

Recent Nuclear Data Activity at the RPI Gaertner LINAC Center

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Abstract. The nuclear data group at the RPI Gaertner LINAC Laboratory uses a 60 MeV pulsed electron LINAC to produce short pulses of neutrons and perform cross section and other nuclear data measurements in a wide energy range from below 1 meV to about 20 MeV. This paper will cover several recent activities that are of interest to nuclear applications.

Interest in thermal neutron scattering evaluations prompted the need for accurate thermal total cross section measurements for validation. To improve the neutron flux in the sub-thermal region (below 0.01 eV) a cold moderator was designed and installed. A polyethylene moderator operating at about 26 K resulted in a factor of 8 increase in neutron flux below 0.01 eV. Using this new capability, several transmission measurements were performed with samples of polyethylene, polystyrene, Plexiglas, and yttrium hydride.

Neutron capture and transmission measurements in the keV energy range were made for ⁵⁴Fe, which will be used in an evaluation effort that is underway. Capture measurements were collected on an array of C₆D₆ detectors that was expanded from 4 to 7 detectors, and a complementary transmission measurement was also performed.

Finally, research aimed at experimental validation of neutron capture gamma production is in progress. Energy dependent capture gamma cascades are measured with the RPI 16-segment gamma multiplicity detector. Measurements are then compared to capture gamma cascades generated from nuclear structure evaluations processed with DICEBOX and transported with a modified version of MCNP. This system provides important information on the completeness of primary gamma-ray databases.

1 Introduction

The Gaertner Linear Accelerator (LINAC) Center at Rensselaer Polytechnic Institute (RPI) uses a 60 MeV electron LINAC to produce short pulses of neutrons that are used to measure nuclear data using different methods [1]. The accelerator is undergoing a major refurbishment [2] that will significantly increase the neutron output at short pulses. This report will focus on three recently developed capabilities and resulting measurements that were performed with the goal of improving nuclear data accuracy and the evaluations using these data.

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2 Experiments

Recent activity reported here includes measurements of thermal total cross sections, ^{54}Fe resonance region measurements and evaluation, and neutron capture gamma-ray spectra measurements and simulation.

2.1 Thermal neutron cross section measurements

Recent improvements in methods used to generate thermal scattering laws (TSLs) has lead to numerous new thermal neutron scattering evaluations that need experimental validation. One of the most important parameters that a TSL computes is the integrated scattering cross section. In the case of moderators, scattering is the dominant cross section because the capture cross section is relatively small. For the purpose of TSL validation, accurate total cross section measurements are required. This type of data can be obtained by performing accurate transmission measurements resulting in total cross section uncertainty below 2%. The required neutron energy range is determined by applications of the TSL and is typically from 0.0005 to 3 eV. In some cases, measurements at several temperatures are desired to validate the TSL at the operating temperature of a system of interest.

The Gaerttner LINAC Center can use different neutron production targets to produce neutron beams that match the desired energy range of an experiment, to generate thermal neutrons the Enhanced Thermal Target (ETT) [3] is used. Measurements with the ETT have a useful energy range from 0.001 eV to 100 eV [4] with a signal to background ratio (SBR) of about 3000 at 0.06 eV [5] however at 0.001 eV the SBR drops to about 5. In order to improve the measurements capability at low-energies, a cold moderator add-on was designed and constructed. This configuration was named the ETTC and utilizes 2.5 cm of polyethylene moderator cooled to about 26 K that was positioned in front of the ETT [6]. This configuration increased the neutron flux below 0.01 eV by further shifting the neutron energy spectrum from higher to lower energies. Quantitatively, the energy shift resulted in a reduction of the SBR at 0.06 eV to 1000 while increasing the SBR at 0.001 eV to 16, enabling measurements down to 0.0005 eV.

Total cross section measurements of polymers including polyethylene, polystyrene, and Plexiglas, were preformed using this system and reported in reference [7], and measurements of yttrium hydride samples were reported in reference [8]. An example of the use of such data is given in Figure 1 where the ENDF/B-8.0 [9] and two ENDF/B 8.1 β 1 candidate evaluations are compared with the experimental data. Additional comparisons of this experiment with other experimental data from EXFOR was given in [7] and indicate that the most common version of Plexiglas used in applications is G type. The agreement (or disagreement) between the experiment and evaluation provides additional validation of the TSL accuracy in calculation of the scattering cross section. Above about 0.01 eV, the evaluations are within the experimental uncertainty of about 2%, below this energy all evaluations are outside the experimental uncertainty with calculated-to-experiment (C/E) ratios greater than 1.0.

2.2 ^{54}Fe Measurements and Evaluation

Iron is an important structural material that is present in different nuclear systems such as reactor cores, shielding, and nuclear fuel processing plants. At RPI, measurements of natural iron and ^{56}Fe were performed, however since iron is used so ubiquitously, re-evaluation of the minor isotopes including ^{54}Fe (w/o 5.8%) is necessary for an accurate new evaluation of natural iron . Due to disagreements between different evaluations of the neutron capture cross section and since there is only one high energy resolution radiative capture measurement of

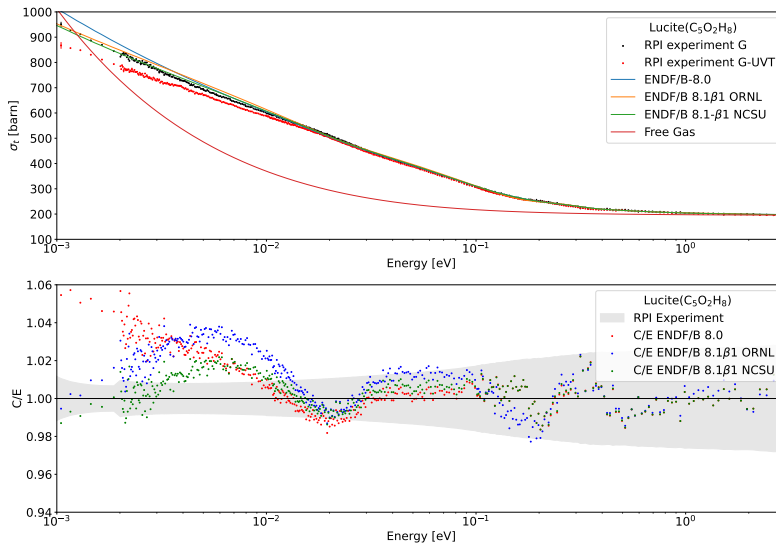


Figure 1. Comparison of the measured total cross section of Plexiglas (Lucite) with ENDF/B-8.0 and two ENDF/B8.1 β 1 candidate evaluations (one from Oak Ridge National Laboratory and one from North Carolina State University) on the top plot, and C/E ratios on the bottom plot.

^{54}Fe from n_TOF [10], both capture and transmission measurements were conducted at RPI of a 96% enriched metallic ^{54}Fe sample with an atomic density of 0.021 atoms/barn.

The radiative capture measurements were conducted using an upgraded C_6D_6 detector array located at a 45 m flight path and was designed to minimize sensitivity to scattered neutrons. This measurement was conducted in the keV energy region, where the data obtained will be most useful from 5 keV to 150 keV. The data was collected using a 10-bit Struck SIS-3305 8-channel 0.8 ns digitizer, and reduced to a capture yield using the pulse height weighting technique (PHWT) and saturated resonance method [11]. Since there are no saturating capture resonances in ^{54}Fe , the capture yield was normalized to the 4.9 eV resonance of Au. The measured capture yield results are shown in Figure 2, where discrepancies are seen in the magnitudes of the experimental yield and SAMMY calculations using ENDF/B-VIII.0 and JEFF3.3 [12] resonance parameters. Additional validation and verification work of the implementation of the PHWT is underway, as well as the generation of a full covariance matrix.

The transmission measurement was conducted using a Li-glass detector and data were collected using an analog electronics setup. These measurements were also focused on the keV neutron energy region, and the data will be used from 5 keV to 150 keV. These data were reduced using the sample-in, sample-out method and background shapes for each sample were obtained using fixed notch materials kept in the neutron beam throughout the duration of the experiment. These notches included Al and Co, which form localized depressions in the neutron flux at resonance energies which can be fit to obtain a time-dependent background function. The current experimental results are shown in Figure 3, where it is possible to see some slight differences between the experimental results and SAMMY calculations using different sets of resonance parameters. The discrepancy seen in the n_TOF parameters indicates the importance of evaluating both transmission and capture data simultaneously. Additionally, a full covariance matrix has been constructed for this experiment.

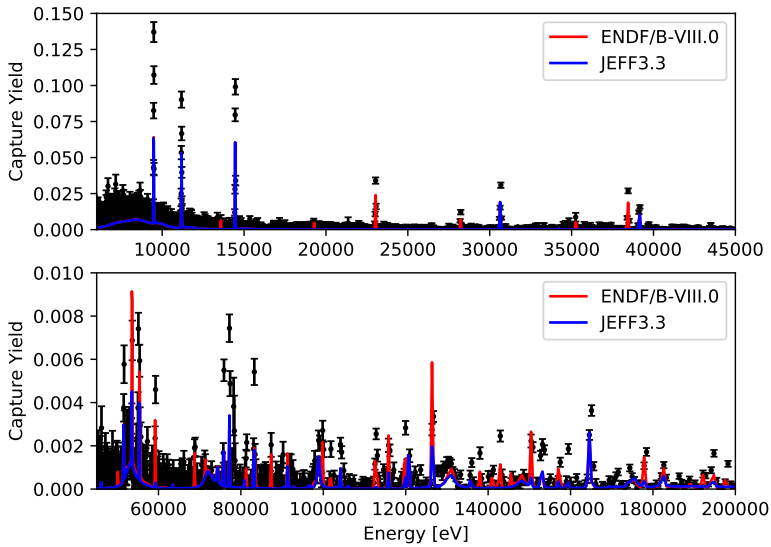


Figure 2. Comparison of the measured capture yield of ^{54}Fe with ENDF/B-VIII.0 and JEFF3.3.

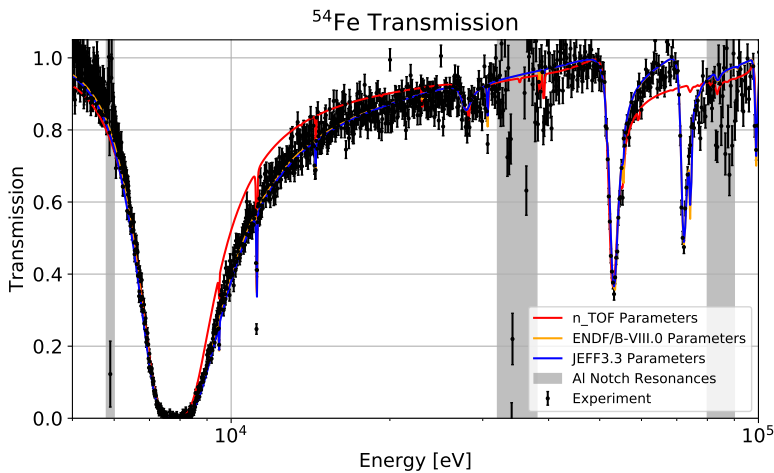


Figure 3. Comparison of the measured transmission of ^{54}Fe with ENDF/B-VIII.0, JEFF3.3, and n_TOF parameters.

Additional work is required to complete the generation of the capture covariance matrix. Once this is completed, a new set of resonance parameters will be fit to the RPI data as well as other relevant high-resolution experiments from EXFOR. These new resonance parameters will improve the iron evaluation as a whole.

2.3 Capture γ -Spectra

The RPI multiplicity detector [13] is a cylindrical NaI(Tl) detector with a volume of about 20 L divided into 16 independent segments. A neutron beam entry hole goes through the center of the detector where the sample of interest is positioned. The sample is surrounded by a ceramic $^{10}\text{B}_4\text{C}$ liner tube to prevent scattered neutrons from entering and capturing in the NaI gamma detector. In this work, a new data acquisition system was installed which digitizes the photomultiplier pulses from each of the 16 detectors as a function of neutron time-of-flight. The event-by-event data includes details of the gamma production in the sample and enables coincidence counting to determine capture gamma-multiplicity. The useful incident neutron energy range of this detector is approximately 0.002-3000 eV to measure both capture yield and gamma spectra. An example of a capture yield measurement of natural uranium is shown in Figure 4. The upper energy limit was selected to reduce the background from scattered neutrons captured in the NaI crystals.

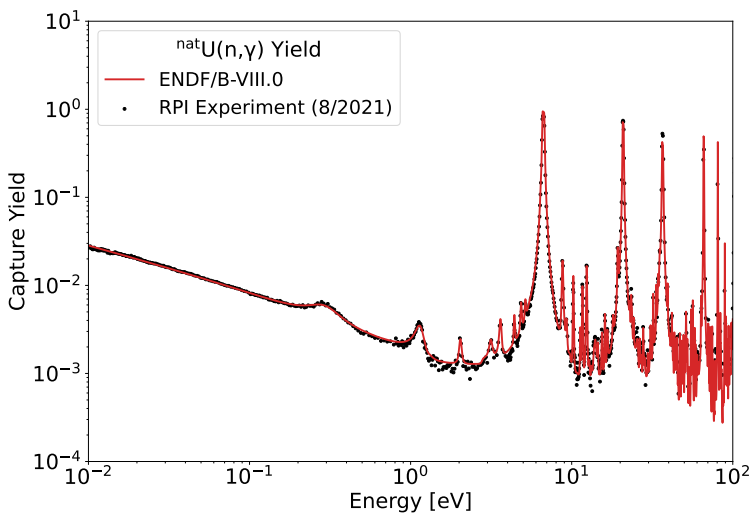


Figure 4. Neutron capture yield of ^{nat}U compared to one collision yield calculations using the ENDF/B-VIII.0 and ENDF/B-VII.I evaluations.

The main objective of this work is to measure the capture gamma spectrum in each of the 16 detectors and also as a coincidence sum of all detectors (total capture event energy deposition). Experimental data is then compared to detailed simulations using the best available capture gamma cascade evaluations. This comparison provides validation of the gamma-ray nuclear data and also provides information on which energy regions of the spectrum need improvement. The experimental data can also be analyzed to compare capture gamma spectra in different isolated resonances.

Forward modeling is used to simulate the experiment and validate the nuclear data being tested. The procedure is as follows: cascades are generated using an external code (i.e., DICEBOX [14]) and are written to a file then a modified version of MCNP-6.2 is run. For each capture event, a gamma-cascade is read from the file and transported through the detector geometry. An event file to tally gamma-energy deposition in detector cells is generated. Finally, the output file can be processed using event-by-event analysis including coincidence and compared to the same measured quantities.

An ^{56}Fe sample was measured to validate the detector system because of the high quality capture gamma cascade data available. The validation shows that experimental gamma-spectra agree with modified MCNP-6.2/DICEBOX calculations for isotopes with well-known capture gamma-ray data as shown in Figure 5. Other samples including ^{55}Mn , ^{59}Co , ^{181}Ta , ^{235}U , and ^{238}U have been measured and will be used for further validation and analysis.

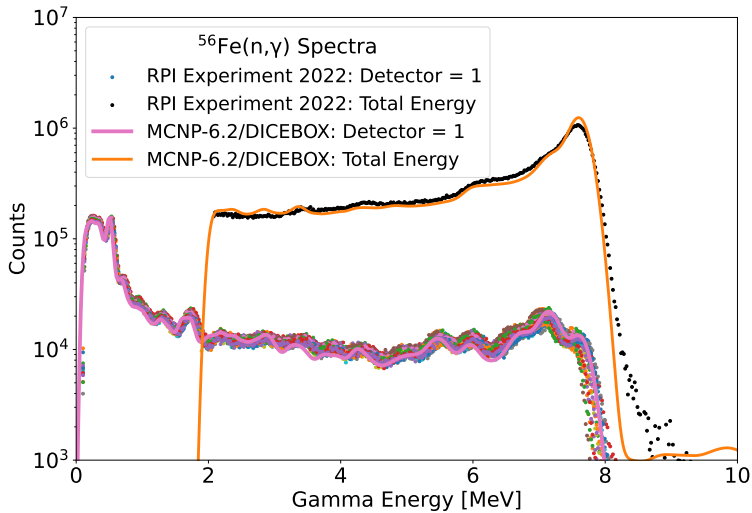


Figure 5. Neutron capture spectra of ^{56}Fe compared to simulations using capture cascades generated with DICEBOX and transported with modified MCNP-6.2.

3 Conclusions

Research at the Gaertner LINAC Center is focused mostly on nuclear data that is relevant to reactor applications and criticality safety. Three recent experiments were reviewed: thermal region total cross section measurements, ^{54}Fe transmission and capture measurements and resonance parameter evaluation, and measurements for validation of neutron capture gamma-ray spectra generated with capture gamma-ray evaluations.

In order to accurately measure total cross sections in the thermal energy range a polyethylene cold moderator operating at a temperature 26 K was designed, constructed, and used to increase the neutron flux below 0.01 eV. Measurements of polyethylene, polystyrene, Plexiglas, and yttrium hydride were used to validate different TSL evaluations. Such data is important for validation of the large number of new TSL evaluations evaluations being generated for potential inclusion in ENDF/B-VIII.1 and other major nuclear data libraries. The data reported in this paper were submitted to EXFOR [15].

^{54}Fe was measured in both neutron capture and transmission adding new data above 5 keV. Comparison of the measured capture yield with evaluations indicates differences that will be resolved in a new evaluation.

Validation of neutron capture gamma-ray cascades evaluations is accomplished using the RPI multiplicity detector. The 16-segment, high efficiency NaI detector, measures the neutron capture gamma-ray cascade as a function of neutron time-of-flight. Data was processed to collect information for each gamma cascade. The results include gamma-ray spectra for

each detector and total energy deposition, and the detected multiplicity. A modified version of MCNP-6.2 can produce the same information and results are compared to the experiments. Such comparison can be used to validate the quality of neutron capture gamma-ray cascade evaluations used for the simulation, an example for ^{56}Fe was given and shows good agreement.

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