ENVIRONMENTAL PROBLEMS

Vol. 9, No. 3, 2024

ASSESSMENT OF RADIATION HAZARD OF CONCRETE AND BACKGROUND RADIATION INDOORS

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https://doi.org/10.23939/ep2024.03.157

Received: 22.07.2024

Abstract. Simulation of the dose rate of building materials γ-radiation in the premises of different designs has revealed the minimal levels of human exposure. It was determined that the exposure dose rate at the given points of a single room depends on the content of natural radionuclides in construction materials and the changing geometry of a person's exposure in the premises. When the exposure dose rate of γ-radiation above an individual plate is determined, it is conventionally divided into the discrete sources, the dose rate from several plates is summed up. It is shown that near a vertical wall with a uniform content of natural radionuclides the exposure dose is higher where the wall is thicker. When radiation is emitted from the floor of a certain thickness, a maximum exposure dose rate occurs, which becomes greater when the layer of half attenuation of the material increases. The exposure dose rate also increases in the corners of the room: the higher the room the greater the dose rate. The results obtained predict the doses of human exposure at various points of the room, which determines the conditions for a person's existence and the support staff work, the rational arrangement of workplaces and machinery, and the optimization of the operating modes of precision equipment.

Keywords: natural radionuclides, construction materials, γ-radiation indoor, exposure dose rate, simulation.

1. Introduction

Natural sources of ionizing radiation are a major factor of human exposure to radiation. Natural radionuclides (NR), which are contained in construction materials used to build walls and floors, create a γ-radiation field in the room and determine the external human exposure. The ratio between the dose rate of γ-radiation indoor and the specific activity of radionuclides in construction materials depends on the γ-radiation spectrum of these radionuclides, the size of the room, the area of windows and doors, the thickness of the walls and the ceilings. Recently, direct measurements of the absorbed dose rate have been carried out using gamma dosimeters in the open air and in the premises built of various materials (Monica et al., 2016; Kovler, Schroeyers, 2017). The levels of human exposure, the annual effective dose and the risk of blastomogenesis have been evaluated (Monica et al., 2016).

Analysis of literature data and problem setting. Dosimetric studies of ionizing radiation were carried out near different building structures (Pečiuliene et al., 2006). The rate of the equivalent dose increases exponentially when approaching the building under study. This empirical dependence remains valid up to 10–15 m from the building. It is shown that the buildings increase ionizing radiation by about 1.5–2 times.

In works (Nuccetelli et al., 2017; Nuccetelli et al., 2012) the radioactivity of construction materials was evaluated using a quantitative characteristic – the activity concentration index *I* offered by the EU safety standards. The values of a more accurate index $I(\rho d)$, which takes into account the thickness and

For citation: Khobotova, E., Hraivoronska, I., Ihnatenko, M. (2024). Assessment of radiation hazard of concrete and background radiation indoors. *Journal Environmental Problems*, 9(3), 157–163. DOI: https://doi.org/10.23939/ep2024.03.157

density of building materials, are less than *I* (Kovler, Schroeyers, 2017).

The absorbed dose in the air of the premises built of such construction materials as concrete, aerated concrete, brick and stone, was calculated by the method of accumulation coefficients (Manić et al., 2015). The conversion factors obtained by interpolating the equivalent doses of the ICRP for isotropic radiation were used. The authors obtained the results: the average effective indoor dose from radiation of building materials is 0.24 mSv/y, for comparison, the outdoor dose is 0.047 mSv/y (Nuccetelli et al., 2017). The absorbed dose rate P_{abs} was calculated at the various points of the concrete premises (Manić et al., 2014). The value of P_{abs} was determined with varying sizes and thickness of the walls, the fitting coefficients which allow to calculate the dose rate for most rooms in practice were derived, an expression was obtained for calculating P_{abs} from a point source in the concrete. By the method of point nucleus using the coefficients of growth (geometric progression) the dose rate conversion factors for ^{238}U, ^{232}Th and ^{40}K for standard rooms were determined, as well as for the rooms with different sets of sizes. The values of the conversion factors are, $nGy \cdot h^{-1}/Bq \cdot kg^{-1}$: 0.76, 0.91 and 0.070 respectively for ^{238}U, ^{232}Th and ^{40}K (Manić et al., 2012).

Subject of the research is identification of minimum levels of human exposure indoor by simulation the dose rate of construction materials γ-radiation in the premises of various sizes and is the radioactive properties of multicomponent concretes, the experimental determination of the specific activities of NR in 7 samples of JSC "Road Repair Construction Management No. 33" multicomponent concretes. The company uses concrete in civil engineering. The authors used the method developed by themselves (Author's license no 29923 UA, 2009).

Objectives of the research:

– analyzing the changes in the exposure dose rate of γ-radiation over an individual plate;

– simulation the distribution of γ-radiation from a vertical wall;

– studying the changes in the exposure dose rate from the floor, made of construction materials with a different layer of half attenuation;

– studying the changes in the exposure dose rate indoor depending on its structure and the specific radioactivity of construction materials;

– developing recommendations for ensuring radiation safety of premises.

In order to achieve the goal, various building structures were considered.

2. Materials and Methods

Gamma-spectrometric analysis of slag was performed using a scintillation gamma spectrometer, the range of measured energies, whose gamma radiation ranges from 50 to 3000 keV. The investigated samples were placed in a 1-liter Marinelli measuring vessel. The average time of measuring the activity of natural radionuclides was 2 hours. The limit of permissible basic error in measuring activity for Marinelli geometry ($P = 0.95$) is less than 25 %. The Akwin software was used to process the measurement results.

Table 1 includes experimental data on the specific activities of radionuclides C_i, obtained by the γ-spectrometric method, as well as the results of the calculation of the effective specific activity C_{ef} of the concretes calculated by the equation (GGN 6.6.1.-6.5.001.98, 1998):

$$C_{ef} = C_{\mathrm{Ra}} + 1.31 C_{\mathrm{Th}} + 0.085 C_{\mathrm{K}}, \text{ Bq/kg},$$

where C_{Ra}, C_{Th}, C_{K} are specific activities of ^{226}Ra, ^{232}Th and ^{40}K respectively in Bq/kg; 1; 1.31; 0.085 – coefficients equal to the ratio of dose levels in the infinite space, created at the same specific activities of ^{232}Th and ^{226}Ra; ^{40}K and ^{226}Ra respectively. The values of these coefficients depend on the energy and quantum efficiency of the natural radionuclides radiation. The main contribution to the value of C_{ef} is made by activity of ^{226}Ra.

Table 1

The results of γ-spectrometric analysis of the samples of concretes

No.	C_i, Bq/kg (contribution in C_{sum}, %)			C_{ef}, Bq/kg
	^{226}Ra	^{232}Th	^{40}K	
1	2	3	4	5
1	42.3	59.1	942	200
2	42.4	54.8	714	175

Contuniation Tabl. 1

1	2	3	4	5
3	46.4	61.2	920	205
4	24.9	46.2	398	119
5	31.3	52.8	–	101
6	22.2	35.7	416	104
7	38.3	34.0	382	115

For the concrete samples, the C_{ef} value exceeds the average for Ukraine (106 Bq/kg) except samples No. 5, 6. However, all the samples of concrete under study belong to class I of the radiation hazard of building materials used in construction without restrictions, C_{ef} <370 Bq/kg. The contribution of radionuclide activities to the value of C_{ef} of concrete samples No. 1–3 becomes smaller in the order $^{40}K > {}^{232}Th > {}^{226}Ra$, for the remaining samples the greatest contribution is determined by ^{232}Th activity.

The dose of external radiation caused by NR in an open area due to the 2π-irradiation geometry is approximately 1/5−1/3 less than the external radiation dose of a person spending a significant part of the time in stone (concrete) rooms (4π-irradiation geometry). Therefore, concrete structures do not created a significant radiation hazard to the people and environment as sources of gamma radiation. The thicker the enclosing structures of premises, the stronger they protect against external radiation: cosmic radiation and radiation from natural background components contained in the soil and atmospheric air. At the same time, a large dose of external radiation is created indoors by NR made from building materials.

Changing the γ-background above an individual plate of size $A \times B \times H$, built of the construction material, in which NR are evenly distributed. At this, a number of conventions were adopted: only γ-radiation was considered, other types of radiation and radon exhalation were neglected; the simultaneous absorption of γ-radiation when passing through the material thickness was taken into account; the material was considered as isotropic, the conditions were stationary (the half-life was considered equal to ∞); the interference of fields from various sources was not taken into account; the dosimeter for measuring the γ-radiation rate was considered as a point with respect to the plate.

Under these conditions, the exposure dose rate P_0, which is created by an arbitrary elementary volume dV_2 of the plate at point O (for h ≥ R), will be equal to:

$$P_0 = \frac{P_S \cdot R^2}{x^2 + y^2 + z^2}, \tag{1}$$

where P_S is radiation rate in point S, created by elementary volume dV_1;

R is the distance from elementary volume dV_1 to point S;

h is the distance from elementary volume dV_1 to point O;

x, y, z are the coordinates of arbitrary point O (Fig. 1).

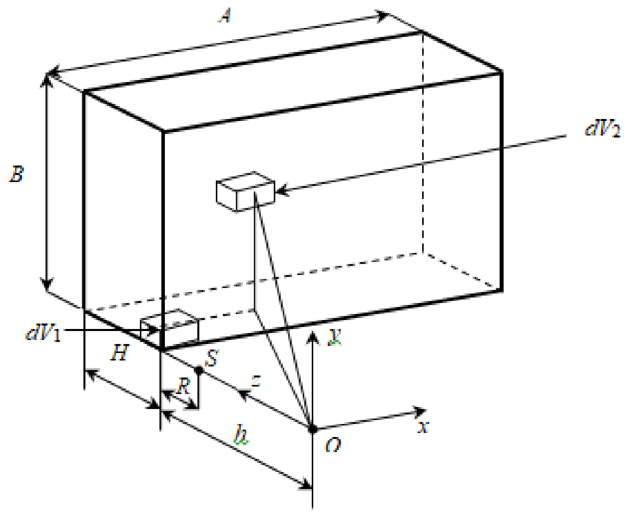


Fig. 1. Coordinate system for calculating the exposure dose rate from elementary volume of material

In order to determine the dose rate of γ-radiation at point O (origin of coordinates) created by the entire plate with dimensions $A \times B \times H$ (Fig. 1), it is offered to conventionally divide the plate into a finite number of single elements (discrete sources). All linear dimensions are given below in relative units (the ratio of plate size or distance to a certain element size). The dose rate will be equal to the sum of the corresponding values for the individual elements, namely:

$$P_{0\Sigma} \approx P_S R^2 \sum_{x=1}^{A} \sum_{y=1}^{B} \sum_{z=h}^{H+h} \frac{1}{(x^2 + y^2 + z^2) 2^{\sqrt{x^2+y^2+z^2} \cdot \left(\frac{z-h}{zd}\right)}}, \tag{2}$$

where $2^{\sqrt{x^2+y^2+z^2}\cdot\left(\frac{z-h}{zd}\right)}$ is the value of attenuation of γ-radiation in the plate material thickness;

$\frac{z-h}{z}$ is a coefficient of similarity of big and small;

$\sqrt{x^2+y^2+z^2}\cdot\left(\frac{z-h}{z}\right)$ is the thickness of material which the ray passes through from volume dV_2 to point O (Fig. 1);

d is the thickness of the layer of the plate material half attenuation (reference quantity).

In order to solve the practical tasks on determination of the γ-radiation dose rate, it is necessary to determine the dose rate at an arbitrary point P_S, created by an elementary volume, for a given material, in the following way: to make a prototype plate with certain dimensions ($A\times B\times N$); to determine experimentally the dose rate $P_{measured}$ ($P_{measured} = P_{0\Sigma}$) at an arbitrary point at a certain distance R; to calculate $P_S \cdot R^2$ as a specific value for the material of a given plate using the equation:

$$P_S \cdot R^2 = \frac{P_{\text{measured}}}{\sum_{x=1}^{A}\sum_{y=1}^{B}\sum_{z=h}^{H+h}\frac{1}{(x^2+y^2+z^2)\cdot 2^{\sqrt{x^2+y^2+z^2}\left(\frac{z-h}{zd}\right)}}}. \quad (3)$$

To determine the dose rate from several plates (indoor), it is necessary to sum up the dose rate from each plate separately.

For the practical determination of the radiation background indoor, a mathematical model (4) has been developed, created in the environment of the computer program Mathcard-14 on the basis of equation (3).

The accuracy of the calculation result can be improved by increasing the number of single elements, while reducing their size. The division of the plate into single elements can be both conditional and real. Brick, blocks and tile can be considered the real single elements.

Calculation for a thin vertical wall built of the construction material that is homogeneous in NR content made possible to construct a scheme of the exposure dose rate distribution (P_{exp}) depending on the distance (Fig. 2 *a*). Near the wall the dose rate increases. Increasing the wall thickness causes a sharper rise of P_{exp} near the wall (Fig. 2 *b*).

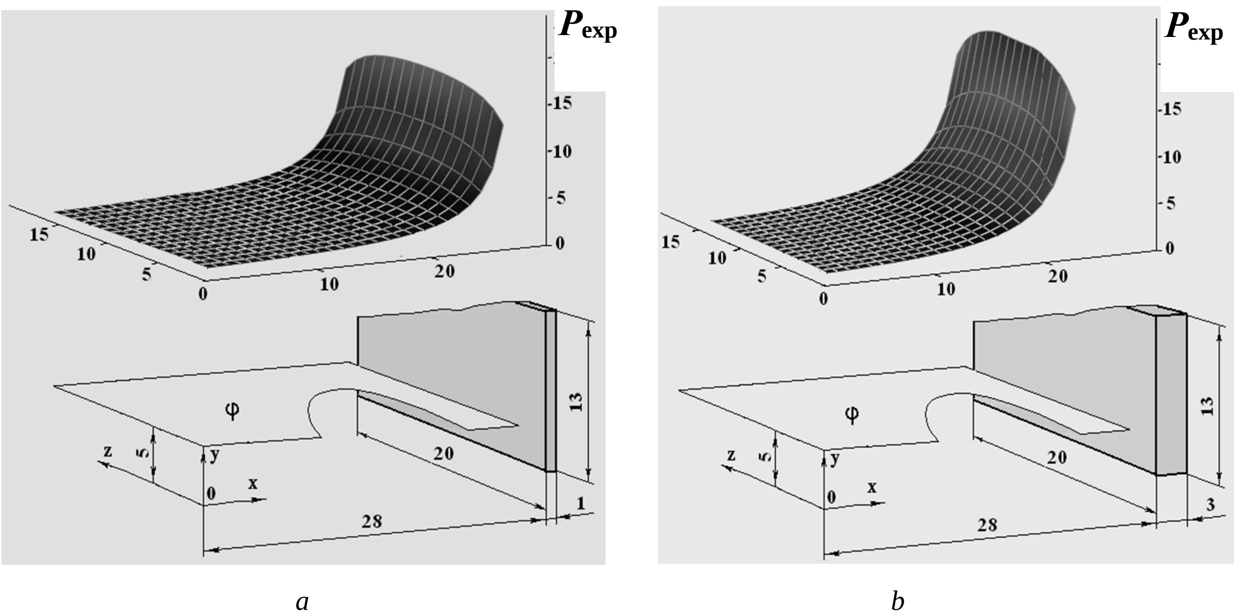


Fig. 2. Distribution of the exposure dose rate from a vertical wall:
a – minor thickness of the wall; *b* – big thickness of the wall

$A :=$ $B :=$ $H :=$ $y0 :=$ $d :=$ $R :=$ $h :=$ $PR^2 :=$

$$
\begin{aligned}
P_{ex}\ \Big|\ & \text{for } x0 \in 1..A-2\cdot h \\
& \quad \text{for } z0 \in 1..B-2\cdot h \\
& \quad\quad L_{x0,z0} \leftarrow \sum_{x=-h}^{A-h}\sum_{z=-h}^{B-h}\left[\sum_{y=H}^{H+h} \frac{P\cdot R^2}{\left[(x-x0)^2+(y-y0)^2+(z-z0)^2\right]\cdot 2^{\frac{\left[\sqrt{(x-x0)^2+(y-y0)^2+(z-z0)^2}\right]\cdot(y-H)}{(y-y0)\cdot d}}} + \right. \\
& \quad\quad \left. + \sum_{y=-h}^{-1} \frac{P\cdot R^2}{\left[(x-x0)^2+(y-y0)^2+(z-z0)^2\right]\cdot 2^{\frac{\left[\sqrt{(x-x0)^2+(y-y0)^2+(z-z0)^2}\right]\cdot y}{(y-y0)\cdot d}}}\right] + \\
& \quad\quad + \sum_{y=1}^{H}\sum_{z=1}^{B-2\cdot h}\left[\sum_{x=A-2\cdot h}^{A-h} \frac{P\cdot R^2}{\left[(x-x0)^2+(y-y0)^2+(z-z0)^2\right]\cdot 2^{\frac{\left[\sqrt{(x-x0)^2+(y-y0)^2+(z-z0)^2}\right]\cdot(x-A+2\cdot h)}{(x-x0)\cdot d}}} + \right. \\
& \quad\quad \left. + \sum_{x=-h}^{-1} \frac{P\cdot R^2}{\left[(x-x0)^2+(y-y0)^2+(z-z0)^2\right]\cdot 2^{\frac{\left[\sqrt{(x-x0)^2+(y-y0)^2+(z-z0)^2}\right]\cdot x}{(x-x0)\cdot d}}}\right] + \\
& \quad\quad + \sum_{x=-h}^{A-h}\sum_{y=1}^{H}\left[\sum_{z=-h}^{-1} \frac{P\cdot R^2}{\left[(x-x0)^2+(y-y0)^2+(z-z0)^2\right]\cdot 2^{\frac{\left[\sqrt{(x-x0)^2+(y-y0)^2+(z-z0)^2}\right]\cdot z}{(z-z0)\cdot d}}} + \right. \\
& \quad\quad \left. + \sum_{z=B-2\cdot h}^{B-h} \frac{P\cdot R^2}{\left[(x-x0)^2+(y-y0)^2+(z-z0)^2\right]\cdot 2^{\frac{\left[\sqrt{(x-x0)^2+(y-y0)^2+(z-z0)^2}\right]\cdot(z-B+2\cdot h)}{(z-z0)\cdot d}}}\right], \\
& L
\end{aligned}
\tag{4}
$$

where A, B, H are dimensions of the premises;

y_0 is the height of the area in the coordinate system (x, y, z);

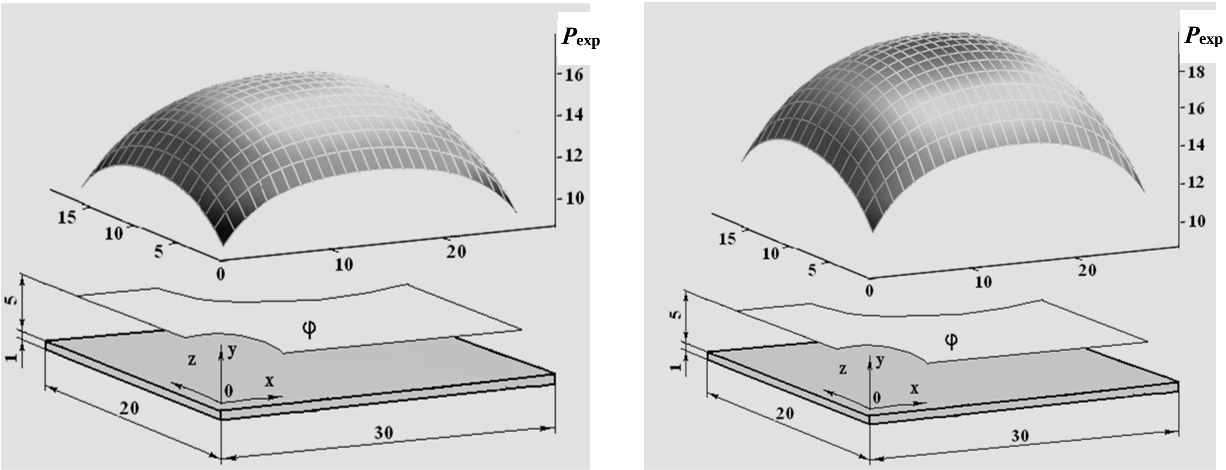
d is the thickness of the layer of the material half attenuation;

h is the plate thickness;

P is the exposure dose rate created by a single element of the plate at the point which is at a single distance R from its center.

Radiation from the floor of a certain thickness, built of the construction materials with a different layer of half attenuation (d). In this case, the calculation shows the presence of a maximum P_{exp} in the center of the plate (Fig. 3). The higher the value of d the greater the maximum value.

The level of γ-radiation in residential and industrial buildings is of particular interest. The γ-radiation rate is determined by two main factors: the content of NR in construction materials and the change in the exposure geometry of a person in the premises (in the room the exposure geometry approaches 4π). Depending on the type of construction materials of the structures, the magnitude of the exposure dose rate varies at different points of the volume of the room.



a b

Fig. 3. The radiation field above the horizontal plate when the thickness of a half-attenuation layer in arbitrary units is: a – *d*=2; b – *d*=6

If the whole room is made of construction material with a uniform NR content, an increase in the dose rate is observed in its corners (Fig. 4). The higher the room the greater the rise of P_{exp} in the corners.

A significant increase of P_{exp} was observed in the corner of the room, where the two walls were made of construction material with a high content of radionuclides (Fig. 5).

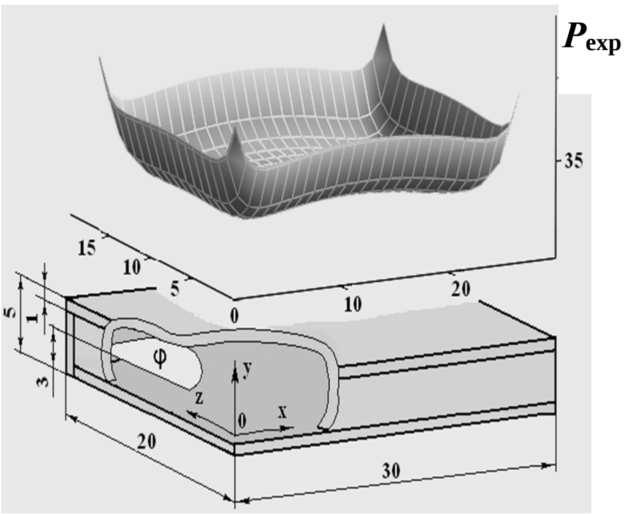


Fig. 4. Radiation background in the premises built of construction material with a uniform NR content

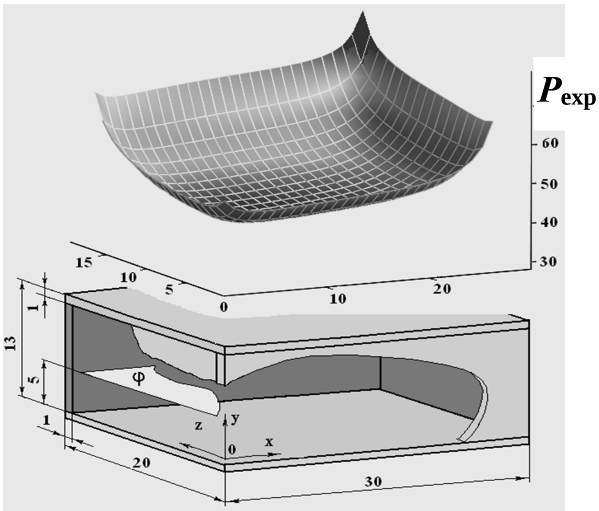


Fig. 5. Radiation background in the center of the room, where the two walls are characterized by increased radioactivity

Recommendations for ensuring radiation safety of the premises. Given the wide range of ionizing radiation, the location of workplaces depends on the parameters and types of radiation from natural and artificial sources, the distance from the radiation source to the workplace, and location at a certain point in the room (Kovalenko, Rudia, 2001). The conditions for a person's existence and the support staff work in stone premises, the location of workplaces, the schemes for rational arrangement of machinery and rationalization of their operation modes, first of all, precision equipment, depend on the distribution of the exposure dose rate.

3. Conclusions

– Simulation of the dose rate of construction materials γ-radiation in the rooms of different sizes revealed the minimal levels of human exposure. It was determined that the exposure dose rate at the given points of a single room depends on the NR content in construction materials and the changing geometry of a person's exposure in the premises.

– When determining the exposure dose rate of gamma radiation over an individual plate, its conditional division into a finite number of discrete sources was offered. Indoors, the dose rate from several plates is summed up.

– A scheme for distribution of exposure dose rate from a thin vertical wall made of construction material that is homogeneous in NR content was developed. Near the wall the dose rate increases with the wall thickness. It is shown that the exposure dose rate has maximum when radiation comes from the floor of a certain thickness. The maximum increases with an increase in the layer of half attenuation of the material. There is an increase of the dose rate in the corners of the room made of a homogeneous building material, the dose rate being greater when the room is higher.

– The conducted research makes possible to predict the probable exposure doses of people at the design phase of residential and industrial buildings, from which the technological support of the radiation safety of construction objects begins. Labor protection and life safety can be improved only on the basis of using technological and organizational procedures when setting up a regulation level for controlled parameters at all stages of the construction industry.

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