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BENCHMARK EXPERIMENT OF NEUTRON RESONANCE SCATTERING MODELS IN MONTE CARLO CODES

Y. Danon*, E. Liu, D.P. Barry
Department of Mechanical Aerospace and Nuclear Engineering, Rensselaer Polytechnic Institute
110 8th St. Troy, NY 12180, USA
danony@rpi.edu, liue@rpi.edu, barryd3@rpi.edu

T.I. Ro
Department of Physics, Dong-A University
840 Hadan-dong, Saha-gu, Busan 604-714, Korea
tiro@dau.ac.kr

R. Dagan
Institut für Reaktorsicherheit (IRS), Forschungszentrum Karlsruhe Gmbh
Postfach 3640,76021 Karlsruhe
ron.dagan@irs.fzk.de

ABSTRACT

Experimental measurements of elastic neutron scattering from ^{238}U resonances were used to benchmark neutron scattering models in Monte Carlo transport codes. It was found that the implementation of the free gas model to determine the scattered neutron energy and angle in popular Monte Carlo codes is inaccurate. Differences up to a factor of two in the energy dependent angular distribution were observed. The experimental data presented here provides validation of an improved free gas model that was developed by one of the authors (Dagan). This improved free gas model allows accurate simulation of the experimental results

Key Words: neutron scattering, resonance, Monte Carlo, neutron transport, experiment

1. INTRODUCTION

Modern Monte Carlo codes, such as MCNP [1], use a combination of sophisticated physics models and accurate nuclear data to model neutron transport in various materials and geometries. This paper focuses on improving the physical model used for neutron scattering in the resonance region.

In many cases, the physical model for neutron scattering must take into account the motion of the target nuclei [2]. In the thermal energy region (< 0.1 eV) the motion of the target nuclei can cause significant up-scattering, resulting in an increased neutron interaction probability. For several materials at thermal energies, this up-scatting phenomena is described by the well known $S(\alpha,\beta)$ scattering kernel [3]. If the $S(\alpha,\beta)$ scattering kernel is not available, the free gas model (FGM) is usually employed in order to determine the kinematics of the scattered neutron. However, in the resonance region most Monte Carlo transport codes neglect the motion of the

* corresponding author

target nuclei and use a down-scattering kinematics model; neither the $S(\alpha,\beta)$ formulism nor the FGM is used.

In this study we used the MCNP5 [1] code which includes the FGM treatment up to 400kT (~10 eV for T=300°K) where k is the Boltzmann constant and T is the material temperature. With a minor modification, the MCNP code was altered to use the FGM above 10 eV, thereby including the motion of the target nuclei in the resonance region. Although this is an improvement over the down-scattering model, this modified version of MCNP does not give accurate results in the resonance region since the FGM assumes a constant cross section [1]. To overcome this inaccuracy, an improved free gas model (IFGM) was developed [4] that correctly uses a varying cross section in the resonance region. The IFGM was implemented in NJOY [5] in order to create a resonance dependent probability tables ($S(\alpha,\beta)$) for ^{238}U.

This paper presents experimental verification of the IFGM and the resonance region $S(\alpha,\beta)$. Several ^{238}U scattering measurements were performed and the experimental data is compared with the modified MCNP calculation using the FGM and IFGM, respectively. This comparison shows the MCNP using the IFGM agrees with the measured data, while MCNP and the modified MCNP using the FGM does not. Calculations performed with the GEANT [6] code showed similar results to the unmodified MCNP using the down-scattering model (i.e., no target nuclei motion).

2. EXPERIMENTAL SETUP

The RPI LINAC facility uses a high energy and pulsed electron beam to produce neutrons through photonuclear reactions. The electron beam impinges upon a water-cooled tantalum target where the electrons are slowed down and produce bremsstrahlung radiation. This bremsstrahlung radiation then interacts with the tantalum and generates photoneutrons. The resulting pulsed neutron source is moderated with a 2.54-cm-thick piece of polyethylene.

The pulsed neutron source was used to perform measurements of the scattering effect from the strong 36.68 eV resonance in ^{238}U. A depleted U sample was placed about 16 cm away from the pulsed neutron source and the scattered neutrons from this sample drift down an evacuated flight tube to a detector located ~25.6 m away from the target.

Two different thicknesses of depleted uranium samples were use in the experiments. The characteristics of these samples are found in Table I. Several experiments were performed for each sample, for both forward and backward scattering angles.

Table I. The depleted U sample characteristics

Sample ID	**Width (cm)**	**Height (cm)**	**Thickness (cm)**	**Weight (g)**
Thin	7.62 ± 0.05	7.62 ± 0.05	0.1536	169 ± 0.5
Thick	7.62 ± 0.05	7.62 ± 0.05	0.329	362 ± 0.5

Experiments were done for a forward scattering angle of 38.9 deg. and a back scattering angle of 143.8 deg. The geometry of the back scattering experiment is show in Figure 1, the sample was placed close to the LINAC generated neutron source and the neutron detector was placed about 25.6 m away from the sample. The detector used was a 7.62-cm-dia. by 1.27-cm-thick piece of Li Glass. This detector has an efficiency which varies as 1/*v* (where *v* is the neutron velocity) in this energy range. The experimental geometry enables a measurement of the scattered neutron spectrum which was expected to differ between the FGM and IFGM models. The product of the neutron flux shape $\phi(E)$ times detector efficiency $\eta(E)$ was measured by using a lead sample for which the elastically scattered neutrons have an energy very close to the incident energy. In the energy range from 10 eV to 100 eV the product behaves like $\phi(E)\eta(E) = CE^{P}$ where C is a normalization constant and p = -1.2.

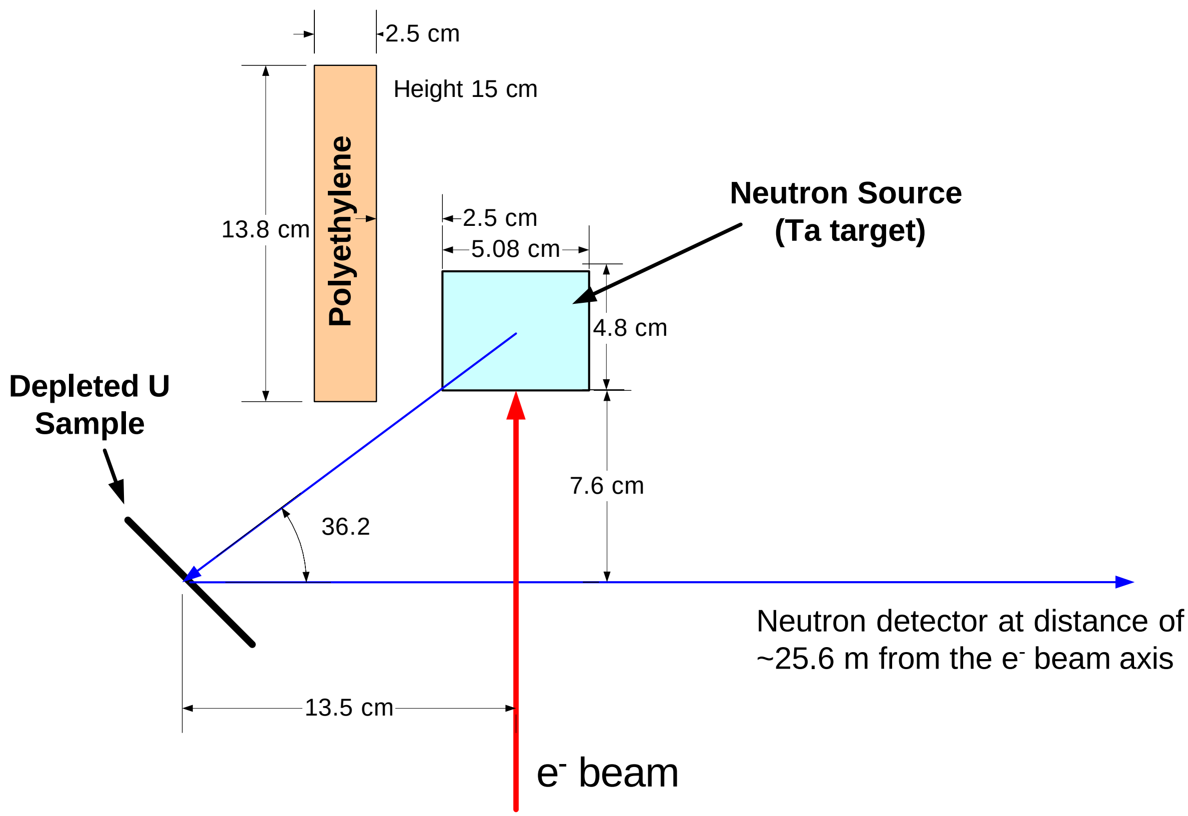

Figure 1 – The geometry of the backscattering experiment

3. RESULTS

Calculations were done with the MCNP5 code using the measured product of the flux shape and the detector efficiency as the energy dependent neutron source. A simplified target geometry was used that modeled the neutron source as a point source at the center of the Ta target. The polyethylene moderator was included in the geometry. It was found that simulating the full target geometry starting with electrons is very time consuming and produces an almost identical detector response.

Comparing the measured data and MCNP calculations for the forward angle shows no discernable differences; however, the backscattering shows large differences as shown in Figure 2. The calculations were normalized to the experimental data at the peak near 37.5 eV. The dip in the measured spectrum occurs at the resonance energy (36.68 eV) and is due to attenuation of the scattered neutrons as they leave the sample and travel towards the detector. These results show that the current version of MCNP5 (and GEANT) underestimatethe measured back angle scattering intensity by about a factor of two. Similar results were obtained for the thicker depleted U sample.

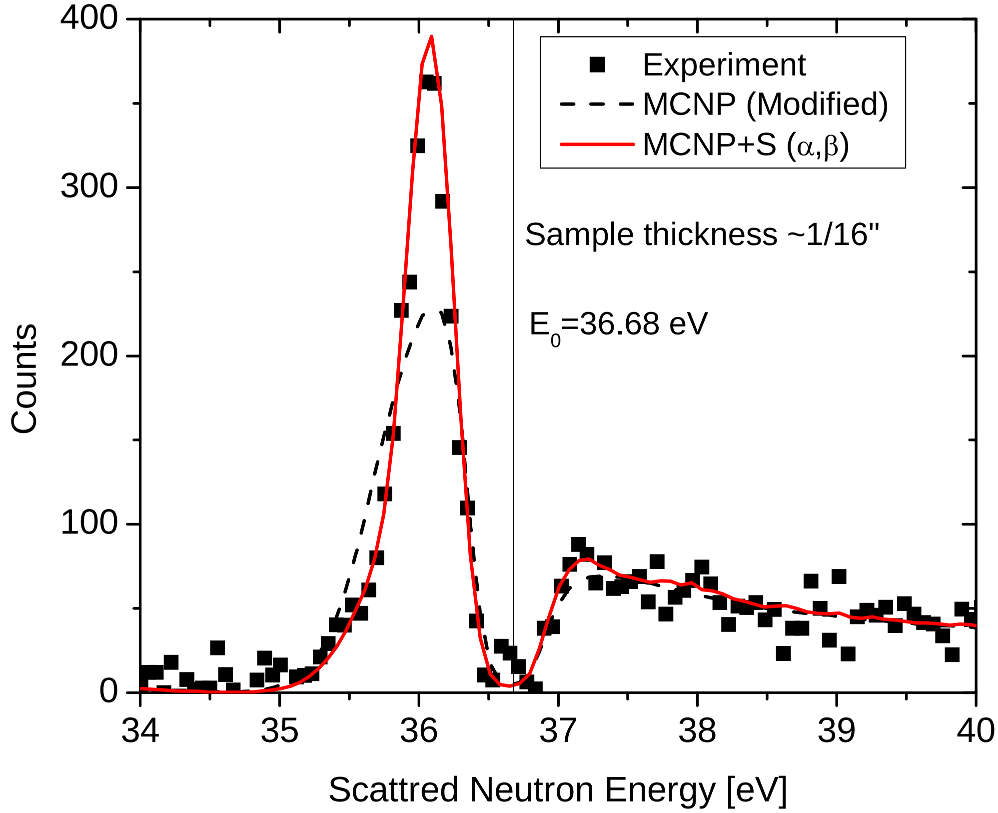

Figure 2 – Experimental and calculated results for neutron back scattering from a depleted U sample (thick sample in Table I). The dashed line was calculated with a version of MCNP where the restriction on FGM above 400 *kT* was removed

4. CONCLUSIONS

This paper shows experimental results that allow benchmarking of resonance scattering models. It is shown that the current neutron scattering model in MCNP5 and GEANT is not accurate in the resonance region. Differences of about a factor of two in the intensity (and shape) of the scattered neutron spectrum are evident for back scattering. Since the total scattering must be preserved in both the calculation and experiment, and because the forward scattering was found to be identical, it is expected that other angles will also show differences. Thus, there is a need for more experiments to validate the IFGM model. This experiment also validates the free gas model at room temperature, and within the accuracy of this experiment, the IFGM model provides an accurate description of the scattered neutron spectrum and there is no evidence of solid state effects.

Using MCNP with its scattering model can introduce error in benchmark calculations of critical systems, specifically in systems where ^{238}U is used as a reflector.

This work also provides an opportunity to develop a new resonance scattering model that will not require the generation of $S(\alpha,\beta)$. It is also important to note that the inaccuracies of the model currently implemented in MCNP will also be seen in other materials.

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REFERENCES

1. MCNP, A General Monte Carlo Code for Neutron and Photon Transport, Version 5, LA-UR-05-8617 (2005).
2. Ouisloumen M. and Sanchez R., “A Model for Neutron Scattering of Heavy Isotopes that accounts for Thermal Agitation Effects”, *Nucl. Sci. Eng*. **107**, 189-200, (1991)
3. G. Bell, S. Glasstone, Nuclear Reactor Theory, Robert E. Krieger Publishing Company, (1970).
4. Rothenstein W. and Dagan R. “Ideal Gas Scattering Kernel for Energy Dependent Cross – Sections”, *Annals of Nuclear Energy*, **25**, p 209, (1998).
5. MacFarlane R. E., NJOY91.38. Code report PSR-171, LANL, Los Alamos NM, (1992).
6. S. Agostinelli et al., GEANT 4 a simulation toolkit, *Nuc. Inst. Meth A*, **506**, 3, pp. 250-303, (2003).