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Influence of inorganic scintillator light output non-proportionality and energy of registered ionizing radiation on radiometric parameters of detectors on their base

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The effect of the non-proportionality in light yield and the radiation energy on the radiometric characteristics of thallium-doped cesium iodide detectors and p-terphenyl ones. The increase of the non-proportionality in the energy and light yield at the recording of 5 MeV and 2 MeV α-particles has been shown to result in an increased background counting rate, decreased detector sensitivity and resolution. These changes in radiometric parameters are influenced significantly by the state of the radiation input surfaces of the CsI(Tl) and p-terphenyl detectors.

Рассмотрено влияние непропорциональности светового выхода и энергии излучения при регистрации малопроникающего излучения на радиометрические характеристики детекторов йодистого цезия, активированного таллием, или на основе n-терфенила. Показано, что увеличение непропорциональности светового выхода и энергии при регистрации α-частиц с энергиями 5 МэВ и 2 МэВ приводит к увеличению фоновой скорости счета, уменьшению чувствительности детектора и его разделяющей способности. На эти изменения радиометрических параметров существенное влияние оказывает состояние входной для излучения поверхности сцинтилляторов CsI(Tl) и n-терфенила.

The scintillation detectors used in radiometry should provide a high sensitivity and energy resolution. When recording the ionizing radiation, these parameters and related to several physical characteristics of scintillators and detectors based thereon. First of all, these parameters will be influenced by light yield and energy resolution [1, 2]. Those characteristics depend in turn on microscale inhomogeneities of conversion efficiency and light collection in the scintillators. A non-proportionality in the light yield and energy of monitored radiation can be observed in the field of low-penetrating ionizing radiation. The non-proportionality of light yield in scintillation materials effects considerably the energy resolution of the detectors. Because the light yield non-proportionality is defined by individual properties of a crystal, its perfection, content of the activator and impurities, there are discrepancies in the non-proportionality values estimated by different authors [3, 4]. The absence of a unique dependence between the resolution and light yield non-proportionality is obviously related to the fact that the contribution of this factor to the resolution is masked by the contributions of other factors, in particular, light collection. In the field of low-penetrating radiations, the prevailing contribution to the resolution is due to micro-inhomogeneities of conversion efficiency. The contribution of light collection inhomogeneity in that field is small. As the energy increases, this contribution must grow due to increase of the crystal volume where scintillations are formed and light collection inhomogeneity. In case of low-penetration radiations recording, the structure defects influence strongly the transformation of energy in scintillators. At the crystal polishing and grinding,

Table 1.

Sample	Energy resolution, %				Non-proportionality, %	
	τ_1		τ_2		τ1, τ_3	τ2, τ_4
	E_1	E_2	E_1	E_2		
1	5.4	7.1	5.3	7.4	9	10
2	6.4	10.3	6.9	10.6	30	35
3	11.0	15.1	10.0	16.0	15	16
4	16.1	18.0	18.0	20.1	25	29

the defect layer is observed to depths up to 40–50 μm. The presence of defects must make a considerable contribution to diffusion mobility of impurities. This may result in an inhomogeneous conversion efficiency and further deterioration of the energy resolution.

It is note that we consider only one factor influencing the energy resolution which is related to spatial inhomogeneities in scintillator and, as a result, to non-proportionality of the light output and energy of monitoring radiation. It is of interest to study the influence of non-proportionality on radiometric performances of detectors for some scintillators.

Detectors on the basis of single crystal scintillators CsI(Tl) (Nos. *1*, *2*) and *p*-terphenyl (Nos. 3, 4) of ∅25×20 mm^2 size have been used in experiments. The surface of crystals subjected to radiation was treated in various manners. The surfaces of samples Nos.2 and 4 were grounded by an abrasive containing electro-corundum of 20 μm grain size, while Nos.1 and 3 ones were polished by the abrasive with 0.3 μm grain size. The scintillators were examined under irradiation with α-particles of $E_1 = 5$ MeV and $E_2 = 2$ MeV energies. The parameters were measured using a Hamamatsu 1307 type PMT at various times of pulse shaping times: $\tau_1 = 1$ μs and $\tau_2 = 2$ μs – for the CsI(Tl) scintillator, $\tau_3 = 0.5$ μs and $\tau_4 = 1$ μs for the *p*-terphenyl one. In Table 1, the characteristics of non-proportionality and peak resolution for the studied samples are presented for variously treated input surfaces. The disproportion of the light output and energy of incident radiation (Δ) as well as amplitude resolution (*R*) which is proportional to energy resolution were calculated as

$$\Delta = \frac{V_1/E_1 - V_2/E_2}{(V/E)_{cp}}; \quad R = \Delta V/V,$$

where *V* is the maximum of amplitude spectrum corresponding to photopeak; Δ*V*, full width at half maximum.

Table 2.

Sample	Sensitivity, pulse/s Bq	Background, cps
1	0.035	0.01
2	0.020	0.06
3	0.009	0.05
4	0.006	0.09

It is seen from the Table that the disproportion of the light yield and radiation energy in the presence of disturbed layer increases by about 20 % for CsI(Tl) and about 10 % for *p*-terphenyl. The absolute value of amplitude resolution gets worse by about 3 % both for CsI(Tl) and for *p*-terphenyl. The larger is the pulse shaping time, the larger light yield non-proportionality is observed in crystals with ground surface, while for crystals with polished surface, the change is insignificant. Further, we defined the sensitivity (η) and energy resolution (κ) of detectors based on the above-mentioned scintillators. The geometry of measurements was identical for all samples. The sensitivity was determined for a Pu-239 α-particle source ($E = 5.15$ MeV) as

$$\eta = \frac{N - N_f}{A}, \tag{2}$$

where *N* is the number of pulses in the energy window corresponding to peak of the total absorption of peak spectrum, in cps; N_f, the background counting rate in the certain energy window, cps; *A*, the source activity of origin in Bq. It is to note that the window width depends on the peak resolution.

In Table 2, values of sensitivity for 4 studied samples and of background counting speed in corresponding windows are pre-

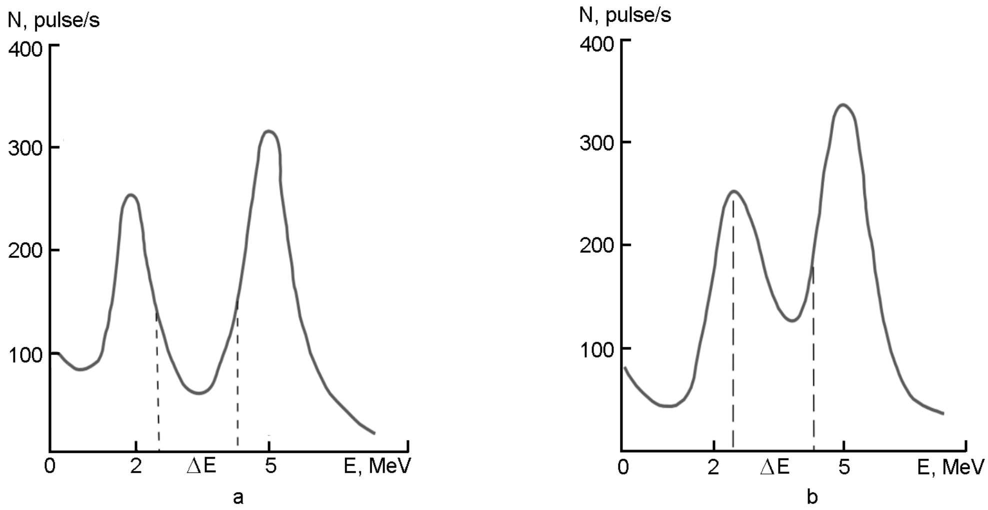

Fig. Pulse-height spectra of samples No.1 (a) and No.2 (b) obtained with 2 MeV and 5 MeV α-particles.

sented. It is seen from the Table that if the radiation is detected in the broken layer of a scintillator, the sensitivity decreases and background counting speed increases as compared to the results for the polished scintillator input surface.

The detector resolution (κ) was determined as the sum of counting rates under overlapped amplitude spectra of pulses at detection of α-particles with E_1 and E_2 energy, under identical experimental conditions and in the same energy range ΔE. The energy range was in the middle between photopeaks of overlapped pulse amplitude spectra. In the Fig. 1, the overlapped spectra of pulse amplitudes are presented at detection of α-particles with energies $E_1 =$ 2 MeV and $E_2 = 5$ MeV for the sample Nos.1 (a) and 2 (b). The energy range (dE) where the cumulative count rate was determined is indicated by dashed lines. The energy resolution κ of the sample No.2 is more than two times worse than for the sample No.1.

Thus, at grinding and polishing of organic and alkali-halide crystals during manufacturing detectors, a disturbed layer is formed on the surface. Its influence on scintillation performances of detectors is seen, in particular, at detection of low-penetrating radiations (α, β, γ, X-ray, etc.). In the spectrometry, it is manifested in nonproportionality of the light yield and radiation energy that will negatively influence the energy calibration of spectrometers. As is seen from the obtained results, the light yield disproportion influences the radiometric parameters of the detector, incrementing background counting rate and reducing the detector sensitivity. So, increase of light yield and energy disproportion for the sample No.2 at detection of α-particles results in sensitivity decrease by a factor of 1.75 in comparison with that parameter for the sample No.1 and by a factor of 1.5 for the sample No.4 in comparison with the sensitivity value for the sample No.3. The increase of disproportion worsens essentially the detector energy resolution at recording α-particles with two energies $E_1 = 5$ MeV and $E_2 = 2$ MeV.

The increase of light yield disproportion at increase of pulse shaping time for scintillators with the disturbed surface layer testifies that the contribution from slow scintillation components to radioluminescence increases. The absolute value of peak resolution is worsened by 3–5 % at disturbed layer formation. Simultaneously, the light yield increases at detection of radiation in the disturbed layer. The contribution to the resolution connected with micro-inhomogeneities of conversion efficiency depends on the α-particle energy, and thus on energy of secondary electrons. It is known [5] that resolution is in inverse proportion to a square root from electron free path. Hence, the resolution is inversely proportional to energy of α-particles.

$$R \sim 1/\sqrt{E\alpha}.$$

Because we used low-penetrating α-radiation, the energy of secondary electrons is insignificant, as a result, the resolution will depend on concentration of micro-inhomogeneities in the surface layer of a scintillator.

Thus, the grinding of radiation input surface for CsI(Tl) and *p*-terphenyl scintillators results in formation of a disturbed surface layer that, in turn, increases the disproportion of the light yield and energy of monitored radiation in comparison with the polished surface. The disproportion between the light yield of CsI(Tl) and *p*-terphenyl scintillators and energy of monitored α-radiation worsens radiometric parameters of detectors on their base. The increase in light yield disproportion and radiation energy with pulse shaping time increase at α-particle detection for scintillators with ground surface testifies that in their radioluminescence the contribution of slow scintillation components increases.

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Вплив непропорційності світлового виходу сцинтиляторів та енергії іонізуючого випромінювання, що реєструється, на радіометричні параметри детекторів на їх основі

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Розглянуто вплив непропорційності світлового виходу та енергії випромінювання при реєстрації низькопроникного випромінювання на радіометричні характеристики детекторів на основі йодиду цезія, активованого талієм, та на основі *п*-терфенілу. Показано, що збільшення непропорціональності світлового виходу та енергії при реєстрації α-частинок з енергіями 5 МеВ і 2 МеВ приводить до збільшення фонової швидкості рахування, зменшення чутливості детектора та його роздільної здатності. На ці зміни радіометричних параметрів суттєвий вплив чинить стан вхідної для випромінювання поверхні сцинтиляторів CsI(Tl) та *п*-терфенілу.