MEASUREMENT OF RADON ACTIVITY CONCENTRATION IN ELEMENTARY SCHOOLS IN TUZLA, BOSNIA AND HERZEGOVINA

by

Amela KASIĆ**, Amira KASUMOVIĆ, and Muhamed HODŽIĆ

Department of Physics, Faculty of Natural Sciences and Mathematics,
University of Tuzla, Tuzla, Bosnia and Herzegovina

Scientific paper
https://doi.org/10.2298/NTRP2403243K

In this paper, the results of measurements of indoor radon activity concentration in fourteen elementary schools in Tuzla, Bosnia and Herzegovina, are presented. Measurements were performed with CR-39 solid-state nuclear track detectors. Radon activity concentration in investigated locations was 6.8-143 Bqm^{-3}. To assess the indoor radon hazards for people, the annual effective dose, excess lifetime cancer risk, and the relative risk of lung cancer were estimated.

Key words: radon activity concentration, elementary school, annual effective dose, excess lifetime cancer risk, relative risk of lung cancer

INTRODUCTION

Radon is an odorless, tasteless, and colorless radioactive gas originating from the soil and rocks due to the natural radioactive decay of radium. Radon behaves as a noble gas due to its complete shell structure, which enables a stable electron configuration. However, random interactions are possible due to its relatively low ionization energy of 10.7 eV. In standard atmospheric conditions, its density is 9.73 kgm^{-3}, and its critical temperature is 104 °C [1].

Materials that contain uranium or radium are sources of radon, as radon is created during radium decay, and radium is a descendant of uranium. Certain rocks, such as granite, light volcanic rocks, sediment rocks containing phosphate, and metamorphic rocks, have increased uranium concentration [2]. Radon, created during radium decay, is released from rocks and soil, through the ever-present pores and cracks. Loose substrates with more pores, such as gravel and sand, release radon more easily than substrates with fewer pores such as clay, which delays its release. Radon movement and release depend on the amount of water in pores, soil porosity, and soil permeability. Soil moisture also plays a significant role in radon emanation and its diffusion within soil. Radioactive radon passes through cracks and faults, mixes with the air, and ascends toward the atmosphere. In permeable soils, such as sand, radon gas from the underlying rocks can easily transfer through the soil and penetrate the surface. Moist clay or other impermeable substrates are mediums that, to some extent, prevent radon from moving through such soil and toward the surface [3].

The factors affecting radon concentration in an enclosed space may be classified into geogenic and anthropogenic. Geogenic factors include radon soil concentration, soil composition (chemical and geological), soil humidity, soil porosity and permeability, pressure differences between the inside and outside of an enclosed space, (including the pressure difference between the soil and the structure's ground floor), and meteorological and seasonal parameters mainly reflecting differences in air temperatures inside the structure and outside. Anthropogenic parameters include construction methods, the size of the structure in direct contact with soil, the number of floors, the permeability of the construction itself (including the presence of cracks on the ground floor or in wall joints), the space surrounding pipes and installations, and the like. The main source of radon gas in an enclosed space is the soil beneath the construction accounting for 85-90 %. Much less radon content originates from construction materials (5-10 %) and subterranean waters (around 5 %). An insignificant portion originates from natural gas (<1 %) [4].

Depending on meteorological parameters, particularly differences in air temperatures inside and outside the structure, there is a pressure difference between the soil and the structure's foundations. The soil plays a major role in radon concentrations in an enclosed space up to the second-floor height. Indoor radon levels tend to reach their maximum during the

* Corresponding author, e-mail: amela.dedic@untz.ba

winter season, with minimum levels found during the warm season (spring and summer). During the summer season, although there is an obvious lack of snow cover, the intent is to keep the air in an enclosed space colder than outside, which again creates a difference in temperatures inside and outside in a similar way as during the winter season, but with smaller differences in values. Besides meteorological factors, other important aspects affecting radon activity concentration in an enclosed space include the quality of construction and ventilation. The strength of ventilation is a factor that reduces radon concentrations and is expressed in the number of complete air exchanges in the space per hour [5]. Radon may penetrate an enclosed space in various ways, including through floors, cracks in concrete and foundation walls, drains, openings around ventilation and plumbing, faucets (particularly in the shower), construction joints, *etc*. Radon typically accumulates mostly in the lower and least ventilated spaces inside the construction, such as the basement [6, 7].

According to the WHO and the USA Environmental Protection Agency (EPA), indoor radon was declared a human carcinogen and is considered the leading cause of lung cancer in non-smokers [8-10]. Radon is estimated to cause over 21 000 lung cancer deaths per year in the United States – more than drunk driving, drownings, or home fires. The risk of dying from lung cancer increases with higher levels of radon gas and the duration of exposure. The time between exposure and cancer diagnosis may be many years [8, 11, 12]. The EU directive from 2013 (2013/59/Euratom) outlines the necessity to monitor radon activity concentration indoors, especially in homes and workplaces. In every EU member state, the reference level for the annual average radon activity concentration in indoor air must not exceed 300 Bqm^{-3}, except under specific circumstances [13].

Radon exposure in schools has a substantial public health influence, affecting schoolchildren and staff. Due to their smaller lungs and faster breathing rates, children are potentially exposed to higher doses of radiation than adults. Considering the health effects of radon, many surveys have been conducted in Europe and worldwide to monitor radon concentrations in schools and kindergartens [14-25]. The main purpose of this study is to determine the radon activity concentration in the elementary schools of Tuzla, Bosnia and Herzegovina, and to evaluate radon exposure for students and teachers in schools. Therefore the annual effective dose for students and teachers, and the excess lifetime cancer were estimated. The relative risk of lung cancer due to indoor radon exposure was also calculated. Obtained values were compared with results from similar studies in Europe.

MATERIALS AND METHODS

Study area

The indoor radon activity concentrations were measured in fourteen elementary schools in Tuzla, Bosnia and Herzegovina. Those schools were selected because there were no data about radon levels and radon-associated health risks for students and teachers.

The Tuzla region is classified as the Perio-Pannonia region, which is the contact zone of the Dinarides and Pannonia lowlands. The basin region is located on the south side of the ridge and is mainly formed by long transverse stream valleys and slopes ending in the Jala River valley. The terrain mildly slopes towards the south. The wider Tuzla region is mostly built from geologically recent sediments (Neogen) important from an economic point of view (coal, rock salt, quartz sand, *etc*.). The formation of the Tuzla basin is related to several phases that followed each other after the Mesozoic period, which conditioned the creation of different deposit layers. The diverse and specific sedimentary formations were created together with paleo-climatic activities. Tuzla has the characteristics of a moderate continental climate. Certain features are influenced by the local relief, the general position relative to the dominant regions in the vicinity (the Bosnian mountain central massif on one, and the Pannonia plain on the other), air currents affecting both tropical and polar air masses and cyclonic activities. The general climate traits include the distinct expression of all four seasons, relative humidity and cloudiness, maximum precipitation during the warmer part of the year, and minimum at the end of winter. The mean annual temperature is 10.1 °C. The coldest month is January with an average temperature of 0.6 °C, and the warmest month is July with an average temperature of 19.4 °C [26].

Experimental set-up and procedure

The indoor radon concentration was measured by the passive method of solid-state nuclear track detectors, type CR-39 (RadoSys, Budapest, Hungary). These detectors are suitable for long-term radon measurements, ranging from a few days to several months. The results obtained represent the average radon concentration for the given measurement interval. The CR-39 detectors are polycarbonate plastic tiles (chips) measuring 10 mm × 10 mm in size and 1 mm in thickness. They have a sensitivity of 2.0 (tracks cm^{-2})/ ($kBqm^{-3}$ per hours), a typical initial background of 0.3 tracks mm^{-2}, and a saturation limit greater than 12 000 $kBqhm^{-3}$ [2, 3].

The detectors, enclosed in small cylindrical diffusion chambers, were placed at measuring locations in elementary school classrooms for three to four months. The measurements were performed at all locations in the same season, from September to December, in the first semester of the school year, when students were at school every day during the work week. The detectors were mounted one meter above the floor, away from heat sources and sunlight. During the measurement period, detectors were not moved. The detectors were placed in classrooms on the first floor of each elementary school, with two or three detectors distributed across different classrooms.

These classrooms were used for classes during the day and each had natural ventilation, especially in the morning hours. After the exposure period, the detectors were collected and taken to the laboratory for further experimental analyses, including chemical etching and track counting. The CR-39 detectors were etched using 1000 g of NaOH granules dissolved in 4 L of distilled water in the RadoBath RB4 Unit, a thermostatic bath designed for the chemical etching of traces on the detectors. The detectors were etched at the temperature of 90 °C for 4.5 hours. After the etching process, a neutralization phase was conducted by adding 200 ml of 15 % or 20 % vinegar into 4 L of distilled water. This was followed by washing with 4 L of distilled water to remove any possible chemical residues. The detectors were then dried, and the final phase involved track counting. This was done with the RadoMeter Unit, which consists of an automated microscope with a B&W CCD camera and magnification capability of 100 times the actual size, operated with appropriate software for track analyses and data processing [2, 3, 27]. The CR-39 detector, diffusion chamber, RadoBath Unit, and RadonMeter microscope are presented in fig. 1.

Estimation of the annual effective dose, excess lifetime cancer risk, and relative risk of lung cancer

Based on the measured values of the radon activity concentration in the classrooms, the annual effective dose received from inhalation of radon by students and teachers was estimated. The annual effective dose was calculated using the following eq.

$$AED = CFTD \tag{1}$$

where *AED* [mSv] is the annual effective dose from inhalation of radon indoors, *C* [Bqm^{-3}] – the radon activity concentration, *F* – the radon equilibrium factor (0.4 for indoor), *T* – the average number of hours per year (1050 hours per year for students and 1230 hours per year for teachers), and *D* – the dose conversion factor for radon (9 nSv $\text{Bq}^{-1}\text{h}^{-1}\text{m}^{3}$) [28]. It was assumed that students in elementary schools spend on average, 1050 hours per year in school buildings, which equates to 30 hours per week for 35 weeks a year. Teachers were assumed to spend 30 hours per week for 41 weeks a year in school. This estimation does not account for additional hours children spend in after-school programs.

The excess lifetime cancer risk (*ELCR*) is calculated using eq.

$$ELCR = AED\ DL\ RF \tag{2}$$

where *AED* [mSv] is the annual effective dose, *DL* – the average duration of life (estimated to be 70 years), and *RF* – the risk factor (0.055 Sv^{-1}) [29].

The relative risk of lung cancer (*RRLC*) due to indoor radon exposure was calculated using eq.

$$RRLC = \exp(0.00087352C) \tag{3}$$

where *C* [Bqm^{-3}] is the radon activity concentration [30].

DISCUSSION AND RESULTS

The results of measurements of radon activity concentration in the research areas of the elementary schools are presented in tab. 1. The results in tab. 1 show that the radon activity concentration at the researched locations

Figure 1. The CR-39 detector, diffusion chamber, RadoBath Unit, and RadoMeter microscope

Table 1. The mean values of the indoor radon activity concentration *C* at investigated locations

Location number	Elementary school	Number of detectors	Exposure time [d]	C [Bqm^{-3}]
1	Kreka	2	126	6.8 ± 2.0
2	Simin Han	2	125	20.9 ± 4.6
3	Novi Grad	2	123	12.0 ± 3.0
4	Jala	2	125	18.8 ± 4.4
5	Sjenjak	2	126	15.2 ± 3.5
6	Bukinje	3	95	31.8 ± 7.1
7	Pazar	2	107	40.3 ± 8.3
8	Music school	2	104	17.9 ± 4.1
9	Miladije	2	95	20.2 ± 4.8
10	Tušanj	3	106	17.4 ± 4.1
11	Mejdan	2	124	83.1 ± 17.3
12	Slavinovići	2	126	9.4 ± 2.5
13	Centar	2	104	18.9 ± 4.4
14	Gornja Tuzla	2	126	143 ± 27
Range				6.8-143
Mean value				32.6 ± 7.0

Table 2. Comparison of radon activity concentration *C* of the present study with similar studies in other countries

Country	C [Bqm^{-3}]	References
Greece	149	[15]
Croatia	93.4	[24]
	147-317	[31]
Republic of North Macedonia	9-379	[35]
	27-242	[36]
Italy		
Parma	30	[33]
Campania region	98	[37]
Neapolitan area	144	[32]
Friuli-Venezia Giulia region	125	[38]
Slovenia	168	[19]
Bulgaria		
Kremikovtsi municipality	287	[39]
Kardzhali district	137	[22]
Ireland	93	[20]
Belgium	120	[21]
Serbia	118	[40]
Bosnia and Herzegovina	32.6	Present study

ranges from 6.8-143 Bqm^{-3}. The highest value of indoor radon activity concentration was found in an elementary school in Gornja Tuzla, at location 14, with a concentration of (143 ±27) Bqm^{-3}. This value is similar to the indoor radon activity concentration in schools in Greece [15], Požega-Slavonia County of Croatia [31], and the Neapolitan area of Italy [32], but lower than in several other counties of Croatia [31]. The lowest value of indoor radon activity concentration was found at location 1, elementary school Kreka, with a concentration of (6.8 ±2.0) Bqm^{-3}. The mean value of radon activity concentration in the investigated area of elementary schools in Tuzla was (32.6 ±7.0) Bqm^{-3}, comparable to the value measured in the Region of Parma, Italy [33].

The radon concentrations measured in schools in Tuzla city are lower compared to those in schools in Banja Luka city, Bosnia and Herzegovina [34, 35]. However, it should be noted that in Tuzla, the detectors were installed in first-floor classrooms, whereas in Banja Luka, the detectors were placed on the ground floor. In Banja Luka, the detectors were exposed for one year, whereas in our measurements they were exposed for just four months, from September to the end of December. The mean values indicated that the indoor radon levels at the investigated locations were not high compared to indoor radon activity concentrations in neighboring or other European countries. A comparison of indoor radon activity concentrations from the present study with those from various European countries is presented in tab. 2. The radon concentrations measured in our study are lower or significantly lower than those reported in studies from neighboring countries. This difference is because the detectors in our study were placed in classrooms on the first floor, whereas in comparative studies, they were placed on the ground floor. The values of indoor radon activity concentration at the investigation locations are within the recommended concentration limits of 300 Bqm^{-3} (Directive 2013/59/EURATOM) [13].

The results for indoor radon activity concentration were comparable with measurements conducted in residential buildings in the Tuzla Canton area, Bosnia and Herzegovina. In this region, the mean values of radon activity concentrations ranged from 18.38-145.31 Bqm^{-3} in the cities of Banovići and Živinice [41] and from 4.2-191.8 Bqm^{-3} in Tuzla City [42].

The results of the annual effective dose with the corresponding standard deviation for students and teachers at investigated locations are presented in tab. 3. The results of the excess lifetime cancer risk and relative risk of lung cancer are also presented in tab. 3. The estimated annual effective dose at the measurement locations for students varies between 0.03 ±0.01 mSv and 0.54 ±0.10 mSv, with a mean value of 0.12 ±0.03 mSv. For teachers, it ranges from 0.03 ±0.01 to 0.63 ±0.12 mSv, with a mean value of 0.14 ±0.03 mSv. These values are lower than those in Bulgarian schools, where the calculated annual effective dose was 0.39 mSv [22], or in Sudanese schools, where it was 0.56 mSv [30]. The estimated annual effective doses in the present study for students and teachers in Tuzla schools are comparable to those in elementary schools in Patras, Greece, where the estimated doses range from 0.03 to 0.34 mSv for students and from 0.04-0.39 mSv for teachers [43]. These estimated values are somewhat lower than the estimated mean annual effective dose value in Europe, which is 1.96 mSv [33], and the worldwide estimated mean annual effective dose of 1.15 mSv [13]. The values of excess lifetime cancer risk ranged from (0.10-2.09)×10^{-3} with a mean value of (0.47 ±0.10)×10^{-3} for students, and from (0.12-2.44)×10^{-3}, with a mean value of (0.56 ±0.12)×10^{-3} for teachers. These values are still below the maximum risk of 10.3×10^{-3} corresponding to an annual effective dose of 2.4 mSv [29].

Table 3. The values of annual effective doses *AED*, excess lifetime cancer risk *ELCR*, and relative risk of lung cancer *RRLC* at investigation locations

No.	Elementary school	AED [mSv]		ELCR ($\times 10^{-3}$)		RRLC [%]
		Students	Teachers	Students	Teachers	
1	Kreka	0.03 ± 0.01	0.03 ± 0.01	0.10 ± 0.03	0.12 ± 0.03	1.01
2	Simin Han	0.08 ± 0.02	0.09 ± 0.02	0.30 ± 0.07	0.36 ± 0.08	1.02
3	Novi Grad	0.05 ± 0.01	0.05 ± 0.01	0.17 ± 0.04	0.20 ± 0.05	1.01
4	Jala	0.07 ± 0.02	0.08 ± 0.02	0.27 ± 0.06	0.32 ± 0.07	1.02
5	Sjenjak	0.06 ± 0.01	0.07 ± 0.02	0.22 ± 0.05	0.26 ± 0.06	1.01
6	Bukinje	0.12 ± 0.03	0.14 ± 0.03	0.46 ± 0.10	0.54 ± 0.12	1.03
7	Pazar	0.15 ± 0.03	0.18 ± 0.04	0.59 ± 0.12	0.69 ± 0.14	1.04
8	Music school	0.07 ± 0.02	0.08 ± 0.02	0.26 ± 0.06	0.30 ± 0.07	1.02
9	Miladije	0.08 ± 0.02	0.09 ± 0.02	0.29 ± 0.07	0.34 ± 0.08	1.02
10	Tušanj	0.07 ± 0.02	0.08 ± 0.02	0.25 ± 0.06	0.30 ± 0.07	1.02
11	Mejdan	0.31 ± 0.07	0.37 ± 0.08	1.21 ± 0.25	1.42 ± 0.30	1.08
12	Slavinovići	0.04 ± 0.01	0.04 ± 0.01	0.14 ± 0.04	0.16 ± 0.04	1.01
13	Centar	0.07 ± 0.02	0.08 ± 0.02	0.28 ± 0.06	0.32 ± 0.07	1.02
14	Gornja Tuzla	0.54 ± 0.10	0.63 ± 0.12	2.09 ± 0.40	2.44 ± 0.46	1.13
Range		0.03 – 0.54	0.03 – 0.63	0.10 – 2.09	0.12 – 2.44	1.01 – 1.13
Mean value		0.12 ± 0.03	0.14 ± 0.03	0.47 ± 0.10	0.56 ± 0.12	1.03

The relative risk of lung cancer ranges from 1.01 % to 1.13 %, with a mean value of 1.03 %. This mean value of the relative risk of lung cancer is comparable to the mean value in Sudan, which is 1.042 % [30].

CONCLUSIONS

The research results do not show increased radon activity concentration in the investigated schools in Tuzla, Bosnia and Herzegovina. Radon activity concentrations in elementary schools in Tuzla are below the EU's recommended maximum value of 300 Bqm^{-3}. The placement of detectors on the first floor and ventilation rate caused by human activities, such as opening doors and windows, in the investigated elementary schools significantly reduced the radon concentration, leading to the observed lower values.

The mean values of annual effective doses due to inhalation of radon for students and teachers are below 1 mSv. The values of excess lifetime cancer risk and the relative risk of lung cancer for students and teachers have been estimated. According to these values, radon exposure does not represent a health hazard to the students and teachers of these schools.

AUTHORS' CONTRIBUTIONS

A. Kasić conceived the idea for the experiments, processed the detectors in the laboratory, drafted the manuscript, and participated in data analysis. A. Kasumović also processed the detectors in the laboratory, contributed to writing the manuscript, and assisted in data analysis. M. Hodžić installed the detectors at the measurement sites and collected the measurement data.

REFERENCES

[1] Baskaran, M., Radon: *A Tracer for Geological, Geophysical and Geochemical Studies*, Basel, Springer, 367, 2016

[2] Hassanvand, H., *et al*., Indoor Radon Measurement in Dwellings of Khorramabad City, Iran, *Iranian Journal of Medical Physics, 15* (2018), 1, pp. 19-27

[3] Durrani, S. A., Ilic, R., *Radon Measurements by Etched Track Detectors-Applications in Radiation Protection*, Earth Sciences, World Scientific, Singapore, 1997

[4] Lopez-Perez, M., *et al*., Determination of the Indoor Radon Concentration in Schools of Tenerife (Canary Islands): A Comparative Study, Air Quality, *Atmosphere and Health, 15* (2022), 5, pp. 825-835

[5] Vogiannis, E. G., Nikolopoulos, D., Radon Sources and Associated Risk in Terms of Exposure and Dose, *Frontiers in Public Health, 2* (2015), 207

[6] Lecomte, J. F., *et al*., ICRP Publication 126: Radiological Protection Against Radon Exposure, *Annals of the ICRP, 43* (2014), 3, pp. 5-73

[7] Clement, C. H., *et al*., Lung Cancer Risk from Radon and Progeny and Statement on Radon, *Annals of the ICRP, 40* (2010), 1, pp. 1-64

[8] ***, The Official Web Arkansas Department of Health, [Internet] 2024, [cited 2024 June 18]. Available from: https://healthy.arkansas.gov/programs-services/public-health-safety/is-my-home-safe/radon-gas

[9] Riudavets, M., *et al*., Radon and Lung Cancer: Current Trends and Future Perspectives, *Cancers, 14* (2022), 13, pp. 3142 https://doi.org/10.3390/cancers14133142

[10] ***, World Health Organization, WHO Handbook on Indoor Radon: A Public Health Perspective, Geneva, Switzerland: WHO, 2009

[11] ***, Environmental Protection Agency, EPA Assessment of Risks from Radon in Homes, Publication 402-R-03-003, Office of Radiation and Indoor Air, United States Environmental Protection Agency. Washington, 2003

[12] Darby, S., *et al*., Radon in Homes and Risk of Lung Cancer: Collaborative Analysis of Individual Data from 13 European Case-Control Studies, BMJ, 330,

223, 2005,
https://doi.org/10.1136/bmj.38308.477650.63
[13] ***, European Commission, Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom, Official J., 13, 1-73, 2014
[14] Turhan, S., *et al*., Health Hazards Due to the Exposure to Radon in Schools of the Cappadocia Region, *Nucl Technol Radiat, 32* (2017), 2, pp. 174-179
[15] Clouvas, A., Xanthos, S., Takoudis, G., Indoor Radon Levels in Greek Schools, *Journal of Environmental Radioactivity, 102* (2011), 9, pp. 881-885
[16] Alhamdi, W. A. H., Indoor Radon Monitoring in Various Ventilation Degree in Some Schools of Duhok City, Iraq, *Nucl Technol Radiat, 38* (2023), 1, pp. 64-69
[17] Erdogan, M., *et al*., Indoor Radon Activity Concentration and Effective Dose Rates at Schools and Thermal Spas of Ilgin, *Nucl Technol Radiat, 35* (2020), 4, pp. 339-346
[18] Vaupotic, J., *et al*., Radon and Thoron Doses in Kindergartens and Elementary Schools, *Radiation Protection Dosimetry, 152* (2012), 1-3, pp. 247-252
[19] Vaupotic, J., Sikovec, M., Kobal, I., Systematic Indoor Radon and Gamma-Ray Measurements in Slovenian Schools, *Health Physics, 78* (2000), pp. 559-562
[20] Synnott, H., *et al*., Radon in Irish Schools: the Results of a National Survey, *Journal of Radiological Protection, 26* (2006), 1, pp. 85-96
[21] Poffijn, A., *et al*., The Radon Problem in Schools and Public Buildings in Belgium, *Radiation Protection Dosimetry, 45* (1992), 1-4, pp. 499-501
[22] Ivanova, K., *et al*., Exposure Due to Indoor Radon in Bulgarian Schools, *Aerosol and Air Quality Research, 22* (2022), 220279
https://doi.org/10.4209/aaqr.220279
[23] Poulin, P., *et al*., Radon Measurement in Schools Located in Three Priority Investigation Areas in the Province of Quebec, Canada, *Radiation Protection dosimetry, 151* (2012), 2, 278-289
[24] Planinić, J., *et al*., Radon in Schools and Dwellings of Osijek, *Journal of Radioanalytical and Nuclear Chemistry, 191* (1995), 1, pp. 45-51
[25] Durcik, M., *et al*., Radon Risk Assessment in Slovak Kindergartens and Basic Schools, *Radiation Protection Dosimetry, 71* (1997), 3, pp. 201-206
https://doi.org/10.1093/oxfordjournals.rpd.a032053
[26] ***, https://tuzlanskiforum.wordpress.com/o-tuzli/[cited 2024 June 18].
[27] ***, RadoSys, User's Manual, RadoSys Company, Hungary
[28] Al Zabadi, H., Mallah, K., Saffarini, G., Indoor Exposure Assessment of Radon in the Elementary Schools, Palestine, *International Journal of Radiation Research, 13* (2015), 3, pp. 21-228
[29] Azhdarpoor, A., *et al*., Assessment of Excess Lifetime Cancer Risk Due to Exposure to Radon in a Middle Eastern City in Iran, *Radiation Medicine and Protection, 2* (2021), 3, pp. 112-116
[30] Elzain, A. A., Assessment of Indoor Radon Doses Recived by the Students and Staff in Schools in Some Towns in Sudan, *International Journal of Science and Research (IJSR), 4* (2015), 1, pp. 2566-2571
[31] Radolic, V., *et al*., Radon Concentrations in Schools and Kindergartens in Croatia – Implications on Design and Implementation of National Radon Action Plan, in: Radolić, V., Poje Sovilj, M., Krajcar Bronić, I (ed) *Proceeding*, 11th Symposium of the Croatian Radiation Protection Association, Osijek, Croatia, Zagreb: CRPA. pp. 367-372 (in Croatian), 2017
[32] Venoso, G., *et al*., Radon Concentrations in Schools of the Neapolitan Area, *Radiation Measurements, 44* (2009), 1, pp. 127-130
https://doi.org/10.1016/j.radmeas.2008.10.002
[33] Malanca, A., Fava, R., Gaidolfi, L., Indoor Radon Levels in Kindergartens and Play-Schools from the Province of Parma, *Journal of Environmental Radioactivity, 40* (1998), 1, pp. 1-10
[34] Ćurguz, Z., *et al*., Active and Passive Radon Concentration Measurements and First-Step Mapping in schools of Banja Luka, Republic of Srpska, *Romanian Journals of Physics, 58* (Supplement), (2013), pp. S90-S98
[35] Stojanovska, Z., *et al*., The Indoor Radon and Thoron Concentrations in Schools of Skopje (Republic of North Macedonia) and Banja Luka (Republic of Srpska) Cities Measured by Raduet Detectors, *Contemporary Materials, XI* (2020), 1, pp. 20-26
[36] Stojanovska, Z., *et al*., Results from Time Integrated Measurements of Indoor Radon, Thoron and Their Decay Product Concentrations in Schools in the Republic of Macedonia, *Radiation Protection Dosimetry, 162* (2014), 1-2, pp. 152-156
[37] Loffredo, F., *et al*., Indoor Radon Monitoring in Kindergarten and Primary Schools in South Italy, *Atmosphere, 13* (2022), 3, 478
https://doi.org/10.3390/atmos13030478
[38] Giovani, C., *et al*., Radon Concentration Survey in Schools of the Friuli-Venezia Giulia Region, North-East Italy, *Radioactivity in the Environment, 7* (2005), pp. 520-527
https://doi.org/10.1016/S1569-4860(04)07062-7
[39] Vuchkov, D., *et al*., Radon Measurement in Schools and Kindergartens (Kremikovtsi Municipality, Bulgaria), *Romanian Journal of Physics, 58* (Supplement):S328-S335, First East European Radon Symposium – FERAS 2012, September 2nd-5th, 2012, Cluj-Napoca, Romania, 2013
[40] Zunic, Z., *et al*., Some Results of a Radon Survey in 207 Serbian Schools, *Romanian Journal of Physics, 58* (Supplement), (2013), S320-S327
[41] Kasić, A., Sakić, Z., Kasumović, A., Measurement of Indoor Radon Concentrations and Doses Assessment in the Area of Tuzla Canton, Bosnia and Herzegovina, *Journal of Radioanalytical and Nuclear Chemistry, 333* (2024), pp. 2621-2628
[42] Kasumović, A., *et al*., Indoor Radon Activity Concentration Measurement and Assessment of Annual Effective Dose in Houses of Tuzla city, Bosnia and Herzegovina, in: Ristić, G., (ed) *Proceedings,* Second East European Radon Symposium (SEERAS), Niš, Serbia, 2014, pp. 1-4
[43] Papaefthymiou, H., Georgiou, C. D., Indoor Radon Levels in Primary Schools of Patras, Greece, *Radiation Protection Dosimetry, 124* (2007), 2, pp. 172-176

Received on October 8, 2024
Accepted on November 23, 2024

Амела КАСИЋ, Амира КАСУМОВИЋ, Мухамед ХОЏИЋ

МЕРЕЊЕ КОНЦЕНТРАЦИЈЕ АКТИВНОСТИ РАДОНА У ОСНОВНИМ ШКОЛАМА У ТУЗЛИ, БОСНА И ХЕРЦЕГОВИНА

У овом раду приказани су резултати мерења концентрације активности радона у затвореном простору у основним школама у Тузли, Босни и Херцеговини. Мерења су извршена помоћу CR-39 чврстих нуклеарних траг детектору. Измерена концентрација активности радона је била у интервалу 6.8-143 Bqm^{-3}. Како би се процениле опасности за људе од радона у затвореном простору, процењене су годишња ефективна доза, ризик од настанка рака током живота и релативни ризик од рака плућа.

Кључне речи: концентрација активности радона, годишња ефективна доза, ризик од настанка рака током живота, релативни ризик од рака плућа