Portable Survey Instruments

RP02.01

Approved Rev: [Date]

Standardized Task Evaluation Program

The Standardized Task Evaluation (STE) program promotes a work-ready workforce through the standardization of common tasks by defining the knowledge and skills required to perform a given task. Subject Matter Experts (SMEs) analyze the task and generate lesson plans, knowledge examination, and performance evaluation elements. These elements are combined to create an STE package.

The Electric Power Research Institute (EPRI) facilitates the development, oversees the quality, and programmatically implements each STE. EPRI STE members have access to these materials and permission to implement these STEs in accordance with their site training and qualification procedures.

10CFR20, Subpart F, Radiation Protection Program

Important Point

- §20.1502 - The licensee shall monitor exposures to radiation and radioactive material at levels sufficient to demonstrate compliance with the occupational dose limits of this part.

Terminal Objective

- When working as a RP technician at a U.S. nuclear utility, the individual will be able to properly select, setup, and use portable survey instruments in order to support worker activities in a radiological control area in accordance with the standards of NISP-RP-02.01, Portable Survey Instruments.

Enabling Objectives

1.) Describe the theory of operation for the following detectors:

- **Gas Filled**
  - GM
  - Proportional Counter
  - Ion Chamber
- **Scintillation**
  - Zinc Sulfide
  - Plastic Scintillation
  - NaI
  - CsI
  - Dual Scintillation
- **Solid State**

Enabling Objectives

2.) Identify the correct instrument to use based on the type of survey to be performed

3.) Describe the preoperational checks required for portable instruments:

- Visual
- Calibration check
- Battery check
- Source check
- Available scales
- Documentation

4.) Identify the risk of an off-scale reading high due to the potential for over-ranging conditions.

Enabling Objectives

5.) Describe conditions that might affect survey instrument response.

6.) Describe the operational characteristics of:

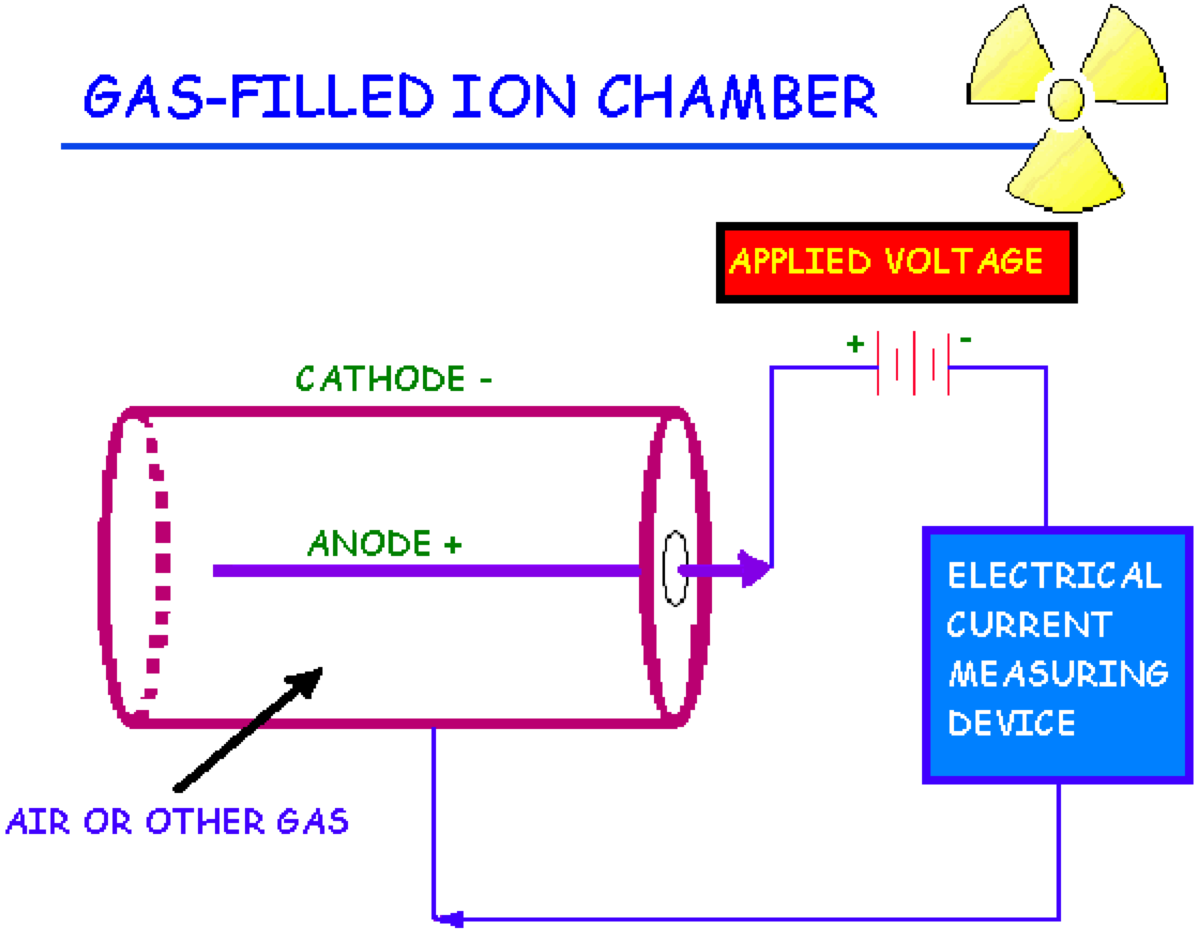
- Gas filled detectors
- Scintillation detectors
- Solid State detectors

7.) Given a correction factor, calculate:

- Ion Chamber, Beta/Gamma readings
- GM tube, cpm to dpm

Gas Filled Detectors

Gas Filled Detector

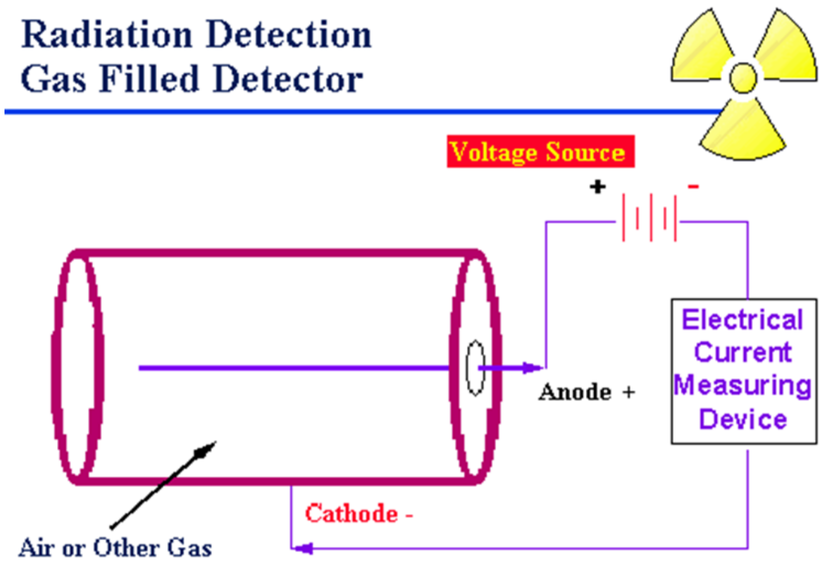


Gas-filled detectors, operate on the principle of collecting ion pairs produced by radiation inside the detector's fill gas.

a. The collection of ions results in an electrical current proportional to the radiation level.
b. By measuring the amount of current, we can determine the radiation level.
c. The electrical output from the detector is commonly called the pulse.

Radiation Detection – Gas Filled Detector

- How is radiation detection possible?
- Due to the ability of radiation to produce ionization.
- The detector is used to indicate the presence of radiation.
- A current measuring device or meter is used to indicate the intensity of the radiation.



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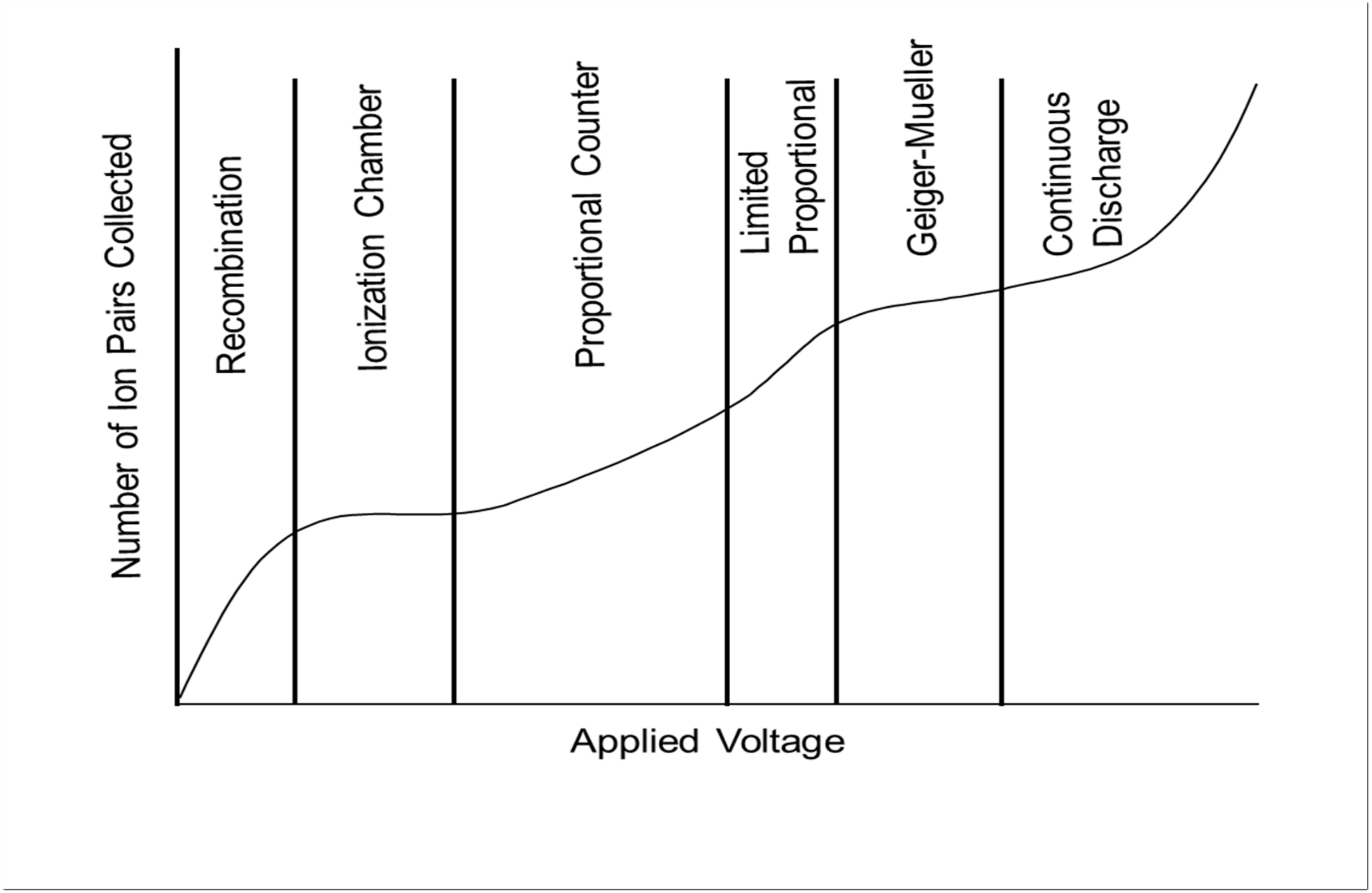
Radiation Detection – Gas Filled Detector

- Factors affecting pulse size in gas filled detectors.
  - Type of radiation
  - Energy of radiation
  - Applied voltage
  - Source strength
  - Distance from the source
  - Medium between the source and detector.

Six Region Curve



Six Region Curve

- Pulse magnitude and duration
- Radiation and Voltage will affect output
- Ion chamber pulse and/or current output vs. detector voltage input.
- Known as the six region curve or the gas amplification curve.

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Six Region Curve

The radiation field must be unchanging or the curve will shift up or down.

The amount of applied voltage, the type of gas, and the energy level of the measured radiation all play a part in the pulse magnitude and duration measured at the output of the gas filled detector.

The more ionizing the radiation or the higher the applied voltage to the detector, the higher the pulse or current seen on the output.

Ion chamber pulse and/or current output vs. detector voltage input.

Known as the six region curve or the gas amplification curve.

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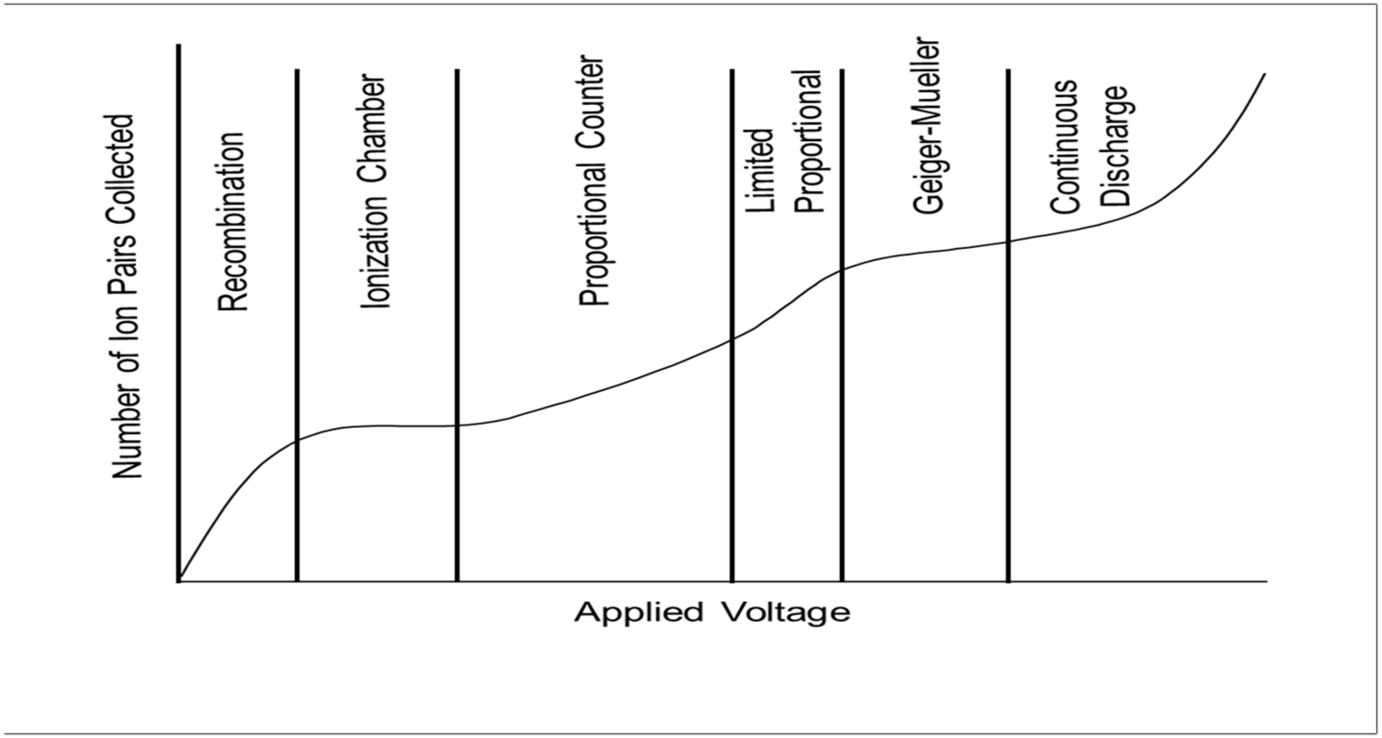
Six Region Curve

- If a gas filled chamber is set in a radiation field of unchanging intensity and the applied voltage is raised from zero to some high value, the gas amplification characteristic curve for a gas filled detector results.



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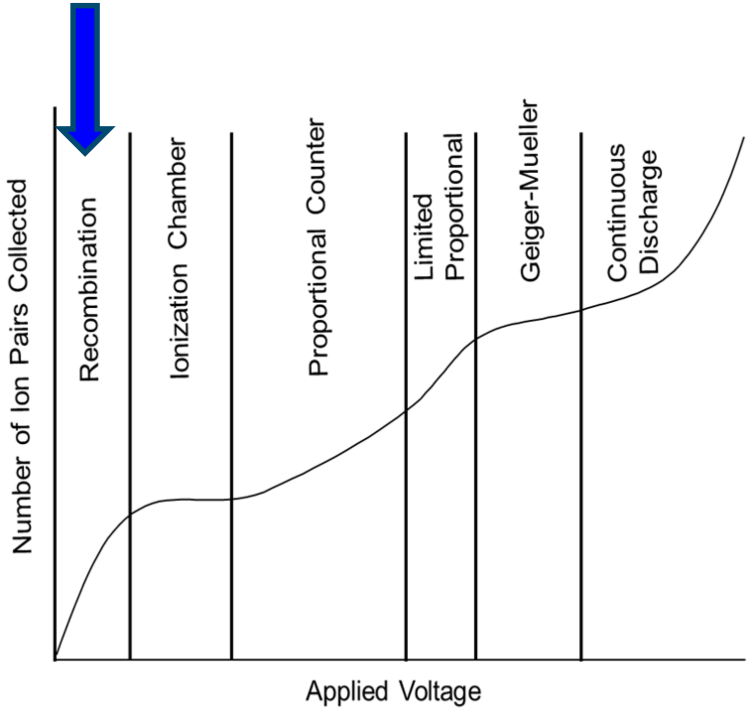
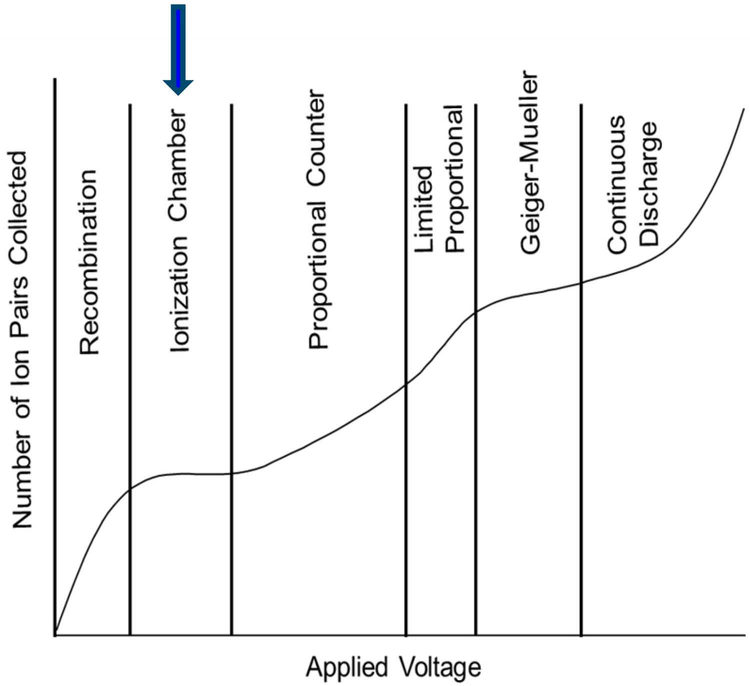
Six Region Curve – Recombination



- Zero voltage – no ionization
- Not enough applied voltage to attract all ion pairs produced
- As voltage increase, ionization occurs, but some ion pairs recombine before reaching electrodes
- NOT USED IN RADIATION DETECTORS

Six Region Curve – Ionization Chamber

One to one ratio



No gas amplification for creating secondary ion events– all primary ion pairs.

- 100% of ion pairs produced are collected
- Output signal from detector is directly proportional to the amount of radiation entering the detector – ideal for dose rate measurements

Advantages of detectors operating in this regions are:

- Accuracy
- Response proportional to dose rate
- Less regulated power supply needed

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Six Region Curve – Ionization Chamber

Beta Radiation

- Beta particles are charged and can be measured directly provided the particle passes through the shielding of the chamber wall (which it normally cannot).
- A window on some detectors allows beta particles to enter, this is shown on slide 94.

Gamma Radiation

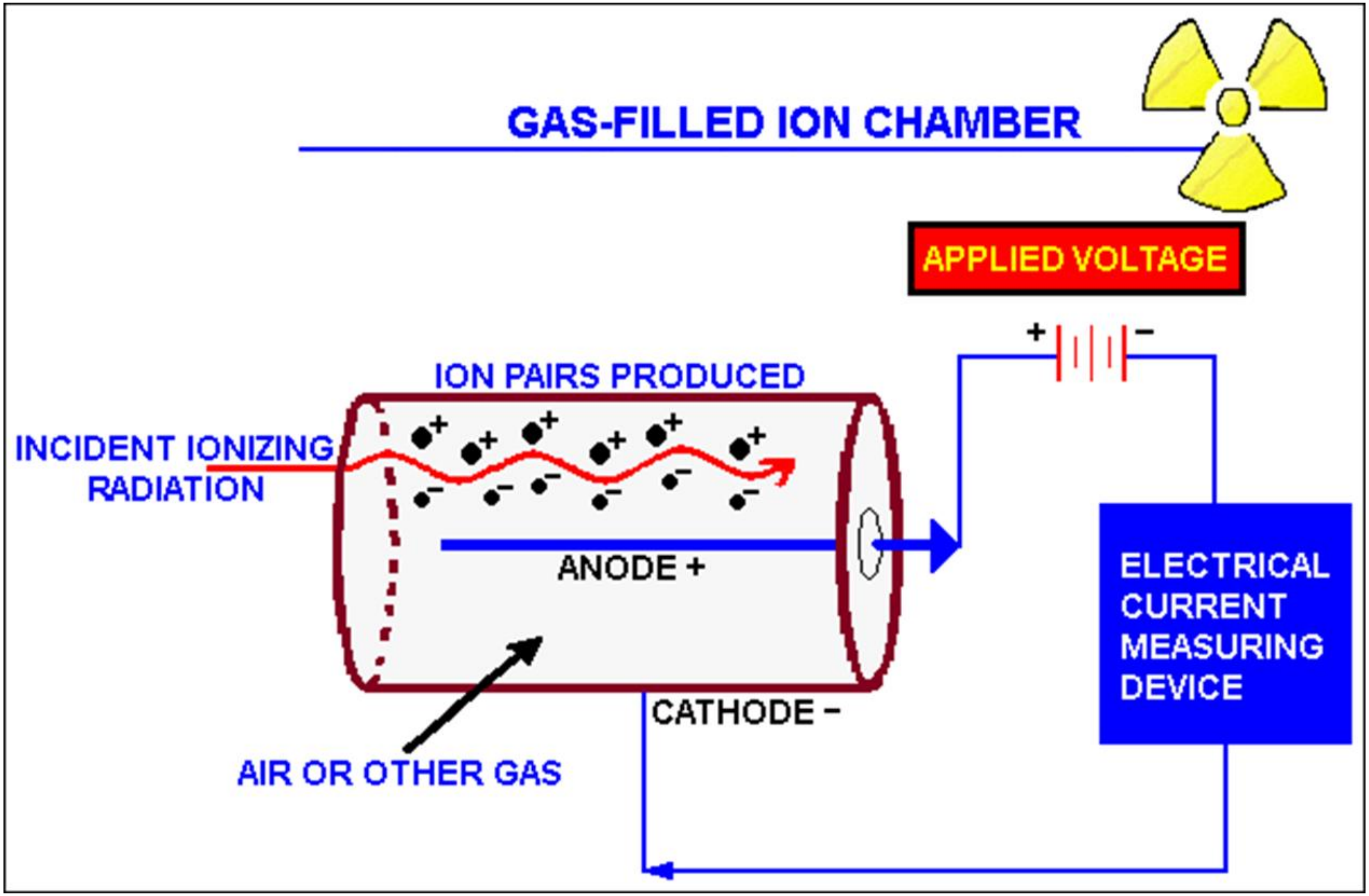
- Detectors rely on fill gas molecules and various gamma interactions with matter to provide ions inside chamber.
- Gamma interactions
  - Photo-electric effect
  - Pair Production
  - Compton Scattering

Six Region Curve – Ionization Chamber

- Pulse size is dependent on radiation energy and type
- Most accurate region because every ion pair created is collected.
- Insensitive to low radiation levels, Generally ionization chamber detectors cannot detect radiation level <2 mr/hr. The amount of current produced is small so a large amount of amplification is required.
- Used for stay time and dose assessment measurements.
- Best for measuring high levels of radiation.

Six Region Curve – Ionization Chamber

Typical Ionization Chamber Detector

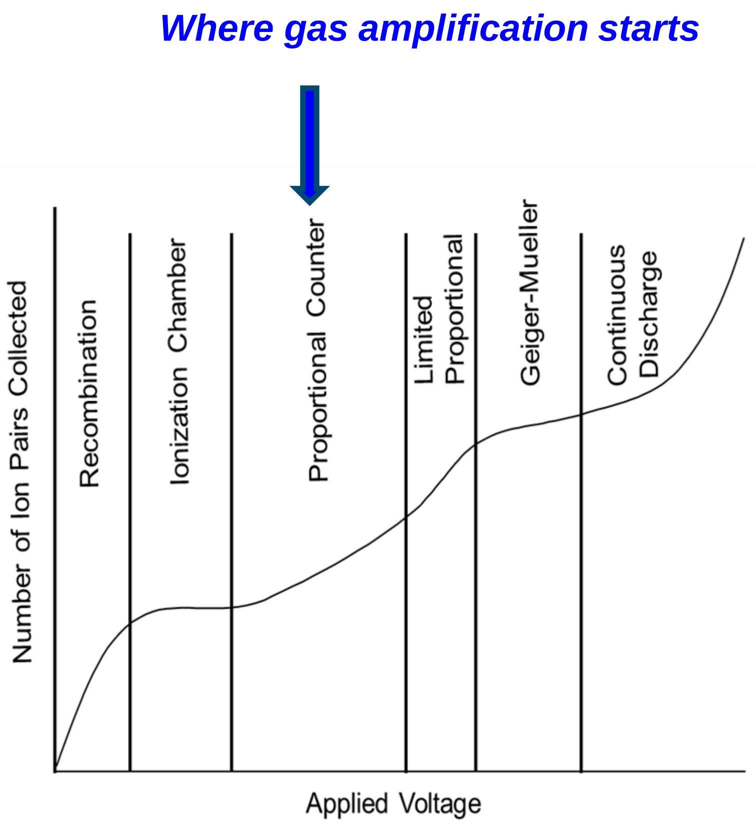


Six Region Curve – Ionization Chamber

<u>Sequence of events of the previous slide:</u>

1. Radiation passes through the chamber.
2. The radiation interacts with an atom of the fill gas.
3. The radiation gives up some or all of its energy to the gas atom.
4. The excited gas atom releases one of its orbital electrons.
5. The electric field causes the electron to drift toward the center (+) electrode (anode).
6. The now positively charged gas ion drifts toward the (-) electrode (cathode).
7. The electron and positively charged atom are collected on the electrodes and produce an electric current which flows through the anode to the electronic metering circuit.

Six Region Curve – Proportional Counter



- Initial ionization occurs
- Amount of signal amplification is the "*gas amplification factor*"
- Detector circuitry measures pulses – more energetic the radiation detected, the higher the pulse

Six Region Curve – Proportional Counter

This region can be used for radiation discrimination of alpha and beta and dose rate measurements. Proportional counters must have a stable power supply because they are voltage dependent.

Examples:

- Tennelec changes voltage for counting smears for alpha and beta.
- Personnel contamination monitors (PCMs) can be used with a circuit that counts pulses and can discriminate types of radiation based on pulse heights.

Some instruments operating in the proportional region can be used to measure beta, gamma and alpha radiations simultaneously because the numbers of ions created by the beta, gamma and alpha are significantly different, depending on the voltage.

Six Region Curve – Proportional Counter

- Uses
  - Quantifying alpha and beta activity
  - Neutron detection
  - X-ray spectroscopy.
- The pulses produced are larger than those produced by an ion chamber

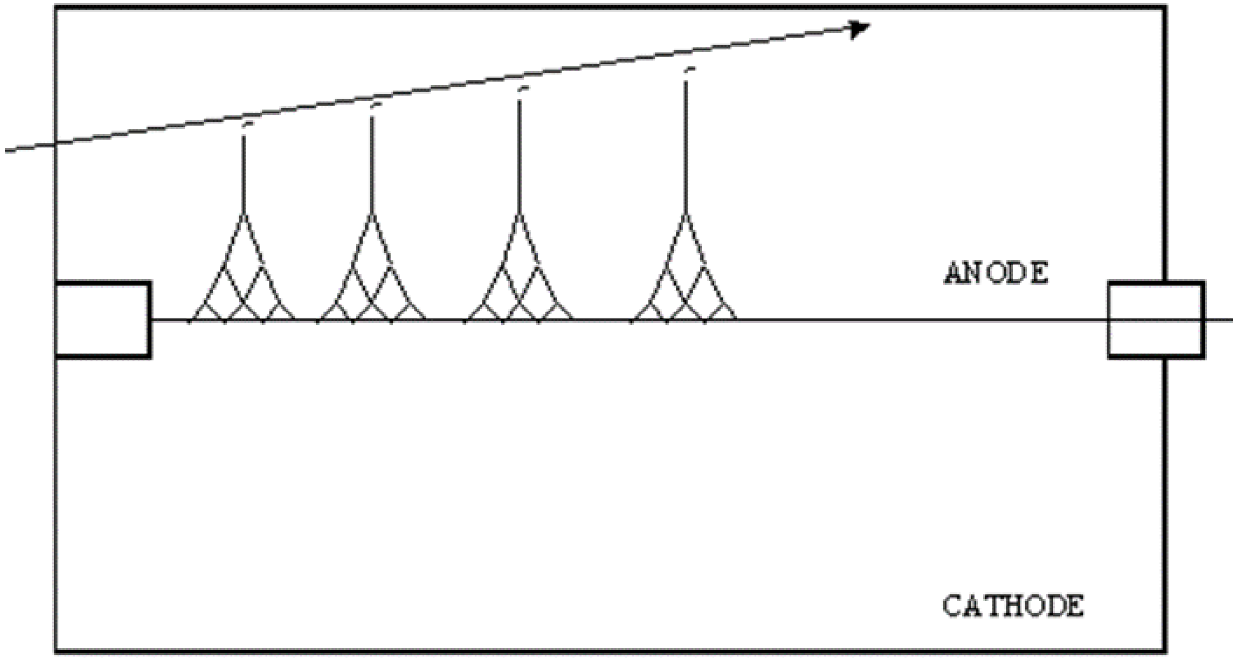
  - Unlike the situation in a GM detector (we'll see later), the pulse size reflects the energy deposited by the incident radiation in the detector gas. As such, it is possible to distinguish the larger pulses produced by alpha particles from the smaller pulses produced by betas or gamma rays. By using a "voltage window" the pulse received may be included or excluded based on whether it is in the "window".

  - The pulses produced by a proportional counter are larger than those produced by an ion chamber. This means that the proportional counter is more conveniently operated in the pulse mode (ion chambers usually operate in the current mode).

Six Region Curve – Proportional Counter

- The size of the pulse in a proportional counter depends on two things:
  - Operating Voltage. The higher the operating voltage, the larger each avalanche becomes and the larger the pulse (must have a stable voltage supply).
  - Energy Deposited in Detector Gas. The greater the energy deposited in the detector gas by an incident particle of radiation, the larger the number of primary ion pairs, the larger the number of avalanches, and the larger the pulse.

Six Region Curve – Proportional Counter



This diagram shows a charged partic*le* traversing the detector gas. Four primary ion pairs (and four resulting avalanches) are produced. It is usually the case that many more ion pairs are produced by incident radiation than the four shown here. **Keep in mind that the four avalanches contribute to a single pulse**.

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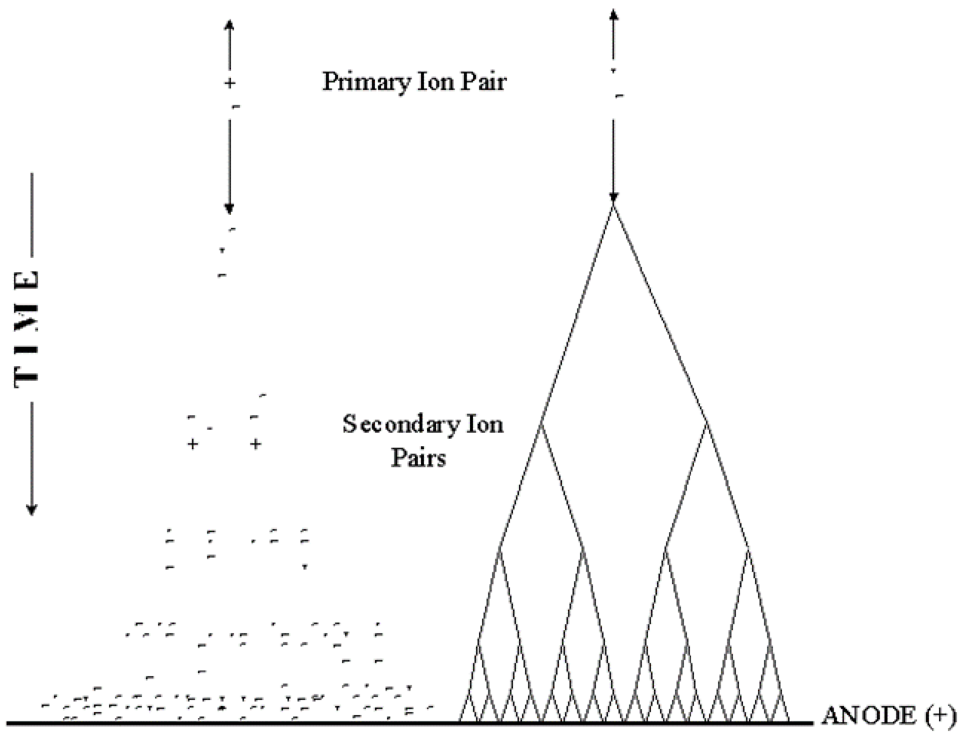
Six Region Curve – Proportional Counter

This diagram shows the Townsend Avalanche. In a proportional counter, many electrons (10 - 10,000) reach the anode for each primary ion pair produced in the gas. The reason is that the electron of each primary ion pair creates further "secondary" ion pairs as it gets close to the anode. These secondary ion pairs are produced in what is called an avalanche.



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Six Region Curve – Proportional Counter

Instruments operating in the proportional region rely on primary and secondary ions to create a current sufficient to be useful in measuring radiation.

Advantages

- Good discrimination
- Detector can be used with a circuit that counts pulses and can discriminate types of radiation based on pulse heights
- Good sensitivity
- Fast response time

Disadvantages

- Requires highly regulated power supply (voltage dependent)
- Fill gas is a compressed gas that is more expensive than the air that fills an air filled ion chamber.

Six Region Curve – Proportional Counter

This region can also be used for neutron monitoring. Typically through 2 methods: fission of U-235 and absorption of B-10.

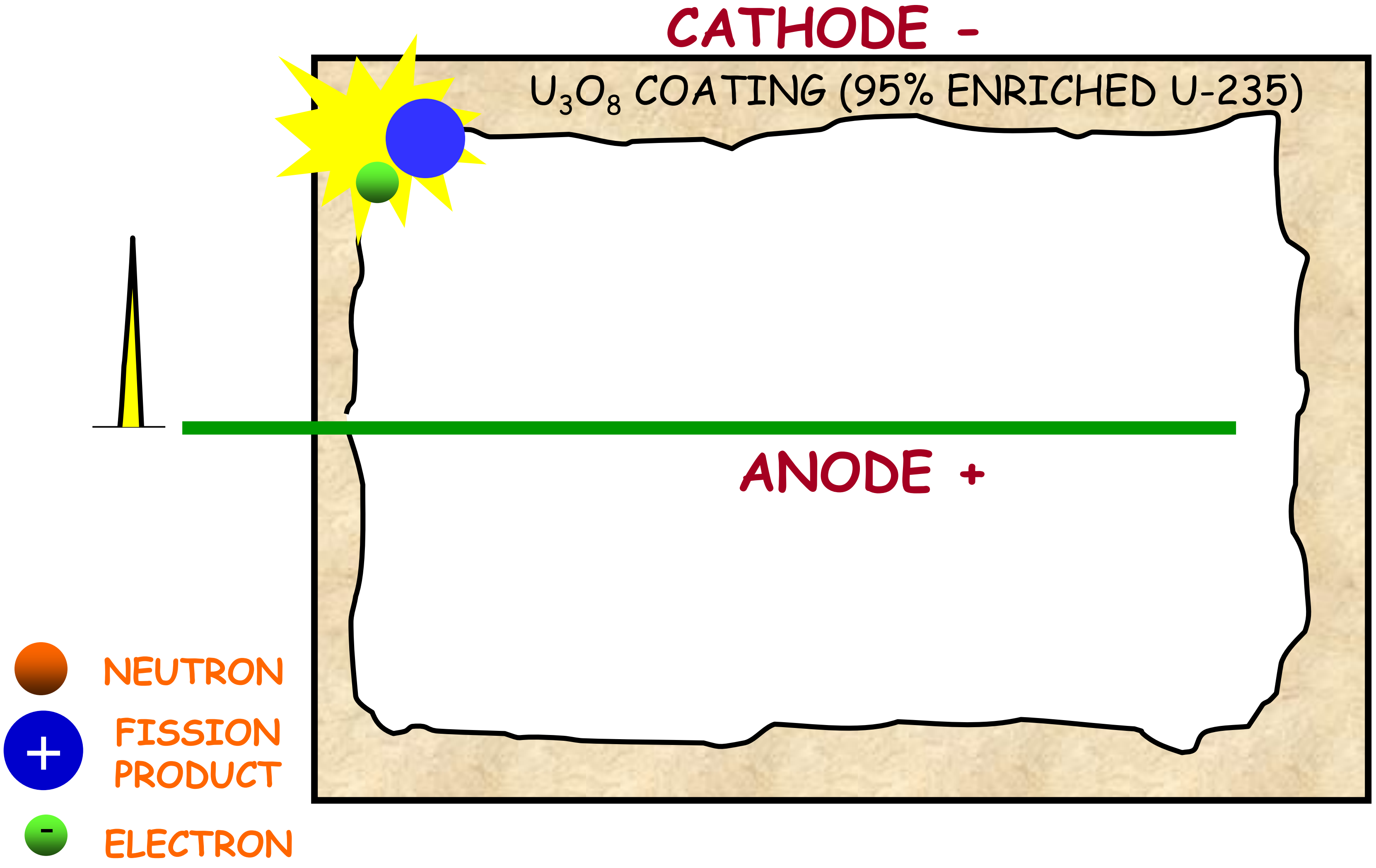
In the following animation, the neutron fission process in the detector only shows one positively charge fission product and one negatively charged electron being released inside the chamber.

In reality, there are two fission products released with each one having multiple positive charges. There would also be multiple negative charges released as a result. This creates a much larger pulse than a gamma interaction with the gas in the detector. The smaller gamma pulses can be discriminated with the external circuitry so that only neutrons are detected.

Plant use: incore or excore neutron detectors (fission chamber detector)

Note that the next slide shows the initial ionization, but also the secondary ionizations produced in the fill gas. This is caused by in increase in the detector applied voltage.

Fission Chamber



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Six Region Curve – Proportional Counter

This is measured with a proportional (region) counter. Only the Boron-10 reacts with the neutron to produce the Li, alpha, and electrons. The alpha causes ionization of the gas and the subsequent current pulse in the detector external circuitry. The alpha is then measured. Example: **Rem Ball**.

A series of current pulses are counted to determine the radiation level.

The amount of current produced in this region is amplified through a process known as gas amplification. For each initial ion pair produced in the detector, 1 million (10^6) secondary ionizations are produced.

Six Region Curve – Proportional Counter

Gas amplification increases the detector's sensitivity to low level radiation. The gas amplification factor (GAF) for a detector is constant at a given applied voltage.

Variations in applied voltage cause variations in GAF, therefore, a stable voltage supply is required.

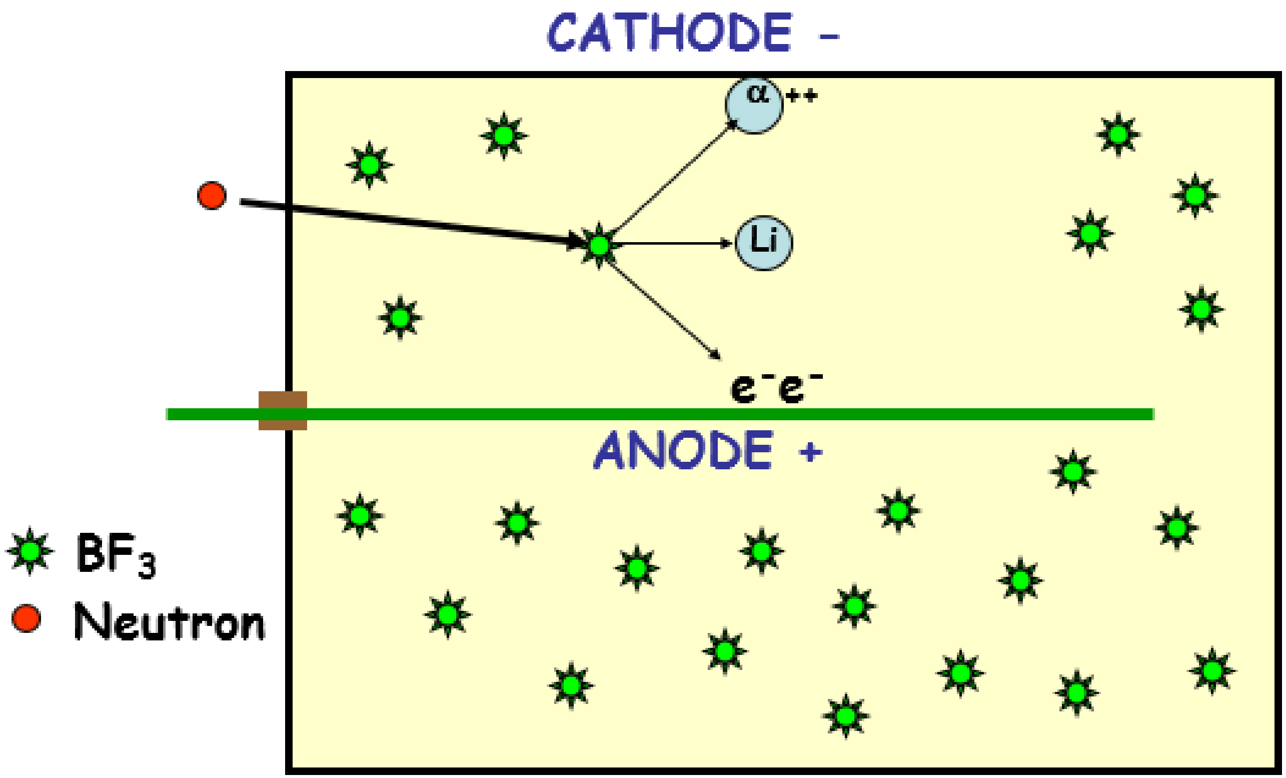
Pulse size is dependent on radiation energy and type, therefore, radiation discrimination can take place.

Instruments operated in this region can be used for Stay Time and Dose Assessment Measurements.

Radiation discrimination is accomplished electronically using a pulse height analyzer (PHA).

Neutron detectors use some form of boron 10 (Bf3= **Boron trifluoride)** because neutrons would not otherwise interact in the detector sufficiently to create a measurable signal. The next slide depicts this interaction.

BF_3 Proportional Detector



$$_{5}B^{10} + {}_{0}n^{1} \longrightarrow {}_{5}B^{11} \longrightarrow {}_{3}Li^{7} + {}_{2}\alpha^{4\,++} + 2e^{-}$$

Six Region Curve – Proportional Detector

Fast Neutron Detection

Thermalization (Slowing Down Fast Neutrons)

- One technique for measuring fast neutrons is to convert them to slow neutrons, and then measure the slow neutrons.
  - **In this technique, a sheet of cadmium is placed on the outside of the detector to absorb any slow neutrons that might be present.**

Six Region Curve – Proportional Detector

Fast Neutron Detection

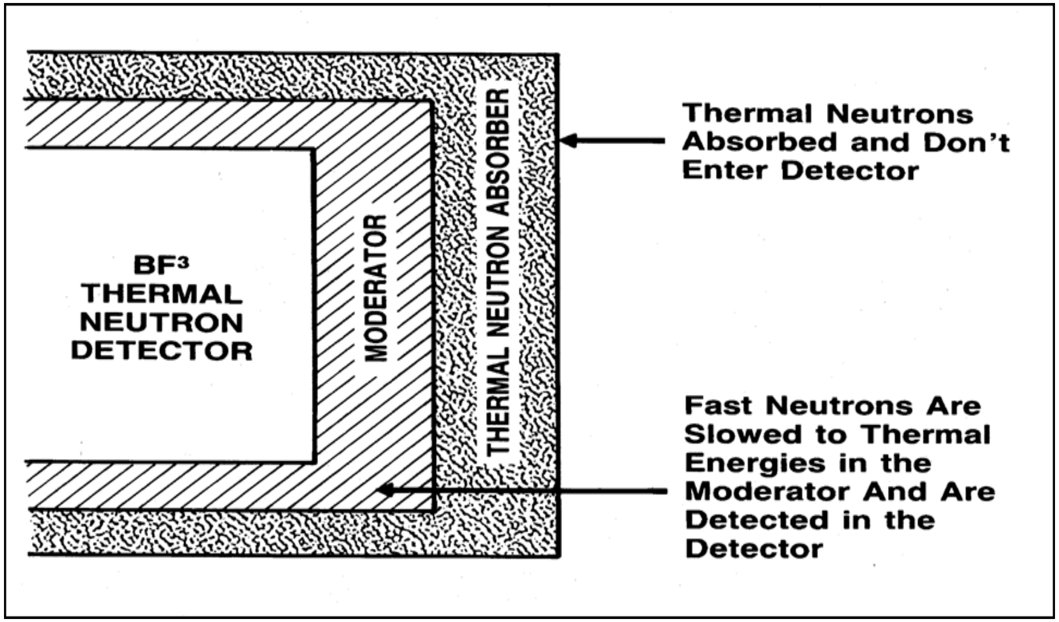
Thermalization (Slowing Down Fast Neutrons)

- A thickness of <u>paraffin</u>, or another good <u>moderator</u>, is placed under the cadmium to <u>convert the fast neutrons to slow neutrons</u>.
- One of the slow neutron detectors is positioned inside the paraffin to measure the slow neutrons, thereby measuring the original fast neutrons.

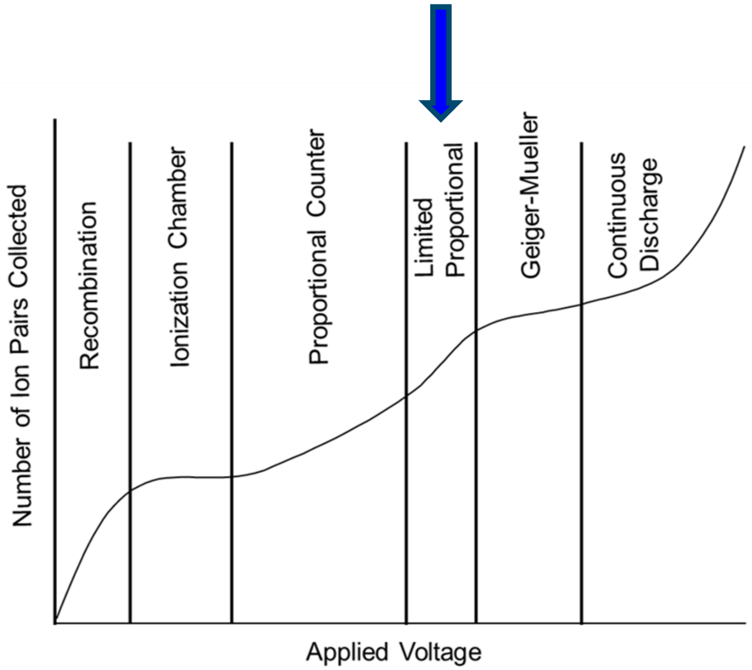
Six Region Curve – Proportional Detector

Fast Neutron Detection

Application- Dose Rate Instrument-BF_3 Neutron Detector



Six Region Curve – Limited Proportional



- A transitional region to the Geiger-Mueller region.
- NOT USED IN RADIATION DETECTION

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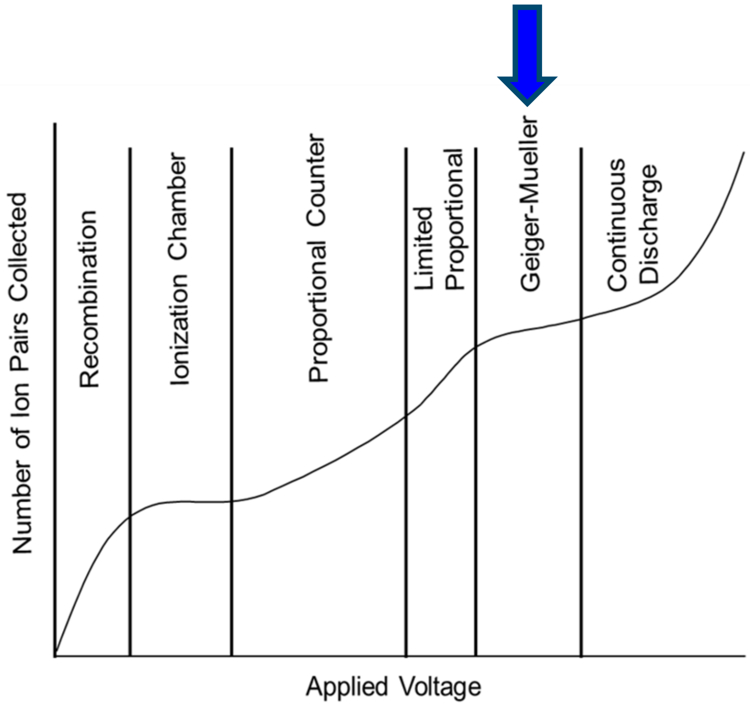
Six Region Curve – Geiger-Mueller



- G-M counters produce the largest signal from an ionizing event
- Ions are moving with such energy that entire tube is flooded with positive and negative ions
- The result is referred to as an avalanche and is one pulse
- Pulses are a count rate

Six Region Curve – Geiger-Mueller

Because of this large gas amplification region (GAF), the pulse size is the same for every event. This prevents any ability to discriminate against different types of radiation.

Examples: **Friskers, Telepoles**

Avalanching causing a pulse that is detected in GM Region.

A series of current pulses are counted to determine the radiation level. The large gas amplification field (GAF) in this region makes this type of detector ideally suited for low level radiation detection. For each initial ion pair produced in the detector, 1 billion (10^9) secondary ionizations are produced. Because the large GAF may lead to continuous discharge inside the detector, quenching materials are added to the gas to prevent it from occurring. The pulse size in this region is constant regardless of the type of energy of the radiation, therefore, the ability to discriminate against the different types of radiation is lost. Because the response of the detectors in this region is dependent on the energy they are calibrated to, **they cannot be used for stay time or dose assessment calculation.**

Six Region Curve – Geiger-Mueller

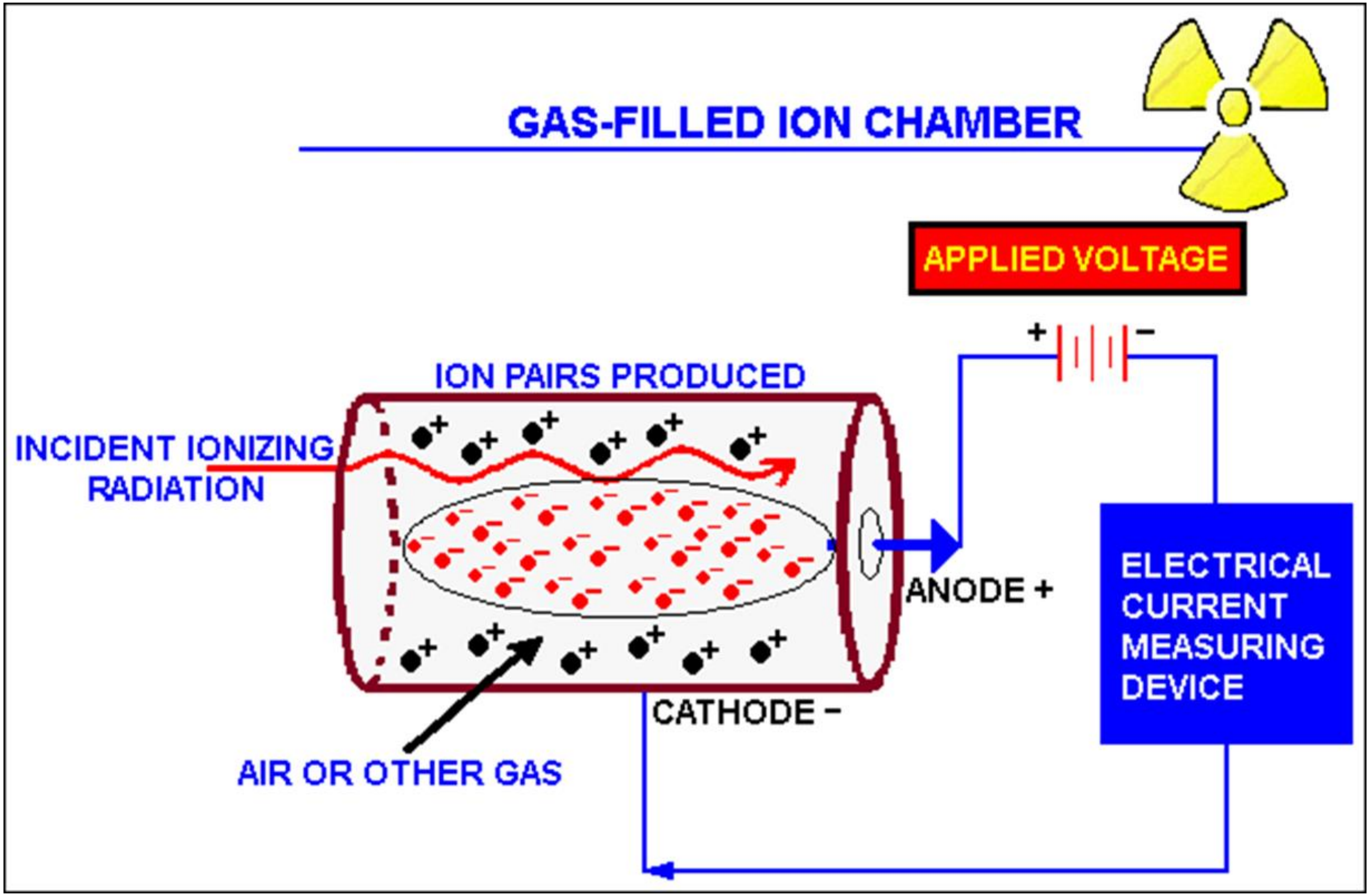
- Beta or alpha particles ionize the fill gas directly

- Gamma and x-rays ionize the gas indirectly by interacting with the metal wall of the GM (via the photoelectric effect, Compton scattering or pair production) in such a way that an electron is "knocked" off the inner wall of the detector.

- This electron then ionizes the gas inside the tube.

- It is true that gamma rays or x-rays might interact with the fill gas rather than the wall, but this is less probable except for very low energy photons.

Six Region Curve – Geiger-Mueller



Six Region Curve – Geiger-Mueller

- At the high voltages associated with the Geiger-Mueller Region, the avalanche created by a single primary electron leads to the creation of other "secondary" avalanches, and so many of these "secondary" avalanches occur that they completely envelop the anode. The pulse eventually shuts itself down when the accumulation of positive ions around the anode reduces the strength of the electric field below that required for continued propagation.

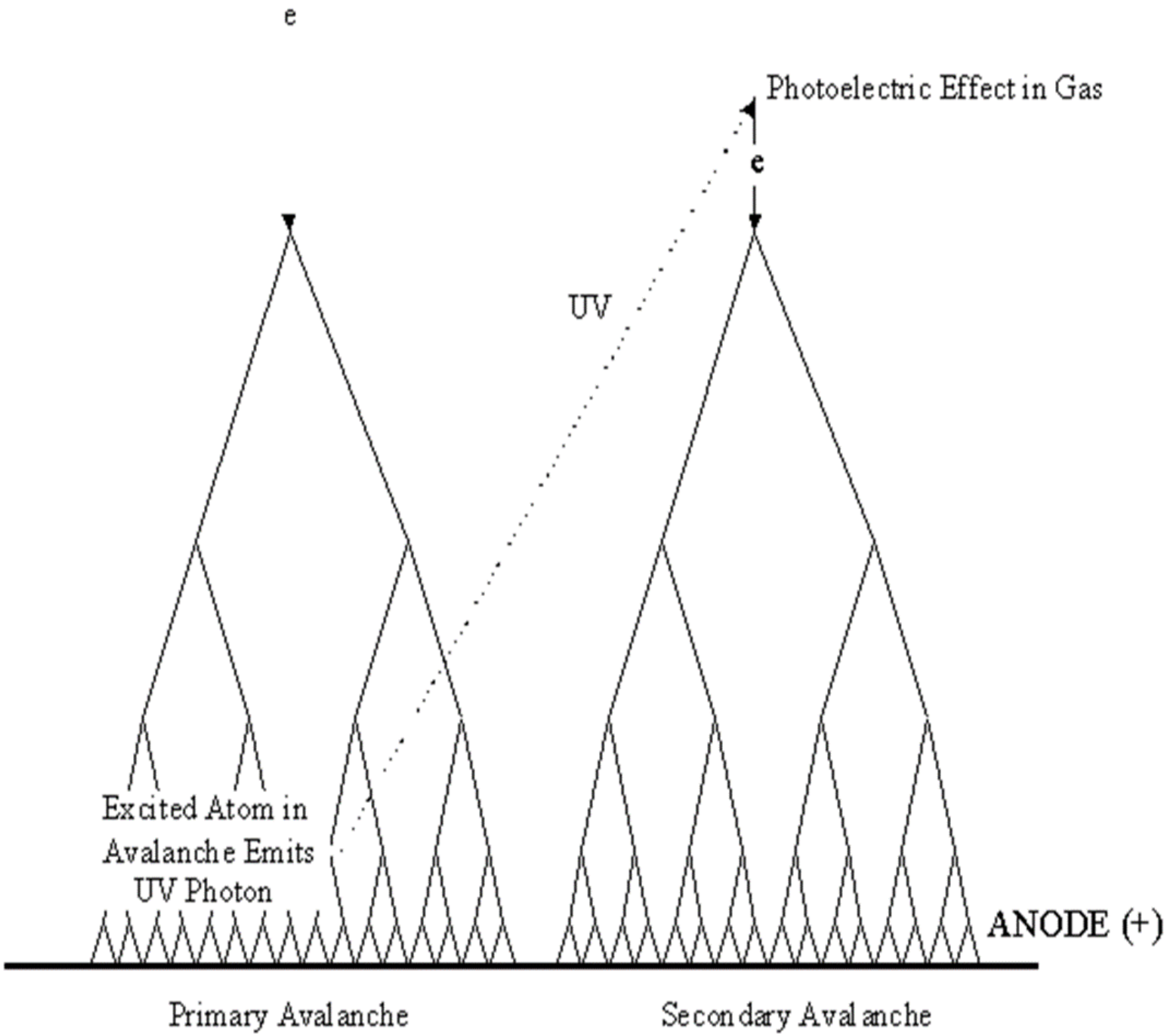
Six Region Curve – Geiger-Mueller

The electric field created by the potential difference between the anode and cathode causes the negative member (electron) of each ion pair to move to the anode while the positively charged gas atom or molecule is drawn to the cathode. As the electrons of the primary ion pairs move towards the anode, they gain kinetic energy (and lose potential energy). If the electric field in the chamber is of sufficient strength (approximately 106 V/m) these electrons gain enough kinetic energy to ionize the gas and create secondary ion pairs. The electrons produced in these secondary ion pairs, along with the primary electrons, continue to gain energy as they move towards the anode, and as they do, they produce more and more ionizations. The result is that each electron from a primary ion pair produces a cascade or avalanche of ion pairs (Townsend avalanche).

Six Region Curve – Geiger-Mueller

The mechanism by which a single avalanche can eventually envelope the entire anode involves the fact that any avalanche not only involves the ionization of gas molecules, it also involves the excitation of gas molecules. The subsequent de-excitation of the excited molecules results in the emission of UV photons. If enough of these photons are produced, some will be absorbed by the gas molecules via the photoelectric effect. This leads to further ionization of the gas and the formation of a second avalanche. **For all practical purposes, the multiple avalanches are produced at the same time - only one pulse results**. The following diagram above shows how a single avalanche can spread along the anode via the emission of UV photons.

Six Region Curve – Geiger-Mueller



Six Region Curve – Geiger-Mueller

Definitions of Dead Time, Recovery Time, and Resolving Time

Six Region Curve – Geiger-Mueller

Dead time is the time period when new ionizing events will not be detected.

Recovery time is the time that the voltage gradient inside the detector is being restored.

Resolving time is the time period between two separate ionizing events so that both are detected.

Six Region Curve – Geiger-Mueller

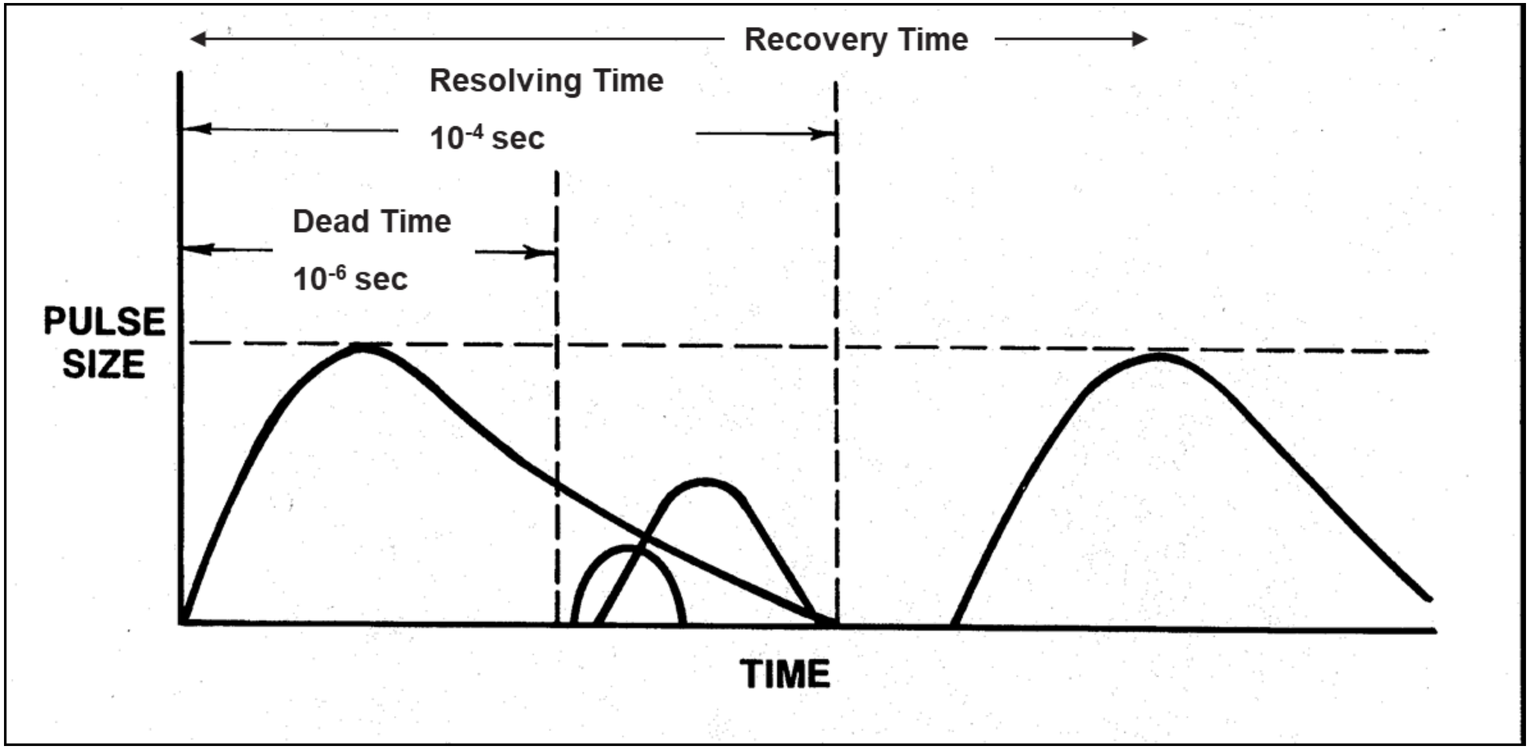
GM detectors experience the longest dead times due to their high gas amplification factor (10^9). Dead times for GM instruments can be from 200 to 300 microseconds whereas the dead time for proportional detectors average about 5 microseconds due to their lower gas amp factors (10^6) . Ion chambers are not affected by dead time due to their low voltage which does not allow for gas amplification.

Because of long dead times in G-M detectors, they can saturate in high fields of radiation.

- Saturation is when a G-M detector reads low in a high field of radiation.
- Saturation in a G-M detector is hard to detect unless the meter's operator sees it occur.

Six Region Curve – Geiger-Mueller

Dead Time: Time from the initial pulse until the detector can produce another pulse



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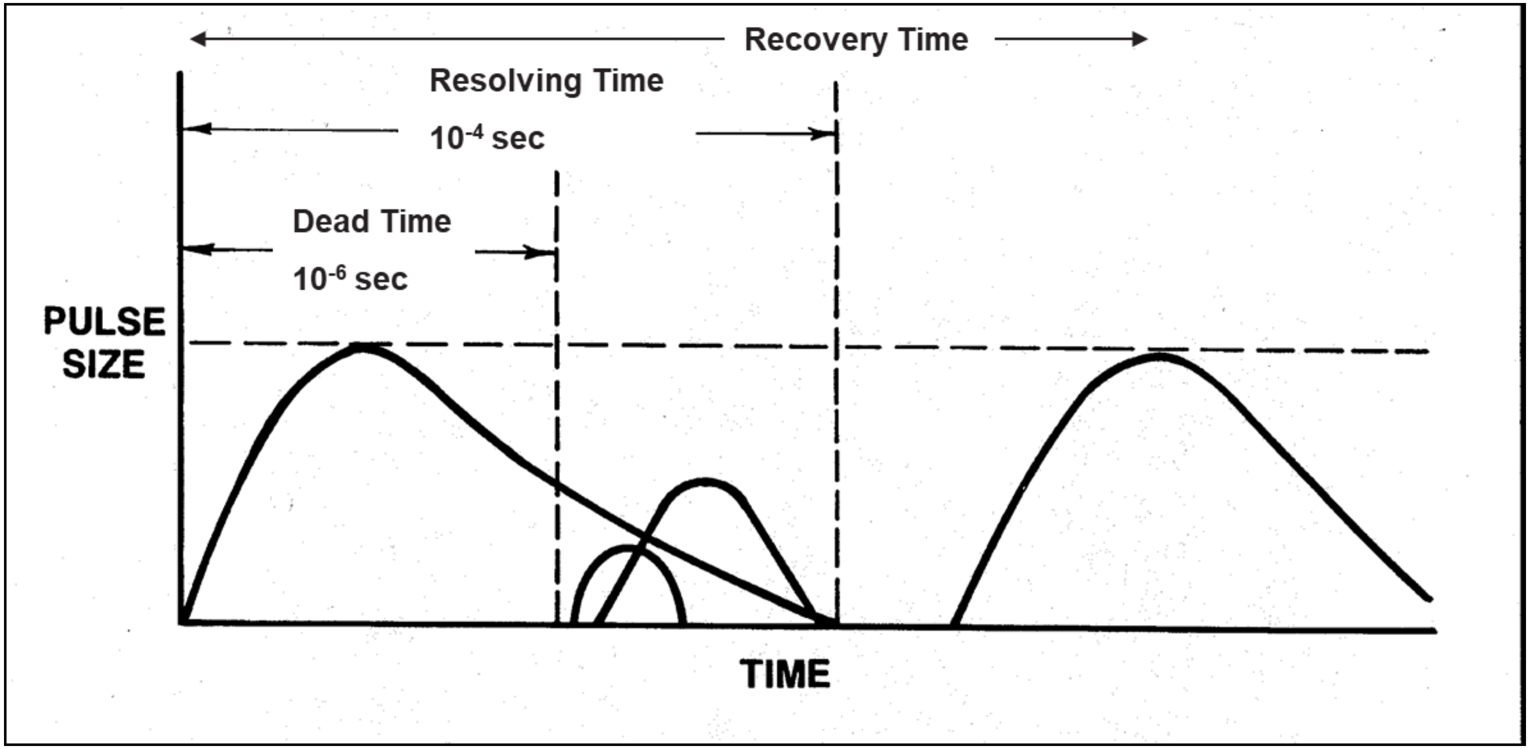
Six Region Curve – Geiger-Mueller

Resolving Time: Time from the initial measured pulse until another pulse can be measured



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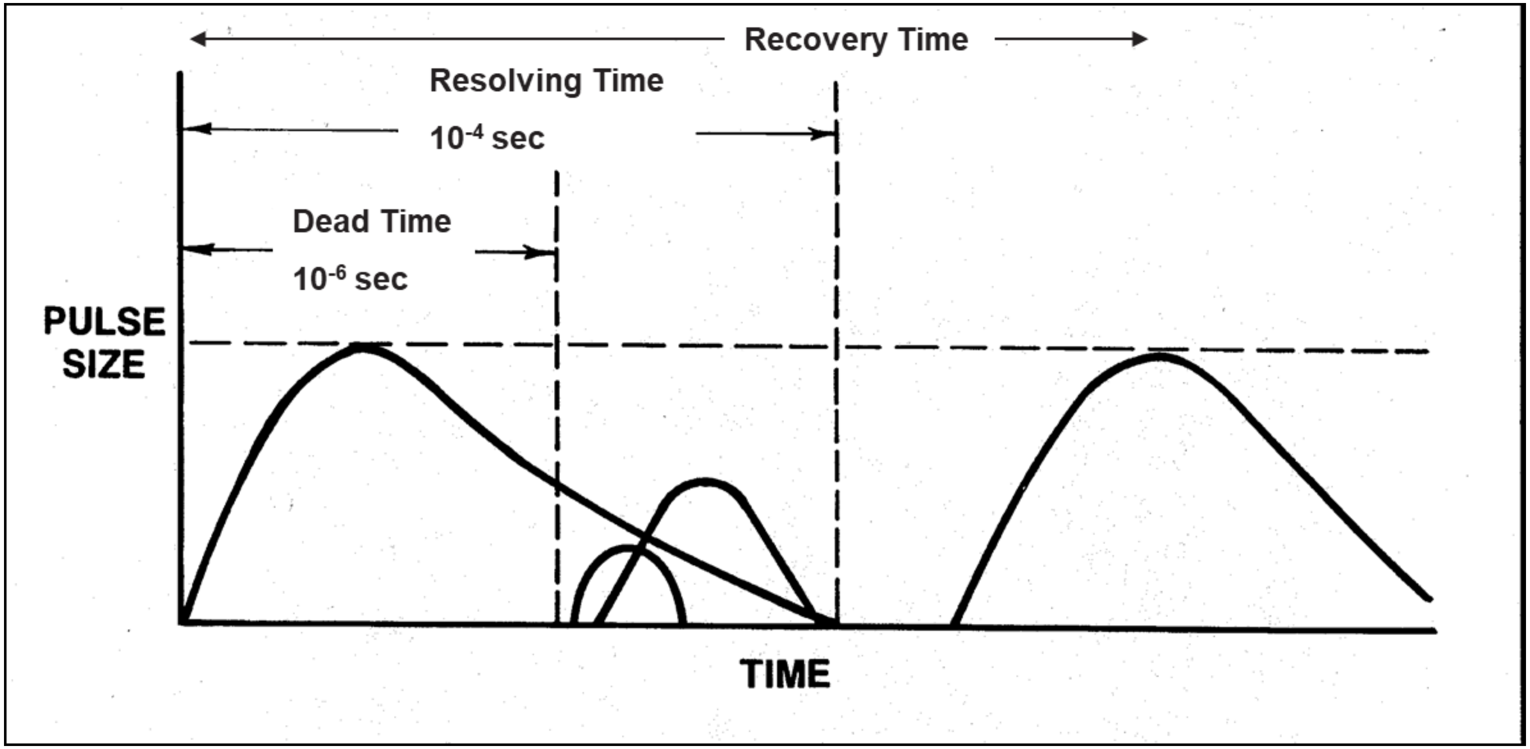
Six Region Curve – Geiger-Mueller

Recovery Time: Time from the initial full size pulse to the next full size pulse is produced by the detector



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Six Region Curve – Geiger-Mueller

Advantages of these types of detectors:

- Unaffected by atmospheric temperature or pressure
- Magnitude of output pulse
- Less regulated power supply
- Greater sensitivity (for comparable size)

Disadvantages of these types of detectors:

- Does not measure true dose (Detector response unrelated to energy deposited)
- Large dead time
- Non-discriminating
- If saturated - detectors fail down scale if a special circuit is not present to prevent a down-scale failure
- Over response to low energy gamma energies (~70 kev)
- Over response to high gamma energies (i.e. N-16 ~6 Mev)

Scintillation Detectors

Scintillation Detectors

Scintillation Detectors and semi-conductor detectors **are not gas filled and do not operate anywhere on the Gas amplification curve**.

1. Scintillation detectors use materials capable of changing the energy of ionizing radiation to visible light via the excitation process.
2. The intensity of the light is proportional to the amount of radiation present.
   a. The light is measured with a photomultiplier tube to determine the level of radioactivity or radiation level.
   b. Different types of phosphors and material are used for detecting the different types of radiation.
      1) ZnS- Zinc Sulfide crystals for alpha detection
      2) Plastic Scintillators for beta detection
      3) NaI Sodium Iodide for gamma detection
      4) CsI- Cesium Iodide for gamma detection

Scintillation Detectors

- Ionizing radiation interacts with phosphor crystalline material to produce light called scintillation.
- Alpha, beta, and gamma scintillators.
- A photo multiplier tube used to convert this light to an electrical pulse.
- A major advantage of the scintillation counter over a gas-filled detector is the much higher counting efficiency for gamma radiation.
- Dual Scintillation Detectors contain a thin plastic scintillator with a coating of ZnS, which are effective in surveying both alpha and beta particles at the same time.

Scintillation Detectors

The detector principle dose does not involve gas amplification. Different phosphor materials are sensitive to different types of radiation.

Examples of instruments: Fast Scan whole body counter, SAM-11 (plastic scintillators) refers to a scintillating material in which the primary fluorescent emitter called a fluor is suspended in the base, a solid polymer matrix.

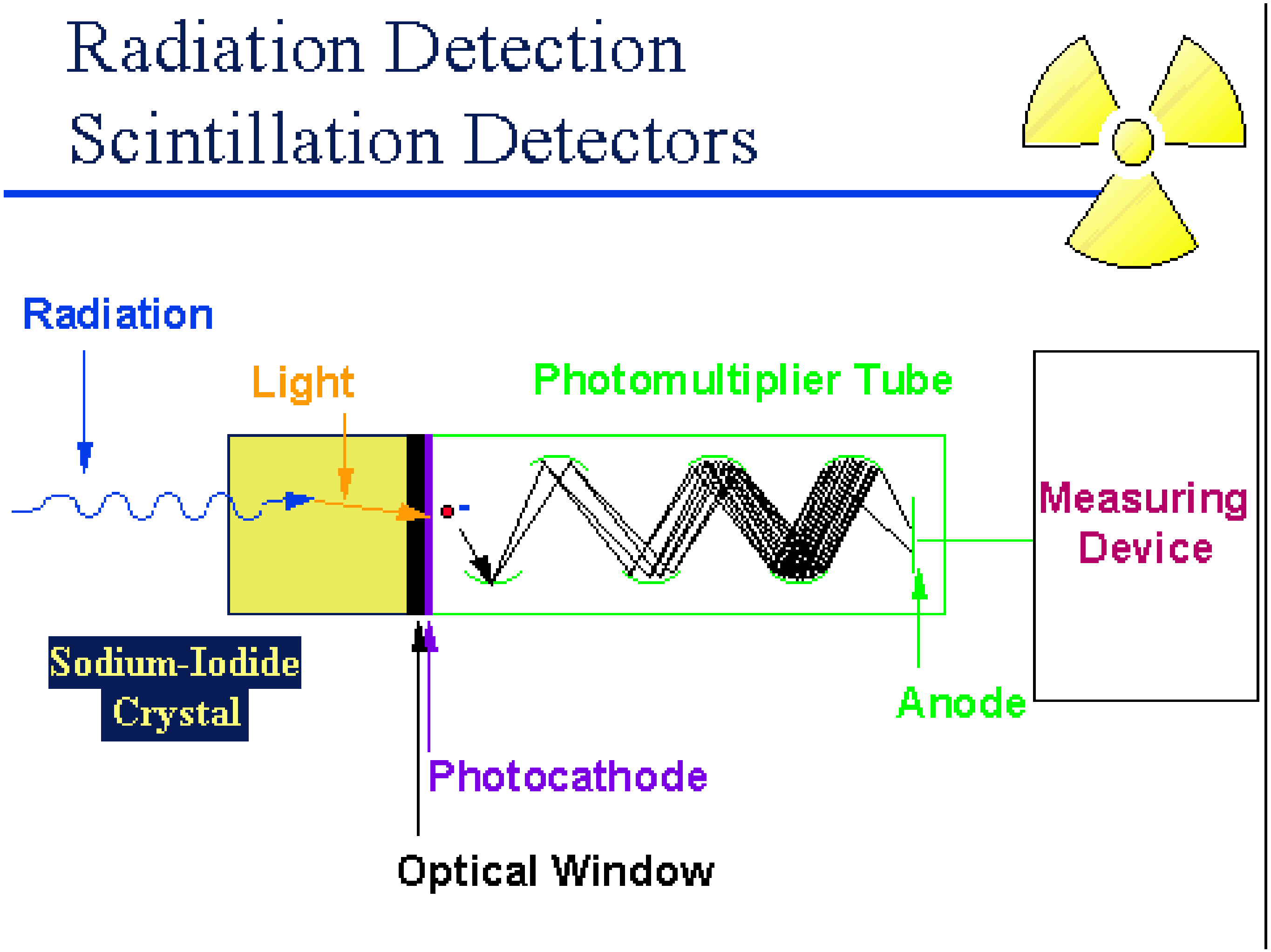
The advantages of plastic scintillators include fairly high light output and a relatively quick signal, with a decay time of 2–4 nanoseconds, but perhaps the biggest advantage of plastic scintillators is their ability to be shaped, through the use of molds or other means, into almost any desired form with what is often a high degree of durability

Scintillation Detectors

Sequence of events in the following slide (alpha, beta and gamma)

1. Radiation enters the crystal material, Radiation interacts with a phosphor atom
2. The phosphor atom gives off a flash of light
3. Light is transmitted through the crystal (also reflected off walls of crystal casing) and collected at the photo cathode of the photo-multiplier tube.
4. Photo cathode converts light into electrons
5. Electron is emitted and is aimed toward the amplifying dynodes.
6. Dynodes, in the Photo multiplier tube, then attract and multiply the number of electrons emitted (from the previous dynode or source).
7. External circuit allows these electrons to be measured or counted.

Scintillation Detectors



Scintillation Detector

Examples of Scintillation Detectors:

Fast Scan Whole Body Counter

SAM 11

Bicron Analyst

ASP with a 50cm or 100cm scintillation probe

Bicron micro-rem

Scintillation Detectors

- Used to detect alpha, beta, and gamma radiation depending on the crystal used.
- Contamination detectors (especially alpha).
- Low level radiation and natural background checks.

Advantages

- Detects low level radiation common to loose surface and fixed contamination
- Readily portable
- Can discriminate energy of gamma

Disadvantages

- Light sensitive
- Easily damaged
- Temperature sensitive

Semiconductor Detectors

Semiconductor Detector

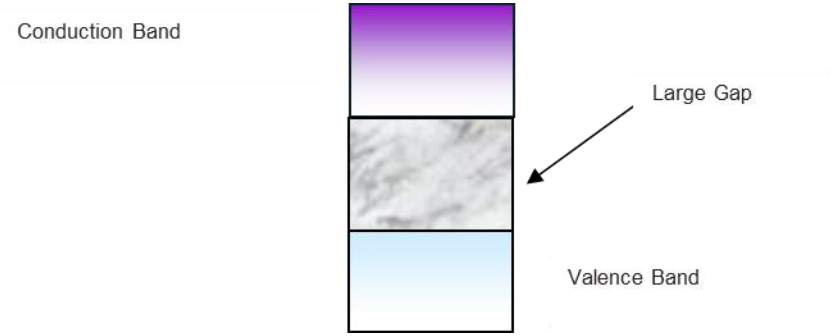
Principles of Semiconductor Detectors

Principles of Operation

- **Introduction**
  - Understanding how a semiconductor detector works requires a knowledge of how electrons travel through a crystalline material.
  - The ability of a material to conduct electricity depends on the material's atomic structure.

Semiconductor Detector

Principles of Semiconductor Detectors

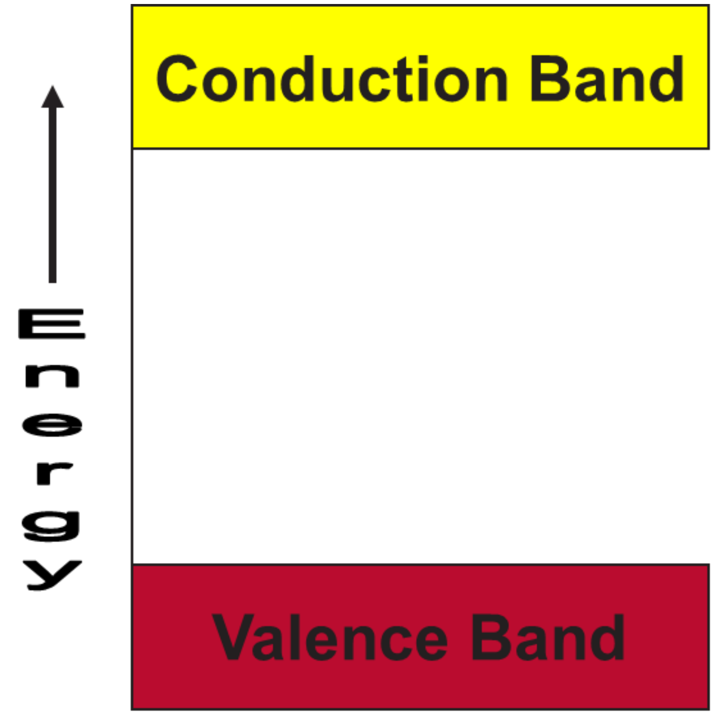


Principles of Operation

- **Insulators**
  - What is an insulator?
  - Give some examples of an insulator.
  - The energy “gap” (difference) between the conduction band and valence band is large.
  - In an insulator the forbidden gap is large, requiring a large amount of energy to move an electron to the conduction band
  - Electron flow (or current flow) is very difficult in an insulator.

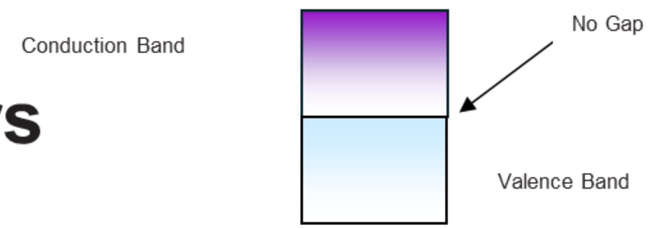
Semiconductor Detector

- In insulators, there is a distinct separation of the two bands and there is a large energy difference between them



Semiconductor Detector

Principles of Semiconductor Detectors

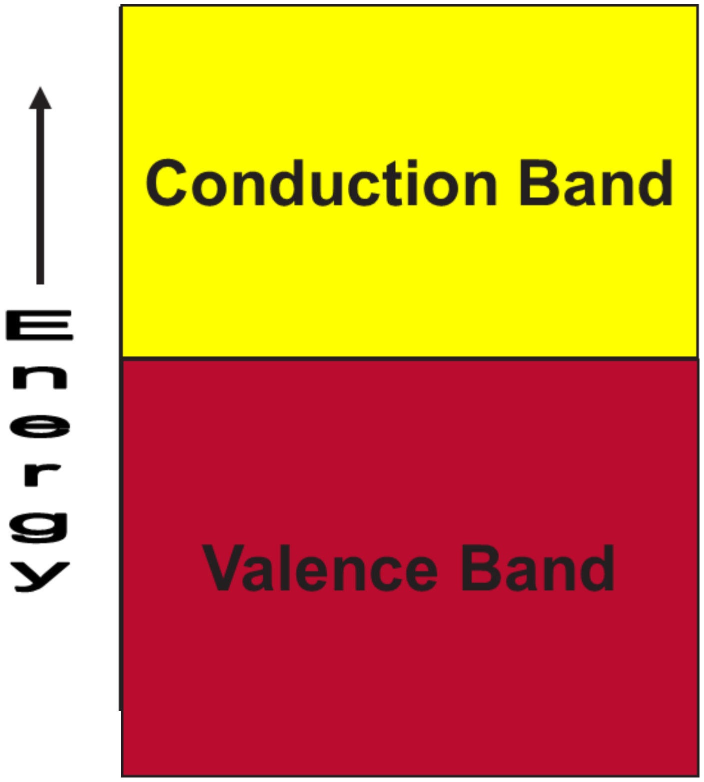


Principles of Operation

- **Conductors**
  - What is a conductor?
  - Give some examples of a conductor.
  - Materials that conduct electricity (or readily support electron flow) are called conductors.
  - In a conductor a significant forbidden gap does not exist, allowing electrons to leave the valence band for the conduction band with very little energy input.

Semiconductor Detector

- In conductors, the valence band and the conduction band overlap
- There is no energy gap to cross in order to reach the conduction band.



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Semiconductor Detector

Principles of Semiconductor Detectors

Principles of Operation

- Valence Band and Conduction Band
  - The valance band refers to an atom's electron shell arrangement, while the conduction band refers to a material's crystalline structure.
  - In the valence band electrons reside in electron shells orbiting the nucleus of an atom.

Semiconductor Detector

Principles of Semiconductor Detectors

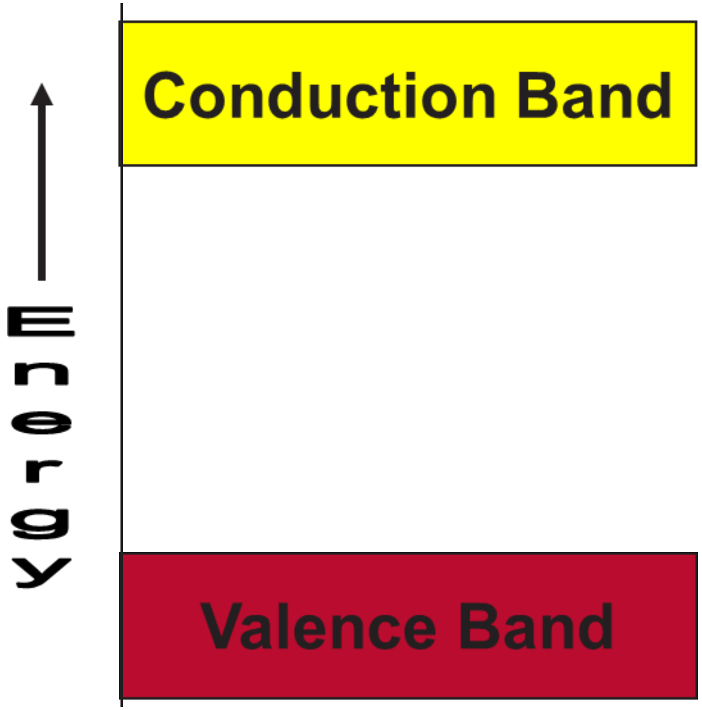
Principles of Operation

- Valence Band and Conduction Band
  - In the conduction band electrons travel through the material's crystalline structure, remaining very loosely bound as they "jump" from atom to atom.
  - Electrons can leave the valence band, but they require excess energy to traverse the "forbidden gap" to reach the conduction band.

Semiconductor Detector

- **Conduction Band**
  electrons travel through the material's crystalline structure.

- **Valence Band**
  electrons reside in electron shells orbiting the nucleus of an atom.



Semiconductor Detector

- 3 electrical classes of material
  - Insulator
  - Semiconductor
  - Conductor
- Semiconductor detector uses the semiconductor type material
- Examples: Electronic dosimeters and gamma spectroscopy equipment

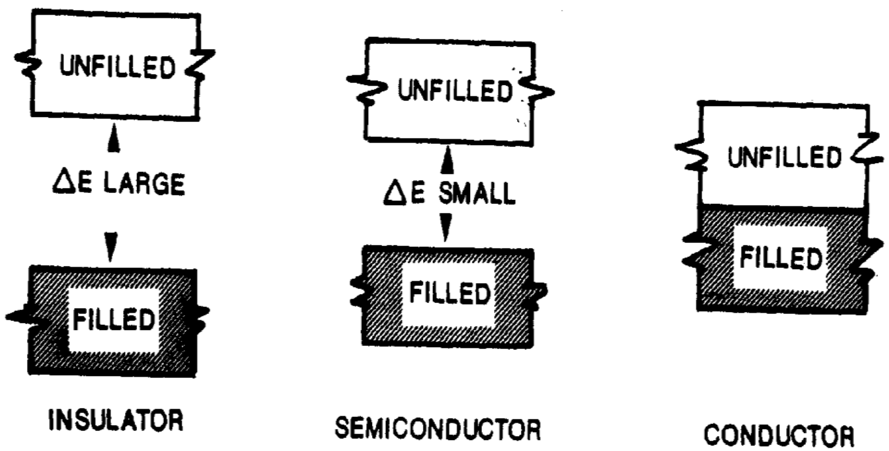


Figure 10.3 Band structure in conductors, semiconductors and insulators. (Adapted from Progress in Nuclear Physics, Vol 9, G.Dearnaley, Semiconductor Counters, Copyright 1964, Pergamon Press, Ltd., Used with permission.)

Semiconductor Detector

Another way of looking at this is like a spark plug. **Insulator** – gap so far apart that the spark wouldn't reach. **Semi-conductor** – gap just right for good spark. **Conductor** – electrons move back and forth. In atoms, electrons are divided into energy levels which tend to form bands. The highest, filled energy level at which electrons occupy is called the valence band and the first level above the **valence band** is known as the **conduction band**. The valence electrons do not participate in conduction.

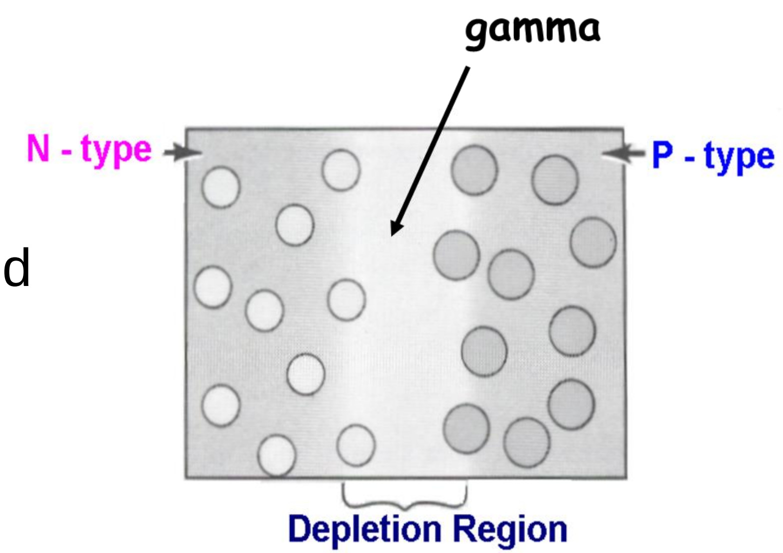
Semiconductor detectors act like gas-filled ionization detectors. The semiconductor is usually silicon or germanium.

Semiconductor Detector

<u>Sequence of events:</u>

1. Electron-hole pairs
2. Radiation interacts with crystal.
3. Electron is raised from Valence band to Conductive band.
4. ”Missing” electron creates a “hole-pair” in the Valence band (similar to electron pair in gas filled detector).
5. In an electric field the “hole-pair” moves toward cathode and electrons moved toward anode to cause current flow/pulse.

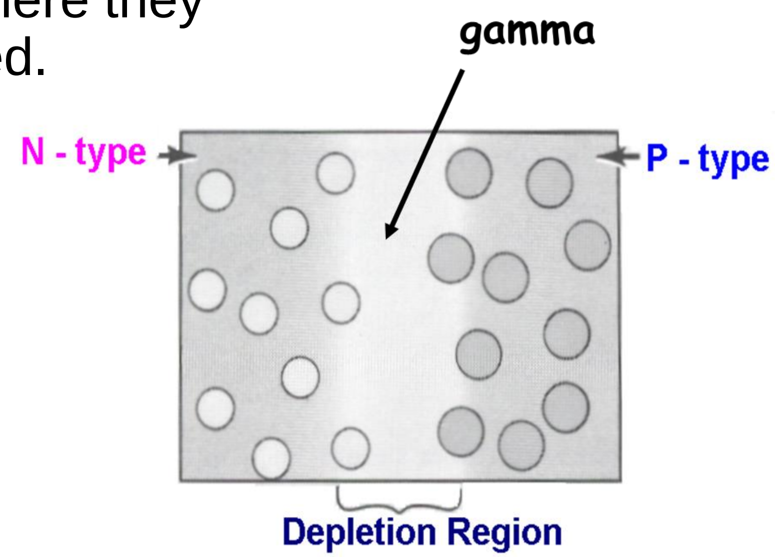
Note: Continued on next slide.



Only a small amount of energy is required to create an electron-hole pair .

Semiconductor Detector

6. Crystal must have a center depletion region formed by use of very high purity materials.
7. Ionizing radiation interacts in center depletion region, leaving “holes”.
8. Center depletion region acts as a solid “fill gas” and “electron hole pairs” are equivalent to ion pairs in a gas filled detector.
9. Under the influence of an electric field, electrons and holes travel to the electrodes, where they result in a pulse that can be measured.



Semiconductor Detector

- Semi-Conductors have a major advantage over scintillation due to better energy resolution (especially for alpha and beta), greater durability and easier of transport.
- There current drawback is the higher cost of Semi-Conductors. As the cost to produce Semi-Conductors goes down, their will be a greater increase in their use in the field.
- They are cooled by liquid nitrogen in order to reduce the thermal generation of charge carriers (thus reverse leakage current) to an acceptable level. Otherwise, leakage current induced noise destroys the energy resolution of the germanium detector.

Semiconductor Detector

Advantages

- Good energy resolution
- Unique energy peaks
- Durability
- Ease of transport

Disadvantages

- High cost
- The detector needs to be cooled

Selecting the appropriate meter

- Determining the appropriate instrument for performance of radiation surveys under various conditions is based on:
  - **Expected Radiation Type(s)** – i.e. General area walkways, Systems with RCS, charging water, gas lines, Containment entries, Fuel Pool.
  - **Expected dose rates** – Initial postings, previous survey maps of the area, RWP.
  - **Environmental conditions** – Temperature, noise, lighting, clearance of mobility (how cluttered with pipes and material in the area).

A pre-job review of area radiological conditions should update you on expected environment of the area to be surveyed.

Selecting the appropriate meter

- Many factors go into choosing the best instrument for a particular survey:
  - **Contamination or radiation survey**
  - **Expected radiation type(s)**
  - **Expected dose rate**
  - **Environmental conditions**
  - **Location of survey**
  - **Reason for survey**

Selecting the appropriate meter

- Contamination survey instruments
  - Normally called friskers
  - Most detect beta/gamma activity
    - Usually Geiger-Mueller type
  - Most commonly analog meters
  - Alpha detectors available
    - Usually scintillation type
  - Most readout in "Counts per Minute"

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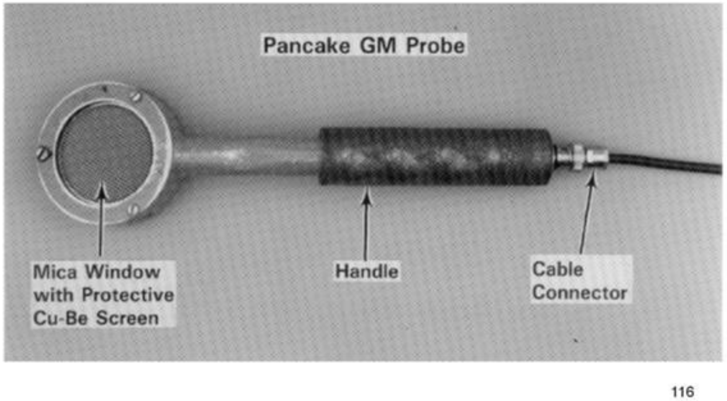
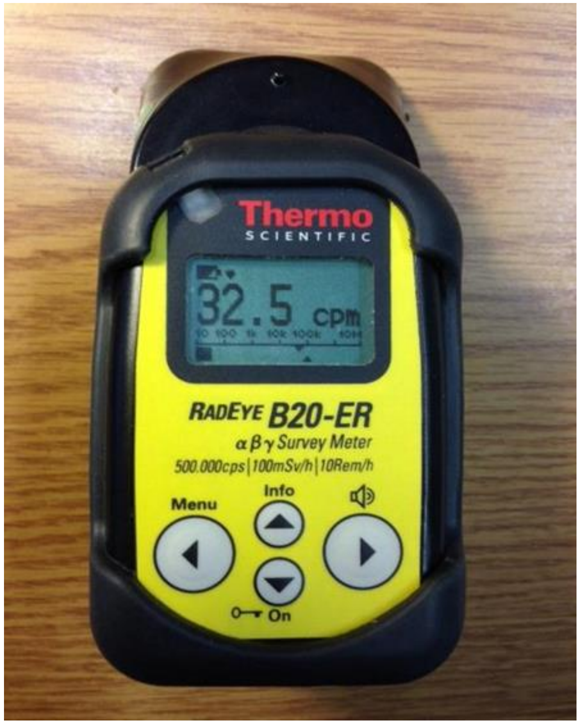
Selecting the appropriate meter

- Contamination survey instruments…
  - Used to detect fixed and/or loose surface contamination
  - Most have separate detector probe
  - Beta/gamma frisker probes generally easily interchangeable in case of damage



Selecting the appropriate meter

- Contamination survey instruments…
  - Analog count rate meters generally have manual range selection among 3 or 4 decades
  - Thermo RadEye B20-ER is exception- Digital display and auto-ranging as frisker with integrated probe
  - RadEye GX and SX types have separate probes



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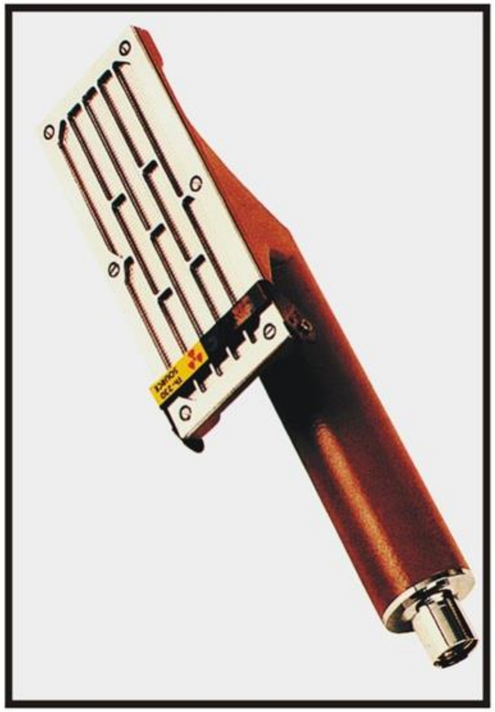
Selecting the appropriate meter

- Contamination survey instruments…
  - Choose instrument with range adequate to cover maximum anticipated count rate
  - Usually 50,000 or 500,000 cpm maximum
  - RadEye B20-ER maximum 500,000 **cps**
  - Alpha or pure gamma direct survey usually conducted with scintillation probe
  - Both probe types are delicate, alpha is light sensitive



Selecting the appropriate meter

- Radiation survey instruments
  - Usually called Dose Rate meters
  - Types for:
    - Beta/Gamma radiation
    - Gamma radiation only
    - Neutron radiation
  - Read out units may be R, REM, or RAD depending on equipment and intended use
  - Analog meters usually have a manual range selection, digital meters are usually auto-ranging

Selecting the appropriate meter

- Radiation survey instruments…
  - Detector type to use depends on intended use of data and method of data collection
  - Ion Chamber:
    - Primarily used to set habitability and stay time requirements
    - May have moveable shield to determine beta dose rates
    - Usually integral detector

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Selecting the appropriate meter

- Radiation survey instruments…
  - G-M detector:
    - May have external probe connected by cable or arm to perform readings away from the detector, possibly including underwater
    - Required for rad material shipping surveys

Selecting the appropriate meter

- Radiation survey instruments…
  - Scintillation detector:
    - Used for sensitivity
    - Detects very low levels of gamma radiation
    - Used to survey clean items exiting protected area
    - Used to survey clean surfaces outside RCA

Selecting the appropriate meter

- Radiation survey instruments…
  - Neutron detector:
    - Various types
    - Detects neutrons indirectly
    - Uses material and electronics to simulate effects on humans

Operability Checks

- Physical condition
- Meter zero
- Calibration date
- Battery check
- Source check response
- Available Scales
- Documentation

Operability Checks

Physical Condition: Ensures all switches, meter movement and detector, including the detector cable, if applicable, are in good condition.

Meter zero: Some meters allow for a physical adjustment of the needle zero.

There is a mechanical zero located in front of the meter handle. This is not to be adjusted as part of the daily performance check.

Calibration date: Check the calibration sticker for verification of calibration within the last six months.

Battery check: Ensure the batteries are within the battery okay range, if batteries are below the battery okay range, replace the batteries prior to performing any work.

Note: Continued on the next slide.

Operability Checks

<u>Source check</u>: Ensures the meter responds to the source correctly. Permissible tolerance is $\pm$ 20 percent.
<u>Available scales:</u> Depending on the radiation dose field to be entered would depend upon the available scales required. Ensure you obtain the proper meter for the radiation field to be entered.

If not immediately signed out for use, instruments that pass pre-operational checks should be turned off and placed in an area or location identified for storage of equipment “ready for use”. The instruments are turned off to conserve the batteries used to power the detector and those used for powering components such as the electrical signal amplifiers. If the battery power indicator shows low on the instrument, then replace all the batteries to ensure adequate power is available to all meter components.

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Operability Checks

Documentation: Site specific procedures give direction on sources to use and anticipated instrument responses. Perform checks in accordance with procedure; then DOCUMENT the results. Follow procedure instructions for instruments that fail pre-operational checks. Defective instruments or those tagged as out of service should be segregated from operational instruments to prevent use of inoperative equipment.

Identify the Risk

The radiation dose field one would be entering would determine the type of meter to be used. Ensure you obtain the proper meter for the expected radiation field to be entered.

An example would be, entering a high gamma field with a tele-pole on a low range setting. The instrument could become saturated and read incorrectly leaving you in a higher dose field causing you a higher than anticipated dose. While a GM detector is great for reading gammas and is very accurate it is not always the best choice as an only meter. A good practice is to enter with 2 separate instruments such as an ion chamber and a tele-pole at the higher setting. The ion chamber may take a little longer to respond but it will not saturate as a GM could.

Conditions that may effect survey instrument response

Geotropism: The effect of gravity on the meter reading depending on how it is held.

Atmospheric pressure: Most often seen on containment entries for certain meters.

High humidity: May inhibit gas interaction particularly in Ion Chambers. Ion chambers have an internal desiccant to remove moisture.

Mixed radiation fields: Neutron interaction can effect proportional counter readings for Alpha (not commonly a problem).

Noble gas atmospheres: Can saturate Ion Chambers. Ion chambers (Ro2 & Ro2A) when saturated will render a false high reading.

Extreme temperatures: Can adversely effect meter's circuity.

Off-scale reading: Improper scale, meter contamination, GM saturation.

Radiofrequency interference: High voltage areas that cause EMF. Electromagnetic Frequency (EMF) that can cause interference with survey instruments are welding units, magnets, walkie-talkies, high voltage lines.

Factors Affecting Alpha Survey Results

- **Probe contamination** – go to a low background area to verify probe contamination or interference from other types of radiation.
- **Distance between the probe and surface being monitored** – hold the detector ~ **¼ inch** from the surface.
- **Climatic conditions** – humidity and atmospheric pressure will affect the response of the detector, especially a gas proportional counter detector.
- **Instrument repair and calibration** – ensure the instrument is in good condition and has a current calibration. (**PROBE and METER CALIBRATED TOGETHER**)
- **Type of surface and overlying material** – irregular surfaces may prevent holding the detector within ¼ inch of the surface being monitored. Liquids or other materials on the surface being monitored will absorb the alpha particles and prevent their detection.
- **Monitoring technique** – the detector must be moved slowly over the surface being monitored to give the meter time to respond.

Operational Characteristics/Correction Factors

There are various types of Ion Chamber meters. (RSO-5, RSO-50, Fluke 451B to name a few) These meters are vented to air, some have a plastic body while others may have a metal body. They will have a Beta window as shown (to the right) to detect Betas, however each meter will have a correction factor.

Determine the gamma dose rate by holding the instrument in a steady position with the window closed and allowing the readout to stabilize.

Determine the beta dose rate by obtaining an open window readings with the instrument in the same position. Apply the following calculation:

To obtain a Beta reading take the open window reading and subtract the closed window reading and then multiply the difference of the two numbers by the beta correction factor. The meter to the left uses a beta correction factor of 4.

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Operational Characteristics/Correction Factors

Beta Dose Rate units in

$$Mrad/hr=(OW\text{-}CW)\times CF_{\beta}$$

where:

***OW*=**

Window Open

***CW*=**

Window Closed

***CF$_{\beta}$*=**

Beta Correction Factor

(BF is provided on the instrument label

or in site procedures)

Some meters will self zero and some may auto range, you must be cognizant of what range your meter is on. Others require manual zeroing and manual Range changing.

Knowledge check

You have an open reading on a valve of 10 mr/h and a closed window reading of 20 mr/h, using a correction factor of 4 what is your Mrad/hr reading? Do your math and give it to the Instructor for discussion.

GM Detector(s)

The Telepole or (Extender) has an extendable probe for surveying inaccessible or high dose areas. This meter is very sensitive but is prone to saturation in very high dose rate areas. Keep in mind that if one is using a GM detector (Telepole) to gain a reading on a specific location that reading will always be higher than that of an ion chamber due to the size of the detector and decreased distance from the source. Keep in mind this detector cannot discriminate between Beta/Gamma

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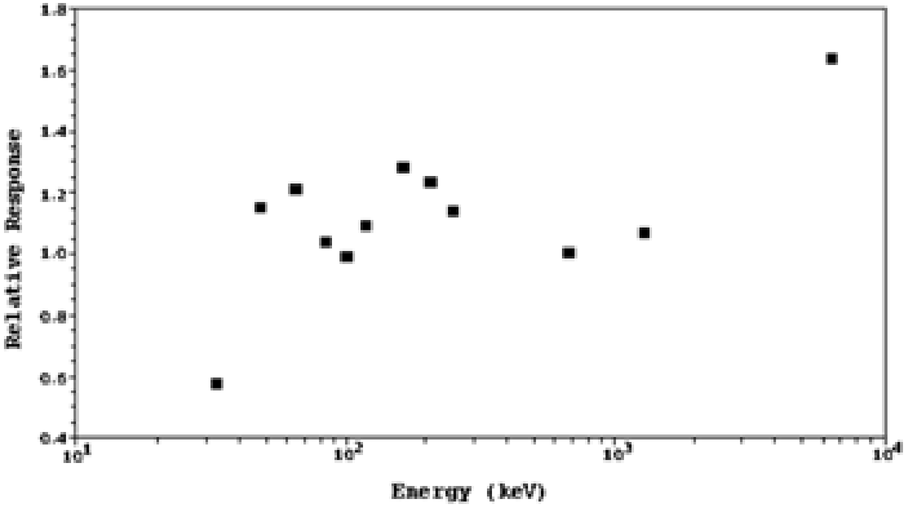
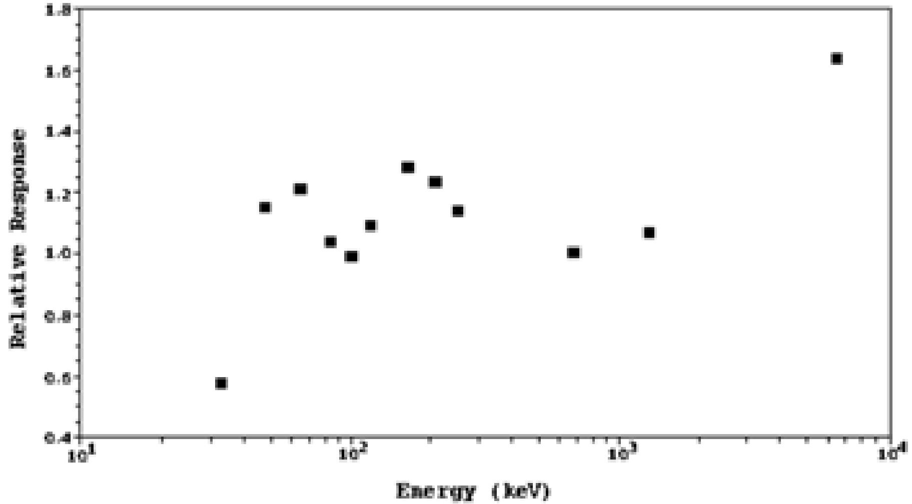
Six Region Curve – Geiger-Mueller Gamma Energy Response Curve



As can be noted in the graph above, the "thin wall" style GM tube with an 80 mg/sq. cm window provides excellent transmission for low energy photons below 100 keV. However, relative to Cs-l37 it does over-respond by nearly a factor of 13 at 70 keV. This results from the high photon influence being transmitted through the cathode wall, a high interaction probability, and the subsequent discharge events being counted. In the intermediate energies the response is relatively flat, but does begin to increase slightly above 1 MeV. The latter is due to the increase in number of secondary charged particles from pair production.

Six Region Curve – Geiger-Mueller Gamma Energy response curve



Over-response below about 200 keV may be reduced by adding a thin layer filter of high atomic number metal over the tube with an appropriate open area. This effectively attenuates a portion of the low energy photon influence. With proper engineering, one can easily obtain a 20% response from 50 keV to 1.25 MeV using a "thin wall" GM tube and energy compensation filter. However, the high atomic number filter actually causes an increased over-response in the 6 MeV range compared to the bare tube. This is no doubt due to energetic secondaries produced in the energy compensation filter, passing through the GM tube cathode wall and causing a discharge.

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GM Detector(s)

The Frisker operates by ac line or internal battery which is continuously trickle charged while the unit is plugged in. Used with G-M tube pancake probe, detects Beta, Gamma, used primarily for personnel monitoring, contamination monitoring. On the Frisker the correction factor from Counts Per Minute or “CPM” to Disintegrations Per Minute or “DPM” is designated by the dial on the face. As an example if your meter is on the times 1 setting and your meter reads 100 CPM to calculate DPM you would multiply 100 by a correction factor of 10 which is 1000 dpm. A correction factor of 10 is used as the meter has a 10% deficiency that needs to be corrected.

Knowledge check

You are counting a smear on the times 1 scale. Your background reading is 100. As you begin your count the meter jumps to 400 cpm. How many dpm is that.

Do your math and give it to the Instructor for discussion.

If counting samples or smears for several minutes on a counter/scaler divide the total counts by the total count time to obtain counts per minute (cpm). Subtract any background activity and ensure background levels are also expressed in counts per minute. Example- The total sample count on a smear for 5 minutes is 1500 counts this = 300 cpm. If a 60 minute background count produces 6000 total counts this would equal 100 cpm background. 300 cpm minus 100 cpm background = 200 net cpm on the smear.

Solid State Detector(s)

A solid state detector in ionizing radiation detection physics is a device that uses a semiconductor (usually silicon or germanium) to measure the effect of incident charged particles or photons.

These types of detectors have a much improved energy resolution and improved stability, however are more expensive and sensitive as previously discussed.

Examples of Solid State Detectors

Scintillation

Semiconductor

Scintillation Detector(s)

The scintillation detectors can detect low level radiation common to loose surface and fixed contamination, it is readily portable and can discriminate energy of gamma. But keep in mind it is light and temperature sensitive and easily damaged. These meters will have an associated correction factor, verify the correction factor prior to using. Counts minus background divided by the correction factor. Example; 100 cpm divided by a correction factor of .45 equals 222 dpm

Semiconductor Detector(s)

The following slide contains a picture of a Gamma Spectroscopy and High Purity Germanium detector

A semiconductor detector in radiation detection is a device that uses a semiconductor (usually silicon or germanium) to measure the effect of incident charged particles or photons.

The semiconductor devices are temperature sensitive. Even a small overheating may cause damage. They are cooled by liquid nitrogen in order to reduce the thermal generation of charge carriers (thus reverse leakage current) to an acceptable level. Otherwise, leakage current induced noise destroys the energy resolution of the germanium detector.

Semiconductor Detector(s)

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Review

Terminal Objective

- When working as a RP technician at a U.S. nuclear utility, the individual will be able to properly select, setup, and use portable survey instruments in order to support worker activities in a radiological control area in accordance with the standards of NISP-RP-02.01, Portable Survey Instruments.

Enabling Objectives

1.) Describe the theory of operation for the following detectors:

- **Gas Filled**
  - GM
  - Proportional Counter
  - Ion Chamber
- **Scintillation**
  - Zinc Sulfide
  - Plastic Scintillation
  - NaI
  - CsI
  - Dual Scintillation
- **Solid State**

Enabling Objectives

2.) Identify the correct instrument to use based on the type of survey to be performed

3.) Describe the preoperational checks required for portable instruments:

    Visual

    Calibration check

    Battery check

    Source check

    Available scales

    Documentation

4.) Identify the risk of an off-scale reading high due to the potential for over-ranging conditions.

Enabling Objectives

5.) Describe conditions that might affect survey instrument response.

6.) Describe the operational characteristics of:

- Gas filled detectors
- Scintillation detectors
- Solid State detectors

7.) Given a correction factor, calculate:

- Ion Chamber, Beta/Gamma readings
- GM tube, cpm to dpm

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