Advanced Safeguard Tools for Accessible Facilities (Thrust Area #3)

Zhong He – UM: Semiconductor γ imaging spectrometers

Sara Pozzi – UM: Neutron multiplicity measurements

Kim Kearfott – UM: Chain-of-custody detectors

Igor Jovanovic – Penn State: Laser-based radiation detection

Jim Baciak & Andreas Enquist – UF: Neutron detectors

October 16, 2015

CHARACTERIZING GAPS & CHALLENGES

Nonproliferation Treaty, Fissile Material Cutoff Treaty

GAPS & CHALLENGES

- Determine the mass, enrichment, and location of fissile material
- Address the He-3 shortage
- Detect clandestine fissile material production

CVT Thrust Area

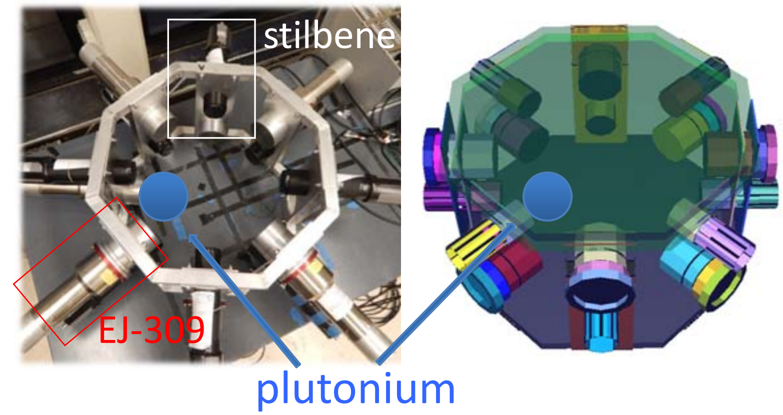
Advanced Safeguards Tools for Accessible Facilities

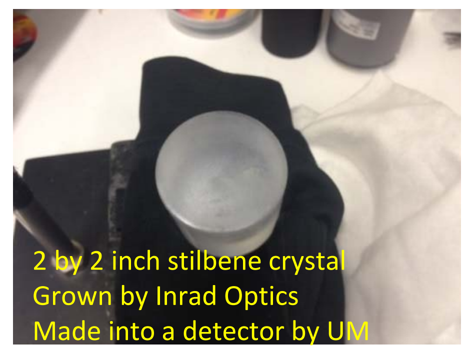
New Safeguards Instruments for NPT Verification

Prof. Sara Pozzi

- <u>Gaps and challenges addressed:</u>
  - Accurately determine the mass of fissile material
  - Address the He-3 shortage

- We are **designing, developing, and validating a <u>new safeguards instrument</u>** <u>that is He-3-free</u>. It can be used to characterize special nuclear material – specifically **the mass of Pu in a sample**
  - It works by counting neutron doubles (coincidences) within a short time window of 40 ns → low accidental rates
  - In-field experiment on special nuclear material with national laboratory collaborators – performed August 2015. Measured two sets of plutonium metal plates (up to 2.1 kg in mass), fuel of the Zero Power Physics Reactor at Idaho National Lab (Dr. D. Chichester)
    - Talk by CVT postdoctoral fellow Dr. Angela Di Fulvio- this session
    - Poster #13 CVT grad student associate Tony Shin
    - Poster #15 CVT grad student associate Mark Bourne
- This concept can also be applied to active interrogation of uranium samples (to determine the mass of U in a sample)

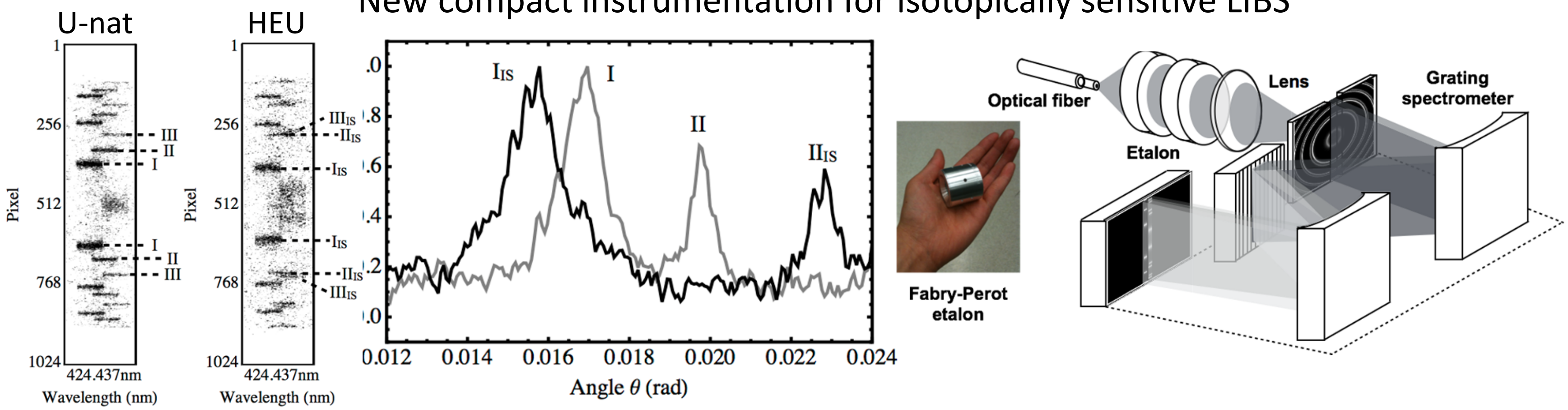




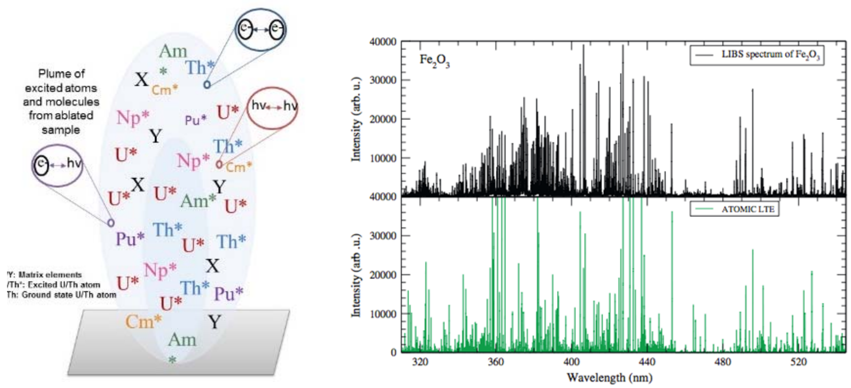
Progress in the development of LIBS for verification applications

Prof. Igor Jovanovic of Penn State

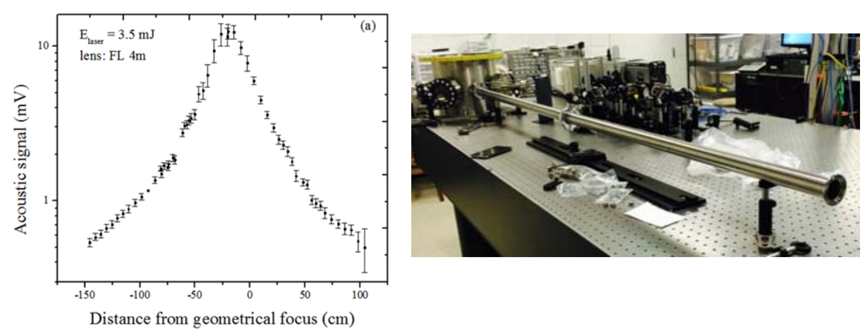
New compact instrumentation for isotopically sensitive LIBS



Deconvolution of matrix effects



Standoff measurements by femtosecond pulse filamentation



DETECTOR DEVELOPMENT FOR NEUTRON DETECTION/ANALYSIS

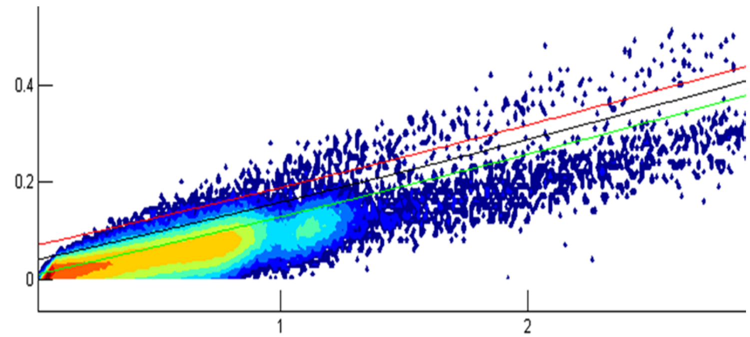
Prof. James Baciak et. al.

Sample results:

- Small & medium volume **metal-loaded organic liquid** test showing emerging photo peak behavior
- The new materials tested have characteristics that are **promising for spectroscopic information of gamma-rays in a neutron detector**

Ongoing work:

- High-throughput data reduction capabilities of digitizers (Struck), for spent fuel neutron measurement applications.
- Larger scale economical organic compound based gamma-detection material for rare fission signatures (high-Energy gamma-rays)



Scatter plot with photo-peak region of a ^{137}Cs source in a mixed field background (neutrons and gamma rays)

Metal-containing liquid scintillator mixes being tested, and compared to EJ309 cells

Chain of Custody Detectors

Professor Kim Kearfott at el.

University of Michigan

Quantitative Characterization of SNMs using 3-D CdZnTe gamma-neutron imaging spectrometers

Zhong He & team

UNIVERSITY OF MICHIGAN

A quick poll:

Please raise your hand if you think that I did a terrible job on describing the gaps and challenges addressed by research and development in CVT thrust area #3

A politician always say that he/she knows everything

A professor may tell the truth!

(1) No gap on existing treaties

(2) No one knows exact gaps on future treaties

(3) We use future treaty proposals as references, and use our imagination to advance technologies!

Polaris (analogue ASIC) 3-D CZT systems

($\Delta E/E \leq$ 1.0% FWHM at ^{137}Cs + $\Delta X \Delta Y$ ~0.8 mm)

↓ (DOD – DTRA)

Orion (digital ASIC) 3-D CZT systems

($\Delta E/E \leq$ 0.6% FWHM at 662 keV

+ $\Delta X \Delta Y$ ~250 μm ⟶ Higher Imaging Resolution

+ Thermal neutron Imaging

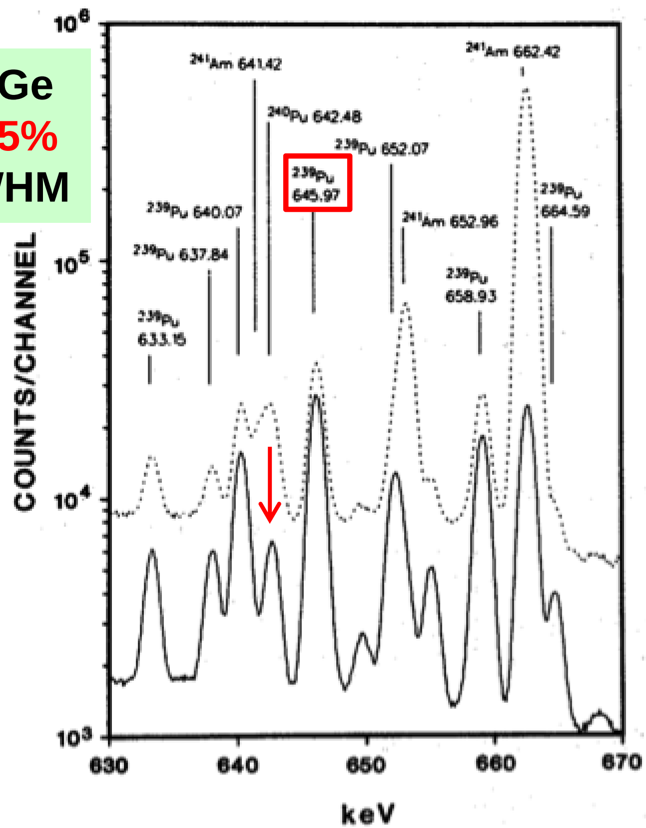
+ Fission neutron detection)

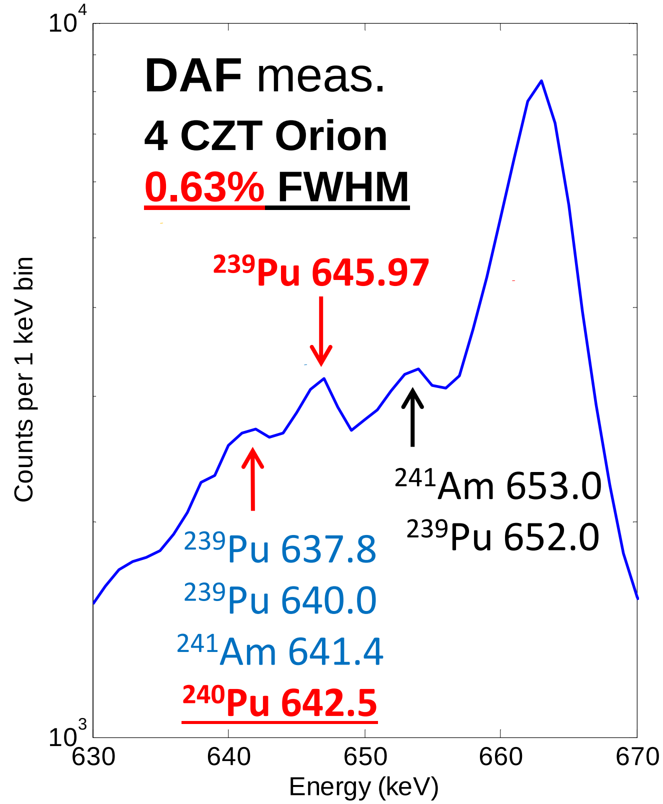
Why aim at $\leq$ 0.6% FWHM?

I knew that we can and should be able to achieve! & can make impact

Dr. John Pratt (DOE NA-42) & Scott Garner (LANL) pointed out the importance to separate **642.3 keV (^{240}Pu)** & **645.9 keV (^{239}Pu)** lines **(ΔE < 3.6 keV $\leftrightarrow$ 0.54% FWHM** (Ref. Dragnev & Scharf, IAEA, 1975)

HPGe
0.25%
FWHM

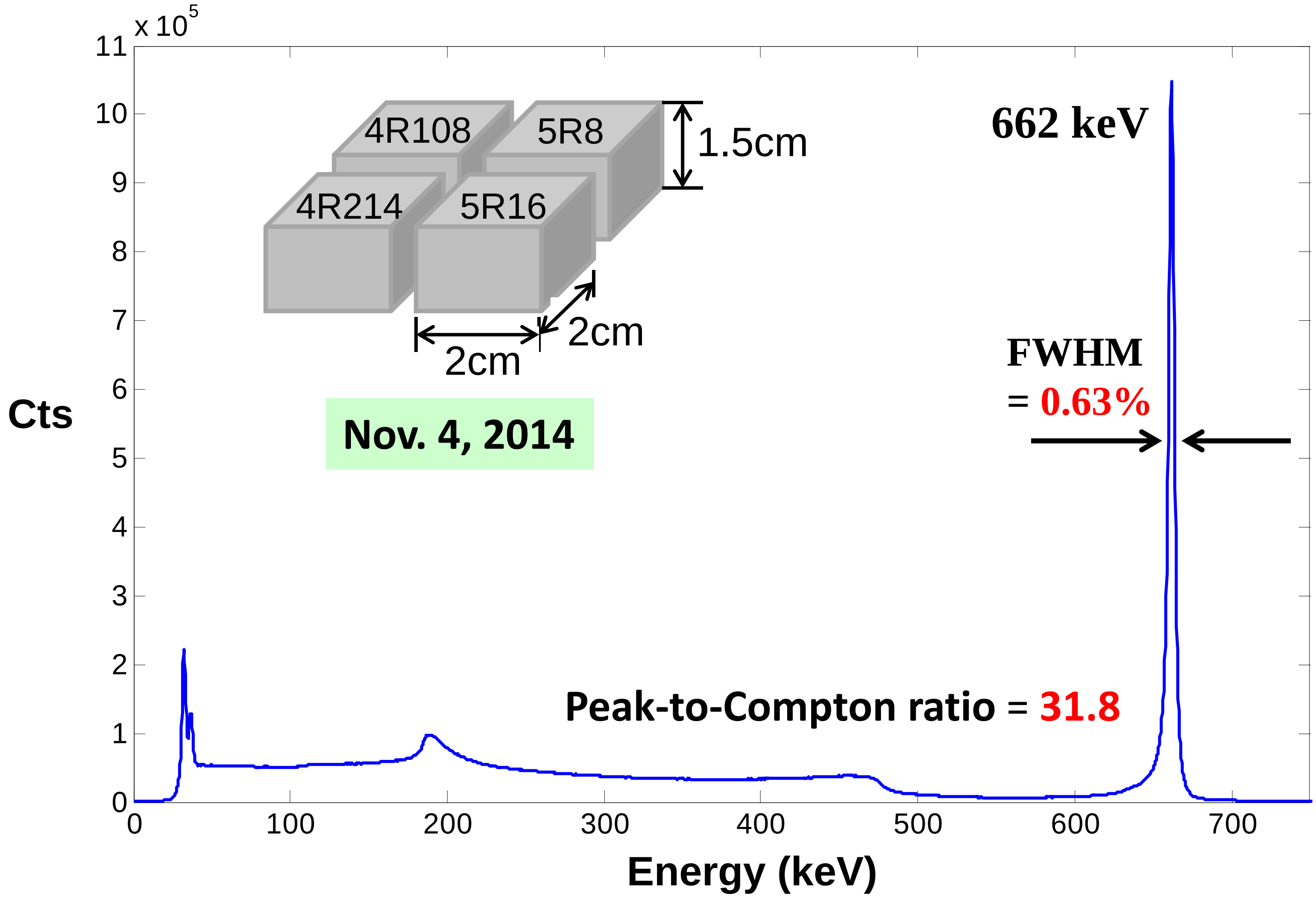




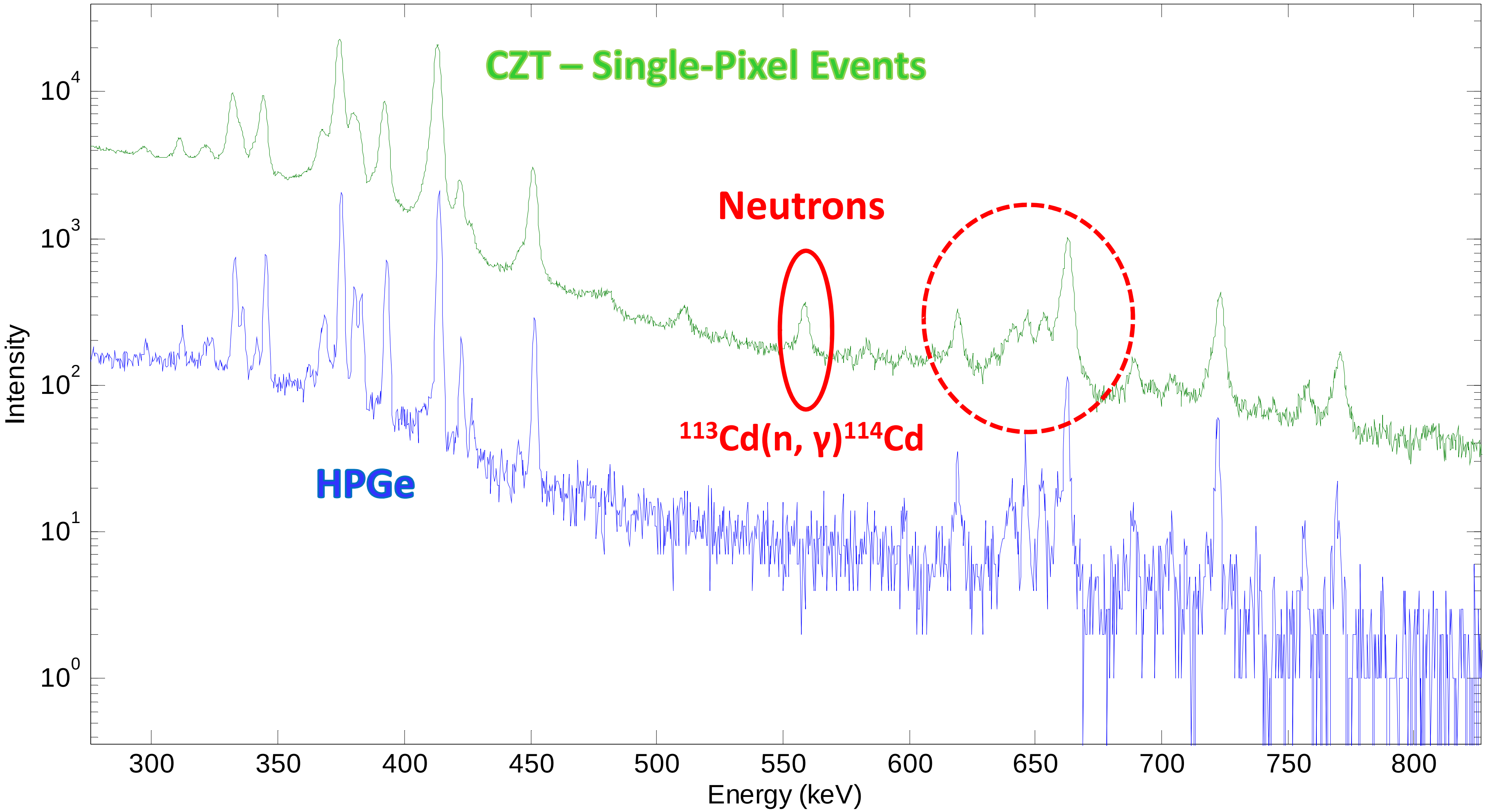
Garner estimated **3.6%** ^{240}Pu $\leftrightarrow$ **5.2%** actual (within 2σ)

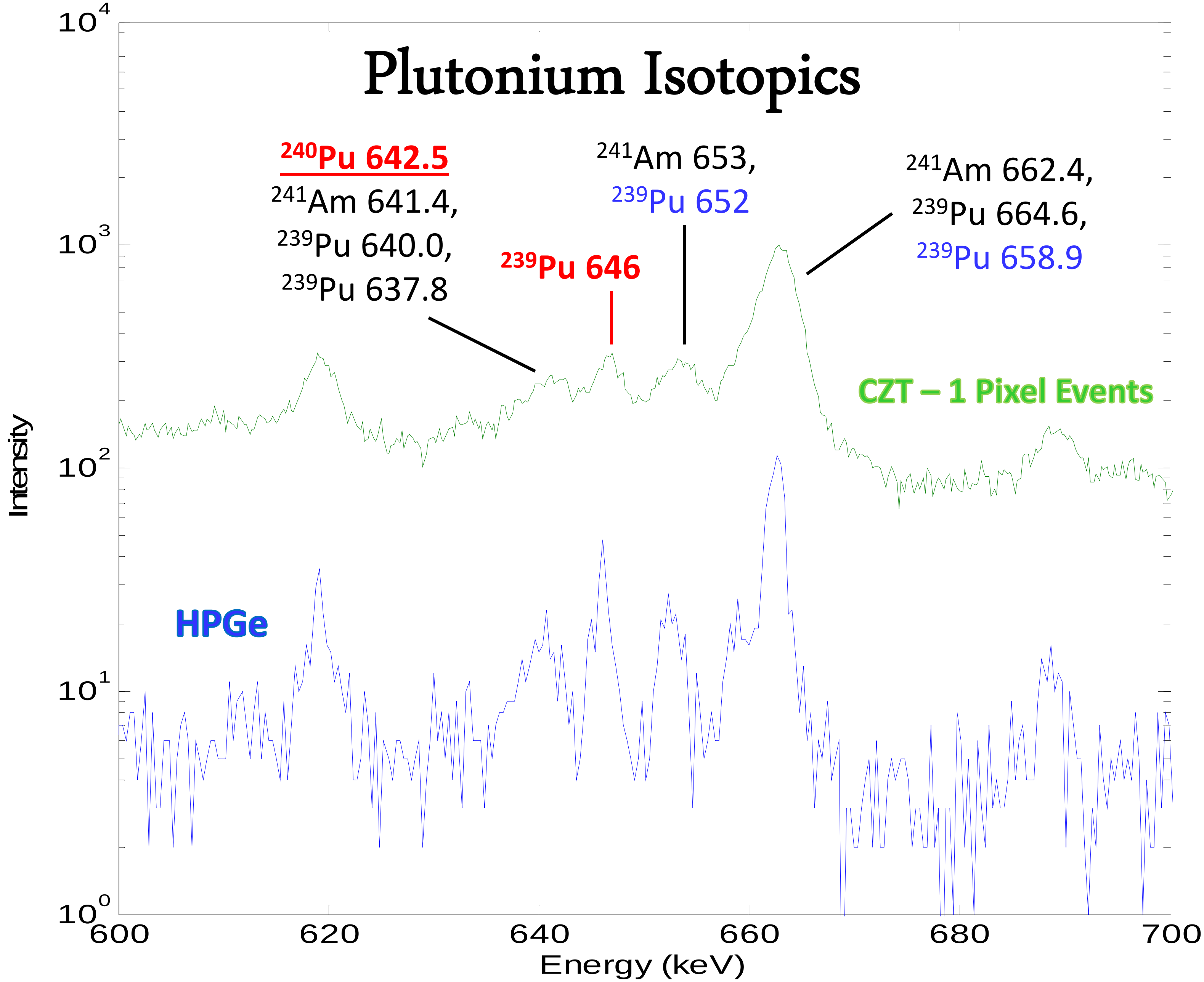
First Orion 4-CdZnTe Array System

All-events (no selection); VAD-UM1.2 (3 MeV) – Sparse Readout

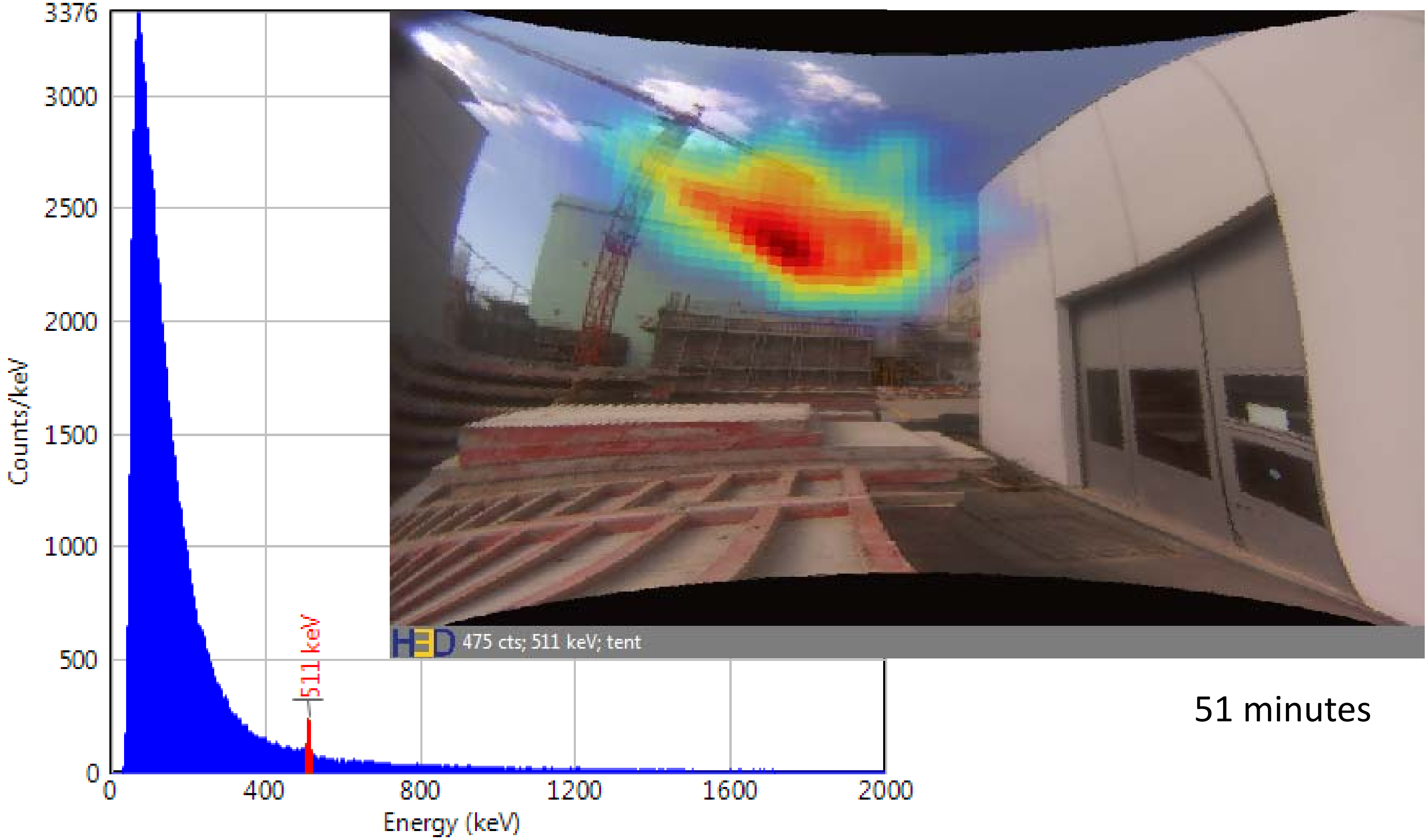


CZT/HPGe Plutonium Spectra Comparison




Plutonium Isotopics
240Pu 642.5
241Am 641.4,
239Pu 640.0,
239Pu 637.8
239Pu 646
241Am 653,
239Pu 652
241Am 662.4,
239Pu 664.6,
239Pu 658.9
CZT – 1 Pixel Events
HPGe
Intensity
10^4
10^3
10^2
10^1
10^0
600
620
640
660
680
700
Energy (keV)

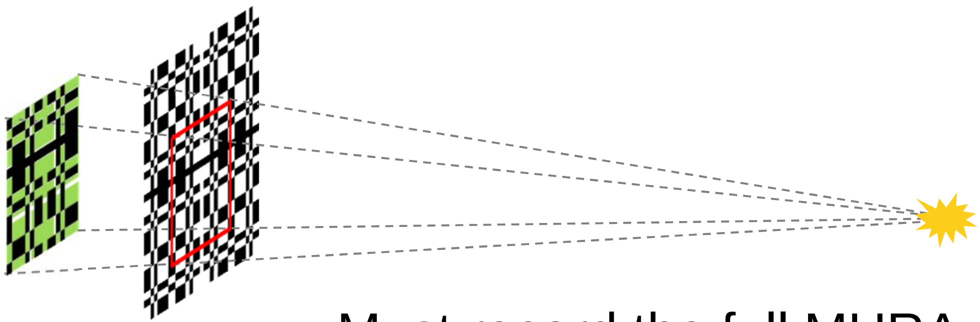
Sky-Shine with Polaris-H



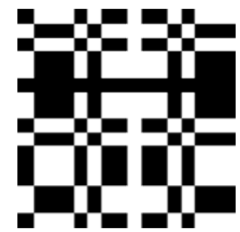
51 minutes

- Can imaging 511-keV sky-shine > **200 yards** from a reactor building.

CAI vs TEI thermal neutron imaging

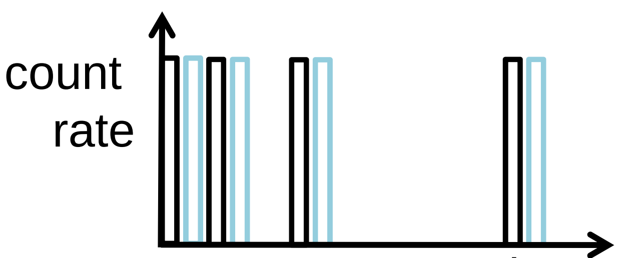


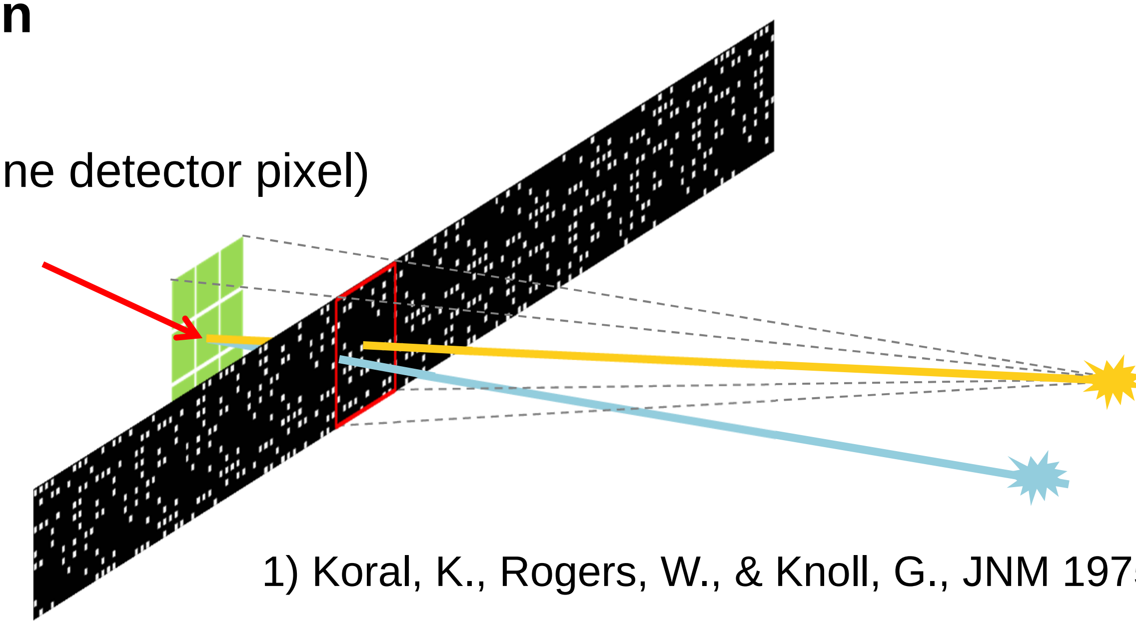
Measured CAI signal



- Must record the full MURA pattern
- **Spatial resolution limited by detector position resolution**

Measured TEI signal (one detector pixel)



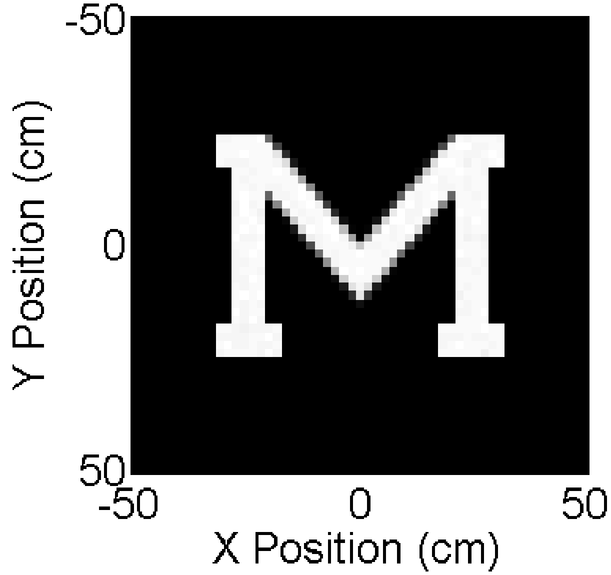


1) Koral, K., Rogers, W., & Knoll, G., JNM 1975

Reconstruction of Geant4-simulated data confirms relative performance

- Same number of emitted thermal neutrons
- 1 mm boron nitride mask
- Detector-source distance = 2 m

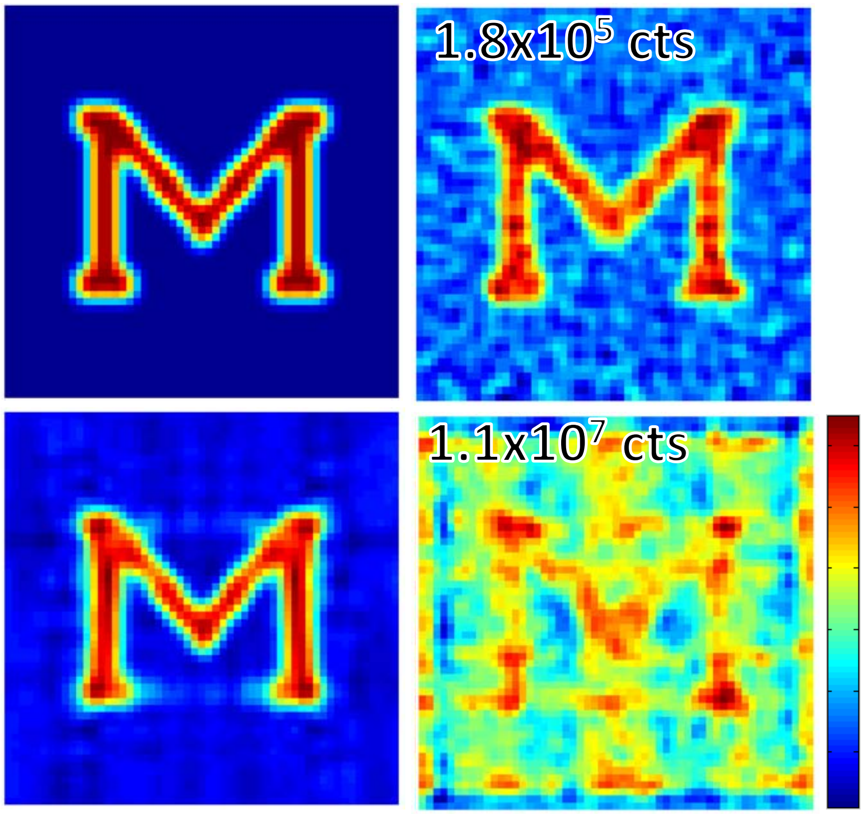
x_{true}



$E[\hat{x}]$ $\hat{x}$

TEI

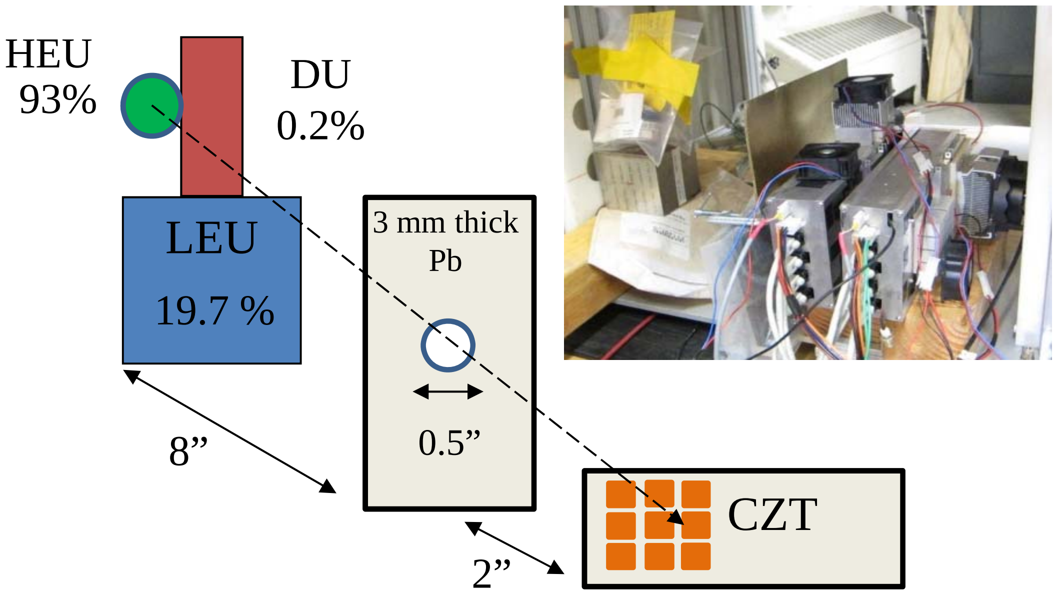
CAI x10

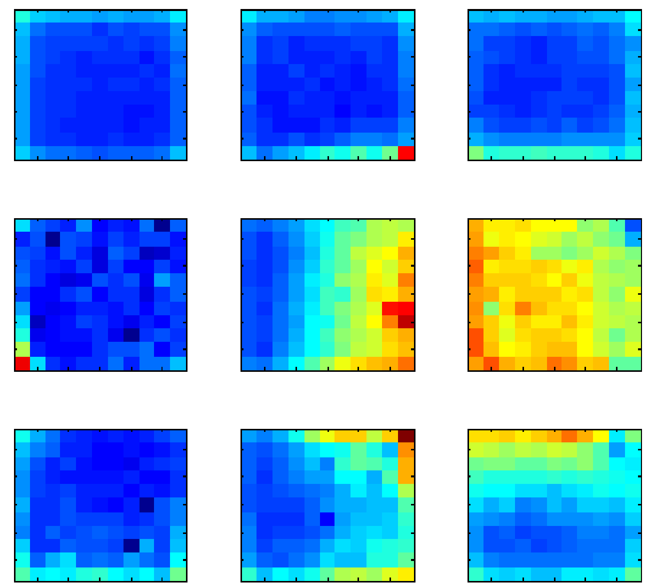


IEEE NSS/MIC 2015 – Seattle, WA

Measurements on SNMs using 3-D CZT Detectors at LANL

Recorded γ image of blocks of LEU/HEU/DU at LANL on an 18-CZT Polaris (analogue) system



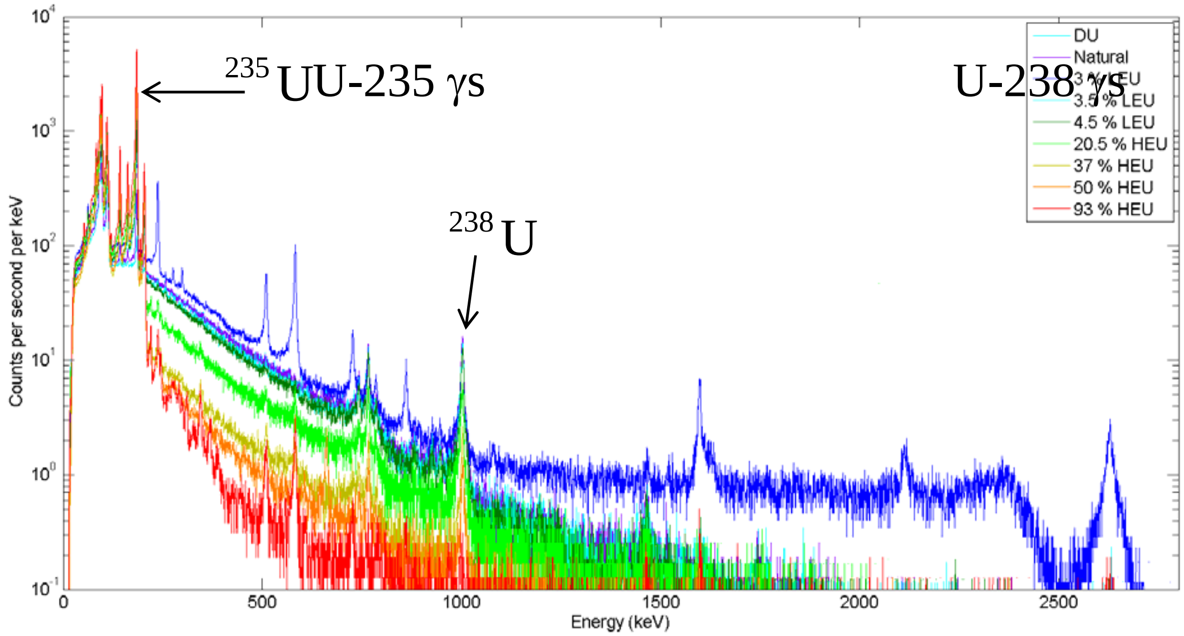


Dr. Christopher Morris & Dr. Zhehui (Jeff) Wang

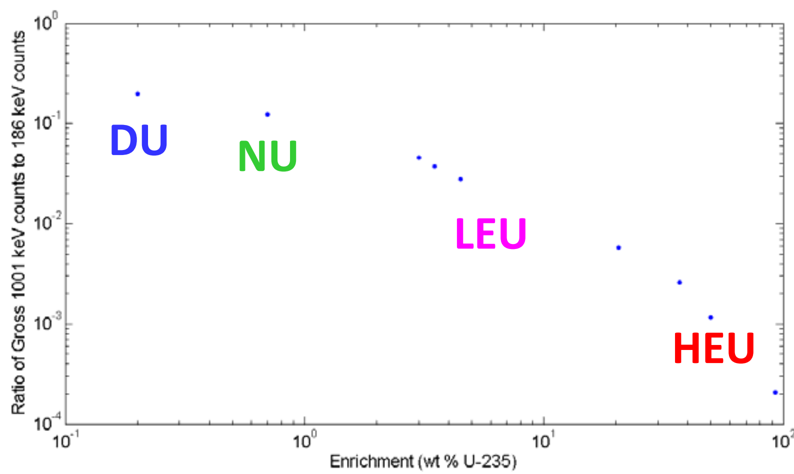
Pin hole image at 186 keV (^{235}U)

Uranium Enrichment Measurements

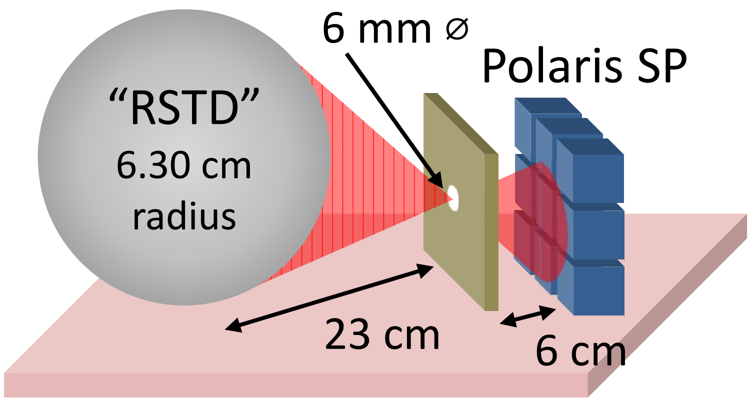
Using 3-D CZT Detectors at Y-12



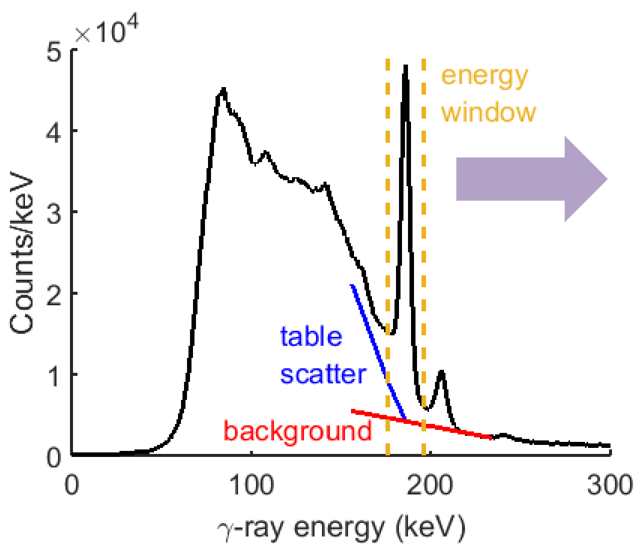
Uranium samples having different enrichment levels have been measured at Y-12 during **May 11 – 14, 2015** (Co-PI: **Dr. Carter Hull**)



Estimate on HEU sphere radius using Polaris SP + pinhole collimator



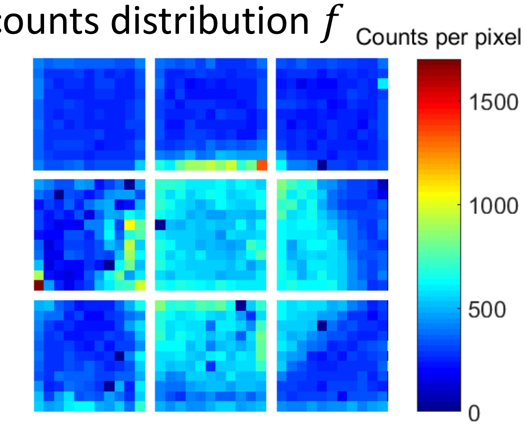
(100 min measurement)



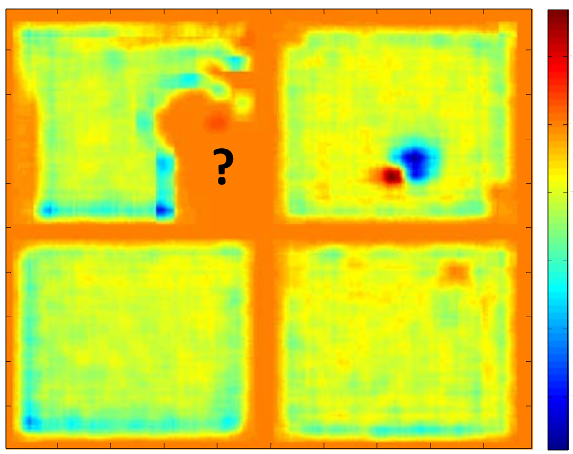
Method

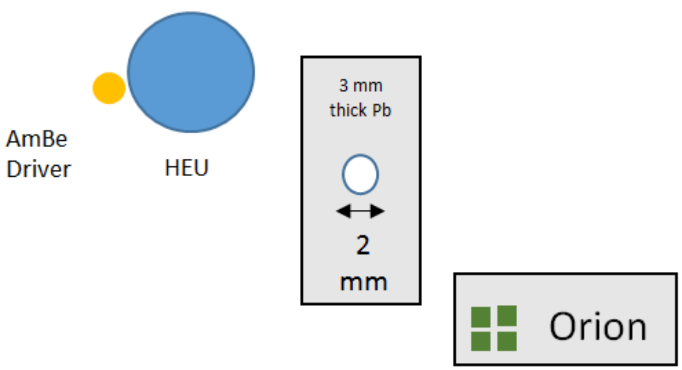
- Calculated $f(\theta)$ using ray tracing algorithm and known background rate
- Multilevel coordinate search found $\hat{\theta}_{ML}$ within "box": x = [0 to 22 cm], y = [0 to 22 cm], R = [1 to 10 cm]
- **Result:** $\hat{\theta}_{ML}$ = [10 cm, 13 cm, **6.46 cm**]

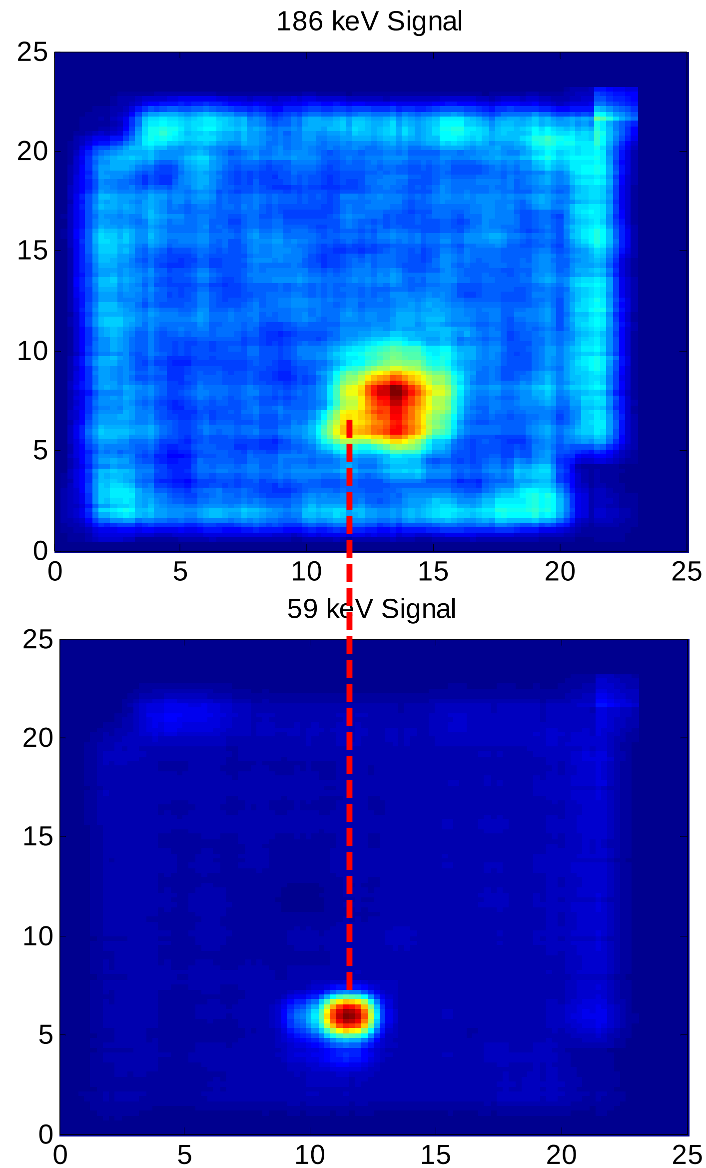
Measured 186 keV counts distribution f



DAF Pinhole Image Reconstruction





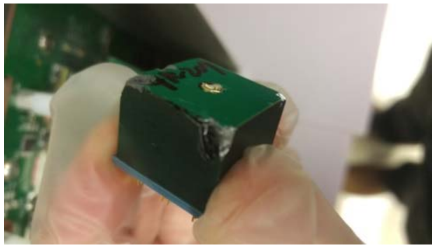


CVT 1st Year Activity Summary

Successes:

- Measurements on uranium and plutonium samples have been made at LANL, Y-12 and DAF – observed/estimated sample enrichments and shapes

Lessons learnt:



- Detachment of CZT detectors during shipment
- Failed first attempt to image dry-cast in Cook Nuclear Power Plant due to humid weather
- High fluxes from SNMs can saturate detector

I am looking forward to my trip tomorrow to IAEA Safeguards Department for a Gamma-Imager evaluation workshop next week (October 19 – 23, Vienna, Austria) – should learn something about gaps & challenges!