Charge collection physics in very large diameter germanium crystals
PHDS Co.

- 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

NPX (150 lbs.)
GeGI-5 (15 lbs.)
Detector is the same size
Gamma Ray Imaging Detectors

10,000 ft² Manufacturing and R&D Facility in Knoxville, TN
The vertical manufacturing process for HPGe Detectors

- Ge Zone Refine
- HPGe Crystal Growth
- Analysis
- Fabrication
- Integration
- Electronics
- Cryogenics

DOE NP

Commercial

GeGI 5
Gamma Ray Imaging Detectors

A product with global impact
137Cs – 1 sec ID, 3-4 sec locate
5 meters away
44 mCi or 1.6 GBq (0.7 mR or 70 Sv)
Gamma Ray Imaging Detectors

Sellafield nuclear facility (UK) – March 2017

6th Floor FGRP
Sellafield nuclear facility (UK) – March 2017

Gamma Ray Imaging Detectors

6th Floor FGRP
Decommissioning Capability Development

END OF YEAR REPORT 2016-17
Gamma Ray 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.

“While 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 last tasks 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:
- Sellafield Ltd
- AREVA

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 >£100,000 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

Benefit Realised from 2018

End of Year Report 2016-17 / future.decommissioning@sellafieldsites.com
Large diameter/volume HPGe Crystals

Best crystals from CZ250

167 mm dia

HPGe

$B = 1.2 \times 10^9 \text{ cm}^{-3} \text{ p-type}$

$P = 7.0 \times 10^{11} \text{ cm}^{-3} \text{ n-type}$

$Al_0 = 8.5 \times 10^{10} \text{ cm}^{-3} \text{ p-type}$

$Al_1 = 5.9 \times 10^{10} \text{ cm}^{-3} \text{ p-type}$
Segmented HPGe detector fabrication
DOE NP Developed

![Image of detector](image)

90 mm dia

Leakage Current vs. Voltage

![Graph](graph)

87 K

80 K

Surface contact physics: $\alpha$Ge, Y, Ag, ...

$$j = j_\infty \exp\left(-\phi - \left(\frac{\varepsilon_0 \varepsilon_{\text{Ge}}}{N_f}\right)^{1/2}(V+V_{\text{depl}})/d\right) / k_B T$$


Gamma Ray Imaging Detectors

90 mm dia

Excessive Leakage Current (and Trapping)

140 mm

Most of the time they do not work....
However, it does work sometimes - so it can be done!

The detector fabrication process?  
OR  
The crystal?
Gamma Ray Imaging Detectors

The detector fabrication process...

Ge sputter target

90 mm

Ge sputter target

140 mm

It’s not the fabrication.....
Gamma Ray Imaging Detectors

140-mm diameter detectors

OR

AND

PHDS
Gamma Ray Imaging Detectors
The problem appears to be the crystal.
1. Grow [100] Crystals
   a. Compare test detectors
   b. Compare full sized 90-mm detectors
   c. Gradually increase diameter to 140-mm+
Gamma Ray Imaging Detectors

Test detector results

[100]-axis crystal

<table>
<thead>
<tr>
<th>Bias = -300V</th>
<th>Bias = -600V</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Axis</strong></td>
<td><strong>FWHM (keV)</strong></td>
</tr>
<tr>
<td>[100]</td>
<td>4.90</td>
</tr>
<tr>
<td>[100]</td>
<td>2.84</td>
</tr>
</tbody>
</table>

Counts vs. Energy (keV)

11 mm
5 mm
\[ FWHM_T \approx \left\{ FWHM_{662}^2 - FWHM_{122}^2 + (FWHM_F_{662}^2 - FWHM_F_{122}^2) \right\}^{\frac{1}{2}} \]

[where \( FWHM_{FE} = 2.355\sqrt{\varepsilon FE} \) at energy \( E \) with \( \varepsilon = 2.96 \text{ eV} \) and Fano factor \( F = 0.12 \).]
Test detector results confirm other orientation is superior to [100] !!
Gamma Ray Imaging Detectors

- Small test detectors
- Large diameter 90-mm detectors

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

<table>
<thead>
<tr>
<th>Before Trap Correction</th>
<th>After Trap Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal Axis</td>
<td>FWHM (keV)</td>
</tr>
<tr>
<td>[100]</td>
<td>2.72</td>
</tr>
</tbody>
</table>

1. Small test detectors
2. Large diameter 90-mm detectors other axes are better than [100]
Gamma Ray Imaging Detectors
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 $\rightarrow$ 140-mm diameter $\rightarrow$ 200 mm diameter

Thank you NP