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Modification of Composite Materials Used for Radiation Protection

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Abstract*— Considered composite materials, which are used as elements of radiation protection. They are made of polystyrene and were reinforced with metal aluminum. As the filler used tungsten powder. Conducted testing of composite materials manufacturing. The criteria for homogeneity control by infrared radiometry. The dependence of hardness of the composite material on the amount of the metal component and the particle size of the filler. Numerical methods, the dependence of radiation-protective characteristics of the composition of the components of the composite material.

***Index Terms*— composition materials, polystyrene, radiation protection.**

I. INTRODUCTION

An important condition for safe operation of nuclear facilities is the radiation protection personnel and equipment. To create an effective protection against ionizing radiation requires special materials [1-3]. These materials must have high radiation-protective characteristics and have additional properties. Additional requirements depend on the application materials. There are two main areas of radiation protection - protection of stationary and portable. In our case, those materials for PPE. Among the protective equipment should be noted individual protective systems (IPS). They are used by operating personnel of nuclear facilities, fire and rescue service, and medicine.

For protection against ionizing radiation apply different materials. They must have high radiation-protective properties. Additional requirements for protective materials are determined by the specific conditions of use. Depending on where the operating material must have a certain heat-insulating properties, mechanical characteristics conform strength. Structure of the material and its properties are changed during operation in the zone of increased radiation exposure. Possible destruction of the material. Modification of the base material with various additives can reduce the rate of development of these processes. Selection of additives allows to obtain a composite material with necessary characteristics [2]. Creation of composite materials is a labour intensive task. It is necessary to choose basis of material, define additions, and develop the technological process of making of composite material. Changing the properties of the composite material depends on the composition of components. The structure of additions influences on descriptions of composites. We must address the technology of additives. Characteristics of the composite material are disturbed in violation of the process.

Our main objective was to create a radiation-shielding material with desired properties, for the needs of individual protection. Work was carried out for the use the material in the personal protective systems. Individual protective systems are designed to protect people from the effects of ionizing radiation. Given the requirements for personal protective systems. The main task - effective protection against ionizing radiation. However, individual protective systems are apply not only on nuclear objects. They are also used in the rescue service and medicine. Therefore, the materials must have additional requirements. These are the properties: effective thermal protection, low weight, flexibility, hardness. The essential requirement is the ease of manufacture and processing of the composite material.

II. CHARACTERISTICS OF COMPOSITE MATERIALS

Composition materials were before developed, where as additions applied an aluminum and tungsten [2]. These elements, used as powder. Characteristics of composite depend on composition of component of filling. Polystyrene was applied as material by base. It has low thermal conductivity, low chemical reactivity and a high durability. There is a well-established manufacturing technology of polystyrene. Melting point 190-200 °C polystyrene. Consequently, the use of composite materials based on polystyrene only in so-called "warm" zone. Radiation-protective properties of pure polystyrene were studied in. Clean polystyrene can provide effective protection against radiation gamma-ray energy of 150 keV. At higher energies (up to 1.5 MeV) the weakening of the absorbed dose is no more than 10%. With the purpose of increase of radiation-protective properties in polystyrene include different additions. Protecting from x-ray and gamma-radiations carried out by heavy metals (Pb, W, Mo) [3]. For protecting from the stream of neutrons there are easy elements (B, H, N, C) [4].). Aluminum is used for reinforcement of composite material [1-3].

III. LEADTHROUGH OF WORKS

Were conducted work on the improvement of heat-insulating properties of composition material. Tasks: and) determining the amount of all the components of the composite material; in) determination of form and structure of

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protective layer. Polystyrene is good thermal insulator. Transfer of heat - diffusive. We will substitute a continuous heat cover layer by the laminate structure. There are changes in the material structure [4]. We will create heat-insulating intervals in continuous material. At these intervals the heat is transferred by radiation. Diffusion heat transfer more than the radiative emission. Increasing the number of periods, reduces the thermal stream. The heat-shielding layer was made in the form of balls. This shape increases the number of intervals. Balls it is simple to produce. Balls size is chosen experimentally. Balls with the diameter of 2 mm and 4 mm. Thickness of protective layer of 10 mm. On this distance there can be 4-5 intervals, diameter balls of 2 mm. If diameter of 4 mm the number of intervals 1-2. These laminates diminish a thermal stream. He is weakened on 15-30%

The composite material was produced on a standard industrial equipment. Individual serial parts were made. The composite material produced by several technological schemes.

The first technology. A granular polystyrene, aluminum powder, tungsten powder is placed into the heating chamber. Mixture is mixed. The screw used for mixing the mixture. The mixture was heated to the temperature 196 °C. This melting polystyrene. The heating was performed until complete melting of granular polystyrene. Blowing, extrusion, casting under constraint, extrusion is used for the manufacture of polystyrene. Balls made of polystyrene by injection molding. The components of the composite material are evenly distributed across the ball. Balls may have an irregular shape.

Second scheme. Changed a technological process. Mixed granular polystyrene and powder-like aluminum. Mixture was heated to the temperature melting polystyrene. Mixture was mixed. Powder-like tungsten was added to molten mixture. Homogeneity of distributing of components is increased. There was an improvement it is used. In first case applied screw. The areas of stagnation appear. The presence of the components prevails therein. Therefore, begin to rotate the entire container. The creation speed of the composite material has been increased. Applied a powder-like aluminum and powder-like tungsten they have different particle sizes. Powdered aluminum has a particle size: 10-20 microns, 50-60 microns. Tungsten particles had a size of 30-40 microns, 200-210 microns. Mixed up components. The size of particles is different. Homogeneity of mixture depends on speed of rotation of capacity. Speed of rotation changed from 10 rev/min to 90 rev/min. Speed of heating, speed of rotation were managed. Size of particles of components, speed of rotation, time of heating was picked up experimentally. Quality of composite material depends on these sizes. He has certain characteristics. The sizes of particles were experimentally found. The particles of aluminum had a size of 10-20 microns. Particles of tungsten - 30-40 microns. Speed of rotation of capacity was equal 35 rev/min. Maximum mixing get at these values. Particle component is uniformly dispersed in the composite material [1]. Heavy tungsten particles accumulate near the wall when the high speed of rotation. The mixture was separated when speed low.

Temperature regime is an important parameter. The homogeneity of the metal component is broken at high temperature. Lumps are formed at low temperature. The melting point of polystyrene is a point of reference. Diagnostics of change of temperatures was carried out thermal imager Ti-814. Its sensitivity of 0.08 °C. Thermal imager makes remote control. Studied the infrared radiation from the surface. Thermal imager was placed over the mixture. Prepared surface temperature. Monitoring made in the manufacturing process of the composite material.

The change in temperature is shown in Figure 1. Is the initial stage of the process?

On the thermo gram area with a higher temperature have a bright color. At these points the material is heated up. Warming up an individual component of the mixture is uneven. Components of tungsten and aluminum have high conductivity. In the area of the heater warms up the whole surrounding volume of the metal powder. Polystyrene is the thermal insulator. Therefore, it heats up differently. Appear melted regions. Metallic components stick on them. The warmed up formed lumps. The warmed up lumps appear. They will heat up. These lumps are moved throughout the volume of the mixture. On the thermo gram (Fig. 1a), they are seen as bright dots.

We will define nature of heterogeneity. We will analyze the graphs of change of temperatures along sections 1 and 2. We will consider a graph which passes on a section 1 (Fig. 1b). There is an environment with a homogeneous temperature 35.2° C. Inwardly area with a temperature 38.7° C. The chart of change of temperature has the appearance of plateau. We have smooth scopes of plateau. The heated area is in more cold volume.

On this plateau is also an area with a temperature of 41.6° C. It is seen in the thermo gram as the white point. Border sharp peak. This hot object in the insulating medium. The heated lump of aluminum or tungsten in polystyrene. Graphs of temperature change along the section shown in №2 Fig. 1c. It has two peaks with a temperature 39.9° C. The shape of the boundaries of the peak can be concluded that at these points are two lump heated material. On the thermo gram, witnessed a significant number of different temperature anomalies. This indicates insufficient power heating and stirring. Thermal control is exercised throughout the entire process of mixing Thermal picture gradually changes during the subsequent increase in temperature of the mixture. Increases the number of areas with a high fever. Increases the overall temperature of the mixture. More and more there is a quantity of melted regions.

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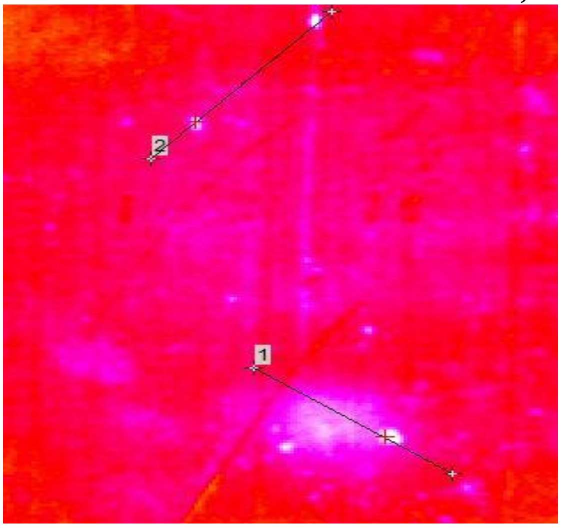

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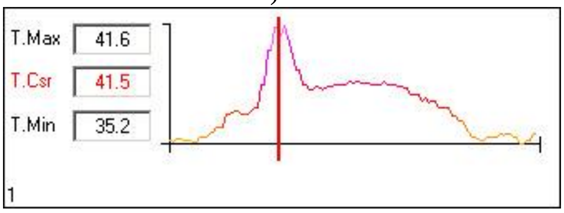

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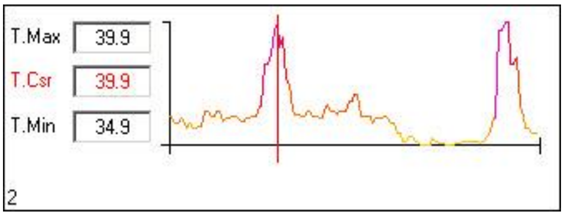


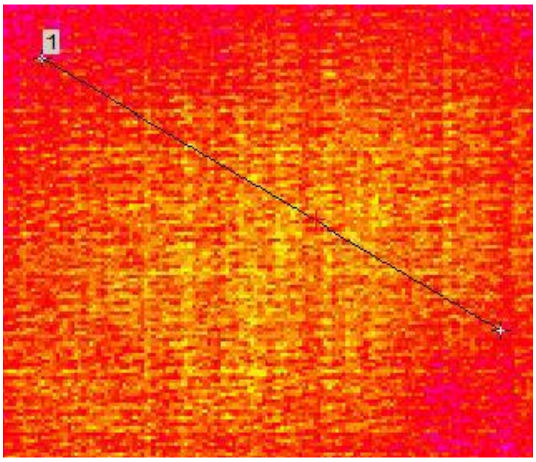
c)

Fig. 1. The thermo gram surface temperature of the mixture (a). The graphs of temperature change along the sections 1, 2 (b, c). Beginning of the manufacturing process.

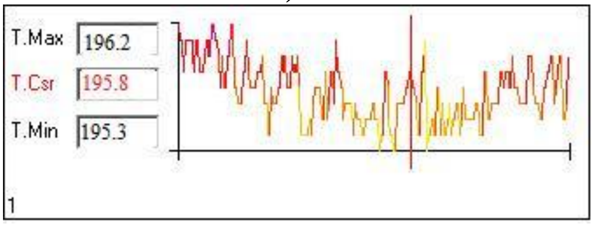
When the temperature of mixture approaches the temperature of melting of polystyrene a thermal picture is smoothed out. Results of thermographic control of mixture are shown on Fig. 2.

Temperature field on the surface of the mixture is shown on thermo gram (Fig. 2). Have a uniform surface color. There are no points of higher or lower temperature. No violations that show structural defects. On Fig. 2c is a graph of temperature changes on the surface of the mixture. Graph given along section 1. Temperature variations are of the 0.9° C.

On this stage it is necessary exactly to maintain the temperature of heater. The density of polystyrene in the liquid state is regulated by the temperature of heater. Lumps appear at a low temperature. Polystyrene evaporates at a high temperature. All mixture is in a drum. A drum is revolved. Select up speed of rotation of drum an experimental way. It is needed to get the even distributing of metallic component. Speed changed from 30 rev/min, up to 70 rev/min. Applied different speeds for every type of composition material. At high-rate metallic component moves on the edge of capacity. At low speed - bad mixed.



a)



b)

Fig. 2. Thermo gram of temperatures on surface of the mixture (a). Graph of change of temperatures on surface of the mixture (b). Melting polystyrene.

IR radiometric control finds to heterogeneity. We can correct them. Additional control was conducted in an optical range. Looked after the color of surface of mixture. Observed color of the surface of the mixture. Appearance on the surface of mixture of bands or spots of other color - heterogeneity shows. Homogeneous material has a uniform color.

Radiation-protective properties of composite materials were studied. They depend on composition. Composition of component was determined from characteristics of composite material. It is necessary to take into account next characteristics:

A) Plenty of polystyrene worsens radiation-protective properties.

B) A small amount of polystyrene degrades heat-shielding characteristics.

C) A small amount of polystyrene complicates production.

D) A large number of tungsten increases the weight, deteriorates the insulating properties.

E) A small amount of aluminum worsens durability.

Therefore, we can obtain various composite materials. For stationary protective devices used heavy composite material. Lightweight and bulk composite material used for personal protective systems. An ionizing radiation all composition materials must well absorbed.

In the present work, radiation-protective composites with different mass compositions. The hardness of the obtained samples was measured. Mass percentage of component is given in Table 1.

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Table 1. Mass constituents of composition materials.

Material	Polystyrene, (PS), mass %	Tungsten, (W), mass %	Aluminum, (Al), mass %
C100104	26.7	47.0	26.3
C080106	19.8	43.6	36.6
C060108	13.9	40.6	45.5
C050109	11.2	39.3	49.5

Hardness measurement made by the method of Rockwell. Hardness of polystyrene measured by this method. Methodology Rockwell checks reinforced materials and materials with inclusions. The composite material is such a material. Hardness of the material (C100104) was equal to the value of 72 on the scale of M. The hardness of the sample is close to the hardness of pure polystyrene (69). The aluminum component was 27% from the volume of mixture. Component tungsten and aluminum - 33%. The hardness of the specimen (C080106) had a value of 80. The amount of aluminum was 40% of the total. The amount of aluminum and tungsten - 45%. For sample (C060108) hardness equal to 82. Aluminum component was - 53%. Maximum hardness was in the sample (C050109). It was equal to the value of 88. Volume percent of aluminum is equal to 60%. When making all samples used, powder-like aluminum and powder-like tungsten. The size of the aluminum particles equaled 10-20 microns. The particle size of the tungsten equal 30-40 microns.

Also determined dependence of hardness of composite material on the size of particle. Were investigated the standards of C080106a, C080106b, C080106c. At their making used a powder-like tungsten and aluminum of different sizes. At the production of material of S080106a, used aluminum with the size of particle of 50-60 microns, tungsten with the size of particle of 30-40 microns. Hardness was increased to 88. Got the value of hardness 90 for the standard of S080106b. The particles of aluminum have a size 10-20 microns. The particles of tungsten have a size 200-210 microns. Got the value of hardness 92 for the standard of C080106c. The particles of aluminum have a size 50-60 microns. The particles of tungsten have a size 200-210 microns.

On the basis of the got results, it is possible to do the followings conclusions:

a) When the amount of metallic constituent grows - hardness of composite material grows;

b) When the size of metallic particles grows - hardness of composite material grows.

However, with increasing amounts of steel components, and their particle size is difficult to obtain uniform distribution of the components. Therefore, the ratio of the plasticizer, the base and the filling is chosen experimentally.

We studied the radiation-protective properties of composite materials. Practical verification of security features is time consuming task. Its solution requires a considerable amount of time. Therefore, numerical mathematical methods are therefore used.

Using mathematical modeling allows to obtain results without practical tests. For modeling the efficiency of absorption of ionizing radiation used package Geant4 v 4.9.6p02 [5]. The calculated results are in good agreement with experimental data.

Calculations are performed for several samples of composite materials. Their composition is shown in Tables 2–4.

Table 2. Mass constituents of composition materials with a high content of metal components.

Material	Polystyrene, (PS), mass %	Tungsten (W), mass %	Aluminum, (Al), mass %
C050010	16.9	00.4	83.7
C050109	11.2	39.3	49.5
C050505	4.8	83.5	11.7
C050901	3.1	95.3	1.6
C051000	2.5	97.1	0.4

All materials from this table have similar characteristics in all respects. Technology of production is similar to high-speed mode and time of manufacture. They have a low thermal protection, since the content of the metallic component is high. The hardness of the samples was in the range of 88 – 92. Homogeneity of distribution of the metallic component by volume of the mixture is 60%.

The weakening of the absorbed dose was calculated according to the method discussed earlier in [1]. The simulation results are shown at Fig. 3-5.

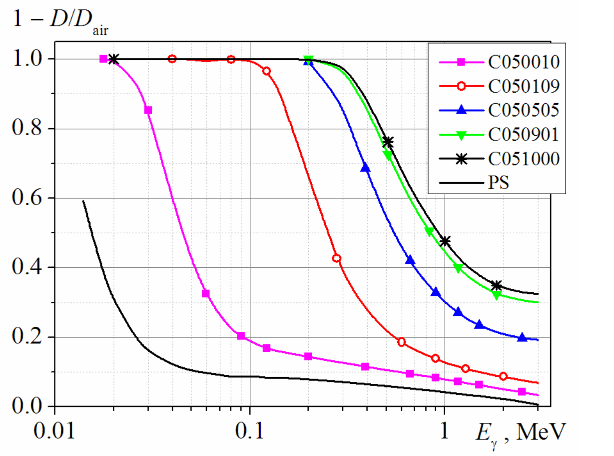

Fig. 3. The weakening of the absorbed dose of gamma radiation with a protective layer of the composite material.

The calculation of the absorbed dose to tissue-equivalent phantom made [6]. Dose which absorbs phantom in the absence of the protection is denoted as D_{air} . From Fig. 3 we see that the lowest attenuating characteristics of pure polystyrene. The highest rates in the composite material C051000. We will continue to use as markers. In all cases, the thickness of the protective layer was chosen to be 1 cm. Radiation-protective characteristics of all the samples differ significantly. They are related to the number of components of tungsten. Samples C051000 and C050901 close in the

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efficiency of absorption of gamma radiation. Half easing remains even at energy of 1 MeV. Samples C050109 and C050505 are useful for protection against gamma rays with energies up to 200 keV. In the second phase have been studied following samples:

Table 3. Mass constituents of composite materials of the second group.

Material	Polystyrene, (PS), mass %	Tungsten (W), mass %	Aluminum, (Al), mass %
C080601	6.9	91.0	2.1
C080403	9.4	82.0	8.6
C080304	11.4	74.7	13.9
C080106	19.9	43.6	36.5

Hardness of these samples is in the range 78 – 82. Metal fraction was 45% by volume of the mixture. Thermic properties of these composite materials is 15% higher than in the previous case. Radiation-protective properties of these materials are shown in Fig. 4.

All samples were fully absorb gamma rays with energies up to 100 keV. At these energies absorbed dose attenuation curves are arranged in a narrow range. They are close to the limit values.

With increasing energy absorption efficiency deteriorates. Upon reaching energy of 1 MeV gamma-ray flux is reduced by 30%. As in the previous case, there is a direct dependence of the absorbed dose on the content in the composite material of tungsten.

The hardness of the samples examined was a little more than that of pure polystyrene and equal to the value of 72-75. Number of metal components was of the 30%. Insulating properties do not differ from polystyrene. On Fig. 5 gives the curves of the change of the absorbed dose of gamma radiation.

For a more complete explanation of the basic characteristics of composite materials has been studied samples presented in Table 4.

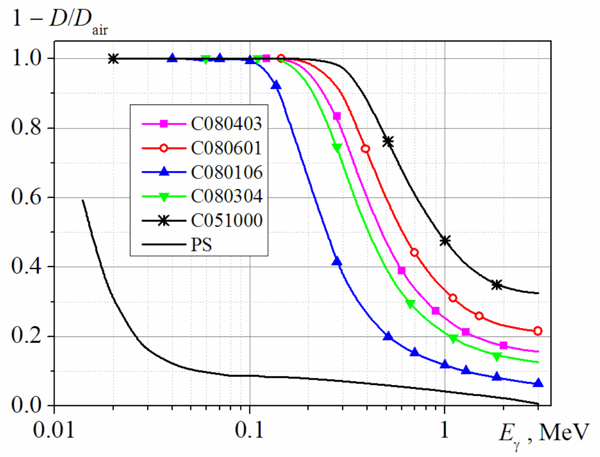

Fig. 4. The weakening of the absorbed dose of gamma radiation with a protective layer of the composite material of the second group.

All samples were fully absorb the flux of gamma radiation in the energy range from 0 to 130 keV. In industrial radiography maximum energy spectrum of the radiation is in the range up to 122 keV. Therefore, these composite materials are useful for radiation protection of the X-ray radiation.

Table. 4. Mass constituents of composition materials of the third group

Material	Polystyrene, (PS), mass %	Tungsten (W), mass %	Aluminum, (Al), mass %
C100402	11.7	82.5	5.8
C100302	14.8	77.9	7.3
C100203	19.1	66.9	14.0
C100104	26.8	46.9	26.3

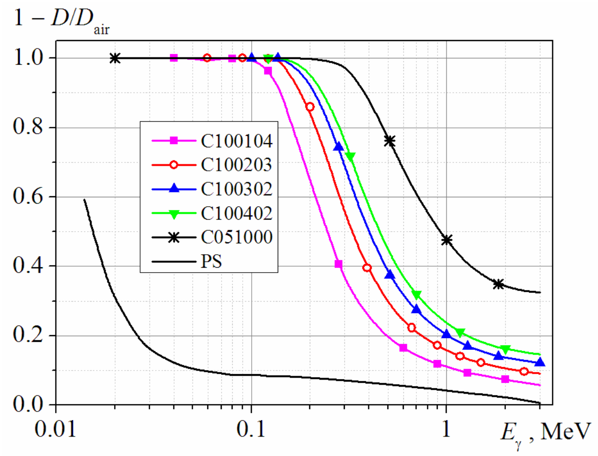

Fig. 5. The weakening of the absorbed dose of gamma radiation with a protective layer of the composite material of the third group.

The deterioration of the radiation-protective properties begins with energy of 150 keV. When the energy of 300 keV seeing half the weakening of the absorbed dose of gamma rays. In this case it is essential, as in a range up to 300 keV is focused maximum amount of gamma-radiation. We will mark that such properties show most samples from this group.

When used in the individual protective systems (IPS) materials should have: a low weight, high thermal insulation properties, to be free flowing. To achieve the flexibility of individual security systems, it is necessary that the friction between the individual elements of the composite material is minimized. At the choice of composition material, it is also necessary to take into account the cost of making, complication of technological process. Material of S100203 conforms to all these requirements. Application of material of C100203 is expedient.

In the manufacture of permanent protection can ignore the requirement of low weight, violation of form of separate elements. Thus, the stationary protection of sources of X-rays can be produced using materials C080304, C050505. Consequently, the problem of selection of the composite material is greatly simplified.

All considered composite materials have differences in their characteristics. Therefore, for each case can pick your necessary composite material.

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IV. CONCLUSION

1. Matrix composite material is manufactured for protection against ionizing radiation.

2. The technological modes are got. The methods of infrared-radiometry are applied.

3. Composition of components composite material for protect was selected.

4. Dependence of the absorbed dose of gamma-radiation from the composition of the protective material is studied using numerical methods.

5. The hardness of the composite material from the amount of metal component has been found.

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