Neutron Transmission, Capture, and Scattering Measurements at the Gaerttner LINAC Center

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INTRODUCTION

The Gaerttner LINAC Center at Rensselaer Polytechnic Institute (RPI) utilizes a 60 MeV pulsed electron Linear Accelerator (LINAC) to produce short pulses of neutrons for nuclear data research.[1] The measurement capabilities include neutron transmission, capture, scattering, and fission. The facility also houses a lead slowing down spectrometer that can be used for cross section and fission related research. The nuclear data measured at the facility is relevant to any neutron application; however, the focus of the research is on improving the accuracy of nuclear reactor and criticality safety calculations. As such, the energy range of interest is from 0.01 eV to 20 MeV, and the experimental setup, including the neutron source and detectors, is optimized to cover this energy range

Recently there has been an emphasis on designing new detection systems to cover the keV energy region for both transmission[2] and capture. This allows transmission measurements in the range of incident neutron energy from about 0.005 eV to 20 MeV and capture measurements in the energy range of 0.01 eV to hundreds of keV.

NEW EXPERIMENTAL CAPABILITIES

A new modular transmission detector was recently installed at a 100m flight path which enables measurements of the total cross section (via transmission) in the energy range from several keV to 600 keV. New data of molybdenum isotopes measured with this detector were presented elsewhere[2].

A neutron capture detection system is under development and will complement the existing capture detector which is based on 16 segments of NaI gamma detectors[3]. As the energy of the neutrons increases to the keV region neutron resonance scattering becomes dominant compared to capture, and scattered neutrons can penetrate the $^{10}B_4C$ liner of the NaI capture detector and get captured in the detector. This creates a so called "false capture" event that cannot be easily discriminated and thus causes an increase in the observed capture yield.[4] In order to solve this problem we plan to use an array of four C_6D_6 detectors which have low sensitivity to the scattered neutrons and thus minimize the "false capture". In order to ensure that the measurement is not biased to variations in the gamma multiplicity and energy distribution of the capture cascades, such a detector system requires the use of pulse height weighting to ensure that the detector response is proportional to the energy of the detected gamma. The overall detection efficiency of each detector is low such that it detects a single gamma from the capture gamma cascade. For a given resonance, averaging the gamma pulse height over multiple gamma cascades and applying the pulse height weighting results in a detection efficiency that is proportional to the total cascade energy which is the binding energy of the target nucleus.

A picture of the detector setup is shown in Figure 1. In order to minimize contributions to the capture yield from the surrounding environment, the detector case and mount are made from low mass aluminum. The data acquisition system (DAQ) is based on a 10 bit 5 GHz digitizer to record the detector signal as a function of neutron time-of-flight (TOF). The system is positioned in a new flight-station building at a neutron flight distance of about 45 m. Initial tests with a single detector were previously reported in reference 5, and full implementation will follow completion of the DAQ software development.

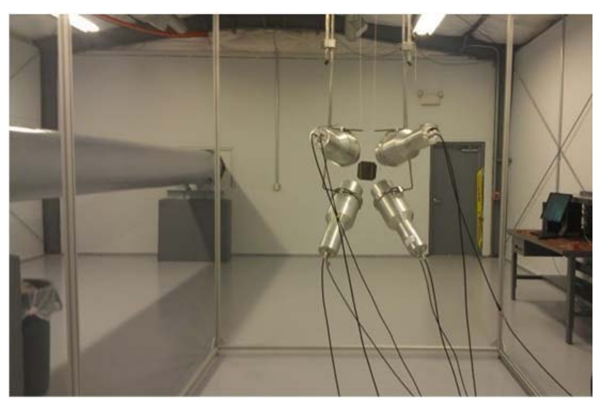

Figure 1 – A picture of the four C_6D_6 detectors mounted on a light aluminum structure surrounding a test sample on a temporary sample holder. The neutron beam direction is into the page.

RECENT MEASUREMENTS

Measurements that were recently completed include: Neutron scattering experiments for Fe-56 and neutron total cross section measurements of elemental Cu. In addition, analyses of measurements of neutron thermal scattering for polyethylene have begun and comparison of the experimental data to evaluations is shown in the following section.

Fe-56 scattering

A neutron scattering system that includes 8 EJ-301 detectors and Acqiris 8 bit digitizers was used for measurements of neutron scattering from Fe-56 in the energy range from 0.5 MeV to 20 MeV. More details on the experimental system are described in references 6 and 7. This system measures the neutron scattering to detectors located at a specific angles and provides information as a function of the neutron time of flight (TOF), which approximately gives the incident neutron energy. Because the measurements use a pulsed white neutron source, a scattered neutron from one incident energy can arrive at the detector at the same time as a neutron scattered from another incident energy. Thus the data provided by this experiment are referred to as quasi-differential data. The measured data were compared with a simulation of the experimental setup using different cross section evaluations for the measured sample. Differences between the simulations and experiments indicate where improvements in the evaluations are needed.

For this measurement a sample with 99.87% Fe-56 with dimensions of 77mm x 152.6mm x 32.2mm was used. Data were measured for three samples: graphite, beam-on background, and Fe-56, for a total of about 95 hours at 8 detector angles. The carbon sample was used for normalization of the simulations to the experiment, verification of the experimental system and analysis methodology, and estimation of accuracy.

The experiment was simulated using MCNP 5[8] and the measured TOF spectrum was compared with the simulations. Separate measurements of the neutron flux and detector efficiencies were done. A normalization factor was calculated from the ratio of the integral of the graphite measurement and simulation for each of the detectors. The average of the 8 normalization factors was used to normalize the Fe-56 data, and the standard deviation represents a systematic error which was found to be 2.3%.

The new measurement and analysis implemented several improvements over results previously published in references 6 and 7: (i) to improve the accuracy, measurement of the incident neutron flux spectrum using a U-235 fission chamber was used to replace previous measurements that used a Li-Glass detector. (ii) The neutron detector efficiency was found by using the known flux shape and by measuring the response of each detector when placed in the neutron beam. This was an improvement over the previous SCINFUL[6] calculations. (iii) A procedure for adjustment of the detection efficiency to account for shifts in the detection efficiency during the different detector positioning was implemented. (iv) A correction was made for "false scattering" due to contributions from gammas that were not sufficiently discriminated by pulse shape analysis (less than 5% correction for neutron energy between 2.5 to 8 MeV, and less than 1% for energy below 2.5 MeV). The MCNP simulations included the effect of room return which amounts to about a 2.4% increase in the simulated counts.

The measured data and simulation for Fe-56 are shown in Figure 2 for a scattering angle of 153 deg. A comparison of the experimental data to the simulation reveals that the measurement resolved some of the Fe-56 resonance structure and overall compares well with the different evaluations. However, a closer look shows that many resonances show discrepancies between the data and evaluations. Such experimental data can improve the evaluations of the angular distribution and the scattering cross sections. The low energy cut-off of the detectors was about 0.5 MeV. Given that the first excited state of Fe-56 is at 0.847 MeV, the data below 1.35 MeV were due to elastic scattering with no contribution from inelastic scattering. These data can help to isolate the observed discrepancies in this energy range.

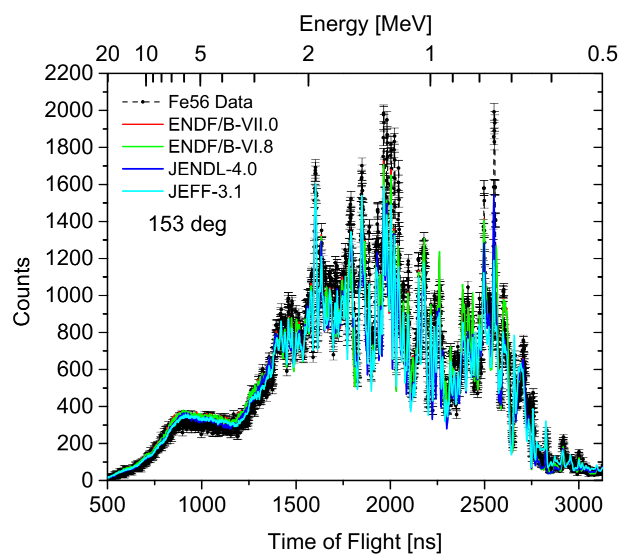

Figure 2 – A plot of the measured neutron scattering spectrum for a Fe-56 sample for a scattering angle of 153 deg. The data is compared with simulations using Fe-56 cross sections from several nuclear data evaluations.

Transmission of Cu

For this measurement a modular EJ-301 detector located at the 250m flight station was used. A detailed description of the setup of this system was given in reference 9. Elemental copper samples (99.99% Cu) with thicknesses of 6 cm and 8 cm were used to measure the transmission in the energy range from 0.5 MeV to 20 MeV. To demonstrate the high resolution of the experiment, the result from the 8 cm sample is plotted in Figure 3 for a limited energy range. An energy shift is noticeable when the data are compared with the evaluations. This was noticed during the experiment when samples of graphite and iron were measured at the same experiment for which no energy shift was observed. This indicates that the evaluations are based on previous measurements (also shown in Figure 3) that had an energy shift.

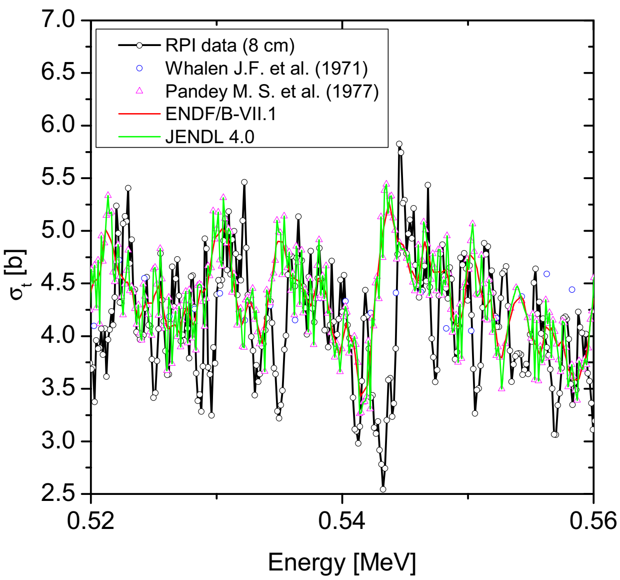

Figure 3 – A plot of the new Cu total cross section measurement in the low energy region and other data and evaluations.

Thermal Neutron Scattering

In the thermal energy region a neutron can lose or gain energy in a scattering collision with the moderator. The double differential thermal neutron scattering cross section is important for thermal reactor applications where the fission rate, and hence the multiplication factor, is driven by thermal neutrons.[10] In reactor calculations the details of the energy transfer are taken into account by the double differential scattering cross section (DDSCS) which is provided as an input to the calculations. Thus the uncertainty in DDSCS is propagated to all calculated quantities including the multiplication factor. For a given moderator temperature this cross section represents the probability of a neutron to scatter from incident energy E and angle Ω, to outgoing energy E' and angle Ω'. The DDSCS of water and polyethylene was measured by RPI at the Spallation Neutron Source (SNS) at ORNL using the SEQOUIA instrument. The sample was 0.15 mm thick medium density polyethylene powder. The raw data for polyethylene was processed to DDSCS and plotted in Figure 4 together with the DDSCS derived from the ENDF/B-VII.1 $S(\alpha,\beta)$ evaluation[11]. Two curves are plotted; one was calculated by direct application of $S(\alpha,\beta)$ to calculate the DDSCS, and the other by using MCNP to simulate the experiment. In the new experimental data the inelastic peak at 160 meV is significantly narrower than the current evaluation, which agrees with some of the observation of reference 12. The differences between the MCNP and direct interpretation of the data could be due to the way the experimental details are implemented in the simulation, the detail of the angular distributions in the MCNP cross section, and multiple scattering. To improve the simulations more work on these issues is in progress.

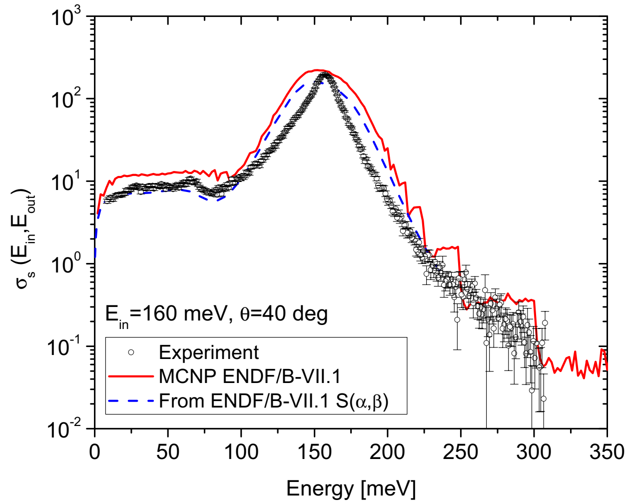

Figure 4 – Neutron double differential scattering cross section of polyethylene measured at room temperature for incident energy of 160 meV and outgoing angle of 40 deg.

CONCLUSIONS

Recent activity at the Gaerttner LINAC Center is focused on development of new capabilities for measurement of total and capture cross sections for keV incident neutron energies. A capture detector with low sensitivity to neutron scattering is currently under construction. Recent measurements include neutron scattering for Fe-56 in the energy range from 0.5 MeV to 20 MeV and elemental Cu total cross sections in the same energy range. Both data sets can be used to improve cross section evaluations. Analysis of a new measurement of polyethylene thermal neutron scattering indicates a narrower energy spread in the inelastic peak around the incident neutron energy. In order to study the effect of the new thermal scattering data on criticality calculations, methods to include the new thermal scattering data in Monte Carlo codes are being developed.

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