



Studies of radon activity in civil engineering and environmental objects

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Abstract

In this article, studies of the radiation (radon) characteristics of the soil, soil-forming rocks and civil engineering buildings of the Volgograd Region are presented. The purpose of the study was to identify factors of the radiation background caused by radon in civil engineering objects. The regularities of radon distribution at the objects of the construction complex and the environment are determined depending on the influence of various factors. The studies made it possible to calculate the averaged annual effective equivalent doses to the population of the Volgograd Region caused by radon and the daughter products of the decay of radon. As a result, the patterns of changes in radon activity in the air of the premises have been established, depending on the time of the year, building materials and the purpose of the room. The result of the work performed is the normative material for use in the construction industry in order to limit the radiation exposure of the population in the region. Also, methodological material for training specialists in the field of radiation research in the building complex.

Keywords: radon, civil engineering, environment, effective equivalent dose, biological effect of radon.

1. Introduction

Until recently, the population of industrially developed countries of the world was firmly convinced that the main danger emanating from radiation is nuclear explosions and emissions of the nuclear industry. But in recent years, it turned out that far from nuclear plants, in areas where there were no radioactive fallouts, a large number of people, at home, receive a significant dose of radiation. The tragic consequences of a long stay in the air with a high concentration of radon was known back in the 16th century, when nothing was known about the gas itself. In the mountains of Southern Germany, miners died of a mysterious disease - "mountain cough". Practicing at the time the famous doctors Agricola and Paracelsus pointed out in their writings about the existence of gases in the mines where people experienced shortness of breath, increased heart rate, and some fainted and died. Neither taste nor smell in the air could not be felt any impurities [1, 5].

By the early 40-ies of this century, almost no one doubted that the main cause of lung cancer in miners is the alpha radiation of radon. Since the early 1950s, regular measurements of radon concentration in mines have been carried out and measures have been taken to reduce it [2, 6]. Since the late 1970s, under the guidance of the Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) of the United Nations, experts from various fields of science have been carefully analyzing the accumulated material on the effect of radon on the human body [3, 15]. As a result, the most important result was obtained: ratio risk - exposition (the relationship between the likelihood of cancer and the time of human presence in the atmosphere with a given radon concentration). In Russia, interest in the effect of radiation on humans has increased markedly since the Chernobyl accident (1986). This is due

to the fact that the consequences of this accident clearly demonstrated all the danger arising from radiation exposure [3, 4, 7].

In 1994, the Federal Target Program "Radon" was adopted in our country, which provided for large-scale studies of volumetric radon activity in buildings and constructions of regions and cities by category of radon hazard, etc. In December 1995, the Federal Law "On Radiation Safety of the Population" was adopted, where it is noted that irradiation of the population with radon and products of its disintegration in residential and industrial premises is limited by standards. Later, these standards were set out in the Norms of Radiation Safety (NRS-99) [6, 13, 14].

On the basis of NRS-99, the objects of control should be, as raw materials of construction materials, and sites allocated for the construction of structures, and completed building structures and buildings. It should be noted that radiation control at all stages of production and construction can ensure the adoption of alternative solutions. Control of radon concentration only within the finished buildings can lead to large economic expenses [12, 14].

1.1. Relevance of research

Natural sources of ionizing radiation contribute the main dose of radiation to the population. Radon together with the daughter products of decay (DPD) contributes about 3/4 of the annual individual effective equivalent dose of radiation received by the population from natural radiation sources. And about half of this dose from all radiation sources. Therefore, it is necessary to investigate the activity of radon in all environmental objects (atmospheric air, soil, water, indoor air, etc.). Since the population of industrially developed countries spend most of the time (about 80%) inside the premises, the radon dose is significantly influenced by the radiation characteristics of building materials and soil under the build-

ing [5, 22]. Depending on the changes in these characteristics, the individual doses in the buildings constructed from different materials and at different sites also change. Therefore, studies of volumetric activity (VA) of radon, factors affecting its change, development of normative and methodological documentation, as well as methods for reducing radon exposure to the population, are an urgent task. The solution of the problem of ensuring safety from radon can be carried out through comprehensive studies of the radiation characteristics of building raw materials, materials, territories, atmospheric air, water, and radon concentrations, in the air of newly constructed and operated residential, public and production buildings [6, 9, 18].

1.2. Purpose of work and research tasks

Decrease in radon hazard of objects of a building complex and premises.

1. Detection of regularities and factors of formation of radiation background caused by radon in the objects of the building complex and premises.
2. Methods and means of reducing the activity of radon and DPD in the building complex and premises of the Volgograd Region [6].

2. Modern state of the radiation background of the building complex objects caused by radon

Among the directions, of scientific interest, few attract so much attention of the population and cause so much controversy, such as the direction of the effect of radiation on man and the environment. Only recently did scientists understand that the most significant of all sources of radiation is the invisible, not having taste and smell, heavy gas (7.5 times heavier than air) radon [6, 19].

A person is exposed to radiation in two ways. Radioactive substances can be outside the body and irradiate it from the outside; in this case they speak of external irradiation. Or they may end up in the air which a person breathes, in food, or in water, and get inside the body; such an irradiation method is called internal [6, 10].

Natural sources of radiation are in total responsible for most of the irradiation to which a person is exposed due to natural radiation. For natural sources of ionizing radiation, a fairly wide spread of effective equivalent dose (EED) values is characteristic. A large variability is also characteristic for doses due to radon and DPD. The number of people receiving radioactive doses from this source, above 20 mSv/yr, is more than one million [6, 11, 16].

According to the estimates of the UNSCEAR, the population of industrially developed countries in the world spends about 80% of their time in residential, public and production premises. Therefore, most people are irradiated in the premises (the largest contribution to the radiation dose in the rooms is made by radon and DPD). Hence the need to control the concentration of radon in the premises, which contributes to ensuring the safety of the vital activity of the population [15, 16].

2.1. Sources of radon penetration into the premises

In nature, radon occurs in two main forms: in the form of radon-222 (^{222}Rn -radon), a member of the radioactive series formed by the decay products of uranium-238 (^{238}U), and in the form of radon-220 (^{220}Rn -thoron), a member of the radioactive series of thorium-232 (^{232}Th). Radon is about 20 times more important than thoron (on the contribution to the total dose of irradiation). Therefore in work, the main attention was paid to the ionizing radiation of radon and DPD [6, 23].

Gaseous radon comes from the earth's crust into the atmosphere. It dissipates in the air, its concentration in the environment is low enough. However, when the gas enters the room, its concentration gradually increases, as it does not dissipate, as it does in the atmospheric air. DPD, directly following radon are sorbed by dust

and moisture, forming alpha-radioactive aerosol particles, and by inhaling them, the human lungs are irradiated [20, 23].

There are several sources of radon penetration into the premises. Building materials, water, natural gas are internal sources, and atmospheric air, the soil under the building is external. Approximate rates of arrival and concentration of radon from various sources are shown in Table 1 [6, 21].

Table 1: The predicted range of variation in the rate of arrival and concentration of radon in buildings from various sources

Source	The rate of arrival, Bq/(m ³ *hr)	Concentration, Bq/m ³
Building materials: concrete, brick	1 - 50	0.7 - 100
Building wood materials	0.05 - 1	0.03 - 2
Soil	0.2 - 200	0.5 - 500
Atmospheric air	0.3 - 15	1 - 10
Water, natural gas	0.01 - 10	0.01 - 10
Total	2 - 200	2 - 500

As can be seen from Table 1, the most significant contribution to the concentration of radon in the premises is made by building materials and soil under the building. The volume activity of radon in the surface layer of the earth is determined by the formula:

$$C = \frac{120000 \cdot \eta \cdot Q \cdot \rho \cdot K_1}{p} \quad (1)$$

where: 120000 - conversion factor of radium (equilibrium with uranium) to volumetric activity of radon, Bq/kg; Q - content of uranium, equilibrium with radium, %; η - emanation coefficient of radon, %; ρ - density, kg/dm³; p - porosity of the rock, %; K_1 - the adjusting landscape coefficient [6, 23].

Volgograd region belongs to the IV group with radon concentration in the surface layer of 3.5 - 7.4 Bq/m³, in addition, according to the results of measurements carried out to date in a small volume, the concentration of radon in the atmospheric air of Volgograd is much higher than the concentration of radon in other cities of Russia. The volumetric activity in the atmospheric air of Volgograd is 8.4 Bq/m³, and for the other cities studied it does not exceed 2.6 Bq/m³ [6, 12], therefore in this work, this region was adopted for analysis. It is known that the highest concentration of radon is observed in the surface layer. This is because radon is heavier than air. With increasing altitude, the radon concentration decreases significantly (see Table 2).

Table 2: Changing the content ^{222}Rn and ^{220}Rn with an increase in altitude above the ground level (for the plain terrain)

Height, m	Contents ^{222}Rn , %	Contents ^{220}Rn , %
0	100	100
1	95.0	95.0
5	90.5	70.0
10	87.0	50.0
25	84.0	20.0
50	74.0	5.0
100	69.0	0.5
1000	38.0	-
7000	7.0	-

Thus, ^{222}Rn concentration in atmospheric air, due to the influence of a number of factors (soil and climatic characteristics, ^{238}U in the rocks content, altitude above ground level, etc.) has different indicators for different territories [6, 17].

Concentration of radon in commonly used water is in most cases extremely small, but water from some sources contains a lot of radon. A high content of radon was found, for example, in the water of artesian wells in Finland and the United States, including in the Helsinki water supply system. The highest recorded specific radioactivity of water in water supply systems is 100,000 Bq/m³, the smallest is zero [6]. According to the estimations of the UNSCEAR, among the whole population of the Earth less than 1% of inhabitants consume water with a specific radioactivity of less

than 1000 Bq/m³ and less than 10% drink water with a radon concentration of 100 Bq/m³ [6, 15].

The main danger is not from drinking water, even with a high concentration of radon, but from its vapors that come with inhaled air into the lungs, which most often occurs in the bathrooms.

Studies conducted in Canada showed that within seven minutes, when a warm shower was switched on (when the radon content in the water was 4.4 Bq/l), the concentration of radon and DPD in the bathroom air increased rapidly (from 140 Bq/m³ to 5500 Bq/m³) and more than one and a half hours passed since the shower was turned off before the radon content reached the initial level [6]. Thus, it is necessary to monitor the concentration of radon in all sources of water supply to the population in order to limit the irradiation caused by the radon content in the water.

3. Concentration of radon in the premises

The greatest exposure caused by radon, the population receives, being in the premises. The radon concentration in the rooms is affected by a number of factors: the supply of radon from various sources, the time of year, the assignment of premises, etc. Depending on these factors, radon VA can undergo significant changes, which leads to different levels of population exposure [5].

3.1. Concentration of radon in premises constructed of various building materials

In Table 3 shows the rate of radon intake from the main building materials used in constructions of buildings and structures in the Volgograd region.

Table 3: Radon exhalation values from building materials of premises

Construction material	Number of measurements	Exhalation of radon, mBq/(m ² * sec.)	
		medium	variations
Ceramic brick	141	2.85	1.52 - 4.89
Silicate brick	127	5.75	3.47 - 8.64
Panels	109	7.43	3.52 - 10.57
Reinforced concrete blocks	52	8.54	5.31 - 12.57
Clay	35	24.87	10.42 - 36.52

From Table 3 it can be seen that the basic building materials (with the exception of clay) give off a relatively small amount of radon. The maximum concentration of radon is observed in the cellars, the premises of the first floors and one-story buildings. The results of studies of radon concentrations for the first floors of buildings constructed from various building materials are given in Table 4, which also shows the average EED due to radon [2, 6].

Table 4: The indices of the equivalent equilibrium volumetric activity (EEVA) of radon in the first floors of the housing fund of the Volgograd Region [6, 8]

Building material	Number of measurements	EEVA radon*, Bq/m ³		Average EED, mkSv/yr
		medium	variations	
Silicate brick	472	44.7	6.5 - 157.6	2726.7
Ceramic brick	295	32.6	3.7 - 106.5	1988.6
Panels	586	26.8	9.1 - 149.7	1634.5
Reinforced concrete blocks	179	52.8	15.2 - 112.3	3220.8
Wood material	126	34.9	11.2 - 126.9	2128.9
Material from clay	22	98.9	53.8 - 218.5	6032.9

* The conversion factor from VA radon to EEVA is taken equal to 0.5

As can be seen from Table 4 for buildings constructed from the same materials is characterized by a large range of variations in

the radon EEVA values, this is due to the fact that radon entering and removing facilities is significantly different for each particular building. In all the buildings studied the concentration of radon is noticeably reduced from the 2 nd floor, and in the rooms of the upper floors it does not change significantly. This is due to the fact that, starting from the second floor, the contribution of the soil under the building to the total VA of radon is practically completely excluded (due to reinforced concrete floors). Concentration of radon in the premises of the Volgograd region in general does not exceed the permissible values [6, 8].

3.2. Change in volumetric activity of radon in the premises during the year

It is established that the volumetric activity of radon and DPD in the premises can vary tens of times, depending on weather conditions, ventilation of rooms, frequency of airing the rooms, etc. We conducted studies of changes in radon concentrations during the year in the premises [6, 9].

The volume activity of radon for floors above the first does not change significantly, therefore, the premises of the first and middle (third) floors were investigated.

Our studies have shown that for all buildings the volume activity of radon reaches its maximum values in the winter period of time. Consequently, the sealing of premises for the purpose of warming leads to the highest concentration of radon. Volumetric activity of radon decreases from March to June, during the summer period is set at a certain level, and then increases from September to January. For the first floors, there is a slight increase in the volume activity of radon in the summer months, due to the fact that the radon exhalation from the soil surfaces increases markedly with increasing temperatures [6, 18].

The climate of the Volgograd region is characterized by considerable continentality. Therefore, in the winter season most of the premises are almost completely sealed, there is no airing. During the summer period, there is a constant flow of atmospheric air into the rooms, so the concentration of radon in them is low enough. Thus, the concentration of radon during the year undergoes significant changes. The most significant factor that influences these changes is the sealing of premises with the purpose of their warming [5, 22].

3.3. Concentration of radon in living quarters for various purposes

Besides building materials, soil under the building and atmospheric air, there are also other sources of radon in the premises: it is water and natural gas. Probably, these sources have the greatest influence on the values of radon concentration in bathrooms and kitchens [5].

We carried out studies of volumetric activity of radon for the premises of the first floors of various purposes (see Table 5). The table also shows the possible average effective equivalent dose due to ²²²Rn, calculated for these rooms. Studies were conducted only for the first floors, because it is for these floors that the maximum values of radon EEVA observed [6, 8].

Table 5: Indicators EEVA of radon in living quarters for various purposes

Type of premises	Time of stay, hr/yr	EEVA radon, Bq/m ³		EED, mkSv/yr
		medium	variations	
Room	4350	38.5	3.7 - 98.3	1673
Kitchen	1050	69.7	18.4 - 216.7	742
Bathroom	350	95.9	24.9 - 229.3	424

As can be seen from Table 5 radon concentration for kitchen and bathroom areas is noticeably higher than for rooms. However, for the Volgograd region this excess is not so significant (for example in Finland the concentration of radon in the bathrooms is about 3 times higher than in the kitchens and 40 times higher than in the

living rooms [23]), since the ^{222}Rn content in the water supply sources of the region does not exceed 10 Bq/m^3 .

Thus, the following factors play a significant role in the concentration of radon in premises: the building materials from which they are built, the type of premises, and the time of the year. Depending on these factors, significant changes in radon EEVA are observed in the premises, which leads to different levels of population exposure [6, 21].

3.4. Radon emission from the surfaces of soils and rocks

The soil under the building is one of the main sources of radon in the premises. Therefore, in areas intended for construction, it is necessary to measure the radon flux densities.

The Volgograd Region is located in the southeast of the Russian Plain. The relief of the edge is typically flat, but quite diverse. The distribution of soils on the territory of the Volgograd region has a number of features. The soil cover is characterized by a change in soil types and subtypes in the direction from north-west to south-east (from chernozems to light chestnut chernozems).

The data of our studies show that for the northern regions of the Volgograd Region the radon flux density from the soil surfaces is somewhat lower than for the southern ones. This is because the exhalation of radon from soil surfaces increases with increasing ambient temperature [6, 19].

The greatest variation in the values of radon emission indices is observed for the city of Volgograd. In Table 6 shows the radon exhalation values from the soil surfaces of different parts of the city of Volgograd [6, 8].

Table 6: Parameters of radon emission from soil surfaces of various districts of Volgograd

No	District of the city	Parameters of radon emission, $\text{mBq}/(\text{m}^2 \cdot \text{sec.})$	
		medium	variations
1.	Voroshilov district	40.24	15.67 - 82.14
2.	Dzerzhinsky district	49.12	19.89 - 92.57
3.	Kirovsky district	37.68	18.03 - 76.11
4.	Krasnoarmeysky district	38.97	21.14 - 75.19
5.	Krasnooktyabrsky district	42.12	19.03 - 107.87
6.	Sovetskiy district	35.68	13.82 - 87.31
7.	Tractorozavodsky district	40.09	24.12 - 86.42
8.	Central district	32.98	11.34 - 99.27

As can be seen from Table 6 for the city of Volgograd there is a fairly wide spread of radon flux density values from the soil surfaces. This is due to the difference in radiation indices in the soil-forming, underlying rocks and soils of the region. According to the results of the conducted studies, among the underlying rocks of the Volgograd region, clays and loam are the most important for radon emission, and limestones and sands are the least.

Based on the results of the conducted studies, we developed the Norms "Permissible levels of gamma radiation, radon in the areas of building and sampling" for the Volgograd region. These Norms regulate the radon danger of the territories allocated for construction and regulate the order of work [6, 8].

Table 7: Criteria for potential radon hazard of the site for building

Category of potential radon hazard	Characteristics of soils in the geological section of the site	VA of radon in soil air at a depth of 1 m, Bq/m^3
I	Breeds with very low radium content. Very low gas permeability.	less than 10,000
II	Breeds with low or normal radium content. Average gas permeability.	from 10,000 up to 50,000
III	Breeds with a high content of radium. High gas permeability.	more than 50,000

Norms provide for the following types of engineering radiation-ecological works for the construction complex: pre-design, design,

control and acceptance. Assessment of the categories of potential radon hazard of the site according to the criteria can be determined from Table 7 [8].

To estimate the category of potential radon hazard, one can also use data on the concentration of radon in premises operated near the sites under study. In those cases when the values EEVA of radon in the air of these premises exceed $100 \text{ Bq}/\text{m}^3$, the area under investigation is classified as potentially radon hazardous.

Therefore, buildings are classified for protection against radon. Class I refers to buildings in which protection against radon is provided by air exchange in the premises. In buildings of Class II, the effectiveness of protection against radon is ensured from 20% to 70% and in buildings of Class III - protection of more than 70%. The category of hazardous building sites is defined by us in the following ranges (see Table 8) [8].

Table 8: The categories of danger of building sites and the requirements for the protection of buildings from radon

Category of radon hazard	The average (in area) density of radon activity flux, $(\text{Bq}/\text{m}^2 \cdot \text{hr})/(\text{mBq}/\text{m}^2 \cdot \text{sec.})$	Requirements for building designing
I	less than 100 / less than 28	It is allowed to use the building without protection from radon
II	from 100 to 300 / from 28 to 84	The moderate protection of the building against radon should be applied
III	more than 300 / more than 84	The strengthened protection of the building against radon should be applied.

According to the results of the conducted studies, the sites allocated for construction, for approximately 50% of the settlements of the Volgograd region, belong to the II category of potential hazard from radon. Consequently, buildings in these areas should be made with obligatory use of moderate protective means of buildings from radon, and in some areas enhanced protection from radon should be applied [6, 8].

4. Scientific novelty of the work

For the first time, large-scale studies (more than 3 thousand measurements) of the radiation characteristics of territories, raw materials, building materials, premises and water were carried out. The regularities of radon distribution at the objects of the construction complex and the environment are determined depending on the influence of various factors (used building materials, time of year, etc.). The averaged annual effective equivalent doses of irradiation of the population of the Volgograd region, due to radon and DPD are calculated [6, 12].

5. Practical meaning

With the participation of authors, the first radiation control center (among the universities of the building profile) in the construction industry was established. A map of the effective specific radium activities of all the deposits in the Volgograd Region was compiled [5]. An effective method (using an electron accelerator) to reduce contamination with radon and DPD of environmental objects in the production of building materials is proposed [6]. Data on the radon flux densities (for all districts) from the soils of the investigated territories allocated for the construction of civil buildings have been obtained. A regulatory material has been developed for use in the construction industry to limit exposure of the population in the region, as well as methodological material for training specialists in the field of radiation research in the construction complex [5, 8].

Implementation of work results

The norms of permissible levels of gamma radiation, radon in the areas of building and sampling of the Volgograd region have been developed and adopted [8]. The results of the research are implemented and used by the enterprises of the construction industry of the Volgograd region in the development of construction materials in quarries, in the production of building materials, in the removal of plots of land for building and construction of buildings. The results of the research are used in the compilation of the radiation-hygienic passport of the Volgograd region [5].

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