Performance of a New Type of Electrical Cooler for HPGe Detector Systems

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Abstract

In the area of Safeguards, the high resolution gamma spectra obtained with high-purity germanium (HPGe) detectors is absolutely necessary for acceptable analysis results. However, the necessity for using liquid nitrogen (LN2) to cool HPGe detectors has been a hindrance to their use in some applications. The most commonly cited problems are unreliable supplies of LN2, irregular detector-filling and the associated costs of the LN2 supplies. In addition, in unattended monitoring stations or remote monitoring locations, a LN2-free solution is a requirement for operation. Until now, LN2 free cooling has suffered from two major limitations: cost and reliability. The mechanical coolers needed to cool the detectors to the required temperature of 90 to 100 °Kelvin have typically had much higher cost than the cost of LN2 for a considerable time. The reliability or working life of previously available coolers has not been high enough to justify their use in remote stations. For example, the time between necessary service for the coolers has been shorter than the time between service for the detector elements themselves. This means that the mechanical system would require service in a shorter time than the LN2 system. A low-cost, low-power cooler system has been developed to address these issues. The system has the high cooling capacity needed for use with modular detector capsules. The use of modular detector capsules greatly reduces the service costs especially in remote systems. Spectrum data has been collected for several different types of detectors over several months. Performance data will be shown for various detector-cooler combinations.

Introduction

The search for a viable low-cost way to cool an HPGe detector without liquid nitrogen has been for years an unobtain for users of these detectors. Physics forbids room temperature operation because of the small germanium bandgap (0.7 eV), which would result in a large thermally-induced leakage current. Germanium detectors must be cooled to reduce this leakage current to the point where the associated noise does not degrade the energy resolution. Normally, HPGe detectors are cooled with liquid nitrogen (LN2) to 85-105 °K inside a specially-designed cryostat. LN2 is a simple way to cool an HPGe detector, but it is not very convenient. Dewar filling also has an associated labor cost. In addition to the running cost and LN2 availability issues, (especially in remote locations), there are potential health and safety hazards: asphyxiation, LN2 burns and explosion of the Dewar should the vent become badly blocked. There may also be a radiation exposure hazard to filling operators.

Automatic fill systems can be expensive to operate and install, and have inherent reliability issues due to possible icing problems.

Attention has recently been given to alternative detector types capable of operating at room temperature, such as cadmium zinc telluride (CdZnTe)[1], but as yet nothing can reproduce the HPGe in terms of its resolution, efficiency and availability of detector element sizes. In some cases, however, these small, moderate resolution room temperature detectors are a better solution than either an HPGe or NaI detector.

There remain, however, applications for which the use of an HPGe detector is mandatory. In Safeguards, the trend towards unattended monitoring makes finding a viable cooler a matter of increasing importance.

For some years, attempts have been made to find an electrical alternative to LN2 cooling[2]. Early coolers were noisy (~70 dB), heavy (>50kg), and required periodic preventative maintenance. The cooling capacity was not sufficient for the use of modular detector capsules, which required the entire detector-cooler assembly to be made as one piece. In addition, they consumed a substantial amount of power and were extremely costly. If the cooler failed or required service, then it was necessary to return the entire detector system for repair.

As a result, until recently, mechanically-cooled HPGe detectors were deployed only when absolutely necessary. Nevertheless, the concept is highly desirable. Mechanical coolers potentially offer a distinct advantage over liquid nitrogen in that cooling can be sustained as long as electricity is available. No filling, manual or automatic, is ever required. The ultimate goal, therefore, for the users of germanium detectors is to have a low cost cooling device that is (a) powered by electricity, (b) can be easily maintained, and (c) does not degrade the performance of the detector – especially resolution. Such a device is now available commercially and is described here.

System description

The new mechanically-cooled HPGe detector system has been developed based upon patented[3] advances in cooler technology, and the patented ORTEC PopTop[6] transplantable HPGe detector capsule technology, in a collaboration between ORTEC and MMR, the cooler manufacturer. The new cooler will reliably and inexpensively cool HPGe detectors to their normal operating temperatures.

The Cooler

The cooler system is based on the Kleemenko[4] cycle and uses mixed-gas refrigerants. Although a cooler using these refrigerant mixtures can attain low temperatures without using phase separators, experience has shown that prolonged refrigeration at these temperatures can only be achieved if the gas stream is cleansed of condensable contaminants, otherwise the expansion nozzles in the cooler will progressively clog and cooling effectivity will decrease, eventually to the point of failure. Conventionally, this is problem is solved by filtration (e.g., a molecular sieve or a series of activated charcoal adsorption filters). The filters, however, are expensive and add complexity to the system.

Moreover, they add substantially to the size of the cooler. The new, patented, design uses a miniature fractionating column containing a packing which presents a large surface area to the vapor. The residual contaminants, which are more soluble in the liquid condensate than in the vapor, are separated from the vapor phase, and collected in the bottom of the column, and are thus retained in the liquid phase, preventing any clogging. The fractionating column purges the refrigerant mixture of both high and low molecular weight contaminants, contains no moving parts and does not add significant volume to the cooler.

This improved cooler design results in the following advantages:

> Commercially available, low-cost but reliable compressors similar to those used in many domestic refrigerators are used in the design. By incorporating low-cost compressors, the cost of the cooler itself is reduced to about the same as the traditional LN2 Dewar and cryostat.
>
> The cooling system is free from clogging problems. Similar coolers using this design have operated over 38,000 hours (more than 4-1/4 years) without failure[5].
>
> The cooler is of small size.
>
> The cooler uses less power (<300W at the operating temperature, ~250W typical) compared to the previous generation mechanical coolers (>500W at the operating temperature).

The PopTop Detector Capsule

The second improvement is the use of the patented[6] ORTEC PopTop® transplantable detector capsule for connection to the cooler. A cutaway drawing of a PopTop capsule is shown in Figure 1. The PopTop design was first introduced in 1986, and since that time has undergone a succession of engineering improvements. It is now considered to be more reliable than conventional dipstick cryostats. There are many thousands of detectors in PopTop capsules with LN2 cooling operating in the field.

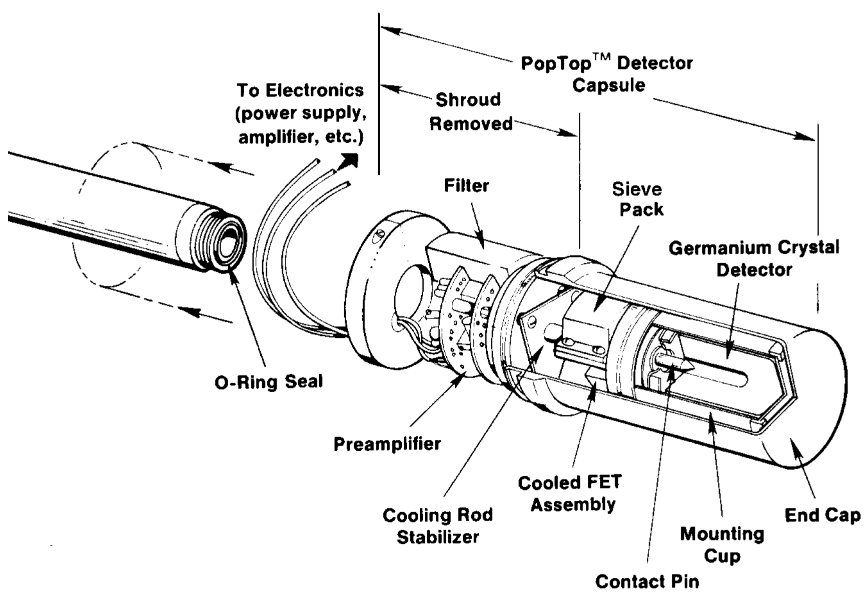

Figure 1

By incorporating the PopTop technology, the cooler can be completely separated from the detector capsule. This allows for quick, easy replacement of either a malfunctioning cooler or detector in the field with no special tools required.

A typical X-COOLER System is shown in Figure 2.

The X-COOLER is designed to work with any ORTEC detector available in PopTop configurations up to 90% relative efficiency. It is small and lightweight. The footprint is less than 0.1 m^2 and it is approximately 20 cm tall. The weight is under 16.5 kg. Power consumption during cool down is approximately 500 watts and less than 300 watts once operating temperature has been reached. The cold head is approximately 60 cm long, and weighs 5 kg, excluding the weight of the detector crystal. Noise from the compressor unit at one meter is less than 54 dB. A flexible hose approximately 2.5 m in length connects the cooler to the cold head.

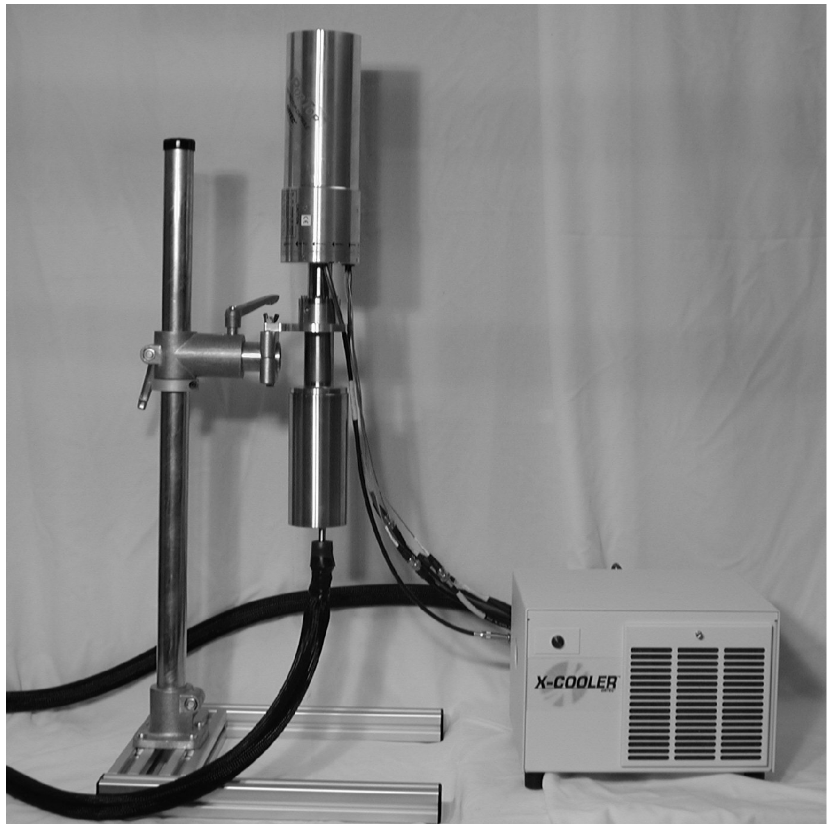

Figure 2

The low mechanical noise of the cold head does not add significantly to the detector resolution. There is no degradation for incident gamma ray energies above 500 keV. Below 500 keV, the degradation in the resolution will be less than 10% of the specified resolution for LN2 cooling. Note that with the PopTop configuration, the same detector can easily be used with LN2 or mechanical coolers.

Performance Data with different Cooler-Detector combinations.

Table 1 presents Data taken with 11 different coolers (both 120 V/ 60 Hz and 240 V/ 50 Hz) and 13 different detectors of various types. In each case, the PopTop detector capsule was first attached to an LN2 cryostat and allowed to cool. Resolution measurements were then made, using either an ORTEC 672 Analog NIM-based system or the DSPEC Plus Digital Gamma Ray Spectrometer.

The detector was then allowed to warm up and the capsule was transferred to the mechanical cooler. When the reached operating temperature, the resolution measurement was repeated.

Detector Type	serial number	Cooler number	Coax Detector relative efficiency	Planar detector area sq mm	LN2 Warranted resolution keV/ev	X-COOLER measured resolution keV/eV	LN2 Measured resolution keV/eV	Energy (keV)
GMX-80-P	N31490A	SN 001002	83%		2.30	2.20	2.26	1332
		SN 001005	83%		2.30	2.26	2.26	1332
GEM-25-P	P11556A	SN 001003	28%		1.85	1.78	1.78	1332
					850	888	828	122
GLP-10180-P	B538	SN 001002	--	80	485	493	480	122
					180	196	171	5.9
GLP-10180-P	B538	SN 001003	--	80	485	475	480	122
					180	194	171	5.9
GLP-10180-P	B538	SN 001060	--	80	485	476	480	122
					180	179	171	
GEM-20-P	P11563B	SN P004	23%		1.80	1.77	1.75	1332
					850	810	*651*	122
SGD-16510-P	C1132	SN P004	--	200	510	510	485	122
		SN P003	--		510	517	485	122
SGD-GEM-25-P		SN P003	--	2000	1.75	1.66	1.70	1332
					750	820	750	122
					870[1]	860	810	122
GMX-45-P	N31276A	SN P003	47%		2.20	2.09	2.10	1332
					--	940	850	122
GEM-45-P	P40881A	SN P003	46%		1.90	1.89	1.87	1332
					900	711	513	122
GEM-10-P	P21603A	SN 010606	14%		1.75	1.65	1.64	1332
					800	655	662	122
GEM-35-P	P11661B	SN 010407	37%		1.85	1.8	1.69	1332
					850	907	724	122
GEM-15-P	P11641B	SN 010402	17%		1.90	1.81	1.78	1332
					820	706	623	122
LOAX-60450-30-P	N21614B	SN 010504	--	2800	700	695	665	122
					450	436	373	5.9
GEM-45-P	P41087B	SN 010403	54%		1.90	1.77	1.66	1332
					900	797	669	122

Table 1 Note: all measurements at 6 uS Gaussian shaping or equivalent except where noted. 5.9 keV and 122 keV resolution is in eV. [1] is at 2 uS shaping.

Results and Discussion

Overall, the X-COOLER measures, on average, 97% of the warranted LN2 figure and 107% of the LN2 measured result. At 1332 keV, the X-COOLER resolution averages 96% of the warranted LN2 resolution and 101% of the measured LN2 resolution. At 122 keV the respective numbers are 97% and 110%.

In all cases, the manufacturer's guarantee that the X-COOLER will not degrade performance below 500 keV more than 10% above LN2 warranted performance for LN2 is met, as is the guarantee that above 500 keV the X-cooled detector will perform within warranted LN2 specifications. This is shown to be true here for a wide variety of detector types including small and large COAX, planar, and low energy COAX detectors. The low energy data on Detector B538 is interesting in that three different coolers yield similar results, showing consistency of cooler performance in terms of microphonics. This data shows satisfactory performance across the full range of ORTEC detectors.

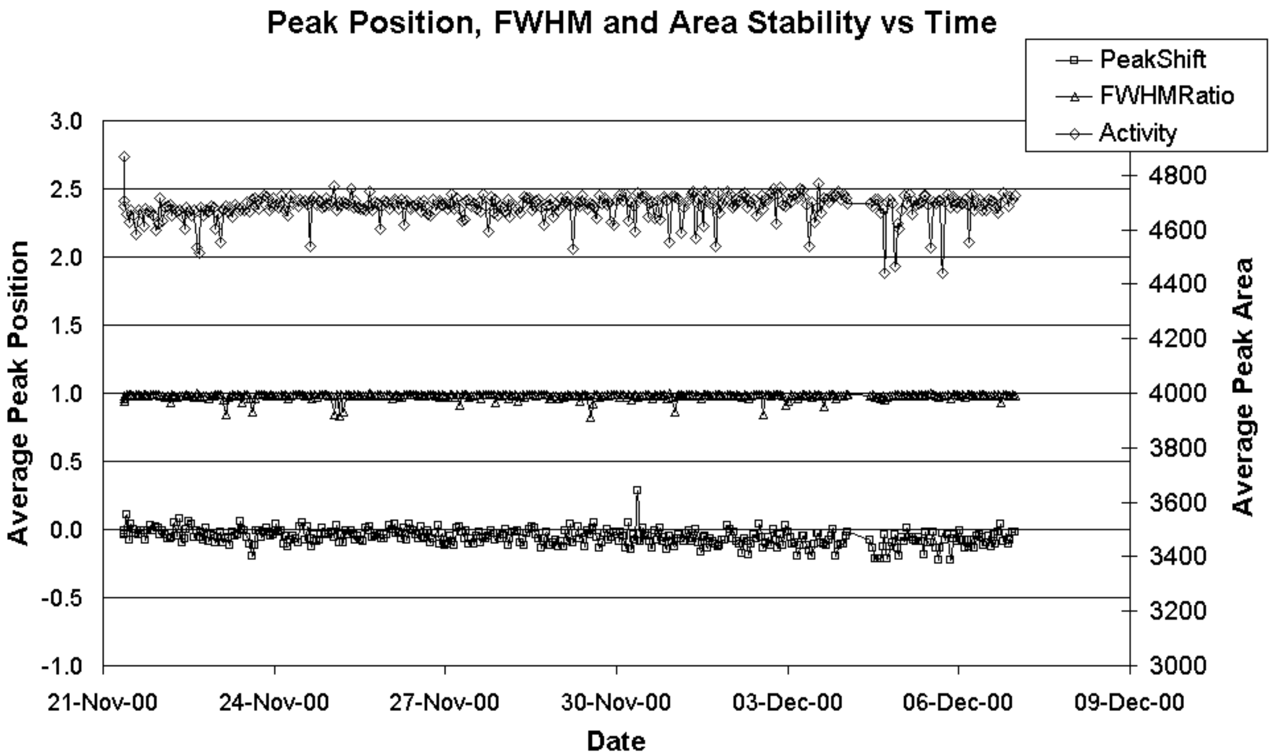

Figure 3

Long Term Stability

Figure 3 shows trend data taken over a period of two weeks in arbitrary units. The 366 spectra of 3600 seconds real time (constant and fixed dead time) were acquired with a mixed-isotope source at a fixed distance from the endcap of a 45% Gamma-X detector (N-type COAX). The count rate was approximately 1400 cps. The spectra were acquired using a DSPEC Digital Spectrometer. The data were acquired, analyzed, and stored using the ORTEC GammaVision QA program. Three peaks were monitored, the 1332 keV and 1173 keV lines of ^{60}Co and 662 keV line of ^{137}Cs. The average deviation of the sum of the three peak areas, the peak position relative to the known energy, and the average of the ratio of the FWHM to the known FWHM from the starting or calibration values were plotted. Over the two weeks, the standard deviation on the reported peak activities was 0.99%, on the average peak FWHM was 2 and on the peak position the standard deviation was 0.01% for all three monitored peaks. The peak position value equates to 0.13 keV at 1332 keV.

Conclusions

A new low cost cooler for HPGe detectors has been developed and is currently being deployed in real world situations. For a variety of detector-cooler combinations it has been shown that the manufacturers resolution performance claims are justified, namely: that above 500 keV no resolution degradation is detectable and that below 500 eV the resolution will be within 10% of the warranted LN2 value.

The system has been shown to demonstrate good long term stability. Work continues on further improvements.

References

1. See, for example, V. Ivanov, P Dogorov, R. Arlt, “Development of Large Volume Hemispheric CdZnTe Detectors for use in Safeguards Applications” Proceedings of the 19th ESARDA Annual Symposium, Montpelier, France, May 1997. EUR 17665 EN, ESARDA 28, p 447

2. See, for example, R.E. Stone, V.A. Barkley, and J.A Fleming, “Performance of a Gamma-Ray and X-ray Spectrometer using Germanium and Si(Li) Detectors Cooled by a Closed-Cycle Cryogenic Mechanical Refrigerator,” IEEE Trans. Nucl. Sci. NS-33(1), 299 (1986)

3. US patent numbers 5,617,739 5,724,832 and 5,644,502

4. A. P. Kleemenko, "One Flow Cascade Cycle", Proceedings of the Xth International Congress on Refrigeration, Copenhagen, 1, 34-39 (1959), Pergamon Press, London

5. See http://www.mmr.com/mmrnew.html

6. US Patent 4,851,684