Fast-Neutron Multiplicity Counter: Summary of Past Experiments

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Introduction & Motivation

Nuclear safeguards implemented to deter spread of nuclear weapons through early detection of misuse in nuclear material or related technology in accessible facilities

Neutron multiplicity counting techniques measure time-correlated fission neutrons emitted from special nuclear material (SNM) to verify the declared amount of fissile material

International Atomic and Energy Agency (IAEA) seeks development in new instruments to:

I. Improve the accuracy, precision, and speed of SNM assay
II. Reduce or eliminate use of ^{3}He while maintaining equivalent performance

Project Objectives

Design, develop, and test a fast-neutron multiplicity counter (FNMC) using organic scintillators for non-destructive assay (NDA) of SNM

FNMC sensitive to emitted neutron energy, angular, and multiplicity distributions due to the absence of moderating material

The proposed system measures correlated fast fission neutrons emitted from SNM to

- Improve on limitations in current state-of-the-art NDA systems (e.g. ^{3}He-based systems)
- Measure new correlated signatures and relate to physical properties of SNM such as fissile mass, multiplication , and contribution from non-fission neutrons

This work presents past experiments and key results that demonstrate the FNMC system capabilities for characterizing SNM using non-destructive assay techniques

NDA of Pu-metal plates and U-oxide samples

Idaho National Laboratory, Idaho Falls ID, U.S.A (2015-2016)

Experiment Goals:

- **Demonstrate system capabilities and characterize performance for NDA**
- **Perform passive and active NDA on Pu- and U-bearing items**

Key Results:

- **Estimated fissile mass with < 4% absolute bias from actual fissile mass**
- **Estimated fissile mass with < 1% relative uncertainty in 4-min assay (for > 50 g)**

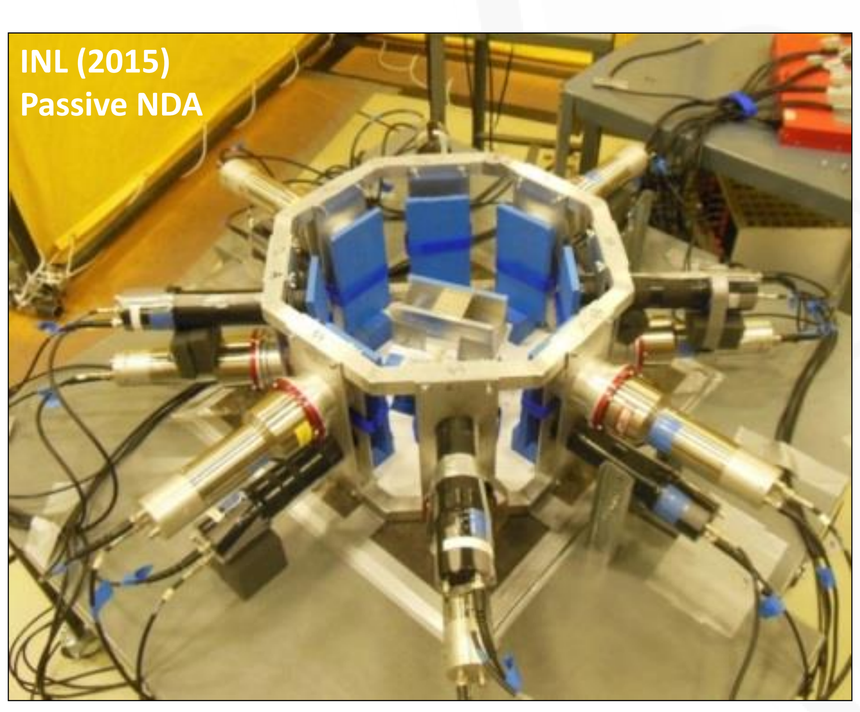

Figure 1 FNMC system with 8 – 7.62 cm Ø x 7.62 cm EJ-309 liquid organic and 8 – 5.08 cm Ø x 5.08 cm trans-stilbene crystal scintillators performing passive NDA (5 – 500g of Pu)

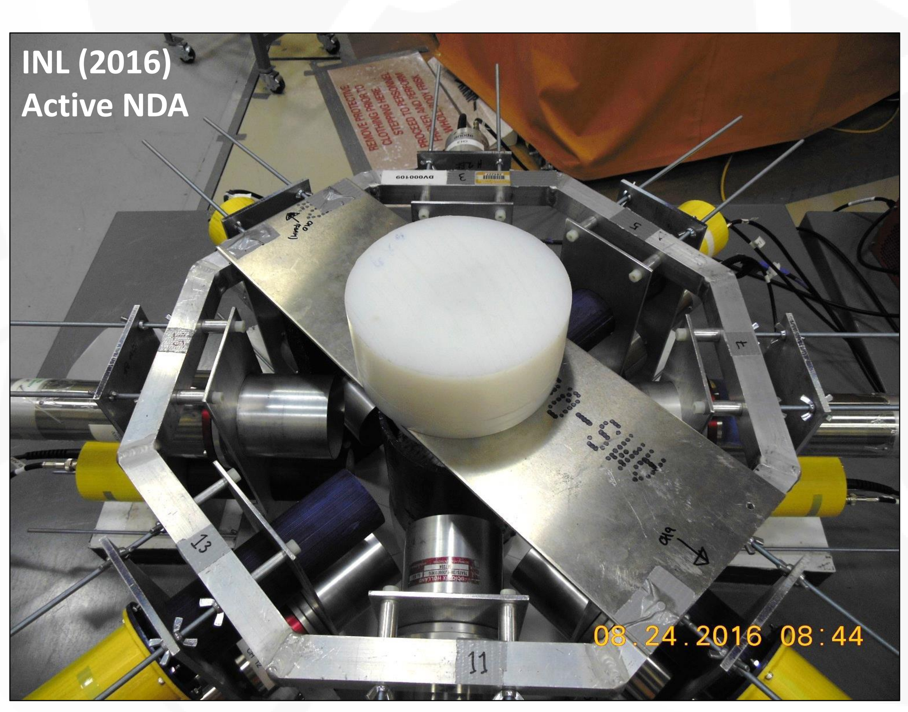

Figure 2 FNMC system with 8 – 7.62 cm Ø x 7.62 cm EJ-309 liquid organic and 8 – 5.08 cm Ø x 5.08 cm trans-stilbene crystal scintillators and two AmLi interrogative sources performing active NDA (40 – 4000 g of U)

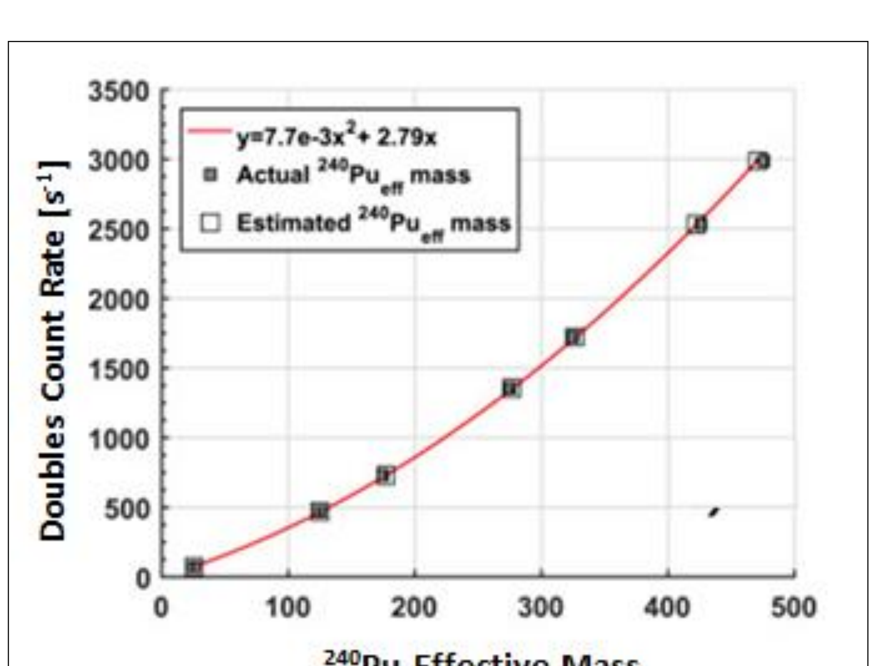

Figure 3 Mass-calibration curve for passive NDA of Pu-metal plates for samples with mass range of 5 – 500 g of plutonium[1]

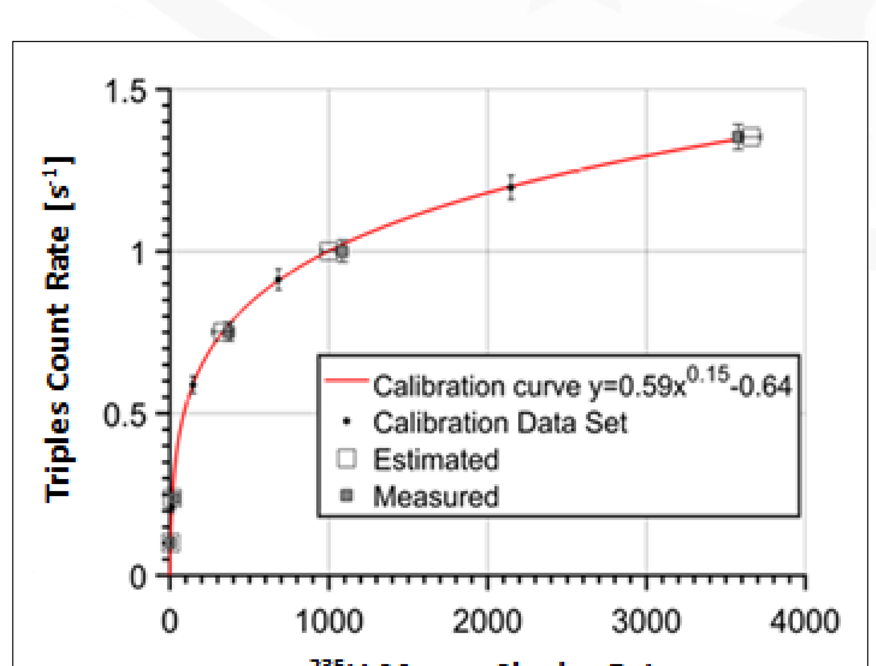

Figure 4 Mass-calibration curve for active NDA of U-oxide samples with mass range of 40 – 4000 g of uranium[2]

Neutron anisotropy dependence on multiplication and contribution from non-fission neutrons

Idaho National Laboratory, Idaho Falls ID, U.S.A (2015)
Los Alamos National Laboratory, Los Alamos NM, U.S.A (2018)

Experiment Goals:

- **Measure neutron anisotropy for low-multiplying Pu-metal samples (from INL 2015)**
- **Measure neutron anisotropy from Pu-bearing samples with different impurities giving varying contributions from non-fission neutrons (i.e. (α,n) neutrons)**

Key Results:

- **Characterized neutron anisotropy versus multiplication (i.e. fission chain length) demonstrating that neutron-neutron correlations appear more isotropic as fission chain lengths increase**
- **Measured neutron anisotropy for Pu-bearing samples with contribution from non-fission neutrons demonstrating the neutron anisotropy appear more isotropic as the α-ratio increases**

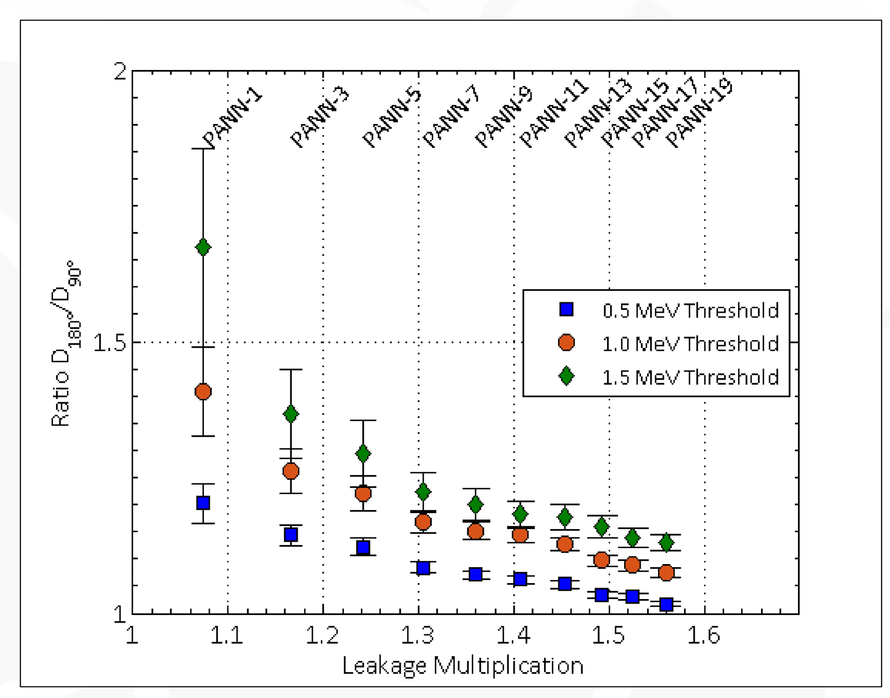

Figure 5 Neutron anisotropy as a function of leakage multiplication for three different detection thresholds showing the neutron-neutron coincidences appear more isotropic as multiplication increases[3]

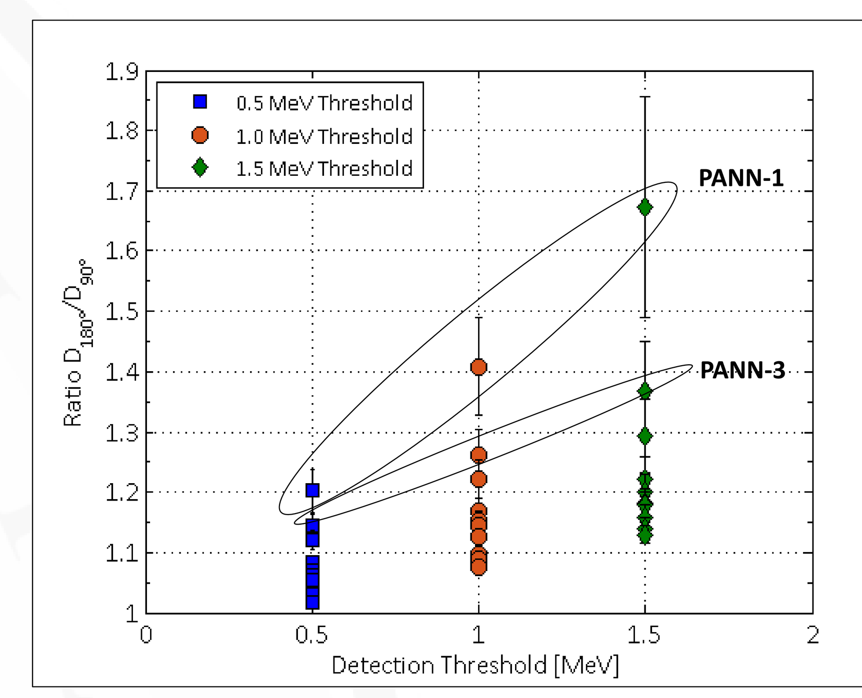

Figure 6 Neutron anisotropy as a function of detection threshold showing a positive correlation for all measured configurations[3]

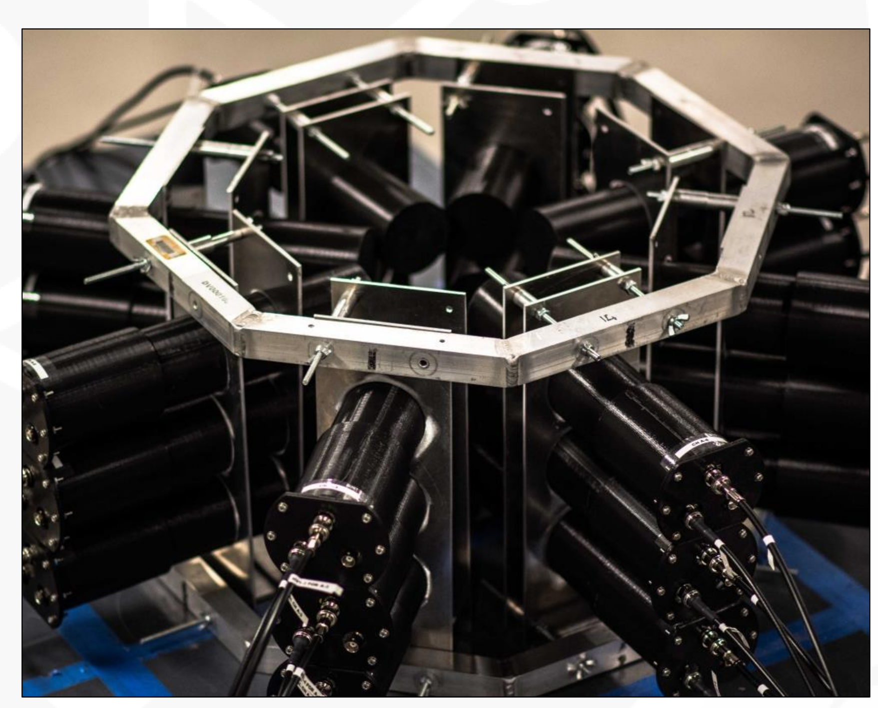

Figure 7 FNMC system with 24 – 5.08 cm Ø x 5.08 cm cylindrical trans-stilbene crystal scintillators used to measure neutron anisotropy for samples with high contributions from non-fission neutron emissions

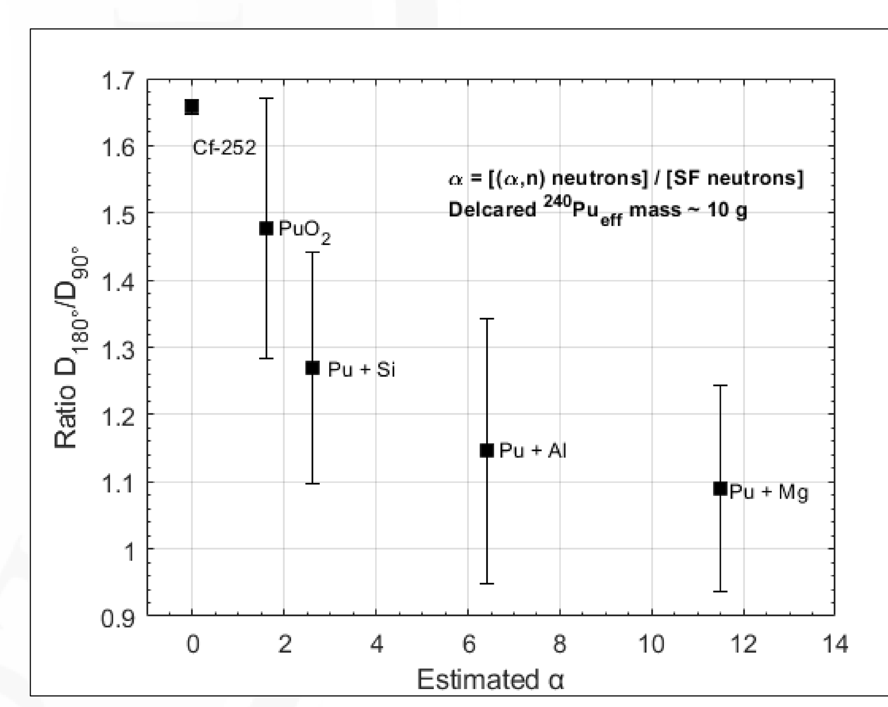

Figure 8 Measured neutron anisotropy as a function of the α-ratio showing the neutron-neutron coincidences appear more isotropic as the contribution from non-fission neutron emissions increase

Conclusions

FNMC system based on organic scintillators has been designed, developed, and tested with passive and active experiments of SNM

We have demonstrated that the FNMC system:

- Estimates fissile mass with passive and active NDA with high precision in relatively short measurement times (< 1% relative uncertainty in 4-min assay, < 4% absolute difference from actual mass)
- Is sensitive to the emitted neutron multiplicity, energy, and angular distributions
- Can relate new correlated signatures (e.g. neutron anisotropy) to physical properties of SNM such as mass, multiplication, and contribution from non-fission neutron emissions

The advances in detection techniques and instruments can be transferred to many applications that utilize organic scintillators for fast-neutron detection

International inspectorates such as the IAEA have transitioned and implemented organic scintillators in next-generation safeguards instruments (e.g. Fast Neutron Uranium Collar FNCL)

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[1]A. Di Fulvio, T.H. Shin, T. Jordan, C. Sosa, M.L. Ruch, S.D. Clarke, D.L. Chichester, S.A. Pozzi, "Passive assay of plutonium metal plates using a fast-neutron multiplicity counter" Nucl. Instr. Meth. Phys. Res. A, 855, 92 (2017)

[2]A. Di Fulvio, T.H. Shin, A. Basley, C. Swenson, C. Sosa, S.D. Clarke, J. Sanders, S. Watson, D.L. Chichester, S.A. Pozzi, "Fast-neutron multiplicity counter for active measurements of uranium oxide certified material" Nucl. Instr. Meth. Phys. Res. A, 907, 248 (2018)

[3]T.H. Shin, A. Di Fulvio, S.D. Clarke, D.L. Chichester, S.A. Pozzi, "Prompt fission neutron anisotropy in low-multiplying subcritical plutonium metal assemblies" Nucl. Instr. Meth. Phys. Res. A, available online *https://doi.org/10.1016/j.nima.2018.09.085* (2018)

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