Active-Induced Time Correlation Signatures for the Characterization of Shielded HEU

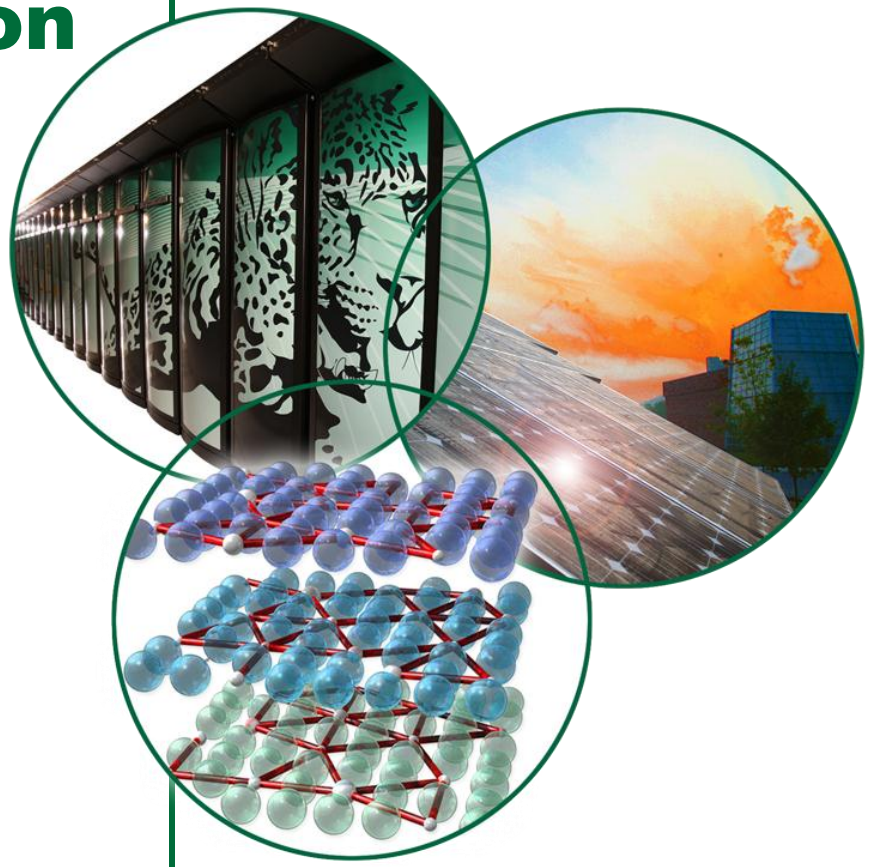
Jason Crye

Seth McConchie

Brandon Grogan

John Mihalczo

Jeffrey Johnson



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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

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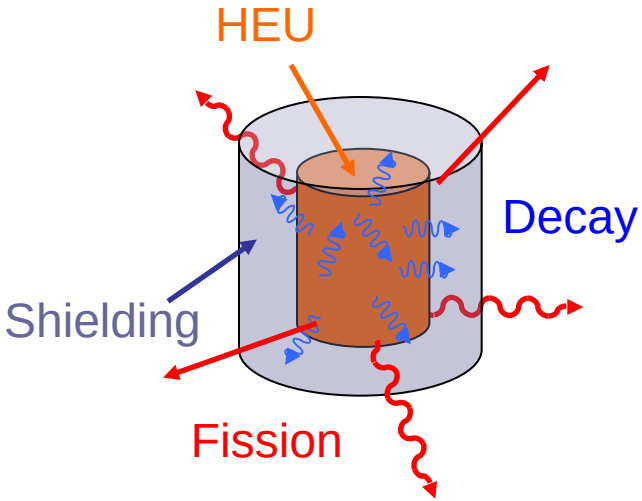
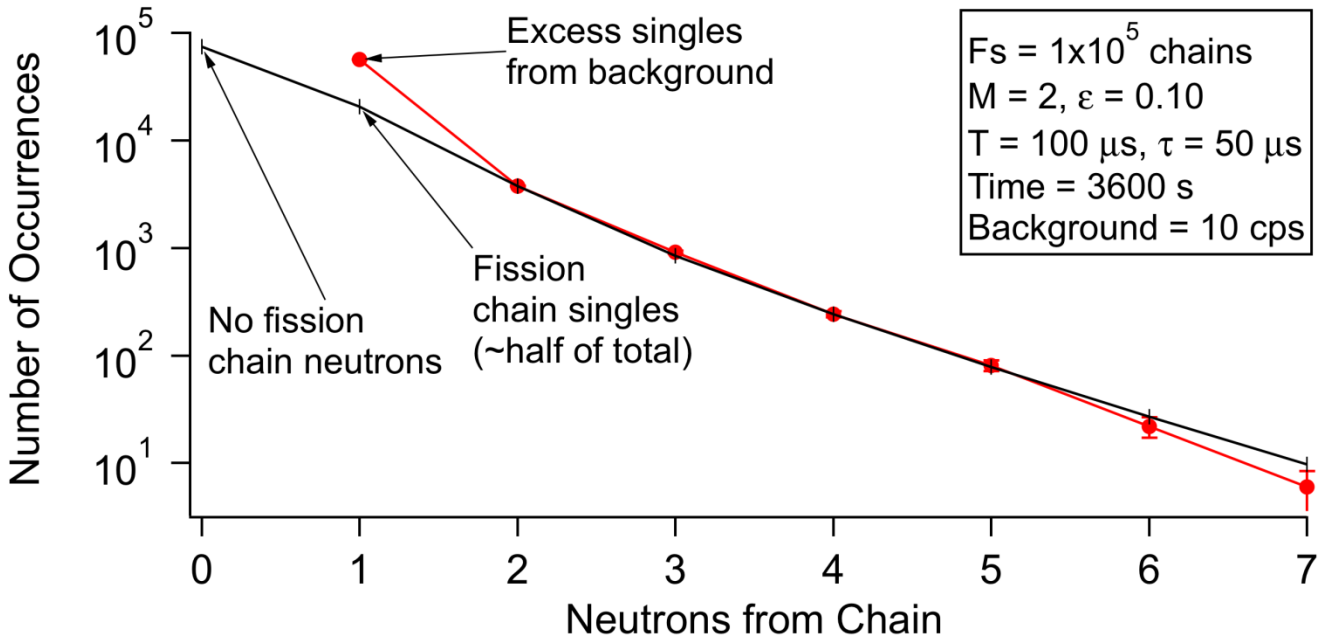
Technical Challenge of Shielded HEU



Isotope	Decay Gamma	Emission Rate	Spont. Fission Rate
^{235}U	186 keV	4.32×10^{4} g^{-1} s^{-1}	0.16 kg^{-1} s^{-1}
^{238}U	1001 keV	7.34×10^{1} g^{-1} s^{-1}	6.77 kg^{-1} s^{-1}
^{239}Pu	414 keV	3.42×10^{4} g^{-1} s^{-1}	10 kg^{-1} s^{-1}
^{240}Pu	643 keV	1.04×10^{3} g^{-1} s^{-1}	472,000 kg^{-1} s^{-1}

- **Modest high-Z shielding of HEU can make detection of signature gamma rays difficult**
- **Low spontaneous fission rate of HEU means neutron singles are mixed with cosmic-ray spallation neutrons**
- **Active fast-neutron interrogation boosts the fission rate to permit detection of fissioning material, and detection of shielding material is also possible with same source**

Fission Chains in HEU



- **Uncorrelated background singles rate adversely affects fitting correlated neutron time distributions**
- **Typically the quantification of neutrons from cosmic-ray spallation effects is non-trivial and requires some knowledge of the environment**
- **Active measurements seek to (1) drive fission chains at higher rates and (2) induce signals where the background may be quantifiable**

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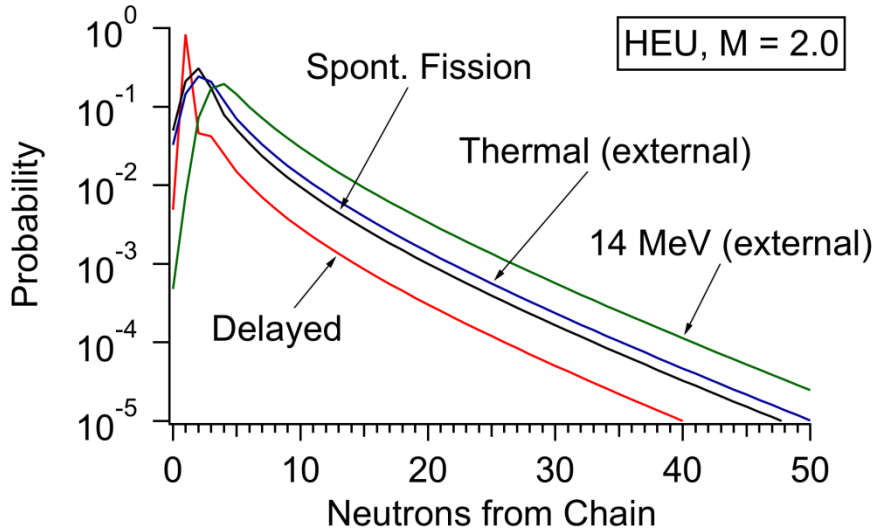
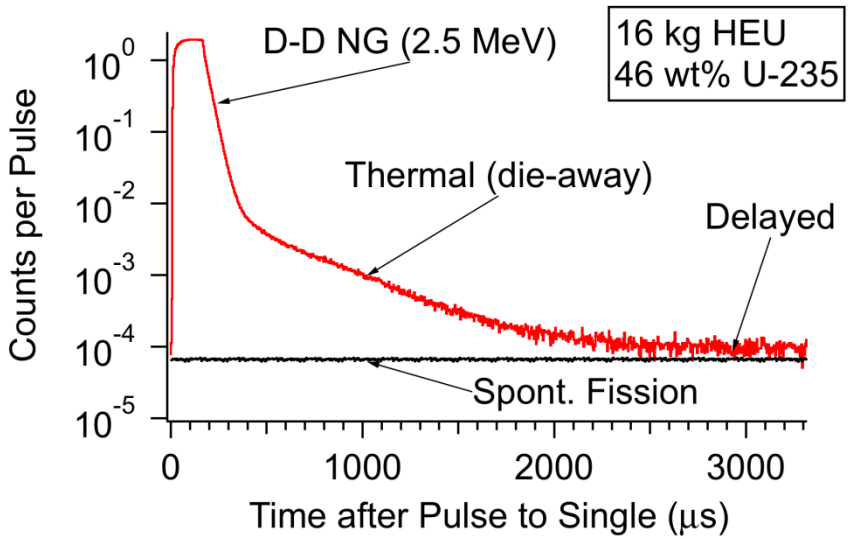
Two Scenarios for Shielding

1. Low-Z shielding like polyethylene or water
   - Effectively absorbs the fission and delayed neutrons
   - Washes out the characteristic time dependence of fission chain neutrons
   - Is less effective for prompt fission gammas, delayed gammas, and thermal neutron capture gammas (2.2 MeV from ^{1}H)
2. High-Z shielding like lead, tungsten, or depleted uranium
   - Effectively absorbs the decay, fission, and delayed gammas
   - Is less effective for shielding fission and delayed neutrons

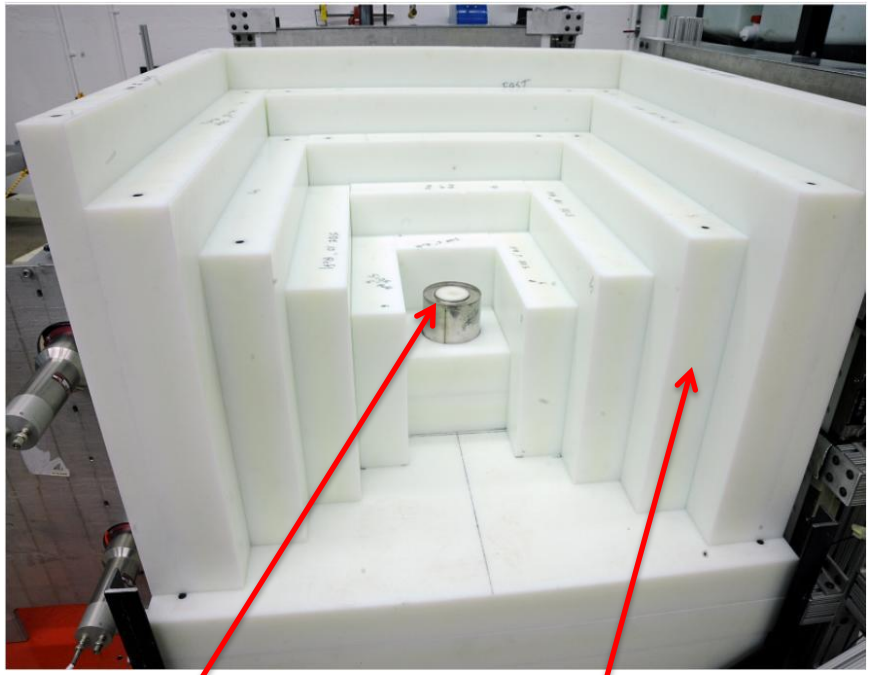
Measurement with Low-Z Shielding – Induced Fissions with a Pulsed Source





- **Pulsed sources exploit multiple fission chain initiation mechanisms in the same measurement (incident 14 MeV neutrons, thermal neutrons, delayed neutrons, and spontaneous fission)**
- **Traditional differential die-away is based upon the reentry of thermal neutrons into the assembly to induce fission**
- **Die-away and delayed time regions typically have low background**

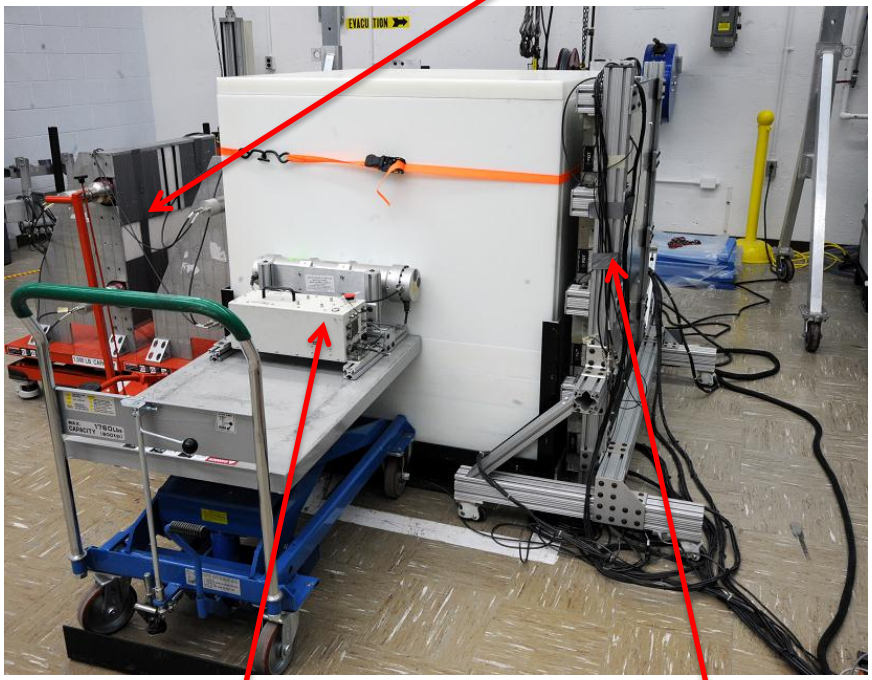
Measurement with Low-Z Shielding (cont.)



18 kg HEU (93 wt%)

Up to 20 in. HDPE

Plastic scintillators

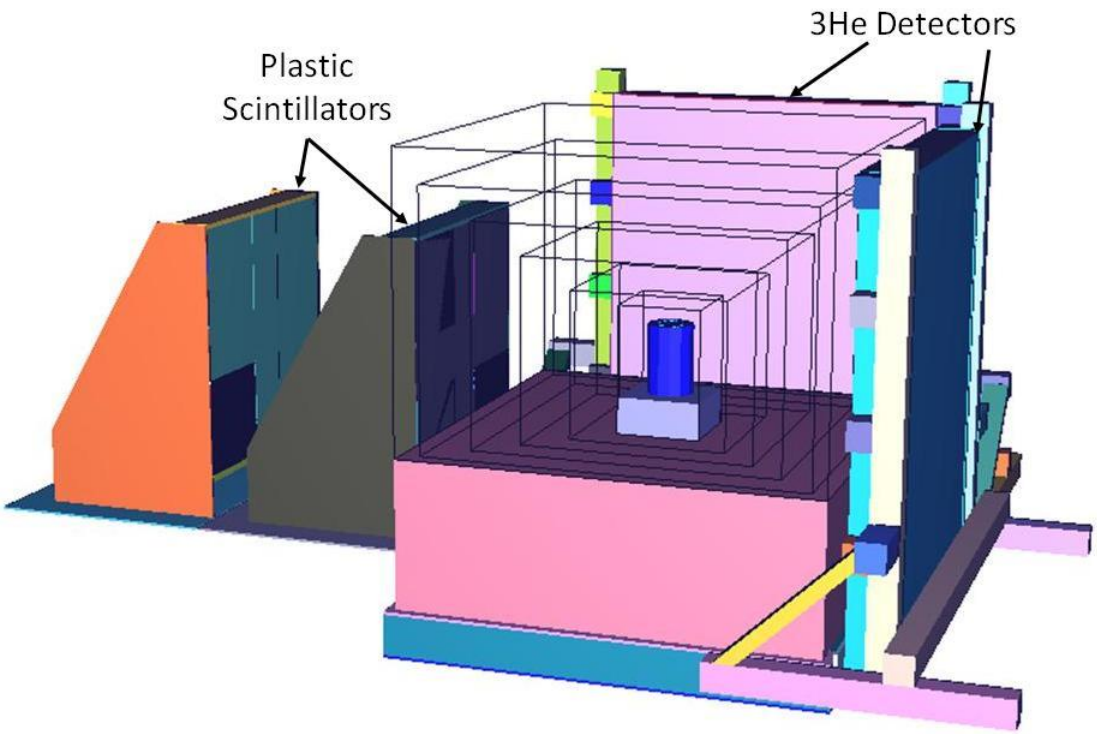


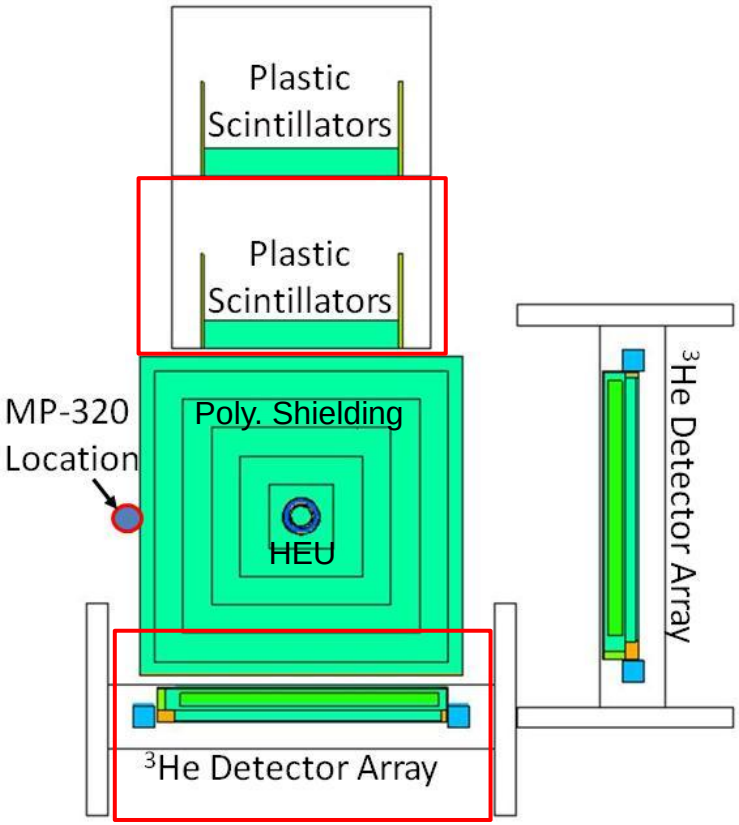
Pulsed D-T NG 300 Hz, 6%, 4×10^7 n/s

He-3 detectors

- Detectors: Eight 27x27x10-in. plastic scintillators and 32 5-cm diameter, 91 cm long, 4-atm moderated He-3 tubes
- Polyethylene thicknesses: 0, 6, 10, 14, and 20 in.

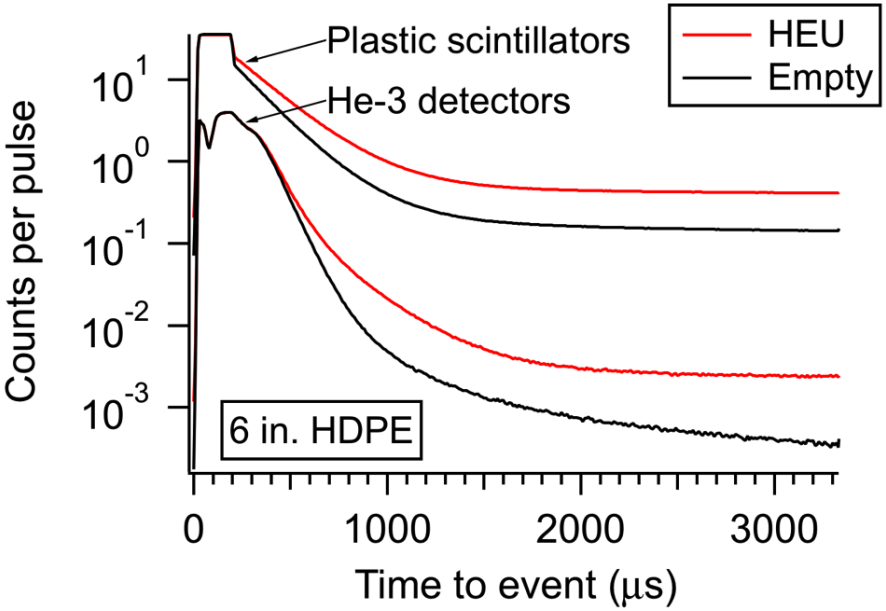
Another Setup View

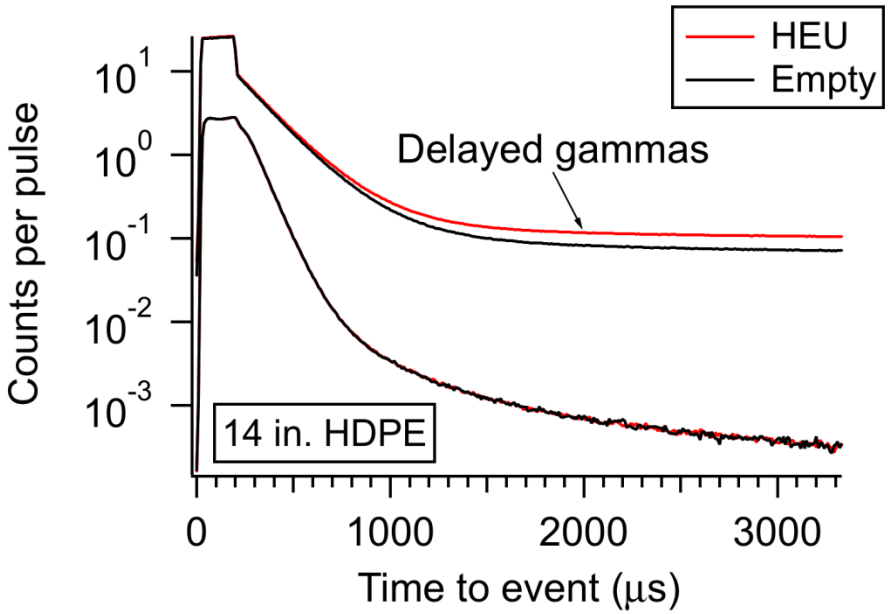




- **He-3 detectors observe attenuation limits of neutron detection**
- **Plastic scintillators look at surviving gamma signals**

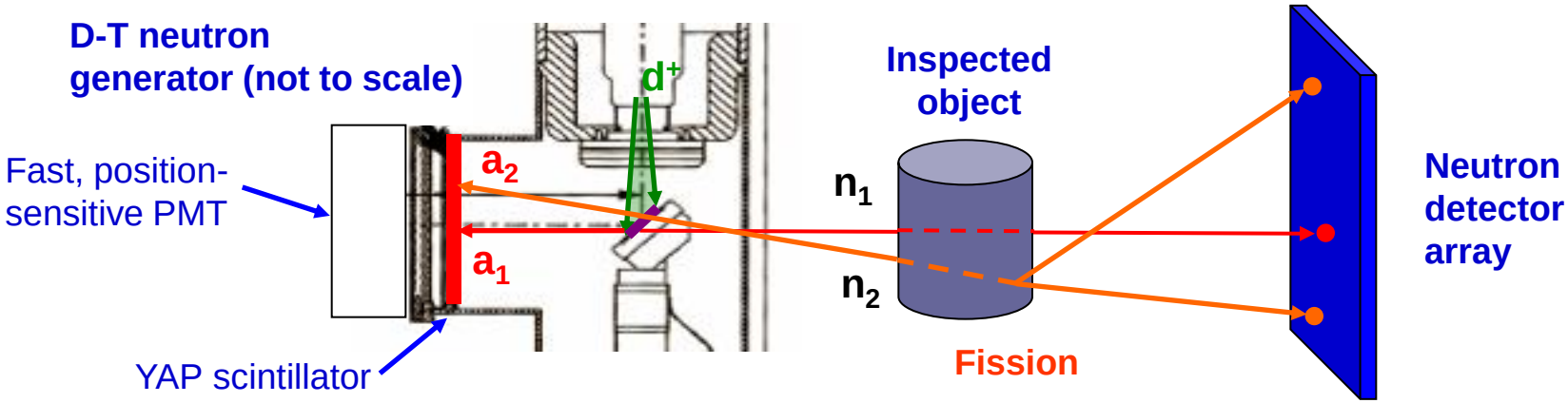
Snapshot of the Dataset

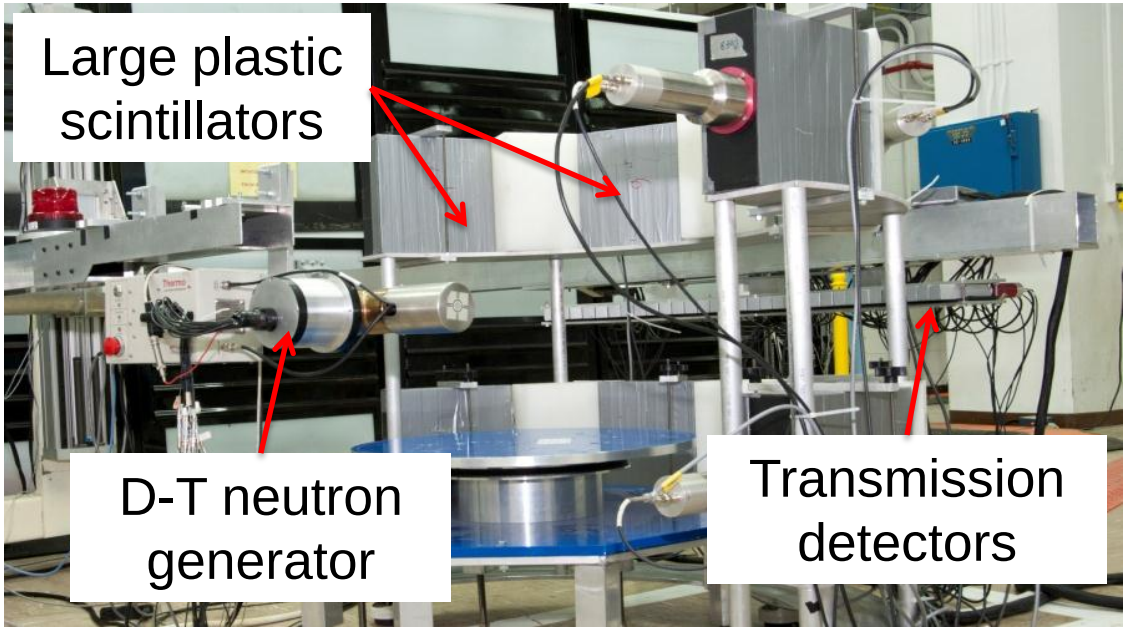




- **Strong neutron and gamma signals through modest amount of polyethylene shielding**
- **Increasing amounts of polyethylene result in long thermal neutron die-away times but delayed gamma signature still evident for high polyethylene thicknesses**
- **Results have been confirmed with MCNP to within a factor of ~2**

Measurement with High Z Shielding – Active-Induced Prompt Correlations



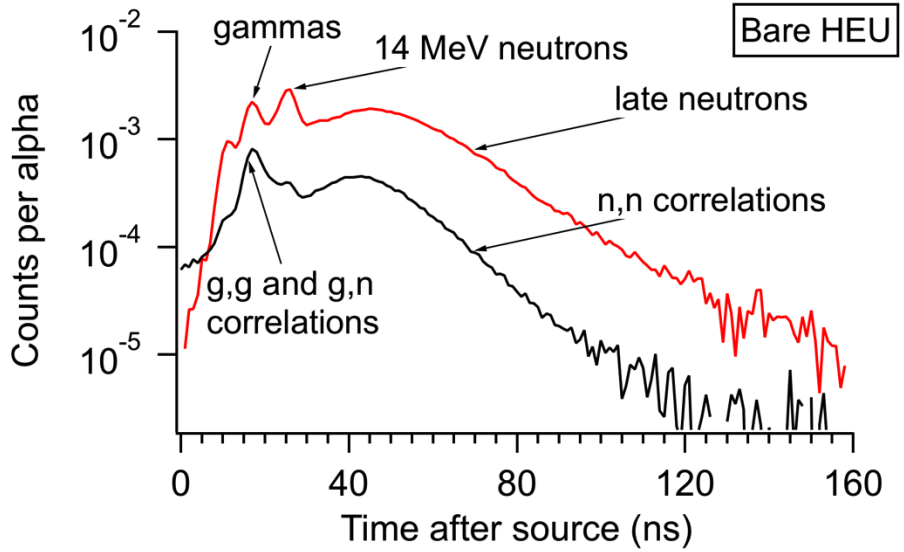


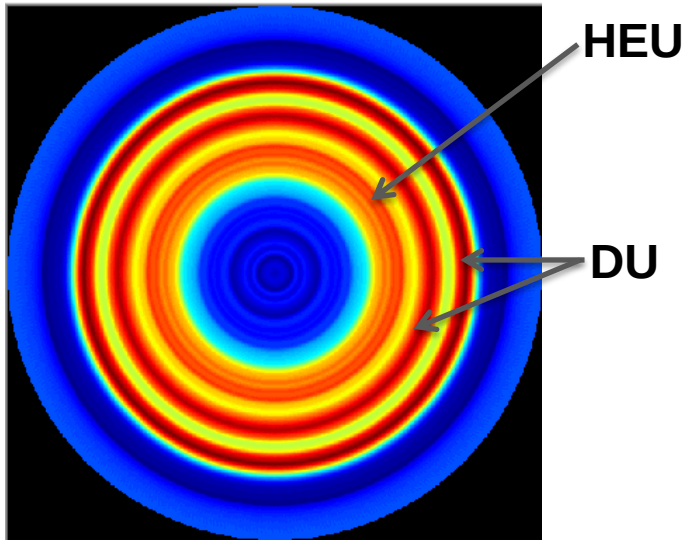
- **Low pixel density**
- **32 large pixel scintillator array for transmission**
- **8 large plastic scintillators for fission neutron detection**
- **16 alpha pixels**

Observables by Example

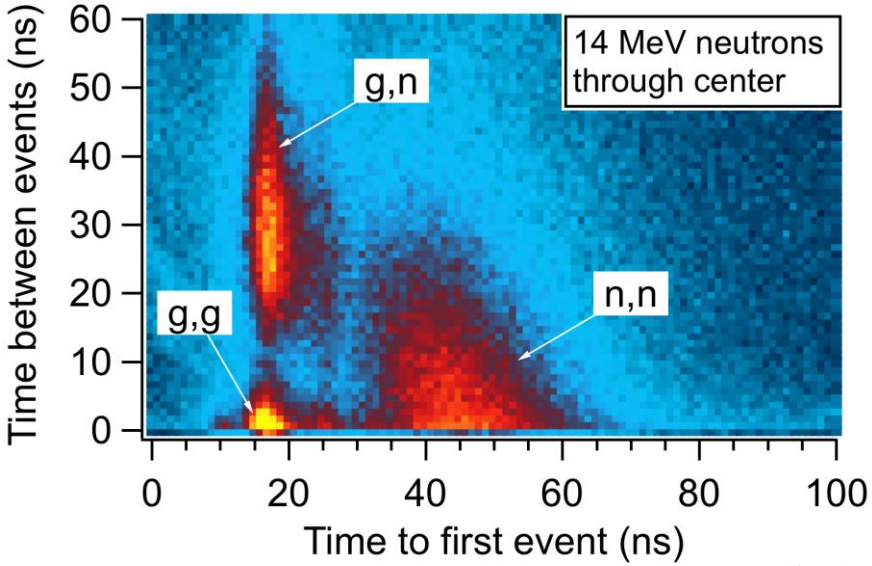
18 kg
HEU or DU

DU shields

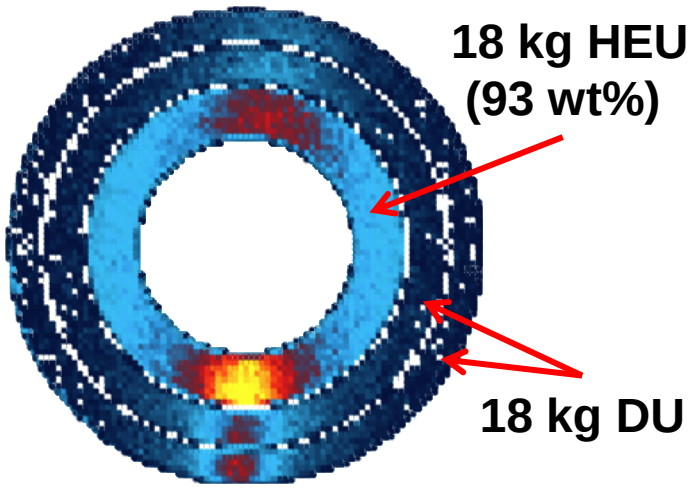


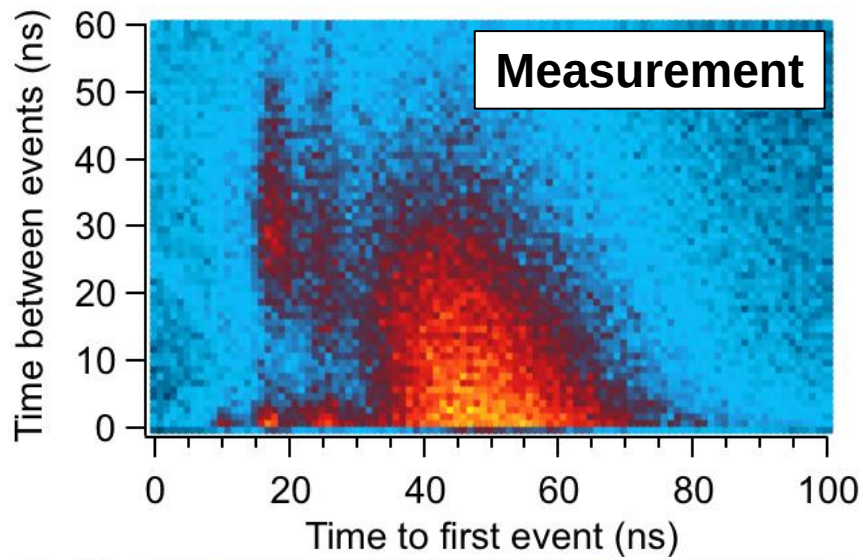


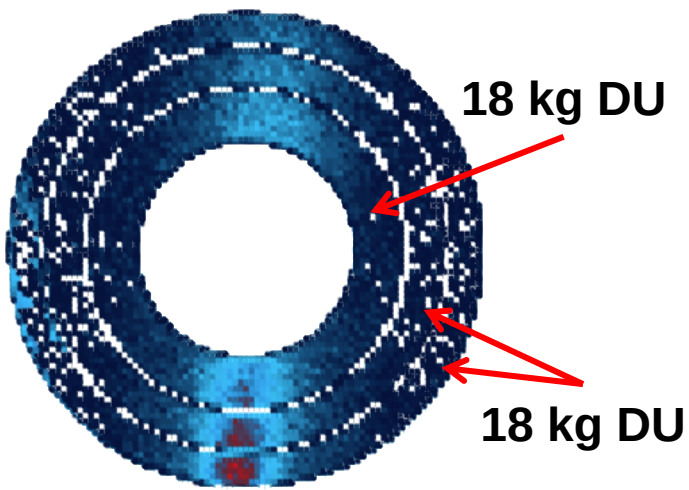
Transmission tomograph

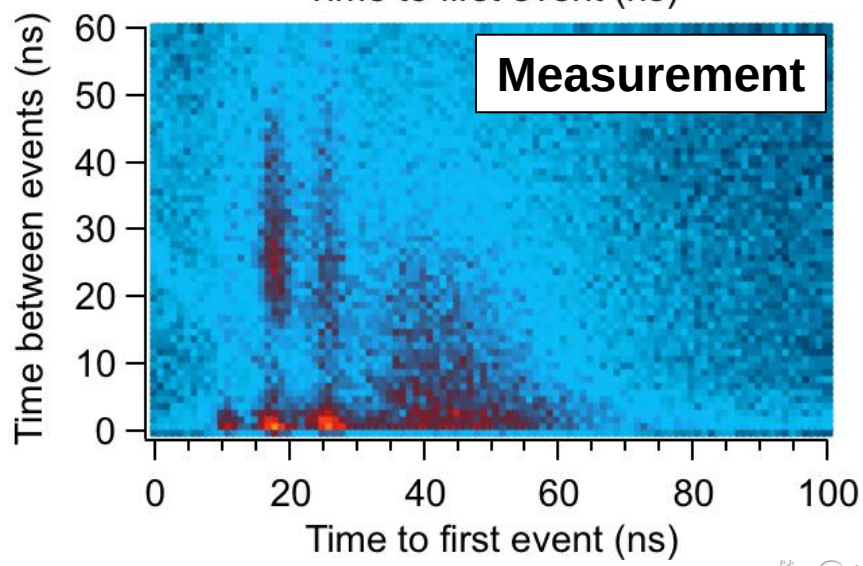


HEU vs. DU – Two Shields



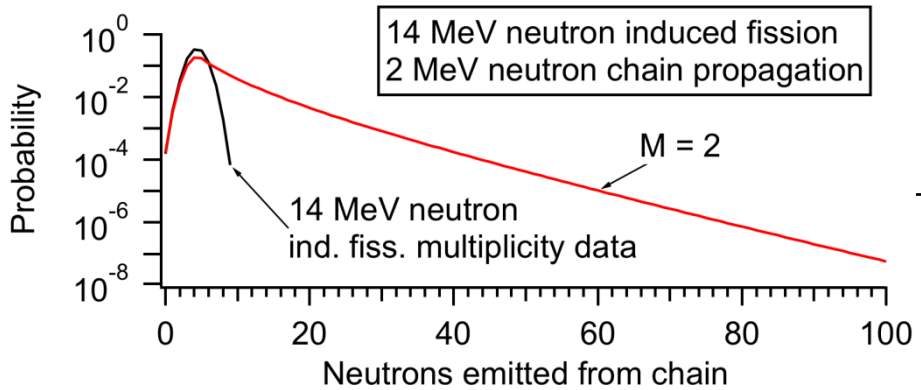




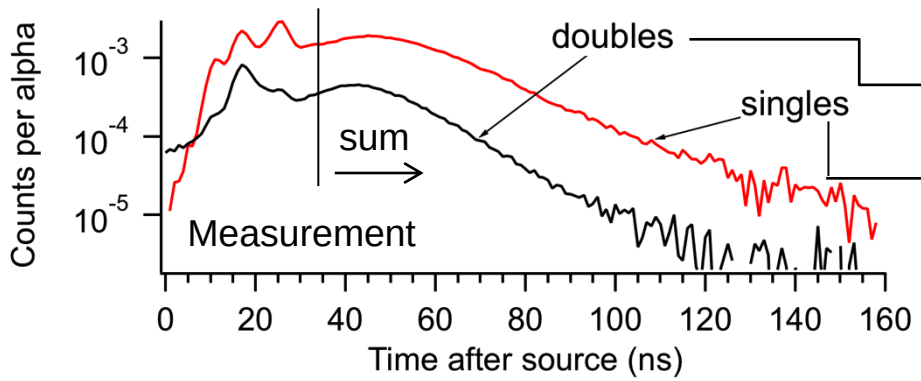


Simulated Fission Densities

Estimating Multiplication



$$\Upsilon_q(p) = \sum_{\nu=q}^{\infty} \binom{\nu}{q} P_\nu(p)$$



$$\frac{y_2}{y_1} = \varepsilon \frac{\Upsilon_2(p)}{\Upsilon_1(p)}$$

$$M = \frac{1}{1-\bar{\nu}p}$$

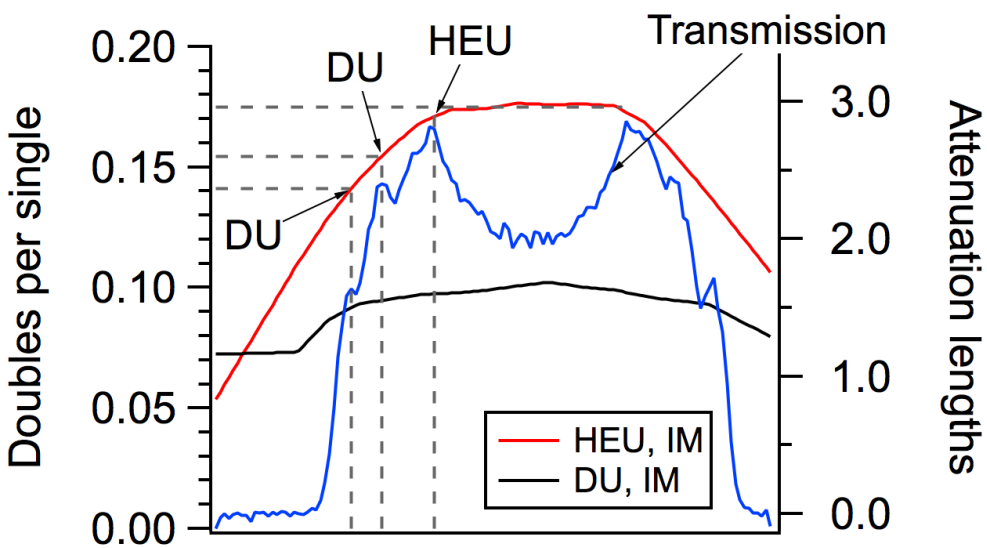
^{252}Cf TOF:
$\varepsilon = 0.047$

- **Assumptions:**
  - **Most of the singles and doubles originate from 14 MeV neutron-induced fission chains, eliminating the external source coupling**
  - **Chains propagate on 2 MeV neutron-induced fissions**
  - **Efficiency can be estimated from a ^{252}Cf measurement**

Measurement of HEU Shielded by DU

	DU		HEU		Imaging
Shield	**Measured M**	**MCNP M**	**Measured M**	**MCNP M**	**Corr. ε**
None	1.14 ± 0.07	1.12	1.73 ± 0.06	1.79	0.047
I	1.16 ± 0.06	1.16	2.00 ± 0.07	2.09	0.039
IM	1.15 ± 0.06	1.19	2.22 ± 0.08	2.26	0.032
IMO	1.12 ± 0.06	1.21	2.46 ± 0.09	2.36	0.026

Statistical 3σ error bars for 2 min. measurement



- **Model works surprisingly well despite competing effects like cross-talk, room return, (n,xn), dead time losses, and non-point-like nature of configuration**
- **Imaging permits estimate of efficiency decrease for DU shielding if boundary can be identified**

Future Work

- Characterize the energy distribution of gammas in the low-Z shielding case
- Determine the limits of extracting parameters like multiplication with tests of increasingly complex configurations
- Use the data as benchmarks for potential improvement to radiation transport models

Acknowledgments

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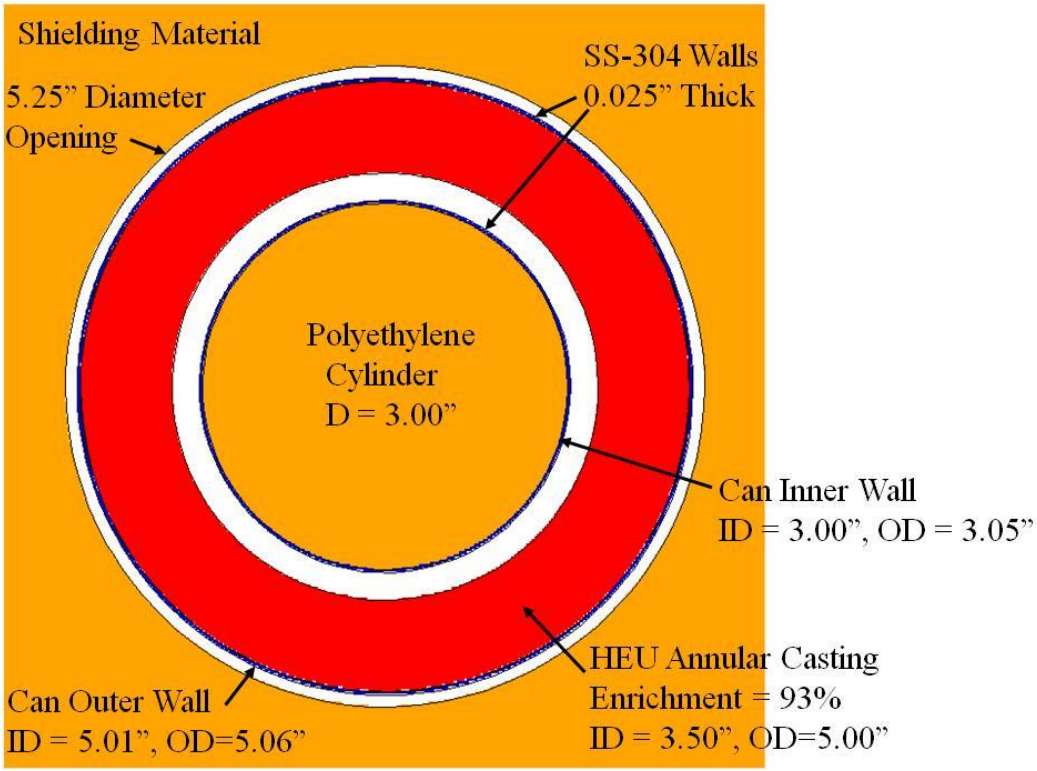
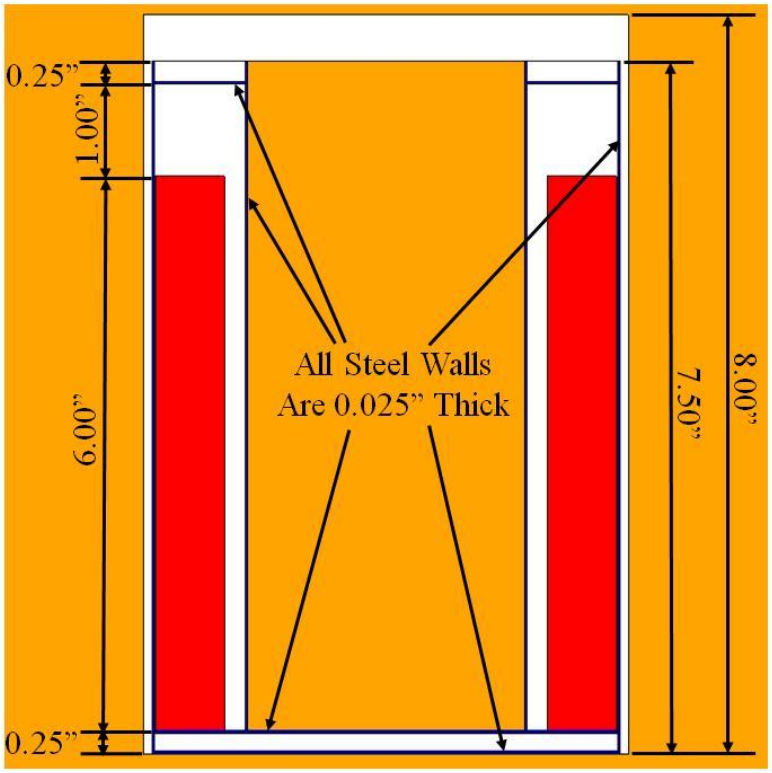
Support

HEU Casting Configuration





Shielding Material	k-eff with poly cylinder	k-eff w/o poly cylinder	Multiplication with cylinder	Multiplication w/o cylinder
Polyethylene	0.873	0.782	7.87	4.59