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Lawrence Livermore National Laboratory

Next-Generation Low-Power HPGe Gamma-Ray Spectrometer To Improve IMS Particulate Radionuclide Station Reliability And Data Availability

T3.1-P27

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LLNL developed a low-power and long-lifetime solution to improve reliability of high-purity germanium-based (HPGe) gamma-ray detectors in International Monitoring System (IMS) particulate radionuclide stations. HPGe is a semiconductor that must be operated under high vacuum at cryogenic temperatures (77-100 K) for energy-resolution analysis of gamma-rays emitted by radionuclides. The challenge is that HPGe detectors often fail after a station power outage because, with the return of power/cooling, impurities condense on the semiconductor surface inside the vacuum cryostat. One solution is to not let the detector warm up during power failures, however, existing HPGe detectors require too much power. LLNL has developed a high-efficiency (140%) HPGe detector which requires as little as 12-20 Watts cooling and could replace the higher-power-requiring detector component in IMS stations. The LLNL system requires only 10-25% of the power of current mechanically-cooled HPGe of similar size and could be kept cold via a small solar cell and battery, thereby improving the likelihood the IMS station will fully recover with restoration of power. Engineered for space applications and environments, this poster discusses the current state of the HPGe system, the operational characteristics, and possible application to the IMS.

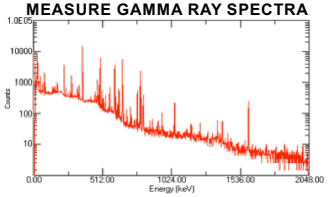
BACKGROUND

- Radionuclide (RN) stations collect air particulates as part of the International Monitoring System. Nearly 80 RN stations are in continuous operation around the world with many in highly-remote locations.
- The particulate filters are measured at the station for gamma-ray emitting radionuclides using high-energy-resolving germanium-based (HPGe) gamma-ray detectors. HPGe must be operated at cryogenic temperatures (77-100K) to identify and quantify whether treaty-relevant radionuclides are present.
- Stations can lose power for extended periods for a variety of reasons which can cause the HPGe detector to warm up. Failure of the detector to recover can cause station down time and reduce RN station data availability.
- LLNL has developed an ultra-low-power and ultra-long-life mechanically-cooled HPGe solution for space science applications which could be implemented terrestrially to improve RN station HPGe reliability. The detector would simply be kept cold through extended outages via a small backup power system such as a small solar panel and rechargeable battery.

RN73, Palmer Station, USA

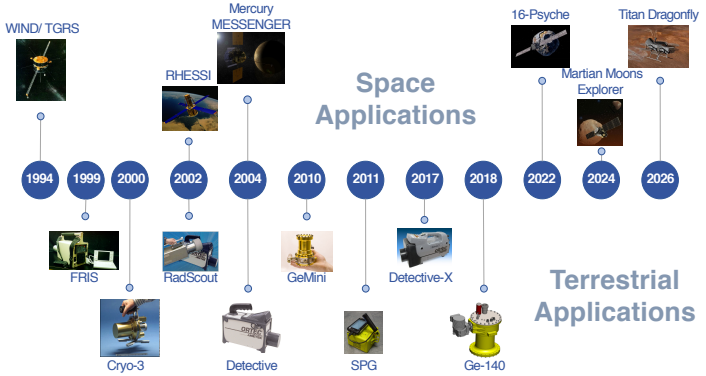
RN13, Douala, Cameroon

IMS PARTICULATE RN STATIONS MEASURE GAMMA RAY SPECTRA



LAWRENCE LIVERMORE NATIONAL LABORATORY HAS A LONG HISTORY OF DEVELOPING HPGE SYSTEMS

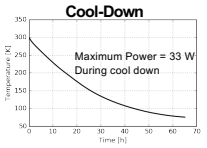
- LLNL develops HPGe-based detector solutions for space and terrestrial applications, many have even been commercialized.



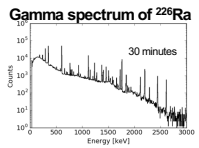
RESULTS

- Being designed with a form factor that should enable retrofit replacement of existing liquid-nitrogen-based or mechanically cooled HPGe.
- Mechanically-cooled HPGe gamma-ray spectra have good energy resolution, power utilization 12-20 Watts, once cold.
- Rapid cool-down options exist but the idea is to simply keep the detector cold all the time since the MBTF is expected to be ≈200,000 hours (>20 y).

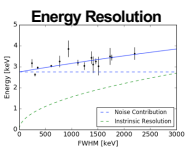
Cool-Down



Gamma spectrum of ^{226}Ra

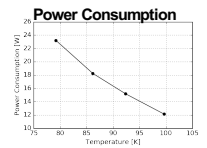


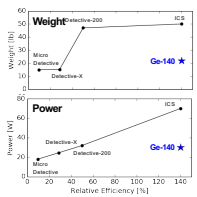
Energy Resolution



- High noise contribution of 2.7 keV (non-optimized preamp)
- 2 keV targeted w/ **optimized preamps**

Power Consumption





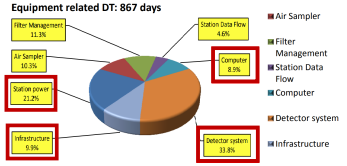
Energy	Energy Resolution (FWHM)
1.3 MeV	3.8 keV (first result) 2.75 keV (goal)
6.1 MeV	6.2 keV
10.2 MeV	9.2 keV

RADIONUCLIDE PARTICULATE STATION DATA AVAILABILITY CAN BE IMPROVED

HPGe DETECTORS REQUIRE COOLING

Cooling of the HPGe to cryogenic temperatures (electrically or with liquid nitrogen produced locally) is required to provide the energy-resolution performance needed to identify and quantify treaty relevant radionuclides.

Distribution of Equipment and Infrastructure Subsystems Failures (%) (All Systems)
1 Nov 2017 - 31 Oct 2018; 69 radionuclide stations
Equipment related DT: 867 days



POWER LOSS RESULTS IN DETECTOR FAILURES

A significant fraction of the data loss in RN particulate stations is attributed to detector system failure, power, or infrastructure (often linked to power cycling the detector cooling system).

Possible contributor to detector failure (cooling loss resulting in HPGe vacuum system failure, for example).

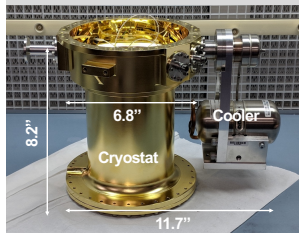
From PTS Report on Data Availability Statistics, ECS/WGB-52/PTS/11 (https://ecs.ctbto.org/file/21617)

GE-140 IS SPACE QUALIFIED, LOW-POWER CONSUMING, WITH HIGH EFFICIENCY AND LONG-OPERATING LIFE

The Ge-140 is derived from LLNL-developed technology for space-based gamma-ray spectrometers.[1,2,3] The designs for space-based and terrestrial applications are complementary as they both require:

- Ruggedness to survive rocket launch or the rigors of hand-held use in the field.
- Low mass, which is at a premium in space, and also important for portable technology.
- Low power consumption for power-starved space applications or to operate all day in the field on a single rechargeable battery.

Ge-140 Detector Hardware



Ge-140 Specifications	
HPGe Detector	10 cm × 10 cm, 7.5 lb P-type coaxial 140% Relative Efficiency
Cooler	Stirling engine cryocooler (Sunpower Cryotel DS1.5)
Weight	17.3 lb (22 lb goal with full packaging)

[1] J. Goldsten et al., "The MESSENGER Gamma-Ray and Neutron Spectrometer" Space Sci. Rev V. 131, no 1-4 Aug 2007 pp 339-391.
[2] "A Hand-Held, Mechanically-Cooled, Radiation Detection System for Gamma-Ray Spectroscopy." Patent # 7,732,781
[3] Nathan Hines et al., "Ge-140: A High-Resolution, High-Efficiency, Mechanically-Cooled Gamma-Ray Spectrometer," to be presented at the IEEE Nuclear Science Symposium in Manchester, United Kingdom, October, 2019.

CONCLUSIONS

- Ge-140 shows tremendous potential as a low-power, long-operating-life solution to chronically failing HPGe in remote IMS stations.
- Low-power utilization with the Ge-140 means that the HPGe could be maintained cold even during extended station power outages via a rechargeable battery and small solar cell.

FUTURE

- Designed to enable retrofit replacement of existing HPGe.
- Technology being licensed to industry for production.
- Likely a couple of years until they are commercially available.

NNSA National Nuclear Security Administration

LLNL-POST-773397

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