



MIRION
TECHNOLOGIES



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Radiation Safety. **Amplified.**

HPGe detector development @ MIRION

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SENIOR RESEARCH SCIENTIST

Outline

New detector technology @ MIRION

- **Overview of MIRION Technologies**
- **Key expertise and technologies (MIRION SyD)**
- **Recent HPGe detector developments**



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A CLEAR & DEFINING PURPOSE



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As a global leader in radiation measurement, we are driven to protect people, property and the environment from the harmful effects of ionizing radiation.

OUR MISSION





Mirion Technologies (Canberra) : Organization Structure

Six divisions to better serve customer needs and react to market demand

Characterization (ChD)



Specialized camera systems for hazardous environments as well as NDA systems and M&E for decommissioning and waste management



Health Physics (HPD)



Fixed and mobile systems focus on protecting individuals from hazardous radiation exposure



Radiation Monitoring Systems (RMSD)



Fixed and mobile systems monitor radiation levels and fission by-products throughout the nuclear plant life cycle



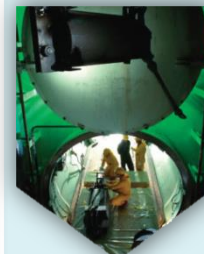
Spectroscopy (SyD)



Radiation measurement solutions for laboratory, in vivo, and in-situ applications.



Sensing Systems (SSD)



Conduit systems used to pass cables through reactor containment structure
Detector systems for plant safety and control



Dosimetry Services (DSD)



Service providing official dose of record reports for workers exposed to radiation





SyD

Spectroscopy Division (**SyD**)

MISSION

To create exceptional experiences for our customers at every touchpoint, leading customers to only think of us for every spectroscopy solution.

Product Lines

- Gamma Spectroscopy
- Customized Research Detectors
- Alpha Spectroscopy
- Alpha/Beta Counting
- Environmental Monitoring

Key Customers

- Nuclear Power and Nuclear Fuel Cycle
- Commercial and State Laboratories
- Federal Governments - Department of Energy, Defense
- Educational and Research Institutions
- Decommissioning and Dismantling through the Characterization division (ChD)
- Nuclear Security/Safeguards
- Industrial, OEM, and Medical





Mirion Locations



◆ Headquarters: San Ramon, CA

◆ SyD fabrication sites:

- ▶ Meriden, CT
- ▶ Oak Ridge, TN
- ▶ Olen, Belgium
- ▶ Lingolsheim, France

} Full complementarity

+ 33 other sites worldwide (sales, fabrication)



Key expertise and technologies

Related to Germanium detectors at MIRION (CANBERRA)





Key expertise and technologies

- ◆ **Product Development and Project Management**
 - ▶ Long background in both developing advanced technologies (specialty detectors) and large-scale products (standard detectors)
 - ▶ Stage Gate development approach based on technology readiness level (TRL) and technical risk assessment

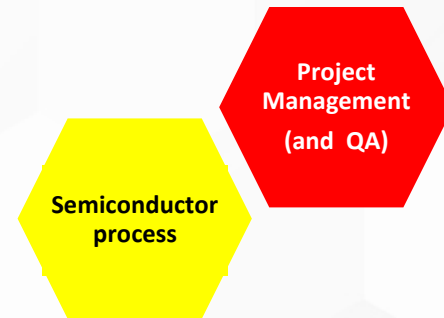


Project
Management
(and QA)



Key expertise and technologies

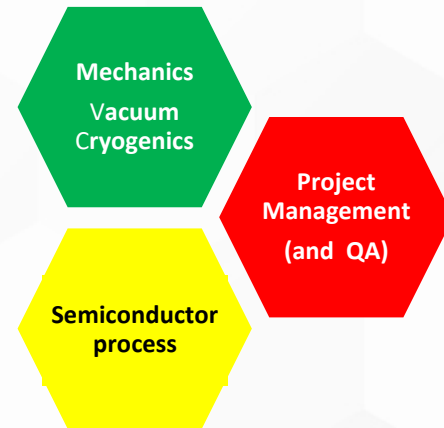
- ◆ Product Development and Project Management
- ◆ Semiconductor Process
 - ▶ Large know-how and proprietary processes (segmentation, passivation)
 - ▶ Driven by modelling
 - ▶ Full and redundant set of process equipment for Si, Si(Li) and Ge: shaping, PVD, CVD, implantation, diffusion, outgassing / annealing capabilities
 - ▶ Thin layer characterization capability (thickness, stress, reliability, charge carrier life time)
 - ▶ Management of clean / radiopure environments
 - ▶ Crystal growing capabilities





Key expertise and technologies

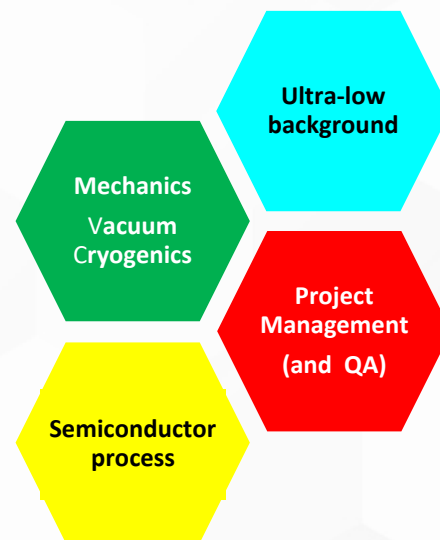
- ◆ Product Development and Project Management
- ◆ Semiconductor Process
- ◆ Mechanics, vacuum and cryogenics
 - ▶ Development of low-vibration and long-life cryocoolers for HPGe
 - ▶ Improved thermal balance (necessary for electrical cooling)
 - ▶ Proprietary technologies to hold and encapsulated HPGe detectors
 - ▶ Long experience with UHV process





Key expertise and technologies

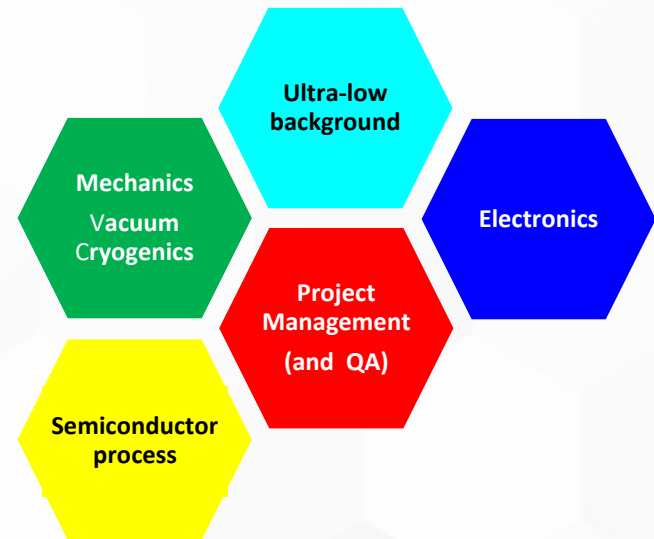
- Product Development and Project Management
- Semiconductor Process
- Mechanics, vacuum and cryogenics
- Ultra-low background
 - Systematic characterization, traceability and underground storage of radiopure materials
 - Collaboration with international low-background laboratories and experiments (double β decay, Dark Matter, neutrino scattering)





Key expertise and technologies

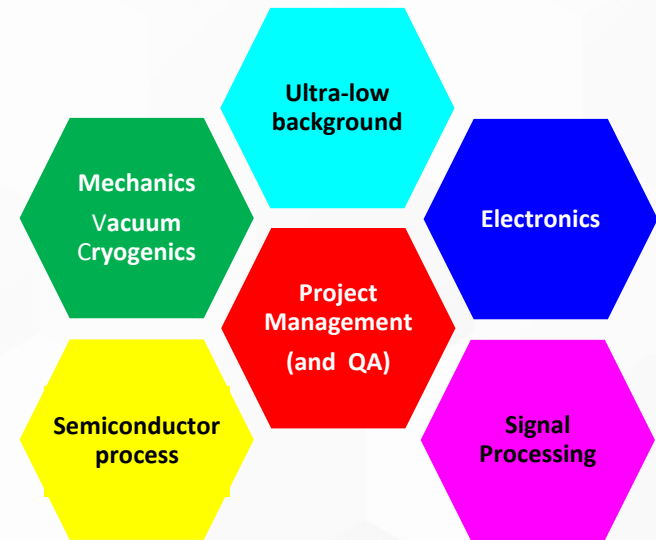
- ◆ Product Development and Project Management
- ◆ Semiconductor Process
- ◆ Mechanics, vacuum and cryogenics
- ◆ Ultra-low background
- ◆ Electronics
 - ▶ Strong expertise in analog electronics
 - ▶ Continuous challenge for low-noise, high count rate, low power, multi-channel and more integrated electronics





Key expertise and technologies

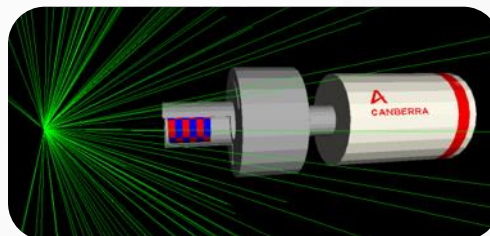
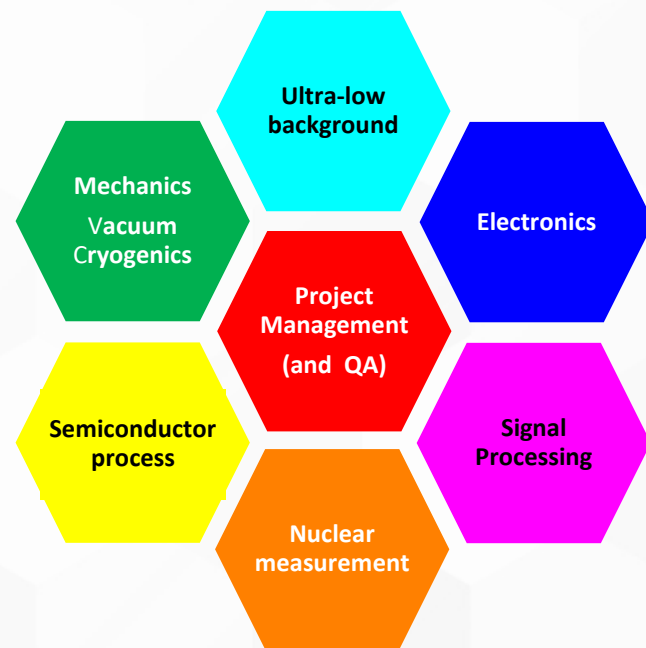
- ◆ Project Management
- ◆ Semiconductor Process
- ◆ Mechanics, vacuum and cryogenics
- ◆ Ultra-low background
- ◆ Electronics
- ◆ **Signal Processing**
 - ▶ Pulse shape analysis techniques transferred from physics to industrial applications
 - ▶ Growing know-how with digital acquisition to characterize multichannel detectors





Key expertise and technologies

- ◆ Project Management
- ◆ Semiconductor Process
- ◆ Mechanics, vacuum and cryogenics
- ◆ Ultra-low background
- ◆ Electronics
- ◆ Signal Processing
- ◆ Nuclear Measurement (spectroscopy)
 - ▶ Alpha, beta, gamma and x-ray spectroscopy is recognized as core competency of MIRION SyD
 - ▶ Unique experience with low background, low noise and multichannel spectroscopy
 - ▶ In-depth modelling of detectors during design and characterization phases





New technologies & Products

MIRION SyD solutions for scientific applications



MIRION (CANBERRA) detector overview

● MIRION (CANBERRA) detector catalog:

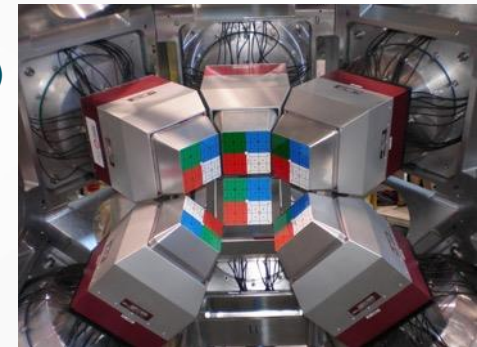
<https://www.mirion.com/products/germanium-detectors>

Type of Radiation			Detector Type
Charged Particle	γ-Ray	X-Ray	
X	X	X	NaI(Tl) Scintillation Detectors - Standard sizes to 3 x 3 in. (7.6 x 7.6 cm). Consult factory for sizes not represented, including annuli for Ge Compton Suppression Systems.
X			PIPS® Charged Particle Detectors - Complete line of rugged detectors for alpha and/or beta charged particle analysis.
	X	X	Ultra-Low Energy Ge Detectors - Spectroscopy from 0.3 to 300 keV.
	X	X	Low Energy Ge Detectors - Low Energy Photon Spectrometers for the energy range of 3 to 500 keV.
	X	X	Broad Energy Ge Detectors - High efficiency and resolution from 3 keV to 3 MeV.
	X		Coaxial Ge Detectors - General γ-ray Spectroscopy from 40 keV to 10 MeV.
	X	X	XtRa Detectors - γ-ray Spectroscopy from 3 keV to 10 MeV.
	X	X	Reverse-Electrode Ge Detectors - Radiation Damage Resistant - Spectroscopy from 3 keV to 10 MeV.
X	X	X	Germanium and Silicon Detectors - For Research and Custom Applications.
	X		Ge Well Detectors - Near 4π counting efficiency for small samples.
		X	Si(Li) Detectors - For X-ray Spectroscopy - 30 keV and below.
		X	Array Detectors - For EXAFS and synchrotron related applications.
		X	X-PIPS™ Detectors - Peltier cooled, Silicon x-ray detectors - spectroscopy from 1 to 30 keV.



Clover detectors (nuclear physics)

- ◆ Configuration: 4 HPGe crystals closely packed in the same vacuum
 - ▶ Segmented or not
 - ▶ LN2 or electrical cooling
- ◆ Heritage:
 - ▶ About 30 years of manufacturing
 - ▶ Large worldwide installed base
- ◆ Ongoing development efforts
 - ▶ Continuous product sustaining to address component obsolescence, RoHS, and improve overall performance
 - ▶ Supply of more complete solutions (fully integrated and qualified system)
 - ▶ Implementation of new technologies such as UHV and streamline configuration (gamma box)

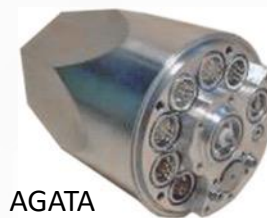




Segmented coaxial detectors (nuclear physics)

Segmented / encapsulated coaxial detectors

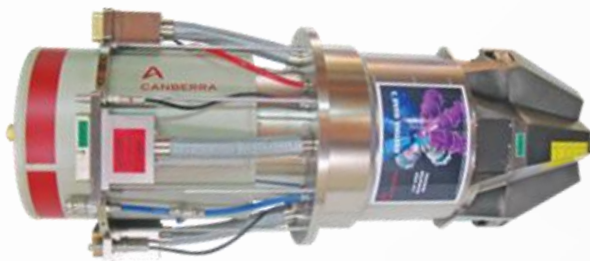
- ◆ Configuration: large N-type coaxial + segmented + encapsulated
- ◆ Main experiments: GRETA (USA) and AGATA (Europe)
- ◆ 20-year heritage, and large installed base
- ◆ Ongoing development efforts:
 - ▶ New encapsulation technique (collaboration with IKP, University of Cologne)
 - ▶ Continuous improvement of performance and long-term reliability



AGATA
encapsulated HPGe



Mars Odyssey
encapsulated HPGe



GRETA Quad module



5 Quads in array



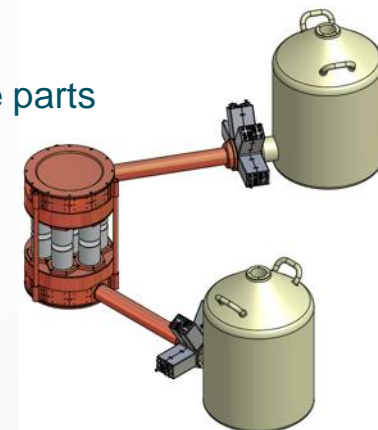
INTEGRAL/SPI - array of
19 encapsulated HPGe



Ultra-low background detectors

Ultra Low Background HPGe detectors for underground labs

- Configuration: coaxial, well or SAGe Well with the best radio-purity for all the parts involved (Ge, Cu, Al, electronics)
- Applications:
 - ▶ Material screening for large experiments in Underground Labs
 - ▶ Low level spectroscopy (sediments, dating)



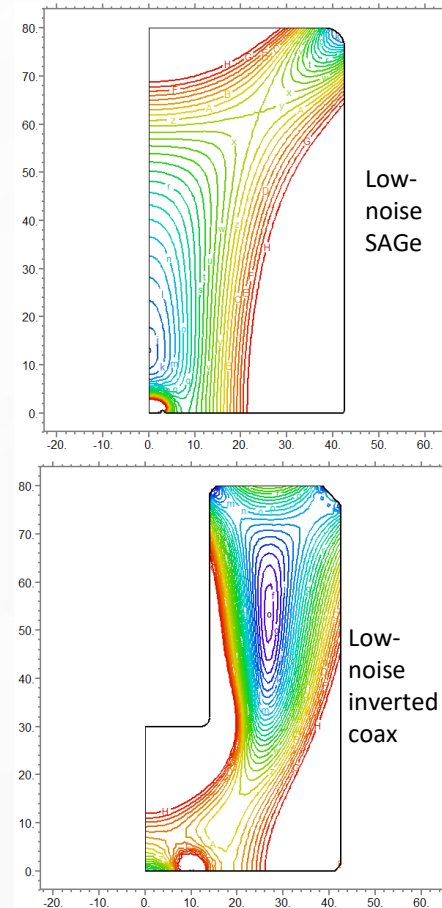
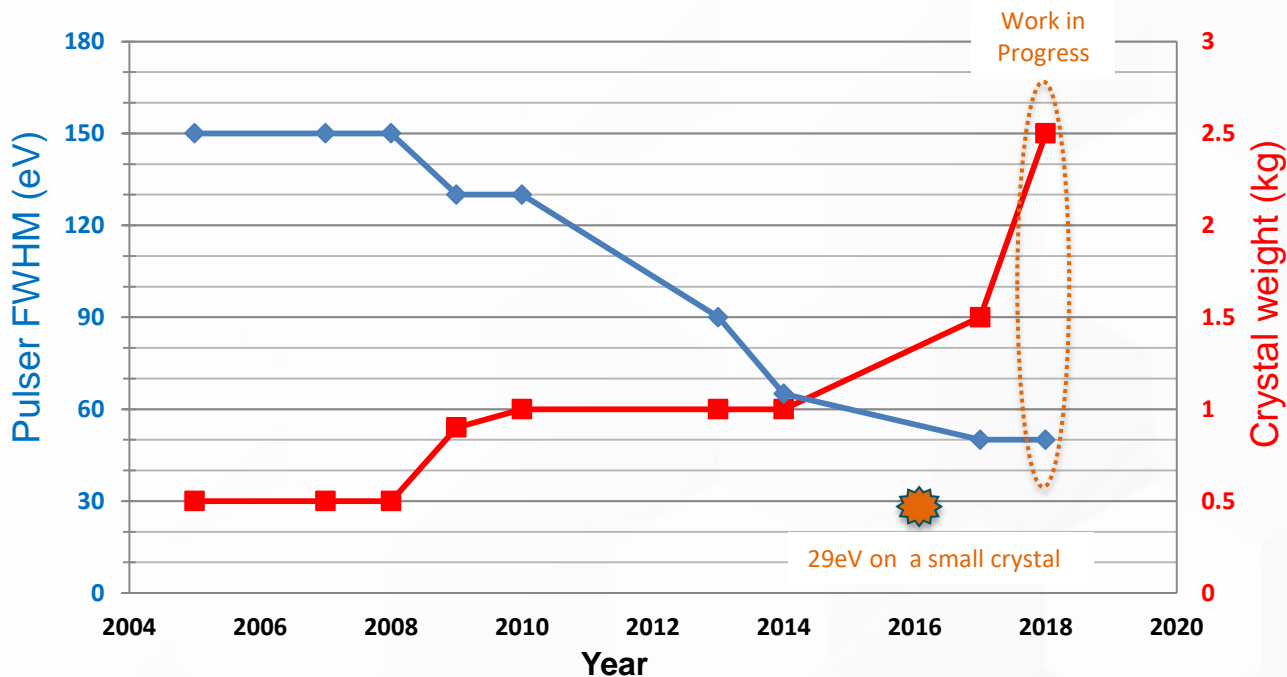
New Point Contact (SAGe) technology Neutrino Physics & Dark Matter search

- Combine best spectroscopy performance: lowest noise, highest efficiency, lowest background
- Application: neutrino physics, MAJORANA, GERDA, CDEX, TEXONO, EDELWEISS, CDMS
- Example of a 1.5 kg electrically cooled HPGe detector



Low-noise low-background PC detectors

- ◆ **Main applications: Dark Matter and neutrino scattering experiments**
- ◆ **Continuous improvement of PCGe Detectors**
 - ▶ Crystal size increased from 0.5 kg to 1.5 kg
 - ▶ Record 29eV FWHM obtained (noise edge <100eV)
 - ▶ 2.5 kg with 50eV FWHM or better in progress
 - ▶ 3 kg with 40eV possible in the near future





Inverted point contact coaxial detectors

◆ Inverted Coaxial detector

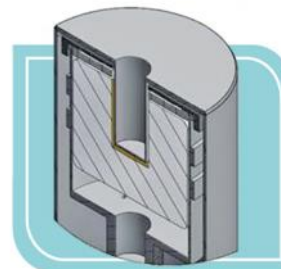
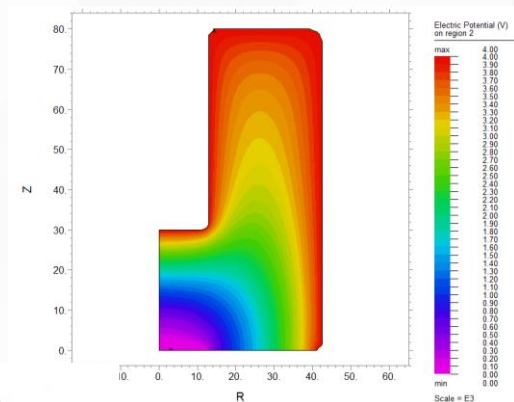
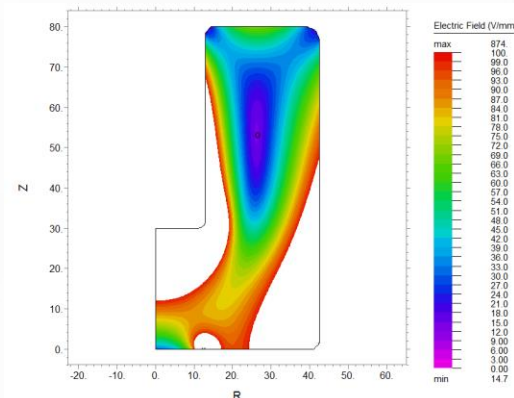
- ▶ Ref. publication: R.J. Cooper et al., NIM A 665 (2012) 25

◆ Application 1: large volume alternative to PPCs (BEGe)

- ▶ P-type HPGe crystals beyond to 3 kg
- ▶ Development for MAJORANA and GERDA experiments

◆ Application 2: well detector (MIRION SAGe™ Well)

- ▶ P-type HPGe crystals of different sizes with thin contacts
- ▶ **Combination of:**
 - Excellent energy resolution at low and high energies (similar to Point Contact / BeGe configurations)
 - Maximum efficiency (similar to well detectors)
- ▶ Collaboration with University of Liverpool on detector characterization





Inverted point contact coaxial detectors

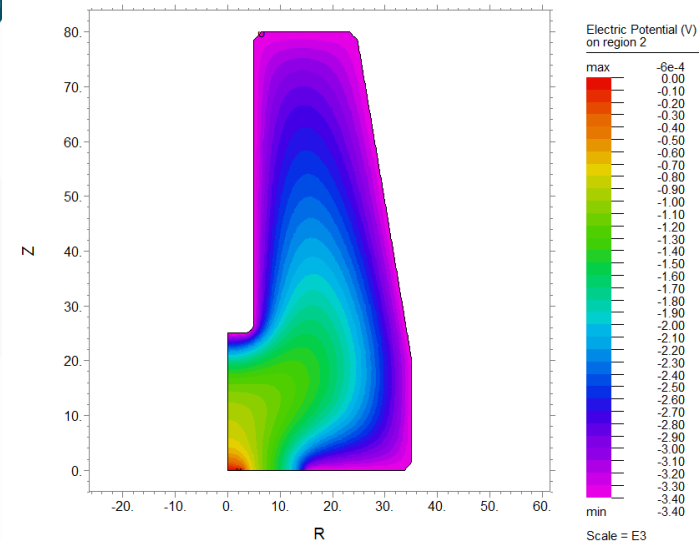
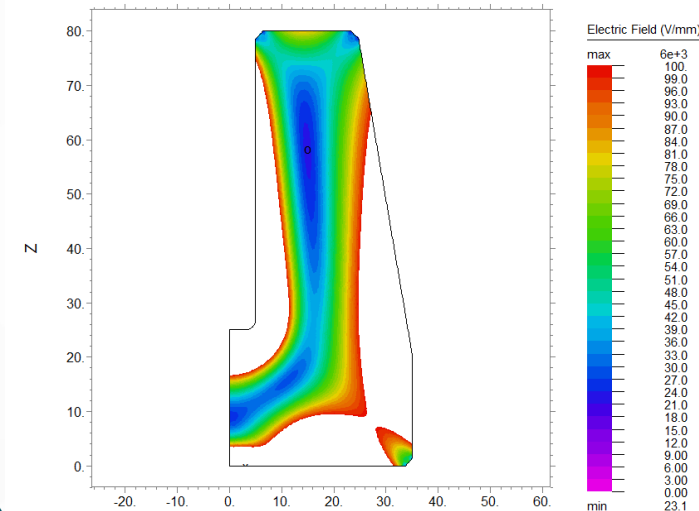
Application 3: position sensitive detector

▶ 1st segmented prototype (2012)

- For ORNL (currently tested in Berkeley)
- N-type crystal

▶ 2nd segmented prototype (ongoing development)

- For University of Liverpool
- P-type crystal





Ultimate x-ray Spectroscopy

Several single and multichannel detectors developed (2016-2018)

▶ HPGe vs Silicon SDD:

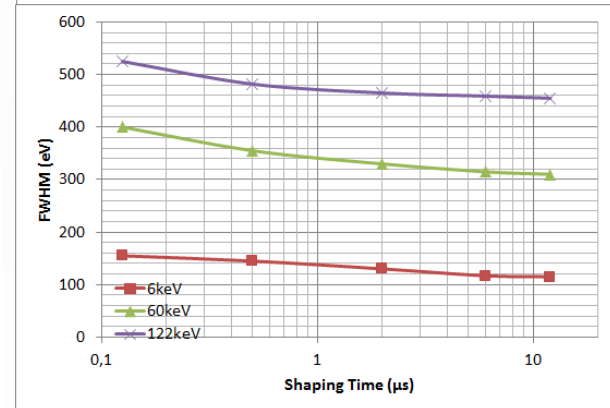
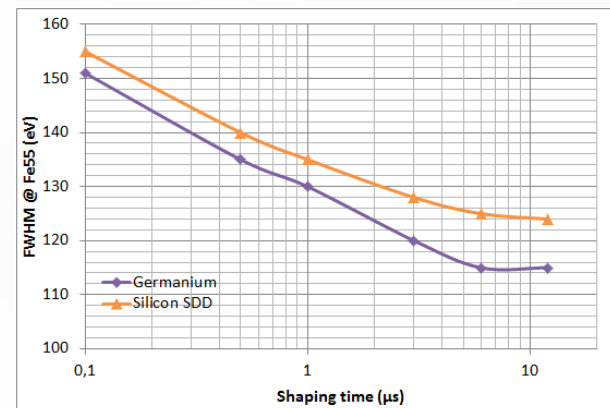
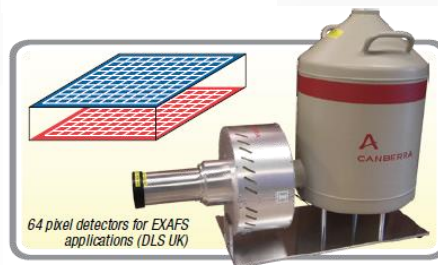
- Superior at low energies
- Higher stopping power above ~30keV

▶ State-of-the-art HPGe Detectors:

- FWHM close to theoretical limit (115eV @ 6keV)
- 150eV @ 6keV above 1Mcps

▶ Achieved performance:

Parameter	Value
FWHM @ 6 keV 0.1μs	150 eV
FWHM @ 6 keV 6μs	115 eV
FWHM @ 14 keV 0.1μs	200 eV
FWHM @ 60 keV 12μs	330 eV
FWHM @ 122 keV 12μs	450 eV
Max. ICR	2-3Mcps

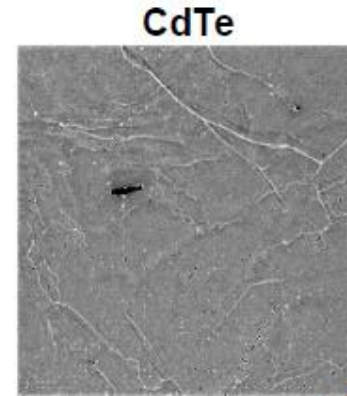
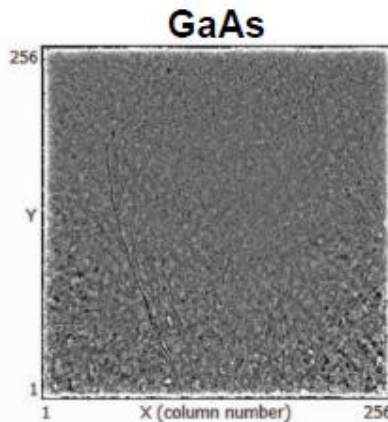
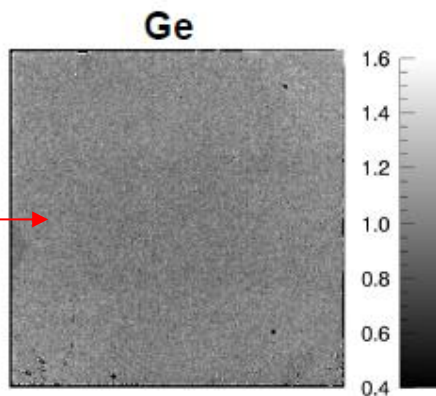
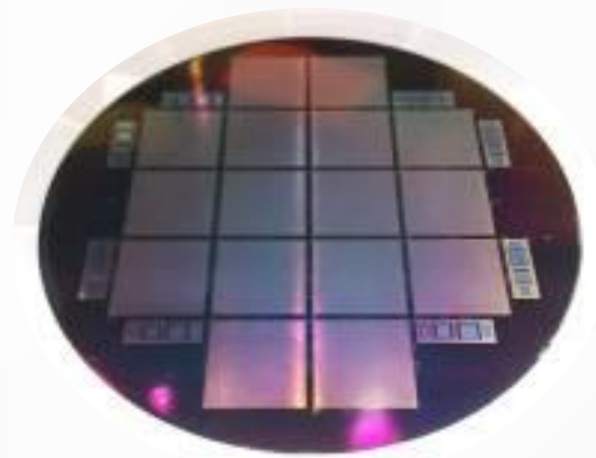




X-ray imagers (highly pixelated sensors)

Developments of HPGe wafers with micrometric pixels

- ◆ Wafers are coupled to user ASICS (e.g. Medipix 3)
- ◆ Application: imaging or very high count rates
- ◆ Down to 55 μ m; arrays of chips possible
- ◆ Advantage of Germanium
 - ▶ High efficiency and stopping power
 - ▶ High quality & large diameter wafers available



D Pennicard | LAMBDA, High-Z sensors and the HORUS simulation tool | Three-way meeting, APS, August 2013 | Page 28





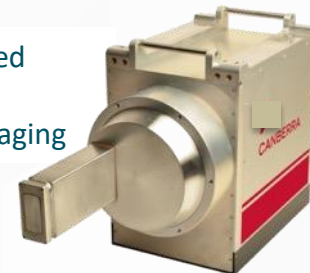
Gamma-ray spectro-imagers (Compton cameras)

Mid-term industrial development:
3rd generation radiation imagers combining

- ▶ High detection efficiency
- ▶ High-resolution spectroscopy



Electrically-cooled
DSSD and pixel
detectors for imaging



Example of industrial application: waste drum imaging in Fukushima



Courtesy of Dr. Motomura (Riken Kobe)



Setup of the imaging experiment

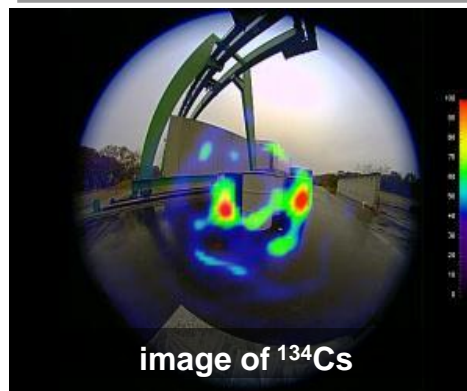
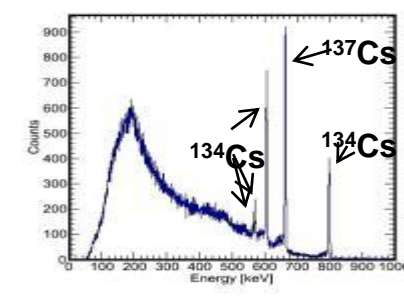


image of ¹³⁴Cs

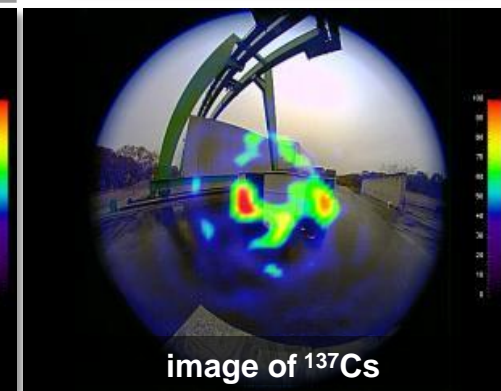


image of ¹³⁷Cs



Electrical cooling solution at MIRION

Cryocooler technology choices at Mirion:

- ▶ Pulse-tube if possible (e.g. CP5, Falcon products)
- ▶ Other technologies also used (e.g. linear stirling coolers) but requiring tradeoffs on reliability / maintenance costs

Best illustration : CP5-plus

◆ Features

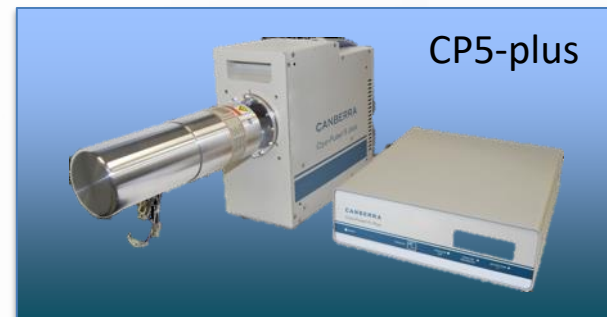
- ▶ Completely LN2 free
- ▶ 5-year full warranty on coldhead
- ▶ Non-CFC/non-flammable refrigerant
- ▶ **Reliability MTTF > 3,000,000 hours**
- ▶ **11 years life time (>99% probability)**
- ▶ No maintenance required
- ▶ Low power demand
- ▶ **Low vibration / low noise**
- ▶ Compact and lightweight
- ▶ No compromise on detector specifications
- ▶ Remote read-out
- ▶ Optional water-cooling for use up to +50 °C

◆ User benefits

- ▶ Safety
- ▶ Low operating cost (no maintenance)
- ▶ High availability
- ▶ Expanded field of applications
- ▶ Quiet: < 55 dB(A) at 1 m

◆ For detailed information on CP5 plus:

- ▶ <https://www.mirion.com/products/cryo-pulse-5-plus-electrically-refrigerated-cryostat>
- ▶ https://www.mirion.com/search?q=CP5-plus_C48083.pdf

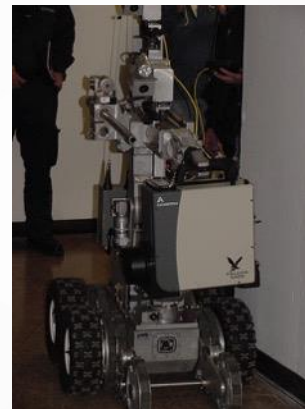




Other electrically cooled solutions for specific environments

Products: electrically cooled / rugged detectors

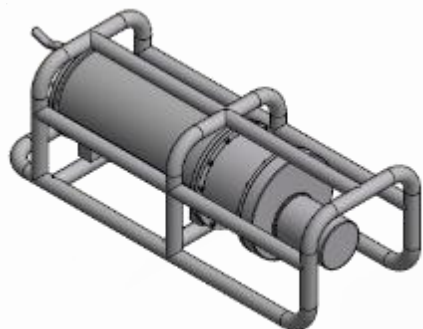
- ▶ Falcon and special ISOCS setups
- ▶ Sealed Probe
- ▶ X-ray scanner
- ▶ Trucks/airborne arrays
- ▶ Immersible detectors
- ▶ Imaging / Spectro-imaging



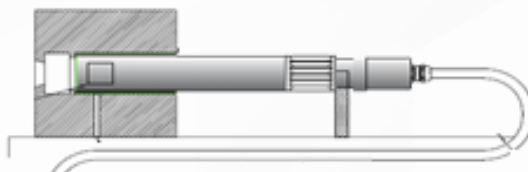
Falcon 5000 (robotics)



Airborne HPGe array



Submersible HPGe
(water monitoring)



Sealed Ge Probe (harsh / confined environment)



CL5 - inline versatile electrically cooled
cryostat for scientific / rugged detectors



Planar DSSD HPGe detector electrically
cooled for gamma-ray imaging



Conclusion

Mirion detector solutions are in use for Scientific exploration in the most remote locations on Earth, underground, and in deep space...



Technology achievements recently brought to HPGe detectors:

- ◆ **Energy resolution:** noise improvement at low energy (from 100 eV down to a few tens eV)
- ◆ **Detection efficiency:** enlarged range of HPGe spectrometer sizes (a few g to several kg)
- ◆ **Count rate:** for x-ray spectroscopy, detectors, electronics and signal processing suited for more than 1Mcps without resolution degradation
- ◆ **Position sensitivity:** increased segmentation (pixel size of a few tens μm) and introduction of PSA on industrial products
- ◆ **Operation:** increased need for electrically cooled detectors, even for scientific applications



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Thank You!

THE MIRION TECHNOLOGIES TEAM LOOKS FORWARD TO
WORKING WITH YOU.

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