The impact of some factors (building materials, seasonality) on indoor radon content in Chelyabinsk region, Russia

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Abstract. This paper reports the results of a study which explores the rate of indoor radon content in four settlements of Chebarkul district in Chelyabinsk region, Russia. A large number of heterogeneous rock formation areas with inclusions of thorium and uranium mineralization is a distinguishing feature of Chelyabinsk region. The natural γ-background in the study area is 110 mSv·h⁻¹. The study provides the obtained results of radon content in winter, spring, summer and autumn in rooms in buildings made of wood, brick, concrete panels. Y-background and equivalent equilibrium volume activity were measured in open areas and in premises with ergonomic PAA-10 and "Alpha Guard 2000". The average annual equivalent equilibrium volume activity of radon for all buildings varied greatly depending on the materials used for construction (from 21.5±2.2 to 176.2±15.6 Bq·m⁻³). The highest values were recorded for the premises made of wood. According to the indoor radon content in the premises made of different building materials, the studied settlements were classified into several categories of being radon hazardous (the first, second and third). The range of annual average values of equivalent equilibrium volume activity in different premises was identified in the reducing order which is the following: winter - autumn - spring - summer. The differences of the mean radon content in different seasons were statistically significant. Conservative estimates of annual doses of radon in all the studied premises ranged from 120 mSv·year⁻¹ to 195 mSv·year⁻¹, depending on the type of construction.

1. Introduction

Many countries including Russia have been controlling indoor radon content for years. There is no doubt that to study the exposure of natural radiation sources, particularly radon and its progeny, on people is important and timely [1].

Natural sources of ionizing radiation are common and permanent environmental factors adversely affecting human health. Radon is generated in soil and other objects of the geological environment containing natural radionuclide radium-226 [2]. Radon enters the indoor air from the ground through the floor slabs, untightened penetration kits and from radium-containing materials in the constructions enclosing the building structures [3, 4]. Radon content and flow are extremely uneven and depend both on geological and geophysical characteristics of the natural environment (uranium and thorium content in the soil and the thorium structure, underlying rocks and groundwater, climatic conditions, seasonality) [5, 6] and on the building constructions, materials and the quality of ventilation systems [7]. Taking these factors into account the exposure of people in residential and industrial buildings can be significantly reduced [8].

Radon enters buildings mainly from soil through foundation cracks and from building materials. Among building materials wood has the lowest specific activity (below 1Bq·kg⁻¹) [9]. Depending on the original components (sand and cement) the activity of concrete, as a rule, is 30-50 times that of wood. The activity of granites, tuff, pumice (200-400 Bq·kg⁻¹) is high [7]. On average, the dose rate in the buildings made of brick, stone and concrete is 2-3 times higher than in those of wood.

Indoor radon content is a time-dependent value that varies daily, in the short-term (3-7 days), seasonally (6 months), in the long-term (2/3- 20 years) [10-15]. Average radon concentration can
fluctuate up to 50% in different seasons and years [16]. The dose from internal radiation generated by radon is more significant [17]. Compared to the outdoor air, in poorly ventilated buildings, radon and its decay products can accumulate in ten-fold amounts. Researchers in many countries have studied increasing radon accumulation as a result of lower air change [18-25]. Indoor radon accumulation in residential buildings is also studied in Russia.

The Ural region has several distinctive features that are associated with increasing thorium and uranium content in the crust [26]. Natural radioactive mineralization of rocks and water-bodies in the region results in high radon concentration in underground water and indoor air. Sverdlovskaya Oblast (the Middle Urals) is one of the most studied in terms of population exposure to natural radioactive sources. Only through a special radon survey, radon content was measured in more than 2.5 thousand of residential buildings [27]. In Yekaterinburg, which is the centre of Sverdlovskaya Oblast, (population ~1.4 m) radon content was measured in 404 apartments of multi-storeyed buildings [27]. In South Ural (the Chelyabinsk region) radiation hygiene is under strict control. The data collected are given in annual comprehensive reports on the environmental situation in the Chelyabinsk region. Comprehensive report of 2016 says it is indoor radon that contributes 50% to the cumulative effective population exposure dose in Chelyabinsk region [28]. But there is no research concerning indoor radon accumulation in the Chebarkul district of the Chelyabinsk region. The current paper is the first research on the issue.

The aim of our research is to study seasonal changes in indoor radon content in residential areas of Chebarkul district in Chelyabinsk region (Russia) and to study the influence of factors related to the characteristics of buildings (materials used for construction) on the radon volume activity.

2. Methods

2.1. Study area

We conducted our research in the settlements of Chebarkul district in Chelyabinsk region (Russia) – the village of Kundravy, the village of Popovo, the village of Timiryazevsky and the city of Chebarkul (Figure 1).

172 houses built of different materials (Table 1) were measured. All the studied houses in Kundravy, Popovo and Timiryazevsky are one-storey buildings. While in Chebarkul, three-storeyed buildings are also studied. Wooden one-storey buildings houses have, as a rule, untightened storage space underneath. There are no similar storage space compartments in modern brick and concrete one-storey buildings buildings. One-storey buildings in Chebarkul are mainly made of wood and bricks, while concrete houses are three-storey buildings with basements for communal services. The research was conducted on the first storeys. The wooden houses are distinguished by their age: many of them are 50-80 years old.

| Settlement    | Number of houses |
|---------------|------------------|
|               | wood | bricks | concrete |
| Chebarkul     | 49   | 27     | 24       |
| Kudravy       | 15   | 3      | 2        |
| Popovo        | 11   | 7      | 1        |
| Timiryazevsky | 10   | 25     | 3        |

2.2. Sample collection

Outdoor and indoor Y-background, as well as indoor equivalent equilibrium volume activity (EEVA) were measured in the residential areas of Chebarkul, Kundravy, Popovo and Timiryazevsky with the help of ergonomic devices RAA-10 and "AlphaGUARD PQ2000". Aerosol radiometer RAA-10 is designed for the rapid measurement of the equivalent equilibrium volume activity (EEVA) of radon and thorium in residential and industrial buildings, as well as out-of-doors, with hygienic standards being controlled. It operates as follows: first, the dispersed phase of short-lived radon progeny from the studied air is settled on the spectrometric filter AFA-RSP 10. It’s activity is then
measured according to the number of registered alpha particles of RaA, RaC and ThC, and EEVA 222 Rn and EEVA 220Tn values are calculated. Alpha Guard 2000, radiometer of radon-222 volume activity, is designed to measure radon-222 volume activity in air ionization chamber.

![Figure 1. Location of the studied settlements: 1 - Chebarkul; 2 - Timiryazevsky; 3 - Kundravy; 4 - Popovo.](image)

Radiation and hygienic research was conducted according to the methodology [29]. A measurement chart was made for each building. The chart contains information about the measurement methods and equipment, address of the object, characteristics and functions of the territory and building, the date of measurement, inspection values of volumic activity (VA) and EEVA of radon, the gamma background rate, the way the buildings are used. For the equipment used and measurement duration, the minimum measured VA value was 15 Bq·m⁻³.

Y-background, both indoors and outdoors, was measured in June-July, 2014, while EEVA was measured in July and September, 2014, and January and April in 2015. On the basis of the data received (Tsapalov et al.) [30] radon content was measured for 7 days every month.

2.3. Data processing

Microsoft Excel 2013 and SPSS 24.0 were used for data analysis and processing. Kolmogorov – Smirnov Test was applied for data normality testing. To compare EEVA rates in different seasons and buildings made of different materials we conducted Mann – Whitney Test.

3. Results and Discussion

The obtained results showed that of all the examined settlements the highest indoor radon content was recorded in Popovo - 0.159 mcSv·h⁻¹, a bit lower in Kundravy – 0.148 mcSv·h⁻¹, in Chebarkul and Timiryazevsky the measurements were 0.137 and 0.132 mcSv·h⁻¹ respectively. The radon content was due to more than 80 % of the environment [28].

The average equivalent dose rate was analyzed in summer (Figure 2). In general, fluctuations in values depending on the type of the building material vary slightly within the statistical errors. Differences from the background values indoors are also insignificant with the exception of the wooden buildings in Kundravy, where there is an increase of the average equivalent dose rate.

Figure 3 shows the results of EEVA of radon in different seasons in the dwellings built of wood, bricks and concrete in Chebarkul district. Season changes of indoor radon content are recorded in all the studied objects. Unlike other studies [8] the current results do not always constitute the specific series of indoor EEVA values summer < spring < autumn < winter with statistically significant differences. However, in contrast to summer and spring, autumn and winter are characterized by higher radon...
concentrations. This could be explained by significantly lower volumes of ventilation in winter, so that the indoor air is not sufficiently diluted, which leads to the radon accumulation.

![Bar chart showing measurement results of average equivalent dose rate indoors in Chebarkul district: A - Chebarkul, B - Kundravy, C - Popovo, D - Timiryazevsky; 1 - background level, 2 - wood, 3 - bricks, 4 - concrete.]

**Figure 2.** Measurement results of average equivalent dose rate indoors in Chebarkul district: A - Chebarkul, B - Kundravy, C - Popovo, D - Timiryazevsky; 1 - background level, 2 - wood, 3 - bricks, 4 - concrete.

Ventilation in the studied houses was absent. The residents aired their apartments opening windows and putting fresh air in and letting polluted air out. We determined time intervals for airing based on the survey and interviewing the residents. Table 2 represents the obtained results. According to the results, time of airing significantly depends on a season.

| season  | < 1 hour | 1-2 hours | 2-3 hours | 3 > hours |
|---------|----------|-----------|-----------|-----------|
| summer  | 1 %      | 3 %       | 41 %      | 55 %      |
| autumn  | 14 %     | 32 %      | 32 %      | 22 %      |
| winter  | 85 %     | 14 %      | 1 %       | 0 %       |
| spring  | 5 %      | 12 %      | 10 %      | 73 %      |

It’s evident that air supply is a way of natural ventilation that must be implemented through opening windows. But our research shows that in winter residents use them only to air their apartments for a short-time, even with the indoor air being stuffy (Table 2).

Figure 3 also shows the comparison of the average values of EEVA by seasons according to the building material. For the settlements of less than 100 years old (Chebarkul, Popovo, Kundravy) there is a tendency towards high values of EEVA for wooden buildings, although the specific activity of wood, as a rule, is lower than 1 Bq·kg⁻¹. That could be due to the fact that old wood has a higher radon permeability. But in the younger settlement Timiryazevsky there is practically no significant difference between EEVA values for different building materials including wood. Apparently, this is due to the age of the settlement, where the walls of wooden buildings have a higher density.

In general, the average annual EEVA rates for almost all the settlements do not exceed the normative values. According to the norms of the Russian Federation SanPiN 2.6.1.2523-09 [8], this value is 200 Bq·m⁻³ in the operated buildings. The reference values recommended by the European Commission for existing dwellings (European Commission (EU), 1990) are Bq·m⁻³. The lowest average annual rates of EEVA are observed in Timiryazevsky (Table 1), as well as in Chebarkul for brick and concrete houses. The highest levels are recorded in wooden houses in Popovo.
Figure 3. Comparison of average seasonal values of EEVA depending on the type of building materials in different settlements of Chebarkul district, using Mann-Whitney test. Different letters indicate statistically significant differences when comparing building materials (p <0.05): a) summer, b) autumn, c) winter, d) spring; 1 - wood, 2 - bricks, 3 - concrete.

4. Conclusions

This paper presents the results of a study of radon volumic activity in the buildings of four settlements of Chebarkul district in Chelyabinsk region. EEVA measurements of indoor air showed that in general, the average annual rates do not exceed the standard values (200 Bq·m⁻³) and range from 21.5±2.2 Bq·m⁻³ to 176.2±15.6 Bq·m⁻³. The following effects of seasonality on the radon content in indoor air were revealed: higher concentrations in autumn and winter compared to spring and summer; a link between EEVA values and the type of building material.

Indoor radon accumulation in winter and autumn can be explained by decreasing airing time. The only effective way to decrease the indoor radon content under the conditions of dominant diffusive mechanism of radon inflow is to change the mode of ventilation. Taking all that into account it’s necessary to reconsider the used methods of air conditions.

Based upon the potential hazard of the studied territory, the settlements can be classified into three groups: non-hazardous - Timiryazevsky (EEVA < 50 Bq·m⁻³), low-hazardous - Chebarkul (EEVA 51-100 Bq·m⁻³) and potentially hazardous - Kundravy and Popovo (EEVA > 100 Bq·m⁻³).

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