Radon concentration in dwellings in the mining area of "Trepča" complex

Koncentracija radona u stanovima u rudarskom području "Trepča" kompleksa

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Abstract

This paper presents the results of radon concentration in ground floor dwellings in the vicinity of the "Trepča" mine. Earlier studies on radon in the area of Kosovska Mitrovica have shown that there are dwellings with high values of this radioactive gas, which can be related to technological activities that can change the concentrations of natural radioactive materials in the environment. According to the World Health Organization, radon is the second leading cause of lung cancer after smoking. The history of lung cancer in miners has been known for more than a hundred years, and epidemiological studies in some mining areas of the world, especially in the areas of uranium mines, have confirmed this connection. The mean values of radon concentration were measured with an Airthings Correntium Home detector (alpha-spectrometric detection method was applied). Radon values in selected dwellings ranged from 19 to 225 Bq/m^3. The results of this research show that there are indications that the level of radon in some family buildings in the area of the complex "Trepča" is slightly elevated. Ground shakings caused by mining activities increase emissions of various gases, including radon, and in such conditions, a constant monitoring is necessary and control in order to reduce radioactivity and identify radiologically sensitive locations.
Keywords: *radon concentration; mining area; "Trepca"; lung cancer*

Izvod

U ovom radu su prikazani su rezultati koncentracije radona u prizemnim objektima u okolini rudnika „Trepča". Ranije studije o radonu na području Kosovske Mitrovice pokazale su da ima objekata sa visokim vrednostima ovog radioaktivnog gasa, što se može povezati sa tehnološkim aktivnostima koje mogu izmeniti koncentracije prirodnih radioaktivnih materijala u životnom okruženju. Prema navodima Svetske Zdravstvene Organizacije radon je drugi vodeći uzrok raka pluća nakon pušenja. Istorija karcinoma pluća kod rudara je poznata više od stotinu godina i epidemiološke studije u pojedinim rudarskim oblastima u svetu, naročito u oblastima rudnika urana, potvrdile su ovu vezu. Srednje vrednosti koncentracije radona izmerene su detektorom Airthings Correntium Home (primenjen je alfa-spektrometrijski detekcioni metod). Vrednosti radona u izabranim objektima su iznosile od 19 – 225 Bq/m^3. Rezultati ovog istraživanja pokazuju da postoje naznake da je nivo radona u nekim porodičnim objektima u području kompleksa "Trepča" malo povišen. Usled potresa tla izazvanih rudarskim aktivnostima dolazi do povećane emisije različitih gasova, uključujući i radon, a u takvim uslovima neohodan je stalan monitoring i kontrola u cilju smanjenja radioaktivnosti i prepoznavanja radiološki osetljivih lokacija.
Ključne reči: *koncentracija radona; rudarsko područje; "Trepča"; kancer pluća*

Introduction

Radon is a natural radioactive gas colorless, tasteless and odorless; approximately 8 times heavier than air; it is formed by decaying of minerals containing uranium and thorium in rocks and soils. Unlike radon, the progenies from its decay are in a solid state, so they adhere to surfaces and dust particles in the air. Inhalation is the main way of radon exposure, and contributes more than 50% to the total annual dose from exposure to natural sources of ionizing radiation [1]. By inhaling contaminated dust, the particles can stick to the lungs and thus increase the risk of lung cancer. The energies of emitted α-particles during the decay of radon and its progeny are in the range of 5.49-8.78 MeV; they perform intensive ionization of the biological system.

Naturally, radon exists in the soil (soil is the main source of radon) and easily reaches indoors through cracks in the foundations of buildings. The source of radon can be water or the material from which the house is made. Although it has a short half-life of 3.825 days, radon (^{222}Rn in the series of ^{238}U) can accumulate indoors in concentrations that are much higher than normal, especially in the lower floors of buildings, basements and garages. The concentration of radon at a given location is very variable and depends on climatic and meteorological factors, morphological condition of soil, etc. Seasonal variations in indoor radon concentration are influenced by several parameters: type of building, radon source, behavior of inhabitants, ventilation and heating. Daily variations in radon concentration are related to atmospheric changes; around midnight and in the early morning hours, the maximum concentration of radon occurs. The average annual radon concentration outdoors is from 0.1 Bq/m^3 to 10 Bq/m^3.

Epidemiological studies have shown that with an increase in radon levels of 100 Bq/m^3, the risk of lung cancer increases by about 16% [2]. According to the World Health Organization (WHO), radon is the second leading cause of lung cancer after smoking tobacco [3]. The WHO recommends that the indoor radon concentration should not exceed 100 Bq/m^3. At the other side, according to the Council of the European Union Directive 2013/59 / EURATOM, EU member states should define a reference national level of indoor radon concentration, which should not exceed 300 Bq/m^3.

Scientific research shows an increased health risk from radon exposure for the population living in mining areas. Uncontrolled accumulation of radon indoors can pose a health risk, having in mind that persons spend 80% of their time in the work and living space. In some places on Earth, the levels of natural radioactivity vary greatly, which can be attributed to anthropogenic activities such as mining. Seismic events caused by mining activity lead to an increase in the emission of various gases, including radon. Also, the reason for the increased risk of high concentrations of radon are cracks in the walls of buildings, which are the easiest way for radon to infiltrate into the buildings, especially in areas that have technologically increased natural radioactivity due to human activities. In such conditions, constant monitoring and control is necessary in order to reduce radioactivity and to identify radiologically sensitive locations.

In some mining areas in the world, especially in the areas of uranium mines, high values of radon concentration were measured in settlements located in the immediate vicinity of mines. Workers in uranium mines are not exposed to higher levels of radon in their workplaces than in their homes (Canada) [4]. Elevated values have also been reported in settlements near lead mines in China [5]. Scientific research in Poland has shown that in mining areas, radon concentrations in 2% of facilities exceed 300 Bq/m^3; such areas are considered "radon-prone" areas [6]. Concentrations of radon in buildings in Upper Silesia, an area in southern Poland in an area with over fifty coal mines, ranged from 7 Bq/m^3 to 360 Bq/m^3, with the highest value obtained in the basement at 679 Bq/m^3 [7]. Indoor radon concentrations in the Gauteng gold mine in South Africa ranged from 1 Bq/m^3 to 472 Bq/m^3 [8]. Indoor radon concentration values in the surrounding settlements around the uranium mine in Bulgaria ranged from 125 Bq/m^3 to 4000 Bq/m^3 [9]. The values of radon concentrations measured in the Baita area, Romania ranged from 15 to 2200 Bq/m^3; the average annual radon concentration of 345 Bq/m^3 for these measurements made in Romania [10] is similar to the value obtained in the

Hungarian uranium mine (400 Bq/m^3) [11]. In a study conducted in 2015, radon concentration was measured in the Trepca underground mine; radon concentration ranges from 54 Bq/m^3 to 691 Bq/m^3; the average indoor radon concentration was 286 Bq/m^3, while on all horizons they were below the permitted levels [12]. Also, previous studies in the area of Kosovska Mitrovica have shown that there are buildings with high values of radon concentration, which can be related to technological activities that can change the concentrations of natural radioactive materials in the environment. Based on the measurements performed so far in the municipalities of Kosovska Mitrovica and Zvečan, and according to some published results, there are indications that a number of dwellings in the vicinity of the mining complex "Trepča" have elevated values of radon concentration. The highest average annual radon concentration of 810 Bq/m^3 is in the basement of one house in the municipality of Zvečan [13]. The authors concluded that high radon values correspond to locations near active faults. According to the Council of the European Union Directive 2013/59/EURATOM, EU member states should identify buildings (residential and working space) where the average annual radon concentration exceeds the reference level and encourage a reduction in radon concentrations in these facilities, as well as provide information at the local level and national levels on radon exposure and associated health risks.

In the territory of the Republic of Serbia in 2016, a national campaign was conducted to measure radon in residential buildings in order to raise public awareness of the harmful effects of radon (Kosovo and Metohija are not covered by this national campaign). The measurement results have been implemented in the European Radon Risk Map. After making such maps, some Scandinavian countries gave recommendations on the migration of the population to other areas, all in order to protect human health.

The aim of the study was to determine the indoor radon concentration in ground floor houses in the mining complex "Trepča", because technologically increased natural activity can cause elevated levels of radioactive radon gas in mining settlements, which is documented above.

Study area and method of measurements

This paper covers the area of the municipalities of Zvečan and Kosovska Mitrovica, and concerns the measurement of radon concentration in ground floor buildings in the settlements around the industrial complex "Trepca", 9 km northeast of Kosovska Mitrovica (Figure 1). The study area lies at an altitude of about 500 m. The region of Kosovska Mitrovica belongs to the zone of tertiary magmatism. The formation of the geological structure in the observed area refers to the period from the Ordovician-Silurian to the Quaternary. Volcanogenic-sedimentary formations are characterized by volcanics, dolomites, marbles, carbonates, phyllites and green shales. Strong volcanic activity produced larger masses of andesite, dacite, latite and pyroclastite in the past. The study area contains significant deposits of Pb, Zn, Mn and Cr. The process of ore formation is connected with volcanic breccia, which consists of common skarn minerals. Lead and zinc deposits have enabled the development of mining activities and formerly the largest Pb-Zn mine in Europe (40 mines and factories), the industrial complex "Trepča". Now, it includes only seven lead and zinc mines, three concentrators, one smelter and one zinc factory. Nine industrial landfills are still located near Kosovska Mitrovica, and are the main source of air, water and soil contamination.

Radon measurements were performed in 11 houses, of which eight houses in Zvečan and three houses in Kosovska Mitrovica. Detectors were installed in ground-floor houses (Figure 2), at height of 1 m from the floor and 0.5 m from the walls, in the summer (during August and September). The measurements lasted for 7 days in one house. Detectors were deployed in the rooms where people spent most of the time, such as living rooms and bedrooms. A common feature of all houses is that they are ground-floor, and that the soil is under the foundation of house. The houses were built in the period from 1920-1985. The age of houses can play a significant role in variations in radon concentrations, especially since earlier building materials used in construction involve the use of local stone for the foundation, and such materials in the area of Kosovska Mitrovica have elevated radioactivity [13]. The building material used in the construction is mostly brick. Ventilation is mostly natural; there is no forced ventilation in selected houses.

Figure 1. *Smelter in Zvečan, a part of complex "Trepča"*

Airthings Correntium Home detectors were used for radon measurements (Figure 2). The applied detection method was alpha-spectrometric, that is based on the process of radon diffusion into the chamber. Detector Airthings Corentium Home measures in the range from 0-9999 Bq/m^3. Uncertainty of device for one month measurement is less than 10%, and accuracy at typical 200 Bq/m^3 is 5-10% for measurement period from 7 days to two months. The detector shows first result after 6-24 hours: long-term (LT) and short-term (ST) average radon concentration. The LT average represents average radon value for current measurement (updated once a day). The ST average changes between showing last-day radon values (updated hourly) and values for the last seven days (updated daily) (Airthings Corentium Home) [14].

Figure 2. *Common look of ground floor house and radon detector Airthings Corentium Home*

Results

Table 1 shows the values of LTA measurements which presents the mean radon concentration averaged over 7 days, while the STA measurements represents the value averaged over 24 hours. Also, the range of radon concentration was presented, the values of standard deviation and coefficient of variation which indicating fluctuations due to radon daily changes in meteorological parameters and behavior of inhabitants.

Mean values of radon concentration in houses in Zvečan are respectively: 84, 25, 50, 49, 182, 33, 204 and 103 Bq/m^3, while the values of radon in houses in Kosovska Mitrovica are: 19, 225 and 106 Bq/m^3, respectively. The mean value of radon concentration for a given set of measurements is 98 Bq/m^3. The highest radon concentration was measured on the last day in the tenth house, but due to the constant concentration during measurements, there are no significant daily fluctuations in radon concentration. However, in five houses radon concentrations are slightly higher than 100 Bq/m^3. The obtained values of LT ranged from 9 Bq/m^3 to 502 Bq/m^3, except in one case when the radon concentration in one day reached an unexplained value of 1308 Bq/m^3.

Coeficient of variation (LT values) show the extent of variability in relation to the mean; coeficient of variation is up to 30% in eight dwellings. However, measurements in other dwellings showed large deviations.

Table 1. Indoor radon concentration, standard deviation and coeficient of variation of measurements

	Radon concentration (Bq/m^3)			Standard deviation (Bq/m^3)		Coefficient of variation (%)
	Mean	Range				
	LT	LT	ST	LT	ST	LT
1.	84	68-115	12-163	20.8	54.4	25
2.	25	23-68	17-163	16.5	53.3	66
3.	50	40-55	22-65	4.7	13	9
4.	49	13-49	1-89	14.4	32.8	29
5.	182	41-258	21-1308	91.1	472	50
6.	33	33-46	29-45	4.6	6.3	14
7.	204	201-502	203-492	110	125	54
8.	103	58-103	56-152	16	31.3	16
9.	19	13-19	9-24	2.5	4.5	13
10.	225	110-225	99-287	53.3	80.4	24
11.	106	88-146	41-153	23.6	42.2	22
Range	19-225	-	-	2.5-110	4.5-472	10-78

The world average annual efective dose from radon exposure (1.15 mSv/y) is based on the concentration of 40 Bq/m^3. This means that the values of radon, and thus the estimated risk for inhabitants in only three dwellings are lower than the world average. The estimated risk is the highest for the houses 5, 7 and 10, with radon concentration above the 100 Bq/m^3 and is estimated to be: 4.6 mSv/y, 5.1 mSv/y and 5.7 mSv/y, respectively.

Conclusion

It is of primary importance to inform the population about the health hazards that can cause high radon concentrations, to solve these problems through education and conducting the protection measures to reduce the potential health risk. The risk of radon exposure to selected inhabitants in mining area was estimated by measuring indoor radon concentration. The whole population is at risk; children and adolescents are a particularly vulnerable group. Intensive ventilation is one of the effective ways to eliminate indoor radon, ie. the habits and behaviors of the residents can significantly reduce radon levels. Conducting the new measurements can help in knowledge of radon levels in the mining area of "Trepča" complex. Environmental control at mining sites is necessary to ensure that mining operations do not generate high radon concentrations, and that population exposure does not exceed the level specified by regulations.

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References

1. UNSCEAR 2008, United Nations Scientific Committee on the Effects of Atomic Radiation, Annex B: Exposure of the public and workers from various sources of radiation, United Nations, New York, 2008.
2. Darby, S., Hill, D., Auvinen, A., Barros-Dios, J.M., Baysson, H., Bochicchio, F., et al.. Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. Brit. Med. J. 330, 2005, 223–227,
3. WHO, World Health Organization,.Air Quality Guidelines for Europe. Geneva, 1987.
4. J. Chen, Comparative study of radon exposure in Canadian homes and uranium mines-a discussion on the importance od national radon program, Radiation Protection Dosimetry, Vol. 177, No. 1-2, 2017, 83–86,
5. Chen, B., He, L., Zhuo, W., 2015. The concentration of environmental radon in China. In: Mazur, J., Kozak, K., (Eds.) of 2nd International conference “Radon in the environment 2015”, Book of abstracts, p.10. Krakow, Poland.
6. M. Wysocka, Radon problems in mining and post-mining areas in Upper Silesia region, Poland, Nukleonika, 2016, 61(3), 307-313,.
7. M. Wysocka, S. Chalupnik, Correlation of radon concentration level with mining and geological conditions in Upper Silesia region. J. Miner. Sci., 39 (2), 199-206, 2003.
8. C.Kamunda, M. Mathuthu, M. Madhuku. Determination of radon in mine dwellings of Gauteng province of South Africa using AlphaGUARD radon professional monitor. J Environ. Toxicol. Stud. 1(1), 2017.
9. K.Ivanova, V. Badulin, Indoor radon measurement in former uranium mining region in Bulgaria, Safety Engineering, 2012, 2(5), 215-219
10. C. Cosma, A. Cucos-Dinu, B. Papp, R. Begy, C.Sainz Soil and building material as main sources of indoor radon in Baita-Stei radon prone area (Romania) Journal of Environmental Radioactivity 2013, 116, 174-179
11. Somlai, J., Gorjanacz, Z., Varhegyi, A., Kovacs, T. Radon concentration in houses over a closed Hungarian uranium mine. Science of the Total Environment, 2006, 367 (2-3), 653-665
12. Bekteshi, S., Kabashi, S., Ahmetaj, S., Xhafa, B., Hodolli, G., Kadiri, S., Alijaj, F., Abdullahu, B. Radon concentrations and exposure levels in the Trepça underground mine: A comparative study. J. Clean. Prod. 155, 198–203, 2017.
13. Gulan, L., Stajic, J.M., Bochicchio, F., Carpentieri, C., Milic, G., Nikezic, D., Zunic, Z.S. Is high indoor radon concentration correlated with specific activity of radium in nearby soil? A study in Kosovo and Metohija. Environ. Sci. Pollut. R. 24, 2017, 19561-19568,
14. Airthings Corentium Home: Radon Detector. Oslo, Norway: Corentium AS. Available: https://www.airthings.com/home