

RADON SURVEY IN THE BUILDINGS OF PRE-UNIVERSITY EDUCATION IN MONTENEGRO

Perko Vukotić^{1}, Ranko Zekić², Tomislav Andjelić², Nikola Svrkota²*

¹ Montenegrin Academy of Sciences and Arts, R. Stijovića 5, 81000 Podgorica, Montenegro

² Centre for Ecotoxicological Research, Bulevar S. De Gola 2, 81000 Podgorica, Montenegro

Abstract: During the academic year 2016/17 (September – June), radon was surveyed in all 519 buildings of the pre-university education in Montenegro – primary, high and vocational schools, kindergartens, institutes for children with special needs and student dormitories. Radon detectors (Radosys,RSFV type) were placed in all classrooms, rooms occupied by children and offices on ground floor, and in some rooms on the upper floors. The total number of detectors was 4078, of which 285 were duplicate (control) detectors. During the radon survey, 11.4% of the detectors were lost or damaged. Average 9-month radon activity concentrations were obtained for 3345 rooms in 507 buildings. Mean values of radon concentrations in the rooms were AM = 243 Bq/m³ and GM = 142 Bq/m³, while the corresponding values for Montenegrin dwellings, found in the national radon survey, were more than twice lower. Radon concentrations above 300 Bq/m³ were found in 23.3% of all surveyed rooms and in 3.4% of the rooms they were above 1000 Bq/m³. Radon activity concentrations above 300 Bq/m³ were measured in some rooms in 44% of the buildings, and those above 1000 Bq/m³ in 9.5% of the buildings. Radon levels in educational buildings are significantly higher than in Montenegrin homes, which means that children and educators are more exposed to the harmful effects of radon in schools and kindergartens than at homes (for equal durations of stay in them). This could be resulting from the type of construction of educational buildings, which are usually large low-rise structures, and from a relatively high average age of these buildings.

Keywords: Radon survey, educational buildings, 9-month long measurements.

1. INTRODUCTION

Radon (Rn) is naturally occurring noble and radioactive gas. It comes from decay of uranium (most important radionuclide of Rn is ²²²Rn – commonly known as radon) and thorium (important radionuclide is ²²⁰Rn – named thoron) in the environment, and it enters into buildings and other closed spaces, where, because of buildup, it can reach high concentrations. Radon (²²²Rn) is a major contributor to the radiation dose received by the general population. There is strong evidence that long-term exposure to radon increases the risk of lung cancer. Therefore, the World Health Organization proclaimed radon as the second most important cause of lung cancer after smoking in many countries[1], and the International Atomic Energy Agency [2] and the Council of the European Union [3] recommended to the member countries the need for addressing long-term risks from radon exposure, by conducting representative radon surveys in dwellings and other

buildings with high occupancy factors for members of the public and by establishing reference levels for indoor radon concentrations.

Montenegro is a Western Balkan country on the Adriatic Sea, with a land area of 13,812 km² and a population of about 620,000. Radon (²²²Rn) measurements in Montenegrin homes for the first nationwide survey were completed at the end of 2015, and the main results were published recently [4, 5]. Immediately after finishing radon measurements in Montenegrin dwellings, a national survey of radon in the buildings of pre-university education began, funded by the International Atomic Energy Agency and the Government of Montenegro.

In total, there are 519 buildings of the pre-university education in Montenegro - 427 school buildings (primary, high and vocational), 81 kindergarten buildings, 4 buildings of institutes for children with special needs and 7 student dormitories. These buildings are usually low rise structures, with only one floor (ground floor) or two floors. In the

* Corresponding author: pvukotic@canu.ac.me

town areas they are mostly buildings with a very large contact area with the ground, while in the country side they usually do not differ from family houses. Educational buildings are typically without basement and heated on wood or electricity, without central heating and ventilation system. Construction materials are mostly concrete and bricks, while in the country side the stone houses are prevailing. The buildings are, on average, relatively old – 65% of them are built before the year 1980.

Montenegro has to comply with new international standards [2], which require establishing a national reference level for indoor radon annual average activity concentration not higher than 300 Bq/m³. This reference level also applies to the schools and kindergartens.

This paper presents descriptive statistics of the radon activity concentrations in buildings of pre-university education in Montenegro and compares them with those found in Montenegrin dwellings.

2. MATERIALS AND METHODS

In order to involve representatives of all schools and kindergartens in the radon survey, the three regional trainings on the method of radon measurement and on completing the accompanying questionnaire were organized for them. At the end of training, radon detectors were assigned to the representatives of educational institutions in a quantity required to cover at least all working rooms on the ground floor in the buildings of their institutions. In the course of radon survey, many activities were carried out with the intention of increasing awareness on radon risk among school children, their parents, teachers, educational and health authorities: a leaflet “Radon in school” and two posters about radon (one for primary, the other for secondary schools) were written, printed and distributed to the schools and educational and health authorities, lectures on radon were held in all schools,

radon experts initiated public media programs on radon and took part in them, etc.

Radon was continuously measured during the whole school year 2016/17 (September – June) in all 519 buildings of pre-university education, in all classrooms, playrooms, offices and bedrooms on the ground floor, and in some rooms on the first floor. In total, 3793 rooms were surveyed with 4078 radon detectors, 285 of them being control detectors, set paired side-by-side with basic detectors approximately at every twelfth location and exposed for exactly the same period of time.

Radosys’ detector of the RSFV type, with two CR-39 chips of different sensitivities, was used for radon measurement. According to the manufacturer’s leaflet [6], it is not sensitive to thoron (²²⁰Rn) and gamma-radiation, and has sensitivity of measuring radon (²²²Rn) up to 80 MBq/m³, which means that it can measure an average 9-month radon activity concentration up to about 12 kBq/m³. After 9-month long exposure, detectors are sent to the Radosys’ laboratory for etching and track counting.

During the radon survey, 11.4% of the deployed detectors were lost or damaged.

3. RESULTS AND DISCUSSION

Average 9-month radon activity concentrations were obtained for 3345 rooms (85.4% of them are on ground floor) in 507 educational buildings countrywide. In four rooms radon detectors were saturated at the exposure level of 24 MBq/m³, which corresponds approximately to a radon concentration of 3600 Bq/m³. Therefore, for statistical purposes, the radon activity concentrations in these rooms were arbitrary taken as equal to 4000 Bq/m³. The frequency distribution of radon concentrations in 3345 rooms is presented at Figure 1, while descriptive statistics of the radon concentrations is given in Table 1.

Table 1. Characteristics of radon activity concentrations in the rooms of educational buildings (9-month average).

Number of rooms	AM (Bq/m ³)	SD (Bq/m ³)	MAX (Bq/m ³)	GM (Bq/m ³)	GSD	C _{Rn} > 300 Bq/m ³	C _{Rn} > 1000 Bq/m ³
3345	243	345	>3600	142	1.09	23.3%	3.4%

AM – arithmetic mean; SD – standard deviation; MAX – the highest radon activity concentration; GM – geometric mean; GSD – geometric standard deviation

The mean values of the 9-month radon activity concentrations in 3345 rooms are AM = 243 Bq/m³ and GM = 142 Bq/m³. They are higher more than

twice than the corresponding mean values of the annual average radon activity concentrations in 953 Montenegrin dwellings (AM = 110 Bq/m³, GM =

58.3 Bq/m³), obtained in the national indoor radon survey [4] and presented in Table 2. Average radon concentrations above 300 Bq/m³ are found in 23.3% of all surveyed rooms in educational buildings and in 3.4% of all rooms the concentrations were above the level of 1000 Bq/m³, which could be considered as

the “urgent action level”, above which mitigation measures are strongly recommended [4]. In the Montenegrin dwellings these percentages are 7.9% and 0.6%, respectively, which means 3 to 5 times lower.

Table 2. Characteristics of radon activity concentrations in Montenegrin dwellings (annual average).

Number of dwellings	AM (Bq/m ³)	SD (Bq/m ³)	MAX (Bq/m ³)	GM (Bq/m ³)	GSD	C _{Rn} > 300 Bq/m ³	C _{Rn} > 1000 Bq/m ³
953	110	182	2320	58.3	2.91	7.9%	0.6%

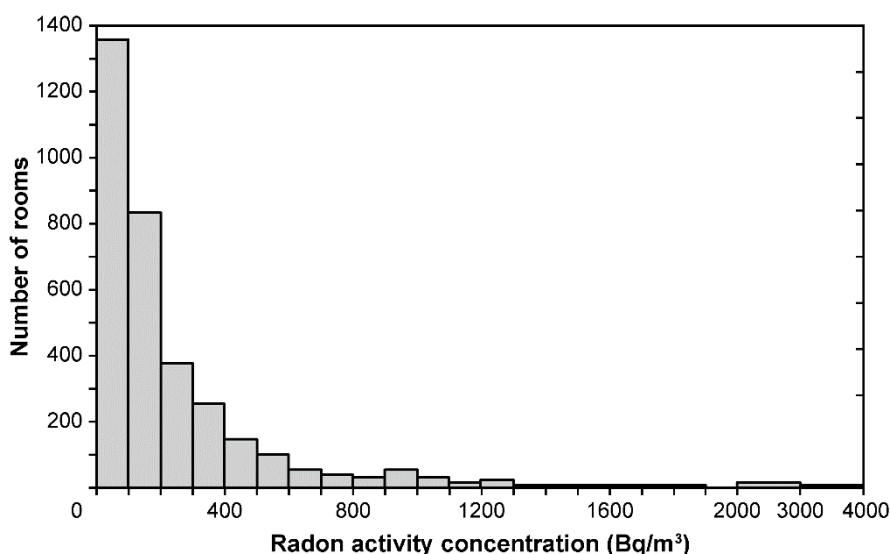


Figure 1. Frequency distribution of radon concentrations in 3345 rooms in educational buildings.

This comparison of the 9-month averages of radon levels in educational rooms (they do not encompass radon levels during summer period of a year) with the 12-month averages in dwellings could seem improper and leading to erroneous conclusions. Indeed, summer radon concentrations indoors are usually lower than in the rest of year, worldwide [7] as in the Montenegrin dwellings [5], due to a smaller indoor-to-outdoor air temperature and pressure differences, but this doesn't have to be true in case of school buildings because this effect could be compensated by the effect of radon buildup caused by closed doors and windows of schools during summer vacations. Such a situation was reported for 29 primary schools of three municipalities in Macedonia, where radon was measured exposing simultaneously

two detectors, one for nine months (during school year, and not during summer vacations) and one for the whole year –it was found that differences between measured annual and 9-month radon concentrations were not significant [8].

The 9-month radon concentrations in the rooms of educational buildings (Table 1) can be also compared with the 6-month (October–April) radon concentrations in Montenegrin dwellings (given in Table 3), measured in the colder half of a year when they are higher than in the other 6-month period [5]. Again, all above mentioned characteristic values of radon concentrations in educational buildings are about two times higher than in dwellings during a colder 6-month period of a year.

Table 3. Characteristics of radon activity concentrations in Montenegrin dwellings during the colder 6-month (October–April) period of a year.

Number of dwellings	AM (Bq/m ³)	SD (Bq/m ³)	MAX (Bq/m ³)	GM (Bq/m ³)	GSD	C _{Rn} > 300 Bq/m ³	C _{Rn} > 1000 Bq/m ³
953	140	265	3798	65.1	3.24	10.5%	1.5%

In 223 of 507 educational buildings where radon was measured, there are some rooms with average 9-month radon activity concentration above 300 Bq/m³, while in 48 of these buildings there are one or more rooms with radon concentration higher than 1000 Bq/m³, as graphically presented at Figure 2.

All results presented here point out that Montenegro has a serious problem with radon in schools and kindergartens, and needs to adopt an

action plan to cope with it in order to protect children, students and people employed in the educational system from exposure to radon. The action plan should approach the radon mitigation of educational buildings gradually, starting with those buildings with the highest radon levels and highest number of their occupants, and applying in the other buildings immediately a regime of air ventilation which corresponds to radon level in the rooms.

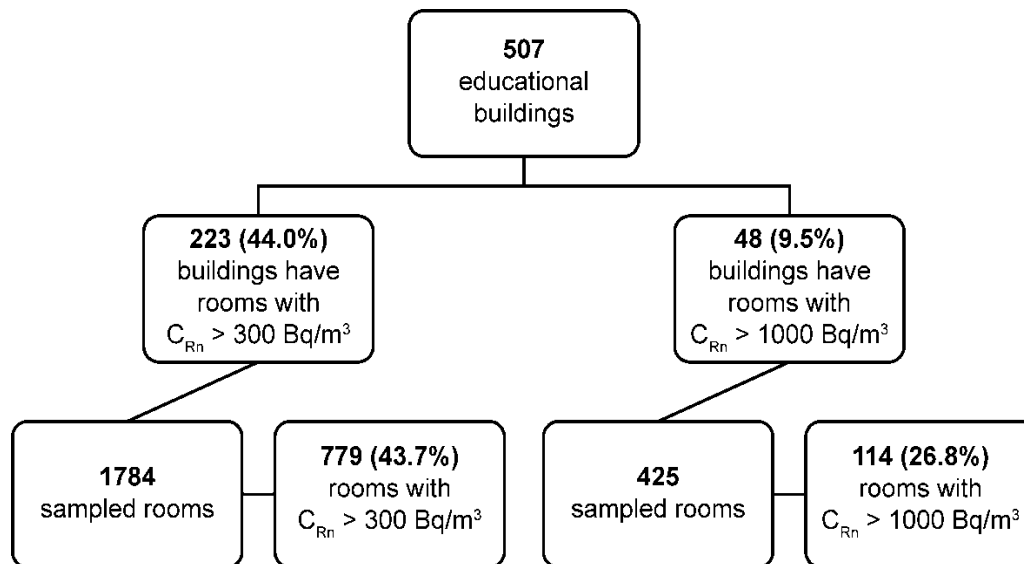


Figure 2. Educational buildings with some rooms having average radon concentrations above 300 Bq/m³ and 1000 Bq/m³.

4. CONCLUSIONS

Radon concentrations in the rooms of educational buildings are, on average, significantly higher than in Montenegrin homes. Their mean values are AM = 243 Bq/m³ and GM = 142 Bq/m³. Average 9-month radon concentrations are found to be above 300 Bq/m³ in 23.3% of all surveyed rooms and higher than 1000 Bq/m³ in 3.4% of the rooms, while in four rooms they reach a value above 3600 Bq/m³.

In 44% of the 507 surveyed educational buildings there are one or more rooms with radon activity concentration above 300 Bq/m³, while in 9.5% of the buildings there are rooms with radon concentration higher than 1000 Bq/m³.

These elevated radon levels are probably caused by the type of construction and age of educational buildings, which are mostly large low-rise structures and relatively old.

Results of the nationwide radon survey in the buildings of pre-university education provide a strong indication that Montenegro has a serious problem with exposure of children, students and educators to

radon in schools and kindergartens, and Montenegrin authorities have to find the appropriate and systematic way to cope successfully with this issue as soon as possible.

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] H. Zeeb, F. Shannoun (editors), *WHO Handbook on Indoor Radon - a Public Health Perspective*, World Health Organization 2009.

- [2] *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*, IAEA Safety Standards Series No. GSR Part 3, International Atomic Energy Agency, Vienna 2014.
- [3] *Council Directive 2013/59/EURATOM of 5 December 2013*, Official Journal of the European Union, 17 January 2014.
- [4] P. Vukotić, N. Antović, A. Djurović, R. Zekić, N. Svrkota, T. Andjelić, R. Svrkota, R. Mrdak, N. Bjelica, T. Djurović, A. Dlabac, M. Bogičević, *Radon survey in Montenegro – A base to set national reference and “urgent action” level*, Journal of Environmental Radioactivity, Vol. 196 (2019) 232–239.
- [5] P. Vukotić, N. Antović, R. Zekić, N. Svrkota, T. Andjelić, R. Svrkota, R. Mrdak, A. Djurović, A. Dlabac, N. Bjelica, T. Djurović, M. Bogičević, *Main findings from radon indoor survey in Montenegro*, Radiation Protection Dosimetry, published on March 06, 2019 as doi:10.1093/rpd/ncz022 (Epub ahead of print).
- [6] *Radosys leaflet*. Available: <http://www.radosys.com/rsfv&rsfw.htm> [Accessed: 19 December 2019].
- [7] *Effects of Ionizing Radiation*, United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly with Scientific Annexes (Annex E), UN, New York 2006.
- [8] Z. Stojanovska, B. Boev, Z. S. Žunić, P. Bossew, S. Jovevska, *Results of radon CR-39 detectors exposed in schools due two different long-term periods*, Nukleonika, Vol. 61 (2016) 385–389.



РАДОН У ЗГРАДАМА ПРЕДУНИВЕРЗИТЕТСКОГ ОБРАЗОВАЊА У ЦРНОЈ ГОРИ

Сажетак: Током школске 2016/17. године (септембар–јун), радон је мјерен у свих 519 зграда предуниверзитетског образовања у Црној Гори – у основним и средњим школама, дјечјим вртићима, ресурсним центрима и ђачким домовима. Пасивни детектори радона постављени су у свим учионицама, играоницама, спаваоницама и канцеларијама у приземљу, и у неким од таквих просторија на вишим спратовима. Укупан број постављених детектора био је 4.078, од којих су 285 контролни детектори, постављени у пару са основним детекторима. Током мјерења изгубљено је или оштећено 11,4% детектора. Средње деветомјесечне концентрације активности радона добијене су за 3.345 просторија у 507 зграда. Аритметичка средња вриједност концентрација радона у тим просторијама је 243 Bq/m^3 , а геометријска средња вриједност 142 Bq/m^3 . Ове вриједности су више него двоструко веће од одговарајућих средњих вриједности у становима Црне Горе. Концентрације радона изнад 300 Bq/m^3 нађене су у 23,3% испитиваних просторија, док су у 3,4% просторија оне биле веће и од 1000 Bq/m^3 . Концентрације радона изнад 300 Bq/m^3 измјерене су у једној или више просторија у 44% испитиваних зграда, а изнад 1.000 Bq/m^3 у 9,5% зграда. Нивои радона у школама и вртићима знатно су виши него у становима Црне Горе, што значи да су дјеца и запослени више изложени штетном дејству радона у њима него код куће (за једнако вријеме боравка у њима). То је вјероватно узроковано типом конструкције зграда школа и вртића, које су обично простране и ниске, као и релативно великом просјечном старошћу тих зграда.

Кључне ријечи: радон, школе и вртићи, деветомјесечна мјерења.



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