Nuclear Data Measurements at the RPI LINAC

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The Gaerttner LINAC Laboratory at RPI uses a 60 MeV electron LINAC as a pulsed neutron source. The neutrons are used for a variety of experiments primarily related to nuclear data measurements. Neutron targets and detectors are optimized for different experiments and several flight paths are available for time of flight measurements. The capabilities include neutron transmission and capture measurements in the energy range from 0.01 eV to 2 keV. An additional detection system is currently being designed and will enable neutron transmission measurements in the energy range of 1 eV to 200 keV. These capabilities allow high accuracy determination of resonance parameters. New detection systems have been recently installed which will enable neutron transmission and scattering measurements in the energy range from 0.4 to 20 MeV. Filtered neutron beams enable high accuracy measurements of smooth cross sections in the energy range from 24 keV to 905 keV The laboratory also hosts a 66 metric-ton lead slowing down spectrometer (LSDS) that is currently used for simultaneous measurements of fission cross section and fission fragments energy and mass distributions of small samples. Detectors for (n,alpha) and (n,p) measurements of nanogram samples with the LSDS are also being developed and tested.

I. Introduction

The Gaerttner Electron Linear Accelerator (LINAC) at RPI was built as a pulsed neutron source designed for nuclear data measurements [1]. The facility started operation in 1961 and has since been used primarily for nuclear data research. Major upgrades completed in 2000 and 2005 ensure its continued operation. The upgrades included replacement of major parts such as klystrons, thyratrons and pulse transformers. In the last upgrade which ended in 2005, a new injector system was installed. This system allows operation with a 5 ns pulse width which is required for new experimental systems operating in the energy range from 0.4 MeV to 20 MeV and will be described later. Another injector with a bigger cathode is currently being tested and is expected to increase the average current by about 50%. At maximum power the LINAC is capable of delivering about 12 kW of average electron power; typically experiments are done using several kW of beam power. Neutrons are produced by interaction of electrons with tantalum plates producing bremsstrahlung that interacts with the same plates to produce photo-neutrons with an evaporation spectrum [2].

The facility is equipped with several neutron producing targets each optimized to a specific energy range covering the range from 0.001 eV to 20 MeV. Measurements are typically done using the time-of-flight (TOF) method and the facility is equipped with several flight paths with lengths of 15m, 25m, 30m, 100m and 250m. Several detectors are available which include Li-glass detectors, a multiplicity capture gamma detector, a neutron scattering array of liquid scintillator detectors and a large volume, modular liquid scintillator detector for transmission measurements. The facility is also equipped with a 66 metric-ton lead-slowing down spectrometer (LSDS) which is used for cross section measurements of small size samples (sub micro grams) and also for studies on the use of a LSDS for spent nuclear fuel assay.

II. Experiments

The activity at the Gaerttner LINAC includes neutron transmission, capture, scattering, and fission measurements. Also (n,alpha) measurements with the LSDS are under development. The details are further discussed in the following sections.

II.A Transmission and Capture Measurements

Typically a set of samples with a variety of thicknesses will be used. Two different neutron producing targets are used: one optimized for the thermal region (0.001eV-20eV) and the other for the epithermal region (1eV-2keV). Li-glass detectors are used for the transmission measurements and are located at 15m for the thermal region and 25m for the epithermal region. A 16 segment NaI(Tl) capture gamma detector located on a 25m flight path is used for the capture measurements. Care is taken to characterize the detectors' dead time and the time dependent background.

Recent measurements include Nd [3], Hf [4], Nb [5], Gd [6], and Mo [7] and were analyzed using the SAMMY code [8] to extract the resonance parameters. An example of the recent Mo measurement [7] is shown in Fig. 1. The data was fitted with the SAMMY code, and a curve calculated with the ENDF/B-VII.0 resonance parameters is also shown for the thick sample. Compared to ENDF/B-VII.0, the RPI data show a narrower resonance and an energy shift. It is important to emphasize that in this case one set of resonance parameters (energy, radiation and neutron widths) provides an excellent fit to all the data sets.

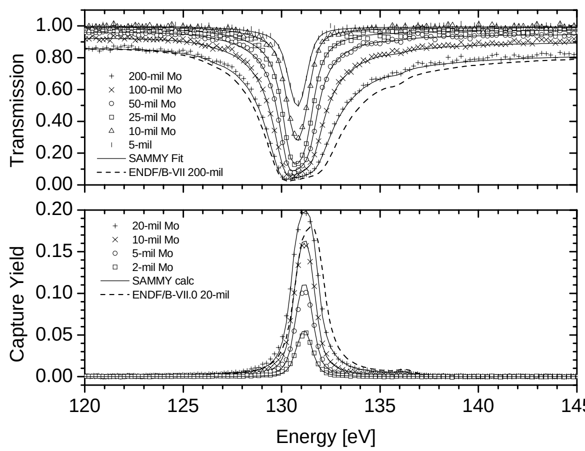

Fig. 1. Measured Molybdenum transmission (top) and capture data plotted with the SAMMY fit. A calculation with the ENDF/B-VII.0 resonance parameters is also shown (1 mil = 0.00254 cm).

The capture detector can also be used for capture-to-fission ratio measurements [9]. In this measurement a 0.12 mm disk of metallic uranium 93.3% enriched in ^{235}U was placed in the capture detector. The gammas emitted from capture and fission reactions were collected separating events with total energy deposit above and below the neutron binding energy in ^{236}U. The data above the binding energy can only be a result of a fission event, below it is a mix of fission and capture. The fission data was normalized to the evaluated data in the thermal region. The multiplicity and the measured fission gamma spectrum are used to extract the capture cross section.

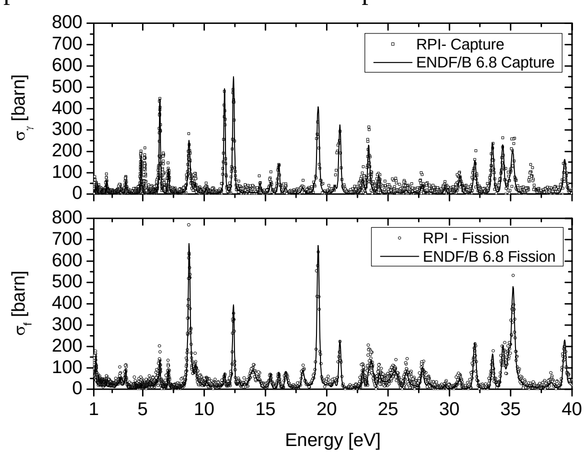

Fig. 2. Results of a simultaneous measurement of the fission and capture cross section of ^{235}U using the RPI multiplicity detector.

An advantage of this method is that a relatively thick sample can be used because the gammas can easily escape the sample. An example of the results is given in Fig. 2. and show excellent agreement for the fission cross section and good agreement with the ENDF/B-VI.8 data.

II.B High Energy Transmission Measurements

A new modular liquid scintillator detector was recently installed at the 100m flight path [10]. This detector is designed to cover a large beam area (~68 cm diam.) which allows measurements with a diverging beam when a small 2" diam. sample is used. The detector uses fast ORTEC 935 constant fraction discriminators and data is taken with a FastComtec P7889 TOF clock. Recent measurements to qualify the detector using graphite show excellent agreement with the ENDF/B-VII.0 data for carbon. In some energy regions our data could help improve the carbon evaluation. The detector can resolve all the sharp carbon resonances but the peaks are not as high as the evaluation. This is attributed to the energy resolution and can be improved by moving the detector to the 250m flight station. A measurement using beryllium samples is now in progress and will complement a lower energy filtered beam measurement that will be described later. The result of the graphite transmission measurement is shown in Fig. 3.

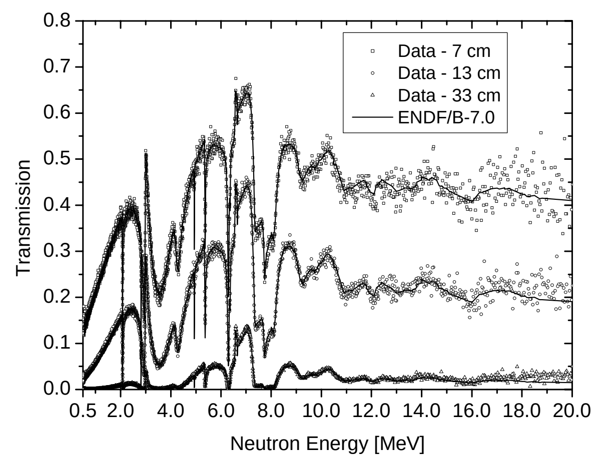

Fig. 3. Measured graphite (carbon) transmission for three sample thicknesses.

II.C High Energy Scattering Measurements

An array of eight 5"x3" EJ-301 liquid scintillators was recently constructed; the array is coupled to Acqiris AP240 digitizers. Software for data acquisition and pulse shape discrimination was written [11]. The system is located at a flight path of ~30m and will be used for angular scattering measurements for incoming neutrons in the energy range of 0.5 MeV to 20 MeV. The system is currently being tested using a graphite scatterer. Qualification of this system includes comparison to Monte Carlo simulations with different evaluated cross section data sets.

II.D Filtered Beam Measurements

Measurements of neutron scattering and transmission with a filtered neutron beam using the TOF method can provide high accuracy data [12,13] for smooth cross section. This method uses a thick filter in which the resonance potential interference minima reduce the total cross section to nearly zero. The filter creates a neutron beam with sharp peaks at discrete energies. Transmission measurements using a 30cm Fe filter can provide 19 discrete data points in the energy range from 24 keV to 960 keV. The advantage of this method is that the filter removes all the neutrons except those that can go through the cross section minima, and results in a very low background measurement. Such a low background measurement enables high accuracy total cross section measurements. Measurements were done on graphite (carbon) and beryllium. The results for beryllium are shown in Fig 4. The results shows best agreement with the JENDL-3.3 evaluation up to about 350 keV where the ENDF/B-VI.8 evaluation is a better fit.

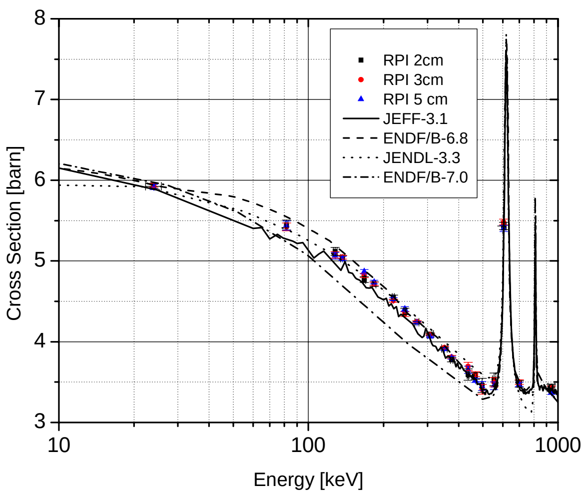

Fig 4 – Total cross section of Beryllium measured using an iron filtered beam

II.E Measurements with the LSDS

The RPI lead slowing down spectrometer (LSDS) is a 1.8m-on-a-side cube of pure lead with a pulsed neutron source in its center. The LSDS is driven by the RPI LINAC generating a pulsed electron beam that hits an air cooled tantalum target in the center of the lead pile. The fast neutrons slow down by successive scattering interactions with the lead. The resulting slowing down energy spectrum at a given slowing down time is approximately a Gaussian with a FWHM of about 30%, and the average neutron energy corresponds to the slowing down time at the peak of the distribution. This enables measurements in a method similar to TOF experiments. As a result of the neutron scattering, the flux in the LSDS is very high; about 3-4 orders of magnitude higher than an equivalent distance (5.6m) time-of-flight experiment. This high neutron flux allows measurements with very small samples (sub micrograms) or very small cross section. We are currently using the LSDS to develop a method for simultaneous measurements of fission cross sections and fission fragment mass and energy distributions of small samples. This is very useful for the study of actinides for which this information does not exist and large samples are unavailable. A double gridded fission chamber is placed inside the LSDS and is used for measurements of energy and relative angle of the fission fragments from which the mass can be deduced [14]. The detector was tested using ^{252}Cf sample and is currently under test measuring ^{235}U. An example of the slowing down time dependent anode pulse height is shown in Fig. 5.

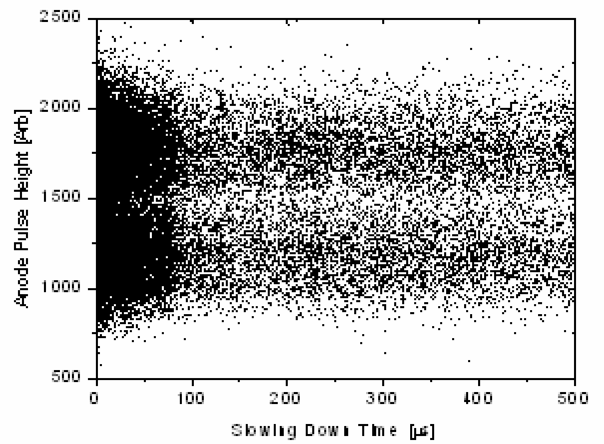

Fig. 5. – A plot of the anode pulse height which is proportional to the fission fragment energy vs. the neutron slowing down time.

Another project with the LSDS is aimed at developing a method for measurements of (n, alpha) and (n,p) cross section on small radioactive samples and samples with low cross sections. Different detector concepts are currently under development. One of them that utilizes solar cells was recently tested in the LANL LSDS [15].

III. CONCLUSIONS

The Gaerttner LINAC Laboratory utilizes a 60 MeV LINAC to perform a variety of cross section measurements including total, capture, scattering, fission, and (n,alpha). The facility was recently upgraded and a new electron injector was installed capable of 5ns to 5 µs pulse widths. The facility is equipped with neutron detectors and a capture-gamma multiplicity detector. The facility also houses a 66 metric-ton lead slowing down spectrometer. Measurements of transmission and capture data in the resonance region are analyzed using the SAMMY code to extract resonance parameters. Recently two new detection systems were added, one for high energy (0.4 MeV – 20 MeV) transmission measurements at a 100m flight path and the other an eight-detector neutron scattering array at 30m flight path. Currently a high resolution large modular detector for resonance total cross section measurements is under construction.

A method for high precision total cross section measurements using an iron filtered beam was demonstrated. A method to utilize the RPI multiplicity detector for simultaneous measurements of fission and capture cross sections was demonstrated. A method for simultaneous measurements of the energy dependent fission cross section and fission fragment energy and mass distributions for small samples was developed and tested on measurements of ^{252}Cf and ^{235}U prior to application to other actinides.

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