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Exposure Due to Indoor Radon in Bulgarian Schools

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ABSTRACT

Indoor radon exposure is the largest contributor to population dose from natural sources. Radon as a natural radioactive gas could accumulate to harmful levels in buildings, such as homes and buildings with public access. In order to assess the exposure due to radon in school the results of indoor radon measurements in 55 state school buildings in 7 municipalities located in one district in southern Bulgaria are considered in this paper. The survey was carried out with passive CR-39 etched track detectors. Radon concentrations ranged from 17 to 868 Bq m^{-3}, with a geometric mean of 117 Bq m^{-3} and a geometric standard deviation of 1.78. The findings revealed that in 30% of the measured buildings the radon concentration was higher than the national reference level of 300 Bq m^{-3}. The statistically significant difference in indoor radon concentrations between municipalities (KW, $p < 0.001$) was obtained. The research was also focused on parameters affecting radon concentration levels such as type of room and floor location. The estimated annual effective dose of 0.39 to 1.07 mSv y^{-1}, applying the ICRP and UNSCEAR methodology, was calculated for students. The results of the measurements were provided to the administrative authorities and measures were proposed to improve the air in school buildings with high radon levels.

Keywords: Indoor radon, Schools, Detectors, Radon exposure, Effective dose

1 INTRODUCTION

Radon (Rn-222) is produced by the radioactive decay of radium (Ra-226), mainly present throughout the earth's crust, in the soil, water, and building materials (UNSCEAR, 2000; WHO, 2009). Generally, radon transports with the under-building soil gas and then emanated to the surface. It can penetrate inside buildings through cracks and joints in the foundation and accumulate to high values if the ventilation is poor (Ambrosino *et al.*, 2020). The accumulation of Rn-222 depends on various factors such as geological setting, meteorological condition, buildings characteristic (Levesque *et al.*, 1997; Schubert *et al.*, 2018), the type, use, and upkeep of the heating, ventilation, and air conditioning system in the school (Davis *et al.*, 2020) and the inhabitant habits. Radon represents public health problem due to increasing the risk of lung cancer in the population (WHO, 2009). This has led to the inclusion of radon in the new regulatory standards. The European Commission in the new Directive has established the reference radon concentration (CRn) for member states of 300 Bq m^{-3} in dwellings, workplaces, and building with public access, to reduce log-life radon risk for the population (EC, 2014). Bulgaria has harmonized its national legislation with European Directive.

Radon exposure is most significant in homes because people spend more of their time there (Sabbarese *et al.*, 2021). However, in workplaces and buildings with public access, such as schools and kindergartens, radon exposure could also be significant. Children are sensitive to air pollution and spend long hours in schools (Spycher *et al.*, 2015). For that, special attention in Bulgarian National Radon Action Plan is given to buildings where children and adolescents spend more time. The investigation of CRn in the schools and kindergartens under the national plan, as well as under the project of Bulgarian the scientific fund is been implemented presently.

The main objective of the study is to assess the exposure due to radon in school. The results

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of indoor radon measurements in 55 state school buildings in 7 municipalities located in one district in southern Bulgaria are considered in this paper.

2 MATERIAL AND METHODS

2.1 Studied Objects

The measurements of the indoor radon concentration in the air were performed in 437 rooms in 55 state schools located in all municipalities of the Kardzhali district. The district is located in the southern part of Bulgaria in the eastern Rhodopes Mountain. The district covers an area of 3209 km^2 and has a population of 158 204 people according to data from the National Statistical Institute 2019 (NSI, 2020). Administratively, the district is divided into 7 municipalities.

2.2 Radon Concentration Measurement and Analysis

CRn were measured in classrooms, cabinets, teachers and school administration offices, gyms, and catering rooms, located on the underground and ground floor and first floor. The survey was carried out in the period from Nov. 2019 to May/June 2020 and approximately overlaid the school year. Since the sampling period covers the winter and spring seasons, it could assume that the measured CRn was representative of the average annual CRn (Sabbarese *et al.*, 2020). The integrated measurements of the average CRn were performed with passive SSNTD detectors The measurement method is based on passive sampling during which the alpha particles of radon transfer their energy to the polymer (CR-39). The energy that is transferred to the medium leaves an area of damage called "tracks". The processing of the detectors in the laboratory consists of etching, where the "tracks" are converted into "etched tracks" (enlarged) and counted with a microscope. The number of "etched tracks" per surface unit area is linked to the radon exposure by the calibration factor (ISO, 2012). The calibration factor is determined in advance for each batch of detectors by an accredited laboratory. A detailed questionnaire was completed for each surveyed building, regarding school characteristics that may be associated with radon concentrations: ventilation systems, building construction, number of stories, presence or absence of a basement, all kinds of energy-saving measures, types of heating, windows, etc. The statistical analysis was performed using IBM SPSS Statistics (Kirkpatrick and Feeney, 2015).

2.3 Effective Dose Assessment of Internal Radon Exposure

For the evaluation of the annual effective dose H due to radon and its progeny, the ICRP and UNSCEAR methodology was applied. The method consists of applying the major exposure factors, such as the time exposed and dose coefficients to the measured radon concentration in the air (Vaupotič and Kobal, 2006). The methodologies are similar but there are some differences in approaches to dose coefficients. ICRP recommends in terms of measurements of Rn-222 gas exposure, the dose coefficient of 3 mSv per m J h m^{-3} corresponds to 6.7 10^6 mSv per Bq h m^{-3} assuming an equilibrium factor, F, of 0.4 (ICRP, 2017). According to UNSCEAR the dose coefficient of 9 nSv per Bq h m^{-3} is considered suitable for average effective dose calculations (UNSCEAR, 2000). The value of 9 nSv per h Bq m^{-3} EEC of Rn-222 corresponds to 1.6 mSv per m J h m^{-3} or 5.7 mSv per working level month (WLM). The parameter "EEC" is the equilibrium equivalent radon concentration, which is the activity concentration of radon gas in equilibrium with its short-lived progeny. In this regard, the Eq. (1) was applied to estimate the effective dose H:

$$H = CRn \times t \times DC, mSv/a \qquad (1)$$

where: CRn is the average radon concentration in every school in Bq m^{-3}; DC is the ICRP dose coefficient nSv per h Bq m^{-3} and t represent the time spent by the pupils in schools for one year in hours. When applying the UNSCEAR dose coefficient the EEC is evaluated by applying the equilibrium factor F, which is usually 0.4. The sources of uncertainty in the estimated annual effective dose H were evaluated. Following the equation uncertainty could divide into (a) uncertainty of determining the average radon concentration, (b) uncertainty of average residence time (c) uncertainties of applying the respiratory tract model parameters, and other ICRP assumptions used in the calculation.

3 RESULTS AND DISCUSSION

The measurements were made according to the national plan in the 55 state school buildings across all 7 municipalities of the Kardzhali district. The descriptive statistic of CRn results is summarized in Table 1. The arithmetic mean of CRn is 144 Bq m^{-3} and the geometric mean is 117 Bq m^{-3}. The arithmetic mean of CRn in the Kardzhali district is lower than the arithmetic means of CRn reported for schools in other regions of Bulgaria - Plovdiv (160 Bq m^{-3}) (Ivanova *et al.*, 2021), as well as in schools in Greece (149 Bq m^{-3}) (Clouvas *et al.*, 2011) but higher than arithmetic means of 118 Bq m^{-3}, obtained in schools of Serbia (Zunic *et al.*, 2013). The coefficient of CRn variation is 73% i.e., lower than the CV = 109% obtained in the pilot study of CRn in Plovdiv (Ivanova *et al.*, 2021), which showed no large CRn variation. The distribution of radon concentration in school buildings is log-normal (KS, p = 0.065) (Fig. 1). The estimation of the parameters of the logarithmic normal distribution was obtained from the distribution of the logarithmic values, which were not corrected with values of outdoor radon concentration. The maximum value of measured CRn is 868 Bq m^{-3}, which is more than twice above the established national reference level of 300 Bq m^{-3}. In 51 school rooms, the CRn was higher than 200 Bq m^{-3}, and in 28 rooms, located in 17 school buildings, it exceeds the national reference level of 300 Bq m^{-3}, defined in the Bulgarian ordinance on radiation protection (or 30% of the investigated buildings). The school's administration was informed about the CRn results and measures for reducing the high CRn were recommended.

The statistically significant difference in the CRn values between all municipalities (KW, $p <$ 0.001) was obtained. The most likely reason for these differences is the geographical location of the buildings as well the possible influence of the geological soil composition on which they are built. Municipalities with CRn above 100 Bq m^{-3} (four) are located in mountainous areas. Comparing studies of radon concentrations in schools from different locations is complicated given that soil deposits of uranium-238 and its decay products, soil permeability, and building characteristics vary greatly by geographic region (Fojtikova and Navratilova Rovenska, 2014; Ivanova *et al.*, 2017). A review of 63 studies, made by Zhukovsky *et al.* (2018) found that average radon concentrations

Table 1. Descriptive statistics of CRn by school type and calculated effective dose.

Type of school	No of school	AM, Bq m^{-3}	SD, Bq m^{-3}	CV, %	GM, Bq m^{-3}	GSD, Bq m^{-3}	Min Bq m^{-3}	Max Bq m^{-3}	Effective dose, mSv y^{-1} (UNSCEAR, 2000)	(ICRP, 2017)
Primary	21	137	106	77	112	1.89	19.6	544.3	0.39	0.73
Secondary	13	148	40	27	143	1.45	79.2	383.8	0.58	1.05
High	12	154	75	49	143	1.31	95.3	210.9	0.57	1.07
TOTAL	**46**	**144**	**83**	**58**	**117**	**1.78**	**19.6**	**544.3**	**0.52**	**0.96**

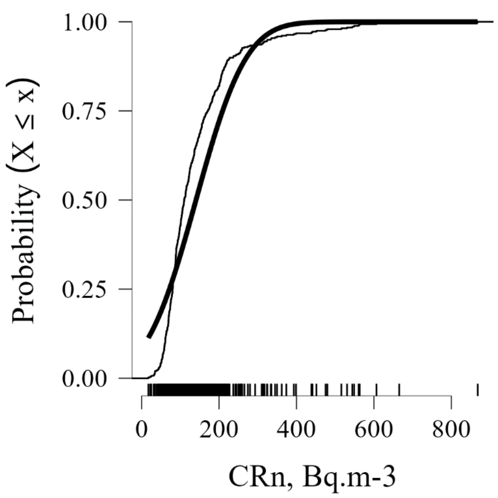

Fig. 1. Cumulative distribution of indoor radon concentration in school.

in schools ranged from a low of eight to a high of 245 Bq m^{-3}, with a GM of 36 Bq m^{-3}, which is lower than in instigated Kardzhali district.

School rooms where CRn is measured are characterized by different sizes, intended, and duration of employment per day. Classrooms are large rooms where basic learning takes place and students usually spend most of their time here, cabinets are smaller rooms and are designed for training in certain disciplines—chemistry, physics, music, etc. Gyms and catering rooms are large rooms located on the basement and ground floor and offices are rooms used by teachers and the administrative staff. The box plot of the CRn data grouped by types of rooms is presented in Fig. 2(a). The highest arithmetic means the value of CRn was found in gyms/catering rooms (AM = 161 Bq m^{-3}), and the lowest in classrooms (AM = 128 Bq m^{-3}). Similar results were obtained during the study in the Plovdiv region (Ivanova *et al.*, 2021). The catering rooms and gyms in schools are usually located in the basements or ground floors while the rooms occupied by pupils, such as classrooms and cabinets, are on the upper floors and are ventilated more often. It was found a statistically significant difference between the classrooms, cabinets, and offices (KW, p = 0.04), which means that the CRn depends on the way of their use too.

Most of the measured rooms (69.6%) were placed on the ground floor, while 16.7% were on the first floor. In most school buildings of the Kardzhali district, the basements are unused so only 13.7% of measurements were performed in the basement. Statistically, a significant difference was not found between CRn by floors, although the radon concentration values decreased with increasing floors (Fig. 2(b)), which can be explained by the not-homogenous number of measured rooms in groups by floors. Studies in Serbia and Portugal reported significant variability between classrooms located on ground floors compared to upper-floor classrooms (Bochicchio *et al.*, 2014; Madureira *et al.*, 2016). Classroom radon concentrations varied significantly by the building's method of construction, types of materials used (e.g., brick vs. concrete), and types of windows installed (Ptiček Siročić *et al.*, 2020).

To estimate the student's effective dose, they would receive, we classified the schools into three groups: primary, secondary and high (Fig. 2(c)). The P-value of Shapiro-Wilk shows a normal distribution of values for the second p = 0.30, but not the first and third group ($p < 0.001$). A statistically significant difference (KW, p = 0.18) was not found between the groups, which means that the dose does not depend on the type of school. The annual effective doses were obtained from measured radon concentrations using Eq. (1) and ICRP and UNSCEAR dose coefficient. Students, depending on the length of the study programs, spend different times in school: in primary school, students are occupied fewer hours than those in high school. According to the Ordinance on Organization of Activities in School Education, 2022 (MES, 2016), pupils spend in primary approximately 800 hours, in secondary school 1020 hours, and in high school, 1080 hours per year or on average they spend 1000 hours $year^{-1}$ (SN. No. 26/01.04.2022) (Table 1). The difference in the estimated effective dose is due to the different dose coefficients. In addition,

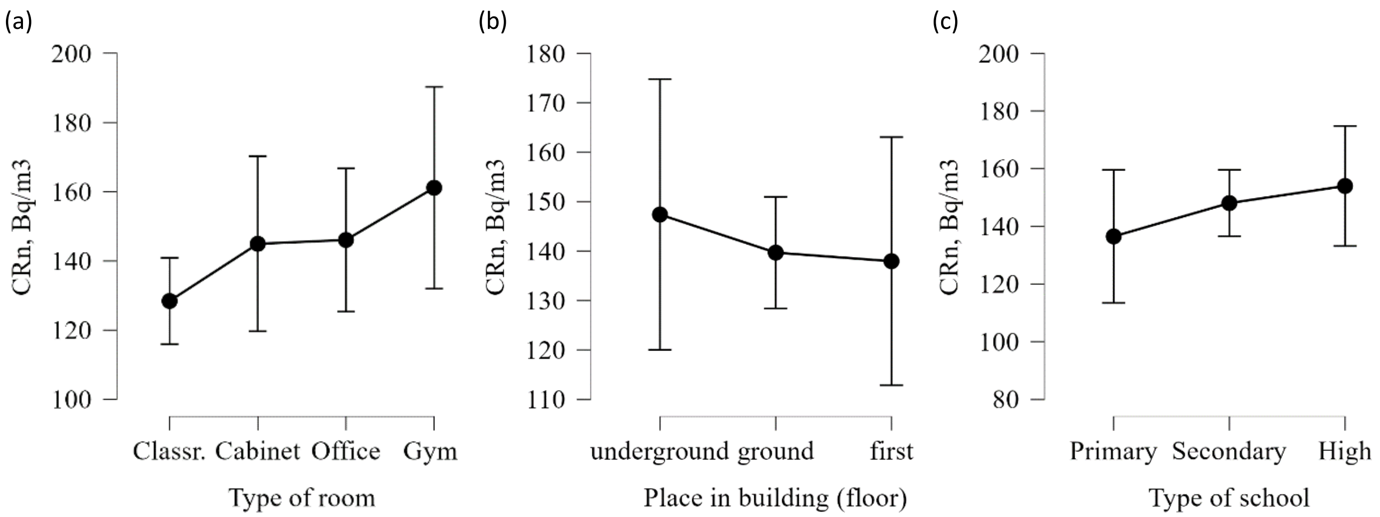

Fig. 2. Descriptive plots of means by (a) type of rooms, (b) type of floors, and (c) type of schools.

in the ICRP approach, the CRn is used for dose calculation, while in the UNSCEAR methodology the EEC is evaluated. The two Commissions have analyzed the sensitivity of dose conversion factors to age. It is established, that there are competing effects tend to offset each other because children have smaller airways that increase deposition by diffusion, but this is partially offset by shorter dwell times (i.e., higher respiratory rates) that reduce deposition by diffusion (UNSCEAR, 2019). That way applying the dose coefficient to the assessment of children's doses could lead to approximately 10% uncertainty. Uncertainties due to the assessment of radon and progeny concentration, include: the measurement, which is assessed to be 0.1, according to our procedure; due to long-term variations of radon concentration, which value of 0.5 is suggested by Onishchenko and Zhukovsky (2019). The value of the uncertainty due to variations in the equilibrium factor was assessed as 0.24 (Onishchenko and Zhukovsky, 2019). Considering this, the estimated combined uncertainty in the dose estimate is approximately 60%.

4 CONCLUSIONS

This survey analysis on indoor radon in state school buildings in Kardzhali district, Bulgaria. The measurements of the indoor radon concentration in the air were performed in 55 state schools located in all municipalities of the district. Radon concentrations in this study ranged from 17 to 868 Bq m^{-3}, with an average value of 144 Bq m^{-3}. The CRn exceeds the national reference level of 300 Bq m^{-3}, defined in the Bulgarian ordinance on radiation protection in 30% of the investigated buildings. Children spend more time indoors. It was estimated that Bulgarian children, on average, spend between 5 and 6 h per day in school buildings. Furthermore, they are more sensitive to environmental hazards exposure compared to the elderly. Therefore, high levels of radon in school buildings may pose health risks. Considering that, for the purpose of radiation protection, the ICRP approach should be applied in the assessment of the effective dose, children could receive approximately 1 mSv per year, staying in school. Respectively, to reduce radon exposure, school buildings should be controlled and high levels reduced.

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DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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