Radon risk reduction to population

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Abstract. Ranking the risks of deaths from various factors affecting the human body shows the leading effect of radon. The main source of radon entry into the dwelling is the soil under the building. Health risks analysis was performed at various levels of radon concentrations. Based on analyses of radon exposure data made in the USA, analytical dependencies of health risks are derived depending on the radon concentration. Analysed the path of penetration of radon in the home. The cost of the work to protect the home from radon penetration has been estimated. Analysis of the appearance of oncological diseases of the respiratory organs for residents of the region according to statistical data depends on the number of floors. The approach to the choice of the level of protection from radon exposure according to the ALARA principle – to ensure the most reasonable achievable level of radon concentration is substantiated. The analysis of the protective properties of various building materials is performed.

1. Introduction

From primitive times, humanity lives in a habitat with different levels of radioactivity. Getting rid of natural levels of radioactivity is almost impossible. Radioactivity is caused by the decay of potassium-40 isotopes, rubidium-87 and atoms of three radioactive families – derivatives of uranium-238 (U-238), uranium-235 (U-235) and thorium-232 (Th-232) [1–5].

The largest share of radiation 80 % of people receive from natural sources (emission of radon gas into the atmosphere, strontium, etc.). Almost 17 % of radiation exposure a person acquires during the passage of medical examinations. And less than 0.1 % of the total number of radioactive radiation accounts for nuclear power plants and other facilities of this type [6–8].

We take into account the fact that the greatest radioactive contamination occurs as a result of natural sources, one of which is radon gas ($^{222}\text{Rn}$). Radon is a natural radioactive gas, it is heavy, tasteless, colorless, odorless. Radon is formed as a result of the decay of uranium and thorium. Vaporizing from the ground or standing out from building materials (concrete, granite, slate, red clay bricks, etc.), radon accumulates in mines, basements, on the first floors of houses. The radon concentration can be 8 times higher than the background values, if the room is not ventilated at a certain frequency.

Radon, entering the human body in two ways: when breathing, with the air or through the digestive system along with water from underground sources (wells, springs, wells). Penetrating into the body, radon can begin to destroy living cells. Especially great danger is the inhalation of air with a radon concentration of more than 200 Bq/m$^3$. Irradiation with high doses of radiation can cause lung cancer, leukemia and other types of cancer [9–13].

The disintegration of radon nuclei in human lungs causes microburns, which can lead to lung cancer, damage to the chromosomes of the bone marrow, as well as damage to the sex, hematopoietic, and immune cells.

The most dangerous are the effects of two toxins: nicotine and the decay products of radon. In figure 1 shows the United States Environmental Protection Agency (EPA) on the number of deaths due to exposure to radon.
Figure 1. Ranking the number of deaths from various causes
1 – exposure to radon; 2 – drunk driving; 3 – fall; 4 – drowning; 5 – fire.

Radon enters the environment from soil, building materials, water, and the combustion of natural gas. The average concentration of radon in atmospheric air is about 5 Bq/m³, and varies significantly in different zones of the Earth's surface (Figure 2) [14–16].

Figure 2. Release of radon into the environment [17–19].

2. Purpose of research
The purpose of research is a quantitative assessment of the effect of radon on health, sources of radon in homes and the choice of priority methods to reduce the negative impact of radon.

3. Presentation of the main research material
Let us consider the main methods of reducing the radon activity in buildings when choosing methods to reduce radon hazard. Obviously it is necessary to follow the rule to reduce the level of radon as much as possible. It is believed that the level in most homes can be reduced to 100–150 Bq/m³. In houses and structures that are operated, the average annual radon-222 EDPA should not exceed 100 Bq/m³. In Russia, the norm for buildings put into operation is 100 Bq/m³, and those used are 200 Bq/m³). It must be remembered: the urgency of action depends on the concentration of radon in the house, the sooner it is necessary to take measures to reduce its concentration or, even, to resettle the residents.

If, as a result of the research, the radon concentration is [20–22]:
• 7400 Bq/m³ or higher, it is necessary to reduce the level to acceptable performance. It is recommended to do this in a few weeks. If possible, consider the appropriateness of temporary resettlement until the radon level in the house is lower.
• 740–7400 Bq/m³ – this level is much higher than allowable for dwellings, it is necessary to reduce it to a lower level. It is recommended to do this for a few months.
200–740 Bq/m³ – this level is also unacceptable for dwellings. Everything necessary is needed to reduce the level to 150 Bq/m³ or lower. We recommend doing this for several years or less if the results are closer to the upper limit of the interval.

150 Bq/m³ – the level acceptable for dwellings or slightly exceeds it.

It is also necessary to take into account the specific living conditions that may affect the degree of risk and necessitate additional measures. The danger of exposure to radon depends on the amount of radon penetrating the room and the time people spend in it.

In the United States, an in-depth analysis of the risks of lung cancer was performed for residents of two states, depending on the current level of exposure. At the same time, risks for residents of Minnesota and Iowa differ significantly [23, 24]. Despite the fact that the effective values of 4 pCi/dm³ are close to the value recommended by the World Health Organization (2.7 pCi/dm³ or 100 Bq/m³), for residents of Minnesota with an exposure level of less than 4 pCi/dm³ the risk will be 20 % and at the level of 2.7 pCi/dm³ – 10 %. At the same levels for Iowa, the risk is 70 % and 60 %, respectively.

Over a 74-year period, approximately 50,000 Minnesota residents and 20,000 Iowa residents can protect themselves from death associated with lung cancer by applying measures to reduce the radon concentration in dwellings at the current level of 4 pCi/dm³.

The authors mathematically processed the logistic dependences of the risk levels of lung cancer depending on the radon concentration (Figure 3). At the same time, the level of risk for Iowa residents is unsubscribed by dependency:

\[ R = R_n^{1.536} \cdot \left( R_n^{1.536} + 4,29 \right)^{-1} \]  \hspace{1cm} (1)

and for residents of Minnesota:

\[ R = R_n^{1.94} \cdot \left( R_n^{1.94} + 53,3 \right)^{-1} \]  \hspace{1cm} (2)

where \( R \) – the risk level in fractions of a unit; \( R_n \) – the radon concentration level, pCi/dm³.

![Figure 3. Dependence of the reduced risk of lung cancer from the concentration of radon.](image)

It should be noted that in the home there is also another source of danger – carbon monoxide. However, a comparison of the risks of deaths shows that the number of deaths due to the prevention of
carbon monoxide will be 30 deaths per year compared to measures to reduce the radon level of about 700 deaths per year.

The number of oncological diseases of the respiratory organs in three districts of the city of Gorlovka was analyzed. Statistical data on diseases in residential areas, depending on the number of floors, are presented in figure 4.

![Figure 4](image)

**Figure 4.** Correlation of the number of oncological diseases from the number of floors

The data obtained allow us to statistically predict the number of patients with upper respiratory tract (bronchi, lungs) in high-rise buildings \((x > 7)\) and proves that the incidence decreases with increasing height of residence.

Sources of income are glad she is in the building shown in figure 5. Radon enters basements and basements through lightweight aggregates of concrete blocks and walls of hollow bricks that come into contact with radon-bearing soil.

When placing the foundation slab directly above the soil, radon penetrates through the gap between the walls and the slab below the floor level, permeable concrete aggregates and unconsolidated passages for water, sewage, gas and electrical wiring pipelines.

![Figure 5](image)

**Figure 5.** Typical Radon Penetration Paths

1 – omissions or lack of mortar (binder) between bricks; 2 – open cavities in the upper part of wall panels; 3 – open cavities in the upper part of the building blocks with penetration into the space between the walls and floors; 4 – pores on the surface of building blocks; 5 – joints between the walls and the floor; 6 – cracks in the masonry or in the joints filled with mortar.
The calculated data on the concentration of free radon, which is not included in the crystal lattice of minerals and is able to move along cracks and pores, is given in table 1 [29, 30].

Table 1. The content of free radon in various rocks.

| Breed          | The concentration of uranium, g/t | Density, g/cm³ | Porosity, % | K_em, % | Radon, Bq/m³ |
|----------------|----------------------------------|---------------|-------------|---------|--------------|
| Sandstones     | 2.9                              | 2.5           | 20          | 30      | 133          |
| Clay           | 4.0                              | 2.0           | 20          | 40      | 200          |
| Carbon shale’s | 15.0                             | 2.6           | 20          | 15      | 500          |
| Coal           | 3.5                              | 1.3           | 15          | 35      | 100          |
| Sedimentary rocks | 2.5                          | 1.8           | 20          | 55      | 80           |

The development of architectural and planning groups of protective measures in the practice of the CIS countries [25, 26] is aimed at:

• the establishment of an intermediate environment (ventilated basement and technical floors, basements) on the route of radon from the soil and the use of ground floor rooms to accommodate premises with a limited time for people to stay in them;
• maximum restriction of premises designed for the long stay of people from places of radon accumulation;
• reduction of radon intake from the soil into the air of the premises, designed for the long stay of people on the basis of engineering and design solutions;
• a decrease in the volumetric activity of radon in the indoor air created by ionizing sources of construction production on the basis of the technical group of protective measures.

To assess the effectiveness of protective measures, it is advisable to determine the insulation characteristics of the screens.

The flow of radon through the barrier decreases with increasing thickness. To take into account the thickness, as an independent parameter that determines the tightness, we use the quotient on the sample thickness and the diffusion length.

The protective properties of insulating materials are estimated by the radon diffusion length "l". The value of "l" corresponds to the thickness of the layer of material, when passing through which the intensity of the flow of radon decreases by e = 2.72 times and is determined by the formula [27, 28]:

\[
l = \frac{D}{\sqrt{\lambda}}
\]

where \(\lambda\) – the radon decay constant, equal to 2.10·10⁻⁶ cm⁻¹; \(D\) – radon diffusion coefficient, m²/s.

The diffusion coefficient of the studied building materials in the order of 10⁻⁹ to 10⁻⁶ m²/s corresponds to a diffusion length of 6 to 100 cm. Thus, the material must be thicker, up to 300 cm, in order to obtain a certain level of protection. Only some concrete, especially with polymer impurities, can prevent diffusion. The polymer fills most of the porous system and closes the path of diffusion through the material.

Insulating materials exhibit different properties with a diffusion coefficient less than 10⁻¹¹ m²/s. The diffusion length is less than 2 mm. For example, the content of carbon black or graphite in black butyl rubber does not lead to an open structure and high permeability to radon.

The emanation of radon in the material of an ionizing source characterizes the emanation coefficient \(\eta\), the value of which for primary materials is from 0.02 to 0.46. Higher values of \(\eta\) are characteristic of secondary minerals that have arisen in rocks as a result of changes in their physicochemical conditions, and can reach up to 0.9.
The coefficient of emanation depends on the process temperature for the main groups of building materials (concrete, ceramic products). The lowest values of $\eta$ were found in materials subjected to high-temperature processing in the process of technological production (Table 2).

It is established that the process of changing $\eta$ in the process of heat treatment is irreversible and occurs due to the removal of physically and chemically bound water and as a result leads to the formation of a new chemical mineral.

**Table 2. Effect of firing temperature on the coefficient of emanation of the produced material by firing $\eta=f(t_{oc})$.**

| Type of material     | $\eta$ | Type of material      | $\eta=f(t_{oc})$ | Emission coefficient $\eta=f(t_{oc})$ |
|----------------------|--------|-----------------------|-------------------|---------------------------------------|
| Sandstone            | 0.17   | Ceramic wall tiles    | 106               | 0.05                                  |
| Clay                 | 0.17   | Ceramic floor tile    | 1100              | 0.01                                  |
| Clay (fireproof)     | 0.13   | Ceramic brick         | 1250              | 0.003                                 |
| Brick (raw)          | 0.12   | Refractory brick      | 1500              | 0.0027                                |

In the implementation of work to isolate residential buildings from radon intake in world practice, the rule of the need to ensure that the level of concentration is as low as permissible, ALARA (As low reasonable achievable).

In table 3 shows the analysis of the profitability of measures to protect against the effects of radon adopted in the United States (cost-effectiveness analysis – CEA). The World Health Organization (WHO) International Radon Program recommends this approach. At the same time, cost per life saved (CLS) is preferred as a measure of effectiveness. Naturally, in each individual country or even in a region, these values may differ significantly.

**Table 3. The profitability of the implementation of measures to reduce the level of radon concentration [31]**

| Parameter                        | Unit of measurement | Basic cost level | Lower cost level | Upper value of costs | Lower threshold |
|----------------------------------|---------------------|------------------|------------------|----------------------|-----------------|
| Radon Threshold                  | pCi/dm$^3$          | 4                | 4                | 4                    | 2.7             |
| Dose                             | pCi/m$^3$           | 150              | 150              | 150                  | 100             |
| Rn concentration measurement     | USD                 | 50               | 25               | 100                  | 50              |
| Equipment installation           | USD                 | 1400             | 800              | 2540                 | 1400            |
| Fan repair                       | USD/year            | 12               | ten              | 14                   | 12              |
| Fan power                        | W                   | 80               | 24               | 150                  | 80              |
| Electricity cost                 | USD/kWh             | 0.10             | 0.08             | 0.12                 | 0.10            |
| Additional payments for heat or cold | USD/year         | 190              | 70               | 400                  | 190             |

4. **Conclusions**

1. Analysis of the effectiveness of measures affecting the radon emanation rate in residential areas shows that to achieve an acceptable level of radon concentrations, it is necessary to use insulating screens. The priorities of screen selection along the radon diffusion length in the material are given.

2. Based on the mathematical analysis of the work of foreign researchers, analytical dependencies of the risk level of diseases on radon concentration were derived.
3. The approach to choosing the level of protection from radon exposure according to the ALARA principle is justified - to ensure the most reasonable attainable level of radon concentration.
4. Analysis of the number of oncological diseases in the city of Gorlovka, Donetsk region. It shows a linear decrease in the level of diseases with an increase in the floors of residence.

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