# Using Simulations To Determine The Energy Resolution Function Of Neutron Time-Of-Flight Experiments

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## INTRODUCTION

High resolution nuclear data are important in their application in neutron transport calculations and their contribution to the understanding of nuclear models and interaction theory. At the Rensselaer Gaerttner Linear Accelerator (LINAC) Center, neutron cross section measurement capabilities exist that provide neutron cross section data in the energy range between 0.005 eV and 20 MeV. Measurements can be performed using different detectors stationed at various distances from a neutron-producing target. For total cross section measurements in the resolved resonance region, it is important to accurately determine the experimental resolution in order to accurately characterize observed resonances and their associated parameters. Monte Carlo simulations involving a detailed model of an experiment can aid in this endeavor because they can provide an accurate representation of relevant parameters including the overall neutron time distribution.

## METHODOLOGY

The resolution function of time-of-flight experiments is defined as the effect of the experimental apparatus on the time resolution and is typically neutron energy-dependent. Its time-dependent functional form was quantified using Monte Carlo simulations of a photoneutron target and detector configuration used in keV-energy transmission measurement. The resolution-broadened transmission experimental data, $T_R(E)$, is given in Equation 1,

$$T_{\mathrm{R}}(E) = \int T(E')\, R(E,E') d\mathrm{E}' \qquad (1)$$

Where $R(E,E')$ is the resolution function and $T(E')$ is the transmission.

### Detector Monte Carlo Simulations

In the upper resolved resonance region (typically keVs), high resolution total cross section measurements have been performed with the Mid-Energy $^6$Li-glass Neutron Detector Array (MELINDA) [1]. The detector employs four identical cube-shaped modules consisting of a 0.5-inch thick $^6$Li-glass scintillator, two 5” diameter out-of-neutron-beam photomultiplier tubes (PMTs), and a low-mass, light-tight Al casing with inner reflective surfaces as shown in Figure 1.

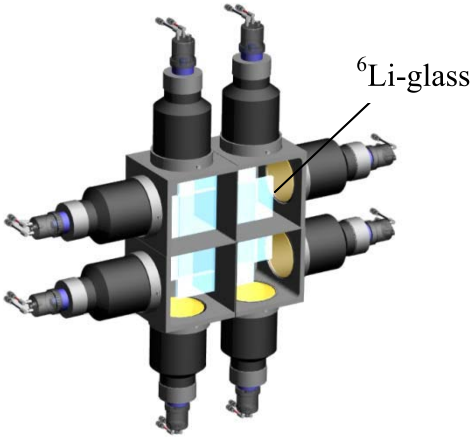

Fig 1. Mid-Energy (keV region) $^6$Li-glass Neutron Detector Array (MELINDA) [1].

Simulations were performed using MCNP5 [2]. The MCNP model of the detector is shown in Figure 2 and included the following components: $^6$Li-glass, aluminum casing, air inside the detector, and borosilicate glass from the PMT face. In each simulation, a uniform source of monoenergetic neutrons (10, 20, 30 and 50 keV) was incident on the front face of the detector. Using a flux tally averaged over a volume, the time distribution of the (n,α) reactions in the $^6$Li-glass was obtained. For each energy, three different simulations were performed in order to isolate the effects of the components of the detector on the resolution function. The simulations performed were: $^6$Li-glass only; the in-beam components ($^6$Li-glass, center Aluminum crosspiece); and the full detector with the Aluminum housing and PMT glass.

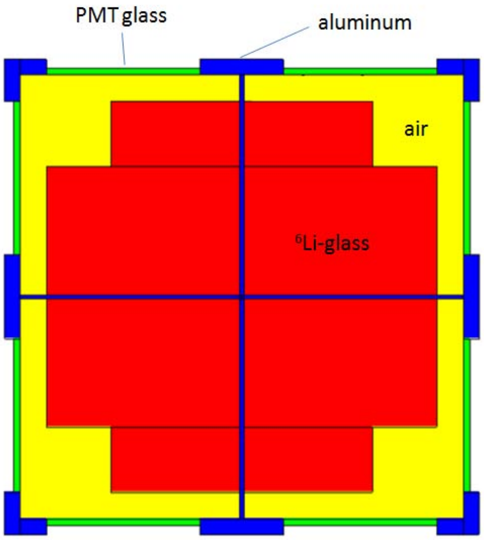

Fig 2. Cross sectional view of MELINDA detector in MCNP

The results of simulations with only the $^6$Li-glass are shown in Figure 3. It can be seen that the distribution of reactions over time was initially characterized by a rectangular distribution which corresponded to the travel of neutrons in the glass before they were absorbed. This was followed by a significant decrease and then an exponential decay. This "tail" was due to multiple scattering events before the neutrons were absorbed.

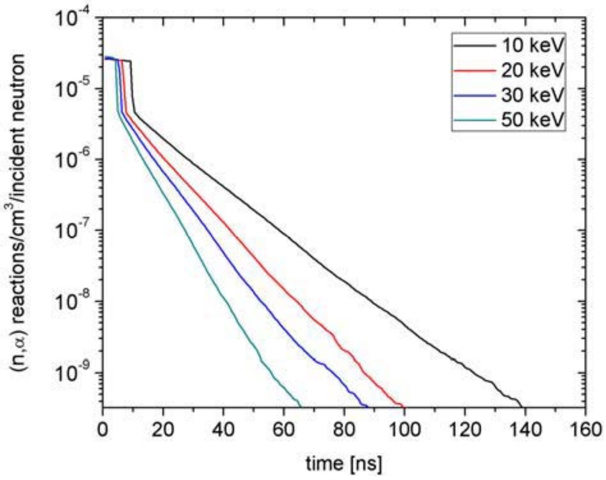

Fig 3. Contribution of the $^6$Li-glass to the resolution function for different energies.

When the center portion of the detector (thin aluminum cross-pieces and $^6$Li-glass) was included in the simulations, the tail increased significantly. The flux decayed at a slower rate when the aluminum is included. When the full aluminum casing and borosilicate glass was included in the simulation, the tail was even larger and seemed to be no longer characterized by a single exponential. These results for 20 keV incident neutrons are shown in Figure 4.

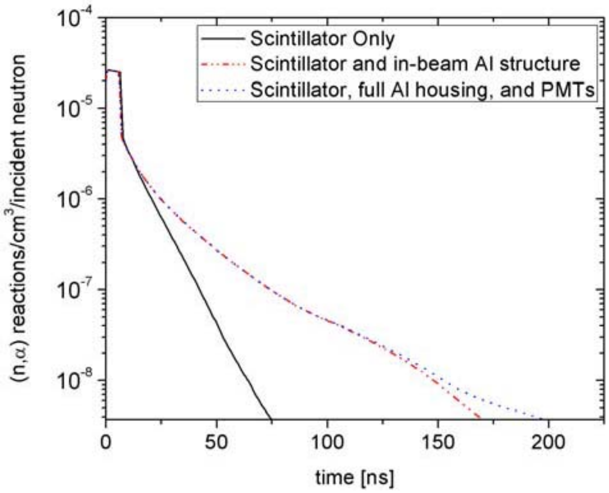

Fig 4. Contributions of different parts of the detector to the resolution function tail at 20 keV.

## Target Monte Carlo Simulations

The MELINDA detector was stationed 100 meters away from a water-moderated tantalum photoneutron target [3] typically used in keV-energy measurements. A detailed CAD model of the target is shown in Figure 5.

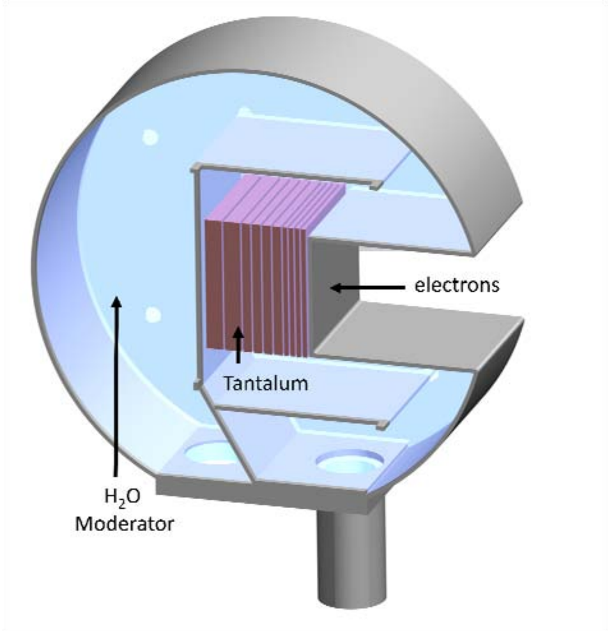

Fig 5. CAD model of the photoneutron target (sectional view). The aluminum housing and internal baffle system was not included in the simulation.

The MCNP model of the target [3] incorporated the tantalum plates and water moderator. In the simulation, a uniformly distributed parallel beam source 3 cm in diameter of 55 MeV electrons was placed 3.4 mm away from the surface of the tantalum plates. The electrons interacted with the tantalum creating bremsstrahlung radiation which produced neutrons through the (γ,n) reaction. Neutron energy was determined from the time-of-flight (tof) to a surface current tally. The tally was placed 2 mm from the side surface of the target on an axis perpendicular to the electron source trajectory. Energy bins were included that were 2 keV wide, centered at 10, 20, 50, and 100 keV. The results are shown in Figure 6 and have a functional form that can be represented by a chi-square distribution [4]. It can also be approximated as a Gaussian with an exponential component representing the distribution asymmetry as contributed from the target moderator [4]. The full width half maximum (FWHM) and resolution (*Δt/tof*, defined as the FWHM divided by the location of the peak centroid) for each distribution is summarized in Table I.

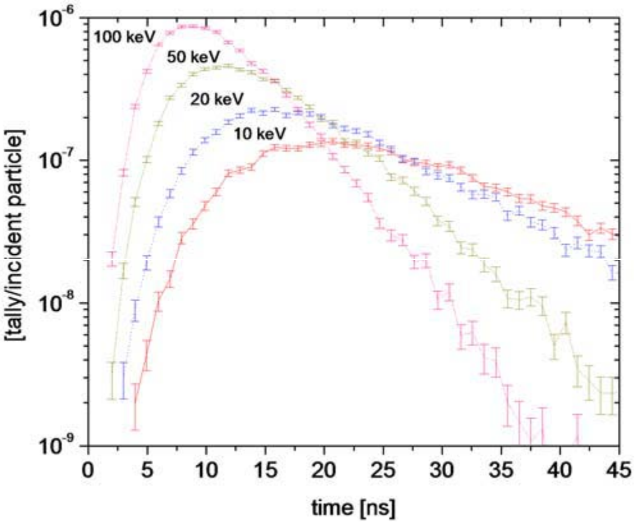

Fig 6. Resolution function shape from moderator and target.

Table I. Approximate widths of the target neutron emission distribution

| Energy [keV] | FWHM [ns] | Δt/tof [%] |
|---|---|---|
| **10** | 21 | 0.29 |
| **20** | 18 | 0.35 |
| **50** | 12 | 0.37 |
| **100** | 9.5 | 0.42 |

**Experimental Data**

The results of the Monte Carlo simulations were implemented in the multilevel R-matrix Bayesian code SAMMY [4] in order to obtain accurate fits to resonances from high-resolution experimental data in the keV-region. The resolution was implemented as the ORELA target resolution option of SAMMY. The target resolution function was fitted to a $\chi^2$ distribution with four degrees of freedom $m$=4 (SAMMY default value) to obtain the mean free path $\Lambda$ for each simulated neutron energy. The $\Lambda$ values were then represented as a logarithmic polynomial in energy. The detector response function was fitted to the SAMMY Li-Glass resolution function that is part of the ORELA resolution function. The detector representation is SAMMY has 3 variables $d$, the time the neutron travel in the detector (a function of the detector thickness), $g$ the amount of tail contribution, and $f$ the exponential decay constant of the tail. It was found that g was energy independent but for $d$ and $f$ the SAMMY code was modified to include the observed energy dependence. A series of new total cross section measurements for the stable isotopes of molybdenum were performed using the detector and target configuration described [5] [6] [7]. A snippet of experimental $^{100}$Mo transmission data with SAMMY fits to observed resonances is shown in Figure 7. The fits were obtained using the calculated energy-dependent resolution function and are in good agreement with the experimental data. ENDF/B-VII.1 does not have resolved resonance representation for the cross section and presents it as a smooth average in this region.

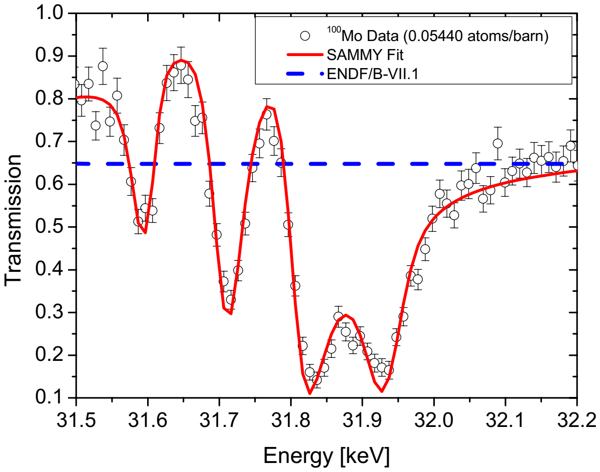

Fig 7. SAMMY fits to resonances in $^{100}$Mo.

## CONCLUSIONS

Monte Carlo simulations quantified the contribution of the MELINDA detector and the photoneutron target to the energy-dependent resolution function. The results were implemented in the R-matrix code SAMMY and provided good fits to experimental isotopic molybdenum data in the keV-region. This methodology can be applied to other detector systems and photoneutron-producing target configurations in order to accurately obtain the experimental resolution of new cross section measurements.

## ACKNOWLEDGMENTS

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