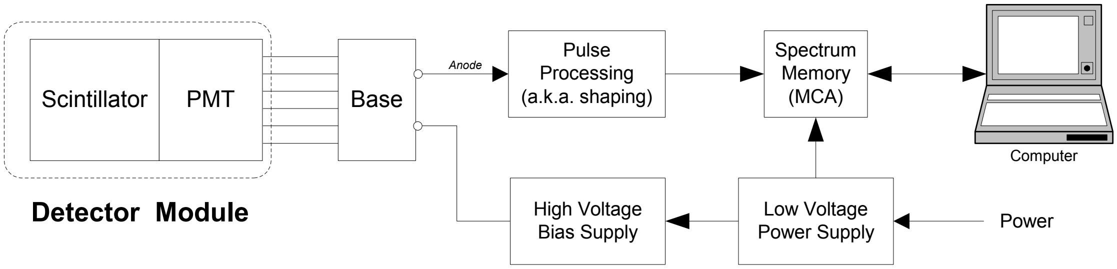
Amptek Gamma-Ray Products: Frequently Asked Questions

Amptek has a family of products, some of which are shown below, which are designed and used for scintillation spectroscopy. This application note is designed to address key questions, particularly in selecting the right product, and to offer application advice which applies across the entire product family.

Photo showing, from right, (1) the Gamma-Rad5, a complete scintillation spectroscopy system; (2) the TB-5 digital tube base plugged into a scintillator/PMT; (3) the DP5G/PCG electronics assembly; and (4) the DP5G digital pulse processor for scintillation spectroscopy.

1 What is the difference between the Gamma-Rad5, TB-5, and DP5G? Which is best in my application?

- All are designed for scintillation spectroscopy and are based on Amptek's digital pulse processing (DPP) technology. They all share the same communications software and protocols.
- They differ in how much of the complete spectroscopy solution they provide, i.e. in how much of the complete solution the customer must provide.



The figure above shows a generic scintillation spectroscopy system. It includes (a) the scintillator and PMT, (b) a tube base which connects the PMT to other components, (c) pulse shaping electronics and MCA, (d) a high voltage bias supply, (e) low voltage power supplies, and (f) computer and external power supply.

A photograph of Amptek's products is shown below while block diagrams are shown on the next page but we can summarize the options here:

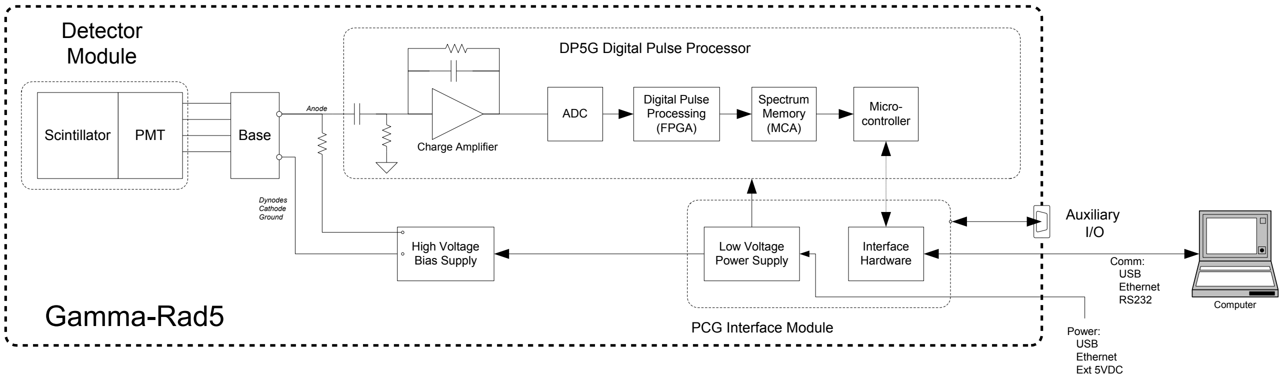
- ***Amptek's Gamma-Rad5*** includes everything (except the computer). It includes the scintillator and PMT, the tube base, the pulse shaping and MCA, the HVPS, and the LVPS. These are integrated in a single, rugged package.

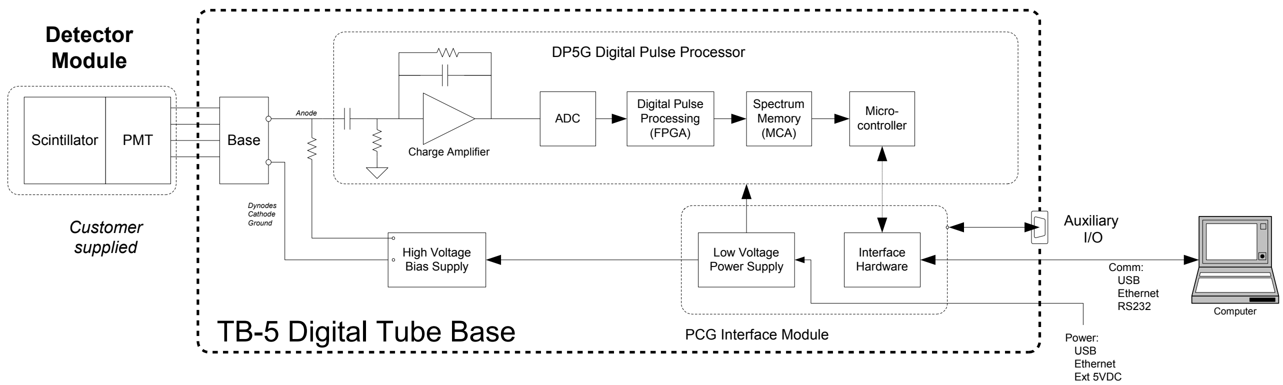
  The user can select the scintillator material and geometry. The most common systems are 76x76 mm, and 76x152 mm, and 10x10x40 cm NaI(Tl) for gamma-ray spectroscopy. Amptek can provide many other materials and geometries, for example $CeBr_3$ for higher resolution gamma-ray spectroscopy, CLYC for simultaneous gamma-ray spectroscopy and neutron counting, and others.
- ***Amptek's TB-5*** includes everything except the scintillator and PMT and is packaged. The user must provide the detector module, which connects to a standard 14-pin tube base in the TB-5.
- ***Amptek's DP5G kit*** includes the signal processing electronics, the low voltage power supplies, and standard I/O connectors. The DP5G kit is designed for standalone use as part of a complete system, e.g. a handheld radiation detector. The user must provide the scintillator and PMT but also the HVPS and pacaking.
- ***Amptek's DP5G*** is the board which provides the pulse shaping and MCA functions in the Gamma-Rad5 and the TB-5. The DP5G is designed only for standalone use as part of a complete OEM system, e.g. a handheld radiation detector. The user must provide the scintillator and PMT but also the HVPS, the LVPS, and connectors.

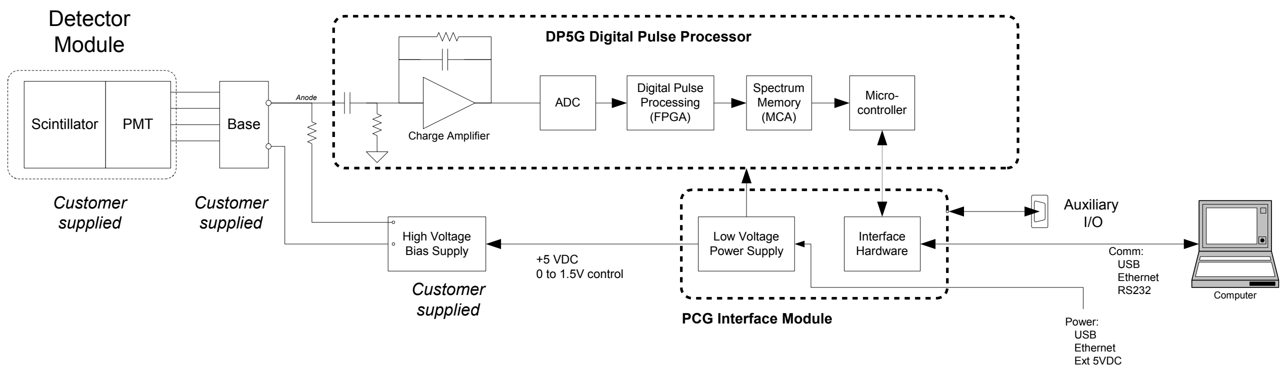
Amptek has an optional, higher speed version of the signal processor, which uses an 80 MHz ADC. It is not generally recommended for NaI(Tl), where the decay time of the scintillator limits count rates, but can be useful with other materials.

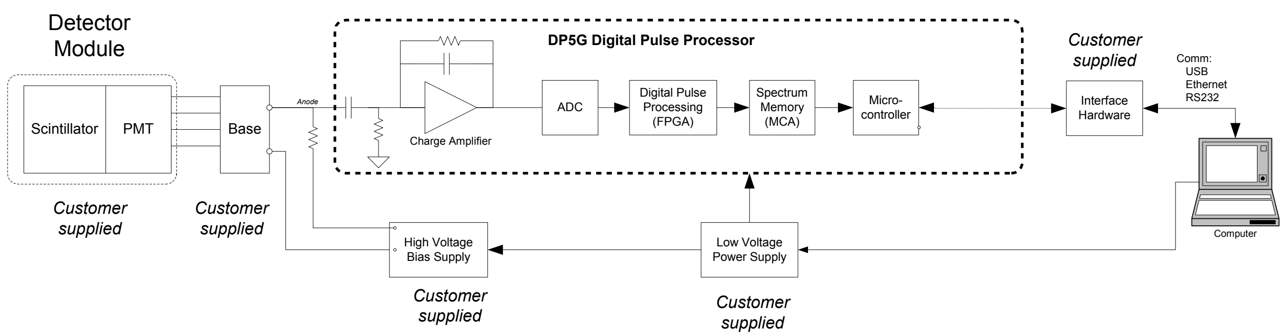
All of these products come with data acquisition and control software, including a library of subroutines for control with the user’s software. A cross-platform library is available for Linux and other uses. Amptek can provide spectrum analysis software, to process the raw spectrum and output the list of identified isotopes and their activities, after appropriate calibration.

Amptek system configurations









These are Amptek's standard scintillation spectroscopy product offerings. We can provide custom versions or help you customize them. Please contact Amptek for more information.

2 Is the Gamma-Rad5 comparable to a turn-key radioisotope identifier?

The Gamma-Rad5 contains all of the hardware required to do gamma-ray spectroscopy and identify isotopes. It includes software to control the hardware, readout the data, and do simple data processing. One can purchase SODIGAM analysis software from Amptek. But the Gamma-Rad5 is not a turn-key radioisotope identifier. The customer must, at a minimum, configure and calibrate the analysis software. In addition, most true “radioisotope identifier ” (RIID) turn-key systems have a simplified user interface for the software and most include battery power, compact displays, etc.

The Gamma-Rad5 is ideally suited to users either (a) developing an RIID or (b) integrating a high performance, rugged gamma-ray sensor into their complete system. For example, the Gamma-Rad5 is well suited to expert laboratory users and customers needing a tailored solution for specific applications not easily addressed by the general purpose turn-key systems. It is also well suited to an OEM making turn-key isotope identifiers or gamma-ray spectrometers.

The Gamma-Rad5 is unique in providing a high performance, integrated, rugged, and yet highly configurable sensor assembly. Configurability is key: the customer can select among many scintillator materials and geometries, has access to a wide range of signal processing parameters, and can tailor the interfaces. The Gamma-Rad5 has many auxiliary I/O signals, simplifying integration with external hardware. It is supplied with a library of subroutines and example code so can be used with a customer's spectrum processing and display software. The same hardware and software interfaces are used with Amptek's other digital processors, which can be used with HPGe, CdTe, SDDs, and other detectors.

3 Do you have a solution for HPGe, CdTe, and other detectors?

Yes, Amptek has a family of signal processors, the DP5 family, which can be tailored to support a wide range of spectroscopy detectors.

- Amptek does not sell HPGe detectors but does provide signal processing electronics and gamma-ray analysis software optimized for HPGe.
    - For benchtop applications, we recommend the PX5-HPGe.
    - For portable applications, we recommend a special configuration of the DP5.
    - For analysis, we provide the GAMMA-W software.
- Amptek provides the X-123-CdTe which includes CdTe radiation detectors. With a thickness of 1 mm, these are optimized for X-ray spectroscopy but can certainly be used in gamma-ray detection, particularly in the <250 keV range.
- A variant of the DP5, with a custom preamp, is used with proportional counters.

All of these digital processors has an identical software interface, supported by the DPPMCA software package and the software developer's kit. A user can readily develop a family of radiation detectors using the same core signal processing and interface technology.

These digital processors all include Ethernet, USB, and RS232 interfaces. With Ethernet, one can easily assembly a network of radiation detectors which can readily include scintillators, CdTe, HPGe, etc. With RS232, one can easily connect the processor to PDAs or small computers to make a family of handheld systems, sharing the core software and processor technology.

4 I am now using a tube base with a preamplifier. Can I use this with your products?

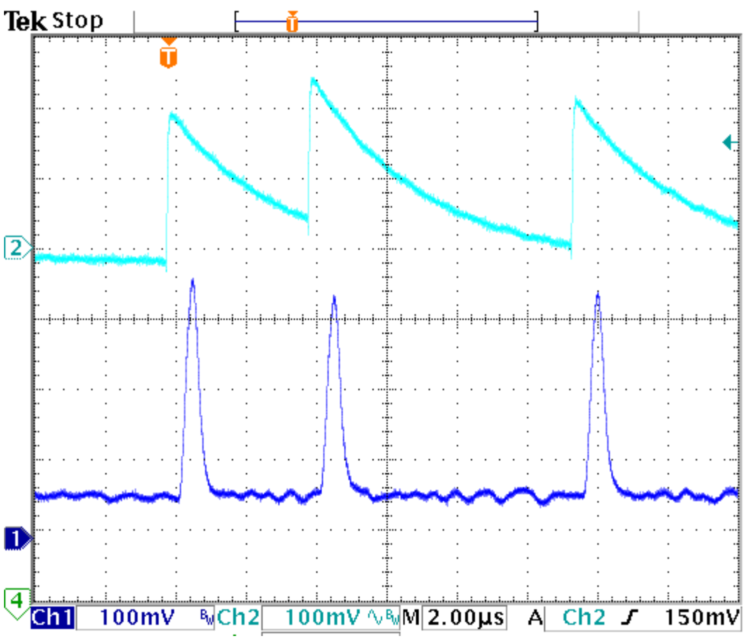
Only if you modify either your preamplifier and/or the DP5G. The first stage of a standard DP5G is a charge amplifier. Its input must be the anode output from the PMT (usually AC coupled). It requires a current pulse as its input. The DP5G's digital circuitry requires a charge amplifier with a 3.2 μs time constant before the ADC.

- If your preamplifier is a charge amplifier, then it can be used if you (a) provide the 3.2 μs time constant and (b) reconfigured the DP5G first stage as a buffer. Rather than putting the 3.2 μs time constant in your preamplifier, you can implement a pole-zero cancellation circuit in the DP5G first stage.
- If your preamplifier is a transimpedance amplifier, then you must reconfigure it as a charge amplifier with a 3.2 μs time constant for use with the DP5G.

For more information, please refer to the *DP5G User Manual*.

5 How can you get good count rates even with a 3.2 μs tail in your preamp?

The algorithm running in the digital pulse processing removes this tail. There is a digital pole-zero circuit which removes the 3.2 μs tail and instead can use a much shorter filter. The plot below shows an oscilloscope trace, illustrating the charge amp output (light blue) and also the shaped pulses (dark blue). This example used a $CeBr_3$ scintillator and a 200 ns T_{peak}. Note that the shaped pulses have much shorter duration than the charge amplifier output. It is the shaped pulse which determines the count rate



6 Do you provide gamma-ray analysis software?

Amptek is now teaming with Dr. Westmeier GmbH to provide the SODIGAM high performance gamma-ray analysis software. This software takes the spectra acquired by Amptek's processors and analyzes it to determine the radioisotopes which are present and to quantify the activity. Once the hardware and software have been configure and calibrated, analysis involves the following steps:

1) SODIGAM takes as its input the raw spectrum and first applies an energy calibration.

2) SODIGAM then searches for photopeaks, within predetermined regions of interest, and fits those peaks as overlapping Gaussians superimposed on a background. This fit gives the intensities of predetermined photopeaks.

3) From these intensities, SODIGAM identifies which nuclides are present, then corrects for the efficiency as a function of energy (based on a prior calibration)

4) Finally, SODIGAM computes the activities of the radioisotopes which are present. This is given in a report, the final output.

Our standard DPPMCA data acquisition and control software obtains the raw spectra, adjusts the hardware parameters, and can perform the energy calibration. DPPMCA then spawns a Sodigam process, passing the data into the analysis software, which then processes the spectrum and prepares a report. To use Amptek's hardware with the Westmeier gamma-ray analysis software, one needs the analysis software and a security plug, available through Amptek. For further information on SODIGAM, refer to Westemeier's website at http://en.westmeier.com/ .

7 What scintillation materials can you use with these products?

Most of them. The algorithms for these processors were designed to be very flexible, permitting most scintillation materials to be used, with appropriate configurations of the processing parameters via software. We have tested with NaI(Tl), CsI(Na), $CeBr_3$, CLYC, and many others. The user manuals provide some guidance regarding how to tailor the parameters. Please note that, even with an optimized system,

8 What are the advantages of digital processing for scintillation spectroscopy?

In both analog and digital pulse processing systems, this preamplifier output goes to a shaping amplifier and then to a multichannel analyzer (MCA). The shaping amplifier's purpose is to permit an accurate determination of the peak height. The pulse shaping removes the DC baseline, reduces distortions due to overlapping pulses, and filters out the broadband noise. The shaping amplifier also amplifies the pulse to permit accurate measurements. Both digital and analog systems have this same purpose and include similar elements: a differentiator (or high pass filter), an integrator (or low pass filter), voltage gain, baseline restoration, etc. In both systems, the pulse amplitude is ultimately obtained in a digital form, yielding an energy spectrum in the MCA memory.

The difference is that the analog processor uses analog circuitry to perform the pulse shaping, then digitizes the peak of the final shaped pulse. The pulse shaping is implemented using op-amps, resistors, and capacitors. The digital processor digitizes the preamplifier output, then shapes the pulse with a digital filter running in an FPGA. The functions are the same, but the digital pulse processor moves the digitization earlier in the signal processing chain.

There are three primary advantages to digital processing: better performance, greater flexibility, and greater stability and reproducibility.

1) The digital processor has a trapezoidal shape, with a finite impulse response (for faster recovery to baseline) and better noise filtering. It provides lower electronic noise and lower pile-up, simultaneously. Researchers derived long ago the ideal filters for use in nuclear electronics, but the transfer functions cannot easily be produced in practical op-amp circuits. Digital filters more closely approximate the ideal transfer functions. This improves performance, specifically better noise filtering with better performance at high count rates.

2) There is no dead time associated with the peak detect and digitization, so a digital processor has considerably higher throughput than an analog system. Further, since it has a finite impulse response, pile-up and other pulse overlap effects are reduced.

3) In an analog pulse processor, most parameters are determined by resistors and capacitors. It is impractical to have many different configuration options in an analog system. In a digital system, shaping time is set by the length of digital delay. In a digital system, one can easily have many more parameters and configuration options. These parameters include not only the shaping time but baseline restoration parameters, pile-up rejection parameters, etc. A digital system has far more configuration options so the user can readily tailor a system to the needs of an application, resulting in better performance.

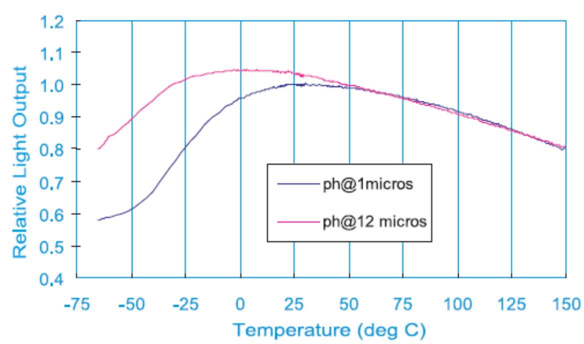
4) Because the analog system relies on resistors and capacitors, its stability is limited to the stability of these components and its reproducibility to their tolerances. In a digital system, the stability and the reproducibility are much better, because they derive from a few very accurate references, eg. the crystal oscillator to set timing. In an analog system, fine gain usually comes from a pot and it is difficult to return to a previous setting, but in a digital system, one can back to exactly the same parameters.

9 How stable are scintillation spectrometers with time, temperature, etc?

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 very important. 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[1]. 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 depends on the PMT, so 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 is larger than the FWHM of common photopeaks so is quite important. The plot to the right shows ^{137}Cs spectra measured over a 5°C range. It also shows the measured photopeak channel versus temperature for a typical unit.

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

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

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 (AD 592) 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 are input to the software, which adjusts the fine gain of the digital processor according to the temperature. The plot to the right shows the result of such a correction: a ^{137}Cs spectrum was measured with NaI(Tl) during a 40°C temperature ramp (over 24 hours). The photopeak width 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 [2],[3], drifts with time are inevitable, arising from changes in ε_s and also from charging of dielectric surfaces (thus changing electron trajectories) and other subtle 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 a 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.

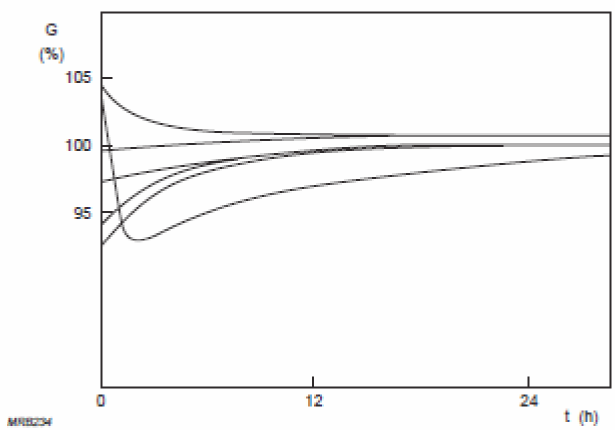


Fig.4.21 Examples of initial low-current drift

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

[2] Photomultiplier Basics and Applications, from Hamamatsu, https://www.hamamatsu.com/resources/pdf/etd/PMT_handbook_v3aE.pdf

[3] Photomultiplier Tubes: Principles and Applications, from Photonis, http://www2.pv.infn.it/~debari/doc/Flyckt_Marmonier.pdf

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. The main challenge to using the ^{40}K peak is that the count rate is very low. This causes several problems:

- 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.

There are other alternatives. 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.

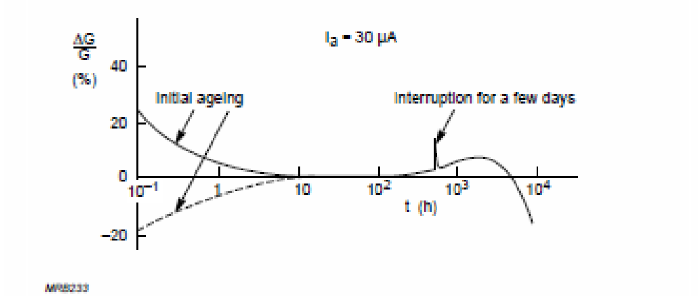


Fig.4.20 Relative gain variation of a photomultiplier operating at high average current

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.

10 Where can I learn more?

Knoll, G.F., **Radiation detection and measurement**, 4th edition, John Wiley & Sons, 2010.

This is the “classic” textbook on radiation detection. Chapters 3 and 4 have very good introductions to the most general issues involving radiation detectors. Chapters 8 through 10 provide good information on the properties of scintillators and PMTs. Chapters 16 and 17 introduce the basics of electronics for these systems.

Gilmore, G., and J.D. Hemingway, **Practical gamma-ray spectrometry**, John Wiley & Sons, 1995

This textbook has much information on gamma-ray sources and spectroscopy, different kinds of detectors (including scintillations), analysis software, etc.