PHDS

Gamma Ray Imaging Detectors

Charge collection physics in very large diameter germanium crystals

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PHDS 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

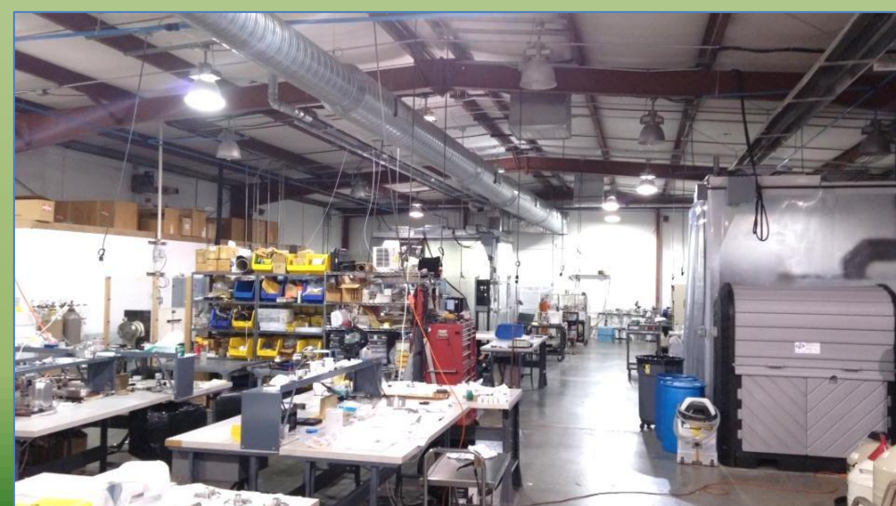
NPX (150 lbs.)

GeGI-5 (15 lbs.)

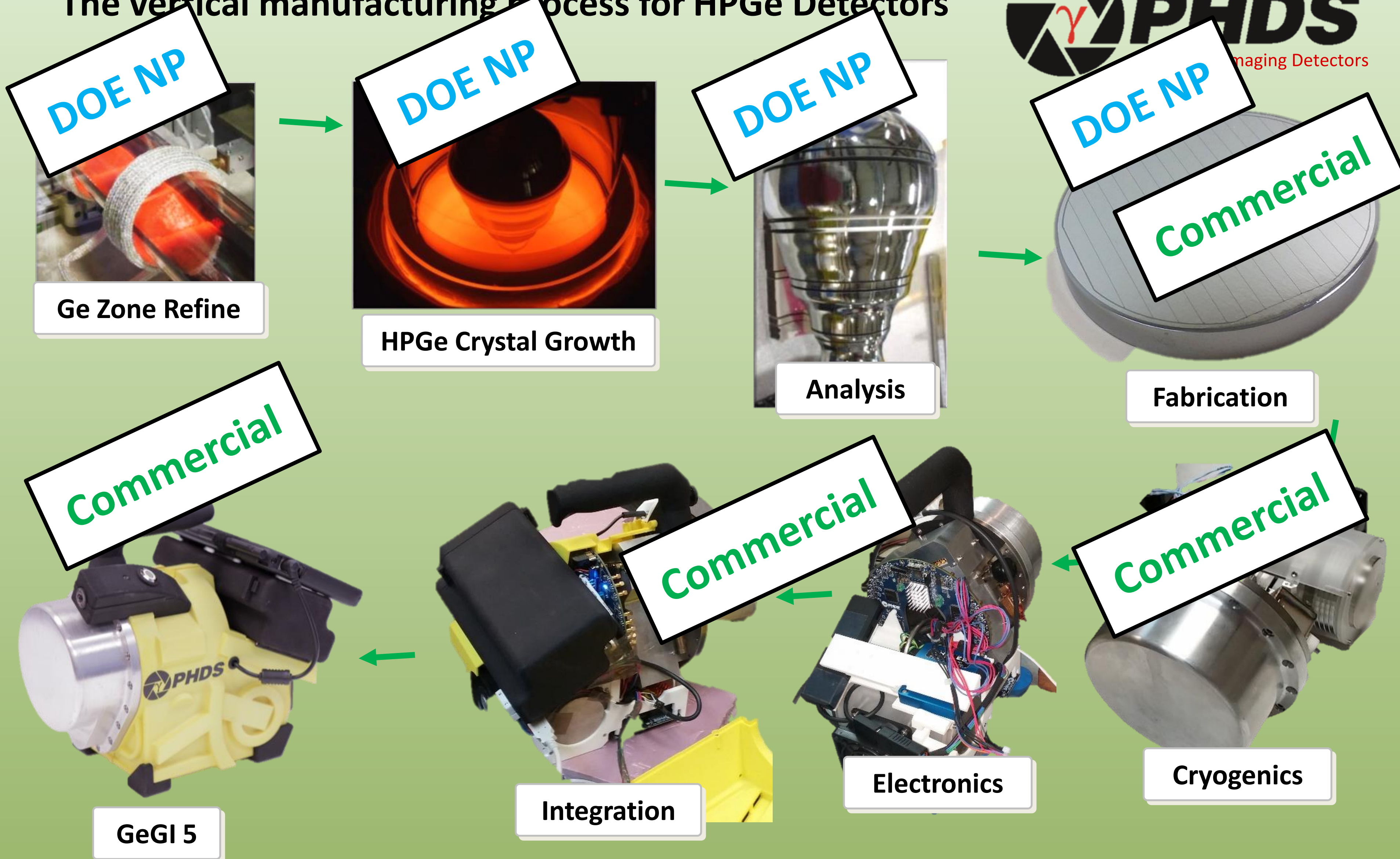
Detector is the same size

- Make new HPGe detector capabilities available

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



The vertical manufacturing process for HPGe Detectors



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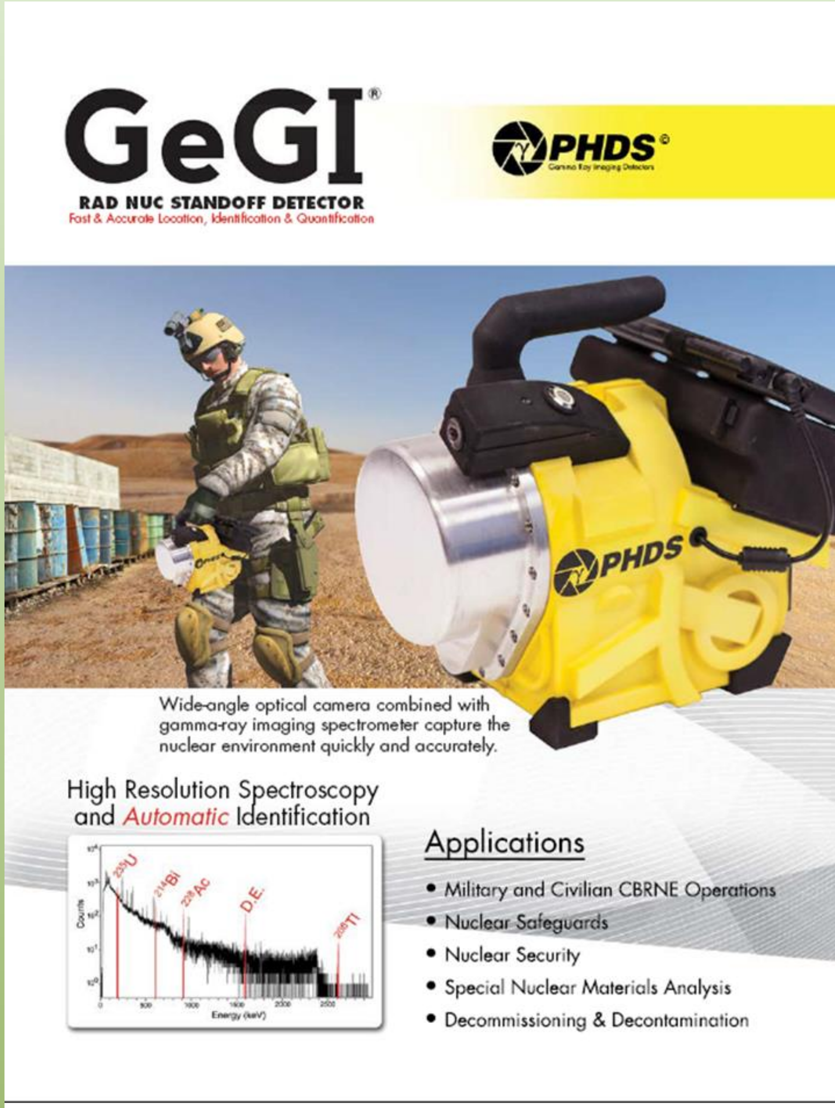
GeGI®
PHDS®
Gamma Ray Imaging Detectors

RAD NUC STANDOFF DETECTOR
Fast & Accurate Location, Identification & Quantification

Wide-angle optical camera combined with gamma-ray imaging spectrometer capture the nuclear environment quickly and accurately.

High Resolution Spectroscopy and *Automatic* Identification

Applications
- Military and Civilian CBRNE Operations
- Nuclear Safeguards
- Nuclear Security
- Special Nuclear Materials Analysis
- Decommissioning & Decontamination


Specifications

Dimensions:	10.5 in x 8 in x 5.5 in (26 cm x 20 cm x 14 cm)
Weight:	15 lbs (6.8 kg)
Battery life:	3 hours internal, 5 hours external, all hot swappable
Power supply:	100-240 VAC, 50-60 Hz
User maintenance:	None
Energy resolution:	FWHM < 2.1 keV (0.3 %) at 662 keV
Gamma-ray Compton imaging field of view:	4π (360°)
Optical (camera) field of view:	2π (185°)
Pinhole imaging field of view:	60° cone
Sensitivity: 10-μCi ^{137}Cs at 1 meter (3.3 μR/hr, 33 nSv/hr)	
Detection and ID time (662 keV) (8σ):	3.7 sec ± 1.0 sec
Location (Compton image) time:	30 sec ± 13 sec
Exposure/rate capacity:	200 kcps (10% Dead time) in 15 mR/hr ^{60}Co
Energy range:	30 keV – 3 MeV
Imaging energy range:	
Pinhole (2.54-cm thick Pb 60°) :	30 keV – 662 keV
Compton:	140 keV – 3 MeV
Isotope library (400 Isotopes):	Auto detect and/or user selected/specified
Isotope Identification:	37 frequently encountered isotopes
Detector (Ge crystal) dimensions:	90-mm diameter, 11-mm thick
Active detector volume:	60 cm³
Active detector area:	55 cm²
Cool-down time:	2.5 hours
Start-up time (cold):	2 minutes
Included:	Rugged daylight-readable glove-touch tablet, pelican case, power supply, battery charger

Features
Standoff Location Detection Identification
Distance Range (10 cm - 50+ meters)
Automatically specifies SNM, NORM, IND, MED
Germanium gamma-ray spectroscopy (16k ch)
Full 360° Standoff Visualization (Compton)
^{235}U (186 keV) ^{239}Pu (375 keV, 414 keV)
User-friendly single-button glove-touch operation
Hot swappable battery operation
Full session save and reload capability
Full data-stream availability
Wireless capable/wireless option can be disabled
Twist-lock mil-spec power connector
Long-lived internal cooler (5 years +)
Reachback file: ANSI N42.42 format
Remote operation

2/3/17

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

A product with global impact

Sellafield nuclear facility (UK) – March 2017

6th Floor FGRP

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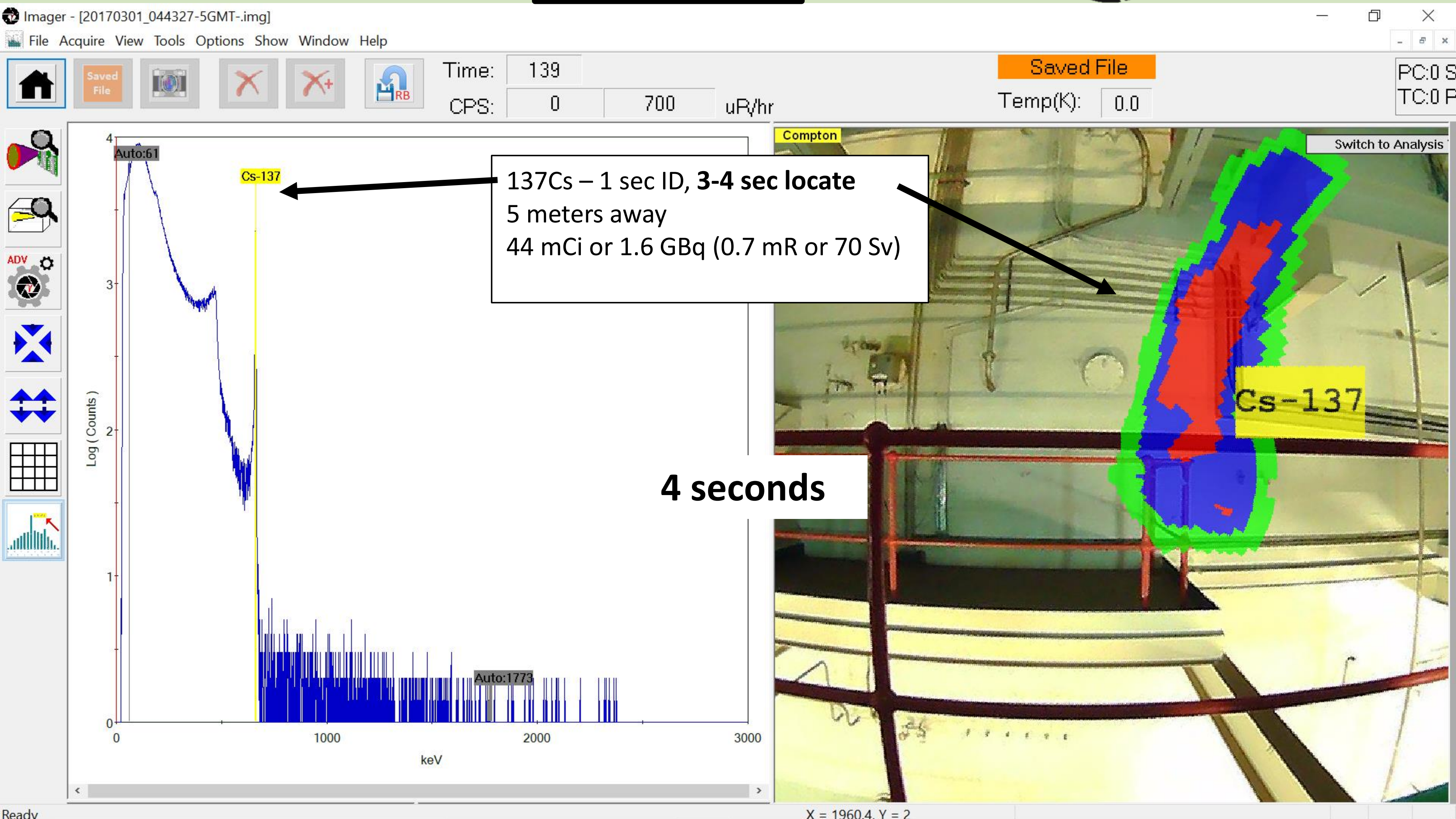

137Cs – 1 sec ID, **3-4 sec locate**
5 meters away
44 mCi or 1.6 GBq (0.7 mR or 70 Sv)

4 seconds

Sellafield nuclear facility (UK) – March 2017

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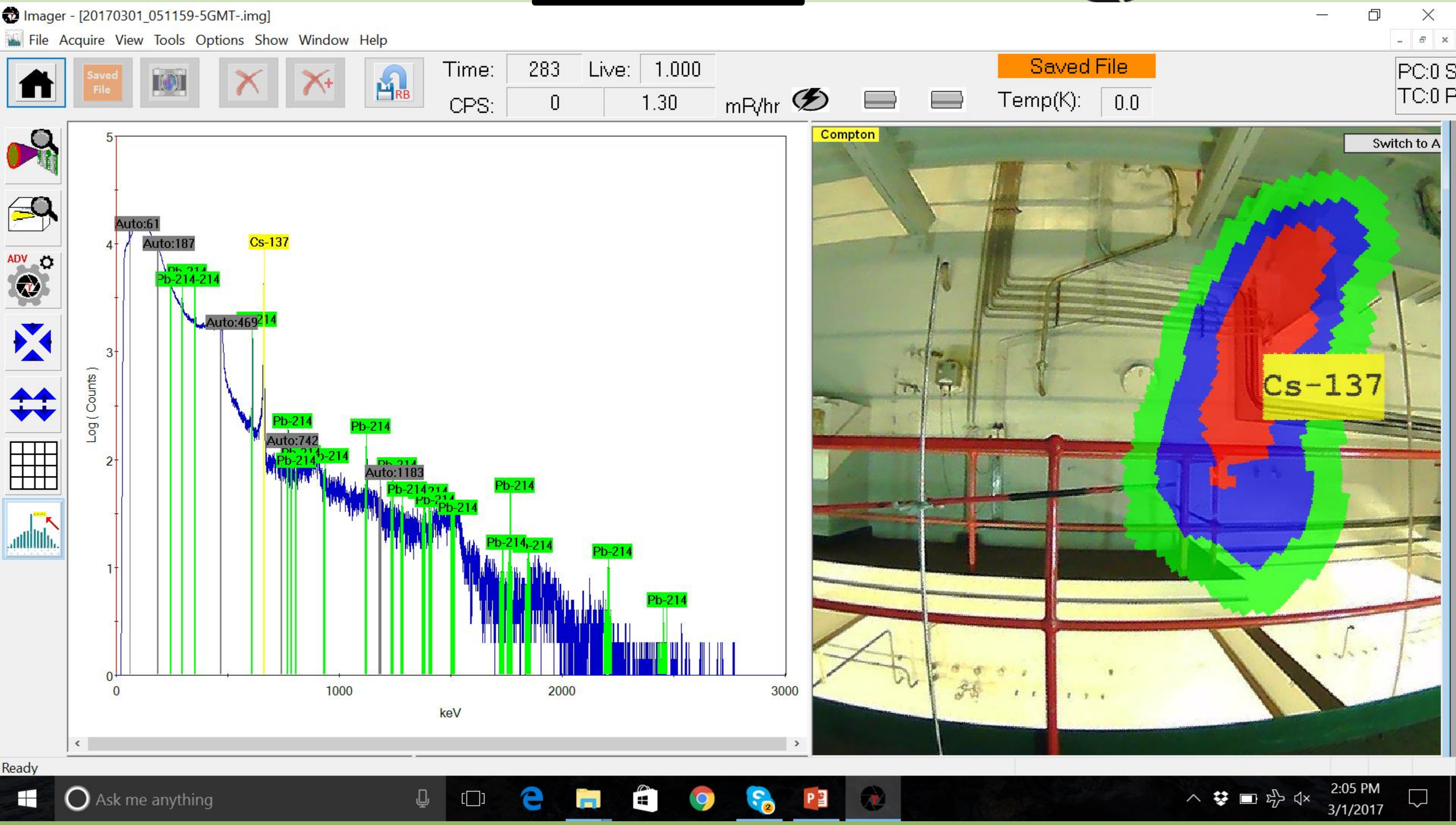

Sellafield nuclear facility (UK) – March 2017

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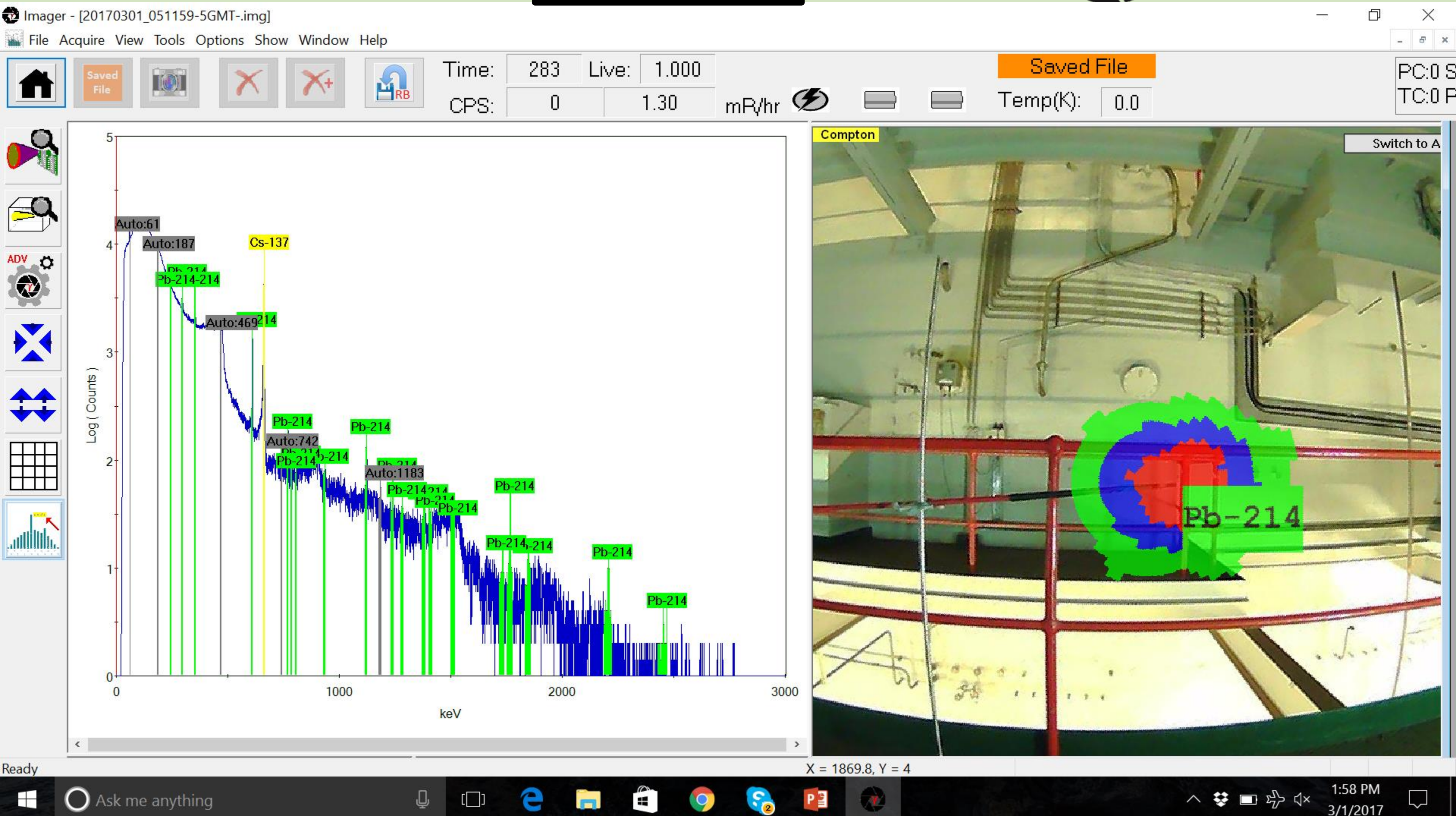
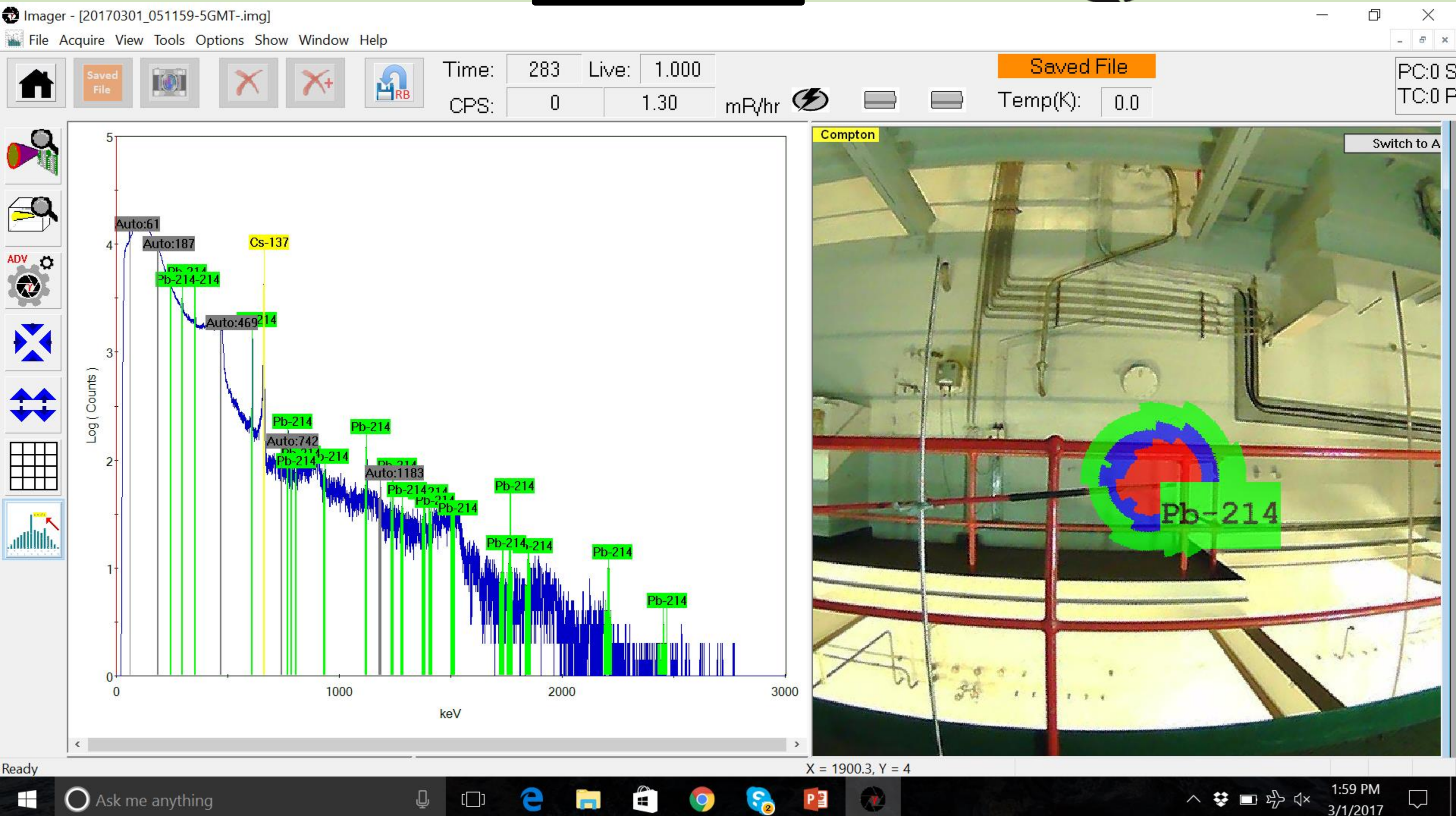
Gamma Ray Imaging Detectors



Sellafield nuclear facility (UK) – March 2017

6th Floor FGRP



Sellafield nuclear facility (UK) – March 2017

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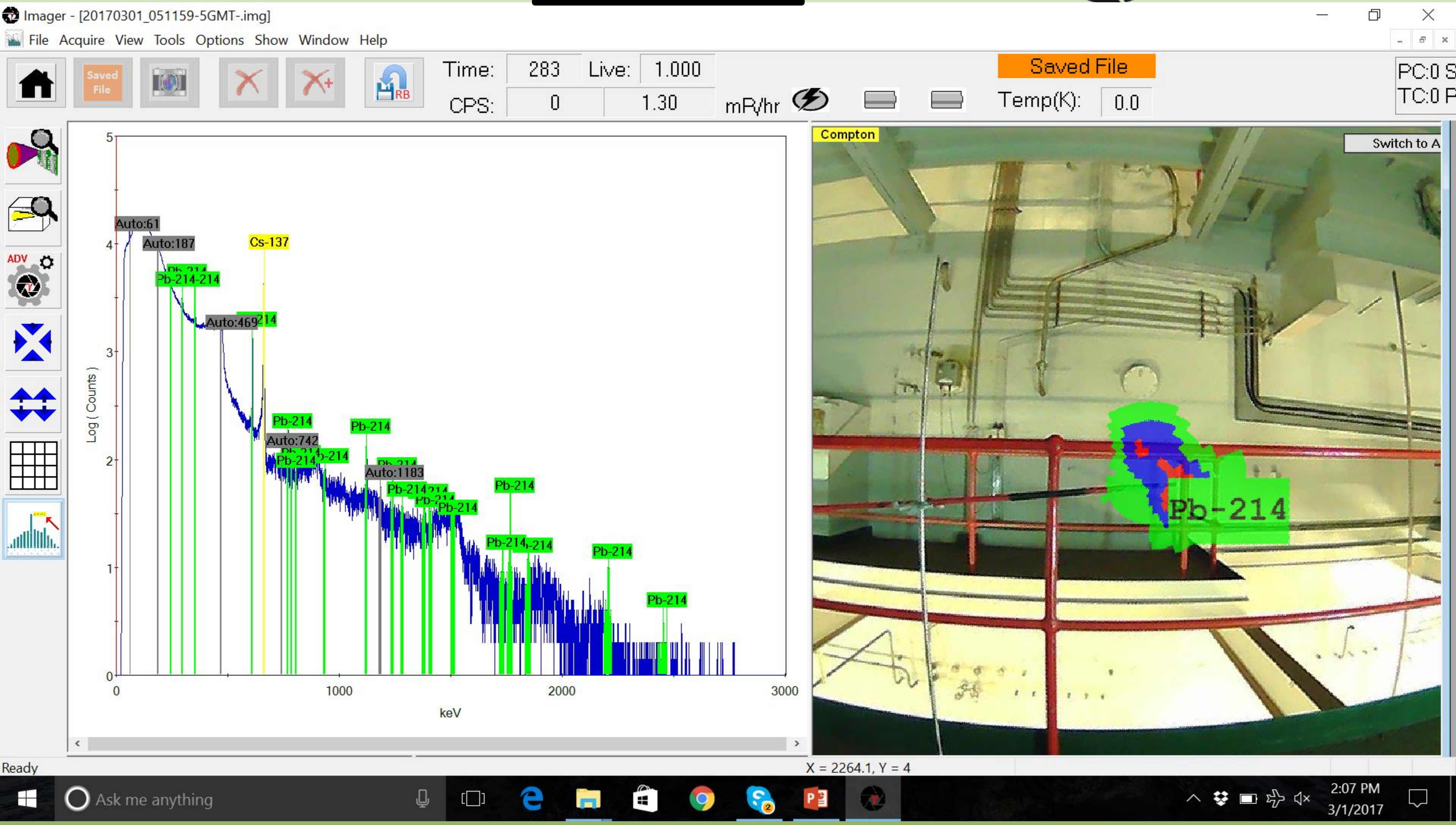

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GeGI was immediately purchased – high sensitivity + excellent resolution – 9 imagers evaluated

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Sellafield Ltd

Gamma Imaging

Plant Characterisation

Understanding the radiation environments is important in order to best determine if any remediation (decontamination, shielding etc.) or controls need to be put in place to protect people.

Current methods to do this involve simple, manually deployed probes which gives limited information about the location and type of any sources.

Advancements in detector technology indicate that new systems may be able to measure not only the dose rate, but also the location, quantity and key sources contributing to the overall dose environment.

"The ability to effectively characterise environments is becoming increasingly important, as the business transitions towards decommissioning operations"

Over the past 2-3 years, Sellafield Ltd has facilitated the demonstration of nine different gamma imaging systems. These technologies varied from small handheld systems, to large, remotely operable, collimated devices. The purpose of these demonstrations was to understand the performance of each system, and which were most appropriate for Sellafield's challenges. This is shown in a report in which future decisions can be made.

The Decommissioning Capability Development team purchased two systems following this report. This included the N-Visage gamma imager and GeGI Gamma-ray imaging spectrometer.

The N-Visage gamma imager, this detector is utilised in high dose environments where there is restricted access and can fit through access holes.

The second system purchased is the GeGI Gamma-ray imaging spectrometer – better suited to fast results in low dose rate areas.

With projects lining up to make use of these new systems, the coming months will see multiple deployments of the new devices. The report also enabling other Sellafield teams to further make vs buy decisions. These systems will be demonstrated all across Sellafield site enabling benefit realisation, with a potential saving of £50k a task with the new technologies.

KEY MILESTONES ACHIEVED

- Active demonstration of two gamma imaging systems
- Internal evaluation report endorsed by the Remediation technical committee
- N-Visage and GeGi gamma imagers purchased

COMPANIES INVOLVED:

HED, PHDS, ANTECH, innovative physics, cavendish nuclear, CREATEC, REACT ENGINEERING LIMITED, MIRION TECHNOLOGIES, AREVA

Benefit Realised from 2018

S F C

CHALLENGE

Measuring the dose environment and the location of radioactive sources

SOLUTION

A range of Fit-For-Purpose gamma imaging systems

BENEFITS

Faster acquisition of results and improved deployment options could save >£100million over the lifetime of the site

CURRENT STATUS

Nine systems tested and evaluated, with two devices purchased

FUTURE ACTIVITIES

Utilising Sellafield's new internal capability and a "watching brief" for additional systems of interest and a program of characterisation so a state of business a usual can be reached

Large diameter/volume HPGe Crystals

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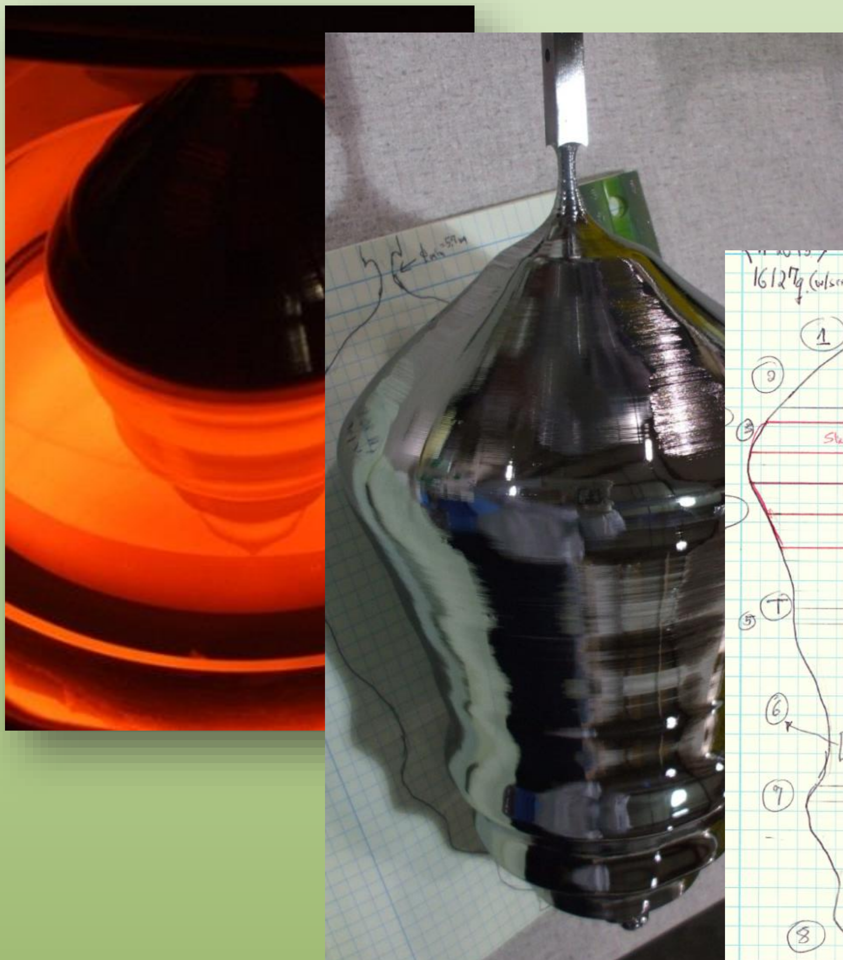
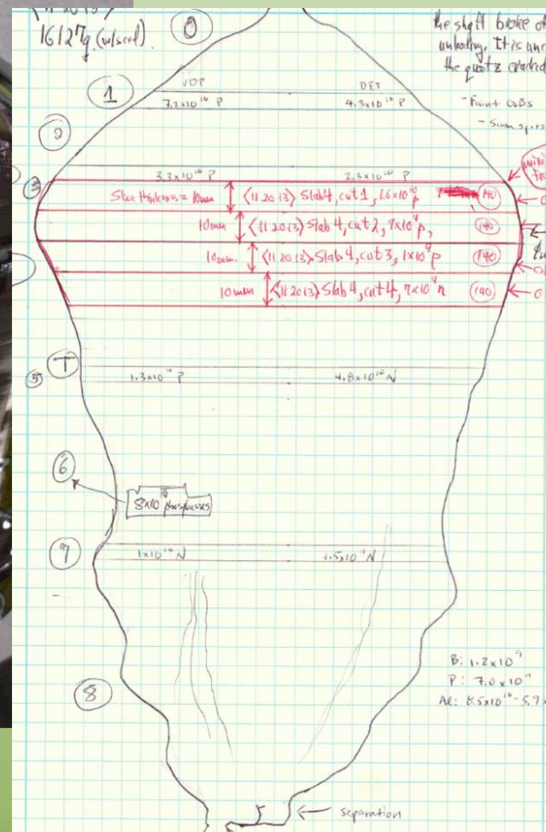
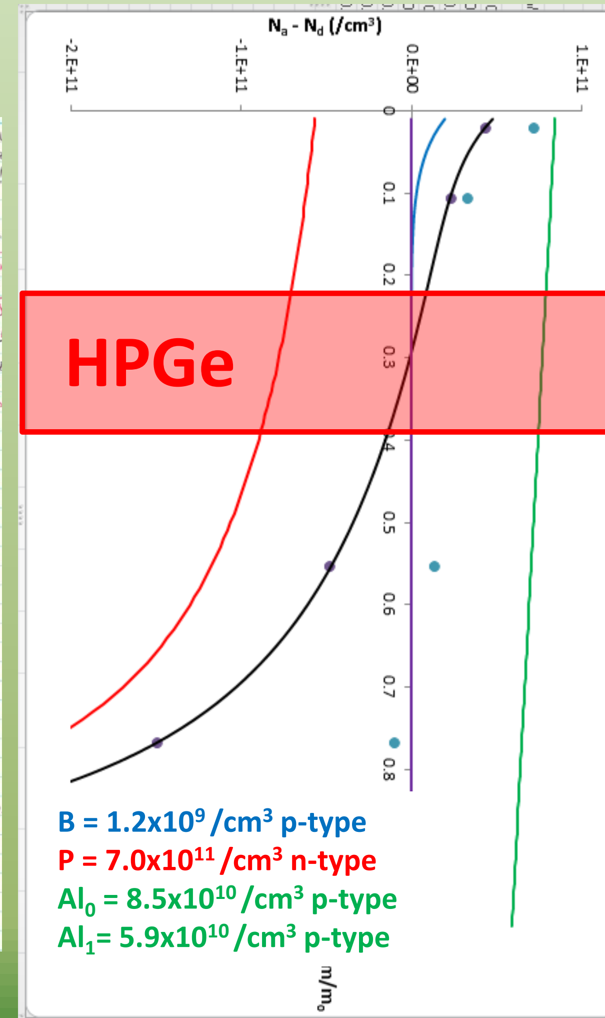


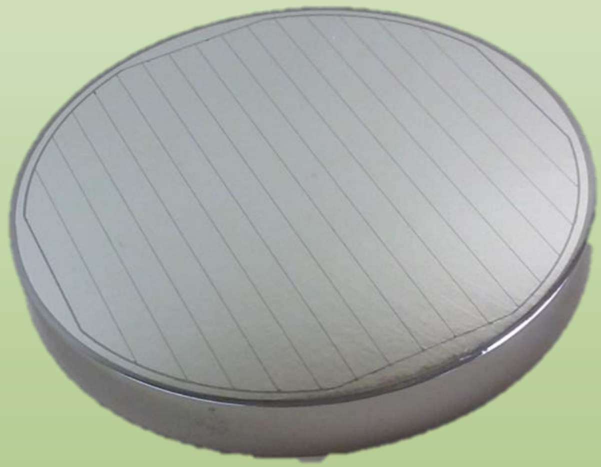




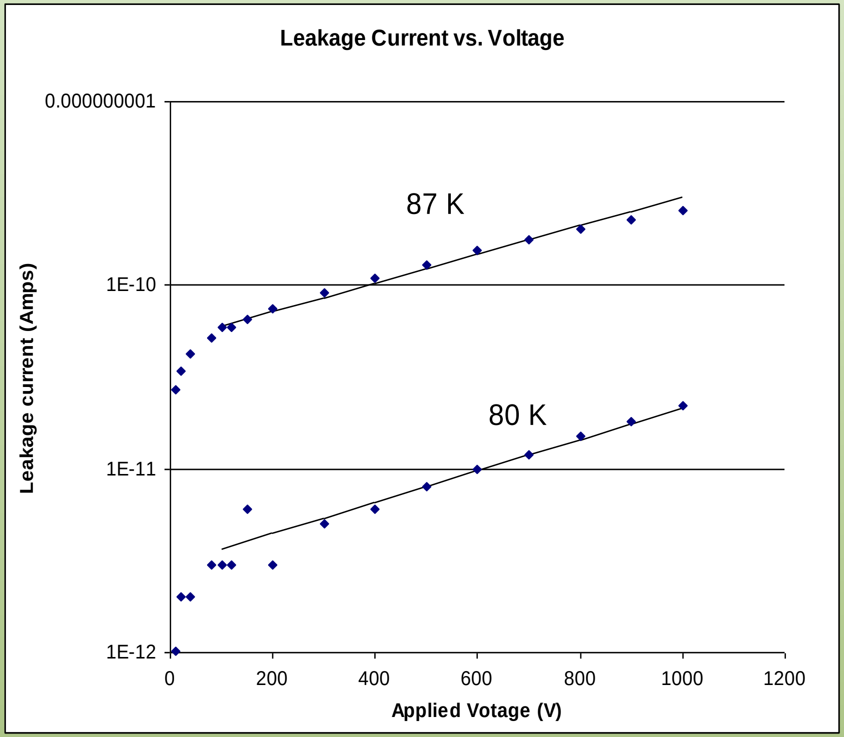
Best crystals from CZ250

167 mm dia

Segmented HPGe detector fabrication
DOE NP Developed



90 mm dia



Surface contact physics: αGe, Y, Ag, …

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

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.

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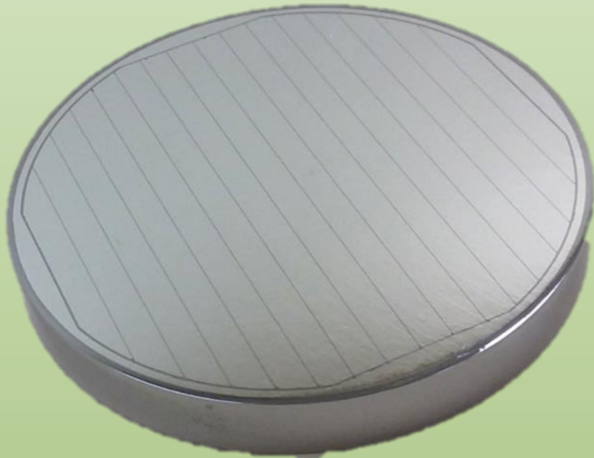
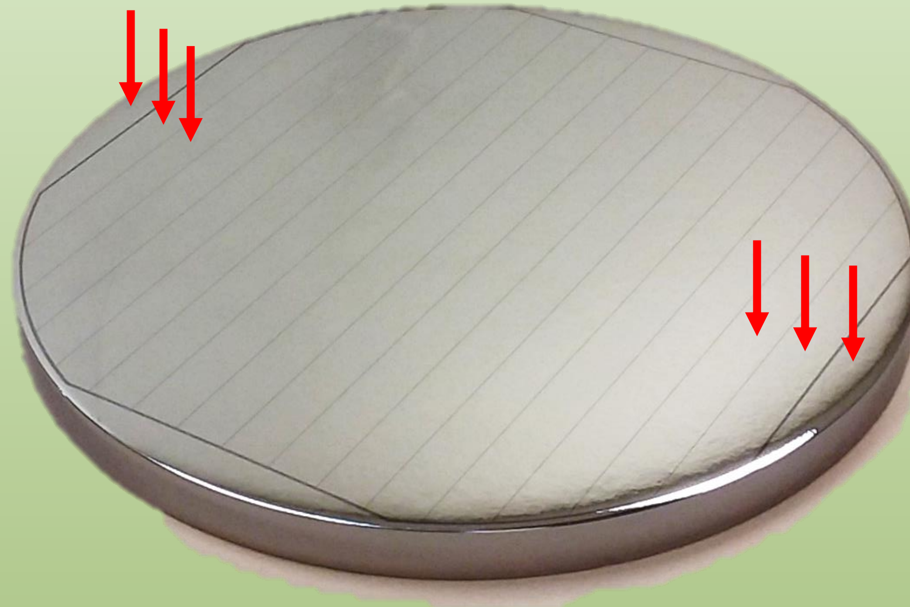
Excessive Leakage Current (and Trapping)



90 mm dia



140 mm

Most of the time they do not work....

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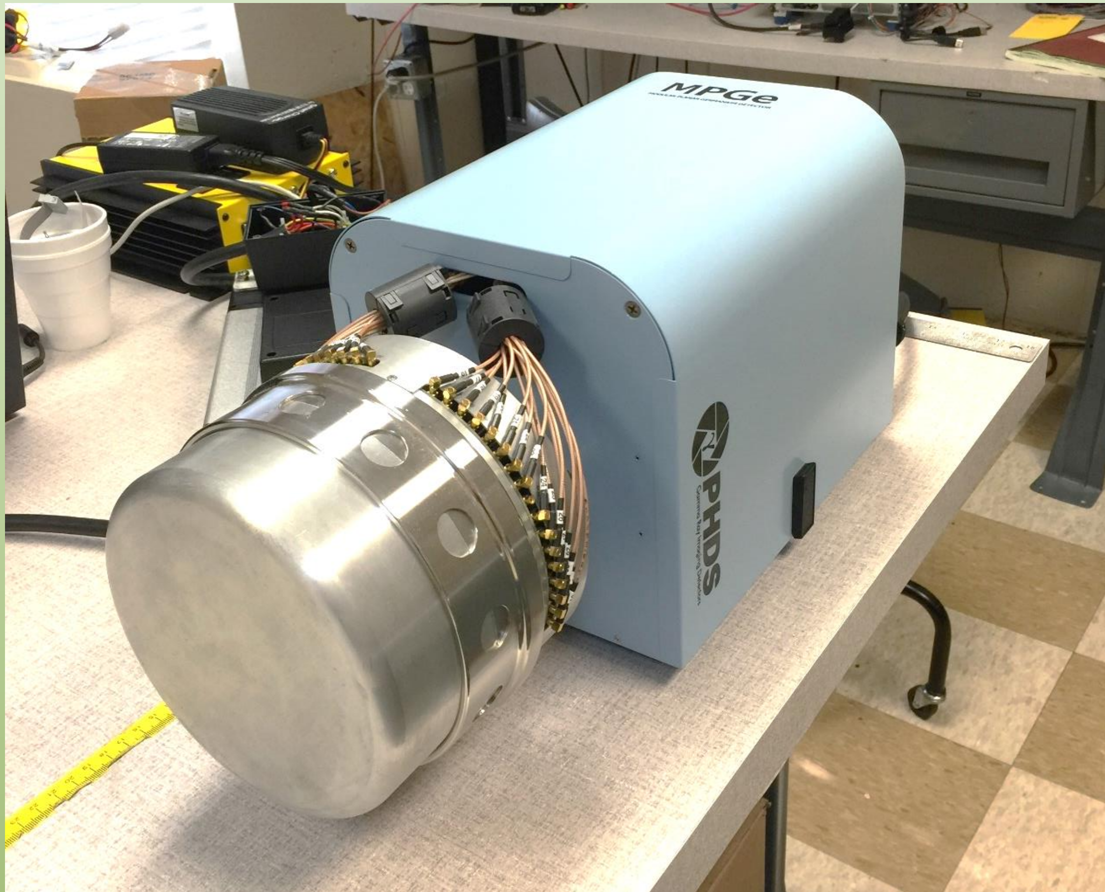
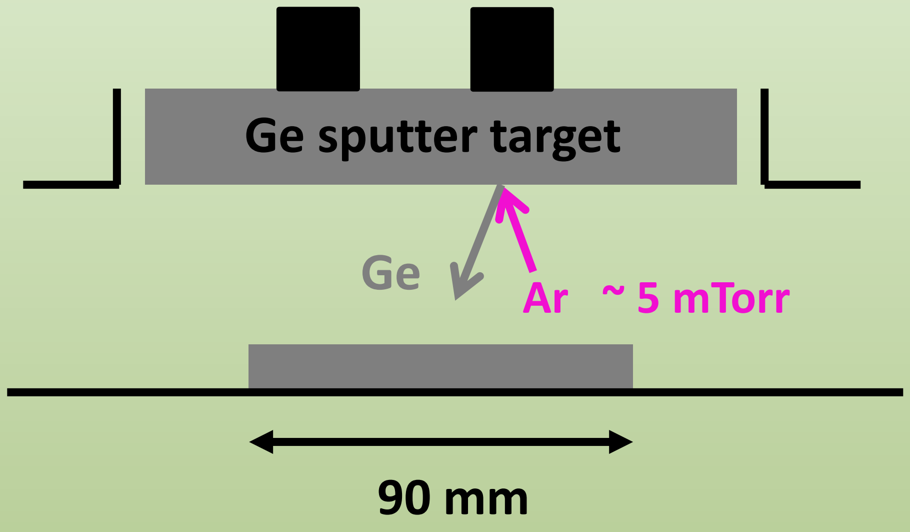
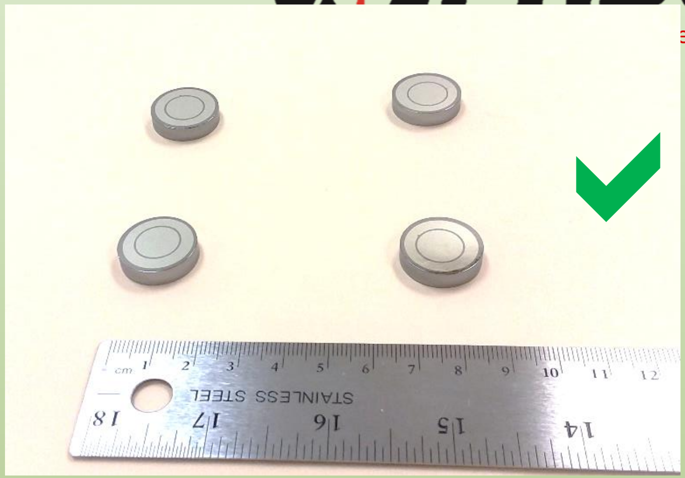
However, it does work sometimes - so it can be done!

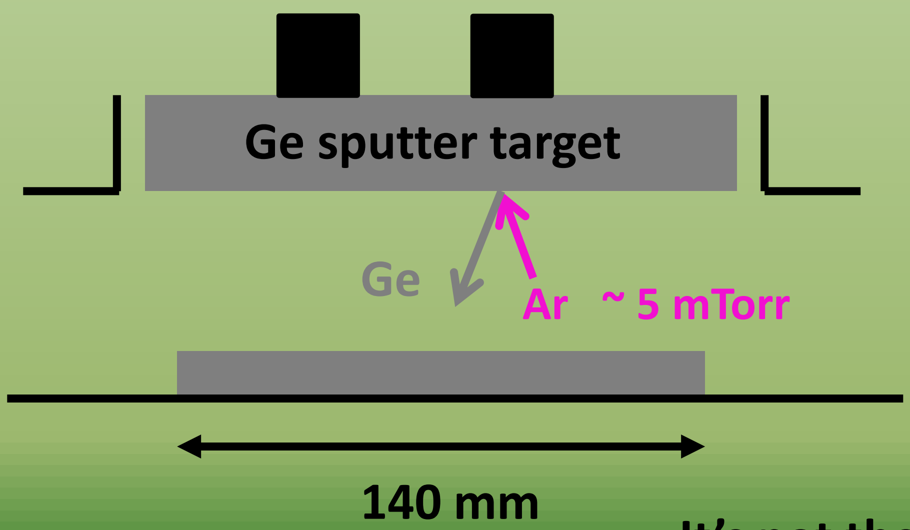


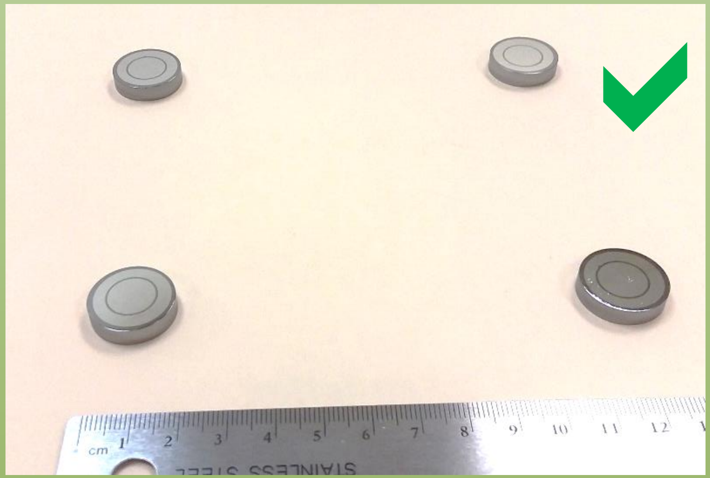
The detector fabrication process?
OR
The crystal?

The detector fabrication process…









It's not the fabrication…..

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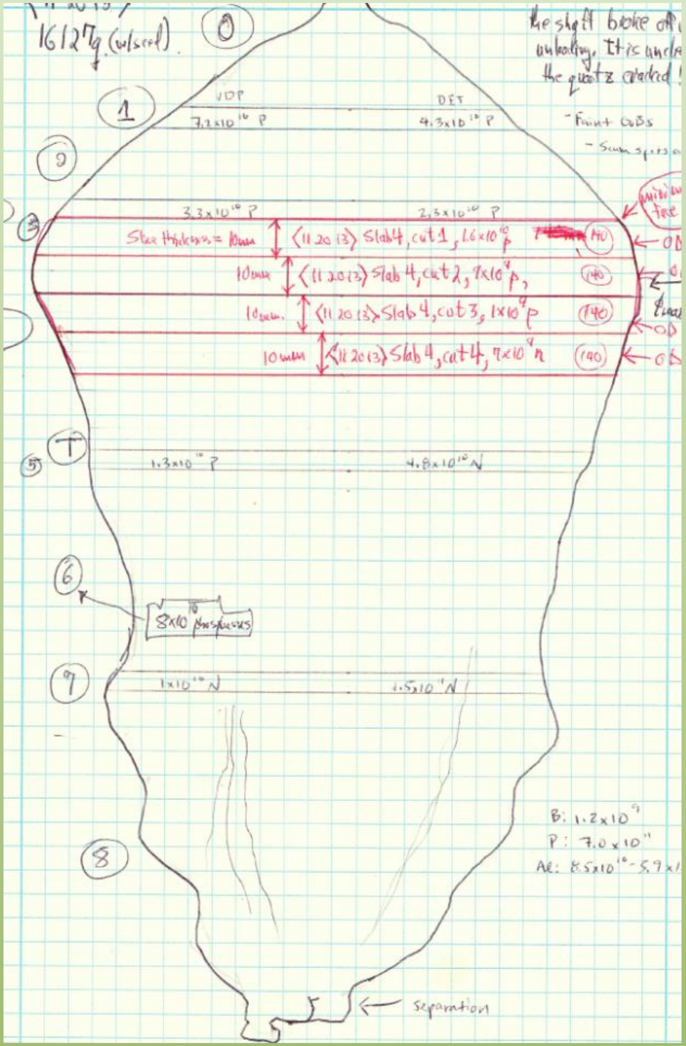
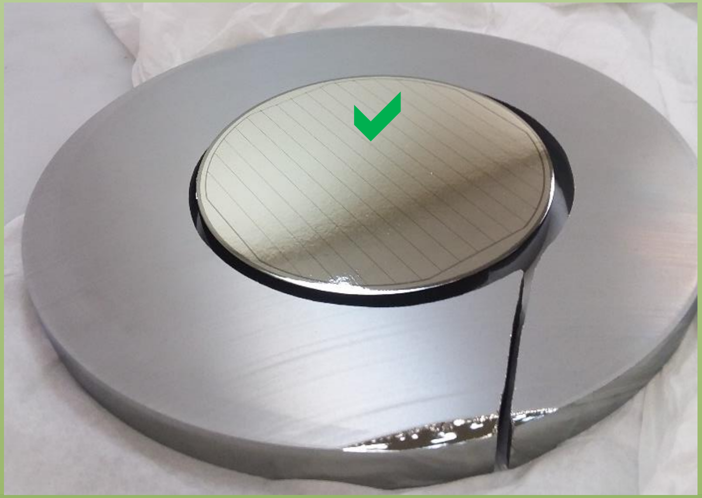


140-mm diameter detectors

OR

AND



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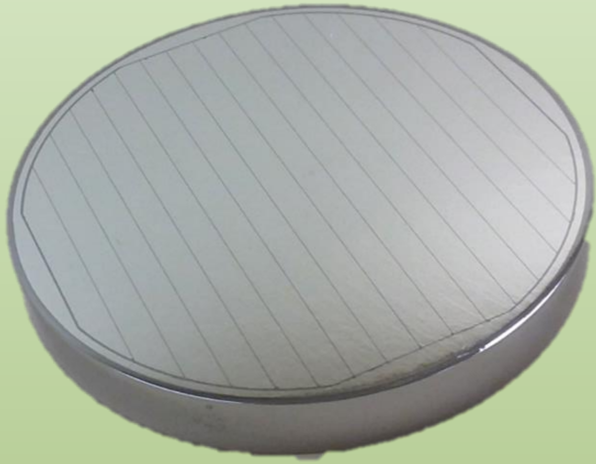
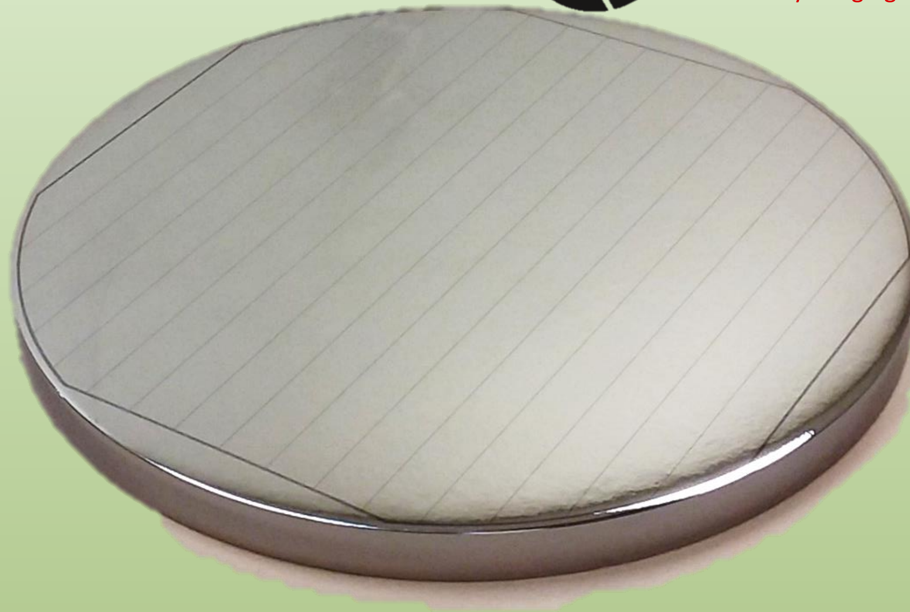


90 mm dia

✓



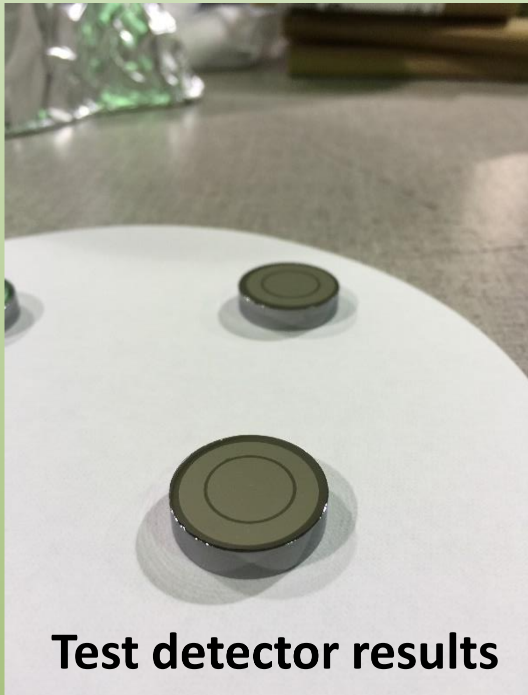
140 mm

✗

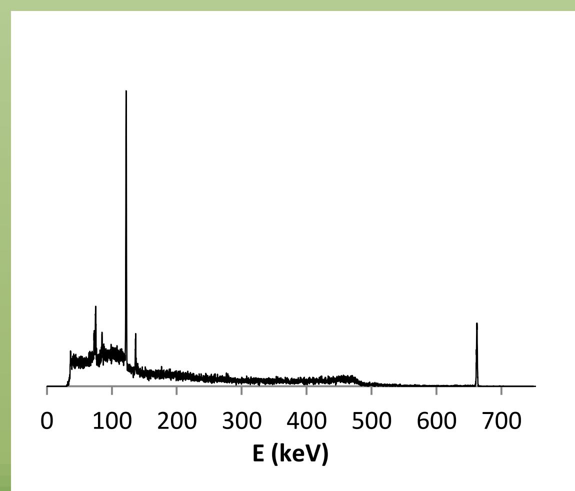
The problem appears to be the crystal

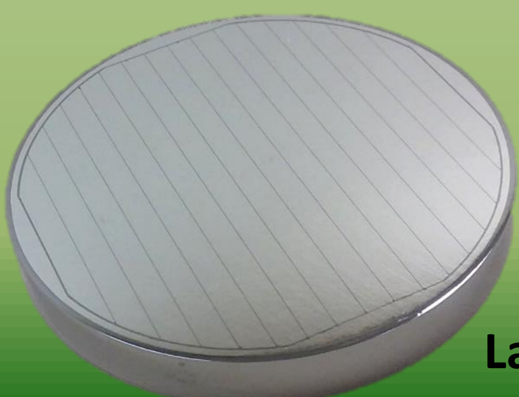
Gamma Ray Imaging Detectors

1. **Grow [100] Crystals**
   a. Compare test detectors
   b. Compare full sized 90-mm detectors
   c. Gradually increase diameter to 140-mm+



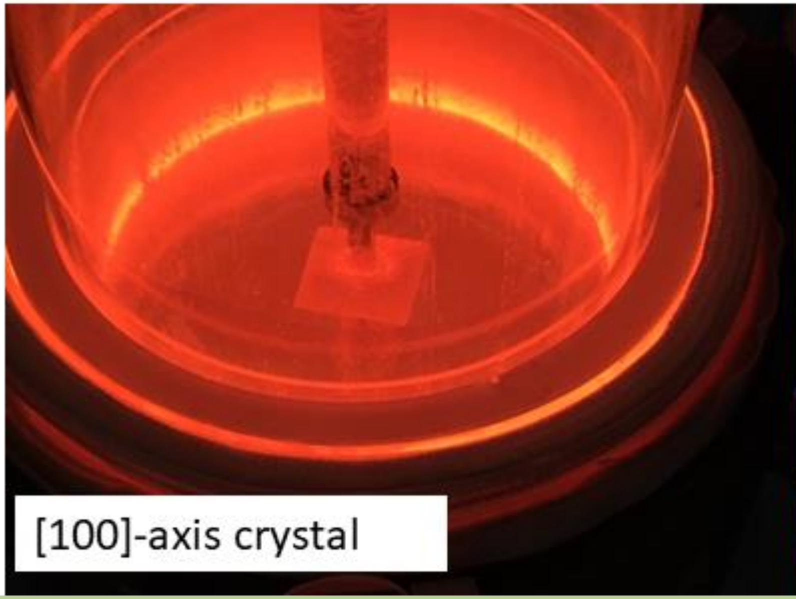
Test detector results

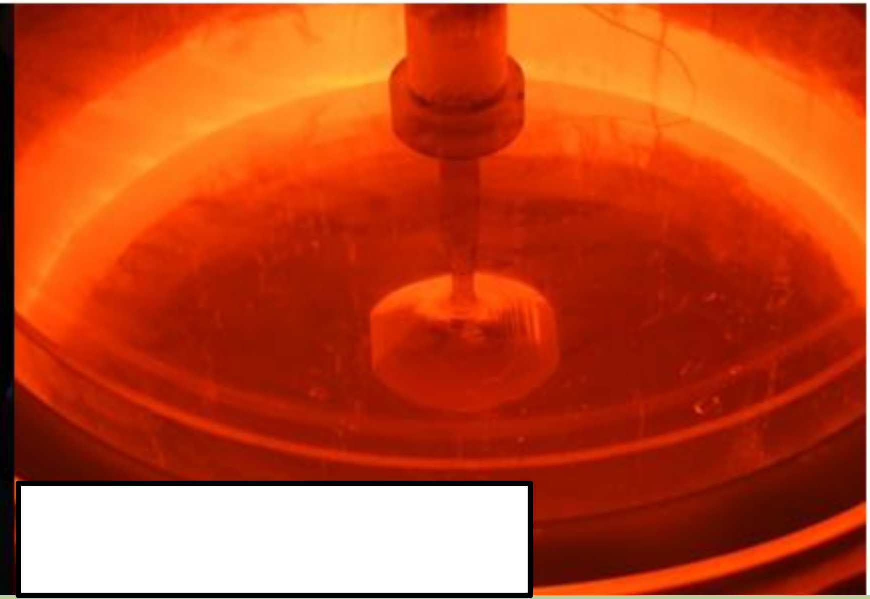




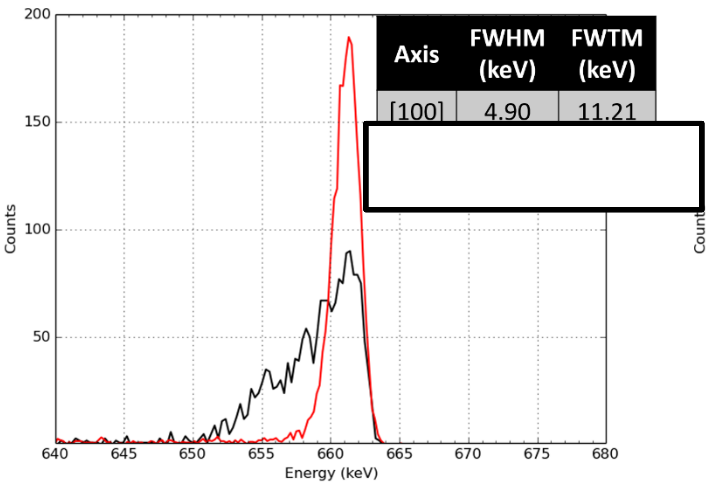
Large-diameter (90 mm) results

Test detector results

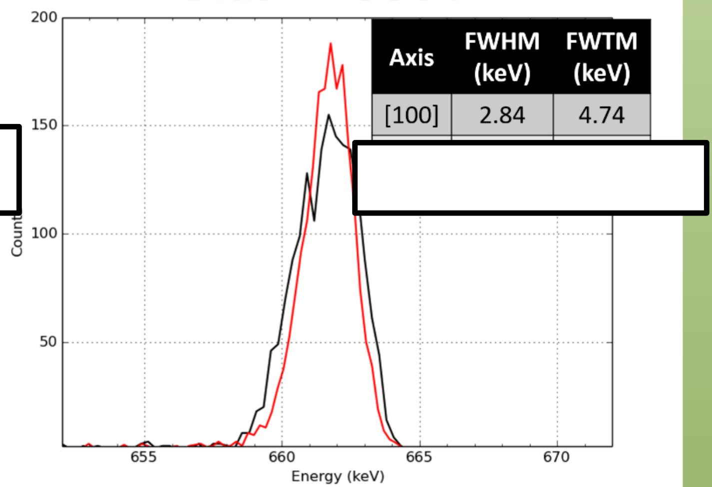


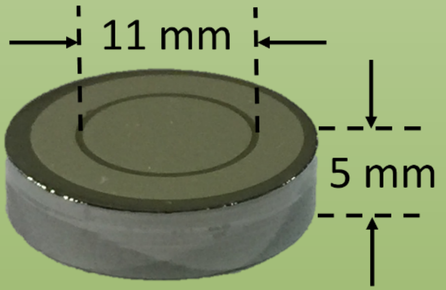


Bias = -300V



Bias = -600V





Test detector results

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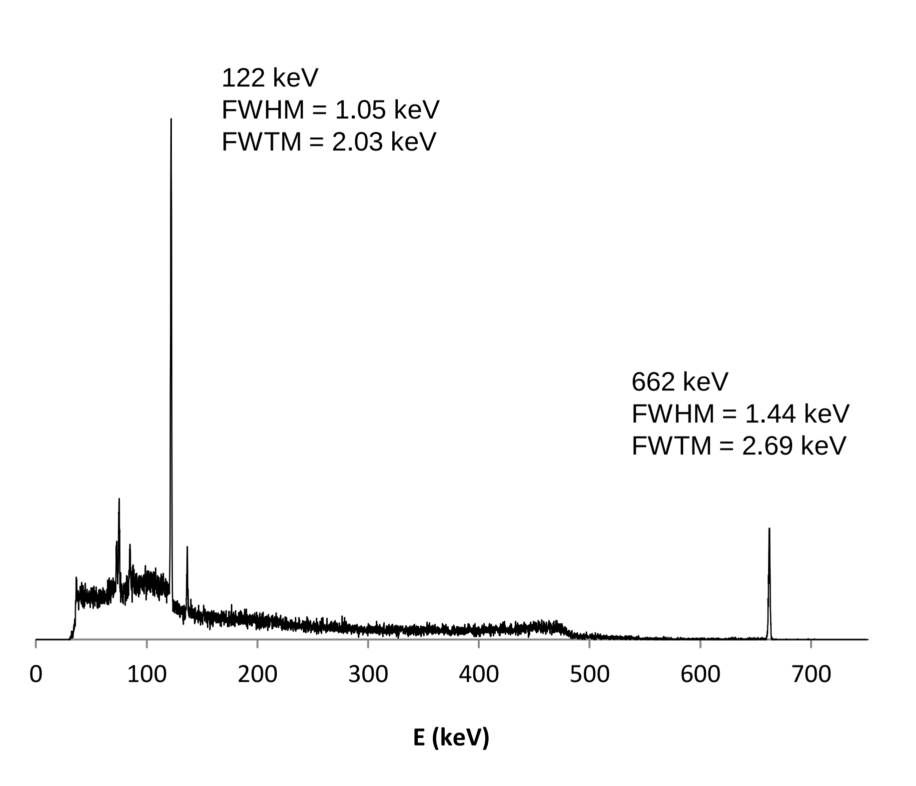
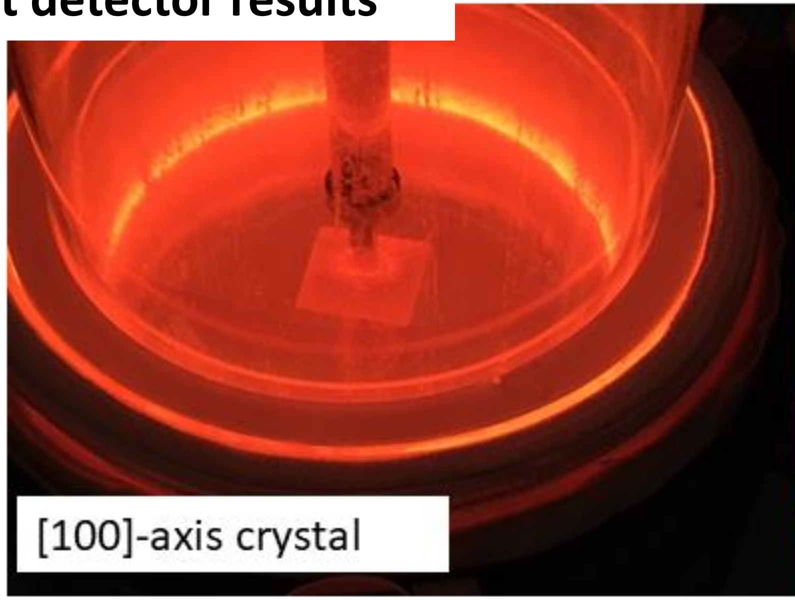
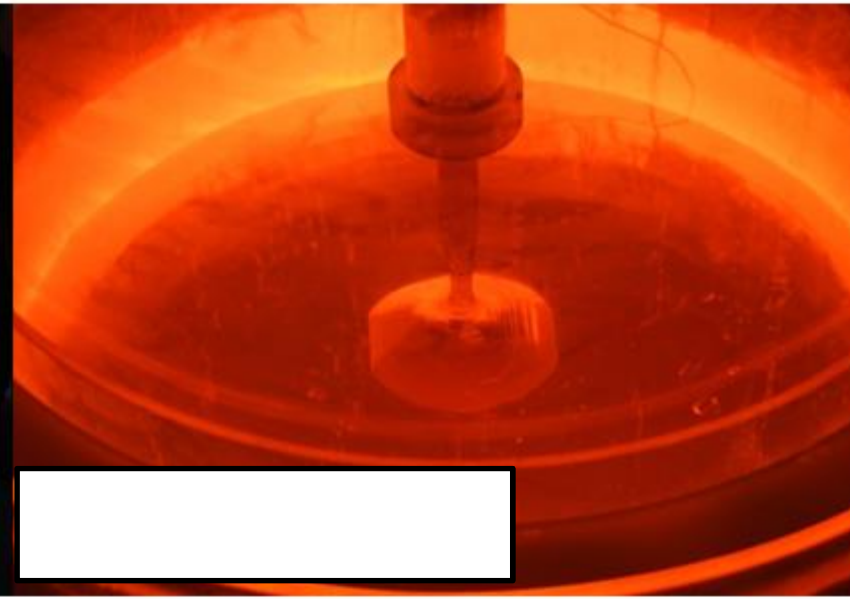


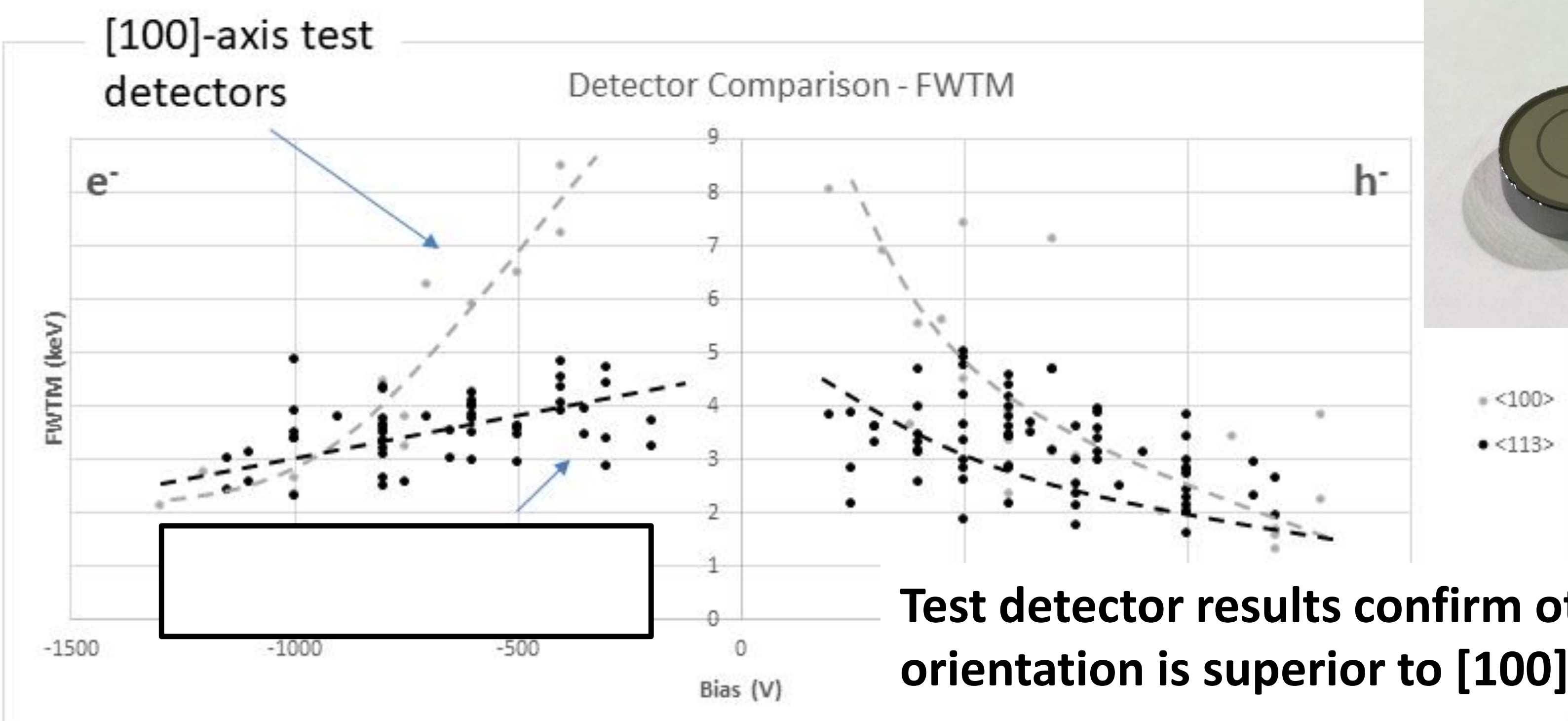
$$\boldsymbol{FWHM_T} \cong \{FWHM_{662}{}^2 - FWHM_{122}{}^2 + (FWHM_{F\,662}{}^2 - FWHM_{F\,122}{}^2)\}^{\frac{1}{2}}$$

[where $FWHM_{F\,E} = 2.355\sqrt{\varepsilon F E}$ at energy E with $\varepsilon = 2.96\ eV$ and Fano factor $F = 0.12$.]

Test detector results

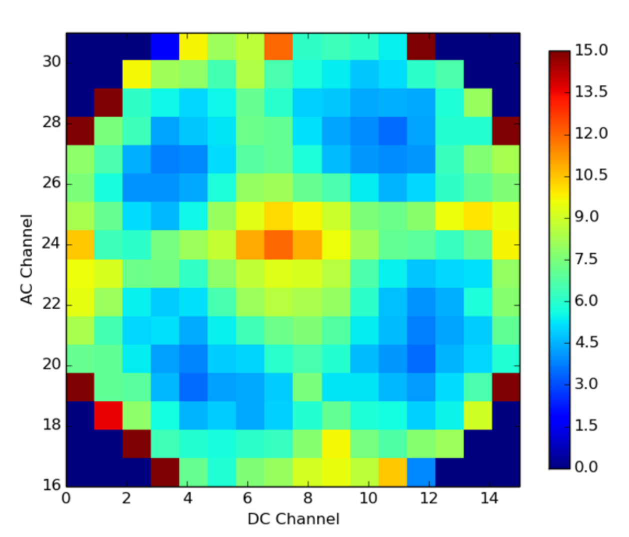


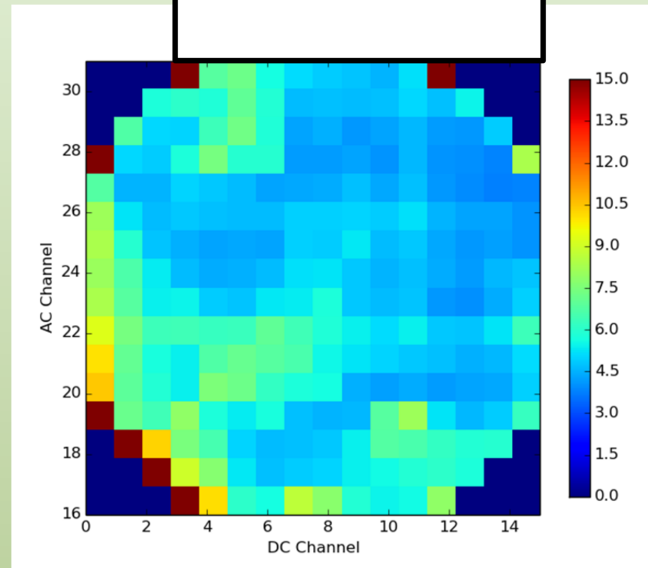




Test detector results confirm other orientation is superior to [100] !!

[100] Crystal





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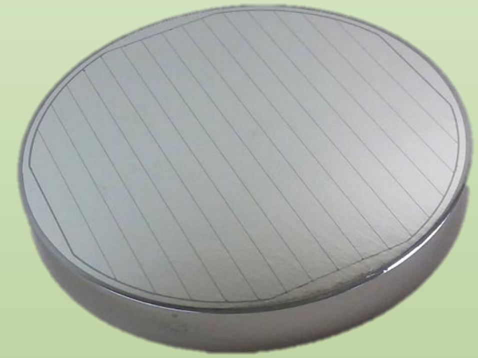
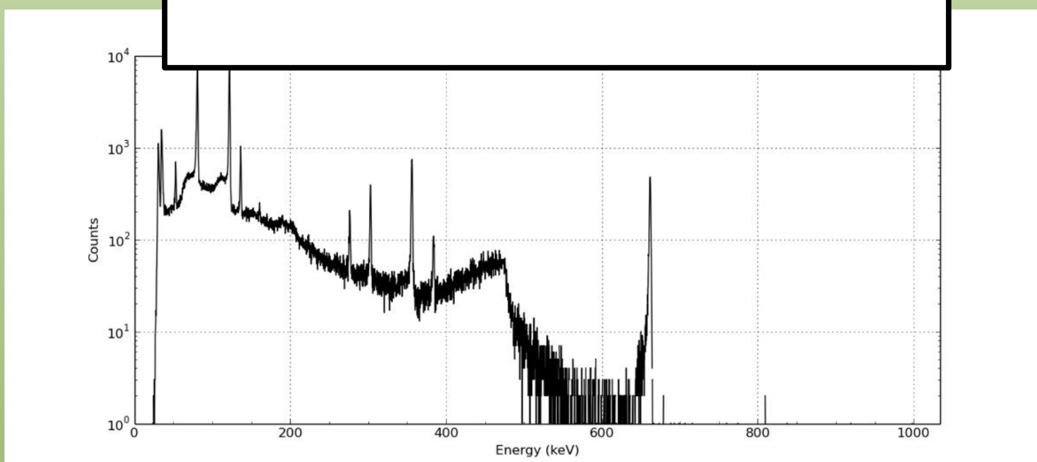


90-mm diameter

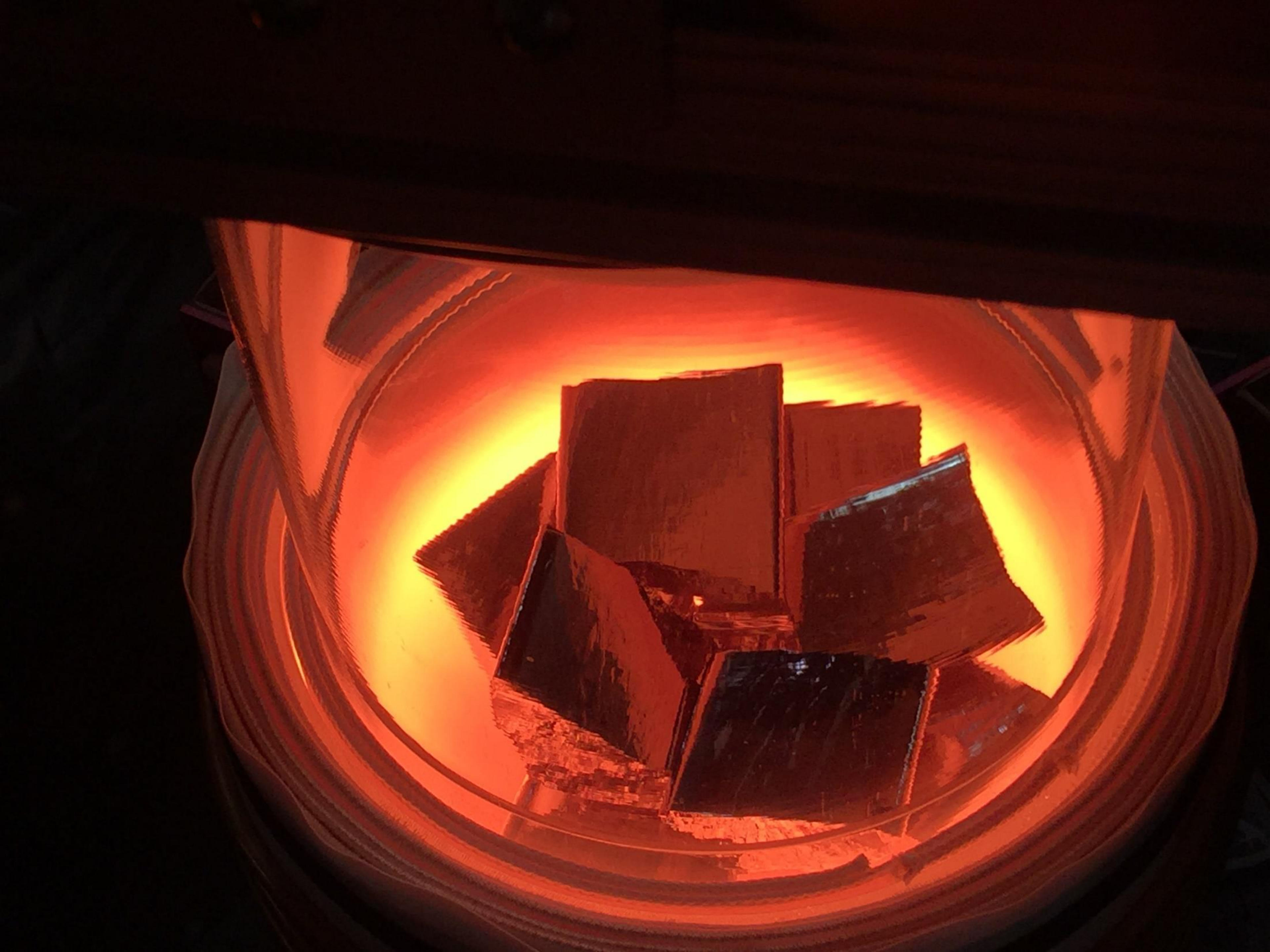
90-mm diameter detector results confirm other axes are superior to (100) !!

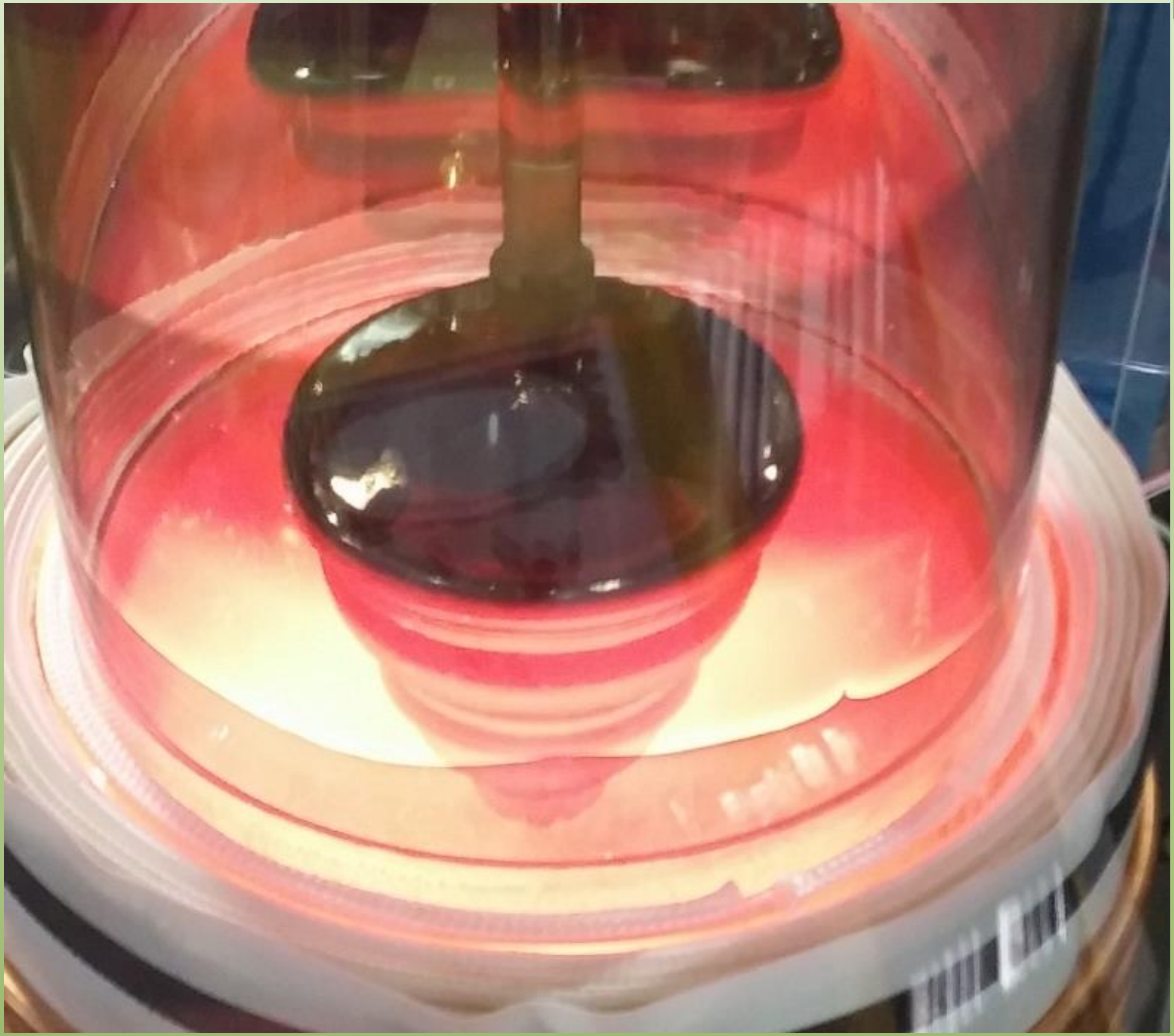


Before Trap Correction			After Trap Correction		
Crystal Axis	FWHM (keV)	FWTM (keV)	Crystal Axis	FWHM (keV)	FWTM (keV)
[100]	2.72	6.48	[100]	2.12	4.52

1. **Small test detectors**
2. **Large diameter 90-mm detectors**

other axes are better than [100]





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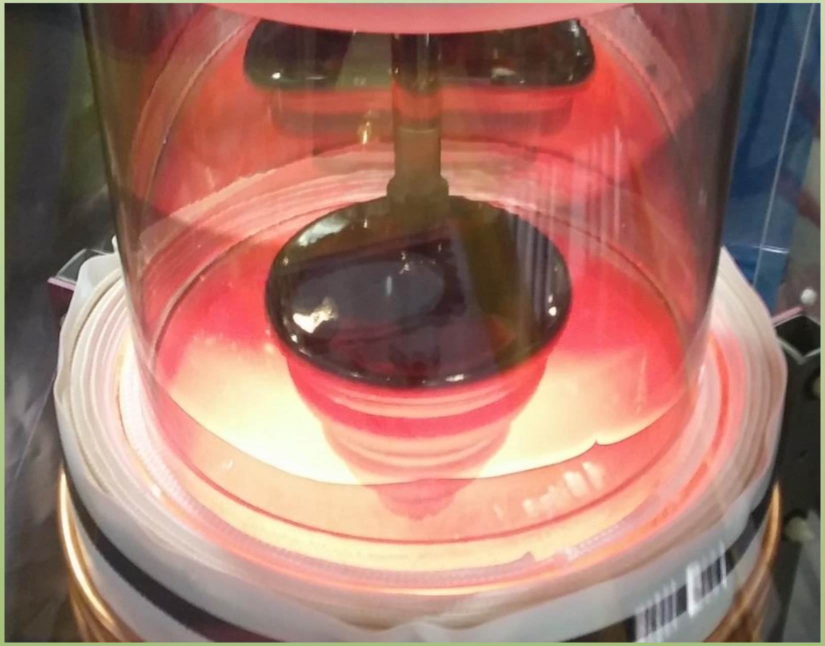

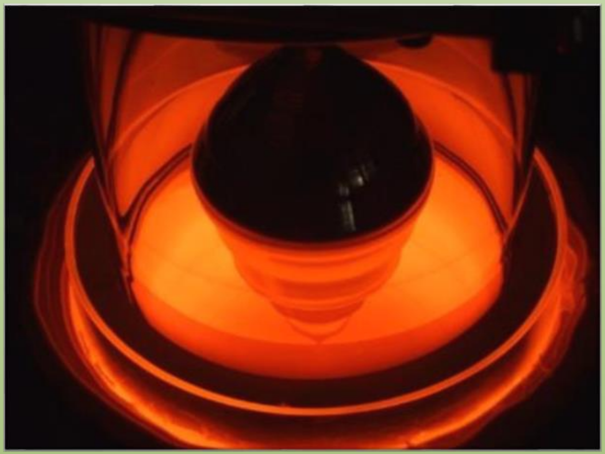

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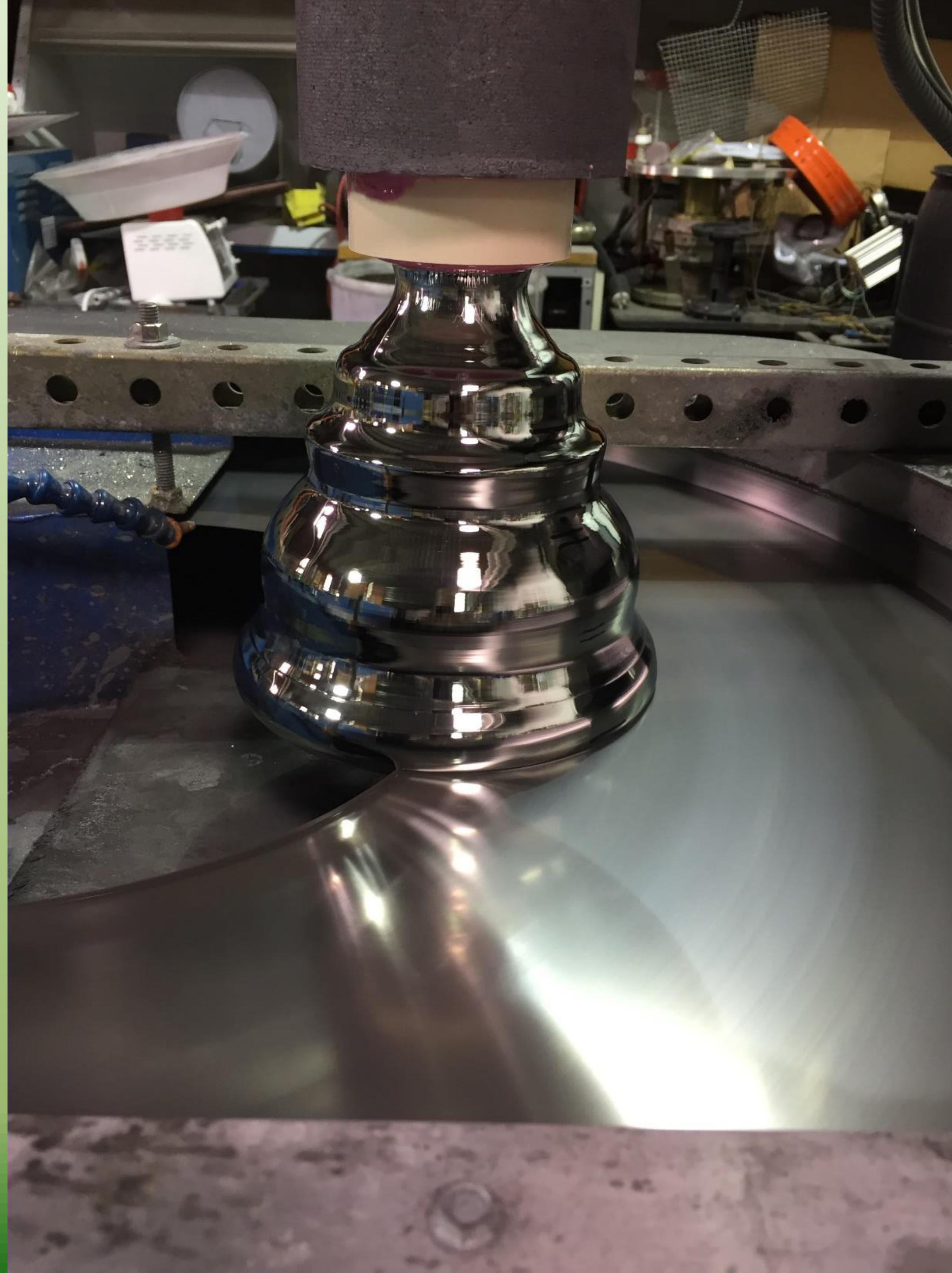

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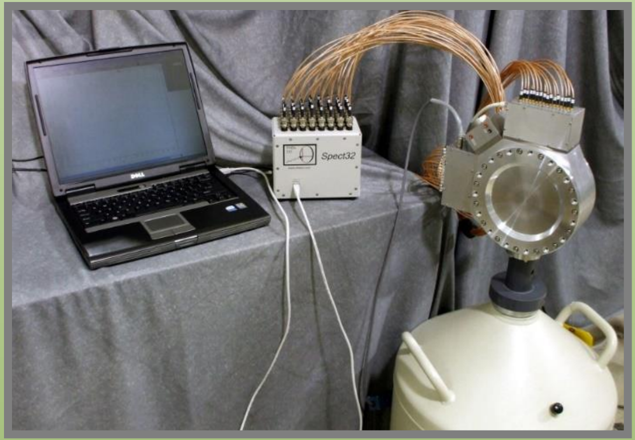
Bringing puller to HPGe level
- **Most of the way there now**

Stabilizing crystal growth
- **Increasing mass incrementally**

Alternative axes will be attempted when new quartz arrives

Siege

90-mm diameter → 140-mm diameter → 200 mm diameter



Thank you NP