G-M Pancake Detectors:

Everything You've Wanted to Know (But Were Afraid to Ask)

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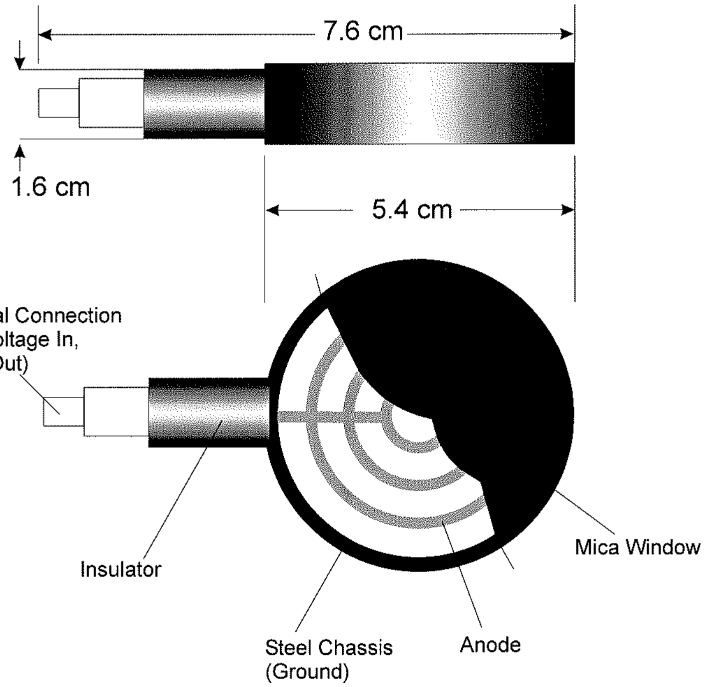


Figure 1. *Schematic of a pancake G-M tube.*

Introduction

The G-M "pancake" detector is probably the closest thing available to a "universal" radiation detector. It is relatively inexpensive, can detect alpha, beta, and gamma radiation, and is simple to use. As such, it is one of the most commonly purchased and used radiation detectors. G-M pancake detectors can be found in virtually all facilities where radioactive materials are used, from commercial nuclear reactors to hospitals and from research institutions to machine shops. However, limitations apply to this detector that are all too often misunderstood or ignored. This article, then, will discuss all the "ins and outs" of the G-M pancake detector that may be of practical interest to the RSO.

Operating Principles

The G-M counter is one of the oldest radiation detector types in existence. It was introduced by Hans Geiger and Walter Müeller in 1928, hence the abbreviation "G-M." (Note: If a person refers to a G-M counter or detector as a "Geiger counter," it immediately pegs him or her as a nuclear novice.)

In its simplest form, a G-M tube consists of a sealed metallic tube (usually steel) filled with a counting gas. A counting gas is one that ionizes by releasing an electron when a particle or photon interacts with it. A small wire or plate (called the anode or positive terminal) is suspended in the center of the tube, electrically insulated from the case. A high voltage is applied between the anode and the cylinder wall (called the cathode, or negative terminal). If the voltage is sufficiently high, any radiation that interacts with the gas will produce an electronic pulse, which can then be recorded by a counting instrument. (See the G-M region of the six-region curve shown on page 16 for more information on how voltage affects the operation of all gas-filled radiation detectors).

In all G-M detectors, essentially every gas molecule is ionized, so the size of this pulse will be the same regardless of the energy of the radiation that caused the pulse. For this reason, G-M detectors cannot electronically distinguish between alpha, beta, and gamma radiation and no isotopic identification can be performed directly.

Construction

Although the G-M tube has evolved over the years, the fundamental design has remained unchanged. The sizes and shapes of G-M tubes, and formulations of the counting gasses used are changed to optimize G-M tubes for specific applications. The G-M pancake is one such optimization.

The shape of the tube itself is the reason for the nickname "pancake" detector. At about 2 inches across and only a little more than a half-inch thick, it does bear some resemblance to a small but thick pancake. The term is also suitable for distinguish-ing it from the other common type of G-M tube, the "hot dog." On the active "face" of the G-M pancake tube a thin layer of mica is substituted in place of steel. Due to the lower density and thickness of mica compared to the steel case, this "window" allows the passage of most alpha and beta particles into the counting region of the tube where they can interact with the counting gas and be detected. Only the lowest energy alphas and betas are stopped. See Figure 1 for a schematic drawing of a typical G-M pancake tube.

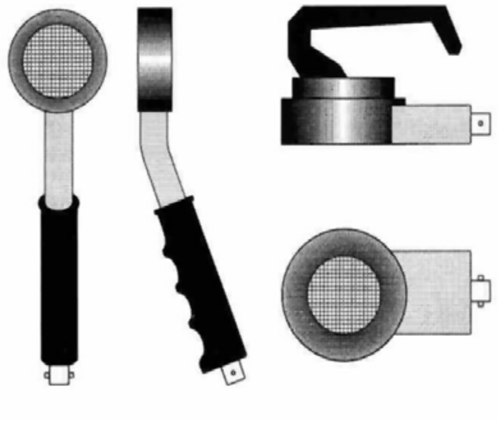


Figure 2. *Typical "spatula" and "back-shielded" G-M probes.*

G-M pancake tubes can be purchased from at least three manufacturers in the United States: OOB Detectors, LND Detectors, and the Nuclear Research Corporation. Several other companies also sell these tubes. Most manufacturers' G-M pancake tubes are, effectively, interchangeable.

Virtually all instrument manufacturers sell one or more detectors that utilize a pancake G-M tube. For example, Ludlum Measurements sells the 44-9, Bicron sells the PGM probe, and Thermo Electron Corporation sells the HP-260. These typically consist of a flat cylinder that houses the tube and a smaller cylindrical handle that extends off at a slight angle.

G-M pancake tubes are also used in other configurations, including back-shielded probes (to reduce background in personnel frisking) and in sample counters. Figure 2 shows drawings of some typical G-M pancake detector configurations. It must be used, of course, in conjunction with a count-rate meter.

Another configuration for pancake G-M detectors becoming increasingly common is that of an integrated unit. In these both the detector, electronics, and display are included in the same relatively small case. This configuration was pioneered most successfully by SE International with their *Inspector*, and later copied by Ludlum Measurements and others.

Beta Response

The primary purpose for which the G-M pancake is intended is the detection of surface contamination from beta-emitting isotopes such as ^{14}C, ^{32}P, and ^{35}S. As such, it should be used with an instrument with a cpm scale. The mica window has a density thickness of about 1.4 to 2.0 mg/cm^2, so any beta particle must be in excess of about 60 keV to be able to penetrate the window and be detected in the counting gas.

A different *efficiency* for each isotope will be noted, however. Efficiency is the number of ionization events or “counts” the detector registers for each actual disintegration that occurs in the source, and is expressed as a fraction of counts per disintegration. Efficiency is determined as shown in this equation:

$$\text{Efficiency} = \frac{\text{cpm}_{\text{source}} - \text{cpm}_{\text{background}}}{\text{dpm}_{\text{source}}}$$

So, if my G-M pancake detector has a background of 50 cpm and I have a source that has a certified activity of 34,000 dpm and reads 6000 cpm on my meter, the efficiency is:

$$= \frac{6000\text{ cpm} - 50\text{ cpm}}{34{,}000\text{ dpm}}$$

$$= \frac{0.175\text{ counts}}{\text{disintegration}}$$

$$= 17.5\%$$

Several things affect the observed efficiency. The first is geometry, or the shape of the radioactive material being measured and the angles at which the radiation is emitted compared to the size (i.e., area), shape, and configuration of the detector. Imagining a small (i.e., small relative to the size of the detector) beta check source, the beta particles will be emitted more-or-less evenly about a 360° solid angle (i.e., 4π steradian). If the G-M pancake detector is placed against this source, however, only half of the beta particles (at best) will be emitted in the direction of the detector, making the G-M pancake a “2π” detector. Assuming that only one beta particle is emitted for each disintegration, then the best possible and theoretical maximum efficiency is 0.50 counts/disintegration or 50%.

Other geometry factors that interfere with the quantification of radioactive material occur as the size of the source of radiation increases to equal or exceed the size of the detector. These are beyond the scope of this article, but are discussed in some detail in NCRP 112.[1]

Instrument manufacturers will often advertise a detector's efficiency in a 2π steradian, making it appear that their detector is twice as efficient as it really is. In comparing two like detectors from different manufacturers, be sure to check whether efficiencies for both are presented in the same geometry. Similarly, if you see an instrument advertised with efficiency given in a 2π steradian, be sure to divide that efficiency in half for an approximation of the efficiency you will actually be able to use.

Another factor that will affect efficiency is the *energy* of the radiation being detected. For the moment, we will deal only with beta particles that are emitted over a range from zero to some maximum energy (measured in kilo electron volts, or keV) that is specific to each particular isotope. Once a beta particle is emitted, it begins to lose its kinetic energy as it travels by interacting with air molecules, the protective screen covering the detector, and the mica window of the G-M pancake tube.

Only after passing through these barriers and entering the interior of the tube can the beta particle interact with the counting gas and be detected. The tritium (or ^{3}H) beta has a maximum energy of 18.6 keV; it can only travel 1/6 of an inch in air. It *cannot* penetrate the mica window of a G-M pancake detector. Even though tritium is a pure beta emitter, the efficiency of all G-M pancake detectors for tritium is exactly zero, regardless of how much tritium may be present.

It is interesting to note that occasionally a manufacturer will advertise a G-M pancake as having an "intrinsic efficiency of nearly 100%." This is true, but it only means that once the beta particle *has entered the G-M tube* it will almost certainly be counted. It can be understood, then, that the greater the energy of the particle, the more likely it is to penetrate the barriers and make it into the active region of the tube to be detected.

For all practical purposes, ^{14}C is the lowest energy beta emitter that can be quantified with a G-M pancake detector. The maximum energy (E_{max}) of the ^{14}C beta is 156 keV, and a typical efficiency with a G-M pancake detector is about 4%. One of the highest energy common beta emitters is ^{90}Sr-^{90}Y (^{90}Y E_{max} = 2,281 keV), for which the typical efficiency is around 20%.

(Since ^{90}Sr and ^{90}Y are in secular equilibrium it can get complicated expressing efficiency. I double the reported "one isotope" activity to account for the presence of the other and *always* refer to it as ^{90}Sr-^{90}Y or ^{90}Sr/Y. The reported efficiency ends up being the roughly average of the two isotopes, weighted a bit in favor of the ^{90}Y.)

It turns out that the efficiency is proportional to the maximum beta energy in a reasonably regular linear fashion, as can be seen in Figure 3. It should be noted that there is a "top end" to observed efficiency. The efficiency for a G-M pancake detector will generally never exceed 25 or 30%, regardless of the particle energy.

If efficiencies for two isotopes with different maximum energies are known, the efficiency for a third isotope with an E_{max} between the first two can be approximated by linear interpolation. It is always best (though not always possible) to determine efficiency with a calibration source of the exact isotope that you will be trying to detect.

The final major influence on efficiency is the distance between the calibration source and the detector. For example, if an efficiency is determined with the source at 1 cm from the detector (as is common in calibrations), then the activity determined for a spot of contamination measured with the detector in contact with the surface will result in an overestimate of the quantity of radioactive material spilled.

Going the other way, if efficiency is determined with the calibration source *in contact* with the detector and the detector is used to count swipes in a constant-geometry holder which puts some small *distance* between the detector and the swipe, an underestimate of the activity present will occur. The point is that you must determine a detector's efficiency in the same way that the detector will be used "in the field."

A good rule of thumb is to calibrate *and* count at a distance of 1 cm from the window of the detector. Calibrating and counting with the source "in contact" with the entry window should not be done.

Alpha Response

It seems to be commonly overlooked or forgotten that G-M pancake detectors can also detect alpha particles with energies greater than 3 MeV (mega electron volts), which includes most common alpha emitters. Efficiency for alpha particles is about 15%; there is much less variation in efficiency based on differing energies for alpha particles than for beta particles. There is still no method, however, for electronically differentiating between alpha and beta activity. Any measurement made will include beta plus alpha.

Gamma Response

G-M pancake detectors are sensitive to gamma and x radiation, but they are not generally preferred for assessing exposure rates, i.e., in units of mR/h or µR/h. Due to the shape of the tube and the fact that the density and thickness of the walls of the tube are irregular (the mica window on one side, the heavy steel case on the other), the response to a gamma or x-ray field will be dependent on the orientation of the detector in that field. Informal testing in our calibration laboratory has demonstrated that this effect is not huge.

Another factor concerning G-M pancake response to gamma and x radiation is the fact that it is extremely dependent on the energy of the radiation. Figure 4 shows a typical G-M pancake "energy-response curve." Exposure-rate instruments are normally calibrated to ^{137}Cs (primary gamma energy 662 keV), so that point on the curve is at a relative response of "1." Were you to use this detector to survey an x-ray machine with an x-ray energy of 50 keV, the detector would indicate an exposure rate 450% greater than was actually there, due to the over response of G-M detectors to low-energy photons.

So, although G-M pancake detectors should not be used to quantify gamma or x-ray fields, the last example does suggest an application. The relatively large surface area of the G-M pancake tube and the over-response to lower photon energies, make it a good choice to *survey* x-ray

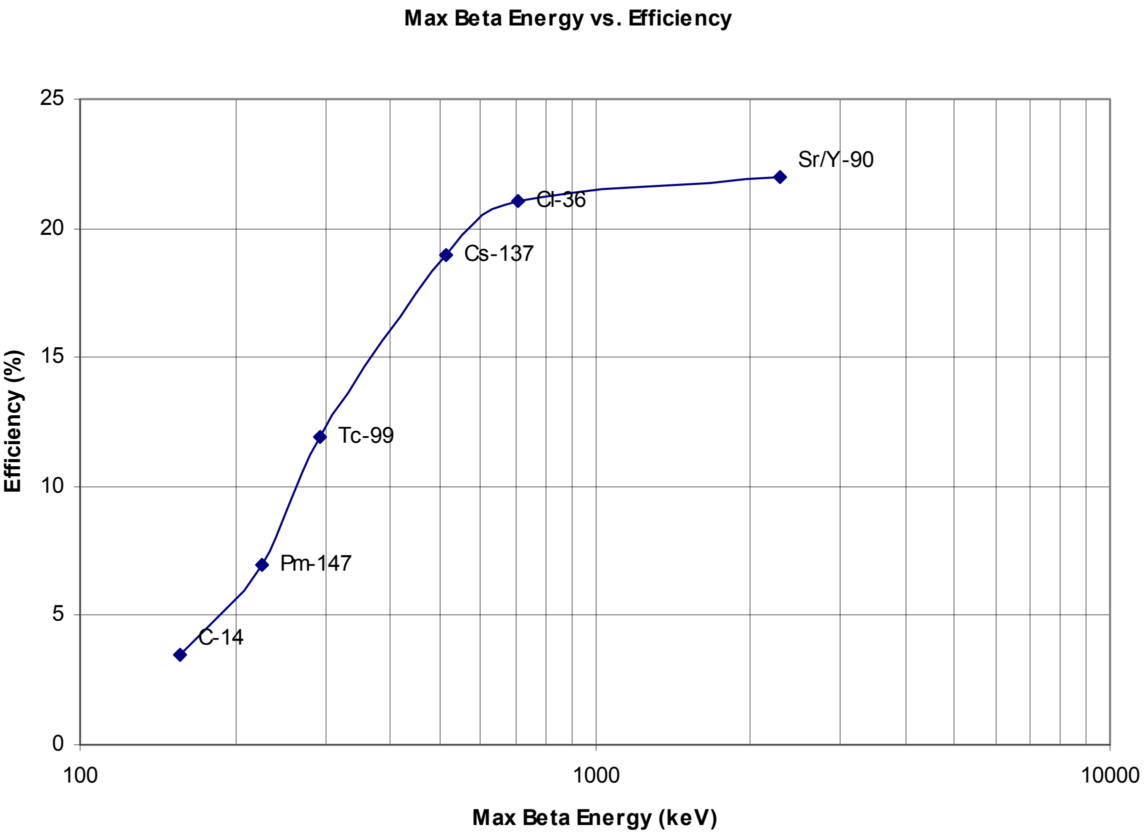


Figure 3. *Beta particle energy vs. efficiency for a G-M pancake detector.*

machines for leakage; if any is found, another instrument can be used to then *quantify* that leakage.

People often ask if G-M pancake detectors can be used for ^{125}I. The answer is generally not. The *efficiency* for gamma radiation remains quite low. The over-response discussed above is only relative to other gamma energies. Measured efficiency for ^{125}I is far less than 1%.

ResponseTime

On a count-rate instrument, the meter needle indicates an instantaneous integrated average of the signal from the detector. The amount of time over which the instrument averages the count rate is the "response time." Response time is also defined as the "time interval required for the instrument reading to change from 10% to 90% of the final reading (or vice-versa) following a step change in the radiation field at the detector." Many instruments have a switch for going between "fast" and "slow" response times.

On fast response, the interval over which the count rate is average is relatively short. Therefore, the needle will respond quickly to a change in the radiation being measured. Due to the random nature of radioactive decay, however, the needle will not remain steady enough to get a "good reading" of the meter. Using slow response, on the other hand, averages the count rate over a longer period of time so a much steadier needle will be observed. However, it will also take substantially longer (up to 25 seconds) for the instrument to respond to a change in the radiation being measured.

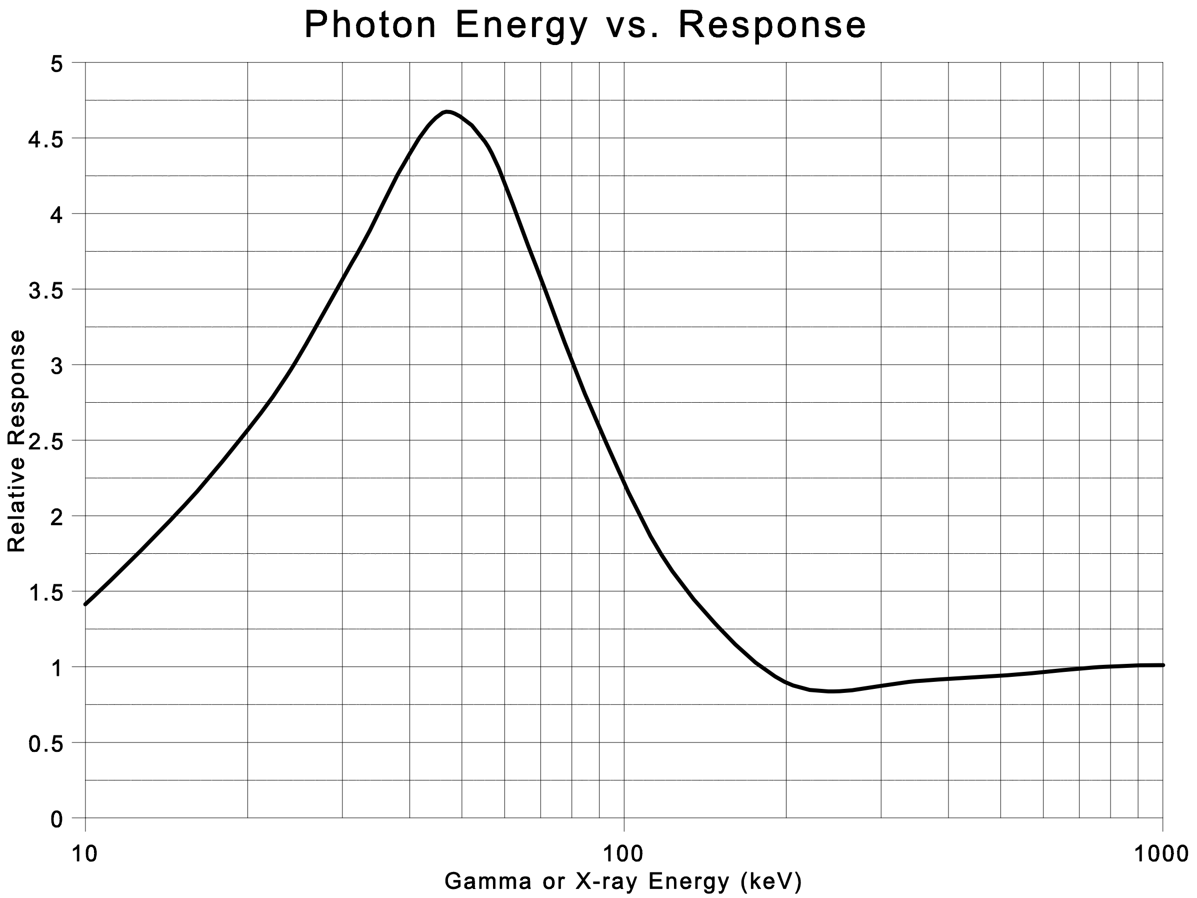


Figure 4. *Typical G-M pancake energy response curve.*

Dead Time and Saturation

When a beta particle (or alpha particle or photon) interacts with the counting gas in a G-M pancake detector, virtually every atom of the counting gas within the tube is temporarily ionized. In takes a length of time on the order of about 200 microseconds for the gas atoms to recombine with electrons and return to ground state. Until a sufficient number of gas atoms have recombined with electrons, it is not possible for another beta particle (or alpha particle or photon) to start a Geiger discharge large enough to be measured by the count-rate meter. This amount of time during which the G-M pancake detector is incapable of registering another event is referred to as "dead time."

Dead time does not significantly affect G-M pancake detectors at relatively low counting rates (say, less than 50,000 cpm). At relatively high count rates (say, 300,000 cpm), efficiency may be as little as half that found for a lower count rate. See Figure 5 for a graph showing count rate versus efficiency for a G-M pancake detector using a ^{137}Cs source. This is the reason that many count rate instruments have 50,000 cpm as the top end of the highest range. Compensation for this dead time loss can be performed in a number of ways.

One common way to compensate for dead time loss is to determine instrument efficiency during calibration for your isotope of interest over a range of activities. A chart or graph of instrument efficiency versus count rate can be affixed to the

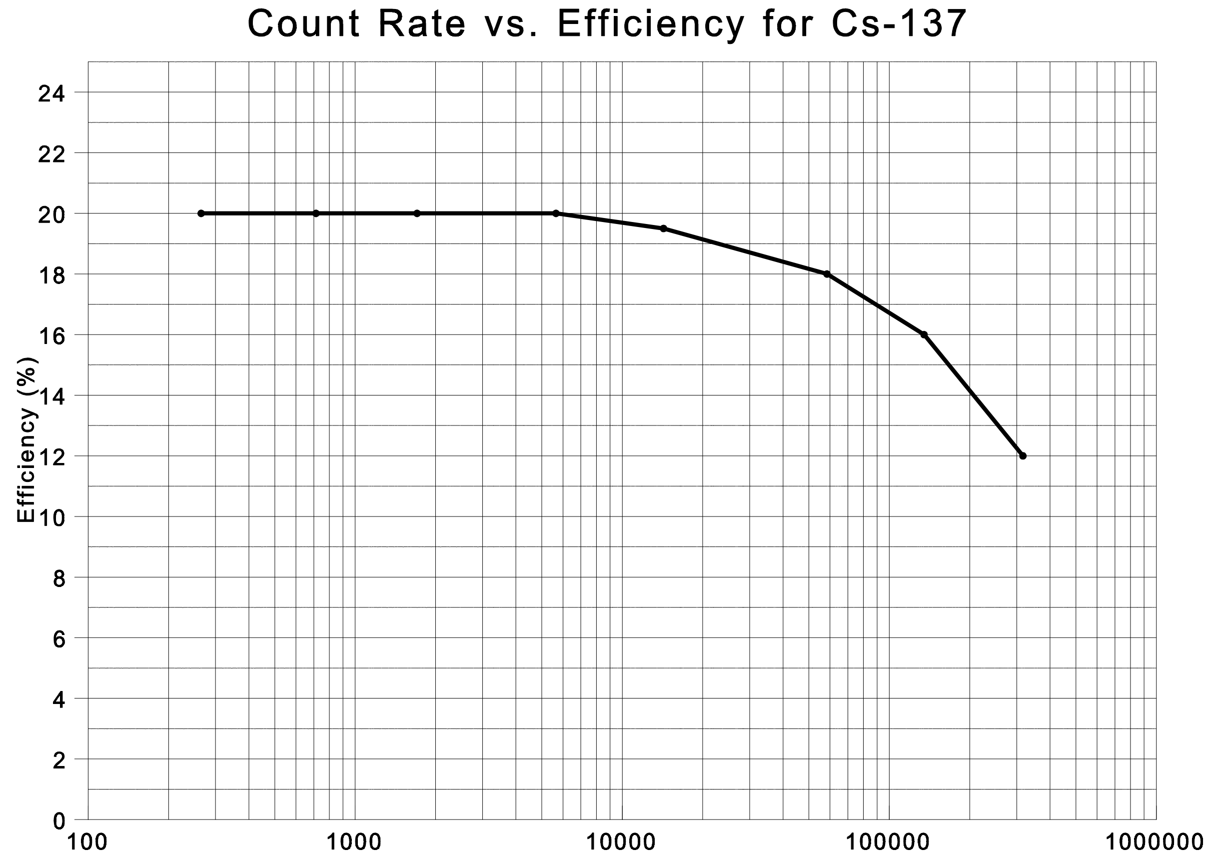


Figure 5. *Count rate vs. efficiency for a G-M pancake detector using* ^{137}*Cs.*

instrument or kept with the calibration documentation. Alternately, many instrument manufacturers offer count rate instruments for use with G-M pancake detectors that are electronically "dead-time compensated." For many facilities, however, the expense of this type of meter, and a more complex calibration, cannot be justified. In general, if you do not have the need to accurately quantify fairly high-activity surface contamination, dead-time compensation need not be a great concern.

In the event that your instrument may be subject to very high count rates, another phenomenon called saturation should be understood. Saturation occurs when the time between each ionizing event is much less than the dead time; the counting gas is essentially kept in an ionized state. The result of this is that in high radiation fields G-M pancake detectors will read zero. Some instruments are available that signal the user of saturation by a light, audible alarm, or some other indication. Saturation of G-M pancake detectors typically occur at around 1,000,000 cpm. Some types of G-M tubes (especially older ones) may be damaged if exposed to saturation levels of radiation, especially for extended periods of time.

Calibration

Calibration must be performed periodically. This is usually every year, but for some licensees may be more frequent. The instrument should be calibrated with the exact detector with which it will be used. Calibrations should also be performed if any substantial repairs are made to the instrument, such as replacing the G-M detector tube or replacing a transformer. Replacing batteries or a cable of the same length *do not* constitute substantial repair and so do not require re-calibration.

Calibration of an instrument with a G-M pancake detector should consist of three parts. The first, often called pre-calibration, is a check to ensure all the parts of the instrument are mechanically sound and in good enough operating condition to continue with the calibration.

Included in the pre-calibration are a contamination survey of the instrument, a check that the meter is mechanically zeroed, making sure the battery check indicator works properly and that batteries are properly installed, that the audio indicator is working, that the different instrument response times are functioning, and that high voltage is being generated. A "precision check" should also be performed to ensure that the instrument and detector are at least performing "reproducibly."

The next part is the electronic calibration. In this, an electronic pulse generator is used to input pulses at a known rate into the count rate meter. The meter response is then adjusted to accurately reflect the incoming pulse rate. This should be performed at two points on each scale (e.g., H1, H10, etc.), at approximately 20% and 80% of full scale. This is the portion of the calibration where the major adjustments are made (if needed). It is called electronic calibration because the detector is not used in this step; electronic pulses are substituted.

In the final calibration step, the detector is again hooked up to the count rate meter and used to determine efficiency or efficiencies. The source used in efficiency determination should ideally be of the isotope or isotopes that are present at your facility, with activities in the range of what you would expect to need to quantify. Alternately, an efficiency-versus-beta energy chart similar to Figure 3 can be developed. Ideally, the physical size of the calibration source should approximate the size of the samples or surfaces the detector will be used for. For example, if you mostly use the detector to count 1.75-inch diameter wipe samples, then 1.75-inch diameter calibration sources would be best.

Note that an electronic calibration alone is not sufficient to satisfy regulatory requirements. A calibration *must* include exposure of the detector to a known source and activity of radioactive material.

Use of G-M Pancake Detectors

When “frisking” a surface, care must be taken not to move the detector so fast that it and the count rate meter are not able to indicate the presence of contamination. Scanning speed should be no more than about two inches, or one detector width, per second. The detector should be held as close to the surface being assessed as practical (e.g., 1 cm) but without touching it, to gain the maximum sensitivity while not contaminating the detector.

Frisking should always be performed with the audible indicator “on” so you don't necessarily have to be looking at the meter to notice an increase in the count rate. The instrument response time should be on “fast” when frisking in order to get the quickest needle response to contamination. The response time should be changed to “slow” when quantifying activity (i.e., measuring as opposed to frisking) in order to get the most accurate average of the count rate.

It has been stated previously that there is no electronic method which can be used with a G-M probe to discriminate between different beta-emitting isotopes. If, however, a spot of contamination is found with a G-M pancake detector and there is only a very short list of potential isotopes, it is possible to determine whether the isotope is a lower-energy beta emitter (i.e., ^{14}C or ^{35}S) or not. If a piece of plastic about the thickness of a credit card or driver’s license is placed between the contamination and the detector, and the count rate drops off to background, the isotope is probably ^{14}C or ^{35}S. If counts in excess of background are still observed through the credit card shield, then it is a higher-energy beta emitter.

Surface contamination is expressed in activity per unit area. The active area of a G-M pancake detector is about 15 cm^2.

Activity per detector area is defined as:

$$= \frac{\mathrm{cpm}_{\mathrm{measured}} - \mathrm{cpm}_{\mathrm{background}}}{\mathrm{efficiency}}$$

$$= \frac{\mathrm{activity}}{15\ \mathrm{cm}^2}$$

For example, if I find a spot of ^{14}C contamination that reads 200 cpm, and my background is 50 cpm and my detector is 3.7% efficient for ^{14}C, the activity is:

$$= \frac{200\ \mathrm{cpm} - 50\ \mathrm{cpm}}{0.037\,\frac{\mathrm{counts}}{\mathrm{disintegration}}}$$

$$= 4054\ \mathrm{dpm}/15\ \mathrm{cm}^2$$

Limits for surface contamination, however, are typically given in units of dpm/*100 cm^2*. A factor can be added to the equation to convert the area to 100 cm^2, as shown by:

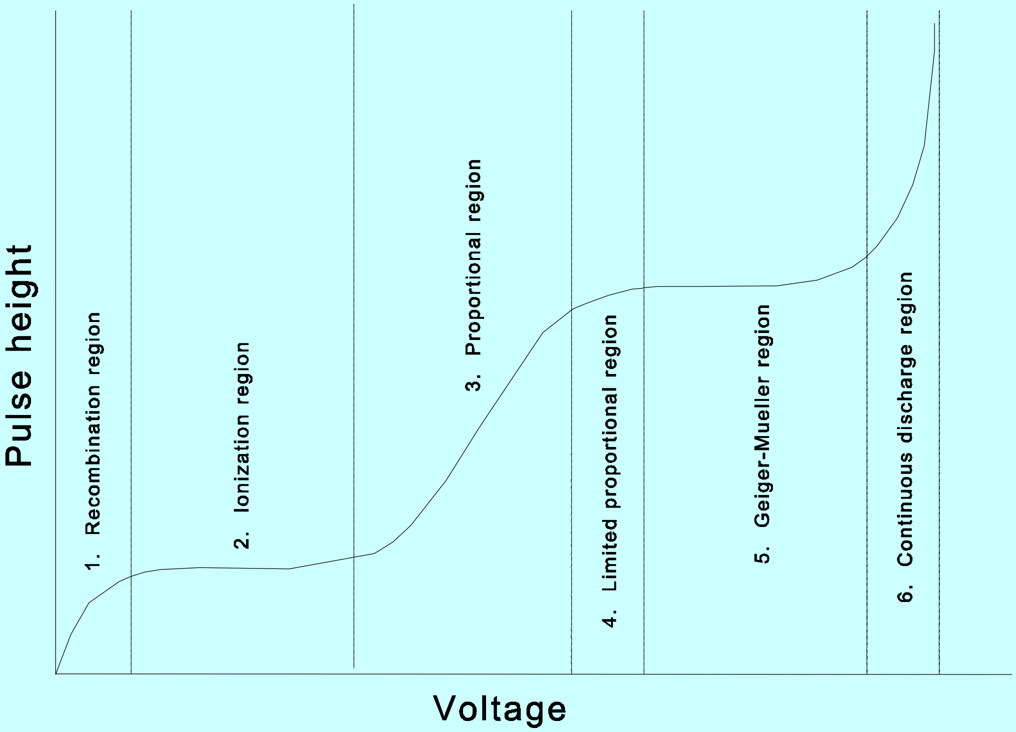
$$= \frac{\mathrm{cpm}_{\mathrm{measured}} - \mathrm{cpm}_{\mathrm{background}}}{(\mathrm{efficiency})\left(\frac{\mathrm{detector\ area}}{100}\right)}$$

$$= \frac{\mathrm{activity}}{100\ \mathrm{cm}^2}$$

Using the parameters from this example, activity per 100 cm^2 would be:

$$\frac{200\ \mathrm{cpm} - 50\ \mathrm{cpm}}{\left(0.037\,\frac{\mathrm{counts}}{\mathrm{disintegration}}\right)\left(\frac{15\ \mathrm{cm}^2}{100}\right)}$$

$$= 27{,}027\ \mathrm{dpm}/100\ \mathrm{cm}^2$$



The Six-Region Curve for Gas-Filled Detectors

All gas-filled detectors (including G-M pancake detectors) detect radiation with different characteristics based on the relative applied voltage between the anode and the cathode. Ion chambers, which respond evenly to different energies of radiation, operate in the second region of the curve. Relatively low efficiency is characteristic of this region. As the detector operating voltage is increased, the detector enters the proportional region (region 3), where pulse height is proportional to the energy of the photon or particle that initiated the pulse. Proportional detectors, therefore, can discriminate between different energies of radiation by analyzing the pulse height. As the detector operating voltage continues to increase, the limited proportional region (region 4) is passed through and enters into region 5, the Geiger-Mueller region. In this region all pulse heights are equal and efficiency is relatively high, although counting efficiency will vary based on energy. Finally, the continuous discharge region is entered where the voltage is so high that arcing occurs between the electrodes.

Individual detectors, such as the G-M pancake, are designed to perform optimally in some specific region of this curve. So, while all of these regions can be observed in any gas-filled detector, typically only one will be of any practical use for each specific detector.

G-M Pancake
"Do's" and "Don'ts"

DO

☐ Calibrate with proper energy source(s)

☐ Source-to-source distance = 1 cm to calibrate and measure

☐ Use "fast" response when searching for contamination

☐ Use "slow" response when quantifying contamination

DON'T

☐ Use it to quantify x- or gamma-radiation if a true exposure rate instrument is available

☐ Try to quantify alpha vs. beta radiation

☐ Use with tritium (^{3}H) or ^{125}I

Conclusion

Despite being one of the oldest types of radiation detectors, the G-M detector remains one of the most useful and widely used, especially the G-M pancake. Still, there are limitations to their utility that must be understood and heeded.

If you have any questions or comments regarding G-M pancake detectors or any other type of radiation detection equipment, please write or call me in care of this magazine.

Paul R. Steinmeyer works as a Health Physicist at Radiation Safety Associates, Inc. His responsibilities include designing new radiation detection instruments.

Reference

1. NCRP Report No. 112, *Calibration of Survey Instruments used in Radiation Protection for the Assessment of Ionizing Radiation Fields and Radioactive Surface Radiation*, National Council on Radiation Protection and Measurements, December 31, 1991.

***Editor's Note:** The original version of this article continues to be one of the most-requested in our archive. It has been expanded here to include additional information.*