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# GeMini: The Next Generation Mechanically-Cooled Germanium Spectrometer

M. Burks

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**GeMini: The Next Generation Mechanically-Cooled Germanium Spectrometer**


Morgan Burks
Lawrence Livermore National Laboratory
7000 East Ave., Livermore, CA 94550


## ABSTRACT


The next-generation mechanically-cooled germanium spectrometer has been developed. GeMini (*GE*rmanium *MINI*ature spectrometer) has been designed to bring high-resolution gamma-ray spectroscopy to a range of demanding field environments. Intended applications include short-notice and surprise inspections where positive nuclide identification of radioactive materials is required. GeMini weighs 2.75 kg (6 lbs) total including the detector, cryostat, cryocooler, batteries, electronics and readout. It is very low power allowing it to operate for 10 hours on a single set of rechargeable batteries. This instrument employs technology adapted from the gamma-ray spectrometer currently flying on NASA's Mercury MESSENGER spacecraft. Specifically, infrared shielding techniques allow for a vast reduction of thermal load. This in turn allows for a smaller, lighter-weight design, well-suited for a hand-held instrument. Two working prototypes have been built and tested in the lab. The target energy resolution is 3 keV fwhm or better for 1332 keV gamma-rays. The detectors currently achieve around 4.5 keV resolution, which is slightly higher than our goal due to microphonic noise. Our present work focuses on improving the resolution through mechanical and electronic means of reducing the microphonic noise. This paper will focus on the performance of the instrument and its applicability for inspectors in the field.


## INTRODUCTION

Germanium-based gamma-ray spectrometers offer the best resolution of any comparable technology. This resolution allows the user to identify a source of radioactive material with certainty, to distinguish between multiple sources, and to identify a source in the presence of a strong background. A significant drawback is the need for germanium to be cryogenically cooled to around 100 K to operate properly. This is typically achieved using liquid nitrogen. This solution is convenient in a laboratory or facility where access to liquid cryogen is available (and the means to constantly replenish it). However, for many field applications such as short notice inspections, emergency use, or for inspections involving traveling to many facilities, it may be impractical or impossible to maintain a constant supply of cryogen. Thus, germanium detectors have seen wide use in the laboratory but limited use in the field.

The advent of improved mechanical-cooling technology has offered a solution to the problem of cooling germanium detectors and has allowed for a new generation of high-resolution gamma-ray detectors to be developed. These systems offer laboratory-grade performance in a wide range of field environments. A mechanical cooler can be thought of as a mini refrigerator. They exploit one of several possible thermodynamic cycles to cool a gas. That gas in turn indirectly cools the detector through a copper cold finger or similar means.

The first portable instrument using this technology was called Cryo-3 and demonstrated many key technologies [1]. Since then, significant improvements have been made in weight and power and led to the deployment of a mechanically-cooled gamma-ray spectrometer (GRS) flying on NASA's Mercury MESSENGER spacecraft. This mission launched in Aug 2004 and first reached Mercury in January 2008. The GRS represents the first mechanically-cooled germanium detector in deep space. To be successful, advances in the thermal shielding were required [2,3] allowing the instrument to operate in orbit around Mercury with its incredibly harsh thermal environment. These advances have now been incorporated into GeMini to make the lightest, lowest power, high-resolution spectrometer yet available.

In addition to the novel thermal design, GeMini incorporates a new rapid cool down feature. The instrument details and rapid cool down are described below.

**GeMini**

We are developing the next generation mechanically-cooled detector called the GeMini spectrometer (for *GE*rmanium *MINI*ature spectrometer). It is based on a germanium crystal and thus gives superior spectroscopic resolution compared to technology such as scintillation detectors, CZT etc. It is optimized for hand-held use and to operate on short notice in a wide range of field environments. It is mechanically cooled using a Stirling-cycle compressor. This allows it to operate indefinitely without need of liquid nitrogen. It is also optimized for low power and thus can operate on a single set of batteries for up to 10 hours. Table 1 gives the specifications for the instrument. These include the original target specifications and the results obtained so far (as the instrument is still under development).

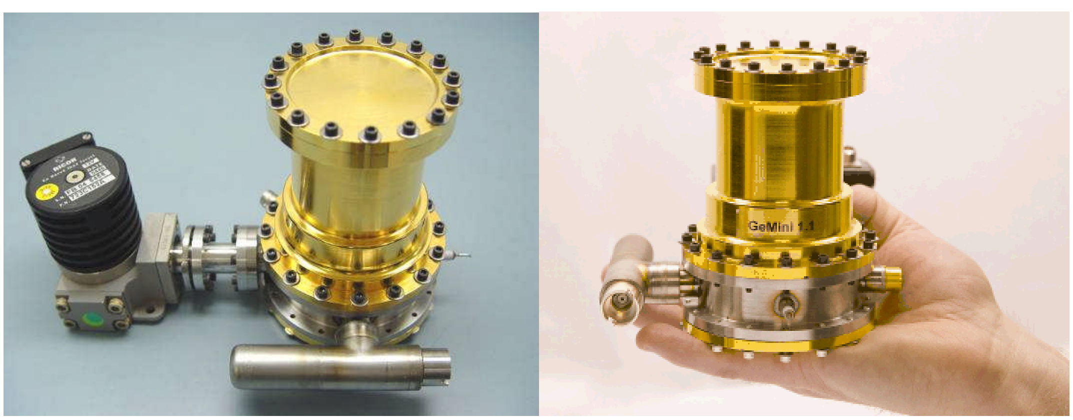


**Figure 1.** Two views of GeMini. In the first picture (left side) the compressor can be seen attached to the instrument.

Figure 1 shows two views of the instrument. In the left most picture, the Stirling-cycle compressor can be seen. The appendage at the bottom of the photo holds the zirconiumallow getter (for vacuum maintenance). The appendage also serves as the pump-out port for initial pump-down.

Figure 2 shows the readout box and interface for GeMini. It is a commercially available product from GBS Elektronik in Germany and is a standard piece of equipment used by the IAEA. It integrates many of the functions needed by a high-purity germanium detector including high voltage supply, low-noise analog power for the preamplifier, and preamplifier input with 4K channel MCA. It also has a data port for communication to a computer running the appropriate analysis software. Note that this piece of equipment is included in the weight and power budgets shown in table 1. A custom readout is designed for the second generation instrument. However, this work is still in progress.


**Figure 2**. MCA 166. This unit is serving as the first generation interface for the GeMini detector. It contains a high voltage power supply, low noise analog power, preamplifier input, multi-channel analyzer and data port for communicating with a palm-top or PC.

**Table 1. GeMini specifications**

| Specifications | Predicted | Achieved to Date |
|---|---|---|
| **Weight (total)** | 2.5 kg | 2.75 kg including electronics & interface |
| **Power** | <10 input | 6 – 10<br>(depending on operating conditions) |
| **Battery Lifetime** | 8 – 10 hours | 10 hours |
| **Resolution** | 3 keV fwhm at 1332 keV | 2.5 keV<br>4.5 keV (w/ cooler running) |
| **Thermal load** | < 500 mW | < 200 mW |
| **Cool-down time** | 15 hours | 10 – 15 (depending on conditions) |
| **Rapid cool-down** | 2 hours | 1 hour! |

## Applications

GeMini is designed for applications that require the superior spectroscopic resolution of a germanium detector. Its hand-held and battery operated allowing it to work well where access is limited, or non existent, to power and liquid cryogen. Some examples where it will prove useful include non-destructive analysis (both attended and unattended), environmental sampling, short-notice inspections, measurement and identification of uranium and plutonium, determination of uranium enrichment levels, and determination of isotopic composition of plutonium samples.

Many of these applications are currently being served with other hand-held devices such as the HM-5 Hand Held Assay Probe (to name just one). These devices are based on other materials such as a NaI scintillator, CZT or other material. These are useful in many scenarios but do not provide the high-resolution spectroscopy that is critical for the applications mentioned above.

**Rapid cool down**

GeMini is designed to be stored at room temperature when not in use for an extended period of time. To achieve a lightweight and low-power design, GeMini utilizes a tiny compressor with a small heat lift capacity. This compressor is sufficient to maintain cryogenic operating temperature but the limited capacity means that the initial cool down ( to approximately 100 K) takes 10 to 15 hours. This cool down time is too long for some applications such as short notice inspections where the instrumentation must be ready when needed.

This problem has been solved in GeMini with the development of a rapid cool down system. This is a new capability that is unique to GeMini. The rapid cool down consists of an extra cooling connection (figure 3). A secondary cooling source (either a more powerful compressor or a liquid nitrogen reservoir, whichever is more convenient) is connected to the instrument. This secondary source cools the instrument in approximately one hour. The secondary source is then removed and the system will then run using the main (small) compressor. The small compressor will maintain temperature as long as needed (up to weeks at a time) as long as power is supplied through batteries or other means. When it is time to return the instrument to storage, the compressor is turned off and the system warms up.

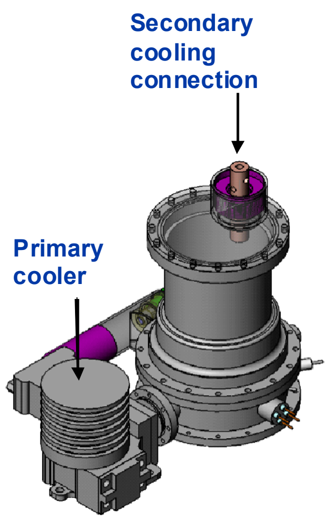


**Figure 3.** CAD drawing of GeMini showing both the primary and secondary cooling interface.

Funding was obtained from NA-241 to develop and demonstrate this new capability. As part of that effort a prototype was built and tested. Figure 4 shows two cool down curves.

The first is the cool down using the small compressor by itself. In this case it took about 10 hours to cool from room temperature to the operating temperature of 100 K. The second curve shows the cool down using an attached liquid nitrogen reservoir. The operating temperature was achieved in one hour. Note that after cool down the reservoir can be removed such that it does not impact the overall size and weight of the system.

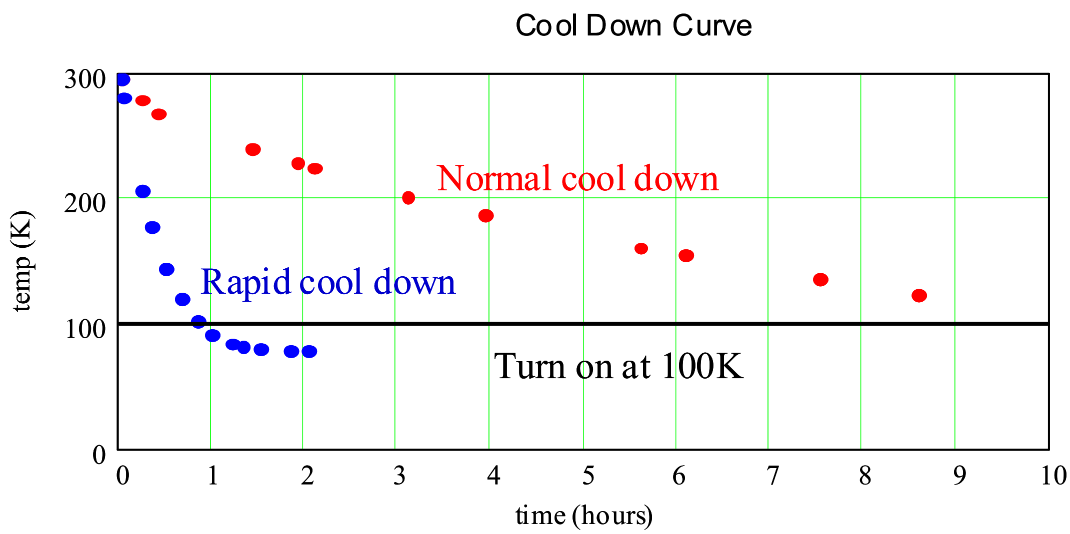


**Figure 4.** Cooling curves for normal cool down (using only the onboard compressor) and the rapid cool down using the secondary cooling interface. The cool down times were about 10 hours and one hour respectively.

## REFERENCES

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