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Levels of Radon Activity Concentration in Air of Coal Mines in Bosnia and Hercegovina

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Abstract: By coal mining and exploatation, radioactive radon gas, which is captured in natural geological structures, is reallocated from the deep coal layers. Hence it is concentrated in the depots and coal seams of the mines or being transported to the surface of the earth where it can significantly change the levels of radioactivity in the working premises and residences. This paper presents the results of a three-year research of radon activity concentration in the air in hole and surface coal mines of Bosnia and Herzegovina. Detected concentrations of radon in the coal gaseous structure, atmosphere and other ambient media are in correlation with the properties of geological structures, technology for obtaining coal and meteo-climatic changes. They were measured with Alpha GUARD PQ 2000 radon portable measuring system (instruments Genitron-Frankfurt) and RadoMeter 2000 (Radosys LTD. Budapest), using the SS-NTD method.

Key words: Radon activity concentration, air, coal mines, Bosnia and Herzegovina.

1. Introduction

The total geological reserves of coal in Bosnia and Herzegovina amount to about 5.647 billion tons, of which the balance is 2.540 billion tons of coal, namely 1.437 billion tons of lignite, and 1.103 billion tons of brown coal. The most important reserves of brown coal are found in the following basins: Middle-Bosnian (deposits: Kakanj, Zenica, Breza and Bila), Banovici (Seona, central basin, Djurdjevik), Ugljevik (Bogutovo Village, Ugljevik-East, Glinje, Mezgraja, Tobut-Peljave), Miljevina and Kamengradsko. The most significant reserves of lignite are found in basins Kreka, Gacko, Stanari, Bugojno, Livno and Duvno.

Coal, as well as majority of natural materials, contains natural radioactive elements [1]. Exploitation of coal and its combustion in power plants in Bosnia and Herzegovina represents potentially the most important process for creation of technologically elevated levels of natural radioactivity. Opening of large open pits enables fast emanation of radon from deeper layers of the Earth's crust [2]. By coal combustion, large amounts of natural radionuclides are discharged into the atmosphere and accumulated over large areas. Landfills where the remains of coal combustion are deposited are also sites with significantly higher concentrations of natural radionuclides.

By digging and mining of coal radioactive gas radon which is contained in it is reallocated from the deep coal layers, thus concentrating in the depots and open excavations or being transported to the land surface where it can significantly change the levels of radioactivity and radio-ecological situation in working premises and residence spaces. Likewise, in coal mines may occure increased accumulation of radon due to its supply through network of fissures and soil

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Fig. 1 Location of coal mines and power plants in B & H.

fractures, especially through a system of groundwaters.

Some coal mines, such as Tusnica coal mine, are notorious for their high radioactivity [3], so it was chosen to be assessed for radiological risk for the workers. Specific activities of ^{238}U, ^{226}Ra and ^{232}Th in the coal of this mine amount to 1,060 ± 88 Bq/kg, 976 ± 30 Bq/kg and 118 ± 31 Bq/kg respectively [4]. These gamma-spectrometric results were the reason for conducting detailed investigations of levels of radon activity concentrations in the coal mines of Bosnia and Herzegovina.

2. Material and Methods

In this work, for measuring of radon activity concentration was used the method of solid nuclear track detectors-SSNTD, and the ionization chamber. The measurement of radon concentrations by the method of nuclear track detectors was carried out with the Radon System (Radosys, manufactured in Hungary, Fig. 2). The basic components of this system are: diffuse dosimeter with the detector type CR-39; system for chemical analysis of detectors; system for

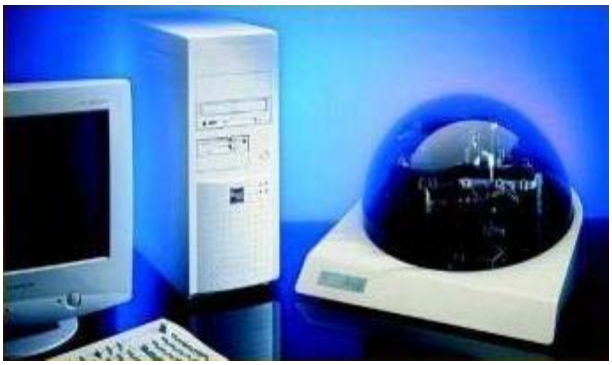

Fig. 2 SS-NTD Radosys which was used for researching.

automatic reading of detectors. We used detectors made poly-allyl-diglycol-carbonate, known as CR-39,with dimensions 10 mm × 10 mm × 1 mm, sensitivity to alpha tracks of 2.9 tracks per $(cm^3 \cdot kBq \cdot h) \cdot m^{-3}$. The exposure time in closed chambers was 90 d. The etching, evaluating and counting processes were performed by the Laboratory for Detection, Dosimetry and Radiation Protection (LDDRP) at the Faculty of Sciences and Mathematics, University of Tuzla, Bosnia and Herzegovina.

Also for measuring of radon activity concentration was used an AlphaGuard PQ 2000 PRO [5] (Genitron Instruments, Frankfurt, Germany). Alpha Guard is an instrument used for permanent monitoring of radon concentration levels in the industry facilities or in air. Measuring range of this system for concentration of radon activity is from 2-2 × 10^6 Bq/m^3, while the temperature range is from -10 to 50 °C. Calibration error for ^{222}Rn is 3%. The cylindrical ionization chamber of the AlphaGuard device has the active volume of 0.56 dm^3. The basic configurations of this sistem are AlphaGuard, Radon Monitor and AlphaExpert software.

Measurements of radon concentrations with AlphaGUARD PQ 2000 PRO were conducted two times, the first time during placing of CR- detectors at the investigated locations, and the second time during their collection. All measurements of radon concentrations in air with AlphaGUARD PQ 2000 PRO were conducted in the measuring cycle of 10 min.

3. Results and Discussion

The results of radon activity concentration measurements in the working environment of coal mines in B&H by nuclear track detectors are presented in Table 1.

The results of radon activity concentration measurements in the working environment of coal mines in B&H with AlphaGuard PQ 2000 Pro are presented in Table 2.

Dosimeters with CR-39 were placed in pit mines on each floor, at various locations where existed strong currents of air ventilation, as well as at the places where ventilation of mines was minimal or did not exist. Likewise, the measurement sites were selected also to observe the influence of groundwaters on the distribution of radon, by placing detectors in the immediate vicinity of waterways, as well as at locations without water.

Given the gamma-spectrometry analysis of coal mine Tusnica [3,4], with special attention was measured radon activity concentration in the area of this open pit (Tables 3 and 4).

Tables 3 and 4 show that the concentrations of radon at this location are rather uniform, that approximately same amounts were obtained by two measuring systems with some exceptions.

Along with measurements of radon activity concentration at the same locations were conducted measurements of gamma radiation equivalent dose rates with the results shown in Table 5.

Measurement locations in Tables 1, 2 and 5 with numbers of 1-4 are open pits with surface coal mining, while the locations in the same tables numbered as 5-9 are hole coal mines.

As seen from the Tables 1 and 2, the highest activity concentrations of radon were measured at the location

Table 1 Radon activity concentration of coal mines in B&H measured by nuclear track detectors.

No.	Name of mine	No. detect.	RAC ($Bq \cdot m^{-3}$)		
			Min.	Max.	Average
1	Cubrici	10	5.1 ± 1.8	44.4 ± 9.2	22.0 ± 5.1
2	Dimnjace	10	12.0 ± 3.9	45.3 ± 10.4	20.9 ± 5.7
3	Drage	16	19.0 ± 4.5	49.8 ± 10.2	24.4 ± 5.5
4	Vrtliste	10	6.9 ± 2.5	36.4 ± 8.3	20.2 ± 5.3
5	Glavni sloj	30	7.2 ± 2.3	71.0 ± 14.1	32.0 ± 7.0
6	Djurdjevik	20	25.0 ± 5.7	75.9 ± 16.4	52.2 ± 10.6
7	Haljinici	10	13.0 ± 3.8	50.1 ± 10.9	27.0 ± 6.6
8	Stara jama	20	9.8 ± 3.0	105.5 ± 20.9	27.3 ± 6.5
9	Raspotocje	20	11.6 ± 3.4	37.8 ± 8.4	20.4 ± 5.2

Table 2 Radon activity concentration measurements in the working environment of coal mines in B&H with AlphaGuard PQ 2000 Pro.

No.	Name of mine	No. detect.	RAC ($Bq \cdot m^{-3}$)		
			Min.	Max.	Average
1	Cubrici	10	5	111	35
2	Dimnjace	10	15	55	32
3	Drage	16	26	60	38
4	Vrtliste	10	14	33	21
5	Glavni sloj	30	12	92	44
6	Djurdjevik	20	5	3,420	280
7	Haljinici	10	24	835	82
8	Stara jama	20	5	78	35
9	Raspotocje	20	9	32	18

Table 3 Mean radon activity concentrations of open pit coal mine Drage (Tusnica) and its immediate surrounding measured with nuclear track detectors.

No.	Location	RAC ($Bq \cdot m^{-3}$)
1	Entrance to the old open pit -1	26.6 ± 5.9
2	Entrance to the old open pit -2	28.7 ± 6.3
3	Separation-1	24.9 ± 5.6
4	Separation -2	25.8 ± 5.8
5	Old warehouse Martinovac	19.0 ± 4.5
6	Warehouse administration building	46.4 ± 9.6
7	Doorkeeper's house (entrance to the mine)	44.3 ± 9.2
8	Spring Mandek-Novakovac. Tusnica	49.8 ± 10.2
9	Location Potkraj 1 (approx. 500 m from the mine)	44.8 ± 9.3
10	Administration building of the mine Tusnica-ground floor	72.6 ± 14.3
11	Administration building of the mine Tusnica-first floor	43.1 ± 8.9
12	Livno-centar (private house)	56.6 ± 11.4

Table 4 Mean radon activity concentrations of open pit coal mine Drage (Tusnica) and its immediate surrounding measured with the AlphaGuard PQ 2000 PRO.

No.	Location	RAC ($Bq \cdot m^{-3}$)	
		15.07.2009.	14.10.2009.
1	Entrance to the old open pit -1	60	26
2	Entrance to the old open pit -2	38	30
3	Separation-1	26	42
4	Separation -2	28	28
5	Front of the entrance / exit to the pit mine New Martinovac	38	35
6	Old warehouse Martinovac.	50	18
7	Warehouse administration building	46	46
8	Doorkeeper's house (entrance to the mine)	32	42
10	Location Potkraj 1 (approx. 500 m from the mine)	34	45

Table 5 Gamma radiation equivalent dose rates in working places of coal mines in Bosnia and Herzegovina.

No.	Name of mine	No. detect.	Gamma radiation equivalent dose rates in air (nSv/h)		
			Min.	Max.	Average
1	Cubrici	10	44	180	97
2	Dimnjace	10	73	108	87
3	Drage	16	80	106	91
4	Vrtliste	10	68	112	90
5	Glavni sloj	30	38	125	72
6	Djurdjevik	20	48	254	134
7	Haljinici	10	56	184	97
8	Stara jama	20	24	152	83
9	Raspotocje	20	45	109	90

No. 6, a brown-coal mine Djurdjevik. The maximum value of radon activity concentration in this mine was measured at about 450 m below ground, at the so-called "forehead" where the miners then carried out blasting in the mine to remove overburden. At that time using the AlphaGuard system there was measured radon concentration at this site in the amount of 3420 Bq/m^3.

Also at this location was then measured the maximum value of gamma radiation equivalent dose rate in air-254 nSv/h.

In this mine measurements were repeatedly carried out over a longer time interval. Levels of radon concentration in the repeated measurements was lower.

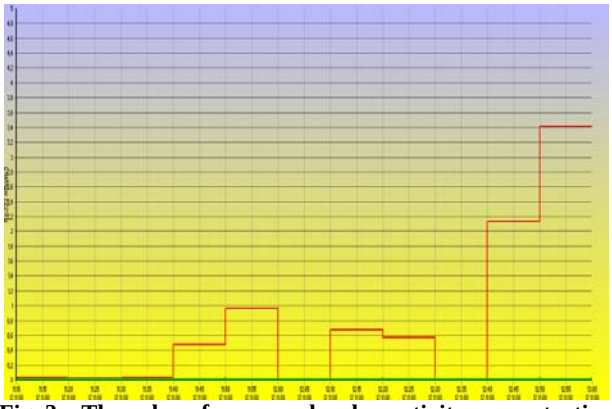

Fig. 3 The value of measured radon activity concentration at hole coal mine Djurdjevik.

The reasons for this tendency may be multiple: more intensive ventilation of the mine, a lesser working activity in the excavation of coal, but also the fact that blasting was carried out in the time of measurement and uncovering of large quantities of coal when there occurs sudden exhallation of radon from coal and byproducts. A detailed gamma-spetrometry analysis will give an answer to this dilemma.

Table 5 shows that the mean value of gamma radiation equivalent dose rates in the workplace of the coal mine Djurdjevik was higher than of other mines and amounted to 134 nSv/h or 1.174 mSv/yr, which is less than the global average annual effective dose from natural sources.

4. Conclusions

The conducted investigations in this paper show that the levels of radon activity in some coal mines were significantly higher than in others. This primarily refers to the brown coal mine Djurdjevik. It is necessary to carry out detailed gamma-spetrometry investigations at this location in order to protect workers. Levels of radon in the area of the mine Tusnica, which was of particular interest, did not deviate extremely from the levels of radon in the air of other mines.

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