FAST NEUTRON MULTIPLICITY COUNTER

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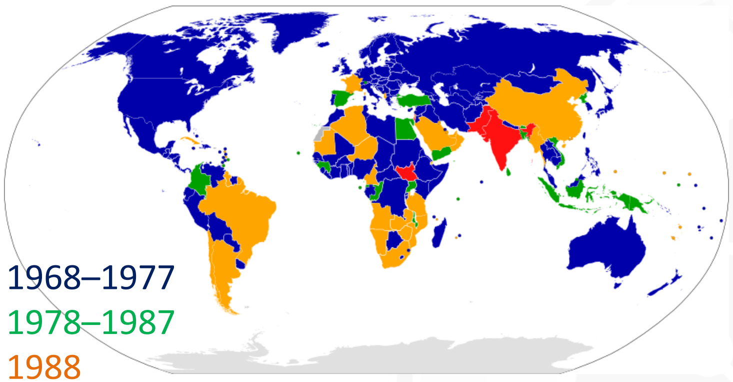
Nuclear Safeguards

Treaty on the Non-Proliferation of Nuclear Weapons



*"support for research, development and other efforts to further the application, within the framework of the International Atomic Energy Agency safeguards system, of the **principle of safeguarding effectively the flow of source and special fissionable materials by use of instruments and other techniques at certain strategic points**"*

NPT, 1968-1970

- The Treaty envisages a review of the operation of the Treaty every five years (art VIII, par 3)

2015 NPT Review Conference, UN – New York City

*"The United States cooperates with countries with advanced fuel cycle facilities to provide technical expertise for **developing instrumentation and systems to improve the effectiveness and efficiency of safeguards implementation."***

*Goals of the International Partnership are to assess and potentially develop approaches addressing **monitoring and verification challenges across the nuclear weapons lifecycle***

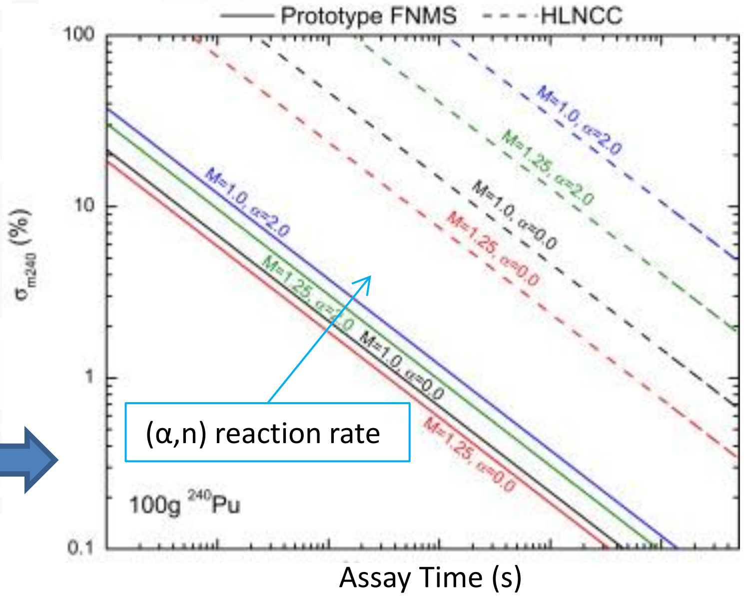
Report of the United States of America, 1 May 2015

Nuclear Safeguards Instrumentation

- Radiation Detection Techniques for multiplicity counting - *passive*
  - Moderated He-3 proportional counters
  - Organic scintillators
    - Nanosecond time scale detection
    - Measurements of higher-order multiplicity events
    - Higher accuracy given the same irradiation time

Canberra®
Passive Neutron Coincidence Well Counter

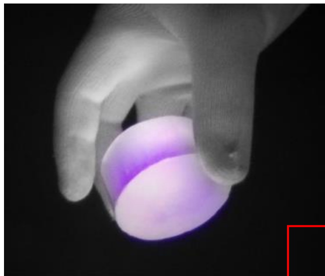
Percent mass variance as a function of assay time for Fast Neutron Multiplicity Systems and High-Level Neutron Coincidence Counter (dashed lines) [1]

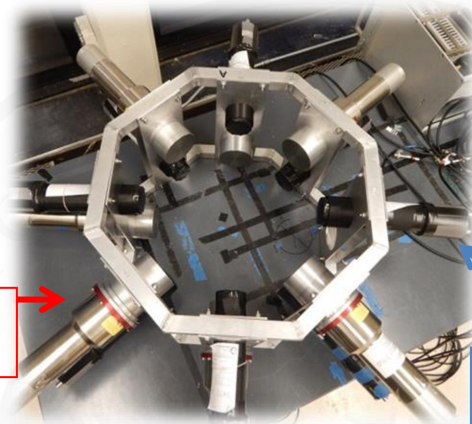


[1] D. Chichester, et al. NIMA, vol. 784, pp. 448-454, 2014

Fast-Neutron Multiplicity Counting

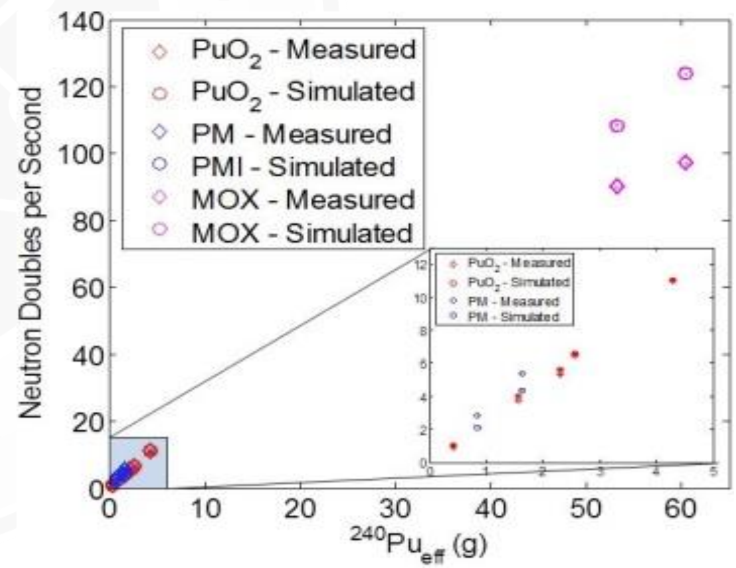
Stilbene crystal





14 bit resolution
500 MHz sampling frequency
DPP-PSD Single count rejection mode

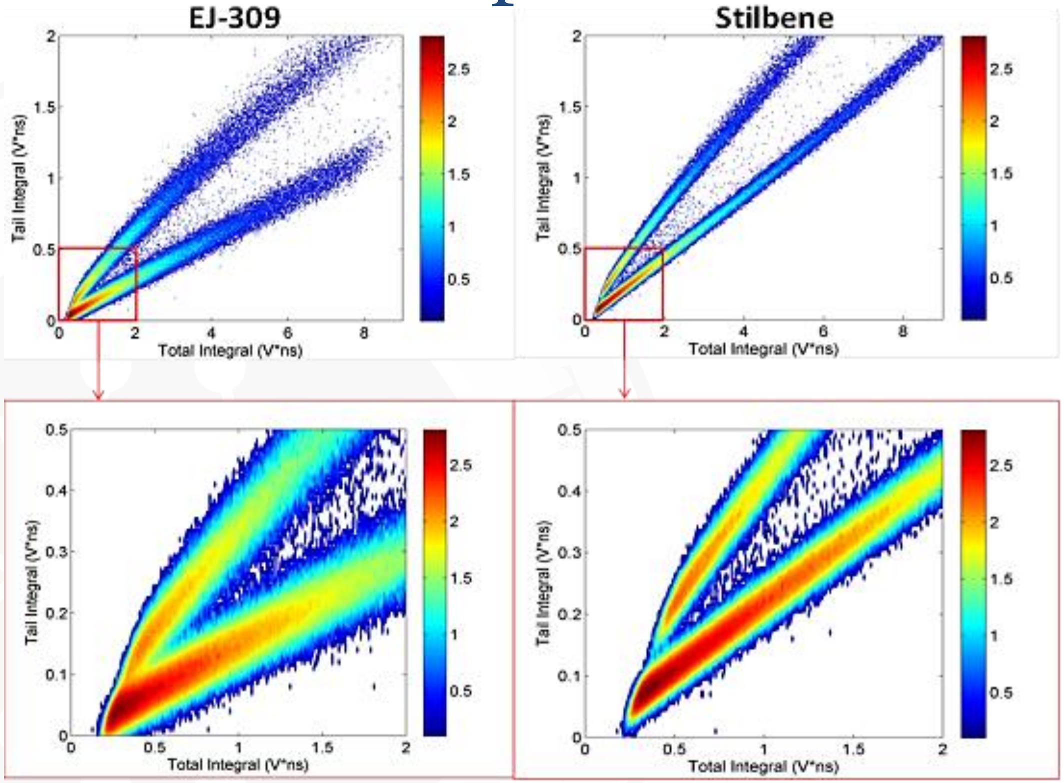
- First prototype: 16 EJ 309 3”x3” liquid scintillators
- Neutron doubles rate proportional to $^{240}Pu_{eff}$ mass measured with 1 cm of lead shielding three material types: PuO_2, PM, and MOX [2].



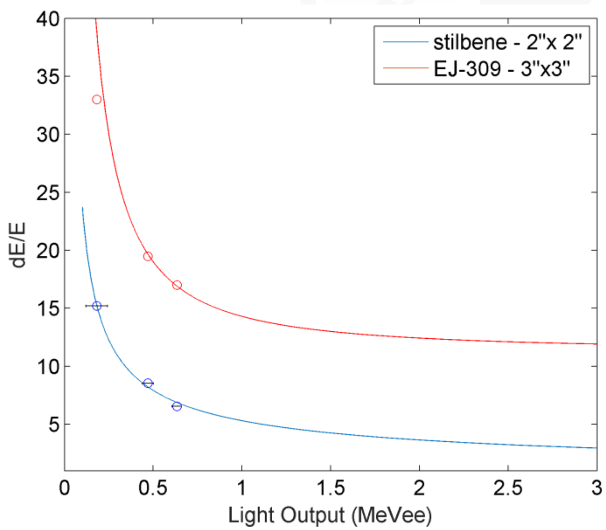
[2] J. L. Dolan, et al. NIMA, vol. 763, pp. 565-574, 2014

Organic Scintillator Response

- Pulse shape discrimination (PSD) and energy resolution improvement through use of stilbene detectors



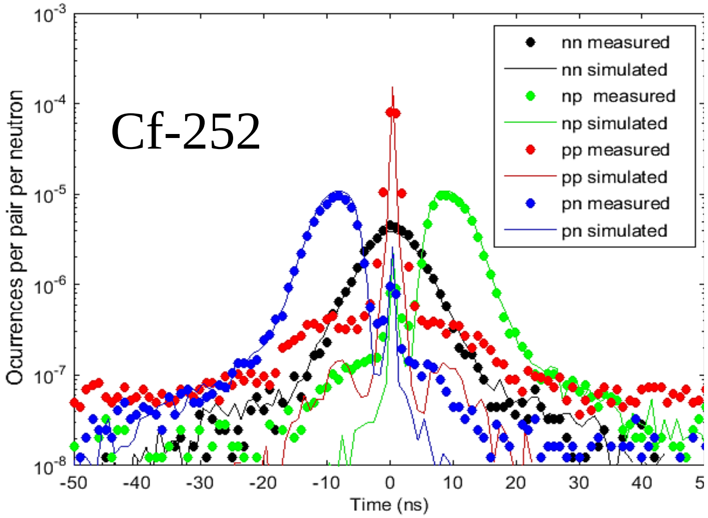
Stilbene detector energy resolution as a function of light output

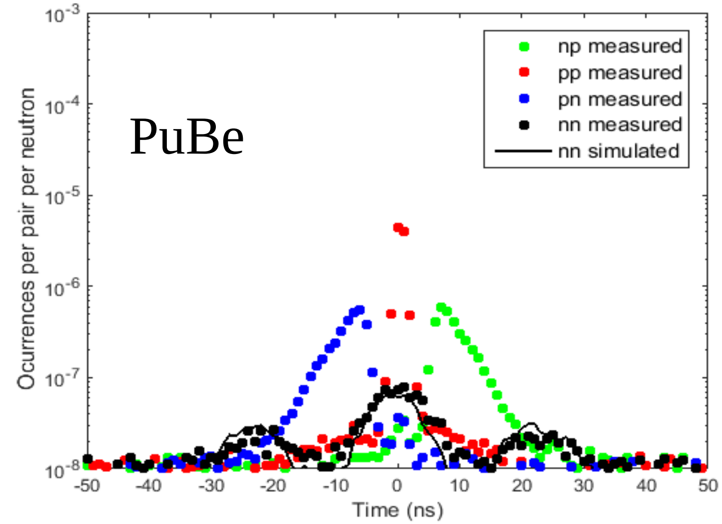


DETECTION THRESHOLD	Light output (keVee)	Neutron energy (keV)*
EJ-309	80	710
stilbene	35	380

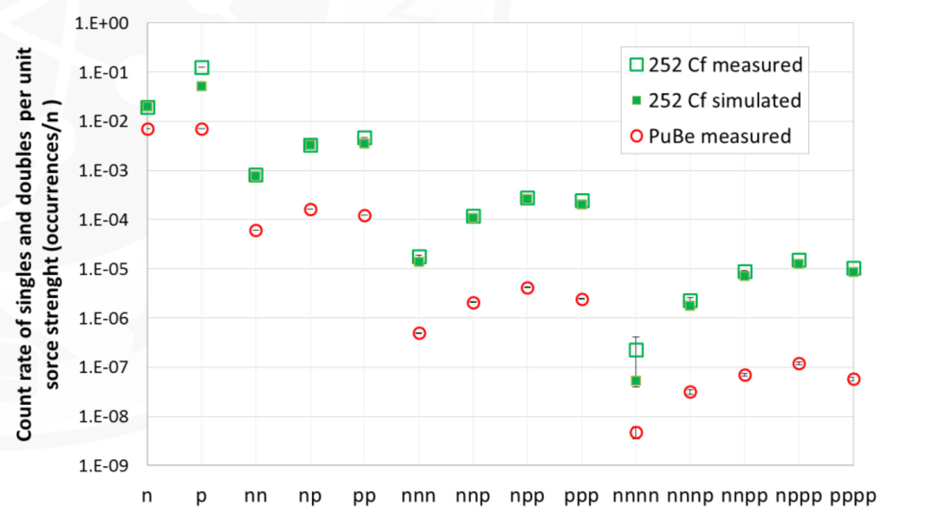
*minimum energy deposited on H in a single collision

Experiments in the laboratory





Count rate per unit source strength

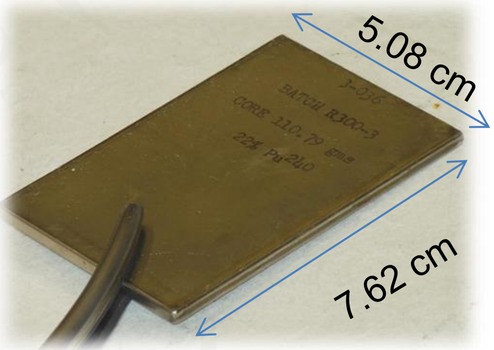


- ✓ Designed and built prototype; tested using radionuclide sources (Cf-252 and PuBe)
- ✓ Validated Monte Carlo simulations using multiplicity dependent spontaneous fission source term (MCNPX-PoliMi)
- ✓ Planned experimental campaign at INL, on plutonium metal plates
- ✓ Temperature dependence range: 20 to 40 °C

Experiment at Idaho National Laboratory

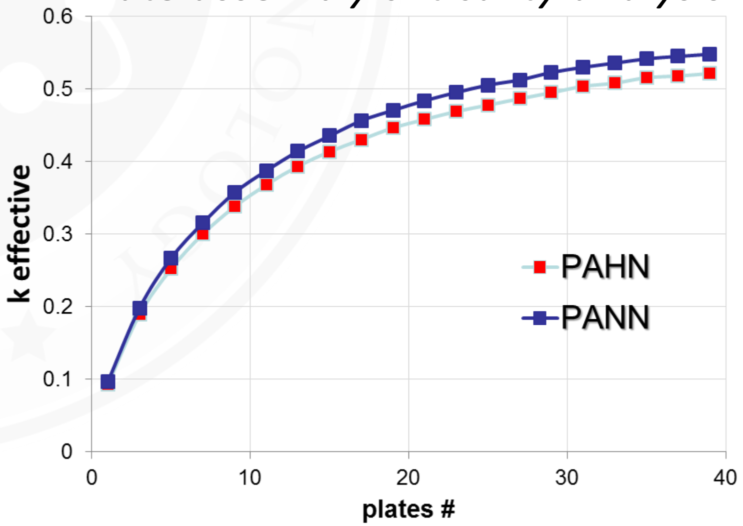
- Measurement of plutonium plates, fuel of Zero Power Research Reactor at Idaho National Laboratory

Single plate ≈ 100 g



	240 Pu mass (g)	239 Pu mass (g)
PAHN	23.8	79.6
PANN	4.6	98.9

Plate assembly criticality analysis



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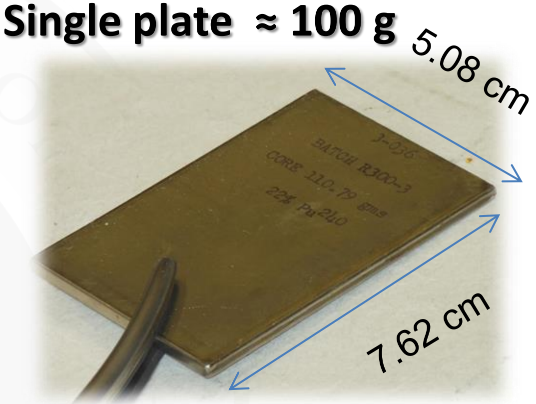

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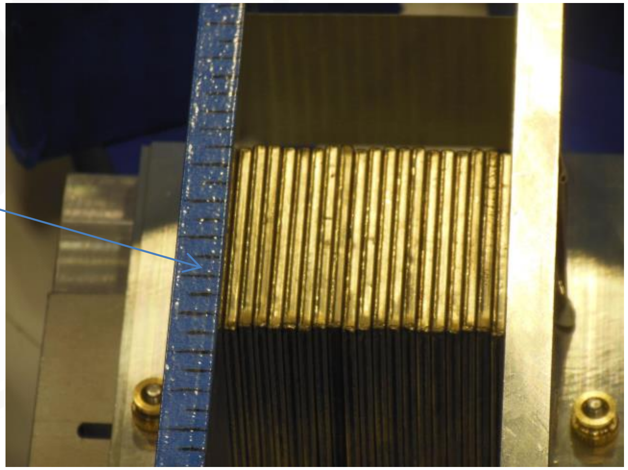
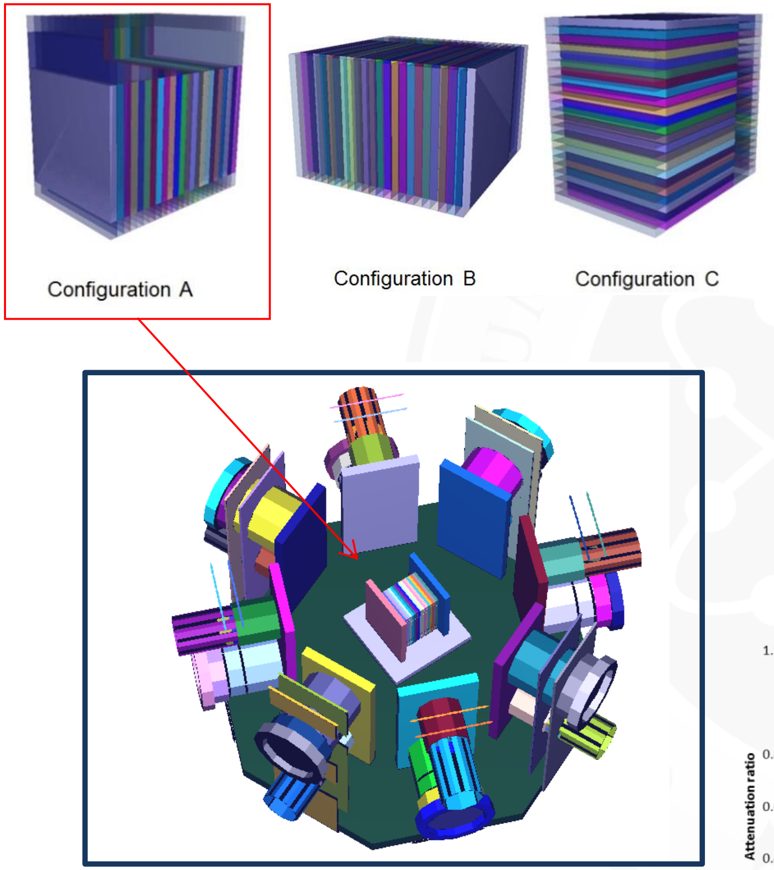


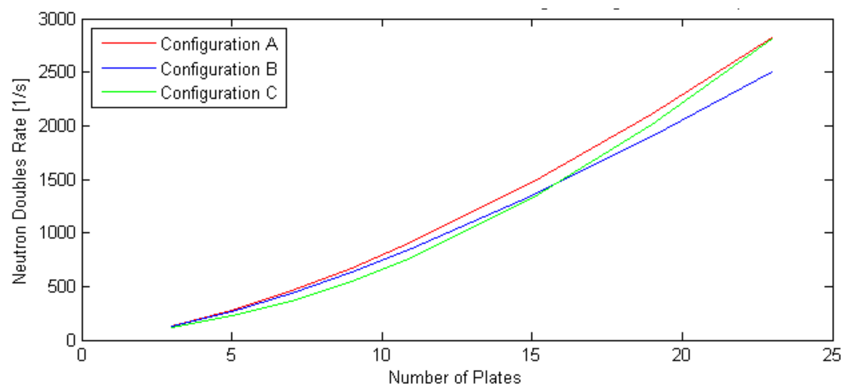
MCNPX-PoliMi model

Simulated and compared several configurations in terms of:

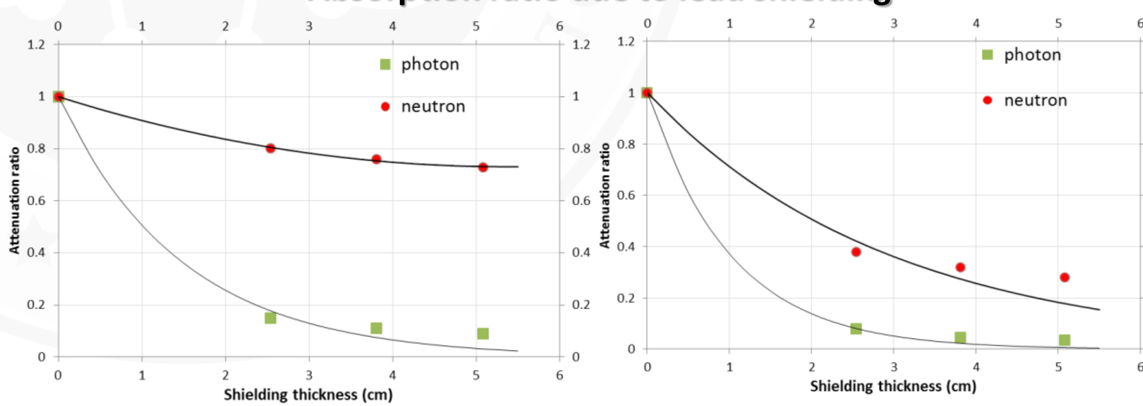
- Solid angle
- Shielding effectiveness for decay photons



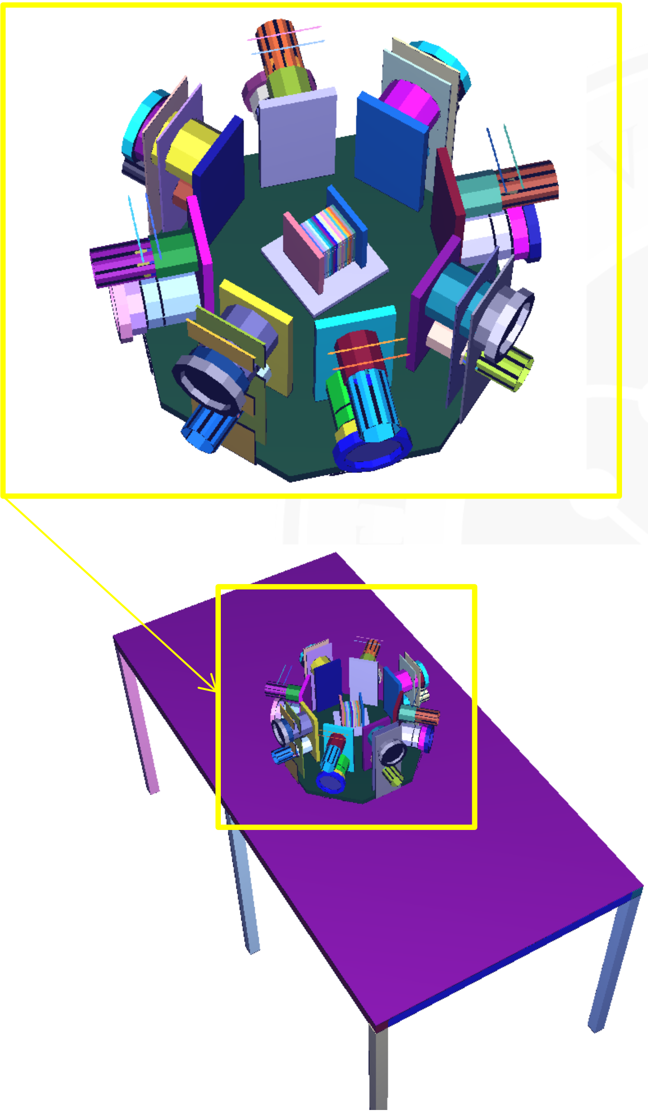
Count rate of neutron doubles

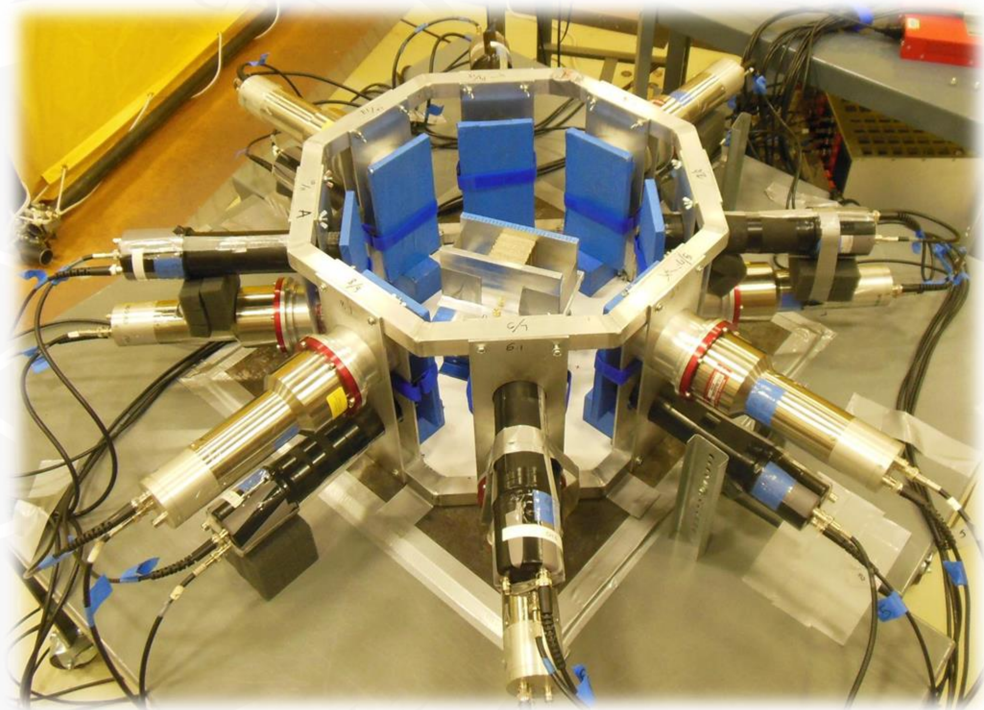


Absorption ratio due to lead shielding

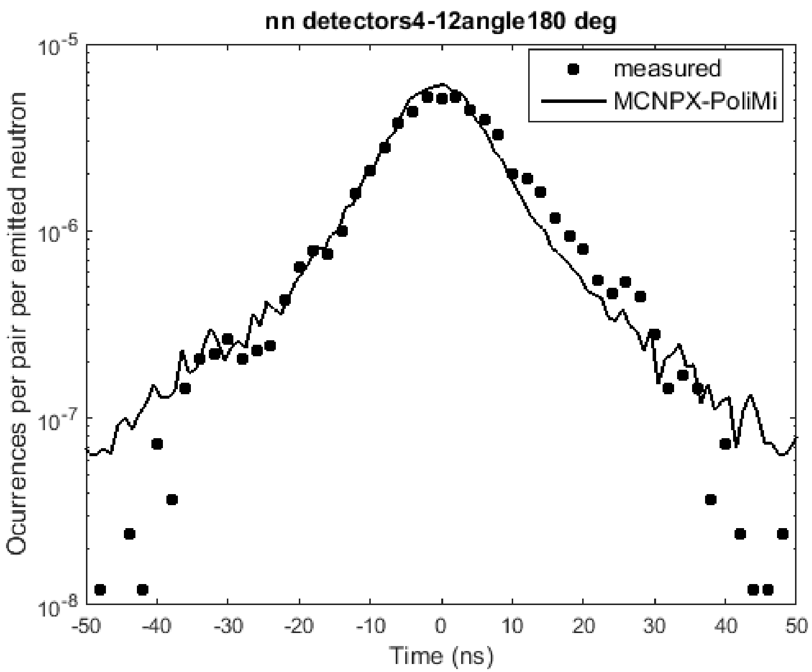


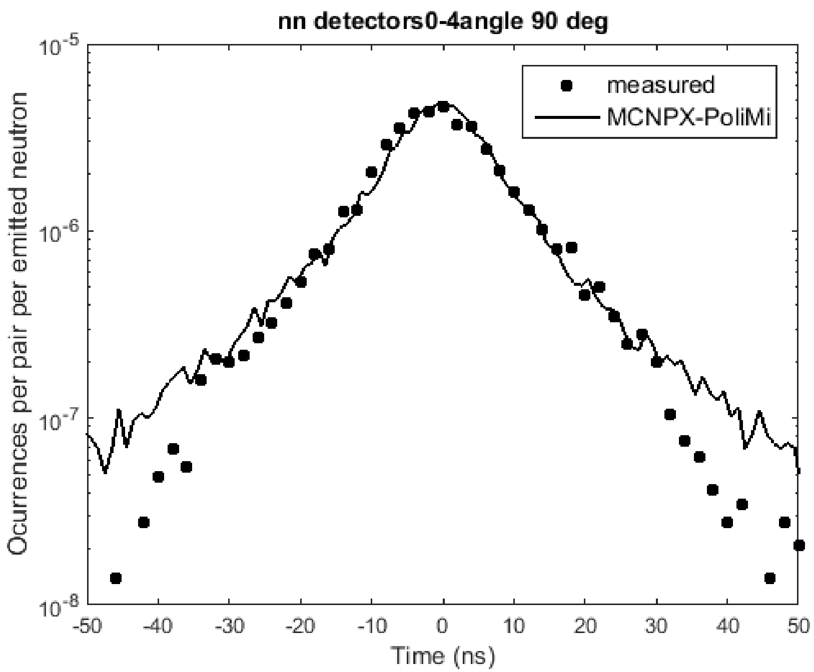
MCNPX-PoliMi model



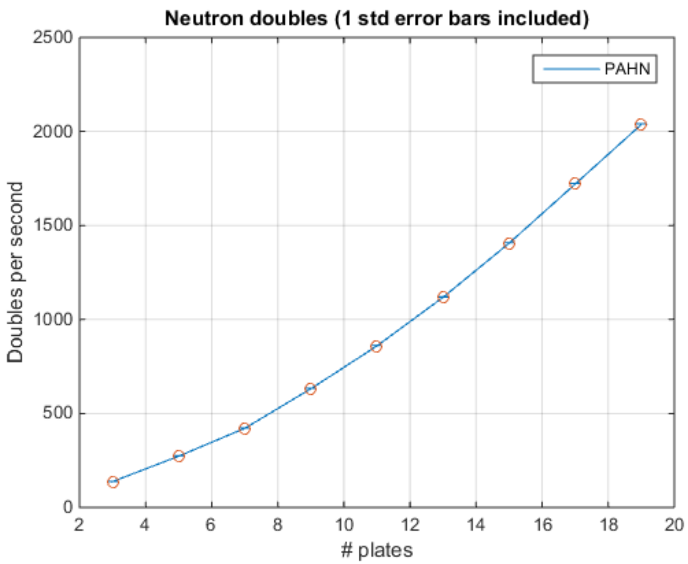


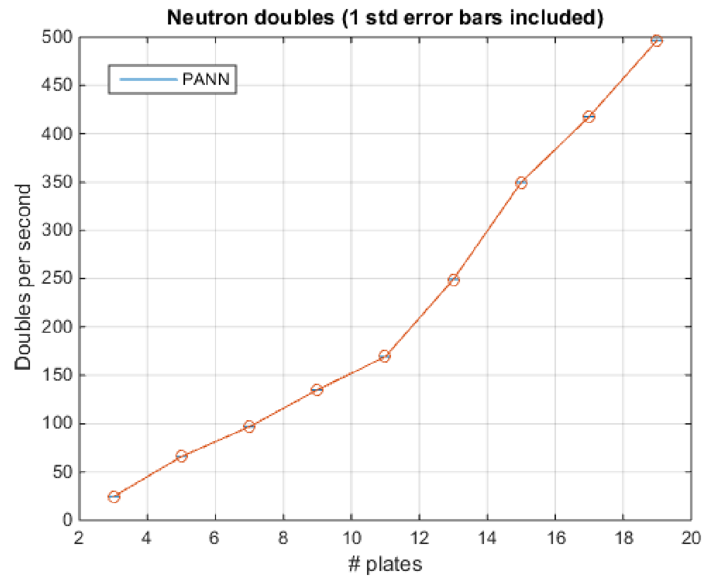
Correlated neutron counts





Measured neutron doubles





	PAHN mass (g)	PANN mass (g)
238Pu	2.33E-04	2.33E-04
239Pu	79.69	98.89
240Pu	23.92	4.70
241Pu	0.65	0.04
242 Pu	0.67	0.00
241Am	1.87	0.23
Al	1.25	1.16

239 Pu Mass range:

- PAHN 1 to 19 plates, 79.7 g to 1.5 kg
- PANN 1 to 19 plates, 98.9 g to 1.9 kg

Conclusions and future work

Project goals:

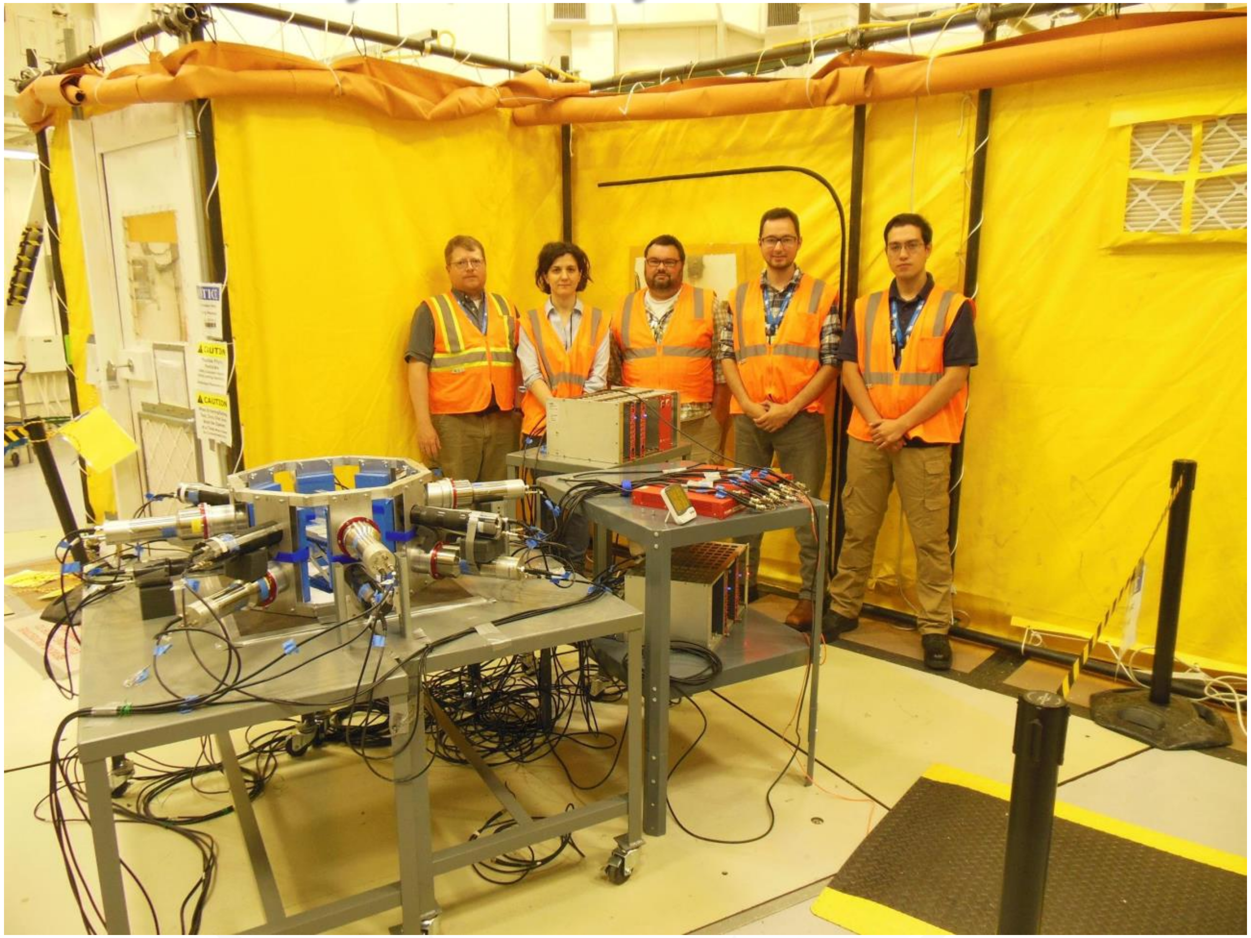
- Accurately determine the mass of fissile material
- Address the He-3 shortage

✓ Successfully measured neutron doubles from plutonium metal plates (Pu-239 content 74% and 94% of the total) for a wide range of masses from 100 g to 2.1 kg

✓ Monotonic increasing trends in neutron doubles

- Analysis of higher multiplicity trends
- Characterization of measurement uncertainty of an unknown sample as a function of measurement time
- <u>Active interrogation mode for U-235 samples</u>

Thank you for your attention!



Thanks to the CVT for making this experimental campaign possible!
Thanks to INL personnel for their kind assistance!