Methods for Detector Comparison

- Detectors categorized by?
  -
  -
  -
- Performance described by?
  -
  -
  -
- Detection Operation Modes?
  -
  -

Methods for Detector Comparison

- Detectors categorized by
  - Function
  - Physical state of the transducer
  - Mode of operation
- Performance described by
  - Efficiency
  - Energy resolution & discrimination
  - Dead time
- Detection Modes
  - Single events (pulse mode)
  - Rate of energy deposition (current mode)

Introduction to Health Physics
Cember (2008)

TABLE 9-1. Radiation Effects Used in the Detection and Measurement of Radiation

EFFECT	TYPE OF INSTRUMENT	DETECTOR
Electrical	1. Ionization chamber 2. Proportional counter 3. Geiger counter 4. Solid state detector	1. Gas 2. Gas 3. Gas 4. Semiconductor
Chemical	1. Film 2. Chemical dosimeter	1. Photographic emulsion 2. Solid or liquid
Light	1. Scintillation counter 2. Cerenkov counter 3. Opticoluminescent dosimeter	1. Crystal or liquid 2. Crystal or liquid 3. Crystal
Thermoluminescence	Thermoluminescent dosimeter (TLD)	Crystal
Heat	Calorimeter	Solid or liquid

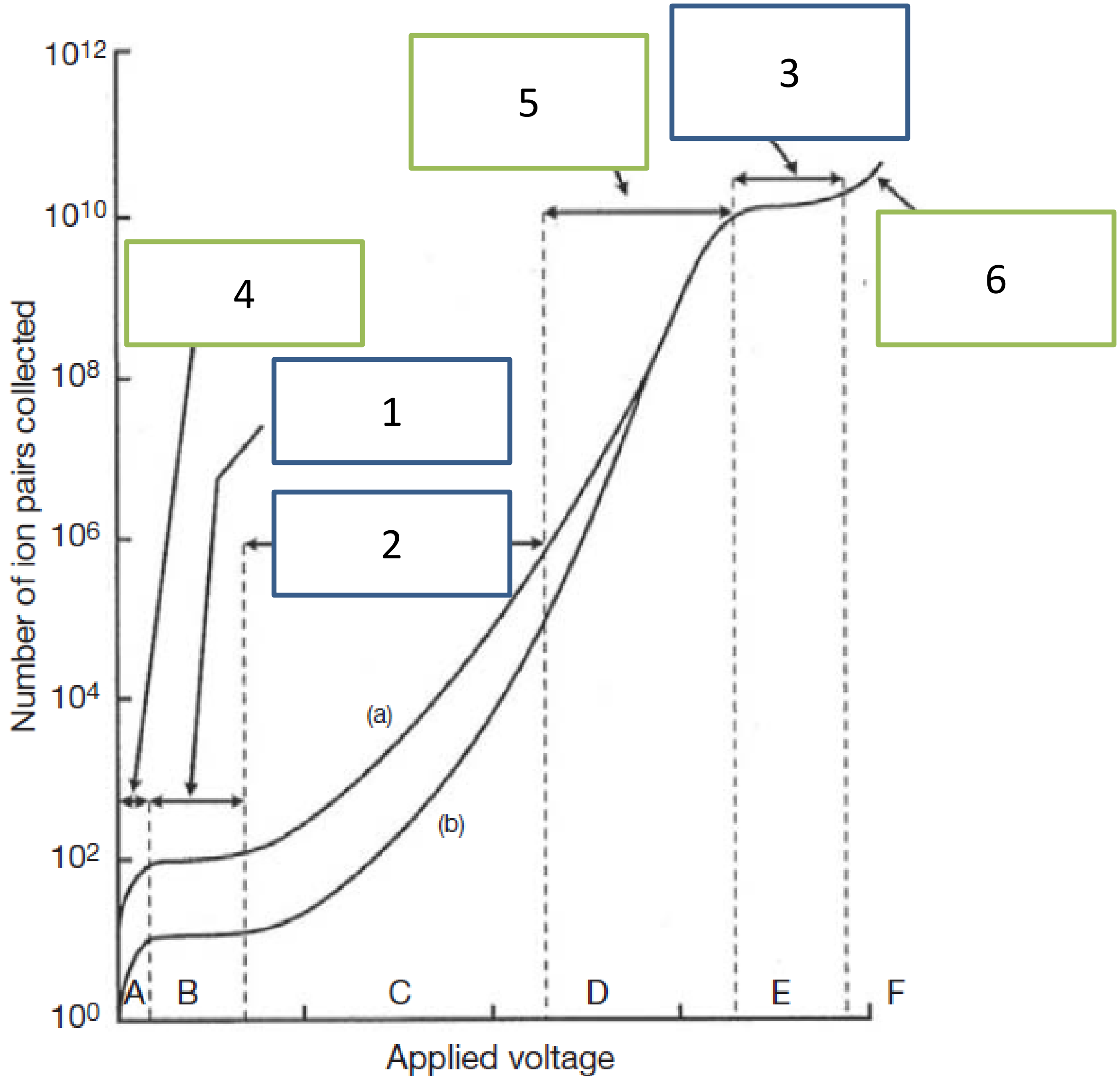
OSHA – Radiation Detection Instruments

OSHA - Introduction to Ionizing Radiation

Instrument	Detection Principle	Applications
Ion Chamber	Ionization of gas (air)	Direct measurement of exposure or exposure rate, with minimal energy dependence.
Geiger-Mueller & Proportional Counter	Ionization of gas w/ e^- multiplication	Detection of individual events (i.e. alpha or beta particles & secondary electrons) for measuring activity (in samples or on surface) & detecting low intensities of ambient x or gamma radiation; Precautions required for energy dependence.
Solid State Diodes	Ionization of semiconductor	Detection & energy measurement of photons or particles. Primarily for laboratory use.
Solid State Diodes	Ionization & excitation followed by light emission	Detection of individual events.
- Solids		- NaI(Tl) – photons; energy spectrometry
		- ZnS(Ag) – alpha particles; detection only
- Liquid		- Detection of low-energy beta emitters mixed w/ scintillation fluid.
Photographic Film	Ionization of Ag Br	Personal exposure monitoring.
Thermoluminescent Detecetor	Excitation of crystal; light release by heating	Personal and environmental exposure monitoring.

- Gas-filled detectors
  - Surveying, personnel/area monitoring, radionuclide dose quantitation
  - Inefficient detection of x-rays & gamma-rays relative to scintillation detectors
    - Ion Chamber
      - Accurate exposure readings from 1 mR to 1 R
      - Current mode operation, short dead times
      - More useful in high radiation fields than GM detectors
      - Relatively low sensitivity compared to GM detectors
    - Geiger-Muller
      - ~10x higher sensitivity than ionization detectors
      - Do not provide accurate measure of exposure, except for a limited range of calibration
      - Pulse mode operation, relatively long dead times (hundreds of microseconds)
      - Not useful in high radiation fields

Regions of Operation for Gas-Filled Detectors



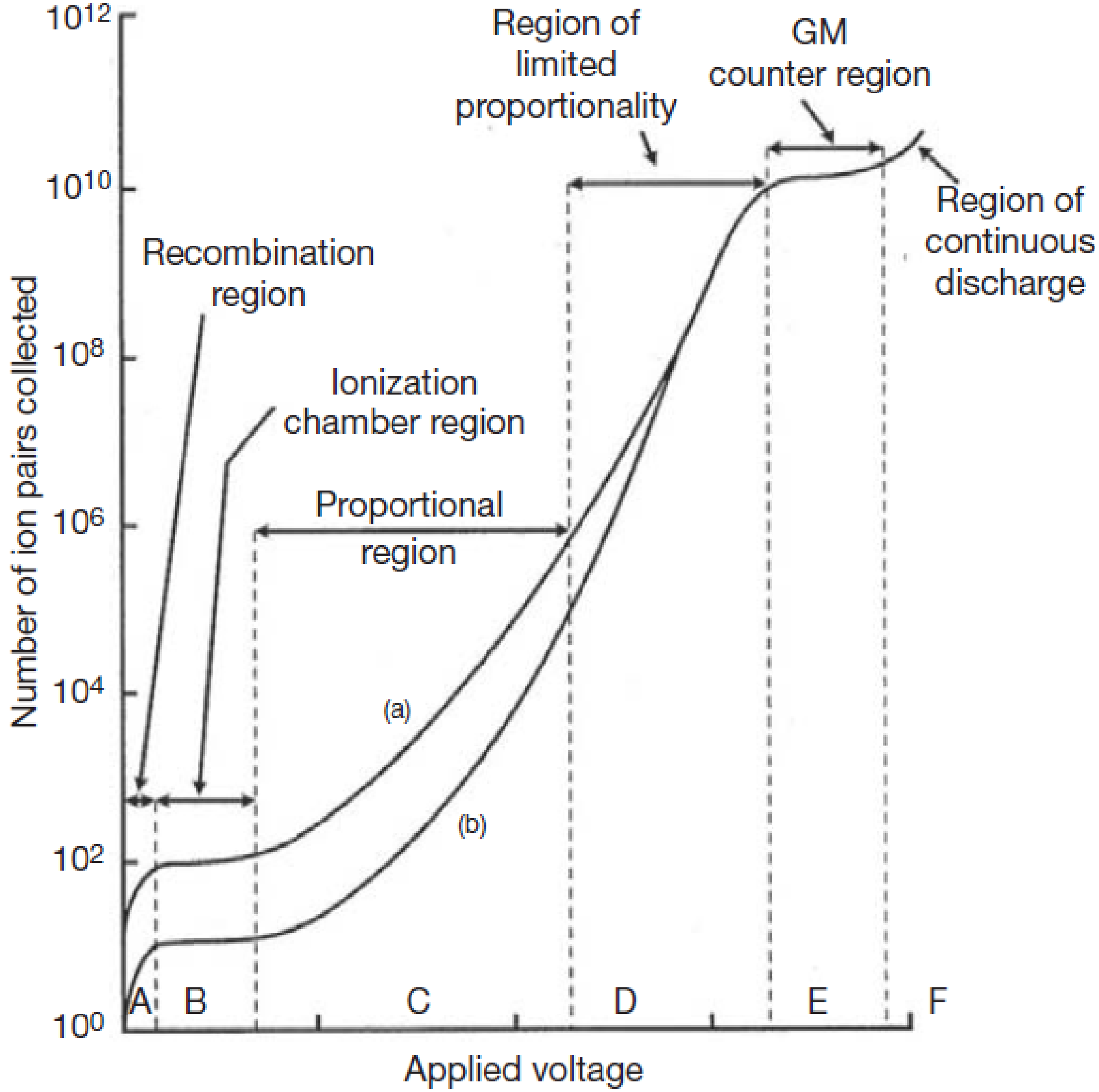


FIG. 4.1. Various regions of operation of a gas filled detector. Region A represents the recombination region, region B the ionization region, region C the proportionality region, region D the region of limited proportionality and region E the GM region. Curve (a) is for 1 MeV β particles, curve (b) for 100 keV β particles.

Radiation Oncology Physics

Podgorsak (2005)

- Most Common Dosimeters
  - Ion Chambers
  - Radiographic Film
  - TLDs
  - Diodes

TABLE 3.1. MAIN ADVANTAGES AND DISADVANTAGES OF THE FOUR COMMONLY USED DOSIMETRIC SYSTEMS

	Advantage	Disadvantage
Ionization chamber	Accurate and precise Recommended for beam calibration Necessary corrections well understood Instant readout	Connecting cables required High voltage supply required Many corrections required for high energy beam dosimetry
Film	2-D spatial resolution Very thin: does not perturb the beam	Darkroom and processing facilities required Processing difficult to control Variation between films and batches Needs proper calibration against ionization chamber measurements Energy dependence problems Cannot be used for beam calibration
TLD	Small in size: point dose measurements possible Many TLDs can be exposed in a single exposure Available in various forms Some are reasonably tissue equivalent Not expensive	Signal erased during readout Easy to lose reading No instant readout Accurate results require care Readout and calibration time consuming Not recommended for beam calibration
Diode	Small size High sensitivity Instant readout No external bias voltage Simple instrumentation	Requires connecting cables Variability of calibration with temperature Change in sensitivity with accumulated dose Special care needed to ensure constancy of response Cannot be used for beam calibration

The AAPM/RSNA Physics Tutorial for Residents:
Radiation Detectors in Nuclear Medicine
Ranger (1999)

LEARNING OBJECTIVES

After reading this article and taking the test, the reader will be able to:

- Describe the physical process of radiation detection and the components of each detector stage.
- Define the terms *efficiency*, *energy resolution*, *energy discrimination*, and *dead time*.
- List and compare the different categories of radiation detectors.
- Describe the characteristics and function of each of the radiation detection devices found in the clinical nuclear medicine setting.

Single-photon-emitting or positron-emitting radionuclides employed in nuclear medicine are detected by using sophisticated imaging devices, whereas simpler detection devices are used to quantify activity for the following applications: measuring doses of radiopharmaceuticals, performing radiotracer bioassays, and monitoring and controlling radiation risk in the clinical environment. Detectors are categorized in terms of function, the physical state of the transducer, or the mode of operation. The performance of a detector is described by the parameters efficiency, energy resolution and discrimination, and dead time. A detector may be used to detect single events (pulse mode) or to measure the rate of energy deposition (current mode). Some detectors are operated as simple counting systems by using a single-channel pulse height analyzer to discriminate against background or other extraneous events. Other detectors are operated as spectrometers and use a multichannel analyzer to form an energy spectrum. The types of detectors encountered in nuclear medicine are gas-filled detectors, scintillation detectors, and semiconductor detectors. The ionization detector, Geiger-Müller detector, extremity and area monitor, dose calibrator, well counter, thyroid uptake probe, Anger scintillation camera, positron emission tomographic scanner, solid-state personnel dosimeter, and intraoperative probe are examples of detectors used in clinical nuclear medicine practice.

Efficiency

- Absolute efficiency:
  - $\varepsilon_{absolute} = \varepsilon_{intrinsic} \times \varepsilon_{geometric}$
- Intrinsic efficiency
  - Ratio of detected events to radiation quanta
  - Determined by stopping power of transducer
    - $P_\gamma = 1 - e^{-\mu x}$
  - Decreases with photon energy, Increases with density
- Geometric efficiency
  - Ratio of radiation quanta incident on detector to total emitted
  - Decreases with increasing source-to-detector distance (IVS)
  - Well chamber designed to achieve >90% geometric efficiency

Energy Resolution

- Spectrometers

$$\frac{FWHM}{PE} \times 100\%$$

  - FWHM = Full width half-maximum
  - PE = photopeak energy

- Affected by
  - size, thickness, state of transducer
  - Photon energy
  - Electronic characteristics

Dead Time

- Pulse mode detectors:
  - Pulse duration or electronic dead time limits the rate of detection due to individual processing
  - Non-paralyzable systems
    - reject events that arrive before complete processing of previous event
  - Paralyzable systems (scintillation camera)
    - also reject these events, but the arrival of a secondary event also extends the dead time which may cause rejection of a tertiary event

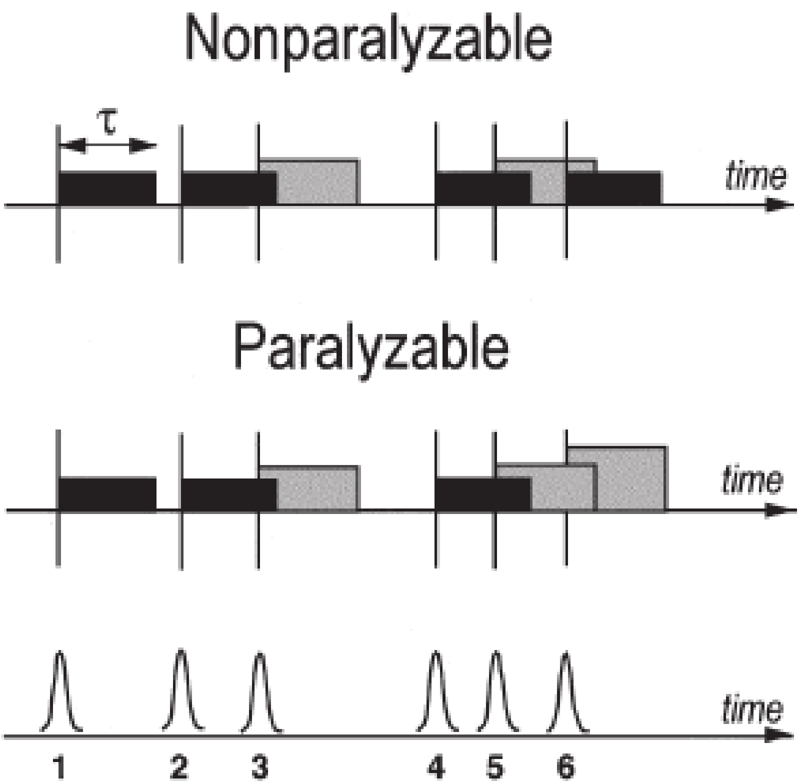


Figure 6. Diagram shows two categories of dead time. Black bars = processed events, gray bars = non-processed events. In a system with nonparalyzable dead time, events that arrive before complete processing of earlier events are rejected (events 3 and 5). In a system with paralyzable dead time, the usual dead time effect is experienced; however, the arrival of a secondary event extends the dead time, causing the secondary event to be rejected. This feature is demonstrated by the rejection of event 6 in addition to events 3 and 5.

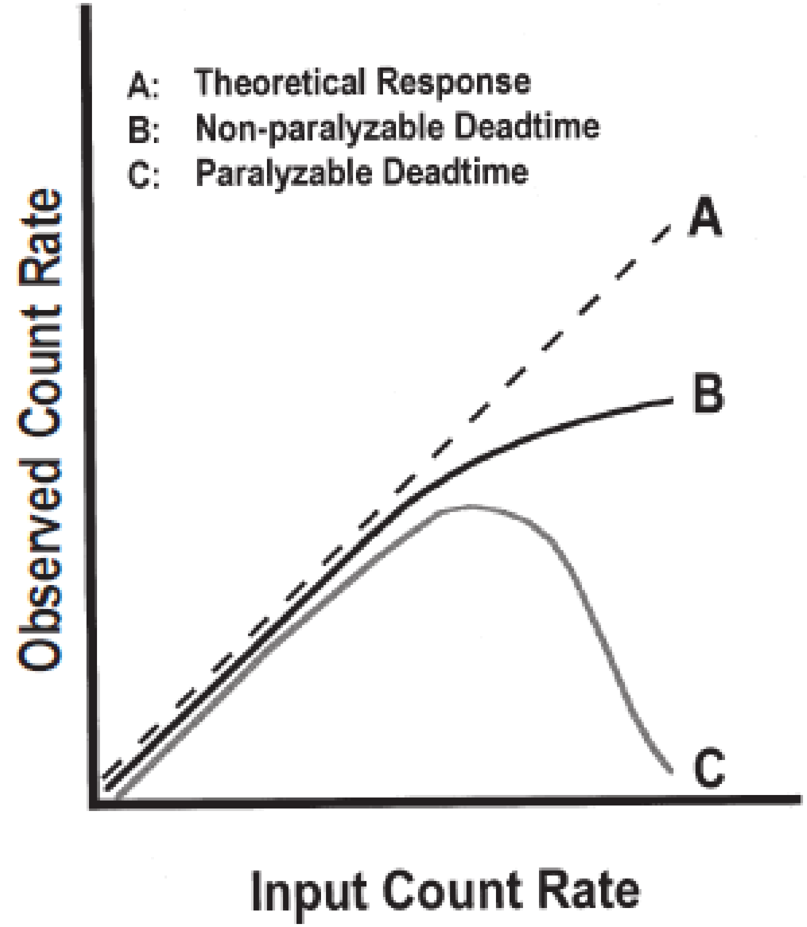


Figure 7. Diagram shows the effects of dead time on counting efficiency. *A* is the response of an ideal detection system: a straight line with a slope of 1. *B* is the response of a nonparalyzable system. The dead time increases with increasing counting rates, an effect that results in significant counting losses and counting rate saturation in the plateau region. *C* is the response of a paralyzable system. Saturation is again experienced; however, as the input rates increase beyond the saturation region, the system becomes paralyzed. The result is a rapid loss of detection efficiency beyond the saturation region.