Measurement of Prompt Fission Neutron Spectrum Using a Gamma Tagging Method

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INTRODUCTION

Since its discovery 75 years ago fission has been at the forefront of nuclear science and engineering research. Although the fission process is being used worldwide to generate safe reliable power, there are several aspects of the fission process which are still not well known. One such parameter of the fission process is the prompt fission neutron spectrum (PFNS). Although the average number of neutrons per fission nu-bar is a well-known quantity, the energy of those neutrons is not as well known. Furthermore uncertainties in these values can have significant impact on the uncertainty associated with reactor criticality and criticality safety measurements [1]. Criticality measurements of k_{eff} are directly sensitive to the prompt fission neutron spectrum [1]. The current uncertainties in the prompt fission neutron spectrum can correspond to up to a 4% uncertainty on k_{eff} for various systems including both fast and light water systems as well as for UO_2 and MOX fuel [1]. This demonstrates a need for more accurate measurement of the prompt fission neutron spectrum.

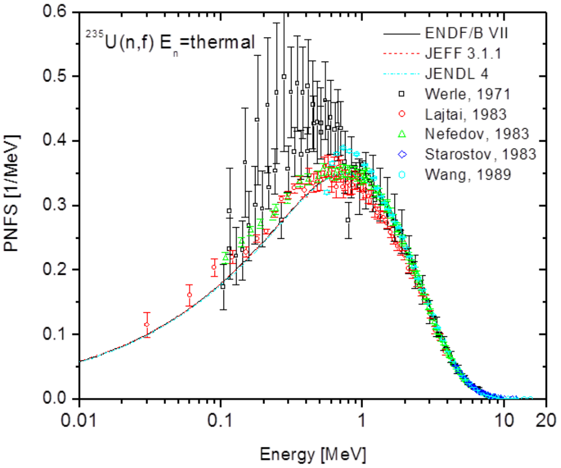

Figure 1: Current experimental data for ^{235}U prompt fission neutron spectrum ratioed, showing datasets from Werle, Starastov, Nefedov, Wang, Lajtai and current evaluations

Figure 1 shows the current measurements and evaluations of the prompt fission neutron spectrum for ^{235}U. While the datasets agree in the peak region and above 0.5 MeV, the available data below 0.5 MeV has very large uncertainties associated with it. All datasets overestimate the current evaluations which are based primarily on the Madland Nix model created at Los Alamos National Labs (LANL) [2]. Since the value of nu-bar is very well known, an increase in this region of the prompt fission neutron spectrum will have to correspond to a decrease elsewhere in the spectrum. This could have a significant impact on criticality calculations. Therefore, a more accurate measurement of the prompt fission neutron spectrum should be undertaken. A method is currently being developed at Rensselaer Polytechnic Institute (RPI) in order to use a fission gamma tag and low energy neutron detectors to measure the prompt fission neutron spectrum of several isotopes focusing on the low energy region below 0.5 MeV.

DESCRIPTION OF ACTUAL WORK

A new method for determination of a fission event is being investigated at RPI. Traditional fission detection is performed with an ionization fission chamber which uses the energy deposited by fission fragments in a fill gas to determine that a fission event has occurred. This limits the amount of mass available for the measurement since the fission foils must be extremely thin to allow the fission fragments to escape. Even state of the art fission chambers such as the PPAC being used at the Chi-Nu project at LANL are limited to several 100mg [3].

The gamma tagging method uses the high prompt gamma multiplicity of fission, rather than the fission fragments, to determine that a fission event has occurred. A coincidence requirement on an array of BaF_2 gamma detectors is used to determine when a fission event has occurred. Since the gamma rays have a higher penetrability in materials than the fission fragments, a much larger mass, on the order of several hundred grams, can be used with the gamma tagging method. A diagram of the setup for the gamma tagging method showing the gamma and neutron detectors can be seen in Figure 2. The diagram shown is for a double time of flight experiment using neutron induced fission on a sample from a white spectrum neutron beam. The current setup also involves a fission chamber in the sample position and therefore only a single time of flight is used to determine prompt fission neutron energy.

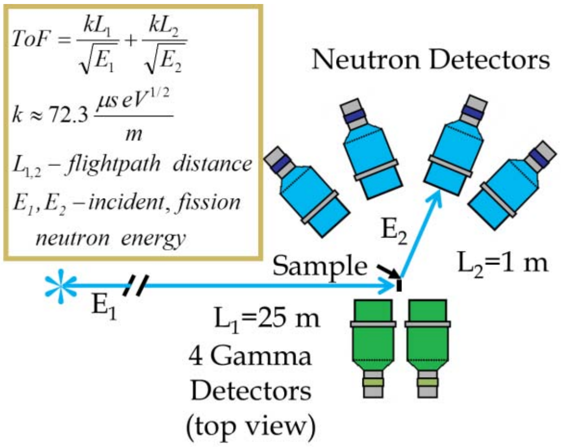

Figure 2: Diagram of the double time of flight experimental setup to determine the energy dependent prompt fission neutron spectrum

The requirement for coincidence that was established is a coincidence of 2 out of 4 gamma detectors firing with a detector threshold setting of 300 keV. The lower limit threshold minimizes the background events detected as well as reducing the events detected through radioactive decay of the sample. A coincidence timing window of 3 ns was used for the measurement. Preliminary modeling of the system using the MCNP Polimi code showed a detection efficiency of the gamma tagging method of 36%. A ^{252}Cf fission chamber was designed and constructed in order to accurately determine the detection efficiency of the gamma tagging method as well as determine the probability for false detection.

The experimental setup for the measurements involves an array of 4 BaF$_2$ gamma detectors which were obtained from Oak Ridge National Laboratory (ORNL), two 5” x 3” EJ-301 high energy liquid scintillator neutron detectors, and one 0.5” x 5” plastic scintillation neutron detector which was used for low energy measurements. All neutron detectors in the current measurement are located at a distance of 0.5 m from the center of the fission source. The fission source in the experiment was a ^{252}Cf fission ionization chamber which was designed and constructed at RPI. The fission chamber includes a 15.4 ng ^{252}Cf sample which was obtained from ORNL. A picture of the experimental setup can be seen in Figure 3.

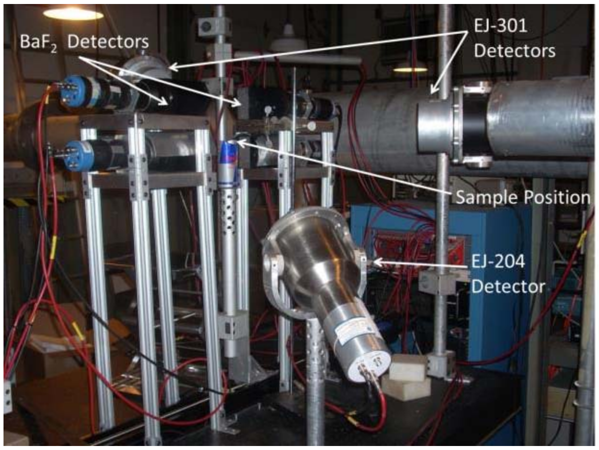

Figure 3: Current detector setup showing four BaF$_2$ gamma detectors 1 0.5" x 5" low energy EJ-204 detector and 2 3"x 5" EJ-301 neutron detectors.

The neutron detection efficiencies for the EJ-301 and EJ-204 scintillators were determined using the SCINFUL code [4]. Curves were generated for each detector for efficiency as a function of incident neutron energy. Due to the reduced thickness of the EJ-204 detector, the background in the detector is lower allowing the detector to be operated at higher voltages. This higher operational voltage allows for amplification of much smaller signals corresponding to lower energy neutrons. Figure 4 shows that below 0.6 MeV the EJ-204 detector has a higher neutron detection efficiency than the EJ-301 detector.

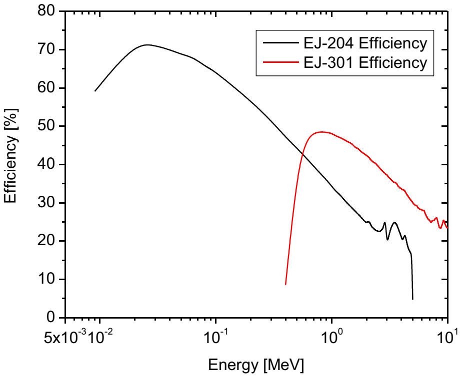

Figure 4: Efficiencies of EJ-301 and EJ-204 detectors as calculated with SCINFUL code

An 8 bit Acquiris AP240 digitizer is used to process the signals from the neutron/gamma detectors and fission chamber. The board stores each waveform collected by the detectors which can then be used for pulse shape discrimination between the gammas and neutrons as well as providing an accurate timestamp which can be used for the coincidence analysis. These boards have an 8 bit amplitude resolution and have a 1 GHz sampling rate allowing for on board nanosecond timing resolution. Since timing is very important for the coincidence measurements the overall timing of the system was determined by looking at the width of the prompt gamma peak obtained with the EJ-301 detector utilizing the gamma tagging method. The system timing resolution was found to be 3 ns which is the timing window used in the coincidence measurements.

RESULTS

In order to determine both the efficiency and the viability of using the gamma tagging method, a comparison was performed between the PFNS measured with the fission chamber to that of the gamma tagging method. The efficiency of the gamma tagging method in the current configuration was found to be 30% and the PFNS for both methods were compared in Figure 5. This shows that regardless of the method used, the shape of the PFNS is the same and therefore, the gamma tagging method can be used to measure the PFNS. The gamma tagging method had better time resolution that the fission chamber tagging as evident from the TOF data below 70 ns.

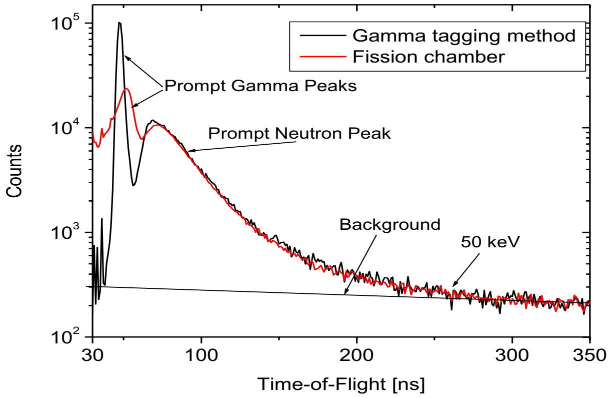

Figure 5: ^{252}Cf prompt fission neutron time-of-flight spectrum measured with an EJ-204 0.5" x 5" plastic scintillator using both a gamma tag and fission chamber tag for the start signal. The gamma tag spectrum is corrected for 30% efficiency.

The low energy region of the prompt fission neutron spectrum, 1 MeV to 50 keV, was determined using a thin EJ-204 detector and can be seen in Figure 6. The solid line represents the current ENDF/B-VII.0 evaluation for ^{252}Cf and additional data from Lajtai, Blinov and Starostov are shown for comparison and all datasets are normalized at 0.8 MeV. The errors for the associated datasets include both statistical and systematic errors while the RPI data only includes the statistical error. This demonstrates that the plastic scintillation detector can be used for measurements down to 50 keV neutron energy.

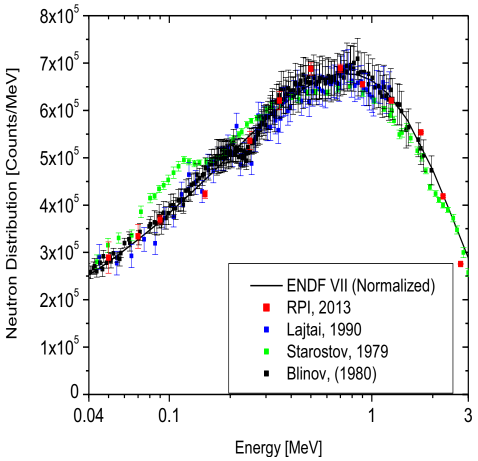

Figure 6: ^{252}Cf prompt fission neutron spectrum low energy region taken with 0.5" x 5" EJ-204 detector compared to current evaluation and datasets from Lajtai [5], Blinov[6] and Starostov[7]

In addition to using the method to measure the PFNS, an experiment was undertaken to determine the effects of orientation of the neutron detectors with relation to the parallel plates in the fission chamber. The PFNS was measured using both the gamma tagging method and fission chamber method with 2 detectors located at 50 cm from the sample parallel to the plates, and one detector at 50 cm perpendicular to the plates. In both cases the high energy EJ-301 liquid scintillators were used to measure the spectrum. Figure 7 shows the ratio of the 90 degree detector to the 0 degree detector as a function of energy for different discriminator settings. This demonstrates that as the discriminator setting increases the counts in the 0 degree detector decrease at a greater rate than the counts in the 90 degree detector. This effect is due to the fission fragments depositing less energy in the 0 degree direction than the 90 degree direction which causes them to discriminate the fission pulses differently. Since the gamma tagging method doesn't require a fission chamber, it doesn't suffer from these effects and it can be seen that the ratio for the zero degree detector to the 90 degree detector is approximately 1 for this detector. Any deviations from unity are most likely due to variations in the individual detector efficiencies.

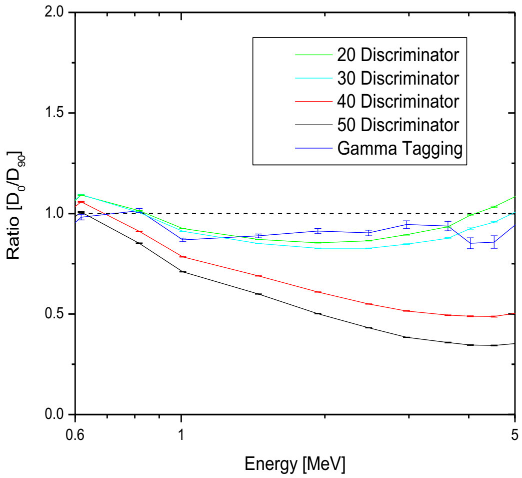

Figure 7: Ratio of counts in a detector at 0 degrees from fission plates to a detector at 90 degrees from fission plates as a function of energy for various discriminator settings compared to the ratio using the gamma tagging method

CONCLUSIONS

The gamma tagging method has been successfully implemented at RPI Measurements have been performed for the PFNS of the spontaneous fission of ^{252}Cf, and this measurement is in agreement with previously measured datasets and evaluations. This allows for the capability of measuring additional nuclides of interest such as ^{235}U and ^{239}Pu. Additionally an angular dependence was found on the prompt fission neutron spectrum as a function of the discriminator threshold of the fission chamber. Due to the nature of the gamma tagging method, a discriminator is not necessary and therefore, this effect will not be seen providing and additional advantage for the gamma tagging method. Additional work includes a comprehensive analysis to investigate the effects of false detection due to events such as inelastic neutron scattering from the sample. Initial measurements of scattering off Pb, which has no fission threshold, are currently being analyzed to determine the magnitude of this false detection effect. In addition MCNP Polimi calculations will be done to quantify this effect and compare to the measured false coincidence rates seen with the Pb sample.

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