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Mathematical Modeling of Radiation Background Plants Construction Materials Industry Enterprises

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Abstract: Background radiation shops enterprises of building materials plays a significant role in the irradiation of their employees. The main source of air pollution radon shops is the allocation of radon in the processing of mineral raw materials in them. The main means of dealing with radon is ventilation. For its calculation at the design stage it is necessary to know the radon release rate being in the shop with bulk material. One of the factors determining the ability of the bulk material emanating is its specific surface area. To refine his prediction is proposed to consider the distribution of grains in the material not only by their equivalent size but also in shape. Proposed a method for the mathematical description of the form of grains of the bulk material which is obtained by using a refined formula for determining its specific surface area. The dependence of the radon exhalation rate from the grain shape of the bulk material. On the basis of a formula dependencies to more accurately determine the amount of radioactivity released the bulk material. Formulas for predicting the average radon concentration and ventilation performance management sufficient to maintain the concentration of radon activity at the recommended level.

Key words: Mathematical modeling, granular material, an emanation of radon, distribution of grains in the material size and shape parameters of the ventilation system, sufficient

INTRODUCTION

Currently installed a special role in radon irradiation of people in common household and industrial conditions.

Radon and its decay daughter products account for about 70% of the dose to the population from natural background radiation. Inhalation of radon and its decay daughter products is >20% of cases of lung cancer (ICRP, 1987) which is the Russian Federation, >9000 cases per year. Radon is released continuously constructions of buildings, land under the building, recyclable materials indoors and constantly accumulating on the premises. Effective equilibrium volume activity of radon in basements insufficiently ventilated rooms, basements and lower floors often exceeds the maximum allowed (200 Bq/m^3) that poses a real threat to the occupants. Radiation Safety Standards (RMOH, 1999) for the newly designed buildings provides a lower level of radon activity (100 Bq/m^3), however, there is currently no method for predicting and calculating the concentration of radon in the design stage of buildings. To reduce the input of radon in space recommended the selection of appropriate materials and designs, special coating internal surfaces of the premises, but the primary means of maintaining the activity concentration of radon at an acceptable level is ventilation. For calculation and design of ventilation systems need to know the amount of radon entering the space (Krisyuk, 1989; EPA, 2003).

MAIN PARTS

The main source of air pollution in industrial premises building materials industry radon is processed into them particulate minerals-sand, clay, gravel, crushed stone, etc. (Goritskii *et al*., 1990). Properties of some bulk materials are given in Table 1.

Amount of activity generated the bulk material is determined by its mass, the specific surface of the material and the rate of radon exhalation through the surface of the grains of the material.

Bulk materials are composed of grains of different sizes and shapes. Size of grains of irregular shape will describe three specific dimensions: the largest grain size-its length δ_1, the largest transverse dimension

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Table 1: Properties of bulk materials, determine the allocation of radon

Materials	Radium concentration activity (C_{Ra}, Bq/kg)	Density (ρ, kg/m^3)	Emanational factor (η)	Material porosity (ε)	Diffusion coefficient (D, 10^{-9} m^2/sec)	Radon diffusion length (L, m)	Maximum radon activity concentration in pore space C_{max}, (10^5 Bq/m^3)
Quartz sand	7.6	2400	0.37	0.12	10.0	0.20	0.56
Gravel, pebbles	14.0	2500	0.07	0.05	8.0	0.28	0.49
Granite rubble	51.0	2700	0.18	0.01	0.5	0.15	24.80

δ_2-wide and the largest size in the direction perpendicular to the previous two-thick δ_3. By these dimensions which can be found empirically grain volume is determined using an empirical relationship:

$$V = \frac{\delta_1\delta_2\delta_3}{2.2} \tag{1}$$

By volume of grain material can find its equivalent size δ, equal to the diameter of a sphere of the same volume:

$$\frac{\pi\delta^3}{6} = \frac{\delta_1\delta_2\delta_3}{2.2} \tag{2}$$

Hence, to obtain an expression equivalent size:

$$\delta = 0.954\sqrt[3]{\delta_1\delta_2\delta_3} \tag{3}$$

From expression (Eq. 3) that the equivalent grain size is almost equal to the geometric mean of three characteristic sizes.

For the mathematical description of the shape of grains can be taken to classify them according to the type of surface (smooth round or square) and the ratio of characteristic dimensions. Depending on the ratio of the length, width and thickness of the grain can be divided into three classes of grain (Sharapov *et al.*, 2007):

- Isometric grain for which all three characteristic dimensions are close in value
- Flat grain size in which the two are similar in size and substantially larger than the third dimension
- Elongated grain whose length is significantly greater than two different sizes

The average value of two almost equal sized grains not isometric call them transverse dimension δ_{ac}, a third dimension-axial δ_{ax}. The ratio of the axial dimension to the cross which characterizes the degree of deviation from the isometric grain shape is called the coefficient anisometer a:

$$a = \frac{\delta_{ax}}{\delta_{ac}} \tag{4}$$

We assume grain isometric if $0.2 \le a \le 4$, flat if $a < 0.2$ and extended if $a > 4$. Distribution of grains of material equivalent to their size is determined by the composition of the grain which can be specified relative mass fractions ΔD_i (delta) individual fractions of the material (δ_{i-1}, δ_i) (Djamarani and Clark, 1997). We assume that all of the ith grain fractions are the same size $\bar{\delta}_i$, equal to the average fraction of boundaries:

Table 2: Distribution of grains of crushed granite in size and shape

Size ($\delta_{i-1}\,\delta_i$) (mm)	<5	5-10	10-20	20-40	40-80	>80
ΔD_{i1}	0.015	0.06	0.12	0.20	0.14	0.03
a_{i1}	0.900	0.50	1.20	2.00	2.40	1.50
Δd_{i2}	0.010	0.04	0.05	0.10	0.07	0.01
a_{i2}	0.200	0.18	0.15	0.18	0.12	0.10
Δd_{i3}	0.005	0.02	0.03	0.05	0.04	0.01
a_{i3}	4.200	5.00	5.30	4.80	4.40	4.10

$$\delta_i = \frac{\delta_{i-1} + \delta_i}{2} \tag{5}$$

Each fraction of the material is divided into three sub-fractions form grains. The proportions of the sub-fractions denoted Δd_{ij} where i = 1, 2, ..., n, Room grain size fraction, a j = 1, 2, 3, form number of grains:

1 Isometric
2 Flat
3 Extended

Must meet the following conditions:

$$\sum_{j=1}^{3} \Delta D_{ij} = \Delta D_i, \quad \sum_{i=1}^{n}\sum_{j=1}^{3} \Delta D_{ij} = 1 \tag{6}$$

For each sub-fraction determined average value of anisometer a_{ij}. Distribution matrix grains of crushed granite in size and shape is presented in Table 2.

A detailed study of the distribution of the grain bulk material necessary to more accurately determine its specific surface SSA (m^2/kg), total surface area of grains in the material per unit of its mass:

$$SSA = \sum_{i=1}^{n}\sum_{j=1}^{3} \Delta D_{ij} \cdot SSA_{ij} \tag{7}$$

where, $SSA_{ij} = S_{ij}/m_{ij}$: specific surface grains belonging i and a fraction having j form (m^2/kg), S_{ij}: surface area of the grain, m_{ij} its mass. The surface area and volume of the grains of bulk material can be calculated by fitting the bodies of their regular shape.

For rounded grains of sand, gravel, pebbles as such bodies will use the ball and ellipsoids of rotation, angular grains of crushed stone will be approximated by a rectangular parallelepiped.

Specific surface rounded isometric grains approximated by a sphere is given by:

$$SSA_{i1} = \frac{6}{\rho \bar{\delta}_i} \tag{8}$$

For flat grains (a<0.2), approximated by an oblate spheroid, the specific surface area is:

$$SSA_{i2} = SSA_{i1} \frac{1}{2\sqrt[3]{a_{i2}^{2}}} \left(1 + \frac{a_{i2}^{2}}{\sqrt{1 - a_{i2}^{2}}} \ln \frac{1 + \sqrt{1 - a_{i2}^{2}}}{a_{i2}}\right) \tag{9}$$

For elongated grains approximated prolate spheroid, we obtain:

$$SSA_{i3} = SSA_{i1} \frac{\sqrt[3]{a_{i3}}}{2} \left(\frac{1}{a_{i3}} + \frac{a_{i3}}{\sqrt{a_{i3}^{2} - 1}} \arcsin \frac{\sqrt{a_{i3}^{2} - 1}}{a_{i3}}\right) \tag{10}$$

For angular particles can be approximated by a rectangular parallelepiped for arbitrary values A_{ij} specific surface area determined by the relation:

$$SSA_{ij} = 0.414 SSA_{i1} \frac{1 + 2a_{ij}}{\sqrt[3]{a_{ij}^{2}}} \tag{11}$$

Radon seeds emanation rate of particulate material also depends on their size and shape. So for isometric grains, the formula (Vetrova *et al*., 2009; Bossew, 2003):

$$E_{i1} = \frac{2\varepsilon D C_{max}}{\bar{\delta}_i} \left(\frac{\bar{\delta}_i}{2L} \operatorname{cth}\left(\frac{\bar{\delta}_i}{2L}\right) - 1\right) \tag{12}$$

Where:

ε = Porosity

D = Diffusion coefficient of radon in the pore space of the material (m^2/sec)

C_{max} = The highest possible concentration of radon in the pore space of the material (Bq/m^3)

L = Radon diffusion length (m) (Table 1)

For flat grains exhalation rate is as follows:

$$E_{i2} = \frac{\varepsilon D C_{max}}{L} \operatorname{th}\left(\frac{\delta_{ax}}{2L}\right) \tag{13}$$

Expressing grain thickness δ_{ax} through its equivalent diameter and coefficient anisometer give Eq. 13 to the form:

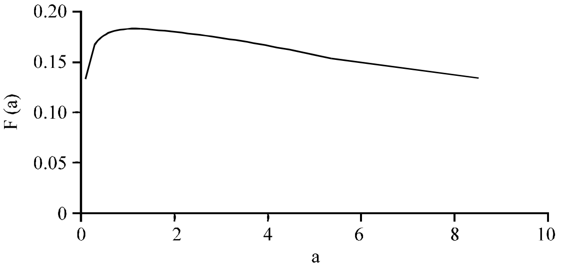

Fig. 1: Dependence of radon exhalation rate from the mineral grain shape (a <1; flat, a≈1; isometric, a>1; elongated grain)

$$E_{i2} = \frac{\varepsilon D C_{max}}{L} \operatorname{th}\left(\frac{a_{i2}^{2/3} \bar{\delta}_i}{2L}\right) \tag{14}$$

Similarly, we derive a formula for the rate of exhalation elongated grains:

$$E_{i3} = \frac{\varepsilon D C_{max} \delta_{ac}}{4L^2} = \frac{\varepsilon D C_{max} \bar{\delta}_i}{4L^2 a_{i_3}^{1/3}} \tag{15}$$

Grains for bulk construction materials condition $\bar{\delta}_i$/L<<1 which by expansion:

$$\operatorname{th} x = x - \frac{x^3}{3} + \ldots x \cdot \operatorname{cth} x = 1 + \frac{x^2}{3} - \ldots$$

allows us to reduce the formula for the rate of radon emanation to the next single mind:

$$E_{ij} = \frac{\varepsilon D C_{max} \bar{\delta}_i}{L^2} F(a_{ij}) \tag{16}$$

Where:

$$F(a_{ij}) = \begin{cases} 0.5a_{ij}^{2/3} & a_{ij} < 0.2 \\ 0.167 & 0.2 \le a_{ij} \le 4 \\ 0.25/a_{ij}^{1/3} & a_{ij} > 4 \end{cases}$$

F(a) diagram showed in Fig. 1. From these graphs, it follows that the highest rate of radon emanation have isometric grains.

Amount of activity released in the production room recyclable bulk material is determined by the following expression:

$$G_A = \frac{m \varepsilon D C_{max}}{L^2} \sum_{i=1}^{n} \sum_{j=1}^{3} \bar{\delta}_i \Delta \bar{D}_{ij} SSA_{ij} F(a_{ij}) \tag{17}$$

where, m = mass located in the premises of the material (kg). Distribution of radon activity concentration in industrial premises occurs differently than in the pore space of the material. The main differences are as follows (Shaptala, 2004; El-Fawal, 2011):

- Distribution of indoor radon occurs mostly not due to diffusion and as a result of radon transport by air currents
- Diffusion of indoor radon in space is not only due to thermal motion of the molecules but mainly due to the turbulent mixing of the moving air environment
- Unlike the porous medium, the allocation indoor radon does not occur throughout their volume and is superficial, i.e., radon is supplied through the internal surface flat and also through the surface of mineral grains processed

As a result of natural and mechanical ventilation of industrial premises in it over time a stationary distribution of radon. The median concentration of radon activity concentration can be estimated by the following balance equation:

$$G_A + \sum_k R_k S_k + C_{in}\frac{G_v}{\rho_{in}} = C\frac{G_v}{\rho} + \lambda CV \qquad (18)$$

Where:

E_k = Radon exhalation rate for k flat inner surface (Bq/(m^2 sec)
S_k = Area k surface (m^2)
C_{in} = Radon activity concentration in the supply air, Bq/m^3
G_v = Productivity of natural and mechanical ventilation (kg/sec)
ρ_{in}, ρ = Density of air supply and air inside the room (kg/m^3)
V = Internal volume of the room (m^3)
C = Activity concentration of radon in indoor (Bq/m^3)

From Eq. 17 for the averaged throughout the internal volume of space activity concentration of radon get:

$$C = \frac{\sum R_k S_k + G_A + C_{in} G_v/\rho_{in}}{G_v/\rho + \lambda V} \qquad (19)$$

From Eq. 17 can also be an expression for the performance of ventilation needed to maintain indoor radon concentration at a given level:

$$G_v = \frac{G_A + \sum_k E_k S_k - \lambda VC}{C/\rho - C_{in}/\rho_{in}} \qquad (20)$$

In fact, the distribution of indoor radon concentration is uniform. Increased activity concentration may accumulate in poorly ventilated, stagnant zones premises, near the process equipment, walls and floors. In this regard, besides maintaining the recommended level of the average concentration of activity is also necessary to monitor the concentration of activity in the workplace. (ICRP, 1993).

FINDINGS

When designing ventilation plants construction materials industry enterprises need to consider radon emanation recyclable bulk material in the shops.

Number of radon emitted particulate material depends on the shape of the grains of the material which affects the value of the specific surface of the material and the rate of radon emanation.

To quantify the effect of material on the grain shape radon emanation can be used anisometer coefficient of grain material and more detailed division into fractions of a material not only on the grain size but also by their shape.

CONCLUSION

The study describes the main factors of background radiation shops construction enterprises: the selection of radon recyclable bulk material and ventilation plant. The effect of grain shape on the bulk material value of its specific surface area and speed escalation radon. To quantify the extent of this impact factor proposed anisometer grains and separation into fractions of particulate material not only the particle size but also on their form. Obtained more accurate expression for the average volume concentration of radon activity at a given performance and material expression to calculate the performance of ventilation sufficient to maintain the plant in its concentration of radon activity at the recommended level.

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