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Measurement of Fission Neutron Spectrum and Multiplicity using a Gamma Tag Double Time-of-flight Setup

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Recent efforts have been made to improve the prompt fission neutron spectrum and nu-bar measurements for Uranium and Plutonium isotopes particularly in the keV region. A system has been designed at Rensselaer Polytechnic Institute (RPI) utilizing an array of EJ-301 liquid scintillators as well as lithium glass and plastic scintillators to experimentally determine these values. An array of BaF_2 detectors was recently obtained from Oak Ridge National Laboratory to be used in conjunction with the neutron detectors. The system uses a novel gamma tagging method for fission which can offer an improvement over conventional fission chambers due to increased sample mass. A coincidence requirement on the gamma detectors from prompt fission gammas is used as the fission tag for the system as opposed to fission fragments in a conventional fission chamber. The system utilizes pulse digitization using Acqiris 8 bit digitizer boards which allow for gamma/neutron pulse height discrimination on the liquid scintillators during post processing. Additionally, a ^{252}Cf fission chamber was designed and constructed at RPI which allowed for optimization and testing of the system without the need for an external neutron source. The characteristics of the gamma tagging method such as false detection rate and detection efficiency were determined using this fission chamber and verified using MCNP Polimi modeling. Prompt fission neutron spectrum data has been taken using the fission chamber focusing on the minimum detectable neutron energy for each of the various detectors. Plastic scintillators were found to offer a significant improvement over traditional liquid scintillators allowing energy measurements down to 50 keV. Background was also characterized for all detectors and will be discussed.

I. INTRODUCTION

Accurate measurements of the prompt fission neutron spectrum, $\chi(E)$, and the average number of neutrons per fission, $\nu(E)$, are very important for precise calculations of reactor criticality models. Although accurate data exists for these values in certain energy ranges, the prompt fission neutron spectrum at energies below 0.5 MeV and above 3 MeV shows very discrepant data with large errors. Fig. 1 shows several experimental datasets for the prompt fission spectrum of ^{252}Cf as well as the current ENDF VII database to a Maxwellian spectrum (kT=1.42 MeV) ratio. ^{252}Cf is often used as a standard for prompt fission neutron spectrum, however there still exists very little data below 0.5 MeV and only 3 datasets with considerable spread below 0.1 MeV. Similarly there is great spread in the datasets for energies above 3 MeV. All associated datasets also include large errors within these regions. This demonstrates a need for more accurate measurements of the prompt fission neutron spectrum even for well-known isotopes such as ^{252}Cf.

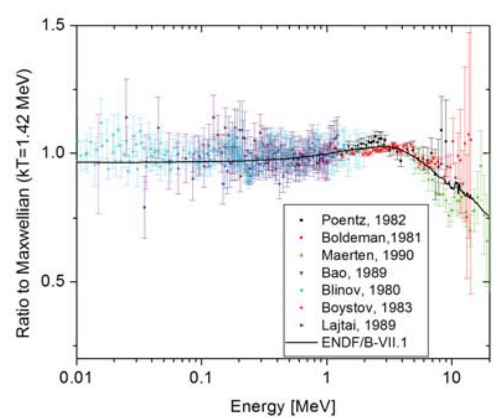

FIG. 1. Current experimental data for ^{252}Cf prompt fission neutron spectrum as a ratio to a Maxwellian at kT=1.42 MeV. showing datasets from Poentz [1], Boldeman [2], Maerten [3], Bao [4], Blinov [5], Boystov [6], Lajtai [7] and current ENDF/B-VII.1 evaluation[8].

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II. GAMMA TAGGING METHOD

Traditional fission detection has been accomplished through the use of fission chambers which measure the fission fragments released from the fission event. The drawback to these detectors is that since the range of fission fragments is very small the thickness of the sample is limited, and therefore the overall fissionable mass is also limited. Even newer multi-plate fission chambers are limited to approximately 100mg such as the PPAC chamber currently used on the Los Alamos Chi-Nu Project [9]. The gamma tagging method utilizes the high gamma multiplicity from fission, 7.98 for ^{252}Cf, and 6.60 for ^{235}U [10], to determine whether a fission event has taken place. An array of four BaF_2 gamma detectors are arranged 10 cm away from the fission source and a coincidence requirement of at least two is used to indicate a fission event. The discriminator for the BaF_2 detectors is set to allow the fission gammas to be detected but minimize low energy gammas from other sources such as radioactive decay and scattering. Due to the higher penetrability of gamma rays much larger samples can be used on the order of several hundred grams. The drawback of this method comes from reduced detection efficiency due to the coincidence requirement as well as false detection from coincidence events particularly from inelastic scattering. The efficiency of the gamma tagging method was calculated utilizing a ^{252}Cf fission chamber and was found to be 30 %. Although this value is much lower than conventional fission chambers, the increase in sample size will compensate for the reduction in detection efficiency.

III. EXPERIMENTAL SETUP

The current experimental setup utilizes a ^{252}Cf ionization fission chamber as the fission source surrounded by an array of neutron and gamma detectors. Four BaF_2 gamma detectors are located 10 cm away from the center of the sample and provide the signal for the gamma coincidence. The neutron detectors consist of two 3"x5" EJ-301 liquid scintillators for high neutron energies, and one 0.5"x5" NE-110 plastic scintillator for low neutron energies. The detection arrangement can be seen in Fig. 2

The fission chamber and detector signals are sent to an Acqiris AP-240 digitization board which digitally stores all of the pulses. These boards have a 8 bit amplitude scale and 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. This shows the system timing resolution to be 3 ns as seen in Fig. 3

The neutron detectors are located 50 cm away from the center of the sample and Time-of-flight (TOF) calculations are used to determine the energy of the incident

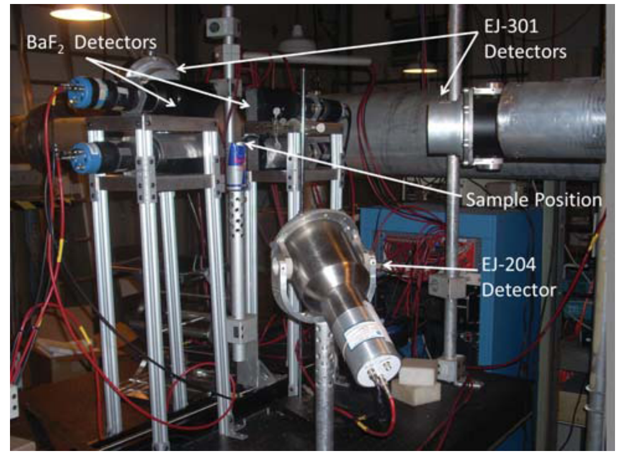

FIG. 2. Current detector setup showing four BaF_2 gamma detectors 1 0.5"x5" low energy EJ-204 detector and 2 3"x5" EJ-301 neutron detectors.

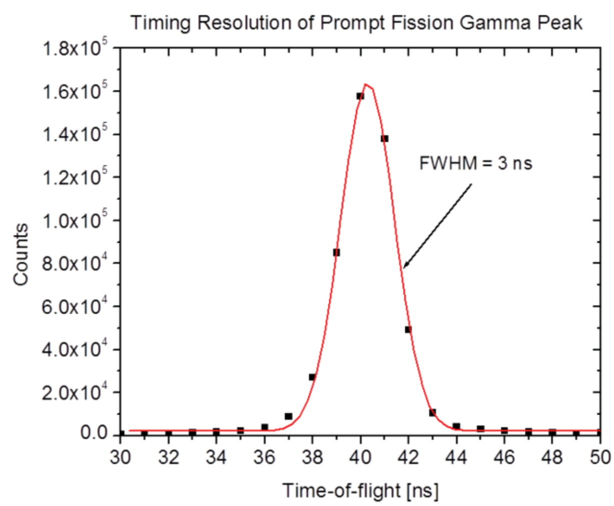

FIG. 3. The timing resolution of the detection system was found to be 3 ns by looking at the width of the prompt gamma peak taken from an EJ-301 detector using the gamma tagging method.

neutron. In order to simulate the conditions that would be met in an accelerator double time-of-flight experiment, the start signal for the digital data acquisition boards was set to a 400 Hz signal. Digital data was taken for 2 ms after each start signal and stored for later post processing.

IV. DATA ANALYSIS

For each pulse recorded by the data acquisition board, the corresponding start time was determined utilizing the onboard global timestamp provided by the board. Once the start number is known for each pulse, all pulses with the same start are analyzed for coincidence. If an event

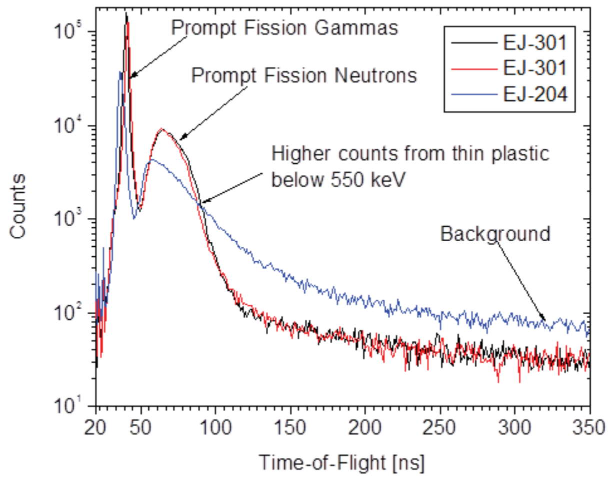

FIG. 4. ^{252}Cf prompt fission neutron time-of-flight spectrum measured using 0.5"x5" EJ-204 plastic scintillators and 3"x5" EJ-301 liquid scintillators. An increase in EJ-204 counts can be observed below 550 keV.

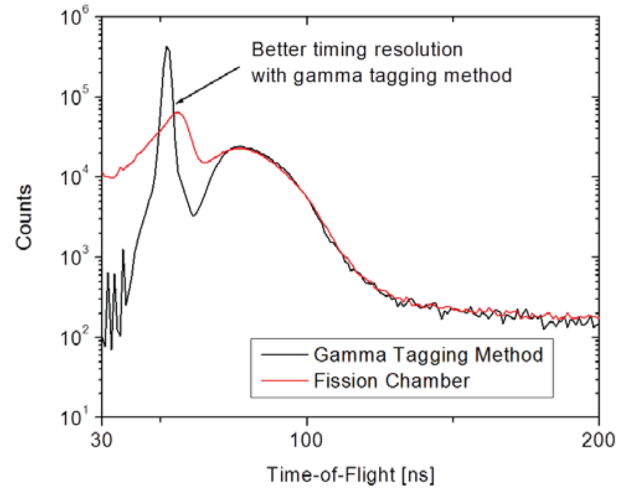

FIG. 5. ^{252}Cf prompt fission neutron time-of-flight spectrum measured with an EJ-301 3"x5" liquid scintillator using both a gamma tag and fission chamber tag for the start signal. The gamma tag spectrum is corrected for 30 % efficiency.

occurs in a window of 3 ns between two gamma detectors, it is classified as a valid fission start. From that start time a histogram is populated looking for any counts in the neutron detectors for 600 ns after the fission start. This allows for full neutron time-of-flight data to be collected as well as providing a significant time after the final time-of-flight pulse to be used in background subtraction. As previously mentioned the background for the measurement was determined using the final 350 ns of the TOF Spectrum. A linear fit to the background variation with TOF was calculated showing a slight time-dependent nature of the background due to neutron moderation and capture in hydrogen in the detector material. This was then subtracted from the data to obtain the net counts in each channel. The time of flight data was next corrected for the time zero of the measurement. The time zero was found to be the center of the prompt gamma peak as seen in Fig. 4. Since pulse shape discrimination is not used during the data analysis, this peak corresponds to the prompt gammas released from the fission event.

A comparison was performed looking at the prompt fission neutron spectrum obtained from both the gamma tagging method and using the fission chamber. The counts in time-of-flight on an EJ-301 plastic scintillator are taken using each method as the start signal. The spectrum for the gamma tagging method was corrected for the 30 % method efficiency and a comparison can be seen in Fig. 5 . This shows that the prompt fission neutron spectrum is the same regardless of which fission tag is used.

Once corrected for the 1.5ns gamma time-of-flight corresponding to a 50 cm flight-path, the data is now in a form allowing for translation from time-of-flight to energy. Since the neutrons of interest in this measurement are low energy, below 1MeV, the non-relativistic form of the neutron time of flight equation is used. The time-

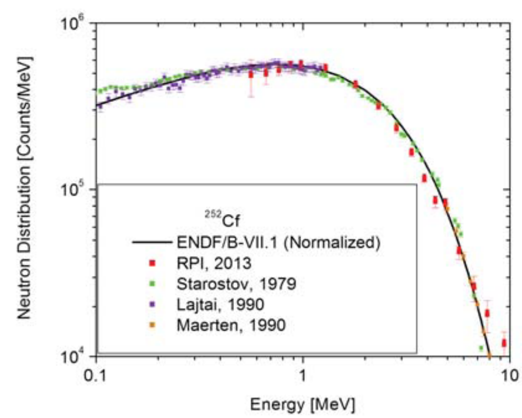

FIG. 6. ^{252}Cf prompt fission neutron spectrum taken with 3"x5" EJ-301 detector compared to current evaluation and datasets from Lajtai [11], Starostov [12], and Maerten [3].

of-flight data is grouped into corresponding energy bins and the prompt fission neutron spectrum can be produced. Neutron detection efficiencies for both the EJ-204 and EJ-301 detectors were calculated using the SCINFUL code [13]. Once the data is corrected for efficiency a final prompt fission neutron spectrum for ^{252}Cf can be obtained. Fig. 6 shows the high energy component of the curve, greater than 0.5 MeV, determined using the EJ-301 detectors. The low energy region of the curve, 2.5 MeV to 50 keV, was determined using a thin EJ-204 detector and can be seen in Fig. 7. The solid line represents the current ENDF evaluation for ^{252}Cf and additional data from Lajtai, Maerten and Starostov are shown for comparison . The errors for the associated datasets

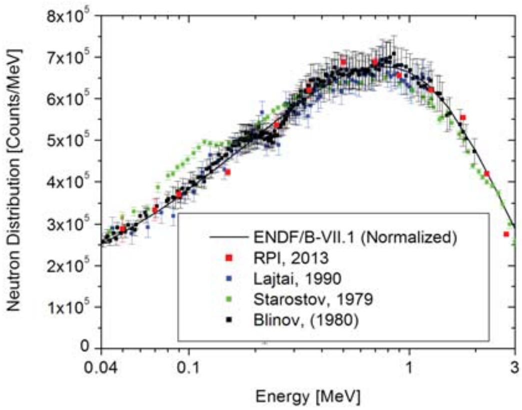

FIG. 7. ^{252}Cf prompt fission neutron spectrum low energy region taken with 0.5"x5" EJ-204 detector compared to current evaluation and datasets from Lajtai and Starostov.

include both statistical and systematic errors while the RPI data only includes the statistical error.

V. CONCLUSIONS

The gamma tagging method has been shown to accurately reproduce the prompt fission neutron spectrum for ^{252}Cf. Through a combination of 3"x5" EJ-301 liquid scintillators and 0.5"x5" EJ-204 plastic scintillators, the prompt fission neutron energy spectrum can be measured from 7 MeV down to 50 keV. This allows for more data in the regions below 0.5 MeV where there is little data and what data exists has large associated errors. This method can now be used to measure additional isotopes of interest such as ^{235}U ^{238}U and ^{239}Pu.

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