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CryoFree Final Report

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Summary: CryoFree, a gamma-ray spectrometer, has been built and successfully tested. This instrument is based on a planar germanium semiconductor detector and is optimized for high-resolution spectroscopy in the range of a 30 keV to a few hundred keV to detect U and Pu. The spectrometer is cooled with a mechanical cryocooler that obviates the need for liquid cryogen. Furthermore, the instrument is battery powered. The combination of mechanical cooling and battery operation allows high-resolution spectroscopy in a highly-portable field instrument. A description of the instrument along with its performance is given.

Figure 1. CryoFree: a mechanically-cooled, high-resolution, gamma-ray spectrometer.

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1.0 Motivation

At present, the IAEA makes hard x-ray and gamma-ray measurements using high energy-resolution germanium planar detectors. These measurements are often made to confirm U and Pu content of the sources being examined. All these instruments (several hundred) must be maintained at cryogenic temperature using LN_2. The need for a supply of liquid cryogen limits the flexibility of these instruments and makes surprise inspections difficult. CryoFree has been developed as a high-resolution spectrometer that is battery powered and mechanically cooled. It is portable and flexible.

2.0 Technical Approach and Instrument Description

Figure 1 shows a diagram of the CryoFree instrument and its major components. Each component is explained in more detail below.

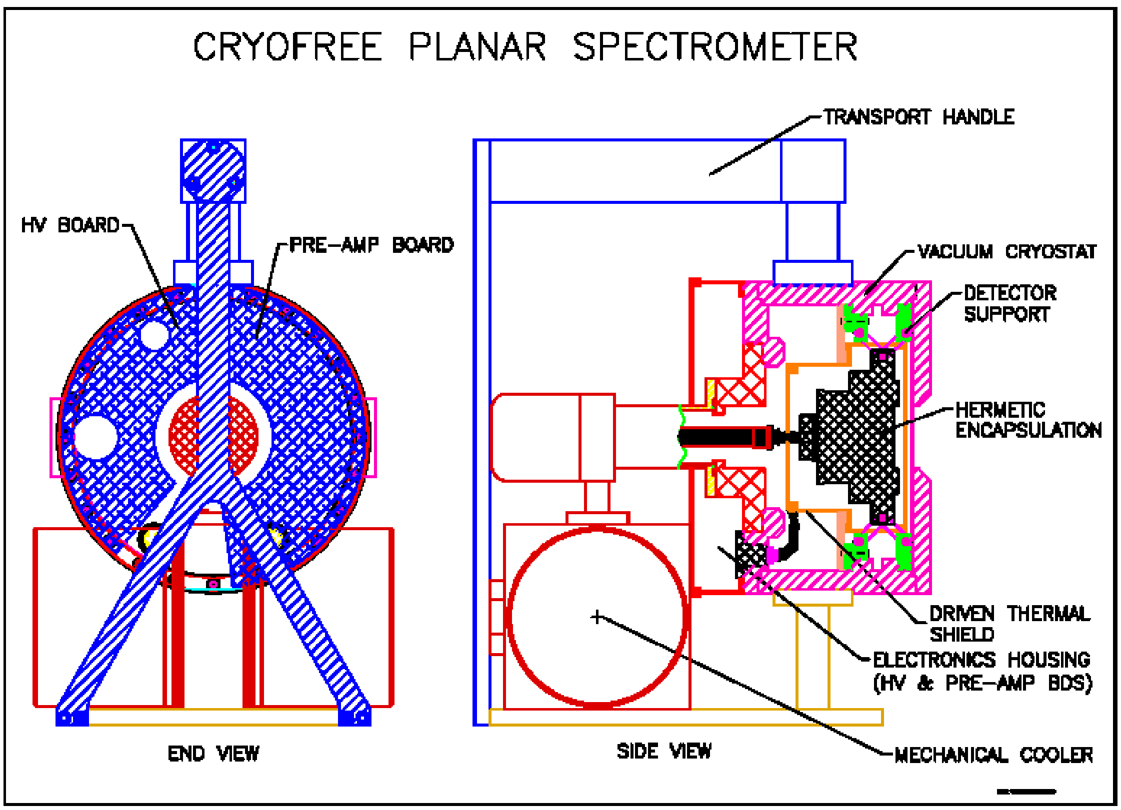

Figure 2. Diagram of CryoFree and its major components.

Germanium Crystal. The detector is based on a planar germanium crystal approximately 36 mm in diameter and 15 mm thick. The thickness was chosen to give good efficiency for the gamma-rays of interest (few hundred keV and below) while being more transparent to higher energy gamma-rays (thus reducing background).

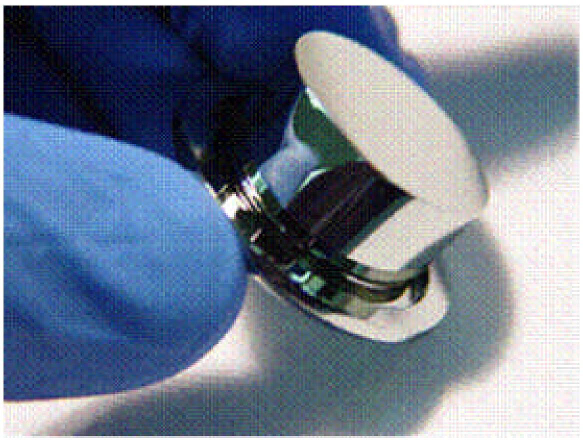

Figure 3. Germanium planar crystal.

Hermetic Encapsulation. The detector is housed inside a hermetic encapsulation. This encapsulation is backfilled with 2 atmospheres of nitrogen. The purpose of the encapsulation is to protect the detector from contaminants that may leak into the system or outgas from the cryostat. This is important because germanium crystals are very sensitive to surface contamination which can cause excessive leakage current resulting in performance degradation or even failure.

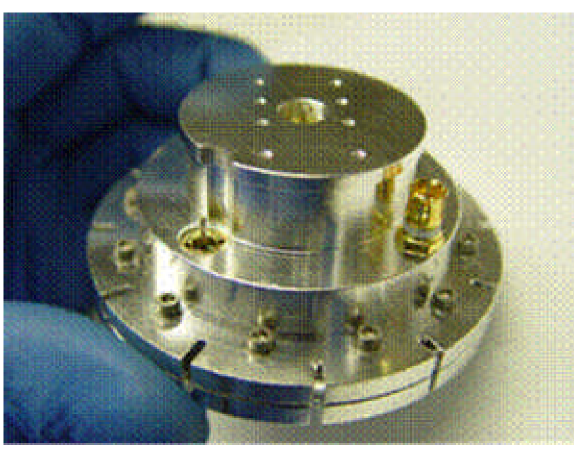

Figure 4. Detector Encapsulation. The encapsulation was back filled with two atmospheres of nitrogen and was designed to protect the detector from contaminants.

Driven Thermal Shield. The detector is kept cold by the use of a mechanical cryocooler. However, extra cooling power is provided with the use of an infrared shield that is cooled with a Peltier cooler. This shield is driven to only about 270 K but this is enough to intercept a significant amount of infrared radiation and reduce the heat load on the cryocooler.

Detector Suspension. The detector is suspended using “S-glass” fibers. S-glass is a magnesia-alumina-silicate glass for aerospace applications. It is useful for this applications because of its high tensile strength and extremely low thermal conduction. These fibers provide both the mechanical support of the detector encapsulation and the thermal isolation from the cryostat.

Mechanical Cryocooler. A Hymatic tandem mechanical cryocooler is used to cool the detector to an operating temperature ~100 K. This “tandem” has two pistons which cycle 180^{o} out of phase from each other to reduce the vibrational modes of the system. This cooler has a nominal heat lift of about 1 W at 80 K.

Figure 5. Hymatic tandem cryocooler.

Electronics. The spectroscopy electronic chain consists of a low-noise charge-sensitive preamplifier followed by a shaping amplifier. The preamplifier has the input transistor mounted inside the cryostat where it was kept at a reduced temperature. This helps reduce the electronic noise as well as minimizes microphonic-induced noise. The shaping amplifier uses two-pole shaping to also minimize the effects of microphonic noise.

The electronics package also includes circuitry for producing and filtering the high-voltage needed to bias the detector. There is circuitry for monitoring the temperature and providing feedback to the controller of the cryocooler.

3.0 Results

The most important performance specification of the spectrometer is the energy resolution. The measured energy resolution of CryoFree is 685 eV FWHM at 122 keV which allows for excellent nuclide identification as well as discrimination between closely spaced gamma-ray lines. This is shown in figure 6.

Figure 7 shows the cool-down curve. This is the time is takes to cool the detector from storage temperature (typically room temperature) to operating temperature of ~100 K.

Figure 8 shows the leakage current as a function of applied bias voltage. At around 400 V the leakage current rises to 1 pA and greater. With increases bias, the leakage current quickly becomes a significant noise source. This leakage is worse than expected due to contaminants on the surface of the detector (discussed in section 4.0).

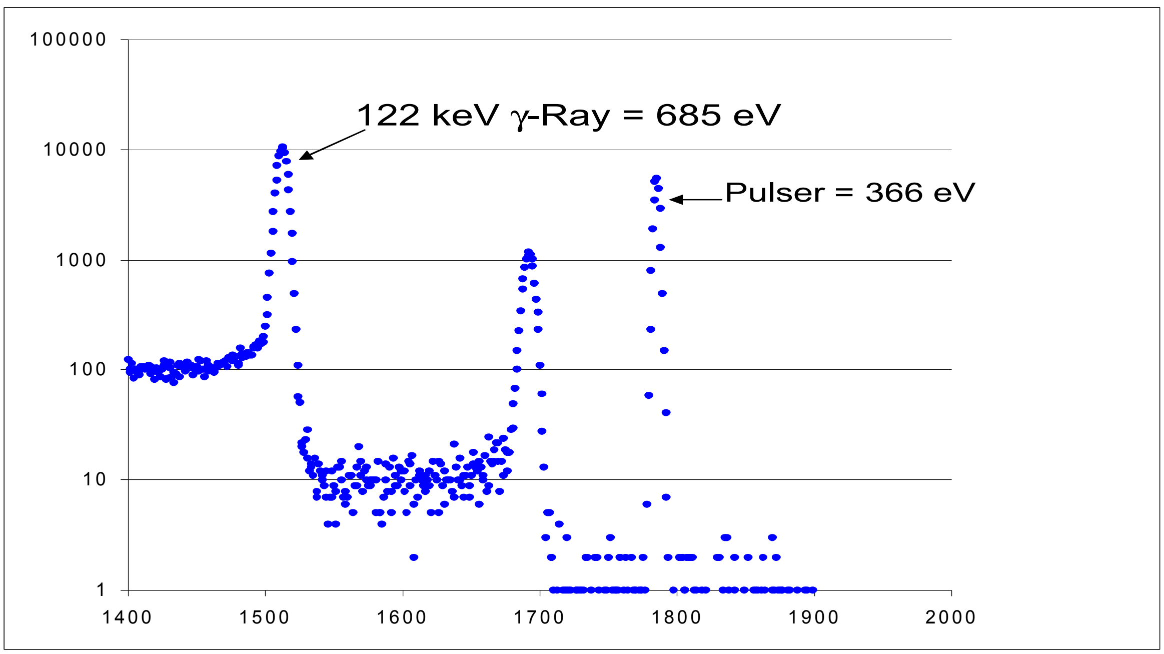

Figure 6. Energy spectrum taken with CryoFree of a ^{57}Co source. The two characteristic gamma-ray lines (122 keV and 136 keV) can be seen with a measured resolution of 685 eV FWHM. In addition, a pulser was used to determine the electronic contribution to the resolution. This was found to be 366 eV.

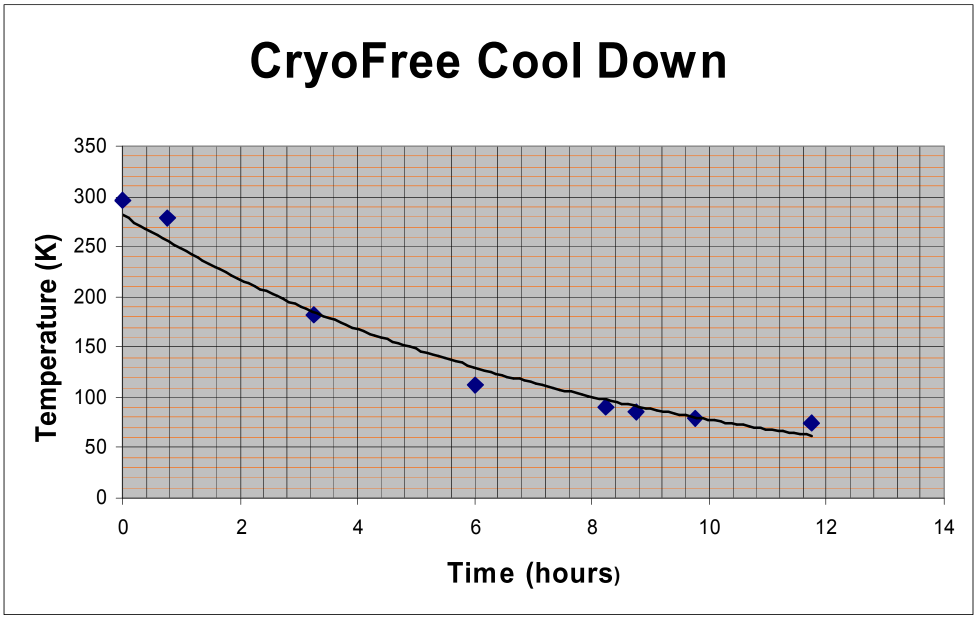

Figure 7. Cool-down curve. The CryoFree operational temperature is at 100 K or below. Starting from room temperature it takes 8 hours to reach this point.

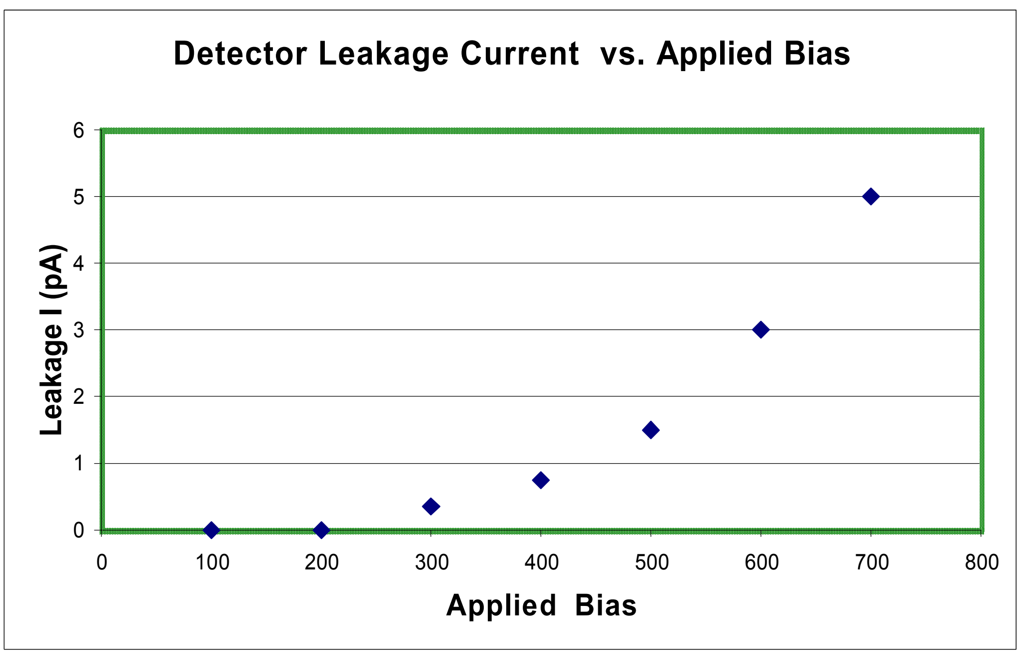

Figure 8. Leakage current. The detector must be operated at a high enough voltage to deplete the detector and achieve good charge collection. However, increased voltage may cause increased leakage current and thus noise contribution. CryoFree could be operated at around 400 V before leakage current became noticeable.

4.0 Technical Issues

There were a few technical issues encountered during the course of this project. The main technical problem was contamination of the detector surface which caused increased leakage current and performance degradation. Normally, the hermetic encapsulation prevents this. However, it was eventually determined that the nitrogen gas itself (used to fill the encapsulation with 2 atm back pressure) was the source of contamination. A clean supply of nitrogen was obtained and it was shown that the detector could then be operated properly.

A second technical problem arose with the cryocooler. The cooler chosen was a new model from Hymatic with significantly greater performance specifications. However, this model gave repeated trouble, did not meet specifications in practice, and was eventually phased out by the company. We have identified and tested a replacement cooler but it has not been integrated into the system.

5.0 Future Prospects

The CryoFree gives a compelling demonstration of the usefulness of a small, lightweight, mechanically cooled germanium detector for field use. The planar geometry of the germanium crystal is ideally suited for high-resolution of gamma-ray lines at moderate energies. Various technical problems were encountered during the project but these were identified and solved. The investigators feel that the technology is now ready for commercialization.