A new cooler for HPGe detector systems.

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Abstract

The search for a practical LN2-free HPGe detector has been a continuing effort for many users of high resolution gamma spectroscopy. For many, it has been the desire to eliminate the worry about supplies of LN2, the manpower costs of detector-filling and the associated year-on-year costs of maintaining LN2 supplies. For others, such as unattended monitoring or remote monitoring locations, a LN2-free solution is an absolute necessity. Until now, LN2-free cooling has suffered from two major limitations. The first is cost. The coolers needed to reach temperatures of 80 to 90 Kelvin have typically cost on the order of tens of thousands of dollars. The second is working life of the cooler. The service intervals for the coolers are typically shorter than for the detector elements themselves. A new cooler system is described which addresses both of these issues: offering an entry cost comparable to a typical LN2 system and a high cooling capacity which means that modular detector capsules can be used. Using the modular detector capsules means that the cooler or the detector can be exchanged in the field when service is necessary. The cooler is much smaller and uses less power than currently available coolers. It is applicable in a wide variety of nuclear spectroscopy applications, including safeguards, waste assay, health physics and counting laboratories. Performance data are presented.

Introduction

Because of the small bandgap (0.7eV), room temperature operation of germanium detectors of any type is impossible, due to the large thermally-induced leakage current which would result. 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 relatively inexpensive way to cool an HPGe detector, but it is not very convenient. In addition to the LN2 cost and availability issues in remote locations, which may totally exclude deployment of these systems, there are potential health and safety hazards: asphyxiation, LN2 burns and explosion of the Dewar when the vent becomes badly blocked. Manual Dewar filling has an associated labor cost. There may also be a radiation exposure hazard to filling operators. Automatic fill systems are expensive to operate and install.

Attention has been given to alternative detector types capable 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.

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. These coolers 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, up until this point, mechanically-cooled HPGe detectors were deployed only when absolutely necessary. Nevertheless, the concept was 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 and is described here.

Description

The new cooler has been developed based upon patented[3] advances in technology using the previously available Kleemenko cycle method. The new cooler will reliably and inexpensively cool HPGe detectors to their normal operating temperatures.

The first improvement is in the cooler design itself. In this design, the reduction (removal) of the contaminants in the refrigerant gas, such as residual oil from the compressor, has been significantly improved. This serves two purposes: (1) it allows commercially available, low-cost compressors to be used in the design, and (2) it provides a long operational life to the cooling system. Similar coolers using this design have operated over 38,000 hours (more than 4-1/4 years) without failure[4]. 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 low mechanical noise of the cold head does not add significantly to the detector resolution. There is no degradation above incident gamma ray energies of 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.

The second improvement is the use of the patented[5] ORTEC® PopTop® detector coupling method. 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.

Figure 1 New cooler with detector

A typical X-COOLER System is shown in Figure 1.

It 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 at one meter is less than 54 dB. A flexible hose approximately 2.5 m in length connects the cooler to the cold head.

Performance Data

Table 1 presents Data taken with 5 different coolers and 8 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 an ORTEC 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 cooler reached operating temperature, the resolution measurement was repeated.

Results and Discussion

In all cases, at 1332 keV, the resolution achieved with the cooler was no worse than 1% above than the measured LN2-cooled figure. In fact, the average shows the data with the cooler to be about 0.5% better than the LN2 measured data, and 3% better than the manufacturer’s warranted LN2 resolution. At lower energies, the 5.9 keV and 122 keV data show that there is some degradation compared to the LN2 result. At 122 keV the X-Cooler data averages about 10% worse than the measured LN2 result, while still being, on average, marginally (1%) better than the warranted figure. The two 5.9 keV data points show that at the lowest energies, the cooler resolution is about 14% worse than for LN2 cooling, but that the cooler data is still within 10% of the manufacturers warranted resolution.

Conclusions

The new cooler has been demonstrated to be able to achieve the manufacturer’s claim 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. For applications such as safeguards isotopic ratio determination, these values are acceptable. This means that the low cost cooler may be used effectively in unattended and attended safeguards applications and in systems for the assay of fissile waste. Work continues to further improve the performance of these systems at low energies.

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

5. US Patent 4,851,684

Table 1

Detector Type	Serial number	Cooler number	Coax Detector relative efficiency	Planar detector area mm^2	LN2 Warranted Resolution keV/eV	X-Cooler measured resolution keV/eV	LN2 measured resolutution keV/eV	Energy (keV)
GMX-80-P	N31490A	001002	83%		2.30	**2.20**	2.26	1332
		001005	83%		2.30	**2.26**	2.26	1332
GEM-25-P	P11556A	001003	28%		1.85	**1.78**	1.78	1332
					850	**888**	828	122
GLP-10180-P	B538	001002	--	80	485	**493**	480	122
					180	**196**	171	5.9
	B538	001003	--		485	**475**	480	122
					180	**194**	171	5.9
GEM-20-P	P11563B	P004	23%		1.80	**1.77**	1.75	1332
					850	**810**	*651*	122
SGD-16510-P	C1132	P004	--	200	510	**510**	485	122
		P003	--		510	**517**	485	122
SGD-GEM-25-P		P003	25	2000	1.75	**1.66**	1.70	1332
					750	**820**	750	122
					870 [1]	**860**	810	122
GMX-45-P	N31276A	P003	47%		2.20	**2.09**	2.10	1332
					--	**940**	850	122
GEM-45-P	P40881A	P003	46%		1.90	**1.89**	1.87	1332
					900	**711**	513	122
Note: all detectors measured at 6 μs Gaussian equivalent except where noted.								
5.9 keV and 122 keV resolution is in eV								
[1] 2uS shaping								