Active Neutron Multiplicity Counting of Kilogram Quantities of Highly Enriched Uranium

MTV Workshop, 2022

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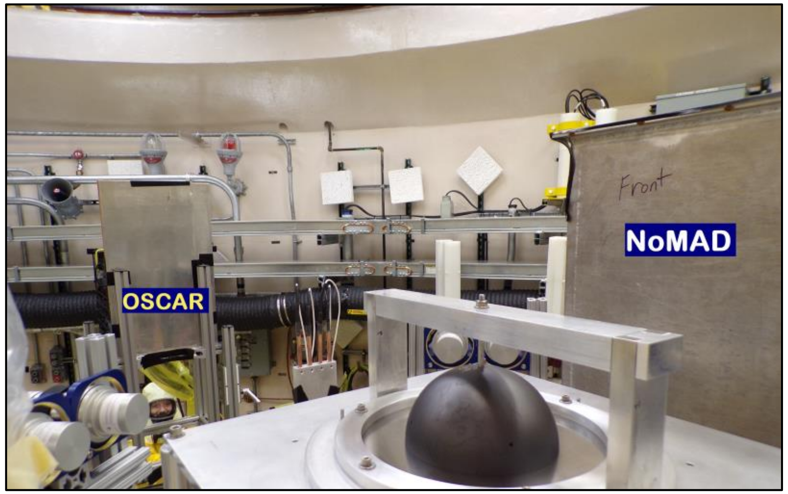
Introduction and Motivation

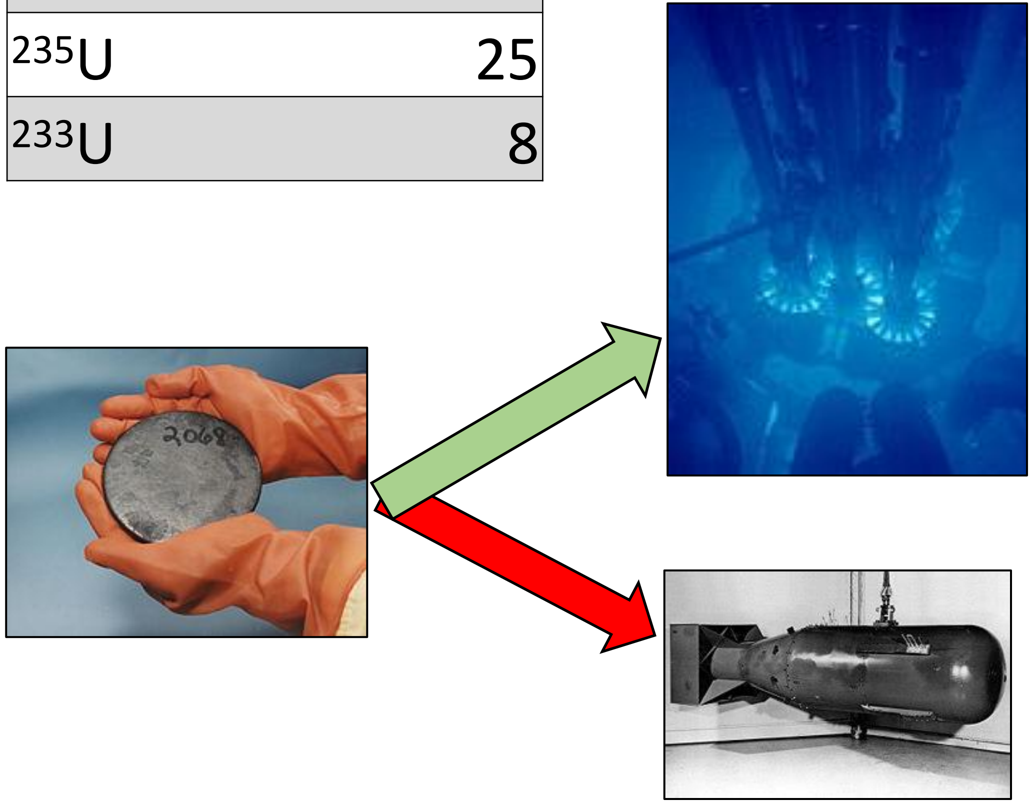
- **M**easured **U**ranium **S**ubcr**i**tical and **C**ritical (MUSiC)
- Benchmark measurements
- Analyze neutron noise techniques for large HEU assemblies, specifically **Neutron multiplicity counting (NMC)**
- Neutron multiplicity counting provides the activity and quantity of fissionable and fissile material
  - Useful in **safeguards** and criticality safety



Mission Relevance

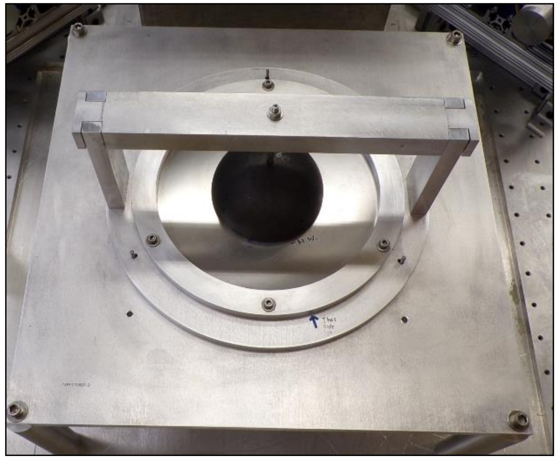
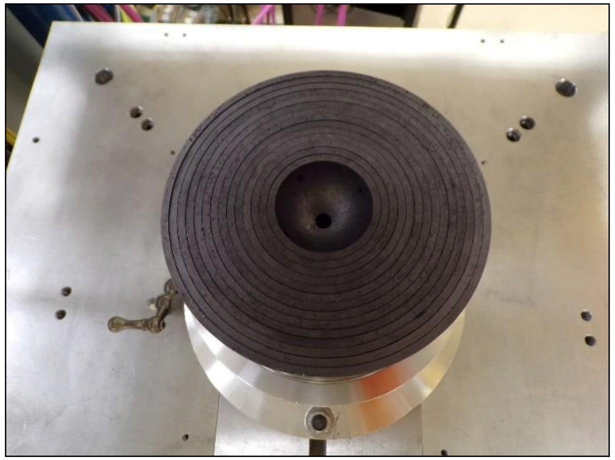
- International Atomic Energy Agency (IAEA) significant quantity (SQ) of HEU = 25 kg
  - We measure configurations of ~10-60 kg HEU
- Neutron multiplicity counting estimates system parameters of special nuclear material (SNM)
- Verifying declared amounts crucial to avoid diversion

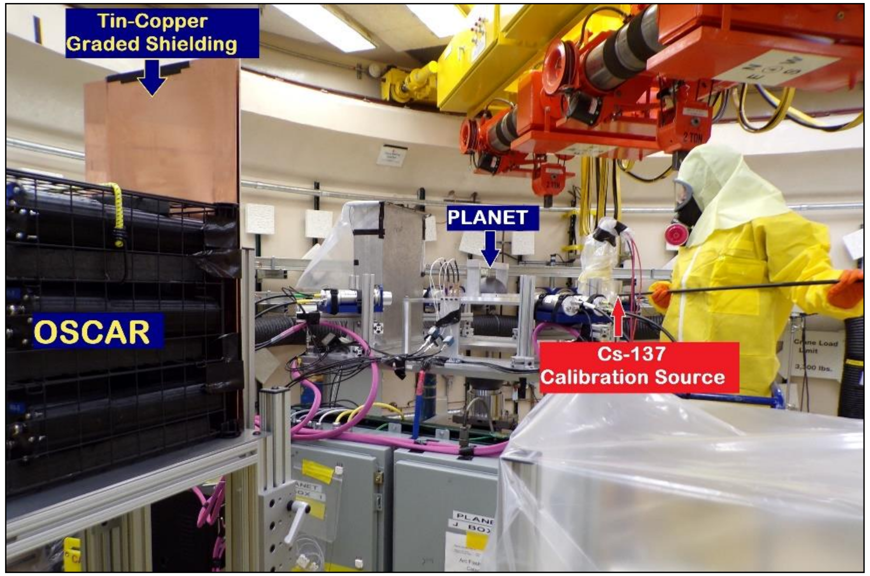
SNM	SQ (kg)
^{239}Pu	8
^{235}U	25
^{233}U	8



Technical Approach

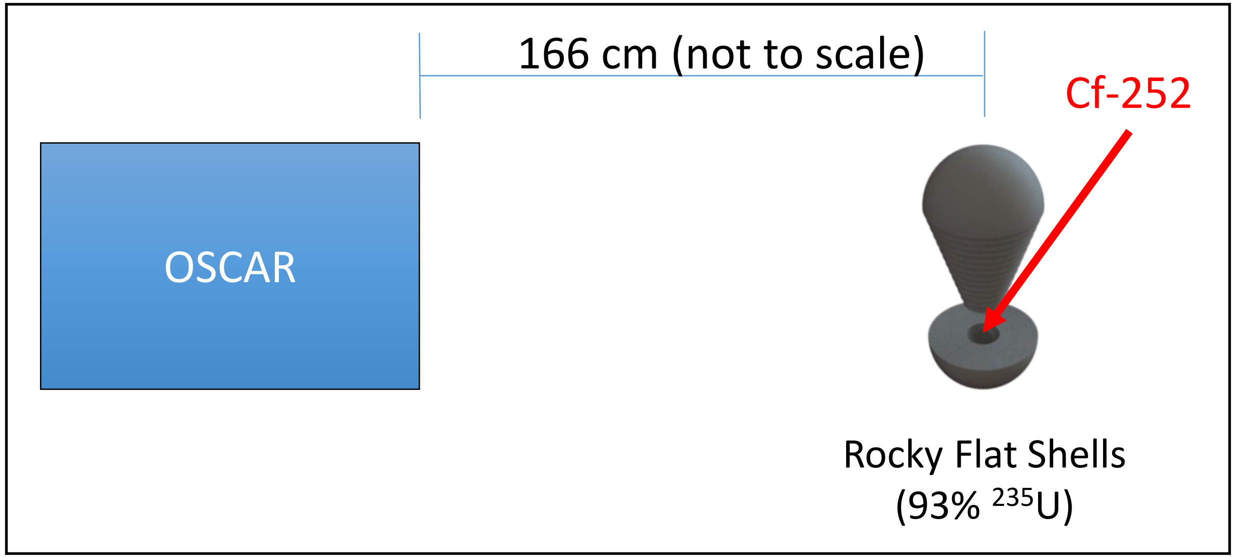
- Experiment at NCERC
- Rocky Flats shells (93% ^{235}U)
    - Cf-252 source at center
- OSCAR – 3 by 4 array of stilbene
    - Measure tens of kg HEU configs
    - PSD for neutron detection
- Analyze neutron pulse times
    - Set gate width τ, sequential gating
    - Use three-parameter model to calculate multiplet rates and system parameters

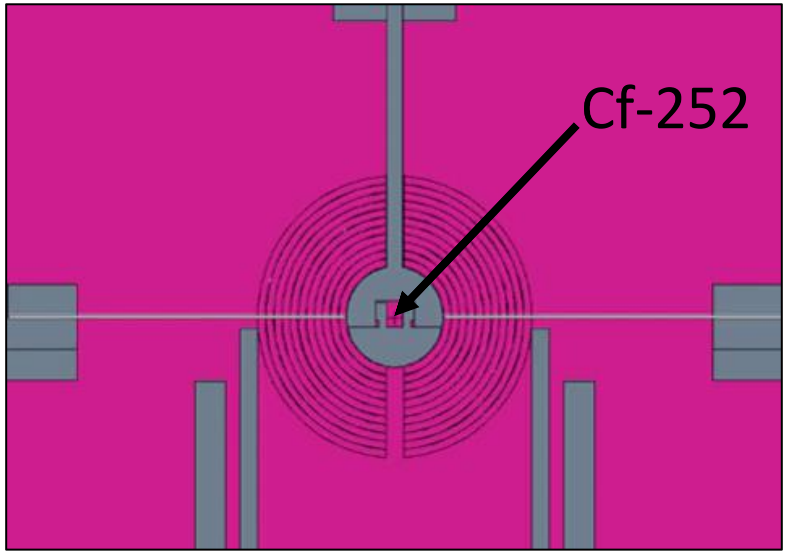





Technical Approach

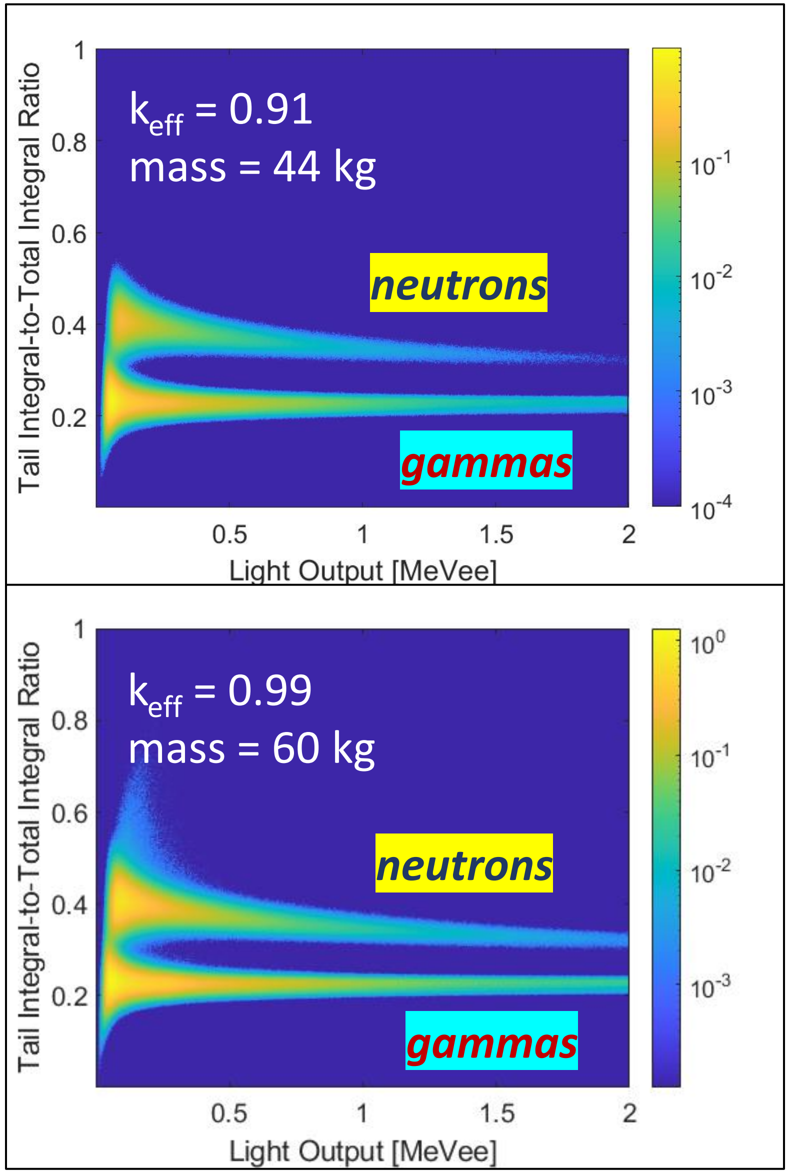
- Measured 166 cm from center for minimum 60 min/configuration
- Simulate configurations in MCNP6.2
  - M_L and k_{eff} for each configuration
- Simulate detectors in MCNPX-Polimi
  - Replicate detector time-correlated neutron response





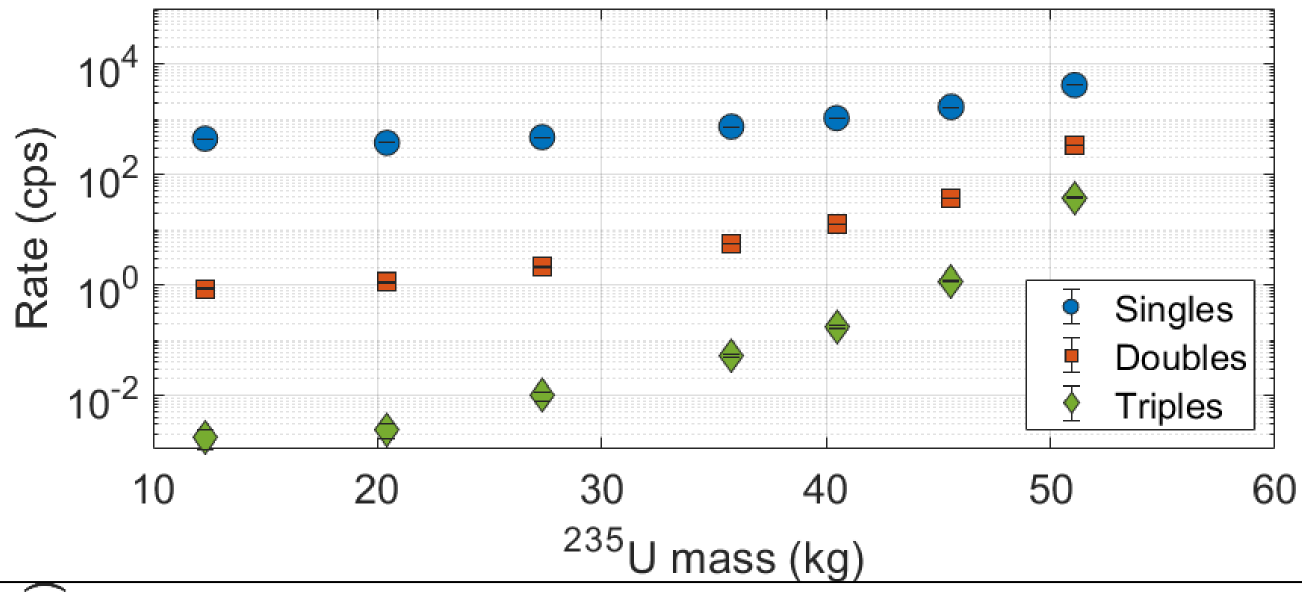
Pulse-shape discrimination

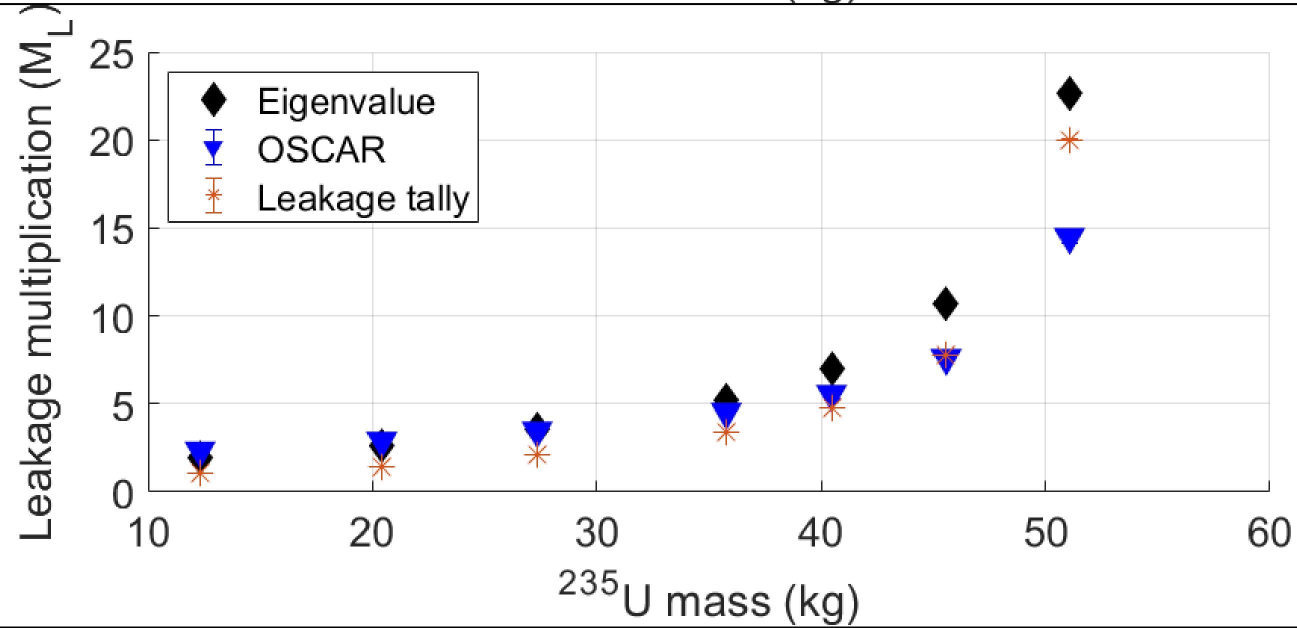
- Measured fast neutrons and gamma rays from kg-quantity highly-enriched uranium
- Increasing intensity of neutron band with each configuration
- Minor pulse pileup above neutron bands for closest to critical configurations
- Take 50 keVee slices and chose best separation
- Take 3σ upper boundary of gamma distribution for each slice and fit with a power function for discrimination line



Results

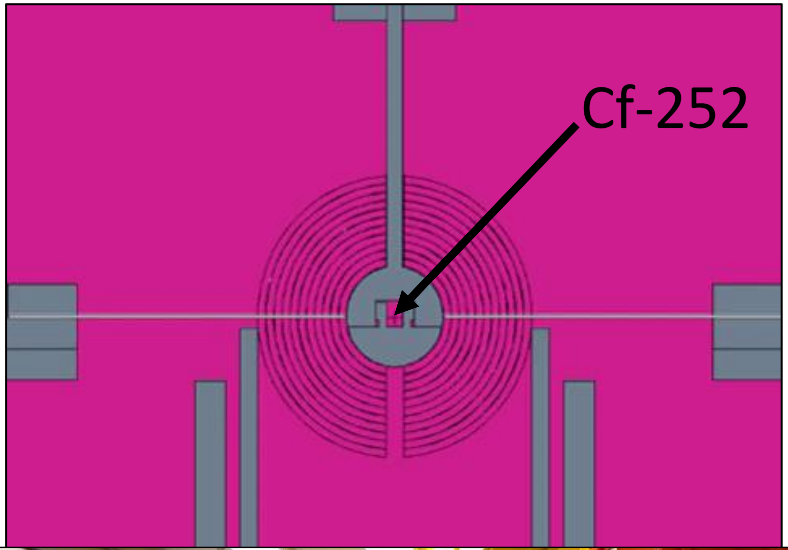
- $\tau = 1\ \mu s$
- Singles, doubles and triples increase with HEU mass
- Leakage multiplication estimates bounded by two simulation values
  - MCNP6.2 KCODE
    - Calculate M_L from k_{eff} eigenvalue
  - MCNP6.2 F1 tally
    - Take M_L as F1 tally value (neutron leaked from assembly per source neutron)

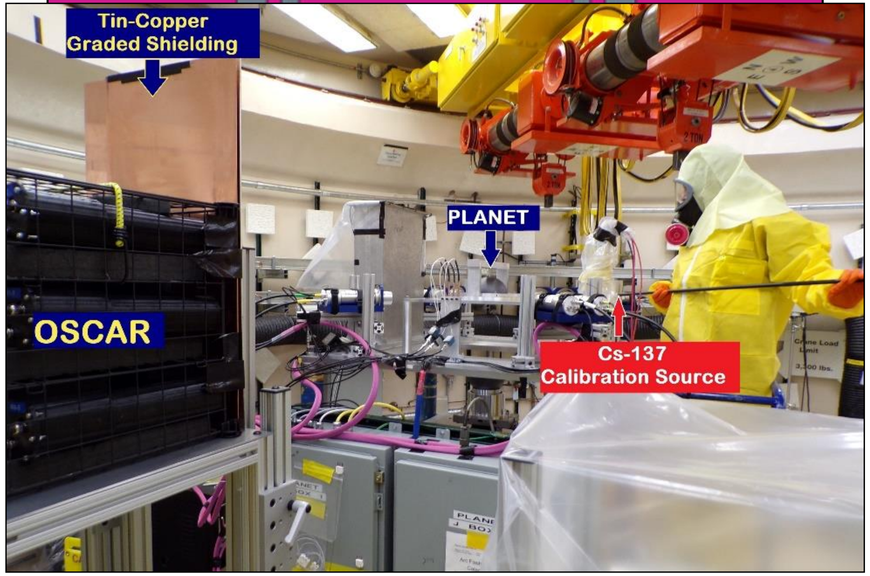




Expected Impact

- First neutron multiplicity counting with safeguards focus on large quantities of HEU with organic scintillators
- Neutron multiplicity counting of bulk HEU provides experimental comparison for “Multiplicity Theory Beyond the Point Model”
- Promote continued use of organic scintillators for measurements at NCERC and elsewhere





MTV Impact

- MTV connected our group closely with NEN-2 at LANL
- We will continue to collaborate with LANL at NCERC and elsewhere
- Explore new system designs for plutonium samples in collaboration with LANL

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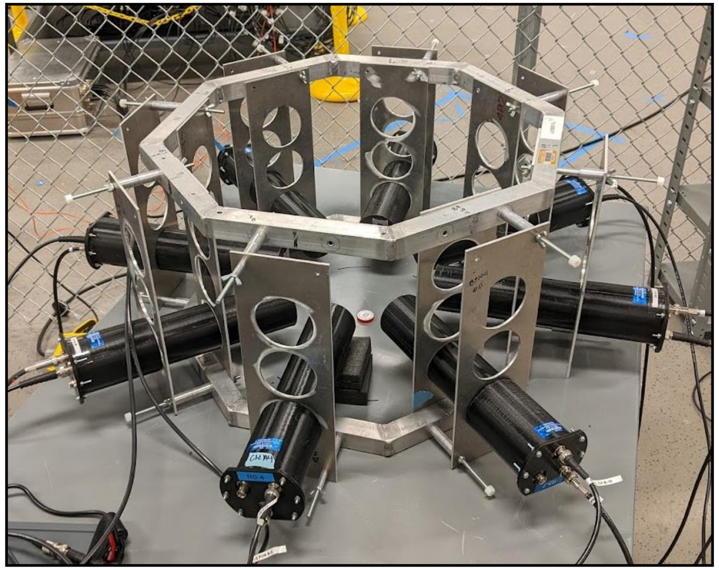
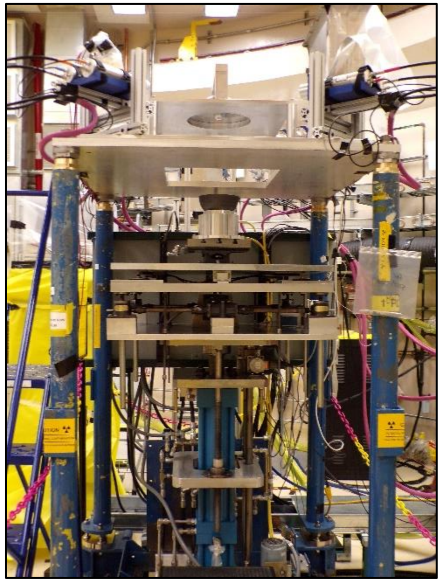
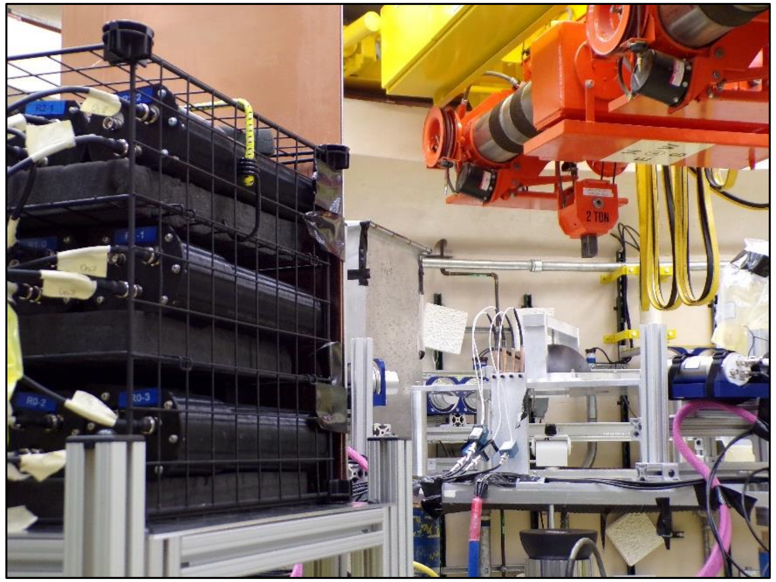
NCERC NATIONAL CRITICALITY EXPERIMENTS RESEARCH CENTER



Conclusion



- First neutron multiplicity counting of > 10 kg quantities of HEU with organic scintillators
  - Precise measurement of multiplets
  - Decent estimates of M_L
- Furthers the use of organic scintillators for neutron noise measurements



Next Steps

- Simulating detector response in MCNPX-PoliMi
  - Validate understanding of measured response
- Validation of “Multiplicity Theory Beyond the Point Model”
  - Compare measured neutron multiplicity counting values to theory
- Coupling of interrogator and sample
  - For $M_L < 2$, has been shown to strongly correlate
  - Investigate for these configurations of $M_L > 2$
  - Estimate sample masses with coupling

Acknowledgements

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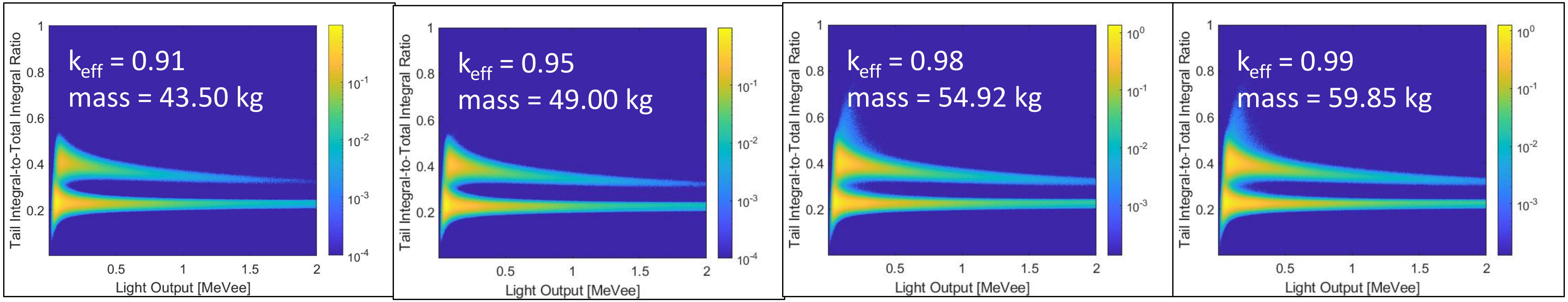
Additional Slides

Pulse-shape discrimination for neutrons

- Increasing intensity of neutron band with each configuration
- Minor pulse pileup above neutron bands
- Take 50 keVee slices and fit neutron and gamma tail-to-total histograms to gaussian
- Take 3σ upper boundary of gamma distribution for data point and fit $ax^b + c$ to discrimination points. All points above $ax^b + c$ are taken to be neutrons



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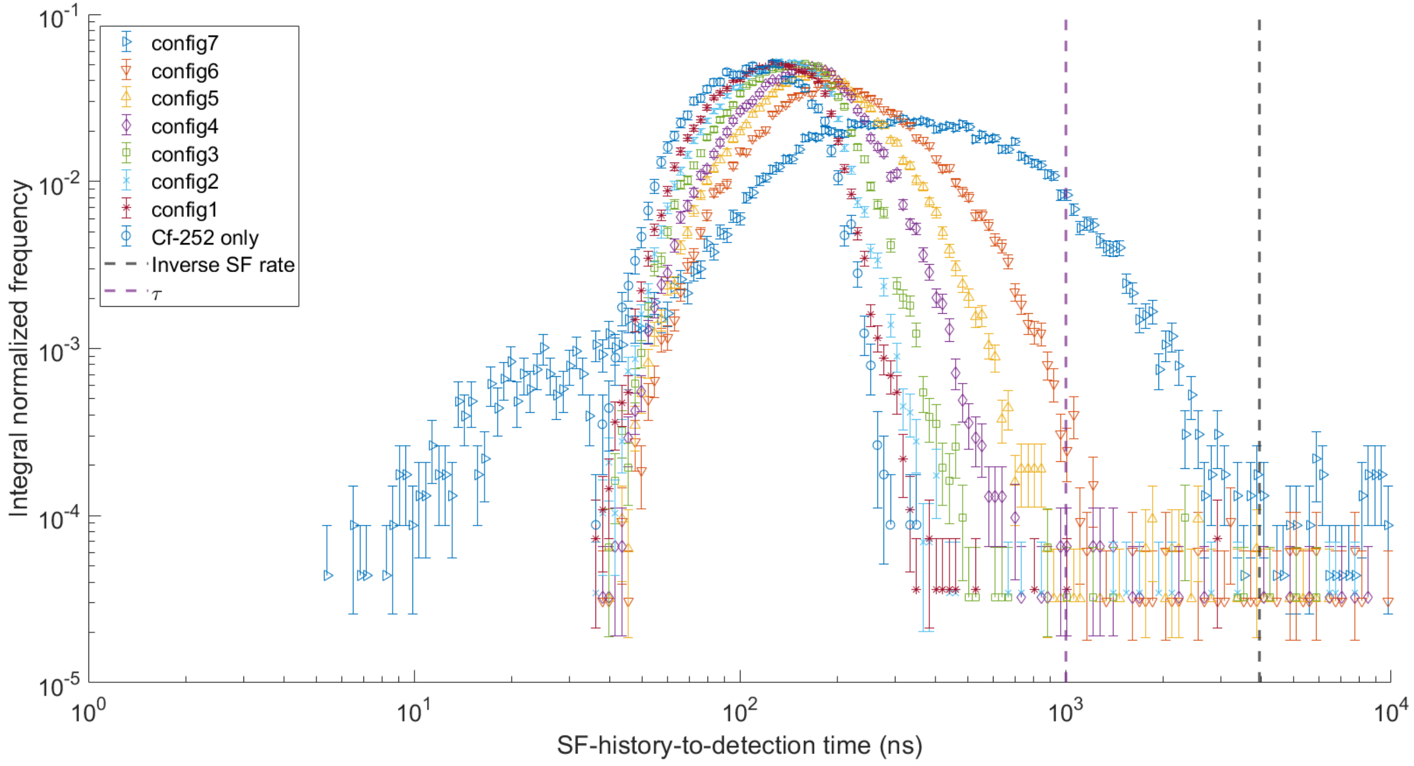
Preliminary PoliMi Results (Time-to-detection)

- Simulation shows the distribution of Cf-252 SF start time to neutron detection
- As our fission chains increase with each configuration the mean of our timing distribution increases
- Surprising quick detections for config7 (closest to critical) need to be further investigated



Feynman-Y Results

- Clearly shows multiplication of doubles rate across configurations
- Further justifies 1 μs τ w/ plateaus
- Saturation of detection system seems to be a lesser issue for doubles than singles