Quasi-differential neutron induced neutron emission reaction measurements at WNR

K. Mohindroo,* E. Blain,*Y. Danon,* S. Mosby† M. Devlin†

*Rensselaer Polytechnic Institute, Gaerttner LINAC Center, 110 8th St., Troy, NY 12180, USA
†P-27, Los Alamos National Laboratory, Los Alamos, NM 87545, USA
mohink@rpi.edu

ABSTRACT

The quasi-differential neutron induced neutron emission reaction measurement (QD-NINE) method provides an additional benchmark which constrains cross-section evaluations and provides a measure of verification for existing evaluations. Experiments are preformed using an array of EJ-309 liquid scintillators at a variety of angles measuring the neutron scattering response from a sample.. An MCNP simulation is then compared to this experimental data and is run using various sets of evaluated nuclear data. Since the isotopes of interest for this measurement, ^{235}U and ^{239}Pu, are difficult to obtain, the WNR facility at LANL was chosen to perform the measurements utilizing the chi-nu detector array. A measurement of carbon has been performed and the high energy cutoff has been extended from 20 to 60 MeV compared with previous measurements using this method. An early stage simulation was compared to the experimental data and the results show good agreement.

INTRODUCTION

Rensselaer Polytechnic Institute (RPI) has developed a method to measure fast neutron scattering using a pulsed neutron source and a liquid scintillator array. Detector response as a function of time of flight at various angles is compared to an MCNP simulation utilizing different sets of evaluated nuclear data. This Quasi-differential neutron induced neutron emission reaction measurement (QD-NINE) method is used to help constrain optical models for data evaluation[1] and verify accuracy of existing evaluations. QD-NINE also provides better coverage of the incident energy spectrum than traditional double differential cross section methods since it utilizes a white source instead of a mono-energetic beam. The assessment of neutron angular distribution is also improved since the traditional methods (such as gamma ray analysis) are based on the detection of gamma rays and fundamentally do not provide any information on the neutron angular distribution. The method has been used successfully on several samples in the past such as ^{238}U, Carbon, Molybdenum and Iron. [2][3]

The objective of this work is to measure ^{235}U and ^{239}Pu. Because the availability of these materials is restricted, we have develop QD-NINE capability at Los Alamos National Laboratory (LANL) Weapons Neutron Research Facility (WNR) using the Chi-Nu detector array in order to perform the measurements.

A measurement of carbon has been performed and the high energy cutoff has been extended from 20 to 60 MeV compared with previous measurements.

THEORY

QD-NINE utilizes a time of flight methodology. Time of Flight (ToF) methods follow a fairly simple logic, the more energy the emitted neutron has when leaving the sample the faster it travels. Therefore, by assessing the time of flight and the distance traveled by the neutron, its energy can be determined.

Equation 1 can be used to translate ToF into energy.

$$E(t) \approx m_n c^2 \cdot \left(\frac{1}{\sqrt{1 - \left(\frac{L}{c \cdot t}\right)^2}} - 1 \right) \tag{1}$$

In Equation 1 m_n is the rest mass of a neutron (939 MeV/c^2), c is the speed of light ($3x10^8$ m/s), L is the sum of the flight path from source to sample and sample to detector (21 m), and t is the time of flight. In this case, a ToF of 1400 ns (low energy cutoff) corresponds to 1.178 MeV and a ToF of 200 ns (a high energy point) corresponds to 63.537 MeV.

As mentioned previously the radiation of interest is neutrons. However, when a detector is placed it is also sensitive to picking up gamma rays which are present due to certain collisions in the sample such as inelastic scattering and neutron capture. Neutrons and gamma rays are distinguished through pulse shape analysis (PSA). Here, the ratio of the tail of the pulse integral to the full pulse integral shows a distinct separation between the charge deposition of neutrons and gamma rays in the detector. This is called the Charge Integration[4] method and can be seen in Figure 1. The selected area shows the detected neutrons as their pulse integral has a longer tail.

EXPERIMENTAL SETUP

The Chi-Nu array at LANL has 54 liquid scintillation detectors (EJ-309) set 1 meter from the sample at various angles in a hemispherical manner (just 28 of these detectors were used in the experiment in order to mitigate crosstalk). The detectors were connected to CAEN VX1730B 16 bit digitizers and data were digitized using a sampling rate of 500 MHz (2 ns/channel). Each detector has a liquid cell that is 17.8 cm in diameter x 5 cm thickness. Additionally, a fission chamber was used to monitor beam intensity. Figure 2 shows the array using 28 detectors.

The flight path to the sample is roughly 20 m and the flight path from sample to detector is an additional 1 m. A cylindrical carbon sample with length 3.516 cm, radius 1.9045 cm, and density 1.677 g/cc was used.

The LANSCE Linear Accelerator proton beam structure was 625 μs long with macro pulses generated at 100 Hz. The macro pulse included about 347 micro pulses, each was 1.8

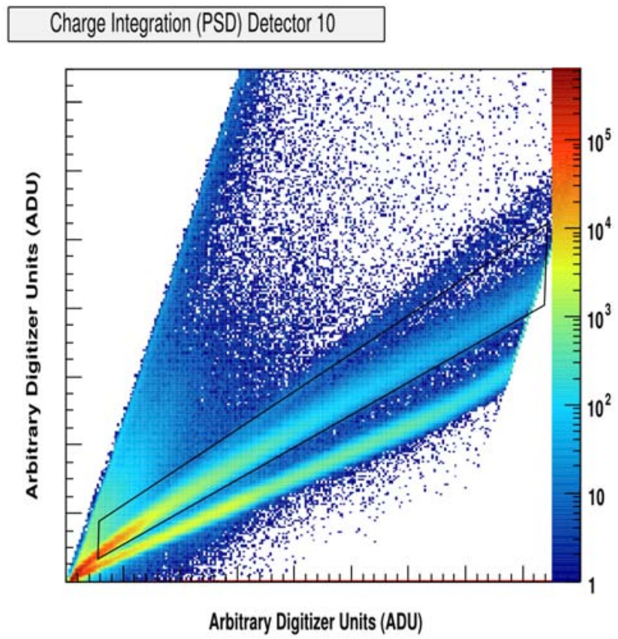

Fig. 1: Tail of the pulse integral vs. the full pulse integral with a cut displayed over the neutron band. The gamma rays and neutrons show clear separation due to the difference in pulse shape. Note that the left vertical line designates the low energy cutoff point (1400ns)

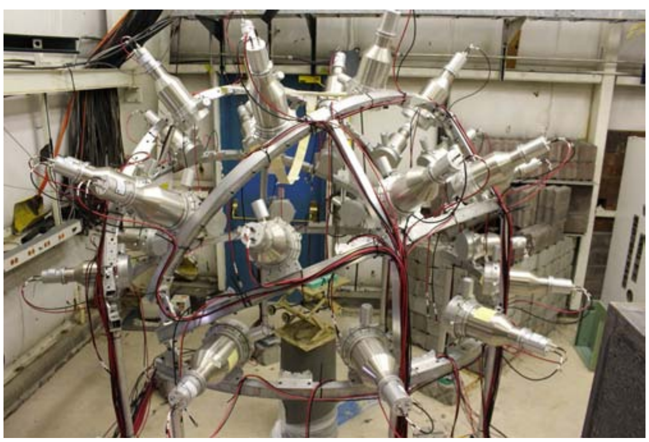

Fig. 2: The Chi-Nu Liquid Scintillator Array using 28 detectors to avoid cross talk. Each detector has a liquid cell that is 17.8 cm in diameter x 5 cm thickness.

μs long during which the time of flight data from neutron scattering was collected.

RESULTS AND ANALYSIS

An MCNP simulation was compared to the data from the LANSCE experiment and was found to be in agreement as seen in Figure 4. The simulation was modified to match the flight path distance, detector setup (without the array support structure) and approximate the LANL flux distribution at 60R (which has greater flux at higher energies and can be seen in Figure 3) as well as efficiencies determined from SCINFUL[5].

The initial simulation geometry is intentionally kept simple in order to slowly implement relevant components. The detectors are not physically modeled and instead f5 tallies are used. f5 tallies are partially deterministic in the sense that each time a particle interacts, the probability that its next collision will occur in the small space surrounding the specified point is calculated and added to the tally. The f5 tallies are modeled using properties which mimic a detector response function using the efficiencies determined from SCINFUL[5].

The sample is a 1.5" diameter by 1.5" length carbon cylinder with a mass of 67.19g placed at the origin. The f5 tallies are place in positions which correspond to the locations of the physical detectors (1 meter from the sample at 30, 45, 60, 75, 90, 105, 120, 135, 150 degrees on both the left and right hemispheres.)

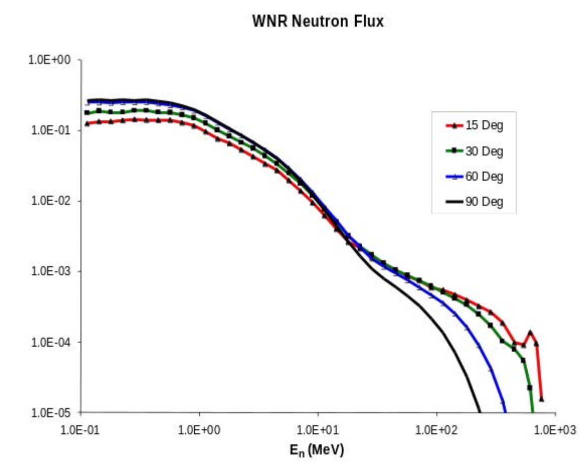

Fig. 3: Calculation of neutron spectra (flux) at several flight paths from target 4 at LANSCE [6].

The source is modeled as a 3cm radius disc which emits neutrons 20m from the sample towards the sample utilizing a specified time and energy distribution and a 2ns pulse width. The radial distribution is sampled from the area of the disc.

The model itself is derived from the work done in [2] so some additional modification will be required to improve the agreement with the experimental data. Most notably, the first flight (pre-sample collision) geometry should be changed to more closely resemble the LANSCE flight path instead of the RPI flight path. Based on the results from several iterations it is currently believed that a portion of the discrepancy is due to the presence of aluminum and some steel in the experimental setup which is not currently accounted for in the simulation. Currently we believe that interaction in this material is occurring in both first and second flight (before and after collision with the sample). This suggests that there may be some advantage to including the high energy detector array structure which is comprised mostly of aluminum, as well a method to account for beam divergence within the neutron flight tube. Variations of the simulation were run in order to include a small aluminum sample holder however, the results of this simulation showed no significant change. Another concern is the potential for room return, that is the possibility of neutrons colliding with walls or shielding on the outskirts of the experimental area and returning to the detectors. A variation of the model including this was also tested and showed little effect. In the work done in [2], there was a lower density of detectors in the experimental space. That leads us to investigate the possibility of cross-talk influencing the observed structures. Although at first this may seem trivial, if the modeling of the detectors becomes too intricate, the simulation slows down excessively.

Additionally, it is noted that the detector efficiencies in the model play a significant role in the resulting shape of the simulation. This is significant as the SCINFUL[5] efficiencies may not be accurate in the high energy region. Therefore, direct measurement of detector efficiencies will be necessary in the coming experiments.

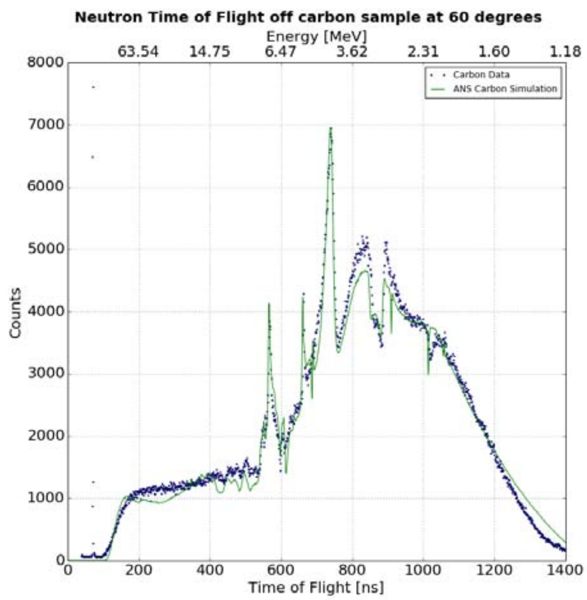

Fig. 4: Comparison of data to MCNP for a detector at 60 degrees measuring carbon. The simulation utilized the LANSCE flux and efficiencies determined by SCINFUL[5]. The data was collected using EJ-309 detectors and 16-bit CAEN digitizers.

It is important to note that the QD-NINE method developed at RPI was originally capable of measuring neutrons in the range of 0.5 Mev to 20 MeV. However the LANSCE LINAC is driven by 800 MeV protons yielding neutrons up to 100s of MeV and thus provides neutrons with much harder spectrum compared with the RPI LINAC which is driven by electrons with a maximum energy of 60 MeV. This, in conjunction with the usage of 16-bit digitizers makes it possible to extend the high energy cutoff. This allows us to see a greater level of structure which was previously not captured by the 8-bit digitizers in the RPI measurement. The reason for this is that the 8-bit digitizers could not effectively store the high energy pulses.

The results show agreement with past carbon measurements which can be found in reference [2].

CONCLUSIONS

The usage of QD-NINE at LANSCE has shown to work well and the higher energy capable flux of the LANSCE LINAC, in conjunction with the use of digitizers with higher effective bits allows for the extension of the upper energy limit beyond 20 MeV. Based on these positive results, it is now possible to measure isotopes of interest such as $^{235}U$and ^{239}Pu.

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