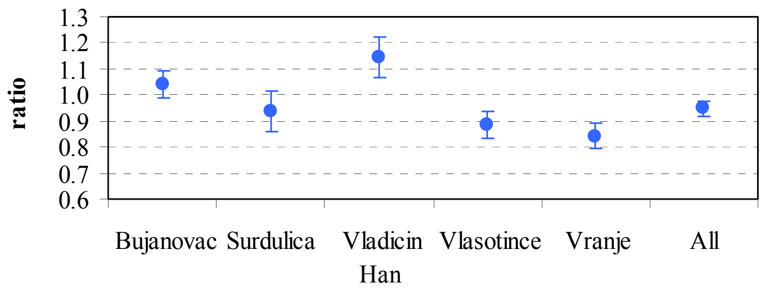

Fig. 2 – The arithmetic mean value of the ratio between radon concentrations measured in the two periods in the Bujanovac, Surdulica, Vladicin Han, Vlasotince and Vranje communities.

Distribution of annual radon concentration fitted log-normal distribution (Figure 3, left). The log-normality as well normality of log-transformed data (Figure 3, right) was confirmed with Kolmogorov-Smirnov and Chi-square goodness-of-fit test between observed and theoretical frequencies ($p > 0.05$).

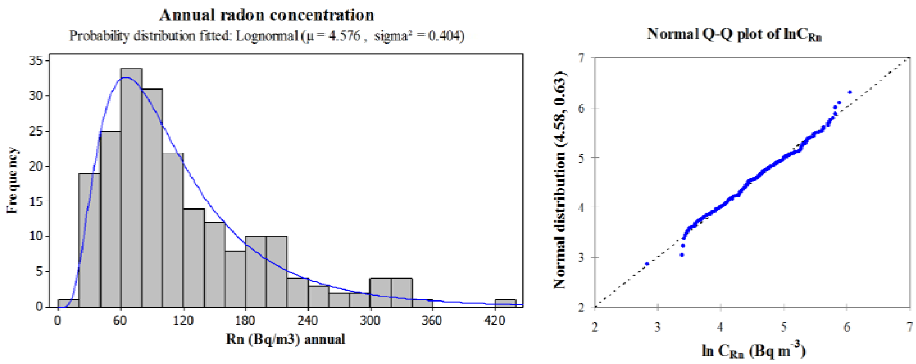

Fig. 3 – Distribution of annual radon concentration fitted log-normal distribution (left) and log-transformed data fitted normal distribution (right).

Taking into account the log-normality of the data, the log-transformed data were considered in the statistical analysis. Because of non-homogeneity of variances of data in the communities (Bartlett test, $p = 0.007$), the Kruskal-Wallis test was applied to test for differences in radon concentration. The test results showed statistically significant differences between the mean concentrations of the communities at 95% confidence level ($p = 0.0002$). Descriptive statistics of annual radon concentration in all 7 communities are given in Table 2.

Table 2

Descriptive statistics of annual radon concentration for field site

	Field site							
	Bujanovac	Crna Trava	Lebane	Surdulica	Vladicin Han	Vlasotince	Vranje	All
N	39	6	26	18	23	35	60	207
Min.	30	51	17	47	31	47	30	17
Median	112	114	63	132	175	93	82	96
Max.	338	217	212	428	310	227	359	428
AM	127	118	69	156	158	101	118	118
SD	72	58	38	101	79	43	90	78
SE	12	24	8	24	17	7	12	5
GM	109	106	60	130	134	94	91	97
GSD	1.8	1.7	1.7	1.9	1.9	1.5	2.1	1.9

N = number of schools; AM = Arithmetic Mean (Bq m^{-3}); SD = Standard Deviation (Bq m^{-3}); SE = Standard Error (Bq m^{-3}); GM = Geometric Mean (Bq m^{-3}); GSD = Geometric Standard Deviation.

For further evaluation, the non-parametric Mann-Whitney U test was applied to determine the differences between mean values in the communities (differences are significant with $p < 0.05$). The Lebane community revealed significantly lower radon concentration than Bujanovac (MW, $p < 0.0001$), Crna Trava (MW, $p = 0.026$), Surdulica (MW, $p = 0.0004$), Vladicin Han (MW, $p < 0.0001$) Vlasotice (MW, $p = 0.001$) and Vranje (MW, $p < 0.031$) (Figure 4). On the same figure, no significant difference between radon concentrations in: Bujanovac and Crna Trava (MW, $p = 0.92$), Surdulica and Vladicin Han (MW, $p = 0.703$), Vlasotince and Vranje (MW, $p = 0.576$), were obtained.

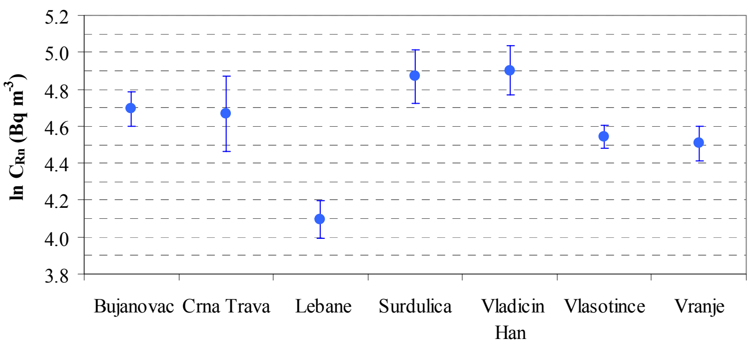

Fig. 4 – The natural logarithm of radon concentration in the 7 communities (error bars represent the standard error).

In addition, we compare our results with radon concentration in schools reported for some other European countries, shown in Table 3.

Table 3

Comparison of the results of indoor radon surveys in schools between Serbian results and other European surveys

Country	No of Regions	No of schools/ kindergartens	Range of radon conc. (Bq m^{-3})	Reference
Greece	8	512	69–177	[2]
Italy (S-E Italy)	1	438	21–1608	[4]
Italy (Parma)	1	49	10–108	[7]
Italy (Neapolitan area)	1	30	144*	[6]
Slovenia		18/7	145–749/ 70–770	[1]
Serbia	**2**	**207**	**17–428**	**Present work**

*average value

For the present survey, the influence of floor levels on the radon concentrations in the different communities was investigated. The schools were classified into three groups: ground floor, mezzanine (means that the room is accessed over a few steps from actual ground level) and first floor. ANOVA test shows that rooms at the ground floor and mezzanine have significantly ($p = 0.005$) higher geometric mean of radon concentration than rooms at the first floor (Figure 5).

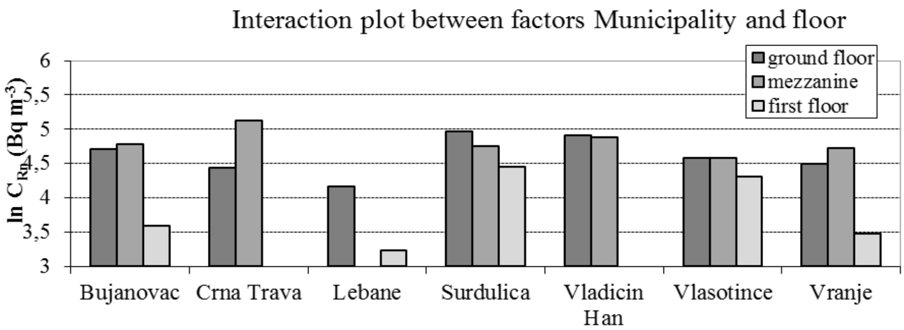

Fig. 5 – Mean ln(C_{Rn}) in communities grouped by floor level.

In order to estimate the annual effective dose E (mSv y^{-1}) expected to be received by the pupils and teachers due to exposure to indoor radon and its decay products, the following formula was used:

$$E = C_{Rn} \cdot F \cdot T \cdot D_{CF} \tag{1}$$

where C_{Rn} is the annual mean radon concentration; F is the equilibrium factor between radon and its decay products, for which the generally recommended value

(=0.4) was used; *T* is the time in hours spent by the pupils and teachers in the school under consideration (for pupils: T = (52 weeks y^{-1}- 15 vacation weeks y^{-1}) x 25 h $week^{-1}$ = 925 h y^{-1} and for teachers: T = (52 weeks y^{-1} - 6 vacation weeks y^{-1}) x 30 h $week^{-1}$ = 1380 h y^{-1}; and DCF is the dose conversion factor for radon decay products. Both the usual UNSCEAR DCF value and the recently updated ICRP one – 9 and 12 nSv (Bq h $m^{-3})^{-1}$, respectively – were considered [13, 14]. The results of annual effective dose for pupils and teachers in all communities by using the UNSCEAR and ICRP DCF are summarized in Table 3.

Table 3

Descriptive statistics of annual effective dose *E* expected to be received by pupils and teachers in the Serbian schools using UNSCEAR and ICRP dose conversion factors

		E (mSv y^{-1})						
		Min.	Med.	Max.	AM	SD	GM	GSD*
UNSCEAR	pupils	0.06	0.32	1.42	0.39	0.26	0.32	1.9
	teachers	0.08	0.47	2.12	0.59	0.39	0.48	1.9
ICRP	pupils	0.08	0.42	1.90	0.53	0.34	0.43	1.9
	teachers	0.11	0.63	2.83	0.78	0.51	0.64	1.9

Min.=Minimum; Med.=Median; Max.=Maximum; AM= Arithmetic Mean; SD=Standard Deviation; GM=Geometric Mean; GSD= Geometric Standard Deviation
*GSD is dimensionless

The estimated annual effective dose for pupils and teachers are higher than in a similar study in the Patras area of Greece where the annual effective doses were 0.1 mSv and 0.2 mSv for pupils and teachers respectively [15].

Assuming that the long-term radon concentration is equal to the radon concentration present during the working hours and that the annual average occupancy is 1000 h per year, the results of an annual average effective dose to an Irish child from exposure to radon is 0.3 mSv [8].

4. CONCLUSIONS

The results presented in this paper allow evaluation of exposure of pupils and teachers to radon and will serve as starting point for comparing radon concentration in primary schools and in dwellings, which will require further studies on the basis of both classical statistical and geostatistical methods. This survey was conducted by an international collaboration which was very effective in both designing and implementing the survey in Serbian primary schools. Due to fruitful collaboration at regional and local levels, the fraction of missing data in this survey is extremely low (less than 1 %). These results will contribute to the Serbian dataset for the European Atlas of Natural Radiation.

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