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Indoor Radon Concentrations of School Buildings in Varna District, Bulgaria

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Abstract: Radon is a radioactive gas that is naturally produced by the breakdown of uranium in soil, rock and water. Recent International Commission on Radiological Protection (ICRP) and World Health Organization (WHO) requirements include controlling indoor radon exposure and settings of a reference level for the annual average activity concentration of up to 300 Bq/m^3 for dwellings and public buildings. Radon measurements in school buildings have long been carried out in many countries. Systematic measurements in schools in Bulgaria have started and are progressing. The study concerns the measurements of radon concentration (CRn) in all state school buildings in one of the Black Sea regions, Varna district, and the analysis of indoor variation. The survey of 1,185 premises of 107 schools was conducted from December 2019/January 2020 to March/May 2020 using a passive method. The AM (Arithmetic Mean) of CRn in the premises of the studied schools on the territory of Varna district is 130 Bq/m^3, and the geometric mean is 97 Bq/m^3. The number of premises exceeding the national reference level of 300 Bq/m^3 is 72 located in 38 schools (about 36% of schools). A statistically significant difference (KW (Kruskal-Wallis), $p < 0.0001$) was found between the radon data, grouped by municipalities. Furthermore, the radon data were classified into two groups based on municipality location: on the Black Sea coast and inland. Schools located near the sea have a higher value of CRn. In order to more accurately assess the exposure of pupils and teachers, the results are divided into four groups, depending on the type of use of the premises and the floor on which they are located. The highest CRn value was found in the study rooms used for specialized education such as physics, chemistry, music etc. (AM = 155 Bq/m^3), which can be explained by their smaller size and less frequent use. A statistically significant difference (KW, $p < 0.0001$) was found, which means that the radon exposure in the examined rooms depends on the type of use. The key to reducing children's exposure in schools is to measure CRn and then apply corrective action to the high levels of radon.

Key words: Radon, schools, measurement, classrooms, Bulgaria.

1. Introduction

Based on scientific findings, policies are being developed worldwide to reduce indoor radon concentrations in buildings, with the common goal of reducing the health risk for exposed individuals [1, 2]. The WHO (World Health Organization) guidelines based on the guiding principle of radiation safety is ALARA (as low as reasonably achievable) principle, recommend a national reference level of 100 Bq/m^3, and wherever this is not possible, the chosen level should not exceed 300 Bq/m^3 [2]. According to Directive 2013/59/EURATOM, Member States are obliged to set the reference values of national legislation for the annual average indoor radon concentration not exceeding 300 Bq/m^3, for existing and new dwellings, workplaces, and buildings with public access. The European Union Directive for radiation protection includes requirements for radon control in workplaces and buildings. The requirements have been implemented in the Bulgarian national legislation [3].

Radon is a naturally occurring colourless and odourless radioactive gas and comes from the decay chain of uranium (^{238}U), which is found everywhere in soils and rocks. Once it reaches the outdoor atmosphere, it is diluted by the other gases and has low concentrations. On the other hand, after entering

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the building envelope, the concentration can rise to dangerous levels if the room ventilation is insufficient. Therefore, the indoor radon concentrations vary with the surfaces and volumes of the enclosed spaces and the air exchange rate [4]. Consistent with structural factors, radon infiltration is driven by concentrations and pressure gradients that exist between indoor and outdoor environments. Radon in buildings is considered to be the most important indoor air pollutant, with harmful impacts on the people health. Building design, construction and ventilation affect the migration paths and accumulation of indoor radon. Radon is one of the most studied air pollutants today, since most of the radiation dose that humans receive from natural radioactive sources is due to the inhalation of radon and its decay products [5].

Schools are a category of public buildings with a high risk of exposure to radon, due to their high occupancy factor and building characteristics. It has long been known that prolonged exposure to high levels of radon (^{222}Rn) increases a person's risk of developing lung cancer [1]. School buildings have been attracted special interest, not only because children are more sensitive to radiation (as well as radon) exposure than adults but also because schools are one of the predominant indoor spaces in children's lives [6]. Therefore, over the last decade, considerable attention has been paid to radon surveys in schools and kindergartens. A number of studies have been published in the scientific literature as a result of radon surveys conducted in schools and kindergartens in different countries. Available data from Bulgarian dwellings [7-9] and surveys in schools and kindergartens [10, 11] indicated that both environments are likely to have radon concentrations in excess of 300 Bq/m^3. Therefore, the investigations are being continued as part of the National Radon Action Plan.

The aim of this study is to determine the difference in indoor radon concentration between all state school buildings in Varna district as well as to analyze the influence of buildings characteristics and habits on their use on radon variations. The analysis was made under the national project of the National Science Fund of Bulgaria within the grant No. КП-06-Н23/1/07.12.2018.

2. Material and Methods

2.1 Area of Study

Varna district is located on the Black Sea coast (Fig. 1) in the eastern part of the Danube plain. The region covers an area of 3,820 km² or 3.44% of the country's territory. Most of the surface of the area is hilly. Varna district is the third largest in population and 12th in area in Bulgaria. The district has 159 settlements, divided into twelve municipalities: Avren, Aksakovo, Beloslav, Byala, Varna, Vetrino, Valchi Dol, Devnya, Dolni Chiflik, Dalgopol, Provadia and Suvorovo (Fig. 1). Varna district is the centre of the north-east coast region and has 11 towns and 148 villages. In this study, we examine the results of CRn measurements conducted in the premises of 107 schools on the territory of Varna districts.

2.2 Design of Survey, Radon Measurements and Analysis

The survey for indoor radon concentration in schools of Varna district was promoted and coordinated by the NCRRP (National Centre of Radiobiology and Radiation Protection), according to working procedures. To measure indoor radon concentrations, detectors of the RSKS-type nuclear track detectors, of the Radosys system were used, consisting of a CR-39 chip placed in a cylindrical diffusion chamber. The detectors were exposed in the premises of the schools' buildings from December 2019 and January 2020 to March and May 2020. The distribution and detectors deployment was conducted by employees of the RHI (Regional Health Inspectorate) Varna with the assistance of senior staff of schools. A detailed questionnaire containing data for characterization of the measurement site is filled in for each surveyed building.

Fig. 1 Map of the location of Varna district in Bulgaria (left) and map of the 12 municipalities in district (right).

During the survey, a questionnaire was distributed, which included a description of the following parameters: exact location, characteristics of the building (presence of a basement, mechanical ventilation system, implemented all energy saving measures; types of sewerage system, heating, walls, windows, etc.) and type of premises. The identification numbers of the detectors, the measurement period and the exact location of the detector in the building were filled in the questionnaire. Based on our experience from previous surveys [10, 11] and international studies [12], indoor radon was measured in the basement, ground floor and first floor premises of the investigated buildings. A blank and duplicate detectors were distributed for QA (Quality Assurance). In the NCRRP Radon Laboratory, the Radosys Watchdog 1.2 QA software is also used for QA of the Radosys RadoMeter microscope system as well. The procedure included reference slides that control the system and allow daily inspection. The total number of detectors provided for the study was 1,260. The percentage loss of the detectors is 6%, so 1,185 results were evaluated for rooms in the schools. After exposure, chemical processing and automated detector readout were performed in NCRRP Radon Laboratory.

Descriptive statistics and non-parametric tests are adopted for data processing using the IBM SPSS Statistics version 23 software. To assess the impact on radon, the measurement results are grouped as follows: 2 groups by geographic location of municipalities—on the Black Sea coast and inland; 4 groups according to the type of use of the premises—classrooms, study rooms (for subject classes such as physics, chemistry, music, etc.), gym/dining rooms and offices; and 3 groups according to the floor on which they are located—basement, ground floor and first floor.

3. Results

3.1 Summarized Results

The average value of CRn in the premises of the studied schools on the territory of Varna district is 130 Bq/m^3, and the geometric mean value is 96.8 Bq/m^3. The systematized results are shown in Table 1.

Table 1 The statistical parameters of indoor radon concentration in schools.

Parameter	CRn
Average AM (arithmetic mean), Bq/m^3	130
Standard deviation, Bq/m^3	128
Median, Bq/m^3	91
Minimum value, Bq/m^3	11
Maximum value, Bq/m^3	1674
Coefficient of variation (CV), %	99
Geometric mean, Bq/m^3	96.8
Geometric standard deviation	2.1

The number of premises in which the CRn exceeds the national radon reference value of 300 Bq/m^3, set in the Bulgarian legislation, was 72, located in 38 schools (that is about 36% of the schools in Varna), while the premises with a CRn over 200 Bq/m^3 are 115. The percentage of premises where CRn exceeded the national reference level was 6%, which is lower than the 7.5% value reported from the three Visegrad countries [13]. The maximum CRn of 1,674 Bq/m^3, was measured in the classroom, which is about five times higher than the national radon reference value. Considering 63 national and regional indoor radon surveys in kindergartens and schools in Europe, Asia, Africa and North America, the AM for CRn of 59 Bq/m^3 was reported [14]. This value is lower than the AM radon concentration in schools in Varna district.

3.2 Summary of Results by Municipalities Location

Analysis of indoor radon data grouped by municipalities in Varna district was performed and a statistically significant difference between them (KW (Kruskal-Wallis), $p < 0.0001$) was found. In addition, the municipalities were classified according to their location on the Black Sea coast in order to assess the influence of the geographic features.

Fig. 2 shows the mean values of the CRn measurements grouped by geographical features of the municipalities. The nonparametric Mann-Whitney (MW) statistical test was applied and the statistically significant difference between the groups was found (MW, $p < 0.001$). The AM of the coastal municipalities (AM = 134 Bq/m^3) was higher than those in the inland (AM = 119 Bq/m^3). One of the reasons for this difference may be the sandy soil and the associated greater soil permeability near the coast than inland. Another explanation could be the stronger wind on the sea coast, which leads to a greater pressure gradient forming between the building and the ground, and accordingly, a greater flow of soil gas and radon to the building. This fact should be studied more carefully in order to draw more definite conclusions.

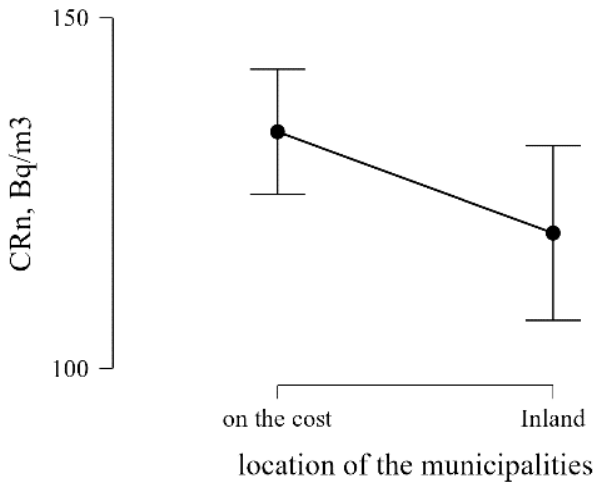

Fig. 2 Mean values of CRn measured in the buildings situated on the Black Sea cost and inland.
Error bars present 95% confidence interval of the mean.

3.3 Distribution of CRn by Floors and Type of Rooms

The radon concentration was measured on the ground floor according to our procedure. Additionally, to test the hypothesis that the radon concentration decreases with increasing floor height, the CRn values were measured in the rooms on the first floor in some randomly selected schools. Radon measurements were also made in the basement of schools, which is used usually for the canteen of the schools. Pupils do not spend much time there, but the staff working there are exposed to radon. A statistically significant difference was found with the test of KW ($p < 0.0001$) and the hypothesis was confirmed. Fig. 3 shows the reduce in CRn with increasing the floor level, i.e. with increasing the distance from the ground, which is the main source of radon.

Specific recommendations were made to improve ventilation of basements used for human habitation, as well as to take corrective measures for high radon concentrations.

In order to be able to assess the exposure of pupils and teachers more precisely, the results are divided into four groups, depending on the type of use of the premises. The highest mean CRn value of 155 Bq/m^3 was determined for the study rooms used for specialized training such as physics, chemistry, music

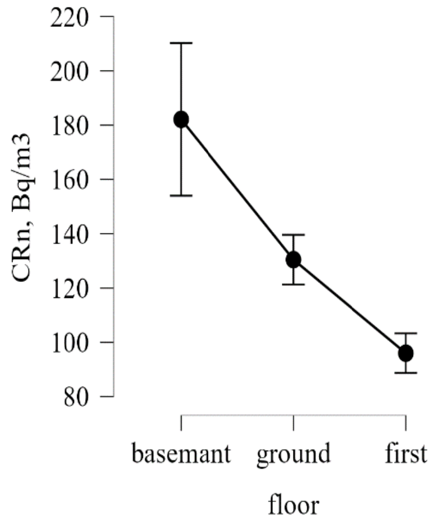

Fig. 3 Mean values of CRn measured in different floors.

etc., which can be explained by their smaller size and less frequent use. A statistically significant difference (KW, $p < 0.0001$) was found, which means that the radon exposure in the examined rooms depends on the type of use. The boxplot of the logarithm of CRn measured in the different premises of the schools is shown in Fig. 4. The lowest value of CRn is found for classrooms. These are the most used premises in schools, often ventilated by opening the windows. This circumstance reduces the concentration of radon in them. Particular attention is paid to gyms, where children do physical exercises. These premises are more spacious, but obviously not well ventilated, as radon concentrations appeared to be higher than in classrooms.

It is recommended that gyms be well ventilated before pupils' classes begin. Bulgaria has issued a regulation on the protection of buildings from radon, which specifies the basic requirements for corrective measures to reduce the radon concentration. All schools with values above the reference level are advised to contact builder professionals to who should take action. It is recommended that radon measurements in school buildings be repeated every 5 years, and more frequently in the case of building renovations.

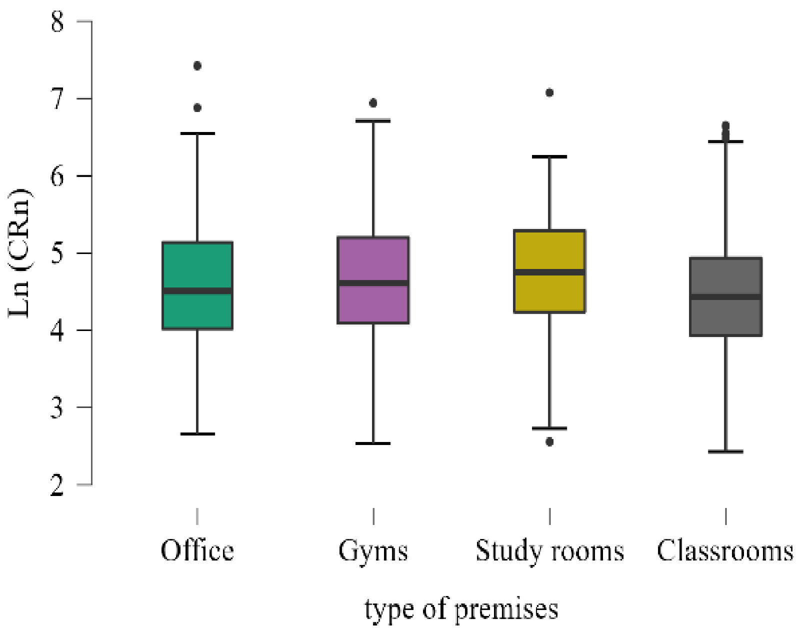

Fig. 4 Boxplot of logarithm of CRn, grouped by premise type.

4. Conclusion

The key to reducing children's exposure to radon in schools is to measure CRn and then apply corrective actions to the high radon concentrations. Therefore, the radon measurement in the buildings with public access (schools and kindergartens) should be continued as part of the National Radon Action Plan.

Based on the radon data collected in this survey, an analysis of the type of room, floor and type of building was conducted. It was found that the CRn decreased with increasing floor height, confirming the conclusion that it is sufficient to conduct surveys at lower floors. The difference between the CRn and the types of premises in buildings has been confirmed, which is evidence that radon levels depend on the type of premises use or the habits of the occupants.

Acknowledgments

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