Plutonium Metal Spontaneous Fission Neutron Cross-Correlation Measurements

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ABSTRACT – A plutonium metal sample was measured by a fast neutron multiplicator counter for characterization of spontaneous fission neutron anisotropy, and for verification of MCNPX-PolMi calculations. Accurate neutron angular distributions 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; thus an anisotropic neutron 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 1 cm-thick shielded U-235, Pu-239 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 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-PolMi calculations and show good agreement.

INTRODUCTION

VARIANCE REDUCTION

Implicit Correlation Method
- Analog coincidence simulations often require many hours of computing, especially in shelled or large standoff scenarios
- MCNPX-PolMi 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

CONCLUSIONS

Measurement
- 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-PolMi simulation results agree well with measurement results
- Further investigation is needed at small detector angles

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METHODS

Measurement
- An array of 16 EJ-309 and 7.62 cm 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 Pu-239, plutonium metal sample was 95.5% ²³⁹Pu and 4.5% ²³⁸Pu
- 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 CAMAC 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-PolMi
- 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

Fig. 1. EJ-309 liquid organic scintillation detector array.

Fig. 2. Pulse shape discrimination plot of tail to total pulse integrals. Neutrons lie above the discrimination line.

Fig. 3. Neutron-neutron cross-correlations distributions at detector angle 82° for the measurement and MCNPX-PolMi analog, MCNPX-PolMi non-analog, and MCNPX calculations.

Fig. 4. Neutron-neutron cross-correlations distributions at detector angle 82° for the measurement and MCNPX-PolMi analog, MCNPX-PolMi non-analog, and MCNPX calculations.

Fig. 5. Normalized neutron-neutron correlations as a function of detector-pair angle for measurement and MCNPX-PolMi simulations.

Fig. 6. Ratio of neutron-neutron correlations for 180° to 90° detector pairs for measurement and MCNPX-PolMi simulation.

Fig. 7. Measurement (left) and MCNPX-PolMi simulated (right) normalized neutron-neutron correlations as a function of detector-detector angles and detector threshold.