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Changes in radon concentration in soils of the city of Tobolsk

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Abstract. As part of this study, measurements of radon flux density were carried out, the average values of volumetric activity of radon from the soil surface in the foothill and upland parts of the city of Tobolsk (Tyumen region, Russia) were determined. Areas were selected that were evenly distributed within the city limits, and coordinates (latitude, longitude) were determined. As a result of the work, it was established that in 56% of the studied areas of the city of Tobolsk, the radon-222 flux density does not pose a danger to the population, the studied areas correspond to the first class, 44% – the second class of radon hazard. According to the soil classification in the study areas, 37.5% is sand, 31.25% is sandy clay, 18.75% is loam sand, and 12.5% is loam. It was found that high concentrations of radon-222 also depend on the granulometric composition of the soils studied.

1 Introduction

To ensure environmental safety when using territories and increasing efficiency in urban planning, more and more attention is being paid to natural radioactivity. According to numerous studies by Russian and foreign scientists, the main radiation background on our planet is created by natural sources of radiation, in particular, radon, which makes up a significant part of the total radiation dose [1,2,3].

Radon is a naturally occurring radioactive gas that can be present in the air indoors, such as in homes, schools and businesses, and makes up a significant portion of the total radiation dose.

Radon (^{222} Rn) is an odorless, colorless, inert gas. Radon is formed by the natural radioactive decay of uranium, which is found in all types of rocks and soil. Radon is radiotoxic and carcinogenic. The unit of measurement of radioactivity is the becquerel (Bq). The half-life of radon is 3.8 days. Half-life is the time after which half of the atoms or atomic nuclei have undergone radioactive decay. French scientist Henri Becquerel introduced radioactivity to the world in 1836. He found that radioactive elements were found throughout the human environment and that they could be of natural origin. Artificial radioactive substances are formed as a result of human activity. This means that during this

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time, half of the radon atoms will undergo radioactive decay. Due to the lack of color, smell and taste, radon cannot be detected without special equipment.

Radon is formed in the depths of the Earth, accumulates in rocks, and then gradually moves through cracks to the surface of the Earth, therefore, the selection and survey of the territory for development is of great importance. The value that is the criterion for the radon hazard of territories is the radon flux density from the soil surface, which is the activity of radon passing through a unit of surface per unit of time and has a unit of measurement of $Bq/m^2 \cdot s$. The value indicates the intensity of gas release to the earth's surface [1,4,5,6,7].

The radon content in the air is standardized according to the average annual equivalent equilibrium volumetric activity (EROA), which should not exceed 200 Bq/m^3 for operating premises, and 100 Bq/m^3 for designed premises.

Radon concentrations and fluxes are extremely uneven - they vary within very wide limits for different regions. The distribution of radon-forming elements in soils depends on many factors. For example, from the nature of the development of rocks in a given territory in certain geological periods, geomorphology, past and current tectonic activity, etc. The maximum reliable information about their content in a specific area is obtained based on the results of radiogeological studies [8,9].

The main regulatory document currently in effect in the Russian Federation is SP 2.6.1.2612-10 "Basic sanitary rules for ensuring radiation safety" with amendments as of September 16, 2013 (OSPORB 99/2010).

This document specifies the permissible values of the radon-222 flux density from the surface of soils and grounds intended for the construction of residential buildings – no more than 80 $mBq/(m^2 \cdot s)$, and no more than 250 $mBq/(m^2 \cdot s)$ for industrial buildings.

There are three classes of radon hazard in territories: first class (PPC less than 80 $mBq/m^2 \cdot s$) - normal ventilation is sufficient for protection). Second class (PPC is 80–200 $mBq/m^2 \cdot s$) - moderate protection is required. Third class (PPC more than 200 $mBq/m^2 \cdot s$) – enhanced protection required [10,11].

In this regard, in recent years, when assessing radon risk, increasing attention has been paid to the study and mapping of geological environment parameters. Currently, a fairly large number of means for measuring the activity of radon and its decay products have been developed and are in use, allowing us to solve scientific and applied problems aimed at ensuring radon safety. Studying the amount of radon in the environment is the main process for eliminating its exposure. This radioactive gas has also found application in modern medicine. Radon baths are used in the treatment of an impressive list of diseases. Given the harmfulness of this gas, only well-trained and experienced specialists can work with it and only with special equipment [12,13,14,15].

Tobolsk is an actively developing city. Due to the development of the oil and gas processing industry, the number of city residents is constantly increasing and more and more territories are being covered by the construction of housing complexes and individual housing buildings. Therefore, it is very important to monitor the territory for radon hazard in order to protect city residents and maintain their health. The aim of the work is to identify radon-hazardous areas in the city of Tobolsk.

2 Material and methods

As part of this study, measurements of radon flux density were carried out, the average values of volumetric activity of radon from the soil surface in the foothill and upland parts of the city of Tobolsk (Tyumen region, Russia) were determined. Areas were selected that were evenly distributed within the city limits, and coordinates in three-dimensional space were determined (altitude above sea level, latitude, longitude).

At the location of the control point, on the site, a square area was prepared, the sides of which were 50 centimeters. The area was cleared of debris, large stones and plants. Holes of the required depth were dug, the diameter of which was at least 15 centimeters. Accumulation chambers were placed in them for four hours, after being shaken in order to evenly distribute the working layer of coal. Then the containers were taken out and moved to the laboratory, where the necessary measurements were taken. The studies were conducted 3-12 hours after the accumulation chamber was removed from the control point.

All measurements were performed using the radon monitoring complex “CAMERA-01” in accordance with the user manual (Fig. 1).

Purpose of the device: measurement of the average volumetric activity (VA) of radon in indoor air over 1– 6 days; measurement of the average 1–10-hour radon flux density (RFD) from the earth's surface and building structures; measurement of radon and radium activity in water samples; measurement of the emanation capacity of samples of building materials and rocks.

Fig. 1. Measuring complex for radon monitoring "CAMERA-01"

Properties of the "CAMERA-01" Complex (number in the State Register of Measuring Instruments of the Russian Federation 26748-04): conducting radiation and hygienic surveys of buildings put into operation after completion of construction, reconstruction or major repairs, as well as existing residential, public and industrial buildings; mapping of territories and construction sites for radon hazard; search for sources of radon entering buildings and structures; assessment of the radiation situation in mines of all types; mapping of tectonic faults; search for uranium deposits.

Various software products were used to create landscape maps. Google Earth is a "virtual globe" program from Google that allows you to view a three-dimensional model of the Earth, high-resolution aerial and space images and various data layers. The software package makes it possible to automate the process of creating maps, as well as improve their clarity.

The determination of the granulometric composition of the soils of the studied areas was carried out using the Rutkovsky method. Rutkowski's field method allows us to identify three main groups of fractions: sand (particle size 2 – 0.05 mm), dusty (particle size 0.05 –

0.005 mm) and clayey (particle size < 0.005 mm). This method is approximate and the simplest for field research.

The Ferret triangle was used to classify soils. The triangular coordinate method (Feret triangle) is used in cases where it is necessary to divide the soil into three main fractions: sandy, dusty and clayey (comprising 100% in total). The method is based on the geometric property of an equilateral triangle, according to which the sum of the perpendiculars dropped from any point inside the equilateral triangle to its sides is a constant value equal to the height of the triangle. The triangle field is divided according to the type of soil: clay, loam, sandy loam, sand. The granulometric composition of the soil is indicated by a point with coordinates for its components – the three main soil formations – sand, dust, clay [1,12,16,17,18].

3 Results

In sixteen districts of the city of Tobolsk (Tyumen region, Russia), taking into account the proximity and distance from the city center, main industrial facilities and highways, one typical site with varying degrees of anthropogenic load was selected. Plot that are subject to varying degrees of man-made pollution are located at a considerable distance from each other (Fig. 2).

Fig. 2. Map-scheme of the location of plots 1-16

Plot 1 – 7 microdistrict, area of house 5 (N 58.231732, E 68.264997); 2 – 4 microdistrict, area of the house 62^{A} (N 58.224554, E 68.305512); 3 – 7^{A} microdistrict, area of the house 27 (N 58.233759, E 68.270417); 4 – 9 microdistrict, area of the house 9^{G} (N 58.228826, E 68.283351); 5 – 11 microdistrict, area of the house 10 (N 58.224552, E 68.306082); 6 – 15 microdistrict, area of the house 28 (N 58.223836, E 68.300556); 7 – 10 microdistrict, area of the house 9 (N 58.245540, E 68.305512); 8 – 6 microdistrict, area of the house 27 (N 58.24554, E 68.305512); 9 – Motorway, 800 meters from Zhukovka microdistrict (N 58.181594, E 68.285180); 10 – Lenin street, house area 164 (N 58.172424, E 68.269146); 11 – Musa Jalil street, house area 2 (N 58.189461, E 68.231394); 12 – Bazarnaya Ploshchad, district of the house 22 (N 58.197113, E 68.241207); 13 – Nikolsky Vzvoz area, part under the mountain (N 58.196572, E 68.255229); 14 – Ermak's Garden (N 58.199220, E 68.256854); 15 – Krasnoarmeysky Lane 6/4 (N 58.208178, E 68.259140); 16 – High bank of the Irtysh River, cemetery area (N 58.216261, E 68.262221).

As a result of the research, it was revealed that Tobolsk is characterized by a fairly wide range of radon values from soil surfaces, which is explained by the heterogeneity of the city's soil, which has different indicators of natural radionuclides. The flux density of radon-222 depends on the granulometric composition of the soils, so its determination was included in the study.

There are many indicators of radon hazard of the territory, which in combination of certain values can form high levels of radon in the soil. At the same time, some of them play a major role in determining the degree of radon hazard of the territory. This is the content of radium in the soil and the permeability of the soil.

The samples taken for soil analysis are almost identical in granulometric composition and correspond to clay, loam, sandy loam and sand.

As a result of the study, it was revealed that the highest sand content in the soil samples of the studied areas 10, 12, 14, 16 (95%), the lowest sand content in the soil samples of areas 5, 6, 7 (50%).

The highest clay content in soil samples was found in plot 7 (10.21%), and the lowest in plot 14 (2.27%).

The maximum dust content was found in soil samples from area 5 (40.93%), and the minimum in areas 10, 12, 16 (1.6%).

According to the soil classification in the study areas, 37.5% is sand, 31.25% is sandy clay, 18.75% is loam sand, and 12.5% is loam.

At 16 study plot, the radon-222 flux density from the earth's surface varied from 24.3 mBq/(m^2·s) to 141.72 mBq/(m^2·s). The highest values were found in section 7 (microdistrict 10, near house 9), which is located in the mountainous part of the city (radon flux density is 199.00 mBq/m^2·s), which corresponds to the second class of radon hazard. The studied area has a soil type of loam. Clay, due to its high accumulation properties, acts as a radon-222 accumulator, thus preventing the gas from escaping to the soil surface, and over time, the radiation permeates the clay, and it becomes radioactive, which can be quite sufficient to increase background radiation. Therefore, an increase in the radon-222 flux density is observed.

In plote 6 (microdistrict 15, near house 28) and 15 (Krasnoarmeyskaya 6/4), the average radon-222 flux density (PPR) values were almost identical (PPR – 95.00 mBq/m^2·s) and (PPR – 94.00 mBq/m^2·s), which corresponds to the second class of radon hazard. The studied plots have a soil type of sandy sandy clay.

The minimum indicators were observed in section 16 (the high bank of the Irtysh River, cemetery territory). This plot is located in the mountainous part of the city (PPR - 9.00 mBq/m^2·s), which corresponds to the first class of radon hazard. The studied plots have a soil type of sand.

According to the results of measurements from the soil surface at 12 of the 13 study plots, the average values of the radon-222 flux density do not exceed 12.00 mBq/(m^2·s), with the exception of plots 1, 3, 4, 5, 6 and 7. Here, increased values of radon-222 flux density from the soil surface are observed – more than 100 mBq/(m^2·s). In order of increasing radon-222 flux density, the sites are arranged in the following order: 16<13<12<14<10<2<11<8<9<15<6<1<3<4<5<7. In plots 15 (94 mBq/m^2·s), 6 (95 mBq/m^2·s), 1 (133 mBq/m^2·s), 3 (146 mBq/m^2·s), 4 (157 mBq/m^2·s), 5 (168 mBq/m^2·s), 7

(199 mBq/m^2·s) an increased radon flux density was observed. The remaining plots do not pose a danger (the radon flux density does not exceed 80 mBq/m^2·s).

Thus, as a result, it was revealed that 56% of the studied areas belong to class 1 and 44% of the studied territories belong to class 2 of radon hazard; no third class was identified. It was found that in the observed areas, the soil surface (with the exception of 1, 3, 4, 5, 6, 7 and 15) is not considered potentially radon hazardous. The results of the study of the radon flux density (RFD) in the surface layer of soils in the city of Tobolsk, Tyumen region are presented in Figure 3.

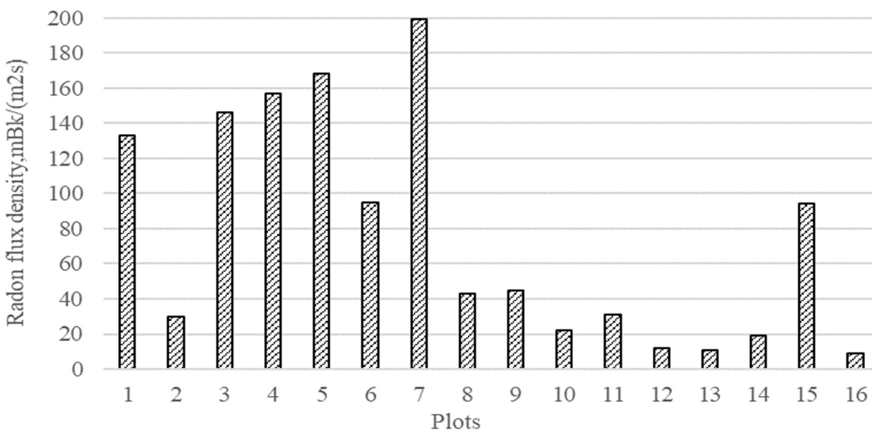

Fig. 3 Average values of radon-222 flux density obtained at the study plots (1-16)

The conducted research is of a practice-oriented nature. The results of the experimental observation confirmed the truth of the proposed hypothesis and the validity of the goals and objectives set in the study.

The theoretical analysis of the literature made it possible to identify key concepts necessary for the development of the experimental part of the work.

Many researchers have noted that radon exhalation from soil surfaces increases depending on the soil composition [13, 14, 15,16]. This was confirmed in our research. There is a fairly wide range of values for radon exhalation from soil surfaces, which is explained by the different soil-forming (underlying) rocks and the heterogeneity of the city's soil, which has different indicators of natural radionuclides.

It has been established that radon emission is associated with an increase in temperature, which causes the expansion of pores in the soil or increases the evaporation of water. Radon emission is directly proportional to atmospheric pressure.

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4 Conclusion

As a result of the work, it was established that in 56% of the studied areas of the city of Tobolsk, the radon-222 flux density does not pose a danger to the population, the studied areas correspond to the first class, 44% – the second class of radon hazard.

Most of these areas are located in the upper part of the city of Tobolsk with modern buildings. This may be due to the granulometric composition of the soil or the total component of the radon flux in the building materials of residential buildings near which the study areas were laid.

According to the soil classification in the study areas, 37.5% is sand, 31.25% is sandy clay, 18.75% is loam sand, and 12.5% is loam.

The study found that soils with the lowest radon content are of the sand soil type, soils with the highest radon content are of the loam soil type, and clay soils are possibly capable of retaining radon-222 flows.

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