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LUNG CANCER INCIDENCE AND CANCER RISK FROM RADIOACTIVITY – SOME DATA FOR THE CAPITAL OF MONTENEGRO

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Abstract. *There is an interest in evaluating and predicting risks due to existing radiation exposure situations, such as radon inhalation or exposure to external terrestrial radiation, both indoors and outdoors – as the greatest contributors to annual effective dose coming from natural radiation sources. That is particularly related to radon exposure and an evaluation of its role in initiating lung cancer, although risk projections have serious limitations being affected by the other important agents contributing to the cancer risk. Cancer risk due to radon inhalation and terrestrial gamma radiation in Podgorica, the capital of Montenegro, is considered here together with available epidemiological data, showing that among different types of cancer diagnosed in Montenegro, lung cancer is among the most common ones. The previous analysis indicated that the lung cancer incidence rate increases from year to year, ~6% annually in the period from 1978 to 2005, with an average standardized incidence rate of 20.8 per hundred thousand. The incidence rate of lung cancer in Podgorica in 2009 evaluated in the present study was found to be around 34.9. Diagnosed cancer types were non-small cell lung cancer in 37%, small cell lung cancer 22%, adenocarcinoma 17%, and mixed – adeno- and non-small cell 24%. Excess lifetime cancer risk due to terrestrial gamma radiation outdoors in the urban area of Podgorica (14 locations) is estimated to be in the range ($\cdot 10^{-3}$) from 0.17 to 0.69, with an average of 0.33, while the risk of lung cancer due to lifetime radon inhalation (153 homes in the region of the Podgorica municipality) – from ~0.04 to ~8.8%, with an average of ~0.8% and median of ~0.4%.*

Keywords: *radon, terrestrial radiation, cancer risk, lung cancer incidence, Podgorica*

1. INTRODUCTION

According to the classification of the World Health Organization (WHO), i.e. its International Agency for Research on Cancer (IARC), all types of ionizing radiation are in group 1 – *agents carcinogenic to humans*. In the monograph on the evaluation of X, γ and neutrons radiation carcinogenic risks to humans [1], all three types were classified into group 1, based on *sufficient evidence* in humans and experimental animals for the carcinogenicity of X and γ radiation, and *evidence* for the carcinogenicity of neutrons – *sufficient* in experimental animals and *inadequate* in humans. Alpha and beta radiations were considered in the later IARC monograph [2] and have also been evaluated overall as *carcinogenic* to humans (radon ^{222}Rn, radium ^{224,226,228}Ra, thorium ^{232}Th, plutonium ^{239}Pu, internalized α-emitters; iodine ^{131}I, phosphorus ^{32}P, a mixture of fission products, internalized β-emitters). Considerations on the same topic can also be found in publications of the other international organizations, such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), International Commission on Radiological Protection (ICRP) [3, 4], etc.

There is an interest in evaluating and predicting future risks due to existing exposure situations, such as radon inhalation or exposure to external terrestrial radiation, both indoors and outdoors – as the greatest contributors to annual effective dose coming from natural radiation sources [5]. That is particularly related to radon exposure and an evaluation of its role in initiating lung cancer, although risk projections have serious limitations being affected by the other important agents contributing to the cancer risk (smoking, first of all) [6].

The available epidemiological data show that among cancers diagnosed in Montenegro lung cancer is one of the most common. Previous analysis [7] indicated that the lung cancer incidence rate in general increases for a few % from year to year, ~6% annually in the period from 1978 to 2005, with an average standardized incidence rate of 20.8 per 100 000. For males, the incidence rate increased from 19.6 to 48.5 per hundred thousand in the mentioned period, as for females – from 3.7 to 11.4. An increase in the mortality rate of lung cancer is also observed in Montenegro – from 19.4 to 26.3 (annually 2% on average) in the period 1976-2005.

The incidence rate of lung cancer in 2009 is analyzed here together with the data on mortality rates

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from the *National programme for cancer control* [8], as well the other lung cancer mortality data available in the recent literature. Podgorica, the capital of Montenegro is in the focus of this study. A land area of the municipality of Podgorica is 1441 km^2, i.e. ~10.4% of the total Montenegro territory (13 812 km^2). It is the largest municipality by the population – 185 937, as registered in the last Census in 2011, contributing almost 30% to the total population (which is around 620 000 [9]).

The present study also evaluates the cancer risk coming from the radioactivity in this region and is based on the *indoor* radon concentrations in Podgorica and Montenegro [10-14], and the data related to the ^{226}Ra, ^{232}Th/^{228}Ac, ^{40}K and ^{137}Cs activity concentrations in uncultivated surface soil. Although the other parts of Montenegro (Coastal [15] and Nikšić [16, 17]) were previously analyzed for the cancer risk due to radioactivity, this is the first more detailed analysis of such a risk for the most populated municipality in the country.

2. Methods

As abovementioned, the data on *indoor* radon concentrations in the Podgorica region [10-14] are used here to calculate the risk of lung cancer due to lifetime exposure to radon. The estimation is based on the UNSCEAR [6], ICRP [18] and U. S. EPA [19] recommendations. Since health risk, as well as lung dose from radon, principally come from the inhalation of its short-lived daughters, lung cancer risk is evaluated using

$$CR_{Rn} = ERD \cdot T \cdot NRC, \qquad (1)$$

where ERD is exposure to radon daughters expressed in a *working-level month per year* (WLM/y) and T (= 70 years) is the average life expectancy. A detriment-adjusted nominal risk coefficient for exposure to radon in equilibrium with daughters (NRC) is taken to be $5 \cdot 10^{-4}$ per WLM (i.e. $85 \cdot 10^{-10}$ per Bqh/m^3), as recommended by the ICRP in 2009 [18] for the population of all ages.

In the UNSCEAR 2006 report [6] the exposure rate of radon daughters is specified in terms of the potential alpha energy concentration (in J/m^3 or *working levels* – WL) derived from linear combination of the short-lived daughters activity (^{218}Po, ^{214}Pb and ^{214}Bi), and the equilibrium-equivalent concentration in Bq/m^3 (daughters concentration in equilibrium with radon gas) which can be converted into potential alpha energy concentration using: 1 Bq/m^3 = $5.56 \cdot 10^{-9}$ J/m^3 = $2.7 \cdot 10^{-4}$ WL. Therefore, ERD is calculated by the formula

$$ERD = A_{Rn} \cdot (2.7 \cdot 10^{-4}) \cdot F \cdot n \cdot 51.5, \qquad (2)$$

with A_{Rn} – the annual indoor radon concentration in Bq/m^3, $2.7 \cdot 10^{-4}$ – abovementioned conversion factor of radon concentration to the WL per Bq/m^3, F = 0.4 – equilibrium factor for radon indoors [6], n = 0.5 – occupancy time (exposure time of 4380 h per year), and 51.5 WLM/y per WL calculated as the ratio of total year hours (8760) and the total working hours per month (170).

The worldwide average indoor radon concentration (arithmetic mean) is known to be 46 Bq/m^3 unweighted and 39 Bq/m^3 population-weighted, with geometric means of 37 and 30 Bq/m^3, respectively [5, 6]. The UNSCEAR reports [5, 6] suggest typical radon outdoor level of the order of 10 Bq/m^3, which is usually significantly below its indoor level.

Annual indoor radon concentrations in 153 homes in the region of the Podgorica municipality were obtained in the nationwide indoor radon survey performed in 2002-2003 and 2014-2015 and they resulted in a radon map and data for the two types of grids: basic – covering the whole territory with 552 squares (5 km x 5 km), and local – 496 cells in total (0.5 km x 0.5 km each), to take into account significantly greater population density in the urban areas. Details about the survey design, homes selection, measuring methods, etc., can be found in references [10-12]. Radon was measured during two six-month periods: April to September and October to March. Generally, in each of the cells, one house was selected directly in the field on a door-to-door approach, and radon was measured in a living room or bedroom on the ground or first floor. Only in Podgorica, as the largest town, as explained in [13, 14], the number of sampled homes in a local square with the highest density of dwellings (in Podgorica in 2011: 55 379 dwellings only for housing [9]) was increased to obtain a nearly uniform sampling ratio of the whole dwelling stock. So, the local grid covering urban area contained 101 measuring points, and a part of the basic/country grid belonging to the region of Podgorica – 52 points.

These homes were mostly surveyed in 2002-2003 [10], with several measuring points added in the second phase of the national radon survey (2014-2015).

Since a register of the malignant lung diseases does not exist in Montenegro, the incidence rate of lung cancer Podgorica in 2009 is analyzed here using the data from the Brezovik – Special hospital for lung diseases in Nikšić, and data of the Oncology Consilium for all lung cancers in Montenegro. The analysis is focused on lung cancer types, patients' age, and smoking habits.

In order to estimate excess lifetime cancer risk (ELCR) due to radioactivity from the soil, 14 locations in the urban area of Podgorica were chosen for the analysis. The first three measuring points (Table 1) had been previously analyzed [20], while the other 11 samples from surface soil layer (0-5 cm) have been measured recently, and they are also included in the present analysis. Direct dose rate measurements by the Canberra Inspector 1000 and an analysis of soil samples from different depths were previously performed on the majority of these locations [21].

Standard procedures were applied for the sampling, soil sample preparation, spectrometer calibration and measurement by the HPGe ORTEC spectrometers GEM-40190 (with the relative efficiency of 40%) and GEM-30185-S (with the relative efficiency of 35%) [22, 23]. Determination of radionuclides, i.e. their activity concentrations in soil samples, was carried out using gamma lines of ^{226}Ra decay products (295 keV, 352 keV, 609 keV, 1120.2 keV, and 1764.4 keV), ^{232}Th/^{228}Ac (338 keV and 911 keV), ^{137}Cs (662 keV) and ^{40}K (1461 keV).

The calculation of gamma absorbed dose rate (in nGy/h) was also done in a standard way (dose in the air, 1 m above the ground, based on radionuclides activity concentration and corresponding dose coefficients)

$$D = A_c(^{226}Ra)\cdot 0.462 + A_c(^{232}Th)\cdot 0.604 + A_c(^{40}K)\cdot 0.0417 + A_c(^{137}Cs)\cdot 0.1243, \quad (3)$$

as well as the annual effective dose due to external terrestrial gamma radiation outdoors

$$E = D\cdot 8760\ h\cdot 0.2\cdot 0.7\ Sv/Gy. \quad (4)$$

Eq. (4) contains the dose conversion factor of 0.7 Sv/Gy and outdoor occupancy factor of 0.2 from the UNSCEAR 2000 report [5].

The ELCR was evaluated using

$$ELCR = E\cdot t_a\cdot CR, \quad (5)$$

where E is the annual effective dose, t_a is the average lifetime taken to be 70 years, and CR is the risk coefficient per Sv equal to $5.5\cdot 10^{-2}$ for the population of all ages [4].

3. Results and discussion

The results of radionuclide activity measurements are presented in Table 1, with the absorbed dose rate and annual effective dose due to terrestrial gamma radiation outdoors shown in Fig. 1. Basic statistics are given in Table 2, including data on indoor radon concentrations, ERD and cancer risk.

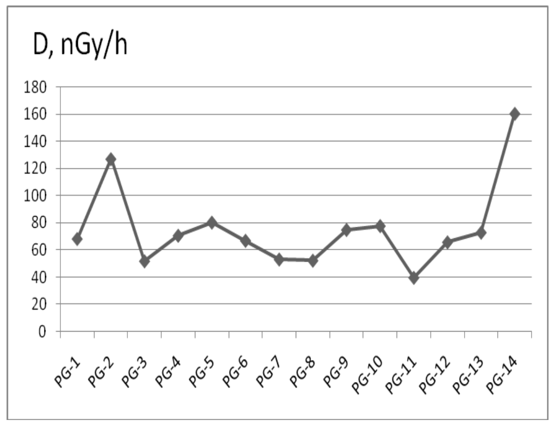
Table 1. Radionuclide activity concentrations in the soil of Podgorica [20, 21]

Measuring point	^{137}Cs, Bq/kg	^{40}K, Bq/kg	^{226}Ra, Bq/kg	^{232}Th (^{228}Ac), Bq/kg
PG-1	105±3	367±13	33.7±1.2	40.2±1.7
PG-2	54.3±1.8	437±15	126±4	72.7±2.6
PG-3	46.6±1.5	336±11	26.7±0.9	32.5±1.2
PG-4	12.7±0.3	473±6	39.5±0.9	51.4±1.4
PG-5	75.0±0.8	292±4	67.8±0.9	45.5±1.1
PG-6	15.6±0.4	394±6	38.7±1.0	50.7±1.4
PG-7	13.1±0.2	386±4	30.2±0.6	35.4±0.9
PG-8	53.3±0.6	304±5	24.9±0.8	35.4±1.2
PG-9	100±1	392±6	39.4±1.0	46.2±1.4
PG-10	10.8±0.4	469±7	60.4±1.1	47.9±1.5
PG-11	1.99±0.20	280±3	28.8±0.7	23.7±0.9
PG-12	7.25±0.40	447±6	33.9±0.7	50.5±1.5
PG-13	24.5±0.3	515±6	41.9±0.8	48.0±1.2
PG-14	111±1	628±8	142±2	91.0±2.0

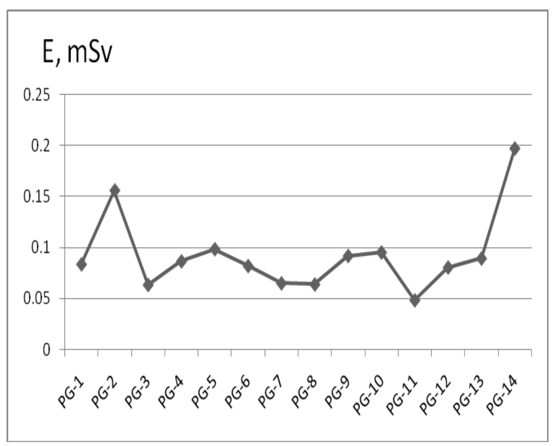
Comparing data from Table 2 with the global median of mean activity concentrations and activity concentrations in soils of the other South European countries, it is clear that an average potassium-40 activity in soil of Podgorica is found to be at a level of the global average and just slightly lower than in the other South European countries (around 432 Bq/kg, based on data from ref. [5]). At the same time, radium-226 activity showed an average higher than the global median of mean activity concentrations (35 Bq/kg [5]) and comparable with one measured in soils of Croatia (54 Bq/kg), as well as thorium-232 with an average of 47.9 Bq/kg (the global median of mean activity concentrations – 30 Bq/kg, and in Croatia – 45 Bq/kg [5]).

Table 2. Basic statistics of the results

	Min	Max	Mean	Std. deviat.	Median
^{137}Cs, Bq/kg	1.99	111	45.1	39.1	35.6
^{40}K, Bq/kg	280	628	409	95.5	393
^{226}Ra, Bq/kg	24.9	142	52.4	36.7	39.0
^{232}Th, Bq/kg	23.7	91	47.9	16.9	47.0
D, nGy/h	39.5	161	75.8	31.7	69.4
E, mSv/y	0.048	0.197	0.093	0.039	0.085
ELCR (10^{-3})	0.17	0.69	0.33	0.14	0.3
ARn, Bq/m3	4	902	84.8	128	42
ERD, WLM/y	0.0111	2.5085	0.2359	0.3565	0.1168
CRRn, %	0.039	8.78	0.826	1.25	0.409



a)



b)

Figure 1. Absorbed dose rate (a) and annual effective dose (b) from terrestrial gamma radiation in the urban area of Podgorica

The excess lifetime cancer risk ELCR is also higher than that for the world related to external terrestrial radiation outdoors –by the amount of $0.2\cdot 10^{-3}$, taking into account the average annual effective dose due to natural radiation sources (0.07 mSv [5]).

An average risk of lung cancer due to lifetime exposure to radon (~0.83%), and its maximum value of ~8.8% is higher than, for example, the risk estimated for workers in some mines (e.g. Khewra Salt Mines, Pakistan – with an average of 0.33% and the range 0.24-0.43% [24]).

It should be noted that 21 measuring points showed CR_{Rn} between 1 and 2%, 7 between 2 and 3%, 4 between 3 and 4%, 1 between 4 and 5% and 5 and 6%, and 2 between 8 and 9%.

In regards to the CR_{Rn} estimation, for the measuring points from municipality of Podgorica belonging to the basic grid of Montenegro radon map (52), the minimum, maximum, average, standard deviation and median were found to be 0.039, 8.07, 0.904, 1.319 and 0.467%, respectively (for the annual radon concentrations: 4, 829, 92.9, 136 and 48 Bq/m^3, and ERD: 0.011, 2.305, 0.258, 0.377 and 0.133 WLM/y, respectively). For the measuring points belonging to the local grid of Podgorica (101), C_{Rn} is found to be with the minimum, maximum, average, standard deviation, and median of 0.058, 8.78, 0.785, 1.214 and 0.341%, respectively (for the annual radon concentrations: 6, 902, 80.7, 125 and 35 Bq/m^3, and ERD: 0.017, 2.508, 0.224, 0.347 and 0.097 WLM/y, respectively).

Epidemiological data on lung cancers diagnosed and treated in Podgorica and Montenegro in 2009 are given in Table 3 (PG – Podgorica, MNE – Montenegro, N – number of patients, M – male, F – female, S – smoker, NS – never smoker, IR – incidence rate).

Table 3. Lung cancers diagnosed in 2009

	N	M	F	S	NS	IR
PG	59	48	11	52	7	34.88
MNE	206	171	35	167	39	33

Table 3 shows that around 28.6% of patients were from Podgorica, having the incidence rate of lung cancer slightly higher than in Montenegro as a whole. The findings presented here confirm that smokers are always at a higher risk (>88% of the patients from Podgorica, and 81% among all the patients), and also confirm a higher risk for males. It is known that lung cancer is the leading cause of cancer deaths among males not only in Montenegro but also worldwide.

Previous research on lung cancer mortality in Montenegro in the period 1976-2000, in correlation with smoking habits [25], revealed increasing tendency of mortality rates, but also that tobacco consumption in the considered period increased by 98.2%. It also confirmed significant correlation between lung cancer mortality rates and smoking.

The patients from Podgorica (average age – 59 years) with diagnosed lung cancer in 2009 were in the age between 60 and 70 years (39%), between 50 and 60 (35.6%), between 40 and 50 (20.3%), younger than 40 – 3.4%, older than 80 – 1.7%. At the level of the country, patients have also been mostly in the age between 60 and 70 years, with 20% of the patients older than 70, and 10% of patients younger than 50 years.

The analysis showed that diagnosed cancer types were: non-small cell lung cancer, i.e., epidermoid (NSCLC), small cell lung cancer (SCLC), ADENO, and MIXED (adeno- and epidermoid), as shown in Fig. 2.

For comparison, Fig. 3 shows lung cancer types diagnosed in the same year in people from the Coastal region in Montenegro – Herceg Novi, Kotor, Tivat, Budva, Bar and Ulcinj (48 in total, with the incidence rate of 38.2 per hundred thousand [15]), as well as from Nikšić (32 in total, with the incidence rate of 42.5 per hundred thousand [16]).

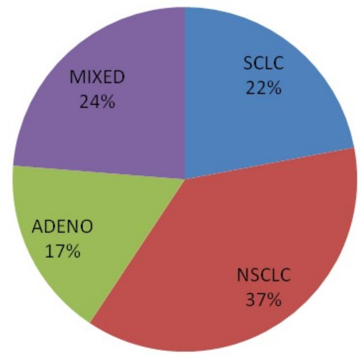


Figure 2. Lung cancer type in 2009 in patients from Podgorica

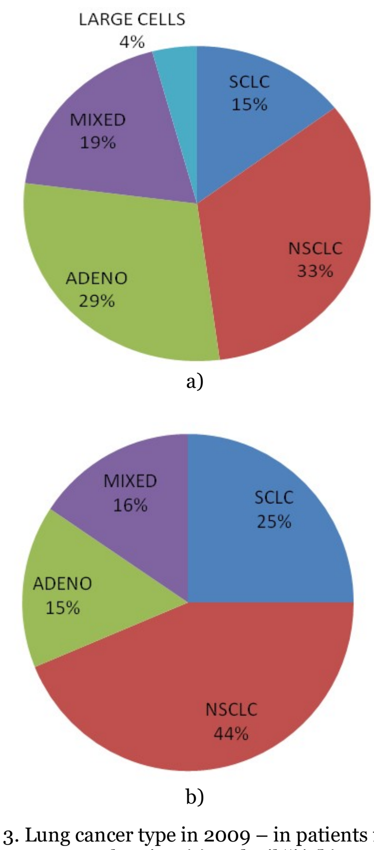


Figure 3. Lung cancer type in 2009 – in patients from the Coastal region (a) and Nikšić (b)

The data on the mortality rate in Montenegro in 2009 [8] show raw rate per hundred thousand of 68.7 for males (the most frequent cause of death among malignant neoplasms), and 20.9 for females (as the second cause of death from malignant neoplasms, after breast cancer).

"Global cancer statistics" for 2012 [26], for example, showed that lung cancer was the most frequently diagnosed cancer in males – overall and in less developed countries. At the same time, prostate cancer was the most frequently diagnosed cancer among males in developed countries. New lung cancer cases in that year (found to be 1.8 million [26]) accounted for ~13% of all diagnosed cancers. The highest incidence rates among males were evaluated for Turkey, the U. S. and Eastern Europe, and among females – for North America and Northern Europe [27]. Having in mind the importance of the relationship between incidence and mortality, it should be noted that the mentioned statistics [26, 27] showed similar lung cancer mortality and incidence rates. The reason is the low survival rate in all countries, including the developed ones.

The data on lung cancer mortality in Montenegro from 1990 to 2015 [28] show an increase in the total number of deaths caused by lung cancer of 82.2% (66.9% – males, 150% – females). Age-standardized rates in the mentioned period (per 100 000) increased from 40 to 43 among males and from 6 to 13 among females [28]. The same data also show that in 2009, 2010, 2011 and 2012, number of deaths caused by lung cancer in Montenegro was – 273 (208 M, 65 F), 301 (228 M, 73 F), 327 (250 M, 77 F) and 294 (214 M, 80 F), respectively, with the age-standardized (to the World Standard Population) rates per 100 000 of 28.2 (46.5 M, 13.4 F), 30.3 (50 M, 14 F), 31.9 (53.3 M, 14.2 F) and 28.3 (44.2 M, 15.3 F), respectively [28].

As it is noted in [27], cigarette-smoking is the main but not the unique cause of lung cancer. Lung cancer can also be caused by various indoor and outdoor exposures to different pollutants. It became clear in recent decades that radioactive radon is the second cause of lung cancer in the general population. Therefore, it is important to evaluate the risk posed by exposure to indoor radon.

On the other hand, as it was pointed out by the Committee on Biological Effects of Ionizing Radiation (BEIR) [29], to disentangle the effects and particular contribution to causing lung cancer of the two kinds of exposure – smoking and radon inhalation, is very complicated. Much higher risk of lung cancer comes from cigarette-smoking, but having in mind their synergetic effect, probability for induction of lung cancer in smokers by radon itself is greater than simple sum of the effect of each one (smoking and radon) alone [29].

It is clear that an evaluation of cancer risk attributable to radiation exposure needs to be considered upon epidemiological data.

Data related to cancer incidence and mortality rates in Montenegro are updated more or less regularly in the recent times, and it could help in further consideration of a possible (any) correlation between received radiation doses and cancer initiation. Here presented results, estimated cancer risks due to external terrestrial gamma radiation outdoors and radon exposure indoors, are baselines for such a consideration for the area of the capital of Montenegro.

4. Conclusions

Cancer risk due to radon indoor and terrestrial gamma radiation outdoors in Podgorica, the capital of Montenegro, is considered together with the 2009-incidence rate of lung cancer, which is the leading cause of cancer deaths among males worldwide.

The lung cancer incidence rate in Podgorica in 2009 is found to be 34.88 per hundred thousand, slightly higher than in the whole country. More than 88% of the patients with diagnosed and treated lung cancer were cigarette-smokers and more than 81% were males. In the highest percent (39%) the patients were in the age between 60 and 70 years. Among diagnosed lung cancers, non-small cell cancer was the most frequent (37%).

An average activity concentration of radionuclides in soil of the urban area of Podgorica is found to be 45.1 Bq/kg for ^{137}Cs, 409 Bq/kg for ^{40}K, 52.4 Bq/kg for ^{226}Ra and 47.9 Bq/kg for ^{232}Th, leading to the excess lifetime cancer risk due to external terrestrial gamma radiation outdoors of $3.3 \cdot 10^{-4}$ in average, which exceeds the world's average for natural radionuclides only.

Annual average indoor radon concentration in the municipality of Podgorica (urban and rural areas) of 84.8 Bq/m^3 exceeds the world's average by a factor of 1.8. The risk factor for lung cancer due to radon exposure is estimated to range from 0.039 to 8.78% with an average of 0.826%.

Obtained results could be used in future research in this particular field, i.e. correlating lung cancer incidence and radioactivity, especially in the light of exposure to radon.

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