# A NEW HIGH ENERGY RESOLUTION NEUTRON TRANSMISSION DETECTOR SYSTEM AT THE GAERTTNER LINAC LABORATORY

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*A new high energy resolution modular neutron transmission detector was developed at the Gaerttner LINAC Laboratory located at Rensselaer Polytechnic Institute. This work is part of an effort to improve existing neutron induced cross section measurement capabilities at the Laboratory in and above the resolved resonance energy region from 1 keV to 600 keV. The overall design optimization process, module construction and qualification of the detector are presented. High resolution time-of-flight neutron transmission measurements on isotopically enriched metallic samples of molybdenum were performed at the 100-meter flight path. Concurrent measurements with another $^{6}$Li-glass scintillation detector positioned on a separate 31-meter flight path were performed to provide additional data in the 1-5 keV region where a higher neutron flux and better signal-to-background ratio is needed for improved statistical accuracy. Methods were developed to accurately determine important data reduction parameters from these measurements such as the detector resolution function, dead time and a precise characterization of the observed background in each measured sample.*

## I. INTRODUCTION

The Gaerttner Laboratory is home to a 60 MeV electron linear accelerator (LINAC) [1]. The LINAC began its operation in December of 1960 and has been used for both teaching and nuclear research. Its application as a pulsed neutron source for time-of-flight (TOF) measurements has provided a large library of nuclear data and cross section data that continue to be used in reactor calculations today [1]. The development of a new high resolution modular neutron transmission detector is part of an effort to improve cross section measurement capabilities at the LINAC in and above the resolved resonance energy region from 1 keV to 600 keV. Highly enriched isotopic metallic samples of four stable molybdenum isotopes, $^{95}$Mo, $^{96}$Mo, $^{98}$Mo and $^{100}$Mo were obtained to perform high resolution cross section measurements at the LINAC's 100-meter flight path with the new detector utilizing a neutron burst width of 6-15 nsec.

## II. HIGH RESOLUTION MODULAR DETECTOR DESIGN

The new modular neutron transmission detector system employs four identical cube-shaped modules each with a $^{6}$Li-glass scintillator, two out-of-beam photomultiplier tubes and a low-mass light-tight aluminum casing with inner reflective surfaces. The modular design allows operational reliability, relatively easy maintainability and lower overall life-cycle cost than a single all-in-one detector system. It also provides functional versatility. For example, placement of each detector at specific angles around a sample can provide a neutron scattering detector.

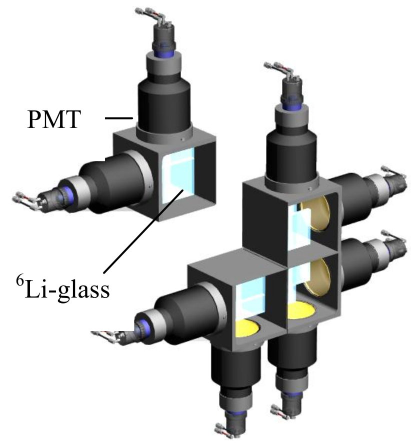


Fig. 1. Detailed Computer-Aided Design (CAD) model of the modular detector system.

$^6$Li-glass has been widely used for neutron detection since its development in the late 1950's because of its high neutron detection efficiency, high light transmission at emission wavelengths, homogeneity, fast luminescence decay times, and large areas that can be fabricated [2,3]. For this detector, 0.5" thick $^6$Li-glass was chosen. The light production in the glass is based on the exothermic $^6$Li (n, α) reaction with a positive Q-value of 4.76 MeV [3] and a *1/v* cross section with a thermal value of 940 ± 4 barns [4]. This makes it suitable for neutron detection from the thermal region all the way through the keV region where a maxima in the cross section occurs near the 244 keV $^6$Li resonance. There is also an increase in efficiency in this faster region due to neutron multiple scattering in the glass. MCNP5 [5] was used to calculate detector efficiency and to estimate the resolution effects of fluctuations in the flight path length of neutrons due to multiple scattering. Light collection optimization experiments were conducted to compare the performance of an unpolished square of $^6$Li-glass (unpolished on the front and back) to a fully polished glass. The latter configuration provided a slight improvement to the pulse height resolution and was subsequently used in each detector module. The housing of each module was made from various thicknesses and alloys of aluminum. The front and back sides that are directly exposed to the neutron beam during measurements were made of 0.005" thick aluminum foil. The inner sides were made of 1/16" thick bendable aluminum sheet (alloy 1100). The outer casing was made of 0.5" thick aluminum (alloy 6061). To optimize light collection in each detector module, experiments were conducted to compare the pulse height resolution enhancement of different specular (mirror-like) and diffuse (rough surface) light reflectors. The 3M Vikuiti™ Specular Reflector (ESR), a thin non-metallic optical enhancement film [6], provided the best light collection (better energy resolution and highest gain). The ESR film was used to coat the inner aluminum faces of each detector module. The other reflectors tested included $TiO_2$, Teflon, white paint and shiny/dull/crumpled aluminum.

## III. DETECTOR ELECTRONICS

Fast electronics were employed to take full advantage of the short neutron burst width provided by the LINAC (6-15 ns) and the fast $^6$Li-glass scintillator response time. For light collection two 5" diameter out-of-beam PHOTONIS XP4512/B [7] photomultiplier tubes (PMTs) were used in each detector module. Out-of-beam tubes were used in order to eliminate direct neutron backscatter into the scintillator glass. Backscatter from the PMT borosilicate glass face (comprised of mostly $SiO_2$) can lead to an overall degradation in the detector energy resolution [8]. As illustrated in Figure 2, the two PMT signals are summed and subsequently fed into an ORTEC 579 Fast-Filter Amplifier that boosts the signal-to-noise ratio. This amplifier performed better than several iterations of custom electronics tested. The amplified signal is then fed to an ORTEC 935 Constant Fraction Discriminator (CFD) that eliminates the majority of the high and low-level noise or gamma-ray background signals and provides constant fraction timing on the fast input signals. It gates the system based on pulse amplitude while maintaining adequate time resolution. After being fed into the CFD, the signals from all four modules are then summed in an ORTEC CO4020 logic unit. The summed output of all four modules is converted to an optical signal for transport to a data acquisition computer using a LuxLink DX7201 Fiber Optic TTL Transmission System. The data acquisition computer houses a FAST ComTec P7889 Time-of-Flight Multiscaler Board with 100 picosecond time resolution [9]. Coincidence testing of two detector modules demonstrated excellent system time resolution of ~5 ns.

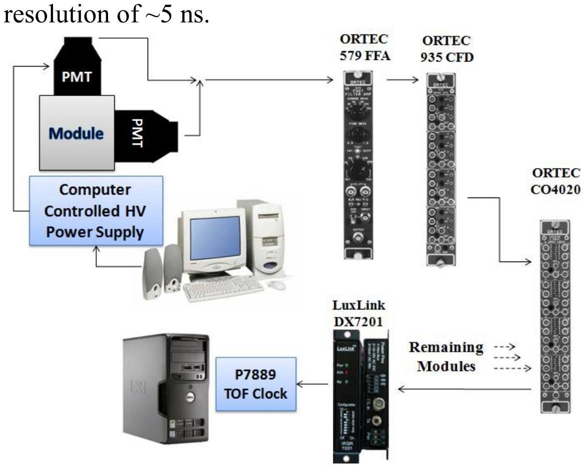


Fig. 2. Schematic of the high resolution detector system electronics.

## IV. DETECTOR COUNT RATE

Initial tests showed that the new high resolution transmission detector at a 100-meter flight path suffered from a low count rate in the 1- 100 keV energy region and saw a large increase in the several hundred keV region. This is both due to the fast nature of neutron evaporation energy spectrum originating from the Pacman [10] photoneutron target, target moderation, loss of neutrons due to the large beam divergence at such a long flight path and finally the intrinsic neutron detection efficiency of $^6$Li-glass. A higher count rate was needed to be achieved in order to obtain adequate counting statistics for high accuracy cross section measurements in the lower keV region where the newer important (resolvable) resonance structure is found. To achieve this, small pieces of $^6$Li-glass were purchased and glued to the sides of the original square piece, effectively doubling the detection area and improving the count rate by a factor of approximately two. Concurrent measurements with another $^6$Li-glass scintillation detector positioned at a separate 31-meter flight path were also performed to provide additional data in the 1-5 keV region where a higher neutron flux and better signal-to-background ratio is needed.

## V. TRANSMISSION MEASUREMENTS

Transmission is one of the simpler cross section measurements both from an experimental standpoint and data reduction standpoint. The measurement is performed by placing a material in a collimated neutron beam and measuring the number of neutrons passing through the material with a neutron detector (and measuring the open beam count rate with no material in the beam) [11].

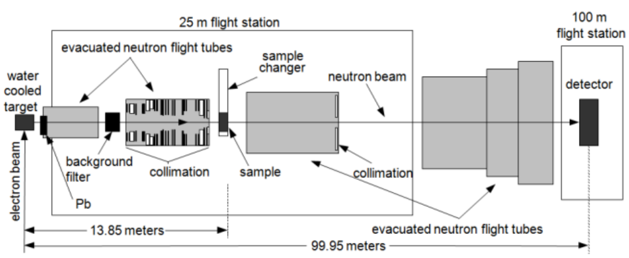


Fig. 3. Transmission measurement experimental setup at the RPI Gaerttner LINAC [9].

The transmission of neutrons through the material is denoted as $T_i$ and is defined as the ratio of background corrected count rate with the sample material in the beam to the background corrected rate in the open beam at TOF channel $i$ [12]:

$$T_i = \frac{\left[C_i^{Sample} - K^{Sample}B_i - B^{Sample}\right]}{\left[C_i^{Open} - K^{Open}B_i - B^{Open}\right]} \quad (1)$$

$C^{Sample/Open}$ = dead-time corrected and normalized count rates of the sample and open measurements.
$B_i$ = nominal time-dependent background count rate
$B^{Sample/Open}$ = steady-state background counting rates for the sample and open measurements.
$K^{Sample/Open}$ = normalization factors for the sample and open measurements

A relationship between transmission and total cross section is given:

$$T = \exp[-N * \sigma_t(E) * x] \qquad (2)$$

$T$ = probability of a neutron of energy $E$ to pass through the sample without interaction.
x = thickness of sample
N = number density of sample
$\sigma_t$ = total microscopic neutron cross section

## VI. BACKGROUND DETERMINATION

A large time-dependent γ-ray background component was observed in the isotopic Mo measurements over the keV energy region. MCNP5 simulations determined that the γ -ray background component was mainly a result of neutron capture in the hydrogen of the target water moderator. A simple method was developed to accurately determine the sample/open background. Two thicknesses of polyethylene were used to extrapolate the gamma-background to zero-thickness polyethylene. Black notch filters were used to determine the neutron background.

## VII. RESULTS

Preliminary transmission data from several measurements were compared with existing experimental and evaluated data of $^{95}$Mo. SAMMY [12] was used to generate Doppler and resolution broadened transmission of the evaluated data. It can be observed in Figure 4 that the new data is in good agreement with the latest evaluation of ENDF/B-VII.0. It can also be observed in Figure 5 that there are many new resonances in the unresolved region above 2 keV where ENDF/B-VII.0 represents the total cross section as a smooth unresolved average cross section. The characterization of these new resonances up to 50 keV will most likely have the largest contribution to cross section libraries.

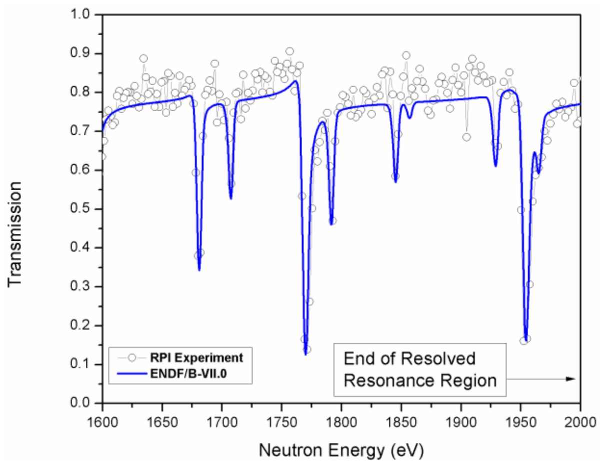


Fig. 4. A Comparison of a snippet of $^{95}$Mo evaluated data in the resolved region to one week of experimental data using the new detector.

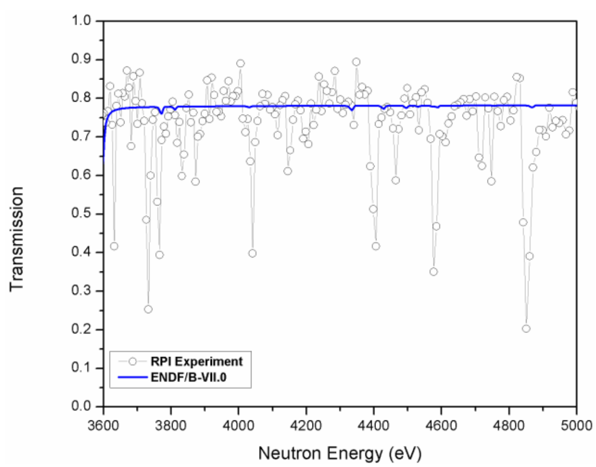


Fig. 5. A Comparison of a snippet of $^{95}$Mo evaluated data in the unresolved region to one week of experimental data using the new high resolution detector.

## VIII. CONCLUSIONS

A new high resolution time-of-flight neutron transmission detector was developed. Preliminary transmission measurements were performed at the 100-meter flight path. An open-beam and sample-in background determination method was developed to correct for both neutron and gamma-ray background. The experimental neutron energy resolution function needs to be calculated using MCNP and verified through an experimental benchmark. Further measurements of isotopic Mo samples need to be performed in order to obtain adequate counting statistics to obtain high accuracy cross section data.

The final data will be fit to extract resonance parameters (energy, incident neutron angular momentum, total width, neutron width, and radiative width) using SAMMY in order to extend the resolved resonance region in Mo isotopes.

## ACKNOWLEDGEMENTS

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