Nuclear Products Catalog

PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.

C/N 863

Princeton, NJ 08542-0863

USA

Tel: (609) 924-7310

Toll Free: (800) 980-9284

Fax: (609) 924-1729

e-mail: nuclearsales@pgt.com

www.pgt.com

Printed in USA

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PRINCETON GAMMA-TECH

About Princeton Gamma-Tech

Princeton Gamma-Tech, founded in 1965, is an international supplier of high-performance gamma and X-ray spectroscopy products, including state-of-the-art, customized germanium detectors and systems. PGT merged with American Nuclear Systems (ANS) of Oak Ridge, Tennessee in 2000, and expanded the product line to include laboratory-based and portable sodium iodide (NaI) detectors and systems.

High-purity germanium (also known as intrinsic germanium) became available in 1972-73. PGT produced the first commercial HPGe planar detectors that did not require lithium drifting, and could be stored at room temperature without performance degradation. PGT then produced the first HPGe coaxial detectors. These semiconductor radiation detectors were sold primarily to nuclear physics research laboratories.

PGT continues to offer a wide selection of systems and components for many different types of measurements in environmental monitoring, health and safety, research, educational, and medical fields.

PGT detectors have been used in a variety of locations including the bottom of a mine for double-beta decay studies of enriched germanium, in the ocean for remote sensing applications, and in a satellite for studies of the solar system. One high-profile use was in the Mars Observer. That detector included a cryostat with variable temperature control to permit in-flight annealing for repair of high energy photon and neutron damage. Its design requirements included the ability to withstand a stress of 50 G's during launch. Even though the mission was ultimately aborted due to satellite failure, the detector functioned according to specification and returned valuable data on solar-flare-induced gamma-ray emissions.

PGT also developed the QUIET ONE™ cryostat design technology, which allows the manufacture of mechanically cooled germanium detectors that still meet the stringent requirement for low microphonics. No other manufacturer offers this option. If your applications require mechanically cooled detectors with low microphonics design, ask for the JT Cool option.

For gamma spectroscopy applications that require sodium iodide (NaI) technology, PGT has a complete line of systems and components to meet your needs. These include general-purpose multichannel analyzers with conversion gains from 1000 channels to 8000 channels and instruments specifically tailored to NaI detectors.

This handbook is divided into several sections:

- **Section 1: Principles of Gamma ray and X-ray Radiation Detection** (starting on page 3) provides detailed technical information about the basic principles of gamma and X-ray spectroscopy.
- **Section 2: PGT Products** (starting on page 28) provides descriptions of and technical specifications for specific products.
- The appendixes (starting on page 81) include useful reference materials and a glossary.

If you require additional information or assistance, please contact the Nuclear Products Department. Our technical experts can help you assemble a new system, select a new detector, or repair and update an older detector purchased from another manufacturer.

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Section 1: Principles of Gamma ray and X-ray Radiation Detection

Princeton Gamma-Tech specializes in the manufacture of semiconductor detectors for detection and high-resolution spectroscopy of gamma rays and X-rays. This section describes the basic principles of gamma ray and X-ray radiation detection.

1.1 Radioactivity

Naturally occurring radioactivity—the emission of penetrating energy from matter—was first studied in depth in the late nineteenth and early part of the twentieth century. Max Planck deduced in 1900 that radiation is transmitted as discrete energy packets, which he called "**photons**." Further work by scientists such as Rutherford, Curie, Einstein, Bohr, and others established the wave-particle duality of radiation, the interrelationship of matter and energy, and the basic understanding of atomic structure.

Figure 1.1 is a simplified representation of the Bohr model of the atom, with a tightly packed nucleus of positively charged protons and uncharged neutrons and with negatively charged electrons in fixed orbits around the nucleus.

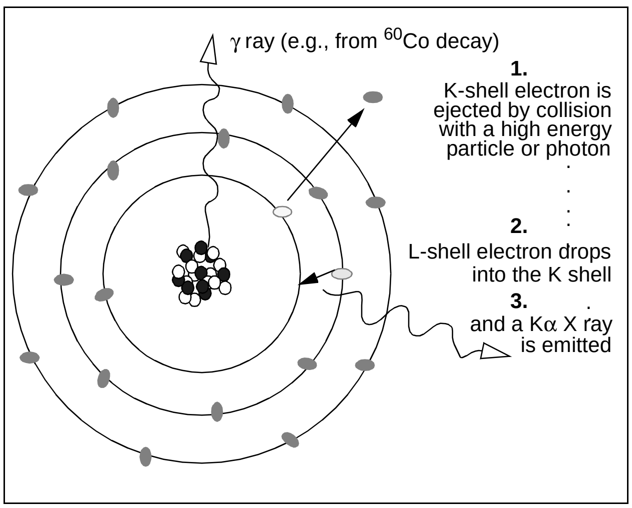


Figure 1.1 Schematic representation of gamma and X-ray generation with a Bohr model of the atom.

The **atomic number** Z, the number of protons in the nucleus, determines the element. The **mass number** A is the total number of protons and neutrons in the nucleus. Protons and neutrons have nearly the same mass, and contribute almost the entire mass of an atom. Atoms having the same atomic number but a different mass number are called isotopes. In **radioisotopes**, the proton/neutron ratio is unstable, and a stable configuration is achieved by emitting particle(s), gamma rays, or both. Radioactivity, or the rate of decay of such a radioisotope, is expressed as the number of disintegrations per second, or the rate of change of the number of nuclei (N) with time:

$$\frac{dN}{dT} = -\lambda N \quad \text{where } \lambda = \text{decay constant} = 0.693/T_{0.5}$$

The decay constant is specific for each radioisotope and represents the probability of decay in the next second. The **half life** ($T_{0.5}$) is the time required for half the current number of atoms (N_0) to decay. The number of radioactive nuclides remaining after time *t* is then given by the equation:

$$N = N_0 e^{-\lambda t}$$

Radiation may then react with matter to produce positively and negatively charged particles called ion-pairs. The three types of **ionizing radiation** are:

- Photons (gamma rays and X-rays).
- Charged particles (protons, electrons and alpha particles).
- Neutrons (indirect ionizations).

This discussion will concentrate on the interactions of photons (gamma rays and X-rays) in semiconductor detectors.

The energy of a gamma ray or an X-ray is characteristic of its source. Gamma rays originate within the nucleus as a result of nuclear transformations and disintegrations, and have energies ranging from approximately 100 eV to 100 MeV. X-rays are the result of electron transitions from a higher-energy to a lower-energy electron shell of an atom, and have energies ranging from a few eV to almost 150 keV.

The basic energy unit for this application is the **electron volt** (eV), equal to 1.6×10^{-19} Joule.

1.2 Photon/Matter Interactions

The three primary processes in which photons interact with matter to give up all or part of their energy in single events are:

- The photoelectric effect (Section 1.2.1).
- Compton scattering (Section 1.2.2).
- Pair production (Section 1.2.3).

For a narrow beam of N_0 photons traversing an absorber material of thickness *y*, the attenuation of the beam is given by the equation:

$$N_y = N_0 e^{-\mu y}$$

where

N_y = the number of remaining photons, and

μ = the total attenuation coefficient for the three processes.

1.2.1 The Photoelectric Effect

In a photoelectric event, the entire photon energy is absorbed by a bound atomic electron which is ejected with a kinetic energy equal to the photon energy minus the binding energy of the electron. The cross-section for the process increases with atomic number ($\sim Z^4$ to Z^5) and decreases rapidly with increasing photon energy ($\sim E^{-3}$). The residual ion may return to its ground state by emitting one or more X-rays or an Auger electron. The low-energy X- ray is almost invariably absorbed in a second photoelectric event before it can escape from the crystal. As a result, the total photon energy appears as electron kinetic energy. Thus, a monoenergetic photon gives rise to a monoenergetic peak in the charge distribution corresponding to the incident photon energy.

1.2.2 Compton Scattering

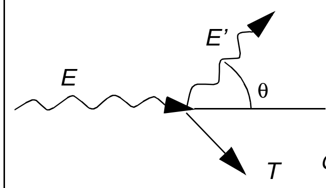
In the Compton Scattering process (shown in Figure 1.2) the photon is scattered by an electron with a partial energy loss which is dependent on the angle of scattering. The kinetic energy imparted to the electron is between zero and a higher value related to the energy of the photon. If the scattered photon escapes before further interaction, the detector will record only a fraction of the incident photon energy. These fractional photon energies appear in the spectrum at less than the full energy peak. As a result, the spectrum exhibits a continuous electron energy distribution, the **Compton continuum**, below the full energy peak of the incident photon.

The cross-section for this process is proportional to the atomic number of the scattering material and is somewhat less energy-dependent than the photoelectric effect. The maximum energy in the Compton continuum is called the Compton Edge (*CE*). Events in which the *CE* energy is exceeded are normally photoelectric events.

1.2.3 Pair Production

In pair production, an incident photon in the field of the nucleus of an absorber atom gives up all its energy to produce an electron-positron pair. Unlike the photoelectric effect and Compton scattering, which are possible at all energies, pair production has an energetic threshold equal to the combined positron-electron rest mass (1.022 MeV). Above this threshold, the cross-section for the event increases rapidly with Z^2 of the absorbing material up to about 10 MeV, beyond which it decreases because of screening effects. The entire photon energy (*E*) is converted to the kinetic energy of the positron-electron pair (i.e., *E* - 1.022 MeV) plus the rest mass of the pair. The positron is annihilated by an atomic electron, producing two 0.511 MeV photons emitted at 180° to each other. None, one, or both of these photons may escape, resulting in a spectral distribution that includes a full energy peak (FEP), a single escape peak (SEP), and a double escape peak (DEP) as shown in Figure 1.3.

Compton effect:



$$E' = \frac{E}{1 + E(1 - \cos\theta)/511}$$

$$CE = \frac{E}{1 + 511/2E}$$

E = energy of incident photon (keV)
E' = energy of scattered photon (keV)
T = kinetic energy of the scattered electron
θ = scattering angle
CE = Compton edge, *T* when θ = 180°

Figure 1.2 Compton scattering.

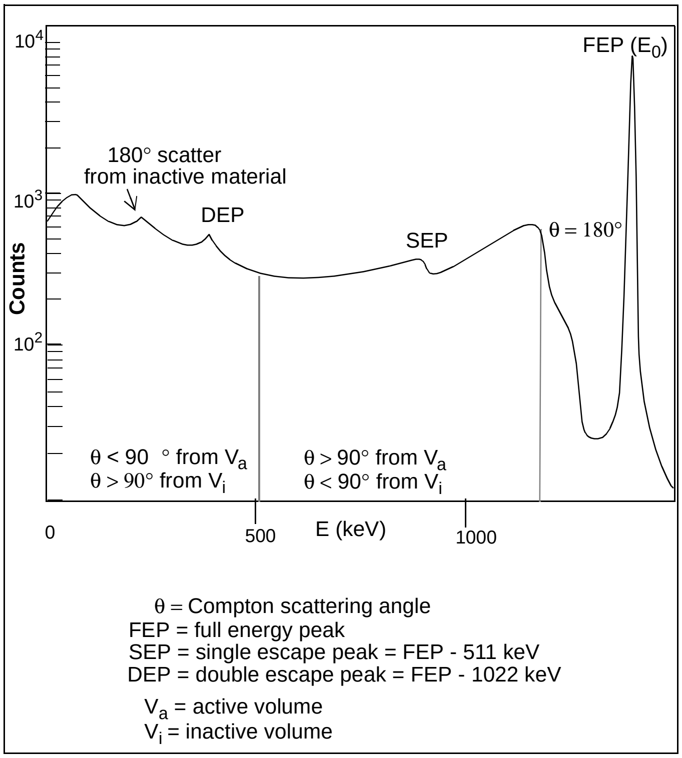


Figure 1.3 Spectral distribution of a monoenergetic 1.4 Mev gamma ray incident on coaxial germanium.

1.3 Radiation Detection

Radiation detectors measure the effects of incident particles or photons on matter. There are three main types of detectors:

- **Gas filled detectors**
  - Ionization chambers
  - Proportional counters
  - Geiger-Müller counters
- **Scintillation detectors**
  - NaI(Tl) and CsI(Tl) crystals
  - Various plastics
- **Semiconductor detectors**
  - High-purity germanium (HPGe)
  - Lithium-drifted silicon (Si(Li))
  - Lithium-drifted germanium (Ge(Li))

PGT specializes in the manufacture of high-purity germanium (HPGe) and Si(Li) detectors for gamma and X-ray detection. HPGe crystals contain a non-zero level of impurities. The type of impurity determines whether the crystal is a p- or n-type semiconductor. For Si(Li) detectors, silicon crystals with p-type impurities are counter-doped with n-type lithium ions. Ge(Li) detectors are no longer manufactured, but some are still in use.

These crystals are fabricated into p-i-n diodes capable of withstanding high reverse-bias voltage with low current (<0.1 nAmp) at cryogenic temperatures. Figure 1.4 is a simple diagram of a detector. When the reverse bias is applied, the intrinsic region (i) is created by depletion of charge carriers. The detector crystal has a lithium-diffused N+ layer about 0.5 mm thick on one surface and a thinner P+ layer, formed by boron ion implantation or metallization, on the other surface.

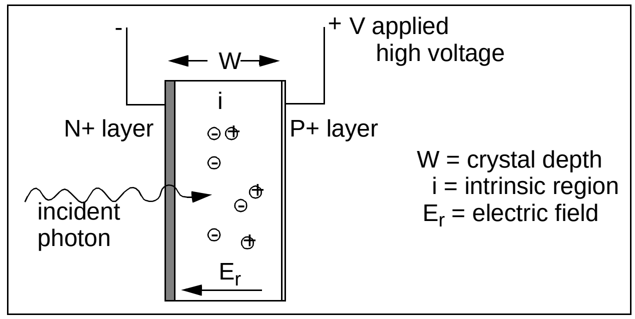


Figure 1.4 Schematic of photon/semiconductor interaction.

In this type of semiconductor radiation detector, a photon interacts within the depletion region to release electrons and holes which move to the contacts of opposite polarity along the lines of the electric field (E_r) established by the applied high voltage. The resulting charge is integrated by a charge-sensitive preamplifier to produce a voltage pulse with height (amplitude) proportional to the incident photon energy.

1.3.1 Photon/Semiconductor Interactions

Not all pulses produced by a mono-energetic photon source will have the same amplitude. Line broadening occurs due to statistical fluctuations and electronic noise. Also, some of the electron-hole pairs are trapped and do not reach the detector contacts, thus producing smaller signals which cause “tailing” on the low energy side of the peak.

Additionally, many of the interacting gamma rays are not completely absorbed in the detector, but are inelastically scattered and escape. This type of interaction yields a low energy Compton background. Finally, some photons reach the detector only after having been scattered by some material surrounding the detector or by the “dead” layer in the detector itself. These rays will also yield lower energy pulses.

The relative importance of the photoelectric effect, Compton scattering, and pair production in germanium and silicon with respect to energy of the incident photon is illustrated in Figure 1.5.

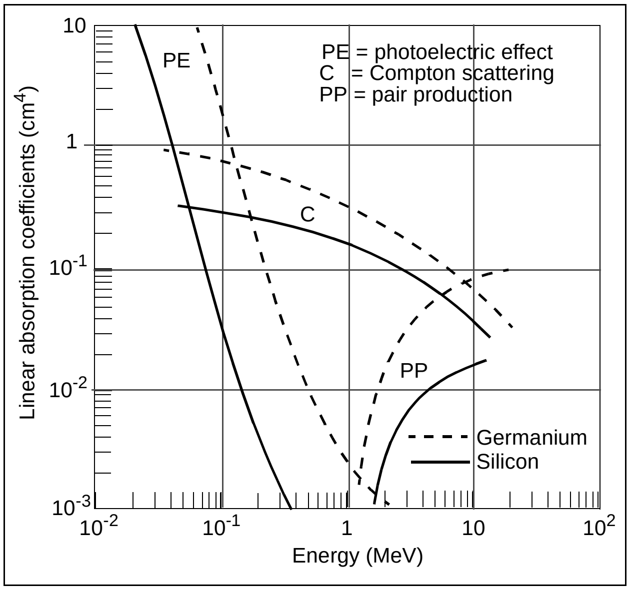


Figure 1.5 Linear absorption coefficients for Ge and Si as a function of gamma ray energy.

In all these absorption processes, one or more energetic electrons result, and these in turn lose their energy largely through Coulomb interactions along the path of the electron in the absorber material. The principal effect of gamma ray interaction with semiconductors is thus ionization, which is shown by the creation of a large number of electron-hole pairs, in direct proportion to the energy of the incident photon. The average energy ε necessary to create such an electron-hole pair is:

- 3.0 eV in germanium.
- 3.76 eV in silicon at 77 K.
- 3.6 eV in silicon at room temperature.

These values are independent of the type or energy of the incident radiation.

The relatively high atomic number, the low values of ε compared with the energy necessary to create an electron-ion pair in a gas, and the fact that they are independent of the type and energy of incident radiation make semiconductor detectors ideal for nuclear spectroscopy.

1.3.2 Fano Factor

Comparison of these values with the forbidden bandgap values of 1.115 eV for Si at room temperature and 0.73 eV for Ge at 80 K provides evidence that not all the energy of the ionizing radiation is used in breaking covalent bonds. Some is converted to phonons in the lattice.

The number of electron-hole pairs (*n*) produced at a given energy of incident radiation is not fixed, as would be the case if all the energy were used in breaking covalent bonds. Nor is there a Poisson distribution to indicate an uncorrelated partitioning of the energy between covalent bond-breaking and lattice vibrations or phonon production. Several competing mechanisms are involved in the energy loss. The Fano Factor (F) has been introduced to account for the variance in the number of electron-hole pairs produced.

If there were no variation in the number of electron-hole pairs, F would be 0. If there were a Poisson distribution of energy loss mechanisms, F would be 1. The actual value is closer to 0 than to 1. In most cases, a value of 0.11 for both silicon and germanium gives satisfactory agreement with laboratory results.

1.3.3 Charge Detection

When a semiconductor detector is used in a spectrometer, the current signal from the detector is converted by a charge-sensitive preamplifier to a voltage signal, which is then processed in the main amplifier and multichannel analyzer (MCA).

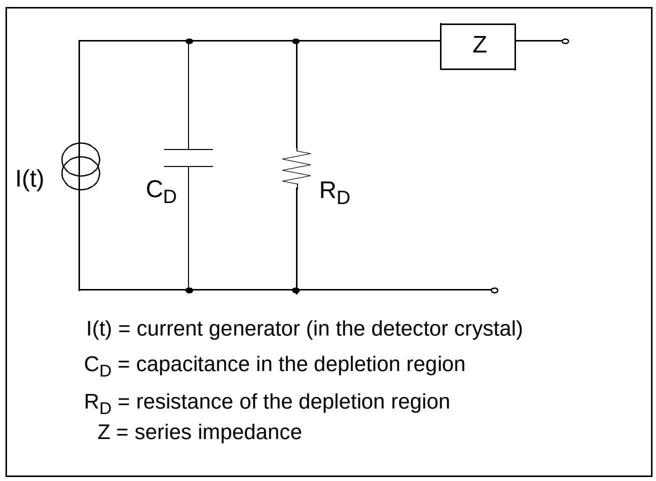


Figure 1.6 Detector equivalent circuit.

Determination of the current induced in the detector, as shown in the equivalent circuit in Figure 1.6, requires first calculating the motions of the charge carriers in the electric field, E_r (see Figure 1.4). E_r is readily calculated from the applied bias voltage, detector geometry, and bulk resistivity of the crystal. Once E_r is known, the following differential equation can be solved:

$$\frac{dr}{dt} = V_d(E_r)$$

r = position of the charge carrier
V_d = drift velocity in the electric field E_r

For the example shown in Figure 1.4, of a detector with plane parallel contacts and a field E_x across a distance *W*, the carrier *q* moving a distance *x* in the direction of the field induces a charge given by the following equation:

$$\Delta q = q\frac{\Delta x}{W}$$

These two equations, or equivalent equations for different detector geometries, yield the contribution to I(t) of every charge carrier. The total induced charge I(t) is obtained by integration over all the charge carriers created.

1.3.4 Preamplifier Rise Time

The rise time (T_t) of the generated pulse can be measured at the preamplifier output. For gamma and X-ray detectors, if the preamp is sufficiently fast, T_t is equal to T_R, the charge collection time. An estimate of T_R can be made from the following equations:

$T_R \cong W \times 10^{-7} s$ for Si at room temperature

$T_R \cong W \times 10^{-8} s$ for Ge at LN_2 temperature

1.4 Counting Systems

Nuclear spectroscopy requires determination of:

- The energy of each voltage pulse induced in the semiconductor detector.
- The number of pulses occuring at each energy.

This is the function of the main amplifier/ADC/MCA system. In its simplest form, the process occurs as follows:

The voltage pulse from the charge-sensitive preamplifier goes to the main amplifier where it is shaped and further amplified. The shaping time is the time required by the amplifier to completely process each pulse. Several integrations are performed to smooth away most of the noise while retaining the information in the pulse.

The height of the pulse from the main amplifier is then converted by the analog-to-digital converter (ADC) to a number proportional to its energy. When this digital value arrives at the multi-channel analyzer (MCA), the channel corresponding to the given energy is incremented by one. The familiar spectrum display is essentially a histogram of the probability density of energies of the detected radiation, or a plot of the number of counts in each channel against the energy in the channel. In addition to counting and storing the data, the MCA provides the mechanisms for displaying, printing, and analyzing the information.

The pulses arrive at the main amplifier at random time intervals. At higher count rates, the system is unable to discriminate between pulses if the time between events is less than 1.5× the peaking time of the main amplifier. The pulses pile up and cannot be processed, resulting in peak broadening. This spectrum degradation becomes significant when the product of input count rate and pulse processing time exceeds 0.5, and it is a dominant factor when this value is >1.

Decreasing the pulse processing time of the main amplifier by decreasing the peaking time reduces the spectrum distortion, but produces a loss in resolution. To compensate, a pileup rejection module is frequently included in the circuitry and the ADC live time is extended to account for the time that the system is unable to process pulses.

A typical PGT nuclear detector system is illustrated schematically in Figure 1.7. The components shown include:

- A germanium detector with an external preamplifier and standard dip-stick cryostat.
- An amplifier and ADC module such as the System 8000.
- A PC with spectroscopy software.

The ADC and the main amplifier with pile-up rejection can be incorporated within the multichannel analyzer so that the output signal from the preamplifier is fed directly to the PC for processing and analysis.

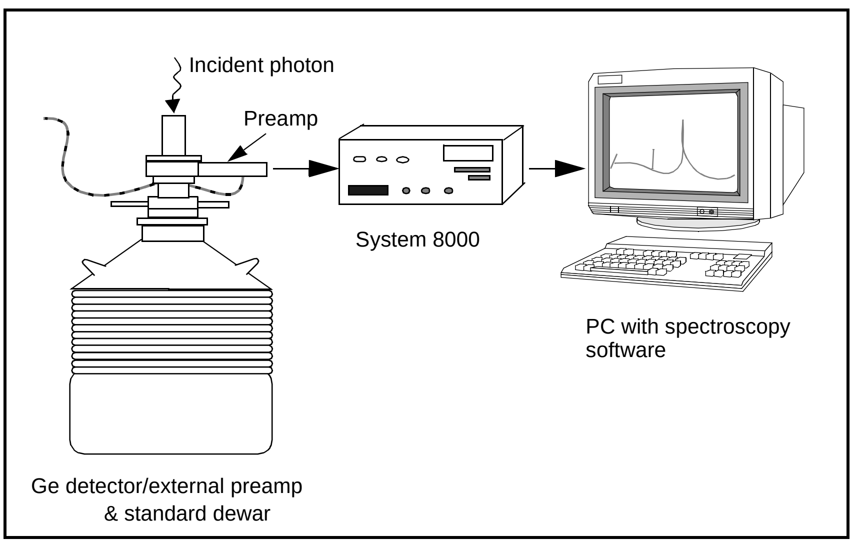


Figure 1.7 Schematic representation of a nuclear spectroscopy system.

1.5 Spectrum Analysis

Detection of photons is only the first step of the analysis process. The spectral peaks must be located (see Section 1.5.1), their energies measured and identified with the correct nuclides or elements (see Section 1.5.2), and their areas quantified (see Section 1.5.3). These functions are done by computer analysis, and require certain preliminary calibrations for channel number vs. energy, detector resolution (peak width), and detector efficiency. A detailed discussion of spectrum analysis can be found in the users manuals for specific spectroscopy software products.

A spectrum peak is a span of channels with photon counts that are statistically higher than those of the underlying continuum. A peak has a centroid with the highest counts, and a roughly Gaussian shape. The more channels per spectrum, the smaller the energy range per channel, but also the fewer counts per channel. Using too many channels may produce a broad, poorly defined peak. Commonly used spectrum sizes are 4096, 8192, or 16,384 channels .

1.5.1 Peak Location

Peak location can be done by looking for differences in successive channels that define a more-or-less Gaussian shape. With a poorly defined, low peak on a background, this may be difficult to identify. More commonly, first or second order or higher derivatives of the spectrum curves are used. Since the spectrum is actually a histogram, the curve is approximated from the gradient of adjacent channels. The curve is smoothed by taking into account several channels at a time to eliminate some of the statistical scatter. The first derivative of the resulting curve changes sign at the centroid of a peak, while the second derivative shows a minimum at the centroid.

Peaks may also be located by cross-correlation with a search function, such as a derivative of a Gaussian distribution. The spectrum data is digitally filtered to define a point in the peak with the background eliminated.

After a potential peak has been found, its acceptability is determined by applying a threshold parameter to eliminate spurious peaks, while ensuring that small real peaks are recognized. The analytical software uses some multiple of the standard deviation to give the desired confidence level.

1.5.2 Peak Measurement

Once a peak has been located, its energy is established by correlating its centroid with the channel energy. To do this, a calibration spectrum is obtained. For nuclear applications, the source consists of nuclides which produce singlet peaks of known energy. Usually two such points are sufficient, since energy calibration is nearly linear over most of the spectrum range. For X-ray applications, the calibration source may be element samples which yield X-rays of known energy when irradiated.

The energy of the located peaks is then matched with the known energies of gamma and X-rays in a nuclide or element library. In most cases, multiple peaks are produced by a given nuclide or element, and it is this set of peaks and their relative intensities that pinpoint an identification. Overlapping peaks may complicate the analysis, and in such cases peak stripping or deconvolution must be performed before the identification can be made.

In addition to the generalized searches that locate, measure and identify all peaks as specific nuclides, library-directed searches can also be done. Peaks of the nuclides or elements of interest are specified and the spectrum is searched in only the selected regions of interest (ROIs). Although this type of search is faster than a generalized search, it is more likely to miss an unexpected peak. Select a search type based on the requirements of the specific analysis.

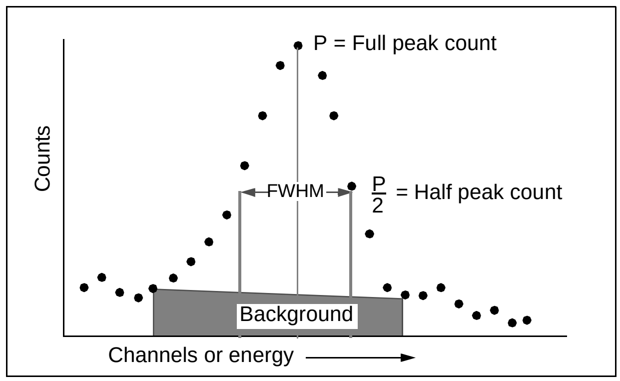


Figure 1.8 Determination of peak area.

1.5.3 Quantitative Measurements

Quantitative analysis determines the area of a peak (peak integral in counts) attributable to the nuclide in question. In Figure 1.8, the background under the peak is assumed to be linear, as shown by the shaded trapezoid. The left and right sides of the peak are commonly defined by the full width half maximum (FWHM) of the full peak height (or some multiple of it).

To relate the net counts in the peak (A) to the activity of the nuclide, the detector efficiency must be known (see “Detector Efficiency” on page 10), along with the half-life and the branching ratio (yield) of the source. An intensity calibration must also be carried out first. The activity in microCuries (µCi) is given by

$$\mu Ci = \left(\frac{A}{(time)efficiency(yield)(3.7 \times 10^4)} \right)$$

The **Minimum Detectable Activity** (MDA) is the activity when A = lower detectability limit.

In addition, for true quantitative analysis of spectra, the collection time must be known. While the MCA is analyzing one pulse, it cannot accept any new pulses for analysis.

This down-time interval is known as ***dead time***. To compensate for dead time, the actual analysis time is extended. The MCA timer is turned off during dead time, and is turned on again as soon as the pulse has been processed and stored. The sum of these "on" times is the ***live time***, or the total time that the system is able to accept pulses. The live time is needed to calculate the true pulse rate and to perform quantitative analysis.

For X-ray fluorescence, quantitation involves a complex fundamental parameters analysis.

1.6 Timing and Coincidence Measurements

Timing spectroscopy involves determining the relationship between two coincident or time-related (as in cascade) events. Applications include:

- Gamma-gamma and gamma-particle coincidence studies.
- Positron lifetime measurements.
- Decay scheme determinations.

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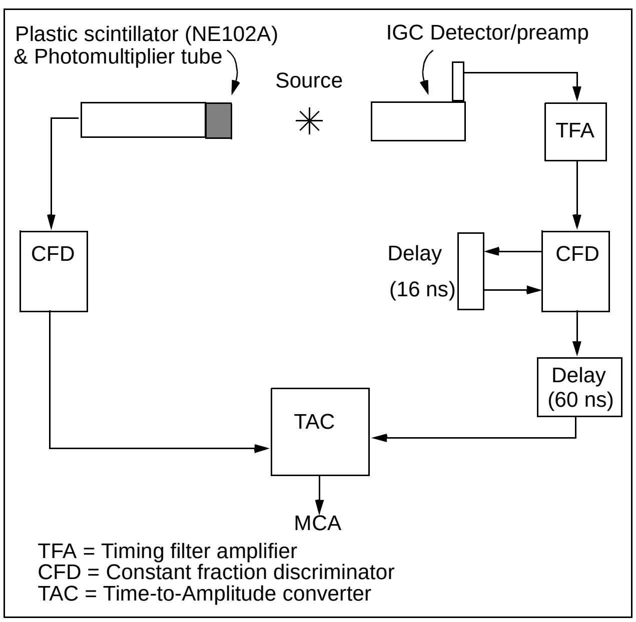


Figure 1.9 Setup for timing measurements.

Basically, the measurements are made by irradiating two detectors simultaneously with the same source. The signal from one detector is used as a start signal in a Time-to-Amplitude Converter (TAC). The signal from the other detector is delayed by a fixed amount and used as the stop signal. Output from the TAC is sent to the MCA where it is displayed as a time spectrum, or more precisely, as a histogram of the number of events detected for each time interval. The distribution of the start-stop time intervals gives a peak in the spectrum. The timing resolution of the system is described in terms of FWHM and sometimes FWTM for the peak. (See "Detector Resolution and Sensitivity" on page 14 for additional information).

The time pick-off unit, which produces an output logic pulse precisely related to the occurrence of an event, is crucial to these measurements. Among the sources of error in the time pick-off measurements are amplitude walk and timing jitter. Amplitude walk refers to the time movement between the input and output pulses of the unit due to differences in shape and amplitude of the pulses coming from the detector. It is usually the most important factor in semiconductor detectors. Timing jitter is primarily due to the statistical fluctuations in the signal from the detector, and is more important in scintillator/photomultiplier systems.

A constant fraction discriminator (CFD) is commonly used to reduce walk and jitter. In this device, the leading edge of the input pulse crosses through a discriminator with a threshold that is a constant fraction of the signal amplitude. This original pulse is added to a delayed, inverted, and amplified version of that pulse to give a zero crossover, which is independent of rise times or amplitudes.

Timing resolution is very dependent on the entire electronics system. Figure 1.9 is a diagram of the system used to measure the timing resolution of some PGT p-type coaxial germanium detectors at Yale University. Measurements were made both with ^{60}Co (1.17 MeV and 1.33 MeV cascade) and with ^{22}Na (511 keV annihilation) sources. In this set of experiments, the timing spectrum was first collected with a 60-nsec delay and then the run was repeated with an additional 16 nsec delay in the germanium detector circuit. Figure 1.10 shows a typical plot. Note the clear separation (deep valley) between the two peaks obtained with and without the 16 nsec delay. The detectors had both excellent energy (1.8 keV) and timing resolution (2.4 nsec).

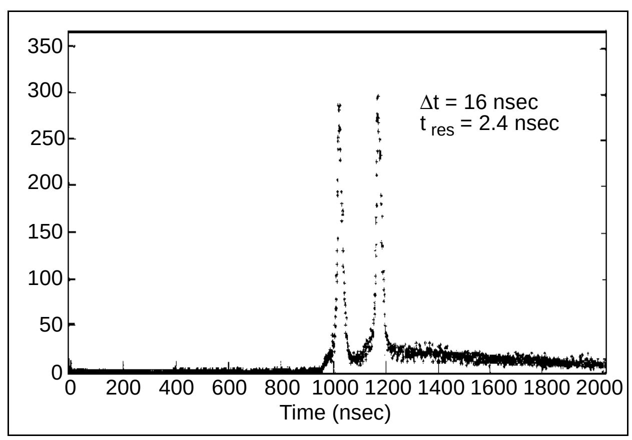


Figure 1.10 Timing resolution of a 20% IGC detector.

1.7 Detector Selection Parameters

The detector characteristics used to judge the suitability of a detector for a particular application include:

- Efficiency
- Energy resolution
- Peak-to-Compton ratio

Generally, the larger the detector, the better the efficiency and peak-to-Compton ratio, with perhaps some loss in resolution. With poorer resolution, however, peaks become somewhat broader and, therefore, not as tall; as a result, the peak-to-Compton ratio decreases. Moreover, very large crystals require a lower impurity concentration (~$l0^9$/ cm^3) at a significantly higher cost.

The following discussion of detector characteristics is based on the ANSI / IEEE Standards 645-1977 and 325-1996. Please consult also ANSI Standard N42.14-1991 and the ANSI / IEEE Standards 680-1978, 300-1988 (R1993), 759-1984B, 1131-1987, 1160-1993, 301-1988, and their updates, as well as any other ANSI / IEEE standards which may relate to your applications. NIST Standard Reference Material (SRM) Standards and US Regulatory Guides for fluorescence applications also contain valuable information.

1.7.1 Detector Efficiency

The number of photons actually counted out of the total number of photons emitted by the sample is defined as the **detector efficiency**. How precisely the energy of each photon is determined is its **resolution**.

1.7.1.1 Counting Efficiency

The counting efficiency of a detector is a function of the active volume and shape (geometry) of the detector crystal, the source/detector geometry, and interactions in the materials in the immediate vicinity of the detector. The tests described in ANSI / IEEE 325-1996 call for a spectral peak at least 6 channels wide at half-maximum, with the total number of counts within the FWHM of at least 50,000.

1.7.1.2 Absolute Efficiency

The ***absolute efficiency*** (E_{abs}) is simply the ratio of counts detected to counts emitted by the source, or more accurately the ratio of net counts (A) in the full energy peak to counts (N_s) emitted by the source. Because E_{abs} is very dependent on the source/detector geometry, both the geometry and the energies at which it is measured must be specified when absolute efficiency is quoted.

To determine N_s, the source intensity I_s must be corrected for the age of the source since calibration, as well as the branching ratio of the particular line used, if applicable:

$$N_S = I_S \times \text{live accumulation time}$$

$$I_S = I_0 \times 0.5^{\Delta t / T}$$

where I_0 = Source intensity at calibration
Δt = Age (time since calibration)
T = Half life

ANSI / IEEE 325-1996 standard requires that Eabs be determined from the spectrum obtained with a calibrated 60Co source placed 25.0 cm from the center of the front of the endcap or 1 cm. from the bottom of the sample hole in a well detector. The net number of counts (*A*) in the full energy peak at 1332.5 keV is determined by integration and background subtraction.

Absolute efficiency is the usual standard for characterizing well detectors and Marinelli beakers. While it is sometimes quoted for large coaxial or planar detectors, this measurement usually does not represent real conditions. Relative and intrinsic efficiencies are better suited for such detectors.

1.7.1.3 Relative Efficiency

Because of the multitude of source/detector geometries in use, a standard efficiency measurement which is independent of geometry and which involves the whole crystal volume is necessary. ***Relative efficiency*** satisfies this requirement.

The efficiency of a coaxial or large planar germanium crystal is determined ***relative*** to that of a 3×3 in. NaI(Tl) scintillation crystal, at a 25.0 cm source-to-endcap distance for the 1332.5 keV line from a ^{60}Co point source:

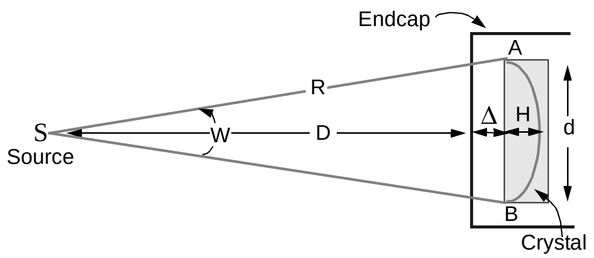
$$E_{rel} = A/A_{NaI} \qquad \text{where } A_{NaI} = 1.2 \times 10^{-3}\, N_s$$

Again, the source intensity N_s must be corrected for the age of the source since calibration.

1.7.1.4 Intrinsic Efficiency

For most planar detectors, the relative efficiency as determined above does not apply, since the 1332.5 keV line is out of range. For these detectors, the active surface area and entrance window absorption are more useful specifications at the lower energies, where the gamma range is well within the thickness of the germanium crystal. Intrinsic efficiency can be used to specify these detectors.

The ***intrinsic*** counting efficiency takes into consideration just those photon events actually reaching the detector window. Thus, while N_s is the total number of photons emitted in all directions by a point source, intrinsic efficiency relates to just the number of photons in the conic section corresponding to the active area of the detector, as shown in Figure 1.11:



$$R = \sqrt{(D + \Delta)^2 + (d/2)^2}$$

D = Source/endcap distance
Δ = Endcap/crystal distance
d = Crystal diameter

$$W = \frac{2\pi RH}{4\pi R^2}$$

W = Solid angle
H = Depth into crystal
R = D + Δ + H

$$I_{Intr} = \frac{A}{N_s \times W}$$

A = Net counts in full energy peak

Figure 1.11 Intrinsic efficiency determination.

The values of Δ and H are very small and not readily determined by the user. However, because they are very small compared with D, $R \approx D$. Also, because R is large compared to the crystal diameter d, $\overset{\frown}{AB} \approx \overline{AB}$ and the surface area $2\pi RH \approx \pi (d/2)^2$. Therefore,

$$W \approx \frac{\pi (d/2)^2}{4\pi D^2}$$

For large planars, intrinsic efficiency at the 60 keV line of the ^{241}Am source at 25 cm. is used to qualify the detector. For lung monitors, the source/endcap distance is 10 cm. Because the intrinsic efficiency measurement is dependent on geometry, the distance D must always be included in the efficiency statement.

Figure 1.12 shows some representative intrinsic photopeak efficiencies for planar germanium detectors of different crystal thicknesses and for a typical coaxial germanium detector. The curves on the left illustrate the percent-transmission for beryllium windows of different thicknesses.

1.7.1.5 Efficiency of Marinelli Beakers

Marinelli re-entrant beaker and well detectors are special geometries for which absolute efficiencies are the norm.

A Marinelli re-entrant beaker is used for large-volume, low-activity samples. In this situation, the analyte surrounds the detector element, usually a large coaxial detector. The Marinelli beaker standard source (MBSS) used to determine detector efficiency consists of a sealed standard beaker filled with the specified volume of uniformly dispersed radioactive material in a liquid or, preferably, solid carrier. Several standards are available (see the MBSS List, Appendix-82). The MBSS must be calibrated as to the photon emission rate at specified energies.

The Marinelli beaker geometry is shown in Figure 1.13. The absolute full-energy peak efficiency M of such a detector assembly is defined as $M = A/N_s$, where A is the number of counts detected in the full energy peak during collection for live time *t*, and N_s is the number of gamma rays originating in the MBSS during time *t*. The 1332.5 keV line of ^{60}Co is the most frequently used line, although at low energies the 88 keV γ ray of ^{109}Cd is preferred.

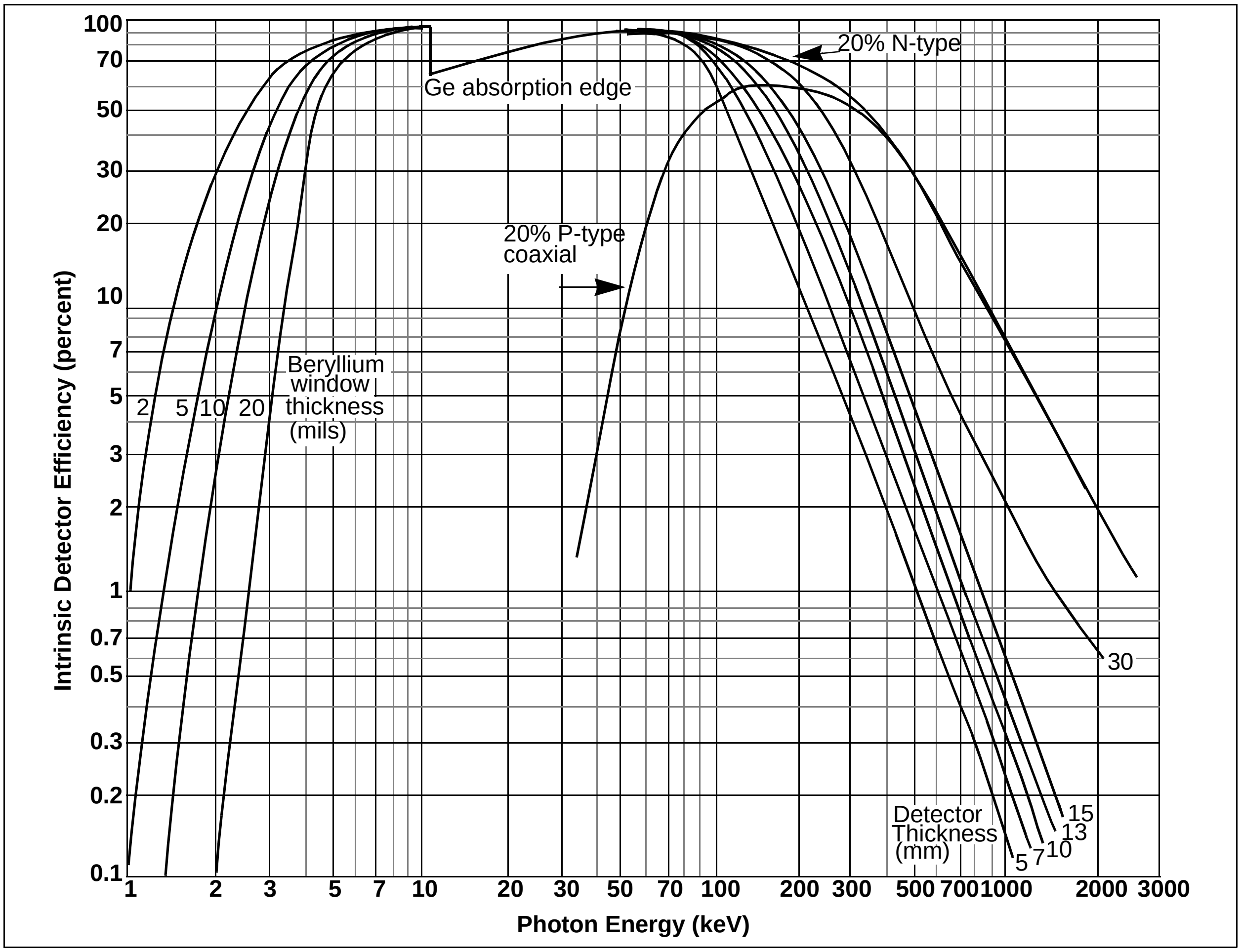


Figure 1.12 Intrinsic Detector Efficiency for various planar crystal thicknesses, determined for a point source approximately 25 cm. from the crystal face, and, for comparison, for typical coaxial detectors.

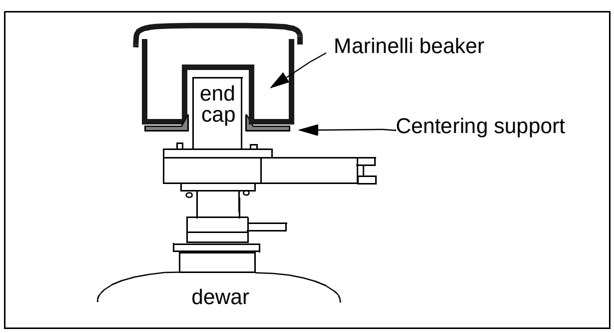


Figure 1.13 Marinelli beaker configuration.

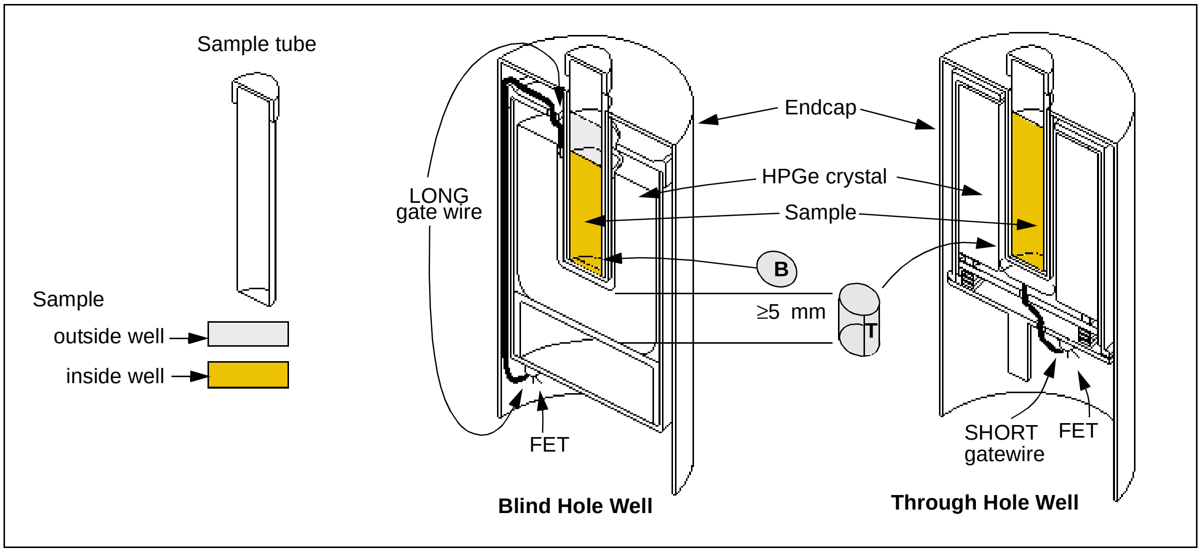


Figure 1.14 Comparison of "blind hole" and "through hole" well detector design.

1.7.1.6 Efficiency and Design of Well Detectors

The usual well detector is a coaxial germanium crystal with a re-entrant cavity well in the endcap that extends into the central hole within the detector element. The sample holder is inserted into the well, and the source is essentially surrounded by active germanium. As a result, the well detector typically has a very high absolute efficiency.

With a high absolute efficiency, the proportion of sum peaks also becomes relatively high. A sum peak occurs when two gamma rays are coincident on the detector, and the sum of their energies appears as a peak in the spectrum. Standard sources specified by ANSI / IEEE 325-1996 to measure the efficiency of a well detector are point sources (<2 mm. maximum diameter) located 1 cm from the bottom of the sample hole. One of the most commonly used standards is ^{60}Co. When the 1173.2 keV line is coincident with the 1332.5 keV line, a sum peak appears at 2505.7 keV. The true number of 1332.5 keV photons is therefore the count in the full energy peak (A) at 1332.5 keV plus the count (A_s) in the sum peak, and the absolute in-well efficiency is given by $W = (A + A_s)/N_s$. The Compton continuum below the sum peak may also be a factor.

PGT reports E_{abs} for well detectors in accordance with ANSI / IEEE 325-1996 for ^{60}Co to give efficiency information about the whole crystal volume and for ^{129}I to give low-energy (40 keV) absorption information.

Additionally, PGT also reports the external relative efficiency of the detector.

There are two designs for well detectors, the "blind hole" and the "through hole," as illustrated in Figure 1.14. The blind hole is the original configuration, used by PGT to manufacture its first Ge(Li) well detectors around 1968.

PGT now uses the through-hole geometry because it results in better performance.

At first glance, it would appear that the blind hole design is more efficient because it has closer to 4π counting geometry. This holds true *only for point sources or very small samples*.

The through-hole well allows for a deeper sample hole, as shown in the illustration. The surface area of the additional well length (T in Figure 1.14) is greater than the area lost (**B**) at the bottom of the well for all standard well diameters. Thus a larger sample volume (longer sample tube) can be analyzed for a given crystal length, and the position of the sample can be centered within the crystal. The result is that more counts from a larger volume can be analyzed in a given time.

Furthermore, the manufacturing process also puts limits on the blind-hole wells. This design requires that the center hole be bored out, which is difficult for large sample holes. For this reason, blind-hole wells are usually offered with sample holes no more than 15 mm in diameter.

Through-hole wells are cored out, a procedure which can be used for much larger sample holes. PGT has manufactured custom well detectors with sample hole diameters of up to 1.3 in. (33 mm). The large sample hole can accommodate both larger samples to reduce counting time and a larger variety of sample sizes and shapes.

Aside from the issue of efficiency, through-hole well detectors also score better in resolution. Blind hole wells are inherently microphonic. As can be seen in Figure 1.14, the contact to the center electrode must be made at the front of the detector crystal, in the small space between the well insert and the center contact. The gate lead must then run from this contact all the way to the FET at the back of the crystal. Very small movements in this wire (for example, from external vibrations) cause capacitance changes at the FET input and result in a microphonic signal at its output. This electronic noise impairs resolution and adversely affects the lower limit of detection. The uncertainty in how quiet the detector environment will be means that counting time must be increased to insure the integrity of the data. In severe cases, the energy peaks may even be considerably misshapen or double peaks may appear.

In contrast, in through-hole well detectors, the center contact extends the full length of the crystal. A very short gate lead is needed from the back of the crystal to the FET. As a consequence, PGT well detectors have outstanding resolution.

1.7.2 Detector Resolution and Sensitivity

The detector resolution is a measure of how accurately a detector system can discriminate the energy of each pulse. Energy resolution determines how well the spectral lines are separated in the MCA display.

The energy resolution for PGT coaxial germanium and well detectors (and sometimes large planars) is defined as the Full Width at Half Maximum (FWHM) for the full energy peak of the 1.33 MeV line of ^{60}Co, expressed in keV. All coaxial detectors are also tested at the 122 keV line of ^{57}Co.The narrower the peaks, the less overlap (convolution) there will be with other spectrum lines and also the fewer background counts will be included in the peak integrals.

FWHM of the 122 keV line of ^{57}Co or the 5.9 keV line of ^{55}Fe is used with planar detectors and with coaxials for lower energy radiation.

Detector resolution is further refined by determining the Full Width at Tenth Max (FWTM) and Full Width at Fiftieth Max (FW0.02M) of the 1.33 MeV line. The “peak shape” ratio, FWTM/FWHM, is ≤1.9 for a very good detector, while the ratio FW0.02M/FWHM is ≤2.65.

The MCA selection itself may impose a limit on resolution. For example, if each channel covers 0.5 keV (energy range of 2 MeV with only 4000 channels available), the difference between detectors with resolutions of 1.17 and 2.2 keV at FWHM is hardly perceptible, but the difference in cost is significant.

1.8 Peak-to-Compton Ratio

Compton scattering is the most important interaction in a germanium detector crystal for gamma rays with energies between 150 keV and 7 MeV. Scattered photons that escape the crystal are not detected, but their recoil electrons produce counts in the energy region below the full energy peak of the incident photon. This continuous background, which is in addition to the background from ambient sources, increases the minimum detectable activity (MDA) of any photons with peaks in that region. Thus, in samples with multiple sources, such as low-activity environmental samples, the additional background due to Compton scattering of the higher energy photons occurs over all the lower energy regions.

The peak-to-Compton ratio is reported as the ratio of the peak height for the 1.33 MeV gamma ray of ^{60}Co to the average height of the Compton continuum over the energy range 1.040-1.096 MeV.

In general, a detector with a higher peak-to-Compton ratio will have higher line-to-background ratios and better counting statistics for complex spectra. The value depends on detector geometry, mount and cryostat configuration, detector efficiency and detector resolution. It increases with detector active volume and decreases with increase in the FWHM. For ultimate detection sensitivity, the Compton continuum can be diminished by using a Compton suppression device.

1.9 System Noise and Microphonics

“Noise” refers to the signal distortion which can obscure important information in the signal. It leads to poor resolution and higher background. System electronic noise is due primarily to the FET and detector components. See “Noise Effects” on page 23 for a discussion of electronic noise. Microphonics refers to mechanically generated noise resulting from such sources as the bubbling of nitrogen in the dewar or heavy equipment in the vicinity of the detector. PGT offers a low microphonics assembly, the QUIET ONE, described on page 25.

1.10 Energy Range

The energy range of interest is another factor in detector selection. X-rays and low-energy gamma rays are not efficiently detected by coaxial germanium crystals. Planar Si(Li) detectors are the choice for X-rays from ~100 eV to 60 keV. For X-rays and low-energy gamma rays over the range 3 keV-1 MeV, planar p-type germanium and semi-planar n-type germanium detectors are ideal.

Coaxial detectors, available in a range of sizes and efficiencies, are used at energies up to 10 MeV. See Table 1.1 for a tabulation of detector types and energy ranges.

1.11 High Count Rates

For high-activity materials, the ability of the preamplifier to process the detector input becomes a controlling factor. The commonly used resistive feedback preamplifier has a standard energy rate product of 50,000 MeV/second, but can be modified to operate at 200,000 MeV/second.

The pulsed optical feedback or transistor reset preamp is used for very low noise applications (soft gamma or X-rays with planar detectors). Energy resolution remains optimal up to the performance limit of most main amplifiers. Its energy rate product is 200,000 MeV/second.

For highest count rates, a transistor reset preamplifier is recommended. It can operate at 800,00 Mev/second or higher. The upper count rate limit and resolution of the system are thus determined by the gated-integrator amplifier and ADC units. A more detailed description of the PGT preamplifiers starts on page 20.

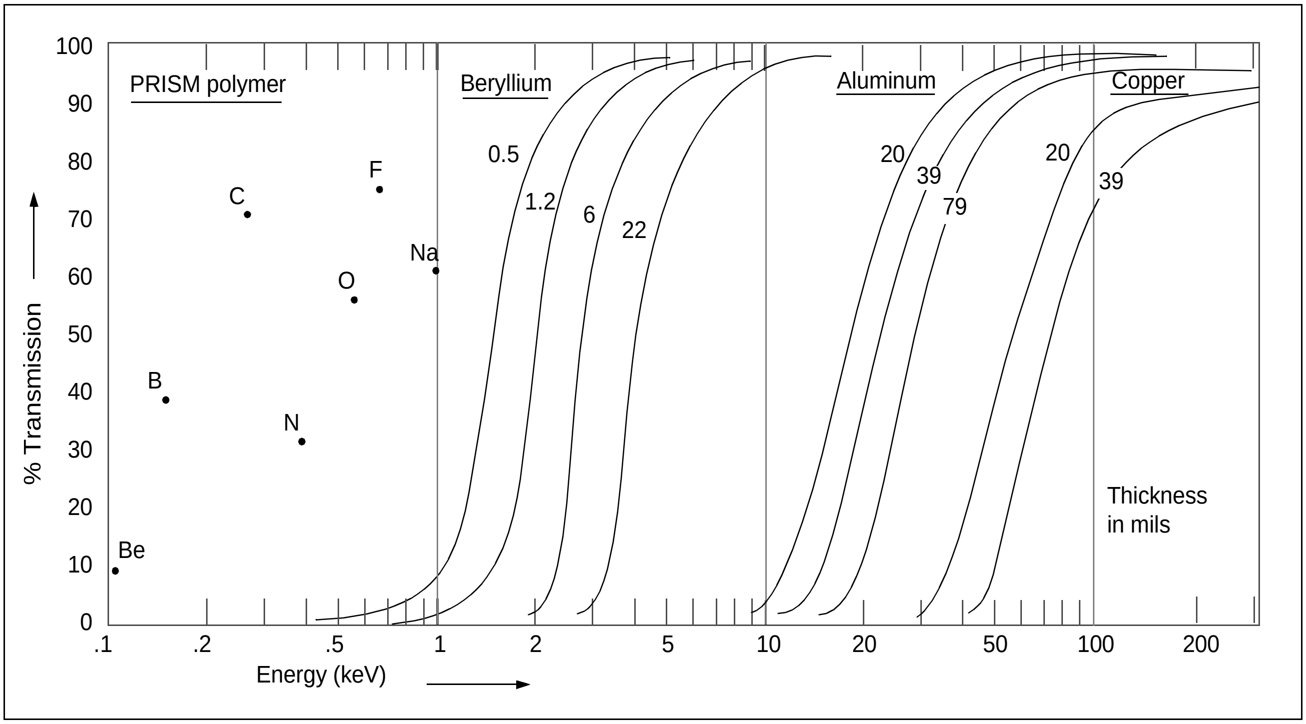


Figure 1.15 Energy transmission curves for window materials of various thicknesses (in mils). Some representative light element data are also reported for a polymer window.

1.12 Window and Endcap Materials

Standard aluminum endcaps absorb significant radiation below 10-20 keV. The use of beryllium or polymer windows can extend the usability range to lower energies. Figure 1.15 illustrates some typical transmissions.

Another useful measure is the thickness of the total window (meaning, in this case, the detector dead layer, cryostat mount, endcap, and entrance window). A window thickness index may be defined as the ratio of the peak areas of the 22 and 88 keV lines of ^{109}Cd.

For thin windows, the thickness index is based on the X-ray fluorescence of a standard glass consisting of oxides of Si, Ba, Ca, Li, Mg, Zn and B. When the glass is fluoresced with an ^{55}Fe source, X-ray lines are produced in the 1-5 keV range. The peak area ratios of these lines to that of the coherently backscattered 5.9 keV line of the source can define the window thickness index.

1.13 Low Background Spectroscopy

For very low activity spectroscopy, in particular for environmental analyses and Minimum Detectable Activity (MDA) determinations, it is frequently necessary to eliminate background radiation. This interfering radiation may come from the naturally occurring radioactive impurities in the detector/cryostat materials or from cosmic sources. Figure 1.16 shows the effects of background radiation and various steps taken to eliminate it. The data were obtained with a PGT detector.

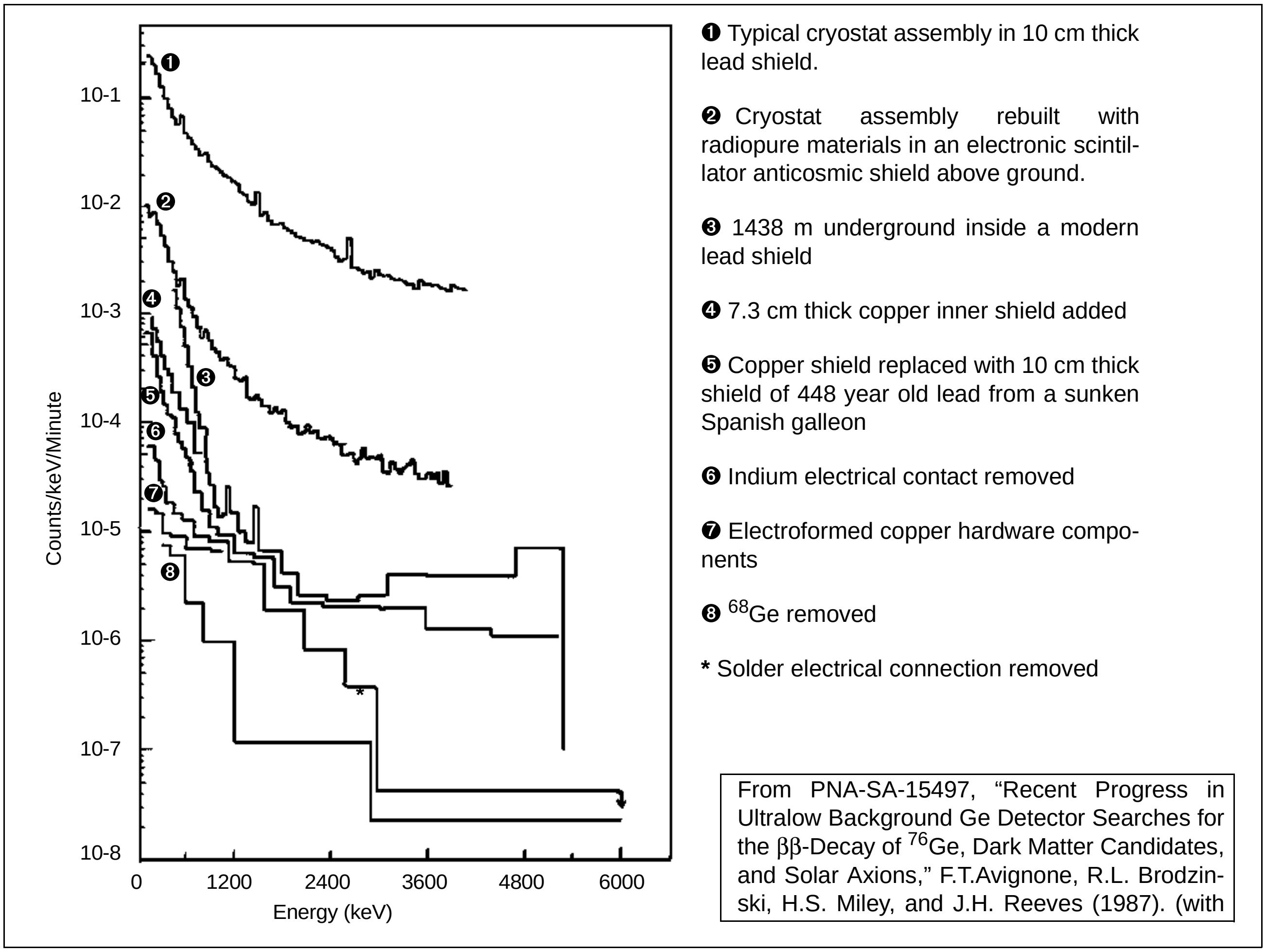


Figure 1.16 Reducing background radiation.

PGT offers the following very low background materials:

Oxygen-free high conductivity copper (OFHC) for the cold finger and detector mounts.

- Ultra-low background aluminum endcap (<1 ppb Th).
- Low-background beryllium or Vespel entrance windows.
- Vespel plastic well insert.
- Activated charcoal getter in place of the molecular sieve.
- Tungsten internal shielding in the endcap.

Typical specifications are shown in Table 1.1.

In addition, the NPR cryostat configuration separates the endcap from a direct line-of-sight with the preamp whose circuit boards and components contain natural residual radiation. The endcap itself may be enclosed in a lead shield.

In selecting a low-background system, there are some general factors that should be considered:

An external preamplifier is generally better than an in-line preamp, because the naturally occurring residual radioactive materials found in the circuit board are not in direct "line-of-sight" with the detector.

The molecular sieve getter, which may have a slightly higher residual radioactivity than activated charcoal, is significantly more effective in adsorbing contaminants and maintaining the vacuum. The NPR cryostat, with or without a lead shield, is a better way to keep the getter from iradiating the detector.

PGT recommends the low-background beryllium entrance window, rather than magnesium, because the latter is much more readily corroded. A Vespel window is also available. For the same window thickness, Vespel has a lower energy transmission (~10% at the 14.4 keV line of ^{57}Co). However, it is less costly.

Material	Application	Pertinent Data
Oxygen-free high-conductivity copper (OFHC)	endcaps (4” and 8”), mounting cup, pedestal unit and nut, cooling rod clamp, and coldfinger	<0.24 dpm/kg ^{208}Tl [a] <0.78 dpm/kg ^{214}Bi <15.2 dpm/kg ^{40}K
Ultra-low background Pechiney aluminum (<1ppb Th)	endcap and crystal holder well insert	96% Al + 4% Si <150 parts per trillion U + Th
50 mm virgin lead	internal shield (8” endcap)	copper-clad
50 mm tungsten	internal shield	
Ultra-low-background beryllium (IF-I and IF-II)	2.5” and 3” entrance window (for n-type detectors)	Vacuum-tight, optically dense foils 99.9% Be (IF-I) with <2 ppm U + <1 ppm Th 99.6% Be (IF-II) with <2 ppm U + <3 ppm Th
Vespel ™ SP-22	entrance window, well insert	40% graphite

Table 1.1 Background Material Specifications

a. dpm = disintegrations/minute (typical)

f you are ordering a new detector with no restrictions (for example, spatial constraints), the following suggestions, in order, will result in increasingly low background counts:

1. NPR cryostat, preferably with an external preamp, and
2. A lead shield.
3. Replace the endcap and internal metal parts with OFHC copper or low-background aluminum (more expensive).
4. Use low-background beryllium or Vespel window for lower-energy spectroscopy.

If you must have a dipstick cryostat, consider the following:

1. Lead shield.
2. Internal shield between the back of the cryostat and the preamp and dewar. Copper-clad lead is preferable, but tungsten is more compact. The choice may depend on how much space is available.

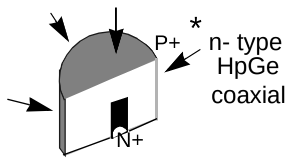
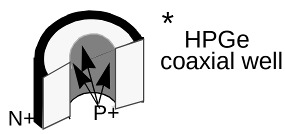
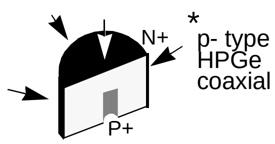
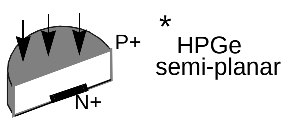
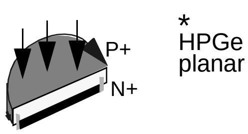
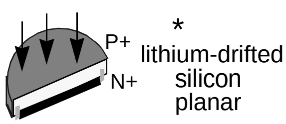
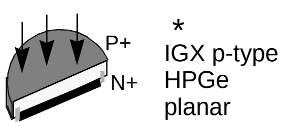
Series	Detector Crystal	Crystal Geometry	Energy Range	Resolution	Sizes	Peak Shape
NIGC	n-type high purity germanium Contact thickness: ~0.3µm		4 keV–10 Mev	5.9 keV: 665–1200 eV 1.33 MeV: 1.8-2.3 keV	10-75%	Peak/Compton 38:1–62:1 FWTM/FWHM 1.9–2.0
IGW	p-type high purity germanium Contact thickness: 0.5 mm external		10 keV–10 MeV	122 keV: 1200-1300 eV 1.33 MeV: 2.10–2.3 keV	50-170 cm^3 Sample hole: 10-20 mm diam. 40 mm depth	FWTM/FWHM 1.9–2.0
IGC	p-type high purity germanium Contact thickness: ~0.5 mm		40 keV–10 MeV	122 keV: 800–1400 eV 1.33 MeV: 1.75–2.30 keV	10-100%	Peak/Compton 37:1–77:1 FWTM/FWHM 1.9–2.0
NIGP	n-type high purity germanium Contact thickness: ~0.3 µm		3 keV–1 MeV	5.9 keV: 420–470 eV 122 keV: 650–950 eV	1500-3800 mm^2 10-30 mm thick	FWTM/FWHM <1.9
IGP	p-type high purity germanium Contact thickness: 500 Å		180 eV–1 MeV	5.9 keV: 120–400 eV 122 keV: 480–610 eV	10-1000 mm^2 5-13 mm thick	FWTM/FWHM <1.9
Si(Li)	Lithium-drifted silicon Contact thickness: 150 Å		109 eV–60 keV	5.9 keV: 138–163 eV	10-60 mm^2 3.5–5 mm thick	FWTM/FWHM <1.9
IGX	p-type high-purity germanium Contact thickness: 150 Å		180eV–100keV	5.9 keV: 120–135eV	10-50 mm^2 4-5 mm thick	FWTM/FWHM <1.9
	* → Incident Radiation P+ layer (ion implantation or metallization); thin N+ layer (lithium diffusion); thick p-type crystal n-type crystal					

Table 1.2 PGT Gamma ray and X-ray Detectors

1.14 Crystal Types and Geometries

PGT selects the best high-purity germanium, HPGe—sometimes called intrinsic, IG—and lithium-drifted silicon Si(Li), crystals available for processing into detector crystals. The crystal size, geometry, type, and contact layers are custom-manufactured.

Note on nomenclature: PGT has been an industry leader since the early days when the term "intrinsic germanium" was commonly used. It is now recognized that "high-purity germanium" or HPGe is a more appropriate term. However, PGT has retained the IG designation in its model numbers to eliminate confusion among models.

The crystals can be fabricated in various sizes and configurations to cover the energy range/count rate best suited for your particular applications. Table 1.2 includes the basic crystal geometries and the applicable energy ranges.

- **NIGC (n-type HPGe Coaxial) Detectors** can measure photons from below 10 keV to 10 MeV with high efficiency. They are less sensitive to neutron damage than other coaxial detectors because electrons are the main charge carriers, and these are not as easily trapped by the damage centers as are holes.
- **IGC (p-type HPGe Coaxial) Detectors** have an energy range of 40 keV to 10 MeV and are suitable for a wide variety of applications, including portable systems. They have a long service life and can be stored warm for extended periods.
- **IGW (p-type HPGe Coaxial Well) Detectors** are useful in measuring low activity radiation because they surround the analyte. Their 'through-hole" design allows for analysis of larger samples at high resolution.
- **NIGP (n-type HPGe Semiplanar) Detectors** offer lower noise and, consequently, better resolution at low-to-moderate energies than any other detector geometry. They are used in lung monitor arrays.
- **IGP (p-type HPGe Planar) Detectors** are rugged in construction and can deliver clean spectra with high efficiency. Their maximum efficiency in the lower energy ranges makes them ideal for spectroscopy of transuranic materials and mixed gamma and X-ray samples.
- **Si(Li) Lithium-drifted Silicon Planar Detectors** are used mainly for X-ray spectroscopy. They are suitable for energies from ~100 eV to 60 keV.
- **IGX (p-type HPGe Planar) Detectors** have a thin entrance window for X-ray spectroscopy in an energy range of 180 eV to 100 keV. They have energy resolutions as good as 120 eV FWHM at 5.9 keV.

It is important to choose the right detector type and size. A detector that is too big not only wastes money, but may also create problems due to high count rates. An undersized detector may be cheaper in price, but expensive in time. Of course, PGT will gladly work with you to meet any special requirements you have.

1.15 Crystal Materials

HPGe has an impurity level of ~$10^{10}/cm^3$. Impurities may be either p- or n-types and determine the parity of the crystal. To fabricate a detector, a thin P+ layer is formed on one surface, usually by boron ion implantation or gold metallization. The thickness of this layer is about 0.3 μm. The other surface is a thicker N+ layer (~0.5 mm) formed by lithium diffusion.

When a bias voltage is applied to the crystal, incident radiation creates charge carriers that are swept toward the oppositely charged contacts. For IGW and IGC detectors, the applied voltage is positive, and holes are the primary carriers.

For detectors with a P+ layer on the face, a negative bias is applied. In this case, electrons become the main charge carriers. Such crystals are less sensitive to neutron damage.

For silicon detectors, the p-type silicon crystals are counter-doped with Li ions to achieve the required impurity level by a lithium drifting procedure.

1.15.1 Crystal Shape

PGT does not use the "bullet" shape for its detector crystals. The variation in the electric field in the crystal, which such a shape supposedly avoids, is minor. The straight-across design of PGT crystals allows for better clamping of the crystal in the endcap which results in lower microphonics—and therefore better resolution!

1.15.2 Dead Layers

The term "dead layer" refers to a thin layer of inactive material on the surface of the semiconductor detector crystal through which the incident radiation passes before reaching the active material. Any radiation absorbed by this layer is lost, that is, does not contribute to the signal induced in the detector.

Where the dead layer is the P+ layer formed by ion implantation or metallization, its thickness is typically about 0.3 μm. For germanium planar and Si(Li) planar detectors, the dead layer is approximately 0.1 μm. The IGC coaxial detector has a lithium-diffusion dead layer ~0.5 mm thick.

For detector crystals mounted in series in a single endcap, there may be both an entrance and an exit dead layer.

1.15.3 Window Materials

In addition to the crystal dead layer, any endcap or window material between the source and the detector crystal has the potential to absorb radiation and thus reduce efficiency. As noted earlier (see page 15), this is especially true at lower energies.

The standard endcap for coaxial and well detectors is aluminum. Beryllium and polymer entrance windows are available for low-energy spectroscopy. Beryllium and supported organic thin windows are used with the Si(Li) X-ray detectors, which can also be operated in a windowless mode for light-element analysis. Note that a detector with a light-element window must be kept in the dark or the endcap covered to protect it from lower-energy radiation (IR, visible, UV).

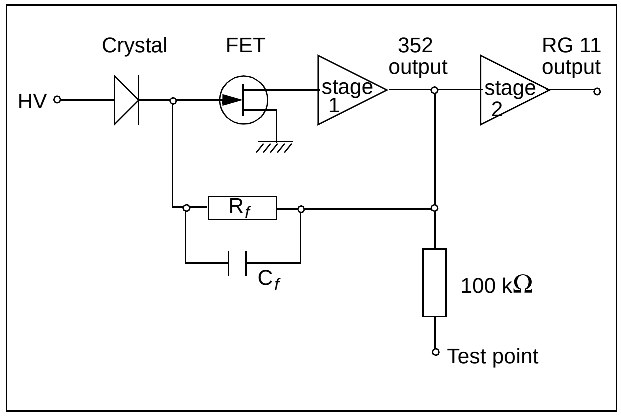


Figure 1.17 Resistive feedback preamplifier.

1.16 Preamplifiers

The preamplifier is an important component in a semiconductor detector. PGT offers three types of preamplifiers:

- **Resistive feedback**
  - PGT RG-11 B/C
  - PGT RG-15 (in-line)
  - PGT 352 Low Power
- **Pulsed optical reset**
  - PGT PO-14B
- **Transistor reset**
  - PGT TR-14 (p and n-type)
  - PGT TR-1

The appropriate choice depends on your application.

The PGT RG-11 B/C or RG-15 (in-line) Resistive Feedback Preamplifier (Figure 1.17) is the type most commonly used for gamma ray counting between 5 keV and 10 MeV. It maintains a closed loop first stage amplification by means of negative feedback through a high-value resistor and a selected low-noise FET. These components are mounted close to the crystal in the cryostat and maintained at liquid nitrogen temperature to minimize the noise and microphonics contribution to system performance.

The PGT 352 Low Power Preamplifier is a resistive feedback model designed for portable detector applications. Its power requirement of <250 mW and operating voltage of ±12 VDC minimize drain from the battery pack on the MCA.

The PGT PO-14B Pulsed Optical Feedback Preamplifier (Figure 1.18) replaces the feedback resistor with light pulses to reset the preamp output. Performance is close to that of an idealized charge-sensitive preamplifier. This preamplifier is ideal for very low noise applications such as the measurement of soft gamma and X-rays using small-to-medium high-purity germanium planar detectors.

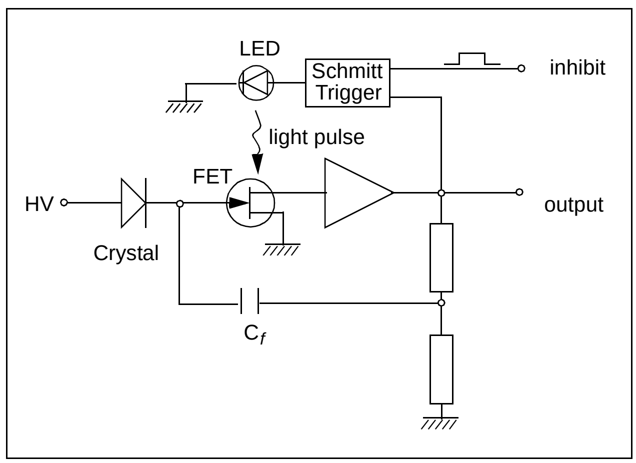


Figure 1.18 Pulsed optical reset preamplifier.

The PGT TR-14 Transistor Reset Preamplifier (p and n-type) is used with coaxial or large area planar detectors for gamma ray and high energy X-ray applications. The preamplifier (shown in Figure 1.19) is designed for high energy rate applications (with a maximum >800,000 MeV/

sec). In this type of preamplifier, the charge accumulating on the feedback capacitor is periodically discharged through a suitably located transistor.

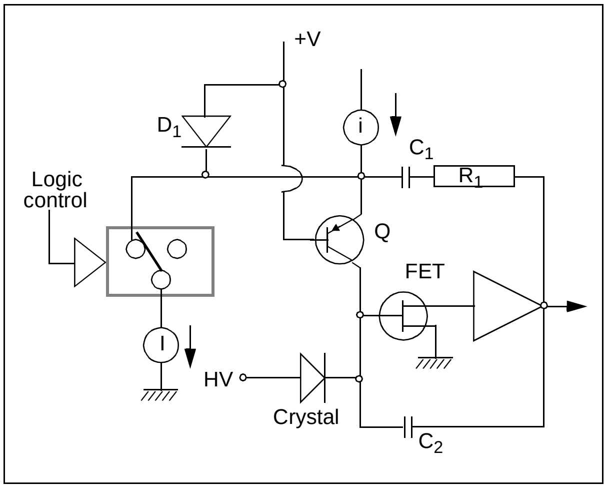


Figure 1.19 Transistor reset preamplifiers.

The PGT TR-1 Transistor Reset Preamplifier is used with low noise, high resolution X-ray detectors, and incorporates a low capacitance FET with built-in reset circuitry for optimum noise performance.

The PGT TR-14 (p and n-type) Transistor Reset Preamplifier (Figure 1.19) is designed for high energy rate applications (with a maximum >800,000 MeV/sec). In this type of preamplifier, the charge accumulating on the feedback capacitor is periodically discharged through a suitably located transistor.

1.16.1 Preamplifier Characteristics

A preamplifier may be characterized by its maximum count rate for a given energy range, its maximum energy rate product, and its decay time or reset time. The decay/reset time describes how quickly the charge induced in the capacitor can be discharged. In the resistive feedback preamplifiers, this is determined by the decay time constant of the RC feedback loop, which is typically on the order of 1 msec. As shown in Figure 1.20, recovery occurs after each event (indicated by the dashed curved line).

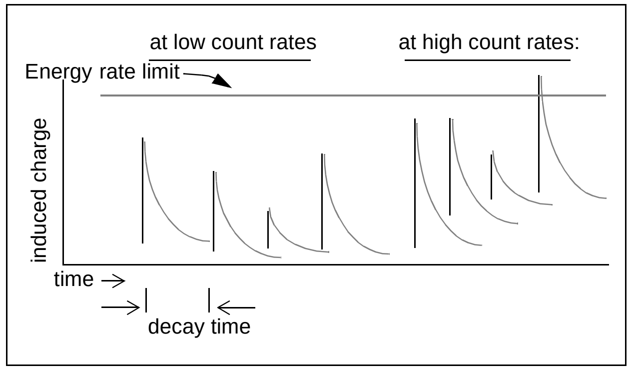


Figure 1.20 Decay pattern for a resistive feedback preamp, showing long recovery after each event.

In a pulsed-reset preamp, the resetting may be either by pulsed light feedback to the FET structure by a light-emitting diode or by a transistor switch, and reset occurs only after many events (Figure 1.21).

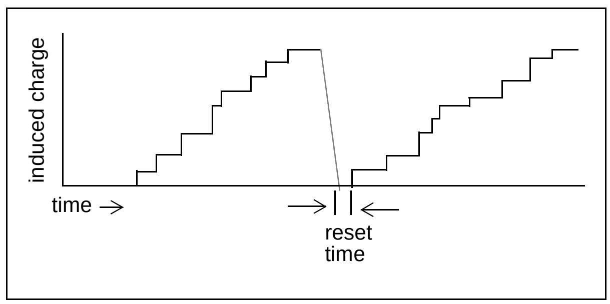


Figure 1.21 Decay pattern for pulsed-reset preamp, showing reset only after many events.

With the pulsed optical (PO) reset, the reset time is approximately 15 µsec, while in the transistor (TR) reset, the time is 6-10 µsec.

In a detector system, counts cannot be processed during system “dead time,” when the preamp and main amplifier are busy. The contribution of reset time to system dead time is very short. In pulsed-reset systems, preamplifier dead time coincides with the reset time, and the maximum energy rate is primarily limited by the collection time per event. Maximum energy rates in excess of 1000 GeV/sec are common in reset type preamplifiers. In the resistive feedback preamps, events can be processed even during the decay time of previous events, as shown schematically for high count rates in Figure 1.20. However, as they pile up on one another, the output level increases until it reaches the maximum of the preamplifier dynamic range (23.3V for the RG-11B and ~10V for the 352). The maximum energy rate is typically limited to 80 GeV/sec.

Further, if the time between events is less than 1.5× the peaking time of the main amplifier, regardless of the type of preamplifier, the pulses pile up and cannot be processed. Main amplifier and ADC (analog-to-digital converter) dead times are the major contributors to system dead time.

1.17 Maximum Count Rate Determination

In a dc-coupled charge-sensitive preamplifier, there is a maximum value for the energy rate product (energy × count rate), above which the preamplifier will shut off. As this maximum energy rate product is approached, the detector system may exhibit severe resolution degradation and peak shifts. For a given preamp, the maximum count rate can be determined by dividing the measured maximum energy rate by the mean energy of the events produced in the detector.

$$\frac{1Q}{2.98eV} \times (1.6 \times 10^{-19} \text{Coulomb} / Q) \times \text{MeV/sec} = I_D$$

\# of charge carriers per energy absorbed × charge per charge carrier × rate at which energy is absorbed = current induced in detector

$$I_D \times R_f = V_{TP}$$

detector current, feedback resistor, test-point voltage

$$ER_{max} = \text{countrate} \times E_{spectrum}$$

energy rate at max V_{TP}, mean energy of spectrum

For example, in a germanium detector with a resistive feedback preamp, 1 MeV of energy falling on the detector produces a charge of 0.53×10^{-13} coulombs. Thus, if 1 GeV/sec is detected, the current generated is 0.053 nAmps. This current flowing through a 10GΩ feedback resistor raises the voltage at the preamplifier test point by 0.53V. As the energy rate is increased to 44 GeV/sec, the test point voltage increases to >23.3 V, at which point the preamplifier shuts down. Therefore, for this example, 44 GeV/sec is the maximum energy rate (ER_{max}) that the detector/preamp assembly can handle. The maximum count rate is determined by dividing this value by the mean energy of the spectrum. In this particular system, the maximum count rate for ^{57}Co would be approximately 440,000 counts/sec.

For a coaxial detector, the feedback resistor value, cold, is typically 5-10 GΩ. The average 7.5 GΩ resistor gives a maximum energy rate of 60 GeV/sec. For the ^{60}Co spectrum with a mean energy of 0.8 MeV, the maximum count rate is 70,000 counts/sec.

It should be noted that the count rates are those observed in the total spectrum. Once the maximum energy rate of a given system is known, count rates for other spectra can be calculated. For example, in the system above with a maximum energy rate of 60 GeV/sec, the maximum total count rate for ^{137}Cs (662 keV line) with a mean energy of ≈0.5 MeV is 120,000 counts/sec.

Using a lower value feedback resistor can yield a higher maximum energy rate, but with a loss in resolution. For high count rates and high energies, the use of a transistor reset preamp is much better.

Count rate is also limited by the pulse-pair resolving time, which is a function of the amplifier-selected peaking time

.

Some representative maximum energy rates for various PGT Preamp/Detector systems are shown in Table 1.3:

Detector	Preamp	Max. energy rate (GeV/sec)
IGC/NIGC	RG-11/15	70
IGP (<500 mm^2)	RG-11/15	6
IGP (>500 mm^2)	RG-11/15	12
IGP (<500 mm^2)	PO-14B	200
IGC/NIGC/IGP	TR-14	400 standard 1000
Si(Li)/IGX	TR-1	200

Table 1.3 Maximum Energy Rates

1.18 High Count Rate Systems

The main amplifier shaping time may have to be decreased at higher count rates. Energy resolution at shorter shaping time becomes worse, however, because of increasing noise attributed to the FET component of the preamp and the detector capacitance. At longer shaping time the system noise will again increase, particularly with resistive feedback preamps, because of the noise from the resistor and detector leakage current.

1.18.1 Noise Effects

System electronic noise is primarily due to the electronics associated with the FET and the detector itself. There are three noise components:

- Parallel noise from detector leakage current and all resistors which are electrically in parallel with the detector, including the bias resistor and the preamp feedback resistor.
- Series noise from total input capacitance, gain, and resistors between the detector and preamp.
- $1/f$ noise.

The value of the parallel and series noise contributions is a function of the pulse processing time, which is the time needed by the main amplifier to completely process a pulse from the preamp, ~ 5× the Gaussian shaping time, τ.

- Parallel noise (N_p) is proportional to $\sqrt{\tau}$.
- Series noise (N_s) is proportional to $1/(\sqrt{\tau})$.
- $1/f$ noise is independent of τ.

Figure 1.22 shows how the parallel and series noise contributions and the total noise in a resistive feedback preamplifier vary with the pulse processing time. Minimum electronic noise (N_{opt}) occurs at T_{opt}, when these two components are equal. The $1/f$ contribution, indicated by the dashed line, does not change the shape or position of the minimum on the time axis, but only its height (noise value). The variation of detector resolution with pulse processing time essentially coincides with the curve for N_{Tot}^2.

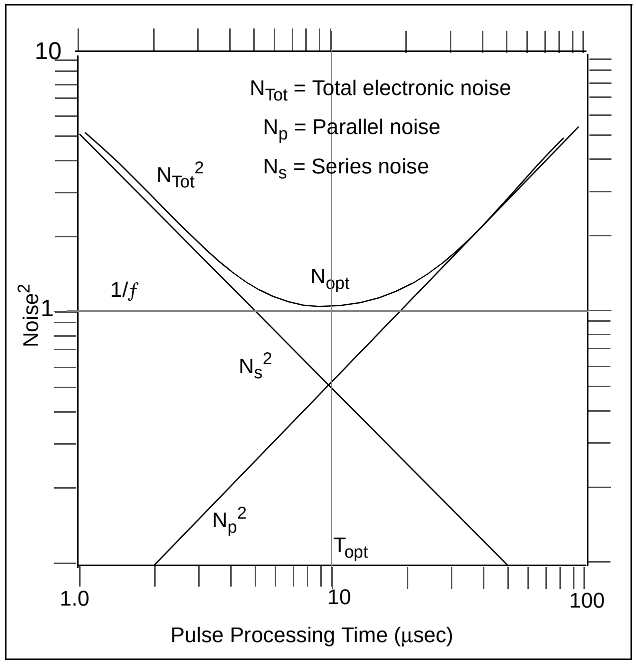


Figure 1.22 Electronic noise contributions as a function of pulse processing time in a resistive feedback preamplifier.

Decreasing the shaping time to 0.5 T_{opt} can double the count rate capability of a system. Increasing the noise, and therefore resolution, can raise the count rate capability by only about 12%.

The optimum shaping time (T_{opt}) for a given germanium detector system is typically around 4 µsec Gaussian shaping time, corresponding to approximately 20 µsec pulse processing time.

N_p is negligible in pulsed-optical preamps and small with transistor-reset preamps. This reduces N_{opt} and shifts the T_{opt} to longer pulse processing time, as shown in Figure 1.23. Therefore, a longer time constant is often used with pulsed reset preamps without loss of resolution. Also,

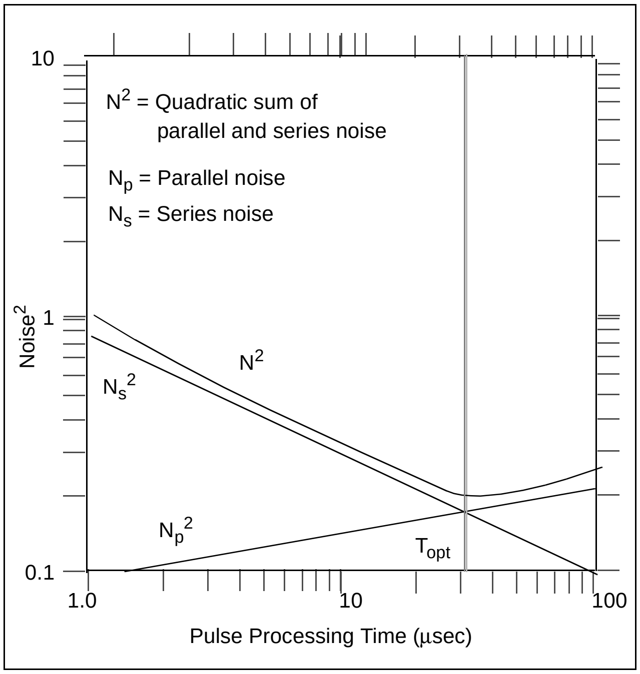


Figure 1.23 Noise contributions in pulsed-reset preamplifiers.

because $1/f$ noise is also smaller, the resolution degradation at short time constants is less than that for resistive feedback preamps.

For a given shaping time, high count rates can lead to the possibility of pulse pile-up in which pulses arrive at the MCA almost simultaneously. The MCA treats such a double pulse as a single pulse of greater amplitude (and energy). This leads to the following types of distortion in the spectrum:

- Extra high-energy counts.
- Fewer counts in the photopeak.
- Increase in the FWHM for the full energy peak.

This spectrum degradation becomes significant when the product of input count rate and pulse processing time exceeds 0.5, and it is a dominant factor when this value is >1.

Decreasing the pulse processing time of the main amplifier by decreasing the shaking time reduces the spectrum distortion, but with a loss in resolution, as shown in Table 1.4. A pile-up rejector can also be used if it is compatible with the MCA.

Source/ line	Count Rate (cps)	% Increase in FWHM with Shaping Time			
		@ 4 μs	@ 2 μs	@ 1 μs	@ 0.5 μs
^{60}Co (1332 keV)	1 000	0	1	4	8
	10 000	5	4	5	8
	20 000	9	6	7	9
	50 000	17	12	10	11
	100 000	20	18	15	14
^{57}Co (122 keV)	1 000	0	5	15	30
	10 000	5	8	16	30
	20 000	9	10	18	31
	50 000	17	16	22	34
	100 000	20	23	28	38
^{55}Fe (5.9 keV)	1 000	0	10	30	60
	10 000	5	13	31	60
	20 000	9	15	34	62
	50 000	17	22	38	65
	100 000	20	28	44	70
These figures are meant as a general guide and assume the use of a suitable main amplifier, pile-up rejector, and multichannel analyzer.					

Table 1.4 Resolution as a Function of Count Rate and Shaping Time

1.18.2 Gated Integrator with TR-14 Preamplifier

A further source of peak broadening, also related to the amplifier shaping time, is called “ballistic deficit.” It arises primarily at high count rates. When a large-volume coaxial crystal is used for its higher efficiency at higher energies, some charges are produced in weaker, less uniform field regions. These charges are not collected as rapidly (that is, they have slow rise times). If the charge collection time in the detector is long compared with the shaking time of the electronics, these pulses will fall short of full energy value. The result is a broadening and low-energy tailing of the spectrum lines.

The effects of ballistic deficit can be compensated for by the use of a gated integrator amplifier (GIA) system. This amplifier has variable shaping times controlled by the rise time of the pulses from the detector, and it operates at a basic short time constant of 0.25 μsec.

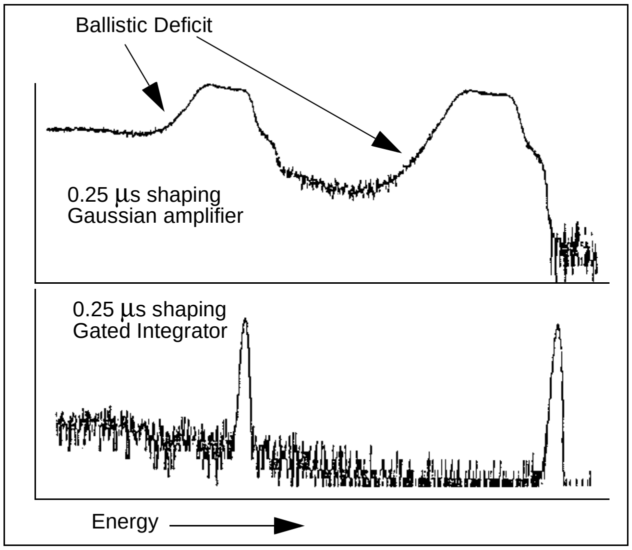


Figure 1.24 Comparison of ^{60}Co spectra obtained with a Gaussian shaping amplifier and with a Gated Integrator amplifier.

Figure 1.24 shows the dramatic improvement obtained with a PGT TR-14 transistor reset preamplifier and gated integrator amplifier system for an n-type coaxial germanium detector at 5000 cps. Maximum energy-rate products for these systems are limited by the amplifier and ADC, rather than by the preamplifier itself.

1.19 Microphonics

Microphonics essentially refers to mechanically generated noise that impacts spectral resolution. Within detector cryostats, noise can be introduced by the mechanical vibration of internal components relative to surfaces at different potentials. Such oscillations may be from:

- The bubbling of liquid nitrogen.
- The vibration of other equipment in contact with the cryostat.
- Environmental noise (such as heavy equipment in the vicinity of the detector).

Even a change of capacitance between the FET gate and high voltage of only 5×10^{-7} picofarad is sufficient to generate a microphonic signal equivalent to that of a 10 keV X ray.

Microphonic deterioration of signals will appear on the MCA as a broadened peak or, in severe cases, as a phantom peak or a double peak.

PGT has developed an ultra-low microphonics mounting system, THE QUIET ONE™, with a Microphonic Rating (MR) of <0.1 at 90 db over the range 100 Hz-10 kHz. MR is a measure of the increase in noise level at the detector endcap due to acoustic noise.

PGT QUIET ONE mountings are available for most PGT high-purity germanium detectors. They are particularly useful for:

- Low-activity measurements requiring well-defined peaks.
- High resolution analysis of complex spectra with multiple isotopes.
- Environmental analysis using portable or truck-installed detectors.
- Nuclear plants and other industrial sites where vibrations from heavy machinery are a problem.

For mechanically cooled detectors, such as JT Cool, the QUIET ONE mount offers the unique advantage of providing the same high performance specifications as a liquid-nitrogen cooled system. No other detector manufacturer can offer this advantage.

For less severe requirements, the user can reduce microphonics due to external vibrations by mounting the dewar and detector on cushioning, such as foam or felt.

1.20 Pulse Processing Electronics and Software

PGT can provide a variety of pulse processing electronics and analytical software to complete a sodium iodide or germanium-based gamma spectroscopy system, or a Si(Li) or germanium-based X-ray spectroscopy system. These solutions include integrated electronics and component electronics. PGT also offers software for HPGe and Na(I) gamma spectroscopy applications. Please see the following sections for additional information about these products:

- “MCA 4000 Multichannel Analyzer” on page 67.
- “System 4000 X-Ray Spectrometer” on page 69.
- “MCA 8000 Multichannel Analyzer” on page 72.
- “System 8000 Gamma or X-Ray Spectrometer” on page 74.
- “MCA 2100R Multichannel Pulse Height Analyzer” on page 65.
- “Quantum MCA Software for Windows” on page 77.

If the system requires various components (for example, special shielding) from other manufacturers, these items can be purchased and integrated into the primary system to create a complete, customized system.

1.21 Cryostats

In a detector system, the crystal is housed in a protective endcap. Both the crystal and the first stage FET of the preamplifier are maintained at cryogenic temperature by a cold finger (cooling rod). This is necessary to reduce the leakage current (from thermally generated charge carriers) which would otherwise degrade the energy resolution of the detector.

Cryogenic temperatures are established and maintained by a liquid nitrogen (LN_2) cryostat assembly. The LN_2 supply is housed in a dewar and is in contact with a copper tubing cold finger. Cooling may also be accomplished mechanically with the JT Cool cryocooler.

Figure 1.25 is an expanded cross-section diagram of a detector with an external preamp, a dip-stick style cryostat, and a standard dewar. The high vacuum of both the cryostat housing and the dewar are maintained with the help of a molecular sieve material.

In dipstick systems, the cryostat and the dewar are separate entities. In unitary systems (Figure 1.25, center and right) the LN_2 reservoir and the cryostat itself are a single, inseparable unit with a single vacuum system.

Cryostats are manufactured in straight-line configurations (facing up, down, or horizontally) or in an elbow (90°) form with either a stationary or swivel head.

The various configurations and sizes can be customized to fit specific needs.

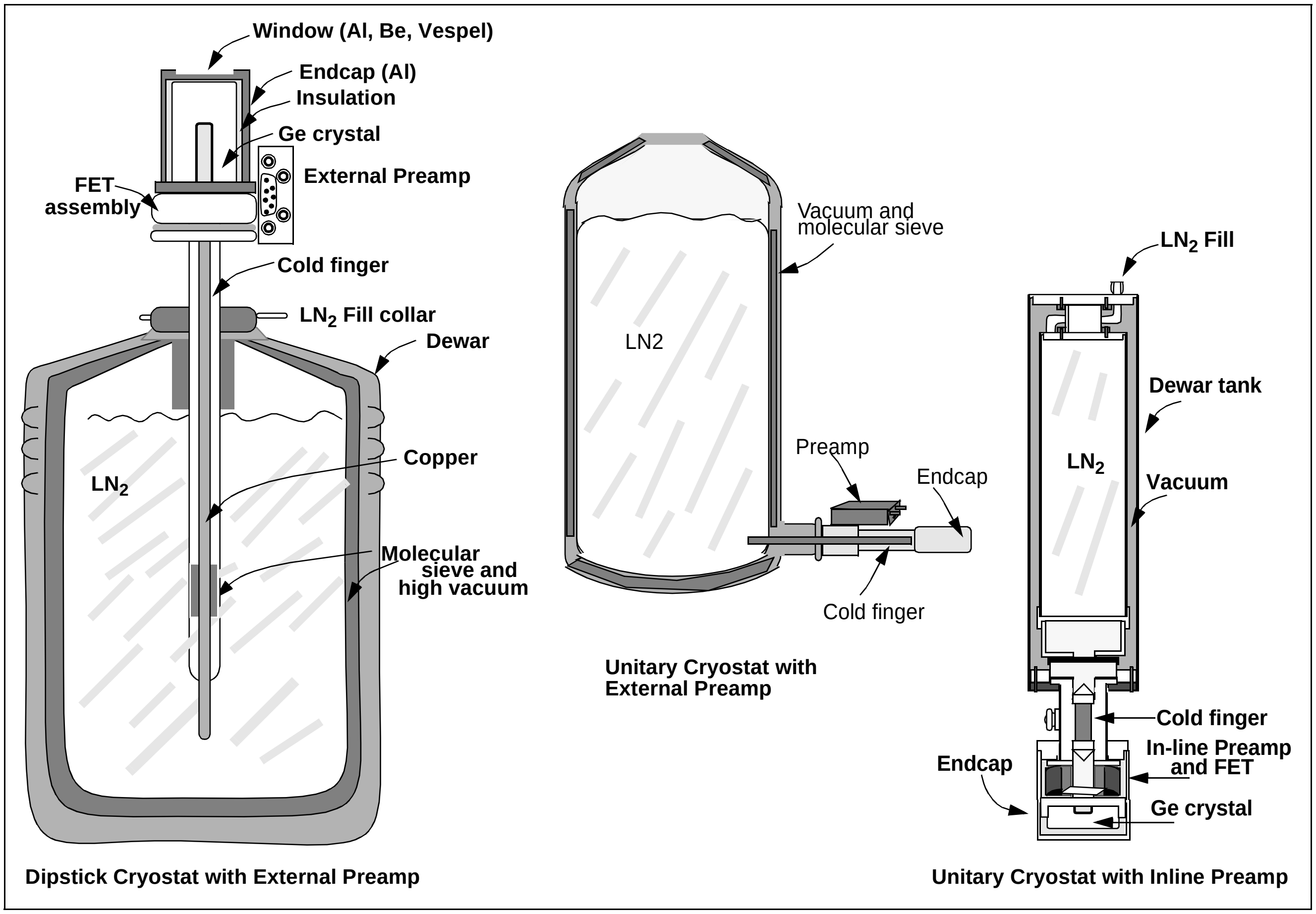


Figure 1.25 Schematics showing major components of a dipstick cryostat (left), and representative unitary cryostats (center and right).

Ultra-low background materials are available for low-level counting systems. These materials include:

- OFHC (oxygen-free high-conductivity) copper endcap.
- Mounting cup, and cold finger.
- Ultra-low background aluminum endcap.
- Low-background Be or Vespel plastic entrance windows.
- Activated charcoal sieve.
- Tungsten internal shielding in the endcap.

Radiation-shielded counting chambers are also available.

1.22 Detector Cool Down Requirements

It is very important that the detector be completely cooled before the high voltage bias is applied. Performance specification sheets which come with PGT detector systems specify the cooling period required before the kV supply is turned on.

It is usually more efficient to maintain the detector “at the ready” by replenishing the LN_2 supply at regular intervals. This information is also furnished with the detector.

If the detector has started to warm up, because the LN_2 has run dry or because of power loss to the mechanical cooler, it is necessary to warm it up completely before cooling it down again. The reason is that the molecular sieve “getter,” which helps to maintain the cryostat vacuum, begins to outgas in the early stages of warm-up. Unless the system is brought to room temperature, these contaminants will deposit on the detector crystal and cause the resolution to degrade.

Section 2: PGT Products

2.1 Introduction

This section provides product specifications and descriptions for the following PGT nuclear products:

- Standard detector crystals
- Dewars
- Cryostats and mechanical coolers
- Special low-background materials
- Preamplifiers and other electronic components

The appendixes include:

- Examples of spectra obtained using different PGT detectors.
- Information on standard radionuclide sources.
- A table of gamma and X-ray critical absorption and emission lines for all elements.

Follow the steps listed below to put together the nuclear spectroscopy system that meets your requirements. PGT can provide complete gamma spectroscopy systems, including analytical software and electronics. Please include specifications with your request.

1. Choose the type of detector crystal based on energy range, activity level (count rate), efficiency, resolution and cost.

2. Select a preamplifier appropriate to the expected count rate.

3. Consider a beryllium window for low-energy gamma rays or a light element window for X-rays.

4. Select the cryostat that is suitable for your holding time requirements, available space, low-background and portability needs. A mechanically cooled detector may be preferable to a standard LN_2-cooled detector. PGT has extensive experience manufacturing non-microphonic, mechanically cooled detectors.

5. Add any special requirements such as lead shields or low-background materials.

6. Select the required electronics. For information on various options, see the sections listed below or contact a PGT employee for assistance.
   - "MCA 4000 Multichannel Analyzer" on page 67.
   - "System 4000 X-Ray Spectrometer" on page 69.
   - "MCA 8000 Multichannel Analyzer" on page 72.
   - "System 8000 Gamma or X-Ray Spectrometer" on page 74.
   - "MCA 2100R Multichannel Pulse Height Analyzer" on page 65.
   - "Quantum MCA Software for Windows" on page 77.

7. Select any other required accessories such as LN_2 autofill systems and dewar supports.

8. Contact the PGT Nuclear Sales Department for additional information on customized options, price quotes and ordering information.

2.2 Ordering Information

PGT employees have extensive experience in designing and manufacturing customized spectroscopy systems. We will be happy to work with you to meet your current and future needs. Please direct your inquiries to the Nuclear Products Group.

To contact PGT:

Phone (609) 924-7310
FAX (609) 924-1729
Toll Free: (800) 980-9284
E-mail: sales@pgt.com
www.pgt.com/Nuclear/index.html

Please mail inquiries to:

Princeton Gamma-Tech, Inc.
C/N 863
Princeton, NJ 08542-0863

2.2.1 Sample Order

A sample "standard" order of a p-type detector of 15% relative efficiency with 1.80 keV resolution at 1.33 MeV, in an NPR cryostat with a 30-liter dewar would be specified as:

IGC15180-NPR-30

2.3 Limited Liability Warranty

PGT warranties that its germanium and silicon detectors are free from all defects in materials and workmanship and will not fail in normal service for a period of one year after delivery, if they are properly cared for.

High-purity germanium (HPGe or IG) detectors are expressly covered for any damage or deterioration that may be caused by warm-ups or by temperature cycling of the detector. PGT warrants that any IG detector will not fail to meet published specifications due to repeated or prolonged warm-ups to room temperature during the warranty period.

PGT is not responsible for damage resulting from exposure to fast neutrons.

It is the responsibility of the user to make sure that the detectors are not handled inappropriately. Mechanical shock can cause internal damage. IG detectors requiring a beryllium entrance window are delivered with a protective cover for the endcap. The beryllium window is very fragile and its accidental breakage is not covered by this warranty.

2.4 Selecting a Detector

The choice of detector for a particular application is based on:

- Energy range of interest
- Efficiency
- Resolution
- Count rate
- Cost

Table 2.1 lists different types of applications and the type of detector appropriate for each one.

Type of Application	Suggested Detector
Large samples (for example, environmental samples in Marinelli beakers) with complex spectra	IGC Series of p-type coaxial HPGe.
Small samples	IGW well detectors with the optional NPR cryostat and low-background materials.
Particle accelerators, with Compton suppression systems, or other high-flux situations	NIGC extended range n-type coaxial HPGe, with transistor-reset preamp for high count rates.
Spectroscopy of transuranic elements and mixed gamma- and X-ray samples	IGP planar detectors.
Body-burden assessment and lung monitoring	NIGP n-type planar crystals in detectors mounted in low-background NPR style cryostats or portable MPS cryostats. Non-LN_2 cooled systems are available.
High-resolution spectroscopy in areas of high vibration (for example, truck-mounted laboratories or industrial sites)	Any detector can be ordered with PGT's proprietary QUIET ONE anti-microphonics mountings.
Space exploration	NIGC in custom cryostat with shock- and vibration-insulated mountings.
X-ray fluorescence analysis of elements from B through U	Planar HPGe and Si(Li) X-ray detectors.
Emergency-response monitoring	Portable MPS or GF spectrometers with either coaxial or planar HPGe.
Non-destructive assay of spent nuclear materials	DUO detector for simultaneous measurements in two energy regimes.

Table 2.1 Applications and Suggested Detectors

2.5 Detector Specifications

2.5.1 Duo Detector

The PGT Duo Detector for high-level radioactive waste detection and analysis is an array of two germanium crystals on a single axis in a common cryostat vacuum. It permits simultaneous detection in two energy ranges (100-450 keV and 600-1000 keV). The combined spectral information improves the precision in the measured isotopic ratios.

The front crystal is a planar (IGP) detector with inherently high resolution for low energy photons. It is sized to reduce the amount of Compton scattering of high-energy photons. Most of these photons pass cleanly through the planar and are absorbed by the n-type coaxial crystal (NIGC) mounted behind it. A lead disk positioned between the two crystals attenuates any low-energy photons that might otherwise reach the coaxial detector, including remnants of Compton-scattered gammas. Each detector has its own preamplifier, either resistive feedback or transistor reset, depending on the anticipated count rates.

The two spectra are generated in just half the counting time required by two separate detectors.

This arrangement results in low MDAs in the low energy region because of the high resolution of the planar, the reduction in background due to Compton scattering, and the narrowing of the region of interest defining the peak. At high energies, the MDAs also improve because the Pb absorber cuts off the low and medium energy photons before they reach the coaxial crystal. These photons would otherwise contribute to background clutter. As a result, both spectra exhibit higher peak-to-background ratios.

This detector was built in collaboration with John Fleissner of the USDOE Rocky Flats Site.

Features:

- p-type planar (IGP) and n-type coaxial (NIGC) detectors mounted on a common axis
- Aluminum endcap with beryllium window

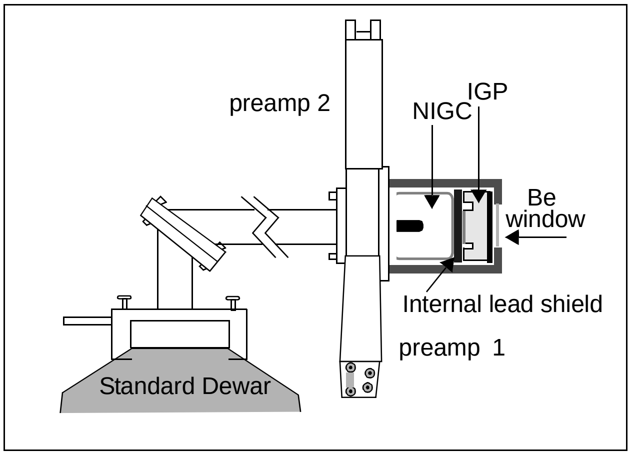


Figure 2.1 Duo Detector

- Elbow dipstick cryostat
- Two RG-11 B/C resistive feedback preamplifiers
- 12-ft bias, signal and power cables
- Standard 32-liter dewar

Options:

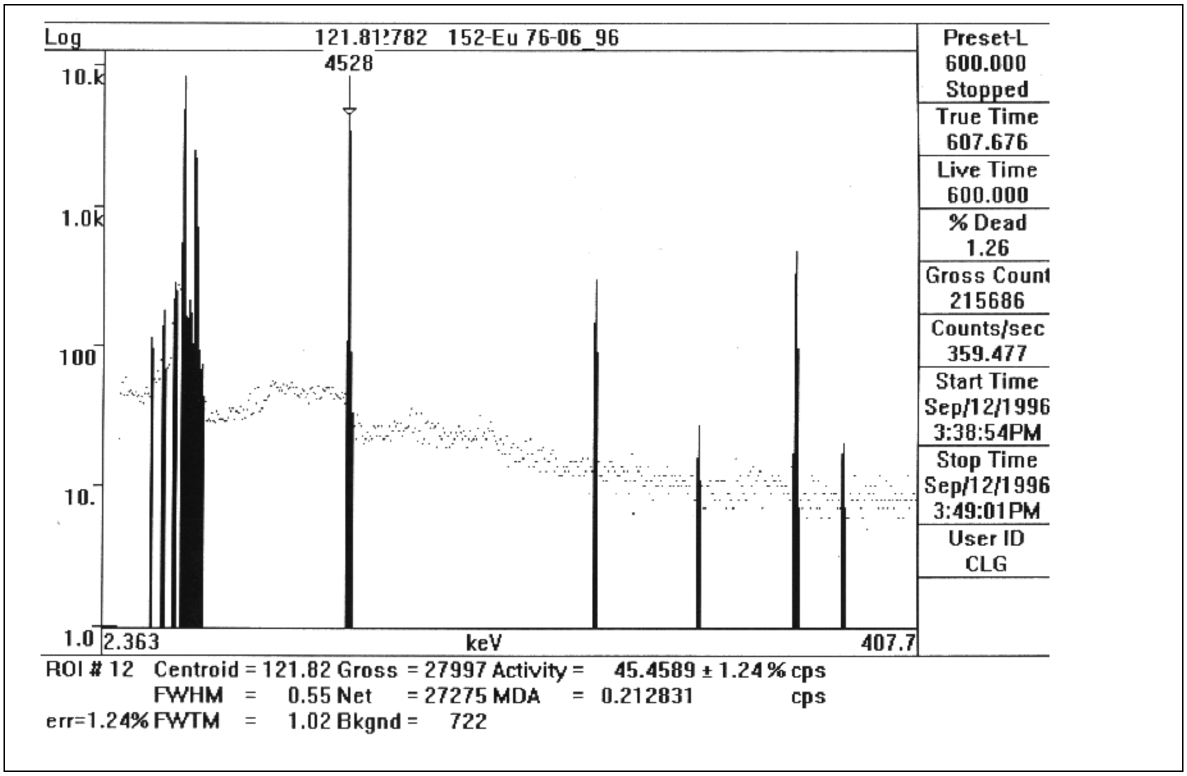
- Planar and coaxial crystals designed for specific energy ranges or distributed sources
- TR-14 transistor reset preamplifiers for applications at count rates higher than 80,000 cps
- Other cryostat designs, including portables
- JT Cool cryocooler

Typical Applications:

- Measurement of Pu and Am isotopes in fuel fabrication facilities
- Non-destructive assay (NDA) of spent nuclear material product, scrap or waste forms
- Personnel dose reduction measurements
- Measurements for dismantlement verifications
- NDA measurements for public safety

Coaxial Efficiency	Planar Area mm^2	Depth mm	Resolution (FWHM) @ 20,000 cps		Peak Shape	
			@122 keV	@1332 keV	FWTM/ FWHM	FWFM/ FWHM
≥10%*	200	≥13.0	< 600 eV	≤ 2.0 keV	< 1.9	< 2.65
~40%	2000	Š15.0	≤ 700 eV	≤ 2.1 keV	< 2.0	<2.70
*(IEEE 325-1996)	For other sizes and energy ranges, call PGT Sales.					

Table 2.2 Duo Detector



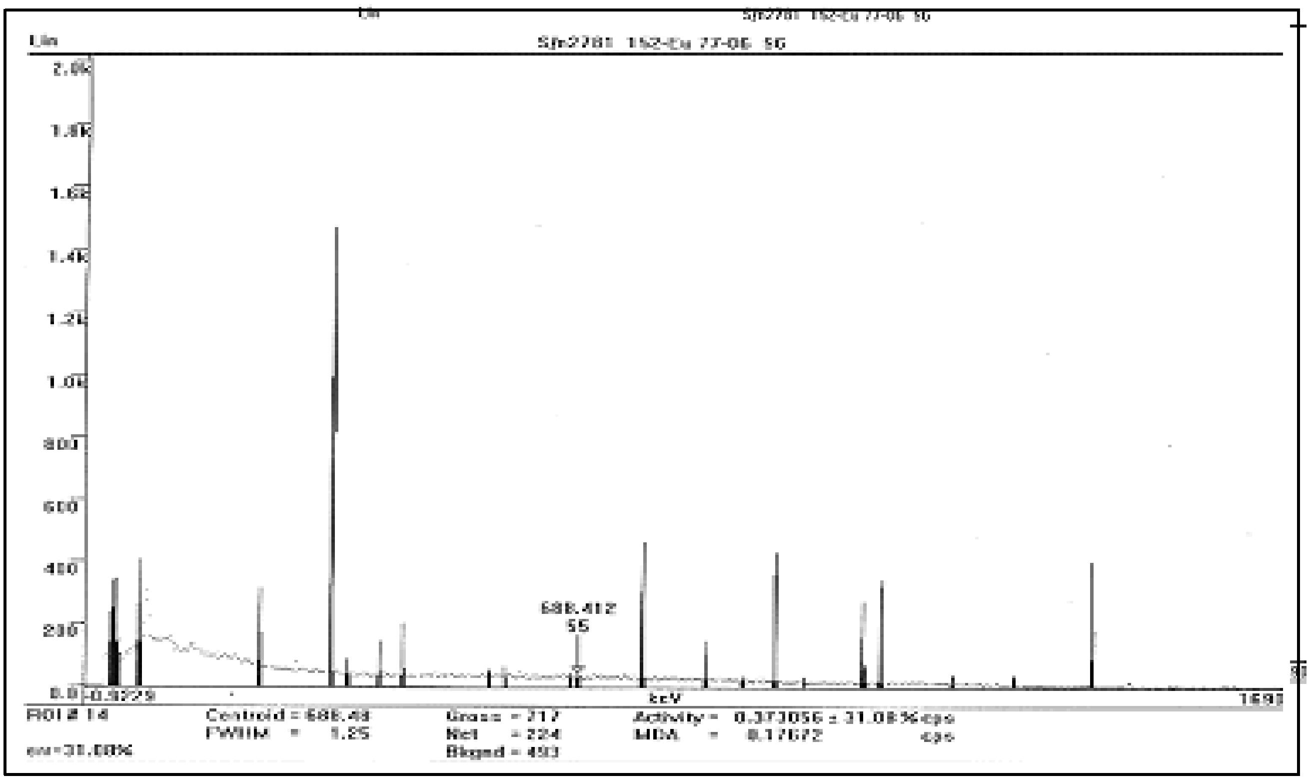


Figure 2.2 Representative spectra obtained from ^{152}Eu with the Duo Detector.

The upper spectrum from the planar detector shows the 122 keV line. Logarithmic display, MDA = 0.21.

The lower spectrum is from the coaxial detector. Linear display, MDA = 0.18 for the 688 keV line.

2.5.2 JT Cool Mechanically Cooled Spectrometer

PGT was the first manufacturer to link a mechanical cooler to an HPGe detector for continuous, long-term gamma-ray spectroscopy without the inconvenience of maintaining liquid nitrogen supplies. PGT's first mechanical cooler, the LAB COOLER, has been in operation around the world for over eight years.

PGT now offers the JT COOL, a compact system in which the compressor can be remote from the coldfinger and endcap. In lung-monitoring applications, for example, this means that there are no bulky LN_2 dewars in the counting room. This feature, combined with the the five-year maintenance-free operation, makes the JT COOL an efficient alternative to systems cooled using LN_2.

Features:

- Closed cycle cooler includes an air-cooled compressor and proprietary refrigerant mixture
- Lightweight compressor has smaller footprint than other mechanical coolers
- Flexible gas lines between the detector and the compressor permit use of the detector in one room with the compressor in another
- Detector head is about the size of a portable cryostat and functions in any position
- Acoustically quiet operation and low mechanical vibration
- Detector performance guaranteed to match that of LN2 cooled cryostats

f

Options:

- p- or n-type coaxial germaniun, planar germanium, or Si(Li) crystals
- Model 483 Controller for continuous temperature monitoring, automatic high-voltage shutoff, and heater-assisted temperature cycling
- 10-, 25- and 50-foot gas lines
- Stand for bench-top operation or a detachable handle for portable use
- Retrofit available for existing detectors, including those of other manufacturers

Typical Applications:

- Nuclear power plants, site characterization, and radiation monitoring
- In-vivo lung monitor installations

Figure 2.3 Germanium Detector with JT Cool option

2.5.3 High-Purity Germanium Coaxial Detectors

PGT p-type germanium coaxial detectors feature standard relative efficiencies up to 100% and excellent resolution and peak symmetry. Their energy range is from 40 keV to 10 MeV. Efficiencies of 10-100% are available. These detectors have a long service life and can be stored warm for extended periods of time.

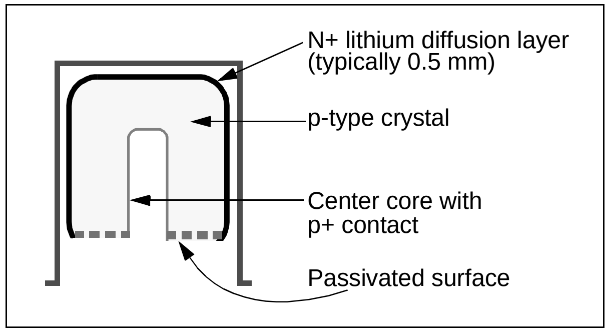


Figure 2.4 P-type HPGe Coaxial Detector

Features:

- p-type high-purity germanium
- Vertical dipstick cryostat
- Standard 32-liter dewar
- Aluminum endcap
- RG-11 B/C resistive feedback preamplifier
- 12-ft. bias, signal and power cables
- Unlimited temperature cycling without loss of resolution

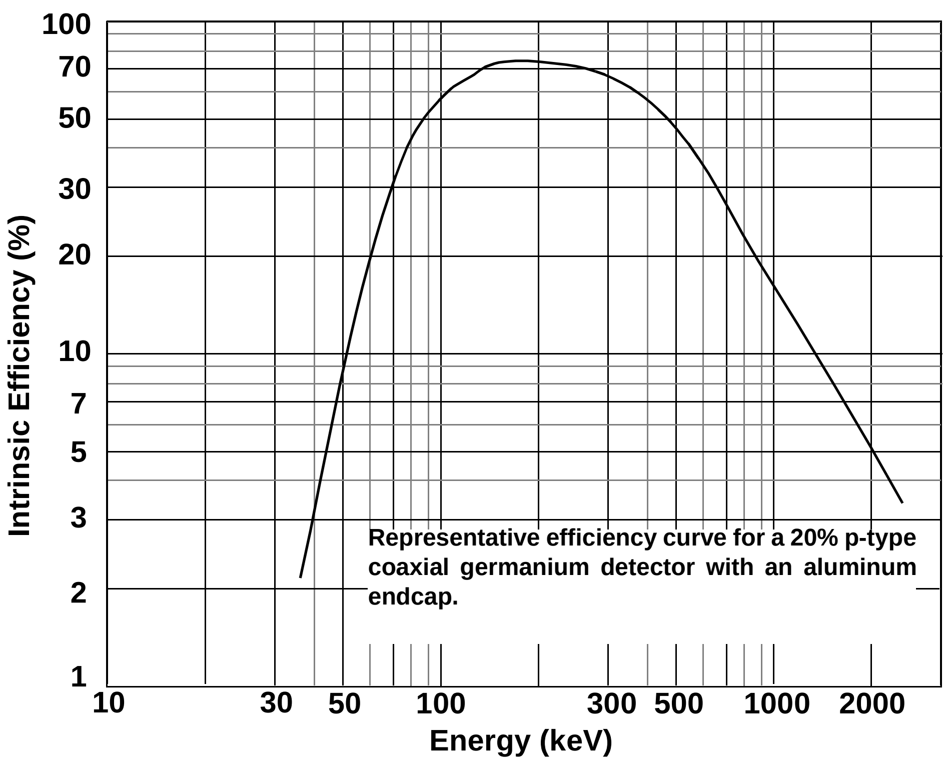
Specifications for standard IGC-Series models are shown on the next page. For other efficiencies, different cryostats or options, please contact PGT.

Options:

- Cryostat configurations to meet your needs
- Portable systems
- JT Cool mechanical cooler
- Ultra-low microphonic QUIET-ONE crystal mounting
- Low-background materials
- Transistor reset preamplifiers
- Low-power preamplifier

Typical Applications:

- Nuclear spectroscopy over the energy range of 40 keV to 10 MeV



Model Number	Relative Efficiency	Resolution (FWHM) @122 keV (eV)	Resolution (FWHM) @1.33 MeV (keV)	Peak/ Compton	Peak shape FWTM/FWHM
IGC10175 IGC10185 IGC10200	10% 10% 10%	800 850 900	1.75 1.85 2.00	42:1 39:1 37:1	1.90 1.95 2.00
IGC15180 IGC15190 IGC15200	15% 15% 15%	800 900 950	1.80 1.90 2.00	47:1 45:1 42:1	1.90 1.95 2.00
IGC20180 IGC20190 IGC20200	20% 20% 20%	825 900 975	1.80 1.90 2.00	52:1 49:1 46:1	1.90 1.95 2.00
IGC25185 IGC25195 IGC25200	25% 25% 25%	850 950 1000	1.85 1.95 2.00	55:1 53:1 50:1	1.90 1.95 2.00
IGC30185 IGC30195 IGC30200	30% 30% 30%	860 950 1000	1.85 1.95 2.00	58:1 56:1 54:1	1.90 1.95 2.00
IGC35190 IGC35200	35% 35%	875 1000	1.90 2.00	60:1 58:1	1.90 2.00
IGC40190 IGC40200	40% 40%	875 1000	1.90 2.00	62:1 58:1	1.90 2.00
IGC45195 IGC45200	45% 45%	900 1000	1.95 2.00	64:1 60:1	1.90 2.00
IGC50195 IGC50200	50% 50%	950 1000	1.95 2.00	65:1 63:1	1.90 2.00
IGC55195 IGC55210	55% 55%	1000 1200	1.95 2.10	67:1 64:1	2.00 2.00
IGC60195 IGC60210	60% 60%	1000 1200	1.95 2.10	70:1 66:1	2.00 2.00
IGC70200 IGC70215	70% 70%	1000 1200	2.00 2.15	75:1 70:1	2.00 2.00
IGC80220	80%	1200	2.20	70:1	2.00
IGC90220	90%	1400	2.20	74:1	2.00
IGC100230	100%	1400	2.30	74:1	2.00

Table 2.3 IGC Series Detectors

2.5.4 N-type Coaxial HPGe Extended Range Detectors

PGT n-type germanium coaxial detectors are useful down to ~3 keV, since they have a standard beryllium entrance window and a thin (0.3 µm) P+ face. In contrast, p-type detectors, with their thick lithium diffusion outer contact and aluminum endcap, are opaque to energies below about 40 keV. The NIGC extended range detectors are therefore the best choice for applications involving both X-ray and high-energy gamma-ray spectroscopy in the same sample.

These detectors exhibit excellent timing characteristics and are appropriate with anti-Compton shielding. They are thus especially suitable for suppression of Compton scattering to reduce background.

The main charge carriers in n-type detectors are electrons, which are less susceptible to traps created by neutron damage. This makes them ideal under conditions of high neutron flux. PGT NIGC detectors have proven themselves in space and high-altitude applications. The detector flown on the Mars Observer annealed itself in space and sent back data on solar-flare induced gamma-ray activities. Further, a neutron damage repair kit allows you to repair these detectors in your own lab if damage does occur.

PGT NIGC detectors have a long service life and can be stored warm for extended periods of time.

Features:

- n-type high-purity germanium, with ion-implanted exterior surface and lithium diffusion center contact
- Vertical dipstick cryostat
- Standard 32-liter dewar
- Aluminum endcap with beryllium window

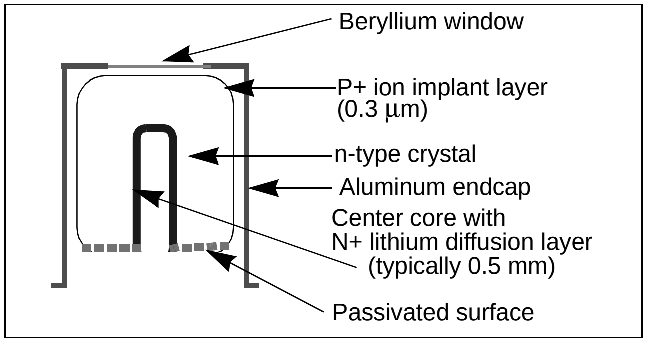
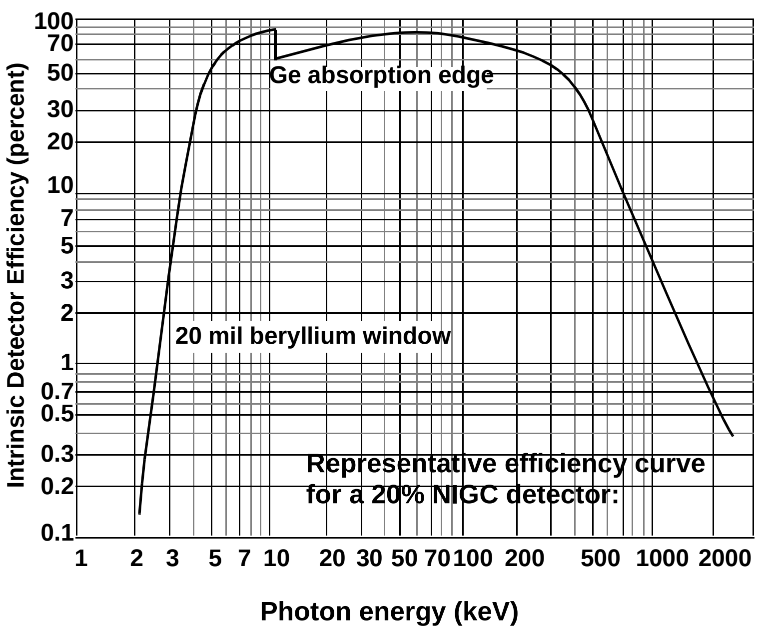


Figure 2.5 N-type HPGe Coaxial Detector

- RG-11 B/C resistive feedback preamplifier
- 12-ft. bias, signal and power cables
- Unlimited temperature cycling without loss of resolution

Options:

- Portable systems
- A variety of cryostat configurations
- Low-background materials, such as OFHC copper endcaps
- Ultra-low background IF-1 beryllium windows
- Transistor reset preamplifier for high count rates (Energy count-rate product limit >800,000 MeV/sec)
- Low-power preamplifier
- JT Cool mechanical cooler
- Ultra-low microphonic QUIET-ONE crystal mounting
- Optional Neutron Radiation Damage Repair Kit



Typical Applications:

- Extended range nuclear spectroscopy down to 3 keV and where neutron flux may be a problem
- With Compton-suppression systems in particle accelerator studies
- High count rate measurements
- Detector of choice for space applications (resistant to damage by high neutron and proton flux)
- Portable systems for field characterization of materials of unknown energy

Optional Neutron Radiation Damage Repair Kit

An optional kit, which includes a special vacuum valve, temperature controller and heater, may be purchased for in-house repair of neutron damage. It is available for any standard cryostat and the MPS multi-purpose spectrometer. Specify 110V or 220V for the power supply.

Model Number	Relative Efficiency	Resolution (FWHM) @5.9 keV (eV)	Resolution (FWHM) @133 MeV (keV)	Peak/ Compton	Peak Shape FWTM/FWHM
NIGC10180	10%	665	1.80	40:1	1.90
NIGC10190	10%	715	1.90	39:1	1.95
NIGC10200	10%	735	2.00	38:1	2.00
NIGC15185	15%	675	1.85	44:1	1.90
NIGC15190	15%	715	1.90	42:1	1.95
NIGC15200	15%	735	2.00	40:1	2.00
NIGC20190	20%	690	1.90	48:1	1.90
NIGC20195	20%	750	1.95	46:1	1.95
NIGC20200	20%	790	2.00	44:1	2.00
NIGC25190	25%	690	1.90	50:1	1.90
NIGC25195	25%	760	1.95	48:1	1.95
NIGC25200	25%	790	2.00	46:1	2.00
NIGC30190	30%	715	1.90	54:1	1.90
NIGC30200	30%	825	2.00	52:1	2.00
NIGC30210	30%	850	2.10	48:1	2.00
NIGC35195	35%	775	1.95	55:1	2.00
NIGC35210	35%	830	2.10	52:1	2.00
NIGC35220	35%	900	2.20	50:1	2.00
NIGC40195	40%	800	1.95	59:1	2.00
NIGC40210	40%	850	2.10	54:1	2.00
NIGC40220	40%	925	2.20	52:1	2.00
NIGC45200	45%	825	2.00	60:1	2.00
NIGC45210	45%	950	2.10	57:1	2.00
NIGC45220	45%	975	2.20	55:1	2.00
NIGC50220	50%	860	2.20	58:1	2.00
NICG50230	50%	1000	2.30	56:1	2.00
NIGC55220	55%	900	2.20	60:1	2.00
NIGC55230	55%	1000	2.30	58:1	2.00
NIGC60220	60%	1100	2.20	60:1	2.00
NIGC60230	60%	1200	2.30	58:1	2.00
NIGC70230	70%	1100	2.30	60:1	2.00
NIGC70240	70%	1200	2.40	58:1	2.00

Table 2.4 NIGC Series Detectors

2.5.5 High-Purity Germanium Well Detectors

PGT germanium well detectors use the “through hole” technology to minimize microphonics and provide higher resolution performance. This is a true coax design in which the crystal is less than 5 mm from the face of the endcap, and the sample can be placed deeper within the detector. The solid angle lost by this geometry is minimal for standard hole sizes and is more than compensated for by better detector performance, particularly at low energies, which translates to **lower Minimum Detectable Activity** values.

The closed-end well detectors manufactured by other vendors are forced by that design to have a longer FET gate wire (as much as 6 inches or more) which significantly degrades resolution due to microphonics.

The bottom line is performance. PGT well detectors offer a lower MDA, faster counting rate and greater sensitivity. PGT believes that the through-hole design makes these well detectors *the best you can buy*.

A more rigorous analysis of the two well detector designs starts on page 13.

The usual energy range is from 10 keV to 10 MeV, but the lower limit can be extended to 5 keV with beryllium or low-Z organic inserts. These detectors are ideal for use with sample changers. A representative efficiency curve is shown on the next page. With larger diameter holes, the efficiency may be somewhat less.

Features:

- p-type high-purity germanium, with vapor-deposited gold center contact
- Vertical dipstick cryostat
- Standard 32-liter dewar
- Aluminum endcap and well insert
- Proprietary microphonic suppression system
- RG-11 B/C resistive feedback preamplifier
- 12-ft. bias, signal and power cables
- Unlimited temperature cycling without loss of resolution

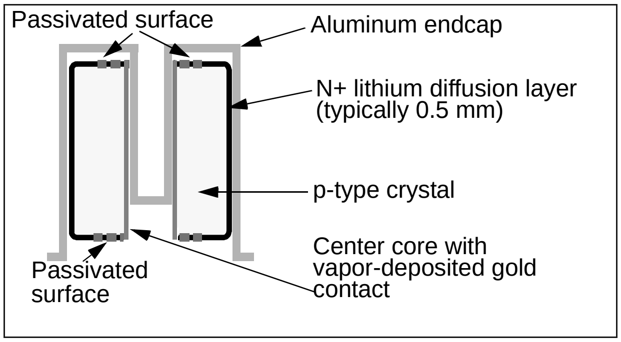


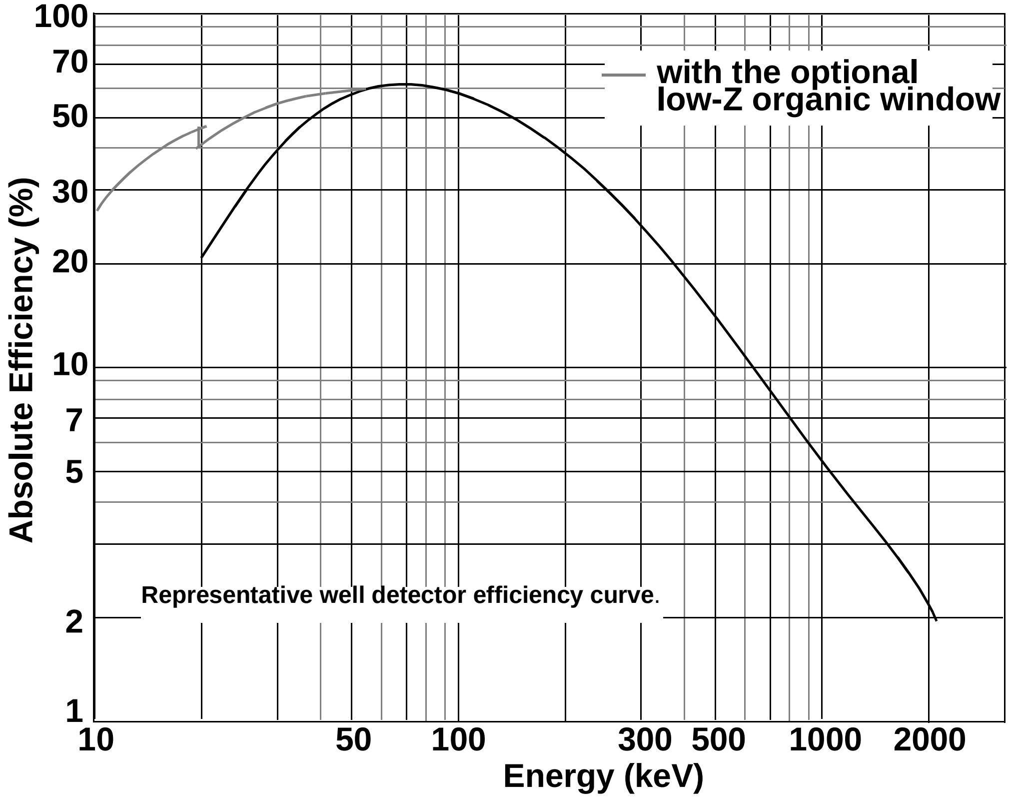
Figure 2.6 HPGe Well Detector

Options:

- Custom well diameters up to 1.3”
- Other crystal sizes, active volumes of 170 cc or more
- Low-background NPR cryostat
- Ultra-low background materials, such as low-background aluminum well inserts and OFHC copper endcaps
- Beryllium or low-Z organic well inserts
- Other cryostat configurations
- Can be mounted in a customized shield for low-background measurements
- Low-power or transistor reset preamplifiers

Typical Applications:

- Analysis of small samples for environmental monitoring and radiochemistry studies
- Coastal and deep-water sediment research
- Water and food pollution analyses
- Geological and biological sample testing
- Neutron activation analysis



Model Number	Active Volume	Well Dimensions (mm)		Resolution (FWHM)	
		Diameter	Depth	@122 keV (keV)	@133 MeV (keV)
IGW5021-10 IGW5022-10 IGW5022-14 IGW5023-14	50 50 50 50	10 10 14 14	40 40 40 40	1.20 1.20 1.30 1.30	2.10 2.20 2.20 2.30
IGW7521-10 IGW7522-10 IGW7522-14 IGW7523-14	75 75 75 75	10 10 14 14	40 40 40 40	1.20 1.20 1.30 1.30	2.10 2.20 2.20 2.30
IGW10022-10 IGW10023-14	100 100	10 14	40 40	1.20 1.30	2.20 2.30
IGW12022-10 IGW12023-14 IGW12025-16	120 120 120	10 14 16	40 40 40	1.20 1.30 1.35	2.20 2.30 2.50
IGW14023-14 IGW14023-16	140 140	14 16	40 40	1.30 1.35	2.30 2.30

Table 2.5 IGW Well Detectors

2.5.6 High-Purity Germanium Planar Detectors

PGT p-type germanium planar detectors have high efficiency in the lower energy ranges, making them the ideal detectors for transuranic materials and mixed gamma and X-ray samples. The combination of the thin entrance layer with a beryllium endcap window allows detection down to ~3 keV.

The IGP detectors are available in sizes from 25 mm^2 to 1000 mm^2 to meet your needs for economical small-area counting at low to intermediate energies. P-type planar detectors retain their high resolution up to 1 MeV. With the optical feedback or transistor reset preamplifiers, energy count rate product limits are 200 and 400 GeV/sec, respectively.

These rugged detectors have a long service life and can be stored warm for extended periods of time.

Some intrinsic efficiency curves for planar detectors are listed on page 12.

Features:

- p-type high-purity germanium, with very thin metallized entrance window
- Vertical dipstick cryostat
- Standard 32-liter dewar
- Aluminum endcap and beryllium window
- RG-11 B/C resistive feedback preamplifier or PO14-B pulsed optical feedback preamplifier
- 12-ft. bias, signal and power cables
- Unlimited temperature cycling without loss of resolution

Options:

- A variety of cryostat configurations available
- Portable systems
- JT Cool mechanically cooled system
- Transistor reset preamplifier
- Ultra-low microphonic QUIET-ONE crystal mounting

Typical Applications:

- Spectroscopy of transuranic materials and of mixed gamma- and X-ray samples

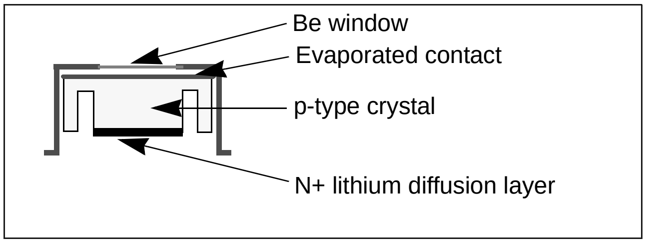


Figure 2.7 P-type HPGe Planar Detectors

Model Number	Area mm^2	Diameter mm	Depletion Depth mm	Resolution (FWHM) @ 5.9 keV (eV)		Resolution (FWHM) @ 122 keV (eV)		Beryllium Window (mil)	Be Window Diameter mm (in.)
				PO-14B	RG-11	PO-14B	RG-11		
IGP25145 IGP25175	25 25	5.6 5.6	5.0 5.0	145 175	165 200	480 495	485 505	1.0 1.0	11.43 (0.450)
IGP55165 IGP55190	50 50	8.0 8.0	5.0 5.0	165 190	180 210	490 540	490 550	1.0 1.0	11.43 (0.450)
IGP105185 IGP107175 IGP110175	100 100 100	11.3 11.3 11.3	5.0 7.0 10.0	185 175 175	195 190 185	490 495 495	495 495 495	5.0 5.0 5.0	27.94 (1.100)
IGP205200 IGP207195 IGP210190 IGP213190	200 200 200 200	16.0 16.0 16.0 16.0	5.0 7.0 10.0 13.0	200 195 190 190	210 215 200 200	495 495 490 490	500 500 495 495	5.0 5.0 5.0 5.0	27.94 (1.100)
IGP505330 IGP507315 IGP510305 IGP513305	500 500 500 500	25.2 25.2 25.2 25.2	5.0 7.0 10.0 13.0	330 315 305 305	345 330 320 320	550 545 540 540	560 555 550 550	5.0 5.0 5.0 5.0	27.94 (1.100)
IGP1005400 IGP1010380 IGP1013360	1000 1000 1000	35.7 35.7 35.7	5.0 10.0 13.0	NA	400 380 360	NA	610 595 585	15.0 15.0 15.0	43.18 (1.700)

Table 2.6 IGP Series Detectors

2.5.7 N-Type HPGe Planar Detectors

PGT's n-type semi-planar germanium detectors offer the best low noise and high resolution capabilities at low-to-moderate energies. The capacitance of these detectors, with a wrap-around P+ contact and a small center N+ contact, is much less than that of a true planar of similar size. This results in lower noise and better resolution than achieved by any other detector geometry at energies of 3 keV to 1 MeV. Also, because the cylindrical walls are charge-collecting and because there are virtually no dead germanium layers beyond the active region, these detectors exhibit better count rate performance and peak-to-background ratios.

As with all HPGe detectors, they are temperature-cyclable and can be stored indefinitely at room temperature.

Standard Features:

- n-type high-purity germanium, with P+ ion-implanted entrance window
- Vertical dipstick cryostat
- Standard 32-liter dewar
- Aluminum endcap and beryllium window
- RG-11 B/C resistive feedback preamplifier
- 12-ft. bias, signal and power cables
- Unlimited temperature cycling without loss of resolution

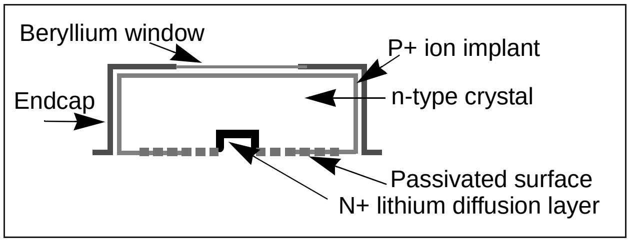


Figure 2.8 N-type HPGe Semi-Planar Detectors

Options:

- Specialized low-background cryostats
- Low background materials (including IF-1 and IF-2 beryllium windows) for low-level gamma ray detection
- Existing detectors can be retrofitted with larger crystals
- JT Cool cryocooler
- Transistor-reset preamplifier
- Ultra-low microphonic QUIET-ONE crystal mounting

Typical Applications:

- In-vivo lung monitoring of actinides—PGT can supply a complete lung-counting room, including hardware, chairs, and PC-based software
- Body-burden assessment
- Measurements requiring a high P/B ratio

Model Number	Active Area (mm^2)	Diameter (mm)	Depletion (mm)	Resolution (FWHM)		Beryllium Window (mil)
				@ 5.9 keV (eV)	@ 122 keV (eV)	
NIGP1510420	1500	43.8	10.0	420	650	20.0
NIGP1513400	1500	43.8	13.0	400	620	20.0
NIGP1516400	1500	43.8	16.0	400	620	20.0
NIGP20010470	2000	50.5	10.0	470	650	20.0
NIGP20013450	2000	50.5	13.0	450	650	20.0
NIGP20016470	2000	50.5	16.0	420	625	20.0
NIGP20020370	2000	50.5	20.0	370	625	20.0
NIGP27030425	2700	58.6	30.0	425	700	20.0
NIGP38303450	3800	69.6	30.0	450	950	30.0

Table 2.7 NIGP Series Detectors

2.5.8 X-ray Detectors

PGT manufactures both Si(Li) and HPGe detectors for X-ray analysis. Si(Li) detectors with a standard beryllium window have a useful energy range of 1-60 keV, while HPGe detectors are suitable up to an energy of 100 keV. Optional light element capability extends the lower limit to below 200 eV. Both HpGe and Si(Li) detectors are fully temperature-cyclable and may be stored indefinitely at room temperature with no degradation in resolution.

The X-ray source can range from nuclear accelerators to secondary X rays generated by fluorescence. X-ray detectors are used extensively for research, quality control and failure analysis. These detectors are also interfaced with scanning electron microscopes for simultaneous qualitative and quantitative microanalysis.

Standard Features:

- High-purity germanium (10, 30 or 50 mm^2)
- Lithium-drifted silicon (10, 30 or 60 mm^2)
- Stainless steel endcap with beryllium window of 0.3 or 0.5 mil thickness for Si(Li)
- Horizontal unitary cryostat with fixed geometry and conflat flange, 7.5 liter dewar
- TR-1 transistor reset preamplifier
- Appropriate bias, signal and power cables
- Unlimited temperature cycling without loss of resolution
- HV cut-off circuitry

Options:

- Variable position (DS) cryostat with manual or motorized slide
- Bellows vacuum seal
- High angle entry configurations; custom configurations for unique applications
- 15 liter dewar
- Thin windows for light element detection
- Low-microphonic crystal mounting
- JT Cool Cryocooler with convenient stand for all-attitude LN_2-free operation

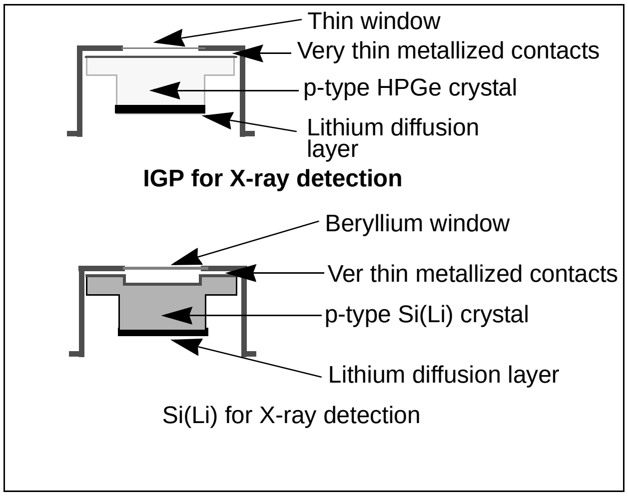


Figure 2.9 P-type HPGe and Si(Li) Planar Detectors

Typical Applications:

- X-ray fluorescence for simultaneous analysis of elements from boron through uranium for research and quality control
- Diagnostics in beam systems and other nuclear reactor applications
- Interfaced with beam systems, scattering chambers and X-ray fluorescence systems
- In EDS systems, for spectra down to 185 eV

Model Number	Crystal Type	Area (mm^2)	eV FWHM @5.9 KeV	Be Window (mils)
LS10133 LS10138	Si(Li) Si(Li)	10 10	133 138	0.33 0.33
LS30138 LS30148	Si(Li) Si(Li)	30 30	138 143	0.33 0.33
LS60155 LS60160	Si(Li) Si(Li)	60 60	155 160	1.00 1.00
IGX10120 IGX10125	HPGe HPGe	10 10	120 125	0.33 0.33
IGX30125 IGX30130	HPGe HPGe	30 30	125 130	0.33 0.33
IGX50130 IGX50135	HPGe HPGe	50 50	130 135	1.00 1.00

Table 2.8 X-ray Detectors

2.5.9 Sahara Silicon Drift Detector

The Sahara Silicon Drift Detector (SDD) is a state-of-the-art X-ray spectroscopy system featuring rapid, efficient Peltier cooling with no moving parts, water or LN_2 required. The Sahara is ideal for applications requiring excellent resolution, high count rate capability and high sensitivity to light elements.

The SDD consists of the following four components:

- Silicon Drift crystal
- Peltier cooling components
- Preamplifier
- Detector housing

The Silicon Drift crystal (Figure 2.10) differs from a traditional Si(Li) crystal in that the charge generated by the interaction of incident X-rays is channeled in a potential well towards a small, central anode of very low capacitance. The Field Effect Transistor (FET) that provides the first stage of signal amplification is incorporated into the silicon chip next to the anode, eliminating stray capacitance and microphonic pick-up normally observed in a Si(Li) detector. The potential well is established by a series of bias rings, each set to a different voltage.

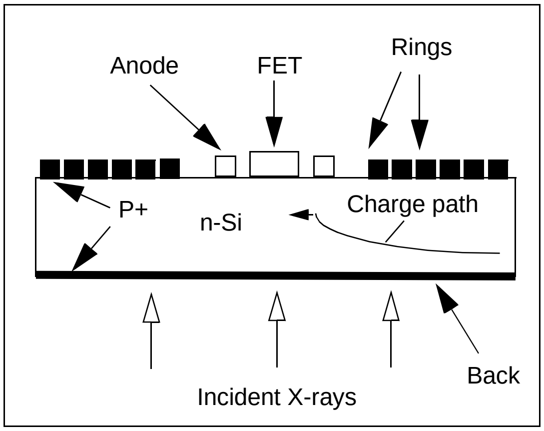


Figure 2.10 Schematic cross section of the SDD crystal

The entire detector volume is sensitive to incoming radiation, as the silicon is completely deleted. The integrated FET is shown on the front side of the detector. A typical crystal thickness is 0.3 mm.

The total capacitance (and therefore Johnson noise) from a 10 mm^2 SDD crystal is a small fraction of that from an equivalent Si(Li) crystal. The low capacitance permits the use of a very short shaping time constant (0.5 µs) in the main amplifier circuit, which in turn reduces the effect of crystal leakage current on the total noise of the system. The insensitivity to leakage current eliminates the need for LN2 cooling. The crystal may be operated at room temperature, but optimum resolution (<145 eV FWHM at 5.9 keV) is achieved when the crystal is cooled below -10° C using Peltier counts.

The crystal has an intrinsically thin entrance window to incident X-rays (the “back” contact, shown in Figure 2.10).

This window allows X-ray detection of light elements, including the carbon kα X-ray at 270 eV. Direct exposure of the cold crystal to oil and other contaminants in the chamber is avoided by using an ultra-thin Polyamide window (with 60% transmisssion at 270 eV) across the front of the crystal housing. The pressure between the crystal and the microscope chamber is equalized by a small hole in the crystal housing (Figure 2.11).

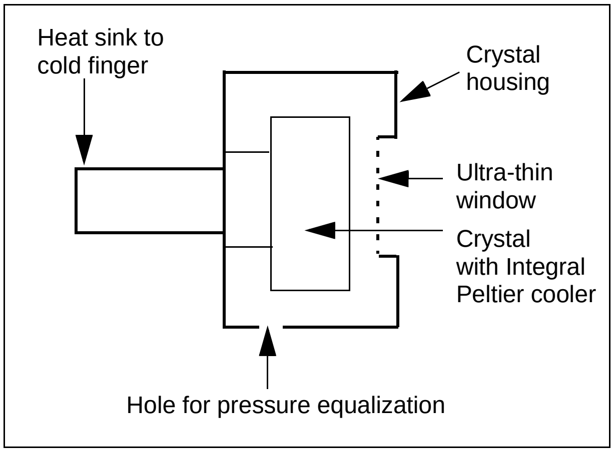


Figure 2.11 Schematic cross section of SDD crystal housing

The SDD incorporates three Peltier cooler devices. One cooler is fabricated into the silicon crystal chip. The others are located at the base of the copper cold finger that connects the crystal to the body of the detector housing. Figure 2.12 illustrates the placement of the Peltier coolers.

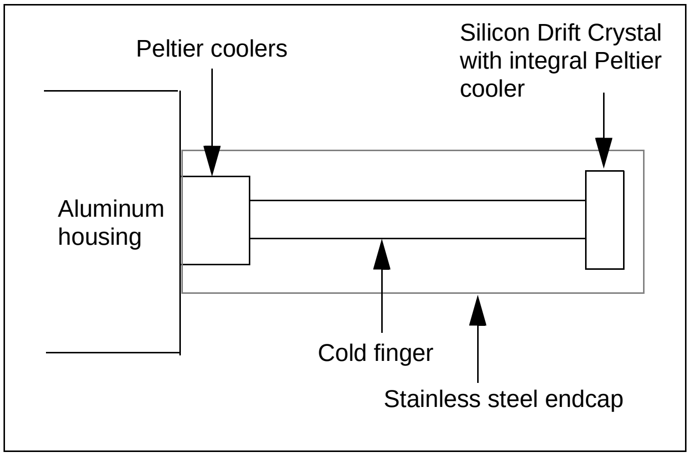


Figure 2.12 Location of the Peltier coolers

Temperature sensors are located integral to the silicon chip and close to the Peltier coolers at the base of the cold finger. Signals from the sensors are fed back to the temperature controller to stabilize the crystal at the optimum operating temperature independent of room temperature.

The preamplifier supplies the various bias voltages for the integral FET and the crystal rings, and amplifies the FET signal.

The dimensions of the detector housing and the microscope interface are dependent on the microscope model. However, all detector models have a cold finger and endcap, and a detector body. The endcap length is dependent on the application. The detector body houses the preamplifier and provides the heat sink for the Peltier coolers. Heat is ultimately dissipated from the air-cooled fins on the detector body.

Standard Features:

- High count rate capabilities, with data acquisition at > 100,000 cps.
- Extremely sensitive to light elements, including the carbon kα X-ray at 270 eV.
- Outstanding resolution (better than 143 eV at Mn for both 5 and 10 mm^2 active areas).
- LN_2-free rapid Peltier cooling (usually within 30 seconds) and automatic temperature control within 1°C for high detector stability.

Options:

- 5 or 10 mm^2 active areas.
- Be window or proprietary ultra-thin window for light element sensitivity.
- Adaptable detector housing design.

Typical Applications:

- X-ray fluorescence with the advantages of small size, high resolution and high count rate.
- Clean-rooms where LN_2 is prohibited.
- Any situation where no LN_2 is convenient or beneficial.
- Any application where high count rate is an advantage.

2.6 Endcap and Window Materials

The endcap portion of the cryostat protects the crystal within the vacuum chamber and is the interface between the incident radiation and the crystal itself. If the endcap material absorbs the incoming photons, a window of higher transmission material is needed.

See page 15 of the introductory section for examples of transmission curves for the various materials.

Endcap Material	Applications
Aluminum	Standard endcap for most applications; useful down to ~20 keV Low-background aluminum available, including Pechiney aluminum (for example, for well detector inserts)
Oxygen-free, high-conductivity copper (OFHC)	Low-background applications; most useful above 40-50 keV
Stainless steel	Low-background applications and where easy decontamination is important (for example, for lung monitors or MPS portable spectrometers)

Table 2.9 Endcap Materials

Window Material	Applications
Beryllium	For energies down to ~3 keV for large-diameter endcaps; lower for smaller-diameter endcaps with thinner windows Low-background Be (IF-I and IF-ll also available)
PRISM polymer	X-ray detectors for elements down to boron (185 eV)
Vespel polymer	Inexpensive, low-background, although somewhat lower transmission than Be; especially useful as well-detector insert

Table 2.10 Window Materials

2.7 Cryostats

In broad terms, cryostat refers to the detector endcap/coldfinger and the liquid nitrogen (LN_2) dewar by which the detector crystal and FET are maintained at cryogenic temperatures.

2.7.1 Dipstick Cryostats

In dipstick cryostats, the vacuum system of the endcap/coldfinger is separate from that of the dewar. These dewars are available in two standard models, as shown at the right. The basic construction is shown in Figure 2.1on page 27.

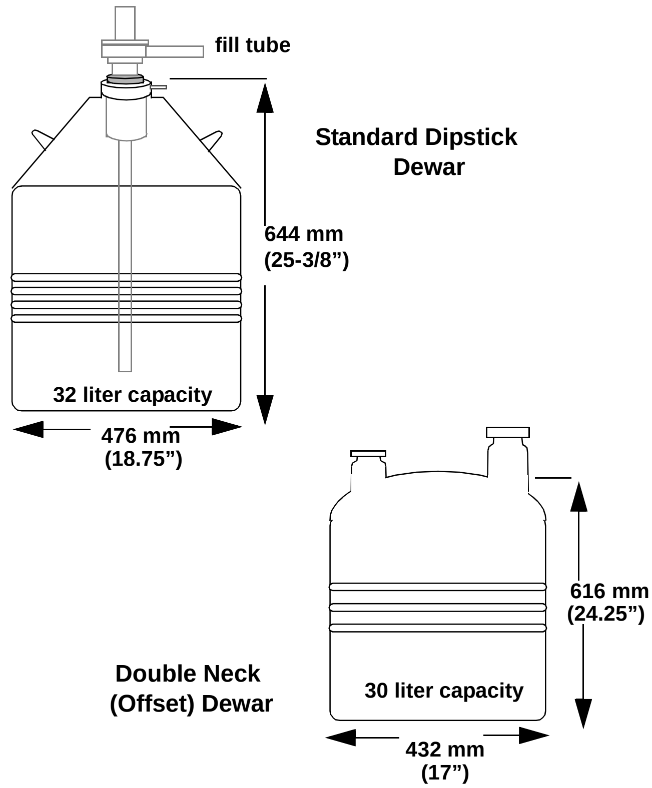
Features:

- Rugged aluminum construction
- Single or double neck models, with 32 liter or 30 liter capacity, respectively
- Holding time of up to 12 days

Options:

- Liquid Nitrogen Auto-fill System

Endcap configurations are shown below.



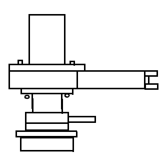
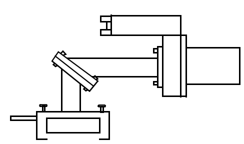
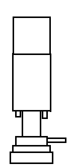
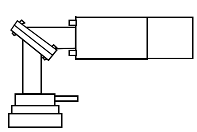
Model Designation	Endcap Configuration	Crystal Type
Vertical Dipstick (SD)		Coaxial Germanium Planar Germanium Planar Si(Li)
Elbow Dipstick (ED)		Coaxial Germanium Planar Germanium Planar Si(Li)
Inline (SDIL)		Coaxial Germanium Planar Germanium
90° Inline (EDIL)		Coaxial Germanium Planar Germanium

Table 2.11 Configurations for Dipstick Cryostats

2.7.2 Unitary Cryostats

In unitary cryostats, there is a common vacuum system for the endcap/coldfinger and the dewar. This provides efficient cooling in a variety of configurations. The endcaps may be in a fixed horizontal or down-looking vertical design. The horizontal cryostats are also available with an extended coldfinger arm for insertion into a low-background counting chamber. The cryoflex option is a swivel arm which allows the endcap to be aimed for maximum efficiency.

Cryostats for X-ray detectors may be ordered in a fixed horizontal geometry or with a slide mechanism for adjusting the endcap/sample distance. A variable-z control is also offered for detectors mounted on an electron column.

These dewars are available in several standard bucket sizes, as well as special portable models. The basic construction is shown in Figure 2.1 on page 27.

Features:

- Rugged aluminum construction
- Standard volumes of 7.5, 15, and 30 liter buckets

Options:

- Stainless steel construction
- Low-background materials
- Liquid Nitrogen Auto-fill System
- Pressurized LN_2 mother dewar for filling portable models

Endcap configurations are shown on the next pages.

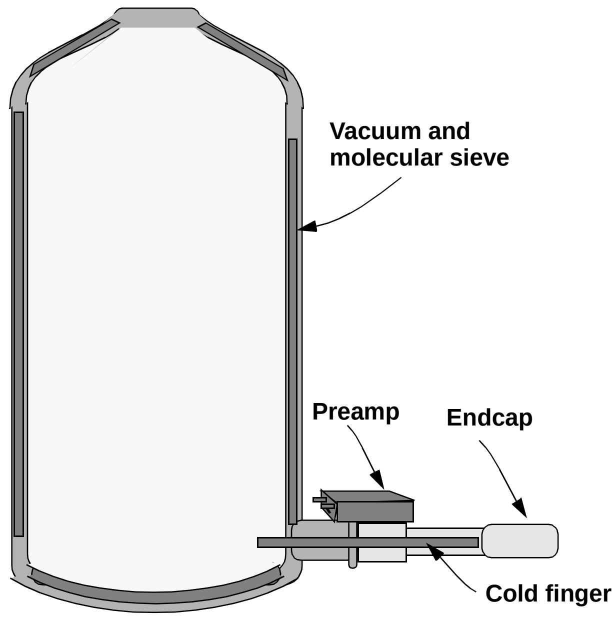


Figure 2.13 Schematic of unitary cryostat construction

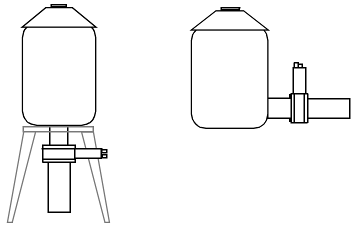
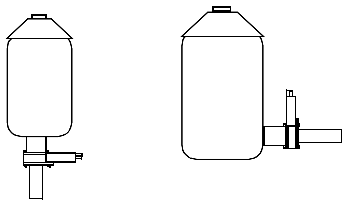
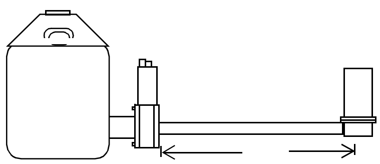
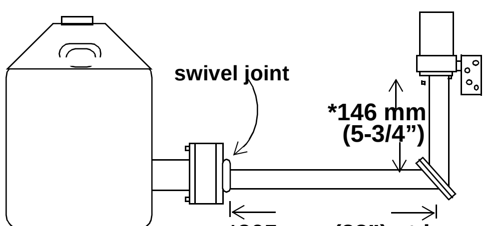
Model Designation	Cryostat Configuration	Crystal Type	Dewar Volume
Coaxial Down-looking (DT) Coaxial Horizontal (HT)		Coaxial Germanium	Aluminum: 7.5 liter 15 liter 30 liter Stainless Steel: 15 liter
Planar Down-looking (DT) Planar Horizontal (HT)		Planar Germanium: ≤500 mm^2 1000 mm^2 1500-2000 mm^2 Planar Si(Li): 10, 30, 60 mm^2	Aluminum: 7.5 liter 15 liter 30 liter Stainless Steel: 15 liter
Low Background (NPR)		Coaxial Germanium Planar Germanium ≤500 mm^2 1000 mm^2 1500-2000 mm^2	Aluminum: 15 liter 30 liter Stainless Steel: 15 liter 20 liter
Swivel Head Low Background (SNPR) Cryoflex (ST)	 **SNPR similar to NPR with added swivel joint**	Coaxial Germanium	Aluminum: 15 liter 30 liter Stainless Steel: 15 liter

Table 2.12 Common Vacuum (Unitary) Cryostats

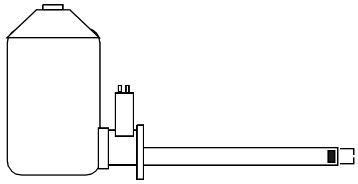
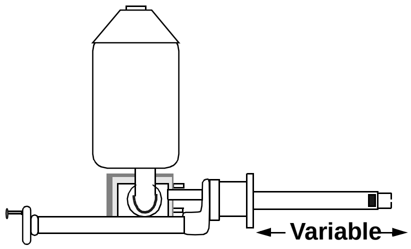
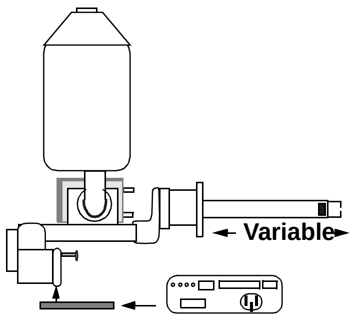
Model Designation	Cryostat Configuration	Crystal Type	Dewar Volume
X-ray Detectors Fixed Geometry (HT)		Planar Germanium 10 mm^2 30 mm^2 Planar Si(Li) 10 mm^2 30 mm^2 60 mm^2	Aluminum: 7.5 liter 15 liter
Variable Distance Slide (DS)	  **Optional motorized control and high-vacuum bellows**		

Table 2.12 Common Vacuum (Unitary) Cryostats (Continued)

2.7.3 Portable Cryostats

Portable cryostat spectrometers are designed to work in all attitudes without risk of LN_2 spillage. They are suitable for use in the field or where space is constrained.

Features:

- Light-weight hand-held or stable bench-top operation
- Compatible with both portable and standard MCAs
- Either in-line or conventional preamplifier mounting
- All-attitude operation
- Custom designs for whole-body monitoring
- Holding times of 12-100 hours

Options:

- Resistive feedback, pulsed optical reset or transistor reset preamplifiers
- Air-tight preamplifier housing to keep out damaging environment
- Internal temperature sensor for high-voltage shut-off
- High purity copper, low-background electronics, and internal shielding
- Lung-counting patient chairs and applications software available

Typical Applications:

- Field use for environmental monitoring
- Space-constrained applications
- Emergency response situations
- Whole body counting and in-vivo lung monitoring
- Nuclear high-spin experimentation

Multipurpose Portable Spectrometer

- Stainless steel cryostat with 1.5-, 5-, or 7-liter capacity
- Easily decontaminated
- Flat cryostat back permits the unit to stand vertically, in addition to resting horizontally on its cradle
- PGT Autofill system or manual fill

Gravity-Feed Spectrometer

- Light-weight aluminum cryostat with 1.2- or 3-liter capacity
- Detachable handle
- Mother dewar and stand keep the spectrometer always “at the ready”

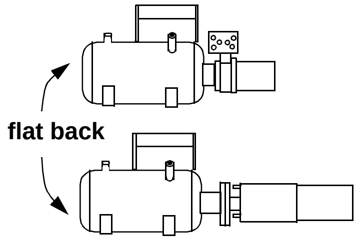
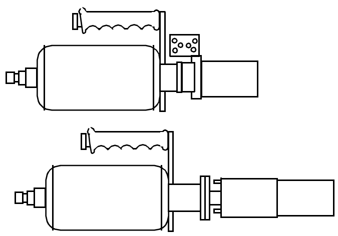
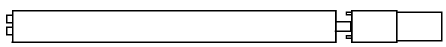
Model Designation	Cryostat Configuration	Crystal Type	Dewar Vol./ Holding Time
Mutipurpose Portable Spectrometer (MPS)		Coaxial Germanium Planar Germanium ≤500 mm^2 1000 mm^2 1500-2000 mm^2	Stainless Steel: 1.5 liter/16 hrs 5.0 liter/72 hrs 7.5 liter/100 hrs
Portable Gravity-Feed (GF)		Coaxial Germanium	Aluminum: 1.2 liter/12 hrs 3.0 liter 50 liter pressurized LN_2 mother dewar
Lung Monitor (DTIL)		Semiplanar Germanium	Stainless Steel: D: 3”, 3.5”, 4” L: variable per specifications

Table 2.13 Portable Unitary Cryostats

2.7.4 Liquid Nitrogen Handling Devices

While small bucket dewars can be refilled manually using just a metal funnel and a length of plastic tubing to keep the overflow away from the electronics, large dewars are best refilled using a transfer device from a storage container.

Features for Autofill Systems:

- Self-pressurized 50-liter aluminum storage dewar on heavy duty casters with 8-ft. insulated transfer hose
- Pressure and liquid-level gauges
- Choice of manual or autofill operation
- Data acquisition may be halted during fill or fill may be delayed until counting is complete
- Remote shutdown and fill command capability
- Rugged vent flow thermistor sensors for use with portable cryostats

Options:

- Fill adaptor for 7.5-, 15-, and 30-liter dewars and for the Multi-use Portable Spectrometer
- Optional level sensor for standard dewars
- Timer or level-controlled model
- Expansion module to accommodate 4 dewars
- Electrically heated dewar head for non-pressurized LN_2 storage dewars.
- Pressurized LN_2 fill dewar for portable models

Features for Gravity Feed Systems:

- 30-liter mother dewar
- Sturdy aluminum stand

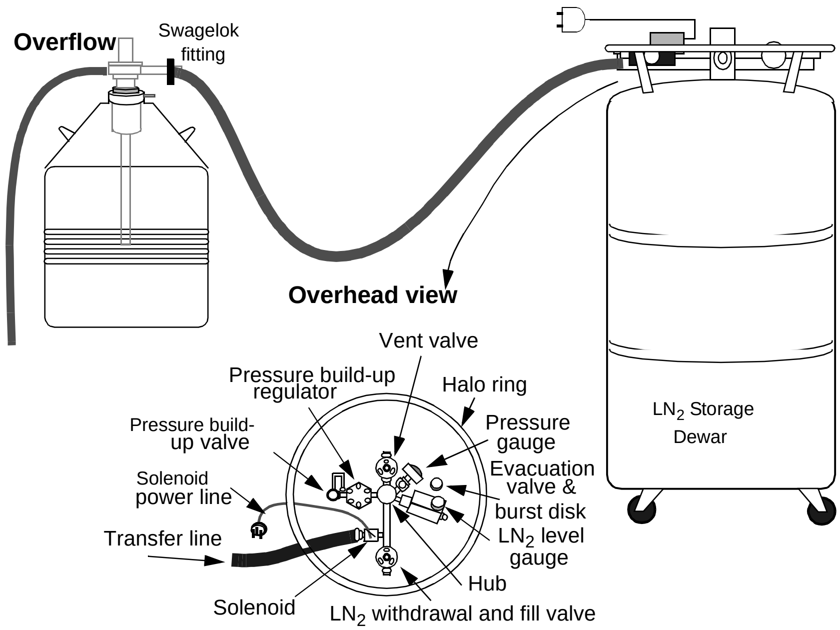
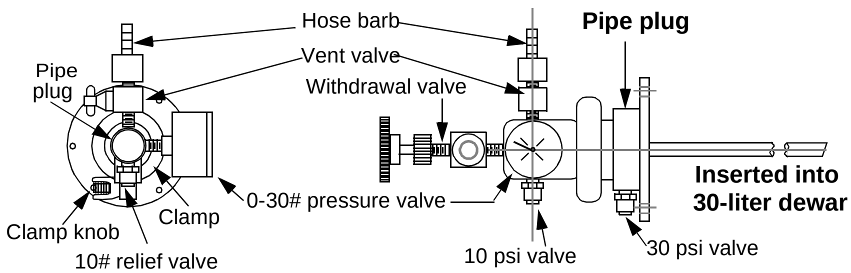
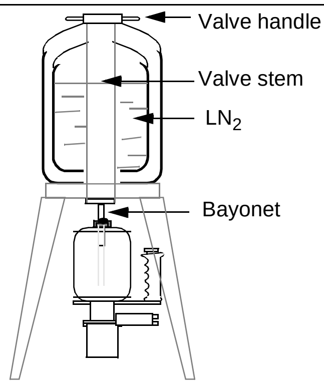
Options:

- Flexible fill line for special applications and spatial constraints

<table>
<tr><th>Model Designations</th><th>Description</th><th>Specifications*</th></tr>
<tr><td>Auto-Fill System:

326-AF
Timer controlled

326-X
without LN_2 storage dewar

326-
Dewar and valve assembly only</td><td>
</td><td>Storage Dewar Capacity: 50 liter self-pressurized with sensor</td></tr>
<tr><td>Optional Manual Withdrawal System</td><td>
</td><td>Mother Dewar Capacity: 30 liters</td></tr>
<tr><td>Mother Dewar and Stand for GF Portable Spectrometer</td><td>
</td><td>Mother Dewar Capacity: 30 liters

Stand:
Aluminum, 36” high or as specified</td></tr>
</table>

Table 2.14 Liquid Nitrogen Handling Devices

2.8 Mechanical Coolers

PGT was the first to offer a mechanical cooler for use where liquid nitrogen is unavailable, too expensive, or inconvenient. PGT's leadership in low microphonic assemblies is proven in these systems. Even where the detector is mounted against a vibrational surface, **gamma spectroscopy resolution remains high.**

There are now several types of mechanical coolers available to suit your particular requirements. Use of a mechanical cooler eliminates the need for LN_2 storage and transfer facilities.

PGT will also retrofit LN_2 detectors to a mechanical cooler, as well as repair the detector itself.

2.8.1 JT Cool

The JT Cool features an AC-powered, air-cooled compressor, which is attached to the cold head by flexible gas lines that have self-sealing fittings at each end. It is designed for continuous maintenance-free operation.

The JT Cool compressor operates with a proprietary refrigerant that is CFC-free. The system is capable of operating at ambient temperatures of 10-35°C. Higher temperatures may lead to gain changes, so it is recommended that the ambient temperature be controlled within the above boundaries.

The smaller footprint and the lighter weight of the compressor ensure more flexibility with this system. The coldhead is integrated into the detector assembly which has the overall appearance and size of a portable cryostat. The detector head has all-attitude operation and may be mounted remotely, up to 50 feet from the compressor. The detector endcap easily fits within all existing lead shields, with an optional mounting stand to further enhance the flexibility of this system.

Standard Features for JT COOL:

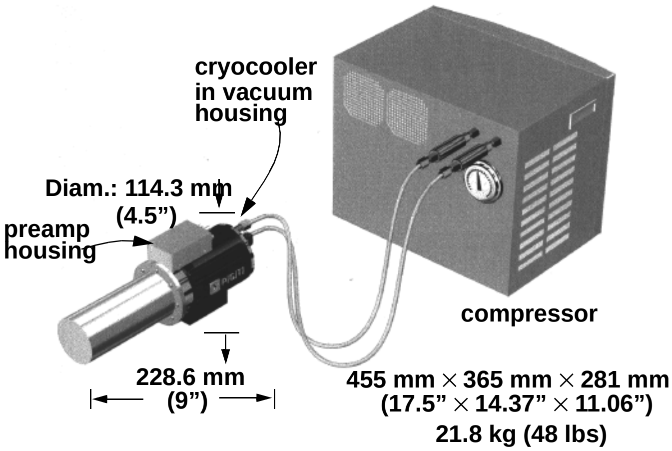
- Closed cycle cooler with air-cooled compressor and proprietary CFC-free refrigerant mixture
- Detector head can be operated in any position
- Power requirement: 115 VAC standard
- Cooling range of 70–290K (-203–20°C)
- Automatic shutoff of high voltage in case of power failure
- QUIET ONE™ crystal mount for elimination of mechanical vibration
- Flexible hose permits use of detector in one room with compressor in another
- 5-year projected service life before any maintenance is required

Options:

- p- or n-type coaxial or planar germanium and Si(Li) X-ray detectors
- Low-background endcaps
- Beryllium and light-element windows
- Stand for bench-top operation or removable carrying handle for portable uses
- Can be mounted on an electron column for energy dispersive spectrometry
- 10-, 25- and 50-ft. hose lengths
- 100 VAC (Japan) and 230 VAC (Europe)
- Copper gas lines

Typical Applications:

- Nuclear power plants, site characterization, and radiation monitoring
- In-vivo lung monitor installations
- Field deployment for monitoring waste or accident sites

<table>
<tr><th>Diagram‘</th><th>Options</th></tr>
<tr><td>
</td><td>Detectors:

Coaxial or planar Germanium:

Si(Li)

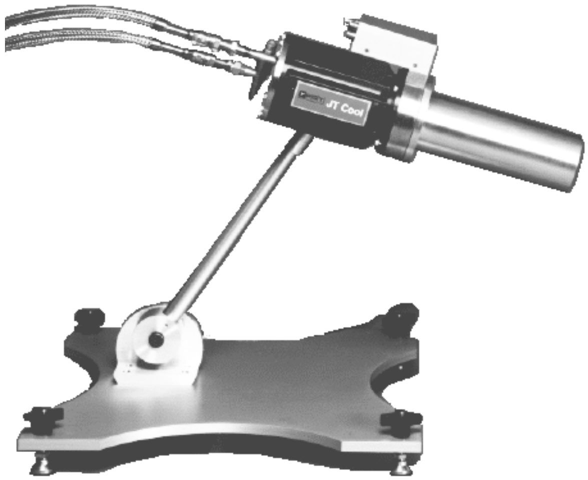
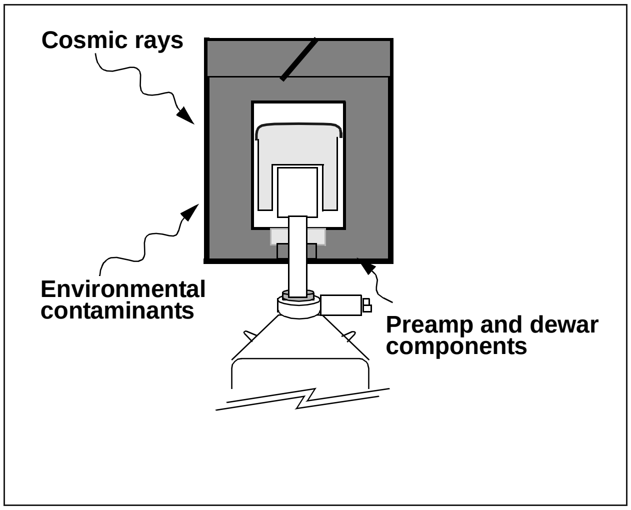
Aluminum endcap</td></tr>
<tr><td>
</td><td>Laboratory stand for all-attitude operation</td></tr>
</table>

Table 2.15 JT Cool

2.9 Radiation Shields

Low-level counting, as in environmental and contamination sampling, requires that ambient background radiation be eliminated. The type of shielding material and the thickness needed to screen the detector depend on the background environment. The most commonly used materials are lead and steel (pre-World War II). Generally, 4” bulk lead is sufficient to stop 1-MeV gamma rays. Above ~5 in. thickness, there is increased probability of interaction of cosmic rays within the shield to give Pb K X-rays. Where this may be a problem, a graded-Z liner is used. Cadmium and copper are frequently the materials of choice. The Cd liner absorbs the Pb X-ray and emits a lower-energy secondary X-ray, which is in turn absorbed by the Cu which then produces a 8-keV X-ray.



Features:

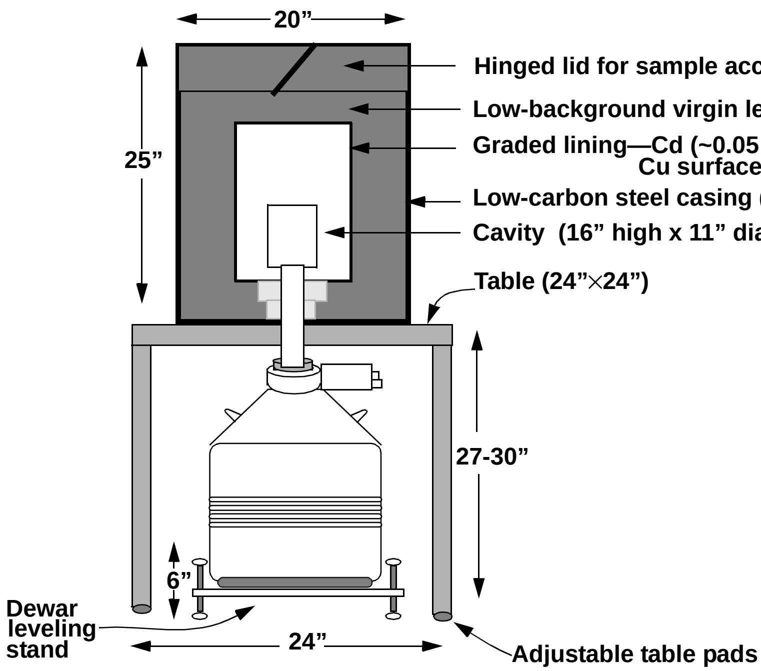
- Low-carbon steel outer jacket (3/8”-1/2” thick)
- Cast virgin low-background lead bulk shield (4” thick)
- Graded liner of cadmium or tin (0.02”) and soft copper (0.064”)
- Floor footprint 2’×2’, weight 2500 lbs
- Designed for vertical dipstick cryostats
- Interior cavity (11”×16”) to accommodate a variety of detector configurations and Marinelli beakers
- Detector plug sized to coldfinger
- Rigid steel support stand with leveling pads
- Clamshell lid for access to sample holder
- Swing-open front access
- Weight ~2500 lbs

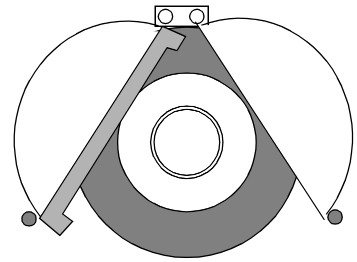
Optional Configurations and Accessories:

- Custom shield for NPR cryostats
- Available with 2”-thick bulk lead
- Sample geometry stands
- Support table leveling device for fine adjustment at table-top level
- Dewar leveling stand
- May be ordered as stackable plates
- Copper/tin lining available

Applications:

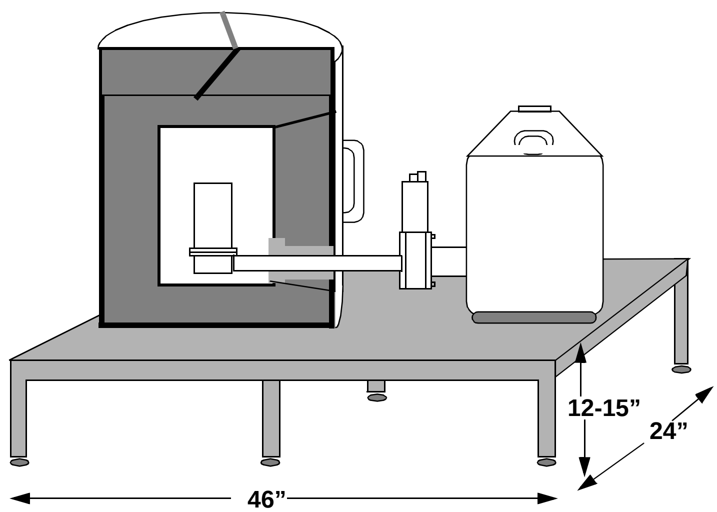
- Low-activity gamma analysis when it is necessary to minimize ambient background





Overhead view of clamshell access for sample

Model 411 SD
with standard dipstick



Model 411 NPR
with horizontal
NPR cryostat

2.9.1 Model MPS-5 Radiation Shields

Shields are available for the 5-liter Multi-Use Portable Spectrometer.

Features:

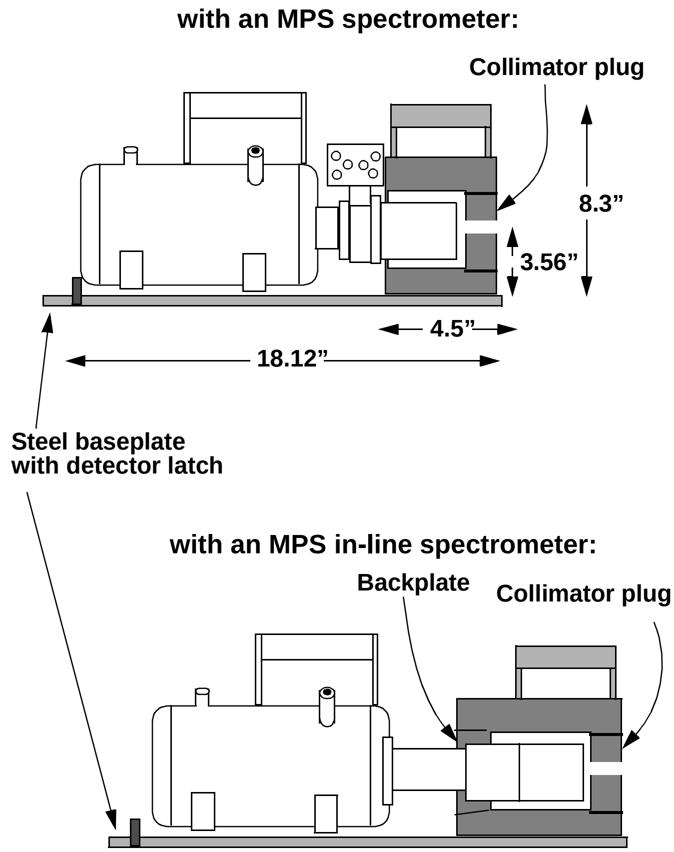
- Low-carbon steel outer jacket (3/8-1/2” thick)
- Cast virgin low-background lead bulk shield (~1” thick)
- Graded liner of tin (0.02”) and soft copper (0.064”)
- Integral steel handle and baseplate with detector attachments and latch for rigidity
- Removable collimator plug with 1/4” aperture
- Weight ~40 lbs. without detector

Options:

- Back plate for in-line detector
- Tripod for *in situ* soil sampling

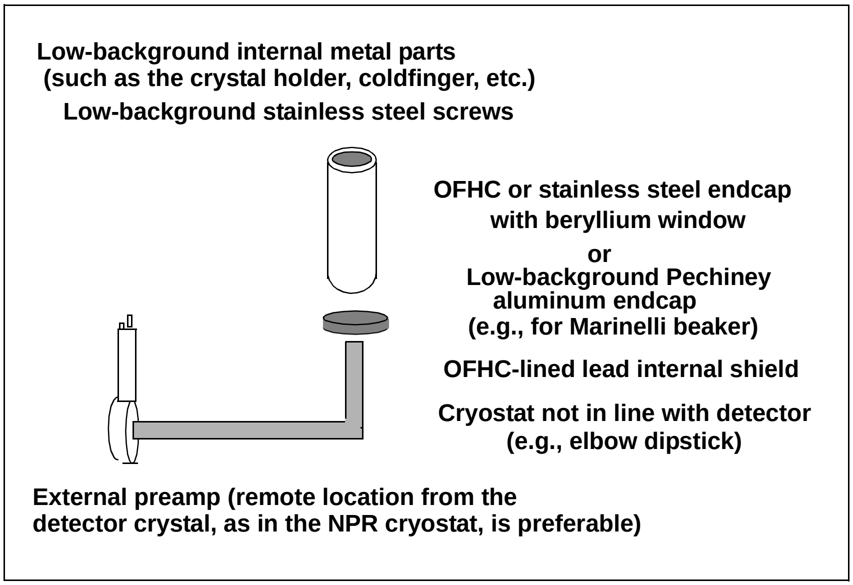
Applications:

- Low-background field analyses, such as *in situ* soil sampling
- Emergency response monitoring



2.10 Low-Background Materials

PGT offers a variety of low-background materials, as shown in the table below. When incorporated into the low-background cryostat designs, with or without a lead radiation chamber, background radiation is significantly reduced.



In selecting a low-background system, there are some general factors that should be considered:

An external preamplifier is generally better than an in-line preamp, because the naturally occurring residual radioactive materials found in the circuit board are not in direct “line-of-sight” with the detector.

The molecular sieve getter, which may have a slightly higher residual radioactivity than activated charcoal, is significantly more effective in adsorbing contaminants and maintaining the vacuum. The NPR cryostat, with or without a lead shield, is a better way to keep the getter from shining on the detector.

PGT recommends using a low-background beryllium entrance window rather than magnesium because magnesium is more easily corroded. A Vespel window is also available. Vespel has a lower energy transmission at the same window thickness (~10% at the 14.4 keV line of ^{57}Co), but costs less.

If you are ordering a new detector with no restrictions (for example, spatial constraints), the following suggestions, in order, would result in increasingly low background counts:

1. NPR cryostat, preferably with an external preamp, and
2. A lead shield
3. Replace the endcap and internal metal parts with OFHC copper or low-background aluminum (more expensive)
4. Use low-background beryllium or Vespel window for lower-energy spectroscopy

If you must have a dipstick cryostat, consider the following:

1. Lead shield
2. Internal shield between the back of the cryostat and the preamp and dewar. Copper-clad lead is preferable, but tungsten is more compact; therefore, the choice may depend on how much space is available.

Material	Application	Material Data
Oxygen-free high-conductivity copper (OFHC)	endcaps (4” and 8”), mounting cup, pedestal unit and nut, cooling rod clamp, and coldfinger	<0.24 dpm/kg ^{208}Tl <0.78 dpm/kg ^{214} Bi <15.2 dpm/kg ^{40}K
Ultra-low background Pechiney aluminum (<1ppb Th)	endcap and crystal holder well insert	96% Al + 4% Si <150 parts per trillion U + Th
50 mm virgin lead	internal shield (8” endcap)	copper-clad
50 mm tungsten	internal shield	
Ultra-low-background beryllium (IF-I and IF-II)	2.5” and 3” entrance window (for n-type detectors)	Vacuum-tight, optically dense foils 99.9% Be (IF-I) with <2 ppm U + <1 ppm Th 99.6% Be (IF-II) with <2 ppm U + <3 ppm Th
Vespel ™ SP-22	entrance window, well insert	40% graphite
		* dpm = disintegrations/minute (typical)

2.11 Electronic Components for Gamma-Spectroscopy with HPGe Detectors

The preamplifier and FET are the first in a series of electronic components required to convert the signal induced in the detector crystal to meaningful data.

2.11.1 Preamplifiers

PGT manufactures resistive feedback, pulsed-optical feedback and transistor reset preamplifiers. The choice is usually based upon the count rate of the intended application. The Model 352 low-power preamplifier is available as an option.

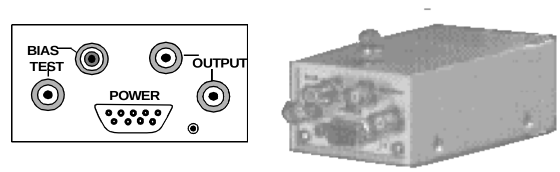
For a resistive feedback preamp, use of a lower value feedback resistor can yield a higher maximum energy rate, but with a loss in resolution. For higher count rates, it is better to use either a pulsed optical or transistor reset system.

Some representative maximum energy rate products for various PGT detectors are shown in the following table. Energy rate products refer to the total spectrum. Note that count rate is also limited by the amplifier-selected peaking time.

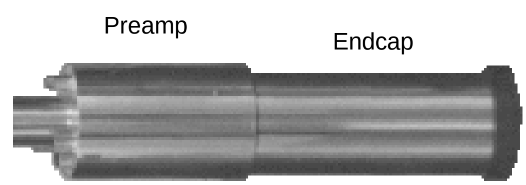
Options:

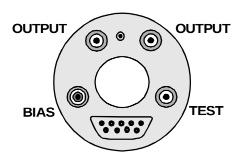
- External configuration
- In-line configuration
- Miniaturized versions for special applications

While an in-line preamp may fit into a smaller opening in a shield or better meet other space requirements, the external preamp is out of direct line with the detector and therefore contributes less background radiation.



Externally mounted preamplifier





In-line preamplifier

Detector	Preamp	Maximum energy rate product (GeV/sec)
IGC/NIGC	RG-11	70
NIGC	PO-14B	250
IGP (<500 mm^2)	RG-11	6
IGP (>500 mm^2)	RG-11	12
IGP (>500 mm^2)	TR-14	400 standard 1000 optional
Si(Li)\IGX	TR-1	200

Table 2.16 Maximum Energy Rates

	RG-11B/C	352	PO-14B	TR-14	TR-1
Charge Sensitivity (nominal) mV/MeV	100	100	50	50	0.01
Input Open Loop Gain	>20,000	>20,000	>20,000	>20,000	>20,000
Input Pulse Polarity	±	±	±	±	+
Output Impedance	93Ω	93Ω	50Ω	50Ω	50Ω
Maximum Cable Length (m)	30	6	30	30	30
Integral Nonlinearity	<0.05%	<0.05%	<0.05%	<0.05%	<0.05%
Decay Time Constant	100µs	200µs	---	---	---
Energy Rate Product (MeV/sec)	60,000	20,000	200,000	800,000	200,000
Isolation (VDC)	>5000	>5,000	>5,000	>5,000	>5,000
Power Requirements (V)	±12, ±24	±12	±12, ±24	±12, ±24	±24
Connectors: Input Detector Bias Timing Output Signal Output Test Pulse Inhibit Signal Power	 Hard wired SHV BNC BNC BNC --- 9-Pin Amphenol	 Hard wired SHV BNC BNC BNC --- 9-Pin Amphenol	 Hard wired SHV -*- BNC BNC BNC 9-Pin Amphenol	 Hard wired SHV -*- BNC BNC BNC 9-Pin Amphenol	 Hard wired using one 13-pin connector
Nominal Current Usage at: 24V 12V -24V -12V	 37 mA 6.4 mA 14.8 mA 3.8 mA	 --- 10.4 mA --- 3.7 mA	 --- 10.4 mA --- 3.7 mA	 27.5 mA † 20.0 mA † 20.8 mA † 1.6 mA †	 56 mA --- 26 mA ---
* Available as an option (BNC unless otherwise specified) † Negative TR-14B					

Table 2.17 PGT Preamplifiers

2.12 NaI(TI) Detectors

PGT offers a variety of sodium iodide detectors for your spectroscopy needs. All NaI(Ti) detectors are integral unitswhich include the photomultiplier tube (PMT). Our products are listed in the following tables:

Model Number	Description
SN15x20PMT1.5	1.5"D x 2.0" NaI(TI) crystal on 1.5" 12-pin PMT
SN20x20 PMT2.0	2.0"D x 2.0" NaI(TI) crystal on 2.0" 14-pin PMT
SN30x30 PMT3.0	3.0" D x 3.0 Na(TI) crystal on 3.0" 14-pin PMT

Table 2.18 Standard Detectors

Model Number	Description
WN15x20APMT1.5	1.5"D x 2.0" NaI(TI) crystal with 0.625" x 1.5" deep well on 1.5" 12-pin PMT

Table 2.19 Well-Type Detectors

Model Number	Description
SN15x20TB	1.5"D x 2.0" NaI(TI) crystal on 1.5" PMT with ruggedized, water-tight housing and integrated tube base
SN20x20TB	2.0" x 2.0" NaI(TI) crystal on 2.0 PMT with ruggedized, water-tight housing, integrated tube base, and carrying handle
SN30x30TB	3.0" D x 3.0" NaI(TI) crystal on 3.0" PMT with ruggedized, water-tight housing, integrated tube base, and carrying handle

Table 2.20 Ruggedized Detectors with Integrated Tube Base

2.13 Quadratic Compression Conversion (QCC™) — The New Way To Do NaI Gamma Spectroscopy

NaI(Tl) spectroscopy has always been challenging because the detector resolution is a strong function of energy. At high energies peaks become very broad and the detector's efficiency drops dramatically. These broad weak peaks are hard to find and difficult to analyze. At low energies the number of peaks is usually quite large and the peaks are closely spaced with reasonable resolution.

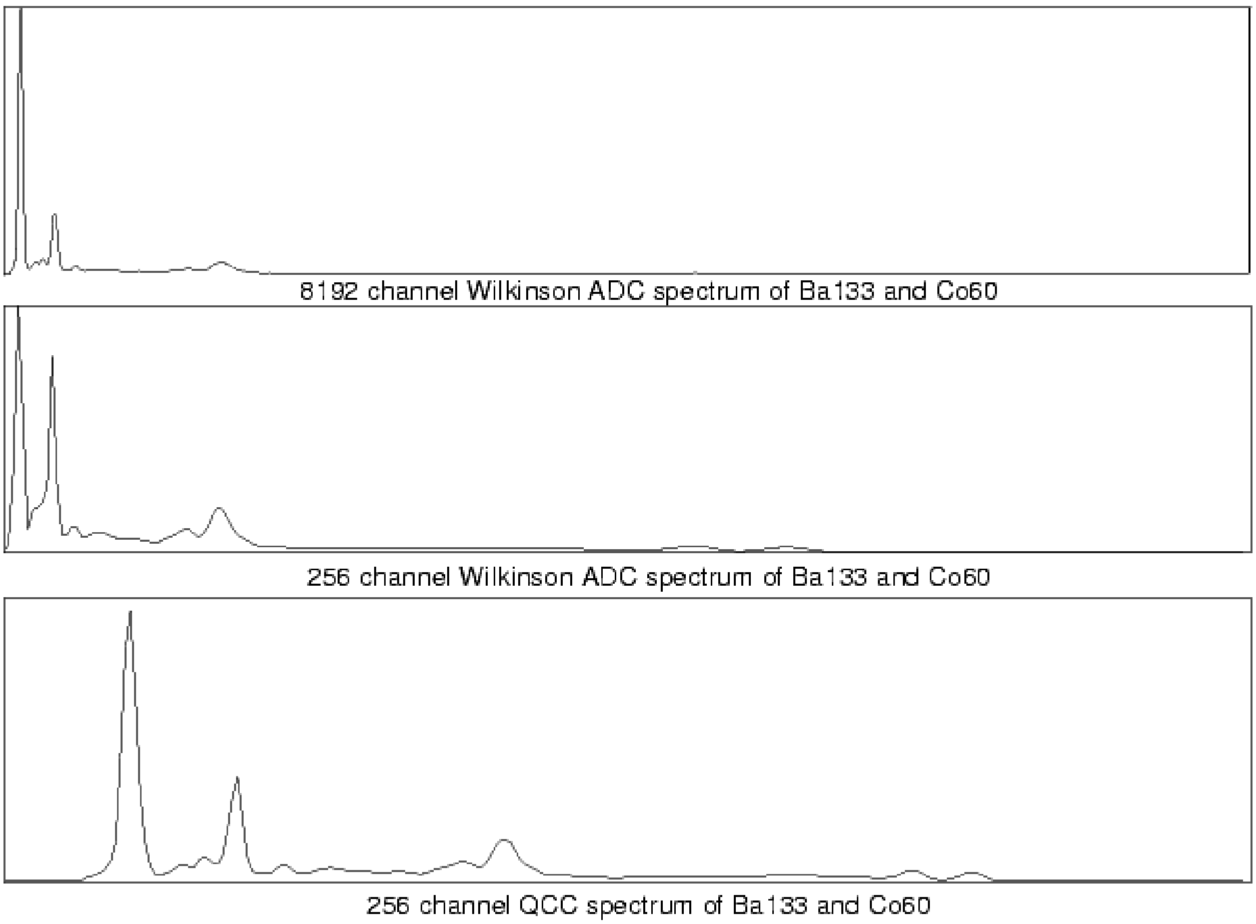


Figure 2.14 Each of the spectra above contains exactly the same data. The 8192-channel Wilkinson spectrum shows all of the spectral detail at low energies but appears to be empty over the high energy range. The 256-channel Wilkinson spectrum shows the high energy peaks better but distorts the low energy region, losing several peaks. The QCC spectrum provides full peak detail at all energies!

In the past, people have addressed these problems by using high resolution ADCs so that the energy per channel was small enough to give good peak resolution at the lowest energies. However at the higher energies the channels were much too fine resulting in peaks being spread out over hundreds of channels. When dealing with very low levels of high energy radiation, the peaks can be very hard to detect because of this wide dispersal. The QCC system solves both problems by having the channel width of the converter at a particular energy be proportional to the energy resolution of the system at that energy. In a QCC NaI(Tl) spectrum all peaks have the same FWHM expressed in channels independent of energy. QCC technology can cover the entire energy range of interest with sufficient resolution to provide accurate spectral analysis while providing enhanced minimum limits for identification.

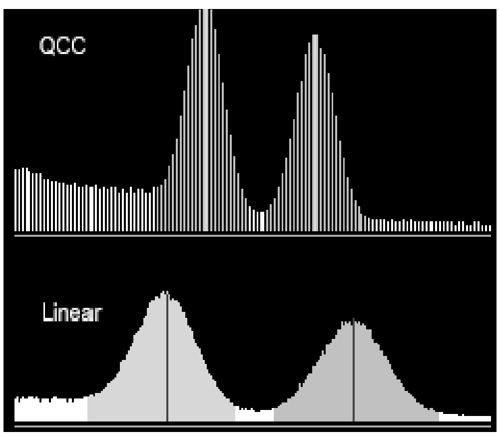
2.13.1 MCA 2100R Multichannel Pulse Height Analyzer

- MCA, bias supply, amplifier, and preamplifier all in one small package
- Patented Quadratic Compression Conversion greatly improves performance
- Easy installation and setup
- No internal slots or reserved memory required
- Includes 32-bit QuantumMCA software

PGT has incorporated the latest in modern electronics in the MCA2100R to provide a complete gamma spectrometer for NaI. The MCA2100R features a fast dual mode ADC and two standard modes of operation—either as a standard 1000 channel MCA in linear mode, or as a 512 channel MCA in QCC™ mode.

What is QCC?

QCC is Quadratic Compression Conversion™, PGT's patented signal processing technique that delivers spectra with uniform channel peak widths from 20 to 2000 keV. This powerful technique employs a pulse processing algorithm that converts a 16k spectrum to a 512-channel spectrum in real time. The peak-to-background ratio of the converted spectrum is significantly improved by using energy channels where they are needed the most. Consequently, the resolving power of the system is greatly improved.



In the figure above, the lower peaks were taken from a conventional 1000-channel linear spectrum of Co60. These are the 1173keV and 1333keV peaks. Notice how the peaks are broad and cover many channels. The upper portion shows the same Co60 peaks taken in QCC mode. In this example, the 1333keV peak of Co60 in the linear spectrum is spread over 75 channels, whereas the same peak in the QCC spectrum is defined by 28 channels. Most important, the peak-to-background ratio of this peak in the QCC spectrum is 5.2 while it is only 2.8 in the linear spectrum. This is almost a factor of two improvement! For low energy peaks, the opposite occurs. The number of channels per peak is increased relative to the number that would be used in a linear spectrum. QCC uses channels where they are needed!

MCA2100R features include:

- Two MCA modes: QCC (512 channels max.) and linear (1000 channels max.)
- 3.5µs successive approximation ADC
- Complete computer control
- Stand-alone operation; no slot required in the PC
- Internal preamplifier for use with NaI detectors
- Bipolar pulse shaping amplifier
- PC communication methods: RS-232 and Ethernet (MCA2100R-EN)
- Easy setup and energy calibration via QuantumMCA™ software

The MCA2100R is packaged as a peripheral to the PC. It does not require any internal PC interface slots or special memory reservations. This avoids problems in upgrading to the newer PCs and operating systems. The MCA2100R communicates via the RS-232 port. Simply connect a serial cable to one of the COM ports on the PC and the other end to the RS-232 connector on the MCA 2100R, and you are ready to go. To connect multiple units to the PC, use a multiple-port RS-232 interface or select the optional Ethernet connection.

The MCA2100R includes QuantumMCA software for qualitative analysis. All hardware setup and calibration functions are made through the software. It is not necessary to set internal jumpers or switches to configure the unit. For ease of setup, the MCA2100R with the QuantumMCA software can perform an automatic adjustment of the detector bias, coarse gain, and fine gain. Simply place a Cs137 source near the detector and press one software button. The unit performs all hardware adjustments. For a more precise energy calibration, the system can perform a quadratic energy calibration and resolution calibration based on a Eu152 spectrum. In minutes, the MCA2100R is ready to use.

For applications that require quantitative analysis, the powerful and user friendly QuantumGold software is available.

MCA 2100R Specifications

ADC

- 3.5µs successive approximation
- 14-bit resolution
- Discriminators (computer adjusted): upper (105% full scale) and lower (0% full scale) in increments of 0.41%
- Zero adjustment via computer in increments of 0.41%
- Maximum throughput: 75,000 cps

Spectrum memory

- QCC mode: 256 or 512 channels
- Linear mode: 250, 500, or 1000 channels
- Maximum counts per channel: 2^{24} -1 (i.e., 16 million)

Amplifier

- Bipolar shaping, 2µs (fixed)
- Built-in dead time correction
- No pole-zero adjustment required
- Coarse gain settings: 1×, 2×, 4×, 8× (computer selectable)
- Fine gain settings: 1 to 2.5× (computer adjustable) in increments of 0.01×

Counting presets

- Real time
- Live time
- Integral of all ROIs
- Integral of selected ROIs
- Gross ROI statistics
- Net ROI statistics
- Total system counts
- Total SCA counts

Computer control by

- RS-232 with the following available baud rates: 2400, 9600, 19200, 38400, 57600, and 115200
- Maximum number of units connected to PC: 8 total via RS-232 or Ethernet

Digital stabilizer

- RJ-45 connection for Ethernet (MCA2100R-EN)

Software

- 32-bit QuantumMCA compatible with Windows 95/98/NT

Accessories

- QuantumGold software for quantitative analysis
- Multiple port RS-232 card
- 14-pin tube base
- Selection of signal, interface, and detector bias cables
- Sodium iodide detectors

2.13.2 MCA 4000 Multichannel Analyzer

Premium Performance at a Price You Can Afford!

- 1000, 2000 or 4000 channels of spectrum memory in a stand-alone package
- Easy installation and setup via RS232 or Ethernet
- No slots or reserved memory required in the PC
- Includes 32-bit QuantumMCA software

The MCA4000 is a high-performance multichannel pulse height analyzer. This MCA was designed to give outstanding performance and value at an economical price. Packaged as a stand-alone unit, it features total computer control, excellent performance and flexibility. There are two ways to connect the MCA4000 to the computer: RS232 and Ethernet. The MCA4000 is also available in three configurations: 1000, 2000 or 4000 channels of spectrum memory. Each unit includes QuantumMCA software for Microsoft Windows, and is compatible with QuantumGold, the full quantitative gamma analysis software package.

The MCA4000 features a 2.7µs successive approximation ADC. With hardware add-one to memory and an on-board 20 MHz processor, there is processing power to spare. Differential non-linearity is less than ±1 percent over the top 99 percent of the range, and integral non-linearity is less than 0.05 percent over the same range. Digital stabilizers are provided for both the gain and offset. Data is stored as 31 bits per channel with an additional 8 bits for ROI information. Flexible live time correction is provided with a choice of simple busy, Lowes, Gedcke-Hale, or external dead time methods.

Full Computer Control

The MCA4000 is fully computer controlled. There are no pots to adjust. Upper level (ULD) and lower level (LLD) discriminators and the ADC zero offset are all computer controlled. Conversion gain can be set in the following increments:

MCA 4001: 250 channels, 500, and 1000

MCA 4002: 250 channels, 500, 1000, and 2000

MCA 4004: 250 channels, 500, 1000, 2000, and 4000

A wide range of presets is available, including live time, real time, integral of all ROIs, integral of selected ROIs, total SCA counts, net ROI statistics, and gross ROI statistics. The MCA4000 has many of the I/O connections you need for configuring any measurement application. External rear panel BNC connections are provided for GATE, REJECT, BUSY-IN, and ADC-INPUT. The polarity of REJECT and BUSY-IN can be programmed from the MCA software. MCA outputs include SCA OUT, PEAK DETECT, and ADC BUSY. The polarity of the PEAK DETECT and ADC BUSY signals can also be programmed from the software. A 44-pin DSUB connector is also provided for ROI outputs and digital control signals.

Analytical Software

For qualitative analysis, the MCA4000 includes QuantumMCA software at no additional charge. However, for those applications that require quantitative gamma analysis, PGT offers QuantumGold as an option. This package features an intuitive, user-friendly interface. The main screen is not cluttered with buttons and controls. Tool-tips allow frequently used functions to be quickly and easily identified.

For the user who wants to control the analytical process, QuantumGold will still be a pleasure to use. The Tools Setup window allows the fine-tuning of parameters associated with the analytical calculations. Some of these controls include peak search sensitivity, line matching for library-based identification of isotopes, and ROI definitions. The efficiency calibration process is as simple as selecting energy lines associated with the various calibration standards, and then pressing one button. The efficiency curve is generated along with a theoretical model for the response of the detector.

The gamma activity report includes all information associated with the analysis. Likewise, each spectrum data file contains all information associated with the calibration that was in effect at the time of acquisition.

Computer and Network Connectivity

Quantum-MCA has a single hardware setup and search utility that establishes communication with PGT multichannel analyzers using RS232 or ethernet. Both methods offer the advantage of connecting the MCA4000 directly to a PC. The RS232 interface is a quick and simple way to connect the MCA 4000 directly to a PC in the field or other location. An unused COM port is all that is needed. Multiple MCA4000s can also use Ethernet connections.

MCA 4000 Specifications

ADC

- 2.7µs successive approximation ADC (12-bit resolution)
- Discriminators (PC adjusted): upper (0 to 105% of full scale) and lower (<1% to 105% of full scale) in 0.03% increments
- Zero adjustment in increments of 0.41% (PC adjusted)
- Maximum throughput: 180,000 cps

Spectrum Memory

- MCA 4001: 250, 500, and 1000 channels
- MCA 4002: 250, 500, 1000, and 2000 channels
- MCA 4004: 250, 500, 1000, 2000, and 4000 channels
- maximum counts per channel: 2^{31} - 1 (i.e., 2.1E9)

Digital Stabilizer

- Internal ADC zero and gain stabilization
- PC controlled time constants
- Balanced channel and ROI centroid modes
- Gain: ±12.5% range
- Zero: ±1.25% range

Multichannel Scaling

- Input Rate: 5 MHz
- Dwell Time: 10 ms to 2.1E7 seconds
- Dead-time: 3µs between passes and 3µs between channels
- Signal sources: internal SCA, any ROI, external input

Counting Presets

• Real time	• Live time
• Integral of all ROIs	• Integral of selected ROIs
• Gross ROI statistics	• Net ROI statistics
• Total system counts	• Total SCA counts

Linearity

- Differential: < ±1% over top 99% of range
- Integral: < ±0.05% over top 99% of range

Battery backup for

- Spectrum
- Setup parameters
- Clock memory

Computer Control

- RS232 baud rates: 2400, 9600, 19200, 38400, 57600, 115200
- Max. number units connected to PC: 8
- Ethernet connection

Front Panel Indicators

- LEDs for: Acquire, Event, Serial Com, AUX I/O in-use, power
- 3-color LED array for dead-time

Rear Panel Controls and Connectors

- Power switch
- 2.5mm power jack
- Fuse housing
- 9-pin D male RS-232 connector
- 44-pin D-sub female connector for ROI output
- ADC input (BNC) 0-10V unipolar or bipolar pulse
- ADC gate input (BNC) (coin. / anti-coin. / off) CMOS/TTL
- Pile-up reject input (BNC) CMOS/TTL
- SCA output CMOS/TTL
- ADC busy out (BNC) CMOS/TTL
- External input counter (BNC) CMOS/TTL

Weight

- 4.06lb (1.85kg)

Dimensions

- 10.4in. (26.4cm) wide
- 12.3in. (31.2cm) deep
- 2.75 (7.0cm) tall

Power Requirements

- 10-18 VDC, 9.6 watts, external
- 12V universal AC supply provided

Software

- 32-bit QuantumMCA compatible with Windows 95/98/NT/2000/XP

Accessories

- QuantumGold software for quantitative analysis
- High-purity germanium detectors
- NaI detectors
- Selection of cables

2.13.3 System 4000 X-Ray Spectrometer

Premium Performance at a Price You Can Afford!

- MCA, bias supply, amplifier all in one package
- Fast 2.7µs ADC
- ROI/AUX IO with up to 15 fast TTL ROIs, definable in the software
- No slots or reserved memory required in the PC
- Includes 32-bit QuantumMCA software

The System 4000 is a complete spectrometer in a single integrated package. It is designed to make X-ray spectroscopy easy. The System 4000 is configured with 4000 channels of spectrum memory, a 0 to ± 1 kV bias supply, and an analog pulse processor with 2µs, 12µs and 24µs shaping times for X-ray spectrometry. The System 4000 has onboard Ethernet and RS-232 interfaces to make connection to the PC or network easy.

High Performance for X-Ray Applications

The System 4000 gamma spectrometer has been engineered to give optimum performance in a wide range of applications with HPGe and Si(Li) detectors. The three computer-selectable time constants offer choices for high throughput applications, standard operation, and highest possible resolution. The shaping amplifier features 8th order triangular and Gaussian filters for minimum series noise and optimum resolution.

Automatic noise discriminators and a gated baseline restorer with rate adaptive restoration give the ultimate in stability even at the highest count rates. To provide the best possible pile-up rejection, even at the lowest energies, the fast channel has adaptive time constants which ensure maximum possible sensitivity. This translates into the best possible performance from your detector system. Computer control of all hardware functions also complements the power and flexibility of the system.

The System 4000 has 15 dedicated TTL ROI outputs and one ROI byte with strobe. The ROI outputs can be directed to counters or rate meters for monitoring individual regions or peaks

Analytical Software

For qualitative analysis, the System 4000 includes QuantumMCA™ software at no additional charge. This package features an intuitive, user-friendly interface. The main screen is not cluttered with buttons and controls. Tool-tips allow frequently used functions to be quickly and easily identified. There are also default parameters for the peak search routine and other steps of the analysis process. So, getting reliable answers quickly is not a problem.

For the user who wants to control the analytical process, eXcalibur will still be a pleasure to use. The Tools Setup window allows the fine-tuning of parameters associated with the analytical calculations. Some of these controls include peak search sensitivity, line matching for library-based identification of isotopes, and ROI definitions. The efficiency calibration process is as simple as selecting energy lines associated with the various calibration standards, and then pressing one button. The efficiency curve is generated along with a theoretical model for the response of the detector.

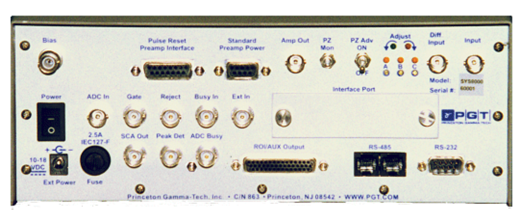
The activity report includes all information associated with the analysis. Likewise, each spectrum data file contains all information associated with the calibration that was in effect at the time of acquisition.

Computer and Network Connectivity

QuantumMCA has a single hardware setup and search utility that establishes communication with PGT multichannel analyzers via RS232. The RS232 interface allows for a quick and simple method of connecting the System 4000 directly to the PC. All that is needed is an unused COM port on the PC. For applications where multiple units need to be connected to the PC, a multiple-port RS232 interface which allows daisy-chaining of System 4000 units together can be used. In any case, a total of eight units can be connected to one PC.

Available configurations

- System 4004X with:
  - 4000 channels of spectrum memory
  - Pulse shaping constants: 3µs, 12µs and 24µs
  - 0 to ±1KV bias supply



System 4000 Specifications

ADC

- 2.7µs successive approximation ADC (12-bit resolution)
- PC adjusted discriminators: upper (0 to 105% of full scale) and lower (<1% to 105% of full scale) in 0.41% increments
- Zero adjustment in increments of 0.41% (PC adjusted)
- Maximum throughput: 180,000 cps

Non-linearity

- Differential non-linearity: < ±1% over top 99% of range
- Integral non-linearity: < ± 0.05% over top 99% of range

Spectrum memory (both models)

- 250, 500, 1000, 2000, 4000 channels
- Maximum counts per channel: 2^{31} - 1 (i.e., 2.1E9)

Digital stabilizer

- Internal ADC zero and gain stabilization
- PC controlled time constants
- Balanced channel and ROI centroid modes
- Gain: ±12.5% range
- Zero: ±1.25% range

Counting presets

- Real time
- Live time
- Integral of all ROIs
- Integral of selected ROIs
- Gross ROI statistics
- Net ROI statistics
- Total system counts
- Total SCA counts

Battery backup for

- Spectrum
- Setup parameters
- Clock memory

Computer control

- RS-232 baud rates: 2400, 9600, 19200, 38400, 57600, and 115200
- Maximum number of units connected to PC: 8

Amplifier

- Gaussian and triangular shaping of unipolar pulses (PC selectable)
- Acceptable input: pos./neg. pulses (step or tail) with rise times of 10ns to 500ns and decay times from <50s to ∞
- Input: single-ended (BNC) or differential (BNC) (PC selectable)
- Pole-zero provided for DCR type preamplifiers
- Pole-zero adjustment assistant eliminates need for oscilloscope
- Gain: from 4× to 1300× (PC control)
- Coarse gain: 4×, 8×, 32×, 64×, 128×, 256×, 512×
- Fine gain: 1 to 2.55× in increments of 0.0007X
- Common mode rejection ratio: ≥500 (typically ≥1000)
- Temperature instability
  - Gain: guaranteed <±50 ppm/°C, typical <25ppm/°C, 0 to 50°C
  - Offset: guaranteed ≤±10mV/°C
- Noise: ≤±0.05% (typical ≤±0.025%)
- Baseline restorer:
  - slow channel: rate adaptive with automatic threshold
  - fast channel with automatic threshold
- Live-time correction modes: simple busy, Lowes, Gedcke-Hale, external

Bias Supply

- 0 to ± 1.2 kV
- External shutdown capability (positive-true or negative-true polarity)
- Ripple: ≤20mV peak-to-peak
- Temperature instability: ≤±0.01% / °C, 0 to 50 °C
- Bias polarity: internally jumper selected

Front panel indicators

- LEDs for acquire, event, serial com, AUX I/O in-use, power, shaping-constant, bias-on, polarity, fault, PUR
- Dead time meter: 3-color LED array, 10%/division

Rear panel controls and connectors

- Power switch
- SHV female connector for detector bias

- 2.5mm power jack
- Fuse housing
- 9-pin D female preamp power conn. (±12V, ±24, HV shutdown, GND)
- 9-pin D male RS232 connector
- 15-pin D female pulse reset preamplifier interface
- 44-pin D female connector for multiple ROI output and aux. I/O
- RJ-11 connectors for RS485
- Pole-zero adjustment on/off
- Pole-zero oscilloscope monitor switch
- One potentiometer for PZ adjustment of each shaping time (3 total)
- Input from detector preamplifier (BNC)
- Differential input from detector preamplifier (BNC)
- Amplifier output (BNC)
- ADC input (BNC) 0-10V unipolar or bipolar pulse
- ADC gate input (BNC) (coin. / anti-coin. / off) CMOS/TTL
- Pile-up reject input (BNC) CMOS/TTL
- Amp busy input for ext. amp. live-time corr. (BNC) CMOS/TTL
- SCA output CMOS/TTL
- Peak detect output (BNC) CMOS/TTL
- ADC busy out (BNC) CMOS/TTL
- External input for alarm and/or auto-shutdown (CMOS/TTL)

Weight

- 7.25 lb. (3.30kg)

Dimensions

- 10.5 in. (26.7cm) wide
- 12.5 in. (31.8cm) deep
- 4.5 in. (11.5cm) tall

Power requirements

- 10-18 VDC, 18 watts, external 12V universal AC supply provided

Software

- 32-bit QuantumMCA compatible with Windows 95/98/NT/2000/XP

Accessories

- QuantumGold software for quantitative analysis
- High-purity germanium detectors
- LN2 fill system
- Selection of signal, interface, and detector bias cables

2.13.4 MCA 8000 Multichannel Analyzer

- 8000 or 16,000 channels of spectrum memory in a stand-alone package
- Easy installation and setup via Ethernet 10/100 base-T or RS-232
- No slots or reserved memory required in the PC
- Includes 32-bit QuantumMCA software

The MCA8000 is PGT's latest multichannel pulse height analyzer. Designed to provide outstanding performance and value at an economical price, its features make pulse-height analysis a pleasure to perform. Packaged as a stand-alone unit, it offers total computer control, excellent performance and flexibility. There are two ways to connect the MCA 8000 to the computer: Ethernet and RS-232. The MCA 8000 is available in two configurations: 8000 channels of spectrum memory and 16,000 channels. Each unit also comes with QuantumMCA software for Microsoft Windows, and it is compatible with the quantitative analysis software package QuantumGold.

The MCA 8000 features an 8.12 µs successive approximation ADC. With hardware add-one to memory and an on-board 20 MHz processor, there is processing power to spare. Differential non-linearity is less than ±1 percent over the top 99% of the range, and integral non-linearity is less than 0.05% over the same range. Digital stabilizers are provided for both the gain and offset. Data is stored as 31 bits per channel with an additional 8 bits for ROI information. Flexible live time correction is provided with a choice of simple busy, Lowes, Gedcke-Hale, or external dead time methods.

Full Computer Control

The MCA 8000 is fully computer controlled. There are no pots to adjust. Upper level (ULD), lower level (LLD) discriminators, and the ADC zero offset are all computer controlled. Conversion gain can be set to 250, 500, 1000, 2000, 4000, 8000, and 16,000 channels (MCA8016 only).

A wide range of presets is available including: live time, real time, integral of all ROIs, integral of selected ROIs, total SCA counts, net ROI statistics, and gross ROI statistics. The MCA 8000 has many of the I/O connections you need for configuring any measurement application. External rear panel BNC connections are provided for GATE, REJECT, BUSY-IN, and ADC-INPUT. The polarity of REJECT and BUSY-IN can be programmed from the MCA software. MCA outputs include SCA OUT, PEAK DETECT, and ADC BUSY. The polarity of the PEAK DETECT and ADC BUSY signals can also be programmed from the software. A 26-pin DSUB connector is also provided for ROI outputs and digital control signals.

Analytical Software

For qualitative analysis, the MCA 8000 includes QuantumMCA software at no additional charge. However, for those applications that require quantitative gamma analysis, PGT also offers QuantumGold sold as an option. This package features an intuitive, user-friendly interface. The main screen is not cluttered with buttons and controls. Tool-tips allow frequently used functions to be quickly and easily identified.

For the user who wants control of the analytical process, QuantumGold will still be a pleasure to use. The Tools Setup window allows the fine-tuning of parameters associated with the analytical calculations. Some of these controls include peak search sensitivity, line matching for library-based identification of isotopes, and ROI definitions. The efficiency calibration process is as simple as selecting energy lines associated with the various calibration standards, and then pressing one button. The efficiency curve is generated along with a theoretical model for the response of the detector.

The gamma activity report includes all information associated with the analysis. Likewise, each spectrum data file contains all information associated with the calibration that was in effect at the time of acquisition.

Computer and Network Connectivity

QuantumMCA has a single hardware setup and search utility that establishes communication with PGT multichannel analyzers via Ethernet 10/100 base-T or RS-232. Ethernet capability allows users to enjoy the benefits of connecting the MCA8000 directly to a PC or to the local area network. The RS-232 interface provides a quick and simple method of connecting the MCA 8000 directly to a PC in the field or other location where Ethernet is not available. For RS-232, an unused COM port is all that is needed.

Available Configurations

- MCA 8008 with 8000 channels of spectrum memory
- MCA 8016 with 16,000 channels of spectrum memory

MCA 8000 Specifications

ADC

- 8.12µs successive approximation ADC (14-bit resolution)
- Discriminators (PC adjusted): upper (0 to 105% of full scale) and lower (<1% to 105% of full scale) in 0.03% increments
- Zero ±2% adjustment in increments of 0.0005% (PC adjusted)
- Maximum throughput: 70,000 cps

Spectrum memory

- MCA 8008: 250, 500, 1000, 2000, 4000, 8000 channels
- MCA 8016: 250, 500, 1000, 2000, 4000, 8000, 16000 channels
- Maximum counts per channel: 2^{31} - 1 (i.e., 2.1E9)

Digital stabilizer

- Internal ADC zero and gain stabilization
- PC controlled time constants
- Balanced channel and ROI centroid modes
- Gain: ±3% of range
- Zero: ±1.25% of range

Multichannel scaling

- Input Rate: 5 MHz
- Dwell Time: 10ms to 2.1E7 seconds
- Dead-time: 3µs between passes and 3µs between channels
- Signal sources: internal SCA, any ROI, external input

Counting presets

- Real time
- Live time
- Integral of all ROIs
- Integral of selected ROIs
- Gross ROI statistics
- Net ROI statistics
- Total system counts
- Peak counts
- Total SCA counts
- External events

ADC Non-linearity

- Differential: <±1% over top 99% of range
- Integral: <±0.05% over top 99% of range

Battery backup for

- Spectrum
- Setup parameters
- Clock memory

Computer control

- Ethernet 10/100 base-T
- RS232 baud rates: 2400, 9600, 19200, 38400, 57600, 115200
- Maximum number of units connected to PC: 8

Front panel indicators

- LEDs for
  - Acquire
  - Event
  - Serial com
  - AUX I/O in-use
  - Power
  - 3-color LED array for dead-time

Rear panel controls and connectors

- Power switch
- 2.5mm power jack
- Fuse housing
- 9-pin D male RS232 connector
- 25-pin DB female connector for ROI output
- 15-pin D-sub high density female auxiliary I/O connector
- Ethernet interface connector (RJ-45)
- ADC input (BNC) 0-10V unipolar or bipolar pulse
- ADC gate input (BNC) (coin. / anti-coin. / off) CMOS/TTL
- Pile-up reject input (BNC) CMOS/TTL
- Amp busy input for ext. amp. live-time corr. (BNC) CMOS/TTL
- SCA output CMOS/TTL
- ADC busy out (BNC) CMOS/TTL
- Peak detect output (BNC) CMOS/TTL

Weight

- 4.06 lb. (1.85kg)

Dimensions

- 10.4 in. (26.4cm) wide
- 12.3 in. (31.2cm) deep
- 2.75 in. (7.0cm) tall

Power requirements

- 10-18V DC, 9.6 watts, external
- 12V universal AC supply provided

Software

- 32-bit QuantumMCA compatible with Windows 95/98/NT/2000/XP
- QuantumGold software for quantitative analysis

2.13.5 System 8000 Gamma or X-Ray Spectrometer

Premium Performance at a Price You Can Afford!

- MCA, bias supply, amplifier all in one package
- Configurations for gamma and X-ray spectroscopy
- Easy installation and setup
- No slots or reserved memory required in the PC
- Includes 32-bit QuantumMCA™ software

The System 8000 is a complete spectrometer in a single integrated package. It is designed to make gamma or X-ray spectroscopy easy. The System 8000 has configurations with 8000 or 16,000 channels of spectrum memory. Each has a 0 to ±5kV bias supply and an analog pulse processor with 2µs, 4µs, and 8µs shaping times. All configurations of the System 8000 have onboard Ethernet and RS-232 interfaces for easy connection to the PC or network.

High Performance

The System 8000 gamma spectrometer has been engineered to give optimum performance in a wide range of applications with HPGe and Si(Li) detectors. The three computer-selectable time constants offer choices for high throughput applications, standard operation, and highest possible resolution. The shaping amplifier features 8th order triangular and Gaussian filters for minimum series noise and optimum resolution. Automatic noise discriminators and a gated baseline restorer with rate adaptive restoration give the ultimate in stability even at the highest count rates. To provide the best possible pile-up rejection, even at the lowest energies, the fast channel has adaptive time constants which ensure maximum possible sensitivity. This translates into the best possible performance from your detector system. Computer control of all hardware functions complements the power and flexibility of the system.

Analytical Software

For qualitative analysis, the System 8000 includes QuantumMCA software at no additional charge. For applications that require quantitative gamma analysis, PGT offers the optional QuantumGold software. This package features an intuitive, user-friendly, interface. The main screen is not cluttered with buttons and controls. Tool tips allow frequently used functions to be quickly and easily identified.

For gamma applications, a fast hardware setup routine using Cs137 eliminates the hassles of manually adjusting the coarse and fine gains. There are also default parameters for the peak search routine and other steps of the analysis process.

For the user who wants control of the analytical process, QuantumGold will still be a pleasure to use. The Tools Setup window allows the fine-tuning of parameters associated with the analytical calculations. Some of these controls include peak search sensitivity, line matching for library-based identification of isotopes, and ROI definitions. The efficiency calibration process is as simple as selecting energy lines associated with the various calibration standards, and then pressing one button. The efficiency curve is generated along with a theoretical model for the response of the detector.

The gamma activity report includes all information associated with the analysis. Likewise, each spectrum data file contains all information associated with the calibration that was in effect at the time of acquisition.

Computer and Network Connectivity

QuantumMCA has a single hardware setup and search utility that establishes communication with PGT multichannel analyzers via Ethernet or RS-232. Ethernet capability allows users to enjoy the benefits of connecting to laboratory instruments from PCs on the local area network. The RS-232 interface offers quick and simple connection of the System 8000 directly to a PC in the field or other location where Ethernet is not available. For RS-232, an unused COM port is all that is needed.

Available configurations

- System 8016G:
  - 16,000 channels of spectrum memory
  - Pulse shaping constants: 2µs, 4µs, and 8µs
  - 0 to ±5kV bias supply
- System 8008G:
  - 8000 channels of spectrum memory
  - Pulse shaping constants: 2µs, 4µs, and 8µs
  - 0 to ±5kV bias supply

System 8000 Specifications

ADC

- 8.12µs successive approximation ADC (14-bit resolution)
- Discriminators (PC adjusted): upper (0 to 105% of full scale) and lower (<1% to 105% of full scale) in 0.03% increments
- Zero adjustment in increments of 0.0005% (PC adjusted)
- Maximum throughput: 70,000 cps

ADC Non-Linearity

- Differential non-linearity: < ±1% over top 99% of range
- Integral non-linearity: < ± 0.05% over top 99% of range

Spectrum memory

- System 8004X: 250, 500, 1000, 2000, 4000 channels
- System 8008G: 250, 500, 1000, 2000, 4000, 8000 channels
- System 8016G: 250, 500, 1000, 2000, 4000, 8000, 16,000 channels
- Maximum counts per channel: $2^{31} - 1$ (i.e., 2.1E9)

Digital stabilizer

- Internal ADC zero and gain stabilization
- PC controlled time constants
- Balanced channel and ROI centroid modes
- Gain: ±3% range
- Zero: ±1.25% range

Multichannel scaling

- Input rate: 5MHz
- Dwell time: 10ms to 2.1E7 seconds
- Dead time: 3µs between passes and 3µs between channels
- Signal sources: internal SCA, any ROI, external input

Counting presets

- Real time
- Live time
- Integral of all ROIs
- Integral of selected ROIs
- Gross ROI statistics
- Net ROI statistics
- Total system counts
- Peak counts
- Total SCA counts
- External events

Amplifier

- Gaussian and triangular shaping of unipolar pulses (PC selectable)
- Acceptable input: positive/negative pulses (step or tail) with rise times of 10ns to 500ns and decay times from <50µs to ∞
- Input: single-ended (BNC) or differential (BNC) (PC selectable)
- Shaping constants (PC selectable)
  - 2µs, 4µs, or 8µs (Gamma systems)
  - 3µs, 12µs, or 24µs (X-ray applications)
- Pole-zero provided for DCR type preamplifiers
- Pole-zero adjustment assistant eliminates need for oscilloscope
- Gain: from 4× to 1300× (PC controlled)
  - Coarse gain: 4×, 8×, 32×, 64×, 128×, 256×, 512×
  - Fine gain: 1 to 2.55× in increments of 0.0007×
- Common mode rejection ratio: ≥500 (typically ≥1000)
- Temperature instability
  - Gain: guaranteed <±50 ppm/°C, typical <25 ppm/°C, 0 to 50°C
  - Offset: guaranteed ≤±10mV/°C
- Noise: ≤±0.05% (typical ≤±0.025%)
- Baseline restorer:
  - Slow channel: rate adaptive with automatic threshold
  - Fast channel with automatic threshold
- Live-time correction modes: simple busy, Lowes, Gedcke-Hale, external

Battery backup for:

- Spectrum
- Setup parameters
- Clock memory

Computer control

- Ethernet 10/100 base
- RS-232 baud rates: 2400, 9600, 19200, 38400, 57600, 115200
- Maximum number of units connected to PC: 8

Bias supply

- 0 to ±5kV in 5V increments (gamma systems)
- 0 to ±1kV in 1V increments (X-ray systems)
- External shutdown capability (positive-true or negative-true polarity)
- Ripple: ≤20mV peak-to-peak
- Temperature instability: ≤±0.01% / °C, 0 to 50 °C
- Bias polarity: internally jumper selected

Front panel indicators

- LEDs for Acquire, Event, Serial Com, AUX I/O In-use, Power, Shaping-constant, Bias-on, Polarity, Fault, PUR
- Dead time meter: 3-color LED array

Rear panel controls and connectors

- Power switch
- SHV female connector for detector bias
- 2.5mm power jack
- Fuse housing
- 9-pin D female preamplifier power connector
- 9-pin D male RS232 connector
- 15-pin D female pulse reset preamplifier interface
- 25-pin DB female connector for ROI output
- 15-pin D auxiliary I/O connector, including external input for alarm and/or auto-shutdown
- Ethernet interface connector (RJ-45)
- Pole-zero adjustment on/off
- Pole-zero oscilloscope monitor switch
- One potentiometer for PZ adjustment of each shaping time (3 total)
- Input from detector preamplifier (BNC)
- Differential input from detector preamplifier (BNC)
- Amplifier output (BNC) 0-8V positive, unipolar
- ADC input (BNC) 0-10V unipolar or bipolar (positive lobe leading) pulse
- ADC gate input (BNC) (coincidence/anti-coincidence/off) CMOS/TTL
- Pile-up reject input (BNC) CMOS/TTL
- Amp busy input for ext. amp. live-time corr. (BNC) CMOS/TTL
- SCA output CMOS/TTL
- Peak detect output (BNC) CMOS/TTL
- ADC busy out (BNC) CMOS/TTL

Dimensions

- 10.5 in. (26.7 cm) wide
- 12.5 in. (31.8 cm) deep
- 4.5 in. (11.5 cm) tall

Weight

- 7.25 lb. (3.30kg)

Power requirements

- 10-18V DC, 18 watts, external
- 12V universal AC power converter provided

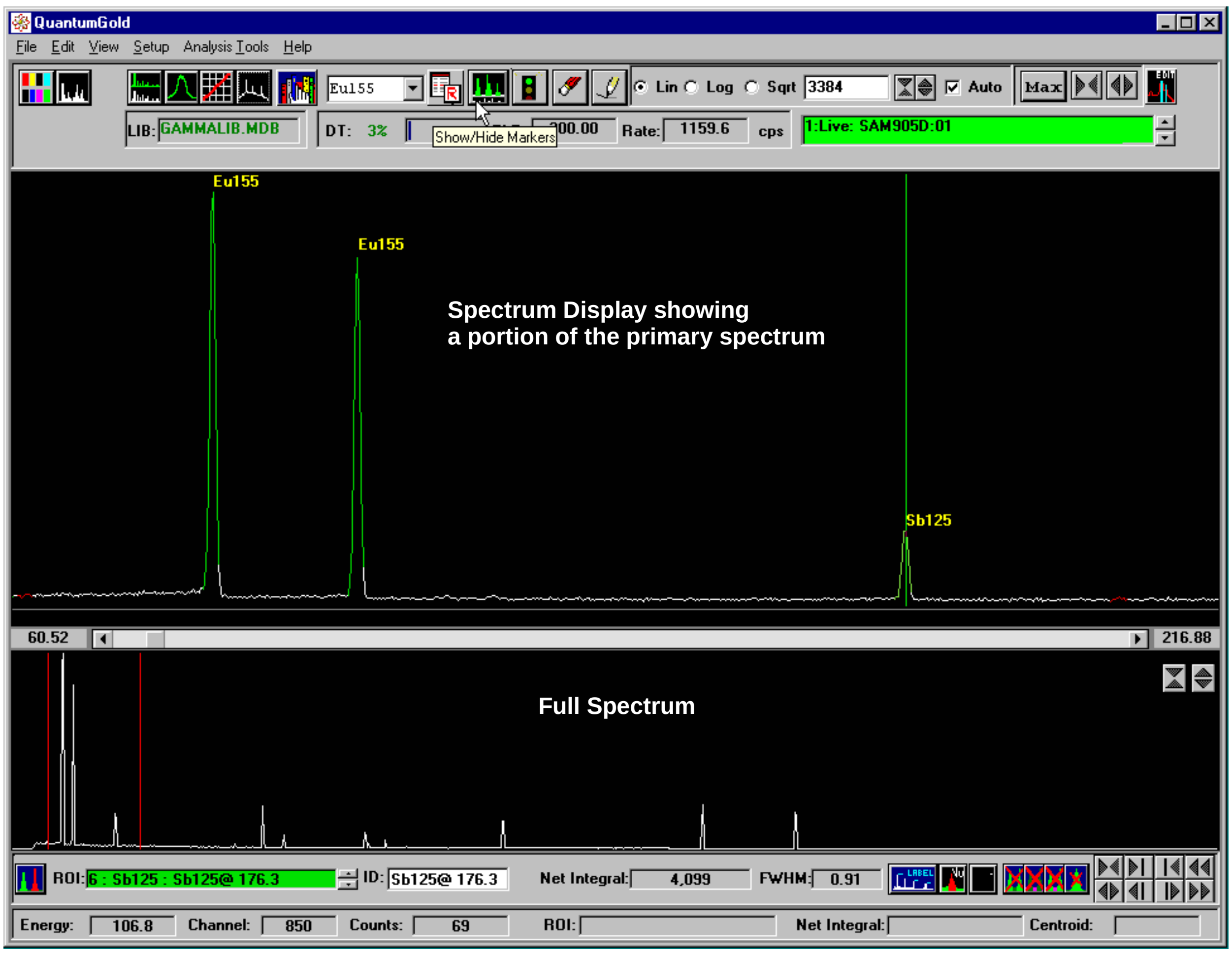
Software

- 32-bit QuantumMCA compatible with Windows 95/98/NT/2000/XP
- Optional QuantumGold software for quantitative analysis.

2.13.6 Quantum MCA Software for Windows

PGT produces the following Microsoft Windows-based applications for MCA control and spectral analysis:

- **QuantumMCA**® is the basic MCA software for qualitative analysis.
- **QuantumGold**™ adds quantitative analysis capabilities to the features of **QuantumMCA**.
- **Quantum GeD** includes both qualitative and quantitative analysis capabilities for germanium detectors *only.*
- **Quantum Ge** includes all the features of Quantum **GeD** except deconvolution analysis.
- **Quantum NaID** includes both qualitative and quantitative analysis capabilities for NaI detectors *only.*
- **Quantum NaI** includes all the features of **Quantum NaID** except deconvolution analysis.



QuantumMCA® is the standard MCA software package. It can control up to eight MCAs at one time with memory management for up to 16,000 channels of real time display and storage for each spectrum. It includes libraries for alpha, beta and gamma analysis, with separate gamma libraries optimized for HPGe and NaI spectroscopy. It is an excellent choice for any non-quantitative task.

Ease of use is a keyword in all Quantum products. The main screen provides direct access to all functionality. The spectrum display area can display up to eight spectra simultaneously in live, static or a mix of modes. Vertical scales include linear, square-root and log, with unique “full view” auto-ranging. Single clicks on the toolbar provide overlapped or tiled display, full-screen spectrum, line markers, radiation popup window, and memory control. The information you need is always readily at hand. The graphic below shows the radiation lines pop-up window with data on Co60. Simply click on a line in the table to place a marker on the screen and bring that section of the spectrum into view. A similar approach is used in all single-line-per-item reports. Click in the list to highlight the peak on the display and bring it into view if necessary. The image at the right shows some of the many hardware controls available to PGT instruments.

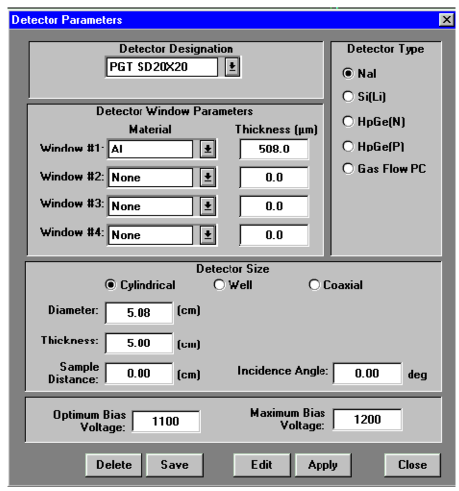
Whether you are setting peak search sensitivities, deciding what lines to use to identify isotopes, or displaying markers, you can choose the fully automated feature or take over control yourself.

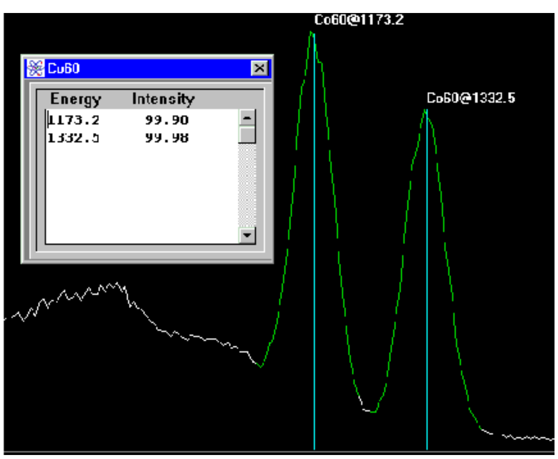
Your investment in QuantumMCA software will always be a good one. With lifetime technical support and a liberal free update policy, you can be assured your software will remain as state-or-the-art as when you first purchased it.

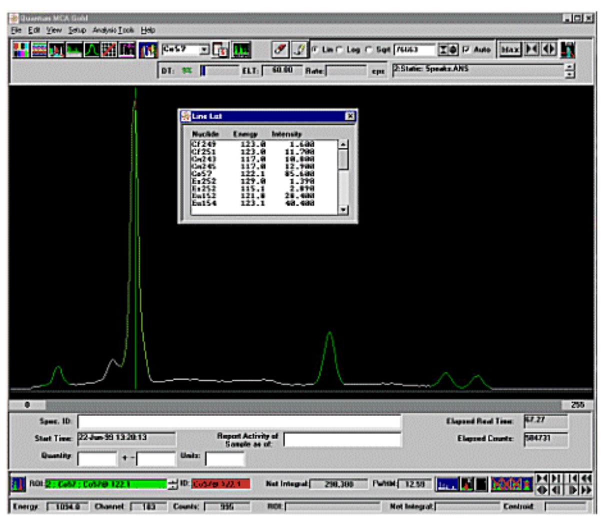
Quantum Gold™ is the premier MCA software package for analysis of spectra. It provides all of the features of QuantumMCA plus the capability for quantitative analysis.

Accurate detector efficiencies are essential for good quantitative analysis. QuantumGold provides a sophisticated detector model which accurately accounts for the effects of detector size and window absorption. Accuracy can be further enhanced by measuring single or multi-isotope standards and fitting the results to the residuals of the calibration function.

The rapid scan analysis algorithm automatically searches the spectrum for peaks, sets ROIs, does a cross-correlation analysis to identify the isotopes and performs a quantitative analysis. Results are available by isotope or by ROI. The ROI-directed method allows the user or the system to set ROIs. This method can include multiple lines to be analyzed. Each ROI explicitly specifies the isotope to be analyzed.







All QuantumMCA software products share a rich feature set and support a wide range of hardware from PGT. Enjoy the convenience of controlling multiple MCA types from a single unified user interface.

Features:

- Software
  - True 32-bit application
  - Simplified user interface
  - New COM interface commands and added functions for QScript
  - Ethernet support for PGT spectrometers and multichannel analyzers that have ethernet capability
- Calibrations
  - Automatic setup of HV, coarse and fine gains using ^{137}Cs source (if hardware allows control)
  - Automated individual isotopic calibrations from single or multi-isotopic standards
  - Multi-point quadratic energy calibrations from standards or manually
  - Sophisticated detector modeling for efficiency calibration curve
  - Sophisticated model-based efficiency curve enhanced by fitting to multiple measured standards
- Analytical Tools
  - Real-time ROI analysis
  - Ability to print all reports or send them to file
  - Spectral output as bitmap, metafile, or text
  - ROI detail report includes calculations of 20+ parameters for each ROI
  - Automated ambient background subtraction
  - Automated or user-directed continuum correction
  - User-controllable peak finder
  - Cross-correlation peak identification against library
  - Multiple quantitative analysis routines available for fully automated or user-directed analysis
  - Gaussian peak deconvolution
- Display Capabilities
  - Complete color control for all aspects of the spectrum display
  - Tile or overlaid modes with dots, lines, or bars display options
  - Linear, log and square-root scaling
  - Unique “full view” auto-scaling of each spectrum independently to permit optimum viewing
  - Fully configurable line markers with labels which can include isotope and energy
  - Popup X-ray line data-window with energy, type and intensity
  - Arbitrary screen annotations which track location relative to peaks
- ROI Capabilities
  - Up to 256 user-defined overlapping ROIs
  - Detailed, continuously updated ROI information
  - User-defined names for each ROI independent of isotopic assignment
  - User-definable continuum background regions
  - Automatic peak labeling with ROI names or associated nuclides
- Reports
  - Graphic spectrum printout reformats screen view for high-resolution printer output. All markers, display settings and annotations are included.
  - By-channel data report, single or multi-column
  - ROI summary report, spectrum plot with ROI data
  - ROI detail report
  - Peak identify report
  - Quantitative analysis reports by nuclide or by ROI (QuantumGold only)

Appendix 1: Radionuclides for Energy Resolution

Radionuclide	Half-Life	Energy
^{55}Fe	2.74 years	5.9 keV*
^{241}Am	433. years	59.54 keV*and 26.3 keV X rays
^{109}Cd	463. days	22.2 keV* (X-ray doublet) 88.0 keV*
^{129}I	1.5×10^{7} yrs	40.0 keV
^{57}Co	272. days	122.1 keV * and 136.5 keV
^{137}Cs	30.3 years	661.7 keV* 31.8, 32.2, 36.4 keV from daughter ^{56}Ba
^{22}Na	2.60 years	511. keV 1274.5 keV*
^{60}Co	5.24 years	1173.2 keV 1332.5 keV*†
^{208}Tl	1.91 years	583. keV 2614.5 keV* (^{228}Th source)
^{152}Eu	13.3 years	Multiple lines 121-1408 keV; prominent lines include 121.8 keV 344.3 778.9 964. 1112.1 1408.0

*γ and X rays preferred for energy resolution measurements
†Preferred for coaxial detector specification measurements

Appendix 2: Radionuclides for Marinelli Beaker Standard Sources (MBSS)

Radionuclide	Half-Life	Energy	Typical Initial Emission (γ/s)
^{109}Cd	462.7 days	88.0 keV	2000
^{57}Co	271.7 days	122.1	250
^{139}Ce	137.5 days	165.8	200
^{203}Hg	46.6 days	279.2	600
^{113}Sn	115.1 days	391.7	1000
^{137}Cs	30.2 year	661.6	500
^{88}Y	106.6 days	898.0 1836.1	3500 4000
^{60}Co	5.27 years	1173.2 1332.5	1500 1500

Appendix 3: Major γ- and X-ray Lines for Various Radionuclides

Nuclide	Type of Decay	Half-Life	Photon Energy (MeV)	Yield
Americium ^{241}Am	alpha	433 years	0.026	2.5%
			0.033	0.1%
			0.043	0.1%
			0.0595	35.9%
			0.012-0.022 (Np L X rays)	~40%
Antimony ^{125}Sb	beta	2.77 years	0.035	4.5%
			0.176	6.8%
			0.321	0.5%
			0.381	1.5%
			0.428	29.8%
			0.463	10.4%
			0.601	17.8%
			0.607	4.9%
			0.636	11.4%
			0.671	1.7%
			0.027-0.031 (Te K X rays)	~50%
Daughter ^{125m}Te		58 days	0.035	7%
			0.109	0.3%
			0.027-0.032 (Te K X rays)	~110%
Barium ^{133}Ba	electron capture	10.8 years	0.053	2.2%
			0.080	2.6%
			0.081	33.9%
			0.161	0.7%
			0.223	0.4%
			0.276	7.1%
			0.303	18.4%
			0.356	62.2%
			0.384	8.9%
			0.030-0.036 (Cs K X rays)	~120%
Barium ^{140}Ba	beta	12.8 days	0/014	1.3%
			0.030	14%
			0.163	6.2%
			0.305	4.5%
			0.424	3.2%
			0.438	2.1%
			0.537	23.8%
			0.602	0.6%
			0.661	0.7%
Cadmium ^{109}Cd	electron capture	462 days	0.022-0.026 (Ag K X rays)	67.7%
Daughter ^{109m}Ag		40 seconds	0.088	3.8%
			0.022-0.026 (Ag K X rays)	~34.5%
Cerium ^{144}Ce	beta	284.3 days	0.034	0.1%
			0.0~~40~~	0.4$
			0.053	0.1%
			0.080	15%
			0.134	10.8%
Daughter ^{144}Pr	beta	17 minutes	0.696	1.53%
			1.409	0.28%
			2.186	0.72%
Cesium ^{137}Cs	beta	30.17 years		
Daughter ^{137m}Ba		2.6 minutes	0.662	85.1%
			0.032-0.038 (Ba K X rays)	~7%

Nuclide	Type of Decay	Half-Life	Photon Energy (MeV)	Yield
Cobalt ^{56}Co	b$^+$ electron capture	78.0 days	0.511 0.847 0.977 1.038 1.175 1.238 1.360 1.771 2.015 2.035 2.599 3.010 3.202 3.254 3.273 3.452	Annihilation 99.97% 1.4% 14.0% 2.3% 67.6% 4.3% 15.7% 3.1% 7.9% 16.9% 1.0% 3.0% 7.4% 1.8% 0.9%
Cobalt ^{57}Co	electron capture	271.7 days	0.014 0.122 0.136 0.692 0.006-0.007 (Fe K X rays)	9.5% 85.5% 10.8% 0.16% ~55%
Cobalt ^{60}Co	beta	5.27 years	1.173 1.333	99.86% 99.98%
Europium ^{152}Eu	beta β^+ electron capture	13.3 years	0.122 0.245 0.344 0.411 0.444 0.779 0.867 0.964 1.086 1.090 1.112 1.213 1.299 1.408	28.2% 7.4% 26.3% 2.2% 3.1% 12.8% 4.1% 14.4% 10.0% 1.7% 13.6% 1.4% 1.6% 20.6%
Gold ^{198}Au	beta	2.696 days	0.412 0.676 1.088	95.45% 1.06% 0.23%
Iodine ^{125}I	electron capture	60.0 days	0.035 0.027-0.032 (Te K X rays)	7% 138%
Iodine ^{129}I	beta	1.57×10^7 years	0.040 0.030-0.035 (Xe K X rays)	7.5% ~69%
Iodine ^{131}I Daughter ^{131m}Xe	beta	8.04 days 12 days	0.080 0.284 0.364 0.637 0.723 0.164	2.4% 5.9% 81.8% 7.2% 1.8% 2%
Iron ^{55}Fe	electron capture	2.69 years	0.0059-0.0065 (Mn K X rays)	28%
Krypton ^{85}Kr Daughter ^{85m}Rb	beta	10.73 years 0.96 μsecond	 0.514	 0.43%

Nuclide	Type of Decay	Half-Life	Photon Energy (MeV)	Yield
Lanthanum ^{140}La	beta	40.27 hours	0.131	0.8%
			0.242	0.6%
			0.266	0.7%
			0.329	21%
			0.432	3.3%
			0.487	45%
			0.752	4.4%
			0.816	23%
			0.868	5.5%
			0.920	2.5%
			0.925	6.9%
			0.950	0.6%
			1.597	95.6%
			2.348	0.9%
			0.2522	3.3%
Lead ^{210}Pb	alpha	22.3 years	0.046	~4%
	beta		0.009-0.017 (Bi K X rays)	~21%
Manganese ^{54}Mn	electron capture	312.5 days	0.835	100%
			0.0055 (Cr K X rays)	~25%
Molybdenum ^{99}Mn	beta	66.2 hours	0.041	1.2%
			0.141	5.4%
			0.181	6.6%
			0.266	1.4%
			0.740	13.6%
			0.778	4.7%
			0.823	0.13%
			0.961	0.1%
Daughter ^{99m}Tc		6.02 hours	0.141	83.9%
Neptunium ^{237}Np	alpha	2.14×10^6 years	0.029	12%
			0.087	13%
			0.186	0.08%
			0.118	0.18%
			0.131	0.09%
			0.134	0.07%
			0.143	0.44%
			0.151	0.25%
			0.155	0.10%
			0.169	0.08%
			0.193	0.06%
			0.195	0.21%
			0.212	0.17%
			0.238	0.07%
Daughter ^{233}Pa		27.0 days	0.075	1.3%
			0.087	2.0%
			0.104	0.7%
			0.300	6.5%
			0.312	38%
			0.340	4.3%
			0.375	0.7%
			0.398	1.3%
			0.0416	1.7%
Plutonium ^{238}Pu	alpha	87.7 years	0.043	I.C.
			0.011-0.022 (U L X rays)	~13%
			0.094-0.115 (U K X rays)	$\sim 2.1 \times 10^{-4}$%

Nuclide	Type of Decay	Half-Life	Photon Energy (MeV)	Yield
Radium ^{226}Ra	alpha	1600 years	0.186	3.4%
Daughter ^{214}Pb	beta	26.8 minutes	0.053	I.C.
			0.242	6.7%
			0.295	16.9%
			0.352	32.0%
Daughter ^{214}Bi	alpha	19.8 minutes	0.273	5.3%
	beta		0.609	41.7%
			0.769	5.3%
			1.120	14.3%
			1.238	5.0%
			1.378	4.8%
			1.764	15.9%
			2.204	5.3%
	allpha	1.62×10^{-4}second	0.046	~4%
Daughter ^{210}Pb	beta		0.009-0.017 (Bi L X rays)	~21%
Ruthernium ^{106}Ru	beta	369 days		
Daughter ^{106}Rh	beta	30.4 seconds	0.512	20.6%
			0.616	0.7%
			0.622	9.9%
			0.874	0.4%
			1.050	1.5%
			1.128	0.4$
			1.562	0.2%
Sodium ^{22}Na	b$^+$	2.60 years	0.511	Annihilation
			1.275	99.95%
Technetium ^{99}Tc	beta	2.13×10^{5} years	0.089	6×10^{-4}%
Thallium ^{201}Tl	electron capture	73.1 hours	0.035	0.22%
			0.032	0.22%
			0.135	2.65%
			0.166	0.16%
			0.167	10.0%
			0.068-0.082 (Hg K X rays)	~95%
Thorium ^{228}Th	alpha	1.913 years	0.085	1.6%
			0.132	0.19%
			0.167	0.12%
			0.216	0.29%
Uranium ^{238}U	alpha	4.49×10^{9} years	0.048	I.C.
Daughter ^{234}Th	beta	24.1 days	0.030	I.C.
			0.063	5.7%
			0.092	3.2%
			0.093	3.6%
Daughter ^{234m}Pa	beta	1.17 minutes	0.043	I.C.
			0.767	0.2%
			0.810	0.5%
Daughter ^{234}Pa	beta	6.70 hours	1.001	0.6%
Daughter ^{234}U	beta	2.48×10^{5} years	0.053	0.1%
Xenon ^{133}Xe	beta	5.25 days	0.080	0.4%
			0.081	36.6%
			0.030-0.036 (Cs K X rays)	~46%
Zinc ^{65}Zn	β^+	243.8 days	0.345	
	electron capture		0.511	Annihilation
			1.115	50.7%
			0.008-0.009 (Cu K X rays)	~38%
Zirconium ^{95}Zr	beta	64.0 days	0.724	44.5%
			0.757	54.6%
Daughter ^{95m}Nb		86.6 hours	0.235	0.2%

Appendix 4: X-ray Critical Absorption and Emission Energies in keV

	Element	Kα1	Kα2	Kβ1	Kβ2	K_{ab}	Lα1	Lα2	Lβ1	Lβ2	Lγ1	L_{Iab}	L_{IIab}	L_{IIIab}	Mα	$M_{V(ab)}$
1 H	Hydrogen					0.014										
2 He	Helium					0.025										
3 Li	Lithium	0.052				0.055							0.003	0.003		
4 Be	Beryllium	0.110				0.112							0.002	0.002		
5 B	Boron	0.185				0.192							0.003	0.003		
6 C	Carbon	0.277				0.283							0.002	0.002		
7 N	Nitrogen	0.392				0.400							0.008	0.008		
8 O	Oxygen	0.525				0.531							0.009	0.009		
9 F	Fluorine	0.677				0.687										
10 Ne	Neon	0.849				0.874						0.048	0.022	0.022		
11 Na	Sodium	1.041		1.067		1.072						0.055	0.034	0.034		
12 Mg	Magnesium	1.253		1.295		1.303						0.063	0.050	0.049		
13 Al	Aluminum	1.486	1.486	1.553		1.559						0.087	0.073	0.072		
14 Si	Silicon	1.740	1.739	1.832		1.840						0.118	0.099	0.098		
15 P	Phosphorus	2.014	2.014	2.136		2.142						0.153	0.129	0.128		
16 S	Sulfur	2.308	2.306	2.464		2.470						0.193	0.164	0.163		
17 Cl	Chlorine	2.622	2.621	2.815		2.820						0.238	0.203	0.202		
18 Ar	Argon	2.957	2.955	3.192		3.203						0.287	0.247	0.245		
19 K	Potassium	3.313	3.310	3.589		3.608						0.341	0.297	0.294		
20 Ca	Calcium	3.691	3.688	4.012		4.038	0.341		0.344			0.399	0.352	0.349		
21 Sc	Scandium	4.091	4.085	4.460		4.496	0.395		0.399			0.462	0.411	0.406		
22 Ti	Titanium	4.510	4.504	4.931		4.964	0.452		0.458			0.530	0.460	0.454		
23 V	Vanadium	4.9452	4.944	5.427		5.464	0.511		0.519			0.604	0.519	0.512		
24 Cr	Chromium	5.414	5.405	5.946		5.9887	0.573		0.581			0.679	0.583	0.574		
25 Mn	Manganese	5.898	5.877	6.490		6.537	0.637		0.647			0.762	0.650	0.639		
26 Fe	Iron	6.403	6.390	7.057		7.111	0.705		0.717			0.849	0.721	0.708		
27 Co	Cobalt	6.930	6.915	7.649		7.709	0.776		0.790			0.929	0.794	0.779		
28 Ni	Nickel	7.477	7.460	8.264	8.328	8.331	0.851		0.866			1.015	0.871	0.853		
29 Cu	Copper	8.047	8.027	8.904	8.976	8.980	0.930		0.948			1.100	0.953	0.933		
30 Zn	Zinc	8.638	8.615	9.571	9.657	9.661	1.012		1.032			1.200	1.045	1.022		
31 Ga	Gallium	9.251	9.234	10.263	10.365	10.368	1.098		1.122			1.30	1.134	1.117		
32 Ge	Germanium	9.885	9.854	10.981	11.100	11.103	1.188		1.216			1.42	1.248	1.217		
33 As	Arsenic	10.543	10.507	11.725	11.863	11.867	1.282		1.317			1.529	1.359	1.323		
34 Se	Selenium	11.221	11.181	12.495	12.651	12.657	1.379		1.419			1.652	1.475	1.434		
35 Br	Bromine	11.923	11.877	13.290	13.465	13.475	1.480		1.526			1.794	1.599	1.552		
36 Kr	Krypton	12.649	12.597	14.112	14.313	14.323			1.638			1.931	1.727	1.675		
37 Rb	Rubidium	13.394	13.335	14.960	15.184	15.201	1.694	1.692	1.752			2.067	1.866	1.806		
38 Sr	Strontium	14.164	14.097	15.834	16.083	16.106	1.806	1.805	1.872			2.221	2.008	1.941		
39 Y	Yttrium	14.957	14.882	16.736	17.011	17.037	1.922	1.920	1.996			2.369	2.154	2.079		
40 Zr	Zirconium	15.774	15.690	17.666	17.969	17.998	2.042	2.040	2.124	2.219	2.302	2.547	2.305	2.220		
41 Nb	Niobium	16.614	16.520	18.614	18.951	18.989	2.166	2.163	2.257	2.367	2.462	2.706	2.467	2.374		
42 Mo	Molybdenum	17.478	18.373	19.600	19.964	20.002	2.293	2.290	2.395	2.518	2.623	2.884	2.627	2.523		
43 Tc	Technicium	18.410	18.328	20.608	21.012	21.054	2.424	2.420	2.538	2.674	2.792	23.054	2.795	2.677		
44 Ru	Ruthenium	19.278	19.149	21.646	22.072	22.117	2.558	2.554	2.683	2.836	2.964	3.236	2.966	2.837		
45 Rh	Rhodium	20.214	20.072	22.712	23.169	23.224	2.696	2.692	2.834	3.001	3.144	3.419	3.145	3.002		
46 Pd	Palladium	21.175	21.018	23.816	24.297	24.347	2.838	2.833	2.990	3.172	3.328	3.617	3.329	3.172		
47 Ag	Silver	22.162	21.988	24.942	25.454	25.517	2.984	2.978	3.151	3.348	3.519	3.810	3.528	3.352		
48 Cd	Cadmium	23.172	22.982	26.093	26.641	26.712	3.133	3.127	3.316	3.528	3.716	4.019	3.727	3.538		
49 In	Indium	24.207	24.000	27.274	27.859	27.937	3.287	3.279	3.487	3.713	3.920	4.237	3.939	3.729		
50 Sn	Tin	25.270	25.042	28.483	29.106	29.190	3.444	3.435	3.662	3.904	4.131	4.464	4.157	3.928		

	Element	Kα1	Kα2	Kβ1	Kβ2	K_{ab}	Lα1	Lα2	Lβ1	Lβ2	Lγ1	L_{Iab}	L_{IIab}	L_{IIIab}	Mα	$M_{V(ab)}$
51 Sb	Antimony	26.357	26.109	29.723	30.387	30.491	3.605	3.595	3.843	4.100	4.347	4.697	4.381	4.132		
52 Te	Tellurium	27.471	27.200	30.993	31.698	31.809	3.769	3.758	4.029	4.301	4.570	4.934	4.613	4.341		
53 I	Iodine	28.610	28.315	32.292	33.016	33.170	3.937	3.926	4.220	4.507	4.800	5.190	4.856	4.559		
54 Xe	Xenon	29.802	29.485	33.644	34.446	34.579	4.111	4.098	4.422	4.720	5.036	5.452	5.104	4.782		
55 Cs	Cesium	30.8970	30.623	34.984	35.819	35.983	4.286	4.272	4.620	4.936	5.280	5.720	5.358	5.011		
56 Ba	Barium	32.191	31.815	36.376	37.255	37.443	4.467	4.451	4.828	5.156	5.531	5.995	5.623	5.247		
57 La	Lanthenum	33.440	33.033	37.799	38.728	38.932	4.651	4.635	5.043	5.384	5.789	6.283	5.894	5.489		
58 Ce	Cerium	34.717	34.276	39.255	40.231	40.440	4.840	4.823	5.262	5.613	6.052	6.561	6.165	5.729	0.833	
59 Pr	Praseodymium	36.023	35.548	40.746	41.772	41.998	5.034	5.014	5.489	5.850	6.322	6.846	6.443	5.968	0.883	
60 Nd	Neodymium	37.359	36.845	42.269	43.298	43.571	5.230	5.206	5.722	6.090	6.602	7.144	6.727	6.215	0.929	
61 Pm	Promethium	38.687	38.160	43.945	44.955	45.207	5.431	5.408	5.956	6.336	6.891	7.448	7.018	6.466	0.978	
62 Sm	Samarium	40.124	39.523	45.400	46.553	46.846	5.636	5.609	6.206	6.587	7.180	7.754	7.281	6.721		
63 Eu	Europium	41.529	40.877	47.027	48.241	48.515	5.846	5.816	6.456	6.842	7.478	8.069	7.624	6.983	1.081	
64 Gd	Gadolinium	42.983	42.280	48.718	49.961	50.228	6.059	6.027	6.714	7.102	7.788	8.393	7.940	7.252	1.131	
65 Tb	Terbium	44.470	43.373	50.391	51.737	51.998	6.275	6.241	6.979	7.368	8.104	8.724	8.258	7.519	1.185	
66 Dy	Dysprosium	45.985	45.193	52.178	53.491	53.789	6.495	6.457	7.249	7.638	8.418	9.083	8.621	7.850	1.340	
67 He	Helium	47.528	46.686	53.934	55.292	55.615	6.720	6.680	7.528	7.912	8.748	9.411	8.920	8.074	1.293	
68 Er	Erbium	49.099	48.205	55.690	57.088	57.483	6.948	6.904	7.810	8.188	9.089	9.776	9.263	8.364	1.347	
69 Tm	Thullium	50.730	49.762	57.576	58.969	59.376	7.181	7.135	8.102	8.472	9.424	10.144	9.628	8.652	1.405	
70 Yb	Ytterbium	52.360	51.236	59.352	60.959	61.313	7.414	7.367	8.401	8.758	9.779	10.486	9.977	8.943	1.462	
71 Lu	Lutecium	54.683	52.959	61.282	62.946	63.306	7.654	7.604	8.708	9.048	10.142	10.867	10.345	9.241	1.521	
72 Hf	Hafnium	55.757	54.579	63.209	64.936	65.313	7.898	7.843	0.021	9.346	10.514	11.264	10.734	9.556	1.581	
73 Ta	Tantalum	57.524	56.270	65.210	66.999	67.400	8.145	8.087	9.341	9.649	10.892	11.676	10.130	9.876	1.644	
74 W	Tungsten	59.310	57.973	67.233	69.090	69.508	8.396	8.333	9.670	9.959	11.283	12.090	11.535	10.198	1.709	1.809
75 Re	Rhenium	61.131	59.707	69.298	71.220	71.662	8.651	8.584	10.008	10.273	11.684	12.522	11.955	10.531	1.774	
76 Os	Osmium	62.991	61.477	71.404	73.393	73.860	8.910	8.840	10.354	10.596	12.093	12.965	12.383	10.869	1.842	
77 Ir	Iridium	64.886	63.278	73.549	75.605	76.108	9.173	9.098	10.706	10.918	12.509	13.413	12.819	11.211	1.914	2.041
78 Pt	Platinum	66.820	65.111	75.736	77.866	78.379	9.441	9.360	11.069	11.249	12.939	13.873	13.268	11.559	1.978	2.122
79 Au	Gold	68.794	66.980	77.968	80.165	80.723	9.711	9.625	11.439	11.582	13.379	14.353	13.733	11.919	2.048	2.206
80 Hg	Mercury	70.821	68.894	80.282	82.526	83.113	9.987	9.896	11.823	11.923	13.828	14.841	14.212	12.285	2.120	2.295
81 Tl	Thallium	72.860	70.820	82.558	84.904	85.529	10.266	10.170	12.210	12.268	14.288	15.346	14.697	12.657	2.195	2.389
82 Pb	Lead	74.957	72.794	84.922	87.343	88.014	10.549	10.448	12.611	12.620	14.762	15.870	15.207	13.044	2.268	2.484
83 Bi	Bismuth	77.097	74.805	87.335	89.833	90.521	10.836	10.729	13.021	12.977	15.244	16.393	15.716	13.424	2.342	2.579
84 Po	Polonium	79.296	76.868	89.809	92.386	93.112	11.128	11.014	13.441	13.338	15.740	16.935	16.244	13.817	2.418	
85 As	Astatine	81.525	78.596	92.319	94.976	95.740	11.424	11.304	13.873	13.705	16.248	17.490	16.784	14.214		
86 Rn	Radon	83.800	81.080	94.877	97.616	98.418	11.724	11.597	14.316	14.077	16.768	18.058	17.337	14.618		
87 Fr	Francium	86.119	83.243	97.483	100.305	101.147	12.029	11.894	14.770	14.459	17.301	18.638	17.904	15.028		
88 Ra	Radium	88.485	85.466	100.136	103.048	103.927	12.338	12.194	15.223	14.839	17.845	19.233	18.481	15.442		
89 Ac	Actinium	90.894	87.681	102.846	105.838	106.759	12.650	12.499	15.712	15.227	18.405	19.842	19.078	15.865		
90 Th	Thorium	93.334	89.942	105.592	108.671	109.630	12.966	12.809	16.200	15.620	18.977	20.460	19.688	16.296	2.991	3.332
91 Pa	Protactinium	95.851	92.271	108.408	111.575	112.581	13.291	13.120	16.700	16.022	19.559	21.102	20.311	16.731	3.077	
92 U	Uranium	98.428	94.648	111.289	114.549	115.591	13.613	13.438	17.218	16.425	20.163	21.753	20.941	17.163	3.165	3.552
93 Np	Neptunium	101.005	97.023	114.181	117.533	118.619	13.945	13.758	17.740	16.837	20.774	22.417	21.596	17.614		
94 Pu	Plutonium	103.653	99.457	117.146	120.592	121.720	14.279	14.802	18.278	17.254	21.401	23.097	22.262	18.066		
95Am	Americium	106.351	101.932	120.163	123.706	124.876	14.618	14.411	18.829	17.677	22.042	23.793	22.944	18.525		
96 Cm	Curium	109.098	104.447	123.235	126.875	128.088	14.961	14.743	19.393	18.106	22.699	24.503	23.640	18.960		
97 Bk	Berkellium	111.906	107.023	126.362	130.101	131.357	15.309	15.079	19.971	18.540	23.370	25.230	24.352	19.461		
98 Cf	Californium	114.745	109.603	129.544	133.383	134.683	15.661	15.420	20.562	18.980	24.056	25.971	25.080	19.938		
99 Es	Einsteinium	117.646	112.244	132.781	136.724	138.067	16.018	15.764	21.165	19.426	24.758	26.729	25.824	20.422		
100 Fm	Fermium	120.598	114.926	136.075	140.122	141.51	16.379	16.113	21.785	19.879	25.475	27.503	26.584	20.912		

Appendix 5: Glossary

ACTIVE REGION The region of a detector crystal in which charge created by ionizing radiation contributes significantly to the output signal.

ADC (ANALOG TO DIGITAL CONVERTER) Electronic instrument that changes the magnitude of an analog signal to a digital form.

ALPHA PARTICLE (α) A helium nucleus, consisting of two protons and two neutrons.

ATOMIC NUMBER (Z) The number of protons in the nucleus of an atom (and therefore also the number of electrons in a neutral atom). It is specific for each element.

BACKGROUND RADIATION Ambient radiation from cosmic rays, radioactive materials in the detector surroundings, or any source other than the nuclide being measured.

BACKGROUND (PEAK) Photon counts in a peak which are not from the monoenergetic line of interest; consisting of background radiation, Compton scattering and degraded photons from higher-energy events.

BALLISTIC DEFICIT Peak broadening, especially at high count rates, when the charge collection time is long compared with the differentiating time constant of the electronics.

BANDGAP The energy difference between the bottom of the conduction band and the top of the valence band.

BETA PARTICLE (β) An electron emitted by a nucleus.

BIAS, DETECTOR Voltage applied to a detector to create an electric field which sweeps out the charge created by the ionizing radiation.

CHARGE COLLECTION TIME The time interval, after the passage of an ionizing particle, for the integrated current flowing between the terminals of the detector to increase from 10% to 90% of its final value.

CHARGE-SENSITIVE PREAMPLIFIER An amplifier, preceding the main amplifier, in which the output signal amplitude is proportional to the charge injected at the input.

COAXIAL DETECTOR A cylindrical crystal with a hole bored partially or completely through the crystal coaxial with its longitudinal axis. The outer surface of the crystal is one contact and the surface of the inner hole is the other.

COMPTON CONTINUUM Continuous electron energy distribution due to elastic scattering when a photon interacts with a bound electron.

COMPTON EDGE (CE) Compton scattering in which the photon is backscattered along its original path and maximum energy has been imparted to the electron.

COMPTON SCATTERING Elastic collision between an incident photon and a bound electron.

CRYOSTAT Vacuum enclosure which includes the end cap with the detector crystal, preamplifier, FET, and coldfinger by which the crystal is maintained at its operating temperature.

CRYOSTAT, DIPSTICK A cryostat whose vacuum is completely separate from that of the dewar.

CRYOSTAT, UNITARY A cryostat whose vacuum is integral with that of the dewar.

DEAD LAYER The layer in a semiconductor detector, often at the contact region, in which none of the energy lost by ionizing radiation contributes to the resulting signal.

DEAD TIME Time during which the electronics are busy processing pulses and no new pulses can be measured.

DECAY The disintegration of an unstable (radioactive) nucleus by spontaneous emission of particles and/or gamma rays.

DEPLETION REGION Region in which the mobile charge-carrier density is less than that needed to neutralize the net fixed donor/acceptor density; The active region of a semiconductor detector.

DMM See MULTIMETER.

EFFICIENCY, ABSOLUTE Ratio of the counts measured by the detector to the total counts emitted by the source during the same live time.

EFFICIENCY, INTRINSIC Ratio of the counts measured by the detector to the counts emitted by the source and actually falling on the detector window during the same live time.

EFFICIENCY, RELATIVE Ratio of the counts measured by the detector to the counts measured by a NaI(Tl) scintillation counter for the same source, geometry, and live time.

ELECTRON A subatomic particle with -1 charge and negligible mass, which revolves around the nucleus in discrete energy levels. In a neutral atom, the number of electrons is equal to the number of protons in the nucleus.

ELECTRON VOLT (eV) Basic unit for measuring the energy of interactions in semiconductor detectors. It is the energy gained by an electron passing through a potential difference of 1 volt.

ELECTRON-HOLE PAIR The product of the interaction of a photon within a semiconductor crystal. An electron is freed and a positively charged “hole” remains. The electron and the hole migrate toward opposite terminals in an electric field.

ENERGY COUNT-RATE PRODUCT LIMIT The highest product of energy and count rate (MeV•cps), in a preamplifier dc-coupled to a detector, which causes no more than a specified fraction (1%) of the pulses to overload the preamplifier.

FANO FACTOR A modification to the Poisson relationship to account for the variance in the number of electron-hole pairs produced in a semiconductor detector.

FULL-WIDTH HALF MAXIMUM (FWHM) Width of a peak at half its maximum height (at the peak centroid); used as a measure of resolution. (See page 8.)

FULL-WIDTH TENTH MAX (FWTM) and FULLWIDTH FIFTIETH MAX (FWFM or FW.02M) The width of the peak at one-tenth and one-fiftieth, respectively, of its full height. FWHM/FWTM and FWHM/FW.02M ratios are used as a measure of peak shape (page 14).

GAMMA RAY Electromagnetic radiation of nuclear origin, with wavelengths of 10^{-9}-10^{-12}cm (energy range of 3 keV-40 MeV).

GEOMETRY, DETECTOR The physical configuration of the detector and sample (size, sample-to-detector distance, angle) which determines what fraction of photon events actually reach the crystal.

HALF LIFE The time required for half of a given number of radioactive atoms to decay.

HIGH-PURITY GERMANIUM (HPGe) Germanium with a net electrically active, uncompensated defect concentration (impurity) level on the order of 10^9-10^{10} parts/cm^3.

INTRINSIC GERMANIUM (IG) Older designation for HPGe.

INTRINSIC REGION Region of a semiconductor crystal having equal numbers of free holes and electrons.

ION IMPLANTATION Process of embedding ions into the surface of a solid by irradiation with a beam of energetic ions; often used to create one of the contacts for a semiconductor detector.

IONIZING RADIATION Gamma rays or alpha or beta particles which interact with matter to produce ions, either directly or indirectly.

ISOTOPES, RADIOISOTOPES Atoms with the same atomic number but different atomic weight, i.e., a different number of neutrons in the nucleus; if the proton/neutron ratio is unstable, it is a radioisotope which undergoes some kind of spontaneous decay to a more stable configuration.

JUNCTION Transition boundary between regions of different electrical properties in a semiconductor or between a semiconductor and a metal.

LEAKAGE CURRENT Total current flowing through or across the surface of a detector crystal with operating bias applied and no external ionizing radiation.

LITHIUM-DRIFTED SILICON (Si(Li)) Silicon crystals which have been counter-doped with Li ions, by the process called lithium drifting, to achieve the required impurity level for use as a semiconductor detector.

MARINELLI RE-ENTRANT BEAKER A specially designed beaker that fits over a coaxial detector endcap so that the sample essentially surrounds the detector (see page 12); useful for the analysis of low-activity samples.

MCA Multichannel analyzer; an electronic device for sorting and counting detected photons; signal pulses are stored in memory as a function of their analog amplitude.

MASS NUMBER (A) The sum of the protons and neutrons in the element nucleus, i.e., atomic weight of an element.

MICROPHONICS Electrical noise due to mechanical or audio vibration in the detector assembly.

MULTIMETER, DIGITAL (DMM) A measuring instrument used to measure voltage, resistance or current during troubleshooting or system setup.

NEUTRON Particle with no charge and a mass of 1, found in the nucleus.

NOISE, ELECTRICAL Unwanted disturbance in an electrical signal which obscures the desired information in the signal.

NUCLIDE See ISOTOPE.

PAIR PRODUCTION Interaction of ionizing radiation with matter which produces an electron -positron pair.

PEAK (SPECTRAL LINE) Sharply peaked portion of a spectrum, usually representing the full energy peak of a monoenergetic X ray or gamma ray.

PEAK-TO-BACKGROUND RATIO Ratio of the counts in a peak to the counts in the adjacent background region.

PHOTOELECTRIC EFFECT Interaction of ionizing radiation with matter in which the full energy of the photon is imparted to an atom which ejects an electron whose energy is equal to that of the incoming photon less the binding energy of the electron.

PHOTON A discrete packet of energy; a quantum.

P-I-N DIODE A detector with an intrinsic or nearly intrinsic region between a p- and an n-region.

POSITRON Antimatter equivalent of an electron, with +1 charge and nearly 0 mass; it annihilates with an atomic electron to produce two 0.511 MeV photons.

PREAMPLIFIER A charge sensitive amplifier which provides the first step in the amplifier chain of a semiconductor detector; to cut down on noise, the input FET is located in the cryostat as close to the crystal as possible.

PREAMPLIFIER, PULSED OPTICAL FEEDBACK A preamplifier in which the charge is induced on the feedback capacitor in a stepwise fashion; the capacitor is periodically reset by a light pulse.

PREAMPLIFIER, RESISTIVE FEEDBACK A preamplifier whose capacitor is reset after each pulse by an RC feedback loop.

PREAMPLIFIER, TRANSISTOR RESET A preamplifier, essentially similar to a pulsed-optical preamp, in which the charge on the feedback capacitor is drained off by a transistor.

PROTON Nuclear particle with charge +1 and mass 1; the atomic number Z is the number of protons in the nucleus.

PULSE PILE-UP The arrival of a second signal pulse before the transient response of the preceding pulse has decayed to a negligible value, thus preventing measurement of the second pulse.

RADIOACTIVITY Nuclear transformation by spontaneous decay (with emission of gamma rays or alpha or beta particles) to achieve a stable proton/neutron ratio in the nucleus.

RESET TIME In a preamplifier, the time required to drain the charge from the feedback capacitor.

RESOLUTION Ability of a detector system to discriminate between peaks (spectral lines) close to one another in energy; the narrower the peaks, the better the resolution. FWHM is used as a measure of resolution.

RISE TIME For the output pulse of a preamplifier, this is the time interval between 10% and 90% of the pulse height; for a sufficiently fast preamp, it is approximately equal to the charge collection time.

SCINTILLATION DETECTOR Detector in which radiation impinging on a phosphor produces a pulse of light, which is converted to an electrical signal by a photomultiplier tube.

SEMICONDUCTOR DETECTOR A detector with a p-i-n diode structure in which radiation produces excess free carriers that are used to detect and measure the incident radiation.

SPECTRAL LINE Sharply peaked portion of the spectrum which is characteristic of the incident radiation, usually the full energy peak for that photon.

WELL DETECTOR A coaxial detector in which the endcap has a well extending into the inner electrode and into which sample is placed; the crystal nearly surrounds the sample, which may be very small.

X RAYS Photons in the energy range between visible light and gamma rays.

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