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Reconstruction of national distribution of indoor radon concentration in Russia using results of regional indoor radon measurement programs

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ABSTRACT

The aim of the paper is a reconstruction of the national distribution and estimation of the arithmetic average indoor radon concentration in Russia using the data of official annual 4-DOZ reports. Annual 4-DOZ reports summarize results of radiation measurements in 83 regions of Russian Federation. Information on more than 400 000 indoor radon measurements includes the average indoor radon isotopes equilibrium equivalent concentration (EEC) and number of measurements by regions and by three main types of houses: wooden, one-storey non-wooden, and multi-storey non-wooden houses. To reconstruct the national distribution, all-Russian model sample was generated by integration of sub-samples created using the results of each annual regional program of indoor radon measurements in each type of buildings. According to indoor radon concentration distribution reconstruction, all-Russian average indoor radon concentration is 48 Bq/m^3. Average indoor radon concentration by region ranges from 12 to 207 Bq/m^3. The 95-th percentile of the distribution is reached at indoor radon concentration 160 Bq/m^3.

1. Introduction

Survey of indoor radon concentrations in a representative sample of houses is a significant stage of national and regional programs dealing with population radon exposure. Indoor radon survey provides the information on distribution of indoor radon concentrations in dwellings and other locations and retrieves the factors most influencing on indoor radon level. The results of indoor radon survey constitute the base for strategy of protection against radon and effective protection measures.

According to its mission, UNSCEAR periodically reviews the results of national indoor radon surveys and estimates average worldwide indoor radon concentration as well as effective dose due to radon. Totally, results of indoor radon surveys from more than 60 countries were included in 2006 report (UNSCEAR, 2009). The UNSCEAR 2000 report gives population-weighted worldwide arithmetic and geometric mean (GM) values 39 and 30 Bq/m^3 respectively with corresponding geometric standard deviation (GSD) 2.3 (UNSCEAR, 2000).

In Russia, protection against radon is required by Federal Law "On protection of population against radiation". Since 1990, Russian Radiation Safety Standards (RRSS) include restriction on indoor annual equivalent equilibrium concentration of radon isotopes. This quantity is calculated as ^{222}Rn EEC + 4.6 ^{220}Rn EEC. In existing dwellings, the restriction is EEC of radon isotopes = 200 Bq/m^3. For new buildings, the more strength restriction is established, EEC of radon isotopes = 100 Bq/m^3. Protection of population of Russia against indoor radon is the responsibility of Russian Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing (Rospotrebnadzor). The approach to indoor radon problem in Russia, developed by Rospotrebnadzor in 1990-s and 2000-s, does not include the indoor radon survey in the national representative sample of buildings. The indoor radon measurements, which were performed in the frames of regional annual radiation monitoring programs, were focused on searching for high radon areas (Kormanovskaya and Stamat, 2010; Svetovidov et al., 2012). In order to control compliance with the restrictions of the RRSS, the measurements in all new buildings were another important task. According to these priorities, regional departments of Rospotrebnadzor were equipped mostly with short term radon measurements devices (grab sampling). Totally eleven types of devices for short term measurements of ECC of radon isotopes and eight types of devices for short term measurements of radon

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concentration are used (ISSDCR, 2014; Zhukovsky and Yarmoshenko, 1997; Zhukovsky et al., 2010). Such devices are relatively cheap and allow prompt control of exposure to radon progeny. Measurements of thoron ECC may be performed using the most of grab sampling devices. In Russia, exposure to thoron progeny is not considered to be an important problem in comparison with the radon progeny. In average, EEC of thoron with the factor 4.6 contributes only few Bq/m^3 to ECC of radon isotope (Zhukovsky and Yarmoshenko, 1998; Yarmoshenko et al., 2002). Only few laboratories were equipped with long term nuclear track detectors (Marenny et al., 2000, 2005). In case of radon gas measurements, equilibrium factor F = 0.5 is used in Russia (Yarmoshenko et al., 2014).

Since 2001, Rospotrebnadzor established the Joint system of the control of the individual doses to the population and an information bank to collect the data of radiation measurements performed by regional departments and other laboratories (Svetovidov et al., 2012). Instructions and guidelines on reporting results of the population radon exposure control were developed by St-Petersburg Research Institute of Radiation Hygiene after Professor P.V. Ramzaev (Stamat et al., 2014). Data in the information bank are annually reviewed and summary is published. Indoor radon data are presented in 4-DOZ Report (Rospotrebnadzor, 2007). Now, information of the 4-DOZ annual reports becomes the largest source of data on indoor radon exposure of population of the Russian Federation. The data collecting system is based on the average values by regions and doesn't include the information on dispersion of indoor concentration. Thus, there is no possibility to analyze the distribution of radon isotopes ECC radon exposure in Russian Federation that is important for optimization of protection against radon exposure (ICRP, 2014). The aim of our analysis is to reconstruct the national distribution of indoor radon concentration using these data.

2. Materials and methods

For our analysis, we used 4-DOZ Reports issued by St-Petersburg Research Institute of Radiation Hygiene after Professor P.V. Ramzaev in the period from 2008 to 2013 (ISSDCR, 2009, 2011a, 2011b, 2012, 2013, 2014). The annual reports summarize the results of radiation measurements and dose assessment in 83 regions of the Russian Federation, which were presented to national data bank according to the requirements of special guidelines (Rospotrebnadzor, 2007). Measurements of indoor radon (^{222}Rn) and thoron (^{220}Rn) EEC and/or radon (^{222}Rn) gas concentration are conducted within the regional radiation measurement programs of most of the regions.

Annual summary 4-DOZ Report includes the average EEC of indoor radon isotopes (^{222}Rn EEC + 4.6 ^{220}Rn EEC) and the number of measurements by regions and by three main types of houses: wooden house, one-storey non-wooden house and multi-storey non-wooden house. The last two groups include houses built using mineral materials such as stone, brick, concrete etc. Thus, the average indoor radon isotopes EEC and the number of measurements represent results of annual regional program of radiation measurements in corresponding type of buildings.

The distribution of indoor radon isotopes EEC in dwellings of Russia was reconstructed considering each annual regional program of measurements in the each type of buildings as the radon survey of a rural territory or a district of urban territory. For the purposes of the analysis, it was suggested that such quasi-surveys conducted over the period of 2008–2013 cover all territory of Russia. Consequently, all-Russian model sample can be generated by integration of sub-samples created using results of the quasi-surveys.

In order to generate the sub-sample of indoor radon isotopes EEC under suggestion on lognormal distribution, it is necessary to know GM and GSD of radon isotopes EEC and the number of generated values (N). For the case of lognormal distribution, the GM can be calculated using the following equation:

$$GM = \exp\left(\ln(AM) - \frac{\sigma_{LN}^2}{2}\right), \quad (1)$$

where AM is arithmetic mean of radon isotopes EEC (Bq/m^3) for each quasi-survey obtained from the 4-DOZ annual reports, σ_{LN} is the natural logarithm of the GSD.

As mentioned above, the exact values of GSD for each quasi-survey are unknown. Therefore, we used some typical values, which were chosen depending on the number of measurements. The dependence of dispersion of indoor radon concentration values on number of measurements reflects higher variability of radon sources in larger territory. Factors influencing the variability are associated with both variation of radon geogenic potential and diversity of types of buildings (the detailed report devoted to factors influencing GSD is under publication). Accepted values of GSD are presented in Table 1.

The number of generated values of radon isotopes EEC in the sub-samples was normalized by population of the region and the number of measurements in the frame of regional radiation monitoring program:

$$N \sim \frac{N_{pop} \cdot N_{meas}}{N_{total}}, \quad (2)$$

where N_{pop} is the population of the region; N_{meas} is the number of measurements in this region in certain type of building in a certain year; N_{total} is the number of measurements in this region in all type of building for the period of 2008–2013. With regard to available computational resources the total size of modeled sample to reconstruct distribution of indoor radon concentrations in dwellings of Russia was limited by 60004. Then, the number of generated values for each i-th quasi-survey is chosen based on the condition $\Sigma N_i = 60004$. Totally data on 874 quasi-surveys were included to the analysis (surveys with $N_{meas}<10$ were excluded). The number of the quasi-surveys and average size of sub-samples by years are presented in Table 2.

To transfer from indoor radon isotopes ECC to the radon concentration we accepted average ^{220}Rn ECC = 0.5 Bq/m^3 and equilibrium factor F = 0.5 (Yarmoshenko et al., 2014). For better simulation of real indoor radon survey, indoor radon concentration bellow 5 Bq/m^3 was accepted equal to 5 Bq/m^3.

3. Results

A sample consisted of 60 004 indoor radon concentrations was generated applying the model described in section Materials and Methods. Indoor radon concentration in model sample follows lognormal distribution as presented in Fig. 1. Arithmetic and geometric means, GSD of indoor radon concentration, and other parameters are presented in Table 3. Parameters that describe indoor radon concentration in three general types of buildings are presented in Table 3 as well. Average indoor radon concentration by region ranges from 12 to 207 Bq/m^3, non-weighted by population inter-regional average indoor radon concentration is 50 Bq/m^3.

4. Discussion

The quality of data on indoor radon collected by regional