Regularities of the Formation of Indoor Radiation Doses Caused to People by External Exposure

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Abstract. The concept of safety and assurance of vital human activities in urbanization is one of the most significant backbone concepts of human ecology. The comfort of residential buildings under construction is largely owed to the radiation properties of the construction materials used. Therefore, the radiation-related hygienic support of technological processes and construction is an important issue for the construction industry. The paper considers the regularities of the formation of indoor background gamma radiation depending on various factors, in particular on the impact of the specific activities of naturally occurring radionuclides in construction materials. The results of the investigation allowed determining that the annual accumulated dose calculated according to the formula and the actual accumulated dose in buildings constructed of various materials comply with the normative documents, however the accumulated doses of human exposure in panel buildings are 4-6 times higher than in other types of buildings.

1. Introduction
The role of various components of natural ionizing radiation sources forming the human exposure level has changed significantly in modern buildings constructed of mineral raw materials. Floor slabs protect against space radiation. Building walls provide shielding against the radiation from terrestrial rocks, in their turn being a radiation source as well. Concrete floor slabs obstruct the penetration of soil radon into indoor spaces, while radon and its daughter products accumulate in indoor air due to the exhalation of radon from those slabs and walls [1-3]. To assess the balance of these processes, it is necessary to know the regularities of the radiation dose contribution from various sources.

The indoor background radiation is considered to be one of the main types of radioactive impact of the environment on human beings [3-5], since people spend most of the time inside buildings. The range of values of indoor background γ-radiation depends on various factors, among which the following ones can be distinguished: the type of material the building is constructed of and the concentration of naturally occurring radionuclides (NOR) in it; the geometry of the building (architectural and planning concept); the density of street development with buildings constructed of various materials; background γ-radiation of the adjacent territories and buildings [6-8]. The data of the radiation dose rates caused by NOR from terrestrial rocks give an indication of the possible levels of the background γ-radiation of regions and populated areas. Figure 1 shows the averaged levels of background gamma radiation in the territories of various countries of the world [9-10].
The indoor background gamma radiation caused by emissions from construction materials is generated depending on the spectrum of $\gamma$-radiation of NOR, the dimensions and form of the room, the area of window and door apertures as well as on the thickness of walls and floor slabs.

Based on the results of the field investigations carried out in various countries of the world, it has been revealed that the absorbed dose rates (ADR) in buildings constructed of various materials differ significantly [9-11], which is confirmed by the data given in figure 2.

In Russia, such measurements were conducted on a smaller scale. However, the measurements taken in the cities of St. Petersburg and Luga, presented in figure 3, prove that the lowest ADR occurs in wooden buildings, though the values of ADR show significant variation in buildings constructed of the same type of materials in various countries and even in various cities of one and the same country [12].
The maximum absorbed dose rate of indoor photon radiation can be assessed through the formula for the calculation of ADR of \( \gamma \)-radiation (nGy/h) in infinite air medium with uniformly distributed NOR [13]. However, the investigations carried out by professor E.M. Krisyuk [14] show that the ADR (nGy/h) generated in infinite air medium can be determined based on the effective specific activity of NOR (\( A_{\text{eff}}, \text{Bq/kg} \)) in the material:

\[
D_{\text{max}} = 1.04 A_{\text{eff}}
\]  

(1)

With the error limit of 10%, the absorbed dose rate for modern masonry buildings \( D_b, \text{nGy/h} \), can be adopted to be:

\[
D_b = 0.76 D_{\text{max}} = 0.79 A_{\text{eff}}
\]  

(2)

The conversion factor from the absorbed dose \( D \) to the equivalent dose \( H \) equals to 0.72 Sv/Gy.[15] It is commonly accepted that the citizens of advanced industrial countries spend 80% of the time indoors, 15% - in transport and 5% - in open space (in gardens, parks etc.). Therefore, the annual effective equivalent dose of \( \gamma \)-radiation (\( \mu \text{Sv/year} \)) for people [16] who live in modern masonry buildings is:

\[
H_b = 4.74 A_{\text{eff}}
\]  

(3)

where \( A_{\text{eff}} = \frac{\sum m_i A_{\text{eff}}}{\sum m_i} \) is the average specific activity of NOR;

\( m_i \) is the annual amount of \( i\)-th construction material used in the region.

Table 1 presents the data on the averaged annual absorbed dose to which residents of various buildings in Volgograd are exposed, calculated according to formula 2 [17-21].

**Figure 3.** Average ADR of gamma radiation in buildings in the cities of St. Petersburg and Luga.
The accumulated annual dose (the calculated one) was determined according to the formula (2) assuming that a particular group of people spend 80% of the total time in a building constructed of a particular material (ceramic brick, silicate one etc.). However, when the situation is considered in more correct way, the working part of the given people (55%) and children (25%) who live, for example, in a wooden building do not spend 80% of their time there, actually they stay inside it for only 10-12 hours, i.e. up to 50% of their time, while 20-30% of the time is spent at working places (in a workshop, school, higher education institution etc.). It was reasonable to find out the contribution added by the correction for working hours per day and per year for the specified city. Therefore, the authors gave the obtained results on the actual accumulated dose for a person staying in a building constructed of a different material. Administrative buildings, a workshop and a school constructed of silicate brick and concrete with the average dose rate of 140 nGy/h (16 μR/h) were considered. As it can be seen in table 1, the final results in both the first and the second variants comply with the regulatory documents. However, it should be noted that people living in reinforced concrete panel buildings and cast-in-situ concrete buildings are exposed to accumulated doses 4-6 times higher than in other types of buildings.

### 2. Conclusion

The authors are carrying out an investigation aimed at adjusting the conversion factors from the equivalent specific activity of NOR to the absorbed dose rate with regard to the regional aspects of the natural radioactivity of construction materials. The given study takes into account the fact that most of buildings are constructed of several materials with various radiation characteristics. Therefore, the authors consider it reasonable to adjust the conversion factors for each material separately.

In order to achieve the stated task, the authors selected standardized buildings with various radiation characteristics in which the obtained results of measurements should be verified by the necessary calculations.

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