INL/CON-12-25977
PREPRINT

Validation of MCNPX-PoliMi Fission Models

IEEE Nuclear Science Symposium

Sara A. Pozzi
Shaun D. Clarke
William J. Walsh
Eric C. Miller
Jennifer L. Dolan
Marek Flaska
Brian M. Wieger
Andreas Enqvist
Natalia Puppato
Enrico Padovani
John K. Mattingly
David L. Chichester
Paolo Peerani

October 2012

The INL is a
U.S. Department of Energy
National Laboratory
operated by
Battelle Energy Alliance

Idaho National Laboratory

INL-CON-12-25977

Validation of MCNPX-PoliMi Fission Models

Sara A. Pozzi, *Member, IEEE,* Shaun D. Clarke, William J. Walsh, Eric C. Miller, Jennifer L. Dolan, Marek Flaska, Brian M. Wieger, Andreas Enqvist, Natalia Puppato, Enrico Padovani, John K. Mattingly, David L. Chichester, and Paolo Peerani

***Abstract*– We present new results on the measurement of correlated, outgoing neutrons from spontaneous fission events in a Cf-252 source. 16 EJ-309 liquid scintillation detectors are used to measure neutron-neutron correlations for various detector angles. Anisotropy in neutron emission is observed. The results are compared to MCNPX-PoliMi simulations and good agreement is observed.**

I. Introduction

In the past few years, efforts to develop new measurement systems to support nuclear nonproliferation and homeland security have increased substantially. Monte Carlo radiation transport is one of the simulation methods of choice for the analysis of data from existing systems and for the design of new measurement systems; it allows for accurate description of geometries, detailed modeling of particle-nucleus interactions, and event-by-event detection analysis.

This work describes the validation of the new Monte Carlo code MCNPX-PoliMi fission models, with particular emphasis on the simulation of spontaneous fission of Cf-252. Experimental data is compared to model data from the MCNPX-PoliMi ver. 2.0. This code was released through RSICC in 2012 as a patch to MCNPX ver. 2.7.0 and as an executable [1].

Code validation is performed using an array of 16 EJ-309 liquid scintillation detectors and performing time-correlated neutron measurements with a Cf-252 spontaneous fission source.

Manuscript received November 11, 2012. This work was supported in part by the U.S. Department of Energy under Grant No. BS123456.

S. A. Pozzi, S. D. Clarke, W. J. Walsh, E. C. Miller, J. L. Dolan, M. Flaska, B. M. Wieger, and A. Enqvist are with the Department of Nuclear Engineering and Radiological Sciences of the University of Michigan, Ann Arbor, MI 48109 USA (tel: 734-615-4970, e-mail: pozzisa@umich.edu).

N. Puppato on temporary assignment at the Department of Nuclear Engineering and Radiological Sciences of the University of Michigan, Ann Arbor, MI 48109 USA. Her student affiliation is Department of Energy, Politecnico di Milano, Italy.

E. Padovani is with the Department of Energy, Politecnico di Milano, Italy (e-mail:enrico.padovani@polimi.it).

J. Mattingly is with the Department of Nuclear Engineering, North Carolina State University, NC 27695, USA (mattingly@ncsu.edu)

D. Chichester is with the Idaho National Laboratory, Idaho Falls, ID 83415, USA

P. Peerani is with the European Commission, Joint Research Centre, ITU – Ispra (VA), Italy

II. MCNPX-PoliMi Source Options

MCNPX-PoliMi allows the user to simulate various spontaneous fission sources by changing the IPOL(1) data card in the input deck. The spontaneous fission sources that can be modeled include Cf-252, Pu-240, Pu-242, etc. For specific information on the usage of these sources please see ref. [1-2].

A. Simulation of Correlated Neutron and Gamma Rays

In the current version of the MCNPX-PoliMi code, neutrons and gamma rays from each fission event are simulated independently of each other. Fig. 1 shows the number of neutrons and gamma rays emitted in the spontaneous fission simulation of the isotope Cf-252. The figure displays the probability of emission of *n* neutrons or gamma rays.

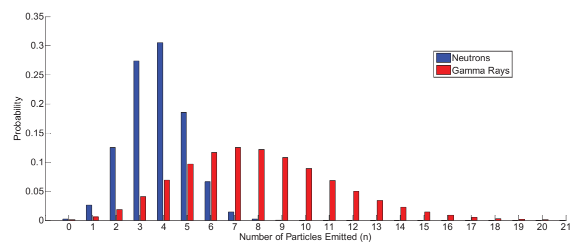

Fig. 1. Probability of emission of *n* neutrons or gamma rays per spontaneous fission of Cf-252.

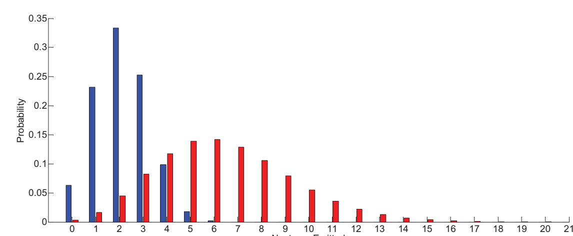

Fig. 2. Probability of emission of *n* neutrons or gamma rays per spontaneous fission of Pu-240.

Neutron energy distributions follow a well-known Watt spectrum shape. In the new spontaneous fission models, the energy spectrum of emitted neutrons is dependent on the multiplicity of the neutrons. Details on these models can be found in Ref. [3-5]. The present work is focused on neutron correlations.

B. Circular Geometry

A simple geometry, consisting of 12 spherical liquid scintillation detectors, was designed to verify the various new fission models in MCNPX-PoliMi. A point spontaneous fission source was placed at the center of the detector assembly, in which 12 idealized, spherical detectors of radius

5 cm were placed at a distance of 40 cm from the source. Fig. 3 shows the geometry for the simulation study.

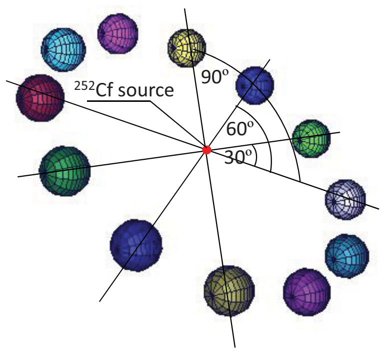

Fig. 3. MCNPX-PoliMi geometry for simulation study of detected neutron pairs for various angles between detectors.

Neutron time-dependent, cross-correlation functions were simulated for all pairs in the assembly. Fig. 4 shows the total (neutron, neutron) pairs for all pairs of detectors separated by the same angle. As expected, the isotropic treatment yields a near-constant number of detected pairs, whereas the anisotropic treatment results in greater correlated counts at 30 degrees and 180 degrees and fewer correlated counts at 90 and 120 degrees when compared to the isotropic treatment. Of all pairs, the 30 degree pairs are the ones that are most affected by cross-talk. In cross-talk events, the same neutron gives a count in two or more detectors. This effect is more prominent in detectors that are close to each other, i.e. those separated by 30 degrees. In these simulations, the detection threshold is set to 70 keVee.

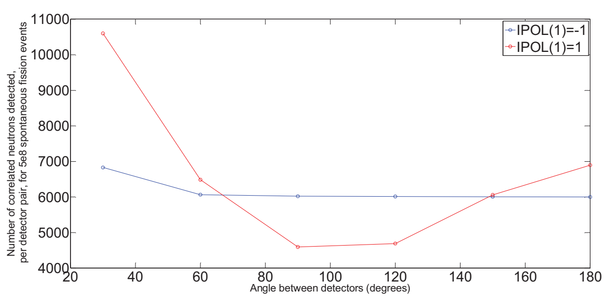

Fig. 4. Number of correlated neutron detections per detector pair as a function of angle between detectors for two different fission models: anisotropic (IPOL(1)=1) and isotropic (IPOL(1)=-1). Statistical error is smaller than the symbol used.

III. Experiments

A set of experiments were performed using 16 EJ-309 liquid scintillation detectors, having diameter 3 inches and height 2 inches. Each detector was calibrated (gain-matched) by analyzing the Compton continuum measured with a Cs-137 source. This approach ensures equal response of the detectors. The detection threshold was set to 70 keVee.

A. Detector Setup and Calibration

Fig. 5 shows a photograph of the experimental configuration, showing the EJ-309 liquid scintillation detectors arranged in two rings. Each ring consisted of eight detectors, directed towards the center of the assembly, where a Cf-252 source with a spontaneous fission rate of approximately 8300 fissions/sec was placed. The distance between the Cf-252 source and the center of each detector face was set to approximately 22.5 ± 2 cm. This configuration allows for various detector pairings, which can be grouped into various angular bins, having bin-width of 10 degrees. In this setup, 12 out of 18 angular bins have detector data, and only 2 out of 12 of these have only one pair of detectors contributing to the data.

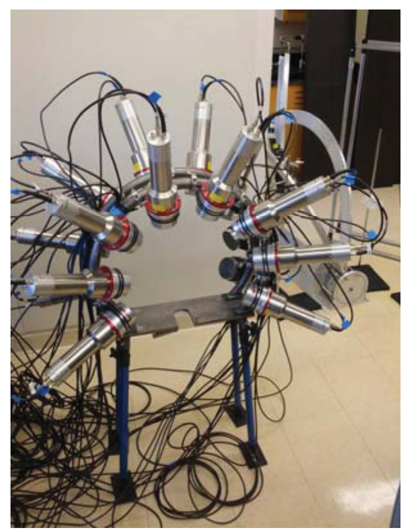

Fig. 5. Photograph of experimental configuration for Cf-252 experiments at the University of Michigan.

Fig. 6 shows the measured and simulated correlated neutron detector counts as a function of angle of correlation (detector angle) for a 960-minute measurement. Variations in the source-to-detector distance generate differences in the solid angle for specific pairs of detectors, which produce some oscillatory behavior in the data. A general trend is apparent in the data, with the largest number of correlations recorded in the lower and upper angles of correlation, and lowest number recorded around 90 degrees. The number of measured correlated neutrons in the 30 degree bin is approximately 70 % higher than in the 90 degree bin. The effect is also present, though not as pronounced, in the 170 degree bin.

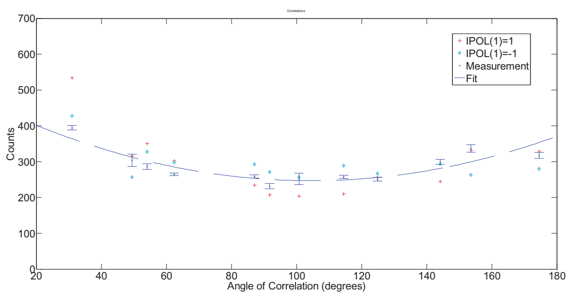

Fig. 6. Measured correlated neutrons as a function of detector angle for Cf-252 spontaneous fission. MCNPX-PoliMi results for various fission models are also shown, corresponding to IPOL(1)=1 and isotropic emission, IPOL(1)=-1.

Comparison of the measured data to simulated data shows good agreement. The trends are well-reproduced in the simulation. In this comparison, the advantage of the use of the anisotropic treatment over the isotropic treatment is clear in the angular bins 150 to 180 degrees. However, the use of the anisotropic treatment over-predicts the number of counts in the 30 degree bin.

IV. Conclusions

New results are presented on the angular distribution of neutron emission from spontaneous fission of Cf-252. Measured data shows anisotropy of emission of neutrons from spontaneous fission events. The measured data are compared to MCNPX-PoliMi simulations using two fission models: IPOL(1)=1 (anisotropic) and IPOL(1)=-1 (isotropic). The results show good agreement between experimental data and model prediction. Future experiments will be needed to evaluate the advantage of the anisotropic model over the isotropic model and to understand the over-prediction in the 30 degree bin.

Acknowledgment

This research was funded in part by the National Science Foundation and the Domestic Nuclear Detection Office of the Department of Homeland Security through the Academic Research Initiative Award # CMMI 0938909, the Department of Energy, Nuclear Energy University Programs Award DE-AC07-05ID14517-00120867, and the Department of Energy, National Nuclear Security Administration, Award number: DE-NA0001025.

References

[1] E. Padovani, S. A. Pozzi, S. D. Clarke, and E. C. Miller "MCNPX-PoliMi User's Manual," C00791 MNYCP, Radiation Safety Information Computational Center, Oak Ridge National Laboratory, 2012.

[2] S. A. Pozzi, S. D. Clarke, W. Walsh, E. C. Miller, J. L. Dolan, M. Flaska, B. M. Wieger, A. Enqvist, E. Padovani, J. K. Mattingly, D. Chichester, and P. Peerani, "MCNPX-PoliMi for Nuclear Nonproliferation Applications," *Nuclear Instruments and Methods in Physics Section A*, vol. 694, pp. 119-125, 2012.

[3] S. Lemaire, P. Talou, T. Kawano, M.B. Chadwick and D. G. Madland, "Monte-Carlo approach to sequential neutron emission from fission fragments," Phys. Rev. C 72, 024601 (2005).

[4] P. Santi and M. Miller, "Reevaluation of Prompt Neutron Emission Multiplicity Distributions for Spontaneous Fission," Nucl. Sci. Eng. 160, pp. 190 – 199, 2008.

[5] T. E. Valentine, "Evaluation of Prompt Fission Gamma Rays for use in Simulating Nuclear Safeguards Measurements," Annals of Nuclear Energy 28(3), pp. 191 – 201, 2001.