PHDS
Gamma Ray Imaging Detectors

PHDS Co. Physics and Technology

Ethan Hull, Ph.D.
CEO and Technical Director
PHDS Corporation, Knoxville, TN

- Introduction to PHDS Co.
- Manufacturing and Technology
- GeGI Instrument Evolution
- Examples of Imaging, Directionality and Isotope ID
  - Search, CBRNE, Safeguards, D&D, Isotope production
- Large point-contact research detectors

History of PHDS Co. Development

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Gamma Ray Imaging Detectors

- Est. Fall 2004 – Nuclear and Solid State Physics Origin
  - History: Custom Nuclear-Physics Detectors
  - Recently: Modular HPGe Systems
- Complete Germanium Detector Manufacturing and R&D
  - Concept Design
  - Crystal Growth
  - Detector Fabrication
  - System Integration
  - Software application
  - Sales & Service
- *Make new HPGe detector capabilities available*

Science Experiment

NPX (150 lbs.)
2008 Laboratory

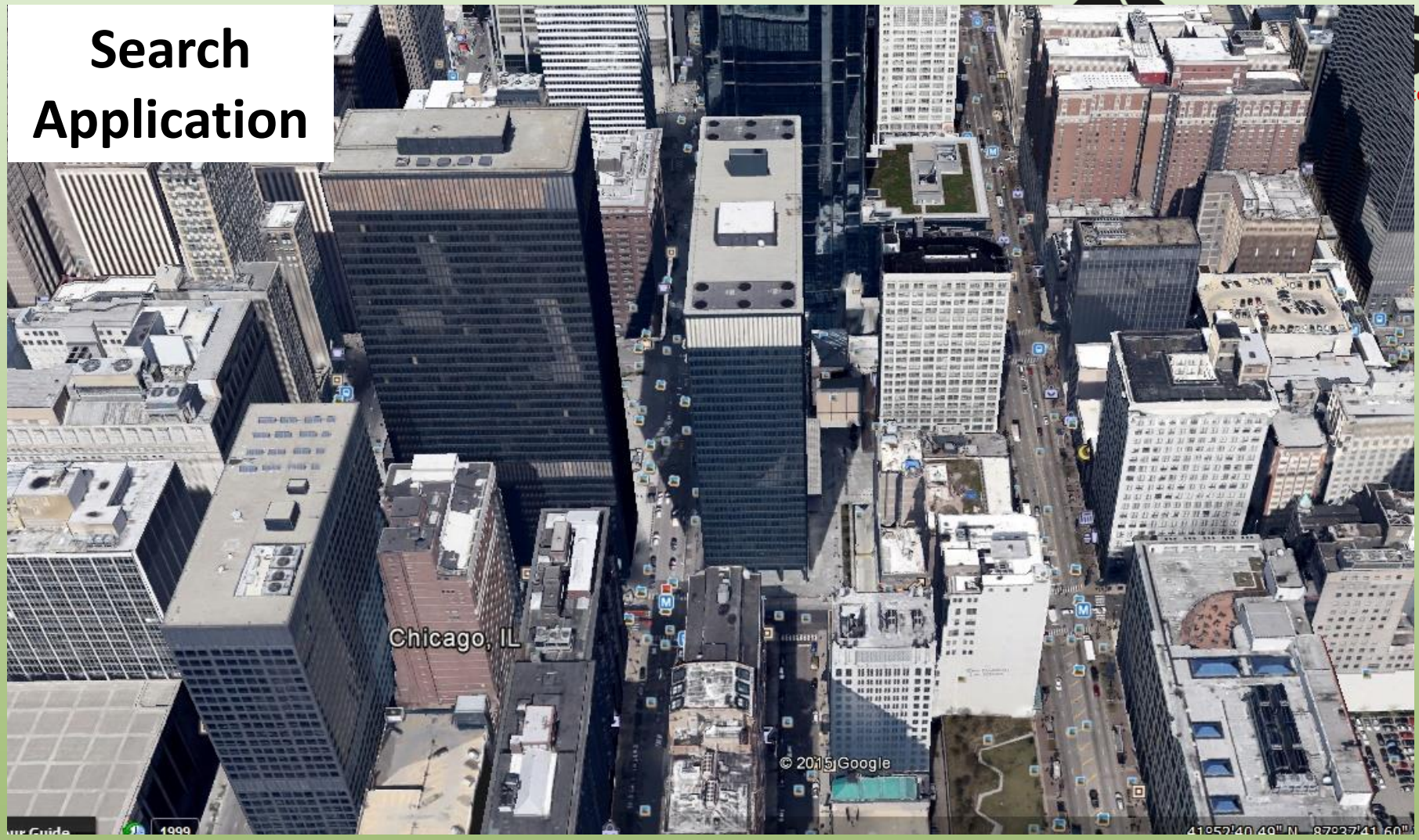
Versatile Global Product

GeGI-5 (15 lbs.)
2017 Hand Portable
Same technical capability at 1/10 th the size and weight

Versatile Global Product

Fulcrum (7-8 lbs.)
2017 Hand Portable

Search Application

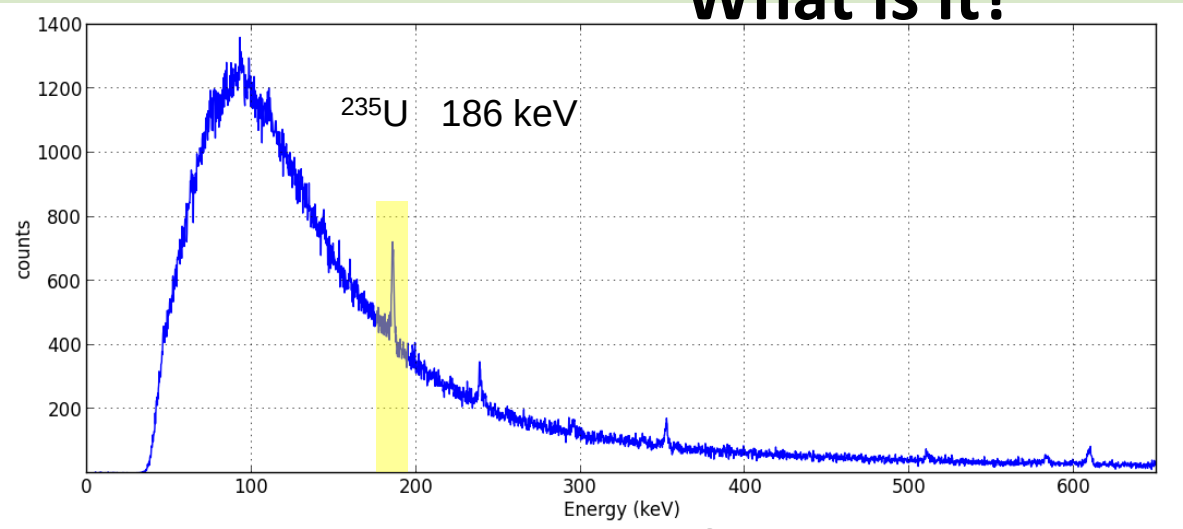


Chicago Radioactive Threat!

What is it?

Where is it?

What is it?



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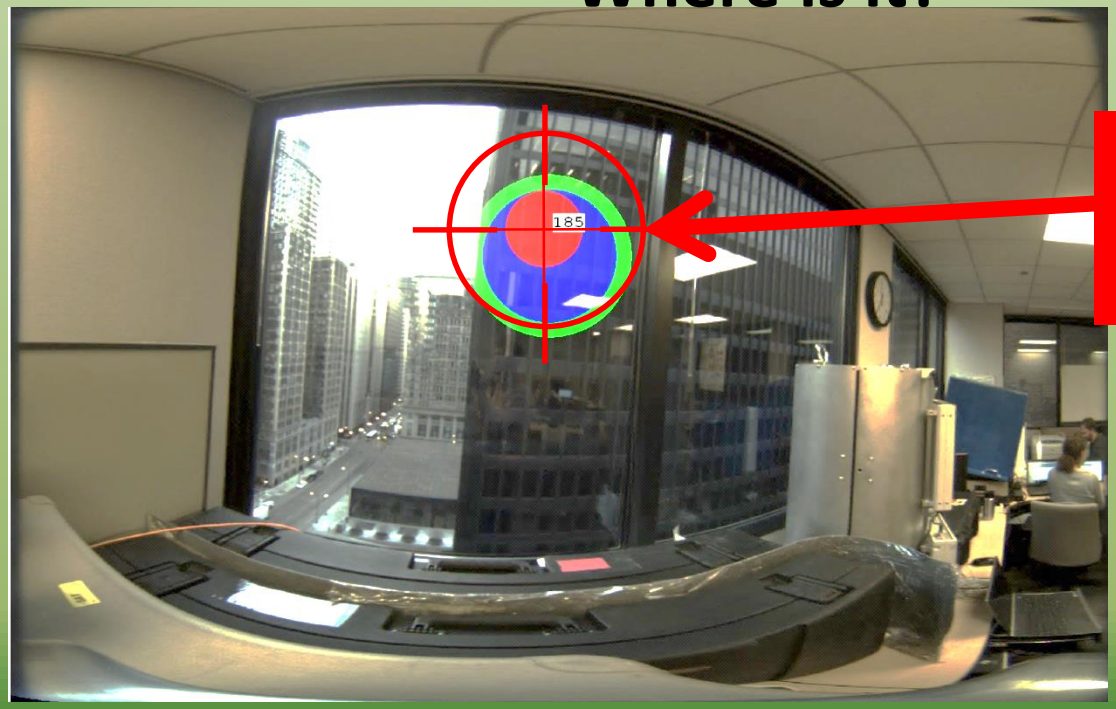
HEU – ^{235}U – Weapons Grade Uranium !

GeGI

Where is it?



In that room, on the 13th floor of the building across the street

Distance: 28 m
Spectral detection: 15 min (8 σ)
Image detection: 39 min (3 σ)

Imaging is powerful.
Direction – Location (ID)

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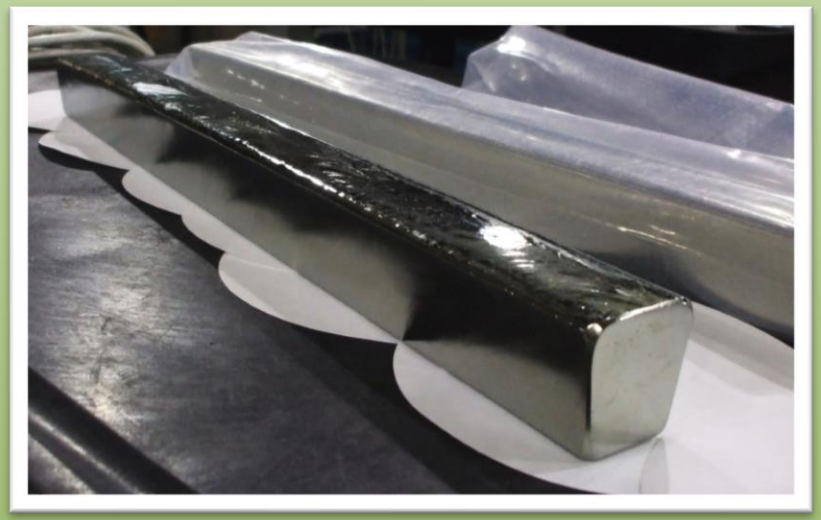
HPGe Physics and Manufacturing



10,000 ft^2 Manufacturing and R&D Facility in Knoxville, TN

Vertical manufacturing of GeGI Imaging Spectrometers

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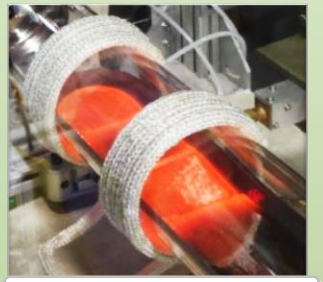
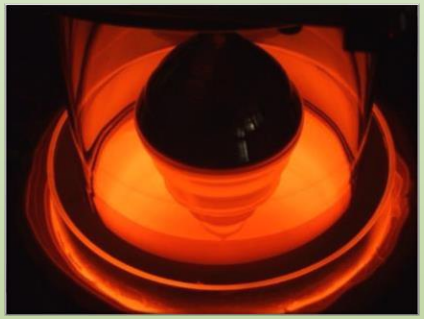


Ge Zone Refine

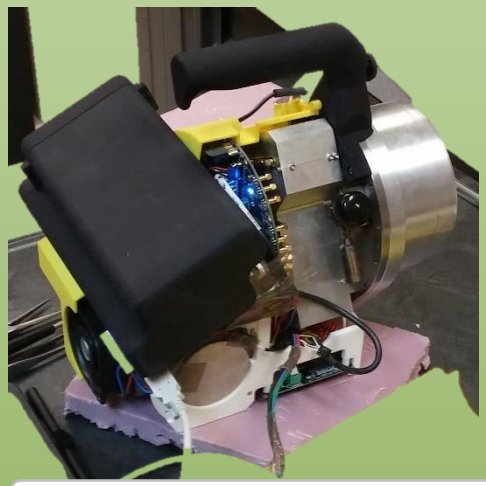


HPGe Crystal Growth

Analysis

Fabrication

Cryogenics



Electronic and Software Integration

GeGI

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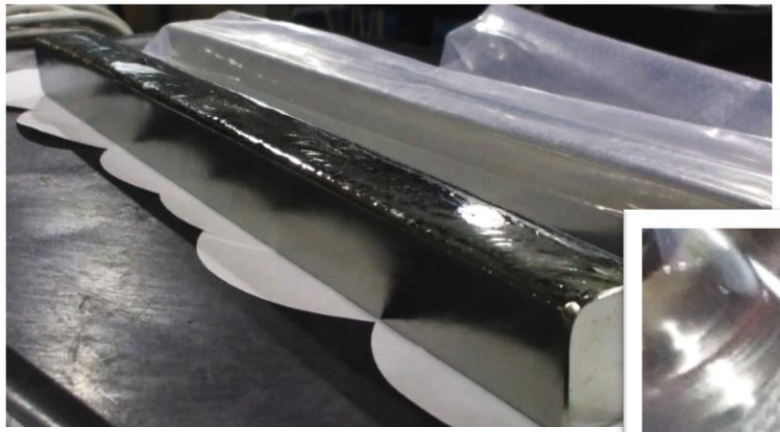
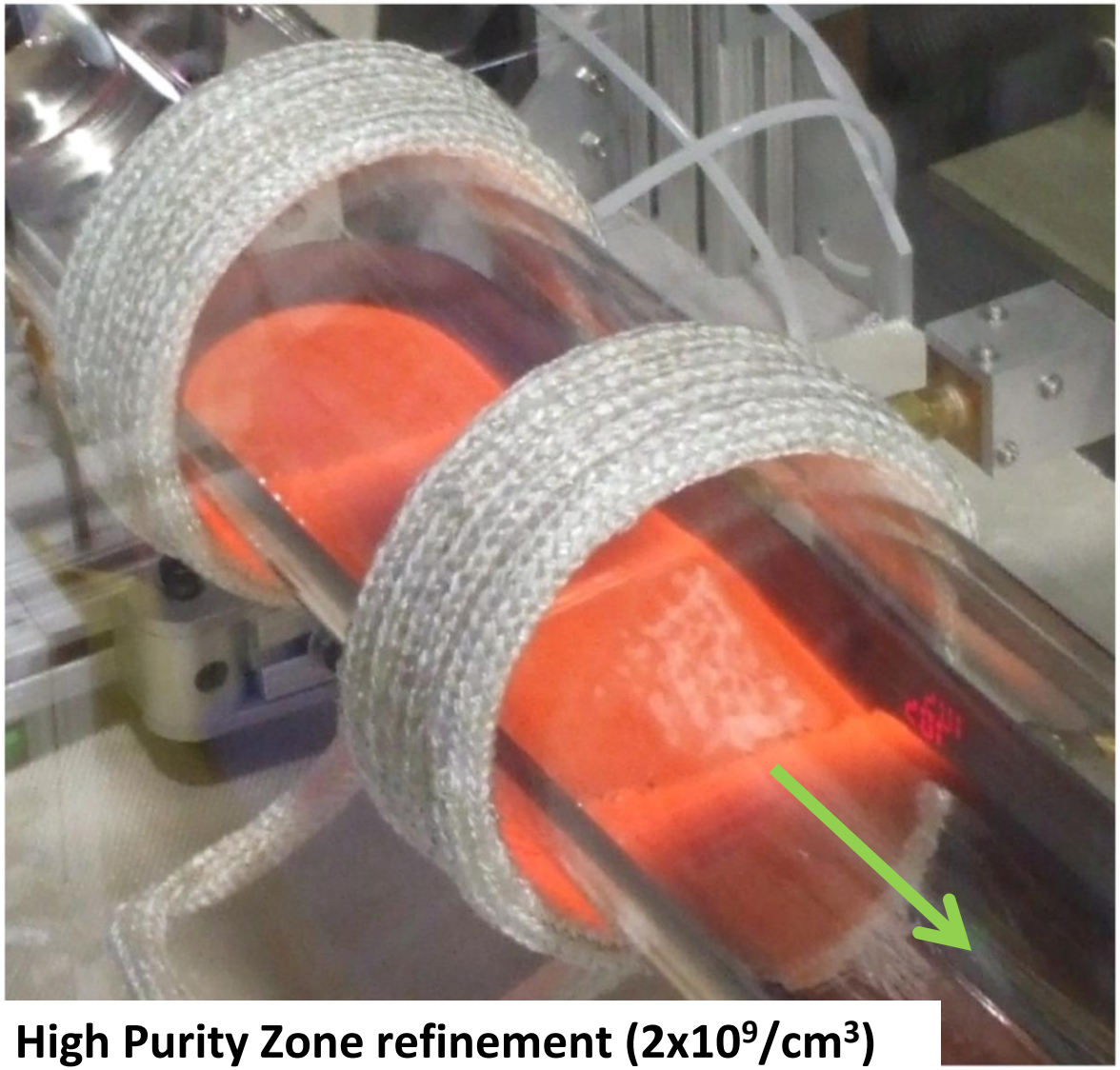


Electronic grade Ge (2x10^{13}/cm^{3})



High Purity Zone refinement (2x10^{9}/cm^{3})

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High Purity Germanium

Growth of Crystal

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Growth of Crystal

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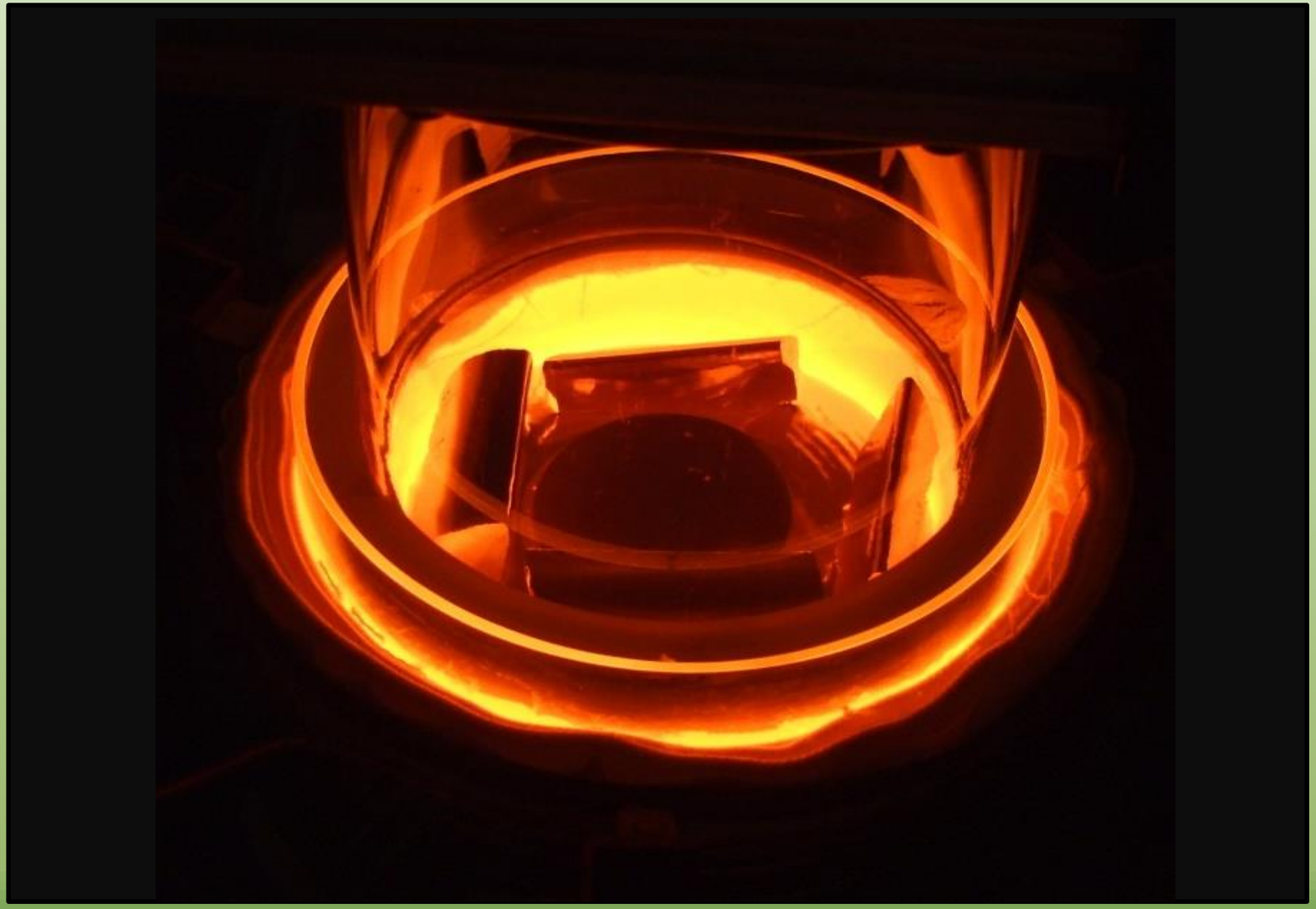

HPGe Crystal

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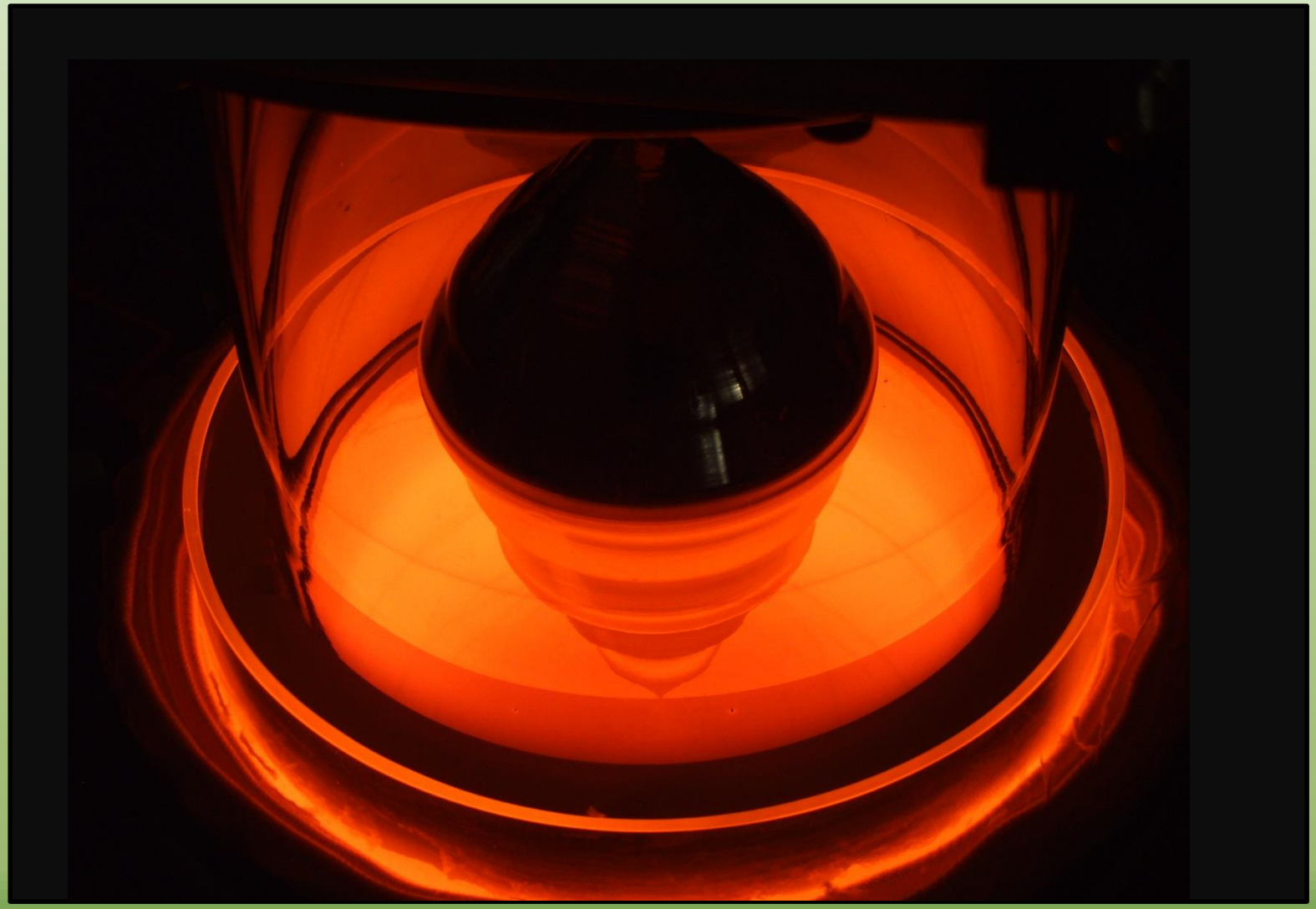

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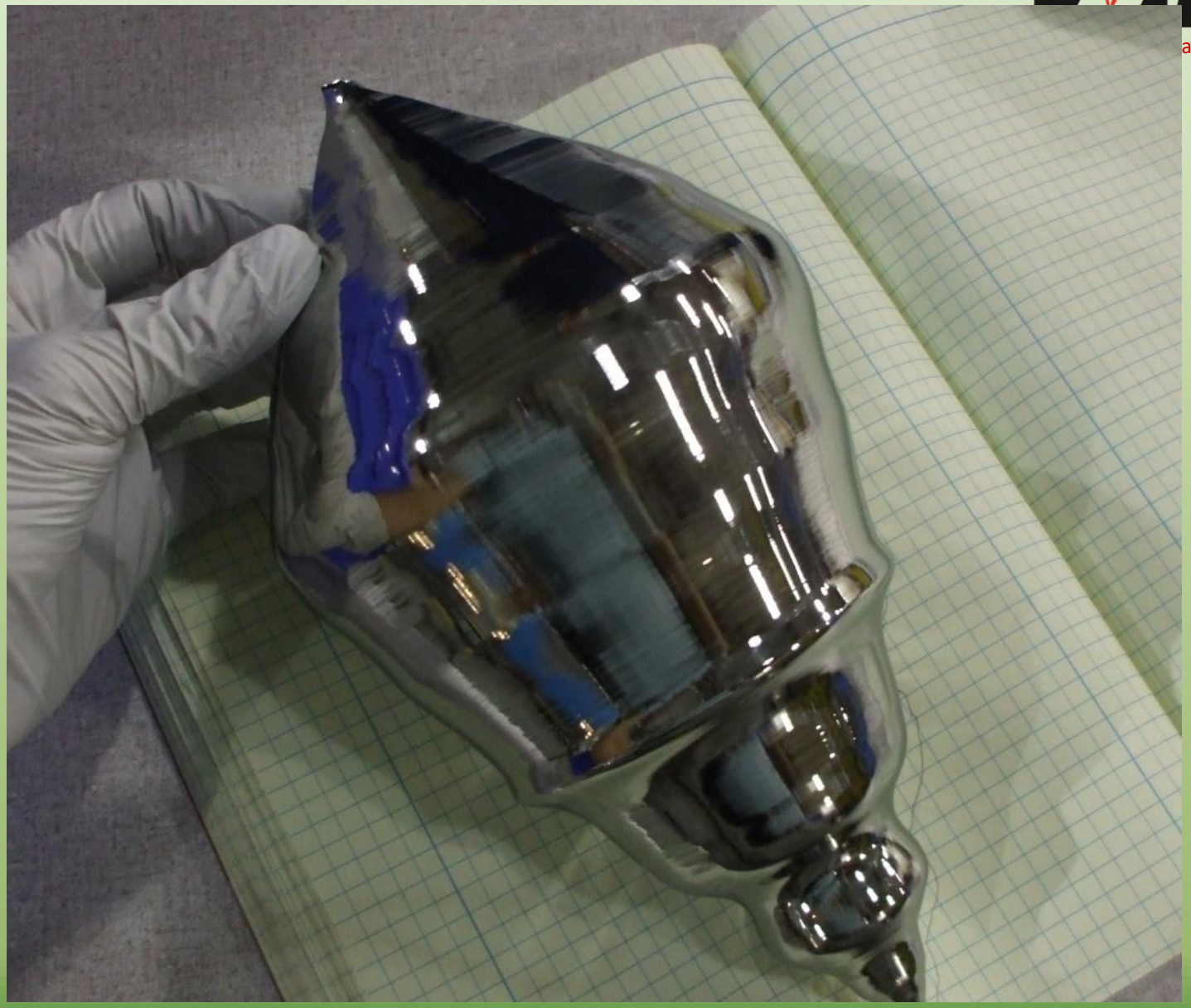

Germanium Crystal Slicing

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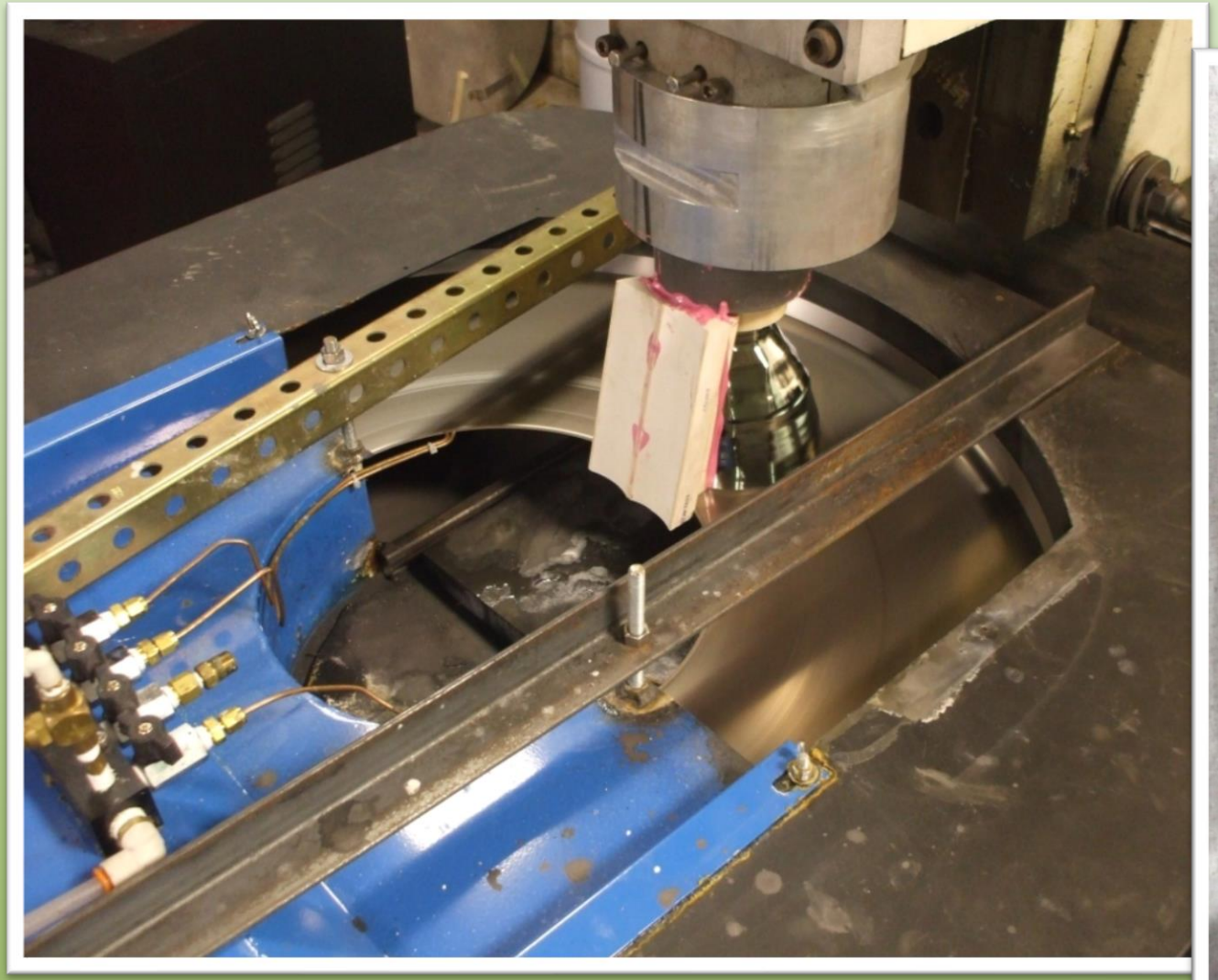

Segmented HPGe detector fabrication

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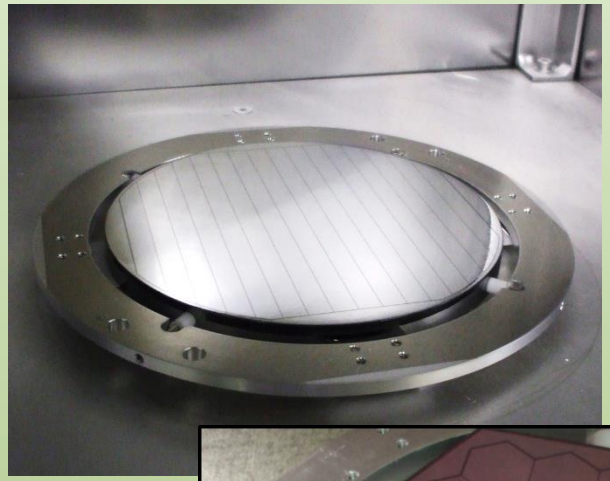

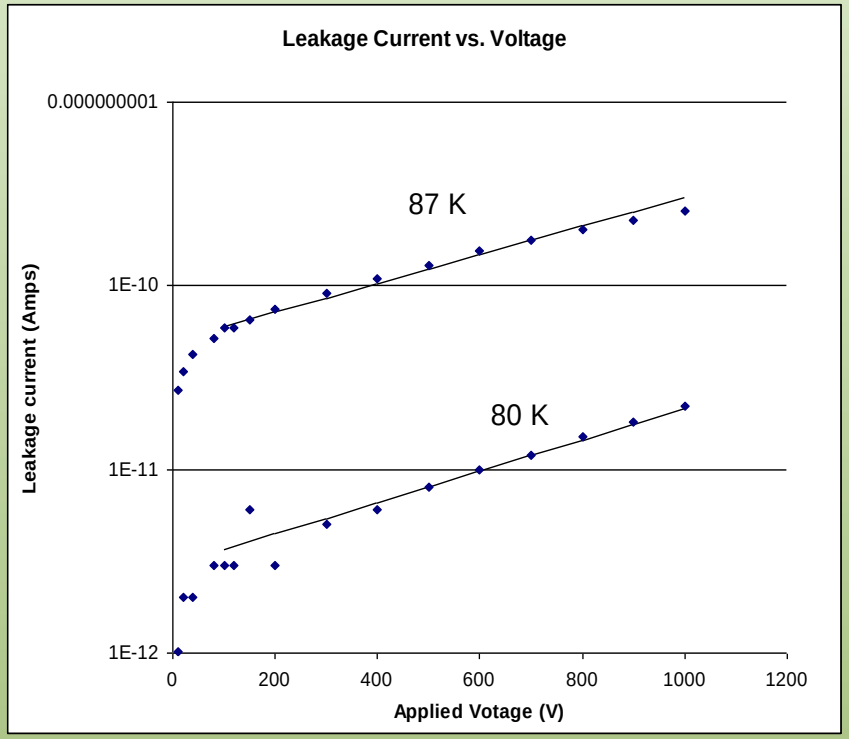

Surface contact physics: αGe, Y, Ag, …

$$j = j_{\infty}\exp(-\{\phi - [(\varepsilon_0\varepsilon_{Ge}/N_f)^{1/2}(V+V_{depl})/d]\}/k_BT)$$

•Segmented Semiconductor Barriers with good noise at ~ 77 K
Non-standard semi

E.L Hull, R.H. Pehl, "Amorphous germanium contacts on germanium detectors," Nuclear Instruments and Methods A, **538**, Issues 1-3, (2005), Pages 651-656.

Hull EL, R.H. Pehl, J.R. Lathrop, B.S. Suttle, "Yttrium hole-barrier contacts for germanium semiconductor detectors." Nucl. Instr. and Meth. A 626–627 (2011) p. 39–42 (2011), doi: 10.1016 / j.nima.2010.10.029.

Into Vacuum cryostat w/cooler

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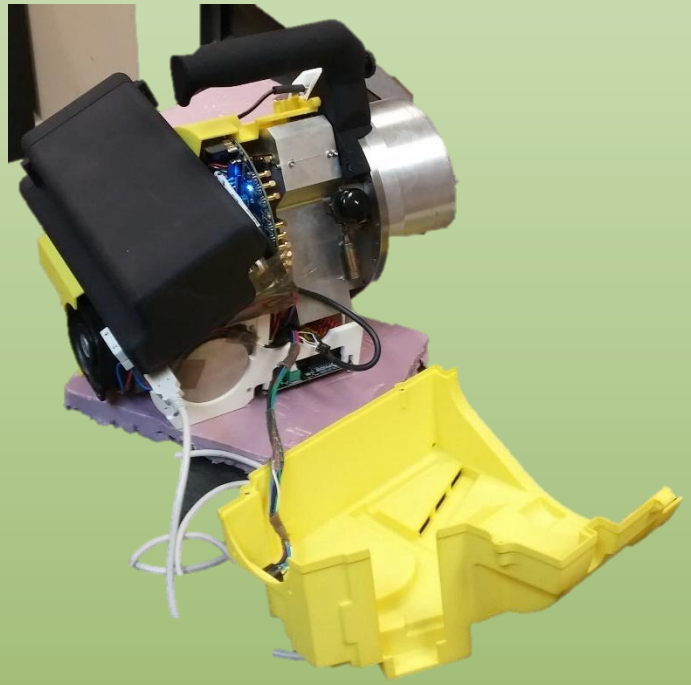
Integration with electronics, battery, camera and Imaging Software



Germanium System Evolution at PHDS Co.

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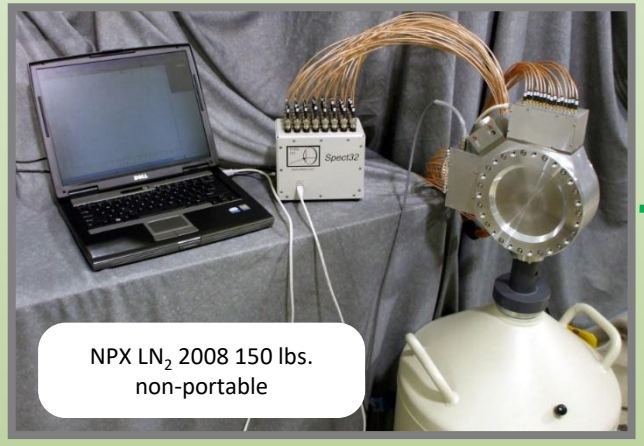

NPX LN_2 2008 150 lbs.
non-portable

NPX-M no LN_2 2009
70 lbs. non-portable

GeGI-1 2010
55 lbs.
Movable

GeGI-3 2013
33 lbs. Transportable

GeGI-4 2015
28 lbs. Personnel Portable

GeGI-5 2017
15 lbs. Hand Portable

Fulcrum 2017
7 lbs. Hand Portable

GeGI

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Gamma Ray Imaging Detectors

x, y, z, Energy

$\Delta x \sim 1.5\ mm$

1. Compton Kinematic Imaging
2. Pinhole Aperture Imaging
   - Other modalities requiring x,y,z,E

1. Compton Imaging

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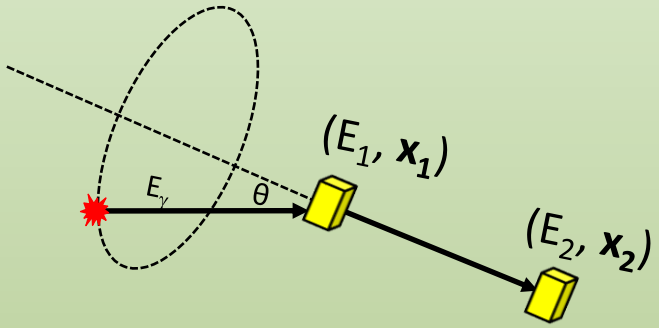
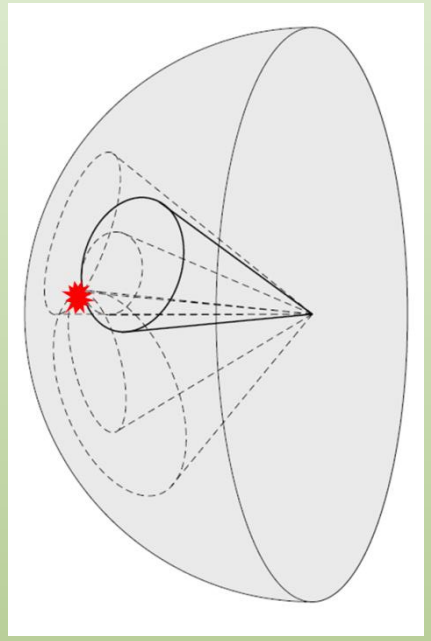
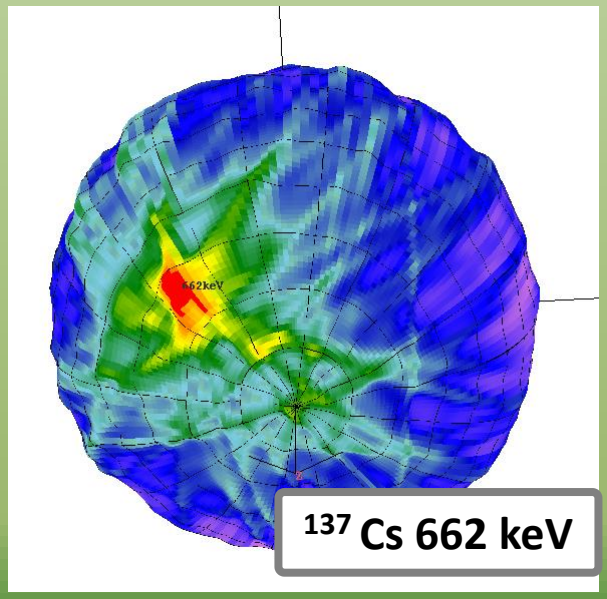


$$\cos\theta = 1 - m_e c^2 \left(\frac{E_1}{E_2(E_1 + E_2)}\right)$$





^{137}Cs 662 keV

- Finds the hottest source fast
- High sensitivity
  - Detector open
  - No collimator or shielding

1. Compton Imaging

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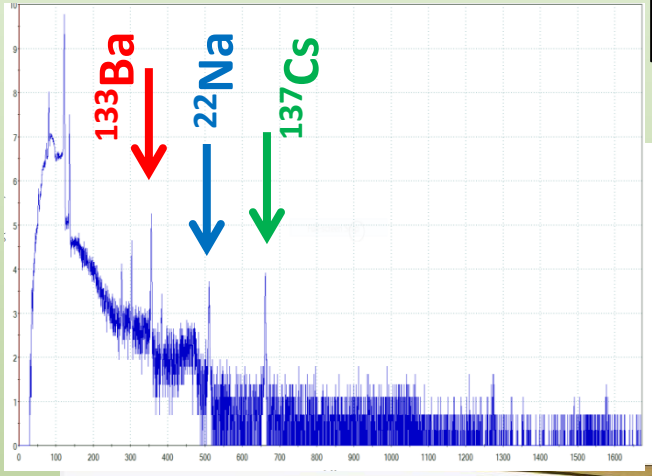

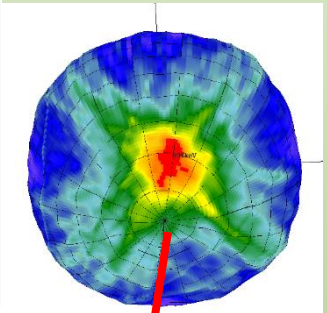

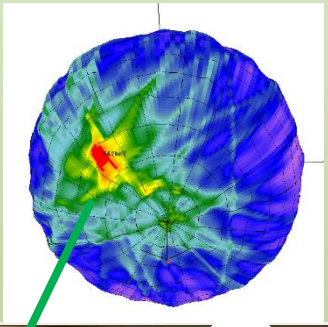

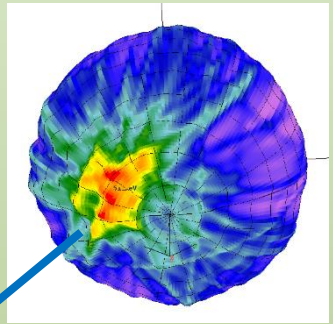

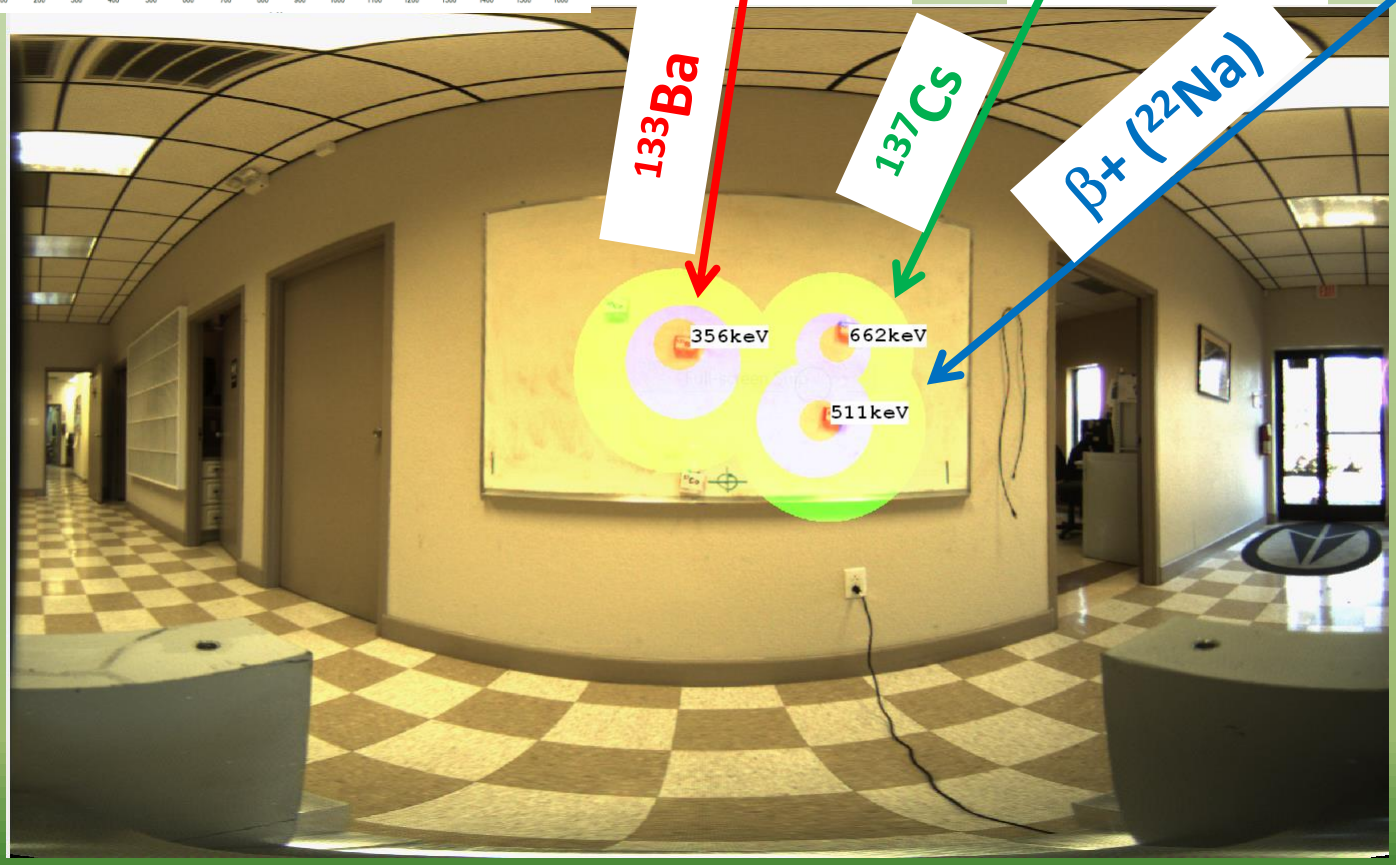

2. Pinhole Aperture Imaging

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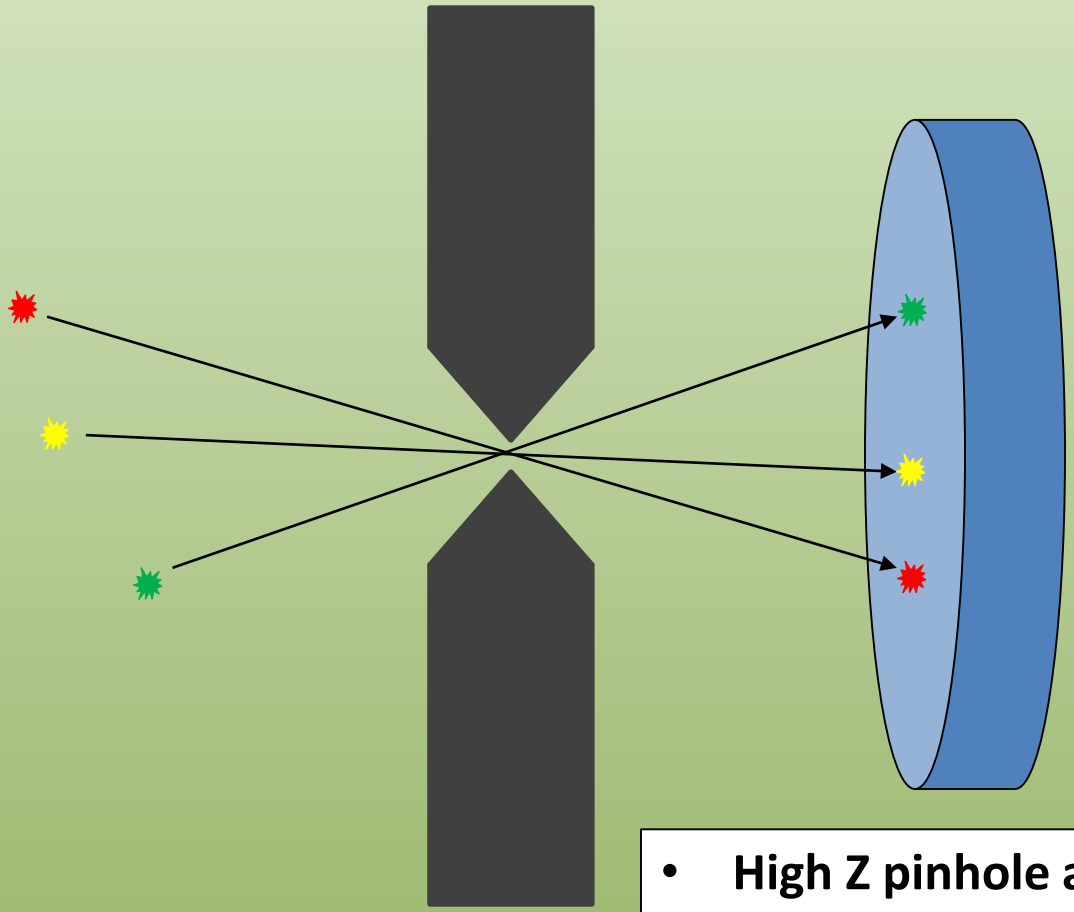

- High Z pinhole aperture
- Excellent detailed structure
- Low sensitivity (pinhole)

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Gamma-ray Imaging Applications

CBRNE Team Training

^{239}Pu ID and Location

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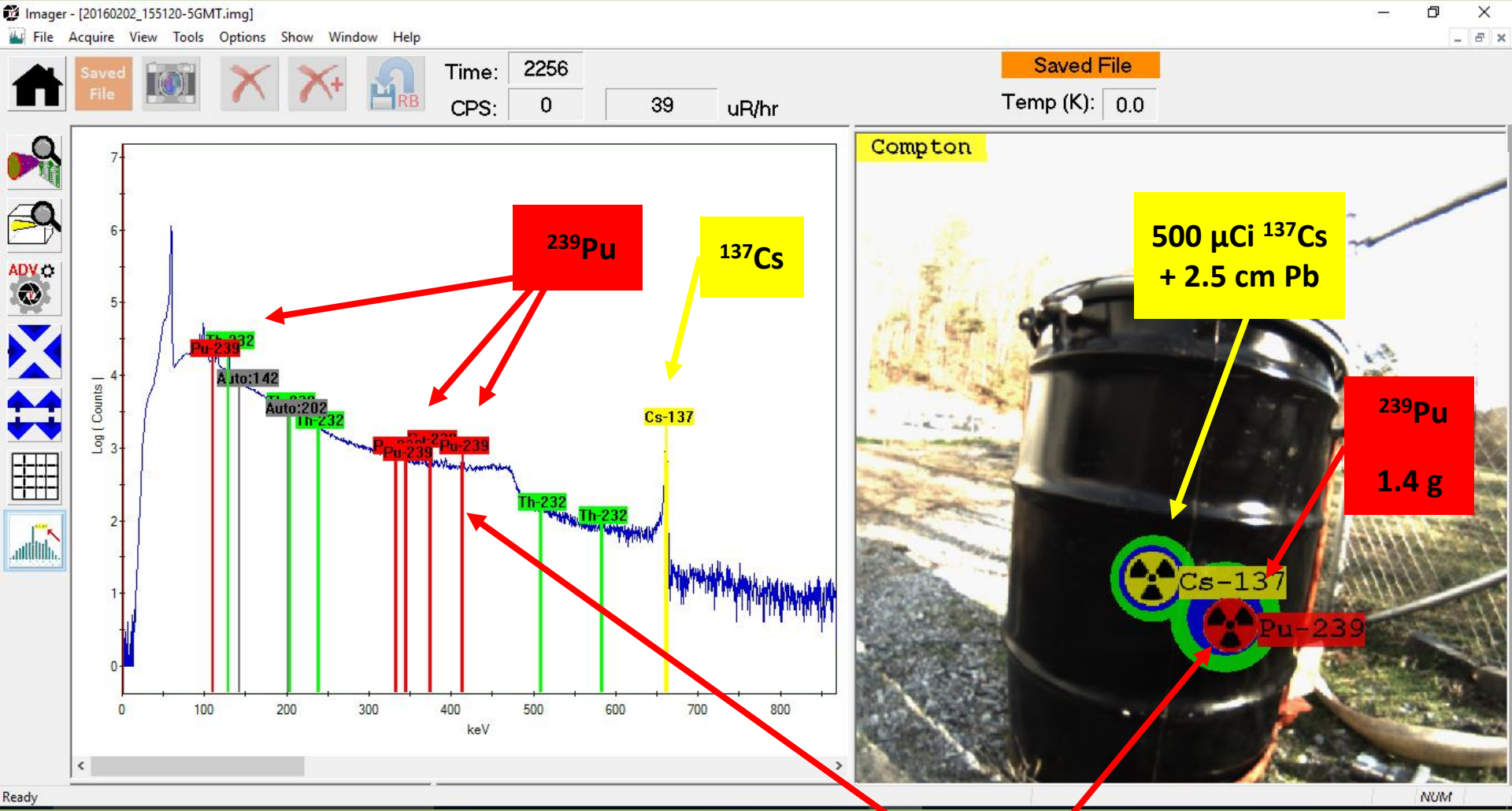

Energy resolution is very important here
This could not be done without imaging

CBRNE Team Training
Push in for a closer look at the ^{239}Pu

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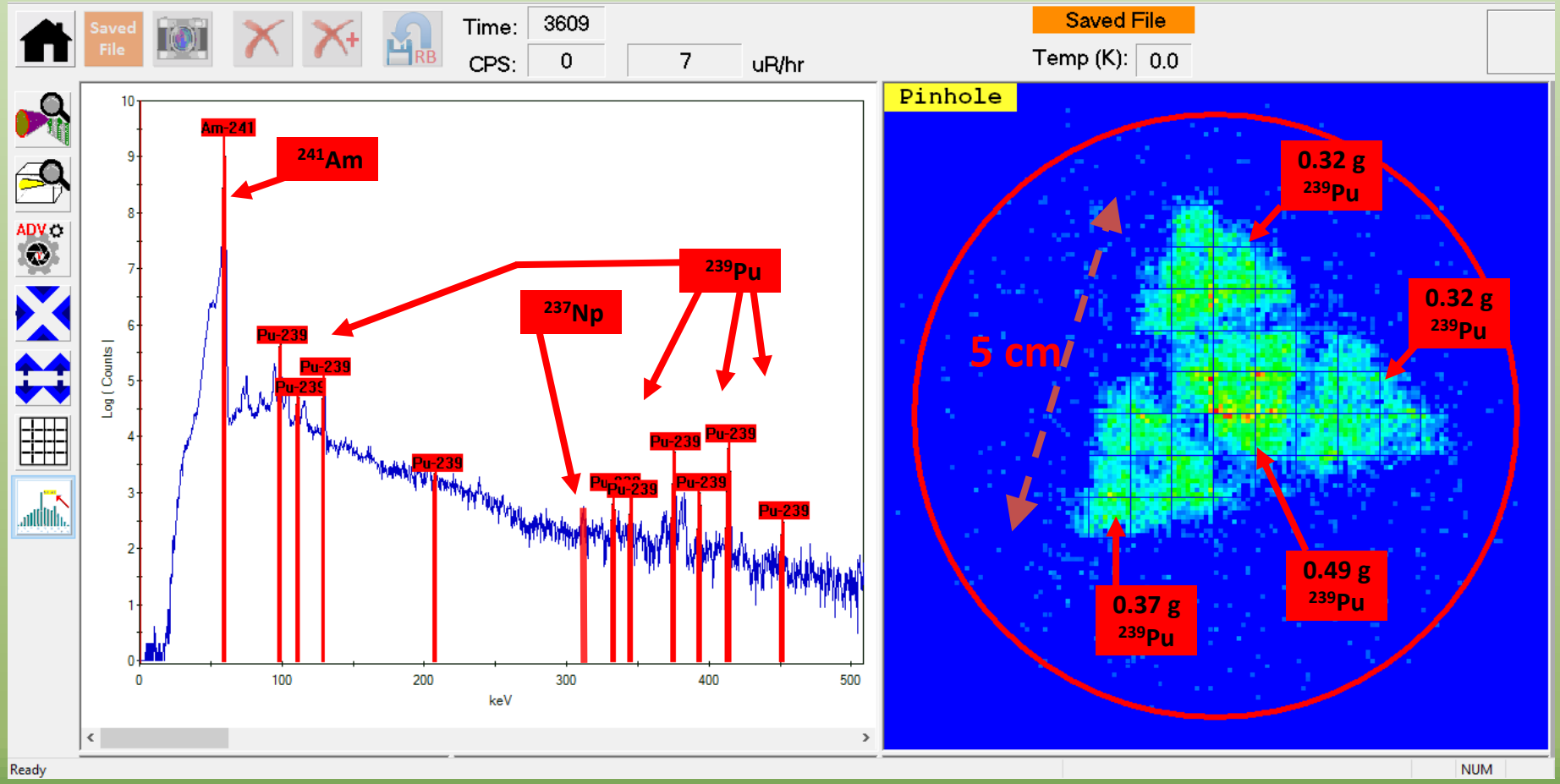
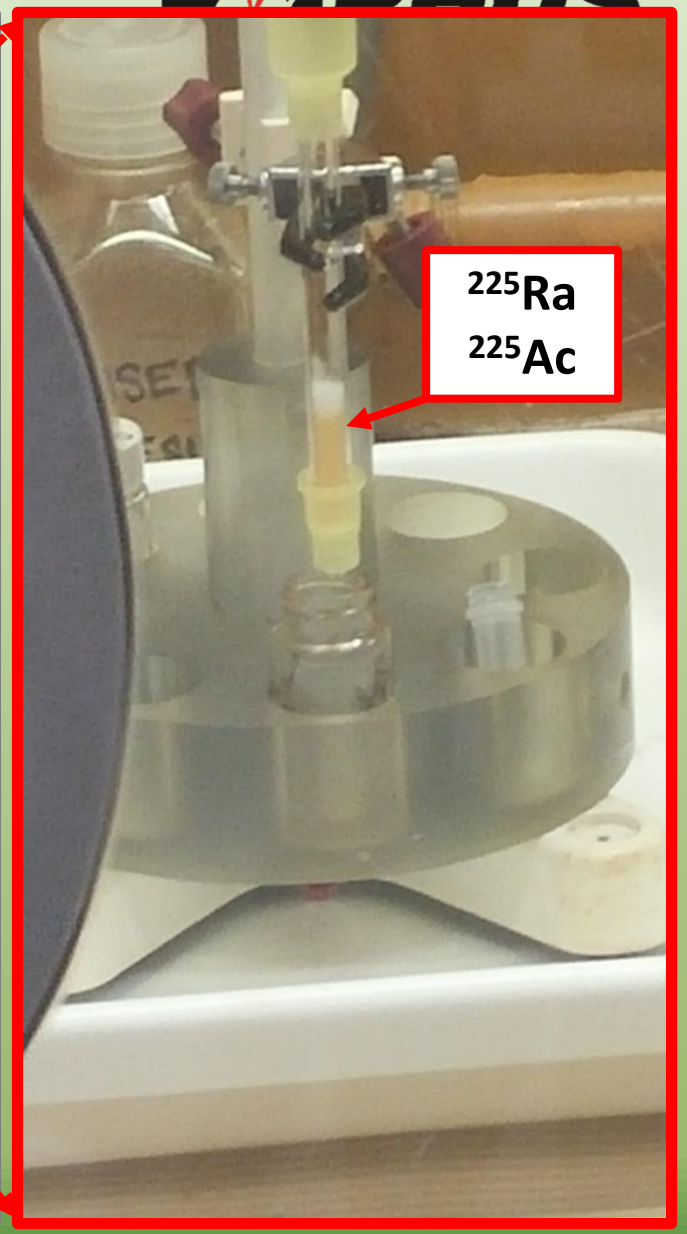
Gamma Ray Imaging Detectors

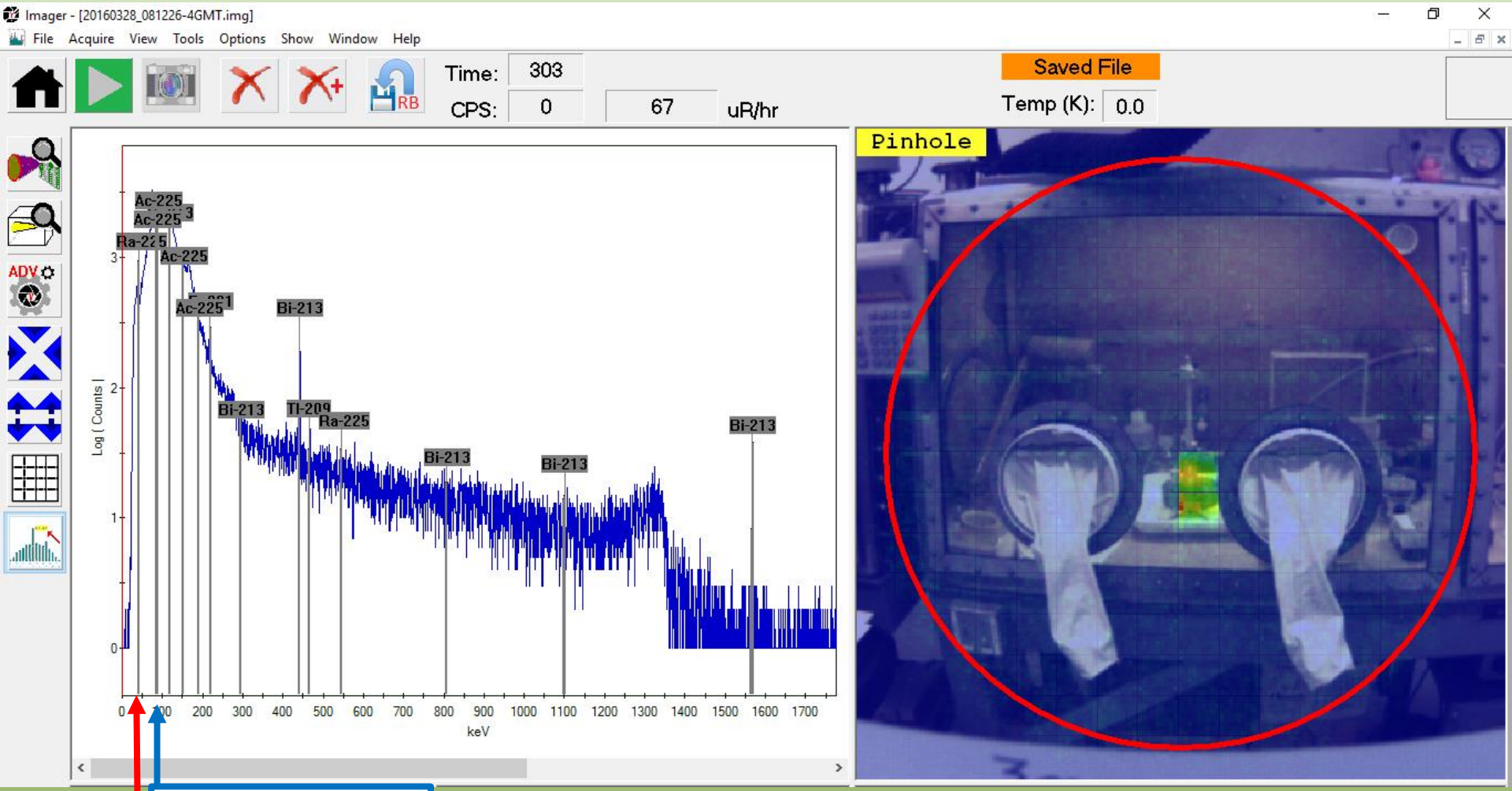


^{239}Pu Structure and Quantification

Radioisotope separation



PHDS
Gamma Ray Imaging Detectors



40 keV ^{225}Ra

PHDS
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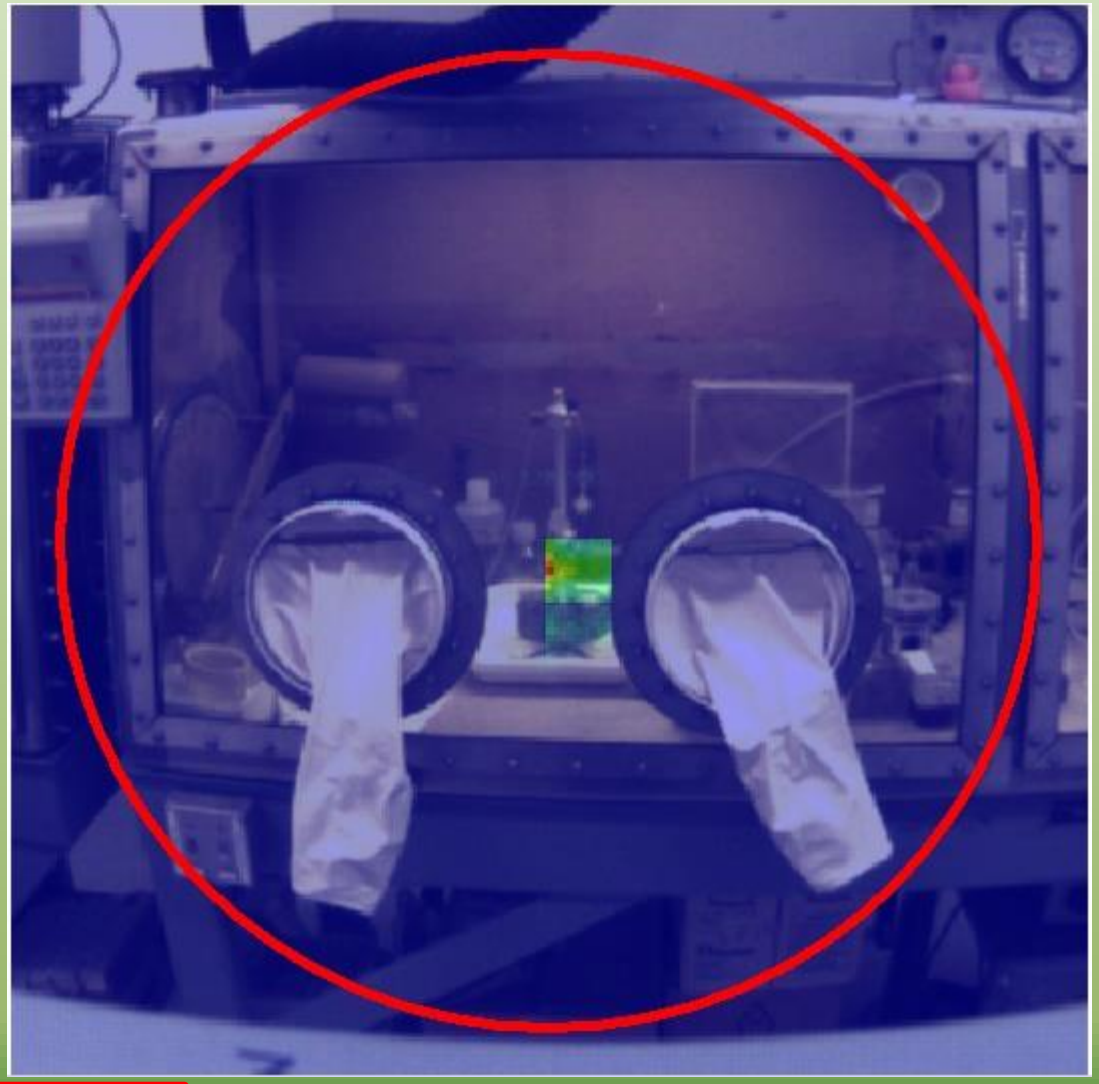
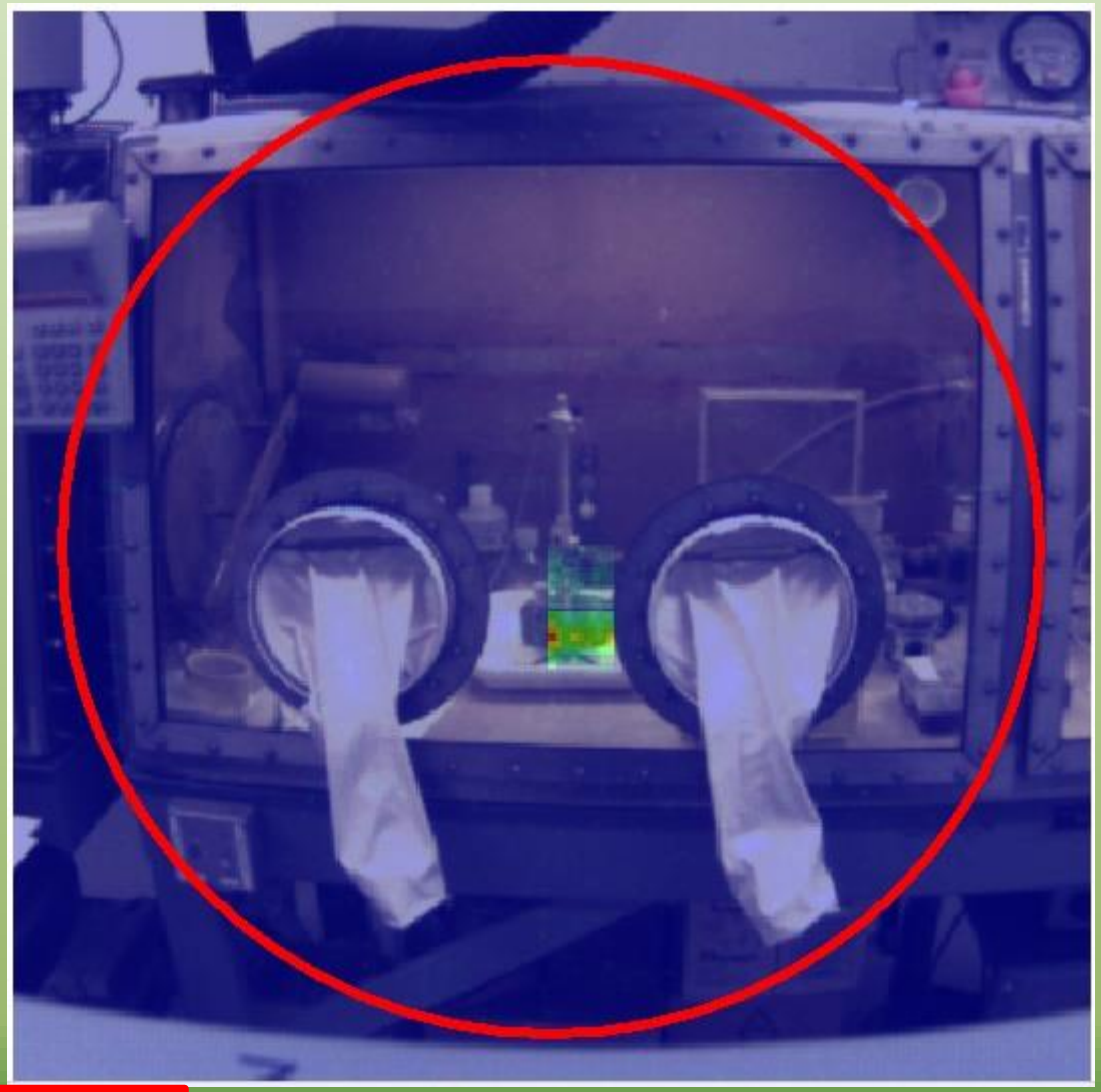


5 min

40 keV ^{225}Ra

PHDS
Gamma Ray Imaging Detectors



10 min

40 keV ^{225}Ra

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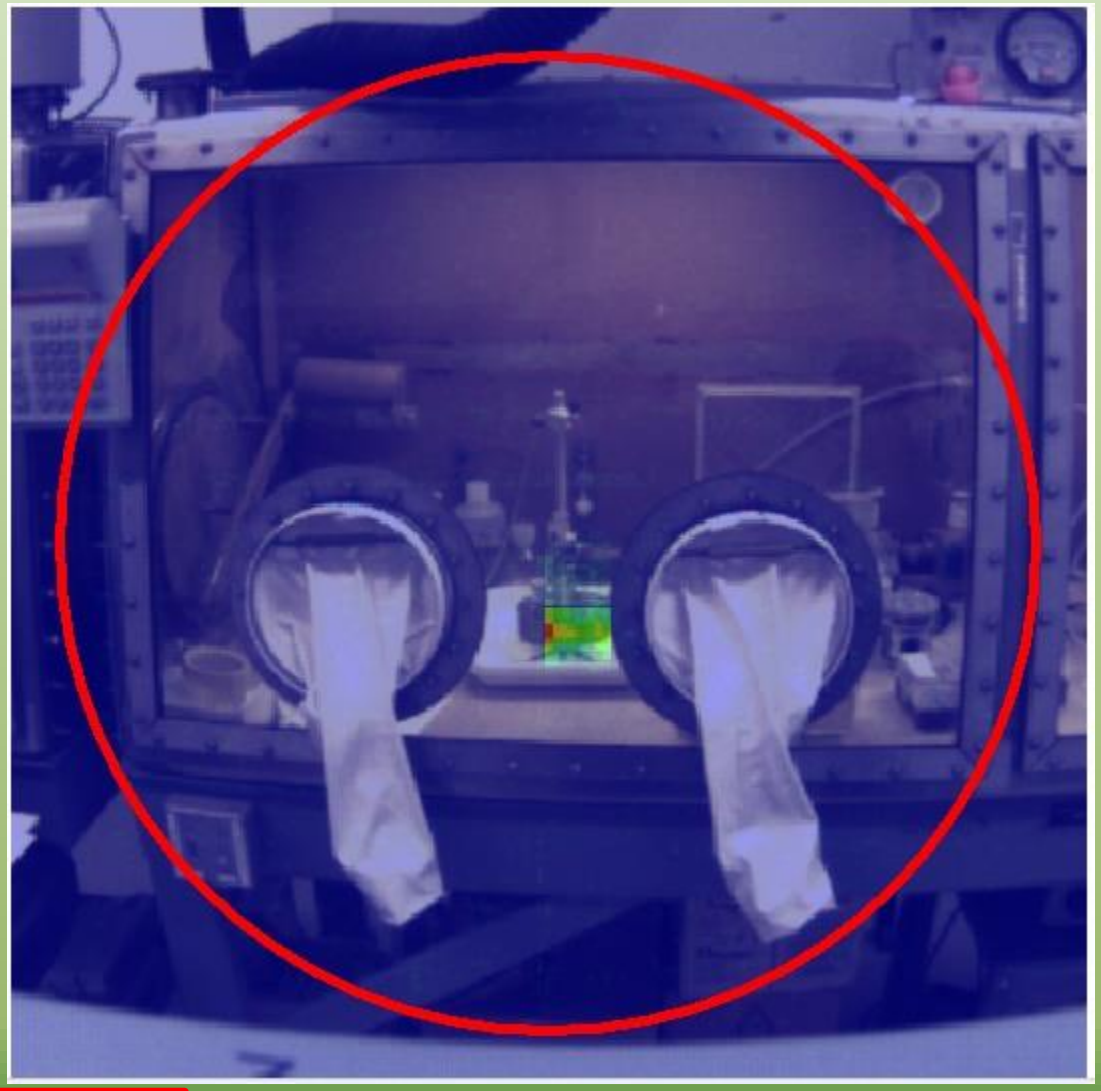
Gamma Ray Imaging Detectors



15 min

99.8 keV ^{225}Ac

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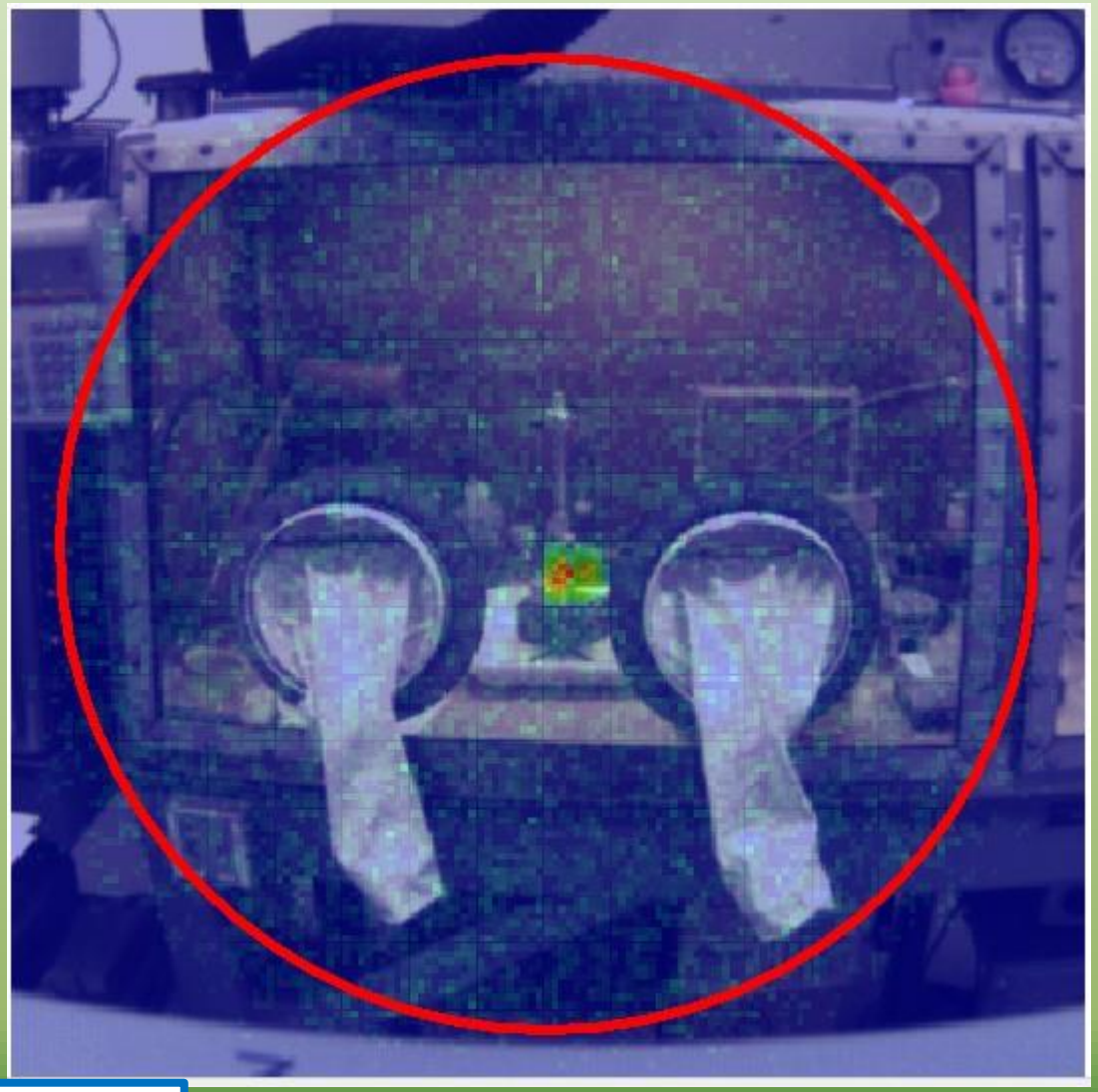
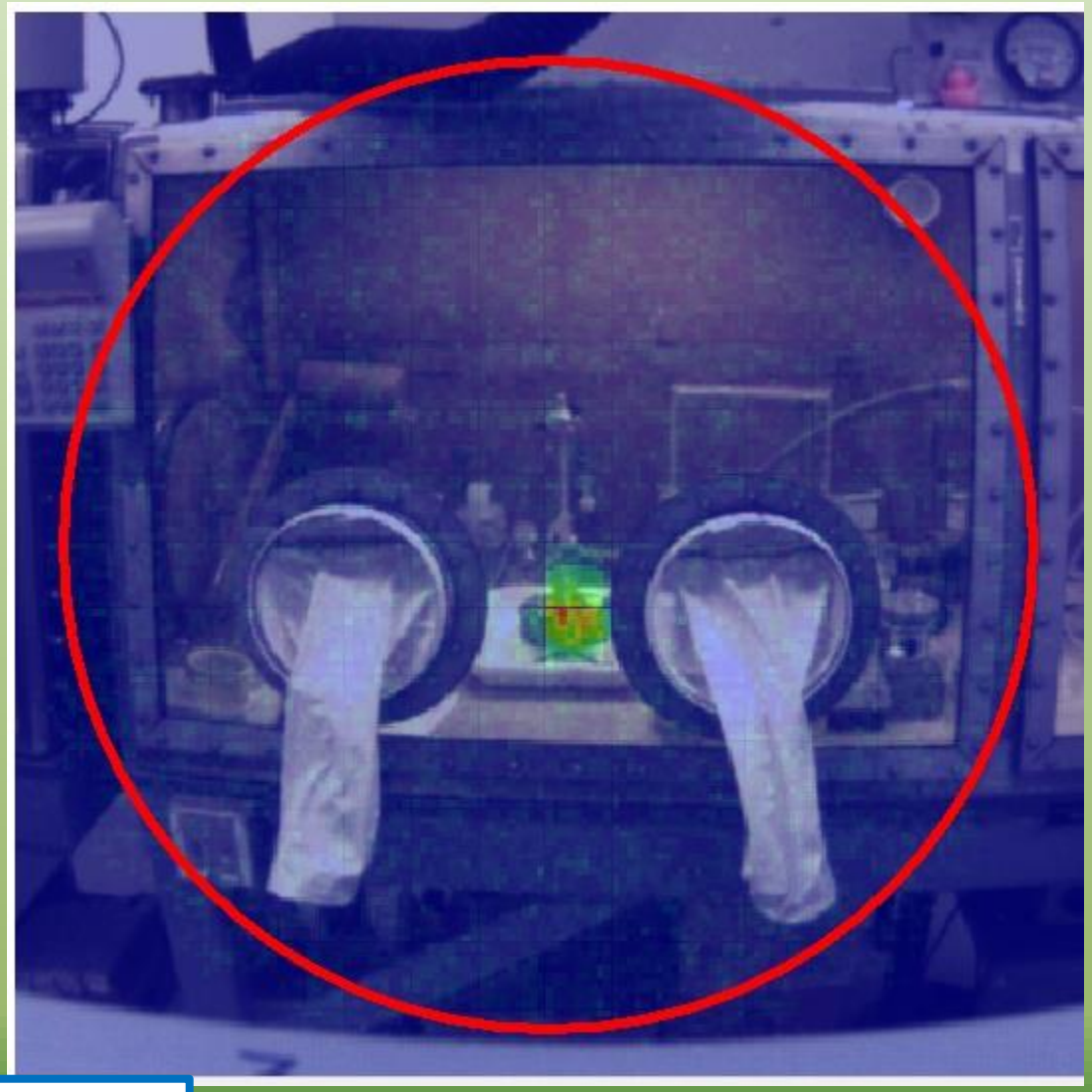


5 min

99.8 keV ^{225}Ac

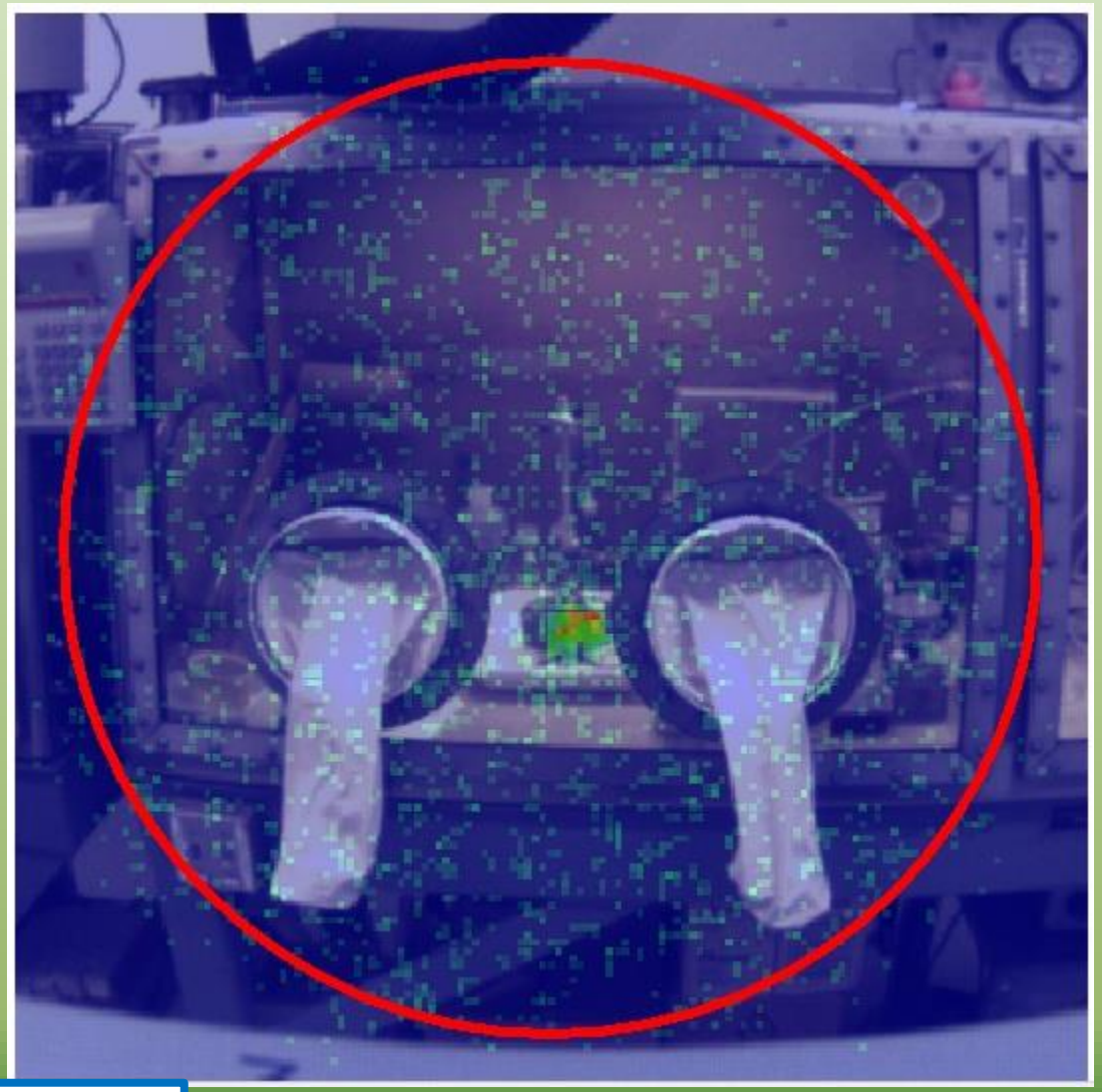
PHDS
Gamma Ray Imaging Detectors



10 min

99.8 keV ^{225}Ac

PHDS
Gamma Ray Imaging Detectors



15 min

Collection Carousel

PHDS
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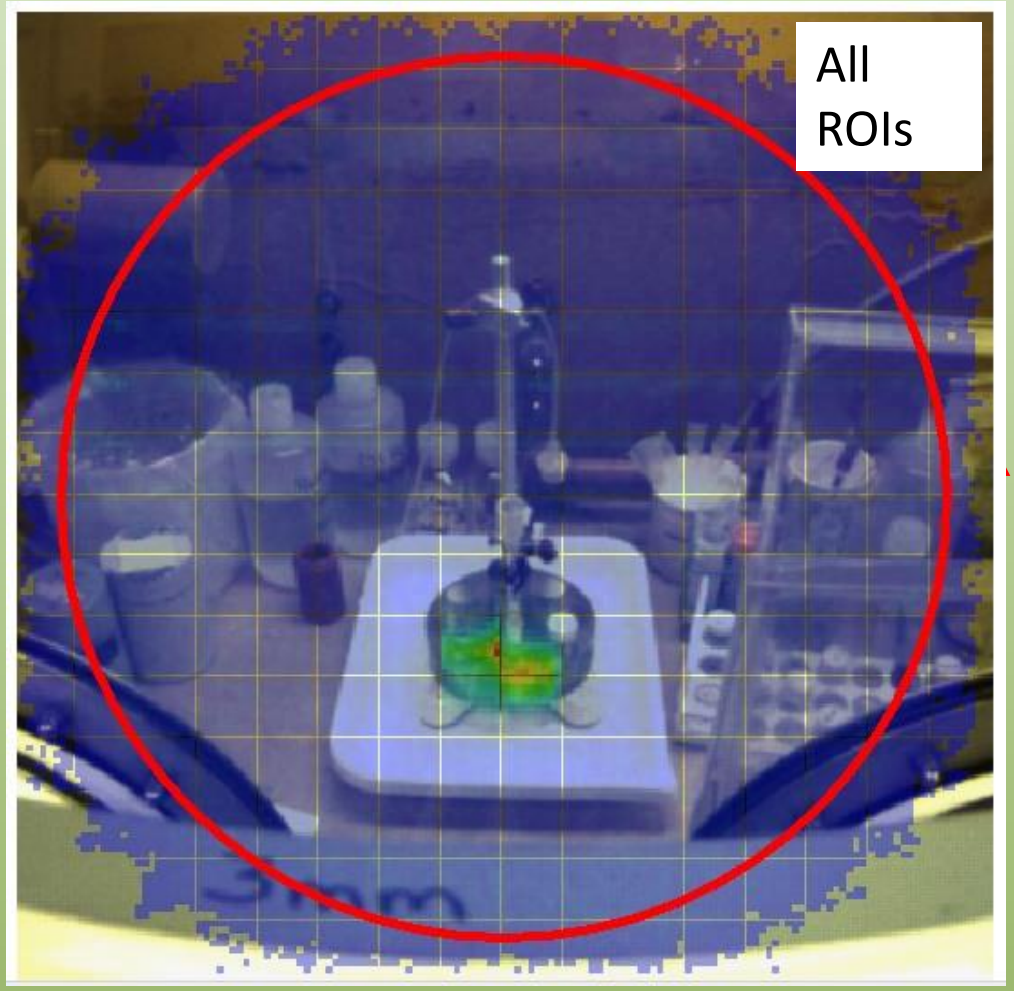
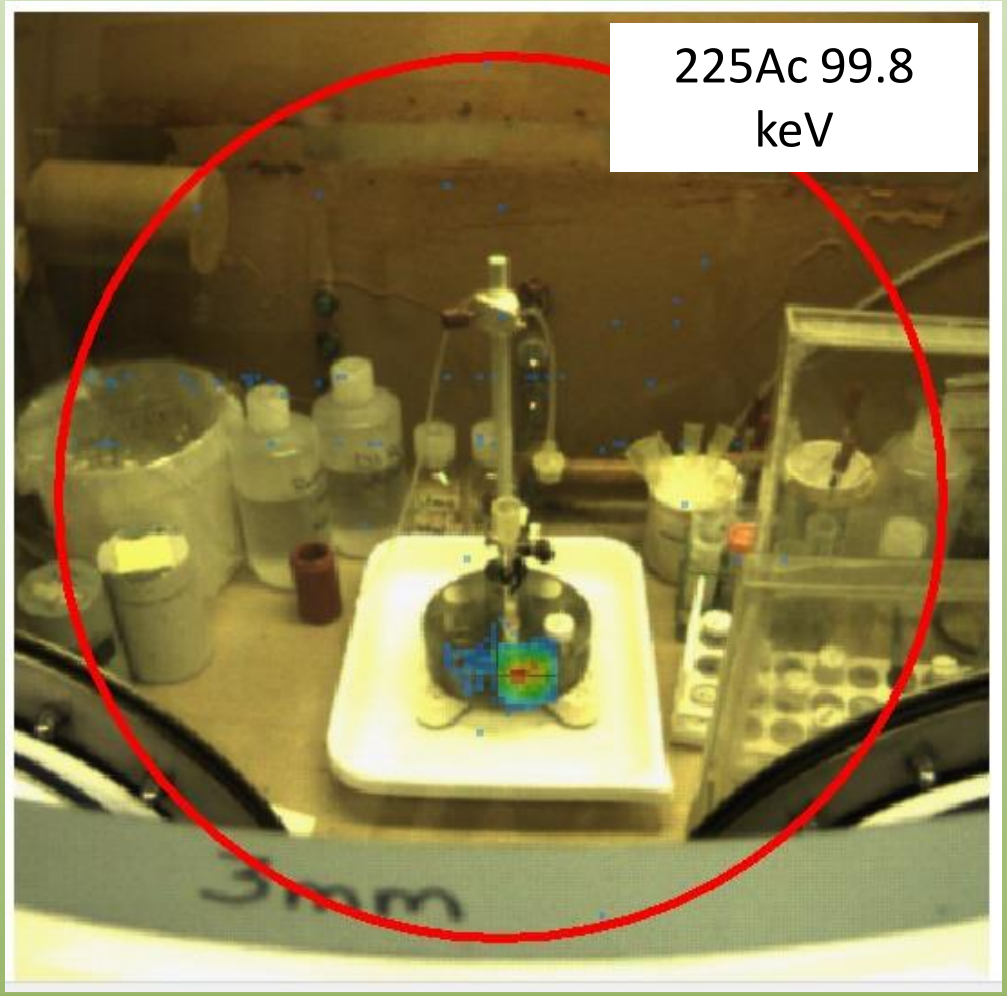


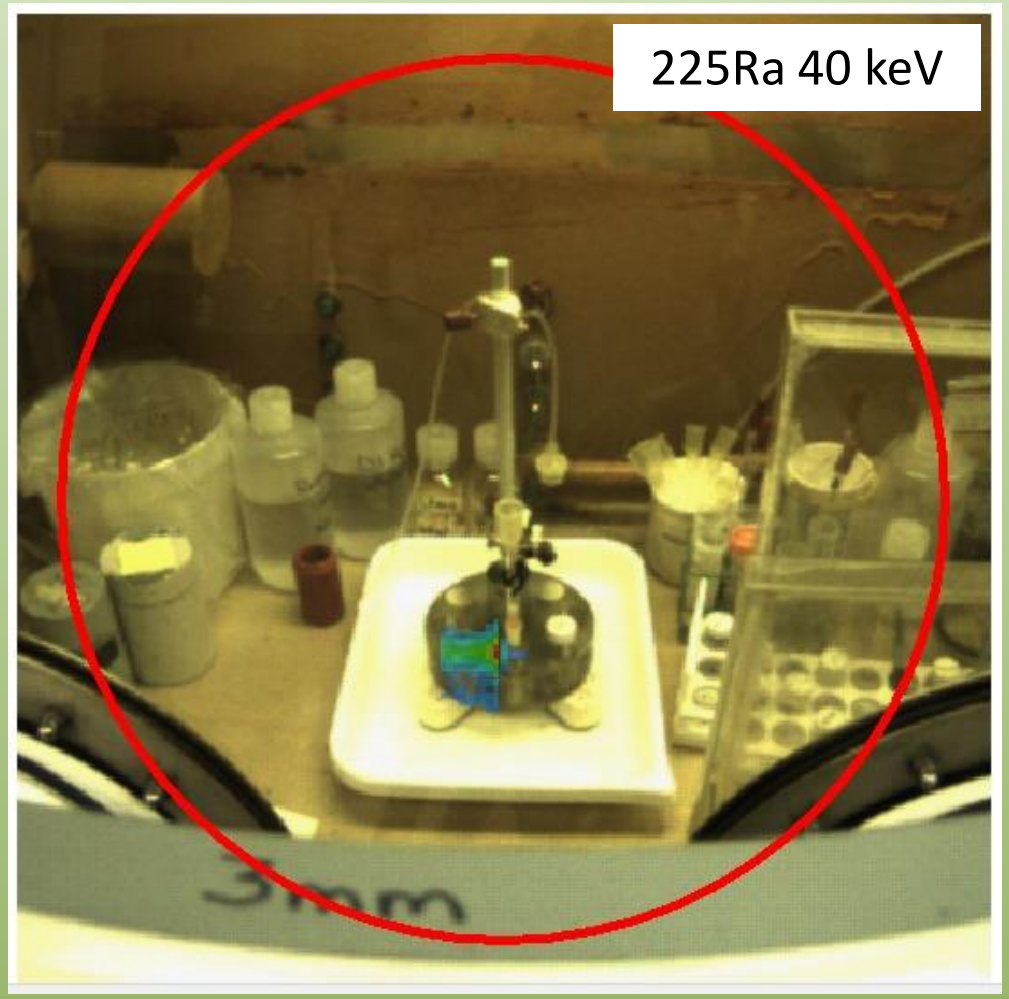
Collection Carousel

PHDS
Gamma Ray Imaging Detectors



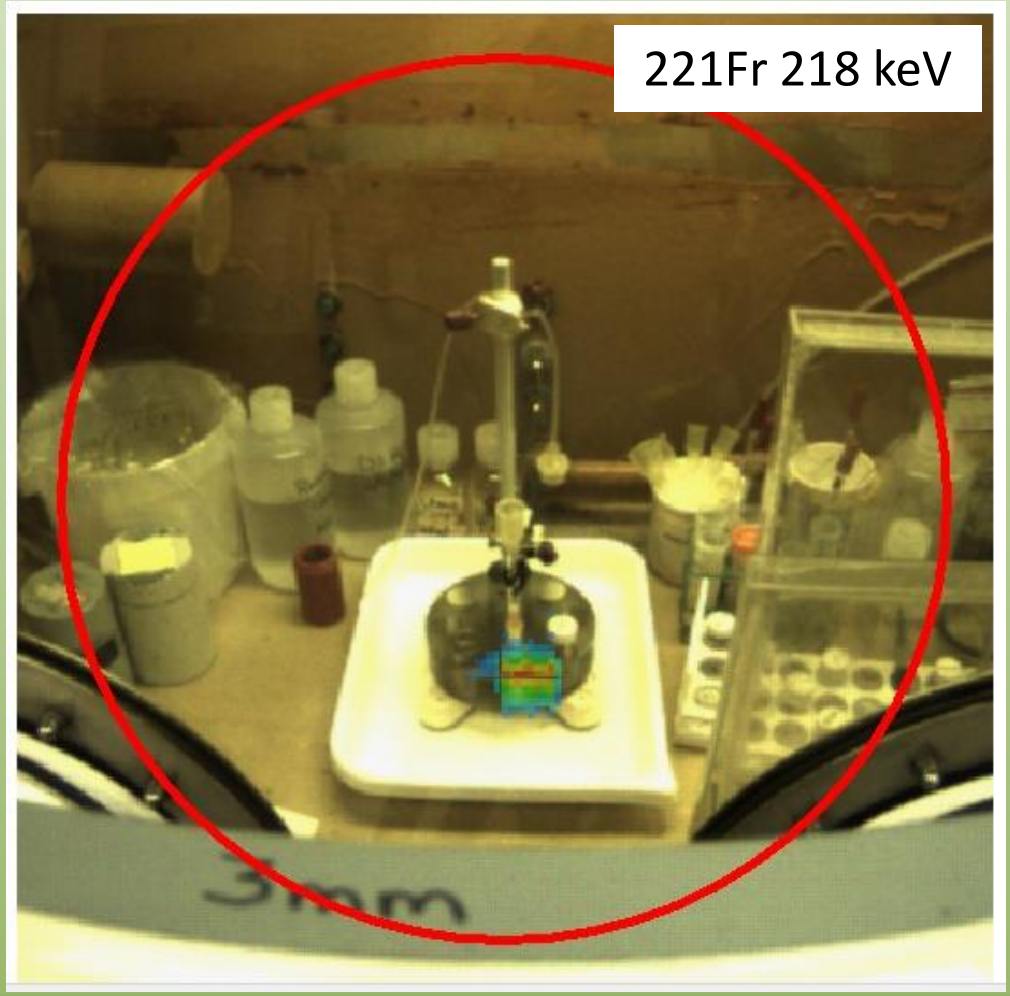
Collection Carousel

PHDS
Gamma Ray Imaging Detectors



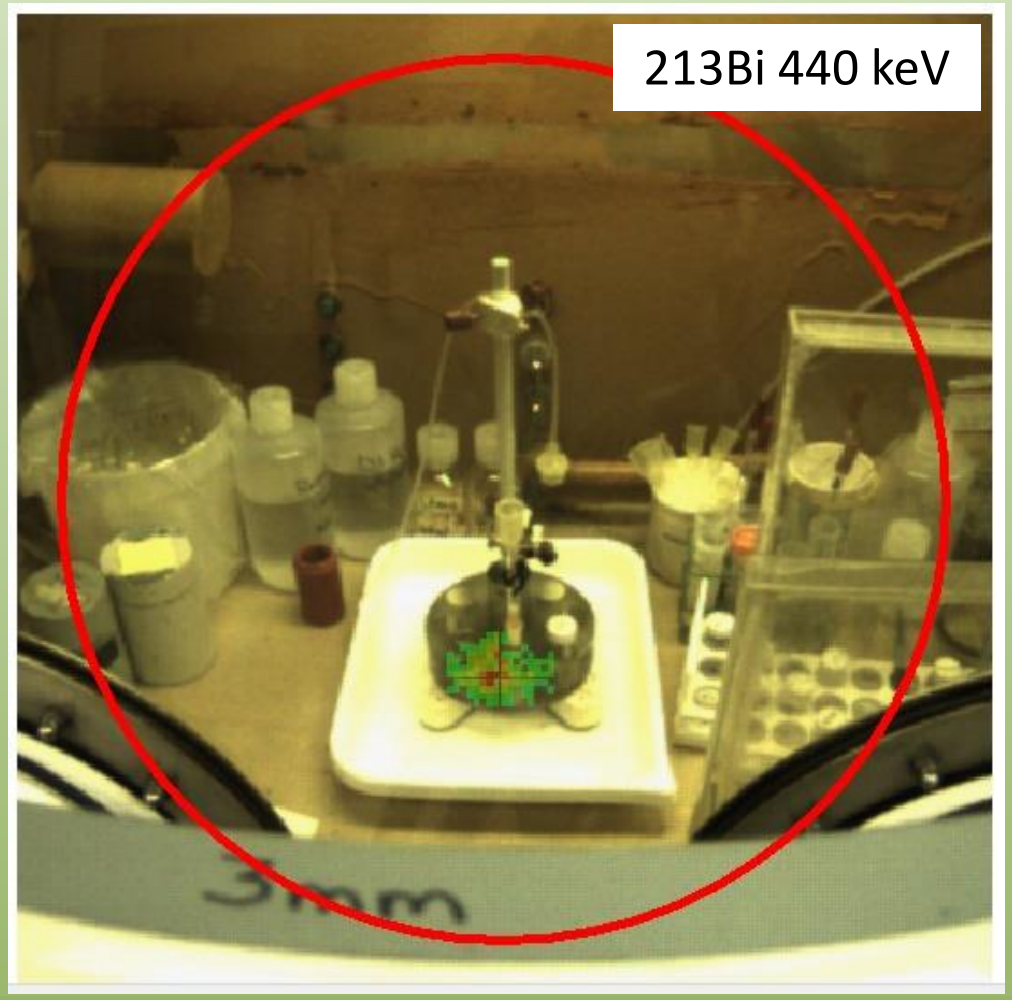
Collection Carousel

PHDS
Gamma Ray Imaging Detectors



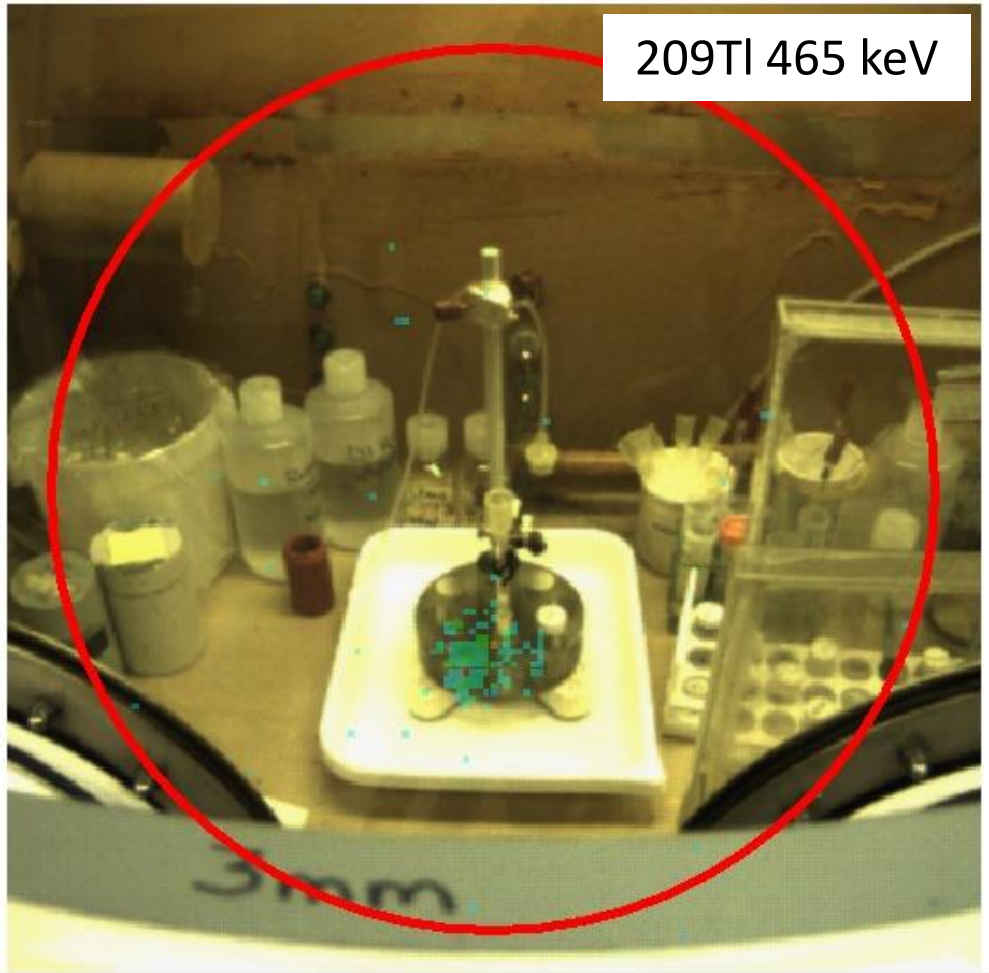
Collection Carousel

PHDS
Gamma Ray Imaging Detectors



Collection Carousel

PHDS
Gamma Ray Imaging Detectors



Special Detectors Designed by Physicists

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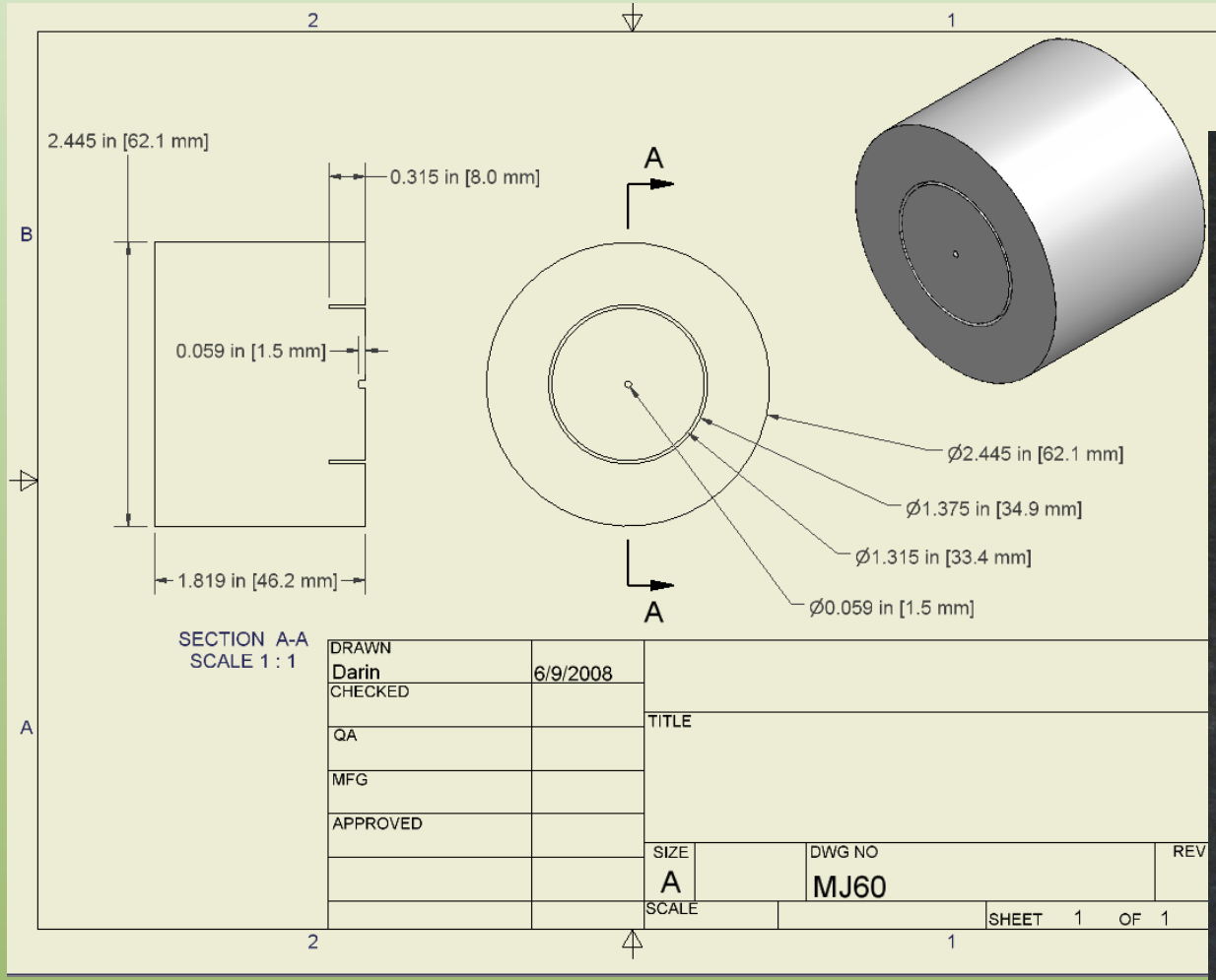
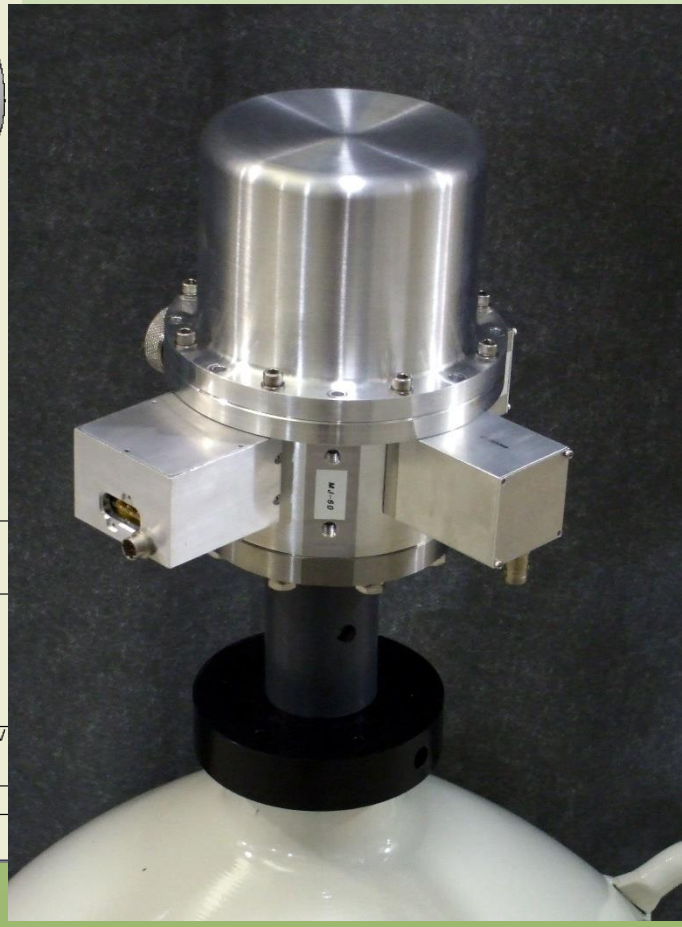
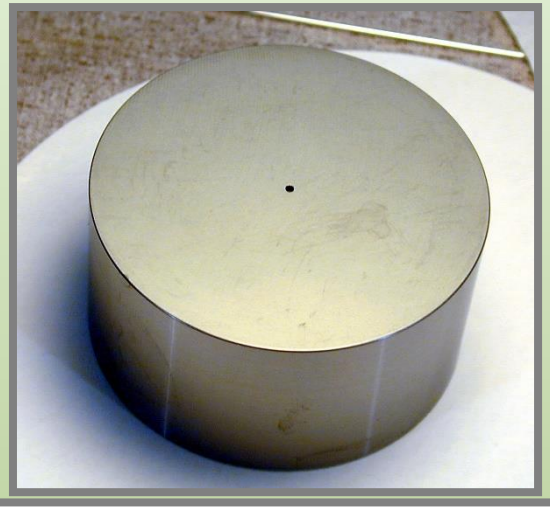
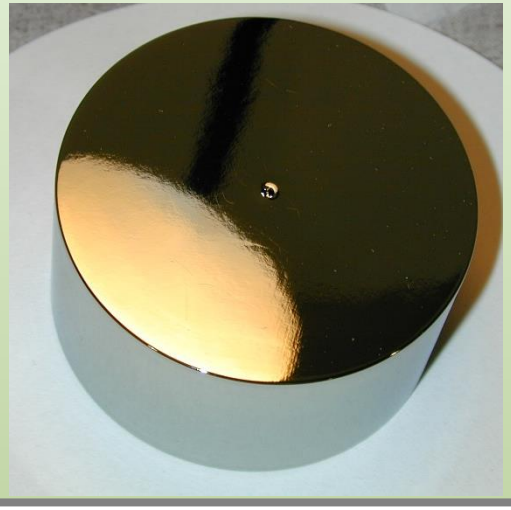
MJ60

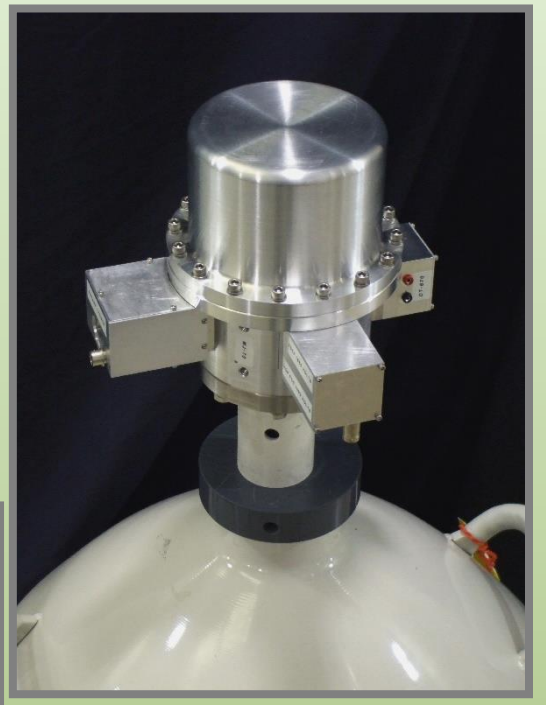


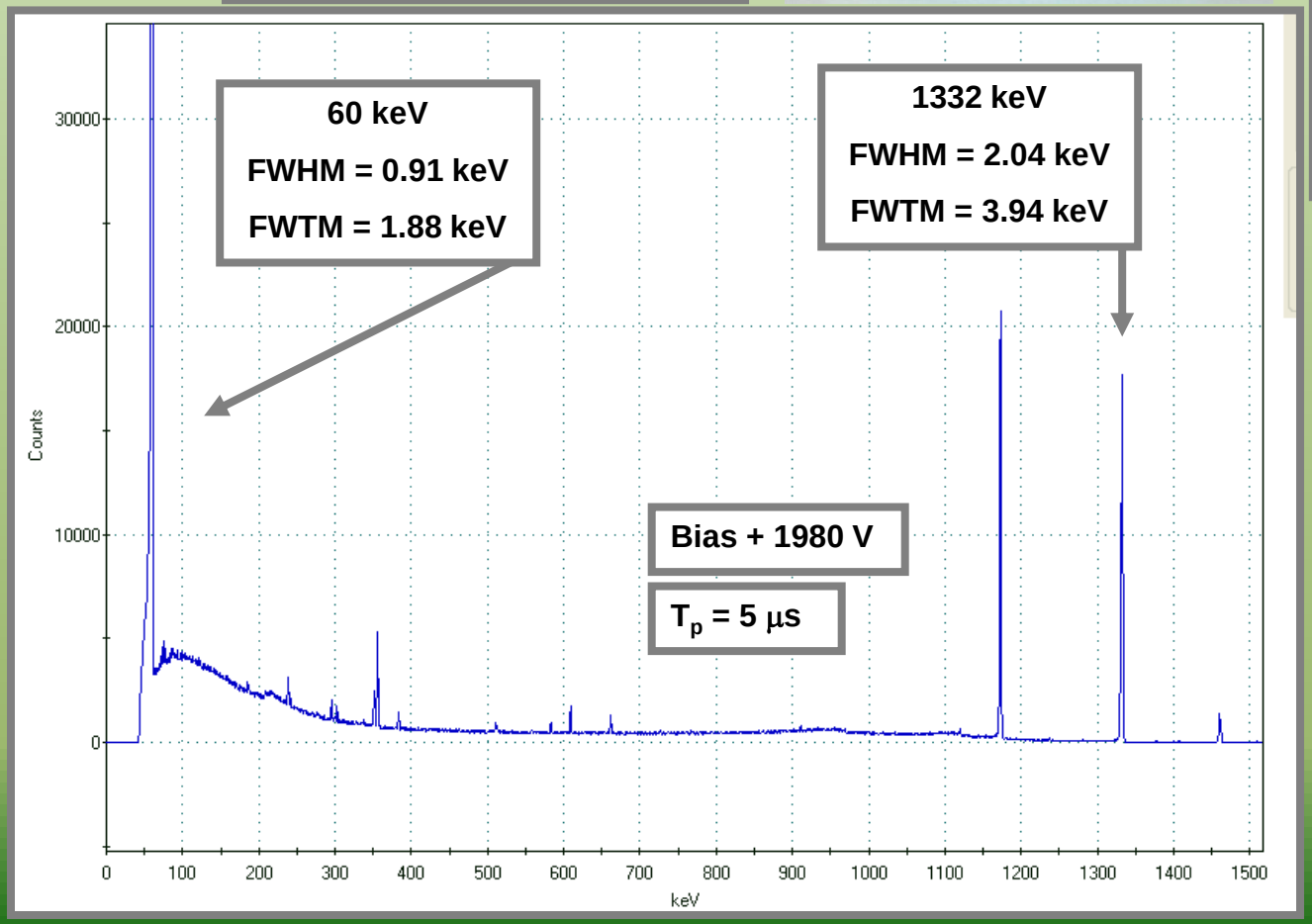


MJ70









Very small p+ contact
1.5-mm diameter
1.5-mm deep
[However 10-pF JFET]

Very Large HPGe Slab

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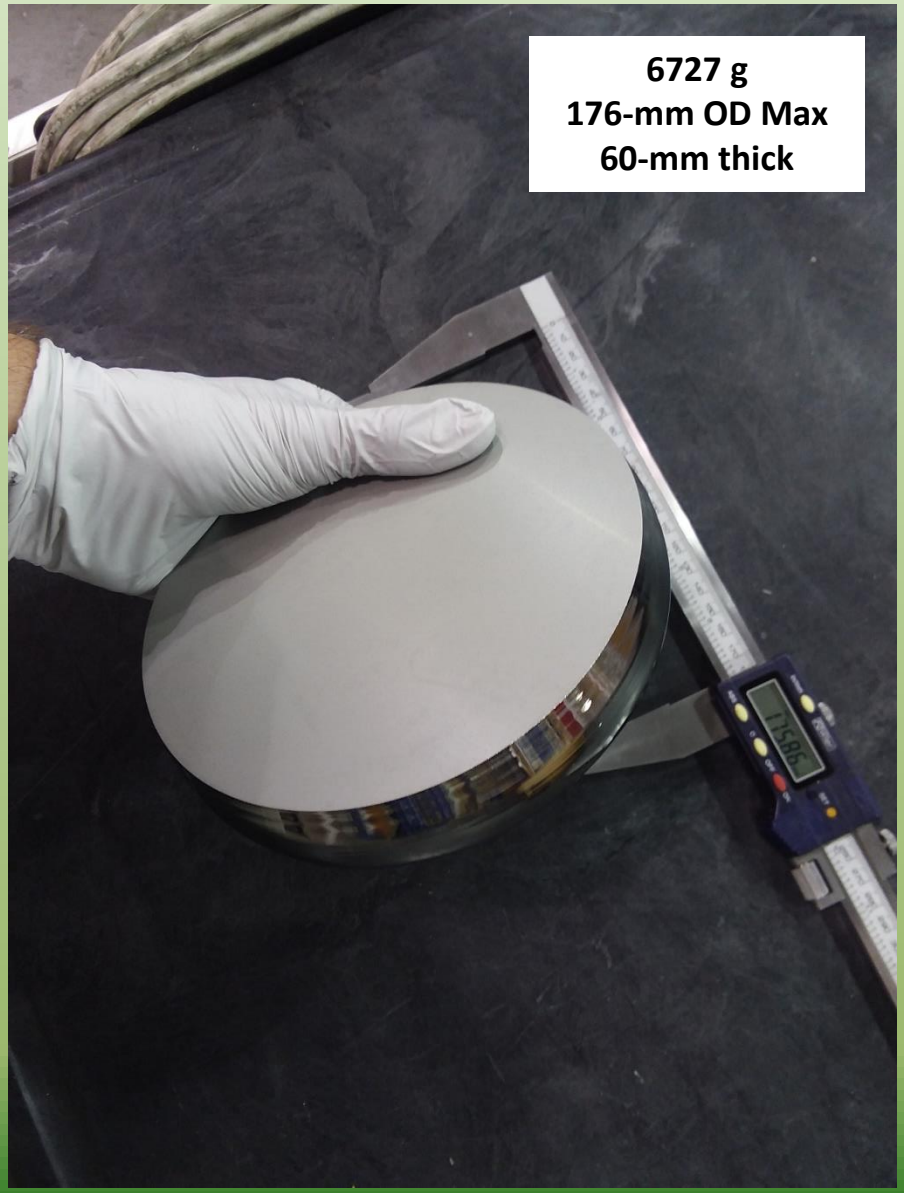

Very Large HPGe Shape

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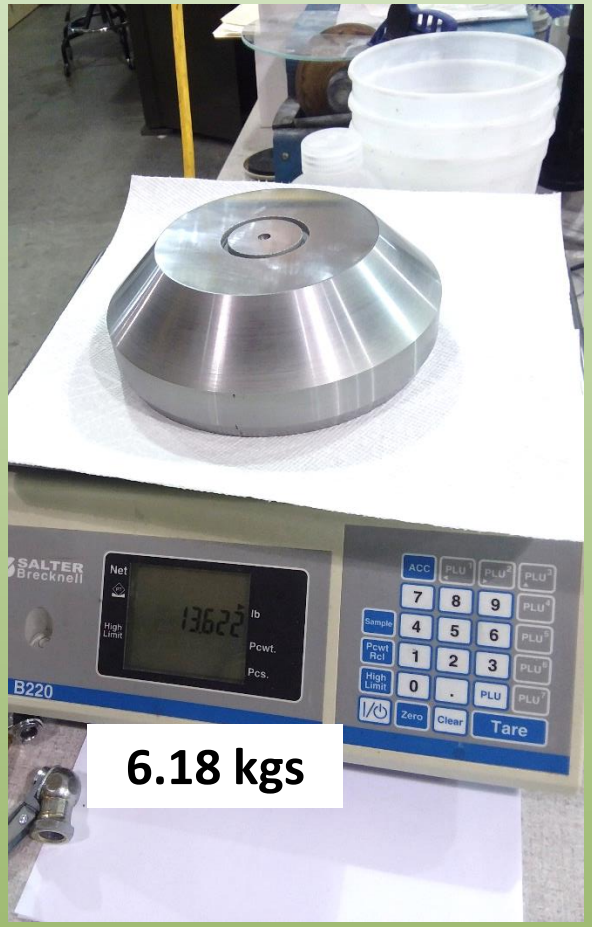
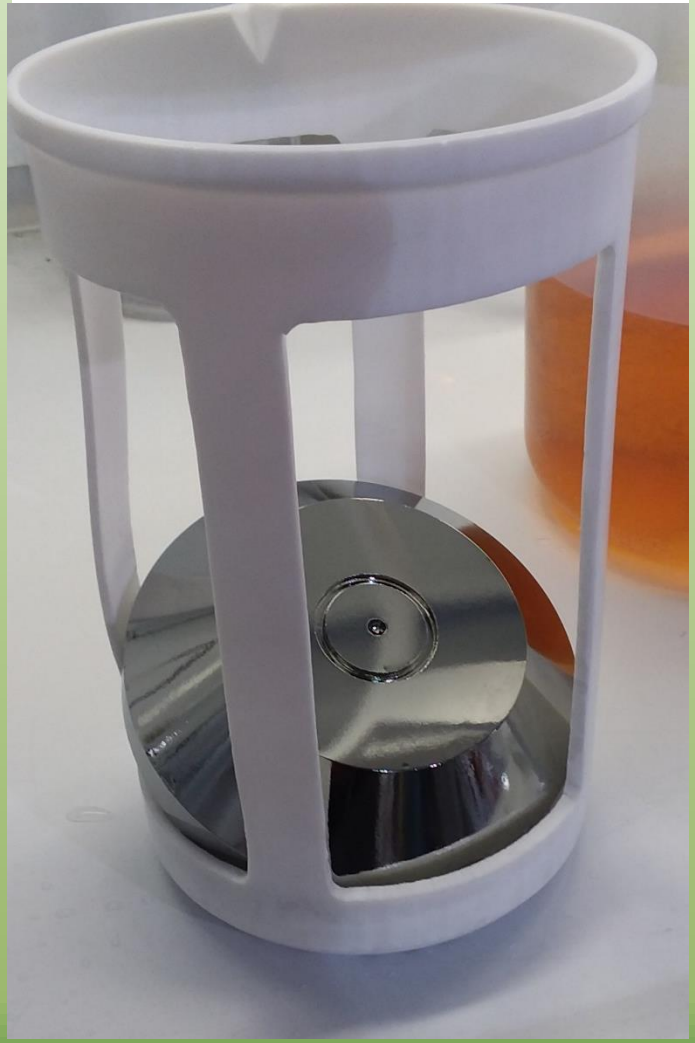
Very Large HPGe Detector

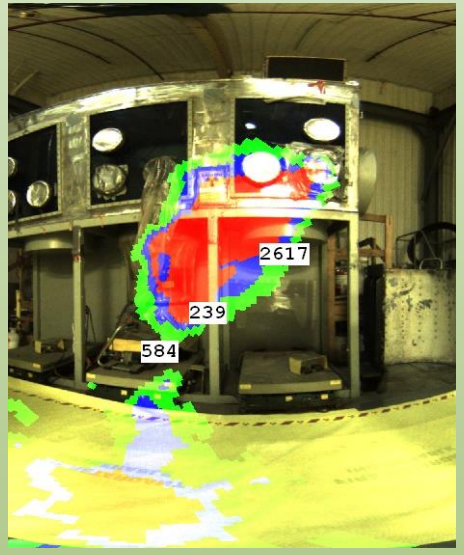




PHDS
Gamma Ray Imaging Detectors

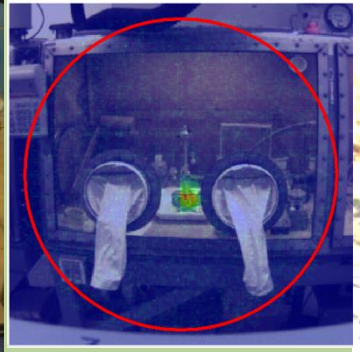
Search

Decontamination
Decommissioning



Nuclear
Materials
Management

Radioisotope
Separation



CBRNE

Nuclear Physics

Thank you!