Plutonium Metal Spontaneous Fission Neutron Cross-Correlation Measurements

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ABSTRACT – A plutonium metal sample was measured by a fast-neutron multiplicity counter for characterization of spontaneous fission neutron anisotropy and for verification of MCNPX-PoliMi calculations. Accurate neutron angular distribution models are important to properly simulating fast neutron coincidence measurements for nuclear nonproliferation and safeguards. A majority of prompt neutrons are emitted from fully accelerated fission fragments; those neutrons carry momentum from the fission fragments, and thus an anisotropic neutron angular distribution is observed in the laboratory reference frame. The fast-neutron multiplicity counter was used with pulse shape discrimination techniques to produce neutron-neutron cross-correlation time distributions from spontaneous fission in a lead-shielded 0.84 g $^{240}Pu_{eff}$ metal sample. Due to neutron anisotropy, the number of observed neutron cross-correlations varied as a function of angle between a detector pair and fission source. Fewer neutron correlations were observed at detector angles near 90 degrees, relative to higher and lower detector angles. Both the neutron correlations as a function of time difference and detector pair angle are compared with MCNPX-PoliMi calculations and show good agreement.

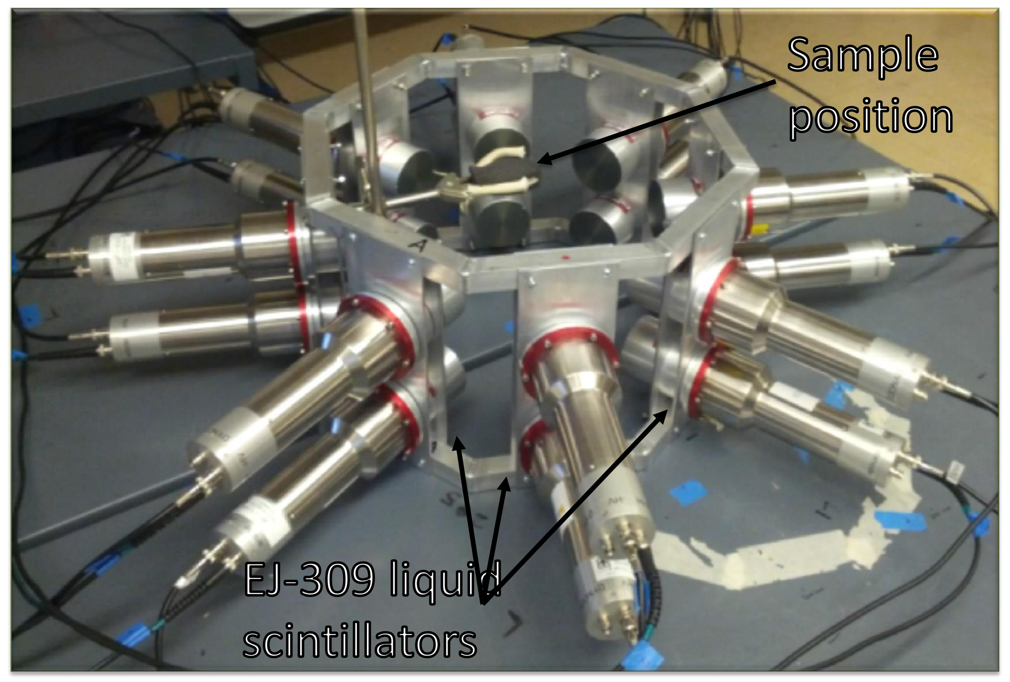


Fig. 1. EJ-309 liquid organic scintillation detector

Introduction

Motivation

- Most prompt neutrons are emitted from fully accelerated fission fragments, thus an anisotropic neutron distribution is observed in the laboratory frame
- Anisotropic neutron emission can help to characterize fissile material
- Coincidence counters can be used for nondestructive assay and nuclear-safeguards applications

Objectives

- Characterize Pu-240 spontaneous fission neutron anisotropy
- Verify MCNPX-PoliMi Pu-240 spontaneous fission neutron models

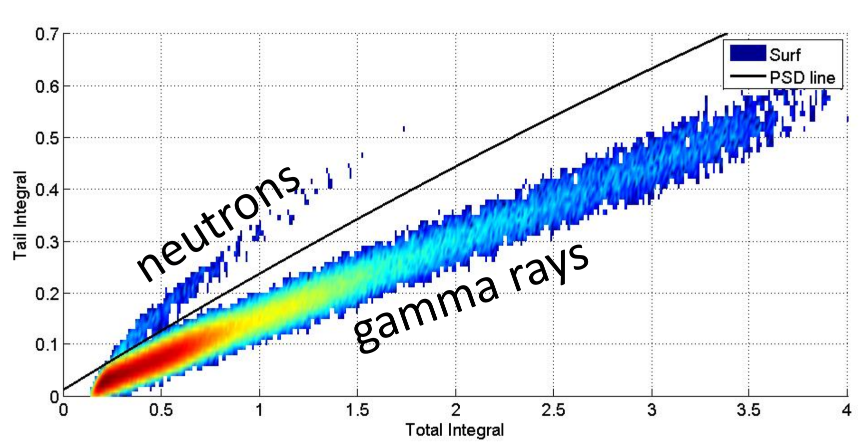


Fig. 3. Pulse shape discrimination plot of tail to total pulse integrals. Neutrons lie above the discrimination line.

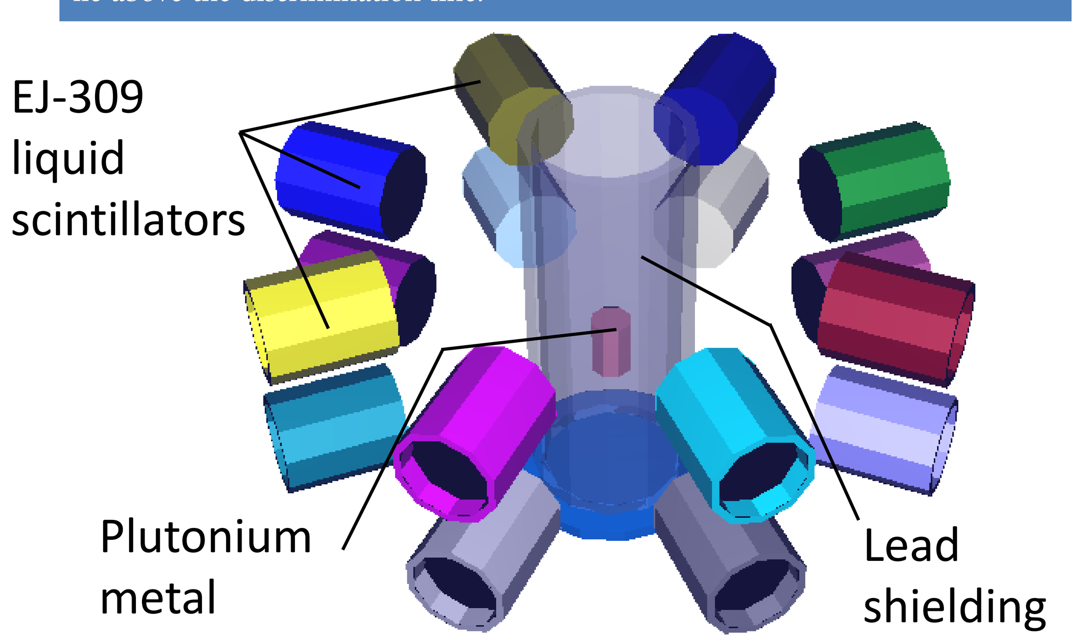


Fig. 4. MCNPX-PoliMi model of the EJ-309 liquid organic scintillation detector array.

Variance Reduction

Implicit Correlation Method

- Analog coincidence simulations often require many hours of computing, especially in shielded or large standoff scenarios
- MCNPX-PoliMi fission models allow for implicit correlation by binning a set of histories on fission fragment direction and multiplicity
- The implicit correlation method agrees well with analog simulation results
- Speed-up factor of over 500 using the standard MCNP figure of merit

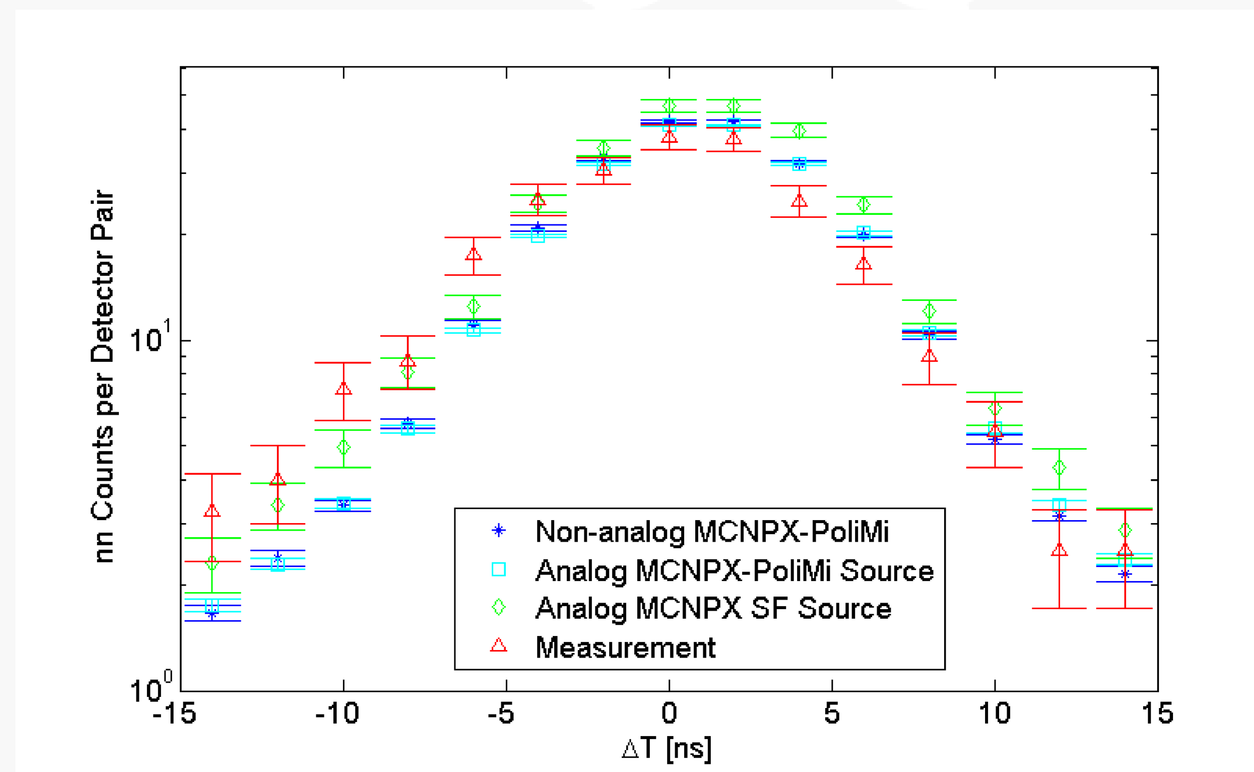


Fig. 4. Neutron-neutron cross-correlation distribution at detector angle 82° for the measurement and MCNPX-PoliMi analog, MCNPX-PoliMi non-analog, and MCNPX simulations.

Methods

Measurement

- An array of 16 7.62cmx7.62cm organic liquid scintillation EJ-309 detectors were used to detect fast neutrons emitted in spontaneous fission from a plutonium metal sample
- The 0.84 g $^{240}Pu_{eff}$ plutonium metal sample was 95.5wt% ^{239}Pu and 4.5wt% ^{240}Pu
- The source was shielded with a 1 cm lead cylinder to reduce the gamma ray count rate
- Detection pulses were digitized and recorded with two CAEN v1720 digitizer boards
- Neutron and gamma ray pulse differences allow for pulse shape discrimination

Simulation

- The plutonium metal source, detectors and holder, lead shielding, and table were modeled in MCNPX-PoliMi
- The post-processing code MPPost was used to measurement detector response
- Pulse height and cross-correlation distributions were produced from spontaneous fission events treated individually

Conclusions

Measurement

- Neutron-neutron correlations are most likely at detector angles near 0° and 180° -- most prompt neutrons are emitted from fully accelerated fragments
- Neutron anisotropy increases with detection threshold
- The ratio of number of neutron-neutron correlations increases with threshold by a factor of about 25% over the range studied

Simulation

- MCNPX-PoliMi simulation results agree well with measurement results
- Further investigation is needed at small detector angles

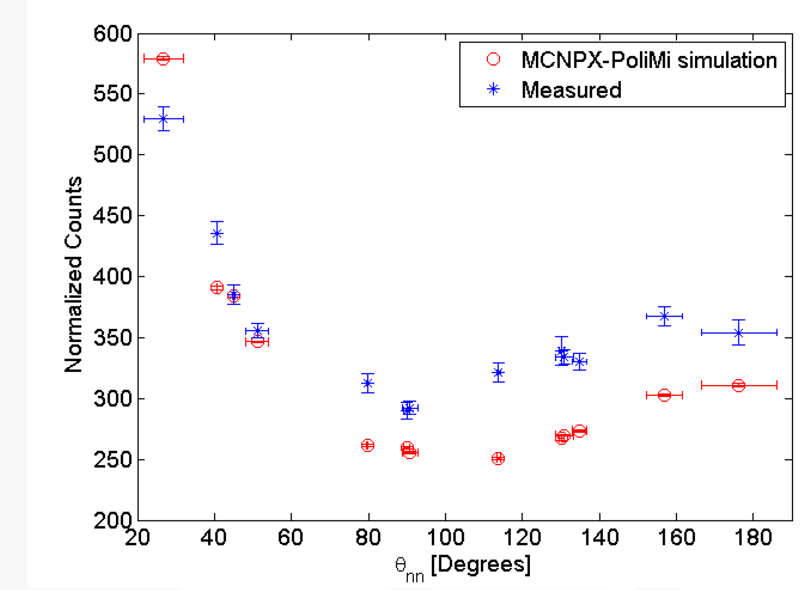


Fig. 5. Normalized neutron-neutron correlations as a function of detector-detector angle for measurement and MCNPX-PoliMi simulation.

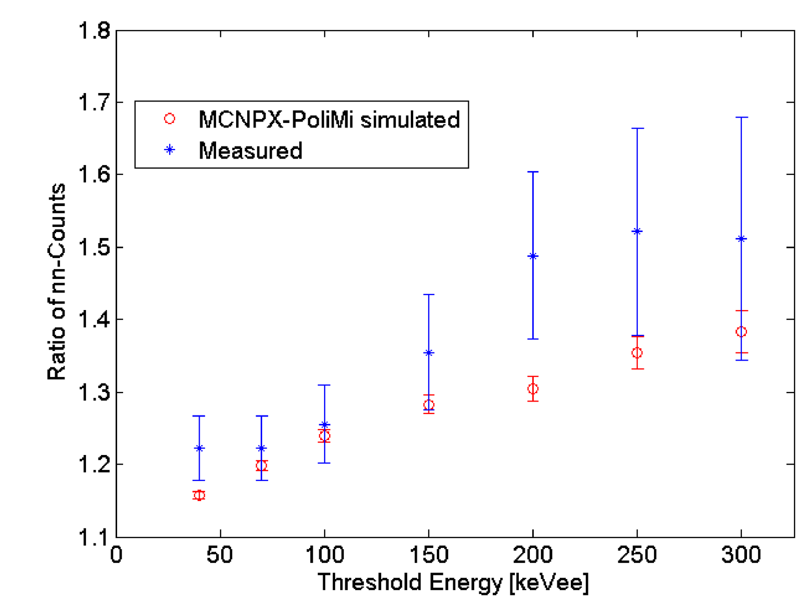
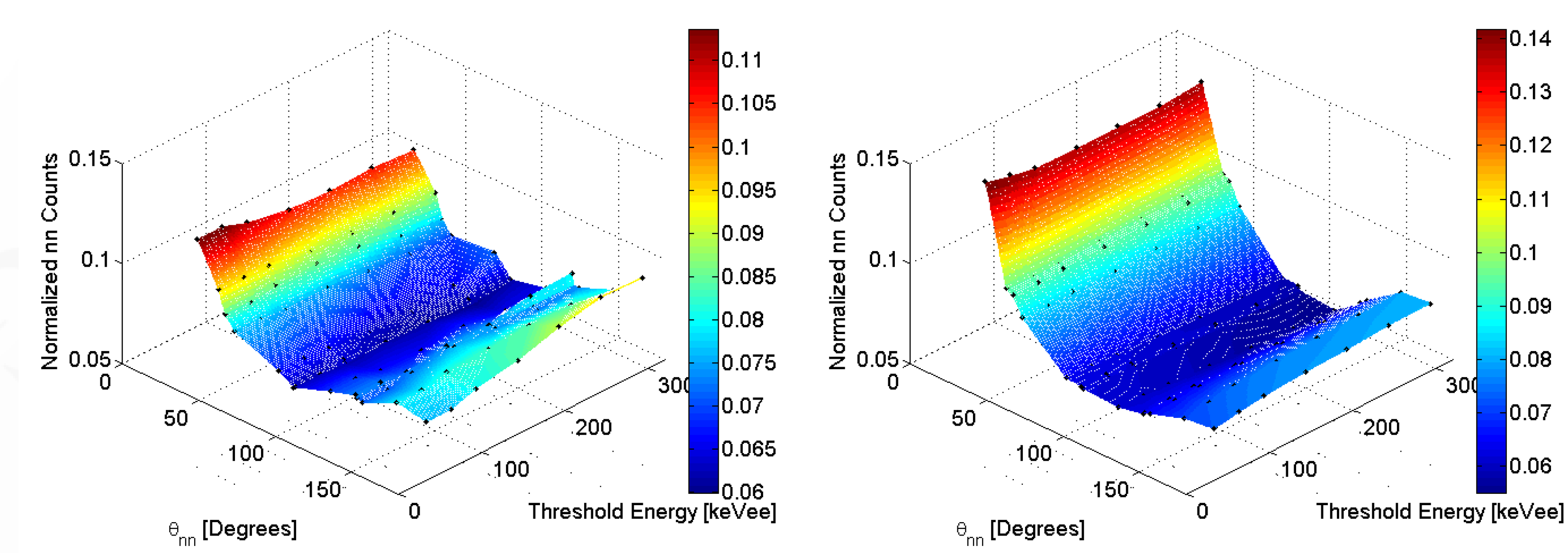


Fig. 6. Ratio of neutron-neutron correlations for 176° to 90° detector pairs for measurement and MCNPX-PoliMi simulation.



Figs. 7. Measured (left) and MCNPX-PoliMi simulated (right) normalized neutron-neutron correlations as a function of detector-detector angles and detector threshold.

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