Journal of Engineering Physics and Thermophysics, Vol. 77, No. 1, 2004

CALCULATIONS OF THE PASSAGE OF GAMMA-QUANTA THROUGH A POLYMER RADIATION-PROTECTIVE COMPOSITE

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UDC 678.046.3

We have investigated the radiation-protective characteristics of a thermoplastic polystyrene composite material filled with a high-dispersion modified lead oxide as well as the dependences of the energy (flux) build-up and transmission factors and albedos on the energy and protective-shield thickness. Calculations of the integral characteristics of the radiation-protective properties of materials have been done.

One of the major problems of the radiation physics and chemistry of polymers is the elucidation of the specificity of the radiation processes proceeding in a substance under the action of different kinds of ionizing radiations.

The information available in this field is limited and conflicting. Researchers give primary consideration to the radiation resistance of pure polymers and composites based on them with metal, quartz, and carbon fillers [1, 2]. Information on the radiation resistance of polymer composites filled with metal oligomers is practically absent. The influence of ionizing radiations is often considered separately from the physical, physicochemical, and chemical radiolysis as well as from the macroproperties of polymer materials.

We have investigated the radiation-protective characteristics in relation to the γ-radiation of a thermoplastic polystyrene composite material filled with a high-dispersion modified lead oxide (85 mass %) [3, 4]. The polymer composite (PC) with a density of 4280 kg/m^3 was obtained by the hot-pressing technique at a pressing pressure of 250 MPa.

The investigations were carried out on the basis of point γ-sources of the type of ^{241}Am, ^{60}Co, ^{139}Ce, ^{113}Sn, ^{22}Na, ^{137}Cs, ^{65}Zn, and ^{57}Co with the use of a set of a metrologically standard volume gamma-source and volume gamma-sources of the type of ^{147}Pm and ^{56}Mn and ^{68m}Co obtained by activation by thermal neutrons in the course of the *n*-, γ-reaction radiant from a neutron source of ^{252}Cf on a neutron-activation facility in the 0.01–1.00-MeV range of γ-radiant energies on a γ-spectrometric complex certified at the All-Union Research Institute of Physico-Technical and Radiation Measurements.

In the case of point γ-sources (PGS), measurements were made in a direct axial "source–specimen–detector" geometry, where the radioisotope was located on the central axis passing through the center of the cylindrical specimen and the center of the NaI (Tl) 63 × 63 crystal detector mounted in the housing. The source was placed at a distance h = 8.5 cm from the detector. A lead collimator (detection unit of the BDBS3-1eM type) with a 1.5–2.0-cm collimation window made it possible to form a narrow monoenergetic beam of γ-quanta.

The detector, the specimen, and the source were situated in a measurement zone bounded by a lead cylindrical 5-cm-thick pillar as a shield against the natural γ-background. The spectrometric data were processed on an AI-1024-type amplitude analyzer as a part of the γ-spectrometer with their printout for calculating the areas of analytical γ-peaks and output to the plotter for obtaining spectrograms. For automatic processing of the γ-spectra and for plotting the required functional dependences, an IBM PC-type computer with "Spectrum" software was used. The irradiation and measurement time was 0.5 h.

In the case of volume γ-sources (VGS), a wide γ-quantum beam with energies E = 59 keV (^{60m}Co) and E = 847, 1811, and 2113 keV (^{56}Mn) was formed.

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Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 77, No. 1, pp. 12–14, January–February, 2004. Original article submitted April 9, 2003.

1062-0125/04/7701-0011

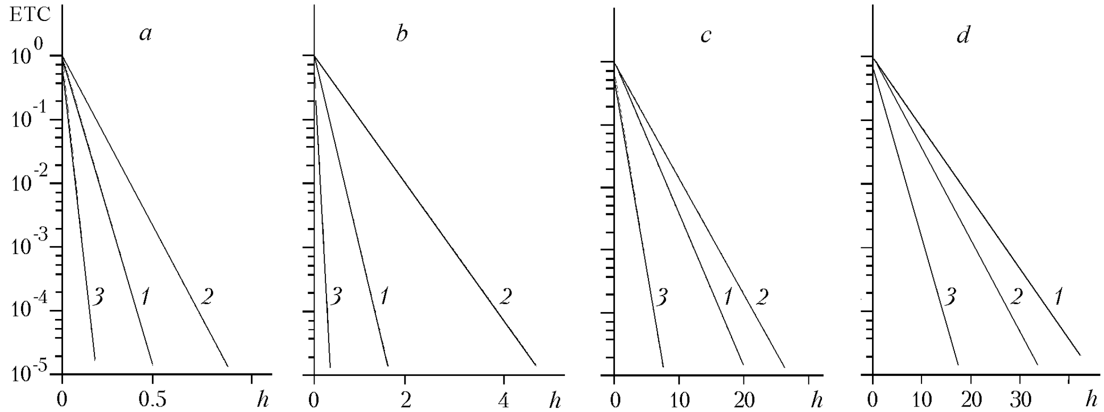

Fig. 1. Energy transmission coefficients (ETC) for a flat monodirectional source with energies of 0.05 (a), 0.1 (b), 0.5 (c), and 1.0 MeV (d): 1) PC; 2) steel; 3) lead. *h*, cm; ETC, rel. value.

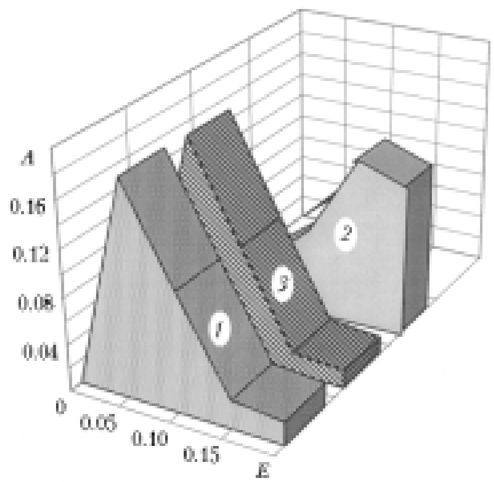

Fig. 2. Energy albedos as a function of the γ-radiant energy for various materials: 1) PC; 2) steel; 3) lead. *E*, MeV.

Comparison of the radiation-protective properties of materials is only possible under the conditions of the specific situation in which they are used. We have considered the problem of using the developed PC for making flat shields. In solving this problem, the quality of the protective composite is largely determined by its thickness (or the layer mass), which provides a given multiplicity of attenuation of radiation.

The dependences of the energy (flux) transmission factors (Fig. 1) and albedos (Fig. 2) on the energy and thickness of the shield for various materials have been obtained. Calculations were made for the case of normal incidence of a uniform γ-radiant flux on a flat layer, which made it possible to obtain the maximum values of the transmission factor. Exactly such values are operated with in practical dosimetry in estimating the efficiency of shields [5].

For high energies ($E > 0.66$ MeV), the main interaction process is the photon scattering by electrons (Compton effect). The mass attenuation factor of photons in this process weakly depends on the chemical composition of the substance. Consequently, the values of the transmission coefficients obtained in the narrow-beam geometry are determined by the mass thickness of protective layers alone. In this case, the key role in the characteristic of the protective properties of a material is played by its density.

The passage of γ-quanta from the sources through the shield wall was modeled by the Monte Carlo method. The physical model of the processes and the contact provision [5] enabled us to carry out calculations for photon energies from 0.01 to 1.00 MeV.

We have carried out calculations of the integral characteristics of the radiation-protective properties of materials. System data for a monodirectional homogeneous γ-source of radiation normally incident on a flat protective PC

TABLE 1. Photon Cross Sections of the PC

E, MeV	$(\mu/\rho)_{bound}$	$(\mu/\rho)_{free}$	$(\mu/\rho)_{phot}$	$(\mu/\rho)_{nar.beam}$	$(\mu/\rho)_{nar.beam-coh}$	$(\mu/\rho)_{\gamma}$	$(\mu/\rho)_{E_\gamma}$
0.010	0.185	0.099	131.679	132.540	131.713	131.68	108.57
0.015	0.182	0.117	42.333	43.096	42.447	42.334	37.404
0.020	0.1790	0.1278	18.8916	19.413	19.007	18.892	17.198
0.030	0.1721	0.1390	6.0009	6.3753	6.1639	6.0106	5.656
0.040	0.1669	0.1429	2.5756	2.8609	2.7155	2.586	2.470
0.050	0.1618	0.1440	1.3029	1.5470	1.4499	1.313	1.267
0.060	0.1575	0.1433	0.7444	0.9634	0.8908	0.759	0.735
0.080	0.1484	0.1401	0.3131	0.4982	0.4533	0.330	0.322
0.100	0.1421	0.1346	0.1581	0.3225	0.2928	0.177	0.174
0.150	0.1277	0.1245	0.0458	0.1839	0.1702	0.069	0.067
0.200	0.1173	0.1150	0.0190	0.1423	0.1343	0.044	0.043
0.300	0.1020	0.1010	0.0056	0.1106	0.1065	0.033	0.032
0.400	0.0914	0.0909	0.0025	0.0955	0.0934	0.033	0.030
0.500	0.0835	0.0830	0.0014	0.0857	0.0845	0.030	0.029
0.600	0.0771	0.0769	0.0009	0.0787	0.0778	0.029	0.029
0.800	0.0678	0.0677	0.0004	0.0686	0.0681	0.029	0.027
1.000	0.0610	0.0609	0.0003	0.0614	0.0611	0.027	0.026

TABLE 2. Numerical and Energy Albedos of the PC

Energy, MeV	0.05	0.10	0.15	0.50	1.00
Numerical albedos	0.0118	0.0529	0.0967	0.1667	0.1459
Energy albedos	0.0101	0.0397	0.0641	0.0596	0.0315

TABLE 3. Numerical and Energy Build-Up Factors

Energy, MeV	NBF, at MFP, cm				EBF, at MFP, cm			
	1	2	4	8	1	2	4	8
0.05	1.0348	1.0577	1.0885	1.139	1.0563	1.0858	1.1209	1.1709
0.10	1.1931	1.3258	1.5479	1.817	1.2955	1.4574	1.7353	2.0016
0.15	1.3717	1.6861	2.2941	2.798	1.5454	1.9325	2.6586	3.1820
0.50	1.7716	2.6165	4.6787	8.961	1.8409	2.6408	4.5376	8.2469
1.00	1.8377	2.7980	4.8727	10.708	1.7176	2.4495	3.9196	7.6653

TABLE 4. Numerical and Energy Transmission Coefficients

Energy, MeV	NTC, at MFP, cm				ETC, at MFP, cm			
	1	2	4	8	1	2	4	8
1.00	0.6731	0.3739	0.0922	0.0039	0.6292	0.3274	0.0742	0.0028
0.50	0.6449	0.3545	0.0855	0.0033	0.6702	0.3578	0.0829	0.0030
0.15	0.5087	0.2300	0.0417	0.0011	0.5731	0.2636	0.0483	0.0012
0.10	0.4382	0.1798	0.0286	0.0006	0.4758	0.1977	0.0321	0.0006
0.05	0.3822	0.1427	0.0198	0.0004	0.3901	0.1465	0.0204	0.0004

layer have been obtained. The system data are given in the form of tables of the international standard (Tables 1–4) with the aid of which calculations are made by the analytical methods used in solving engineering problems. The results have been obtained with regard for the build-up factors containing the scattered and fluorescent radiations formed as a result of the photoeffect.

Results and Discussion. The dependences of transmission factors on the shield thickness on a semilogarithmic scale are well approximated by the linear function (see Fig. 1). This permits estimating the characteristic of a material, the ratio of the layer thickness of the material being investigated to the thickness of the lead layer thickness having the same transmission factor. Note that this ratio weakly depends on the value of the transmission factor.

Using the results obtained, it is easy to make a qualitative comparison of various specimens of materials in solving practical problems of radiation protection.

As for the albedo, the γ-radiation weakly influences its value in passing through the protective wall of the specimen, especially in lead. The change in the albedo value in lead and steel depending on the primary radiation energy is extreme (Fig. 2). For lead-containing materials (including the PC), the maximum value of the albedo is attained at an energy of 0.1 MeV and in steel — at 0.5 MeV. The increase in the albedo by 4 and 8% in the PC as compared to lead and steel is due to the presence in the PC of lighter elements.

Thus, equivalent radiation protection of the PC with respect to lead is achieved by increasing the protective-shield thickness by a factor of 2.0–2.3 with the preservation of the close indices as to the protection mass per surface unit, and with respect to steel — by decreasing the protective-shield thickness and mass by a factor of four and five, respectively.

The albedo value for the PC slightly increases (by 3–8%) as compared to the data for lead and steel and is extreme in the energy spectrum with a maximum at 0.1 MeV.

NOTATION

A, energy albedo; *E*, γ-radiant energy, MeV; $(\mu/\rho)_{bound}$ and $(\mu/\rho)_{free}$, mass attenuation factors for incoherent scattering by bound and free electrons, cm^2/g; $(\mu/\rho)_{phot}$, mass attenuation factor for the photoeffect, cm^2/g; $(\mu/\rho)_{nar.beam}$, mass attenuation factor of the narrow beam, cm^2/g; $(\mu/\rho)_{nar.beam–coh}$, mass attenuation factor with no account of coherent scattering, cm^2/g; $(\mu/\rho)_{\gamma}$ and $(\mu/\rho)_{E_{\gamma}}$, mass attenuation factor for γ-quanta and γ-quanta energy absorption, cm^2/g; MFP, mean free path of a photon, cm; NBF, numerical built-up factors, rel. value; NTC, numerical transmission coefficients, rel. value; EBF, energy build-up factor, rel. value; *h*, protective-shield thickness, cm. Subscripts: bound, bound electrons; free, free electrons; phot, photoeffect; nar.beam, narrow beam; nar.beam–coh, narrow beam with no account of coherent scattering; γ, gamma-radiation.

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