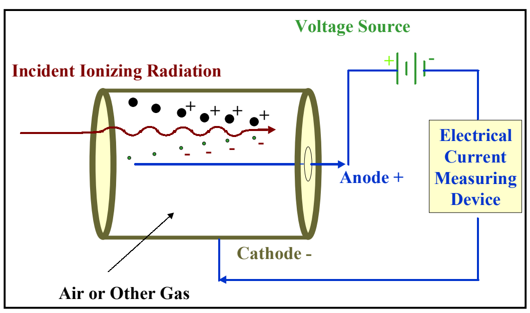
Chapter 10 - Radiation Detection and Measurement

The most widely used radiation detectors are devices that respond to ionizing radiation by producing electrical pulses. The pulses are generated by the imparting of energy to electrons by the ionizing particles in the sensitive volume of the counter.

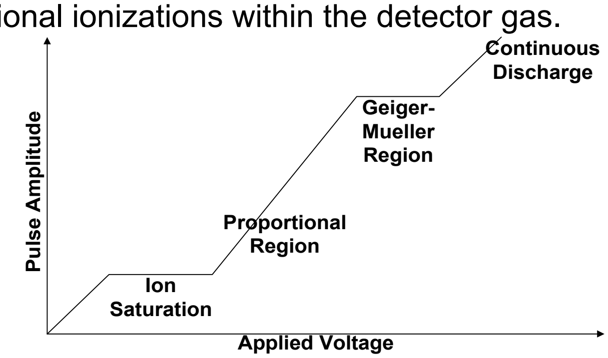
There are two major modes of signal production. In one mode, the deposited energy serves to trigger an output electrical pulse of constant form every time an interaction occurs. The output pulse is constant regardless of the amount of energy deposited in the detector or the nature of the particle. The Geiger-Mueller counter exhibits this type of behavior.

In the other mode, the magnitude of the output pulse is proportional to the amount of energy deposited in the detector. Scintillation counters, gas proportional counters and semiconductor detectors exhibit this type of behavior.



In gas-filled detectors, the detector measures the electrical charge or current resulting from ionization of the gas by the radiation. Gas-filled detectors maintain an electric field within the gas. The field causes electrons and ions created by the incident radiation to migrate to their respective collecting electrodes.

As the electric field is increased, the freed electrons are accelerated and achieve sufficient kinetic energy to cause additional ionizations within the detector gas. The electrons freed by these ionizations are accelerated by the field and cause additional ionizations. Thus, the initial ionizing event can lead to a cascade of ionizing events and free electrons. This phenomenon is known as a "Townshend avalanche" after its discoverer. Under proper conditions, the number of secondary ionization events can be kept proportional to the number of primary ion pairs formed, but the total number of ions can be multiplied by a factor of many thousands.

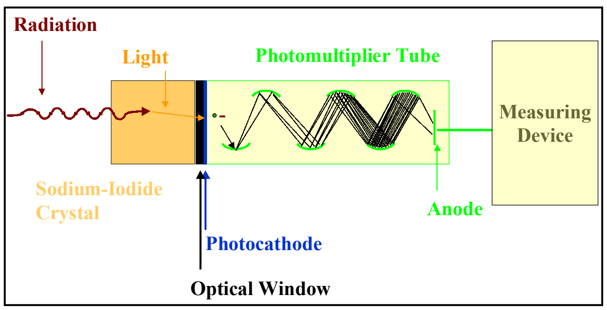


If the applied voltage is sufficiently high, the space charge created by the positive ions becomes dominant in determining the subsequent history of the pulse.

Under these conditions, the avalanche proceeds until a sufficient number of positive ions have been created to reduce the electric field below the point at which gas multiplication can occur. The process is then self-limiting, and will terminate when the same total number of positive ions have formed regardless of the number of initial ion pairs created by the incident radiation. Then each output pulse from the detector is the same magnitude, and no longer reflects any properties of the incident radiation. This is the Geiger-Mueller region of operation.

If the applied voltage is increased still further, eventually the gas goes into continuous discharge making it useless as a detector.

In scintillation detectors, the detector measures light flashes produced in the scintillator by the radiation. The light sensitive portion of the photomultiplier is its photocathode. The photocathode converts incident light photons into low-energy electrons. The electron mutiplier section of the photomultiplier tube acts as an amplifier boosting the electrical signal produced by these electrons sufficiently to be measured.



The ideal scintillation material should convert the kinetic energy of the charged particles into detectable light with high scintillation efficiency. The light yield should be proportional to the deposited energy over as wide a range as possible. The medium should be transparent to the wavelength of its own emission for good light collection. The decay time of the induced luminescence should be short so fast signal pulses can be generated. The material should be of good optical quality and able to be manufactured in sizes large enough to be useful as a practical detector. Its index of refraction should be near that of glass to permit efficient coupling of the scintillation light to a photomultiplier tube.

No material meets all these criteria. The most widely used scintillators include inorganic alkali halide crystals, organic-based liquids and certain plastics. The inorganic alkali halide crystals have the best light output and linearity, but are relatively slow responding. Organic scintillators are much faster, but yield less light. The high Z-value of their constituents and high density of inorganic crystals favors their use for gamma spectroscopy. Organic-based liquids are favored for beta spectroscopy.

If your laboratory is interested in purchasing a survey instrument, contact the Radiation Safety Office before selecting one. Our recommendations are based on experience with various brands and take into account ease of calibration, reliability, versatility, ruggedness, ease of servicing, and value. Instruments ordered out of catalogues may not meet your individual needs.

We encourage radiation workers to use portable survey instruments to find contamination. The authorized user shall ensure that individuals conducting such surveys are knowledgeable in the capabilities, use, and maintenance of the survey instrument. The Radiation Safety office can provide training in survey instrument use and maintenance. Authorized users shall make sure that instruments operate correctly and are maintained in a serviceable condition.

It is important to select an instrument that is appropriate for the radionuclides used. The most common instruments are "rate meters" that display counts per unit time, used with either Geiger-Mueller (GM) detectors or scintillation detectors. Ion chambers, which measure exposure rate, are useful in certain applications.

There are two basic types of Geiger-Mueller (GM) detectors: long, thin end-window detector (shown on the left) and short, broad "pancake" detector (shown on the right.) Both types operate on the same principle, but the pancake detector usually has higher counting efficiencies.

Counting efficiency is the ratio of counts detected per unit time (e.g., cpm) divided by the activity of the source expressed as disintegrations per unit time (e.g., dpm).

Efficiency = counts per minute/disintegrations per minute = cpm/dpm

GM detectors cannot be used to measure H-3 radiation because the 18 keV beta particle is so weak. Counting efficiency for gammas may be very low (for I-125, as low as 0.01%). GM detectors are not recommended for measuring gamma contamination in the laboratory. Scintillation detectors are superior for that purpose.

GM detectors may over-respond by a factor of up to 10 when measuring exposure rate from low-energy photons such as I-125. Consult your instrument manual for your instrument's unique energy-response curve.

Measurement of exposure rates is more accurately performed with an "energy compensated" GM detector or an ionization chamber instrument. At very high counting rates, GM detectors may become "saturated" and the meter reading will fall to zero, potentially causing a false sense of security. When performing surveys or entering areas where significant exposure rates or contamination are expected, always approach the area cautiously with the survey meter turned on. A rapid increase in count rate followed by a drop to zero indicates a high radiation field. Saturation may occur when measuring radiation fields resulting from a few microcuries of P-32.

Response time for rate meter/GM combinations may be relatively slow. Perform surveys slowly enough to detect small changes in count rates. About 3 cm/second is a good survey rate. GM survey meters may take 10 seconds or more to reach 90% of final value. Pancake detectors have about twice the counting efficiency for beta emitters than end-window detectors. Typical counting efficiencies for end-window detectors range from about 6% for C-14 to 25% for P-32.

Scintillation Detectors: Scintillation detectors are used for detecting and measuring gamma photons, and are the best detectors for I-125 contamination. Efficiency may be several orders of magnitude higher for gamma photons than GM detectors. Scintillation detectors do not become saturated. The meter will "peg" on the high end of the scale in an extreme radiation field. Scintillation detectors are fragile. They contain glass photomultiplier tubes and brittle, thin crystals. They are significantly more expensive than GM detectors.

Plastic scintillators are available for detecting beta particles. Restrict their use to beta particle detection; they are not for gamma photons. Gamma and beta scintillators are made out of different materials and have different operating characteristics.

Tritium (H-3) is detectable with liquid scintillation detectors.

Ionization Chambers : Ionization chambers (ion chambers), are designed to measure exposure rate. Some instruments may read out in dose equivalent rate (mrem/hr). They are useful only in measurement of gamma fields. Most unsealed gamma-emitting radionuclides are used in small quantities that do not present significant exposure problems. The Radiation Safety office uses ion chambers to measure exposure rates from waste containers, larger sealed sources and some processes. An alternative to the ion chamber is the energy-compensated GM detector. When used, the entire detector volume of the ion chamber must be in the beam of radiation for the measurement to be accurate.

Survey Meter Maintenance: You should avoid contaminating meters and detectors. You can cover the probe to protect it from contamination. Protective coverings (e.g., plastic wrap) on GM detector windows reduce counting efficiency. Switch off meters before changing detector probes. Probes may operate at different voltages and may be damaged if meters are left on. Consult your owner's manual. Verify instrument performance each time you use the instrument by counting a standard, long-lived check source. Use the same counting geometry each time and record the results. Typical check sources are 1 uCi or less of C-14 for GM detectors and I-129 for thin-crystal scintillation detectors. These sources may be purchased from radiopharmaceutical and instrument suppliers. Check sources shall be safeguarded to control their use and prevent their loss. If you purchase a check source, you should inform the Radiation Safety Office. Old lantern mantles--such as used in gas camping lanterns--are effective and inexpensive check sources because they contain radioactive thorium. The mantle does not have to be removed from the plastic bag. Simply place the detector near the mantle to verify instrument performance. Check the batteries each time you use your survey instrument. Most instruments use common D cells or 9-volt batteries. Replace them when they are low to prevent unreliable readings and damage to the instrument. Measure your check source after changing the batteries to verify instrument response. The attachment point between cable and detector may be the weak link. Do not hold the detector by the cable. Do not pull the detector out of its cradle by the cable. Thin windows on GM tubes are extremely fragile, so never touch them! If the window is punctured, the tube is ruined and will have to be replaced. Corrosion from batteries or corrosive atmospheres can destroy an instrument quickly. Replace low batteries promptly and perform a visual check occasionally. Do not keep survey meters in fume hoods or cabinets in which you use or store corrosives; the fumes can quickly render the instrument useless. If the instrument will not be used for an extended period of time, remove the batteries and attach a tag stating that batteries have been removed.

Survey instruments are fragile and expensive. Protect them from bumps and falls. They may be top-heavy if the detector is in a cradle on top of the instrument. Broken scintillation detectors may cost several hundred dollars to replace. Component failure is relatively rare. Keep all instrument manuals, calibration reports, and related materials for reference in the event of instrument failure. Many instruments work best if the humidity is low. High humidity may cause the meter to read much higher than background even when no radiation source is present. A small container or porous bag of silica gel desiccant placed inside the instrument's case may prevent problems. Inspect color-indicating silica gel frequently for color change.

Calibration: The Radiation Safety Office provides calibration services for survey meters. Calibrate your meters at least annually and following each repair. Rate meters are calibrated electronically if they have counts-per-minute or counts-per-second scales. The batteries, high voltage, and input sensitivity are also checked. Sources of differing emissions and energies may be measured, and counting efficiencies are calculated. In some cases, exposure rate measurements are made using a Cs-137 source.

Each portable survey instrument should be checked for proper operation before it is used. You should check the survey instrument's calibration sticker, battery, speaker, background, and probe before using it to survey.

1. Check the calibration sticker:

You should note the latest date of calibration**.** If the date of calibration is more than six months, don't use the survey instrument.

2. Check battery:

You should turn the switch on the rate meter to "BATT" or flip the "BATT" switch to "ON." The needle on the meter face should move to a position within or beyond the indicated area on the meter face scale. If the instrument fails this test, you should replace the batteries before using of the instrument.

3. Check speaker

If there is an audio switch on the rate meter, turn it to "ON." Set the rate meter to a scale of "X1." The rate meter should "click" or "chirp." If the speaker doesn't function, the survey meter may be used. The surveyor will need to check the reading on the rate meter face frequently.

4. Check background:

Go to an area with an expected low background rate. Note the count rate when the rate meter is switched to the "X1" scale. The background rate will vary from as little as 10 cpm up to several hundred cpm. Do not use the survey meter if it doesn't register a background rate.

5. Check probe:

Hold the probe window to the supplied check source. Note the counting rate. Do not use the survey meter if the cpm registered doesn't fall within $\pm$ 20% of the expected reading for that check source