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RADIATION SAFETY

Analyzing Composite Materials by Characteristic Radiation

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Abstract—Characteristic X-ray spectra of materials containing heavy-metal components irradiated with gamma rays are measured. The samples are irradiated with photons with energies of 122.06 keV (85.5%) and 136.47 keV (10.7%) emitted by a cobalt-57 source and include tungsten, lead, and bismuth plates and a sample of a radiation-protective composite material. The characteristic radiation from the samples and incident photons passing through the samples are detected with a low-background gamma spectrometer based on a high-purity germanium (HPGe) detector. The measured intensity of the characteristic X-ray radiation from the protective material amounts to 10% of that of the primary radiation. The elemental composition of the radiation-protective material is determined by peak positions in the spectra of the characteristic X-rays from the samples of W, Pb, and Bi. The analyzed composite material features Pb as the dominant heavy component, whereby the primary photon radiation from the source is attenuated by a factor of 3.7. The density of the lead component in the protective material was determined.

Keywords: characteristic radiation, radiation-protective material, composite material, metals, photons

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1. INTRODUCTION

Given the ever increasing number of potentially hazardous objects, one needs to analyze the characteristics of new composite materials toward developing individual protective devices against harmful anthropogenic factors. In order to reduce absorbed doses at irradiated sites and in space missions, new composite materials containing heavy metals are developed [1]. Penetrating radiation largely arises from gamma and beta radiation and neutrons. These can be efficiently absorbed by heavy components of composites and transformed to local X-ray and electron radiation. Special radiation-protective uniforms for firemen involve composite materials with lead and tungsten microparticles [2], whereby the absorption rate of external radiation is increased by several times. The absorption of gamma and beta radiation in protective materials helps reduce the energy and penetrating power of radiation, thus protecting the vital organs of personnel.

2. EXPERIMENTAL METHOD

Low-energy gamma rays interact with matter (such as a composite material) through the processes of photoelectric absorption and Compton scattering, whereby the energy and intensity of the primary radiation are reduced. These interactions produce characteristic X-rays and Auger and conversion electrons. Secondary electrons are almost fully absorbed by the heavy components of the composite, while the X-rays leave the composite material and are detectable. For probing the characteristic X-ray radiation of samples containing lead (75 and 85 keV), tungsten (59 and 67 keV), and bismuth (77 and 87 keV), we irradiate composite materials with photons with energies of

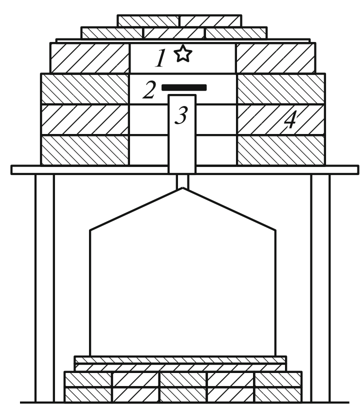

Fig. 1. Schematic of the low-background gamma spectrometer with high-purity germanium (HPGe) detector, showing the cobalt-57 gamma source (*1*), the irradiated sample (*2*), the HPGe detector (*3*), and the lead and tungsten shield (*4*).

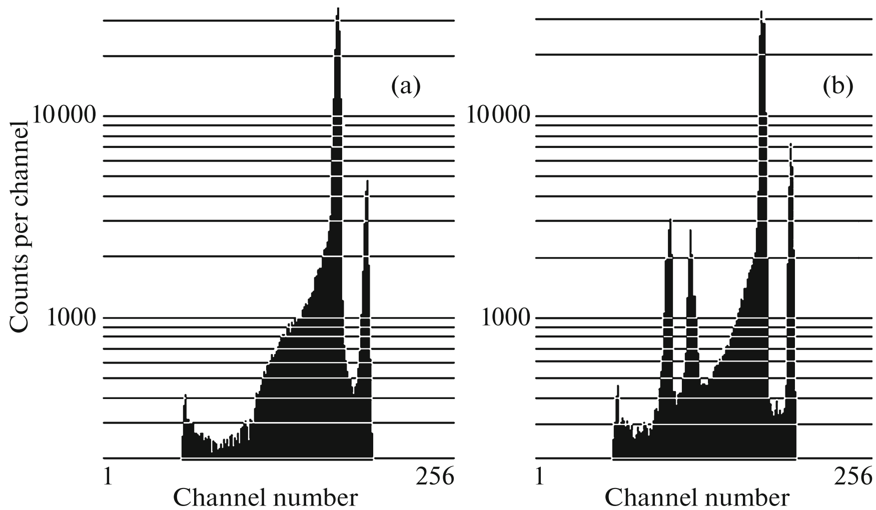

Fig. 2. Spectra of photons from the open Co-57 source (a) and the source covered with the protective material (b) as measured with the low-background gamma spectrometer.

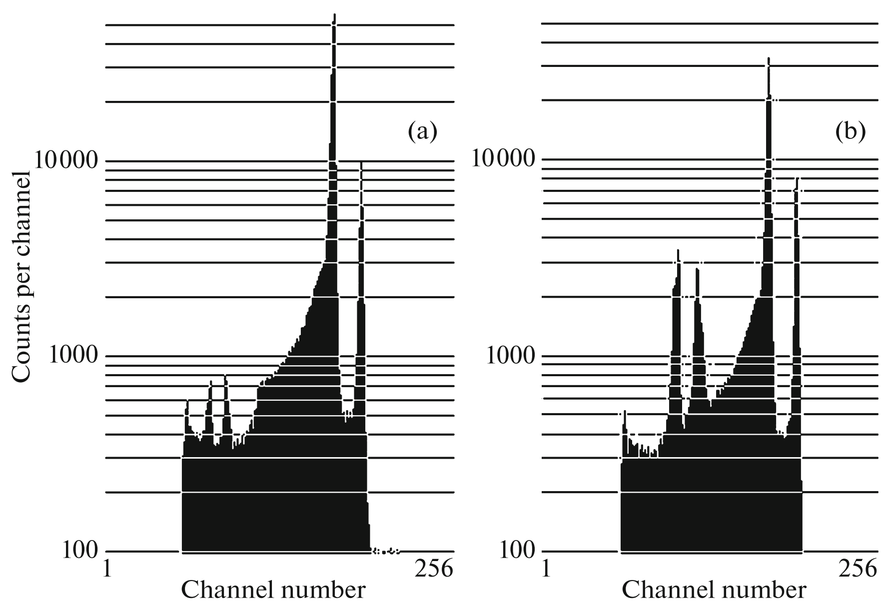

Fig. 3. Spectra of secondary X-rays and primary photons observed with the Co-57 source covered with tungsten (a) and lead (b) plates.

122.06 keV (85.5%) and 136.47 keV (10.7%) emitted by a cobalt-57 source and then measure the spectra of final-state photons. X-rays emitted by the protective material and photons from the source are detected using a low-background gamma spectrometer based on a high-purity germanium (HPGe) detector [3]. The experimental setup is schematically shown in Fig. 1.

The elemental composition and radiation-protective characteristics of the composite material are estimated by the energy and intensity of characteristic X-rays and by the attenuation of the primary photon flux.

3. EXPERIMENTAL RESULTS

We irradiate the Pb, W, Bi, and protective-material samples with photons from a Co-57 source and measure their characteristic X-ray spectra and the attenuated spectra of primary photons. The spectra of primary Co-57 gamma rays and of X-rays emitted by the radiation-protective material are shown in Fig. 2.

Photon spectra corresponding to an open Co-57 source and to a source covered with the protective material have been measured for 50 and 150 s, respectively. The peaks observed in the characteristic X-ray spectrum indicate that the protective material contains a heavy component. The intensity of characteristic radiation amounts to 10% of that of the 122-keV line of the source. Upon comparing the areas under the 122-keV peak in the spectra obtained with and without the sample, one concludes that the protective material attenuates the primary photon flux by 3.7 times.

The peaks observed in the X-ray spectrum are identified using the photon spectra measured with the Co-57 source covered with the lead and tungsten samples (see Fig. 3). The peaks in the spectrum of X-rays emitted by the lead plate (Fig. 3b) imply that the protective material contains a lead component. Taking into account that the absorption of radiation energy in lead is described by a mass coefficient of 2–5 $cm^2 g^{-1}$, from the observed attenuation of radiation, we estimate that the area density of lead in the protective material is about 0.3–0.6 g cm^{-2}.

4. CONCLUSIONS

Gamma rays as the most widespread and penetrating type of radiation can be efficiently absorbed by heavy components of a composite material and transformed into characteristic X-rays. Given a material of unknown content or a multicomponent composite, characteristic radiation can be the only means for determining its elemental composition. For applying this method, one needs reference samples and a bank of spectra of characteristic radiation for the components of composite materials. The results of our investigations can help develop composite materials for efficiently absorbing radiation and reducing its harmful effects on humans.

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