ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Milano

INFN-2025-09-MI
18-12-2025

Sealing Strategies for HPGe Detectors Operating in Cryogenic Vacuum Environments: Design, Testing and Performance

G. Secci[1,2], A. Capsoni[1], L. Manara[1], D. Viganò[1], S. Capra[1,2], W. Raniero[3] and S. Coelli[1]

1 - INFN sezione di Milano

2 - Università degli Studi di Milano

3 - INFN Laboratori Nazionali di Legnaro

Abstract

Segmented high-purity germanium detectors play a key-role in advanced gamma spectroscopy. However, their technical and manufacturing details are proprietary and not publicly disclosed by industry. To address this gap, INFN launched the N3G Project, aimed at designing new segmented high-purity germanium detectors and developing the technical know-how to independently operate and maintain them. Within this framework, this technical note describes the procedure and instrumentation used to vacuum-seal the capsule containing the HPGe detector, ensuring operation in a controlled environment.

Key-words: HPGe Detectors, High-Vacuum Systems, Porous Getters, Leak Tests

Pubblicato da Laboratori Nazionali di Frascati

Technical Note INFN-2025-09-MI

Sealing Strategies for HPGe Detectors Operating in Cryogenic Vacuum Environments: Design, Testing and Performance

G. Secci[1,2], A. Capsoni[1], L. Manara[1], D. Viganò[1], S. Capra[1,2], W. Raniero[3] and S. Coelli[1]

1 - INFN sezione di Milano
2 - Università degli Studi di Milano
3 - INFN Laboratori Nazionali di Legnaro

Abstract
Segmented high-purity germanium detectors play a key-role in advanced gamma spectroscopy. However, their technical and manufacturing details are proprietary and not publicly disclosed by industry. To address this gap, INFN launched the N3G Project, aimed at designing new segmented high-purity germanium detectors and developing the technical know-how to independently operate and maintain them. Within this framework, this technical note describes the procedure and instrumentation used to vacuum-seal the capsule containing the HPGe detector, ensuring operation in a controlled environment.

Key-words: HPGe Detectors, High-Vacuum Systems, Porous Getters, Leak Tests

Introduction

To protect and insulate High-Purity Germanium (HPGe) detectors from contaminants and humidity, they must be enclosed in vacuum-tight capsules. These enclosures ensure vacuum integrity and simultaneously act as infrared shields. The capsule designed in the framework of the **N3G (Next Generation Germanium Gamma detectors**) project consists of a cylindrical aluminium case, hereafter referred to as the canister**,** closed by a stainless steel flange. The flange integrates the electrical feed-through connectors, used to transmit the signals from the detector to the front-end electronics, and a vacuum inlet port, for evacuation and maintenance of the internal vacuum (Fig.1).

To enhance the vacuum stability, a porous getter that can be activated when needed is included within the capsule. Although stainless steel is not transparent to gamma radiation, it is an appropriate material for the flange, as it is located on the side opposite the detector's radiation entrance window and does not interfere with the incoming radiation or detector performance.

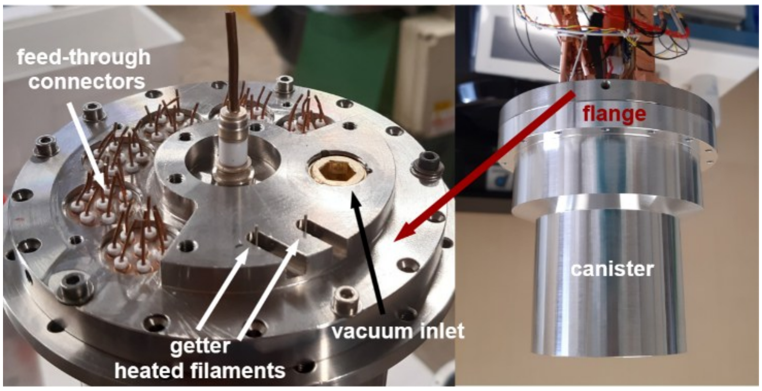

Figure 1: View of the N3G capsule, consisting of an aluminium case (canister) closed by a stainless steel flange. Details of the flange are shown on the left.

The flange is sealed by means of a HelicoFlex® gasket seated in a properly dimensioned groove (outer diameter 98.10 mm, inner diameter 89.10 mm, depth 3.20 mm). The sealing fastening is achieved by means of 16 steel screws, size M3. The evacuation port of the capsule is closed by a dedicated threaded plug that compresses against a smaller HelicoFlex® gasket housed in a groove with a diameter of 13.0 mm.

HelicoFlex Gaskets

The HELICOFLEX® seal is a high-performance metal sealing solution designed for use in demanding environments such as aerospace, vacuum systems and nuclear applications. Its effectiveness relies on a combination of a soft metallic outer layer and an internal helical spring (Fig. 2). The outer metallic lining is specifically chosen to be softer than the flange material it seals against. When the seal is compressed between two flanges, the soft metal undergoes viscoplastic deformation. This means the metal permanently deforms, flowing into the microscopic irregularities on the flange surfaces to create a tight, leak-proof seal.

Inside the seal, a helical spring provides the necessary elasticity. This spring maintains consistent pressure on the metallic lining, helping the seal adapt to any surface imperfections and compensate for small movements or changes in the system over time[1].

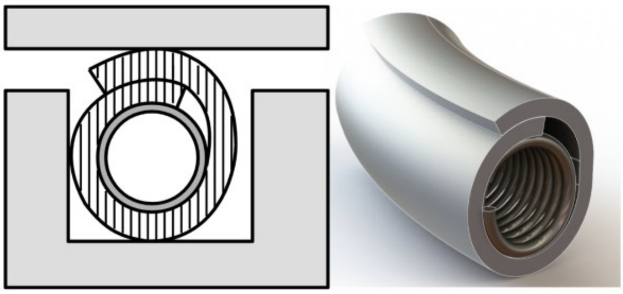

Figure 2: Section and rendering of a HelicoFlex® gasket
(adapted from Technetics Group datasheet[1])

Non-Evaporable Getters (NEGs)

Non-evaporable getters (NEGs) are solid materials, typically made from reactive metals like zirconium, titanium, or vanadium, that remove gases from vacuum systems through chemisorption rather than evaporation. Engineered with a porous structure to increase surface area, NEGs require thermal activation (450–900 °C) to expose their reactive sites. Once activated, they effectively absorb gases such as O_2, N_2, H_2, CO, and CO_2, but are ineffective against noble gases and light hydrocarbons. Since they remain solid and do not emit vapor, NEGs are ideal for maintaining ultra-high vacuum conditions in sensitive applications like particle accelerators, space instruments and semiconductor manufacturing.

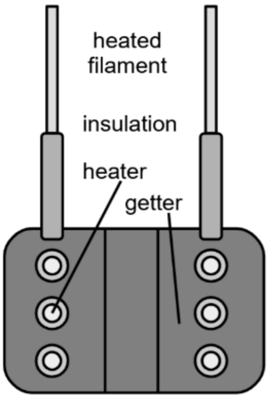

Figure 3: Typical configuration of a zirconium-based sintered porous getter.
Adapted from SAES Getters S.p.A datasheet[2]

Among the various types of non-evaporable getters available, porous getters (Fig. 3) offer particular advantages for our specific application, due to their high surface area and enhanced gas sorption efficiency. Specifically, the ST 172 porous

---

[1] Technetics Group, HelicoFlex® spring-energized metal seals, https://www.italseal.it/technetics-helicoflex.html

getter from SAES Getters S.p.A. has been used[2]. The ST 172 is a zirconium-based getter from the ST 707® family, capable of achieving a significant level of activation at temperatures as low as 450–500 °C over a short activation time (10 min). This type of getter is particularly well suited to our application: its operating temperature and activation time, together with the optimized capsule design, prevent detector heating, which is essential to avoid diffusion phenomena in Germanium.

The ST 172 non-evaporable getters are coated with a thin, compact oxide layer formed upon their first exposure to air after sintering. This passivation layer prevents gas sorption and must be removed through activation, which involves heating the getter under vacuum conditions better than 10^{-3} mbar, or in an ultra-pure noble gas atmosphere (with oxygen impurities below 1 ppm). The activation process drives the oxides into the bulk material, exposing a clean surface capable of effective gas sorption. During activation, gases—primarily hydrogen—are released from the getter, temporarily increasing the chamber pressure. Once the getter cools, it reabsorbs the hydrogen, allowing rapid pressure stabilization. Additional gas release may occur due to desorption of previously sorbed gases and outgassing from nearby heated components. Over time, as the getter absorbs gases, its pumping speed decreases. To restore performance, the getter can be reactivated by reheating it to a temperature near the original activation point, for a similar or slightly shorter duration. Getters operating at room temperature and not exposed to air can typically be reactivated multiple times, regaining near-original performance. In contrast, getters used at high temperatures may only partially recover their sorption capacity. Reactivation can be carried out in situ within sealed devices and serves as an effective method to maintain vacuum performance over the device's lifetime.

Leak Detection Using Tracer Gas and Mass Spectrometry

Performing a leak test is essential to ensure the capsule's vacuum integrity and to detect any possible leaks.

Leak detection with tracer gas is typically performed using a mass spectrometer, which offers high sensitivity and very short analysis times. The mass spectrometer is pre-calibrated to detect the specific mass of the tracer gas and is integrated into a specialized, self-contained unit. This unit operates independently of the vacuum system under test and includes its own pumping system, along with the necessary tools for connection.

The most commonly used tracer gas is helium. When using helium, sensitivity levels of 10^{-11} mbar·L/s can be achieved. With proper precautions and the use of accumulation methods, even higher sensitivities are possible. However, it is important to consider certain limitations: helium can cause memory effects in some types of pumps and may permeate through the walls of certain materials. These effects can compromise the reliability of measurements below the value given[3].

Mass spectrometer-based leak detectors are among the most widely used systems in both research laboratories and industrial vacuum applications. In theory, any gas could be used for leak detection. In practice, helium is preferred due to the following advantages:

- It is non-flammable and non-toxic
- It has a very low molecular mass, allowing it to pass quickly through even the smallest leaks
- As a noble gas, it is chemically inert and does not react with other substances
- It is present in the atmosphere in very low concentrations (around 5 ppm), minimizing background interference
- It is relatively inexpensive compared to other tracer gases

When using a helium leak detector, but the component under test is intended to be leak-tight in air, it is essential to account for the difference in diffusion rates between helium and air. It follows that:

$$Q_{air} = Q_{He}/2.7 \qquad (1)$$

where Q_{air} and Q_{He} are the leak rates of air and helium respectively, expressed in mbar·L/s.

---

[2] SAES Getters S.p.A., ST 171® and ST 172 Sintered Porous Getters. Available at: www.saesgetters.com

[3] B. Ferrario and A. Calcatelli, Introduzione alla tecnologia del vuoto. Patron, 1999.

Capsule Sealing Procedure and Leak Test

Before sealing the capsule, an accurate cleaning procedure was carried out using IPA (isopropyl alcohol). The flange, the canister, the HelicoFlex® gaskets, the o-rings and the connecting components required to interface the capsule with the leak detector were cleaned.

Then the vacuum port HelicoFlex® gasket was placed into its groove and secured with the custom designed cap. The tightening torque τ applied was derived from the specifications given in the datasheet, according to the following procedure. Knowing the appropriate load per unit length (Y=150N/mm) and the gasket mean diameter (D=10.8mm), the minimum seating load (F) was calculated:

$$F = \pi Y D = 5087\ N \qquad (2)$$

As the sealing is performed by screwing in a single cap, this is the value to be used in the tightening torque calculation:

$$\tau = \mu F d_{screw} = 0.15 \cdot 5087 \cdot 0.0132 \ = \ 10.07\ Nm \qquad (3)$$

where μ is the friction coefficient and d_{screw} is the vacuum port threaded plug stress-diameter. Thereafter, the second HelicoFlex® gasket was placed in the flange groove and secured by assembling the canister. Based on its compression load (Y = 175 N/mm) and mean diameter (D = 94.30 mm), the seating load was calculated using Eq. (2): F = 57028 N. This load was then divided over the 16 screws: F_{screw} = 3564 N. Following Eq. (3), the tightening torque $\tau = 2.13$ N·m was found. This calculation was carried out using the following parameters: $\mu = 0.15$ (steel screws on steel) d_{screw} = 4 mm (stress-diameter of an M3 screw).

After completing the tightening procedure, the capsule was mounted on the Pfeiffer ASM 310 leak detector. By blowing helium around the vacuum inlet, leak rates between $5{\cdot}10^{-10}$ mbar·L/s and $8{\cdot}10^{-10}$ mbar·L/s were measured (Fig. 4, peaks *a* and *b*). These values are consistent with the type of gasket used. When helium was subsequently introduced around the groove of the flange, the leak rate increased to $1.8{\cdot}10^{-8}$ mbar·L/s (Fig. 4, peak *c*), indicating the presence of a leak in the area surrounding the flange groove. Consequently, a higher tightening torque $\tau = 2.3$ N·m (10% increase) was applied in order to compress the HelicoFlex® gasket sufficiently to bring the flange and the canister into near contact. The helium leak test was then repeated, and a leak rate of $8{\cdot}10^{-10}$ mbar·L/s was measured. In this case as well, the result essentially corresponds to the limit achievable with the type of gasket used. To ensure lower leak rates and enhanced vacuum performance, the use of HelicoFlex® Delta gaskets is necessary, as they provide greater sealing efficiency than standard HelicoFlex® gaskets..

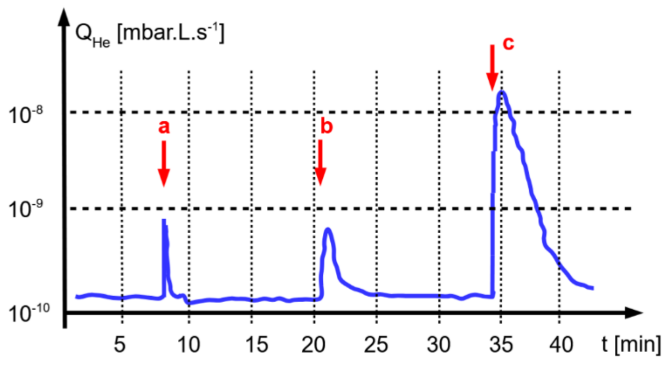

Figure 4: Leak test results: (a) and (b) refer to helium blown around the vacuum port, (c) refers to helium blown around the flange groove

Since the designed capsule has an internal volume of approximately 0.3 L, the measured leak rate can be used to estimate the time required for the internal vacuum to degrade by a given amount. For example, to determine how long it takes for the pressure inside the chamber to increase by 10^{-5} mbar, the following relation can be used:

$$\Delta t = \frac{\Delta P \cdot V}{Q_{He}/2.7} = \frac{10^{-5} mbar \cdot 0.3\ l}{8 \cdot 10^{-10} mbar \cdot l \cdot s^{-1}/2.7} \approx 3\ h \qquad (4)$$

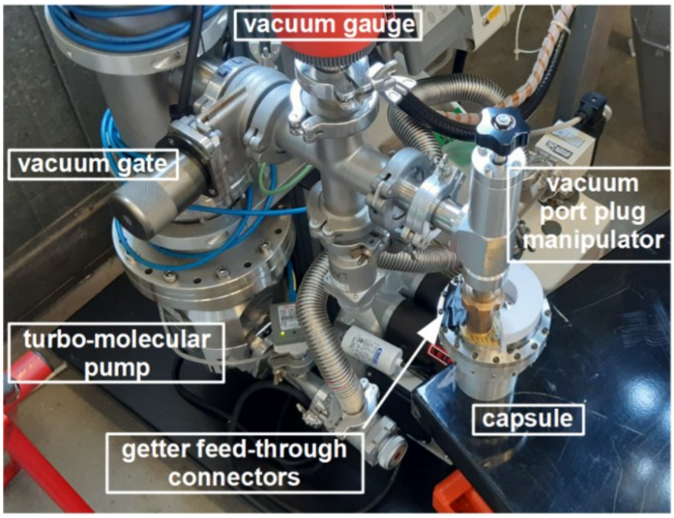

Figure 5: Experimental setup arranged to assess the capsule vacuum tightness

To mitigate this behaviour, a getter material is activated to absorb residual gases and maintain a stable and prolonged vacuum.

Getter Activation

After completing the leak tests, the capsule was detached from the leak detector and connected to a pumping system made of a dry vacuum pump (PFIFER ACP28) and a turbo-molecular pump (Edwards NEXT 400), as shown in Fig. 5. Moreover, a vacuum valve and a vacuum gauge were installed between the capsule and the pumping system. This arrangement ensures a controlled evacuation of the capsule and provides the option to isolate it when needed.

Before starting the getter activation procedure, additional leak tests of the two HelicoFlex® gaskets were carried out. To assess the integrity of the HelicoFlex® gasket seated in the flange groove, the capsule, with the canister properly screwed onto the flange, was evacuated while keeping the cap open. This operation was made possible by a dedicated manipulator (Fig. 5), which connects the flange vacuum port to the pumping system and allows its cap to be screwed and unscrewed under vacuum. On the other hand, to assess the integrity of the vacuum port HelicoFlex®, the cap was closed and the system was evacuated up to the flange, with the canister left open. In both configurations, starting from atmospheric pressure, a vacuum level below 10^{-6} mbar was achieved within a couple of hours, showing no signs of macroscopic leaks.

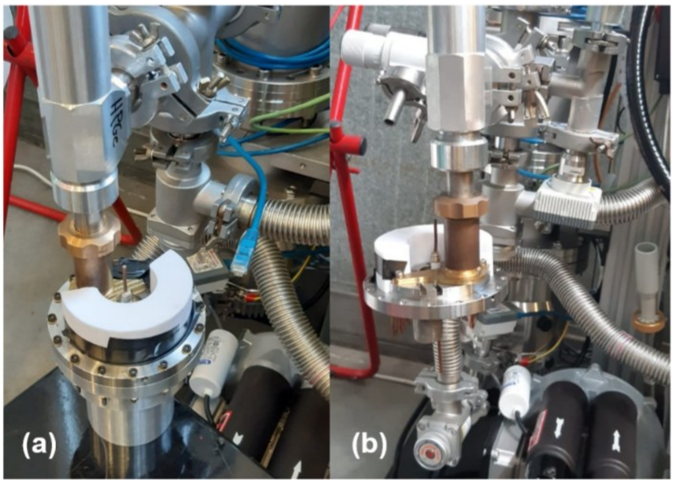

Figure 6: HelicoFlex additional tests

At the end of this procedure, a Pt100 temperature sensor was installed inside the capsule, in close proximity to the getter. The installation was carried out using two of the available electrical feedthrough connectors. The getter was then activated by applying a current of 6 A across its terminals for 10 min. During the activation, temperature and pressure were continuously monitored, while the vacuum pumping system remained in operation.

During this process, the getter heated up and, through radiative heat transfer, warmed the surrounding volume. As shown in Fig. 7, the region closest to the getter reached a maximum temperature of 58 °C. This temperature is considered acceptable, as it remains well below the typical annealing temperatures for germanium detectors (100–120 °C). Furthermore, the temperature began to decrease immediately after the getter was deactivated.

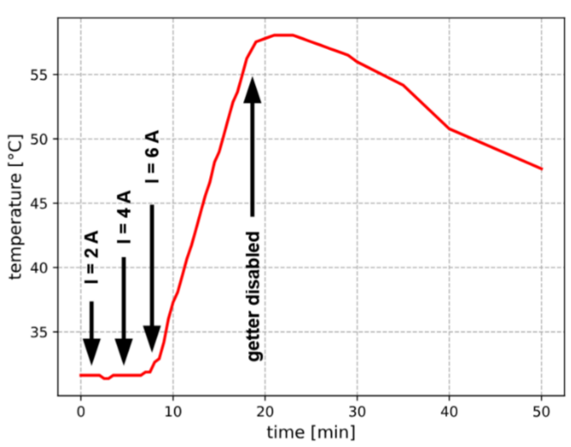

Figure 7: Temperature profile during getter activation

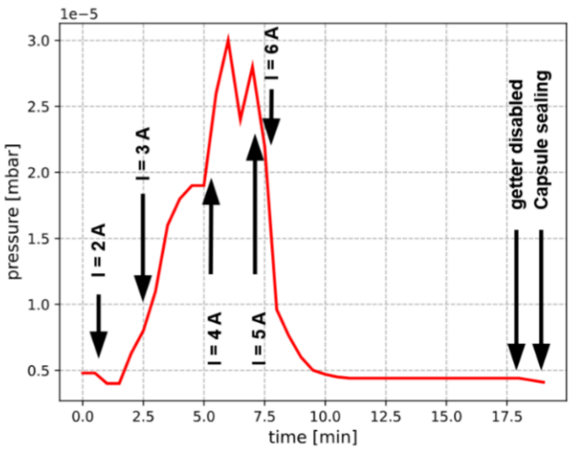

Figure 8: Capsule pressure profile during getter activation

Fig. 8 shows the pressure values measured during the getter activation. As observed, once the current exceeded 2 A, the getter passivation layer was removed and pressure increased. As a consequence, to counteract vacuum degradation, a stepwise activation approach was adopted, with the vacuum pumping system kept in operation to continuously reduce the internal pressure of the capsule. After the getter was fully activated, the pressure decreased again and, with an inner pressure lower than $0.5 \cdot 10^{-5}$ mbar, the capsule was sealed and isolated from the vacuum pumping system. During the cap tightening operation, air trapped between the threads caused a pressure increase up to $1.2 \cdot 10^{-5}$ mbar.

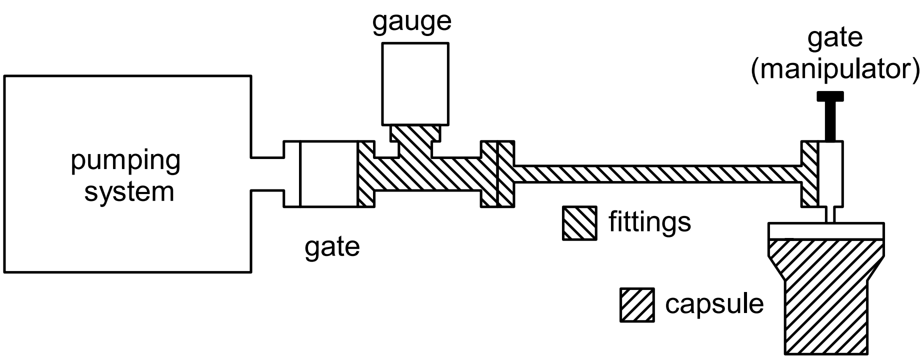

Figure 9: Schematic representation of the vacuum connections adopted for capsule evacuation, provided to clarify the reference points and volumes used in the evaluation of the achieved vacuum levels.

After five days, the vacuum gate between the capsule and the pumping system was reopened. Once the pressure between the gate and the flange vacuum port reached a value of approximately $P_{fittings} = 1.4 \cdot 10^{-5}$ mbar, the cap was unscrewed. The pressure rose to $P_{tot} = 2.2 \cdot 10^{-5}$ mbar. Referring to Fig. 9 and considering that the volume of the fittings located between the gauge and the capsule is approximately equal to 1.5 times the capsule volume, the total volume into which the gas expanded after the cap was opened was:

$$V_{tot} = V_{capsule} + 1.5\, V_{capsule} = 2.5\, V_{capsule} \qquad (5)$$

Assuming constant temperature, the ideal gas law, i.e the conservation of the number of moles, gives us:

$$P_{tot} \cdot V_{tot} = P_{fittings} \cdot V_{fittings} + P_{capsule} \cdot V_{capsule} \qquad (6)$$

From which we obtain

$$P_{capsule} = \frac{P_{tot} \cdot 2.5\, V_{capsule} - P_{fittings} \cdot 1.5\, V_{capsule}}{V_{capsule}} = 3.4 \cdot 10^{-5} \text{ mbar} \qquad (7)$$

Thus, upon activation of the getter, internal pressure increased by approximately $2.2 \cdot 10^{-5}$ mbar over five days , compared to the expected rise within just six hours in the absence of the getter (Eq. 4). This suggests that, assuming the same experimental conditions and an initial vacuum level of approximately $1.0 \cdot 10^{-6}$ mbar the internal pressure would rise to around $9.0 \cdot 10^{-5}$ mbar in just under one month. This defines the operational time window for our detectors before reactivating the getter to restore the initial vacuum conditions. However, it must be noted that in the real experimental set-up, the capsule operates at cryogenic temperature and is not exposed to atmospheric conditions, but rather placed inside a cryostat with a vacuum level better than $1.0 \cdot 10^{-3}$ mbar - $1.0 \cdot 10^{-4}$ mbar. This experimental configuration is much more favourable, as the reduced pressure gradient between the inside and outside of the capsule helps maintain the internal vacuum level, while cryogenic conditions further improve it [4]. Consequently, much longer operational time window for our detectors should be expected.

To progress this work, the next step will involve the development of a hot cathode to be integrated into the capsule, enabling more accurate in situ pressure monitoring. Unfortunately, preliminary investigations indicate that commercially available devices of sufficiently small size and capable of measuring such low pressures are currently not available. The results obtained may eventually allow for an evaluation of the replacement of the currently adopted HelicoFlex® gaskets with HelicoFlex® Delta gaskets, which would provide superior sealing performance under equivalent tightening conditions. Finally, it will be necessary to repeat these tests with the capsule at cryogenic temperature.

Conclusions

In this work, we have presented the main design considerations, the test and the qualification procedures required to operate a capsule under cryogenic high-vacuum vacuum conditions, specifically for the liquid nitrogen temperatures foreseen for the HPGe operation. Particular attention was given to the use of appropriate sealing technologies, such as HelicoFlex seals, and to the implementation of getter materials which work as chemical pumps that help maintain static vacuum over extended periods. We also described in detail the leak detection procedures adopted, including mass spectrometry and helium sniffing techniques.

The sealing tests performed demonstrated the capsule's excellent leak-tight performance under the specified conditions: over a period of five-days the pressure inside the chamber increased approximately of $2.2 \cdot 10^{-5}$ mbar .These results validate the effectiveness of the adopted solutions and provide a solid basis for future developments.

Building upon these findings, we are currently investigating the application of the same design principles and sealing strategies to alternative closure systems, including those based on flexible membranes. A patent has recently been deposited regarding the container technology with polymeric sealing membranes[5].

Further details, including the specific implementation of the developed solutions, can be found in the Ph.D. thesis of G. Secci[6] and in this paper[7].

---

[4] Dorothy Hoffman, Bawa Singh, and John H Thomas III. Handbook of vacuum science and technology. Elsevier, 1997.

[5] L. Manara, S. Coelli, G. Secci and S. Capra, "Container for radiation detector and detector apparatus", Patent IT102023000009687, Also published as WO2024236424A1. Granted on March 29, 2025.

[6] G. Secci, "Design, development and validation of novel electrical contacting systems, mechanical encapsulation solutions and high-resolution integrated charge-sensitive preamplifiers for advanced high-purity germanium detectors", Ph.D. Thesis, Università degli Studi di Milano, Milano, Italy, 2026.

[7] G. Secci et al. "Read-Out and Electrical Connection of Modern High-Purity Germanium Detectors: Innovative Flexible Systems and Integrated Charge-Sensitive Pre-amplifiers". In: 2025 20th International Conference on PhD Research in Microelectronics and Electronics (PRIME). IEEE, 2025. p. 1-4.