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A method to measure prompt fission neutron spectrum using gamma multiplicity tagging

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ABSTRACT

In order to improve on current prompt fission neutron spectrum measurements, a gamma multiplicity tagging method was developed at the Rensselaer Polytechnic Institute Gearttner Linear Accelerator Center. This method involves using a coincidence requirement on an array of BaF_2 gamma detectors to determine the timing of a fission event. This allows for much larger fission samples to be used due to the higher penetrability of gammas compared to fission fragments. Additionally, since the method relies on gammas as opposed to fission fragments, the effects of the low level discriminator, used in fission chambers to eliminate alpha events, are not seen. A ^{252}Cf fission chamber was constructed in order to determine the viability of this method as well as the efficiency when compared to a fission chamber. The implemented multiple gamma tagging method was found to accurately reproduce the prompt fission neutron spectrum for the spontaneous fission of ^{252}Cf and to detect 30% of fission events.

1. Introduction

Accurate nuclear data are important for reducing the uncertainty of nuclear simulation codes such as Monte Carlo N Particle (MCNP) [1] and GEANT [2]. These codes require cross-sections and other nuclear data such as energy spectrum for prompt fission neutron emission in order to simulate nuclear processes. This data comes from evaluated nuclear data libraries such as the Evaluated Nuclear Data File (ENDF) [3], the Joint European Fission Fusion (JEFF) [4] evaluation, and the Japanese Evaluated Nuclear Data Library (JENDL) [5]. These evaluated nuclear data libraries combine experimental results with theoretical calculations in order to best determine the value for the nuclear data. Fig. 1 shows several experimental datasets for the prompt fission neutron spectrum (PFNS) for thermal neutron induced fission of ^{235}U as well as the evaluations from ENDF, JEFF and JENDL. This shows that there is very little experimental data for the PFNS for ^{235}U particularly in the region below 0.5 MeV. Additionally, the existing data often have large associated experimental errors and, after proper normalization, the shapes do not agree with the evaluated nuclear data libraries. As seen in Fig. 1 all three evaluations are lower than the experimental data in the region below 0.5 MeV. Therefore, more accurate measurements are needed, particularly in the energy region below 0.5 MeV, in order to more accurately represent the PFNS in simulations codes.

One of the limitations to current PFNS measurements is the mass of fissionable material which can be used in the measurements. Typical PFNS measurements are preformed using a fission chamber to determine when a fission event has occurred. These chambers are advantageous due to high efficiency for detecting fission; however, they are limited by the total mass of fissionable material they contain. Conventional fission chambers utilize the energy deposition of fission fragments in a gas volume to determine when a fission event has occurred. Due to the limited range of fission fragments in material, on the order of microns, the fission samples are required to be very thin to allow the fragments to escape the sample [6]. This limits the fissionable mass available in the experiment. Advanced multi-plate fission chambers such as the Parallel Plate Avalanche Counter (PPAC) chamber used at the Chi-Nu experiment station at Los Alamos National Laboratory (LANL) contains 100 mg of fissionable material which is distributed across 10 sample cells with approximately 10 mg of material per cell [7]. This both complicates the fission chamber and requires time of flight corrections based on the sample's location in the detector. These mass limitations require much longer experimental run times in order to get statistically significant data.

In order to increase the sample mass that can be used for PFNS measurements, the prompt fission gammas can be used as a tag that the fission event has occurred. This has been done previously for PFNS measurements of the spontaneous fission of ^{252}Cf [8]. This method uses any gamma event as the fission start time. While this works well for measurements of spontaneous fission due to the low gamma background rate, it does not work for neutron

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0168-9002/

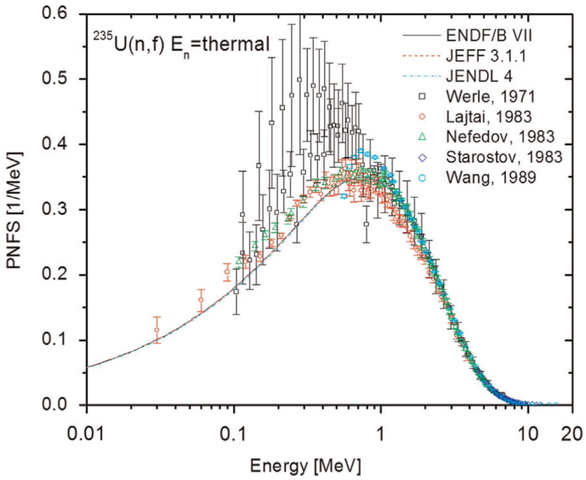

Fig. 1. The PFNS for ^{235}U thermal neutron induced fission showing several relevant datasets as well as the most recent evaluations from ENDF, JEFF and JENDL data libraries.

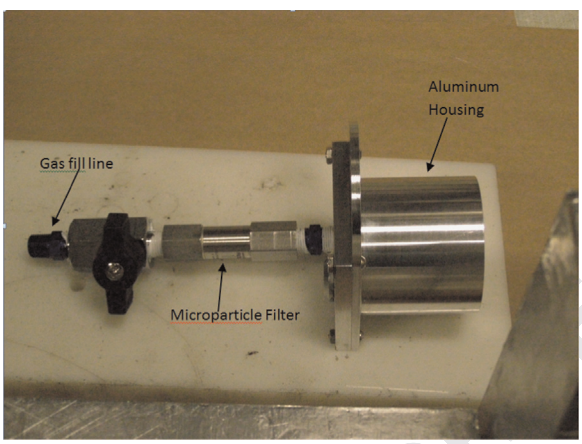

Fig. 2. The ^{252}Cf fission chamber used in the spontaneous fission PFNS measurements. The microparticle filter used to prevent fission fragments from contaminating the gas fill line, along with the gas fill line and aluminum housing, is highlighted. The sample plate is located in the center of the aluminum housing.

induced fission where the incident neutron beam provides a large gamma background. Therefore, multiple gamma tagging would be preferable for measurements of neutron induced fission. A multiple gamma tagging technique was previously utilized at the University of Massachusetts Lowell [9]; however, large scattering backgrounds caused difficulties in the measurement. Additionally, gamma tagging has been used to measure the fission cross-section with the gamma multiplicity detector at the Gaerttner Linear Accelerator Center at Rensselaer Polytechnic Institute (RPI) [10]. Through the implementation of digital data acquisition, a new multiple gamma tagging method has been developed at RPI in order to measure the PFNS of several isotopes (Fig. 2).

2. Gamma tagging method

In order to improve the count rate for prompt fission neutron spectrum measurements, a multiple gamma tagging method was developed at RPI using the RPI neutron scattering system [11]. The gamma tagging method utilizes the high average fission gamma multiplicity, 6.53 for ^{235}U, 6.78 for ^{239}Pu, and 6.95 for ^{252}Cf [12], along with the higher penetrability of gamma rays to allow for much more massive samples to be used. An array of four gamma detectors was oriented next to the fissioning sample, and a

Table 1
Results from MCNP Polimi modeling for the optimization of the number of gamma detectors used for gamma tagging. The total detection volume was conserved and each detector was modeled as 5 cm thick. Gamma coincidence was used to determine fission and false fission %.

of det.	Det. rad. (cm)	Fiss. %	False fiss. %	FOM
2	7.0	17.3	3.7	4.8
3	5.7	28.3	3.7	7.6
4	**4.9**	**28.7**	**3.7**	**7.7**
5	4.4	30.9	4.1	7.6
6	4.0	31.4	4.1	7.6
7	3.7	31.3	4.3	7.2
8	3.5	32.5	4.4	7.4

coincidence requirement on the array was used to determine when a fission event has occurred. For this application the gamma energy is of little importance, and only the timing of the gamma was required for coincidence. Therefore, BaF_2 detectors were chosen as the gamma detectors of choice, and the timing of the fast detector response component was used for coincidence timing.

Several MCNP Polimi [13] simulations were performed in an attempt to optimize the gamma detector arrangement for the multiple gamma tagging method. For these simulations a ^{235}U sample was placed 10 cm from an array of BaF_2 crystals. A 1 MeV neutron beam was used to induce fission on the ^{235}U sample. Three EJ-301 detectors were modeled as 5 in. diameter by 3 in. thick detectors, which are the size of detectors used currently at the RPI neutron scattering system and located at a distance of 50 cm from the sample. In order to determine which detector configuration was best for the BaF_2 detectors, a figure of merit (FOM) was determined. This FOM is the ratio of the percent of fissions detected with the gamma tagging method over the false fission percent and is given in Eq. (1). The FOM is designed to increase the efficiency of the detection method while limiting the false fission contribution thus a larger FOM is better. The valid fission events are selected by seeing two gammas in coincidence that result from a fission event. The false fission percent is the percentage of events that contain a gamma coincidence of two or greater coming from an event other than fission. This includes events from capture as well as inelastic scattering; however, due to limitation on the simulation, it does not included events from mixed sources such as one gamma from fission and a second from capture. Cross-talk between the detectors was not included in either a valid fission or false fission event in the simulation. A separate simulation was preformed in order to quantify this effect. A 1/4 in. lead shield was placed around each detector to limit the cross-talk. The cross-talk between detectors was found to be less than 1% of total fission events:

$$FOM = \frac{FissionPercent}{FalseFissionPercent} \quad (1)$$

The first simulation performed looked at optimization of the number of gamma detectors used for the coincidence measurement. For all gamma detectors in this simulation the thickness of each detector was kept constant at 5 cm. In order to give equal weighting to configurations with different number of detectors, the detector radius was changed for each configuration of detectors in order to preserve the total volume. The results of the MCNP Polimi simulations can be seen in Table 1. Here the FOM is highest for 4 detectors. Although the probability to detect fission is increasing with number of detectors, the FOM is maximized at 4 detectors.

The second parameter which was optimized was the thickness of the gamma detectors. For these simulations the radius of the detector was constant at 4.9 cm, and four detectors were used