MECHANICALLY COOLED LARGE-VOLUME GERMANIUM DETECTOR SYSTEMS FOR NUCLEAR EXPLOSION MONITORING

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Sponsored by the National Nuclear Security Administration

Award No. DE-FC52-06NA27323
Proposal No. BAA06-37

ABSTRACT

Compact, maintenance-free, long-lived, mechanically cooled germanium-detector systems are being developed to operate large-volume germanium detectors for field applications. These detector systems are necessary for remote long-duration liquid-nitrogen free deployment of large-volume germanium gamma-ray detectors. The Radionuclide Aerosol Sampler/Analyzer (RASA) nuclear explosion monitoring system will benefit from the availability of these new detector systems. Three prototype detector systems (RASA 1, RASA 2, and RASA 3) have been developed, fabricated, and tested. The cryostats have been demonstrated to cool very large detectors to temperatures as low as 50 K. The vacuum design has demonstrated no measurable degradation for at least two years. These detector systems have been demonstrated to successfully instrument high-purity germanium detectors. Microphonic noise from the vibrating cooler can obscure the gamma-ray spectroscopy. The single most-significant technical issue encountered during this program has been microphonic noise. Recent advances have led to a better understanding of the source and the sensitivity to microphonic noise. The third-generation system, RASA 3, has recently demonstrated good spectroscopic performance with the cooler operating at full power. The performance appears to be repeatable. The microphonic noise issues have been greatly reduced by mechanical changes afforded by the new RASA 3 design, making the detector system design viable for nuclear explosion monitoring.

OBJECTIVES

PHDs Co. is developing mechanically cooled detector systems for large-volume germanium detectors. Maintenance-free Stirling-cycle mechanical coolers are being used. These coolers have operating lifetimes exceeding five years. The relatively large heat lift of these coolers quickly cools a detector to very low operating temperatures for gamma-ray spectroscopy measurements. Lower operating temperature improves the reliability of germanium detectors by lowering surface leakage currents (Pehl et al., 1973). These features will make liquid-nitrogen free operation of the largest germanium gamma-ray detectors viable and convenient for nuclear explosion monitoring. The RASA detector system will benefit from the availability of such detectors (Bowyer et al., 1997; Miley et al., 1998).

Mechanical cooling of germanium detectors has historically been a difficult endeavor. The viability of mechanically cooled germanium detector systems depends upon three major technical issues: temperature, vacuum, and vibration. Previous years have seen analysis of these factors and their impact on detector performance (Hull et al., 2006). The first two prototype detector systems, RASA 1 and RASA 2, were then brought to working order with a coaxial germanium detector (Hull et al., 2007; Hull et al., 2008). During the evolution of these first two prototypes, extremely low operating temperatures were achieved in an extremely stable vacuum system showing no degradation. However, there were problems with microphonic noise that could not be controlled or even duplicated from one thermal cycle to the next. Most recently, a third prototype germanium detector system (RASA 3) has been designed and fabricated. The system employed a right-angle design in the body of the cryostat that places the axis of the cooler orthogonal to the axis of the detector. With this new modification, reasonably good gamma-ray spectroscopy has been consistently achievable with the cooler operating at full power. This encouraging result should lead to a viable PHDs Co. design for cooling RASA coaxial germanium detectors in a cryogenic system that has great longevity, reliability, and performance.

RESEARCH ACCOMPLISHED

The older prototypes, RASA 1 and RASA 2, were used in an attempt to continue troubleshooting the insidious microphonic noise issue. A photograph of RASA 2 is shown in Figure 1. On separate trials, the following steps were made in an attempt to identify the source of the microphonic noise in the detector. Each change required cycling the detector from cryogenic temperatures up to room temperature, making the change, and then again cooling the detector. The detector and the infrared shield were both floated to bias voltage. The position and mounting of the junction field-effect transistor (JFET) were changed. The circuit board holding the JFET was changed to make it nearly 100% ground plane relative to the gate lead of the JFET. A grounded copper faraday cage was built around the JFET. A grounded copper faraday cage was also built around the detector contact pin connected to the gate of the JFET. An external JFET was installed on the system. Large (~0.2 μF) high-voltage filter capacitors were added on the bias line. The bias line was internally shielded. The aluminum parts were sanded and cleaned. Extra lateral supports were added to limit the sideways motion of the detector and infrared shield. The copper cooling braids were changed in width and length (this helped on one occasion). The copper braids were replaced with folded copper and aluminum foils. The Sunpower Cryotel CT cooler was replaced with the much smaller Cryotel MT cooler having somewhat less vibration. Despite all of these changes on the RASA 1 and RASA 2 detector systems, the microphonic noise was not greatly improved. Changes to the copper braid did result in slightly better microphonic noise on one occasion, but the result could not be repeated. The change finally making the difference was the switch to the new RASA 3 cryostat. Apparently the right-angle design of the system provided the necessary isolation to allow the detector to function with consistently less microphonic noise.

Figure 1. The RASA 2 prototype is a relatively compact overall design. This prototype system places the detector directly in line with the axis of the vibrating mechanical cooler. The coaxial germanium detector is held inside the rightmost end of the aluminum cap. The cooler is shown on the left next to the fan.

The later part of the third year of this project has seen a single extremely significant accomplishment—the microphonic noise problems associated with the vibrating cooler were finally diminished. After attempting numerous fruitless modifications (described above), the RASA 3 cryostat has proven to stabilize the microphonic noise problems from the vibrating cooler. Taken from our planar imaging detector designs, the RASA 3 employs a right-angle cryostat. The coaxial germanium detector is held at a right angle with respect to the axis of the linear Stirling-cycle cooler. For the past few years, PHDs Co. has had the capability of fabricating planar germanium detectors in similar cryostats having no significant microphonic noise issues. Planar orthogonal strip detectors have been fabricated having 16 × 16 orthogonal strips displaying no significant microphonic noise issues from the vibrating cooler. In many ways orthogonal-strip germanium detectors are far more complex than single-channel coaxial germanium detectors. Because it has 32 external JFETs, one might conclude that the orthogonal strip detectors would be far more vulnerable to microphonic noise than a single-channel coaxial detector, since the single-channel coaxial detector has an internal JFET. Surprisingly, the orthogonal-strip detectors are virtually free of microphonic noise. The only significant difference between these planar-detector systems and the RASA systems is the right-angle cryostat design of the strip detector systems. In our first two RASA detector systems (RASA 1 and RASA 2), the detector shared a common centerline with the cooler axis, as shown in Figure 1. It was hypothesized that this mechanical configuration allowed a problematic resonance to cause the detector itself to vibrate excessively in its mounting, despite holding the detector with ~ 100 lb of force in compression.

The RASA-3 mechanically cooled detector system was assembled and debugged. The fully assembled system is shown in Figure 2. A PHDs Co.-fabricated p-type coaxial germanium detector was removed from the RASA 1 cryostat and loaded into the RASA 3 system. After several minor modifications the system successfully cooled the detector into the 50–60 K region. With the detector at these temperatures, the operation of the detector should be much more stable long term. The long-lived cooler and the metal-sealed cryostat should provide operation of the detector for more than 5 years.

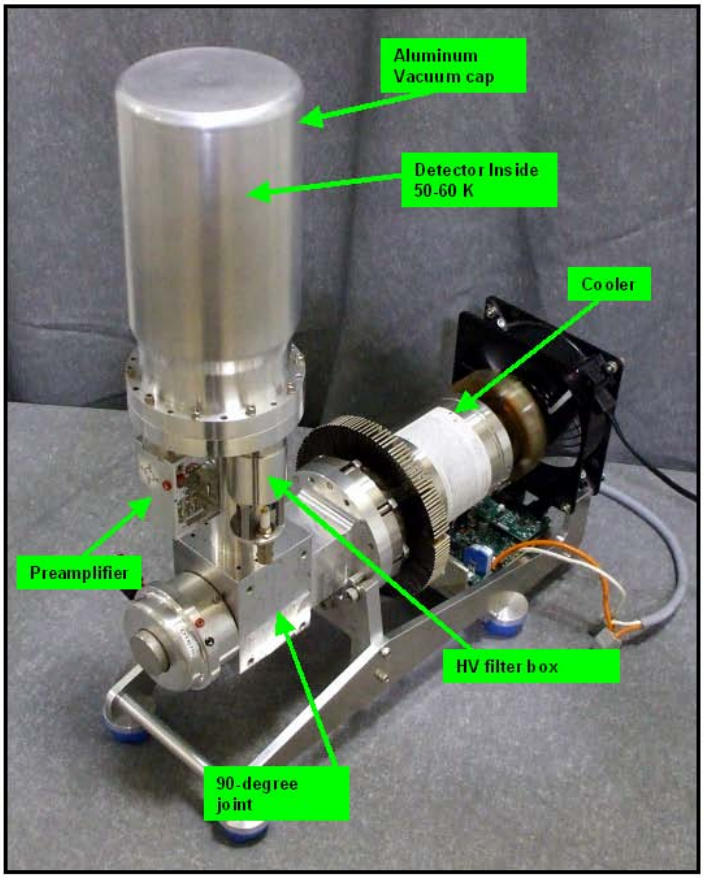

Figure 2. The RASA 3 prototype shown here holds and cools a 70-mm-diameter, 70-mm-long coaxial germanium detector. The 90-degree joint separates the cooler axis from the detector, keeping the vibrating cooler from directly affecting the detector. This detector system successfully cools the detector to the 50-60 K region while adding very little microphonic noise from the mechanical cooler. Some additional size was added to accommodate the right-angle design. The RASA 3 detector system still allows the detector to be placed in the proper location near the filter paper in the RASA station.

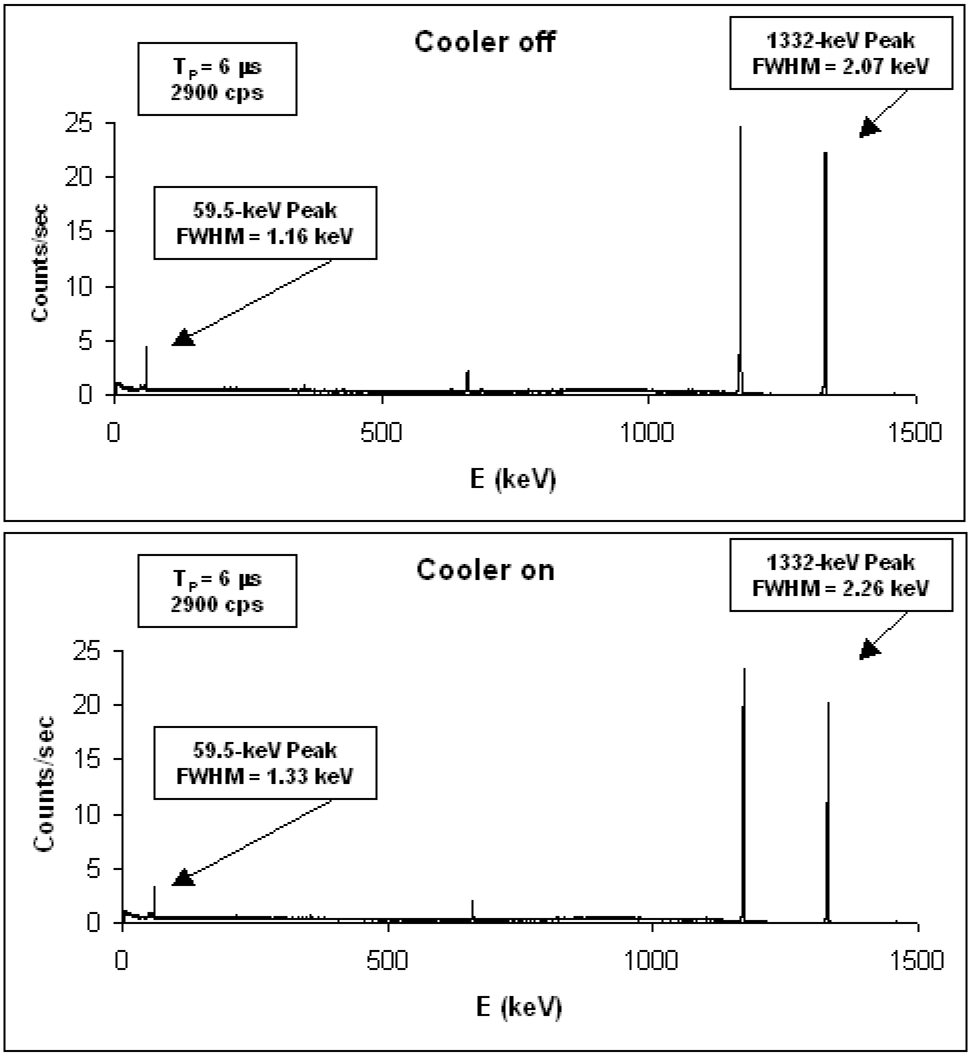

Figure 3. These energy spectra were accumulated from the detector in RASA 3 using a unipolar peaking time of 6 μs. The top view shows the spectroscopy with the cooler switched off briefly, while the bottom view shows a spectrum accumulated with the cooler operating at full power. There is still a small component of degradation from microphonic noise when the cooler is operating. No special electronic filtering was used to eliminate microphonic noise for this measurement.

Aside from the spectroscopy shown in Figure 3, the microphonic noise was analyzed on the oscilloscope. The signals from the detector preamplifier were shaped in a TC244 shaping amplifier using a peaking time of 6 μs. Very little microphonic noise was visible on the baseline. This was established with the 122-keV gamma-ray peak set to 6 V on the oscilloscope. This allows the baseline JFET channel noise to be easily observed on the 100- and 200-mV voltage scales. Channel noise from the JFET dominates when the cooler was not operating. When the cooler is switched on, there is a brief burst of noise when it starts, and then the noise almost immediately returns to the cooler-off level. The microphonic noise has not been eliminated through the use of any special electronic filtering—it has simply been eliminated from the system altogether. This result, along with the spectroscopy, was heralded as a great success. More important, the good performance appears to be stable with the new RASA 3 design. The system has been operated for weeklong periods with no degradation. In addition, the detector and all internal parts have been completely disassembled and reassembled multiple times with no significant degradation in detector performance. During the past few years, this had been the most significant problem. The performance was not repeatable. Sometimes disassembling the system would improve or degrade the performance dramatically.

There was never any certainty with respect to the origin or sensitivity to the microphonic noise issues. The new right-angle design in the RASA 3 cryostat appears to make the significant difference necessary to provide stable and repeatable detector performance.

CONCLUSIONS AND RECOMMENDATIONS

The RASA 1 and RASA 2 prototype detector systems have been designed, fabricated, and tested as demonstrations of a new integrated mechanical cooling detector system suitable for use with RASA stations. These two systems cool large coaxial detectors to extremely low temperatures in a 100% metal sealed cryostat providing long-lived detector operation. However, the usefulness of RASA 1 and RASA 2 were constantly hindered by a microphonic-noise problem degrading the spectroscopy of the detector. Fortunately, the third generation prototype, RASA 3, has demonstrated good spectroscopy that is nearly free of microphonic noise issues. Moreover, this encouraging result appears to be repeatable. Along with the low operating temperature and excellent quality vacuum, the improvement in the microphonic noise makes the PHDs Co. RASA 3 cryogenic system viable for use in RASA stations.

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