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Determination of resistance to radon entry of underground walling at stage of construction design

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Abstract. The dose from radon and its progeny is a controlled component of the radiation load on the population, and therefore can be reduced by the use of appropriate construction technologies. The article shows that the convective flow can be reduced to zero by choosing the appropriate floor construction, whereas the diffusion cannot be completely excluded, and the diffusion radon flux can only be reduced to a certain level. An approach to the assessment of the required radon-protective characteristics of the building is proposed under the assumption that there is no convective radon entry. As a radon load on the underground part of the building, the radon potential of the soil, determined by the results of gamma-spectrometric analysis of the soil from the construction site, was used. The procedure for calculating the geometric characteristics of layers with high resistance to radon permeability based on the required radon concentration in the ground floor premises of the building after its construction and the radiation characteristics of the soil on the construction site is shown.

1. Introduction

Human vital activity takes place within the biotechnosphere – an area in which both exist and affect each other's natural environment and urban-technical objects created by man. The problem of negative human impact on the Biosphere has long been well studied and a number of global environmental projects are currently being implemented. At the same time, the problem of assessing and reducing the harmful effects of natural factors on humans has not been studied enough, although it is also of great socio-economic importance.

Biotechnosphere is a system formed by two fundamentally different subsystems and obtained properties that are not typical for these subsystems. In urban conditions the factors of natural environment are subjected to the changing influence from the technical objects, turning into technogenically changed natural factors that often negatively affect human health. One example of this negative transformation is the exposure of the population to radon in buildings.

Radon is formed during the decay of radium-226 in the earth's crust [1], after which it passes from the surface layers of the soil into the atmosphere, where it disperses almost instantly. The concentration of radon and its progeny in the atmosphere rarely exceeds 5-7 $Bq\cdot m^{-3}$, which corresponds to a negligible dose of internal human irradiation. The situation changes when radon penetrates into the buildings, accumulating in confined spaces. In the premises of the lower floors, under certain conditions, its concentration can reach units-tens of thousands of $Bq\cdot m^{-3}$.

The need to limit the exposure of the population to radon and its progeny is legislated in all countries with a temperate climate. In the Russian Federation, there is a two-level standard providing for the non-exceedance of the equivalent equilibrium radon concentration (EERC) of 100 Bq·m^{-3} for new buildings and 200 Bq·m^{-3} for buildings was built before 1991 [2,3].

But with the development of life technologies the requirements for the quality of the internal environment of the premises with a long stay of people are becoming increasingly stringent, so the levels that are acceptable at the moment, can stop being such in the foreseeable future. Since the average period of a certain building operation constructed in accordance with the modern technologies implementation is 50-150 years [4], so it is difficult to expect that the above control levels will remain unchanged for such a long period of time. In order to ensure that the building has not become environmentally unsafe in terms of ionizing radiation during the operation period, it is necessary to ensure its radon-protective properties at the design stage. Thus, the purpose of the radiation and environmental safety system of construction is the commissioning of buildings with minimal levels of radon, the achievement of which does not require fundamental changes in the design and construction technologies.

As studies of domestic and foreign scientists [5-10] have shown, the main source of radon entering into the building is the soil at its base, since radiation control of raw materials and products of construction products has made it impossible for radon to be significantly supplied from building materials. Therefore, high resistance to radon penetration of underground walling ensures its radiation and environmental safety.

2. Results and discussions

The concentration of radon in the soil air increases as it moves away from the surface of the day and reaches the maximum value at the depth of about 5 m [11], radon does not have time to diffuse from greater depths to the surface of the day due to the small half-life (3.8 days for ^{222}Rn). Thus, the concentration of radon at the lower boundary of the soil block can be considered as constant, and the block of soil from which soil air radon is able to reach the foundation, received the "active layer" name in the Miklyaev and Gulabyants works [12-15].

The construction of the building changes the distribution of radon concentration in the soil massif [16], blocking the ways for its release into the atmosphere. The concentration of radon in the soil air under the building appears to be higher than at the same depth in the undisturbed soil. Therefore, the process of formation of the radon environment in the building should be considered exclusively within the framework of a single system of environments "ground-atmosphere-building".

In order to substantiate the approach to ensuring radon safety of construction objects, the principle of destruction can be applied, according to which the negative state of the system can be transformed into an acceptable exception to one of the elements. Under the negative state we understand the excess EERC value 100 Bq·m^{-3} in the ground floor apartments, which is possible with the simultaneous presence of radon sources in the soil, the routes of its transport through the underground walling and the driving forces that cause this transfer. Then the permissible radon situation in the building (the favorable state of the system) is provided by the exception of one of these factors.

The first of the radon hazard factors is the source of radon formation. In table 1 the results of radon levels measuring in the premises of two closely located children's educational institutions of the city of Luhansk are presented.

Gamma-spectrometric analysis of the soil, selected on the territory of these preschool facilities which was made in the laboratory of radiation safety in the construction of Research Institute of Building Physics (Moscow) has shown the average content of radium-226 in soil

$$C_{Ra} = 35.0 \pm 6.8 \, Bq{\cdot}kg^{-1}.$$

Thus, control levels exceeding is also possible in areas with an average content of natural radionuclides in the soil. Therefore, the source of radon is present at any site of construction and its exception in principle is impossible.

Table 1. Results of radon levels measuring.

Children's educational institution, address		**Rooms number**	**EERC, Bq·m^{-3}**	**Average value, Bq·m^{-3}**
Kindergarten No. 57, Rudya str., 91	Ground	6	260.9	220,7
	1 floor	3	140.3	
Kindergarten No. 10, Rudya str., 73 A	Ground	6	222.4	165,7
	1 floor	3	52.3	
House of children and youth creativity "Radost", Chapayeva str., 55 A	Ground	12	35.3	32,1
	1 floor	9	27.9	

It is also impossible to exclude the driving forces of radon transfer into the building. Temperature-induced pressure difference ΔP causes a convective flow of radon a_{con}

$$a_{con} = A\cdot \Delta P / \left(R_u \cdot V\right) = A\cdot\rho\cdot g\cdot H\cdot\left(T_{indoor} - T_{soil}\right) / \left(R_u\cdot V\cdot T_{indoor}\right) \tag{1}$$

where A is the radon concentration in convective flow, Bq·m^{-3}; T_{indoor} and T_{soil} are the indoor and soil air temperatures, respectively, K; H is the neutral level height in the building, m; R_u is the floor construction resistance to convection, Pa·s·m^{-3}; V is the room volume, m^3.

Likewise, the difference in the volume activity of radon concentrations ΔA in the soil and indoor air causes a continuous diffusion of radon entry into the building

$$a_{dif} = \Delta A\cdot S_f \,/\, R_{tot}, \tag{2}$$

where R_{tot} is the total radon resistance of the floor structure, s·m^{-1}; S_f is the floor area, m^2.

Thus, the only way to ensure the radon safety of the building remains the elimination of radon entry routes to the premises. Sealing of the underground shell of the building (sealing of cracks and joints) allows reducing to zero level the convective flow of radon. But the diffusion does not have certain routes, and the transport of radon is carried out over the entire floor area, so one can only reduce the diffusion of radon into the premises of the ground floor to a certain level.

Convective transport provides a significantly greater flow of radon into the building than the diffusion one, so its elimination is of paramount necessity. Convective admission takes place in buildings without a solid foundation, similar to the kindergartens discussed above. For the development of convection, it is necessary to have continuous cracks and pores connecting the soil mass with the internal volume of the building. Concrete slabs do not have through pores, therefore, in the absence of joints in the direction of radon transfer or sealing, the floor structure becomes a reliable obstacle to convective flows.

The confirmation of the decisive influence of the floor structure on the radon entry mechanism is provided by the results of radon levels measuring in the premises of the House of children and youth creativity «Radost» located in the immediate vicinity of the kindergartens surveyed. This building had two floors and a monolithic foundation in the form of a reinforced concrete slab, resting on the footer. The EERC values for all rooms on the ground floor did not exceed 40 Bq·m^{-3}, which indicates a different mechanism for radon entry into this building.

Measurements have shown that the tightness of the underground shell of the building is a necessary, but an insufficient condition for ensuring its radon safety. Diffusion flow of radon should be reduced as much as possible due to the rational design of the floor structure.

For prognostic estimates of radon levels mathematical models of diffusive radon transport are used [17–19], but as a first approximation, an estimate of the required radon-protective ability of the building at its design stage can be obtained by means of the following reasoning. From the formula (2) can be obtained the diffusion flow density q_f through the horizontal walling

$$q_f = \Delta A / R_{tot}. \tag{3}$$

The q_f value is expressed by means of the planned EERC value in the premises of the designed building and the geometric characteristics of the ground floor

$$q_f = EERC\cdot(\lambda + n)\cdot V / \left(F\cdot S_f\right), \tag{4}$$

where $\lambda = 2.1\cdot10^{-6}$ s^{-1} is the radon decay constant; n is the air exchange rate in the room, s^{-1}; F is the equilibrium factor; S_f is the floor construction area in contact with the ground base, m^2.

When calculating it is advisable to take in (4) the rate of air exchange n = 0.1 h^{-1} = $2.78\cdot10^{-5}$ s^{-1} (low air exchange during the cold period of the year) and F factor in the interval 0.4-0.5 according to ICRP recommendations [20]. Then the task is to determine the required of floor structure radon resistance for a given radon load ΔA on the building foundation

$$R_{tot} = \Delta A / q_f = \Delta A\cdot F\cdot S / \left(EERC\cdot\left(\lambda + n\right)\cdot V\right). \tag{5}$$

Since the radon concentration in the soil air is thousands of times greater than in the indoor one, it is possible to take

$$\Delta A = A_{soil} - A_{indoor} \approx A_{soil}.$$

It was noted above that the radon concentration in the soil air at the building base approaches to the radon potential of the soil, not reaching it. Therefore, the radon potential can be taken as the radon load on the building foundation

$$P_{Rn} = A_{soil} = C_{Ra}\cdot\rho_{soil}\cdot k_{em} \tag{6}$$

where C_{Ra} is the specific radium activity in the soil, Bq·kg^{-1}; ρ_{soil} is the soil density, kg·m^{-3}; k_{em} is the radon emanation coefficient.

In fact, the radon activity at the building foundation with an airtight underground part is 10–15% less than the radon soil potential. This stock allows not to take into consideration the radon exhalation from the surface of the building materials, which is small and usually amounts to q_m = 2-3 mBq·m^{-2}·c^{-1}.

Resistance to radon permeability of the floor structure is determined by the number and physical characteristics of the layers of the building base, and with sufficient accuracy it can be represented as a sum

$$R_{tot} = \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} \left(\lambda \cdot D_i\right)^{-1/2} \cdot sh\left(H_i \cdot \left(\lambda / D_i\right)^{1/2}\right), \tag{7}$$

where n is the layers number in the floor construction; H_i are the layer thickness, m; D_i are the radon diffusion coefficients in the layers of materials, m^2·s^{-1}.

The values on the right-hand side of (6) are determined by the gamma-spectrometric analysis of the soil, selected at the construction site at the depth of the foundation. From (5) the required floor structure resistance to radon entry can be found. Having done this by means of the formula (7) it is easy to find the required thickness of the layer that provides the greatest resistance to radon entry (reinforced concrete base plate).

3. Conclusion

The proposed approach allows estimating radon levels in the premises of the lower floor of the designed building without the use of mathematical modeling. However, its scope is limited to buildings, built with modern technology that is to say, having a sealed underground shell.

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