Use of mica-based composite materials for radiation protection of buildings

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Abstract. Radioactive emission is widely applied in different fields of sciences, in various technologies, and in medicine. For its safe use the protective screens shall be used that limit the impact of radiation on a human being. The paper deals with study and analysis of opportunities for applying different materials for protecting buildings and premises from radiation. Studies have shown that phlogopite micalex has high radiation resistance. Calculations of masses of conventional panels made of different materials ensuring two-fold and ten-fold attenuation of X-ray and gamma radiation are presented. Studies revealed that micalex is the most promising and economically feasible material that can be used for those purposes. A new area for micalex application, namely, for radiation protection of buildings and structures of different purpose has been proposed.

1. Introduction

“Green” houses are more and more widely recognized by population. The main concept of such buildings consists in reduction of their impact on the environment, human beings, and human health. Sustainable construction is closely related to the concept of people protection from natural or man-induced impact of infrastructure facilities located in the neighborhood of dwelling housing. Mills producing radioactive ores in Irkutsk oblast, in other regions of Russia, and abroad are hazardous for human health. According to data of the World Nuclear Association as of 2015, Russia possesses 9\% of the world uranium resources and produces about 3-3.5 thousand ton of uranium annually. The main uranium deposits in Russia are located in the Trans-Baikal area and in the West Siberia. Uranium ore is open-pit mined. Primary uranium treatment is an environmentally hazardous process. Radiation pollution in the areas of uranium ore production and treatment is thousands times higher than the permissible radioactive background. One of the uranium enrichment mills of Russia (out of four) is located in Angarsk, Irkutsk oblast. Uranium enrichment process generates radioactive wastes, a part of them being buried right on the territory of the mill [2-5]. Emissions from chemical processes, use of phosphate fertilizers in agriculture, operating or abandoned nuclear test bases, areas for disposal of nuclear wastes and other chemical substances, and natural emissions of radionuclides in the tectonic faults have negative impact on human health as well [6,7]. In this connection, there is a real demand for structures protecting humans from negative impact of radiation.

2. Methods and materials
Samples of phlogopite micalex (mica - 60%, low-melting glass 203 - 35%, volcanic ash - 5%) were used for studies. Electro physical and mechanical characteristics of micalex were determined following standard techniques set forth in GOST; to determine a linear coefficient of micalex gamma-radiation attenuation the radiometry methods were used.

3. Results and discussion

Screens are the most efficient and universal method of protection from radiation. Materials used for manufacture of screens for different types of radiation differ in composition, structure and properties. Gamma rays have the highest penetrability and, hence, are most hazardous for human health. For protection from gamma radiation the highly dense materials composed of chemical elements with high nuclear weight are used, they are lead, steel, concrete, etc. Thickness of screens made of those materials is rather high and, hence, their manufacture and erection especially for dwelling houses is technologically difficult and economically inefficient [8]. Barite X-ray protection plaster is an alternative for internal protection of premises. It is predominantly used in medical facilities and research laboratories for protection of premises that are close to rooms with X-ray equipment. A drawback of this method of protection is complexity of its application: the layer applied shall not exceed 10 mm, and it needs reinforcement and polishing after hardening. Moreover, hazardous baryte dust (BaSO₄) shall be coated with common plaster, painted, covered with wallpaper or plastic panels. In view of the above said, it is necessary to note that ability of mica and mica-based composite materials [9,10] to protect from radiation is underestimated. In the course of the patent search conducted, we came across a patent describing a room for temporary stay of people (a mica room) for relaxation after emotional stress, for protection from hazardous noise and radiation of any kind [11].

The premise was arranged on the base of a maritime container whose walls, floor, ceiling, door and a transparent part of the window were made of mica. Protection of people exposed to higher radiation implies enhancement of radioactive protection of places for durative stay of people, i.e., special protection is required for work places located close to a radioaction source, as well as protection of homes. For siding the premises, it is advisable to use the so-called mica fits. The cost of such fits is high as production of large sheets of mica is labor intensive, and after cutting the shapes of desired size a large amount of scrap is generated which damages environment in the areas of mica production and processing. Micalex is a universal composite material with a number of useful characteristics. It is produced by hot pressing of a mixture of powdered mica and finely dispersed soft glass, and this process practically does not generate scrap [12]. Micalex has high mechanical and dielectric strength, low water absorbency, high heat and chemical resistance, which improves fire safety and sanitary-hygienic micro flora of the building after it has been sided with micalex. Average density of micalex is 2800-3000 kg/m³, i.e., it is similar to that of heavyweight concrete whose fillers are steel, carbonate of magnesia, baryte, and iron ore.

Previous studies [13] on identifying the optimum mix of micalex for radiation protection have shown that samples with the following composition: mica – 60%; low-melting glass 203 – 35%; volcanic ash – 5% have the best radiation resistance characteristics. It should also be noted that a linear attenuation coefficient of phlogopite micalex is higher than that of muscovite one. This difference may be due to different structure of phlogopite and muscovite and due to higher heat resistance of phlogopite mica. Phlogopite dehydroxylation process occurs at higher temperatures, which allows maintenance of the structure and density of the input material for a longer time period. When X-rays and gamma radiation go through the substance, their intensity attenuates exponentially following the law described by equation (1):

\[ I = I_0 e^{-\mu d} \]  

where \( I_0 \) – intensity of radiation falling on the surface of a substance; 
I - intensity of radiation leaving the substance; 
\( \mu \) - linear coefficient of radiation attenuation in the substance that depends on the substance nature;
\( d \) – thickness of absorbing layer of a material.

The linear attenuation coefficient in this equation is the main characteristic of material resistance towards X-ray and gamma radiation that depends on the type of protection material and on energy of penetrated X-ray and gamma radiation.

Linear coefficients of gamma-radiation attenuation for micalex of optimum composition were calculated for radiation energy of 10 and 15 MeV. Table 1 [17] gives values of the most popular radiation protection materials, such as lead, aluminium, steel, concrete, water, and micalex for comparison.

**Table 1. Linear attenuation coefficients of different materials vs gamma radiation energy**

| Material       | Radiation energy, MeV |       |       |
|----------------|------------------------|-------|-------|
|                |                        | 10    | 15    |
|                |                        |       |       |
| Lead           |                        | 0.5520| 0.6280|
| Aluminium      |                        | 0.0619| 0.0584|
| Steel          |                        | 0.2330| 0.2410|
| Concrete (common) |                   | 0.0369| 0.0000|
| Water          |                        | 0.0220| 0.0193|
| Micalex        |                        | 0.2200| 0.1870|

Analysis of data in Table 1 shows that gamma radiation linear attenuation coefficient for micalex is 5.96 times higher than that of concrete. The difference is dramatic. Linear attenuation coefficients for micalex are comparable to those of steel, and are inferior to those of lead by a factor of 2.51-3.36 only, whereas lead density is 3.77 times higher than that of micalex.

Physical mass of protection screens is an important parameter to be taken into account during buildings engineering: it shall be minimum subject to maintenance of all the protective properties. To determine the efficiency of micalex use in terms of this indicator, the thickness of protection screens for radiation energy of 10 and 15 MeV was calculated. Thickness of material layers most frequently used in engineering calculations is the one that ensures two-fold of ten-fold attenuation of gamma and X-ray radiation. Mass of materials was calculated for a conventional panel with dimensions of \((1 \text{ m} \times 1 \text{ m} \times d \text{ m})\), where \(d\) is thickness of the material layer needed for two-fold attenuation of the X-ray and gamma radiation.

**Table 2. Thickness of two-fold attenuation of X-ray and gamma radiation at different radiation energies; volume of conventional panels and their mass for different materials**

| Material | Density \( \rho \), kg/m\(^3\) | Layer thickness \( d \) (cm) at radiation energy of 10 MeV | Volume V \((1\text{ m} \times 1\text{ m} \times d \text{ m})\), m\(^3\) | Mass m, kg | Layer thickness \( d \) (cm) at radiation energy of 15 MeV | Volume V \((1\text{ m} \times 1\text{ m} \times d \text{ m})\), m\(^3\) | Mass m, kg |
|----------|-------------------------------|-----------------------------------------------|-----------------------------------------------|------------|-----------------------------------------------|-----------------------------------------------|------------|
| Lead     | 11300                         | 1.256                                         | 0.01256                                       | 141.928    | 1.104                                         | 0.01104                                       | 124.752    |
| Aluminium| 2700                          | 11.198                                       | 0.11119                                       | 302.346    | 11.869                                       | 0.11869                                       | 320.463    |
| Steel    | 7890                          | 2.975                                         | 0.02975                                       | 234.728    | 2.876                                         | 0.02876                                       | 226.916    |
| Water    | 1000                          | 31.507                                       | 0.31507                                       | 315.070    | 35.914                                       | 0.35914                                       | 359.140    |
It is obvious that for calculated masses presented in Table 2, a conventional micalex panel of equal size and equal radiation attenuation efficiency is lighter than a lead panel by a factor of 1.5, and lighter than a steel panel by a factor of 2.48. A ratio between a concrete conventional panel and a conventional micalex panel is 4.57, which evidences the economic inefficiency of using conventional concrete for protection from radiation. For the case of heavyweight concrete, the mass ratio diminishes, but the cost of concrete would be much higher than that of micalex. Therefore, utilization of micalex for protection from radiation turns out to be most efficient. Results for 15 MeV radiation energy are similar. With the radiation energy growth the efficiency of micalex use becomes lower than that of lead. In the 15-25 MeV range the efficiency of using both materials will be equivalent. At higher energy values, the use of lead becomes more efficient. It should be noted that radiation energy of 20 MeV and higher is not practically used in industries.

Masses of a conventional panel were also calculated for tenfold attenuation of X-ray and gamma radiation. Mass of materials was calculated for a conventional panel with dimensions of (1 m × 1 m × d m), where d is thickness of the material layer needed for tenfold attenuation of X-ray and gamma radiation.

Data presented in Table 3 show that ratios between lead and steel mass to micalex mass remained the same, which confirms conclusions given in Table 2.

Thus, authors propose new field of application for mica- and glass-based composite materials, that is, for radiation protection of buildings and structures of different purpose.

**Table 3. Thickness of panels for tenfold attenuation of X-ray and gamma radiation at different radiation energies; volume of conventional panels and their masses for different materials**

| Material        | Density ρ, kg/m³ | Layer thickness d (cm) at radiation energy of 10 MeV | Volume V (1m × 1m × d m), m³ | Mass m, kg | Layer thickness d (cm) at radiation energy of 15 MeV | Volume V (1m × 1m × d m), m³ | Mass m, kg |
|-----------------|------------------|-----------------------------------------------------|-------------------------------|------------|-----------------------------------------------------|-------------------------------|------------|
| Lead            | 11300            | 4.1713                                              | 0.041713                      | 471.357    | 3.6665                                              | 0.036665                      | 414.315    |
| Aluminium       | 2700             | 37.1985                                             | 0.371985                      | 1004.360   | 39.4278                                             | 0.394278                      | 1064.551   |
| Steel           | 7890             | 9.8823                                              | 0.098823                      | 779.713    | 9.5543                                              | 0.095543                      | 753.834    |
| Water           | 1000             | 104.6630                                            | 1.046630                      | 1046.630   | 119.3049                                            | 1.193049                      | 1193.049   |
| Concrete (common) | 2300           | 62.4007                                             | 0.624007                      | 1435.216   | -                                                   | -                             | -          |
| Micalex         | 3000             | 10.4663                                             | 0.104663                      | 313.989    | 12.3133                                             | 0.123133                      | 369.399    |

4. Conclusion

The study presented is devoted to the problem of radiation protection of humans in the places with high radiation background. The subject of analysis was radiation pollution of the Irkutsk oblast. The paper demonstrated the need for engineering and constructing the buildings resistant towards radiation. Linear attenuation coefficients for X-ray and gamma radiation at different values of radiation energy were calculated. Thickness of layers for two-fold and ten-fold attenuation of radiation was calculated for materials most demanded and most frequently used for radiation protection. Masses of conventional panels of equal area for thickness ensuring twofold and tenfold attenuation of radiation were calculated.
and compared. Studies performed allowed conclusions on economic feasibility of using micalex for radiation protection.

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