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OUTDOOR AND INDOOR AMBIENT DOSE EQUIVALENT RATES IN BERANE TOWN, MONTENEGRO

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Abstract. *This paper presents the results of ambient dose rate measurements conducted in the air of Berane town, Republic of Montenegro. Measurements were performed by Geiger-Müller counter - Radex RD1503+, in the middle of October 2015. An average daily value of 114.8 nSv/h of ambient dose equivalent rate was obtained, spanning from 50-160 nSv/h in the morning and 70-177 nSv/h in the evening. Analysis of the impact of spatial variations on gamma radiation levels shows a very weak correlation between indoor ambient dose rate and outdoor ambient dose rate measured either in the morning (r = 0.09) or in the evening (r = 0.19). Building materials or stuff in buildings do not contribute additionally to ambient dose rates. Due to the lack of published data of dose rates, these results are the first measurements of radiation levels in Berane town.*

Key words: *Ambient dose equivalent rate, correlation, indoor, measurement, outdoor*

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1. INTRODUCTION

Natural radiation in the environment constantly and unavoidably comes from terrestrial radionuclides in rocks and minerals of the Earth's crust and cosmic radiation, as well as continuous production of cosmogenic radionuclides from cosmic space and atmosphere [1]. An important component of natural radiation is terrestrial radiation of ^{40}K and radionuclides from ^{238}U and ^{232}Th series. The main characteristic of these radionuclides is a long half-life, comparable to the age of the Earth. Another component of natural radiation is cosmic radiation that consists of charged particles of very high energies. It rarely reaches the Earth's surface, since it disappears in the interactions with the atmosphere and creates secondary radiation. In the interaction of a cosmic ray with the nuclei of hydrogen, nitrogen, argon, oxygen and other atoms in the atmosphere, cosmogenic radionuclides are produced. The most important are ^{3}H, ^{7}Be, ^{14}C and ^{22}Na, yielding the average individual annual effective dose of 0.01 μSv, 0.03 μSv, 12 μSv and 0.15 μSv, respectively [1].

More than 2/3 of the total annual dose received by the population comes from natural sources of radiation [1]. Worldwide average value of annual dose from natural sources is estimated to be 2.4 mSv, of which the inhalation of natural radioactive gas radon contributes 52%, external terrestrial radiation 20% and cosmic & cosmogenic radiation 16%. Ingestion of ^{40}K and radionuclides from ^{238}U and ^{232}Th series amounts the remaining 12%. According to the recommendations of international organizations [2-4], the lower value of the typical range of the total average worldwide exposure to natural radiation sources is 1 mSv/y. The typical range for total cosmic and cosmogenic sources is 0.3-1.0 mSv/y, while 0.3-0.6 mSv/y is the typical range for total external terrestrial sources which depend on radionuclide content in soil and building materials [1].

There are areas in the world with high natural radiation background (in Brazil, USA, China, India) due to the elevated content of radionuclides in the soil or rocks, intensity of cosmic radiation, geographical location, etc. [5]. Basic radiation, which is registered in normal conditions, comes from cosmic radiation and natural radionuclides, and depends on the geology of the terrain, an altitude of measuring point, and it is characteristic of a certain location.

In addition to natural sources of radiation, as a result of human activity, the artificial sources of ionizing radiation are also present in the environment. After World War II, some fission products, such as ^{137}Cs and ^{90}Sr, appeared in the environment as a consequence of nuclear technologies used for military and peaceful purposes.

The variation of terrestrial gamma radiation is usually greater than the variation of cosmic radiation. Higher radiation levels are associated with igneous rocks (granite), and lower levels with sedimentary rocks [1]. Therefore, it is important and desirable to measure the gamma absorbed dose rate or ambient dose equivalent rate everywhere in human environment, where it is possible. Since no

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documented data exist about radioactivity in town Berane, the aim of this work was to point out the preliminary results of radiation levels, i.e. background radiation.

2. Experimental

2.1. Geology of the studied area

In terms of physical geography, Berane municipality is very diverse with complex processes in the geological past from the Tertiary period which influenced the formation of primary ore (lead and zinc), pedological and hydrological characteristics. The Berane basin represents a tectonic-erosive enlargement incorporated into the Police, Krčevo and other surfaces. The composition of Berane basin involves mainly Paleozoic sediments, Triassic limestones and Neogene sediments. Bjelasica massif is composed of Paleozoic shales (sandstones, phyllite). On the opposite side, Cmiljevica is made up mainly of Triassic limestone, with pad of shales and cherts. Neogene sediments (clay and marlstone) cover a large expanse on the right side of Lim, hill Jasikovac, a part of Budimlje, and most of the Police surface. It is mainly found in groundwater sources. While the right side of the basin is represented by Neogene undulating relief, the left side has three fluvial-glacial (gravel, sand) terraces [6].

Temperature relations and winds correspond to moderate-continental types, whereas the rainfall corresponds to Mediterranean climate effects. The average annual rainfall is 923.2 mm [6].

The municipality of Berane (42°50'N-19°52'E) is located in North-Eastern part of Montenegro and covers an area of 647 km^2. Berane municipality had a population of 33,970, according to the census of 2011. Berane town itself has 11,073 citizens [7].

2.2. Method of measurements

Indoor and outdoor dose rate measurements were conducted in the middle of October 2015 in Berane town. The measurements were performed at the height of 1m above ground, outdoor in the morning and in the evening of the same day, and indoor in nearby buildings; indoor measurements were conducted in the evening. Four measurements were made at one measuring point. For all locations, elevations and the ages of the building construction were noted. There was no rainfall on the day the measurements were done, and on the preceding 2 days. The map of Berane town with seventeen measuring points is presented in Fig.1.

The measurement was performed by Geiger-Müller counter, Radex RD1503$^+$. Radex model RD1503$^+$ operates on a temperature range from -18 °C to +65 °C. The measuring cycle is 40 seconds for the ambient gamma dose rates in the range from 0.05 to 9.99 μSv/h [8]. The measurement uncertainty of the unit for gamma rays is ±15% [8]. Due to low detector's response, detection of high-energy particles from cosmic radiation was negligible.

Instruments for gamma dose rate measurements are calibrated and based on an ambient dose equivalent from which the dose estimation is possible. Ambient dose equivalent H*(10) at a point of the radiation field is the dose equivalent that would be produced by the corresponding expanded and aligned field at a depth of 10mm in the ICRU sphere, on the radius opposing the direction of the aligned field (for penetrating gamma radiation) [2].

Figure 1. Map of Berane town with locations of ambient dose rate measurements

3. Results and discussion

Ambient dose equivalent rates were measured at 17 different locations in the town of Berane marked on Fig. 1. The results of the indoor and outdoor ambient dose equivalent rate measurements are presented in Table 1. Since, the use of Radex monitor is limited for high cosmic ray measurement, the dose rate of natural radiation known as a terrestrial type of radiation, as well as radionuclides in the air (radon progenies, ^{7}Be and ^{22}Na in the atmosphere) were measured." Assuming that average outdoor radon concentration of 10 Bq/m^3 would contribute about 2.5 nSv/h, and contributions from gamma radiating ^{7}Be and ^{22}Na are far below 1 nSv/h [9], the total contribution of this component to the dose rate is very small.

In addition, dose rates in air were changed from place to place and also with time, assuming that diversity of the soil composition affects more variations on total dose rates than cosmic radiation. Also, meteorological conditions, micro relief and vegetation of ground could influence the variation of measured dose rate [9].

A descriptive statistic of dose rate measurements is given in Table 2. The dose rates varied in the range of 50-160 nSv/h with an average value of 112.4 nSv/h in the morning; the average value in the evening was 117.1 nSv/h (70-177 nSv/h); the average daily dose rate in Berane is calculated to be 114.8 nSv/h. The maximum values were measured outdoors in hospital surroundings (location no. 17, Fig.1). The Kolmogorov-Smirnov test of normality shows normal distribution of both, outdoor and indoor data set results (this is also evident from Table 2, as low value of skewness); and the median around the mean values.

Dose rates measured in nearby buildings varied from 90 to 167 nSv/h, with an average value of 128.1 nSv/h. There was no significant difference between measured dose rates concerning the elevations or the age of building construction.

Since the Report of population exposure to ionizing radiation in the Republic of Montenegro is not available, a comparison with the results of ambient dose equivalent rates is not possible. According to data from Serbian Radiation Protection and Nuclear Safety Agency, the average value of 114.8 nSv/h of ambient dose equivalent rate is comparable with the values in other towns in Serbia (e.g. Zlatibor, Novi Sad) [10].

Table 1. Outdoor and indoor ambient dose equivalent rate measurements in Berane town

Location number	Ambient dose equivalent rate (nSv/h)		
	Outdoor		Indoor
	Morning	Evening	Building
1.	50	85	130
2.	135	147	155
3.	105	142	152
4.	102	97	155
5.	152	82	167
6.	120	107	127
7.	122	110	142
8.	90	137	92
9.	135	127	115
10.	140	160	147
11.	117	130	110
12.	90	100	110
13.	115	70	110
14.	85	75	145
15.	107	115	90
16.	85	130	135
17.	160	177	95

Table 2. Descriptive statistics of ambient dose equivalent rate measurements in Berane town

Parameter	Ambient dose equivalent rate (nSv/h)		
	Outdoor		Indoor
	Morning	Evening	Building
Minimum	50	70	90
Maximum	160	177	167
Mean	112.4	117.1	128.1
Median	115	115	130
SD*	27.8	30.5	24.3
Geomean	108.7	113.3	125.8
Skewness	-0.30	0.20	-0.16
Kurtosis	0.22	-0.65	-1.23

* SD-Standard Deviation

The annual average effective dose for the population of Berane town is calculated to be 0.2 mSv using the 0.2 occupancy factors for exposure outdoors; similarly, for exposure indoors, the annual average effective dose is estimated to be 0.9 mSv (0.8 occupancy factor is assumed). In fact, annual effective doses will be lower than the 0.2 mSv and 0.9 mSv. This is because the ambient dose equivalent rate ($H^*(10)$) is a conservative estimate for effective dose E for the decay gamma rays. The relevant figure is Fig. 64 of ICRP 74 [11]. The $H^*(10)$ to effective dose conversion depends on the gamma ray energy spectrum and irradiation geometry. However, in the idealized case of ^{40}K, ^{232}Th and ^{238}U uniformly distributed in the soil, the effective dose is about 60% of H*(10), meaning 0.2->0.12 mSv/y and 0.9- >0.54 mSv/y. This means that the total effective dose for Berane (0.66 mSv/y), in reality, is closer to the worldwide average of 0.48 mSv/y for terrestrial radiation.

Correlation analysis of the impact of spatial variations on ambient dose equivalent rates shows that a very weak correlation exists between the indoor and outdoor dose rates: Pearson's coefficients are r=0.09 (in the morning) and r=0.19 (in the evening). Correlation between outdoor dose rate measurements is presented in Fig. 2; correlation coefficient between them is 0.45.

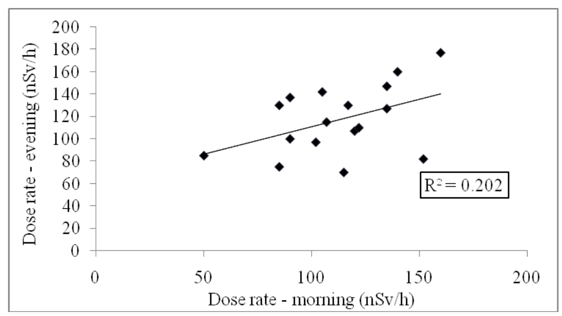

Figure 2. Correlation between outdoor dose rate measurements (morning/evening)

The Mann-Whitney Test showed there were no significant differences in values between the outdoor and indoor gamma dose rates at a significant level of $p<0.01$. Since there are no major differences in values between the outdoor and indoor gamma dose rates, one can conclude that buildings did not contain a high percentage of ^{40}K, ^{232}Th and ^{238}U and progeny, which would additionally contribute to the ambient dose rate. For most measurements, the difference between indoor and outdoor measured values was up to 30 nSv/h [12]. If the indoor dose rate differs from the outdoor dose rate in the range of 100-200 nSv/h, than we can assume an increase of the specific activity of natural radionuclides regarding building materials [13].

4. Conclusion

First measurements of outdoor and indoor ambient dose equivalent rates in Berane town were presented in this paper. The obtained results showed an average outdoor dose rate of 115 nSv/h, without relevant difference in the time of day when measurements were done. The average dose rate measured inside nearby buildings was 128 nSv/h. Therefore, we conclude that any material used for selected building construction (some of them were embedded in several centuries before) does not contribute additionally to ambient dose rate.

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