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AMETEK® MATERIALS ANALYSIS DIVISION

# GAMMA-RAD5 User Manual




**AMPTEK, Inc.** 14 DeAngelo Drive, Bedford, MA 01730-2204 USA

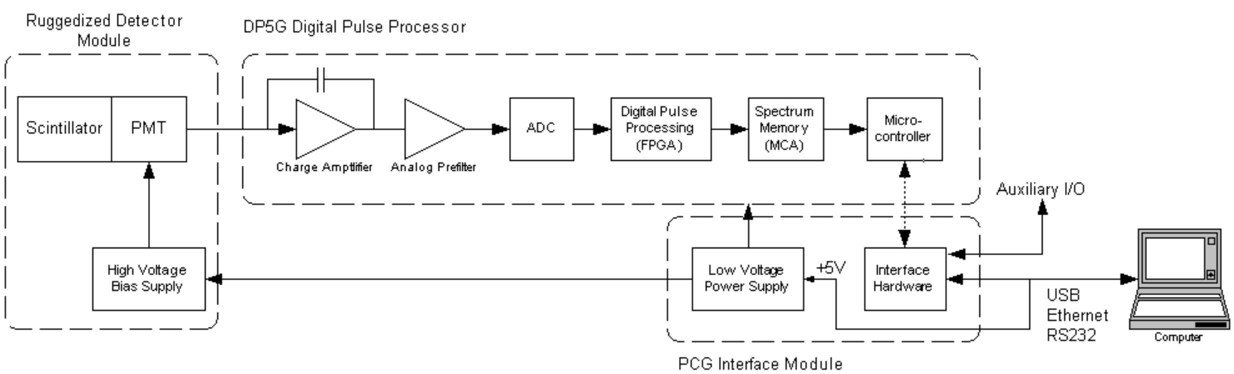
+1 781 275-2242 Fax: +1 781 275-3470 www.amptek.com sales@amptek.com

# 1 Introduction

## 1.1 GAMMA-RAD5 Description

The GAMMA-RAD5 is a complete, integrated gamma-ray spectrometer. It includes a scintillator and PMT, a digital pulse processor based on Amptek's DP5 called the DP5G, all the hardware and software necessary to control and communicate to a PC, and all power supplies. It is a single, integrated, portable module.

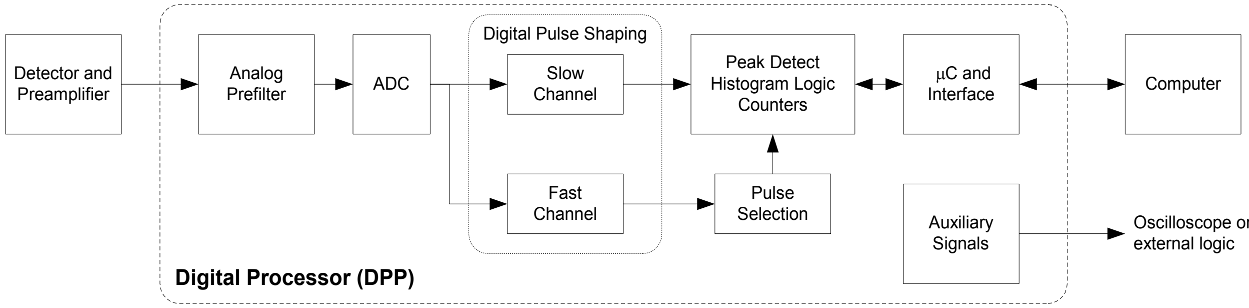
Several key innovations make this system ideal for field use. First, the scintillator and PMT are ruggedized to protect against mechanical shock and vibration. Second, the Ethernet interface permits operation over long distances: 100 m via Ethernet or, with Internet software, globally while the USB interface permits a single connection (power and data) to virtually any computer. Third, it has a flexible digital architecture so it can be easily tailored for specific applications. The GAMMA-RAD5 is ideally suited for a wide range of gamma-ray spectroscopy measurements, from lab applications to most harsh field homeland security applications.




GAMMA-RAD5 Block Diagram.

## 1.2 DP5 Family

Amptek has a family of products built around its core DP5 digital pulse processing technology, designed for pulse height spectroscopy. It was originally designed for the detection of ionizing radiation, principally X-ray and gamma-ray spectroscopy. A generic system, illustrated below, includes (a) a sensor, a.k.a. detector, (b) a charge sensitive preamplifier, (c) analog prefilter circuitry, (d) an ADC, (e) an FPGA which implements pulse shaping and multichannel analysis, (f) a communications interface, (g) power supplies, (h) data acquisition and control software, and (i) analysis software.




The core DP5 technology shared by all the systems includes the ADC, the FPGA, the communication interface, and the data acquisition and control software. All products in the DP5 product family include nearly the same digital signal processing algorithms, the same communication interfaces (both the primary serial interfaces and the auxiliary I/O), and use the same data acquisition and control software. The DPPMCA software package is a complete, compiled data acquisition and control software package used across the family; Amptek also offers an SDK for custom software solutions.

The products in the DP5 family differ in the sensor for which they are designed, which leads to changes in the analog prefilter, power supplies, and form factor. They also differ in their completeness: some of Amptek's products are "complete", with elements (a) through (i), while others offer only a portion of the functionality for the user to integrate into a complete system.

### *1.3 Options and Variations*

*Detectors*

The standard detector is a 76 x 76 mm (3" diameter x 3" long cylindrical) NaI(Tl) scintillator. But the GAMMA-RAD5 can be provided with various custom detectors. These include but are not limited to:

76 x 152 mm NaI(Tl) (3 x 6 in)

10 x 10 x 40 cm NaI(Tl) (4 x 4 x 16 in)

25 x 25 mm $LaCl_3$ (1 x 1 in)

76 x 76 mm BGO (3 x 3 in)

*Enhanced GAMMA-RAD5*

In Sept 2015, an enhanced version was released which includes Power over Ethernet (PoE) and also includes higher gain in the charge amplifier. This higher gain permits lower HV bias on the PMT, in turn offering some performance improvements.

*High and low speed*

The GAMMA-RAD5 is available using either a 20 MHz or 80 MHz ADC. The 20 MHz ADC is sufficient for most NaI(Tl) applications, where the count rate and timing are limited by the decay time constant of the scintillator, and it draws less power than the 80 MHz option. The 80 MHz ADC can be operated at 20 MHz but still draws more power. It is recommended for use with faster scintillators.

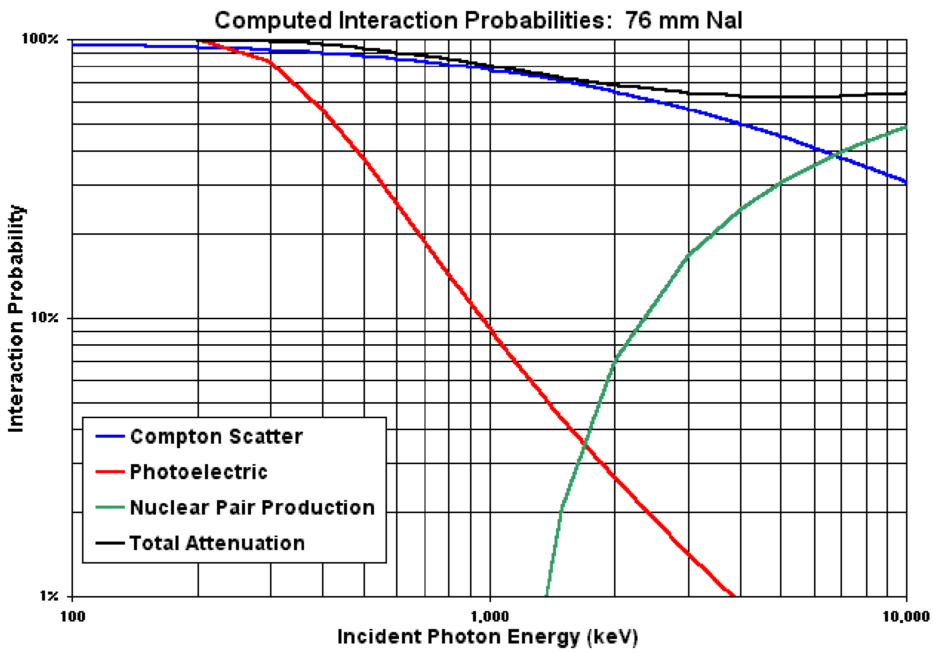
*Analysis Software*

The GAMMA-RAD5 is supplied with Amptek's standard DPPMCA data acquisition and control software. In addition, the SODIGAM analysis software may be purchased to do quantitative analysis of the gamma-ray spectra. SODIGAM processes the spectra to determine both the radioisotopes and their activity in a sample.

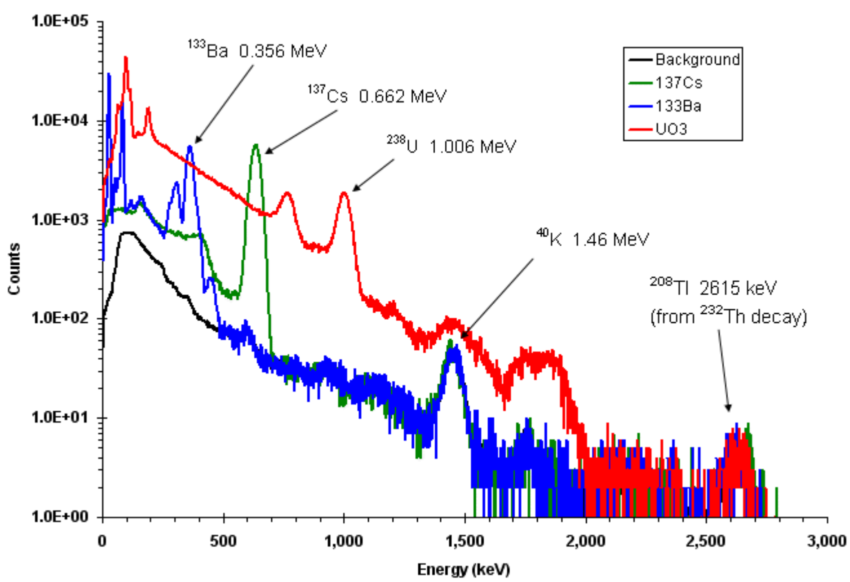
# 2 Specifications

## *2.1 Spectroscopic Performance*

The energy resolution depends mostly on the scintillator material. For the standard material, NaI(Tl), the resolution is specified as <7% FWHM at the 662 keV line of $^{137}$Cs, for 76x76 mm and 76x152 mm detectors. The computed interaction probability in 76 mm of NaI(Tl) is shown below.




The plot below shows spectra from several different sources, measured with a typical GAMMA-RAD5, using a 76x76 mm NaI(Tl) scintillator.



## 2.2 *Processing, physical, and power*

Several of the GAMMA-RAD5 specifications differ from those in the standard, family-wide manual. Specifications not listed here are unchanged from the standard in the family.

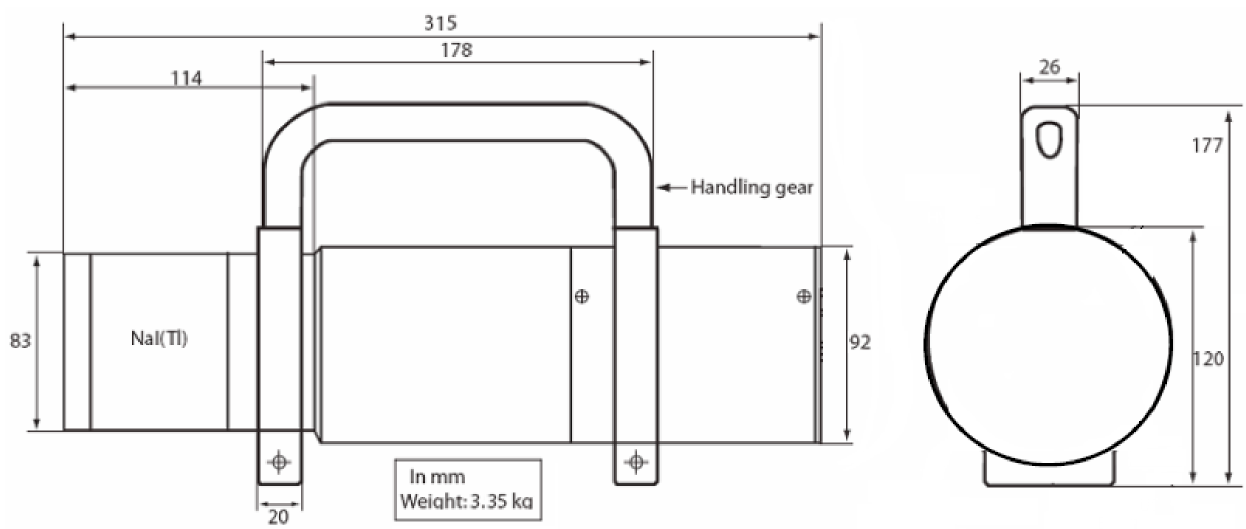
| **Pulse Processing Performance** | |
|---|---|
| Gain Settings | Four software selectable coarse gain settings are available: 3 MeV full scale to 750 keV full scale. Fine gain is adjustable between 0.75 and 1.25.<br>System gain can also be changed by changing the HV on the PMT. |
| Pulse Shape | Trapezoidal, software selectable from 0.8 to 102.4 µs. The flat top has 63 software selectable values for each peaking time.<br>For NaI(Tl), $T_{peak}$ is usually set to 2.4 µs and $T_{flat}$ to 1.0 µs, with a pulse shape similar to an analog 1 µs shaping time.<br>The fast channel, used for pile-up rejection and pulse shape discrimination, has a pulse pair resolving time of 0.25 or 0.5 µs. |
| Pulse pair resolution | This is approximately equal to the sum of $T_{peak}$, and $T_{flat}$, and the scintillator time constant. |
| Gain Stabilization | The gain from the NaI(Tl) and PMT is well known to vary with temperature. A software gain stabilization algorithm is available. |
| Maximum Count Rate, Dead Time, and Throughput | With the typical configuration, $T_{peak}$=2.4 µs, the maximum input count rate is 1.5 x $10^5$ cps with a throughput of >50% and good baseline stability and pile-up rejection. At $T_{peak}$=0.8 µs, the maximum input count rate is 2 x $10^5$ cps. |
| Custom Configuration | The DP5G is set at the factory for either a 20 MHz or 80 MHz clock. For NaI(Tl), the 20 MHz is standard, yielding the specifications listed above. The 80 MHz setting allows for peaking times down to 0.1 µs in the slow channel and 0.05 µs in the fast channel but draws more power. The 80 MHz setting is recommended for custom scintillation materials with faster decay times, fast pulse shape discrimination, or other unique requirements. |

| **Physical** | |
|---|---|
| Dimensions | 31.5 cm long x 9.2 cm diameter (76x76 mm scintillator) |
| Weight | 3.35 kg (76x76 mm scintillator)<br>5.0 kg (76x152 mm scintillator) |
| **Environmental** | |
| Temperature range | -25°C to +65°C |
| Temperature gradient | 10°C per hour<br>**This is a survival limit**; more rapid changes may crack the scintillator-to-PMT interface. |
| Hermeticity | The scintillator and PMT are mated with a robust and hermetic seal.<br>The electronics enclosure is not hermetic. It will not keep out moisture or dust. |

| **Power** | |
|---|---|
| Nominal Input: | @ +5 VDC:<br>165 mA (0.85 W) typical , 20 MHz ADC, USB interface<br>190 mA (1.0 W) typical , 20 MHz ADC, Ethernet<br>80 MHz ADC adds 30 mA (typical) |
| Input Range: | +3 V to +6.4 V |
| Power Source: | USB bus for USB interface<br>External DC<br>PoE for Ethernet interface |

# 3 Mechanical Interface

## *3.1 Dimensions*




This is for the 76mmx76mm NaI(Tl) scintillator, which is the most common. Contact Amptek for drawings of other configurations.

## *3.2 Connectors*


*USB*

Standard USB type B jack.

*Ethernet*

Standard Ethernet connector (RJ-45). Newer models support PoE.

*AUX-1 and AUX-2*

LEMO connector, P/N Lemo EPK 00.250.NTN.

*AUX-3*

15 socket D connector which includes (a) the lines for a serial RS232 interface, (b) the AUX_OUT_1 and AUX_OUT_2 digital input/output lines, and (c) the 8 SCA outputs. The RS232 lines connect to a MAX3227.

| Pin # | Name | Pin # | Name |
|---|---|---|---|
| 1 | GND | 9 | SCA8 |
| 2 | RS232-TX | 10 | SPARE |
| 3 | RS232-RX | 11 | SCA7 |
| 4 | SCA6 | 12 | SCA1 |
| 5 | SCA5 | 13 | SCA2 |
| 6 | GND | 14 | SCA3 |
| 7 | AUX_OUT_1 | 15 | SCA4 |
| 8 | AUX_OUT_2 | | |

*PWR*

A +5 VDC adapter is provided, which is needed only when using Ethernet or RS232. When using USB, the USB bus provides the power. Newer units include PoE. If the GAMMA-RAD5 is to be connected to an external power supply the connector information is below:

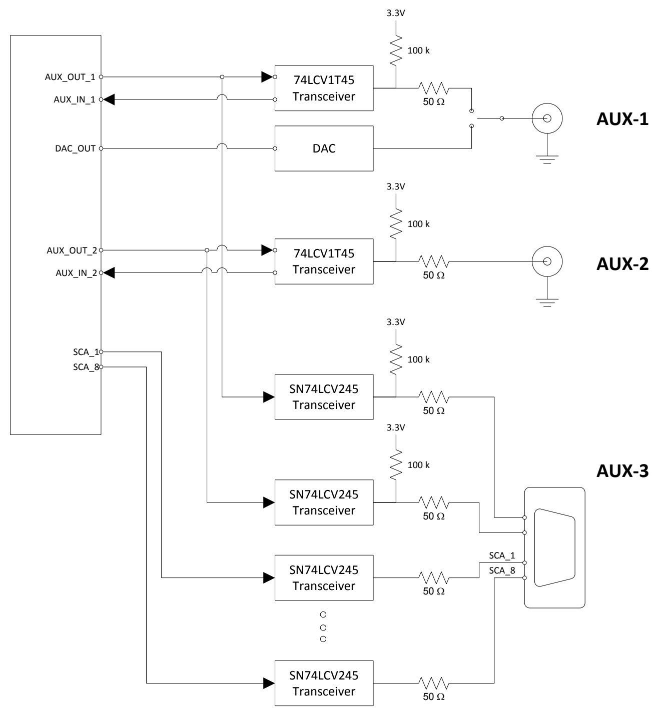
- Molex 39-30-1020, Digi-Key WM1351-ND
- Mates with Housing: Molex 39-01-2020, Digi-Key WM3700-ND
- Terminal: 16 ga. – Molex 44476-3112, Digi-Key WM1913-ND
- 18-24 ga. – Molex 44476-1112, Digi-Key WM1914-ND

# 4 Electrical Interface

## *4.1 Communications Interface*

The USB and Ethernet interfaces are unchanged from those of the standard DP5 family.

*AUX-1*




This is a primary auxiliary input/output connector. It can be configured as (1) the analog output, (2) the AUX_OUT_1 digital output, or (3) the AUX_IN_1 digital input. AUX-1 can be used for diagnostic purposes by displaying analog outputs, e.g. shaped pulses or the ADC input. It can be used as a digital input, e.g. to count pulses from a $^3$He neutron monitor. It can also be used to display digital outputs, e.g. as an output count indicator.

As shown to the right, a software controlled switch selects between the DAC output and a bidirectional digital transceiver (SN74LVC1T45) with 50 ohm series impedance and a 100 k pull-up resistor.

*AUX-2*

This is a digital input/output connector. It can be configured as (1) the AUX_OUT_2 digital output, (2) the AUX_IN_2 digital input, or (3) as the Gate input. It is connected to a bidirectional transceiver (SN74LVC1T45) with a 50 ohm series resistance and 100 k pull-up.

*AUX-3*

This provides additional signal lines. The 8 SCA lines are driven by a SN74LVC245 buffer. The RS232 lines are driven by a MAX3227 transceiver.

## *4.2 Power Interface*

| | |
|---|---|
| Absolute Maximum Power Supply Voltage | +6.0 VDC |
| Absolute Minimum Power Supply Voltage | +4.0 VDC |

Input power outside this range will damage DP5 components.

## *4.3 Thermal Interface*

Thermal control of the GAMMA-RAD5 is very important, for two key reasons.

First, the temperature change cannot exceed 10$^o$C per hour. **This is the absolute maximum; exceeding this can cause the interface between the scintillating crystal and the PMT to crack**. The unit can be used over a wide temperature range but changes must be slow!

Second, as discussed in application note, the gain of a PMT is a strong function of temperature. Amptek provides a precise temperature sensor (AD592, accurate to 0.5$^o$C) which is mounted on the PMT, near the crystal, to monitor the PMT temperature. This can be used in algorithms to stabilize the gain and correct for thermal drifts.

# 5 Design

## *5.1 Summary*

The GAMMA-RAD5 consists of two major subassemblies: (1) the sensor assembly, consisting of the scintillator, PMT, and HVPS, and (2) the electronics assembly, consisting of Amptek's DP5G digital pulse processor for scintillation spectroscopy and Amptek's PCG LVPS & I/O boards.

## *5.2 Scintillator and PMT*

The scintillator and PMT are supplied to Amptek as an integrated module, from various vendors. The PMT is mounted in a hermetic package with reflective material. It is mated to the scintillator photocathode using materials and methods which provide good optical coupling but also is robust to mechanical shock. A mu-metal shield around the PMT reduces the effect of magnetic fields. Because the scintillator/PMT module is separate from the electronics, we can easily customize units to accommodate different scintillators. Materials we have used include:

NaI(Tl): This is the most common material used for gamma-ray scintillation spectroscopy. It offers good resolution (7% FWHM at 662 keV), good stopping power, count rates up to >100 kcps, is fairly rugged, is available in large volumes (e.g. 10 cm x 10 cm x 40 cm) and is relatively inexpensive.

$CeBr_3$, $LaBr_3$: These newer materials are used in higher resolution gamma-ray spectroscopy. They feature 3-4% FWHM at 662 keV but are more expensive and available in smaller volumes.

CsI(Na): This is also used for gamma-ray spectroscopy. It has higher stopping power but poorer energy resolution and is limited to lower count rates.

CLYC: This material provides simultaneous gamma-ray spectra and thermal neutron counting. It uses Amptek's pulse shape discrimination algorithms to distinguish the gamma-ray and neutron interactions.

NaI(Tl)/LiI(Eu) Phoswich: This sandwich scintillator also provides simultaneous gamma-ray spectra and thermal neutron counting. The NaI(Tl) provides the gamma-ray spectroscopy, the LiI(Eu) counts thermal neutrons, with pulse shape discrimination used to differentiate.

EJ-410: This is a fast neutron counter. It uses an innovative material to detect fast neutrons. Though this material doesn't require complete spectroscopy, a customer was able to mix many different detectors in a single distributed system, using PoE to provide power, all with the same interface hardware and software.

## *5.3 DP5G and PCG*

The electronic assembly inside the GAMMA-RAD5 consists of Amptek's DP5G signal processor and the PCG power supply and interface cards. These are both documented in a separate User Manual for the DP5G so will not be discussed in detail here.

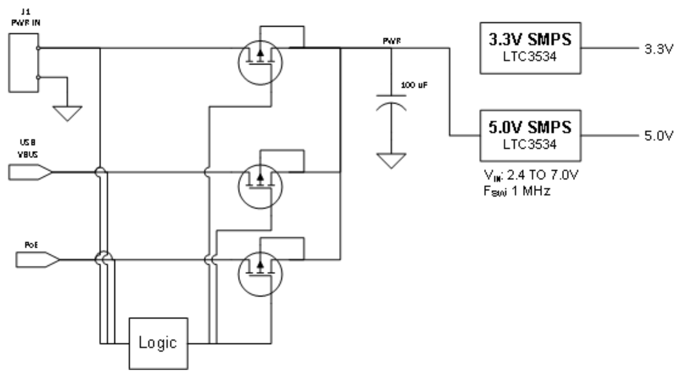
The DP5G provides the signal processing function. It is in the DP5 family but has been optimized for use in scintillation spectroscopy. The primary change is that the analog prefilter includes a charge sensitive preamplifier. The current pulse which is output from the scintillator is fed directly to this charge amplifier; its voltage pulse is then input to the ADC. This schematic is shown in the DP5G User Manual.

The DP5G uses the same basic pulse shaping logic but the ideal settings are slightly different, due to the characteristics of the scintillator and PMT. There are two major changes. First, the light output from the scintillator decays exponentially with time, with a time constant that depends on the scintillator material. This means that the input pulses have an infinite impulse response, rather than the finite impulses from a semiconductor detector. This alters the dead time and pile-up properties. Second, the high gain of the PMT means that electronic noise is negligible, so the noise properties of the pulse shapers are much less important. These points alter the optimum processor settings. The "DP5G User Manual" includes a detailed discussion on optimizing the processor for various scintillators.

The PCG boards provide the low voltage power supplies and the communication and auxiliary connectors.

### *5.4 Power supplies*

The low voltage power supplies are on the PCG board. As shown below, and discussed in the DP5G manual, the input power (USB, PoE, or external) is switched by MOSFETs into low voltage switching power supplies. The 3.3V supplies the DP5G, while the 5V supplies the HV power supply.




The high voltage power supply is a Cockcroft-Walton, in which each stage is connected directly to a PMT dynode. This approach provides the most stable biasing, making gain independent of count rate, and is the most efficient, for the lowest power dissipation.

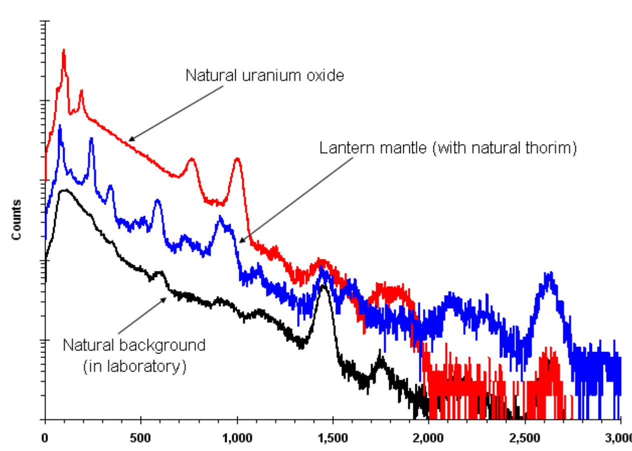
## 6 Application Advice

The most important application advice applies to all of Amptek's scintillation spectroscopy products (GAMMA-RAD5, TB-5, and DP5G pulse processor). This can be found in a separate application note, entitled "Scintillation Products FAQ". Important sections include (1) one on understanding gain stability in scintillator/PMT products and correcting for gain drifts, and (2) one on understanding and estimating minimum detectable activity.

### *6.1 Sample GAMMA-RAD5 applications*

*Nuclear safeguard or environmental monitor*

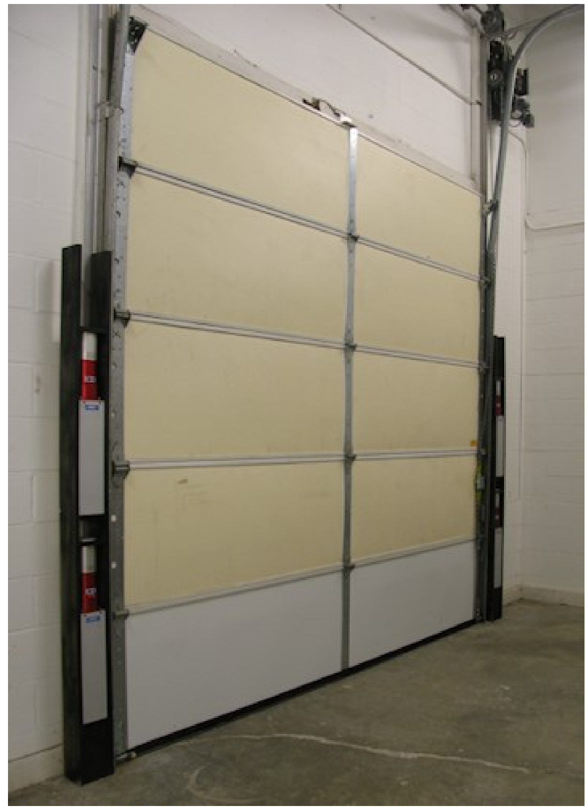
The plot to the right shows typical spectra measured in a lab. The black spectrum shows natural background radiation in the lab. The red spectrum was obtained from a sample of natural (unenriched) $UO_3$. The blue spectrum was obtained from a lantern mantle, made of thorium. The GAMMA-RAD5 detects the increased count rate due to the additional source but also, because the spectrum is different for each radioisotope, can distinguish special nuclear material, industrial materials, medical isotopes, and naturally occurring



radioactive material. Data analysis software is important for accurately distinguishing these materials and quantifying the amounts present.

*Portal Monitors*

The image to the right shows a portal monitor, using four different modules, each with a 10 cm x 10 cm x 40 cm (4”x4”x16”) NaI(Tl) scintillator for maximum sensitivity. The use of Ethernet allows a widely distributed system, over a range of 100 meters, easy to set up. With PoE, even the power can be easily distributed over this range.



In some applications, a standard spectroscopy mode (reading signals every second or every 5 seconds) is sufficient. Other applications benefit from list mode, where each gamma interaction is time tagged and list of (energy, time) pairs is transmitted. This permits easily aggregating data as vehicles or people pass.

*Shipping Container Monitor*

The image to the right shows an application that takes full advantage of the ruggedization of the GAMMA-RAD5. The GAMMA-RAD5 modules are mounted on the VeriSpreader™ bar of the crane that lifts shipping containers. Radiation detection is carried out during routine handling so there is no delay in processing. The spectroscopy performance keeps the false positive rate at a very low level, which is a vital concern.


*VeriSpreaderTM is a trademark of VeriTainer Corporation U.S. Patent 6,768,421.