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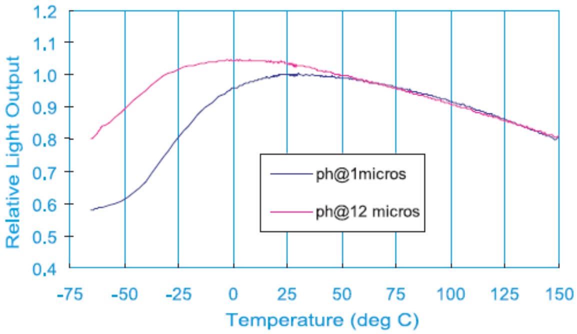
AMETEK
MATERIALS ANALYSIS DIVISION

How stable are the Gamma-Rad5, TB-5, and Amptek's other scintillation spectroscopy products?

The signal processing electronics and power supplies provided by Amptek are very stable, with temperature coefficients of <50 ppm/°C. However, the gain of scintillators and photomultiplier tubes (PMTs) exhibit significant drifts with temperature and time. Only the gain should change but its changes are often significant. Understanding these drifts and how to correct for them is very important for accurate analyses.

Temperature coefficient

The light produced by a scintillator is typically a function of temperature. The plot to the right shows the temperature coefficient of NaI(Tl), a common scintillation material[i]. This is unavoidable (it arises from physical processes in the scintillator) but is predictable so one can correct for it.



PMTs also have a temperature coefficient: the gain of the PMT arises from the emission of secondary electrons from the dynodes, and the secondary emission coefficient ε_s decreases with temperature. Because the PMT gain is an exponential function of ε_s, even small changes in temperature can be important. The temperature coefficient will be constant for a give PMT but varies among PMTs of the same model. One can correct for it but each unit should be calibrated.

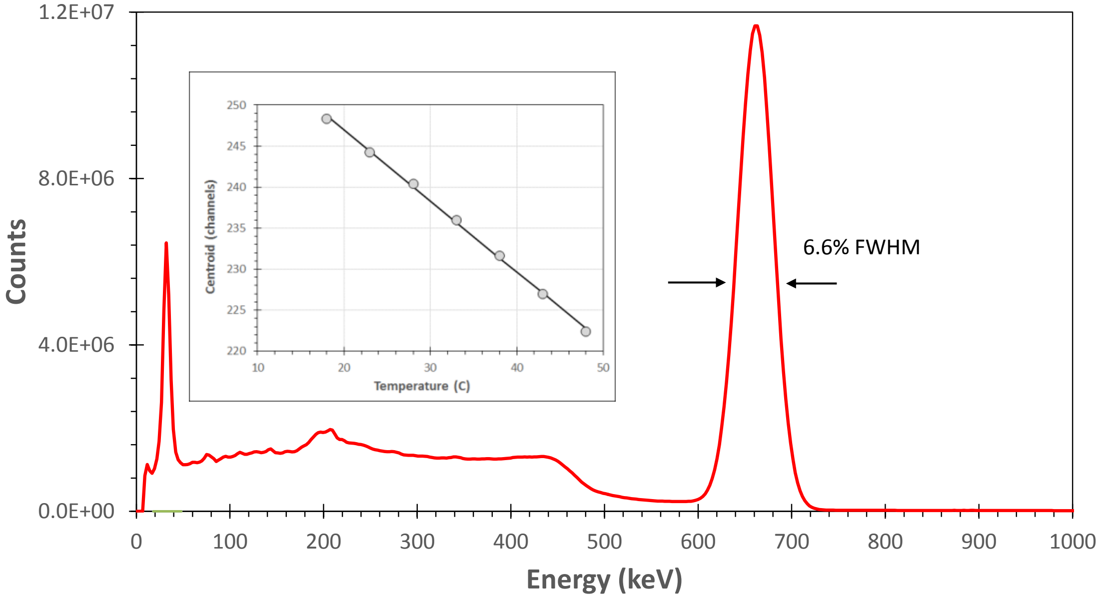
Amptek has measured total temperature coefficients (scintillator and PMT together) of 0.5 to 1.5%/°C for NaI(Tl). In a typical lab environment, daily temperature changes up to 5 °C are common; this results in a change that can be larger than the FWHM of common photopeaks so is quite important.

Gain is not the only quantity which depends on temperature but Amptek's signal processing algorithms are insensitive to the others. The efficiency, resolution, are largely independent of temperature. Note that Amptek's Gamma-Rad5 may be used over a wide temperature range (-25 °C to +65 °C) but that the rate of thermal change must be limited to<10°C/hour. If the temperature changes too rapidly, mechanical stress can crack the scintillator crystal.

Correcting for temperature

Amptek's products include a precision temperature sensor (AD592) with an accuracy of 0.1°C, mounted near the PMT. To correct for the temperature-dependent gain, we recommend the user measure the temperature coefficient of a particular unit, fit the data to a gain versus temperature curve, and then adjust the gain as a function of temperature.

Amptek's software includes algorithms to perform the adjustment. In tests at Amptek, the temperature was changed in 5°C steps from 15°C to 40°C. It was important to wait long enough at each step for the gain to stabilize. These data were fit to a straight line. The results of the fit were then input to the software, which adjusted the fine gain of the digital processor according to the temperature. The plot below shows the result of such a correction: a ^{137}Cs spectrum was measured with NaI(Tl) during a 20°C temperature ramp (over 20 hours). The photopeak was 6.5% at constant temperature and 6.6% during the temperature sweep, with the correction applied. Without correction, the photopeak was 10% FWHM and not Gaussian.



Drift with time

The scintillator's light output does not change with time. The gain of the PMT, however, does change with time. According to PMT manufacturers [ii],[iii], drifts with time are inevitable, arising from changes in ε_s from charging of dielectric surfaces (thus changing electron trajectories), and other effects.

As used in a typical scintillation spectroscopy application, the gain drift can eventually reach a value as low as 1% per month but only after extended, steady operation. During the first day of operation, the gain may change by several percent. The figure to the right (from Photonis, a PMT manufacturer) shows typical gain versus time for the first day for several PMTs. (the same model) After the first day at constant temperature and HV bias, the gain change should drop to about 1% per day and may then eventually drop to 1% per month or so. If high voltage is removed, then the entire stabilization process must be repeated: it may change by several percent in the first day after high voltage is applied.

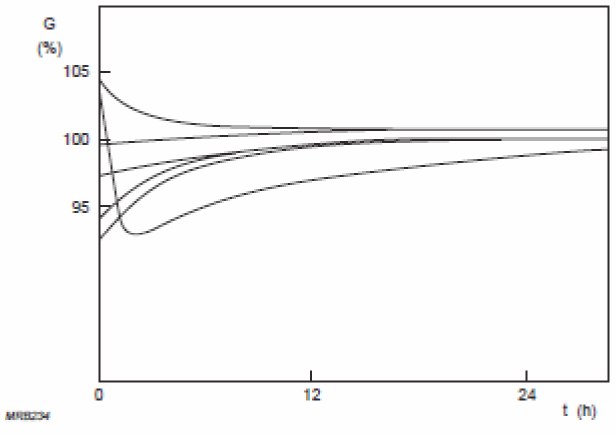
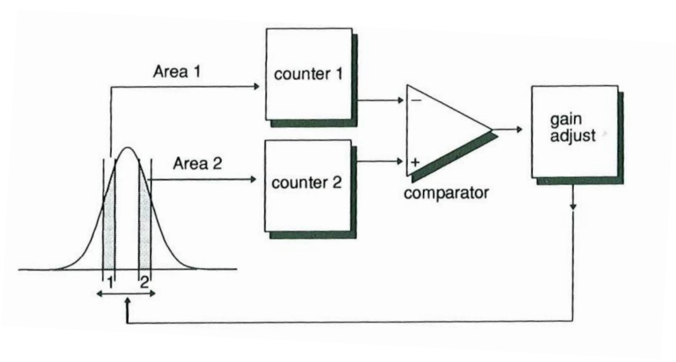


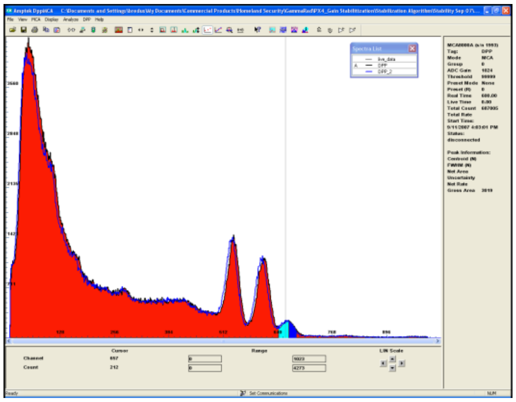
Fig.4.21 Examples of initial low-current drift

Correcting for temporal drift

The best way to correct for temporal drift is to track an actual photopeak in the spectrum. The ^{40}K photopeak is commonly used because it is ubiquitous in the environment: there is potassium in nearly every rock and building material and some fraction is radioactive, emitting a 1.461 MeV gamma-ray. One can track the centroid of this peak, but an even more sensitive method is to set a region of interest on either side of the centroid; a change in this ratio indicates a change in gain and can be used to command a new fine gain setting.

In the figure below, the block diagram on the left illustrates a “spectrum stabilizer”. Such modules were often implemented in hardware but with Amptek’s digital processors can also be implemented in software. The plot on the right shows a spectrum measured with an Amptek GammRad showing the ^{60}Co photopeaks and also the ^{40}K peak, with two ROIs.





The main challenge to using the ^{40}K peak is that the count rate is very low:

- It can take a long time, a large fraction of an hour, to obtain enough counts to accurately estimate gain. If the temperature changes during this time, correction is difficult. Therefore, we recommend the user first run a temperature correction and then estimate temporal drift from the temperature-corrected result.
- If the gain is corrected too quickly, with too few counts, fluctuations from counting statistics lead to fluctuating gain corrections and this will decrease resolution. One must pay careful attention to the optimum.
- Although ^{40}K is ubiquitous, the count rate varies significantly from one location to another (depending on the materials in the environment). Care must be taken to ensure good statistics under many conditions.

Because the details of the algorithm needed to tailored to a particular application, Amptek has not yet released a general purpose algorithm or included this in standard software. Our algorithms first implement the temperature correction discussed above. From, the temperature corrected spectra, the counts in the two ^{40}K ROIs are determined. These counts must be summed or averaged over a long period of time (often longer than the spectral data acquisition interval), and then the gain correction estimated. Logic is needed to identify overlapping peaks and other possible error sources.

There are alternatives to ^{40}K correction. Scintillators can be purchased which contain a weak radioactive source, providing a constant calibration reference. In some application, however, these gamma-rays will degrade the detection limit. Scintillators can also be purchased with an optical pulser; these pulses can be used to measure gain. The challenge is that optical pulser circuits tend to exhibit variations with temperature and time so stabilizing them is not trivial.

Lifetime and aging

PMTs are also subject to aging: as charge is extracted from the dynodes, the surface of the material which has a high secondary electron emission coefficient changes, reducing emission and thus gain. This ultimately limits the lifetime of a PMT but is usually not important in scintillation spectroscopy applications where the current is low.

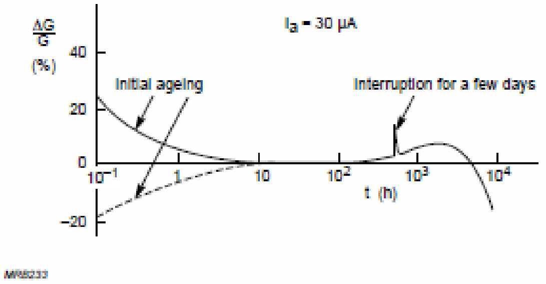


Fig.4.20 Relative gain variation of a photomultiplier operating at high average current

The total charge which can be extracted is usually hundreds or thousands of coulombs. PMTs are often used in optical measurements with a large anode current and in this cases, aging limits the life. In most scintillation spectroscopy applications other factors limit lifetime, e.g. handling or leaking of He through the glass envelope.

References

The gain stability, drift with time, lifetime, and aging of PMTs are discussed in detail by the major PMT manufacturers. Both Hamamatsu and Photonis have prepared PMT User Manuals with excellent and details discussions of these issues. Algorithms to stabilize gain are also discussed in the literature.

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[i] NaI(Tl) Data Sheet, St. Gobain, http://www.crystals.saint-gobain.com

[ii] Photomultiplier Basics and Applications, from Hamamatsu,

https://www.hamamatsu.com/resources/pdf/etd/PMT_handbook_v3aE.pdf

[iii] Photomultiplier Tubes: Principles and Applications, from Photonis,

http://www2.pv.infn.it/~debari/doc/Flyckt_Marmonier.pdf