Fission-fragment detector for DANCE based on thin scintillating films

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A fission-fragment detector based on thin scintillating films has been built to serve as a trigger/veto detector in neutron-induced fission measurements at DANCE. The fissile material is surrounded by scintillating films providing 4π detection of the fission fragments. The scintillation photons were registered with silicon photomultipliers. A measurement of the 235U (n, f) reaction with this detector at DANCE revealed a correct time-of-flight spectrum and provided an estimate for the efficiency of the prototype detector of 11.6(7)%. Design and test measurements with the detector are described.

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1. Introduction

Nuclear fission is a phenomenon where a nucleus splits typically into two fragments accompanied with prompt emission of neutrons and γ rays. Model description of the fission process requires measurements of correlations between all particles produced by the fission. Multidetector arrays are commonly used to simultaneously measure the emitted neutrons and γ rays. An active target registering one or both fission fragments is often used to label the beginning of a fission event for a multidetector system. Neutron capture is a competing process to the neutron-induced fission measurements at DANCE. The scintillating films have to be thin, homogeneous and without holes. Commercial scintillator paint can be used in contrast to the pioneering work done by Muga [5] on thin scintillating films. Many factors can impact the final thickness and the quality of the scintillating film. The solvent used to dilute the scintillator paint as well as the dilution of the paint are major factors. A solvent with a high vapor point will evaporate easily, causing the

2. Production of thin scintillating films

The production of thin scintillating films is a critical step in building a TFD. The films have to be thin, homogeneous and without holes. Commercial scintillator paint can be used in contrast to the pioneering work done by Muga [5] on thin scintillating films. Many factors can impact the final thickness and the quality of the scintillating film. The solvent used to dilute the scintillator paint as well as the dilution of the paint are major factors. A solvent with a high vapor point will evaporate easily, causing the
paint to dry quickly before it can become uniform and thin. The extent to which the paint is diluted with solvent impacts the viscosity of the paint solution and how thin the final film can be produced. Finally, the speed at which the spin coater is spun will also change the thickness – faster speeds produce thinner films. In addition, uneven speeds will give non-uniform films.

A precision spin coater KW-4A1 was used for the uniform deposition of thin scintillating films onto a 7 µm thick aluminized Mylar substrate. The Mylar substrate was attached to a 10 cm diameter silicon wafer using double-sided tape. The silicon wafer was placed in the center of the vacuum chuck of the spin coater and then the house vacuum was turned on. The spin coater was programmed to a speed of 1000 rpm and a spin time of 50 s. Thin scintillating films were produced by covering the Mylar substrate with plastic scintillator material. The plastic scintillator that was used to fabricate the scintillating films was the commercially available EJ-2962 plastic scintillator paint. The scintillator paint was not diluted with solvent. A 2 mL aliquot of the plastic scintillator material was placed in the center of the Mylar substrate that was mounted on the spin coater using a transfer pipette as soon as the spin coater reached the desired speed. Over a period of a few days the thin scintillating films began to separate from the Mylar substrate. The film was detached from the substrate, left to dry completely and then cut to a square with area of 5 × 5 cm². The typical thickness of the produced films was 10–15 µm considering density of 1.02 g/cm³.

3. Design of the fission-fragment detector

The TFD has been designed to consist of several films, each containing 1–2 mg of fissile actinide material. The deposition is performed by “stippling.” The actinide material is first dissolved in nitric acid and then a small drop of it is placed on the film. The films are left for a day in a fume hood until the acid evaporates. Only a spot with diameter of 2–3 mm containing the fissile material remains on the film. The stippling method creates a relatively stable deposit, but it will provide removable contamination if touched. It has to be noted that the stippling method is a low cost and easy to perform technique, but it leaves the contamination if touched. It has to be noted that the stippling method is relatively stable deposit, but it will provide removable contamination if touched. Only a spot with diameter of 2

4. Performance of the fission-fragment detector

A TFD with 0.9 mg of 235U has been tested at DANCE. The uranium was enriched to 235U to 99.9%. The fissile material was distributed over three films. An additional two blank films were used as a first and last film of the detector, cf. Fig. 1. A low-pass filter has been installed to remove the noise collected by the power line. A bias voltage of 28.5 V has been applied to the SiPMs.

Fig. 1. Schematic drawing of the prototype TFD. The detector consists of five films, the middle three of them have small deposition of 235U. All films are attached to acrylic light-guide rings glued together in a solid body. The scintillations are registered by a ring of 19 SiPMs connected in parallel. The electronic scheme is shown in the bottom panel. The TFD is secured in an aluminum canister with Kapton windows to prevent contamination of the DANCE beam line. The TFD is evacuated and vented through a HEPA filter.
A time-of-flight (TOF) spectrum was collected from the time difference between the proton-beam pick-off signal and the TFD. The TOF spectrum is compared with the $^{235}$U ($n,f$) cross-section from the evaluation ENDF/B-VII.1 [7] in Fig. 3. The counts from the TFD were converted to units of cross-section by dividing the spectrum with $1/E_n$ which is the shape of the neutron flux at flight path 14, cf. Fig. 3 in Ref. [8]. Because of the similar slope of the two spectra (cf. Fig. 3), the efficiency of the TFD is assumed to be constant. Deviations of the cross-section obtained with the TFD from the ENDF evaluation are result of inaccurate transformation of time-of-flight to incident-neutron energy which we have used in this analysis. The transformation does not include the broadening of the neutron flux by the water moderator and other components of the neutron-production target at Lujan Center.

An estimate of the efficiency of the detector can be obtained by comparing the DANCE TOF spectrum containing all events with the one tagged on the TFD. The peak areas of the $^{235}$U ($n,f$) resonances are proportional to the DANCE efficiency only, while the ones tagged on the TFD are proportional to the product of the DANCE and TFD efficiencies. The ratio of the two areas will give us the efficiency of the TFD with uncertainty completely statistical. The two spectra are shown in Fig. 4. A weighted average of the three strong resonances gives a value of 11.6(7)% for the TFD efficiency.

Sensitivity of the detector to $\gamma$ rays and neutrons was studied with a $^{252}$Cf source with neutron-emission timing [9] with $\alpha$ activity of 30.3 kBq. A blank detector without any $^{235}$U deposition was placed in a piece of beam pipe. The pipe ended with a break-out box with feedthroughs for powering the detector and taking the signals out. The other end of the pipe was covered with a thin aluminum foil for light insulation and behind it the $^{252}$Cf source was positioned. The distance between the source and the middle of the detector was 50 cm. A TOF spectrum, shown in Fig. 5, has been measured for 32.6 days. Integrating the neutron peak in the TOF spectrum and considering the solid angle of the detector, the activity of the source and the measurement time we calculated an efficiency of 0.03% for detecting neutrons with energies above 0.5 MeV. The efficiency decreases for lower energy neutrons and is 0 for neutrons with energies below 0.5 MeV. The $\gamma$ ray and neutron sensitivity of the detector will not influence measurements at DANCE because the neutron flux at flight path 14 is negligible for neutron energies above 0.5 MeV and measurements cannot be performed for these energies.

5. Summary

A fission-fragment detector based on thin scintillating films has been designed as an alternative trigger/veto detector to the PPAC for use with the DANCE array. Two TFDs have been built and tested in measurements at DANCE, one of the TFDs contained 0.9 mg of $^{235}$U, while the other TFD was blank. The TFD provided a TOF spectrum from the $^{235}$U ($n,f$) reaction very similar to the ENDF/B-VII.1 evaluation. The detection efficiency has been estimated to be 11.6(7)%, it will be a subject of further improvements as using more efficient SiPMs and preamplifier attached at the ring printed circuit board. A bench-top measurement with a $^{252}$Cf source and a blank TFD revealed that the small sensitivity of the detector to $\gamma$ rays.
rays and fast neutrons will not affect future measurements at DANCE.

The TFD exhibits a number of advantages in comparison with the PPAC. It is relatively easier to build at smaller cost than a PPAC detector. The fissile material can be stippled onto the scintillating films, a much simpler method than the molecular plating used for the PPAC samples, and the material can be easily recovered after the measurement. The TFD does not need high electric fields, electrical connections and is free of possible electrical sparking and damages of the detector typical for the PPAC. The only electrical connections are between the ring with SiPMs and the signal and power cables. These connections can be tested in a lab prior to encapsulate the TFD in the aluminum canister.

A disadvantage of the TFD is the hydrogen contained in the films and the scattering of the neutron beam from it. The scattered neutrons could cause signals in the DANCE BaF\(_2\) detectors if they are captured in any of the barium isotopes. These DANCE events will be filtered out only if the TFD is used as a “trigger” detector. If the TFD is used as a “veto” detector then an additional measurement with an identical blank TFD is required to estimate the neutron-scattering background in the DANCE events.

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