Courtesy of the GRETA collaboration (taken by S. Noji)

Encapsulated Detectors

Encapsulated Germanium Detectors for Gamma Measurements

Encapsulation drastically enhances the germanium detector reliability and leverage compact and high efficiency array detector configurations for various applications.

FEATURES

- For compact construction of multi-element detectors for gamma-ray applications
- Makes very large efficiency with unmatched solid angle coverage possible for gamma-ray spectroscopy
- Easy radiation damages (neutron/proton) annealing in Nuclear Physics experiments
- In situ annealing in space applications
- Large choice of shapes (pentagonal, hexagonal) for compact matrix assemblies
- Essential for complex cryostat development, particularly with segmented detectors
- Total reliability thanks to Ultra-High Vacuum Technology
- Easy detector handling and exchange operation
- Comfortable access to the cold front end electronics without any risk for the HPGe detector

DESCRIPTION

Mounting and operation of several HPGe detectors in a common vacuum with minimum spacing between consecutive elements makes a real challenge. Encapsulation techniques have been developed to minimize such problems. Placing each encapsulated detector into its own vacuum in an individual aluminum canister makes it possible to separate the vacuum of each detector from the cryogenic vacuum shared by all detectors. Encapsulation drastically enhances the germanium detector reliability. This technology is key for many applications, particularly in space, and especially if associated with ultra-high vacuum. It was demonstrated that encapsulation allows to address ruggedized applications as for space exploration.

In Nuclear Physics experiments encapsulated germanium detectors can now be easily handled by the users. They may be stored, exchanged or rearranged and be adapted to various applications with different types of cryostats. On a multi-detector array system, it will now be possible to anneal only those detectors affected by radiation damages.

This encapsulation technology gives easy access to the front-end electronics (FETs). A FET replacement or a specific preamplifier sensitivity or fine tuning for high count rate ability is now possible without any risk for the HPGe crystal kept safely in its own vacuum sealed canister.

On request Mirion can provide the needed training for users who need to acquire skills to safely handle these encapsulated detectors.

APPLICATIONS

Such a detector is easy to use, reliable and robust. So, it may be used in a large range of scientific and industrial applications such as:

- Array of detectors for gamma spectroscopy (ex: MINIBALL, AGATA, GRETA nuclear physic experiments)
- Research laboratory – Nuclear medicine
- Environmental measurements
- Industrial quality control
- Homeland Security
- Space experiments, thanks to its in situ regeneration capabilities after radiation damages (ex.: INTEGRAL, MARS ODYSSEY, SELENE,...)
- Assistance to Engineers (ex: design of complex cryostats and/or multi-elements detector electronic)

DESCRIPTION

A capsule may be **regenerated** many times and can be thermally annealed in an ordinary oven from neutron or proton radiation damages, without pumping. The lifetime of such a detector may be estimated to a minimum of seven years without service. But in reality it is much more: The first EUROBALL capsules were delivered in 1992 and are all still in operation. Encapsulated detectors hardness enables a **wide application range**, such as part of the payload of nacelles, space launchers, etc...

Compact arrays may be designed. The capsules manufactured for EUROBALL offer a typical wall thickness of 0.7 mm with a distance between cap and crystal of only 0.7 mm. These encapsulated detectors may be in contact with one another offering a 3 mm distance between consecutive crystals and a 1.4 mm total aluminium wall thickness.

For better follow-up of scientific progress, some segmented crystals have been encapsulated to offer high **granularity**, in addition to the previous advantages.

The detector granularity qualifies the number of independent cells constituting this detector. Such detectors allow a significant reduction or gamma-ray broadening due to the Doppler effect.

Moreover, the use of internal and external contacts of the crystal provides information on the interacting **position**:

- Vertically and transversally, by analyzing signals induced by mirror charges.
- Radially by making a pulse shape analysis.

Accurate localization of the interaction points allows not only reduction of the Doppler effect broadening, but also gamma-ray tracking.

In addition to these benefits, the segmented detector encapsulation allows the design of complex cryostats, thus signal optimization which is of much interest for pulse shape analysis.

The feasibility of the germanium detector encapsulation was studied in the frame of a collaboration between Mirion, the Jülich research center and the University of Cologne in Germany.

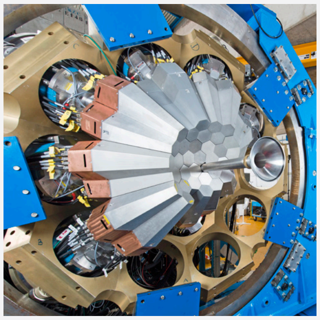
NUCLEAR PHYSICS APPLICATIONS

EUROBALL:

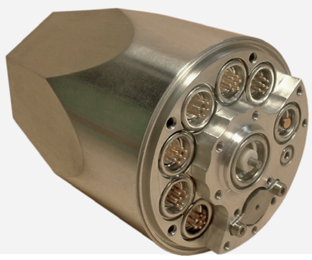
- A EUROBALL capsule and CLUSTER array for EUROBALL (seven encapsulated HPGe detectors)
- Hexagonal tapering – 70 mm (diameter); 78 mm (height)
- FWHM resolution: <2.3 keV
- Relative efficiency: >55%
- Aluminum wall thickness: 0.7 mm
- Cap-to-Ge distance: 0.7 mm
- Add-back efficiency: about 600% for a complete cluster consisting of seven EGC HEX type encapsulated detectors
- More than 150 units delivered

AGATA:

- AGATA detector and the AGATA array at GANIL in 2017 consisting of the first 10 "triplet" detectors.
- AGATA detector description:
  - Hexagonal irregular tapering (three different shapes)
  - Initial Ge crystal dimension: diameter 80 mm and height 90 mm
  - Outer p+ contact segmented in 36
  - FWHM resolution: < 2.35 keV
  - Relative efficiency: > 80%
  - Al wall thickness: 0.7 mm
  - Cap-to-Ge distance: 0.7 mm
- Total encapsulated detectors of the AGATA project: 180 capsules



By courtesy of AGATA collaboration. NOTE of the AMB: AGATA design was created by STFC Daresbury UK.

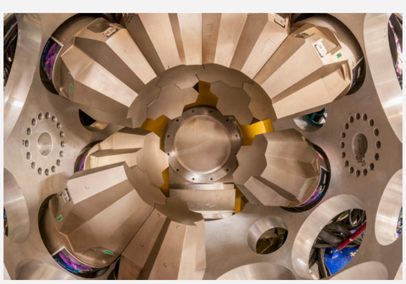


GRETA:

- GRETA ''Quad'' detector and the GRETA array consisting of 10 "Quad" detectors at NSCL in 2017.

Photo of a GRETA ''Quad'' detector

- A GRETA "Quad" detector is consisting of four encapsulated detectors in a common cryostat with 148 preamplifiers.
- GRETA encapsulated detector description:
  - Hexagonal irregular tapering (two different shapes)
  - Initial Ge crystal dimension: diameter 80mm and height 90 mm
  - Outer p+ contact segmented in 36
  - FWHM resolution: < 2.35 keV
  - Relative efficiency: > 80%
- The GRETA array will consist of 30 "Quad" detectors which represents a total of 120 capsules.



Courtesy of the GRETA collaboration (taken by S. Noji)

COMPEX:

The COMPEX ''Quad'' detector and four COMPEX detector used at GSI in Germany.

The off-centered cryostat design makes it possible to bring the ''Quad'' detector detection heads very closely together to enable an efficient detection plane of 23 cm x 23 cm for the observation and characterization of new superheavy elements.

Prof Rudolf's team is characterizing at GSI on Tasca Recoil Separator the superheavy element with 114 protons (Z = 114) Flerovium. According to nuclear structure models, this would be a magic number, so this nucleus would be more stable than its neighbors with 113 or 115 protons.

- Typical performance of each individually encapsulated HPGe crystal:
  - FWHM at ^{60}Co: 1.90 keV
  - FWHM at ^{57}Co: 800 eV
  - Relative efficiency: 28%
  - Total HPGe material weight per clover: 2.6 kg

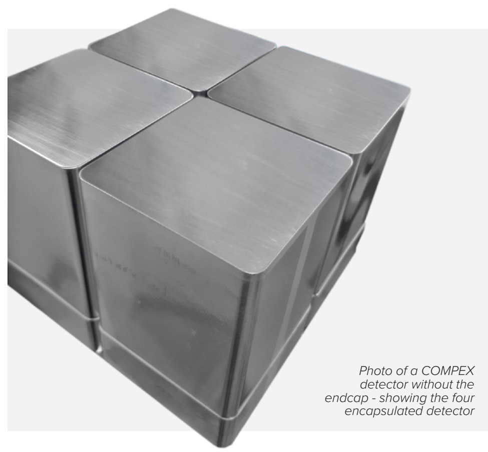


Photo of a COMPEX detector without the endcap - showing the four encapsulated detector

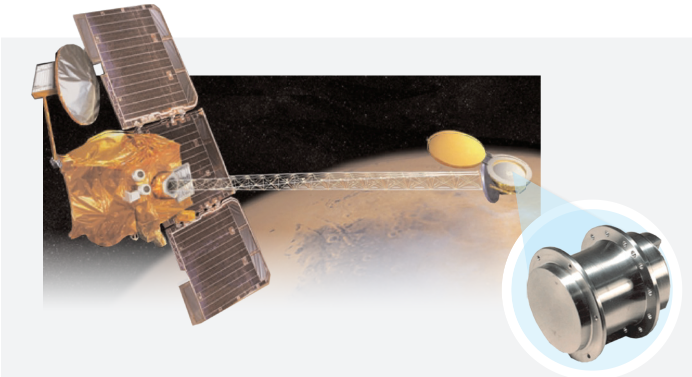
Photo of four COMPEX Quad detectors at GSI in 2019. Courtesy of Prof Dirk Rudolph (Photo taken by Anton Samark-Roth) Lund University.

SPACE APPLICATIONS

THE MARS ODYSSEY MISSION

(ref.: Intespace - Toulouse, NASA, Univ Arizona)

This mission consisted of putting a satellite into orbit to detect the presence of water (ice) on the Mars planet by using (n,γ) reactions.

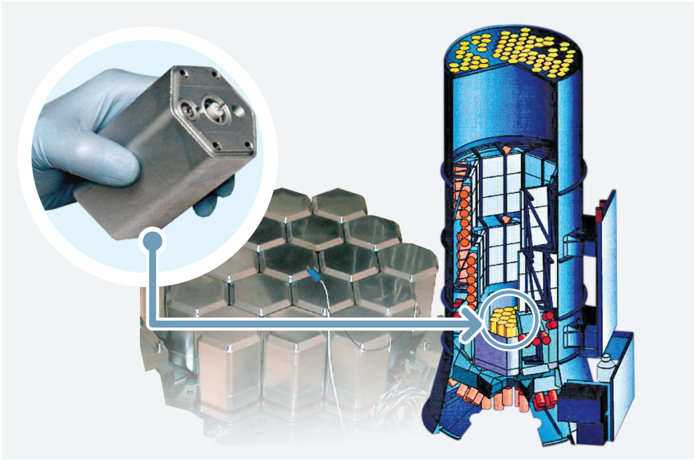


DETECTOR TYPE:

- Coaxial HPGe, N Type, titanium encapsulated, relative efficiency 50%
- Encapsulation offers sealed ultra-high vacuum conditions, therefore longer life and possibility to anneal the detector from radiation damage without pumping or opening to the space environment.
- The technology developed offers lightweight sensors, a very important criterion for space devices. The use of titanium is another important feature: aluminum would conflict with gamma rays of interest.

SPI INTEGRAL SPECTROMETER:

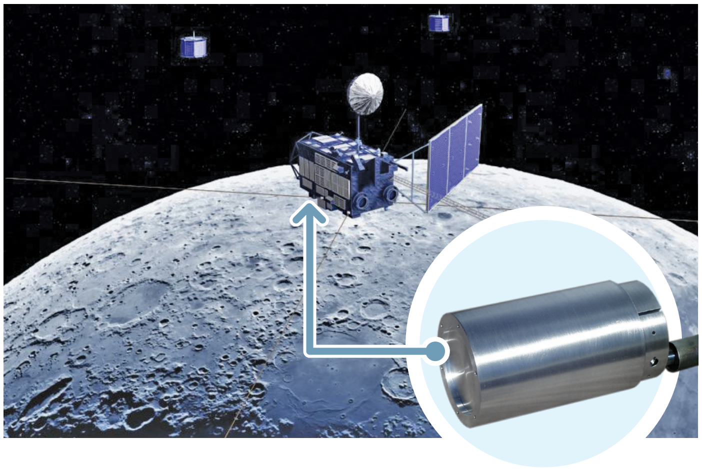
(ref.: Intespace - Toulouse)



- Launched in October 2002
- An array of 19 encapsulated Ge detectors
- All still in operation
- Relative efficiency 40% each
- Crystal to crystal gap: 3.5 mm

DETECTOR TYPE:

- Encapsulated coaxial HPGe detector for the GRS.
- Detector size: 60% efficiency.



THE SELENE MISSION (ref.: JAXA - ISAS - NASDA)

- Lunar orbiter mission “KAGUYA”
- Mission duration: one year
- The GRS had an excellent energy resolution 20 times superior to those used in past lunar missions

DETECTOR TYPE:

- Encapsulated coaxial HPGe detector for the GRS.
- Detector size: 60% Relative efficiency.

ISO 9001 SYSTEM CERTIFIED MERIDEN CT ATLANTA GA OAK RIDGE TN CONCORD ON

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