PHDS
Gamma Ray Imaging Detectors

Nuclear Physics Gamma-ray Imaging System for Real-Time Rare Isotope Harvesting, Monitoring and Radiochemical Separation – NP Imager

DE-SC0017245 5/21/2018 – 5/20/2021

Ethan Hull Ph.D PI, CEO and Technical Director

Matt Kiser, Ph.D. Director of Physics

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A collaboration with: ORNL (Jared Johnson, Jon Garrison, Riley Hunley, Klaus Ziock)
MURR (Heather Hennkens and Alan Ketring)
NSCL (Greg Severin)

- **PHDS Co. Introduction**
- **NP Imager Concept**
- **Continued NP Imager Prototype Development**
- ***Sales of NP Imager Products!!***

PHDS Co. History

PHDS
Gamma Ray Imaging Detectors

- Est. Fall 2004 – Nuclear and Solid-State Physics Origin
  - History: Custom Nuclear-Physics Detectors (Lab)
  - Recently: Modular HPGe Systems (Lab and Field)
- Complete Germanium Manufacturing + R&D at PHDS Co.
  - Concept Design
  - Crystal Growth
  - Detector Fabrication
  - System Integration
  - Software application
  - Sales & Service

Enabling Capabilities
From rocks to software

Science Experiment

NPX (150 lbs.)
2008 Laboratory

Versatile Global Commercial Product

GeGI (15 lbs.)
2016 Hand Portable Imager + Spectrometer
10x less size and weight

Versatile Global Commercial Product

Fulcrum (7-9 lbs.)
2018 Hand Portable Spectrometer

Specialty Operations Product

LoPro (8-11 lbs.)
2020 Specialty Spectrometer

From *Frontiers* of Nuclear Physics
to *Frontlines* of Nuclear Security

PHDS Co. now manufactures and sells 4 HPGe products

PHDS
Gamma Ray Imaging Detectors

PHDS
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PHDS Co. now supports 4 products

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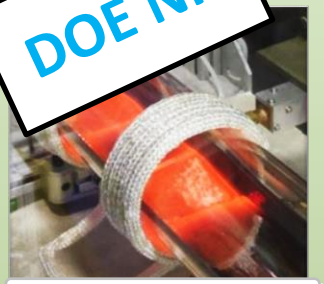
10,000 ft^2 Manufacturing and R&D Facility in Knoxville, TN

Vertical manufacturing at PHDS Co.

PHDS
Imaging Detectors

DOE NP



Ge Zone Refine

DOE NP

HPGe Crystal Growth

DOE NP

Analysis

DOE NP

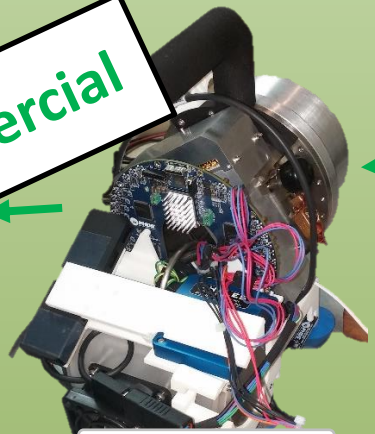
Commercial

Fabrication

Commercial

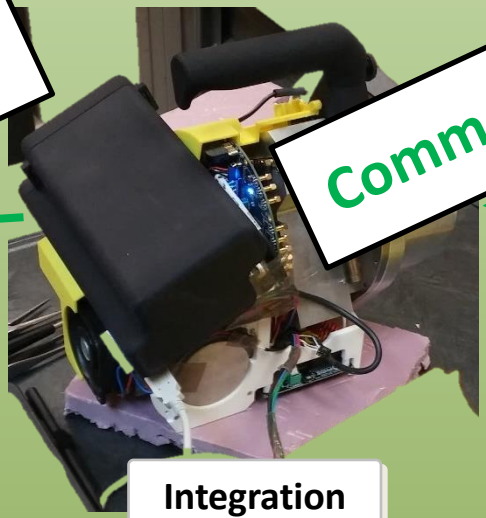
Cryogenics

Commercial



Electronics

Commercial



Integration

Commercial Products

DOE NP

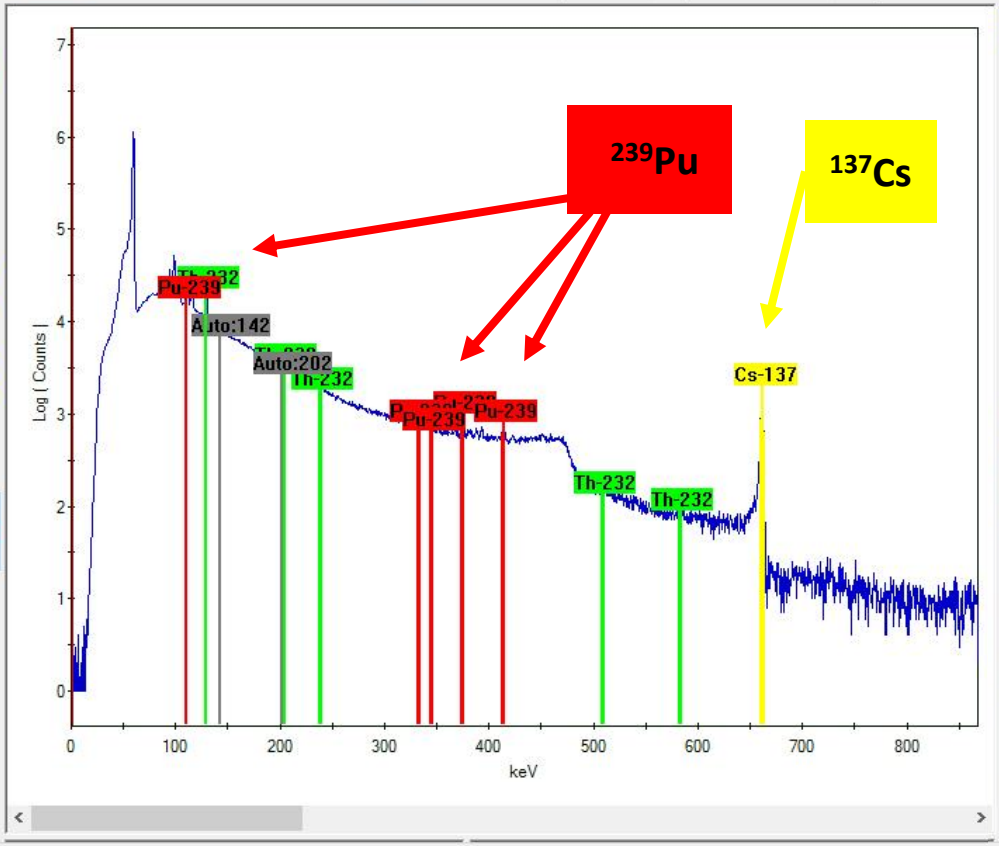
From rocks to software

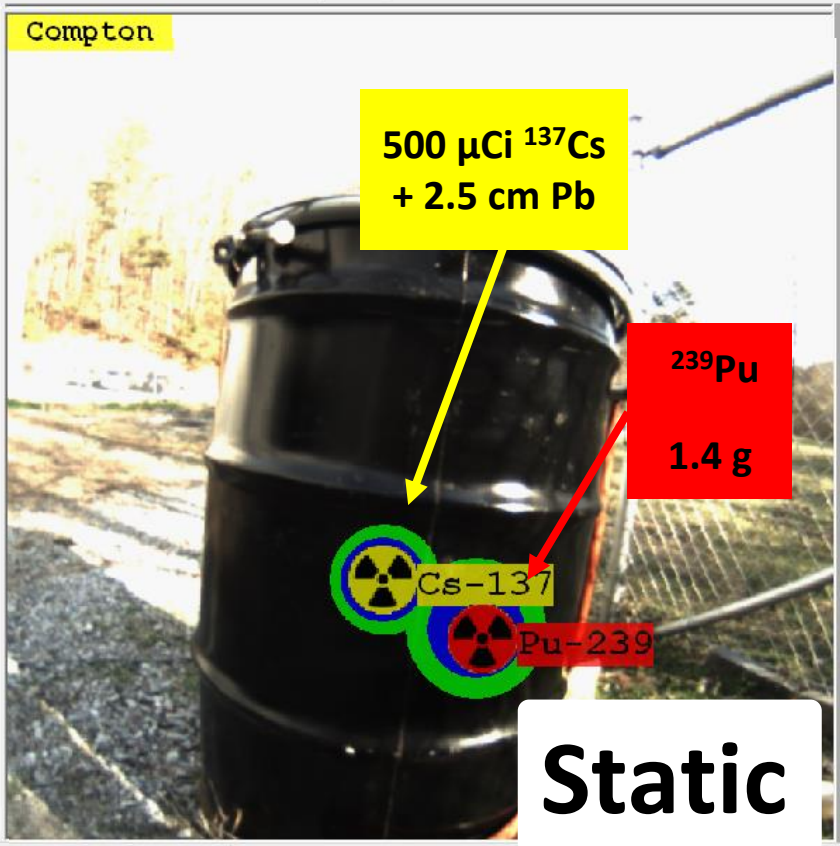
Motivation

CBRNE Team Training
^{239}Pu ID and Location

PHDS
Gamma Ray Imaging Detectors

Imager - [20160202_155120-5GMT.img]
File Acquire View Tools Options Show Window Help
Saved File
Time: 2256
CPS: 0
39 uR/hr
Saved File
Temp (K): 0.0





Static

Ready

Radiochemistry is Dynamic → Things necessarily move
NP Imager combines *Imaging, Spectroscopy and Time.*

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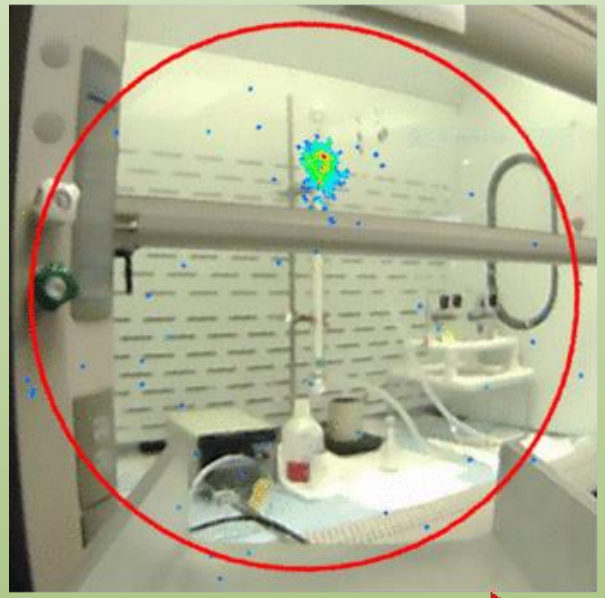
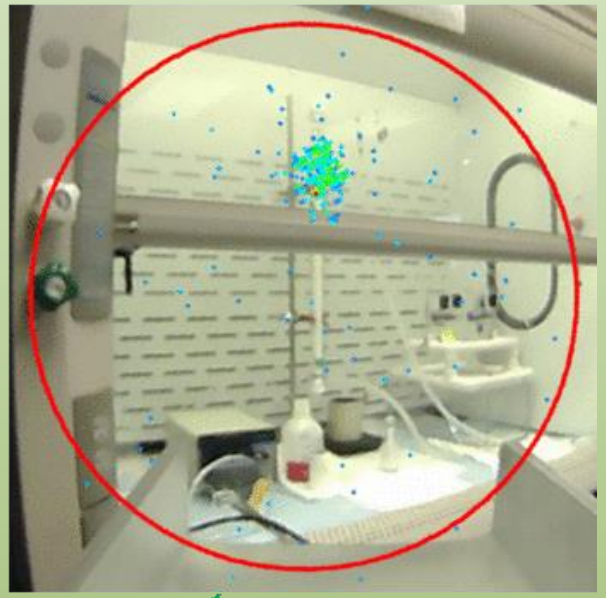
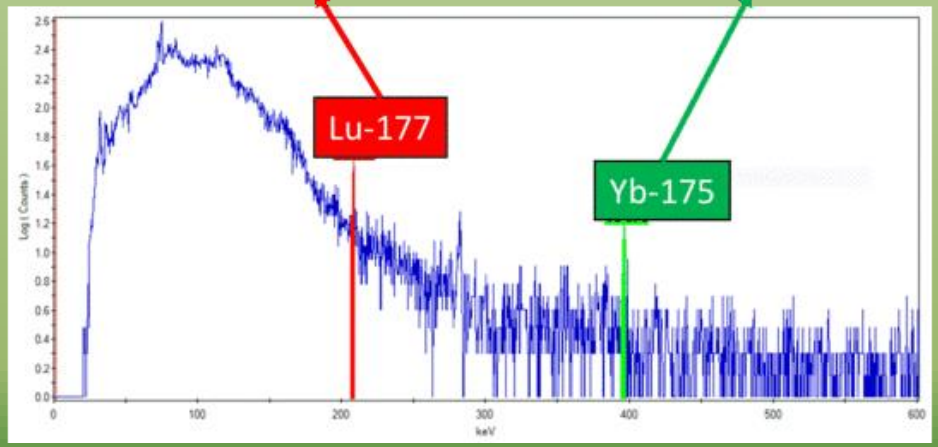
^{177}Lu/^{175}Yb Column Separation at MURR

t = 0 - 10 minutes







NP Imager Technical Development
Phase-II Prototypes

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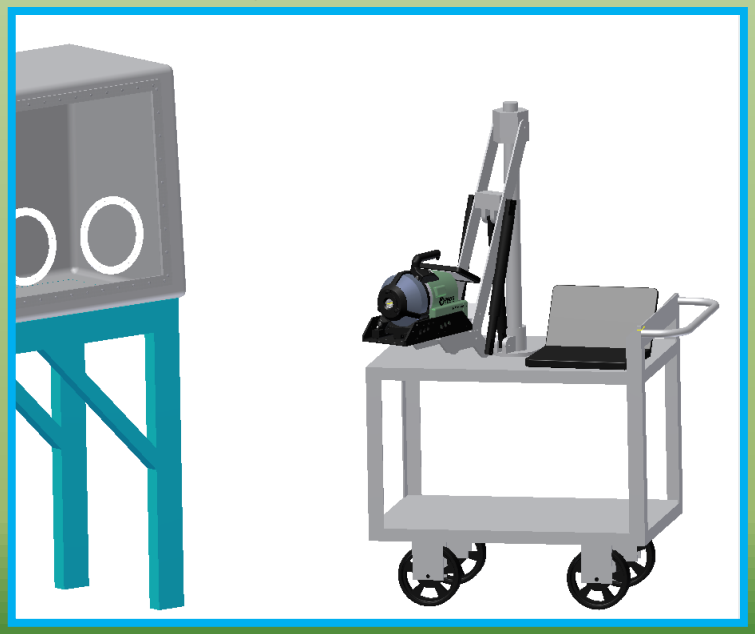
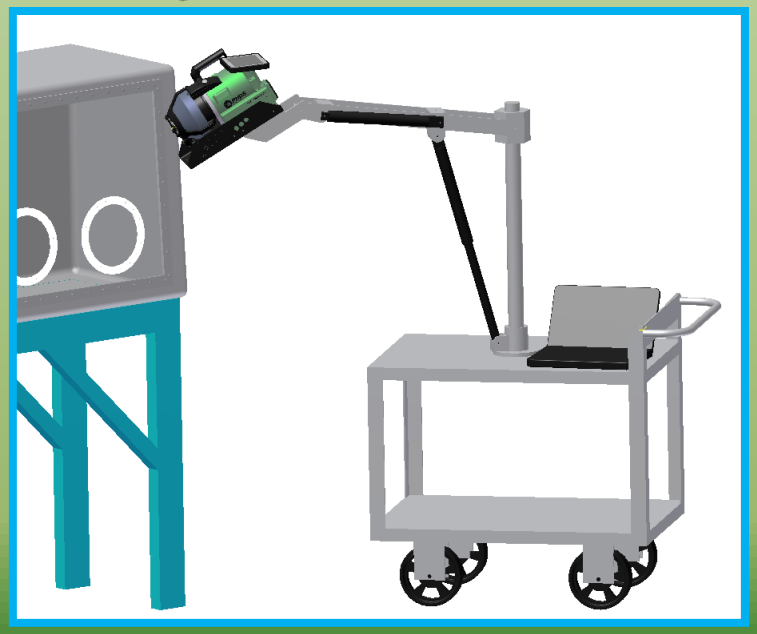
Concept Design





Summary of the NP Imager Phase II SBIR

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Phase II prototypes were delivered to:

1. MURR – Heather Henkens
2. ORNL – Jared Johnson and Klauz Ziock
3. NSCL – Greg Severin

Multiple collaborative efforts took place at all 3 DOE sites.

Throughout the program development with engineering units at PHDS Co. (see recent coded aperture example later – slides)

The major result: The Phase II program has been able to build the products up to reasonable commercial readiness and sell some products for DOE applications.

Summary of the NP Imager Phase II SBIR

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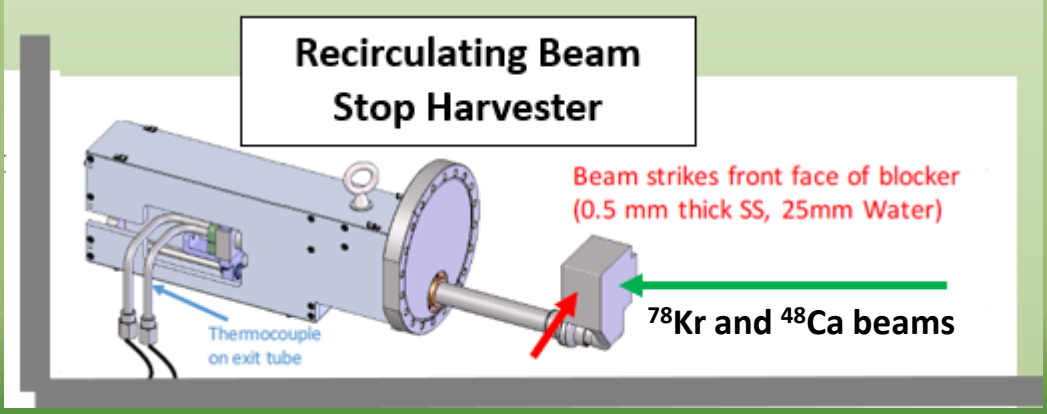
1. MURR – Heather Henkens and Alan Ketring
   - Wide variety of MURR-isotope separation images (prev slide)
   - Feedback regarding the need for shielding

1. ORNL – Jared Johnson and Klauz Ziock
   - Wide variety of ORNL isotope separation images
   - Value of the fusion of Compton imaging to recognize “other sources” (slides)

2. NSCL – Greg Severin
   - Novel measurements of production and harvesting (78Kr and 48Ca beams)
   - Recent mass transport calculation/NP Imager AGREEMENT (Greg’s slides)



Recall how NP Imager is used

NSCL

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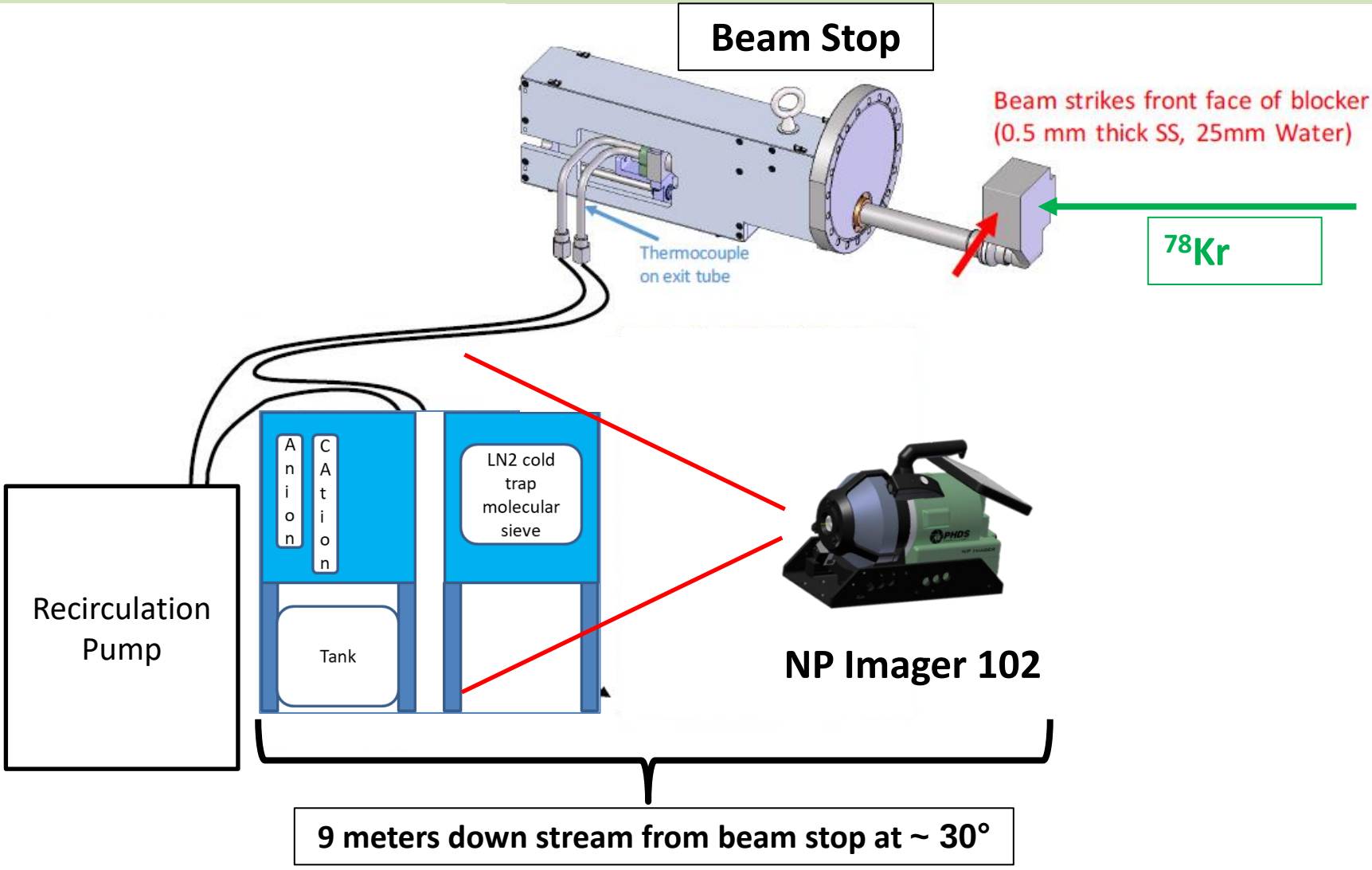

NSCL

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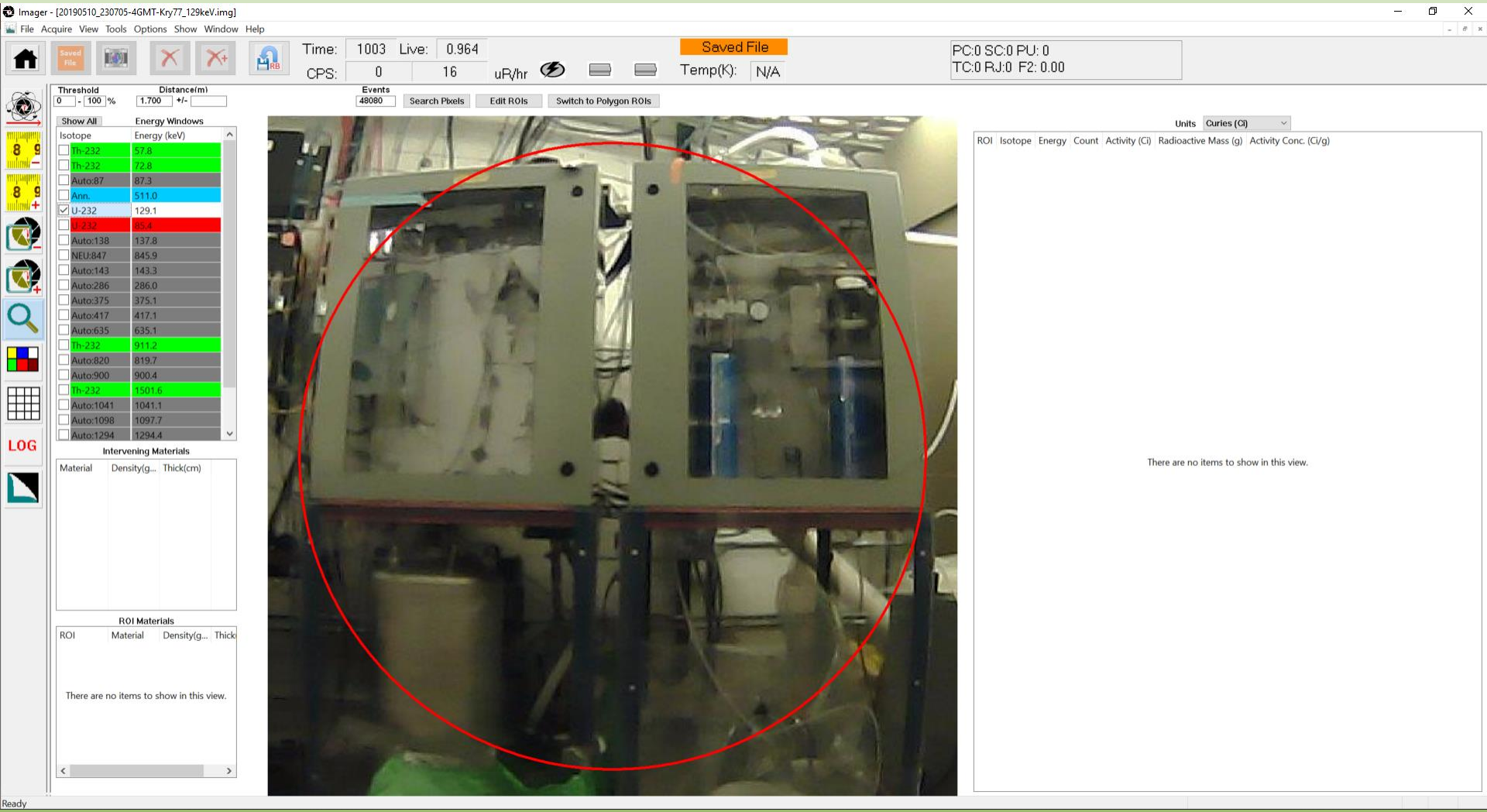
Gamma Ray Imaging Detectors



NSCL

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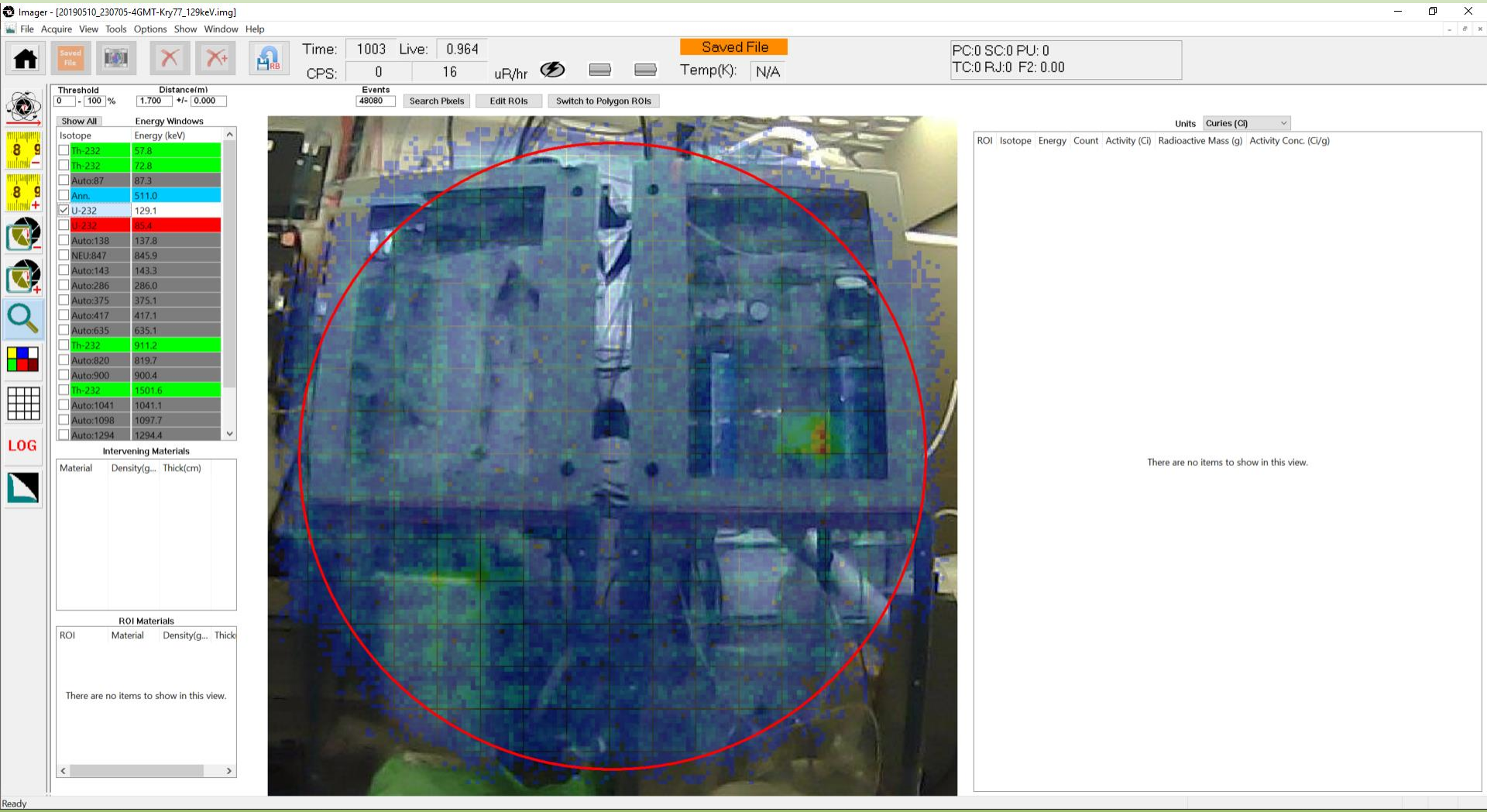

NSCL

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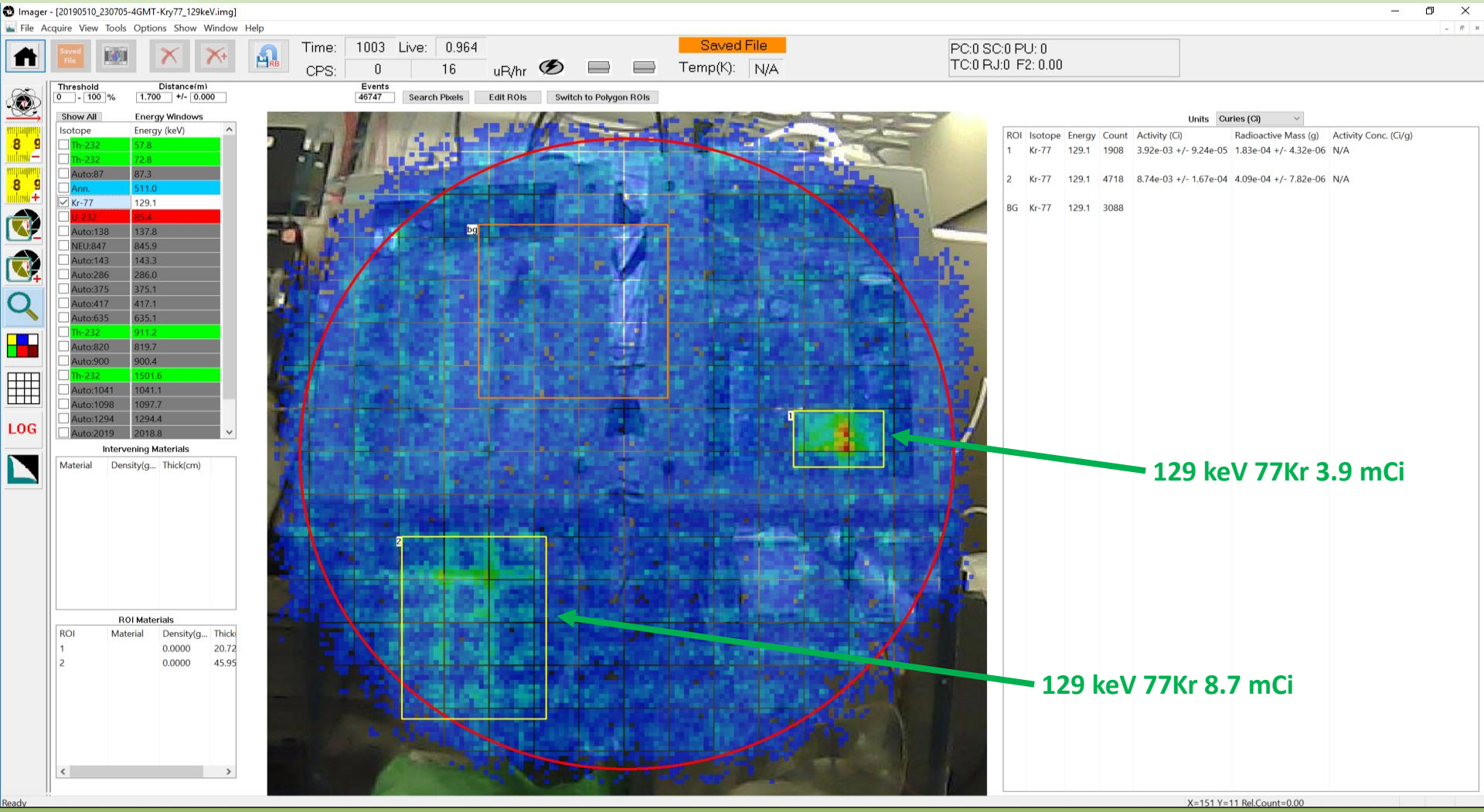

Uranium Imaging at ORNL REDC

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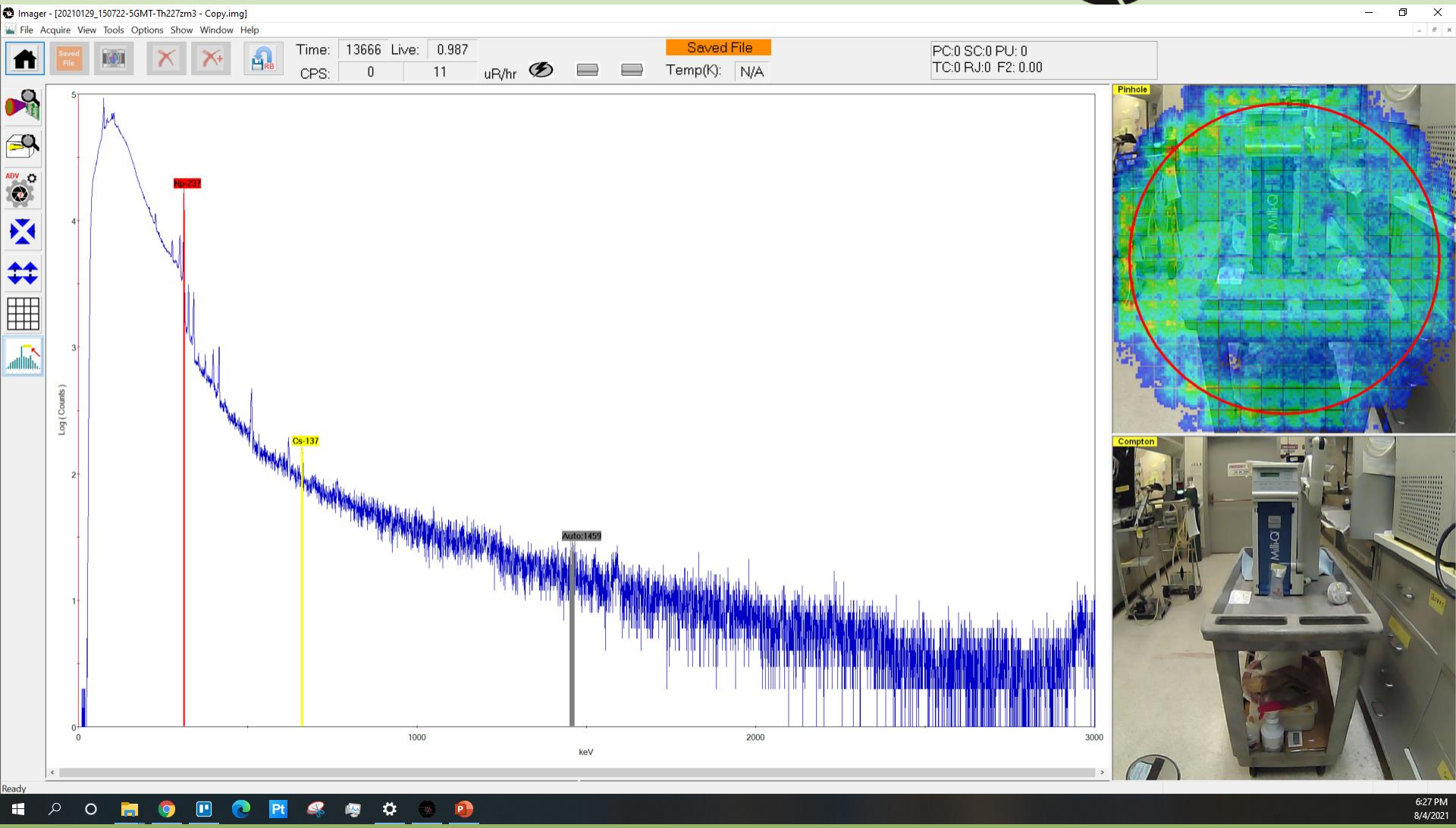
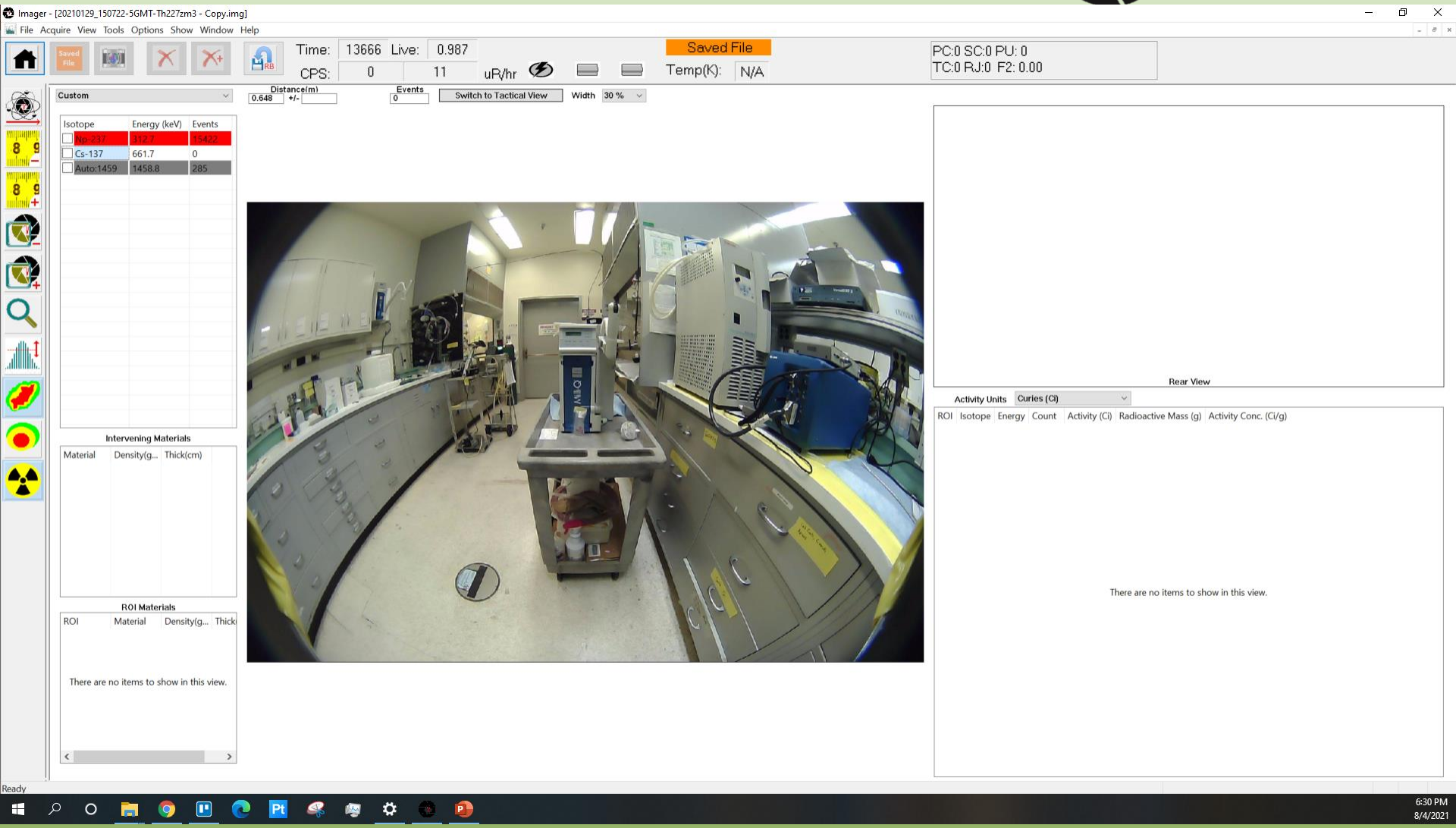


Uranium Imaging at ORNL REDC

PHDS
Gamma Ray Imaging Detectors



Uranium Imaging at ORNL REDC

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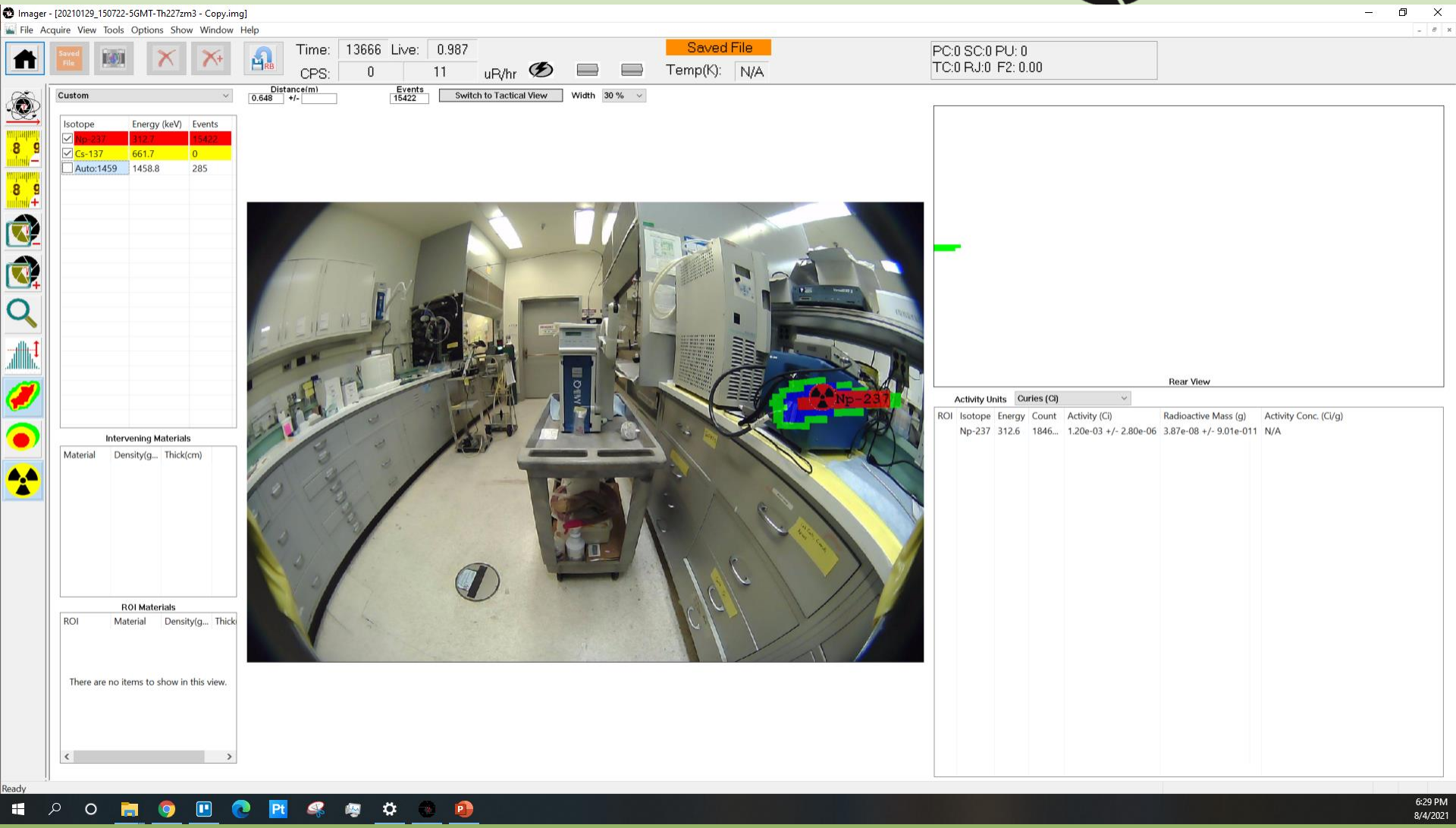
Gamma Ray Imaging Detectors



NP Imager Coded Aperture Development
On the bench at PHDS with NP Imager Engineering Model

PHDS
Gamma Ray Imaging Detectors

Collaborators at ORNL – Coded aperture expert – Klaus Ziock

Primo Automated Coded Aperture System

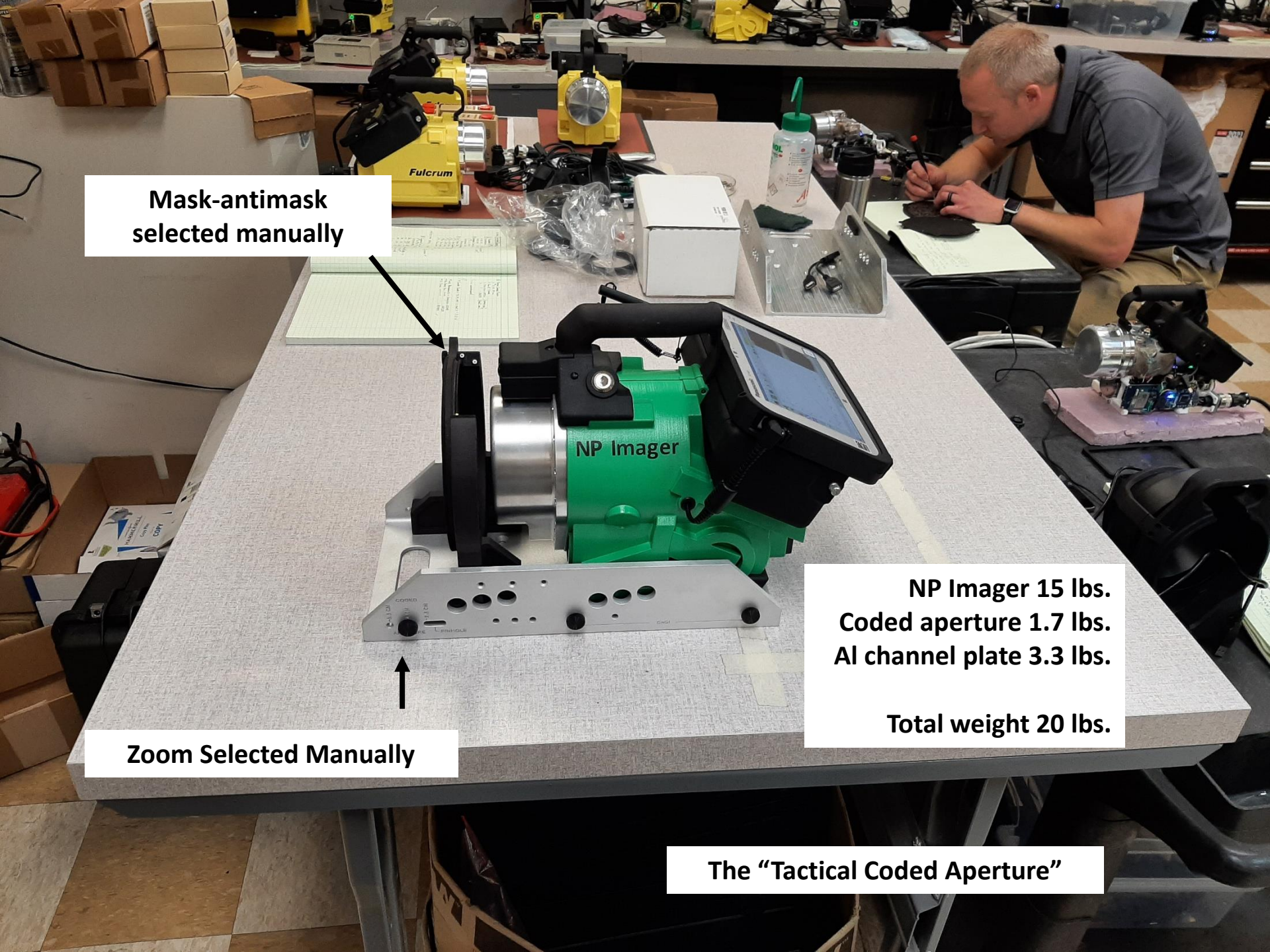
Controls
Mech structure
Variable zoom
Auto rotate

Best of the Best for imaging quality

77 lbs.!


Fulcrum
NP Imager


Fulcrum
NP Imager


Mask-antimask
selected manually
NP Imager
NP Imager 15 lbs.
Coded aperture 1.7 lbs.
Al channel plate 3.3 lbs.
Total weight 20 lbs.
Zoom Selected Manually
The “Tactical Coded Aperture”

NP Imager Pinhole Imaging

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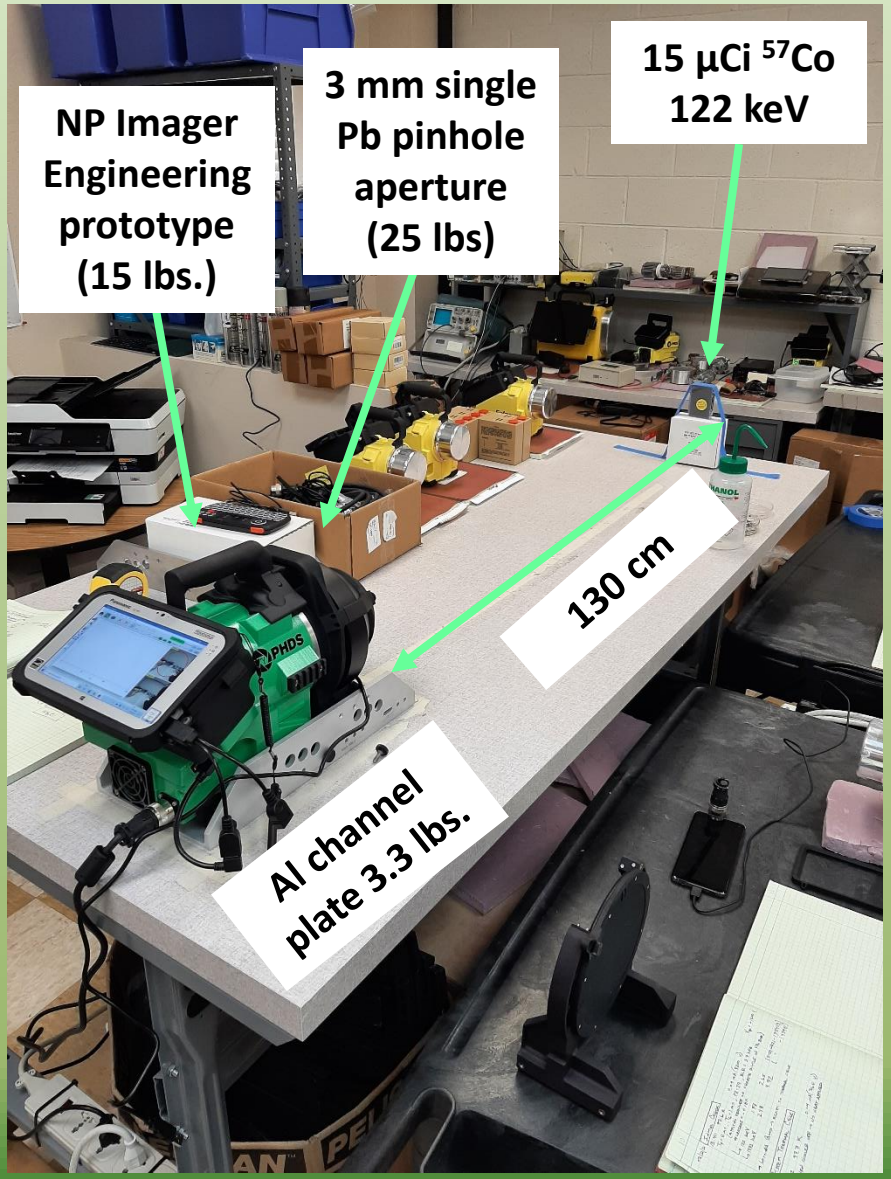

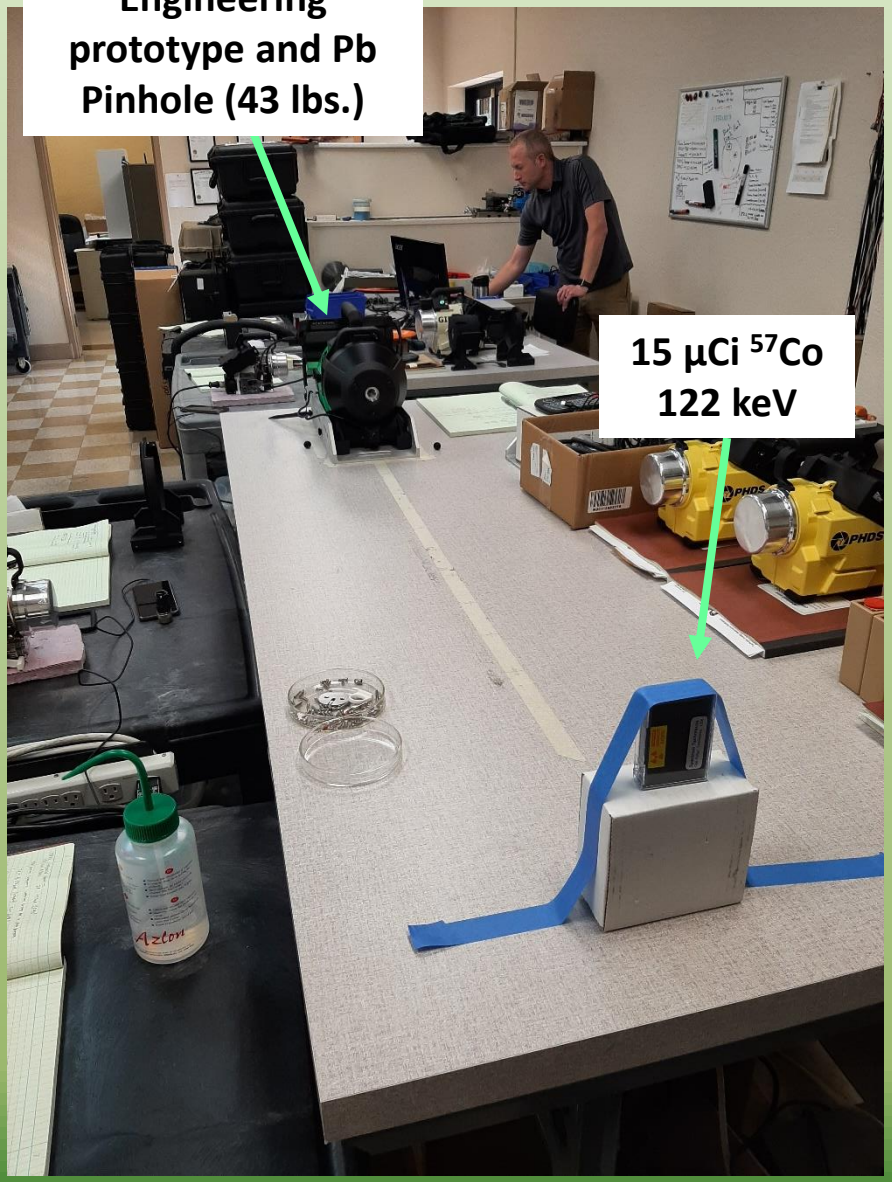

NP Imager Pinhole Imaging

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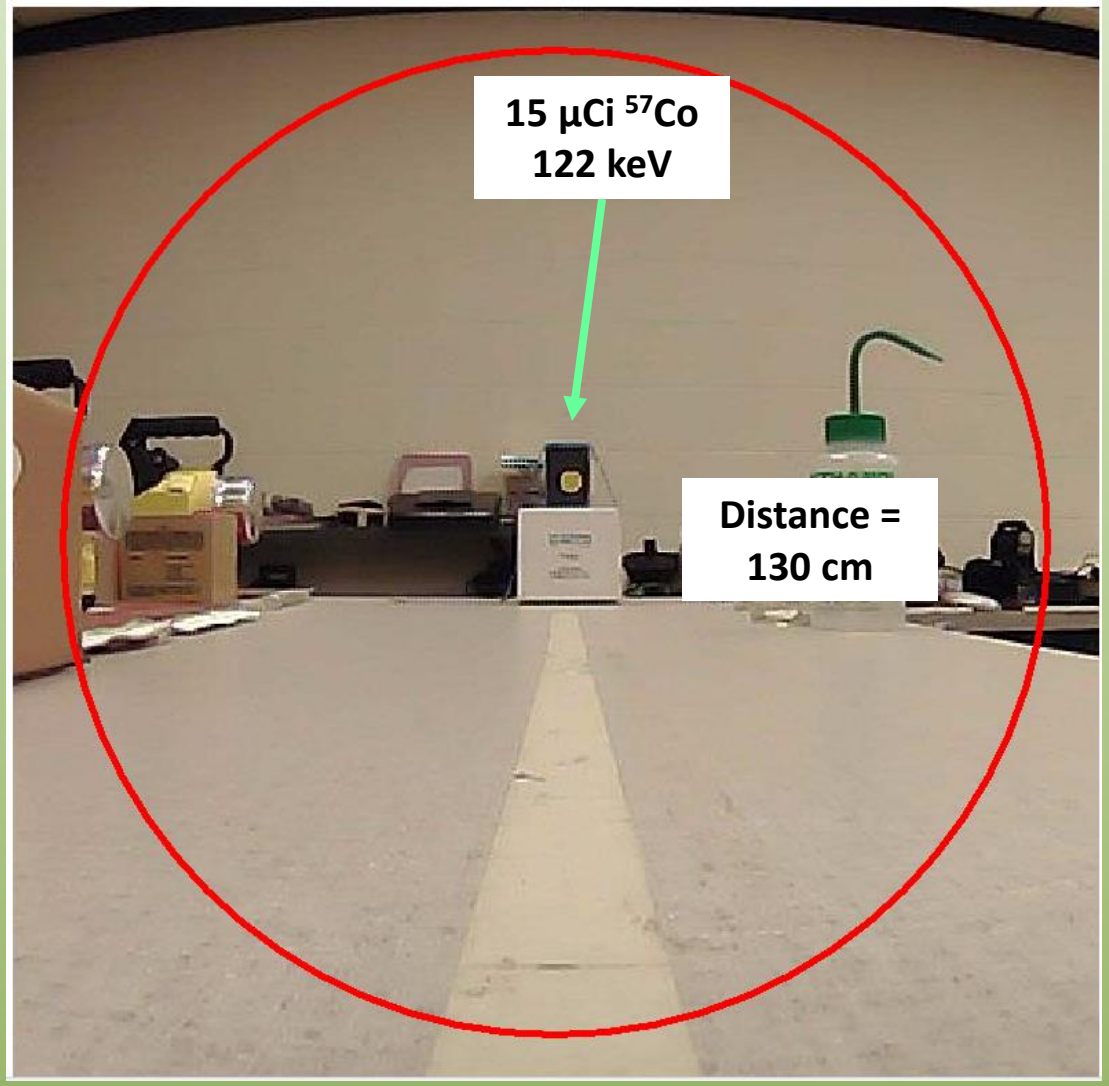

0
min

NP Imager Pinhole Imaging

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1 min

NP Imager Pinhole Imaging

PHDS
Gamma Ray Imaging Detectors

2 min

NP Imager Pinhole Imaging

PHDS
Gamma Ray Imaging Detectors

3 min

NP Imager Pinhole Imaging

PHDS
Gamma Ray Imaging Detectors

4 min

NP Imager Pinhole Imaging

PHDS
Gamma Ray Imaging Detectors

5 min

NP Imager Pinhole Imaging

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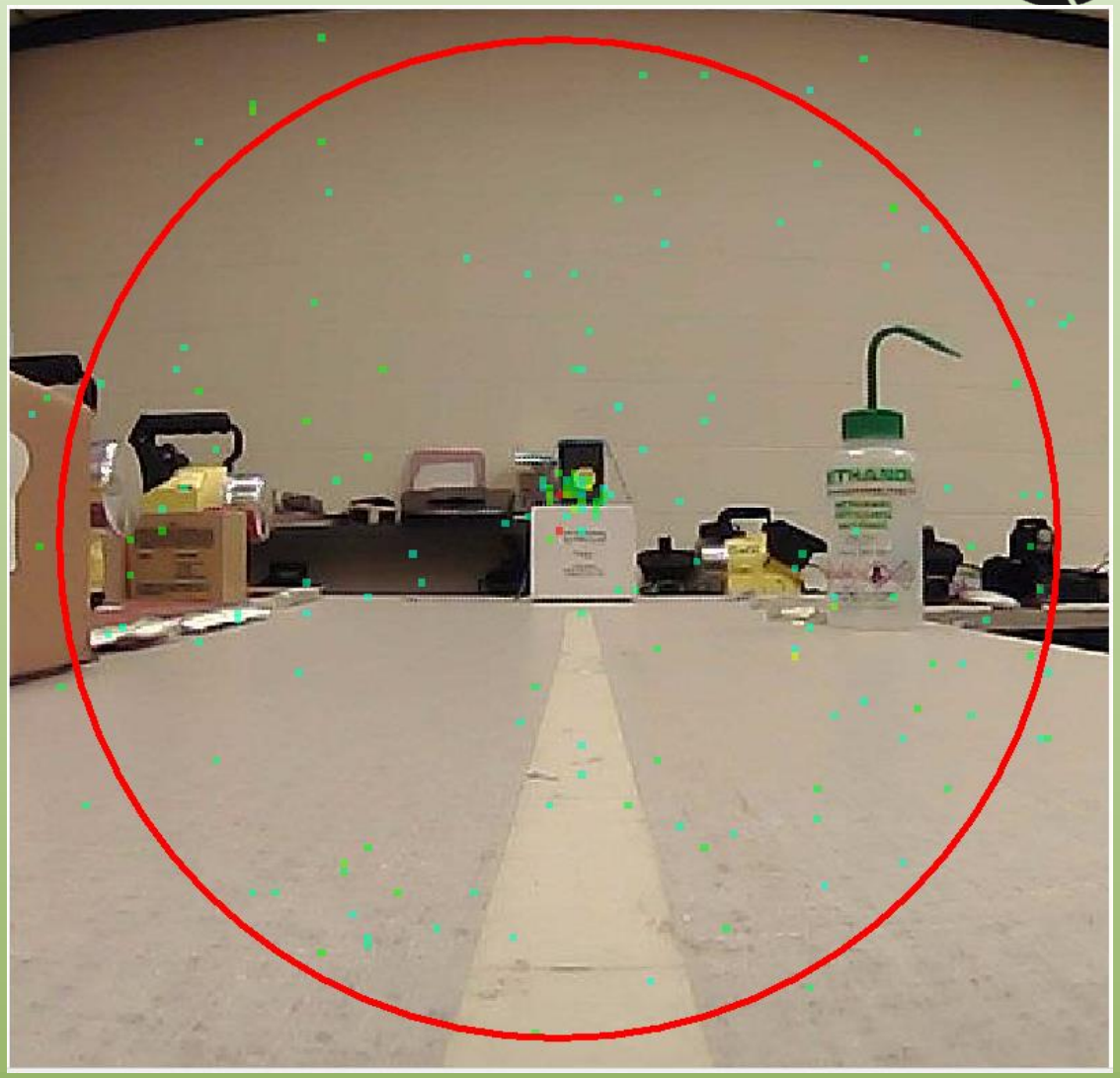
Gamma Ray Imaging Detectors



6 min

NP Imager Pinhole Imaging

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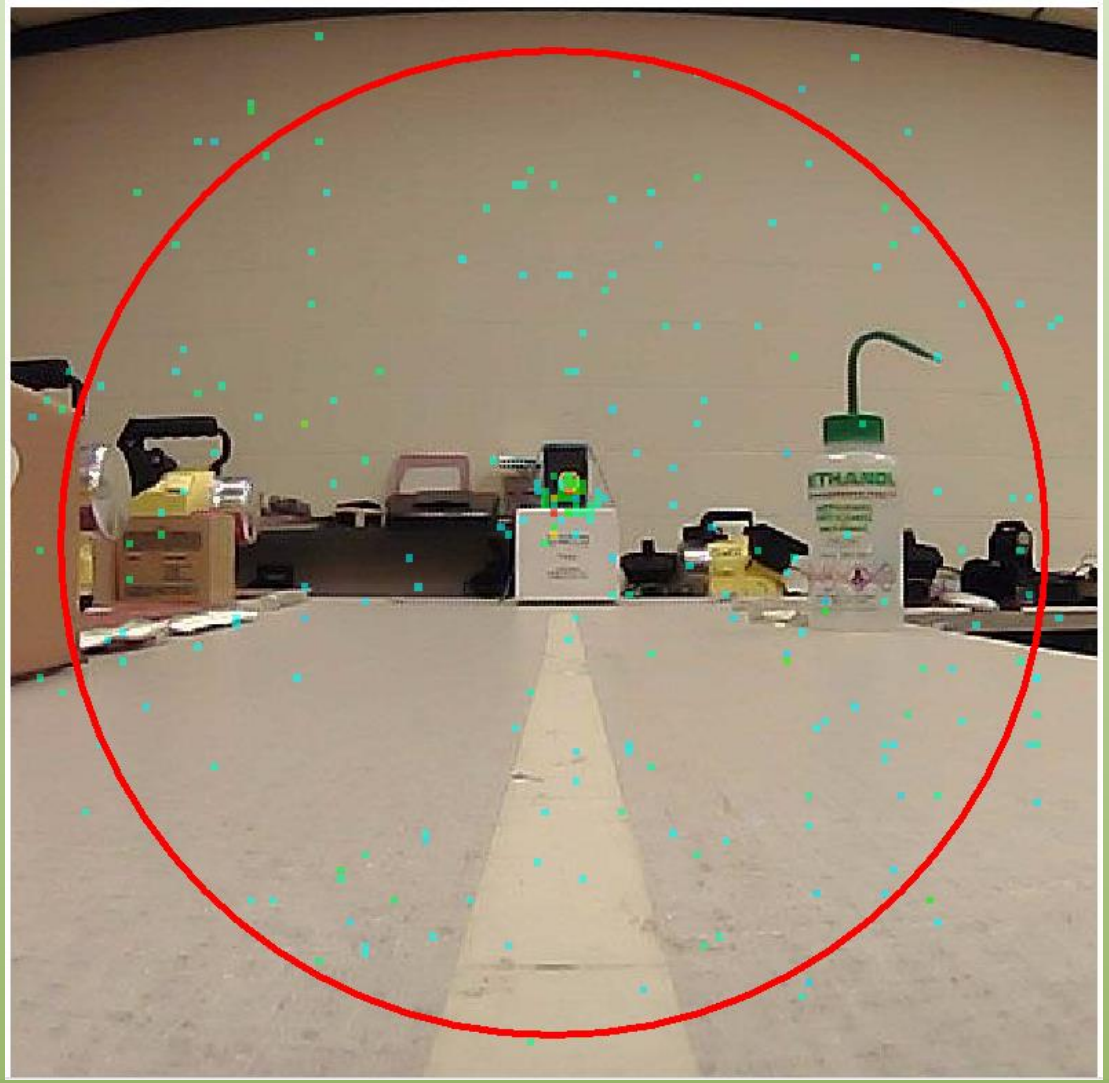
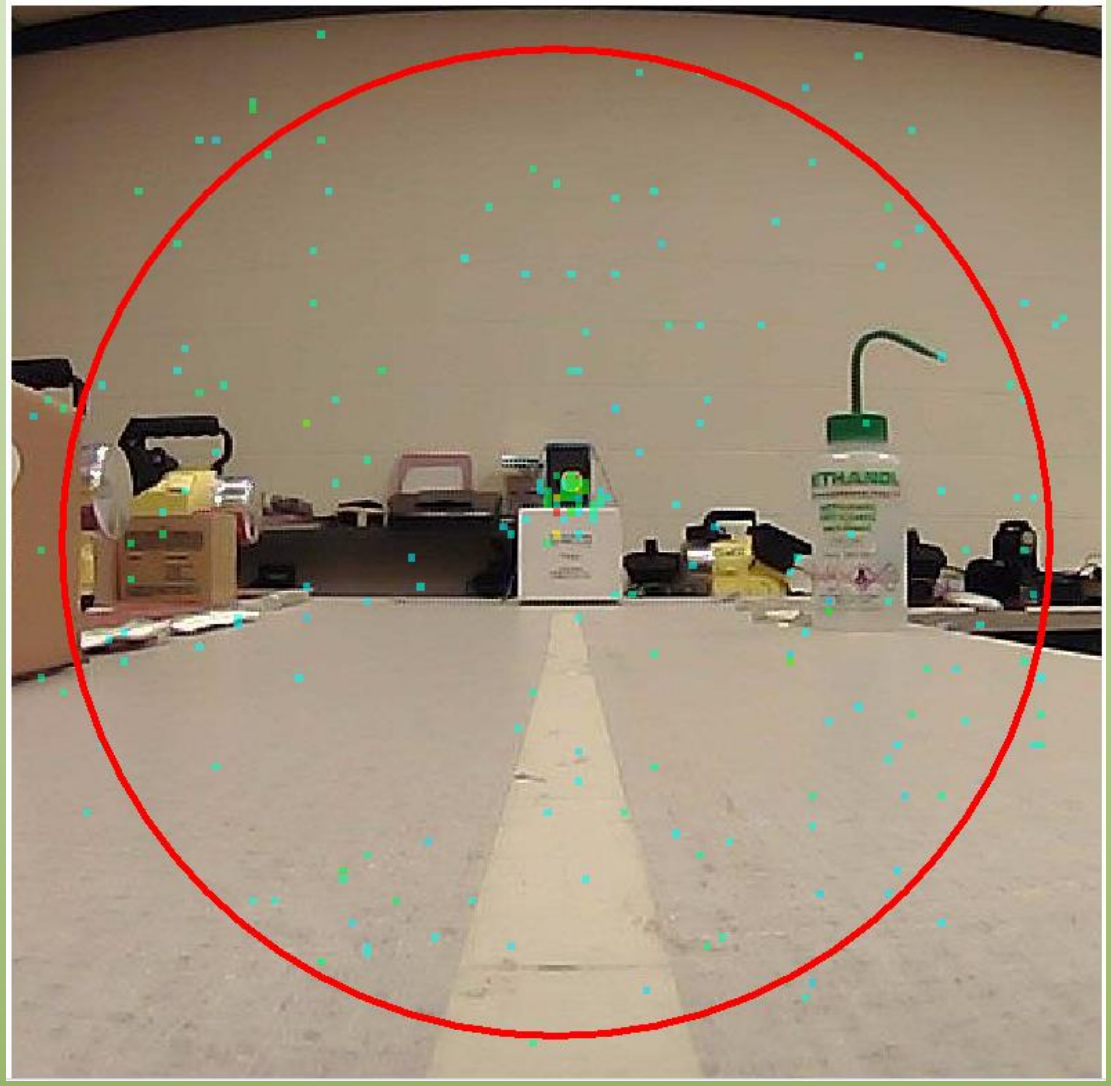


7 min

NP Imager Pinhole Imaging

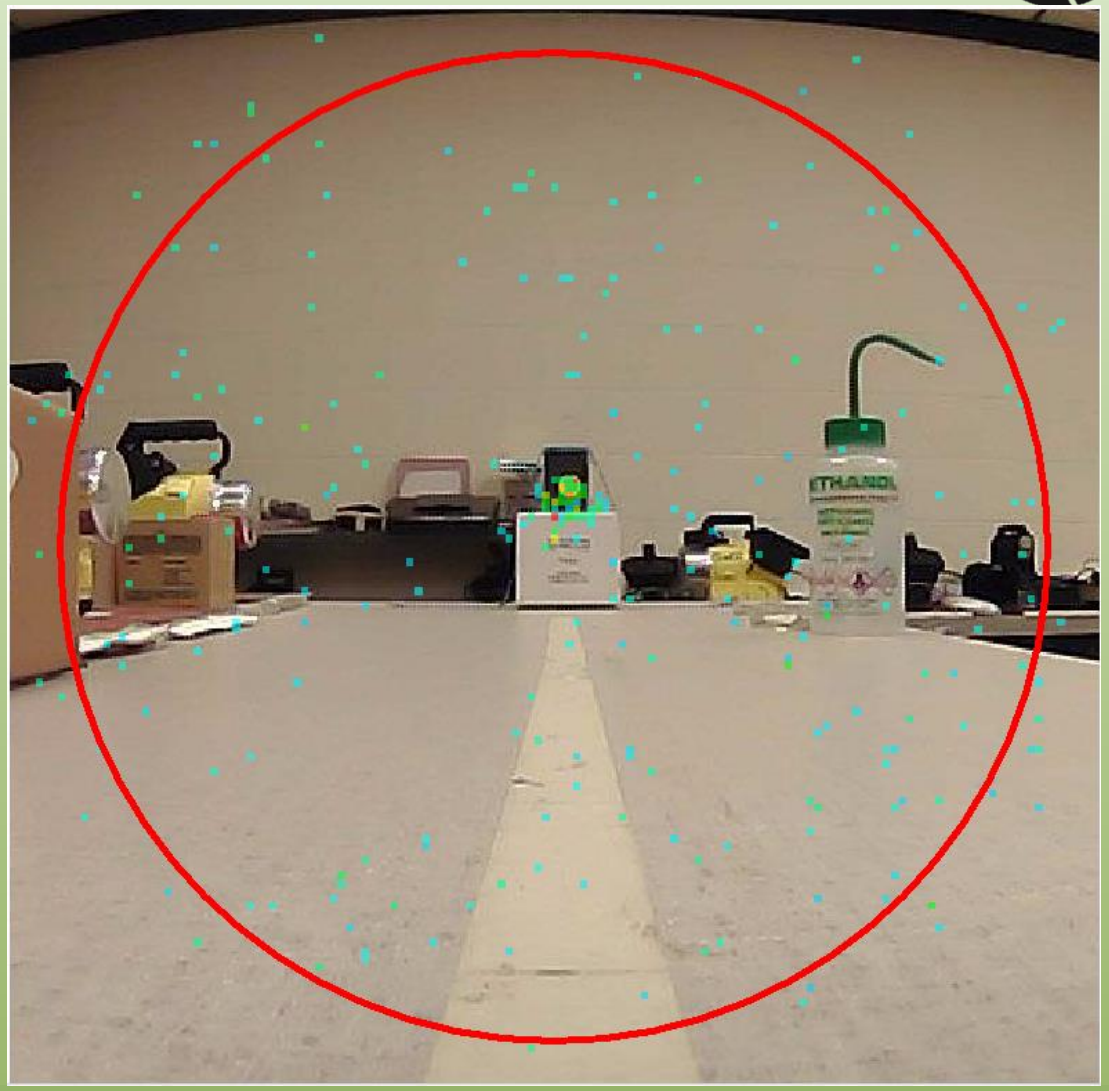
PHDS
Gamma Ray Imaging Detectors



8 min

NP Imager Pinhole Imaging

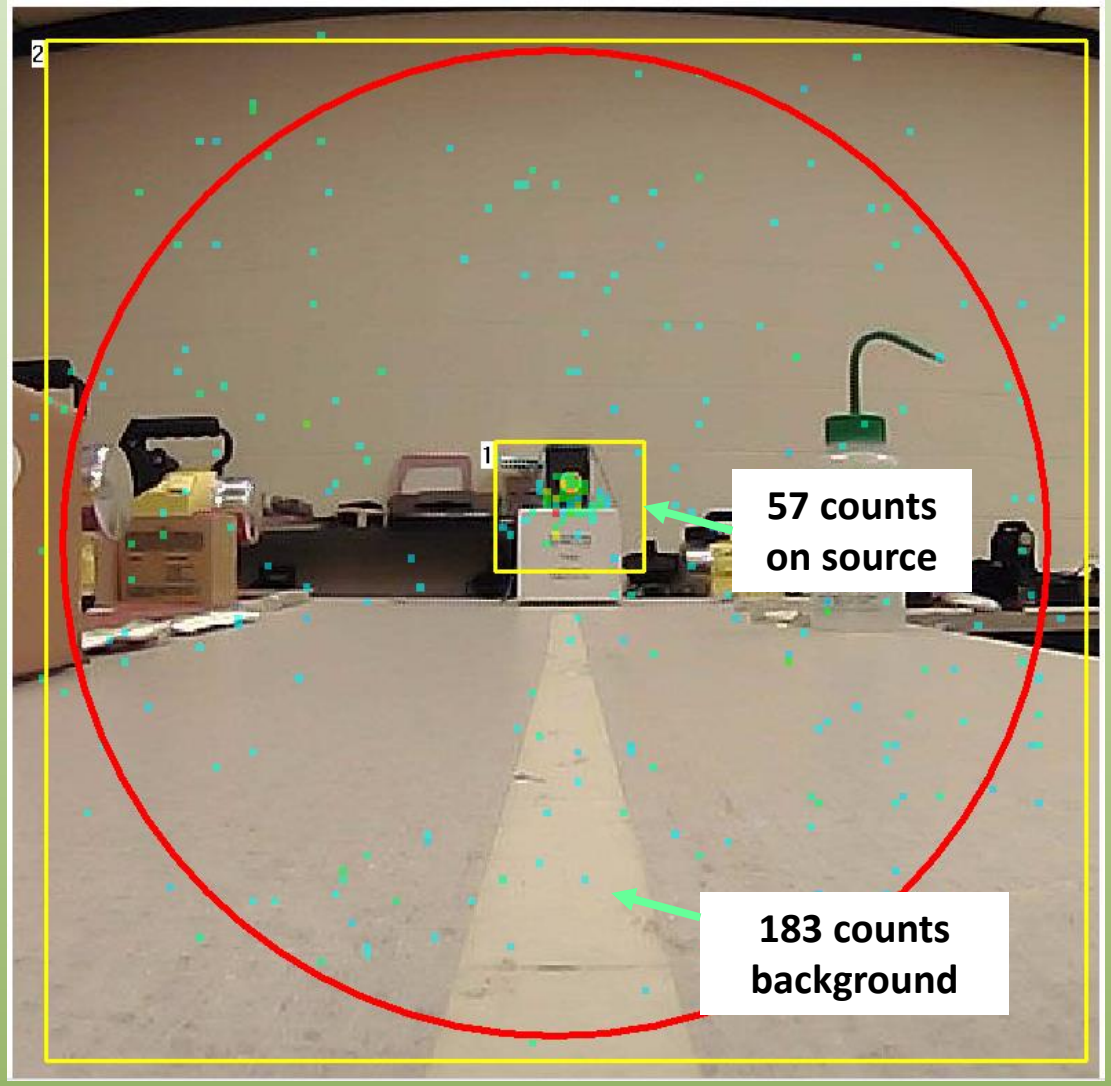
PHDS
Gamma Ray Imaging Detectors



9 min

NP Imager Pinhole Imaging

PHDS
Gamma Ray Imaging Detectors



9 min

0.41 cps total count rate

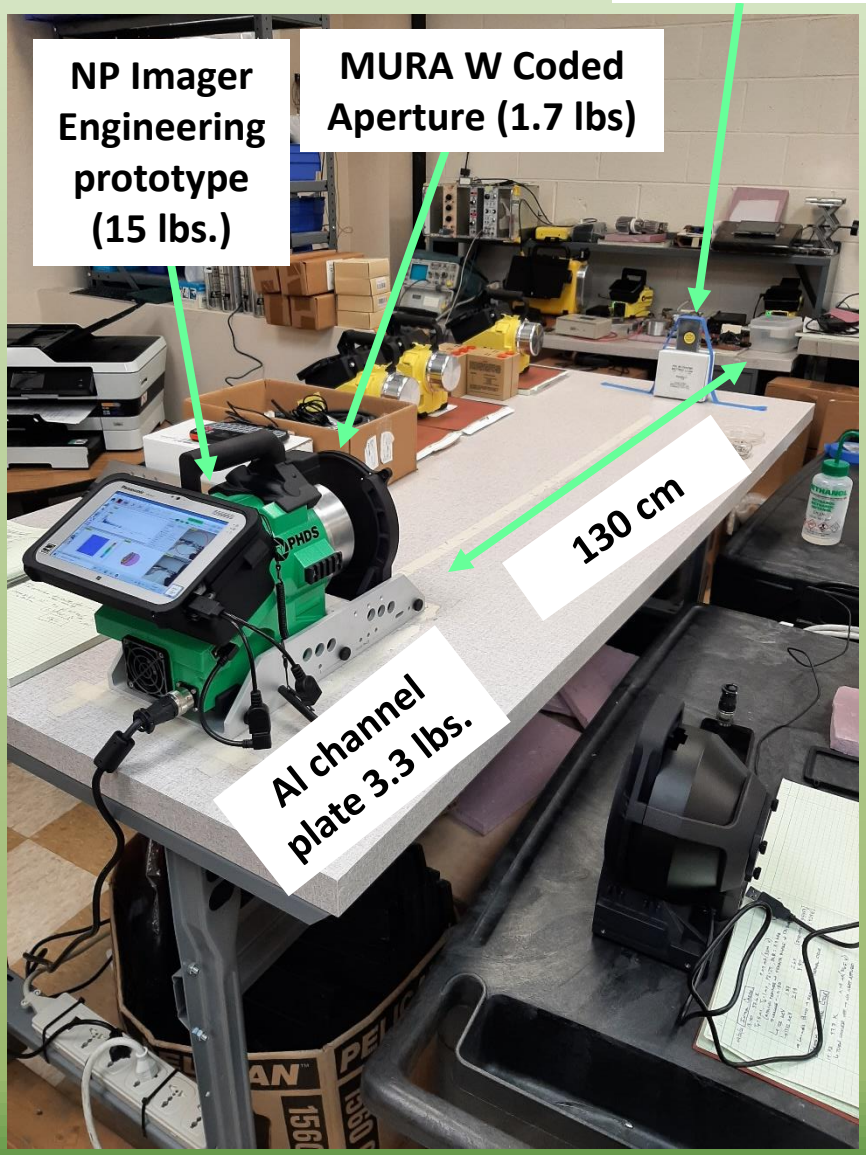
240 total counts

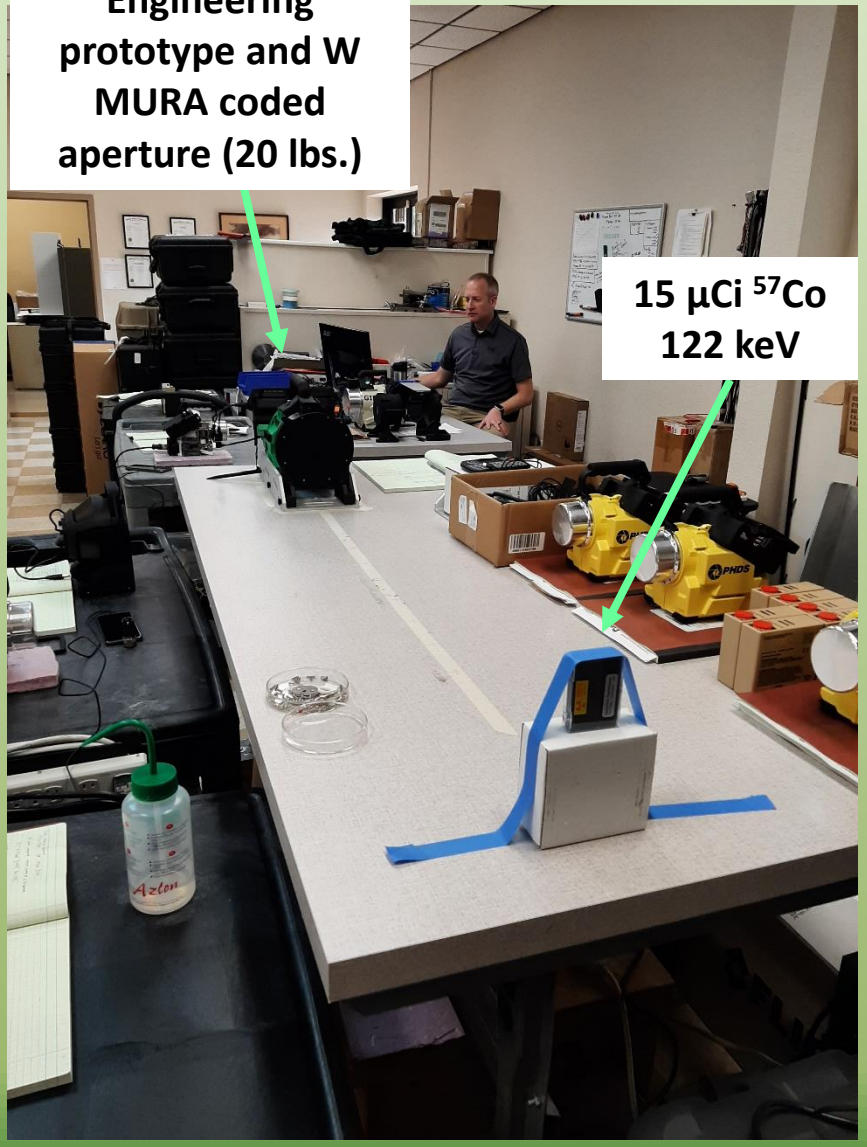
All gated on 122 keV

NP Imager Coded Aperture Image

15 µCi ^{57}Co 122 keV

PHDS
Gamma Ray Imaging Detectors





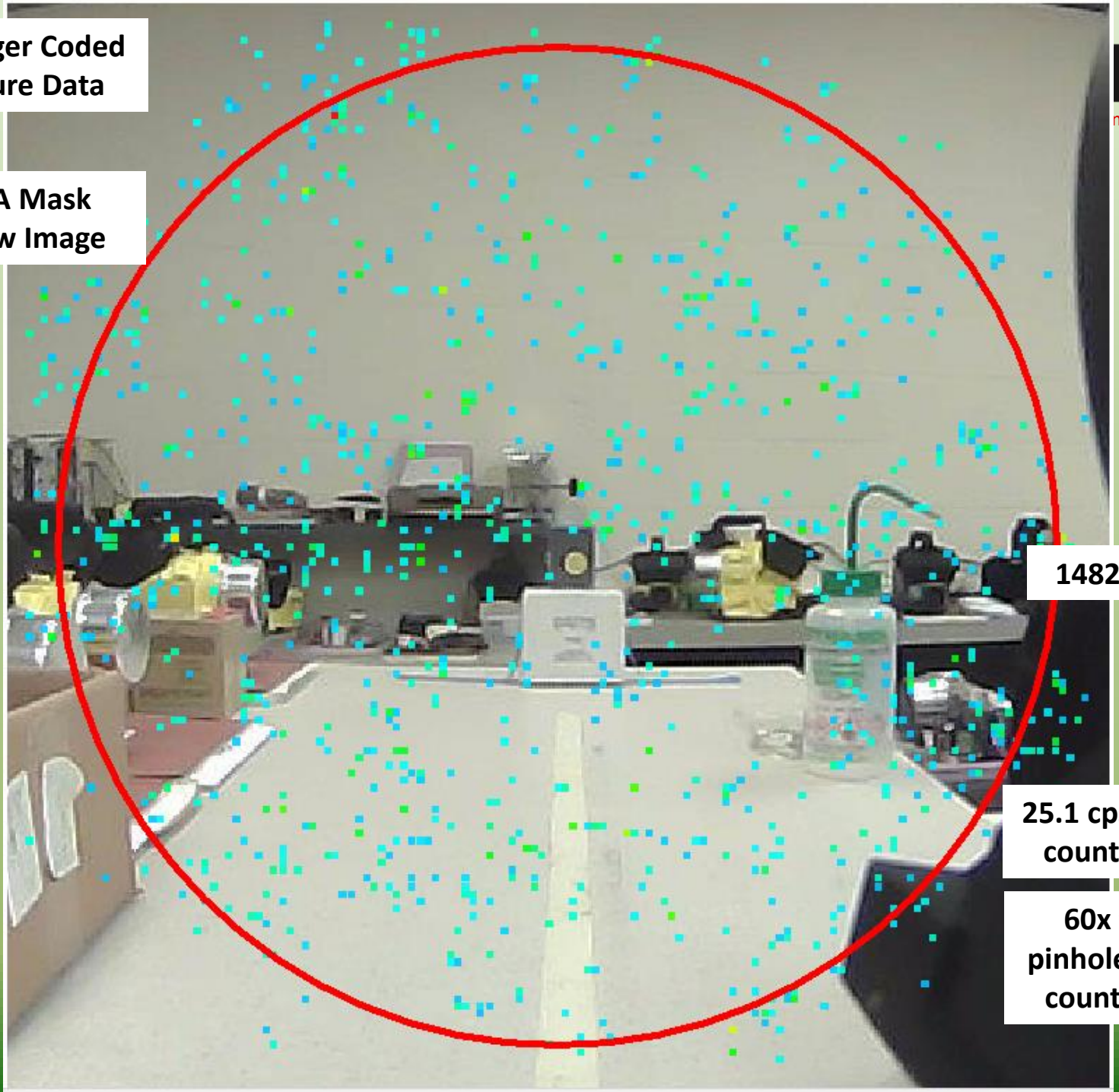
NP Imager Coded Aperture Image

IDS
maging Detectors

0
min

NP Imager Coded Aperture Data

MURA Mask Shadow Image



IDS
maging Detectors

1 min

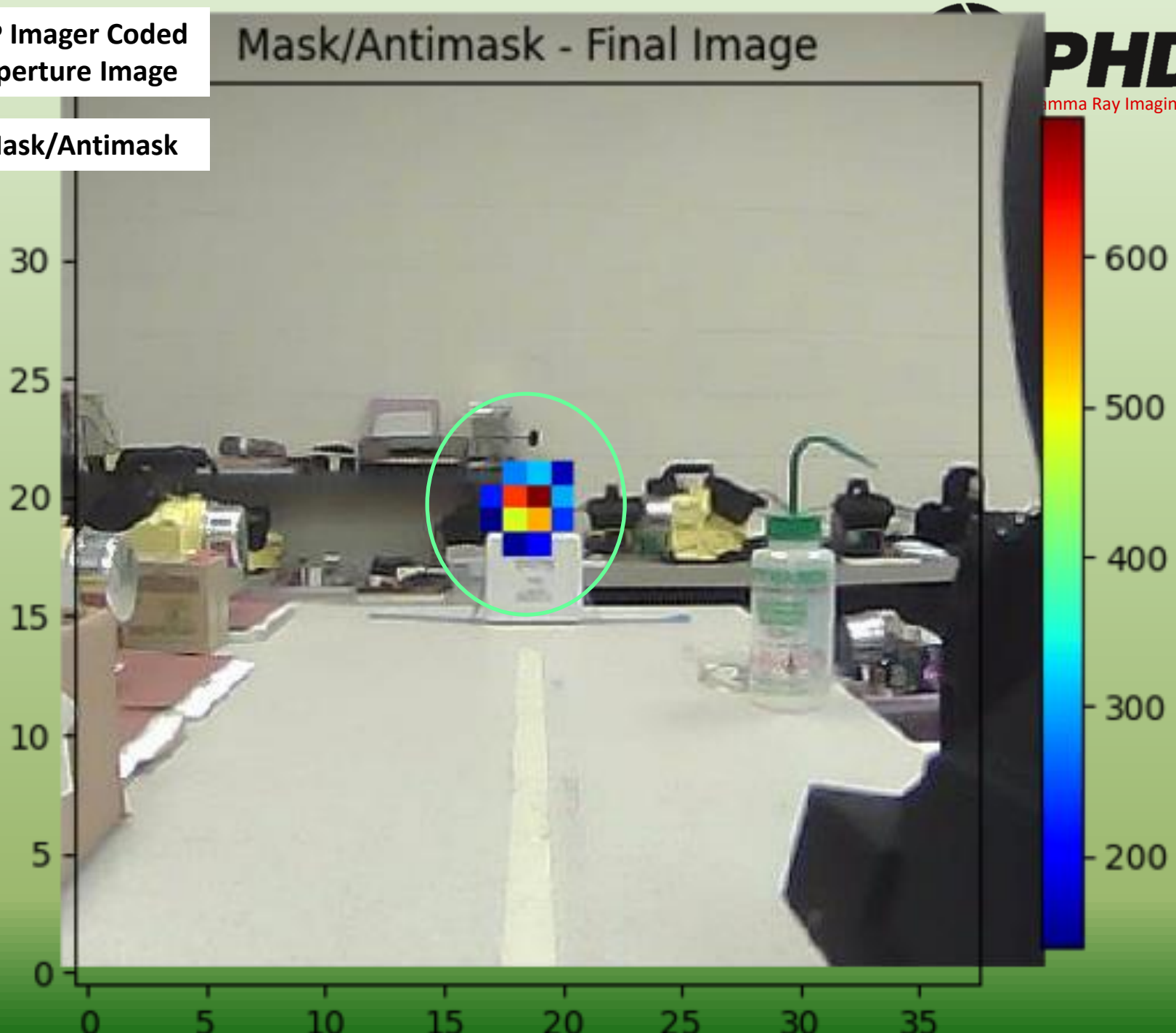
1482 counts

25.1 cps total count rate

60x the pinhole total count rate

NP Imager Coded Aperture Image

Mask/Antimask

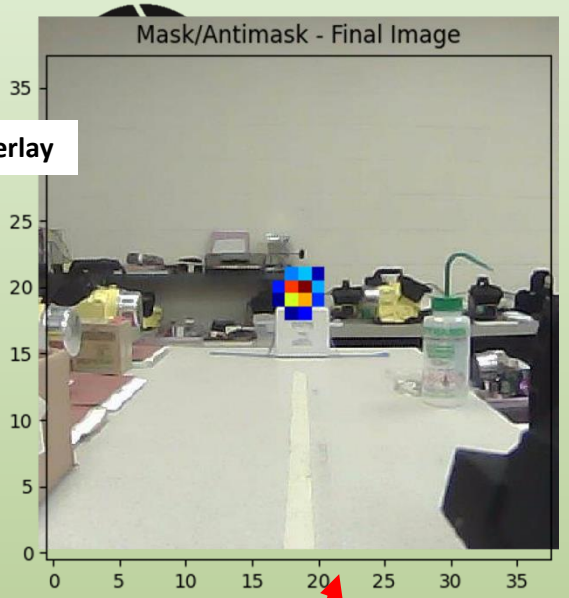


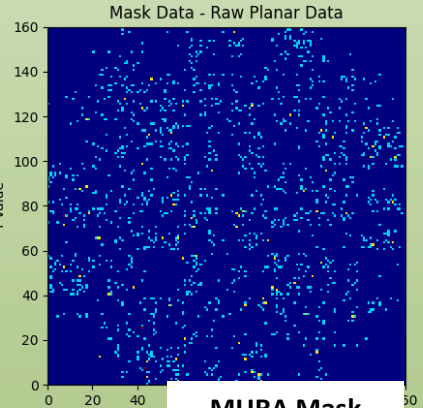
PHDS

mma Ray Imaging Detectors

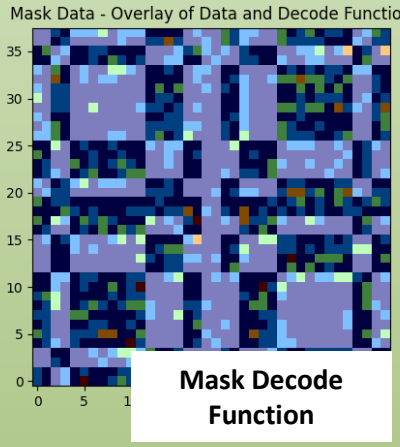
MURA Mask Shadow Image

Optical Overlay

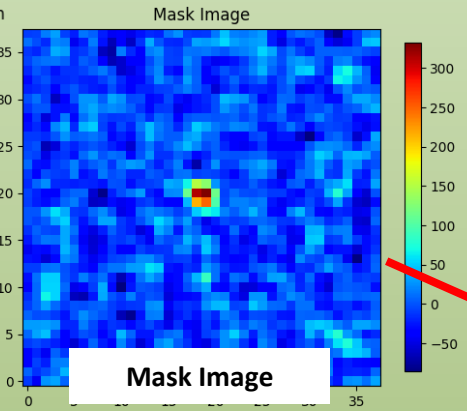




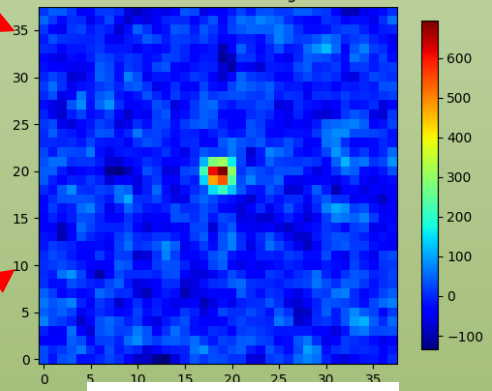
MURA Mask Shadow Image



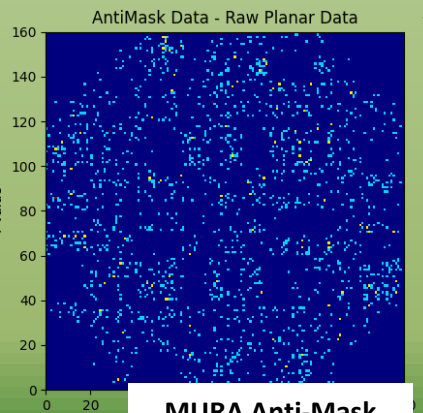
Mask Decode Function



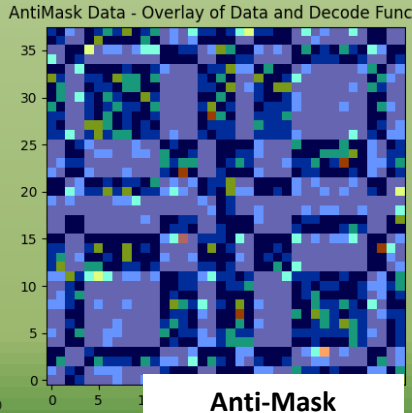
Mask Image



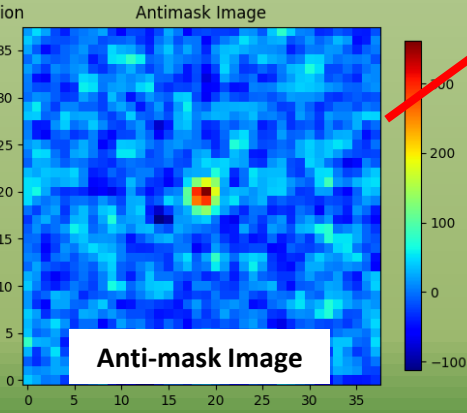
Complete Mask/Anti-mask Image



MURA Anti-Mask Shadow Image



Anti-Mask Decode Function



Anti-mask Image

Comparison
Pinhole vs. Coded Aperture

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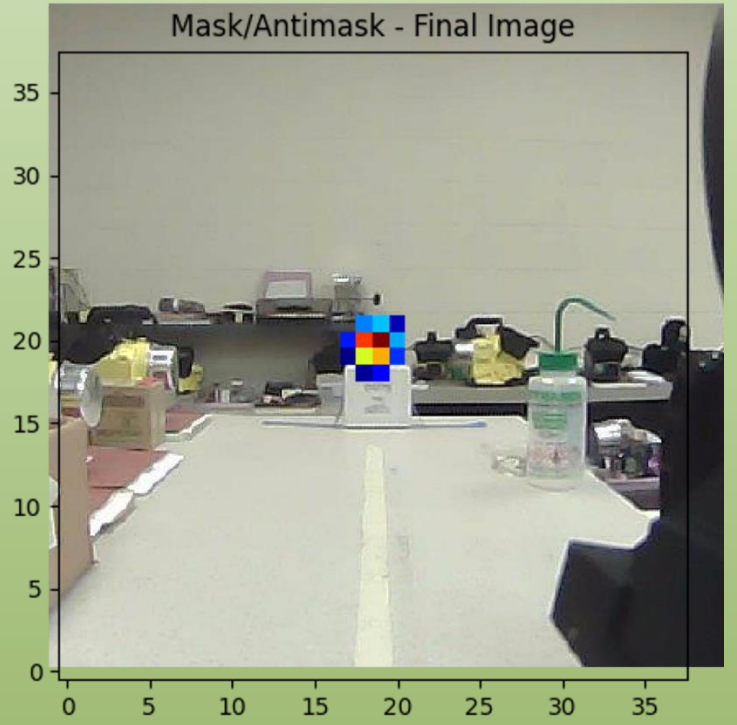
Pinhole 2 min

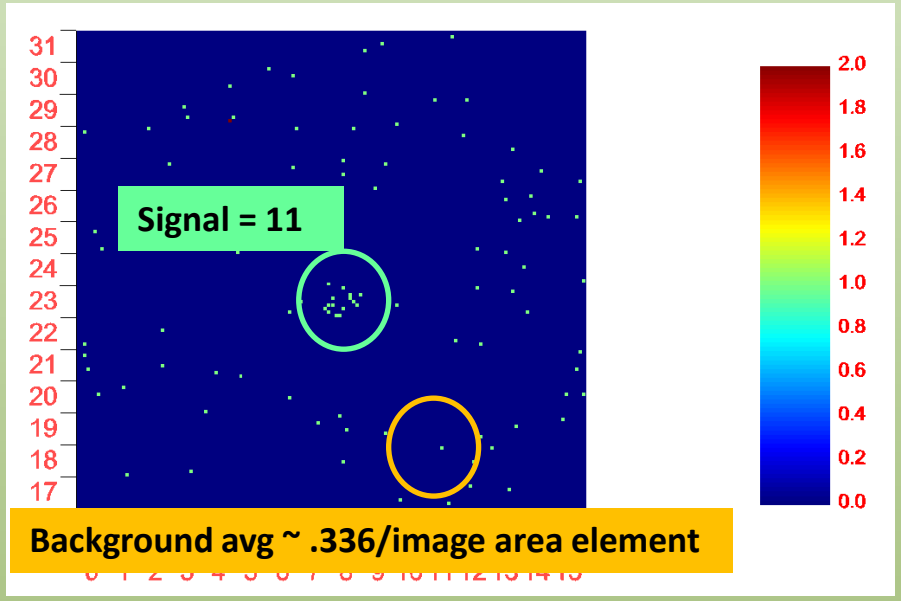
Coded Aperture
1 min + 1 min = 2 min



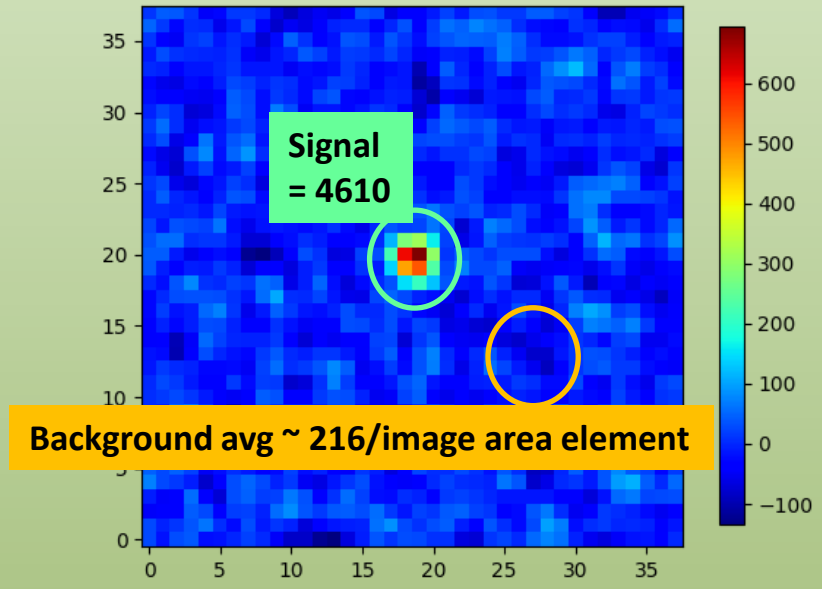
Comparison
Pinhole vs. Coded Aperture

PHDS
Gamma Ray Imaging Detectors

Pinhole 2 min



Coded Aperture
1 min + 1 min = 2 min



Signal/SQRT(background) = 19

Signal/SQRT(background) = 313

313/19 = 16.5
With a single point source

PHDS
Gamma Ray Imaging Detectors

Remaining Coded Aperture Product Challenges

Quantitative Analysis

Additional sources decrease the signal to background in image space
nontrivial reconstruction of activity

Use at higher energies

Thicker aperture – sacrifices spatial resolution – pixel size
Compton imaging may take over here

Press on with the existing capability.
Go ahead and make a product!

PHDS
Gamma Ray Imaging Detectors

NP Imager

Nuclear Physics – Radiochemistry Imaging Spectrometer

HPGe Isotope Identification
Source Location Imaging
Source Distribution Imaging
Quantitative Imaging
Compact Detector System

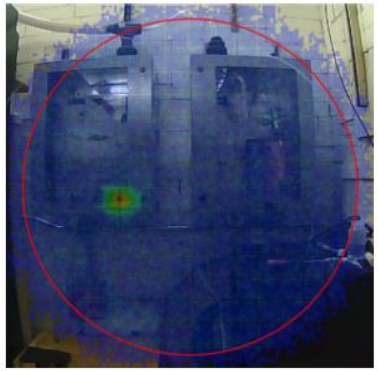
NP Imager

PHDS
Gamma Ray Imaging Detectors

NP Imager Specifications:	
Weight (Detector):	15 lbs. (6.8 kg)
Dimensions (Detector):	10.5" x 8.0" x 5.5" (26 cm x 20 cm x 14 cm)
Battery life:	3 hrs internal (hot swappable), 6-8 hrs external
Power supply:	100-240 VAC, 50-60 Hz
User maintenance:	None
Energy resolution:	FWHM < 2.1 keV at 662 keV
Gamma-ray Compton imaging field of view:	4π (360°)
Optical camera field of view:	2π (180°)
Pinhole imaging field of view:	up to 60° (depends on Zoomfactor)
Zoomfactor Gamma-ray Image Magnification	x1 - x6
Imaging Range:	(10 cm - 50 meters)
At 10 μCi ^{137}Cs at 1 meter (3.3 μR/hr, 33 nSv/hr)	
ID time (spectroscopy):	3.7 sec +/- 1 sec (662 keV, 8σ)
Location (imaging) time:	30 sec +/- 13 sec (Compton image)
Exposure rate capacity:	200 kcps (~10% Dead time in 15 mR/hr ^{60}Co)
Energy range spectroscopy (16k ch):	30 keV - 3 MeV (12 MeV option)
Energy range Compton Imaging:	150 keV - 3 MeV
Energy range Pinhole Zoomfactor Imaging:	30 keV - 662 keV
Isotope Library:	400 isotopes (Auto detect or user selected)
Isotope Identification:	37 frequently encountered isotopes
Isotope Categories:	SNM, NORM, IND, MED
HPGe detector crystal dimensions:	90-mm diameter, 11-mm thick
Active detector volume / area:	67 cm^3 / 61 cm^2
Cool-down time:	4 hours
Detector startup time:	2 minutes

Heavy Duty
Imaging Gantry

Tablet or Laptop
operation



Radioisotope Harvesting Image

Pinhole Imaging
Aperture

2590 300 W-hr
External battery

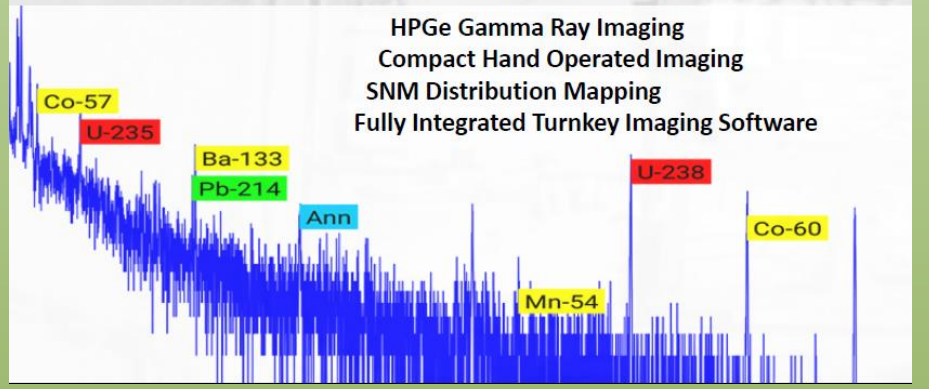
20210129
Specifications subject to change

PHDS Co. 3011 Amherst Road, Knoxville, TN 37921 (865) 202 6253 www.phdsco.com sales@phdsco.com

PHDS
Gamma Ray Imaging Detectors

Tactical Coded Aperture

High resolution fast-accumulation planar imaging mask for NP Imager and GeGI



Releasing Tactical Coded Aperture Software with ImagerPro this fall

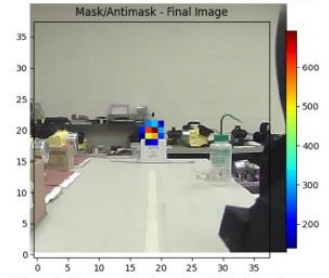
PHDS
Gamma Ray Imaging Detectors

Tactical Coded Aperture

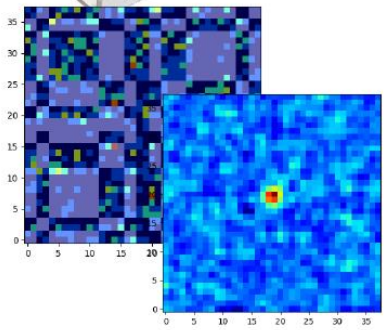
Tactical Coded Aperture Specifications:	
Weight:	1.7 lbs.
Dimensions:	4" x 7.5" x 8" (10 cm x 19 cm x 21 cm)
Battery life (internal hot swappable):	No battery or power required
User maintenance:	None
Spatial resolution:	FWHM < 2.2 degrees at 122 keV
Gamma-ray throughput	50%
W mask thickness	2 mm
Energy range:	40 keV - 662 keV
Point source sensitivity	1 second to locate 1 μCi ^{57}Co at 1 meter
Compatible Detector Systems	GeGI and NP Imager
Mask-Antimask Operation	Manual, prompted by app

Lightweight Compact Form Factor

Tactical Coded Aperture can be used with NP Imager OR GeGI



Integrated Gamma-Ray Imaging-Optical Overlay



20210805
Specifications subject to change

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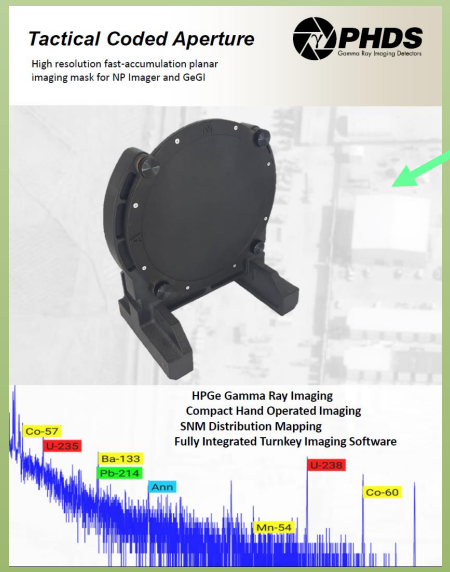


NP Imager Product Sales

PHDS
Gamma Ray Imaging Detectors

As of August 13, 2021

NP Imager Item	Sold	Shipped	Pending
NP Imager HPGe Detector			
Fully Automated MURA			
Tactical Coded Aperture			

DOE National Labs
DOE NNSA
Private industry research

Brock Roberts
Electrodynamic

NP Imager

Nuclear Physics – Radiochemistry Imaging Spectrometer

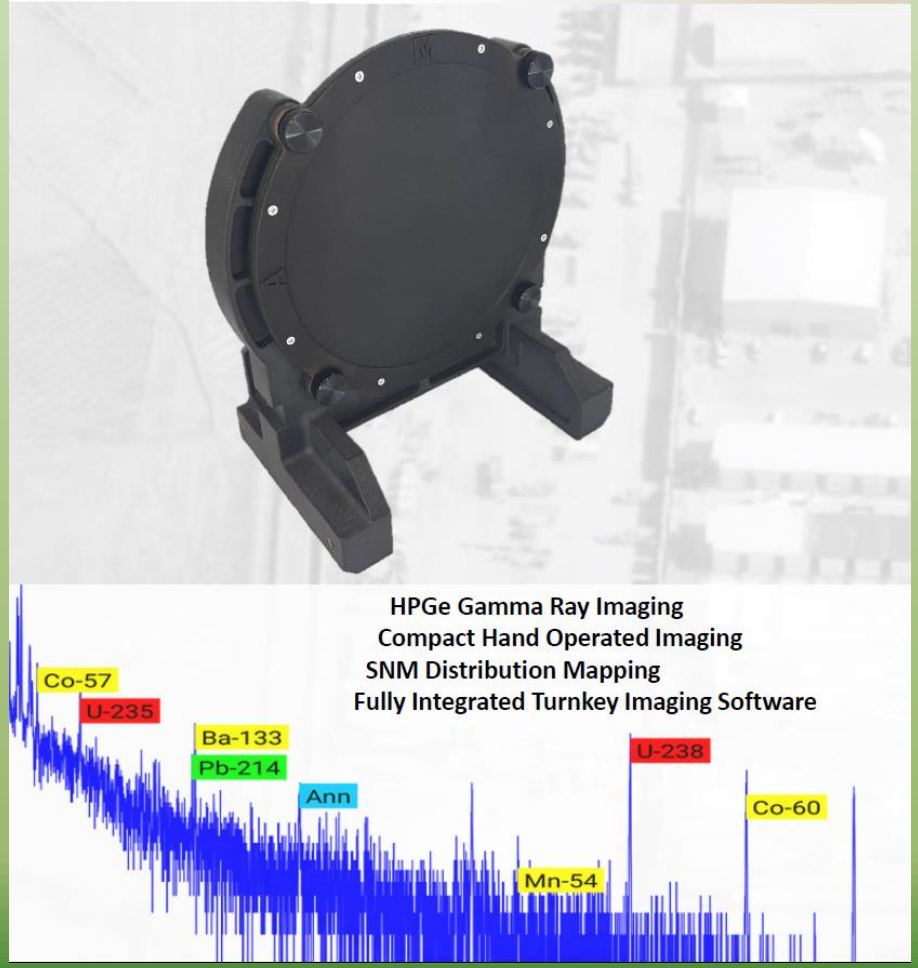
PHDS Gamma Ray Imaging Detectors

PHDS
Gamma Ray Imaging Detectors

Tactical Coded Aperture

High resolution fast-accumulation planar imaging mask for NP Imager and GeGI

PHDS Gamma Ray Imaging Detectors



Thank you, DOE NP, for the NP Imager