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Monitoring indications of high purity germanium detector failure

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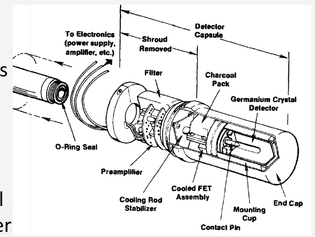
Abstract

The CTBTO aims to maximize data availability and spectral quality from its radionuclide network. The radionuclide network will consist of 80 stations of which many are in remote locations. In order to achieve the data availability goal, it is important to exploit possibilities to predict failures of the gamma detectors. High resolution gamma detectors require reliable cooling and good cryostat vacuum. PTS staff are developing ways to monitor these parameters and will present some exemplary cases in this presentation. The electrical cooling systems CP5 and CP5+, manufactured by Canberra, are operated in a mode which keeps the detector temperature at a constant level. When the detector vacuum deteriorates more power is needed to maintain the same detector temperature. Therefore cooling power consumption is a very good benchmark for an adequate detector vacuum and should be included in the State of Health. By monitoring the full width at half maximum (FWHM) for a selected peak and observing a steady widening over time one can infer deteriorated detector vacuum. On the other hand ORTEC X-Cooler II and X-Cooler III are operated by supplying constant power. When the vacuum deteriorates the Cooler cannot absorb the higher load which leads to an increase in crystal temperature and detector resolution.

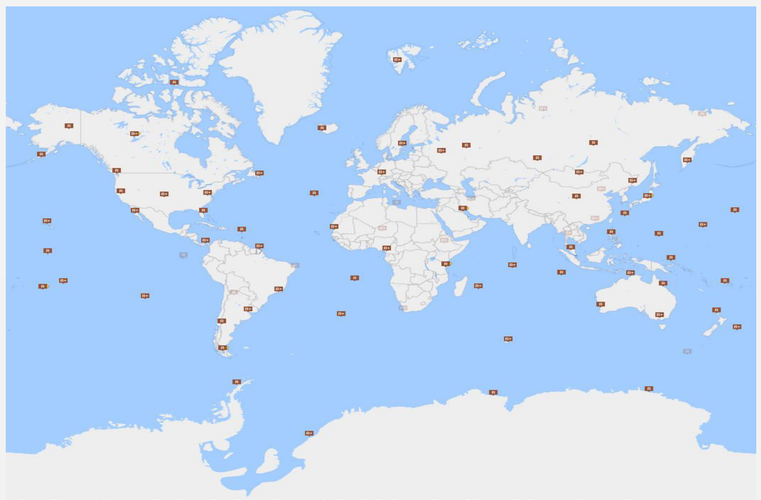
HPGe detector operation

HPGe detectors are operated in cryostats at a temperature of around 100K in order to keep the thermally-induced leakage current low. Molecular sieves or activated charcoal are integrated in the cryostats as adsorbent material to maintain adequate vacuum for reliable operation. The molecular sieves trap gas molecules at low temperature. Once the detector temperature starts to increase due to increased internal pressure the molecular sieve begins to outgas at a higher rate until the cooler fails to maintain cryogenic temperature.



The energy resolution is comprised of several contributing factors, one of which is leakage current. Therefore the FWHM can be used to monitor the quality of the detector and anticipate required service or repair.

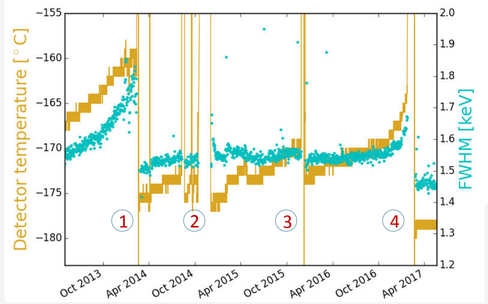
Radionuclide network

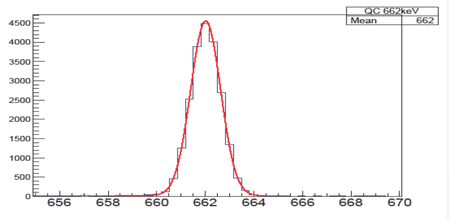


The above figure depicts the locations of the 80 CTBTO radionuclide stations. The dark boxes represent the certified stations.

Cooling systems

Electrical cooling with constant power





The FWHM @ 662keV derived from the daily QC measurement. Peak fitting performed with a ROOT based script.

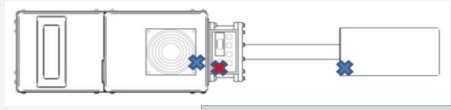
① Detector warm up followed by a thermal cycle
② UPS failure
③ Power outage
④ Detector warm up followed by evacuation

Thermal cycling leads to lower temperature & FWHM
Thermal cycling combined with evacuation provides better results

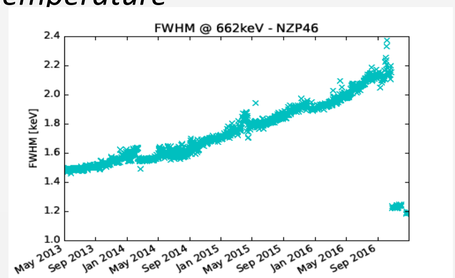
Electrical cooling with constant temperature

For electrical cooling systems which maintain a constant detector temperature a good benchmark for the vacuum quality is the power consumption of the cooling systems. This parameter will be included in the SoH monitoring in the near future. Data on the power consumption are currently provided on request.

Despite the constant temperature on the cooler side, deterioration of the cryostat vacuum is responsible for an increased temperature gradient.



Monitor power consumption & FWHM



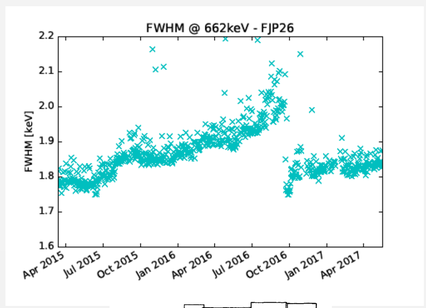
The above diagram shows the trend in the FWHM @ 662keV over a period of more than three years. The reported power consumption in September 2016 was 185W. It was reduced to 80W after evacuation.

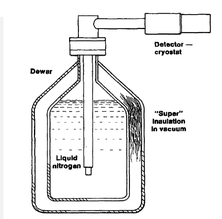
Liquid nitrogen cooling

Similar to the electrical cooling with constant temperature, liquid nitrogen cooled detectors have constant temperature at the tip of the cold finger. The increased temperature gradient between the cold finger tip and the Germanium crystal results in increased leakage current and hence energy resolution degradation.

The detector at FJP26 is cooled with liquid nitrogen which is generated by an Elan system. The trend in the FWHM as monitored using a QC source shows clear signs of vacuum degradation. In September 2016 the detector system, including the MCA filter parameters, was optimized resulting in improved energy resolution. However, the trend of energy resolution deterioration persists.

Monitor FWHM & liquid nitrogen consumption

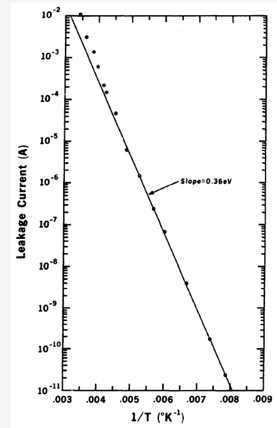




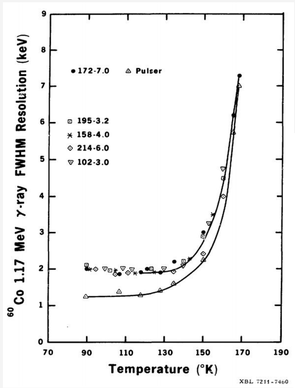
Temperature vs. FWHM

According to Pehl [1] the leakage current is correlated with the detector temperature via surface states. The leakage current is mainly responsible for the degradation of the energy resolution at higher detector temperatures.

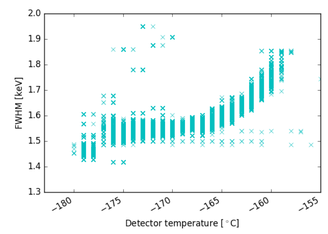
The shaping time constant can be adjusted in order to minimize the effect of the leakage-current noise at higher detector temperatures.



3. Leakage current as a function of 1/T for detector 195-3.2. The data plotted were obtained with 500 Volt bias.



Operational Characteristics of Germanium detectors at higher temperatures, R. H. Pehl et al.



GBP66: Correlation between the detector temperature and FWHM

Summary

- Monitoring trends in temperature, cooling power consumption and FWHM are helpful tools to monitor vacuum quality
- Thermal cycling is a temporary fix
- Cooling systems which are designed to adjust the power consumption for constant temperature and liquid nitrogen cooled systems allow for an extended response time
- The anticipation of failures and the resulting response time is beneficial, especially when shipping times and importation is a challenge
- Adjusting the shaping time constant can improve the energy resolution in case of significant leakage current
- Threshold criteria to be defined based on technology, data availability, data quality and cost

References

[1] Operational characteristics of Germanium detectors at higher temperatures, R. H. Pehl et al., LBL-1568
[2] Radiation Detection and Measurement, G. F. Knoll