PROGRESS ON USING A LEAD SLOWING-DOWN SPECTROMETER TO MEASURE NEUTRON CAPTURE CROSS SECTIONS

N.W. Thompson, A. Lewis, J. Thai, A. Daskalakis, E. Blain, and Y. Danon
Gaerttner Linear Accelerator Center,
110 8th Street
Rensselaer Polytechnic Institute, Troy, NY, 12180, USA
thompn4@rpi.edu; danony@rpi.edu

ABSTRACT

Nuclear data is required for simulations of nuclear reactors and other nuclear applications. The accuracy of this data is crucial, and is increasing becoming a limiting factor on the accuracy of nuclear simulations. This work describes the progress of further developing the method of using a Lead Slowing-Down Spectrometer (LSDS) to measure neutron capture cross sections at the Gaerttner Linear Accelerator Center (LINAC) at Rensselaer Polytechnic Institute (RPI). Simulations have been performed with the Monte Carlo-N Particle (MCNP) transport suite of codes in order to design and optimize the experiments. This work improves on previous works by specifically measuring neutron capture in the keV region for developing average capture cross sections in the resonance region. This paper discusses the methods used, the results of these measurements, and the method's usefulness in measuring neutron capture data.

KEYWORDS
Nuclear, Data, Capture, Neutron, LSDS

1. INTRODUCTION

As computational tools for simulating nuclear interactions become faster and more accurate, one limiting factor in the accuracy of calculations is the accuracy of nuclear data. In this paper, "nuclear data" refers to the probabilities of interactions with atomic nuclei. Nuclear data is required to accurately simulate a large number of applications, including existing nuclear reactors for energy production, medical isotope production, detectors for national security, and development of advanced reactors and fusion energy systems [1][2].

1.1 RPI LINAC and LSDS

The LINAC at RPI was specifically designed to measure nuclear data and fine nuclear structure [3]. The LINAC is a 60 MeV electron linear accelerator which is used to create a short pulse of neutrons through (e, γ) and (γ, n) reactions with a tantalum target. In most measurements at the LINAC, detectors are positioned at flight stations, ranging from 25 to 250 meters from the neutron producing target , and the time-of-flight method is used to determine neutron energy. The LINAC has been used to measure neutron capture, scattering, and fission cross sections, as well as prompt fission neutron spectrum and fission fragment distributions.

At the LINAC is also a Lead Slowing-Down Spectrometer (LSDS), a large cube (1.8 m) of high purity lead with a neutron producing target in the center. Neutrons are slowed down through successive collisions with the lead nuclei. Due to the low average lethargy in each collision, it takes many collisions, and therefore a considerable amount of time for the neutrons to thermalize (2 ms). Over that time, neutrons in the lead will have an average neutron energy which is related to time by Equation 1 [4]:

$$E = \frac{k}{(t - t_0)^2} \qquad (1)$$

where E is average neutron energy in eV, t is the slowing down time, k = 165,000 eV*μs^2, and t_0 = 0.3 µs. Figure 1 is a photograph of the RPI LSDS.

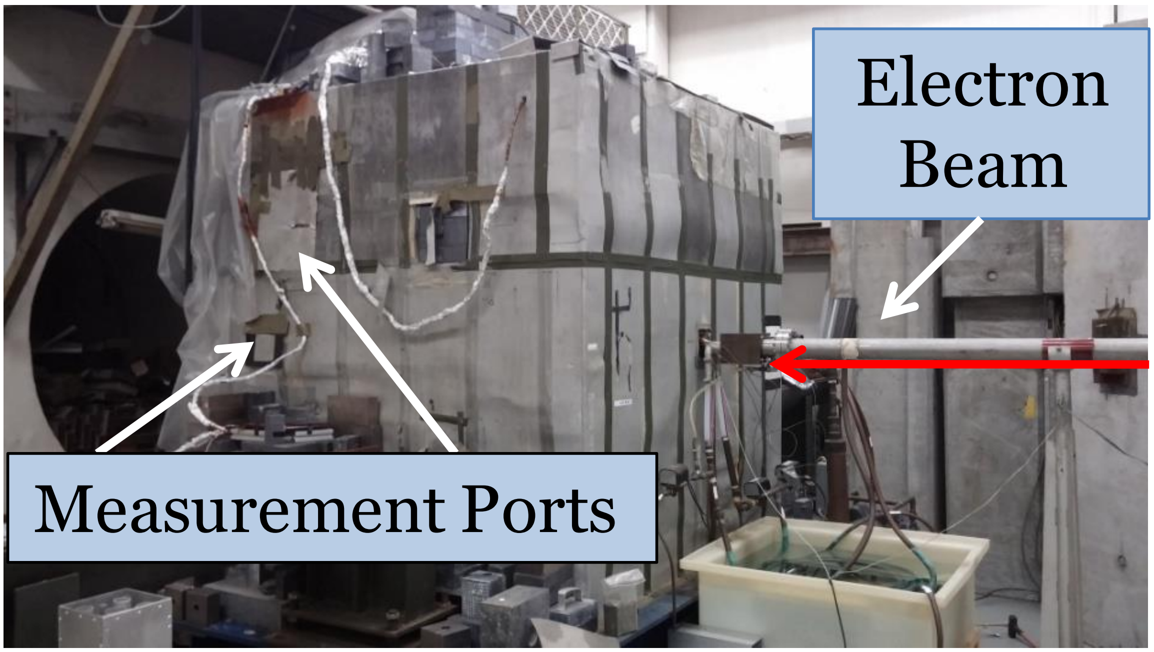

Figure 1: Photograph of the RPI LSDS

The neutrons energy resolution of the LSDS is approximately 30% between 1 keV and 10 eV and can be modeled by Equation 2 [5]:

$$\left[\frac{\Delta E}{E}\right]_{FWHM} = \left[0.0835 + \left(\frac{0.128}{E}\right) + 3.05 * E * 10^{-5}\right]^{0.5} \qquad (2)$$

where $[\Delta E/E]_{FWHM}$ is the full width half maximum energy resolution, and E is the energy in eV.

2. MEASURING NEUTRON CAPTURE CROSS SECTIONS WITH THE RPI LSDS

This work builds on previous work at RPI presented at the 2014 ANS Winter Meeting [6], more details on the previous work can be found in Reference 4. To make the measurement, yttrium aluminum perovskite scintillators doped with cerium ($YAlO_3$:Ce, referred to as YAP) were mounted to a Hamamatsu R762 photomultiplier, and positioned inside one of the measurement ports of the LSDS next to a small sample. During the measurement, some of the neutrons in the LSDS are captured in the sample, and some of the capture gammas are detected by the scintillators. These detectors were connected to a digital data acquisition system (Acqiris AP240), and digital signals from the detector were recorded as a function of time after LINAC pulse (slowing down time). Measurements were performed using 1.905 cm (0.75 in diameter), 2 mm and 5 mm thick YAP scintillators.

Figure 2 details some of the measurement result. Additionally, earlier MCNP simulations of the experiment included two parts per million of hydrogen in the lead of the LSDS, it was found through a chemical analysis of the lead that the hydrogen content in the LSDS is one part per million. Simulations which took into account this smaller amount of hydrogen matched the experimental results much better, particularly the shapes of the peaks and valleys. These measurements were also taken with the following LINAC beam conditions; electron energy that varied from 53 and 55 MeV, a 253 ns electron pulse width, and a beam current of 0.05 μA.

As can be seen in Figure 2, the simulation and experimental results for natural tantalum (which is almost entirely ^{181}Ta) match very well from 0.1 eV to 300 eV, but above this point there are differences. This is particularly interesting as the unresolved resonance region in tantalum begins above 330 keV. The experiment and simulation for silver also matched very closely, up until 150 keV. The sample mass for the Ta sample was 0.425 g, and the sample mass for the Ag sample was 0.983 g.

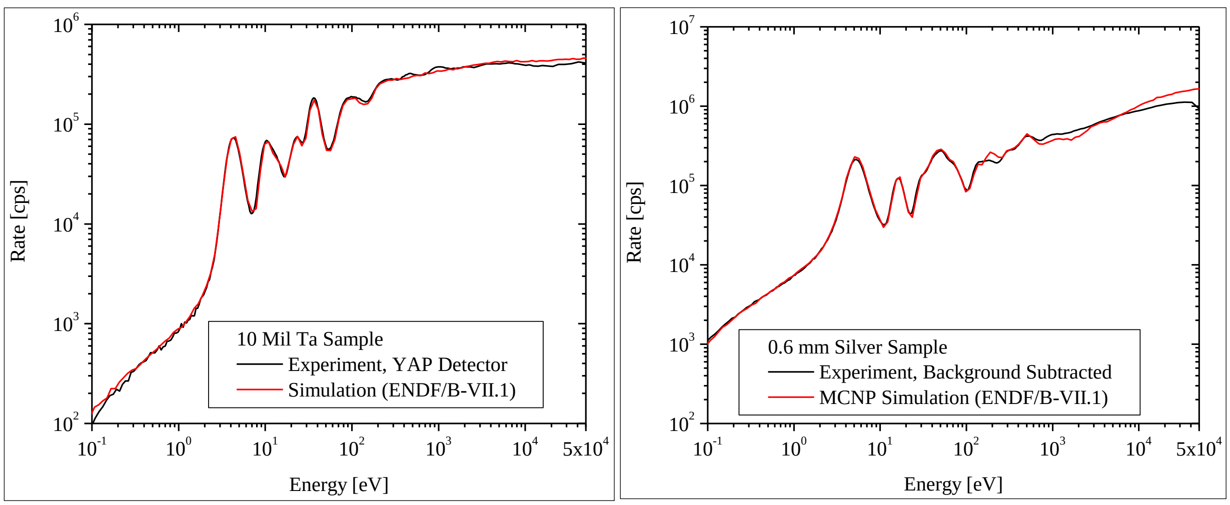

Figure 2: Measurements of Tantalum and Silver compared to MCNP5 [7] simulations using ENDF/B-VII.1 [8] cross section libraries.

Measurements were also made with two detectors measuring in coincidence, where the sample being measured was place between the two detectors. Due to the gamma cascade resulting from a capture having multiple gammas, there is a probability that both detectors will detect gammas from the same capture event, and this probability is higher than both detectors detecting two uncorrelated gammas from different events at the same time. Results of these experiments showed that while when measuring in coincidence, the signal to background ratio was much higher (about five times better), but the overall count rate was much lower (ten times lower), and other difficulties arose in subtracting background and being able to reproduce results of measurements; if the detectors, sample, or surrounding materials moved at all between measurements, then an accurate measurement could not be made.

3. CONCLUSIONS

Progress has been made towards measurement of neutron capture rates using an LSDS. In particular, measurements of neutron capture rates have been made and improved upon, and simulations of those experiments have also been improved. Next steps include completing analysis of experimental data and implementing a weighting function to take detector efficiency into account.

ACKNOWLEDGMENTS

The authors would like to thank the Stewardship Science Academic Alliance for their funding of this research, Grant numbers DE-NA0002906, DE-NE0001814. The authors would also like to thank the LINAC staff; Peter Brand, Matthew Gray, Azeddine Kerdoun, Larry Krusieski, and Martin Strock.

REFERENCES

1. L. Bernstein, D. Brown, A. Hurst, J. Kelley, F. Kondev, E. McCutchan, C. Nesaraja, R. Slaybaugh, and A. Sonzogni, "Nuclear Data Needs and Capabilities for Applications," *Lawrence Berkeley National Laboratory and the Nuclear Science and Security Consortium at U.C. Berkeley*. Berkeley, California, USA. http://arxiv.org/pdf/1511.07772 (2015).
2. R. Bahran, J. Hutchinson, M. Smith, and A. Sood, "A Survey of Nuclear Data Deficiencies Affecting Nuclear Non-Proliferation," *Proceedings of the 2014 Institute for Nuclear Materials Management Annual Meeting*, Atlanta, GA, LANL Report LA-UR-14-26531. (2014).
3. M. Yeater, "Neutron Physics," *Proceedings of the Symposium held May 5-6, 1961, at Rensselaer Polytechnic Institute*, Troy, New York. Academic Press, NY (1962).
4. N. Abdurrahman, "System Performance and Monte Carlo Analysis of Light Water Reactor Spent Fuel Assay Using Neutron Slowing Down Time," *Ph.D. Thesis, Rensselaer Polytechnic Institute*, 1991.
5. B. Becker et al., "Nondestructive Assay Measurements Using the RPI Lead Slowing-Down Spectrometer," Nuclear Science and Engineering, vol. 175, pp. 124-134, 2013; dx.doi.org/10.13182/NSE12-66
6. N. Thompson, A. Lewis, E. Blain, A. Daskalakis, and Y. Danon, "Neutron Capture Cross Section Measurements Using a Lead Slowing-Down Spectrometer", *Transactions of the American Nuclear Society*, Vol. 111, Anaheim, California, November 9–13, (2014).
7. X-5. Monte Carlo Team, "MCNP-A General Monte Carlo N-Particle Transport Code, Version 5," *LA-UR-03-1987*, Los Alamos National Laboratory, 2003.
8. M. Chadwick et al., "ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data," *Nuclear Data Sheets*, Vol. 112, no. 12, pp. 2887-2996, 2011.