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Abstract

A new low-mass multiple gas-filled parallel-plate avalanche counter for the fission-fragment detection has been developed to mark the fission occurrence in measurements of the prompt fission neutron energy spectrum as a function of incident neutron energy. It was used successfully for the neutron-induced fission of ^{235}U and ^{239}Pu with a total mass near 100 mg each and the spontaneous fission of ^{252}Cf. Both the incident neutron energy and the prompt fission neutron energy are measured by using the time-of-flight method. The design and performance of this avalanche counter are described.

Keyword:
Fission, Uranium, Plutonium, Californium-252, Parallel-plate avalanche counter

I. Introduction

Two neutron detector arrays have been developed to provide the precision data on the prompt neutron emission in the neutron-induced fission of actinide nuclei as a function of incident neutron energy at the Los Alamos Neutron Science Center (LANSCE) [1,2], where neutrons are produced by bombarding a tungsten target with a pulsed 800 MeV proton beam. One array consists of 22 ^{6}Li-glass detectors for the detection of neutrons with the energy below ~ 1 MeV [1,2]. The other, consisting of 54 organic liquid scintillators, is for the detection of neutrons with energy above 600 keV [1] and also can be used for the measurement of the prompt γ emission in fission [3].

For the prompt fission neutron energy spectrum measurement, the energy is determined using the time-of-flight method; that is, the time difference between the fission occurrence and the detection of neutron for a given flight path. Therefore, the neutron energy resolution is determined directly by time resolutions of both neutron and fission detectors. For the fission-fragment detection, the detector requires not only a good timing response but also an ability to bear the radiation damage and intense α-decay rate of source samples. A parallel-plate avalanche counter (PPAC) has many advantages for this application, which include fast timing, resistance to radiation damage, and tolerance of high counting rate. A PPAC also can be tuned to reduce the sensitivity to low-Z particles, which is important for experiments with α-emitting actinides. Therefore, a PPAC is an ideal detector for experiments requiring a fast and clean trigger for fission. In the following sections, the description is given for the design and performance of a low-mass multiple PPAC for the prompt fission neutron energy spectrum measurements, which are carried out at a flight path of 21.5 m from the neutron source at LANSCE.

II. Design of a low-mass multiple parallel-plate avalanche counter

Two design principles are followed for the architecture of the current PPAC for the detection of fission fragments. One is to minimize the mass of construction material to reduce the scattering of incoming and outgoing neutrons and the other is to maximize the mass of target material to enable the measurement to be completed in a reasonable time frame with adequate statistics, while the target still is thin enough to allow the escaped fission fragments to be detected by PPAC. The goal is to have a PPAC capable of accommodating up to 100 mg of highly radioactive nuclei such as ^{239}Pu. Shown in Fig. 1 is a schematic view of this detector system. It consists of (a) an aluminum cylindrical chamber 10 cm in diameter and 17.8 cm in length with a wall thickness of 1.59 mm, (b) a cap to accommodate vacuum feedthroughs for transmitting 10 signals, and (c) a target assembly of 10 electrically separated PPAC modules on a common support. The thin wall of the cylindrical chamber is possible due to the use of surface-mountable gas feedthroughs, made of aluminum, instead of the standard tube fitting, for the gas flow in and out of the PPAC.

The newly designed multi-foil PPAC contains ~ 100 mg of target material distributed over 10 titanium foils of 3 μm thickness. The target material is electrodeposited over an area of 4 cm diameter with the surface density about 400 μg/cm^2 on each side of a

titanium foil using the electroplating cell described in Ref. [4]. The loaded titanium foil of 3 μm thickness is then sandwiched between two 2.5 μm aluminum foils, forming the cathode. Two anodes, made of the same thickness aluminum foil, are placed at either side of cathode with a separation distance of 3 mm. A Pt foil of 5 μm thickness, is added to each anode to stop both α and fission fragments from going to the adjunct PPAC's to avoid multiple triggers for a given event. All thin foils are held by G-10 fiberglass rings of 0.80 mm thickness. Then the assembly of the 10 individual PPAC's is inserted into a cylindrical chamber with open ends for the neutron beam entrance and exit. The open ends are sealed with 25.4 μm Kapton foil. Several identical assemblies have been constructed, each with a different actinide, ^{235}U, ^{239}Pu, or ^{252}Cf.

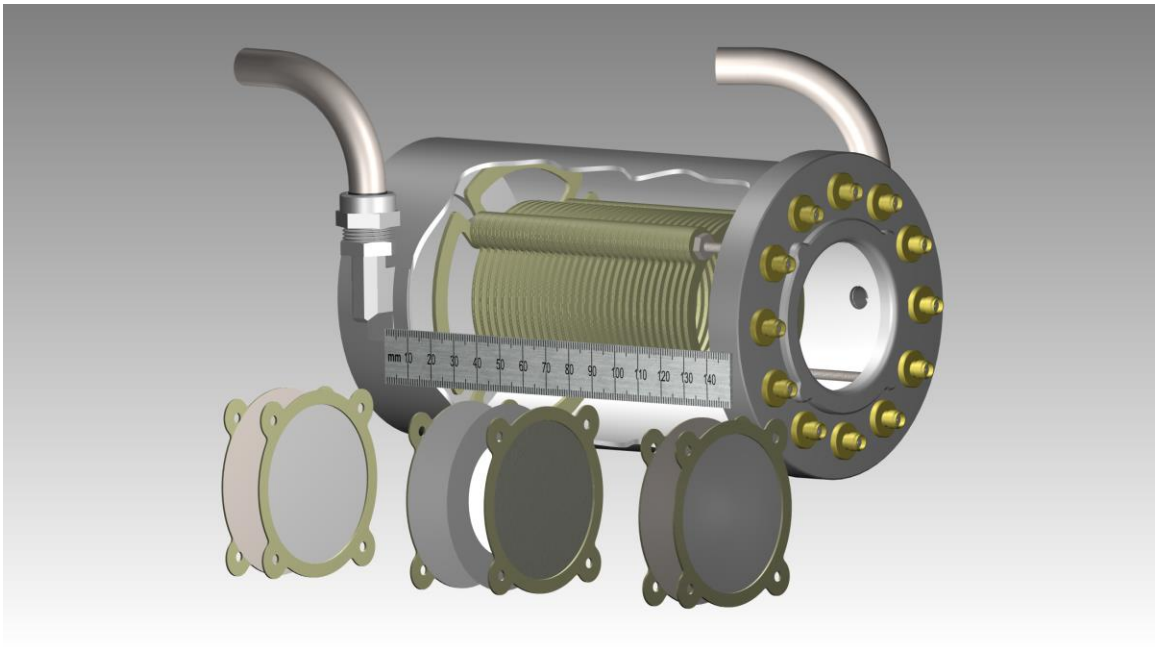

Fig. 1 An assembly of 10 individual PPAC's is housed in a cylindrical chamber. Each PPAC, shown in the lower half, has a cathode consisting of a titanium foil with the target material marked by the white area, sandwiched between two aluminum foils as well as two anodes mounted on either side of cathode. Each anode consists of aluminum and platinum foils and placed 3 mm away from the cathode. All thin foils are support by G-10 fiberglass rings except for the self-supported target foil.

III. Operation and performance

For stable operation of a PPAC, a stable gas pressure with continuous gas refreshing is required. This can be achieved by using a specialized gas handling system to regulate the gas flow via a feedback loop on the measured gas pressure against the preset value. Details of this gas handling system and its operation are described in Ref. [5].

The PPAC is operated typically at ~ 4.0 torr of isobutane with a gas flow up to 50 sccm. Two anodes in each individual PPAC are electrically connected and biased at ~ +400 V, producing pulse heights on the order of 1 mV for fission fragments. Each PPAC signal is

processed separately by a fast amplifier with a gain of about 600 and a bandwidth of 500 MHz before being sent to ZTec digitizers model 4441 with a sampling rate 400 MS/s to extract the pulse information for each event including its time, pulse height, and three pulse integrals: (1) a short integral on the order of 20 ns over the peak of the pulse; (2) a longer integral over the tail of the pulse; (3) a long integral preceding the pulse for determining the background. The "pulse integral" referred to later in this article is the background-subtracted short pulse integral.

As mentioned earlier, the energy for incoming and outgoing neutrons is determined using the time-of-flight method. The incident neutron energy is determined by the time difference between the fission occurrence detected by PPAC and the primary proton beam pulse. An example is given in Fig. 2, where a typical spectrum of this time difference is plotted against the pulse height of fission fragments. It is derived from the measurement of the neutron-induced fission of ^{235}U, placed in a PPAC with a total mass of 112 mg. The photo-fission events, caused by prompt high energy γ rays produced in the neutron production target, can be seen as an isolated vertical line in Fig. 2 with the time difference of 0 ns relative to γ rays from the neutron source and can be used in the absolute neutron energy calibration. The time resolution is better than 1.5 ns, which yields an energy uncertainty of better than 1 % for neutron energy at 20 MeV, at the PPAC location of 21.5 m from the neutron production target. Despite possible spallation reactions occurring at the highest neutron energies, fission events can be uniquely indentified through the entire incident neutron energies.

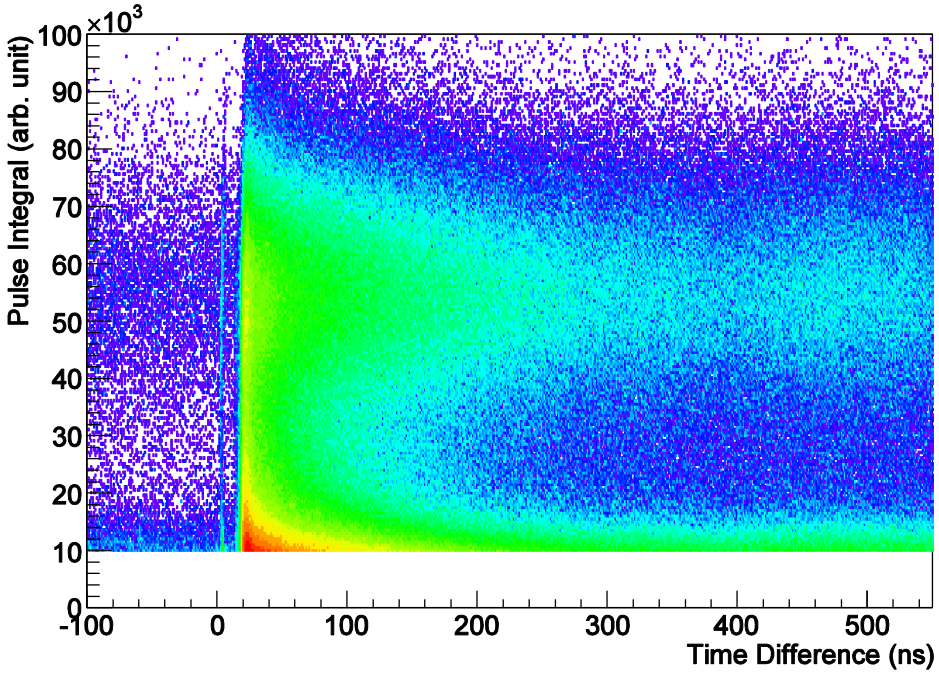

Fig. 2 The pulse integral of charged particles detected by PPAC vs the time difference between PPAC and the proton beam pulse is plotted for neutron-induced reactions on ^{235}U. The photo-induced fission events have no time walk, shown as an isolated vertical

line with the time difference of 0 ns relative to the prompt high-energy γ rays produced in the neutron source and can be used as the absolute calibration for the incident neutron energy.

For the prompt fission neutron spectrum, the energy of the outgoing neutron is determined by the time difference between the fission occurrence detected by PPAC and the neutron arrival in the neutron detector. Two types of neutron detectors are used for the current measurements; the ^{6}Li-glass detector array for neutron energies below 1 MeV [1,2] and the organic liquid scintillator array for neutron energies above 600 keV [1]. For the ^{6}Li-glass detector, the neutron is uniquely identified by the known Q-value (4.78 MeV) of the ^{6}Li(n,α) reaction. The full characterization of this detector array has been performed using a PPAC with ~ 1 μCi of ^{252}Cf [2]. A typical spectrum for the time difference between PPAC and ^{6}Li-glass detector vs. the pulse height measured by the ^{6}Li-glass detector is given in Fig. 3. A signal-to-noise ratio of better than 30 to 1 is observed. The achieved time resolution of ~ 5 ns gives an energy resolution about 27 % for a neutron energy at 300 keV over a flight path of 30 cm.

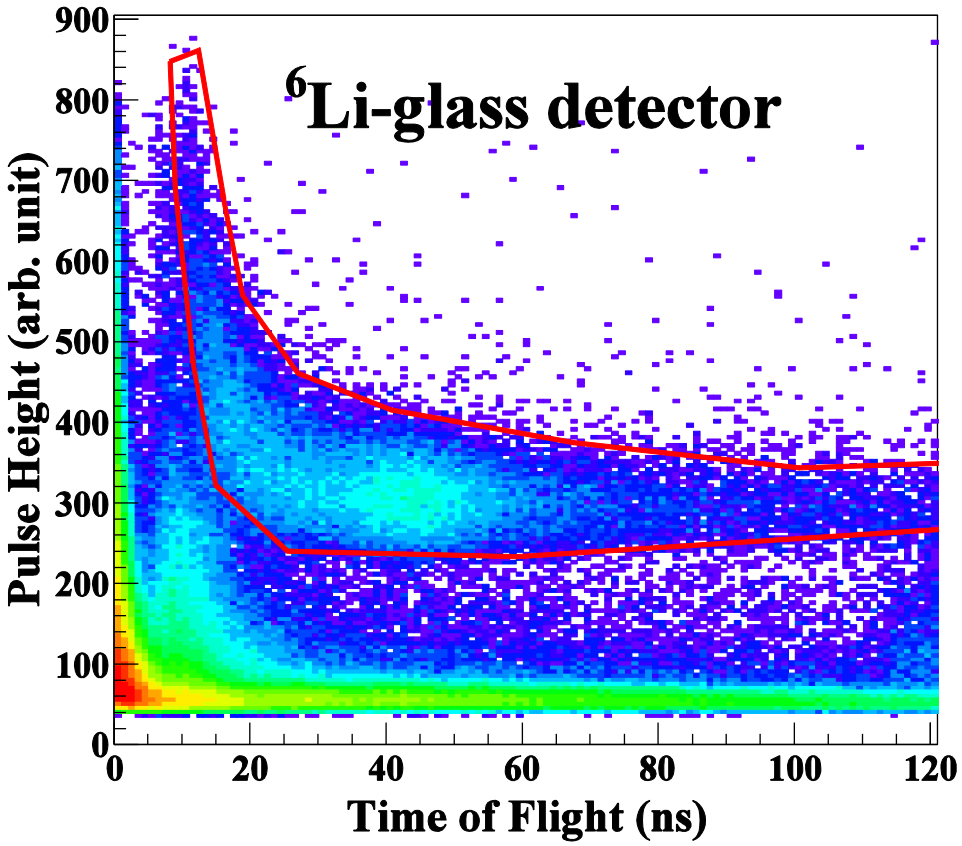

Fig. 3 The pulse height measured by the ^{6}Li-glass detector vs. the time difference between PPAC and ^{6}Li-glass detector is plotted for the spontaneous fission of ^{252}Cf. The neutron events are encircled by the red line, where the resonance state for the ^{6}Li(n,α) reaction with neutron energy at 244 keV is visible.

The organic liquid scintillator array is employed for the detection of prompt fission neutrons with energy above 600 keV. Neutrons are recognized using the pulse shape discrimination (PSD) method and their energy is determined by the time difference between the fission occurrence detected by PPAC and the neutron detected by scintillator. Shown in Fig. 4 is a typical spectrum of this time difference for the neutron-induced fission of ^{239}Pu with and without the PSD applied. The target material is placed in a PPAC with a total mass of 94 mg. The background γ events are suppressed by nearly a factor of 4 after the PSD method is applied. The achieved time resolution is better than 2 ns, which yields an uncertainty of better than 9 % and 30 % for neutron energies at 1 MeV and 10 MeV, respectively, over a flight path of 62 cm. The energy resolution will be improved by increasing the flight path to 100 cm in the future measurement.

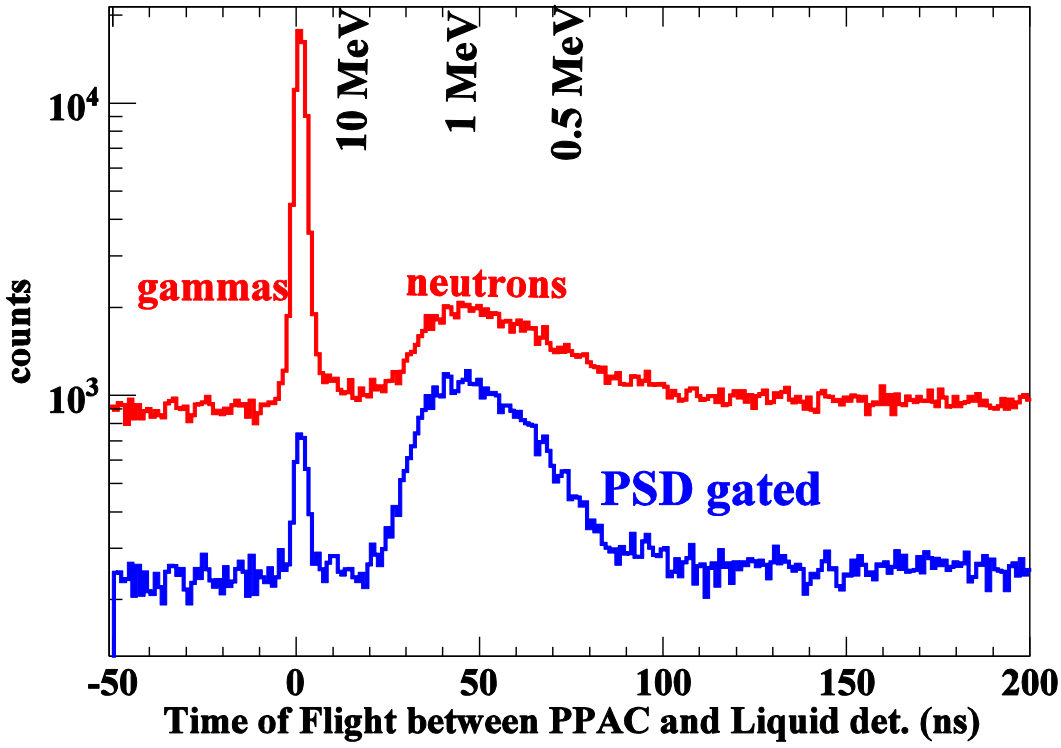

Fig.4 Shown in the red line is the spectrum of the time difference between the fission occurrence detected by PPAC and the prompt fission neutrons or γ's detected by organic liquid scintillation for the neutron-induced fission of ^{239}Pu. Neutrons are identified in the scintillator using the PSD method and shown in the blue line. Prompt fission γ's detected by scintillator have no time walk and can be used as the absolute calibration of neutron energy. The locations corresponding to the neutron energies at 0.5, 1.0, 1nd 10 MeV are marked.

IV. Discussion

Despite this success, two issues are identified for this new PPAC and solutions will be implemented for the future planned measurements.

One is related to the down-scattering of outgoing neutrons due to the hydrogen content in the G-10 fiberglass rings. This issue is identified through numerical simulations of the effect on neutrons passing through the PPAC with all the material included using MCNP [6]. We are replacing G-10 rings with aluminum rings to minimize the distortion of the measured spectrum. The aluminum ring has an insulated layer on one side through the anodization. The other is the effect of the field orientation on the pulse height measurement in an extreme radioactive environment such as ~ 2 x 10^7 α/s in each individual PPAC with ~ 10 mg of ^{239}Pu. By swapping the current cathode-anodes configuration to an anode-cathodes one, the ratio of fission fragments to α particles is enhanced by about 22 %. This may be attributed to the exhaustion of isobutane in the close proximity to the target, resulting in the loss of the primary ionized electrons and leading to the change of the gas gain. With these modifications, we think this newly developed multiple PPAC is reasonably optimized for the study of the prompt neutron emission in fission.

V. Summary

A low-mass multiple PPAC has been successfully developed for the fission-fragment detection to study the prompt neutron emission in fission. Initial measurements for the neutron-induced fission of ^{235}U and ^{239}Pu as well as the spontaneous fission of ^{252}Cf have been fielded using this newly developed PPAC together with two neutron detector arrays for both low- and high-energy fission neutrons. These PPAC's have demonstrated excellent time characteristics and worked very well in separating fission from α for ^{235}U as well as ^{252}Cf and reasonably well for ^{239}Pu.

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