Passive Time Coincidence Measurements with HEU and DU Castings

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Passive Time Coincidence Measurements with HEU and DU Castings

- **Participating Laboratories**
  - **Oak Ridge National Laboratory**
  - **NNSA Y-12 National Security Complex**
- **Investigators**
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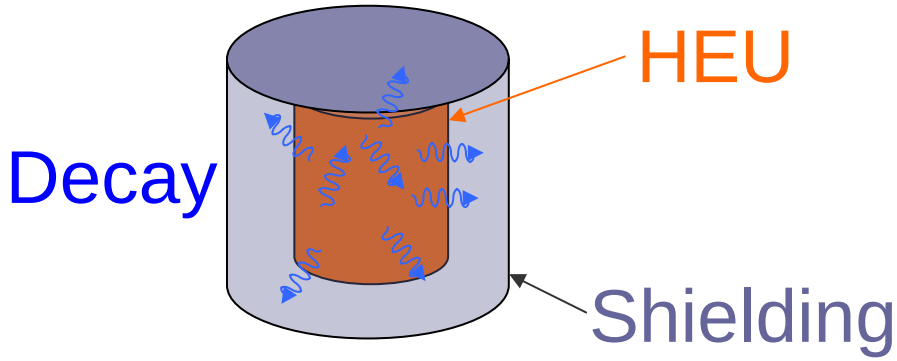
  - **S. McConchie (ORISE)**
  - **M. Hassler, T. Hawk (Y-12)**
  - **J. Henkel (UT)**

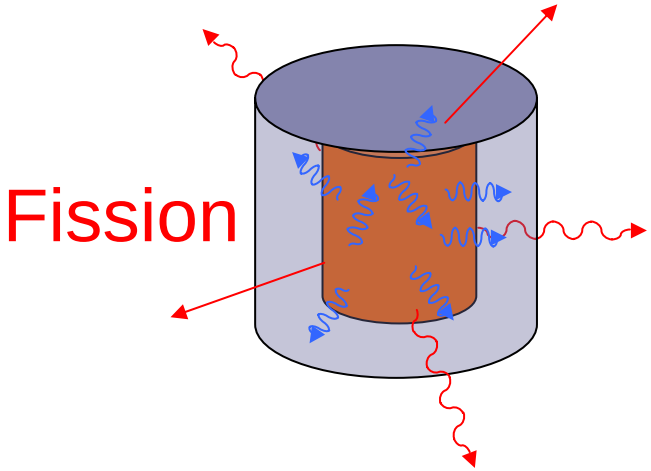
Passive Measurement Program

- **Evaluate the ability to passively determine the presence of highly enriched uranium (HEU) and distinguish it from depleted uranium (DU)**
- **Compare the utility of ^{3}He detectors and liquid scintillators**
  - **^{3}He detectors provide neutron coincidence information on the time scale of 100s of microseconds**
  - **Liquid scintillators with pulse shape discrimination provide neutron and gamma coincidence information on the time scale of 10s to 100s of nanoseconds**
- **HEU and DU measurements with ^{3}He detectors presented here**

Passive Detection Signatures

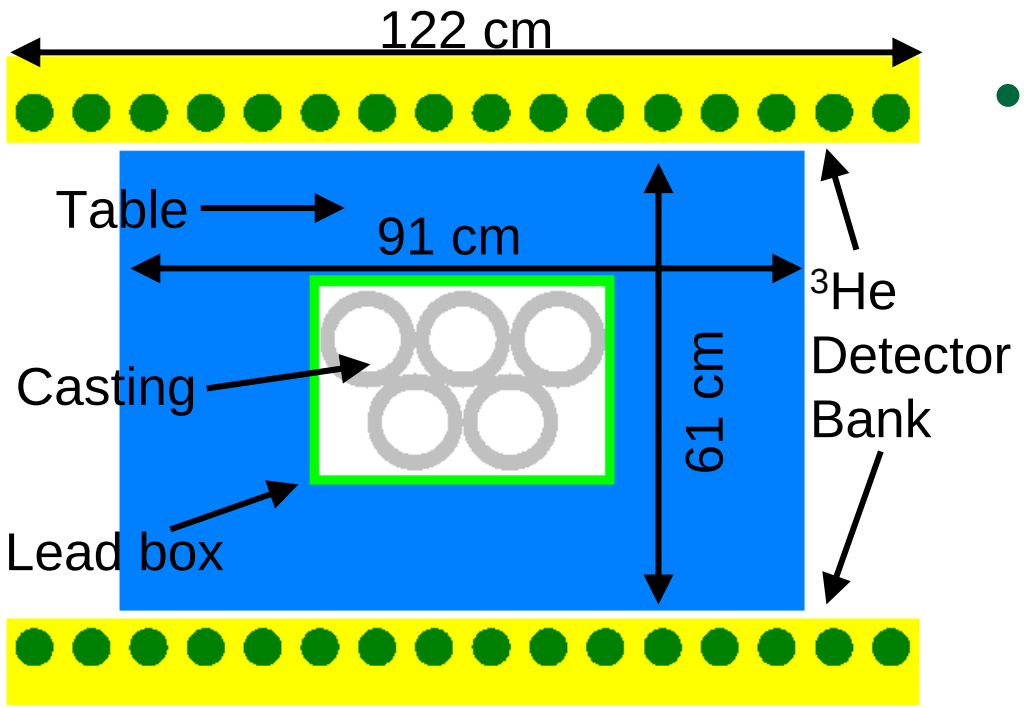
- **Passive detection of HEU is possible with either decays or fissions**





- **^{235}U decay yields 186 keV gamma (8×10^{7} γ s^{-1} kg^{-1}) difficult to detect through shielding**
- **^{235}U fission emits multiple neutrons and gammas**
  - **Correlated in time and more penetrating**
  - **Spontaneous fission rate is low (1.6×10^{-1} fissions s^{-1} kg)**

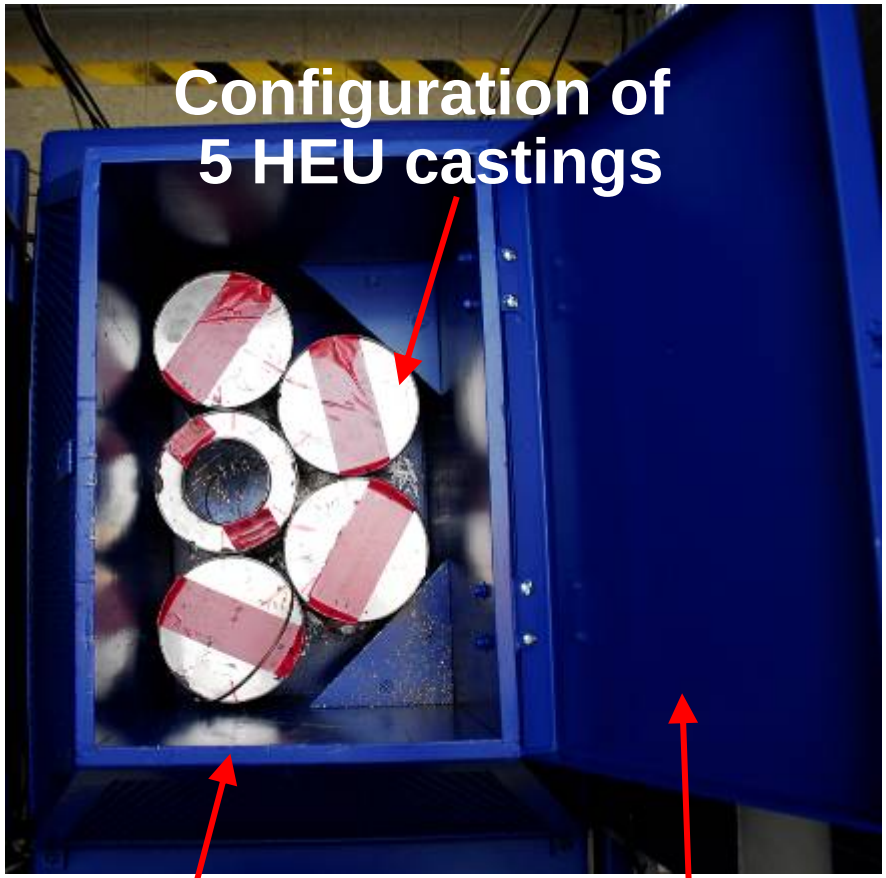
Experimental Setup

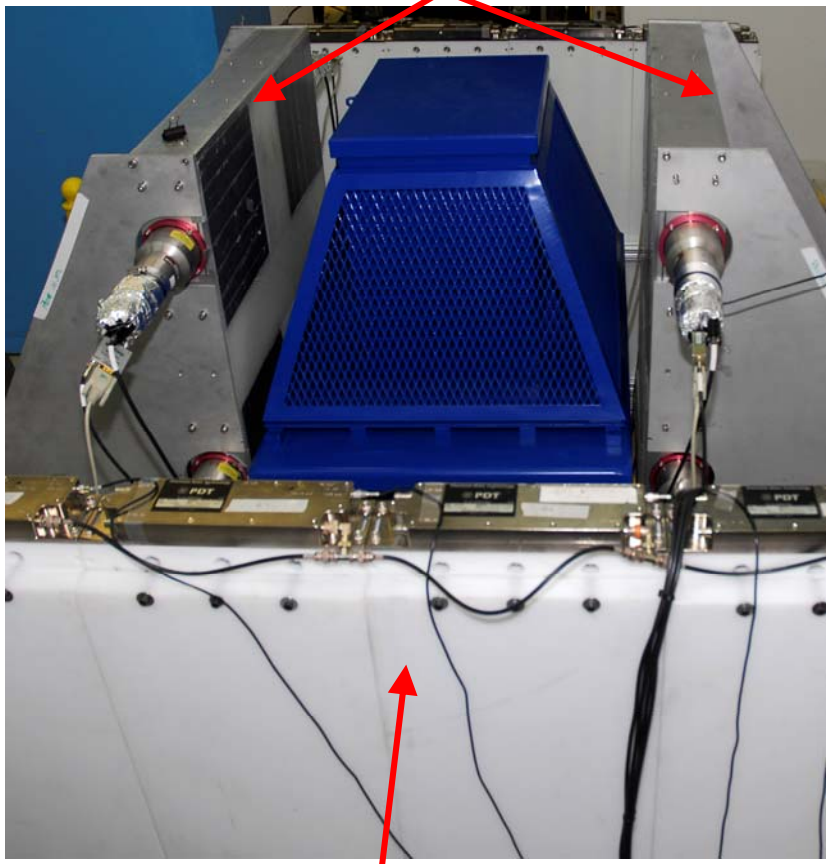


- **Casting samples:**
  - **1 to 5 HEU castings (93 wt%, 18 kg ^{235}U per casting)**
  - **1 to 3 DU castings**
  - **0.063 cm thick steel can enclosure**
  - **12.7 cm OD, 8.9 cm ID, 15 cm length**

- **Castings placed in 1.27 cm thick lead box on table**
  - **Bottom of box was 61 cm from floor**
- **2 banks of 32 poly moderated ^{3}He detectors**
  - **5 cm diameter, 91 cm length, 4 atm**
  - **Each bank located 30.5 cm from center of lead box**

Experimental Setup (Including Liquid Scintillators)





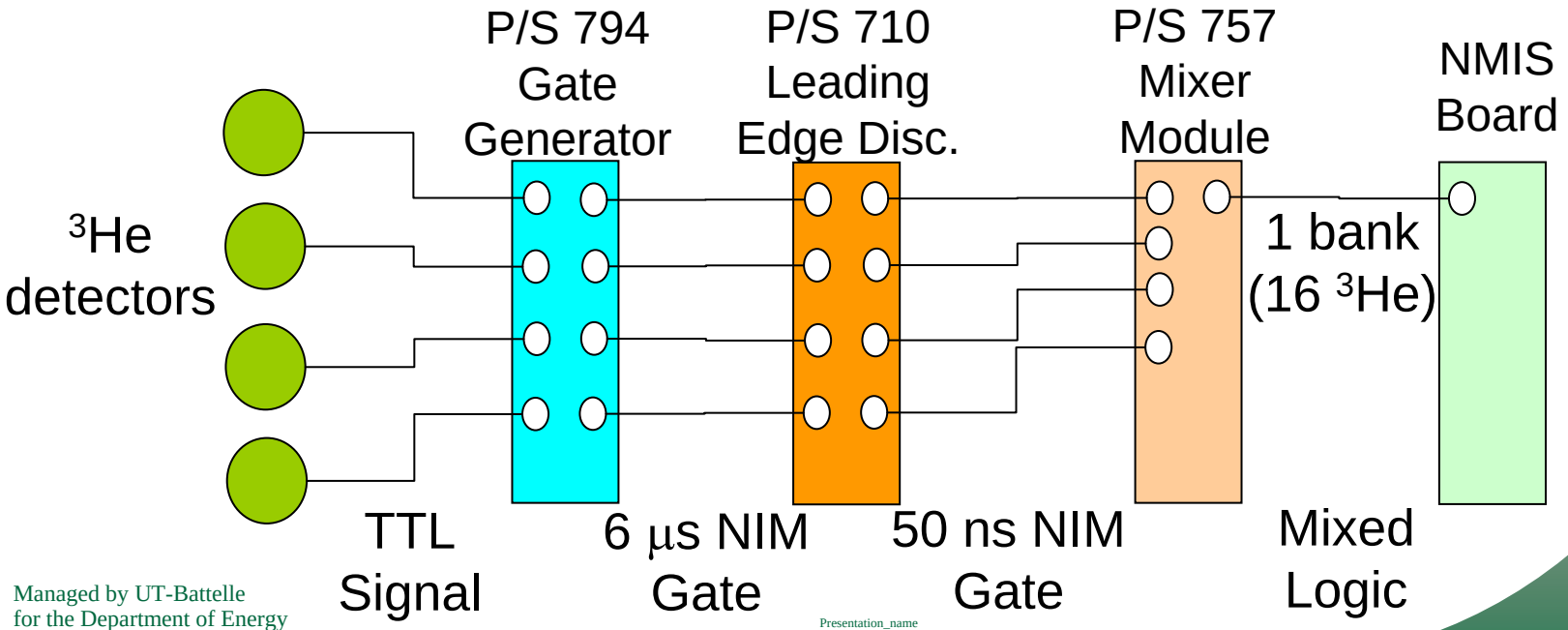
Lead liner

Steel box with lid open

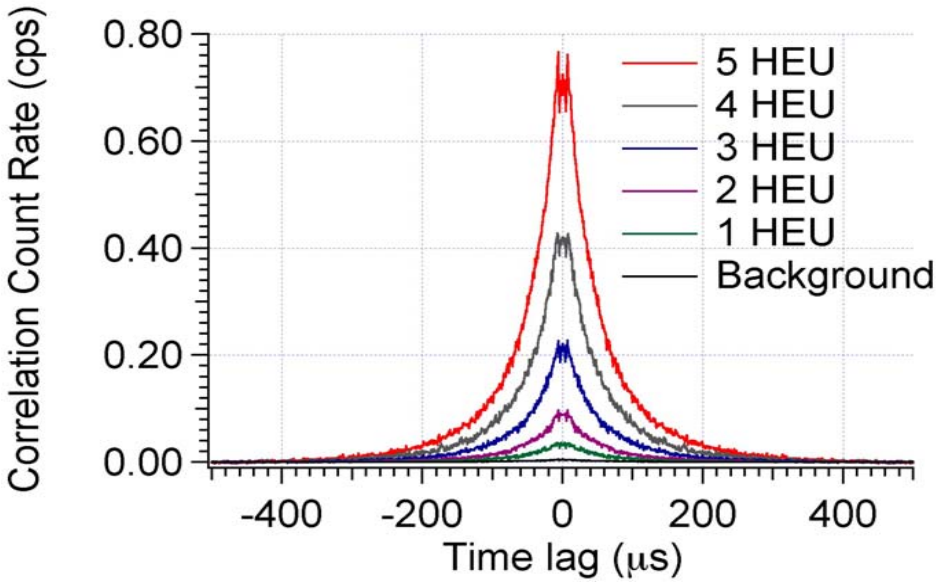
Bank of 16 moderated ^{3}He detectors

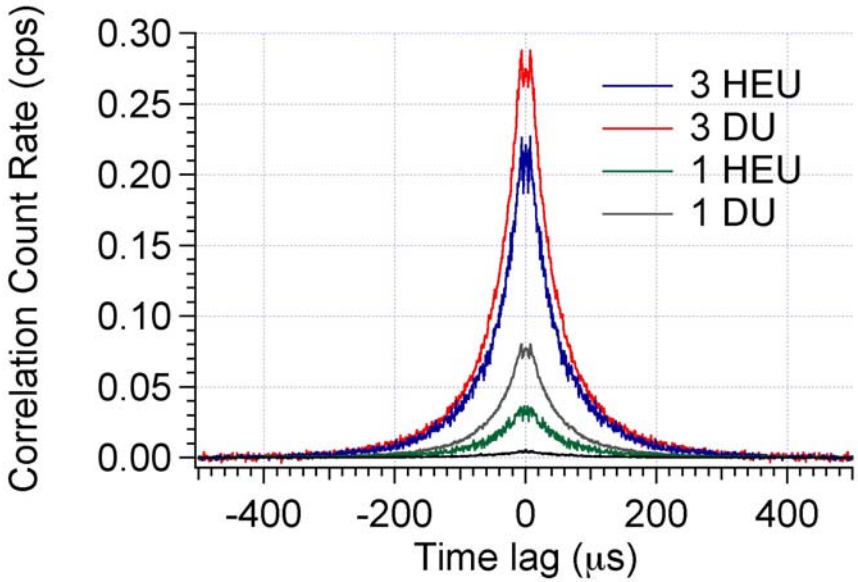
Electronics Setup with NMIS

- **Fast (1 GHz) online 10-channel time correlation processing with simultaneous list mode acquisition**
  - **2 dual card boards in PC with appropriate NMIS software**
  - **Online analysis gives time correlation functions, Feynman variance, multiplet rates, and multiplet probability distributions for an input time window**
  - **Offline analysis used to determine correlation functions and multiplet distributions for arbitrary window size and to calculate Feynman variance as a function of window size**



Neutron Coincidence Time Distributions

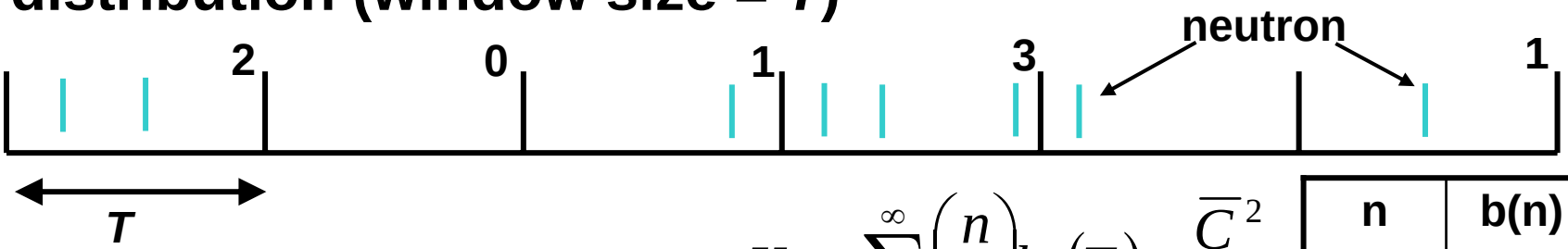




- **Neutron efficiency determined to be ~12.8% using Cf-252 fission chamber**
- **Measurement times ranged from 48 min to 70 min for the HEU samples and 191 min to 874 min for the DU samples**
- **Difference in doubles rate evident from HEU and DU neutron coincidence time distributions**
- **Normalizing to the same peak height shows a slightly higher amplitude doubles die-away for the HEU samples with the time constant determined by the moderator for the detector**

Feynman Variance (Y2F)

- **Feynman variance (Y2F) is related to the probability that two neutrons are from the same fission chain**
- **Calculated from the "random" gate multiplicity distribution (window size = *T*)**



- **The efficiency, fission rate, and multiplication can be estimated from *A***
- **Passive measurements on an HEU sphere have been performed at LLNL using this framework[1]**

$$Y_2 = \sum_{n=2}^{\infty} \binom{n}{2} b_n(T) - \frac{\overline{C}^2}{2!}$$

$$\overline{C} = \sum_{n=1}^{\infty} n b_n(T)$$

$$Y_{2F} = \frac{Y_2}{\overline{C}} = A\left(1 - \frac{1-e^{-\lambda T}}{\lambda T}\right)$$

n	b(n)
0	0.2
1	0.4
2	0.2
3	0.2

[1]Verbeke, et al, UCRL-PROC-231582, 2007.

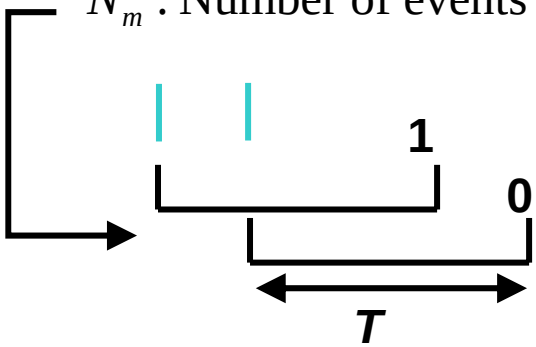
Multiplet Distribution

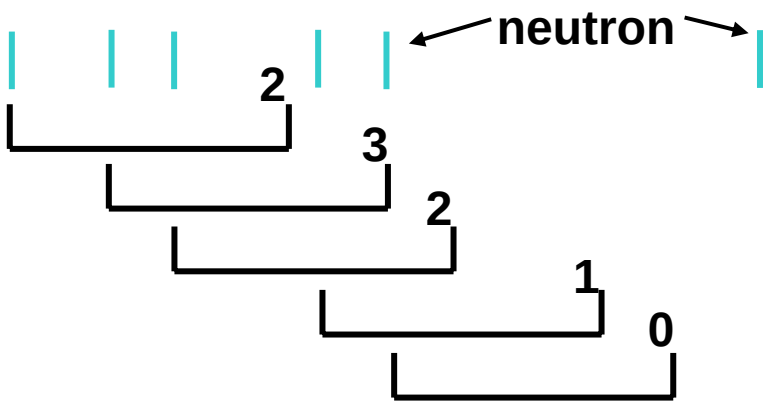
- **Multiplets[2] of order *m*, R_m, are the number of times *m* events occur in a time window, *T***

$$R_m = \frac{1}{B_0}\left(\sum_{\upsilon=0}^{\infty} B_\upsilon\right)\left[N_m - \sum_{\upsilon=0}^{\infty} R_{m-\upsilon} B_\upsilon \left(\sum_{i=0}^{\infty} B_i\right)^{-1}\right]$$

B_m : Number of events with m signals in a randomly triggered inspection interval

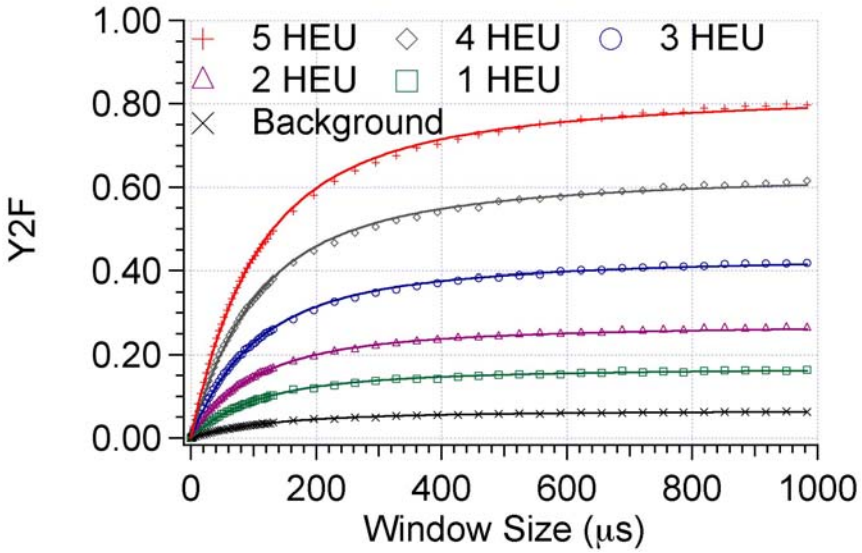
N_m : Number of events with m signals inside an event triggered inspection interval

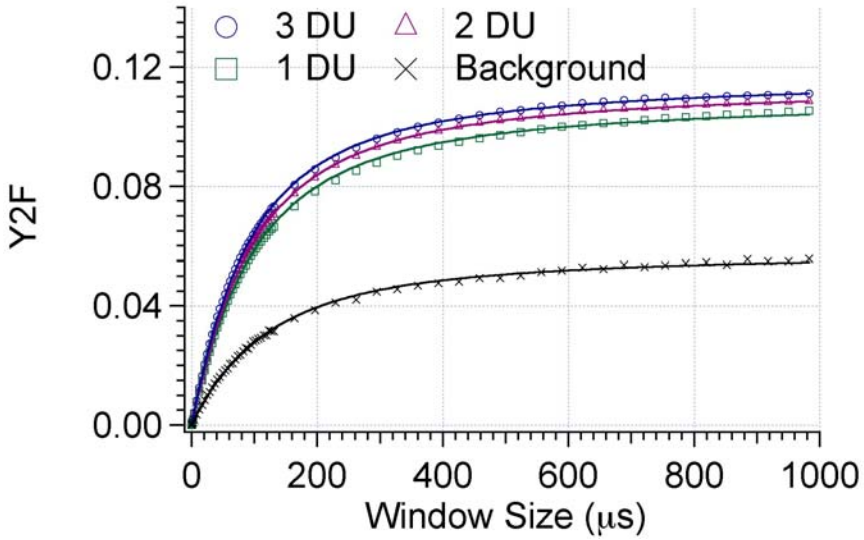


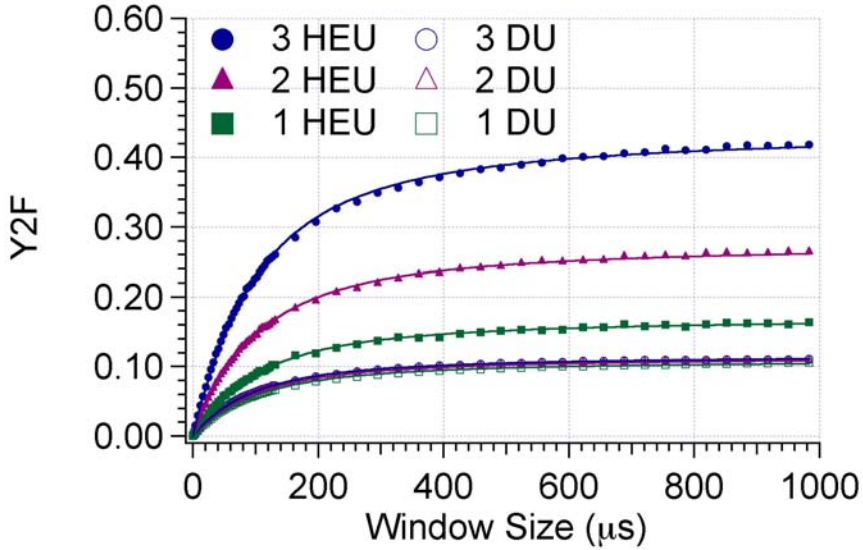


[2]R. Dierckx and W. Hage, Nucl. Sci. and Engr. 85, 325-338 (1983).

HEU and DU Comparisons – Y2F

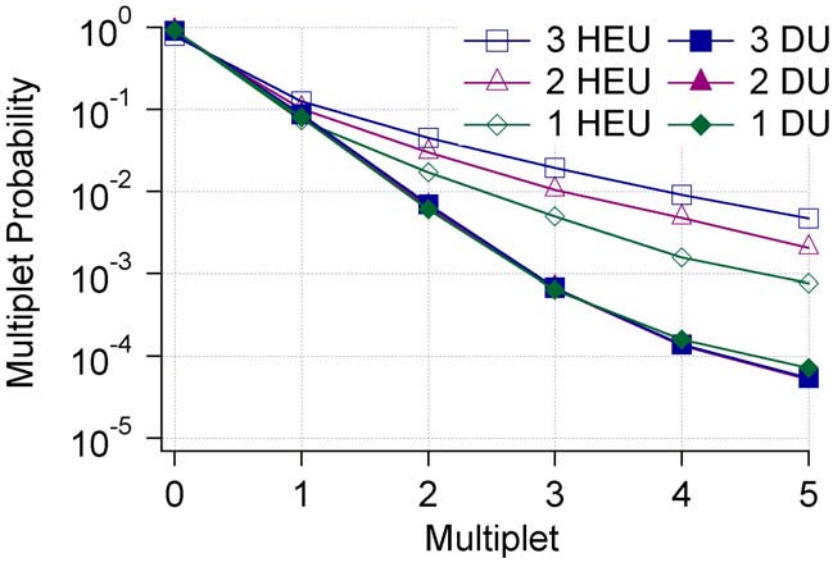


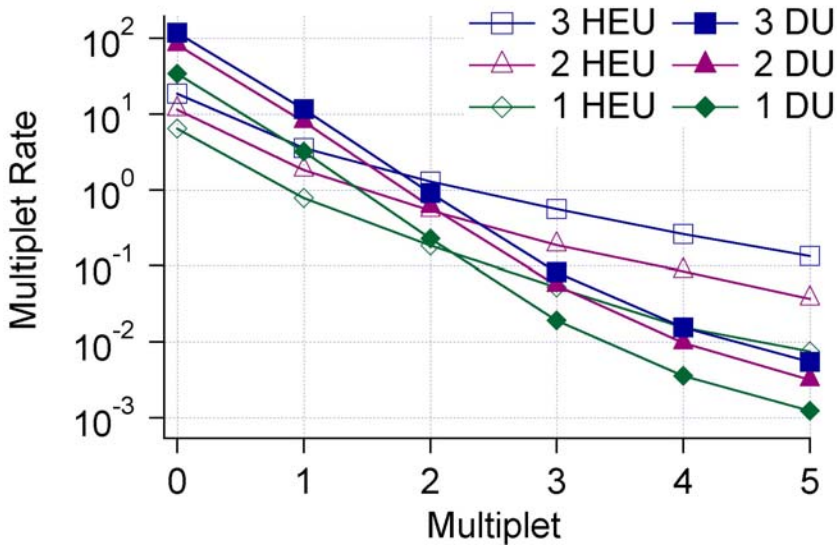


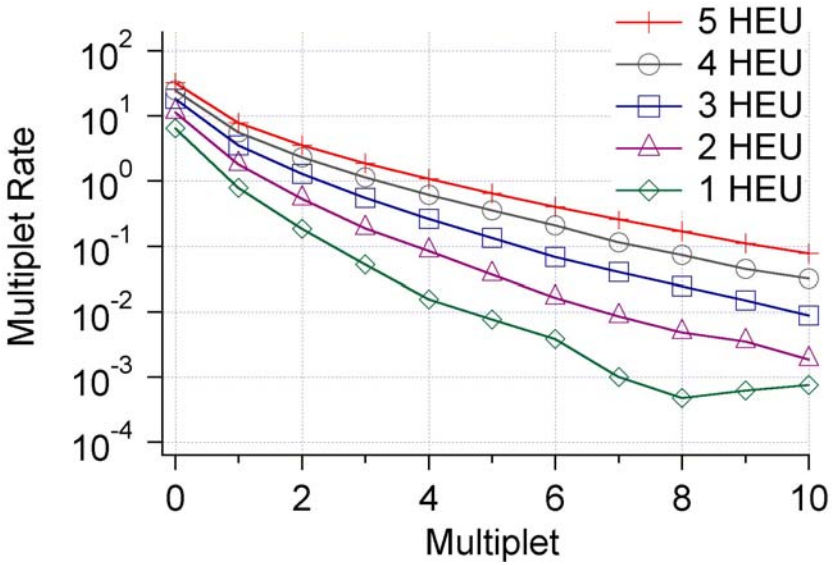


- **Y2F is sensitive to the number of castings**
- **HEU is distinguishable from DU for any number of castings**

HEU and DU Comparisons – Multiplets

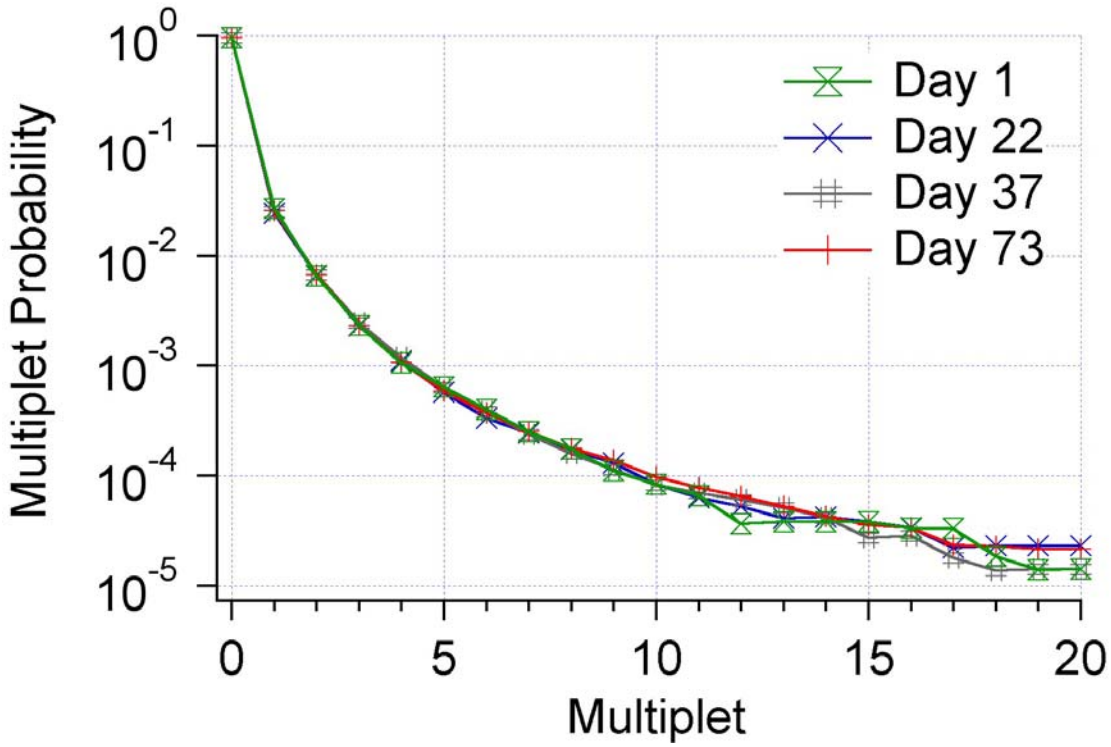






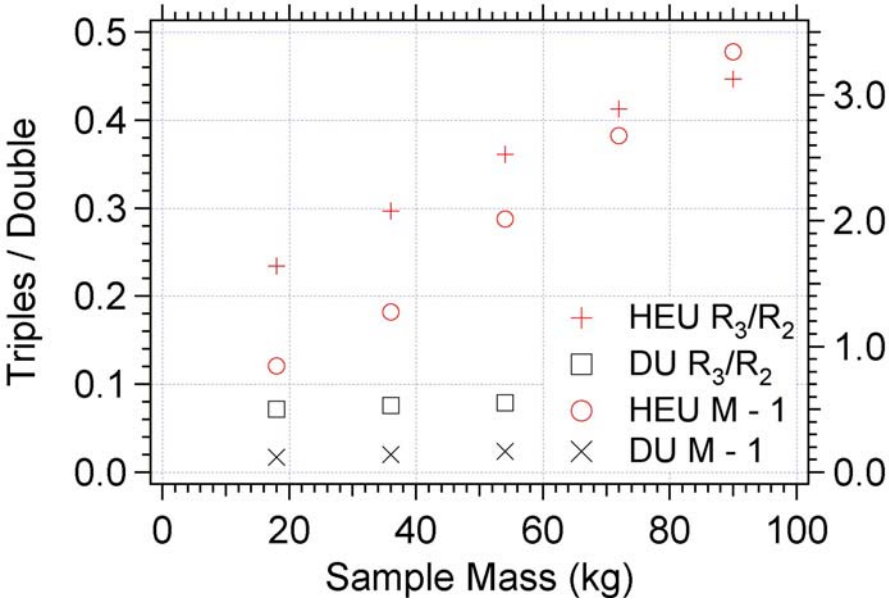
- **HEU and DU distinguishable for triples in probability space**
- **HEU amount dependence evident**

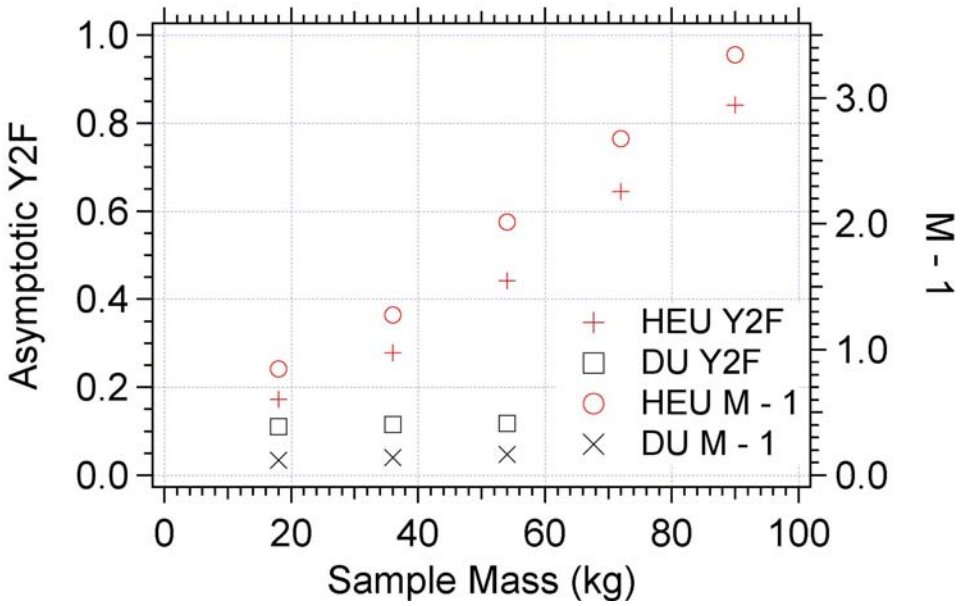
Background Stability



- **Background is stable with the movement of fissile materials around the measurement room over 73 days**

MCNP Simulations





- **Castings, lead box, and floor modeled in MCNP5 to calculate k_{eff} (multiplication)**
- **Triples/double and multiplication give linear trend with mass**
- **Feynman variance and multiplication trends have similar slopes**

Conclusions and Future Work

- **HEU presence and amount can be distinguished from DU using time coincidence methods**
  - **HEU and DU not distinguishable by doubles rate alone – need to estimate the multiplication**
  - **HEU and DU distinguishable by quadruples rate for the samples and geometry, but count rates are low**
- **Future work includes:**
  - **Using the point kinetics framework to estimate multiplication and fission rates**
  - **Analysis of measurements with liquid scintillators that respond on the time scale of the fission chain multiplication process**
- **Characterize the contribution of cosmic rays to the multiplet distributions**