Radiation Detectors - Overview

Introduction to Radiation Detectors

Two Categories of Detector Systems

1. Passive Integrating Detector Systems

    - do not require power during deployment
    - do not record individual interactions of radiation
    - might or might not need to be processed
    - cannot provide real time readout (usually)
    - most passive detectors are dosimeters
    - e.g., TLD, film dosimeter

2. Active Detector Systems

    - require power
    - real time readout
    - usually register individual interactions of radiation
    - e.g., GM detector

Passive Integrating Detector Systems

Passive Integrating Detector Systems

General

- Radiation interactions produce some type of change in the "detector."
- The accumulated change due to multiple interactions of radiation is determined at the end of the deployment period.
- The accumulated change is related to the quantity of interest.
- Primarily used as dosimeters to measure dose.
- Might be used to assess the average level of radiation during deployment, e.g., radon concentration.

Passive Integrating Detector Systems

Examples

Detector	Effect Related to Exposure	Principle Types of Radiation Assessed
Thermoluminescent dosimeters (TLD)	Intensity of emitted light when heated	Gamma rays, x-rays, betas, neutrons
Optically Stimulated Luminescence (OSL) dosimeter	Intensity of emitted light when exposed to light	Gamma rays, x-rays, betas,
Film dosimeters	Darkening (OD) of film	Gamma rays, x-rays, betas
Pocket dosimeters (electroscope)	Displacement of fiber due to decrease in charge	Gamma rays, x-rays, neutrons
Bubble dosimeters	Number of bubbles produced	Neutrons
Electrets	Decrease in voltage/charge	Radon, gamma rays, x-rays
Chemical dosimeters	Change in color	Gamma rays, x-rays
DIS dosimeters	Change in current	Gamma rays, x-rays

Active Detector Systems

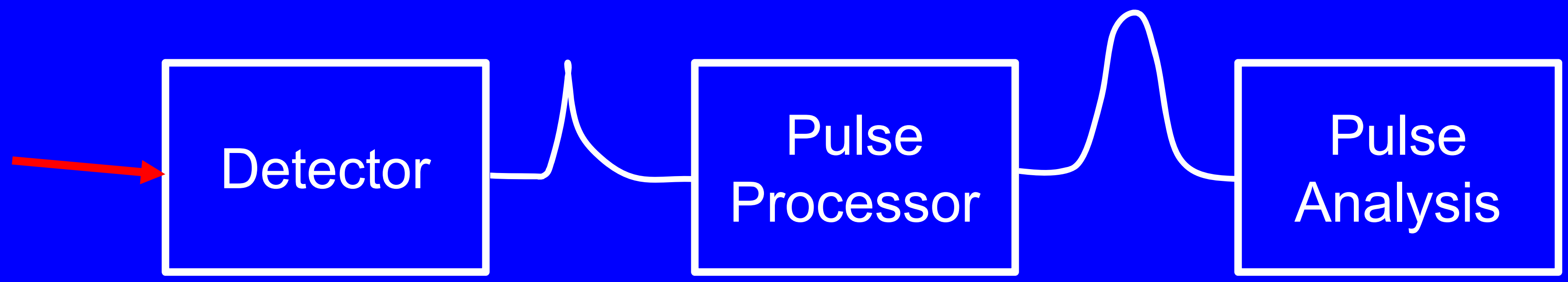
Active Detector Systems

System Components

Systems operating in the pulse mode consists of a:

1. Detector
2. Pulse processing device
3. Pulse analysis device

Simplified block diagram:



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1. Detector

- An electronic pulse is produced each time a "particle" of radiation (alpha, beta, gamma, neutron, etc.) interacts with the detector. The greater the intensity of the radiation, the more pulses per unit time.
- With many detectors (e.g., proportional counter, NaI detector) the greater the energy deposited in the detector, the larger the pulse size.
- With some detectors (e.g., GMs), the size of the pulse is not related to the energy deposited.
- If the pulses are very small and difficult to distinguish from electronic noise, the system might measure the current from the detector rather than analyze the individual pulses.

Active Detector Systems

1. Detector

Three categories of active detectors:

- Gas detectors (three types)
- Scintillation detectors (many types)
- Semiconductor detectors (three types)

Active Detector Systems

1. Detector

Types of Gas Detectors	
Detector	**Principle Types of Radiation Assessed**
Ion Chamber	Gamma rays, x-rays
Proportional Counter	Alphas, betas, neutrons
Geiger-Mueller (GM) Detector	Gamma rays, x-rays, betas

Active Detector Systems

1. Detector

Examples of Scintillation Detectors	
Detector	**Principle Types of Radiation Assessed**
Sodium Iodide (NaI)	Gamma rays, x-rays
Lanthanum Bromide or Chloride ($LaBr_3$, $LaCl_3$)	Gamma rays, x-rays
Cesium Iodide (CsI)	Gamma rays, x-rays
Plastic	Gamma rays, x-rays, betas
Zinc Sulfide (ZnS)	Alphas
Liquid Scintillation (LSC)	Betas, alphas
Lutetium Oxyorthosilicate (LSO)	Annihilation photons
Bismuth Germanate (BGO)	Annihilation photons
Glass (lithium, cerium)	Neutrons

Active Detector Systems

1. Detector

Types of Semiconductor Detectors	
Detector	**Principle Types of Radiation Assessed**
Diode	alphas, betas
Lithium Drifted: Silicon (SiLi) Germanium (GeLi)	 x-rays gamma rays
High Purity Germanium (HPGe)	gamma rays, x-rays

Active Detector Systems

2. Pulse Processor

- Usually a preamplifier and linear amplifier.
- Less commonly, a biased amplifier might be employed.
- Some detectors (e.g., GM detectors) might not require amplifiers.
- Linear Amplifiers:
  - increase the size of all the pulse by the same factor, the gain.
  - change the shape of the pulses. In doing so, they also filter out noise.

Active Detector Systems

2. Pulse Processor

- Biased amplifiers:
  - apply a linear gain to those pulses coming out of the linear amplifier above a specific amplitude (the bias level).
  - this eliminates pulses from the linear amplifier below a certain size.
  - the remaining pulses are spread over the entire spectrum.
  - most common application is in alpha spectroscopy.

Active Detector Systems

3. Pulse Analysis

- Threshold
  - Pulses smaller than the threshold setting are assumed to be electronic noise and are not analyzed.
  - The appropriate threshold setting depends on the magnitude of the noise and the size of the radiation-generated pulses. This depends on the detector type.
  - Since GM detector pulses are large, a high threshold setting can be used, e.g., 30 - 300 mV.
  - Some pulses produced by scintillators and proportional counters are small. As such, these detectors employ a much lower threshold, e.g., 5 mV.

Active Detector Systems

3. Pulse Analysis

- Threshold cont.
  - If different types of detector might be connected to the same rate meter or scaler, a compromise threshold might be used, e.g., 30 mV.
  - The threshold is often set at the factory and not easily changed. However, with some meters the threshold can be displayed and adjusted without having to open up the instrument.
  - With so-called "smart" systems, the meter can identify the probe to which it is connected and adjust the threshold accordingly.

Active Detector Systems

3. Pulse Analysis

- Window
  - In some situations, it can be advantageous to limit the analysis to radiation-generated pulses in a certain size range.
  - Some meters have two “windows” that allow the user to select the size of the pulses to be counted (e.g., small pulses, large pulses, or small and large pulses).
  - Other systems employ upper and lower level discriminators that screen out pulses above and below a user specified size. The threshold can be considered a zero adjust for the lower level discriminator.

Active Detector Systems

3. Pulse Analysis

Pulse analysis can involve:

a. Counting the pulses
b. Pulse height analysis
c. Pulse shape (duration) analysis

Active Detector Systems

3. Pulse Analysis

a. Counting the Pulses

The count or count rate can be related to the:

- exposure rate (e.g., mR/hr)
- dose rate (e.g., mrad/hr, mGy/hr)
- dose equivalent rate (e.g., mrem/hr, mSv/hr)
- activity of a source (e.g., dpm, Bq)

The device used to count the pulses is either a:

- rate meter, or
- scaler

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3. Pulse Analysis

a. Counting the Pulses – Count Rate Meter

- For our purposes, a count rate meter reads out in cpm (or cps) or has been calibrated to convert the count rate into a quantity such as exposure rate (mR/hr) or dose equivalent rate (mrem/hr, mSv/hr).
- Count rate meters employ an analog display (i.e., bouncing needle) or a digital display wherein the displayed count rate is "updated“ every second or so.
- When used to search for radiation/radioactivity, a count rate meter is usually set to a "fast response.” A slow response is preferred when accurate measurements are desired.

Active Detector Systems

3. Pulse Analysis

a. Counting the Pulses - Scaler

- Scalers perform counts over a selected time (e.g., 1 min).
- Primary applications: laboratory analyses, measuring alpha and beta surface contamination.
- Scalers permit the count to be read from an unambiguous digital display. Nevertheless, their main advantage is their ability to measure smaller increases above background than can be detected with count rate meters.
- Some combination instruments can function either as a ratemeter or as a scaler.

Active Detector Systems

3. Pulse Analysis

b. Pulse Height Analysis

- If the detector pulse height is related to the amount of energy deposited in the detector by the radiation, pulse height analysis (PHA) can be used to determine the energy of the radiation.
- Since the energy of radiation is characteristic of the radionuclide that produced it, pulse height analysis can be used to identify the radionuclide(s).
- The process by which we measure the energy of radiation is called spectroscopy.

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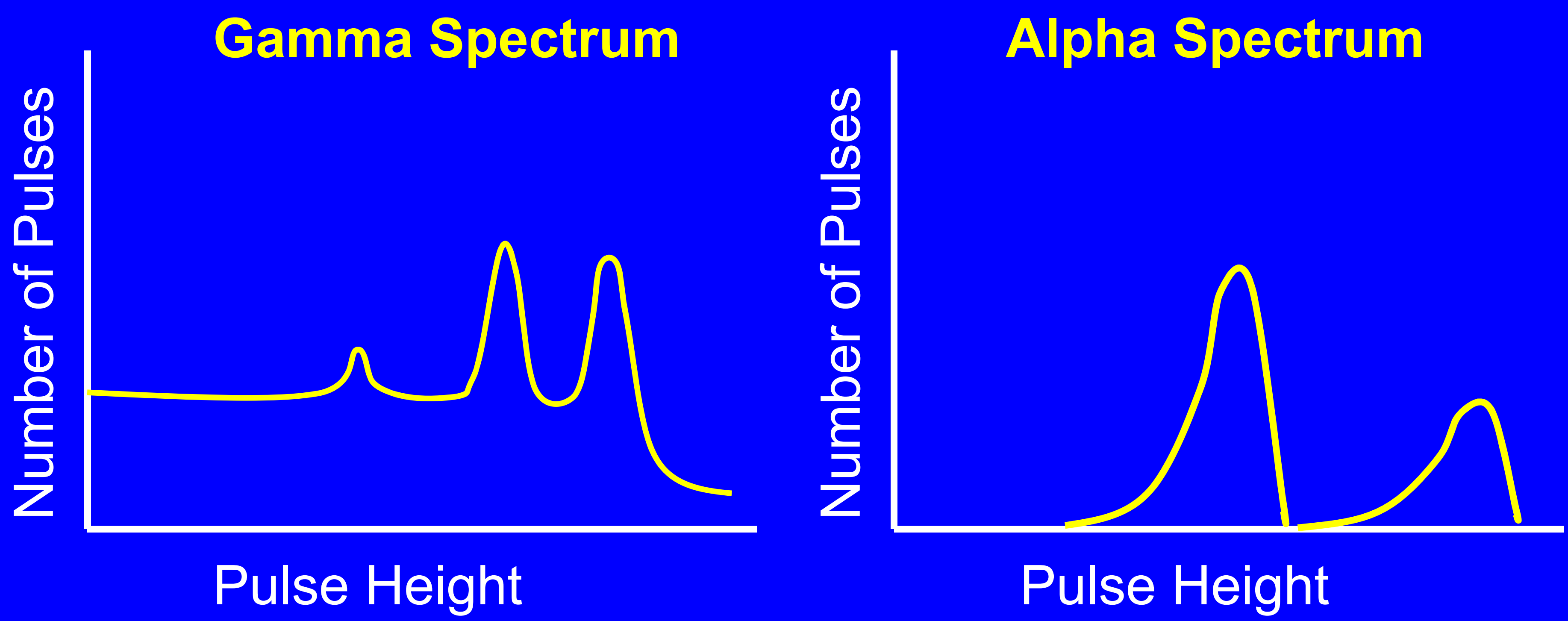
3. Pulse Analysis

b. Pulse Height Analysis

- The number of pulses displayed as a function of pulse height (or energy) is a spectrum.



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3. Pulse Analysis

b. Pulse Height Analysis

- A very simple form of pulse height analysis might be used to identify the type of radiation responsible for a pulse.

- For example, alpha pulses produced by proportional counters are usually larger than pulses produced by beta particles. By dividing the pulses into two size categories, it is possible to obtain simultaneous, but separate, measurements of alpha and beta activity.

Active Detector Systems

3. Pulse Analysis

c. Pulse Shape Analysis

- Pulses produced by different types of radiation (e.g., alphas and betas) can differ in shape. As such, pulse shape analysis might be used to distinguish the different radiation types.

- The pulse shapes might differ because the pulse rise time reflects the distribution within the detector volume of the deposited radiation energy and this distribution varies for different types of radiation.

Active Detector Systems

3. Pulse Analysis

c. Pulse Shape Analysis

- Pulse shape analysis can also be utilized to prevent two overlapping pulses from being misinterpreted as a single large pulse. This process is referred to as pile-up rejection.
- Individual "legitimate" single pulses coming out of an amplifier have a near-gaussian shape unlike overlapping pulses which can appear distorted.