Digital Spectrometer for Prompt Fission Neutrons Spectra Measurement

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Abstract

This paper presents a digital neutron spectrometer based on simultaneous digitizing of the signals from the fission chamber and a scintillation detector. The scintillation detector based on stilbene crystal. The intrinsic detection efficiency of the used stilbene crystal and the energy dependence of the light output for the recoil protons were measured. It is shown, that the method allowed us to achieve time resolution of 1.5 ns and an excellent n/γ separation down to neutron energies of 375 keV.

1. Introduction

Prompt neutron spectra are very important for criticality calculation for nuclear reactor. The most precise method for neutron spectra measurement is the time of flight method [1, 2]. For fast neutron registration, organic scintillators are often used. Unfortunately, they have significant registration efficiency of gamma rays accompanying nuclear fission process. Good separation of events caused by neutrons and gamma rays is the actual problem, especially for particles having low energy.

This work presents a spectrometer with simultaneous digitization of signal from the fission chamber and signal from the PMT with the organic scintillator. It is shown that the method can achieve time resolution of about 1.5 ns and good n/γ separation up to neutron energies of 375 keV.

2. Experimental setup

Neutron spectrometer consists of the fission chamber, a scintillation detector based on the stilbene crystal, a radiation shielding and the dual channel waveform digitizer. Experimental setup is shown in figure 1 (*a*).

^{252}Cf target of about 67000 fragments per second is located on the fission chamber cathode. The neutron flight path was 2 meters. The stilbene crystal with a diameter of 1.5 cm and a thickness of 5 mm was used in combination with a photomultiplier Enterprise 9813QB.

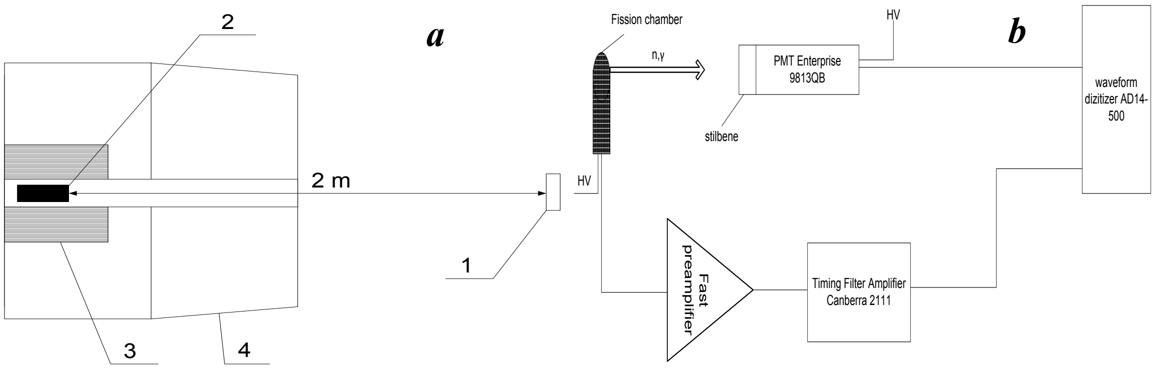

Fig. 1. *a - Experimental setup. 1 – fission chamber, 2 – neutrons detector, 3,4 – detector shielding. b - Electronic block-scheme of experimental setup.*

Block diagram of the experimental setup is shown on figure 1 (*b*). Both channels of the waveform digitizer Ultraview AD14-500 with a sampling rate of 500 MHz and a resolution of 14 bits were used to record signals from the fission chamber and signals from the photomultiplier anode. Simultaneous digitization of both signals made possible to carry out not only the analysis of form and an amplitude distributions of signals, but also to conduct studying the time characteristics of the signals received by different inputs. The neutron channel signals above the threshold were used as the trigger. Figure 2 shows an example of a single event.

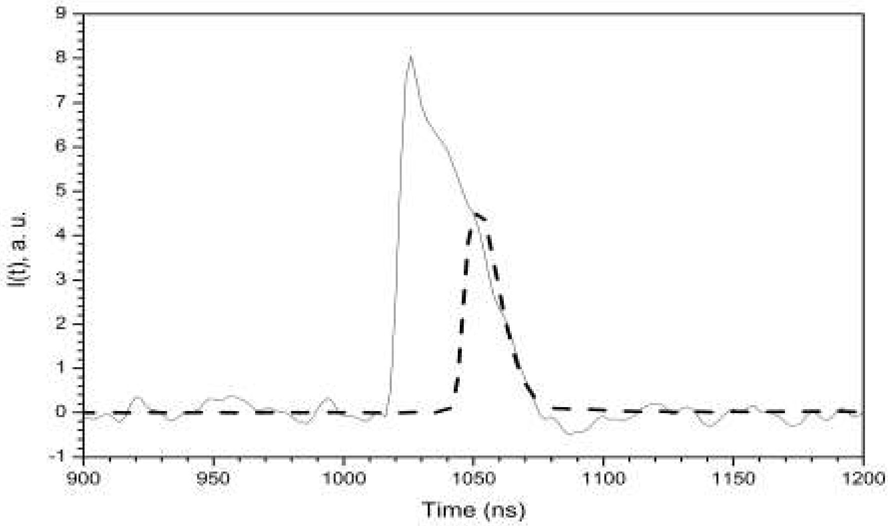

Fig. 2. *An example of a single event, which contains oscillograms from fission chamber (solid line) and neutron detector (dashed line).*

3. Signal processing

Correlation analysis of the signals was used to determine the type of the detected particle and event time.

At the preliminary stage of the work response of scintillation spectrometer for electron registration was determined using a standard gamma source – ^{60}Co by averaging the signals (solid line in Figure 3). The resulting signal was used for further processing to determine the type of the detected particle and the time of its occurrence by correlation analysis of the similarity in the shape of the processed signal and the swatch signal. The amplitude of the correlation peak for the signals caused by gamma quanta is greater than for the signals from neutrons due to the difference in their form. Furthermore, the position of the correlation peak allows us to find the true time of occurrence of the processed signal.

In this work, during the analysis of the array of all received oscillograms, three main types of signals from the neutron detector were identified - the signals from the recoil protons (dashed line in Figure 3), electrons (solid line) and the signals produced by the luminescence of quartz input window PMT during deceleration of fast electrons in it (dotted line). The signal from the recoil protons corresponds to the proton kinetic energy 1.7 MeV. These signals are normalized to their area.

Neutron detector calibration was performed using ^{60}Co and ^{137}Cs sources by the right edge of the Compton electrons distributions for corresponding gamma-quanta.

The two-dimensional spectrum is shown in the Figure 4 (*a*). On the axes – the time of flight of the particle and separation parameter R (eq. 1), produced using ^{252}Cf source. The separation is made in the parameter R, equal to the ratio of the maximum correlation peak to the area of signal (eq. 1).

$$R = \frac{MCP}{A} \qquad (1)$$

The figure clearly shows three well-localized event group corresponding neutrons (the lower part of the spectrum), the gamma quanta (the middle part of the spectrum), and the events corresponding to the luminescence of quartz input window of photomultiplier (upper part of the spectrum). The numbers in Figure 4 (*a*) are showing region of neutrons (1) and region of background associated with gamma quanta from inelastic scattering of fast neutrons on the detector material and structural materials.

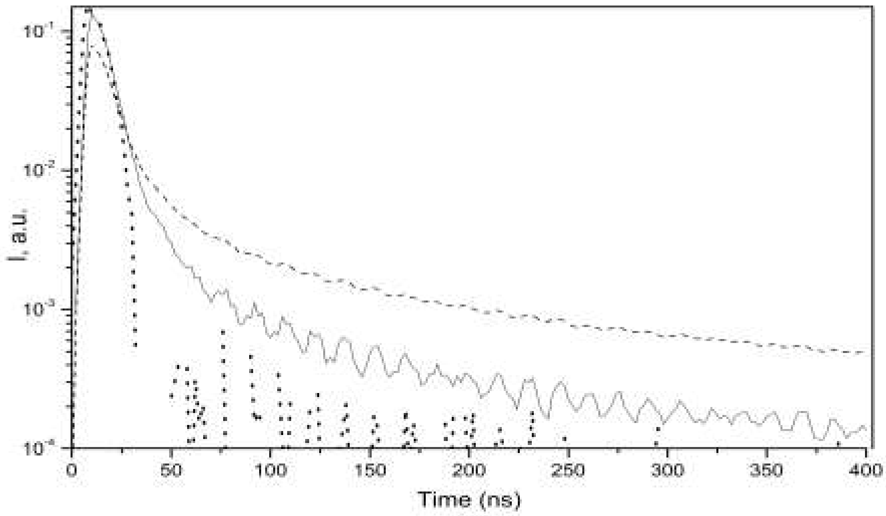

Fig. 3. *The response of the neutron detector on electrons, recoil protons and outbreaks in a quartz input window.*

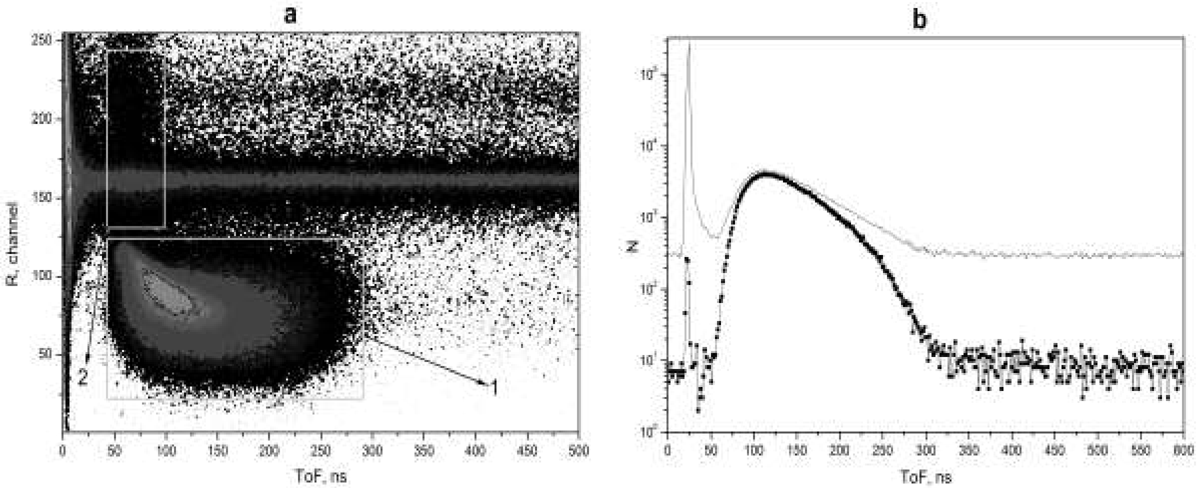

Fig. 4. *a) - The two-dimensional spectrum with the axes: time-of-flight and the value of separation parameter R. b) -Integral TOF spectrum (red line) and the neutron time of flight spectrum (point) after the suppression of background gamma rays. Solid line - background.*

Partial one-dimensional time-of-flight spectrum (Fig.4, b) can be obtained from the two-dimensional time-of-flight spectrum by setting the appropriate window to the parameter R. The reached degree of suppression background of gamma-quanta is 350 at a threshold of 250 keV neutron energy.

The intrinsic detection efficiency of neutron detector (fig. 5) has been obtained on the basis of the standard spectrum of ^{252}Cf prompt fission neutrons taken from ENDF-BVII.1 [3] library and the spectrum obtained experimentally.

A correction on the width of a bin (eq. 2) was applied for the correct image of the received data, as pointed on the graph. This adjustment must be done to areas of rapid change in the spectrum, since in this areas average energy bin is shifted. This adjustment was made on the basis of the expression proposed in [4] and used in the [5].

$$E_b = T\,ln\frac{E_2 - E_1}{T(e^{-\frac{E_1}{T}} - e^{-\frac{E_2}{T}})} \qquad (2)$$

Here E_1 and E_2 - boundary energy of bin, T - the decay constant, the resulting description of the areas of spectrum exponential change.

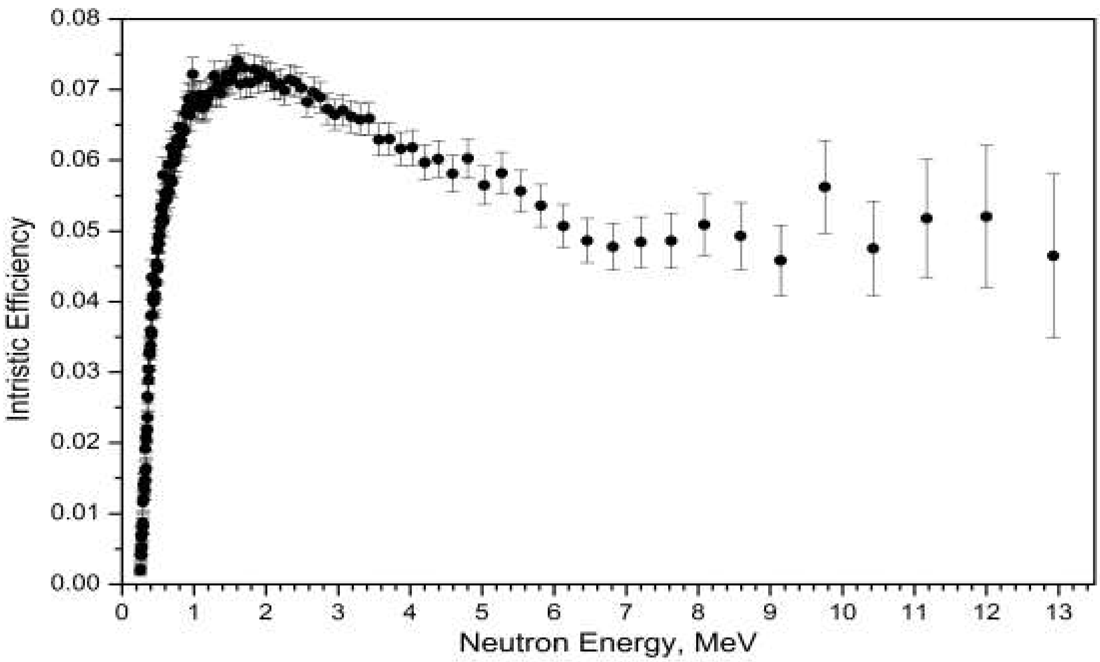

***Fig. 5**. Intrinsic detection efficiency for stilbene crystal used in the work.*

4. Results

Figure 6 shows the separation quality for the method of correlation analysis. Measure the quality of the separation in the work served as a parameter Figure of Merit, which is a ratio of the difference of the first moments of the distributions to the sum of the widths at half-height (eq. 3).

$$FoM = \frac{M_\gamma + M_n}{FWHM_\gamma + FWHM_n} \qquad (3)$$

Figure 7 shows slices of two-dimensional spectrum at different energies and their fitting by Gaussians. It is shown that separation quality increases with energy increasing. Processing method used in this work allowed us to identify confidently the pulses of electrons and protons at energy 40 keVee, which corresponds to a neutron energy of 400 keV.The present quality of the separation results to ability of high quality measurements with very low detection threshold of 260 keV.

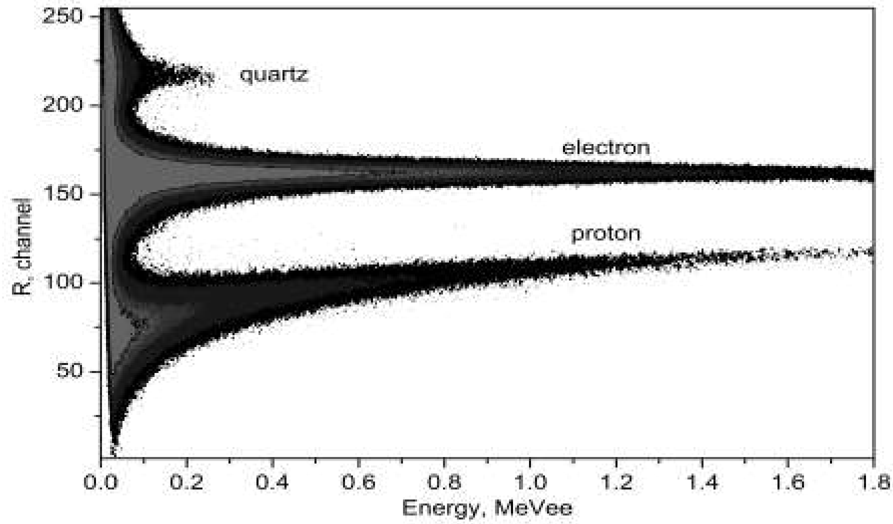

Fig. 6. *The two-dimensional spectrum in the axes of parameter R - energy in MeVee.*

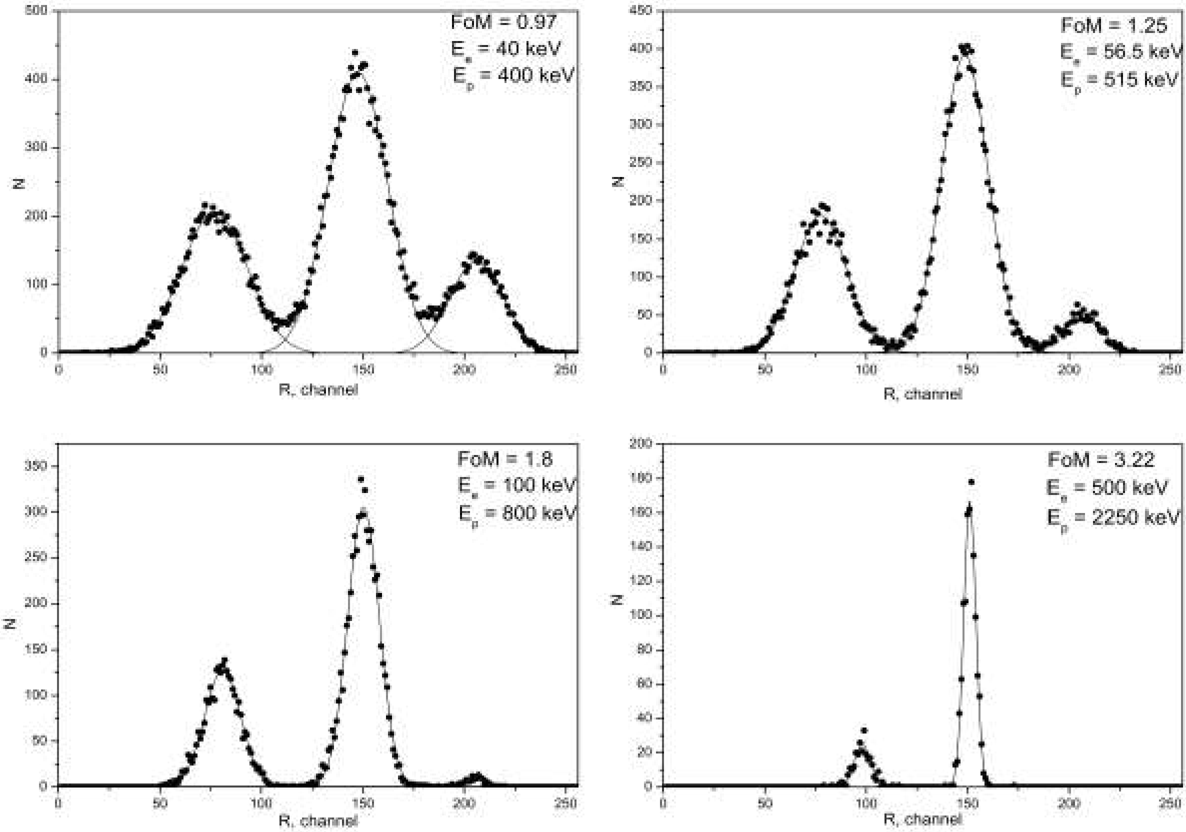

Fig. 7. *Slices of the two-dimensional spectrum (fig. 4) at different energies.*

Time resolution in the work was estimated by the peak width of the prompt gamma rays (fig. 8). The peak width at half maximum was 1.5 ns throughout the range above the threshold. This time resolution makes measurements in the field of high-energy neutrons up to 13 MeV possible.

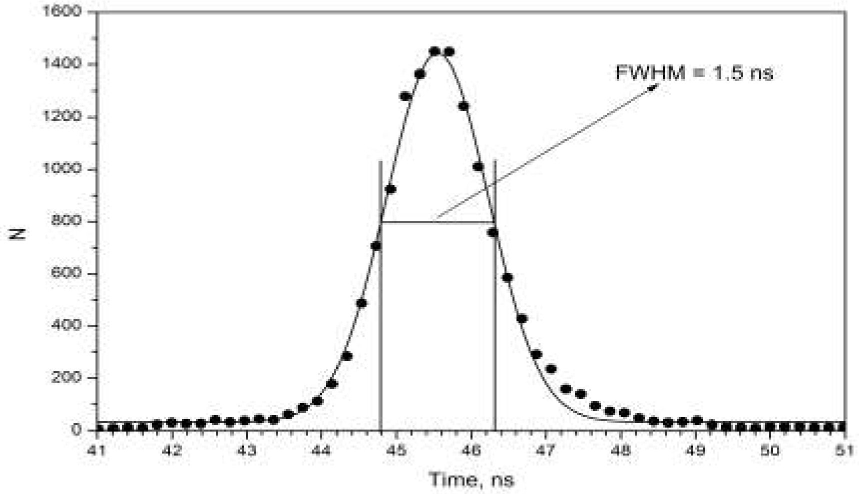

Fig. 8. *Time resolution in the work.*

In this work, the energy dependence of the light output of protons for stilbene crystal was experimentally measured. There are several approaches to the empirical description of the energy dependence of the light output for heavy charged particles [6-8]. The best way for description of the data obtained in this study was the method proposed Cecil (eq. 4) in paper [8]. The result of empirical description is presented in fig. 9 (solid line).

$$L(MeVee) = a \cdot E_p - b \cdot \left(1 - e^{-cE_p^d}\right) \quad (4)$$

Here a = 0.45±0.01, b = 0.76±0.06, c = 0.54±0.03, d = 1.032±0.08.

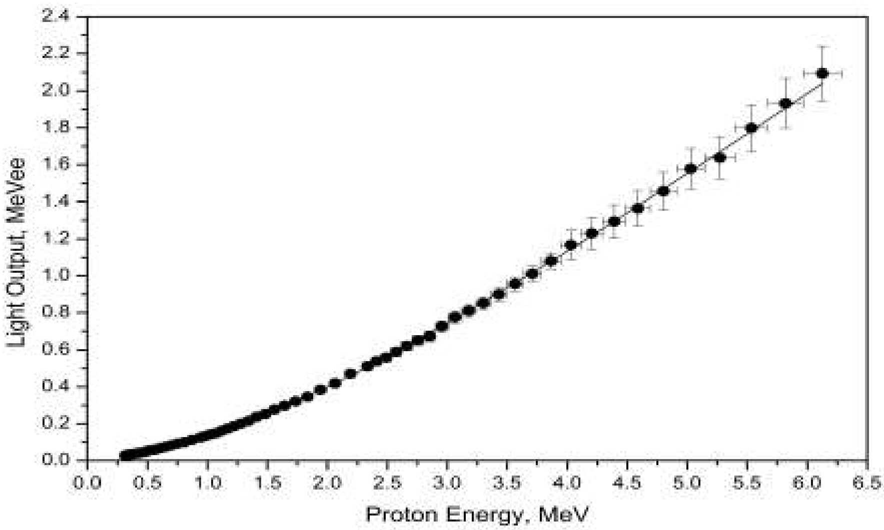

Fig. 9. *Light output for recoil protons. Points - experiment, line - an empirical description by eq.4.*

5. Conclusion

The main parameters of the neutron spectrometer based on the waveform digitizer and time-of-flight technic were shown. Simultaneous digitization of neutron detector signals and fission chamber signals got 1.5 ns time resolution. Intrinsic efficiency of the spectrometer was presented. It was shown that the method of correlation analysis of signals enabled to get good n/γ separation up to the energy of 40 keVee (recoil protons energy of 375 keV). Light output for the recoil protons for the stilbene crystal was obtained.

References

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