Fission-neutrons source with fast neutron-emission timing

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Abstract

A neutron source with fast timing has been built to help with detector-response measurements. The source is based on the neutron emission from the spontaneous fission of ^{252}Cf . The time is provided by registering the fission fragments in a layer of a thin scintillation film with a signal rise time of 1 ns. The scintillation light output is measured by two silicon photomultipliers with rise time of 0.5 ns. Overall time resolution of the source is 0.3 ns. Design of the source and test measurements using it are described. An example application of the source for determining the neutron/gamma pulse-shape discrimination by a stilbene crystal is given.

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1. Introduction

In detector development, neutron sources with timing signals are used in measurements of the detector response to neutrons, efficiency, pulse-shape discrimination, etc. The spontaneous fission of ^{252}Cf is the process used to build such sources. The fission-neutron spectrum has a broad distribution, but the time-of-flight technique allows selection of quasi-monoenergetic neutrons in a broad range of energies from 0.5 to 10 MeV (see e.g. Ref. [1]).

The spontaneous fission of ^{252}Cf is a convenient process for building a neutron source because it provides 3.75 neutrons per fission on average, while the two fission fragments can be used for determining the time when fission and prompt neutron emission respectively occurred. The most popular ^{252}Cf neutron sources are based on ionization chambers (see e.g. Ref. [2]). The time signal is generated by ionization of gas in the chamber by the fission fragments. If the distance between the ^{252}Cf deposition and anode is small, then the signals from the α particles will be negligible and

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rejected. Scintillation-gas counters are also used for registering the fission fragments. Each of the noble gases is a scintillator emitting light in the ultraviolet range. A fission-neutron source with timing given by gas scintillator is easy to build in a bullet-like container with a ^{252}Cf deposition in the middle and a photo-multiplier tube. These sources also provide a natural α -particle rejection.

In the present article, we report design of a fission-neutrons source using ^{252}Cf deposited on a thin scintillation film for registering the fission fragments and thus providing a timing signal (trigger) time when the prompt neutrons were emitted. The source is easy to produce. It is completely sealed, removing any possibility for cross contamination. The light from the scintillation layer is registered by two silicon photomultipliers (SiPM) keeping the size of the source small and convenient to use. We used SiPMs produced by SensL [3].

2. Source design

To keep the ^{252}Cf fission-neutrons spectrum unperturbed, we reduced the plastic materials to a minimum. A thin layer of scintillating paint EJ-296 [4] was deposited as a thin film on two glass plates each with area of $1\text{ cm} \times 1\text{ cm}$ and thicknesses of 0.1 cm . A regular microscope slide was used for the glass plates because of its good light transparency. A couple of hours after painting the scintillation paint was dry, but relatively soft. The area of the film was reduced to $0.6\text{ cm} \times 0.6\text{ cm}$, by cutting the film with a scalpel, to match the area of the SiPMs. A less than 1 mL drop of HNO_3 acid solution of ^{252}Cf was deposited on top of the scintillation film of one of the glass pieces in the middle of the painted area. The scintillation film of the other glass plate was covered with a $1.4\text{-}\mu\text{m}$ thick aluminized Mylar foil and glued to glass at the 0.2 cm wide band outside the scintillation film. The aluminized Mylar foil stops the light transfer between the two scintillating films. Depending on the concentration of the californium solution (typically 5 ml solution corresponds to $10\text{ }\mu\text{Ci}$ α -activity of ^{252}Cf), the drop usually dries in a few hours. The two glass plates are glued together by applying glue outside the scintillation film area with the scintillation surfaces facing each other after the californium deposit has dried. A sketch of the assembly is shown in Fig. 1. To insure that the ^{252}Cf deposition is sealed well between the two glass plates, epoxy was applied at the edge of the plates. The epoxy was dark to prevent light crosstalk between the two glass plates.

We used two MicroFB-60035 SiPMs [3] to read the light from the two sides of the source. The SiPMs have an area of $0.6\text{ cm} \times 0.6\text{ cm}$, and they were mounted on pin adapter boards, allowing easy handling (model MicroFB-SMTPA-60035). A simple electrical scheme, shown in Fig. 1, was

Figure 1. (Color online) Schematic drawing of the assembly of the source (left panel). Scintillation paint is deposited on two glass plates facing each other, ^{252}Cf is deposited on one of the painted surfaces and covered with aluminized Mylar foil, and the three pieces are glued together. The edges of the glass plates are sealed with epoxy. Two SiPMs are attached to the glass plates with optical grease (right panel). The electronic scheme is depicted. “C” and “A” stand for the cathode and the anode, respectively, of the SiPM.

used to extract a “standard signal” that provides spectroscopy information. The MicroFB-60035 SiPM also provides a “fast signal” output, which we did not use. However, an independent fast signal can also be produced by differentiating the “standard signal” with a high-pass filter, for example.

The SiPMs were coupled to the two sides of the source with optical grease EJ-550 [4]. The source and the two SiPMs were placed in a small aluminum box with dimensions of 1 in. $\times$ 1 in. $\times$ 0.5 in. The interior of the box was covered with black tape. The box was sealed to prevent light leaks and radiation contamination. The signal and power cables were epoxied (black) in place where they enter the box for light tightness and strain relief. A photograph of the neutron source is shown in Fig. 2.

3. Pulse-height spectra

The source provides unipolar positive signals greater than 50 mV from fission fragments. The operating voltage of the SiPMs is from 25 to 30 V. In our measurements we applied 28.5 V to both SiPMs. Due to the SiPM’s internal capacitance of 3.4 nF, the signals have long exponential tails with a length of about 1 μs . Typical signal waveforms can be found in Ref. [3]. We used a two-channel 400 MHz 14-bit self-triggering digitizer ZT4441 [5] to collect 5- μs long waveforms of the signals. Pulse-height spectra are collected by integrating the signal over 1 μs from the leading

Figure 2. (Color online) A photograph of the neutron source with open box cover. The ^{252}Cf source and the SiPM boards are labeled. The two BNC-connector cables provide the power voltage for the SiPMs, while the two LEMO-connector cables give the output signals, see Fig. 1 for reference.

edge of the pulse and subtracting the baseline averaged over $2\ \mu\text{s}$ before the leading edge of the pulse. Measured pulse-height spectra from each side of the neutron source and a diagram of the setup are shown in Fig. 3. The energy resolution differs depending on whether ^{252}Cf was deposited directly on the scintillating film or the aluminized Mylar foil was between the ^{252}Cf deposit and the scintillating film. The intense low-energy part of the spectra is due to α -particles from ^{252}Cf and electrons from the β decay of the fission fragments. Better separation of the fission fragments can be seen when coincidences between the two SiPMs are required.

The long tail of the SiPM signals limits the amount of ^{252}Cf material to be used in the source. Pile-up of signals will reduce the efficiency of the source and modify the pulse-height spectrum. The results presented in Sections 3 and 4 were obtained using a very weak prototype ^{252}Cf source with α activity of 100 Bq that avoids any pile-up effects. If a higher rate of the source is demanded, then it can be produced in a fragmented design using more pairs of SiPMs such that each pair measures the light output from smaller fraction of the deposited ^{252}Cf . A second approach for increasing the rate of the source for time-of-flight (TOF) measurements is to differentiate the source signals and measure coincidences between one of the SiPMs and a neutron detector. The registered α decays of ^{252}Cf will not lead to coincidences because no neutron is emitted. Still this approach provides

Figure 3. Pulse-height spectra measured from each side of the ^{252}Cf source and a diagram of the setup. The spectra were measured for the same number of events. The top histogram is measured from the side of the source where ^{252}Cf is directly deposited on the scintillating paint (the bottom glass plate in Fig. 1), while the bottom histogram corresponds to the opposite side with the aluminized Mylar foil in between (the top glass plate in Fig. 1). The parts of the spectra corresponding to signals from α -particles, light and heavy fragments from the spontaneous fission of ^{252}Cf are labeled.

accidental coincidences if the neutron detector is sensitive to γ -rays.

4. Time resolution

The scintillating paint and the SiPMs have fast rise times of 1 and 0.5 ns respectively, providing fast timing response of the source. We carried out a coincidence measurement between the two SiPMs to determine the time resolution of the source. A diagram of the setup is shown in Fig. 4. The two SiPMs were powered by 28.5 V. Each of the signals was split into two. One of the copies was connected to one of the input channels of the ZT4441 digitizer, while the second copy was inverted and discriminated by a constant-fraction discriminator (CFD) CAEN N842 [6]. Two CFD modules, one for each SiPM of the source, were used to avoid possible crosstalk between input CFD channels of one module and to set individual threshold for each of the SiPMs. A coincidence signal between the two SiPMs was generated by a LeCroy 465 module; this signal was used as an external trigger to the ZT4441 digitizer, providing a lower data rate than if each channel self triggered. Waveforms of the two SiPMs were recorded for 5 μ s and processed in off-line analysis.

A two-dimensional pulse-height spectrum from this measurement is shown in Fig. 4. The quantities “Channel number 1” and “Channel number 2” correspond to the integrated pulses from the two output signals of the source over 1 μ s with subtracted baselines measured for 2 μ s prior the pulses. Accurate times of the pulses were deduced by the crossing point of a linear fit of the rise slope of the signal and the baseline. A spectrum of the time differences between the two SiPMs was collected with applied software cut to the pulse-height spectrum (cf. Fig. 4 upper panel) to reduce the number of random coincidences. The time spectrum in Fig. 4 was fitted with a Gaussian function with a linear background. A time resolution (full width at the half maximum) of each side of the source of 299 ps was determined from the fit.

Measuring the rate of coincidences between the two SiPMs (the rate of the trigger signal in Fig. 4) of 1.566(8) 1/s, we estimated an efficiency of the timing signals of about 50%, by comparing this coincidence rate with the fission rate of 3.1 fission/s of the deposited ^{252}Cf . A reason for missing coincidences is the total internal reflection of the scintillation inside the thin film and its absorption in the black epoxy on the outer edge of the scintillator sandwich. A similar effect has been observed in Ref. [7]. Stopping the heavy fragments inside the ^{252}Cf deposit or the aluminized Mylar foil when they are emitted tangential to the scintillating film can also cause some reduction of the efficiency.

Being semiconductor elements, the SiPMs produce significant thermal noise. We measured noise root mean square (RMS) of the baseline of 0.43(4) mV. Radiation damages in the SiPMs are expected to increase the noise RMS with time. A ^{252}Cf source with 1 μCi α activity increased the noise RMS of the SiPMs by a factor of three to 1.3(2) mV while being in contact with the SiPMs for six months. Replacing the SiPMs with new non-irradiated SiPMs reduced the noise RMS to 0.46(7) mV. We have not performed a detailed study of the noise RMS with the dose received by the SiPMs, but signs of radiation damage to the SiPMs have been observed.

5. Application

We present an example of an application of the fission-neutrons source with fast neutron-emission timing. We used the source to determine the pulse-shape discrimination (PSD) properties of a stilbene crystal for various neutron energies. The stilbene crystal, with dimensions of 0.5 in. $\times$ 0.5 in. $\times$ 3 in., has been attached to a 2-inch photo-multiplier tube at the small-area side and wrapped with thin light-insulation plastic foil. The neutron source, containing ^{252}Cf with 1 μCi α activity, has been placed at 25.4 cm distance from the long axis of the stilbene crystal. The detector has been placed in a lead housing with a wall thickness of at least 5 cm to reduce the ambient room background. A square opening in the housing with area of 1 in. $\times$ 1 in. was left between the source and the detector. The signals from the source and the detector were recorded by a desktop digitizer CAEN DT5730B [6].

A TOF spectrum between the stilbene detector and the neutron source is shown in the top panel of Fig. 5. Accurate times of all input signals were obtained by using a numerical CFD method of finding the zero-crossing point of the bipolar residuum waveform after subtraction of the inverted and delayed pulse. The TOF spectrum was obtained as a time difference between digitizer channels 0 and 1 (cf. Fig. 5). Using the TOF measurement, we have selected two regions of TOF intervals. Most of the events in region 1 come from prompt fission γ rays, while region 2 contains mostly events from prompt fission neutrons. For each of the two TOF regions, we have recorded a two-dimensional pulse-height spectrum (a PSD plot) to demonstrate different scintillation light decay patterns for different type of incident radiation as γ rays and neutrons. The two-dimensional spectra are shown in the bottom two panels of Fig. 5. The first quantity “Channel number 1” corresponds to the integrated pulse from the stilbene crystal over the first 20 ns, while the second quantity “Channel number 2” is the full integral of the signal over 400 ns. Both integrals started

150 from the beginning of the signal. The length of the full integral of the pulse was kept fixed while the
151 length of the short integral was optimized to obtain good PSD. More details on the PSD method
152 with stilbene detectors can be found in Ref. [8].

153 6. Summary

154 A fission-neutrons source with fast neutron-emission timing has been designed based on ^{252}Cf .
155 The source is permanently sealed, with small dimensions, low operating voltage and is easy to
156 use. The SiPMs provide fast high-amplitude signals suitable for pulse-height analysis and applying
157 coincidence conditions. The measured time resolution of the source is 0.3 ns.

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Figure 4. (Color online) A coincidence measurement between the two SiPMs of the ^{252}Cf source for determining the time resolution of the source. The two-dimensional pulse-height spectrum (upper panel) was used to apply a software cut depicted with red lines to remove the majority of the coincidences due to β -particles. The time spectrum is presented on the bottom panel. The spectrum is fit with a Gaussian function with a linear background shown in red.

Figure 5. (Color online) A time of flight measurement (the top panel) between the fission-neutron source and a stilbene crystal and pulse-shape discrimination plots for the stilbene crystal (the bottom panels) for two regions of the time-of-flight spectrum. Channel number 1 and Channel number 2 correspond to short and long integration intervals of the signal from the stilbene crystal. A diagram of the setup is shown in the drawing.