Radiometric characteristics of combined detectors on the basis of organic and inorganic scintillators and the use thereof in radiational situation monitoring

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Two types of combined detectors have been developed and manufactured. The first detector type is intended to detect the α and β radiation while the other one, for β and γ radiation. The obtained parameters of the developed detectors (background counting rate, sensitivity, and the minimum detectable activity) have provided the applicability thereof for detection of α,β and β,γ radiation in common or separately.

Разработаны и изготовлены два типа комбинированных детекторов. Первый тип детекторов предназначен для регистрации α- и β-излучений, второй — β- и γ-излучений. Полученные параметры фоновой скорости счета, чувствительности и минимальной детектируемой активности для разработанных детекторов обеспечили возможность их применения для совместной и раздельной регистрации α,β- и β,γ-излучений.

The detectors for ionizing radiation radiometry should provide a maximum sensitivity to the mixed radiation field component to be measured, a minimum one to the background component of the mixed region, and a maximum difference of signals from the excited component to be measured and the background one [1, 2]. The above conditions are satisfied simultaneously only seldom. However, it is known to solve the problem by using in the detecting systems several scintillators being in optical connection to each other, that is, combined detectors [3]. Such detectors provide a selective detection not only by means of amplitude discrimination but also by the signal resolution according to the pulse shape.

The first condition of the high-quality operation of a detecting device is satisfied by means of a lowered recording threshold, a high light yield of the scintillators and a high enough energy resolution, and the absence of pulse miscounting under high loadings. The second condition for the efficient operation of a detecting devices in mixed ionizing radiation fields can be provided by lowering the background radiation detection efficiency of the first scintillator. This is attained by using thin scintillators as the first ones in a combined detector. The third condition is fulfilled by using scintillators with considerably differing decay time values. When considering a "fast" scintillator and a "slow" one, the ratio of current pulses corresponding to the scintillation intensities therein is

$$L = \frac{I_f}{I_s} = \frac{\tau_s}{\tau_f},$$

where τ_l, τ_b are the decay time values for the slow and fast scintillator, respectively.

Recently, some designers have proposed the use of combined detectors in radiometers [4, 5]. So in [4], the NE-102 scintillator is used as a β radiation receiver and a

NaI(Tl) one to record γ radiation. The Harshaw Co. has advertised a combined detector where a CaF_2(Eu) scintillator is joined with a NaI(Tl) one through a quartz window [5]. The α and β radiation components are resolved in that detector by amplitude discrimination with selection of corresponding windows. In [6], the inventors have used an $A^{II}B^{VI}$ semiconductor scintillator as the first one and an oxide scintillator as the second one. A common drawback of such combined detectors consists in that the first scintillator detects to a considerable extent the more hard radiation that is detected by the second scintillator. Consideration of the known designs evidences that it is necessary to improve the detecting devices based on combined scintillators by selecting thickness of the scintillators, improving the joining methods thereof, and increasing the active surface area of the scintillators.

Two types of combined detectors were manufactured for experiments in this work. The I type detector is a polystyrene scintillation plastic disk of 8 mm thickness with a thin (40 to 50 μm) CsI(Tl) film applied onto its surface. The II type detector consists of a 50 mm thick double-window NaI(Tl) detector and a *p*-terphenyl film (100–120 μm). Both detectors were 100 mm in diameter. The first combined detector is intended for simultaneous and separated detection of α and β radiation; the second one, for β and γ radiation detection.

The type I combined detector provides the detection of α radiation through the accompanying X-ray and soft γ ones. So when ^{239}Pu radionuclide is decomposed, the most intense radiation (>4 % per decay) is the X-ray one with the average energy of 17.06 keV while at decomposition of ^{241}Am, the 59.54 keV X-rays (5.7 % per decay) are of interest. Those radiation types accompanying the α decay were used to detect the ^{239}Pu and ^{241}Am radionuclide radiation in "thick" samples (where the α particle free path is less than the sample thickness).

To study the spectrometric and radiometric parameters, the combined detectors were included into detecting blocks comprising a detector, a PMT, the PMT power supply, the output signal formation, amplification, and matching devices. The minimum detectable activity (MDA) at 0.95 confidence level was determined as $\text{MDA} = \frac{2}{\eta}\sqrt{\frac{N_f}{t}}$ where η is the detecting system sensitivity defined as the ration of the pulse number detected

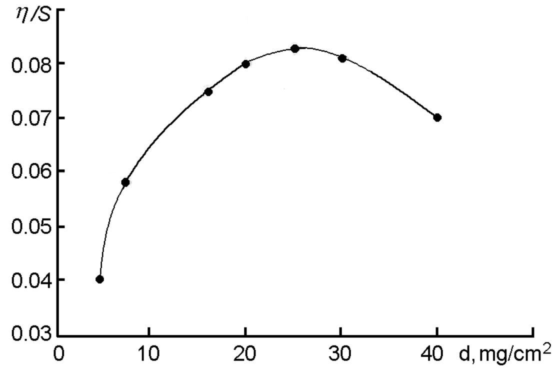

Fig. 1. Dependence of the *p*-terphenyl film specific sensitivity (η/*S*) on the thickness (*d*) at detection of β radiation from ^{90}Sr+^{90}Y radionuclide.

from a known activity source within the prespecified energy window to the source activity; N_f, the counting rate of the background radiation within the corresponding windows of the amplutide spectrum; *t*, the measurement duration.

The specific sensitivity η/*S* was determined as $\eta = N/A$ (pulses/(s·Bk)), where *N* is the count rate in the corresponding energy region; *A*, the radionuclide activity. The block proper background was measured for blocks being both inside and outside the protective shell. The signal-to-noise ratio (*P*) was determined as $P = N/N_0$ where *N* is the pulse number corresponding to the maximum of the amplitude distribution; N_0, that for the amplitude distribution minimum. The measurements were done using a ^{137}Cs conversion electron source from the OSIKE kit.

To determine the optimum thickness of the *p*-terphenyl film, the specific sensitivity (η/*S*) as a function of the film thickness (*d*) was measured when detecting the β radiation of ^{90}Sr + ^{90}Y radionuclide within a fixed energy window. As is seen from Fig. 1, the maximum sensitivity of 0.6 to 0.65 pulse/(Bk·s) is attained at the film thickness corresponding to 25 mg/cm^2.

Since the combined detectors intended to detect the ionizing radiation simultaneously and separately, the count characteristics (CC) thereof were to be studied. The detector count characteristic is the dependence of its counting rate (V) on the PMT supply voltage (E), the other parameters (the signal collection, formation, and amplification time, the PMT noise level). The main CC parameters are the plateau length, slope,

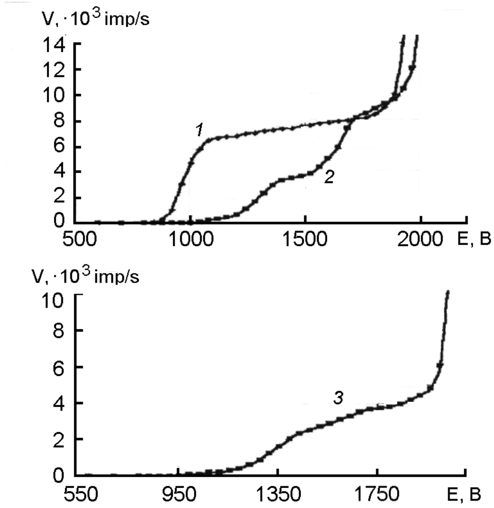

Fig. 2. Counting characteristics of a combined detector based on CsI(Tl) film and scintillation plastic at detection of α radiation from ^{239}Pu (*1*), β radiation from ^{90}Sr+^{90}Y (*3*) and radiation from ^{241}Am (*2*).

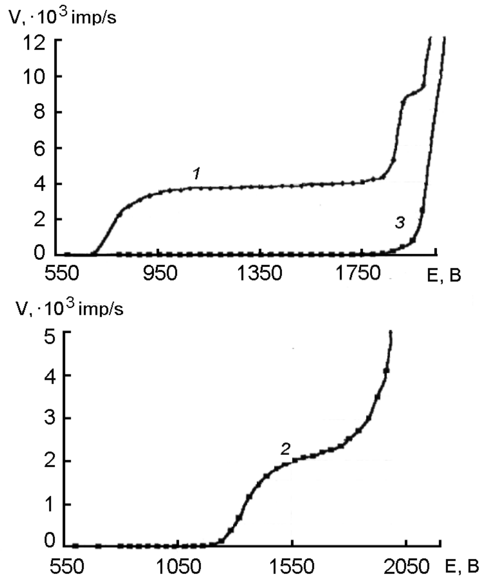

Fig. 3. Counting characteristics of a combined detector on the basis of a NaI(Tl) single crystal and a *p*-terphenyl film for detection of β radiation from ^{90}Sr + ^{90}Y source and γ one from ^{137}Cs

and level. Fig. 2 presents the CC for CsI(Tl) film and *p*-terphenyl one. The detectors were irradiared with γ radiation of ^{241}Am (E_1 = 60 keV and E_2 = 17 keV), ^{239}Pu and β one of ^{90}Sr + ^{90}Y. The two steps for the CsI(Tl) film are due to detection of radiations differing in energy. The PMT supply voltage for such a system is to be selected within the CC diapason intended to detect the 17 keV radiation; however, in that case, the operation conditions are within the high noise zone due to high voltage. In such cases, special amplifiers are to be used providing lower PMT voltages and the CC shift towards lower voltages.

Table 1. Radiometric parameters of the Type I block

Parameters		Energy range				Slow scint. 17 keV	Fast scint. 2400 keV
		12–25 keV	150–2400 keV	12–25 keV	150–2400 keV		
Signal/noise ratio	1.4	–	–	–	–	–	–
Background rate in protection, pulse/s	–	0.5	3.0	–	–	–	–
Sensitivity, pulse/(Bk·s)	–	–	–	0.002	0.003	–	–
Signal level, V	–	–	–	–	–	0.1	0.19

Table 2. Radiometric parameters of the Type II block

Parameters		Energy range				Slow scint. 662 keV	Fast scint. 2400 keV
		570–740 keV	150–2400 keV	570–740 keV	150–2400 keV		
Signal/noise ratio	1.5	–	–	–	–	–	–
Background rate in protection, pulse/s	–	3.5	1.0	–	–	–	–
Sensitivity, pulse/(Bk·s)	–	–	–	0.05	0.04	–	–
Signal level, V	–	–	–	–	–	0.5	0.4

Fig. 3 shows the CC of a combined detector on the basis of a NaI(Tl) single crystal and a *p*-terphenyl film for detection of β radiation from $^{90}Sr + ^{90}Y$ source and γ one from ^{137}Cs.

Consideration of the count characteristics for the combined detectors made it possible to select the operating voltage for the detecting blocks providing the optimum radiometric characteristics. The characteristics obtained for the blocks are presented in Tables 1, 2, and 3.

To conclude, the composition and design of combined detectors have been optimized to provide the necessary radiometric characteristics. A correlation has been established between optical and scintillation characteristics of scintillation elements included in the combined detectors. The count characteristics of the detectors have been studied to optimize the sensitivity thereof at the detection of ionizing radiation. Basing on the combined detectors designed, detecting blocks have been manufactured intended to detect the radiation from ^{239}Pu, ^{241}Am, ^{40}K, and ^{137}Cs in the first block, and from ^{137}Cs, ^{40}K, ^{226}Ra, ^{239}Th, and ^{90}Sr in the second one. The radiometric characteristics of the blocks make it possible to use those in radiometers for joint and separated detection of α,β and β,γ radiation.

Table 3. Minimum detectable activity values for the Type I and Type II blocks

Block type	^{239}Pu	^{90}Sr	^{137}Cs
I	2.6 Bk	0.4 Bk	–
II	–	0.6 Bk	0.5 Bk

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Радіометричні характеристики комбінованих детекторів на основі органічних та неорганічних сцинтиляторів та їх застосування для контролю радіаційної обстановки

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Розроблено та виготовлено два типи комбінованих детекторів. Перший тип детекторів призначений для реєстрації α- та β-випромінювань, другий — для β- та γ-випромінювань. Одержані параметри фонової швидкості рахування, чутливості та мінімальної детектовної активності для розроблених детекторів забезпечили можливість їх застосування для спільної та роздільної реєстрації α,β- та β,γ-випромінювань.