Development of an In-Beam Neutron Flux Monitor for Time of Flight Capture Measurements

E. Blain,[1] Y. Danon,[1] B. McDermott,[1] A. Youmans,[1] J. Brown,[1] N. Thompson,[1] A. Weltz,[1] K. Mohindroo,[1] G. Leinweber,[2] R. Block,[2] M. Rapp,[2] D. Barry[2]

[1]*Rensselaer Polytechnic Institute, Gaerttner LINAC Center, Troy, NY 12180, USA*
[2]*Bechtel Marine Propulsion Corp., Knolls Atomic Power Laboratory, P.O. Box 1072, Schenectady, NY 12301, United States*
blaine2@rpi.edu

INTRODUCTION

Accurate nuclear data are important in several aspects of nuclear engineering, such as reactor simulations, nonproliferation, and criticality safety [1]. One of the nuclear data measurements that requires reduced uncertainties in its related cross-sections is neutron capture. The neutron capture cross-sections have particular deficiencies in the incident neutron energy range from 1 keV to 1 MeV [2]. This is due to the predominance of scattering reactions in this energy region. In order to provide more accurate measurements in this energy region, a new experimental setup has been designed and created at Rensselaer Polytechnic Institute (RPI) [3]. This experiment utilizes several C_6D_6 detectors in a low mass system to minimize the effects of neutron scattering on the experiment. In order to determine the capture yield for the measurements, several additional factors need to be known about the neutron beam including the energy dependence of the neutron flux incident on the sample. A detector made from a thin piece of EJ-204 plastic scintillator was designed to measure the neutron flux, as a function of incident neutron energy, during the capture measurements.

THEORY

In order to experimentally measure the capture cross-section for various materials, the capture yield must be determined. Equation 1 provides the equation for determining the capture yield at a given neutron energy, where $R(E)$ is the gamma count rate measured in the detector, $\eta_\gamma(E)$ is the detector gamma efficiency, $\phi(E)$ is the neutron flux incident on the sample, and A is the area of the sample. This capture yield can subsequently be used to obtain the capture cross-section using Equation 2, where $\sigma_\gamma(E)$ is the capture cross-section, $\sigma_t(E)$ is the total cross-section, $T(E)$ is the transmission through the sample, and Y_{ms} is the multiple scattering yield. Accurate knowledge of the incident neutron flux shape is necessary for accurate measurements of the neutron capture yield and therefore cross-section. In order to measure the neutron flux for neutron capture measurements at the RPI detector system, a B_4C plate was used, and the capture rate from the plate was measured. This provided an accurate measurement of the flux at lower energies using the $^{10}B_4C(n,\alpha)$ reaction; however, at higher energies this measurement suffered from competing reactions in the B_4C and no longer gave an accurate representation of the incident flux. Therefore, a new way to measure the flux in the high energy region above 1 MeV needed to be determined.

$$Y_\gamma(E) = \frac{R(E)}{\phi(E)\eta_\gamma(E)A} \tag{1}$$

$$Y_\gamma(E) = \frac{\sigma_\gamma(E)}{\sigma_t(E)}(1 - T(E)) + Y_{ms} \tag{2}$$

RESULTS AND ANALYSIS

In order to accurately measure the incident neutron flux for capture measurements, a thin plastic detector was constructed. This scintillator was selected in order to utilize the well known cross-section for the (n,p) scattering reaction with H. The thin detection volume reduces the interactions from gammas and thus the gamma background of such measurement. One of the primary concerns with in-beam flux monitors is their recovery from the high gamma flash signal generated by the neutron-producing target in a time-of-flight (ToF) measurement. Therefore, the detector thickness was chosen at 3 mm in order to minimize the recovery time from the gamma flash while still maintaining a high enough detection efficiency. A 5" square 3 mm thick plastic scintillator was placed inside an aluminum detector shell and coupled to two 5" photomultiplier tubes as seen in Figure 1. Aluminum windows were stretched on the front and back faces of the aluminum shell in order to minimize the neutron beam interaction with the detector materials. The photomultipliers were also located on the sides of the scintillation material out of the neutron beam to prevent interactions between the tubes and the beam. The two photomultiplier signals are summed to reduce the noise from the individual photomultiplier tubes. The detector was placed 3 m from the capture detector setup to reduce scattering from the beam monitor into the C_6D_6 capture detectors.

Once the in-beam flux monitor was designed, one of the most important quantities which needed to be determined was the energy dependent neutron detection efficiency shape. The neutron detection efficiency as a function of energy must first be known in order to accurately determine what the neutron flux is as a function of incident neutron energy. In order to determine this quantity, an experiment was performed using a ^{252}Cf spontaneous fission chamber previously developed at RPI [4]. By measuring the prompt fission neutron spectrum as a function of ToF the efficiency could be calculated using the evaluated prompt fission neutron spectrum, which is a standard in this energy region, as seen in Equation 3 where $R_{Cf}(E)$ is the detector count rate from the measurement, F_1 is a proportionality constant, $\phi_{Cf}(E)$ is the prompt fission neutron spectrum of ^{252}Cf, and $\eta(E)$ is the unnormalized detector efficiency shape. Figure 2 shows the calculated neutron detection efficiency as a function of energy. Once this quantity is determined the neutron detector can be placed in the neutron

Fig. 1. Image of the in-beam neutron flux monitor placed in the neutron beam and situated far from the detector setup to avoid scattering into the capture detection setup.

beam and the neutron flux from the accelerator beam can be measured.

$$R_{Cf}(E) = F_1\phi_{Cf}(E)\eta(E) \tag{3}$$

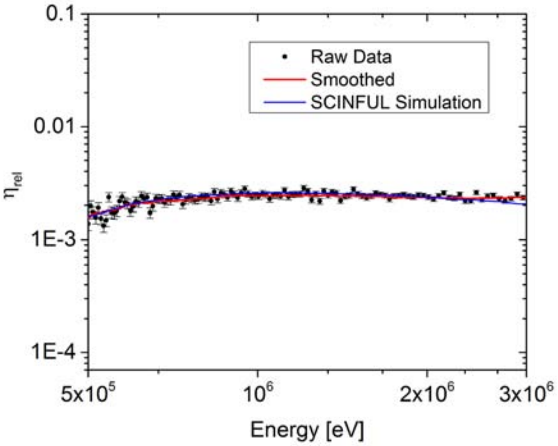

Fig. 2. The measured relative efficiency for the EJ-204 flux monitor as a function of incident neutron energy showing both the raw data, the smoothed efficiency, and a simulation using the SCINFUL code [5], with a 340 keV discriminator, in the energy range from 500 keV to 3 MeV.

Once the detector efficiency had been determined, the detector was placed in an incident neutron beam and the flux was determined using Equation 4, where $R_{linac}(E)$ is the count rate from the in-beam measurement, F_2 is a proportionality constant, and $\phi_{linac}(E)$ is the energy dependent flux shape from the LINAC. Figure 3 shows the measured flux in the incident neutron energy range from 500 keV to 3 MeV as well as an MCNP simulation of the flux. The simulation includes full target geometry and starts with 60 MeV electrons incident on the neutron producing target. The structure in the flux measurement corresponds to several materials in the incident neutron beam including oxygen, aluminum, and lead. Additionally, the overlap between the B_4C flux measurement and the in-beam plastic flux measurement can be seen in Figure 4. This shows a good overlap between the fluxes in the region between 500 keV and 1 MeV and also highlights the necessity for the in-beam flux monitor in the higher energy region above 1 MeV.

$$R_{linac}(E) = F_2\phi_{linac}(E)\eta(E) \tag{4}$$

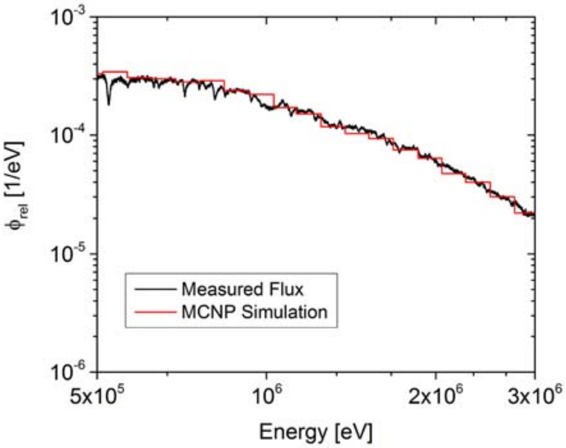

Fig. 3. The flux measured with the EJ-204 in-beam flux monitor compared with MCNP simulation in the energy range from 500 keV to 3 MeV. The structure seen in the measured flux corresponds to materials in the neutron beam including oxygen, aluminum and lead.

CONCLUSIONS

An in-beam flux monitor was designed and constructed at RPI in order to provide an accurate measurement of the incident neutron flux for neutron capture measurements. The detector efficiency was determined using the ^{252}Cf prompt fission neutron spectrum and the detector was shown to accurately measure the neutron flux in the energy range from 0.5 MeV to 3 MeV. This provides a significant improvement over the previous method of using B_4C to determine the neutron flux in this region and reduces the uncertainty in the capture measurements performed.

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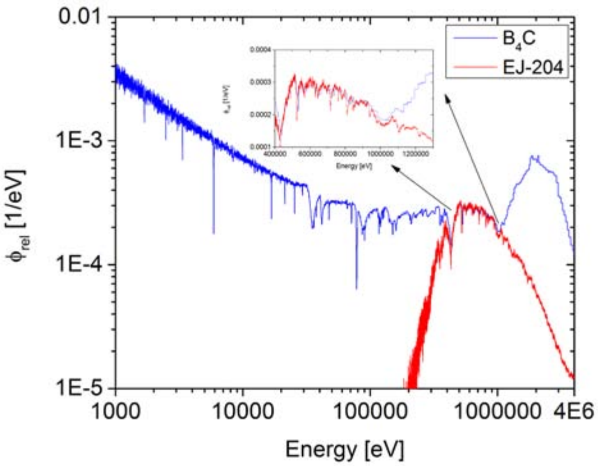

Fig. 4. A comparison of the incident neutron beam flux for the new RPI capture detector measured with B_4C and a plastic in-beam flux monitor. There is good agreement between the measured fluxes in the region from 500 keV to 1 MeV and the plastic flux monitor more accurately represents the predicted flux compared to the B_4C measurement in the region above 1 MeV.

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