Measurements of Environmental Radon Activity Concentration Outdoors in Bosnia and Herzegovina

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Abstract: Radon is a unique natural element because it is an inert gas and at the same time radioactive in all of its isotopes. It is known fact that exposure of the population to high concentrations of radon gas, leads to irradiation of primarily respiratory organs, which can cause lung cancer. For reliable prospecting of radon activity concentration in the living environment, the first input parameter is the concentration of outdoor radon in the air. This paper presents the results of a three-year research of radon activity concentration in the air of Bosnia and Herzegovina. At the measurement locations were registered daily and seasonal variations of the outdoor radon concentrations, whose average values were in the range of 15-38 Bq/m³. They were measured with Alpha GUARD PQ 2000 radon portable measuring system (Genitron Instruments - Frankfurt).

Key words: Radon activity concentration, outdoor exposures, Bosnia and Herzegovina.

1. Introduction

One of the middle members of each natural series is the isotope of the noble gas radon: ²²²Rn, ²²⁰Rn and ²¹⁹Rn with the disintegration half-time of 3825 days, 55.6 s and 3.96 s respectively. Their immediate predecessors are radium isotopes which decompose into radon by α -decay. Because of the very short half-life, as well as for the concentrations ratio ²³⁵U/²³⁸U in the nature, which is 0.00719, the isotope ²¹⁹Rn can be ignored, while the isotope ²²⁰Rn is of less importance due of its short half-life [1].

Because of the longest lifetime and isotopic abundance, the greatest importance of the natural isotopes of radon has ²²²Rn and the term radon will refer to this isotope. In its decay series, radon gas over its short-lived decay progeny is transformed into stable lead ²⁰⁶Pb, emitting 5 alpha particles of energy up to 7.7 MeV, beta radiation energy up to 2.8 MeV and gamma-ray photon energy up to 2.4 MeV [2].

The concentration of radon in the air is variable and depends on a number of meteorological parameters. Due to the relatively long half-life (3.82 days), radon can stay relatively long in the atmosphere before it decays.

So it takes part in the turbulent transfer through the atmosphere and can reach to its higher layers, and travel long distances. Also, seasonal changes in meteorological conditions affect the variation of radon concentration in air, as well as the concentration of natural radioactivity of air in general.

The degradation products of radon and thoron in most cases are positively charged, from 80% to 85% of them, and are chemically active [2]. They interact with negative ions present in the atmosphere and in the process of exchanging charges there occurs their attachment to natural aerosols. This is the origin of naturally occurring radioactive aerosols. Increased relative humidity creates favorable conditions for increased condensation of water vapor and sorption of radioactive decay products as emanation of the particles of water vapor. The resulting active aerosols

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deposit under the influence of gravitational forces on the surface of the earth, where they remain on the vegetation, and easily penetrate into the soil.

Land contains different concentrations of uranium, which also leads to the release of certain amounts of radon from the soil. Radon reaches the atmosphere by diffusion through the pores and cavities in the soil, binding to the air or water [2]. For a given concentration of radon in the soil, the concentration of this gas that emanates in the atmosphere depends on the permeability of the soil (if the soil is dry, wet, frozen or covered with snow) and meteorological conditions (soil temperature and air temperature, atmospheric pressure, wind speed and direction of blowing). Concentration of outdoor radon rapidly decreases with altitude.

Ecological area of B & H is a complex ecosystem, with different geological composition of rocks,

vegetation cover, the area in which are manifested different intensities of turbulence in atmospheric pressure, temperature, humidity, which interact with each other including a variety of geochemical processes, which may be due to natural or anthropogenic influence.

Measurement of the activity concentration of radon outdoors were conducted at 92 measurement locations throughout Bosnia and Herzegovina (Fig. 1)

Reliable measuring of the concentration of outdoor radon requires special conditions, primarily silence of winds. It was one of the reasons of frequent measurements postponed because weather conditions sometimes did not allow continuous work. Radon gas is seven times heavier than air, and above ground it is present only in places where its exhalation is enabled. When radon reaches a height of about 1 m above the ground, its dispersion is determined by factors of

Fig. 1 Positions of measurement locations in the territory of B & H.

Fig. 2 AlphaGuard PQ 2000 PRO which was used for the research.

atmospheric stability.

2. Material and Methods

LDDRP (Laboratory for detection, dosimetry and radiation protection) at the Faculty of Sciences and Mathematics, University of Tuzla, Bosnia and Herzegovina, since 2004 has been engaged in measuring radon concentrations in all ambient environments, using different methods and modern measuring systems.

For the purpose of these studies, for measuring of radon activity concentration was used an AlphaGuard PQ 2000 PRO (Genitron Instruments, Frankfurt, Germany) [3].

Alpha Guard is an instrument used for permanent monitoring of radon concentration levels in the industry facilities or in air (Fig. 2). Measuring range of this system for concentration of radon activity is from $2 \sim 2 \times 10^6$ Bq/m³, while the temperature range is from -10 °C to 50 °C. Calibration error for ²²²Rn is 3%. The cylindrical ionization chamber of the AlphaGuard device has the active volume of 0.56 dm³. The basic configurations of this sistem are AlphaGuard, Radon Monitor and AlphaExpert software.

The measuring system Alpha GUARD PQ 2000, was installed to 1-1.5 m above the ground. All

measurements of radon concentrations in air with AlphaGUARD PQ 2000 PRO were conducted in the measuring cycle of 5 and 10 min. In this way, we obtained output of 5 and 10 min values of the activity concentration of radon, which is very essential for the screening of radon.

During the intense winds, measurements were interrupted, because in such circumstances, the registered values of concentrations of outdoor radon are of little importance. In other words, due to the relatively long half-life (3.82 days), radon carried by turbulent currents can cross large distances, so that the measurements in such conditions would be very unreliable.

3. Results and Discussion

Measurements of the activity concentration of outdoor radon were conducted at 92 sites. Time intervals of the measurements were in the range 3 ~ 6 h, and in some locations even longer, depending on the meteorological conditions in the field. At some locations, where the weather conditions (intense winds) changed during the measurement, the measurement was done at intervals.

Table 1 shows the mean activity concentration of outdoor radon at 92 measuring locations.

Table 1 Radon activity concentration measured with AlphaGuard.

No.	Location	RAC [Bq/m ³]			No.	Location	RAC [Bq/m ³]		
		Average	Min.	Max.			Average	Min.	Max.
1	Jezero Modrac	18	4	38	47	Blagaj	18	1	43
2	Tuzla	27	7	65	48	Međugorje	20	5	44
3	Živinice	23	8	77	49	Čapljina	19	3	35
4	Banovići	22	4	63	50	Neum	17	4	39
5	Olovo-Bakići	38	15	85	51	Huntovo blato	18	3	43
6	Sarajevo-K. glava	25	8	59	52	Stolac	15	3	44
7	Igman-Malo Polje	26	9	48	53	Ljubinje	25	8	69
8	Bjelašnica-B. Do	25	4	65	54	Popovo polje.	27	9	65
9	Boračko jezero	22	7	60	55	Trebinje	18	1	60
10	Ivan-Sedlo	18	4	43	56	Bileće	19	5	48
11	Fojnica-park	26	8	60	57	Gacko	35	13	79
12	Zenica-K.park	28	4	85	58	Čemerno	30	11	70
13	Nemila	19	5	49	59	Tjentište	24	7	67
14	Zavidovići	20	6	43	60	Foča	22	8	55
15	Visoko-pir. Sunca	19	4	54	61	Kalinovik	31	9	66
16	Lukavac	32	14	77	62	Goražde	19	5	61
17	Vareš	27	6	69	63	Pale	20	3	51
18	Srebrenik	22	8	55	64	Višegrad	18	6	54
19	Gračanica	23	2	51	65	Rogatica	20	7	62
20	Doboj	23	7	60	66	Podromanija	22	5	67
21	Tešanj	26	4	57	67	Sokolac	20	6	56
22	Teslić	25	9	62	68	Han Pijesak	24	8	53
23	Kotor Varoš	22	1	58	69	Kladanj	25	4	56
24	Vlašić-Babanovac	24	5	47	70	Tišča	23	5	50
25	Travnik	23	6	45	71	Srebrenica	21	6	51
26	Bugojno	21	8	54	72	Zvornik	20	7	44
27	Ramsko jezero	22	3	47	73	Kozluk	26	9	67
28	Jablanica	19	2	50	74	Ugljevik	37	8	86
29	Mostar	20	6	48	75	Dvorovi	23	6	50
30	Jajce	25	4	43	76	Brčko	20	5	52
31	Šipovo	21	1	53	77	Orašje	22	5	54
32	Mrkonjić Grad	24	7	59	78	Gradačac	27	3	66
33	Ključ	26	6	44	79	Bosanski Brod	19	4	55
34	Sanica	18	6	42	80	Derventa	24	7	49
35	Sanski Most	19	3	48	81	Prnjavor	31	6	67
36	Bosanski Petrovac	19	8	43	82	Potkozarje	25	6	54
37	Kulen Vakuf	17	4	38	83	Prijedor	24	5	51
38	Drvar	19	6	51	84	Gradiška	19	3	54
39	Bosansko Grahovo	22	6	53	85	Bosanska Dubica	21	3	48
40	Glamoč	29	7	84	86	Novi Grad	22	7	55
41	Livno	33	12	70	87	Bosanska Krupa	29	7	73
42	Tomislavgrad	22	5	54	88	Bihać	23	4	58
43	Buško jezero	20	8	62	89	Izarčić	20	6	51
44	Posušje	19	5	56	90	Cazin	18	2	45
45	Grude	18	4	42	91	Velika Kladuša	21	2	57
46	Široki Brijeg	19	7	40	92	Ponikve	24	6	63

Mean values of the activity concentration of radon in air on the studied sites, were in the range of 15 to 38 Bq/m³. The highest mean value was measured at the site No. 5, Olovo, 38 Bq/m³, where the maximum activity concentration of radon during the measurement was 85 Bq/m³. This locality is an area without industrial plants, real mountain beauty, ecologically preserved, but that does not mean that the radiological levels are ideal. The increased concentration of radon in this area, which was also observed in previous studies, may be due to the geological substrate, underground streams and fissures, or deposits of ores and rocks with increased uranium content.

The mean activity concentration of radon outdoors, which were above 30 Bq/m³, were detected in the investigated localities: No. 81- Prnjavor, 31 Bq/m³, No. 16 - Lukavac, 32 Bq/m³, No. 41- Livno, 33 Bq/m³, No. 57 - Gacko, 35 Bq/m³ and No. 74-Ugljevik, 37 Bq/m³. On most sites studied, the mean activity concentrations of radon were above the average values in the world, which vary in the range from 10 to 20 Bq/m³.

For some explored sites, increased levels of radon are understandable, because they are the points of

strong thermal power facilities, such as Tuzla, Ugljevik, Gacko and industrial cities of Lukavac and Zenica. The increase in the level of radon in these locations is due to technological processing of coal and its combustion in thermal power plants, as well as the production of coke and other raw materials. Of course, we have to take into account individual heating places in the winter, and especially the traffic with high frequency. For site No. 41- Livno, the cause of increased activity concentration of radon is coal with increased content of uranium.

A special case of high radon concentration is the area Slana Banja in Tuzla. At this location we detected high levels of exhaled radon gas a few years ago [8]. On this site, recorded were the levels of radon in the course of 24 h (Fig.4). The maximum value of the activity concentration of radon during this time period of measurement was 464 Bq/m³, and the measured mean value of 230 Bq/m³.

This extreme level of outdoor radon for now is a scientific enigma, which is interesting from geological, seismic and health aspects.

On the basis of the obtained values of the activity concentration of outdoor radon in air, an assessment of

Fig. 3 The value of measured radon activity concentration at the locality No. 16-Lukavac.

Fig. 4 The value of measured radon activity concentration at the locality No. 2-Slana Banja Tuzla.

Table 2 The estimated annual effective dose received by the population through inhalation of radon outdoors.

No.	Location	H_{out} (mSv)	No.	Location	H_{out} (mSv)
1	Jezero Modrac	0.170	47	Blagaj	0.170
2	Tuzla	0.236	48	Međugorje	0.189
3	Živinice	0.217	49	Čapljina	0.179
4	Banovići	0.208	50	Neum	0.160
5	Olovo-Bakići	0.359	51	Huntovo blato	0.170
6	Sarajevo-K. glava	0.236	52	Stolac	0.141
7	Igman-Malo Polje	0.245	53	Ljubinja	0.236
8	Bjelašnica-B. Do	0.236	54	Popovo polje.	0.255
9	Boračko jezero	0.208	55	Trebinje	0.170
10	Ivan-Sedlo	0.170	56	Bileće	0.179
11	Fojnica-park	0.245	57	Gacko	0.331
12	Zenica-K.park	0.264	58	Čemerno	0.283
13	Nemila	0.179	59	Tjentište	0.227
14	Zavidovići	0.189	60	Foča	0.208
15	Visoko-pir. Sunca	0.179	61	Kalinovik	0.293
16	Lukavac	0.302	62	Goražde	0.179
17	Vareš	0.255	63	Pale	0.189
18	Srebrenik	0.208	64	Višegrad	0.170
19	Gračanica	0.217	65	Rogatica	0.189
20	Doboj	0.217	66	Podromanija	0.208
21	Tešanj	0.245	67	Sokolac	0.189
22	Teslić	0.236	68	Han Pijesak	0.227
23	Kotor Varoš	0.208	69	Kladanj	0.236
24	Vlašić-Babanovac	0.227	70	Tišća	0.217
25	Travnik	0.217	71	Srebrenica	0.198
26	Bugojno	0.198	72	Zvornik	0.189
27	Ramsko jezero	0.208	73	Kozluk	0.245

(table 2 continued)

No.	Location	Hout (mSv)	No.	Location	Hout (mSv)
28	Jablanica	0.179	74	Ugljevik	0.350
29	Mostar	0.189	75	Dvorovi	0.217
30	Jajce	0.236	76	Brčko	0.189
31	Šipovo	0.198	77	Orašje	0.208
32	Mrkonjić Grad	0.227	78	Gradačac	0.255
33	Ključ	0.245	79	Bosanski Brod	0.179
34	Sanica	0.170	80	Derventa	0.227
35	Sanski Most	0.179	81	Prnjavor	0.293
36	Bosanski Petrovac	0.179	82	Potkozarje	0.236
37	Kulen Vakuf	0.160	83	Prijedor	0.227
38	Drvar	0.179	84	Gradiška	0.179
39	Bosansko Grahovo	0.208	85	Bosanska Dubica	0.198
40	Glamoč	0.274	86	Novi Grad	0.208
41	Livno	0.312	87	Bosanska Krupa	0.274
42	Tomislavgrad	0.208	88	Bihać	0.217
43	Buško jezero	0.189	89	Izarčić	0.189
44	Posušje	0.179	90	Cazin	0.170
45	Grude	0.170	91	Velika Kladuša	0.198
46	Široki Brijeg	0.179	92	Ponikve	0.227

the annual effective dose received by the population due to inhalation of radon gas in the investigated area (Table 2) was made. To estimate the annual effective dose of radiation, which comes from the inhalation of radon outdoors, it is necessary to take into account a number of input parameters. It is assumed that the average length of stay in the open air is 20% of the time during the day. The conversion factor for radon radiation dose is $9\text{nSv}(\text{Bq}\cdot\text{h}\cdot\text{m}^{-3})^{-1}$, while the balance factor of radon outdoors is 0.6 [2]. Then the annual effective dose is calculated according to the formula:

$$H_{out} = C_{Rn} \cdot F_{out} \cdot t \cdot 0.2 \cdot D \quad (1)$$

where, H_{out} – the requested annual effective dose that comes from the inhalation of radon in outdoor space (mSv); C_{Rn} – radon activity concentration in air (Bq/m^3); $F_{out} = 0.6$ – the balance factor of radon outdoors; t – time, or the average number of hours per year $D = 9 \text{ nSv}/(\text{Bq}\cdot\text{h}\cdot\text{m}^{-3})$ – conversion factor dose for radon.

The estimated annual effective dose received by the population from inhalation of radon outdoors is in the range from 0.141 to 0.359 mSv. According to the UNSCEAR report (2000), at a radon activity concentration of $10 \text{ Bq}/\text{m}^3$, the annual effective dose

due to inhalation of radon outdoor is 0.095 mSv.

4. Conclusions

Knowing the activity concentration of outdoor radon is of great importance for the levels of radon in residential and work areas. Based on the obtained results it can be concluded that at majority of the investigated locations the values of annual effective dose from inhalation of outdoor radon were above the average value for the world.

References

- [1] Adrovic, F., Jakupi, B. and Vasić, P. 1995. "Measurements of Radon Concentration, Radiation Measurements." 25 (1): 643-4.
- [2] UNSCEAR 2008 Report to the General Assembly - Scientific Annexes, Sources and Effects of Ionizing Radiation. 2010. United Nations Scientific Committee on the Effects of Atomic Radiation, UN, New York.
- [3] Alpha Guard PQ2000 Multiparameter Radon Monitor. 1998. User Manual, Genitron Instruments, Germany.
- [4] Kasic, A., Hankic, E., Kasumovic, A. and Adrovic, F. 2013. "Levels of Radon Activity Concentration in Thermal Waters of Bosnia and Herzegovina." *Journal of Materials Science and Engineering B* 3 (8): 539-44.
- [5] Durrani, S. A. and R. Ilic, R. 1997. Measurements by

Etched Track Detectors: Applications in Radiation Protection, Earth Sciences and the Environment, World Scientific, Singapore.

- [6] Alpha Guard PQ2000 Multiparameter Radon Monitor. 1998. User Manual, Genitron Instruments, Germany.
- [7] Vidic, A., Ilic, D., Deljkic, D., and Adrovic, F. 2011.

“Exposure of Workers in Tusnica Coal Mine.” *Radiation Protection Dosimetry* 144 (1-4): 672-74.

- [8] Kasic, A., Hankic, E., Kasumovic, A. and Adrovic, F. 2013. “Levels of Radon Activity Concentration in Thermal Waters of Bosnia and Herzegovina.” *Journal of Materials Science and Engineering B* 3 (8): 539-44.