Radiation-protective properties of emergency clothing for firefighters

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Abstract: - A method for determining the effectiveness of radiation-protective clothing under external radiation exposure has been developed and tested in laboratory conditions. The attenuation coefficient of gamma and beta radiation from radionuclide sources by a composite shielding material has been measured. A method is proposed for determining the composition of the material from the spectrum of characteristic radiation, which significantly affects the exposure of personnel in radiation protective clothing.

Key-Words: - radiation protective clothing, composite material, radionuclide source, gamma radiation

1 Introduction

The increase in the number of potentially hazardous objects makes it urgent to study the characteristics of new composite materials to create personal protective equipment against the harmful effects of technogenic factors. To reduce the risk of exposure at radiation facilities of nuclear power, composite materials with metal microparticles are created. The metal components of composites efficiently absorb the most common radiation gamma and beta radiation and convert it into localized X-ray and electron radiation.

The interaction of gamma radiation with metal atoms through photoabsorption and Compton scattering reduces the energy and intensity of the primary radiation. On the basis of polymer matrices modified with different fillers, composite materials are created that have special performance characteristics and specified strength properties for fracture toughness and shear.

Microparticles of lead, tungsten and rare-earth elements are used to create radiation-protective composite materials. Composite materials with heavy metal components increase the absorption of radiation by several times. High-impact polystyrene is used to create a dielectric radiation-protective composite material with high mechanical properties and high resistivity (10^{14} Om·cm) [1].

Research on emergency radiation fields at radiation facilities has led to the development of new personal protective equipment - emergency radiation protective clothing. A new industry was created, producing, together with enterprises of the textile and haberdashery industries, personal protective equipment based on new radiation-protective materials.

The use of composite material in special protective clothing is necessary to significantly reduce the energy and penetration of radiation and protect the vital organs of personnel.

2 Improving the effectiveness of radiation protective clothing

The task of developing highly effective radiation-protective polymer composite materials filled with metal particles is urgent.

Radiation-shielding polymer materials and composites with a service life of about 15 years have technological and operational disadvantages. It is important to create polymer composites with high physical-mechanical and radiation-shielding characteristics.

Currently, research is underway to improve the means and methods of emergency radiation protection for firefighters to ensure the environmental cleanliness of nuclear power. The work is carried out in interdisciplinary scientific research: applied nuclear physics, environmental safety problems, nuclear medicine.

To improve the special protective clothing for firefighters and increase radiation safety at nuclear power plants, it is urgent to introduce new composite materials for the manufacture of firefighters' uniforms. Under these conditions, it is necessary to carry out an examination and verification of the effectiveness of radiation protective products and materials in emergency radiation fields of external gamma and beta radiation.

2.1 Development of a method for measuring the protective properties of a composite

It is required to develop spectrometric and dosimetric methods for non-destructive testing of the radiation-protective properties of a composite material. To do this, it is necessary to measure the absorption coefficient of gamma and beta radiation by the material using laboratory spectrometers and radiometers using standard low-intensity radionuclide sources of cobalt-57 and strontium-90.

The creation of effective emergency radiation protective clothing requires quality control and uniformity of the wide-sheet composite material. This requires a control and measuring stand for monitoring the absorption of gamma and beta radiation by the protective material. The stand should allow automatic measurements at the specified points of irradiation of the broadband composite material, move and align the gamma source and detector. The control of the mode of measurement and accumulation of experimental data should be carried out using software modules for contactless digitization and correction.

2.2 Development of a metal component control in a composite material

To control the technological and operational parameters of the composite material in the manufacture of personal protective equipment for personnel, it is necessary to develop a method for determining and checking the elemental composition of the metal component of the composite.

The metal microparticles intensively absorb external radiation and reduce its effect on the body, thereby ensuring the radiation-protective properties of the composite material. In doing so, they emit characteristic X-rays, which are monochromatic [2].

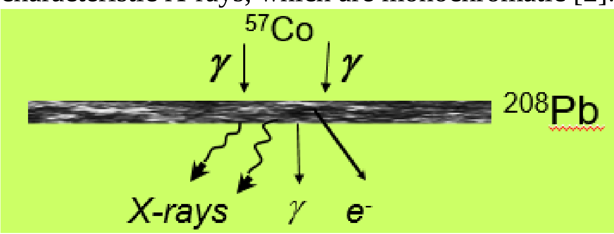

Fig.1 Рентгеновское характеристическое излучения металла в композите при гамма облучении композитного материала.

By registering the characteristic radiation of metals in a composite under gamma irradiation from ^{57}Co radionuclide source can determine the composition of the protective material.

3 Methods for measuring and monitoring the radiation-protective properties of a composite material

A method has been developed for measuring and checking the radiation-protective properties of a composite material using a gamma-spectrometer based on a scintillation detector with a NaI (Tl) crystal. A scintillation detector measures the direct spectrum of gamma radiation from ^{57}Co radionuclide source and the spectrum of attenuated radiation transmitted through the material (Fig.2).

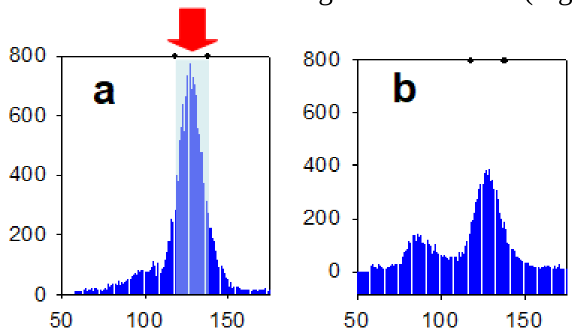

Fig.2 Spectra of gamma radiation from a cobalt-57 source (a) and transmitted through a protective material (b), measured by a scintillation detector.

In a given range of spectra in the energy region of 122 keV, the fluxes of direct gamma radiation and attenuated radiation transmitted through the material are determined. The attenuation coefficient of monochromatic gamma radiation at an energy of 122 keV is defined as the ratio of the direct gamma radiation flux incident on the material to the attenuated flux transmitted through the material.

To measure the fluxes the SKS-07P-G41 spectrometer was created (Fig.3).

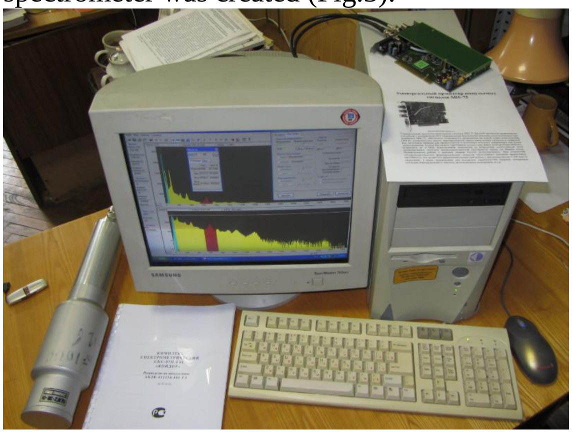

Fig.3 Gamma spectrometer SKS-07P-G41 based on a NaI (Tl) scintillation detector and an SBS-75 pulse signal processor.

The SKS-07P-G41 gamma-spectrometer has a scintillation detector with a NaI (Tl) crystal, a pulse signal processor SBS-75 and an operator's computer with a program for controlling and pre-processing the spectrum "Analyzer emulator". The measurement of gamma fluxes is carried out during a fixed live time of collecting statistics with a constant geometry.

Using the SKS-07P-G41 spectrometer, direct and attenuated fluxes of gamma radiation were measured for several samples of radiation-protective material. (Fig.4).

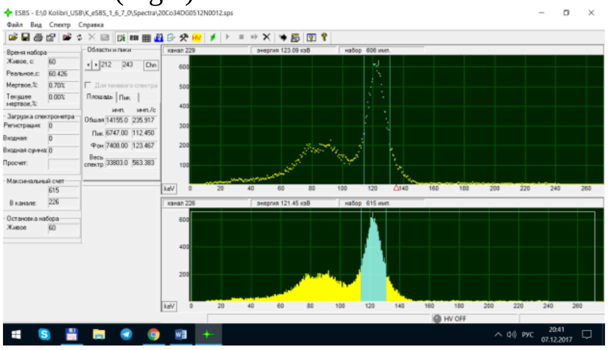

Fig.4 Spectrum of gamma radiation from a 57Co source, measured with the SKS-07P-G41 gamma spectrometer.

The measurement of the fluxes of gamma radiation was carried out by a non-destructive method by irradiating the composite material with a 57Co source with an activity of 105 Bq. The count rate during measurement did not exceed 1000 s-1 with a dead time of less than 1%. The flow measurement time was 60 s. The flows in a given channel interval were determined using a control program. The attenuation coefficient of gamma radiation of the lead composite material measured with an accuracy of 1% was 3.5.

The attenuation of external beta radiation by the composite material was measured using a radiometric system based on an MKS-01R radiometer (Fig.5).

Fig.5 Radiometric system for measuring attenuation of $^{90}Sr(^{90}Y)$ beta source material.

The fluxes of beta radiation from $^{90}Sr(^{90}Y)$ beta source and from the material measured by a beta radiation detector were accumulated in the radiometer and transmitted using the electronic module Raspberry Pi 2 via a local network to the server for processing and visualization on a time diagram (Fig.6).

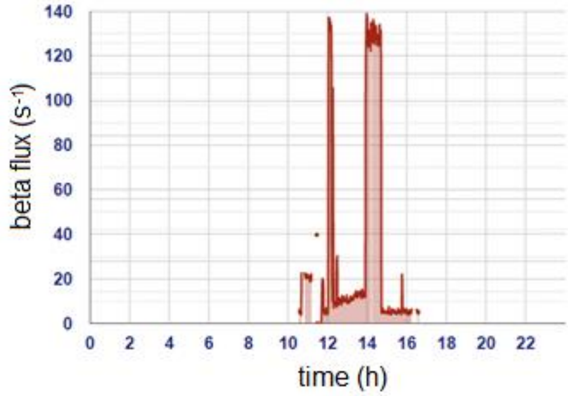

Fig.6 Diagram of beta particle fluxes from the $^{90}Sr(^{90}Y)$ source obtained using a radiometric system.

The radiometric module allows real-time measurements of the attenuation of external beta radiation by the radiation-protective material from the $^{90}Sr(^{90}Y)$ source. The measured attenuation of beta radiation by a lead composite is about 200.

For the manufacture of special protective clothing for firefighters of the insulating type, a wide-sheet composite material is used. Checking the homogeneity of the radiation-protective properties of the material is carried out at the control and measuring stand (Fig.7).

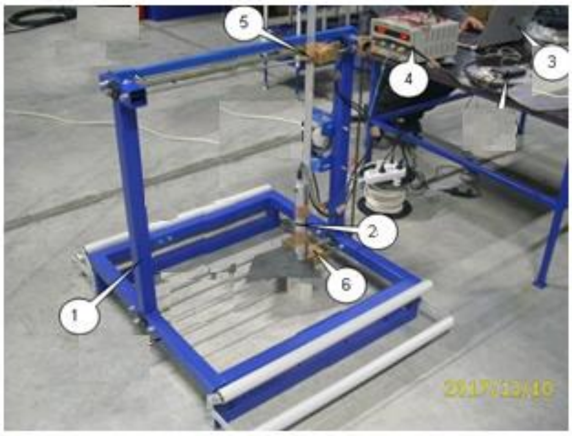

Fig.7 Test bench for testing sheet composite material. 1 - frame, 2 - detector, 3 - spectrometer processor, 4 - power supply, 5 - detector movement carriage, 6 - gamma source movement carriage.

The test bench consists of a supporting structure, systems for moving the source and detector, and supply systems for sheet protective material. When the sheet composite material is fed, after a certain period of time, the flux of gamma radiation is measured from the ^{57}Co source, which has passed through a local area of the sheet material. After collecting statistics, the detector and the source are synchronously moved horizontally to the next specified area of the material, where the fluxes are measured again. Measurement and movement of the detector are performed automatically at regular intervals under the control of the software module.

When irradiated with gamma quanta from a ^{57}Co source, characteristic X-rays, Auger electrons, and conversion electrons are generated in metallic microparticles of the composite material. Conversion and Auger electrons are almost completely absorbed in the composite radiation shielding material.

A low-background detector made of ultrapure germanium was used to measure the spectrum of secondary radiation from the irradiated composite radiation-shielding material (Fig. 8).

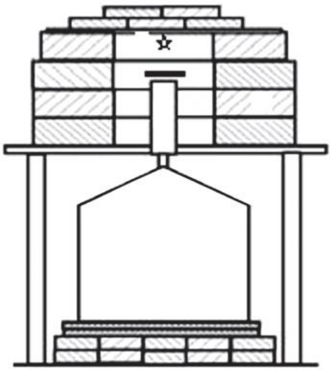

Fig.8 Low-background spectrometer based on ultrapure germanium detector [3].

In addition to the peaks from the ^{57}Co source at 122.1 keV and 136.5 keV, the spectrum contains X-ray peaks with energies of 75 keV and 85 keV (Fig.9). The measurement time for the secondary radiation spectra was 150 s.

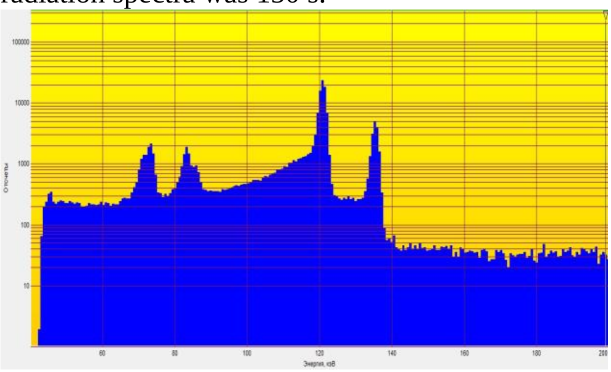

Fig.9 Spectrum of secondary radiation during irradiation of a composite material, measured by a Ge detector.

The energy of the characteristic radiation and the elemental composition of the metal component of the composite material are determined from the peaks of monochromatic radiation in the gamma spectrum of secondary radiation.

The measured spectrum of secondary radiation from a Pb plate has similar peaks at the same energies (Fig.10).

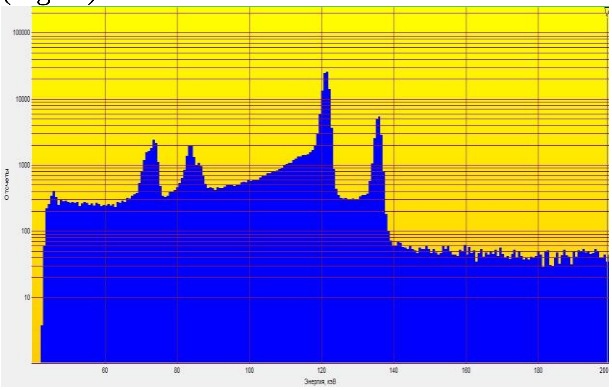

Fig.10 The emission spectrum from a lead plate, 1 mm thick, measured with a Ge detector.

The peaks in the spectrum of secondary radiation from the tungsten plate are located at energies of 59 keV and 67 keV (Fig.11).

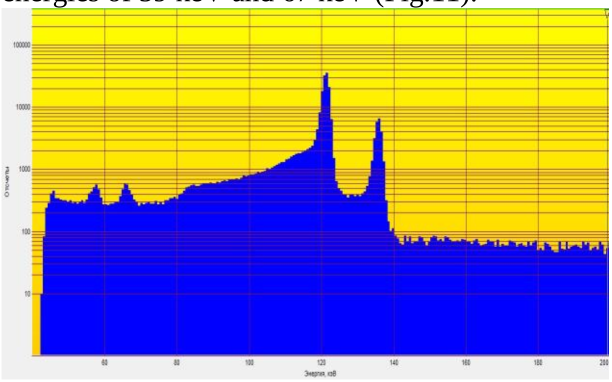

Fig.11 The spectrum of radiation from a tungsten plate, 1 mm thick.

This means that the filler of the polymer radiation-shielding material is lead microparticles. Secondary radiation introduces an additional dose of radiation to personnel wearing radiation protective clothing. This is a harmful factor, that needs to be reduced. This is especially important for a material that has a large attenuation coefficient of external gamma radiation, measured for a bismuth plate with a thickness of 5 mm. (Fig.12).

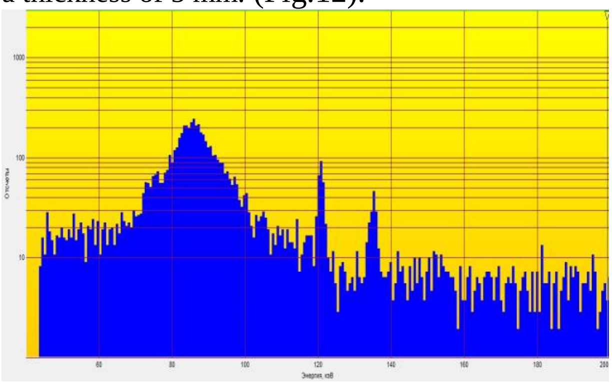

Fig.12 Secondary radiation spectrum from a bismuth plate, 5 mm thick.

The intensity of the characteristic radiation for the lead material was more than 15% of the radiation transmitted through the material with an attenuation coefficient of about 3.5. The same value for tungsten is 2% when the external radiation is attenuated by a factor of 2. When external radiation is weakened by a factor of 10 or more, secondary radiation becomes dominant in the exposure of personnel wearing radiation protective clothing.

4 Conclusion

The developed spectrometric method for measuring the radioprotective properties of composite materials using radionuclide sources makes it possible to test the effectiveness of emergency protective clothing for firefighters under external radiation exposure.

Measurement of the attenuation coefficient of external radiation by the material and the spectrum of the characteristic radiation of the composite allows to optimize its composition and performance.

The secondary characteristic radiation and convection electrons generated by the external radiation are emitted from the inner layer of the composite material of the protective clothing. This radiation can significantly increase the residual radiation dose of protected personnel.

To increase the effectiveness of individual radiation protective clothing, the composite material must have a density gradient of the distribution of the metal component over the thickness.

References:

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