Simultaneous Measurement of Fission Neutron Multiplicity and Spectrum Using a Gamma Tagging Method

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There is currently a need for highly accurate measurements of fission neutron multiplicity ($\bar{\nu}$) and spectrum for ^{235}U particularly in the range of sub 1 MeV fission neutron energy. These measurements increase the accuracy of calculations used to model nuclear fission systems. Gamma tagging is a new method for accurately measuring these quantities. This method utilizes an array of gamma detectors and a coincidence requirement on the detectors to determine whether a fission event has taken place. A detection system has been built using EJ301 liquid scintillation detectors and preliminary results with ^{60}Co have shown that the system is capable of determining the necessary coincidence for the gamma tagging. The system will also utilize a newly developed lithium glass detector array to allow for accurate measurements down to fission neutron energies in the keV region. The system is currently being tested by measuring the spontaneous fissions spectrum of ^{252}Cf and the preliminary results look promising. When the gamma tagging method has been verified, the system will be used to obtain accurate measurements for $\bar{\nu}$ and fission neutron spectrum for ^{235}U. After these measurements have been completed the system can be utilized to measure other fissile materials.

I. Introduction

With the increase in computational power the current limitations on nuclear simulations using computer codes such as MCNP lie in the accuracy of the nuclear data libraries [1]. In particular measurements made in the epithermal range for a variety of materials including Uranium and Plutonium isotopes are needed. Chadwick et al. [2] cites the need for improvement in the prompt fission spectrum for both ^{235}U and ^{239}Pu. The authors note that an improvement in this value could also assist in the modeling of the LANL Np-U critical assembly which currently calculates a low k_{eff} value. Figure 1 shows current

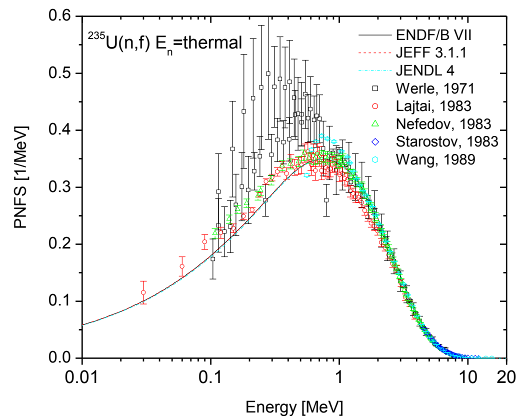

Figure 1: Experimental data and evaluations for the prompt fission neutron spectrum for ^{235}U highlighting the lack of experimental data in the epithermal region

measurements for the prompt fission neutron spectrum of ^{235}U. This highlights the fact that there is little experimental data in the epithermal range and the data that does exist has large errors associated with it. ^{6}Li-glass detectors are being investigated for neutron detection capabilities in this lower energy range. A novel technique for determining accurate $\bar{\nu}$ values is being developed and tested at RPI to provide accurate measurements for $\bar{\nu}$ particularly in the epithermal region. This method utilizes a coincidence requirement on prompt fission gammas to determine if a fission event has occurred.

II. Gamma Tagging Method

A new method for measuring prompt fission neutron spectra is being developed at RPI. This method uses gamma tagging instead of a traditional fission chamber to determine that fission has occurred. In traditional fission chambers, the fission products are measured and these show that a fission has taken place. The significant drawback to this method is that due to the minimal penetrability of fission fragments the samples need to be very thin in order to allow the fission products to escape the sample and interact with the detector. Therefore, the mass of the sample to be measured is severely limited. A way to increase the sample mass is to create a multi plate fission chamber. However, these are very complicated and expensive to build. The gamma tagging method allows for much larger samples to be measured by utilizing the gamma multiplicity from the fission event. Unlike conventional fission chambers, a coincidence requirement on an array of gamma detectors is used to determine that fission has occurred. Since the gammas can penetrate much farther through materials this allows for larger sample sizes to be measured increasing the efficiency of the measurement. The MCNP Polimi code was used to model the detection system and determine the optimal coincidence requirement. This was found to be a requirement of at least two of an array of four detectors to receive gammas. This resulted in the highest efficiency while reducing the probability of false fission events being recorded. False fission is characterized as events which meet the gamma coincidence criteria, however, they are not from fission but instead from a combination of capture, scattering, radioactive decay, and background. Current false coincidence analysis has been run with MCNP Polimi looking at fission and capture gammas. Further work with MCNP Polimi will involve modeling the entire detection system, by adding in scattering and decay components, to determine the false fission detection rate for the entire system.

III. Experimental Setup

The gamma tagging method involves using a double time of flight (TOF) measurement at the RPI Gaerttner Linear Accelerator (LINAC). The LINAC is a 60 MeV electron linear accelerator which accelerates the electrons through a series of nine RF accelerator sections and can reach a peak current of 3 amperes. The electron beam is incident on a tantalum target that releases neutrons through a combination of bremstrahlung and photonuclear interactions creating an isotropic white neutron source with a production rate of 10^{13} neutrons/second. The beam is then collimated down a flight-path out to the detection setup located at 31m from the source.

For the current experiment the detector setup consists of an array of eight EJ301 liquid scintillation neutron detectors. These operate as both the gamma and neutron detectors; however BaF_2 detectors are being investigated to replace the gamma detectors. The addition of BaF_2 detectors for gammas may help reduce the false fission detection rate from that of the liquid scintillator setup. The detection setup can be seen in figure 2. Here the gamma detectors are very close to the source to provide a large solid angle efficiency for the gamma multiplicity detection. The neutron detectors are placed at a 0.55m flight-path away from the sample to provide the second TOF component. While this flightpath provides poor energy resolution at higher energies it is acceptable for neutron energies below 5 MeV which includes the range of interest. All detectors are connected to Agilent/Acqiris AP240 digitizers which digitize and save every pulse collected. Pulse shape analysis to determine if they are gamma or neutron events. These digitizers have a collection rate of 125k samples/second. This analysis allows for the current use of the EJ301 detectors as both the gamma and neutron detectors simultaneously.

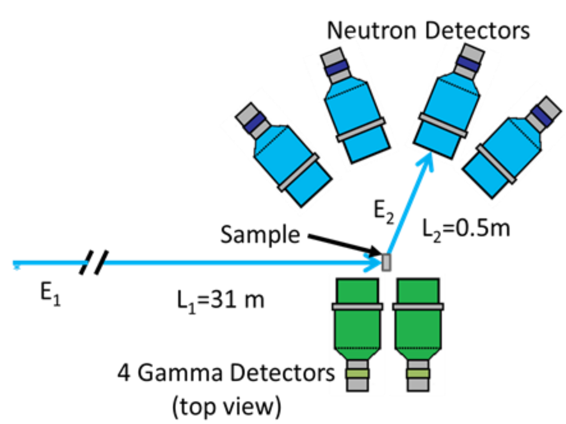

Figure 2: The detection setup with the two separate flightpaths for the TOF experiment. This also distinguishes the gamma detectors which remain close to the beam and the neutron detectors at an equivalent solid angle flight-path

Due to the coincidence requirement on the fission gammas the timing resolution of the detection system must be determined. This was found by determining the timing difference between decay gammas of a ^{60}Co source. Figure 3 shows that the timing resolution of the system. A Gaussian fit of the data shows that the system has a FWHM resolution of 3ns. In order to obtain the total detection efficiency for the system, experiments will be performed with a fission chamber of known mass.

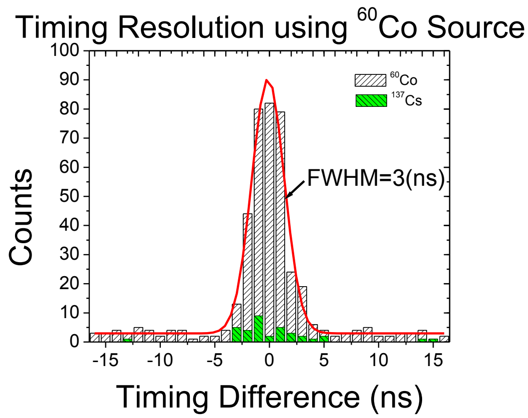

Figure 3: The timing resolution for the detection system to be 3ns. This was found by determining the timing difference between decay gammas of a ^{60}Co source.

IV. Pulse Shape Analysis

The use of the digitizer boards allows for accurate pulse shape analysis to be performed on the recorded data. This is used to distinguish between gamma and neutron pulses on the EJ301 scintillation detectors. Gamma and neutron pulses have differing shapes which allow for this analysis to be performed. Previous work done at RPI by F. Saglime [3] demonstrated how the system can be used for pulse shape analysis. Pulses are characterized by determining fall time and total pulse integral. The fall time is defined as the time between 10% and 90% of the total pulse integral. Figure 4 shows a scatter plot of fall time vs. pulse integral that was used to determine the gamma and neutron windows for analysis.

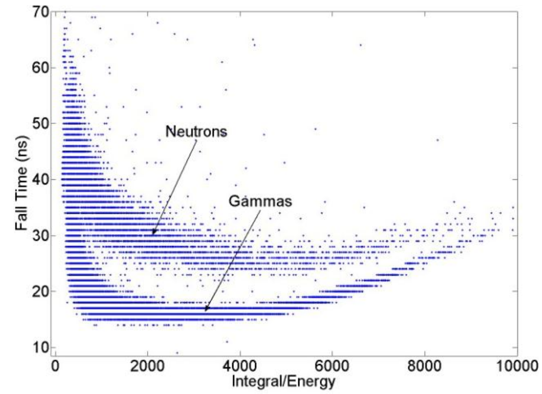

Figure 4: Fall time vs. pulse integral scatter plot used to determine the pulse windows for gamma and neutron pulses used in pulse shape analysis on the EJ301 liquid scintillators

V. Low Energy Detectors

One of the main goals in this analysis is to increase the accuracy of $\bar{\nu}$ in the epithermal region. The current EJ301 detectors are very inefficient below 500 keV and therefore other detectors must be investigated to operate in this region. Recently a new modular ^{6}Li-glass detector has been in development at RPI [4]. This detector employs four square modules each with 0.5" thick ^{6}Li-glass scintillator. These detectors provide a fast response time and provide much higher efficiency in the 1 keV to 600keV region. With the future implementation of these detectors in the system $\bar{\nu}$ and fission spectrum can be accurately measured from the several MeV region down to 1 keV.

VI. Results

A recent experiment was performed at RPI utilizing the gamma tagging method to obtain the spontaneous fission neutron spectrum for ^{252}Cf. For this experiment a $5x10^{6}$ n/s sample was used. Seven of the possible eight EJ301 detectors were utilized and pulse shape analysis was performed to distinguish gamma and neutron events. All detectors were placed at 55cm from the source to achieve the longest flight path possible for the current detector setup. In order for an event to be considered a fission, gamma pulses must be received from two of the detectors within a 3 nanosecond window. Furthermore, a neutron must be detected by one of the detectors in the following 300ns and the time of flight is taken as the difference between the two values. The timing between 100ns to

300ns was used to determine the background coincidence rate for the system using these conditions. Although preliminary results show that fission can be distinguished using this method, there are concerns which must be addressed before accurate data can be obtained. Primarily the efficiency of the detection method must be obtained by determining the actual number of fissions detected by the system. Further improvements with false fission coincidence modeling could provide insight into this problem. This will allow the values obtained through the method to be normalized to the current ENDF values for ^{252}Cf to accurately determine the fission spectrum. Further difficulties include poor energy resolution at high energies due to a short flight-path, and poor detection efficiencies at energies lower than 1 MeV.

VII. Conclusion

The new technique for simultaneously measuring $\bar{\nu}$ and fission spectra at RPI has shown promising results so far. The timing resolution of the system has been determined to be 3ns which is acceptable for the coincidence criteria. Pulse shape analysis is capable of accurately distinguishing the neutron and gamma events. The ^{6}Li-glass currently in development at RPI will allow for measurements in the epithermal region. Preliminary results with ^{252}Cf look promising for being able to determine fission events using the gamma tagging method. However, further work needs to be done to accurately determine the efficiency of the detection method. Once the system has been fully developed by measuring ^{252}Cf measurements of ^{235}U will be done.

References

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