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# ASSESSMENT OF RESIDENTIAL RADON EXPOSURE IN BULGARIA

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**In the light of the new ICRP requirements the first National radon survey has been conducted in Bulgaria in the period 2015–16. Indoor radon concentrations were measured for 1 y in 2778 dwellings of whole Bulgarian territory in order to obtain the systematic data for the distribution of radon. The arithmetic mean is 111 Bq m$^{-3}$ and the geometric mean is 81 Bq m$^{-3}$ with geometric standard deviation of 2.15. On the base of the data, an annual effective dose to the Bulgarian population due to indoor radon exposure was estimated at 5.2 mSv and excess lifetime cancer risk at about 2%. The evaluation has been made using the ICRP dose coefficient of $6.7 \times 10^{-6}$ (mSv h$^{-1}$)/(Bq m$^{-3}$), 7000 h occupancy per year and value of 0.4 for the equilibrium factor. This preliminary assessment allows consideration and planning the long-term appropriate radon and exposure reduction measures in the new national action plan.**

## INTRODUCTION

Naturally occurring radon in indoor air has been classified as a known human carcinogen by the International Agency for Research on Cancer as the second leading cause of lung cancer after tobacco smoking(1). The link between exposure to radon and lung cancer was initially demonstrated in epidemiological studies on miners, the results of which formed the basis for the recommendations by the World Health Organization (WHO) on radon exposure in dwellings. The studies on indoor radon and lung cancer in Europe, North America and Asia provide strong evidence that radon causes a substantial number of lung cancers in the general population(2). The new recommendations of ICRP include the control of indoor exposure due to radon and establishment of a reference level for the annual average activity concentration up to 300 Bq m$^{-3}$ for the existing dwellings and public buildings. A radon concentration of 300 Bq m$^{-3}$ in homes corresponds to an annual dose of approximately 10 mSv using the dose conversion convention, based on the revised nominal risk coefficient(3).

Radon ($^{222}$Rn) is a noble gas produced by radioactive decay of radium ($^{226}$Ra), which is contained in soils and rocks. $^{222}$Rn and its decay products contribute to more than half of the human exposure from natural sources(4). Considering the fact that people spend 80% of their time at home, many worldwide investigations of indoor radon exposure have been stimulated and published in the literature(4–6). The evaluation of the frequency distribution of radon concentration levels and exposure to radon in dwellings could be obtained with nationwide radon surveys designed and conducted in a way as to be representative of population exposure in homes. The methodologies and techniques to design and carry out a nationwide survey with the aim to estimate the distribution of annual average radon concentrations have been presented in an IAEA report(7). In the light of the new recommendation, the national survey was designed and carried out under the Bulgarian National Program from 2015 to 2016.

The annual effective dose to the Bulgarian population due to indoor radon exposure and the excess lifetime cancer risk has been assessed using the data presented in the paper.

## MATERIALS AND METHODS

Bulgaria is an European country and occupies a portion of the eastern Balkan Peninsula, bordering five countries: Greece and Turkey to the south, Macedonia and Serbia to the west, and Romania to the north. The population in 2015 is 7.2 M and population density per sq km is 65.3. According to the Classification of Territorial Units for Statistics in Bulgaria, the territory of the country is divided into six statistical regions. The statistical regions, on their side, are aggregations from the 28 districts and 264 municipalities(8). The population in these districts is not uniform and ranges from approximately 1 million in Sofia and three hundred thousand in Vindin (Table 1).

### Radon measurement

The survey was promoted and coordinated by the National Centre of Radiobiology and Radiation Protection (NCRRP) and carried out in collaboration

**Table 1. Distribution of the annual effective dose due to radon, the population and the radon concentration arithmetic mean (AM) in 28 regions on Bulgaria.**

| Regions | Population | AM [Bq $m^{-3}$] | Annual effective dose [mSv $a^{-1}$] |
|---|---|---|---|
| Blagoevgrad | 310 321 | 89 | 4.2 |
| Burgas | 412 684 | 76 | 3.6 |
| Varna | 472 654 | 101 | 4.7 |
| V.Tarnovo | 242 259 | 145 | 6.8 |
| Vidin | 88 867 | 114 | 5.4 |
| Vratsa | 168 727 | 138 | 6.5 |
| Gabrovo | 112 334 | 133 | 6.3 |
| Dobrich | 178 438 | 110 | 5.2 |
| Kardzhali | 150 837 | 126 | 5.9 |
| Kyustendil | 123 431 | 174 | 8.1 |
| Lovech | 129 222 | 89 | 4.2 |
| Montana | 134 669 | 76 | 3.6 |
| Pazardzhik | 260 814 | 101 | 4.7 |
| Pernik | 123 770 | 145 | 6.8 |
| Pleven | 248 138 | 114 | 5.4 |
| Plovdiv | 671 573 | 138 | 6.5 |
| Razgrad | 115 402 | 133 | 6.3 |
| Ruse | 223 489 | 110 | 5.2 |
| Silistra | 111 957 | 126 | 5.9 |
| Sliven | 189 788 | 174 | 8.1 |
| Smolyan | 109 425 | 131 | 6.1 |
| Sofia city | 1 323 637 | 92 | 4.3 |
| Sofia region | 234 185 | 118 | 5.5 |
| St. Zagora | 321 377 | 89 | 4.2 |
| Targoviște | 113 694 | 81 | 3.8 |
| Haskovo | 233 415 | 121 | 5.7 |
| Shumen | 174 476 | 89 | 4.2 |
| Yambol | 122 276 | 212 | 10.0 |
| **Bularia** | **7 101 859** | **111** | **5.2** |

with Regional Health Inspectorates. The measurements were done for 1-y-period, from April 2015 to March 2016. Each district received 100 detectors or a total of 2800 detectors were distributed across the territory of the country. The sampling points have been divided according to the population density in municipalities, then to towns and villages, in order to achieve the population-based residential radon survey. Time integrated radon concentrations were measured using CR-39-based detectors. The detectors were calibrated at the radon chamber of an accredited laboratory and the radon concentrations have been evaluated in accordance with the ISO standard(9). The dwellings have been randomly selected. The detectors were deployed on the ground floor in dwellings, according to the procedure in the rooms where the inhabitants spent the most of their time, generally the living room, bedroom and nursery (child room). During the survey, the questionnaires were completed, which contain information about the type of building construction, year of construction, habits of its inhabitants and others.

### Radon dose and risk

To estimate the lung cancer risk arising from exposure to radon decay products different approaches can be used. In this paper, the new biokinetic and dosimetric models and dose coefficients according to the ICRP 137(10) is used. For dose estimation due to inhalation of radon and radon decay products in buildings, in most circumstances, ICRP recommends a dose coefficient of 3 mSv per mJ h $m^{-3}$ (approximately 10 mSv per WLM)(10). The corresponding dose coefficient expressed in terms of radon ($^{222}$Rn) gas exposure depends on the equilibrium factor $F = 0.4$ between radon gas and its decay products and referred to 3 mSv per mJ h $m^{-3}$, and corresponds to $6.7 \times 10^{-6}$ mSv per Bq h $m^{-3}$(10).

There is a general agreement among scientists that alpha irradiation of cells in the bronchial epithelium is responsible for the development of lung cancer(2). For the estimation of the dose to the Bulgarian population, which includes both smokers and non-smokers, the following formula was applied:

$$H \text{ (mSv a}^{-1}\text{)} = \text{AM} \times K \times T \quad (1)$$

where AM is the arithmetic mean radon concentration in units of Bq $m^{-3}$, $K$ is the ICRP dose coefficient of $6.7 \times 10^{-6}$ (mSv $h^{-1}$)/(Bq $m^{-3}$)(10) using a reference value of 0.4 for the equilibrium factor and $T$ is the time in 7000 hours home occupancy per year.

The excess lifetime cancer risk (LCR) was estimated, according to ICRP Publication 103(3), using the following equation:

$$\text{ELCR} = H \times \text{DL} \times \text{RF} \quad (2)$$

where H (mSv $a^{-1}$) is the annual effective dose from radon exposure, DL is the average duration of life estimated to 70 y and RF is the detriment-adjusted nominal risk coefficients for stochastic effects after exposure to radiation at low dose rate for the whole population ($5.5 \times 10^{-2}$ $Sv^{-1}$), recommended by ICRP 103(3).

Statistical analysis of the evaluation of influence to radon concentration of different factors was applied with commercially available statistical software: XLSTAT Pro 7.5 (Version 2014.5.03).

## RESULTS AND DISCUSSION

### Overall results

The chosen door-to-door approach in the distribution of detectors allowed obtaining a low percentage of nonresponses (0.78%). The number of detectors from which result has been obtained is 2778 from 2800 distributed detectors. The frequency distribution of the radon concentrations measured in dwellings in Bulgaria is shown in Figure 1.

Radon concentrations vary geographically from one district to other. The best fit for indoor radon concentrations data distribution was with a log-normal, function. The minimum and maximum concentrations were found to be 11 Bq $m^{-3}$ and 1314 Bq $m^{-3}$, respectively, with a geometric mean (GM) of 81 Bq $m^{-3}$ and geometric standard deviation (GSD) of 2.15. The arithmetic mean (AM) is 111 Bq $m^{-3}$ with a standard deviation (SDV) of 105. Population-weighted radon concentration was calculated to be 108 Bq $m^{-3}$ using the statistical data of the population density[8]. Overall, 88% of the measurement dwellings have radon concentrations lower than 200 Bq $m^{-3}$, 12% of the dwellings have radon concentrations above 200 Bq $m^{-3}$ and the other 4.4% have radon concentrations greater than 300 Bq $m^{-3}$. The results are comparable to those obtained for the Visegrad countries (Slovakia, Hungary and Poland) where the annual average of radon concentration have been less than 200 Bq $m^{-3}$ in 85% of the studied houses[11]. The AM and GM are comparable to the obtained results from the national survey in Republic of Macedonia (AM = 105 Bq $m^{-3}$ and GM = 84 Bq $m^{-3}$)[12] and slightly higher than those in Transylvania—Romania (AM = 82.5 Bq $m^{-3}$)[13]. The AM value achieved in this study is lower than that obtained from surveys in some rural communities of the Balkan[14] (AM = 191 Bq $m^{-3}$) but higher than the AM (73 Bq $m^{-3}$) and GM (52 Bq $m^{-3}$) in Greece reported in UNSCEAR 2006[6].

## Radon dose and risk

The results of the annual effective doses due to radon exposure that have been evaluated for each

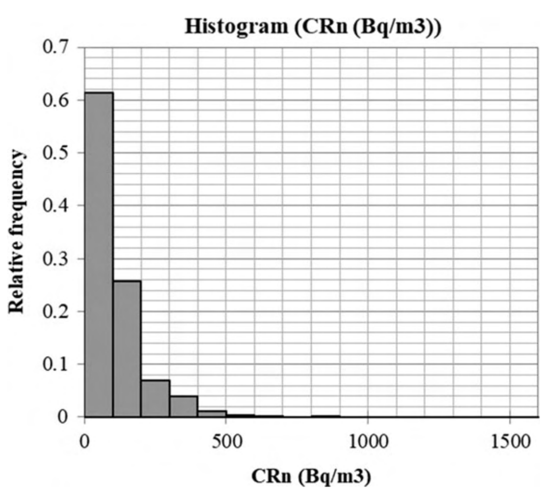


Figure 1. Frequency distribution of indoor radon concentrations in Bulgarian dwellings.

Bulgarian district based on about 100 measurements per district are provided in Table 1. On average, the annual effective dose to the Bulgarian population due to indoor radon exposure has been estimated to be 5.2 mSv. The number of population in each district is also presented in Table 1. The highest assessed annual effective dose (11 mSv $a^{-1}$) is for Yambol district while the lowest annual effective dose (4 mSv $a^{-1}$) is in Burgas region and Montana region. The estimated annual effective dose (5.2 mSv $a^{-1}$) from the current National Survey data is higher than the previously assessed (1.22 mSv $a^{-1}$) in 1992 according to the literature[15]. The annual effective dose is comparable to that for the Iranian population of 5.5 mSv $a^{-1}$[16] and is lower than the annual effective dose for the South Italy of 8.2 mSv $a^{-1}$[17]. According to the questionnaire, the time, which most of the Bulgarian population spends at home could be assessed to approximately 6000 h per year. The annual effective dose has been evaluated at 5 mSv $a^{-1}$ for 6000 h. The mean excess lung cancer risk estimated in this work with the help of equation (2) of the Bulgarian population due to radon is 2%. The estimate does not involve population-specific adjustments for factors like smoking habits, age-distribution and sex. The average of excess lifetime cancer risk (ELCR) is higher compared to the estimated risk of 1.3% due to radon exposure for the American population[18].

## Factors influencing the variations of radon

The main reason for lung cancer is the smoking habit of people and the combination of radon and smoking significantly increases the risk. To analyze the influence of smoking in a room on the radon concentration, a question in the questionnaire has been asked about the habit of smoking in the building. The influence has been assessed using the Kruskal–Wallis test. The analysis showed that the difference in the indoor radon concentration in the smoking and non-smoking rooms, was statistically significant with error probability $p < 0.10$ (KW, $p = 0.06$) Figure 2.

The somewhat higher concentrations are found in the non-smoking rooms in comparison to the smoking rooms (Figure 2). This could be explained with the higher frequency of opening the windows in the rooms, where people smoke.

The influence of the time spent at home to the radon concentration has also been analyzed. The groups were divided to '<12 h' and '12–24 h' time spent at home. The opening of the windows in the premises would affect the radon concentration. The idea of assessing the impact of the time spent at home on the concentration of radon is to assess people's habits to open the windows. There are no significant differences in the results for the two groups.

The lack of distinction between the groups with different time spent at home shows that the ventilation

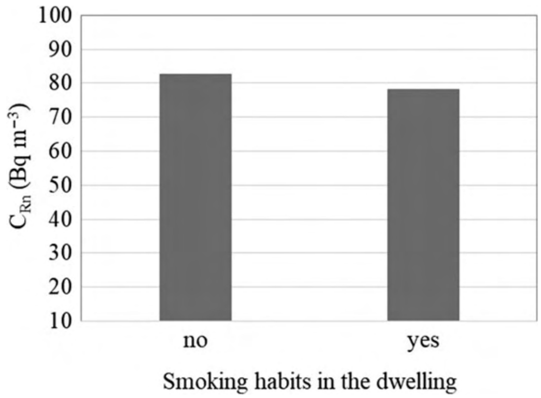


Figure 2. Geometric means of indoor radon concentrations (CRn) grouped by the smoking habits

of the premises and respectively the concentration of radon do not depend on these habits.

## CONCLUSION

The first systematic data of radon concentrations on the Bulgarian territory has been obtained. The evaluated geometric mean was 81 Bq $m^{-3}$ with a geometric standard deviation of 2.15 and the arithmetic mean—111 Bq $m^{-3}$. The preliminary assessment of radon exposure to the Bulgarian population has been obtained under the National Radon Program. The estimated annual effective dose on the assumptions of 7000 h home occupancy per year was found to be 5.2 mSv $a^{-1}$. These values lead to a preliminary estimate for the mean excess lifetime cancer risk of the Bulgarian population due to radon exposure in dwellings of about 2%.

The influence of people's habits for opening the windows for ventilation on the concentration of radon in the building has been evaluated. The data are grouped according to the smoking habits in the room, which had a small, but significant effect on radon variation, while the time spent in the house had no influence on the radon concentration in our study.

These data could be used as a base for the National Radon Program for future measures.

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