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Investigation of the Possibility of γ-Background Discrimination in a Neutron Spectrometer with a Proportional Counter of Recoil Protons

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Abstract—The possibility of expanding the range of neutron spectrum measurements to lower energies in fields of mixed n–γ radiation via separation of pulses from recoil protons and γ-induced electrons, using the proportional counter developed for neutron spectrometry at the All-Russia Research Institute of Experimental Physics, has been investigated. With the use of a digital oscilloscope, a data set on the shape of counter pulses under irradiation in a field of mixed n–γ radiation (^{252}Cf) and in a field of γ rays (SOSGI-M set) has been obtained. Mathematical processing of the obtained data set showed a possibility of distinguishing pulses from recoil protons and electrons; hence, for the ^{252}Cf source, the lower boundary of the neutron spectrometer operating range can be reduced to ≈80 keV.

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NEUTRON SPECTROMETER ON THE BASIS OF A PROPORTIONAL COUNTER

A neutron spectrometer with a proportional gas counter of recoil protons has been developed at the All-Russia Research Institute of Experimental Physics (VNIIEF) and has been used in neutron measurements for several years [1, 2]. The main parameters of the counter are as follows: length 1 m; diameter 75 mm; filling with methane under 3 atm, with a small amount of ^{3}He; relative energy resolution 3.66%; lower and upper energy detection limits 50 keV and 8 MeV, respectively; and detection efficiency for the ^{252}Cf source of spontaneous-fission neutrons approximately 13.9%.

A drawback of proportional gas counters is their sensitivity to γ rays, which form a background in almost all neutron measurements. For this reason, measurements of neutron spectra in the low-energy region are hindered because of the distortions introduced into the experimental apparatus spectrum, which lead to errors in reconstructed neutron spectra. The value of the energy below which the γ background manifests itself depends on the material and geometry of the counter, as well on the composition and pressure of the working gas. For the counter used in this study, this energy (without application of any discrimination techniques) is 0.5 MeV.

METHODS OF BACKGROUND DISCRIMINATION

The effect of γ background can be decreased in different ways, for example, by physical screening of γ rays or using the calculation method. Physical screening makes it possible to significantly decrease the background; however, problems related to the distortion of the measured neutron spectrum arise in this case. The calculation method for taking into account the γ background is fairly difficult and has a low accuracy.

The best method for discriminating the γ background is the use of electronic tools, which make it possible to distinguish pulses from recoil protons and electrons by their shape. The technical implementation of pulse-shape discriminators for proportional counters is based on the division and rise-time methods [3].

The schemes of γ-discriminators for proportional gas counters, based on these methods and described in the literature, are fairly complicated [3–6]. Therefore, before developing γ-background discriminators for our neutron spectrometer, we had to analyze the pulse shape peculiarities upon detection of neutrons and γ rays by our proportional counter; choose the method for separation; and, using mathematical processing of the data obtained, estimate the quality of separation and the γ-background discrimination threshold.

EXPERIMENTAL INVESTIGATION OF THE POSSIBILITY OF γ-BACKGROUND DISCRIMINATION

To carry out this investigation, the neutron spectrometer was supplemented with a channel for measuring the pulse shape (Fig. 1), which included a Canberra 2111 fast amplifier (FA) and a TDS-3034B digital oscilloscope (DO) (Tektronix), connected to a personal computer (PC) through an RS-232 interface.

The minimum leading-edge time of a pulse from the counter upon detection of neutrons and γ rays is 500 ns. A 1105A charge-sensitive preamplifier (PA) has an intrinsic rise time of about 10 ns, which makes it possible to measure the shape of the output pulse leading edge almost without distortions. The fall time of this preamplifier is fixed at a level of 50 μs; this value may result in superpositions of pulses. The frequency band of the fast amplifier is in the range from 1 kHz to 45 MHz. A TDS 3034B storage digital oscilloscope makes it possible to digitize the input signal with a sampling rate up to 100 MHz.

The operating voltage of the counter, supplied by a high-voltage source (HVS), was chosen to be 3.2 kV. Concerning the energy resolution of the counter, the most optimal value is 2.7 kV; however, the gas amplification coefficient at a voltage of 3.2 kV is larger than at 2.7 kV by a factor of about 2.5. This choice made it possible to obtain a higher signal-to-noise ratio.

The spectrometric channel, including a spectrometric amplifier (SA) and an analog-to-digital converter (ADC), was used to tune the operating mode: measure the relative energy resolution of the counter in a field of thermal neutrons and perform energy calibration of the analyzer scale. Access to the data recorded by the analog-to-digital converter from the CAMAC crate bus was provided by an ADC/CAMAC interface module. A crate controller (CC) was used to connect the CAMAC crate to the personal computer.

A special program was developed on the basis of the CRW DAQ package to control the digital oscilloscope and collect data [7, 8]. This program provides remote control of the oscilloscope and makes it possible to automatically read data from the oscilloscope memory and record oscillograms of pulses on the hard disk of a personal computer. Transfer of each oscillogram took≈5 s. The data were recorded in a file in the form of a time–amplitude text table.

In analysis of the pulse shape, the oscilloscope was triggered by an input signal; the triggering level was chosen to be 30 mV, which corresponds to an energy of 0.05 MeV. To obtain a high time resolution, the scan time was chosen to be 5 μs; in this case, the prehistory was recorded for a time interval equal to 8% of the scan chosen. As a result, the zero level of a signal could be reliably determined. The digitization frequency was 50 MHz, and, correspondingly, the coordinates of 2500 points were recorded in the oscilloscope memory.

Measurements in mixed fields of neutron and γ radiation were performed with a ^{252}Cf source, which was located at a distance of ≈1.5 m from the face of the counter on its symmetry axis. The SOSGI-M set served as a source of γ rays. This set includes six sources (the energies of the strongest γ lines are indicated in parentheses): ^{56}Co (0.511 MeV), ^{110m}Ag (0.658 MeV), ^{133}Ba (0.081 MeV), ^{152}Eu (0.122 MeV), ^{182}Ta (1.122 MeV), and ^{192}Ir (0.316 MeV). In addition to these lines, the emission spectra of the isotopes entering the set contain a large number of weaker lines. With allowance for the substrate contribution to the energy spectra of the isotopes, we can state that the sources of this set cover a wide energy range and provide a continuous spectrum of γ rays.

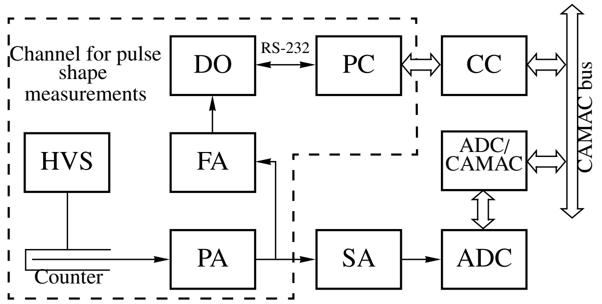

Fig. 1. Neutron spectrometer with a channel for pulse shape measurements.

In addition to the measurements with fast neutrons and γ rays, we performed measurements with thermal neutrons, which allowed us to calibrate the recorded data in energy units with respect to the peak of the ^{3}He(n, p)T reaction. The ^{252}Cf isotope placed in a polyethylene moderator was used as a source of thermal neutrons.

RESULTS

In the experiments, the recorded neutron and γ-ray pulses were digitized using the digital oscilloscope (Fig. 1); i.e., each recorded pulse was represented in the form of a table including 2500 pairs of numbers; in each pair, the first and second numbers were, respectively, the current time and the value of the voltage pulse envelope at this time. As a result of the measurements performed, we accumulated a large number of data files (about 60 000 oscillograms). Processing of each oscillogram is a fairly complicated procedure, because it is necessary to filter noise, exclude pulses of large amplitude (that are beyond the measurement range), find and exclude overlapped pulses, and determine particular shape parameters for appropriate signals.

Within the CRW DAQ package [7], using the built-in programming language Daq Pascal, we developed a special software, which made it possible to process the obtained data both manually and automatically. The graphical interface of the processing program includes a control panel, a graphical window for displaying a current oscillogram, and two spectrometric windows for displaying the intermediate values obtained. The control panel makes it possible to set lists of files subjected to processing. In the manual mode, one can observe the pulse oscillogram, perform its visual analysis, and take a decision about its further processing. The manual mode is convenient when the number of recorded signals that should be looked through and pro-

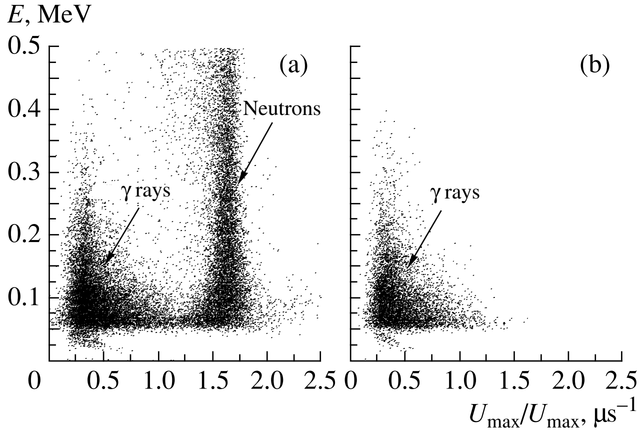

Fig. 2. Two-dimensional distribution of pulses for (a) a source of mixed neutron and γ radiation and (b) a set of γ-ray sources.

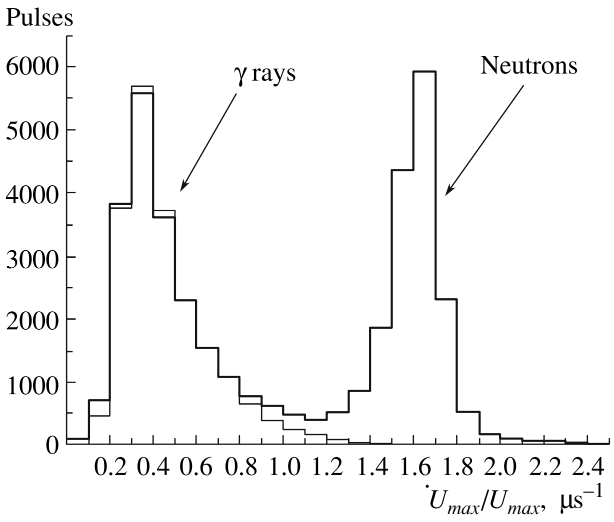

Fig. 3. Distributions of pulses over the parameter $\dot{U}_{max}/U_{max}$ in the energy range from 0.05 to 0.5 MeV for a source of mixed neutron and γ radiation (bold line) and a set of γ-ray sources (thin line).

cessed is small. In the automatic mode, all graphical windows are closed (to increase the operating speed), and a user cannot control the processing.

During processing of oscillograms, they were smoothed by calculating the weighted average integral value with a variable window width. The closer a point to the leading edge, the narrower the smoothing window.

Further processing included the following operations: pulses of irregular shape, distorted by noise pickup, were rejected; binding to the pulse leading edge was performed; the maximum amplitude U_{max} of the smoothed pulse was found; the leading-edge time t_{le} was determined in the range from 0.1 to 0.9 of the maximum amplitude; and, finally, the maximum of the time derivative ($\dot{U}_{max}$) on the pulse leading edge was calculated.

As a result of the processing of the set of oscillograms obtained in calibration measurements, the distribution of maximum pulse amplitudes was constructed, which contained a peak due to the ^{3}He(n, p)T reaction. Energy calibration of the measuring channel, $E(U)$, was performed with respect to the position of this peak. With allowance for the result of the energy calibration, the parameter U_{max} was renormalized to the parameter E.

These data were used to construct two-dimensional $t_f - E$ and $\dot{U}_{max}$–E distributions for both the source of mixed neutron and γ radiation and for the γ-ray source.

The $\dot{U}_{max}$–E distribution, obtained with the ^{252}Cf source, clearly demonstrates two groups of events related to detection of neutrons and γ rays. With a decrease in energy, these regions are partially overlapped. Actually, the beginning of overlap determines the threshold of the γ-background discrimination. The corresponding distribution, obtained from the results of the measurements with the γ-ray source, confirms correct identification of these groups.

In accordance with the division technique, we obtained a two-dimensional distribution of events in the $\dot{U}_{max}/U_{max}$–E coordinates, which is more convenient for analysis. The parameter $\dot{U}_{max}/U_{max}$ is inversely proportional to the time of electron avalanche in the proportional counter. For the ^{252}Cf source, the groups of events related to neutrons and γ rays, are well separated (Fig. 2a). The distribution obtained for the γ-ray source (Fig. 2b) is in agreement with the distribution of the γ component in Fig. 2a.

The data obtained suggest that the distributions of neutron and γ-ray pulses are fairly well separated, and they can easily be discriminated according to the parameter $\dot{U}_{max}/U_{max}$. In this case, it is obvious that the quality of discrimination depends on the energy of protons and electrons, while the discrimination level should be set on the basis of a compromise between the lower measurement limit and the coefficient of γ-background suppression.

For more correct comparison of the spectral characteristics of the γ rays from the ^{252}Cf source and the SOSGI-M set of γ sources, we obtained distributions of the number of pulses over the parameter $\dot{U}_{max}/U_{max}$ for the entire energy range under study: from 0.05 to 0.5 MeV (Fig. 3). In this case, the data for the SOSGI-M set were renormalized proceeding from the conditions of equality of the areas under the γ-ray distributions. It can be seen that the shape of the distributions of γ-ray pulses is almost the same in both cases.

To perform preliminary estimation of the low-energy range, which still allows reliable separation of pulses from recoil protons and electrons, we chose the criterion of 5% ($P = 0.95$) overlap of distributions, which is in no way related to the discrimination threshold. This means that, if for a given energy the ratio of the distribution overlap area to the area of the recoil proton distribution amounts to 5%, specifically this energy should be considered as the lower measurement limit. To obtain such an estimate, the experimental data were approximated by a sum of two lognormal distributions.

First, we approximated the energy cut for the lowest energy range: 0.05–0.06 MeV. The ratio $\Delta S_{\rm com}/S_{\rm n}$ of the common area under the curves approximating the distributions of the parameter $\dot{U}_{max}/U_{max}$ for neutrons and γ rays to the area under the neutron curve turned out to be 27%. Approximation of the subsequent energy cuts and calculation of the fraction of the common overlap area allowed calculation of the ratio $\Delta S_{\rm com}/S_{\rm n}$ for different energy ranges.

The energy dependence of the parameter $\Delta S_{\rm com}/S_{\rm n}$ was used to construct a plot, which is shown in Fig. 4 by a solid line. It can be seen that, with an increase in energy, the curve crosses the 5% barrier at a value of ≈0.084 MeV on the abscissa axis. Specifically this value can be considered as the lower threshold energy in measurements of the spectra of spontaneous-fission neutrons from the ^{252}Cf source, using the counter described above under the following conditions: filling with methane to a pressure of 3 atm (with addition of a small amount of ^{3}He) and a cathode voltage of 3.2 kV.

We deliberately reported the threshold value with indication of the specific parameters. With invariable parameters of the counter (voltage, pressure, etc.), the γ-discrimination threshold depends on the source parameters. The ratio $N_\gamma/N_{\rm n}$ of the number of γ photons emitted by the ^{252}Cf source to the number of emitted neutrons is ≈2.5. Suppose we have a neutron source yielding neutron and γ-ray spectra of approximately the same shape as those for ^{252}Cf but with the ratio $N_\gamma/N_{\rm n}$ equal to unity (it is known that the $N_\gamma/N_{\rm n}$ ratio for many neutron sources is much smaller than 2.5). Since γ-ray distributions are wider than the neutron ones, one might expect that a decrease in the relative contribution of the γ rays emitted by a neutron source will make it possible to reach the 5% barrier at lower energies. This fact indicates that the discrimination threshold for γ rays will decrease with a decrease in their relative contribution.

To determine the discrimination thresholds for other sources, it is sufficient to use the experimental data obtained for the ^{252}Cf source. To this end, all the approximating curves obtained for this source should be renormalized according to the new values of the $N_\gamma/N_{\rm n}$ ratio. Then, exactly as previously, one has to construct the energy dependence of the relative overlap of areas and determine the γ-ray discrimination threshold at the point of intersection of the plotted curve with the line of the 5% barrier. Figure 4, along with the curve for the ^{252}Cf source, shows also the data for the ratios $N_\gamma/N_{\rm n} = 0.2$, 0.3, and 0.7, at which the γ-discrimination thresholds turned out to be 0.061, 0.067, and 0.077 MeV, respectively. It can be seen that these values, as was expected, are below the previously obtained threshold of 0.084 MeV for ^{252}Cf.

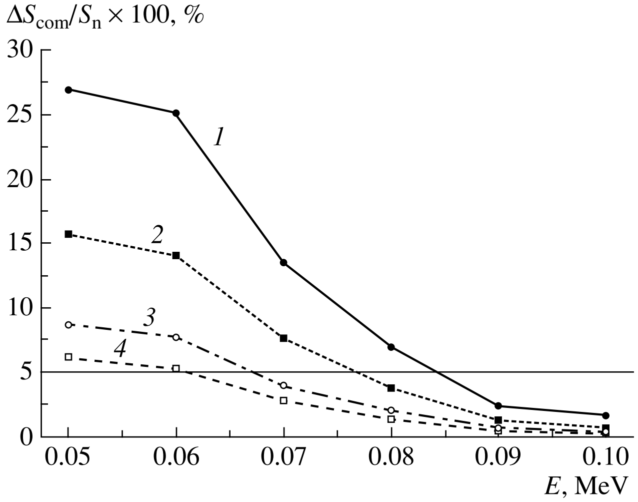

Fig. 4. Energy dependences of the relative overlap of the areas of the $\dot{U}_{max}/U_{max}$ distributions for neutrons and γ rays at the ratios $N_\gamma/N_{\rm n}$ = (*1*) 2.5 (^{252}Cf), (*2*) 0.7, (*3*) 0.3, and (*4*) 0.2. The horizontal line shows the 5% allowable overlap threshold.

CONCLUSIONS

The investigation performed showed that the neutron spectrometer based on the proportional counter of recoil protons can be supplemented with tools for γ-background discrimination, which make it possible to distinguish pulses of recoil protons and electrons according to their shape. The discrimination quality depends on the energy of protons and electrons, and the discrimination level should be set on the basis of a compromise between the lower measurement limit and the coefficient of γ-background suppression. For example, for ^{252}Cf, we found the lower energy separation threshold for neutron and γ-ray pulses to be ≈80 keV.

The further development of this study is the arrangement of a specific scheme of γ-background discrimination and its incorporation into the registration system of the spectrometer. This scheme is intended for analysis of the leading edge of counter pulses in the experimental channel.

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