Chapter 9

Instrumentation

Objectives

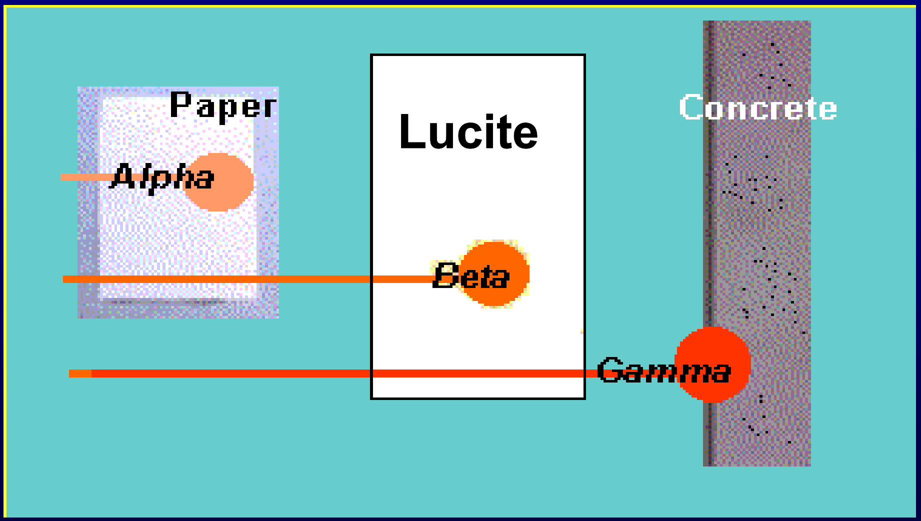
- Describe the interaction of radiations with each type of detector (gas-filled, solid state, and other commonly used portable HP detectors)
- Discuss the three high-voltage regions in which gas-filled detectors operate

Objectives

- Determine which types of detectors are appropriate for a given set of radiation detection circumstances
- Describe the advantages and disadvantages of different types of radiation detectors

Methods of Radiation Detection

- **What types of radiation will need to be detected and what are their characteristics?**
- **What qualities or characteristics would a detector need in order to detect the radiations of interest under real world circumstances?**



Detecting Alpha Radiation

- Alpha particles can be stopped with a sheet of paper
- Zinc sulfide scintillation detectors have thin mylar windows and are commonly-used alpha detectors
- Portable gas proportional detectors with very thin mylar windows can also be used

Detecting Beta Radiation

- Beta particles are more penetrating than alphas, but can be stopped with a relatively thin layer of Lucite (plastic) or other low-Z materials
- Gas-filled detectors must have thin windows
- Solid, plastic scintillators (polymerized organic scintillators) are becoming more prevalent in the industry

Detecting Gamma Rays

- Gamma rays are very penetrating and require dense shielding
- Hence, the most efficient gamma detectors are solids, as large as practical
- Gamma ray detectors include sodium iodide and germanium crystals as well as plastic scintillators
- To measure gamma dose rates, portable dose rate meters are frequently gas-filled ionization detectors

Detecting X-Rays and Low-Energy Photons

- X-rays are typically lower energy than gamma rays, and some radioisotopes emit low-energy gammas.

- Detectors that are most efficient for lower energy photons have a thinner solid detector and may have side shielding added to reduce background.

Detecting Slow Neutrons

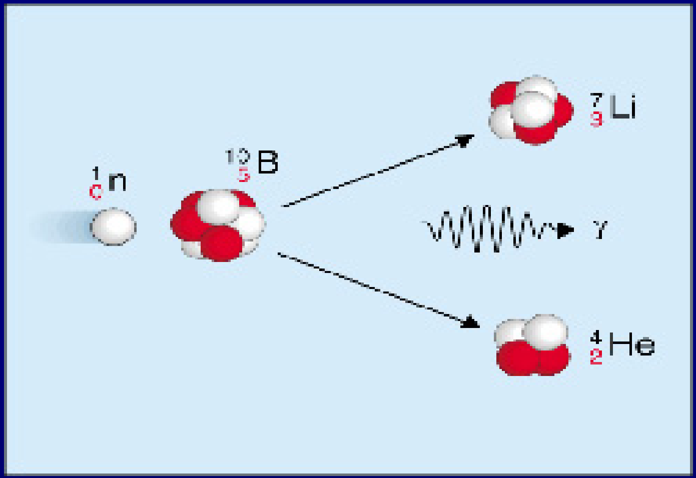
- Slow neutrons can be detected using boron trifluoride (BF_3) gas-filled tubes
- Other detectors utilize lithium or helium as the interacting media (less shipping hazard than BF_3)
- Detectors are also made of fissile material such as uranium and plutonium (the fission products are what are actually detected)

Detecting Fast Neutrons

- Fast neutrons can be detected by using a slow neutron detector surrounded by hydrogenous material to slow down the fast neutrons
- Also, recoil proton detectors do not rely on first slowing down the neutrons

Neutron Detectors

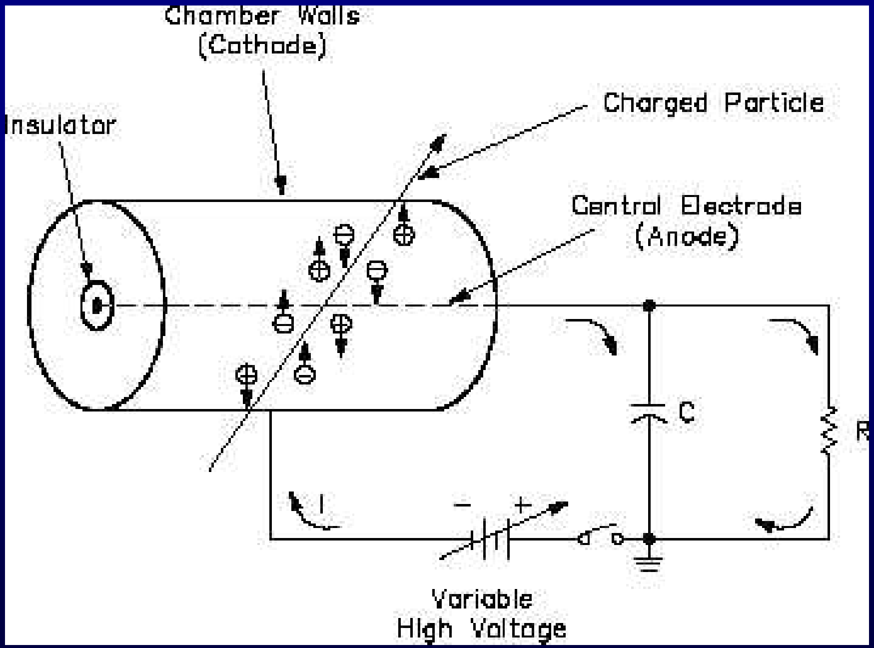
- A common neutron detector uses a tube filled with BF_3 gas
- When a neutron interacts with the boron, an alpha particle is emitted through the reaction $^{10}B(n,\alpha)^{7}Li$
- The alpha particles ionize the gas and cause a pulse
- The pulse information is then correlated to the neutron flux rate, and consequently to a dose equivalent value



- Often the detector probe is positioned in a sphere of material with a low atomic number. This helps slow down, or thermalize, the neutrons to increase the interaction probability

Gas-Filled Detectors

- Characterized by operating voltage that is applied to a gas-filled detector element
- Detector anode collects electrons formed during ionization of the detector gas by incident radiation
- The earliest radiation detectors
- "Geiger Counter" is one popular example

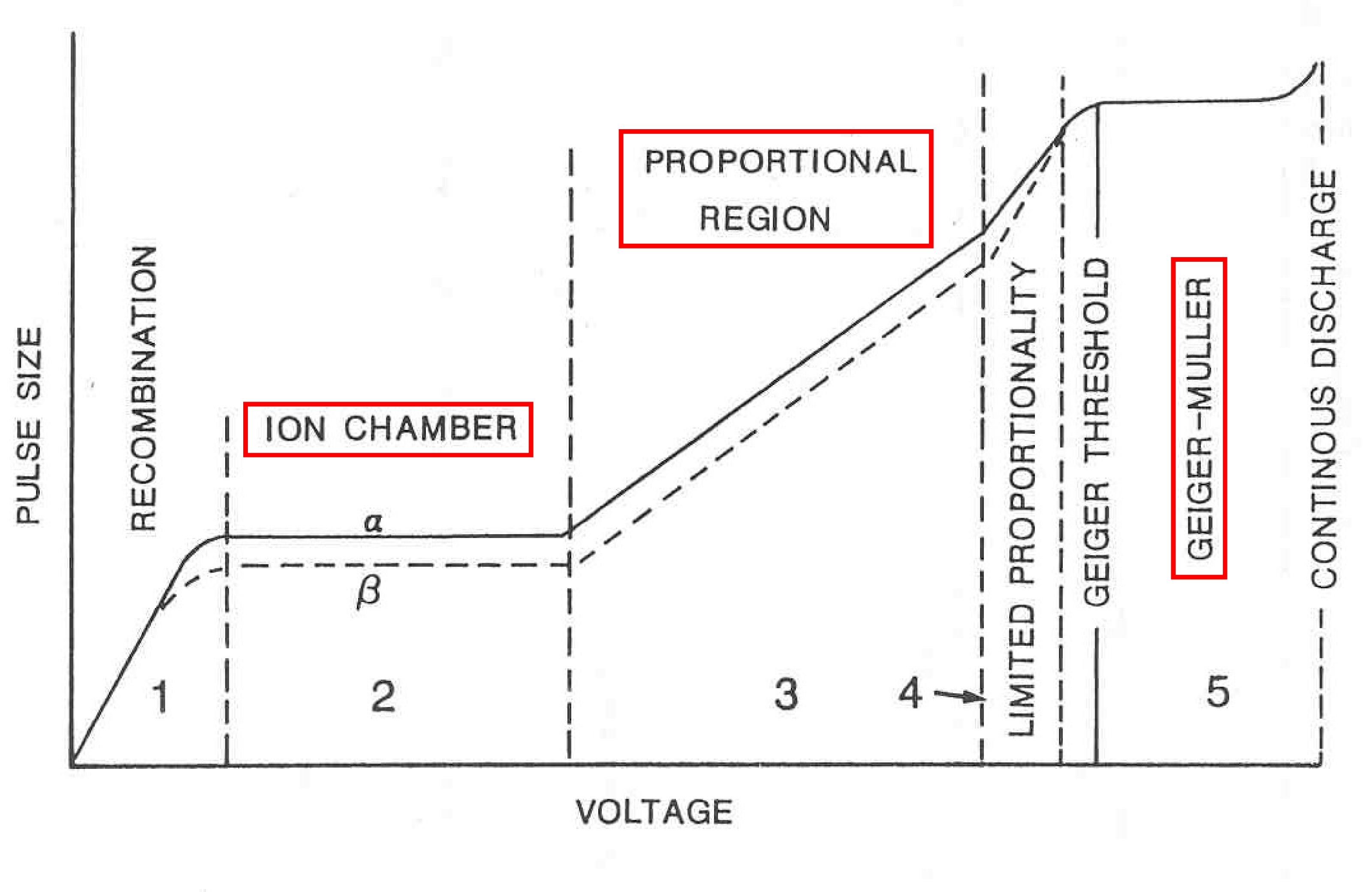


Gas-Filled Detectors

- Three high voltage regions in which gas-filled detectors operate:

1. Ionization region
2. Proportional region
3. GM region

Gas-Filled Detectors



Ionization Region

- Signal is measured that is equal to the energy deposited in the detector by directly ionizing particles
- These types of detectors can be used to differentiate between alpha, beta or gamma
- If meter is set to discriminate between the output created by an alpha or beta particle, the count rate of either particle can be determined

Proportional Region

- Uses higher voltage settings than ionization region
- Can still discriminate between different types of radiations
- Main advantage is that the signal coming from the detector will not require amplification to properly process the pulse in the metering system

Geiger-Mueller (GM) Region

- Voltages cause gas multiplication of electrons, with primary electrons causing many secondary ionizing events
- Pulse size detected is same whether the incident radiation is alpha, beta, or gamma
- Thus, detectors operating in this region cannot discriminate between various types or energies of incident radiation

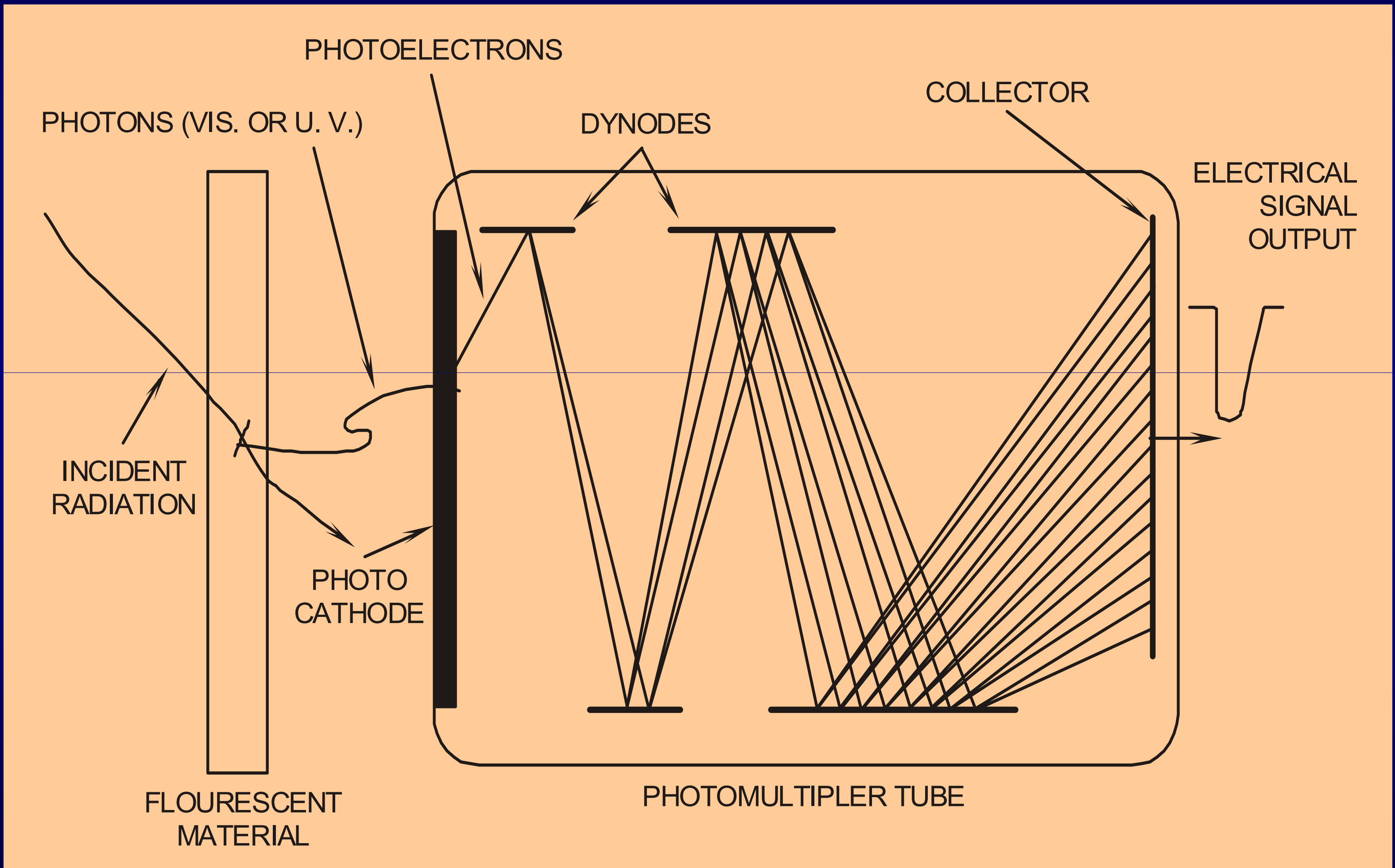
Gas-Filled Detectors

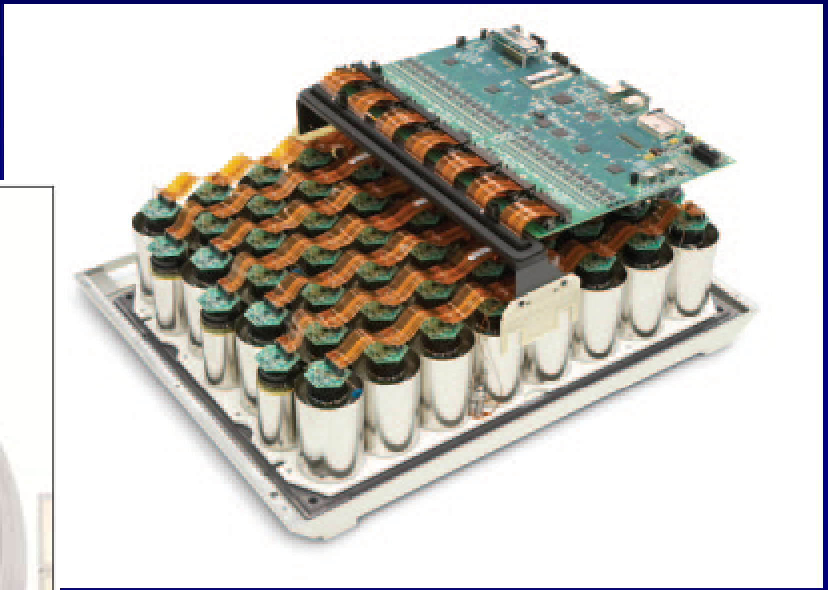
- Ionization chambers typically used for measuring dose rates
- Proportional counters typically used for quantification of contamination during surveys and counting smears/air samples
- GM detectors typically used to detect presence of radiation, e.g. beta contamination friskers and low dose rate (< 200 mR/hr) meters

Solid-State Radiation Detectors

- The scintillation process changes the kinetic energy of ionizing radiation into visible light
- The visible light is fed into a photosensitive cathode that converts a fraction of the light photons into photoelectrons
- The photoelectrons pass through a photomultiplier tube (PMT) which generates an electrical signal proportional to the scintillator light output

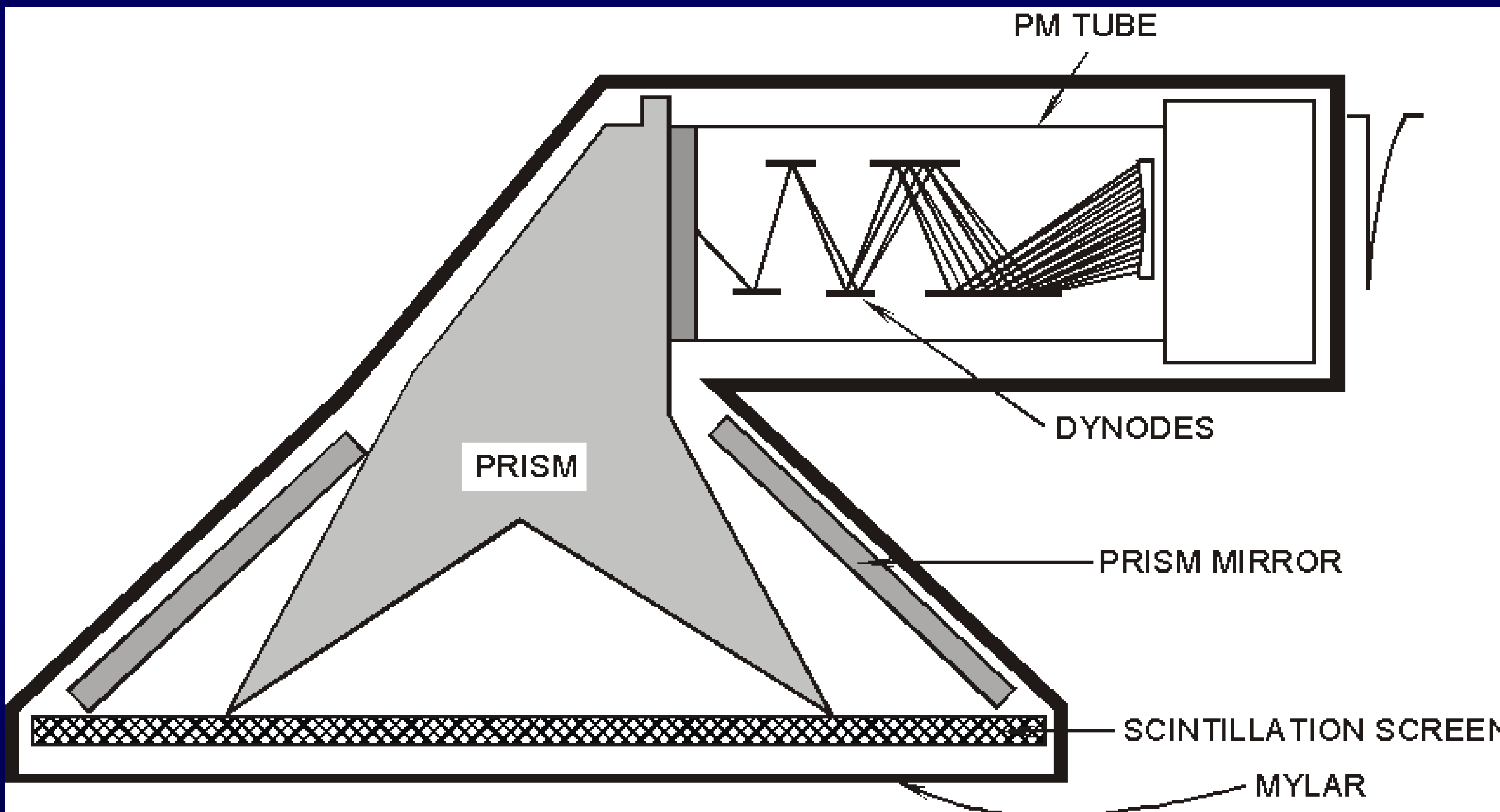
Scintillation Detector (gamma)





The x-ray imaging chain and gamma ray detector are integrated onboard the BrightView XCT, providing integral registrations of SPECT and CT data sets. (Provided by Philips Healthcare)

Scintillation Detector (alpha)



Solid-State Radiation Detectors (cont.)

- Most common uses are detection of gamma rays (e.g. NaI) and alpha particles (e.g. ZnS)
- Liquid scintillation counting used for low-energy betas, due to self-absorption within sample (e.g. Tritium and C-14)
- Scintillation crystals such as sodium iodide activated with thallium (NaI(Tl)) have higher detection efficiencies for gamma rays

Portable Instrument Selection

- Be sure the instrument design is appropriate for the type and energy of radiation you will encounter
- Verify your instrument's calibration is current (calibration is recommended every 6-12 months)
- Perform a visual inspection and battery check
- Source check the instrument to ensure operability

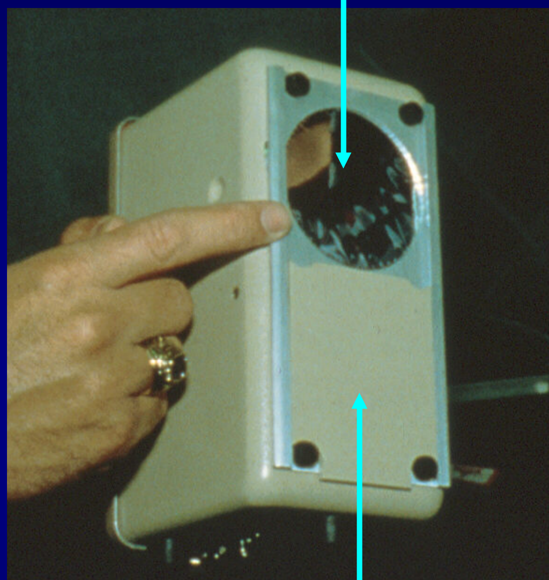
Instrument Examples

The types of portable hand-held instruments included are a sample of what you may see or use

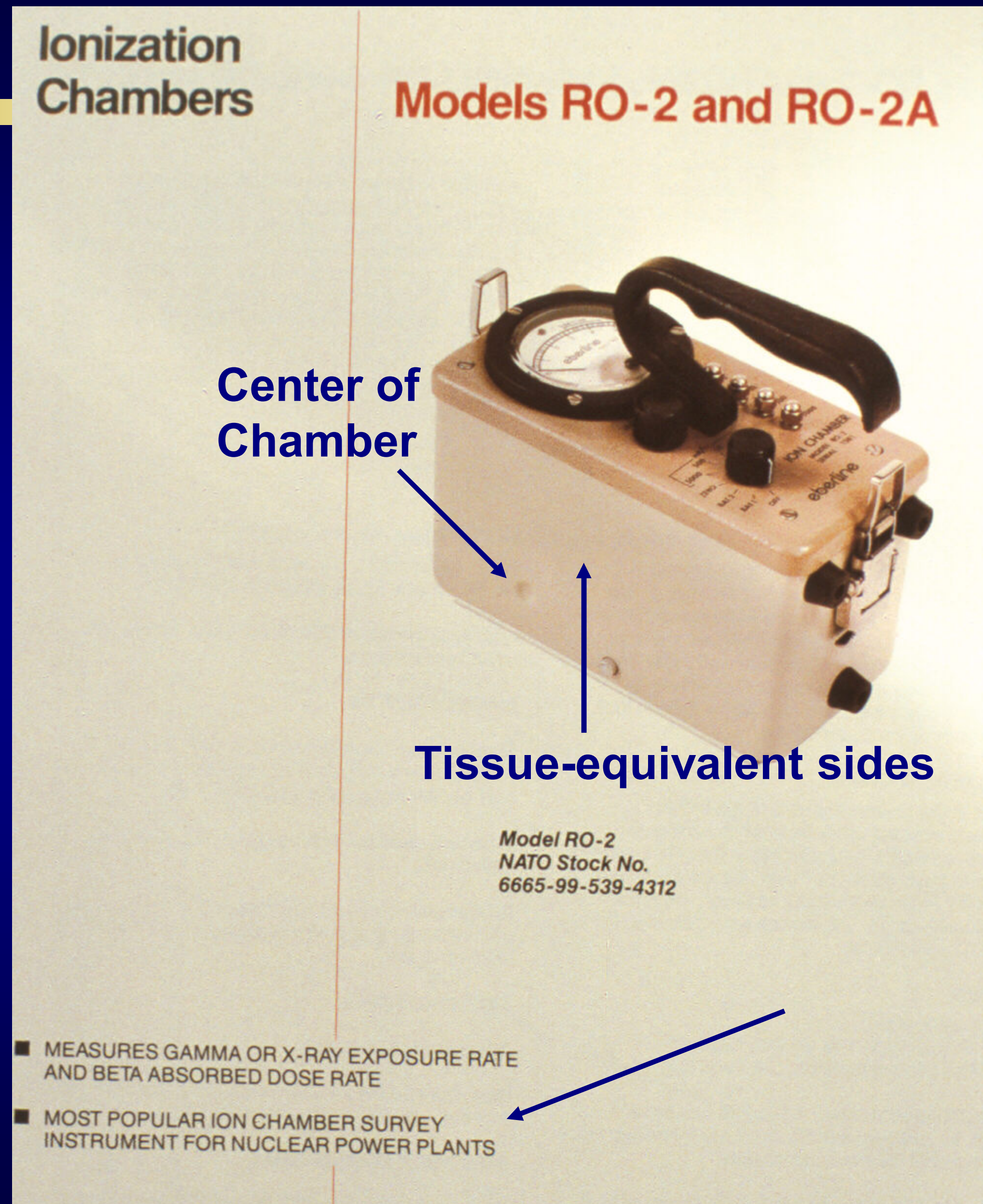
Air Ionization Chamber

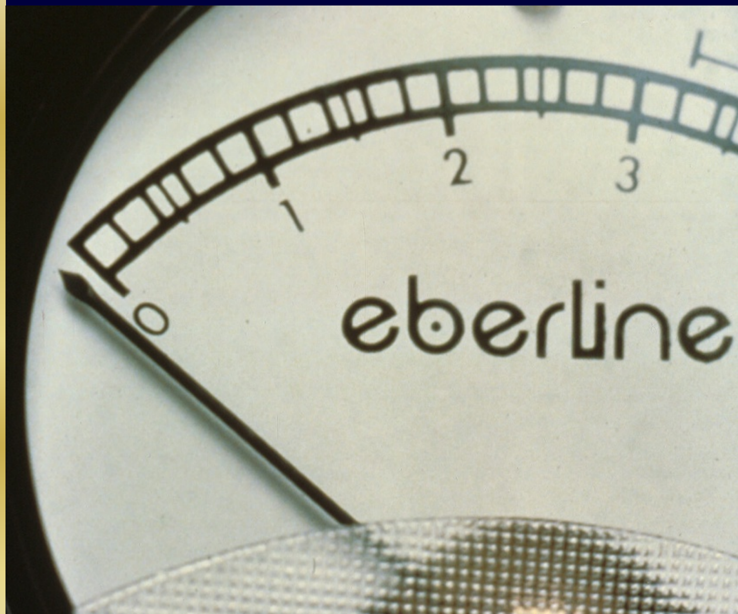
- Application – exposure and exposure rate monitoring
- Display units - mR/hr (mR)
- Sensitivity – good, but slow response time (may be used for beta but requires a conversion factor)
- Efficiency - poor for photons
- Calibration - once or twice per year

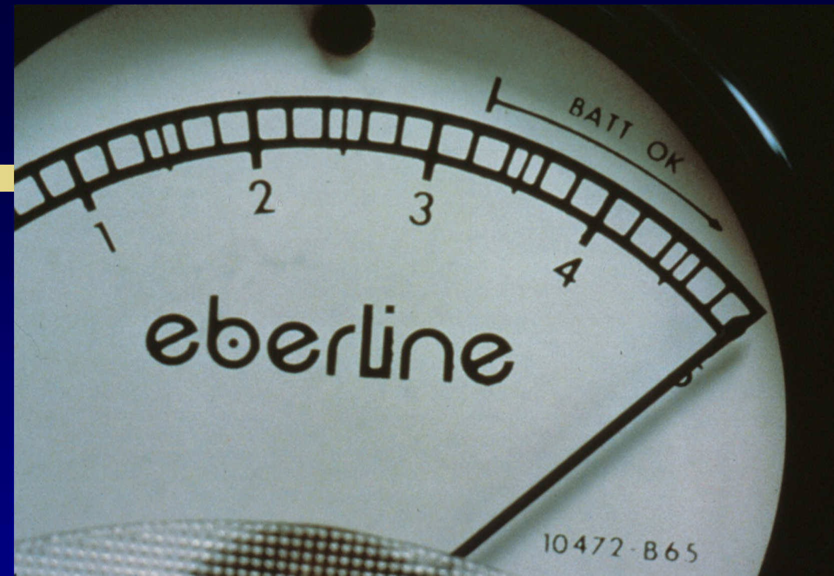
Mylar Window



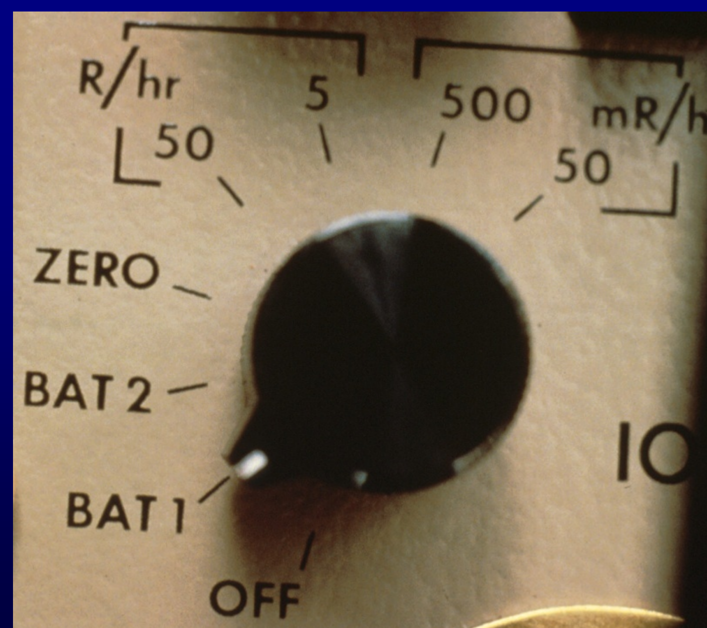
Sliding
Beta Shield







Eberline RO-2 Air Ionization Chamber



Ionization Chambers:
Eberline Model RO-20

DETECTOR

Five linear ranges: 0-5, 0-50, 0-500 mR/hr; 0-5, 0-50 R/h
Air filled ionization chamber vented to atmosphere
Detector Volume 13.4 in^3
1,000 mg/cm^2 walls
Chamber window 7 mg/cm^2
Beta shield 1,000 mg/cm^2
$\pm$30% from 8 keV to 6 MeV
$\pm$15% from 33 keV to 6 MeV

EXTERNAL CONTROLS

Rotary switch for Off, Battery check, and scale
Zero knob

Sample Ionization Chambers
Bicron RSO 50E

Five linear ranges: 0-5 mR/h to 0-50 R/h
Energy range 12 keV to 7 MeV
Weight only 1.4 kg

A compact, rugged, lightweight ion chamber dose meter for beta, gamma and X-ray detection and measurements of superficial or deep doses

The 1000 mg/cm^2 shutter makes deep dose versus shallow dose measurements possible.

Ionization Chambers: Victoreen Model 440RF/D

The 440RF/D is a highly sensitive, RF shielded survey meter suited for measurement of background or low radiation levels.

It is the basis of measurement for radiation exposure in the color television industry. This instrument is also used to measure ionizing radiation from radar and transmission towers where RF may be present.

Internal software-controlled pressure transducer and temperature sensor automatically apply standard air density correction factors from 70 to 106 kPa to the unsealed ion chamber

Range (μSv/hr)	Response (sec)
0-10	7
0-30	7
1-100	5
0-300	5
0-1000	5

Pressurized Ion Chamber

Model 450
non-pressurized

Model 450P
pressurized

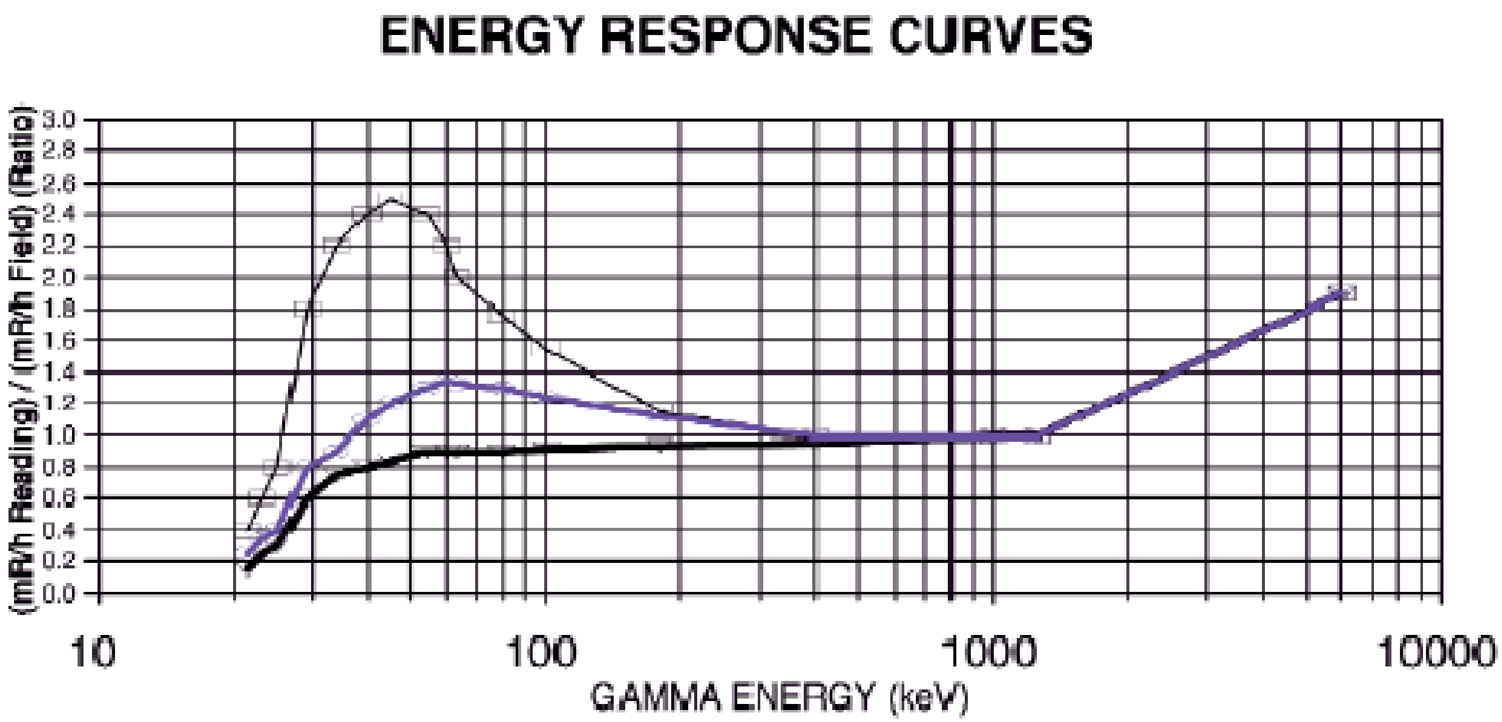
Model 451P

GM Detector (pancake)

- Use - general surface and personnel frisking
- Display units - counts/minute (cpm)
- Sensitivity - very good beta radiation detector
- Efficiency
  - – varies with beta energy from 5-30%
  - – gamma efficiency < 1%

Energy-Compensated GM Detectors

- The response of GM detectors depends on the energy of the incident photons.
  - higher curve shows a GM detector response with the window opened, so that it responds to beta particles
  - middle curve is the GM detector with the window closed
  - lower curve shows the response of an "energy compensated" GM detector



Eberline Energy-Compensated GM

Application: Beta/Gamma exposure surveys

Detector Type: Energy compensated GM

Detector Range: 3 R/hr (with dead time correction)

Energy Range: 30 keV to 6 MeV

Dead Time: 100 uSec nominal

Wall Material: Stainless steel

Wall Thickness: 30 mg/cm^2 (tube only)

Gamma Sensitivity: ~1,200 cpm/mR/h (^{137}Cs)

Eberline HP-190A End Window GM

Application: Alpha/Beta/Gamma surveys

Detector Type: uncompensated GM, end window

Dead Time: 200 uSec nominal

Mica Window Thickness: 1.4 to 2.0 mg/cm^2

Gamma Sensitivity: ~ 2,500 cpm/mR/h (^{137}Cs)

Beta Efficiency (4π): ~ 35% $^{90}Sr/90Y$, ~ 25% ^{99}Tc, ~ 10% ^{14}C
Alpha Efficiency (4π): ~ 6% ^{241}Am

Eberline Monitor 4 (pocket-sized meter)

FEATURES
- Compact
- Easy to Use
- Low Cost
- Carrying Case Included

DETECTOR
- GM, uncompensated

RANGES
- 0.5, 5, 50 mR/h and 500, 5k, 50k cpm

OPTIONS
- Energy Compensated GM

Ludlum Model 2401P "Pocket Meter"

Built-In Pancake GM

DETECTOR: Pancake GM

SENSITIVITY: ~ 3,300 cpm/mR/hr (^{137}Cs gamma)

ENERGY RESPONSE: Energy dependent

METER DIAL: 0 - 0.15 mR/hr; 0 - 500 cpm; BAT OK

MULTIPLIERS: X1, X10, X100

LINEARITY: Reading within ±10% of true value

AUDIO: Built in speaker (with silence feature on main switch)

RESPONSE: Typically 5 seconds from 10% to 90% of final reading

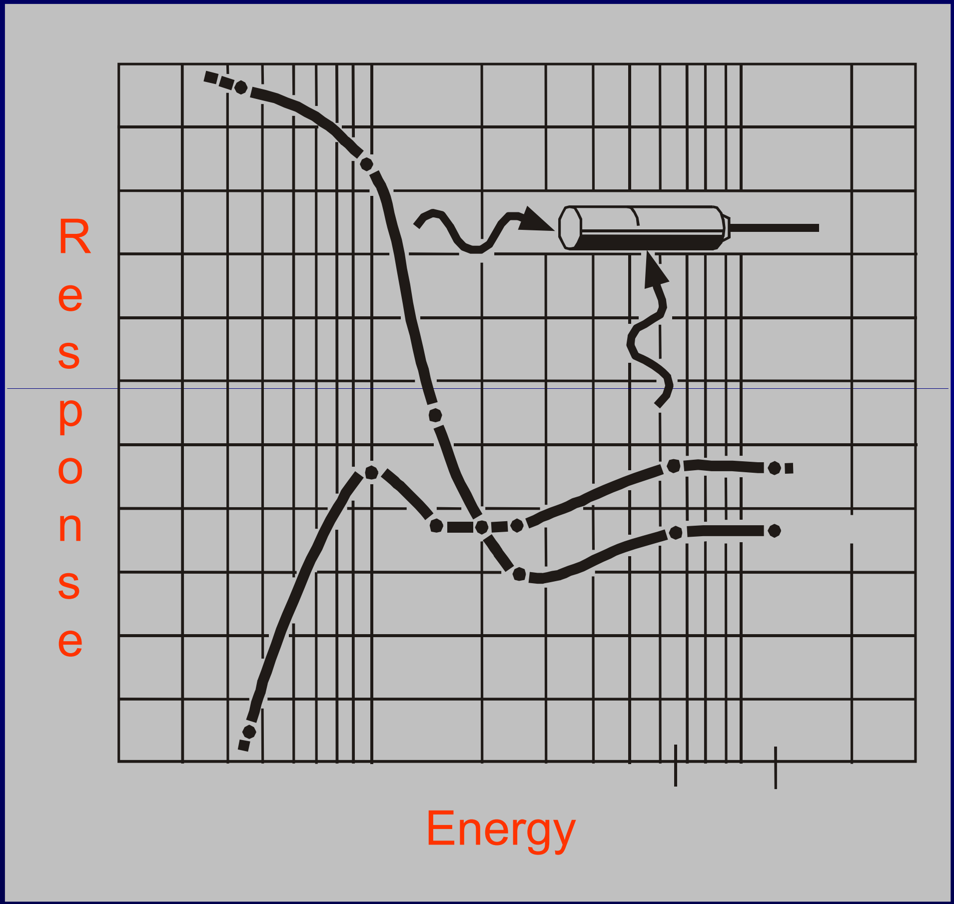
Ludlum Model 3-97EP

Explosion Proof Internal 1" X 1" NaI(Tl) Gamma Scintillator
& Internal Energy-Compensated GM Detector

INDICATED USE: Gamma Survey
DETECTORS: 1" X 1" NaI(Tl) scintillator
SENSITIVITY: Typically 175 cpm/microR/hr (Cs-137 gamma)
ENERGY RESPONSE: Energy dependent - Energy compensated GM
ENERGY RESPONSE: Within ±15% of true value from 60 keV - 3 MeV
WORKING ENVIRONMENT: Explosion proof housing for extreme environments
METER DIAL: 0 - 100 mR/hr, BAT TEST
MULTIPLIERS: X0.1, X1, X10, X100, X1k
LINEARITY: Reading within ±10% of true value with detector connected
CALIBRATION CONTROLS: Located in meter housing
RESPONSE: 4 seconds from 10% to 90% of final reading
RESET: Push-button to zero meter
POWER: 2 each "C" cell batteries
BATTERY LIFE: Typically 450 hours with alkaline batteries
CONSTRUCTION: explosion proof housing
TEMPERATURE RANGE: -4^{o} F(-20^{o} C) to 122^{o} F(50^{o} C)
SIZE: 6.5"(16.5cm)H X 8"(20.3cm)W X 7"(17.8cm)L
WEIGHT: 14 lbs (6.4 kg) including batteries

Directional Response

The response of GM may be directionally dependent depending on the shape of the detector and whether it has an end-window or not.



Bicron Surveyor 2000

0 – 240,000 cpm (0 – 200 mR/h) external probe
0 – 2000 mR/h internal probe

High dose rate X-ray and gamma ray fields are measured by an internal GM detector, and beta, X- or gamma countrates are measured using an external “pancake” probe.

GM Dead Time

At higher count rates, the detector may be processing an event which renders it unable to detect subsequent events until the processing is complete. This is called the instrument "dead time."   The vendor specifications will identify the dead time for a detector. Dead time can be significant factor at higher count rates.

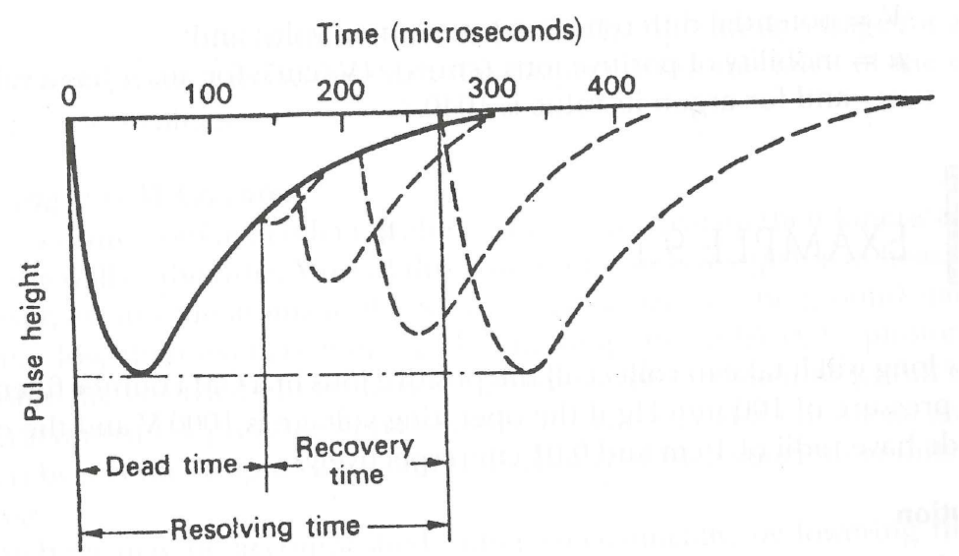
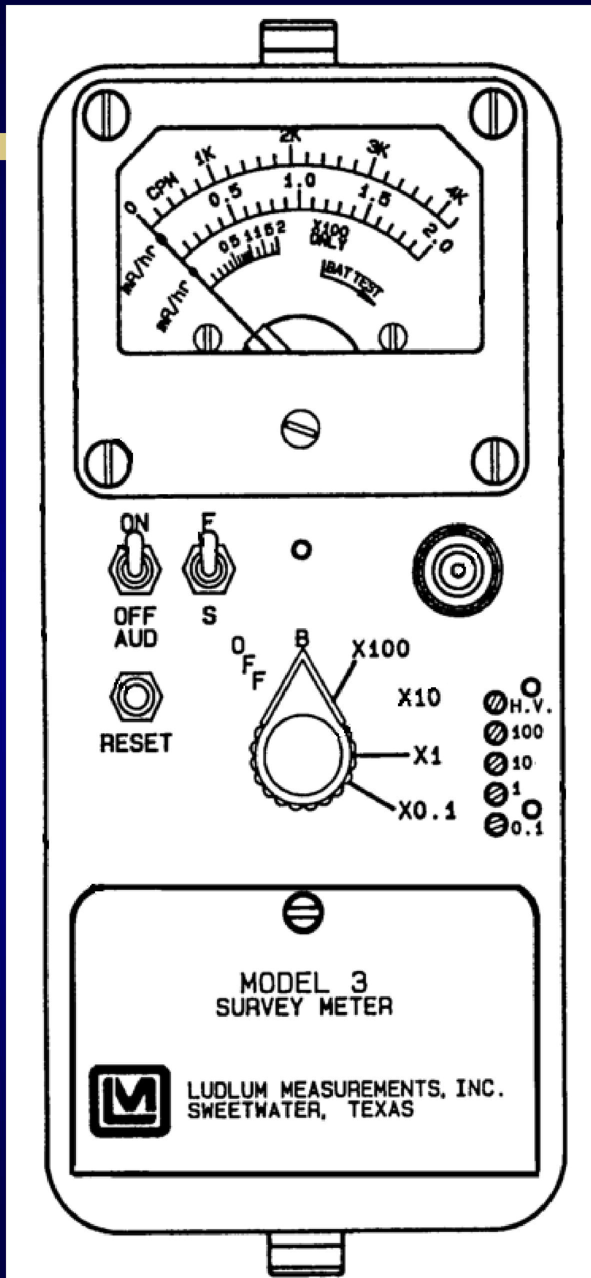


Figure 9-7. Relationship among dead time, recovery time, and resolving time.

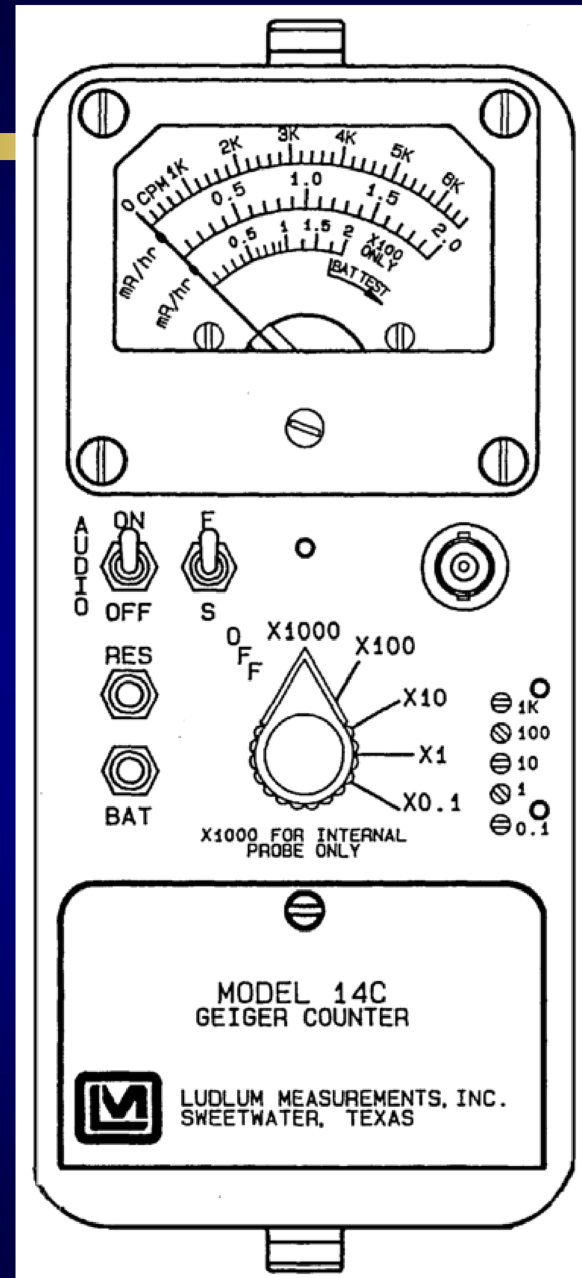
Bicron "Radiographer"

Portable survey meter with an internal energy-compensated GM detector, automatic dead time compensation, anti-saturation circuit and HV and battery checks

- **Three linear ranges, spanning from 0 – 1000 mR/h**
- **Response times optimized for each range**
- **Energy compensated: 40 keV to 1.2 MeV**
- **Weighs only 1 kg**



Survey Meter Controls



The Area Monitor Probe (AMP-100 or AMP-200) are high-range GM tube-based detectors designed to be continuously used in areas where high exposure levels exists.

- Features
  - Waterproof to at least 20 meters depth
  - Readout of dose rate and accumulated dose
  - Dead time correction
  - Ranges of 0.001 R/h up to 10,000 R/h

Eberline RM-14

Stationary frisking station for use with GM probes. The unit has a rechargeable battery as well as visible and audible alarms.

Ludlum 44-9 "Pancake" GM Probe

INDICATED USE: Alpha beta gamma survey; Frisking

DETECTOR: Pancake type halogen quenched GM

WINDOW: 1.7 plus or minus 0.3 mg/cm^2 mica

WINDOW AREA: Active - 15 cm^2 ; Open - 12 cm^2

EFFICIENCY(4π geometry): Typically 5% - C^{14}; 22% - Sr^{90}/Y^{90}; 19% - Tc^{99}; 32% - P^{32}; 15% - Pu^{239}

SENSITIVITY: Typically 3300 cpm/mR/hr (Cs^{137} gamma)
ENERGY RESPONSE: Energy dependent (over responds for low energy gammas)
DEAD TIME: Typically 80 microseconds
COMPATIBLE INSTRUMENTS: General purpose survey meters and scalers

Eberline HP-210 Series GM "Pancake"

Application: Beta/Gamma surveys
Detector Type: GM, non energy compensated
Operating Voltage: 900 V +/- 50V
Dead Time: 50 μsec nominal
Mica Window Size: 1.75 inch diameter (4.4 cm)
Mica Window Thickness: 1.4 to 2.0 mg/cm^2
Background Sensitivity: ~3,600 cpm/mR/h (^{137}Cs)
Beta/Gamma Efficiency: ~22% ^{137}Cs, ~16% ^{60}Co
Beta Efficiency (4π): ~ 32% ^{90}Sr/^{90}Y, ~ 15% ^{99}Tc, ~ 6% ^{14}C
Alpha Efficiency (4π): ~ 25% ^{241}Am

Model HP-210AL: Aluminum with 1:1 window to bkg ratio (0.7 kg)
Model HP-210L: Lead shielded with 4:1 window to bkg ratio (1.9 kg)
Model HP-210T: Tungsten shield with 4:1 window to bkg ratio (1.9 kg)

Ludlum 44-40

Window Area: Active - 15 cm^2 Open - 12 cm^2
Window: 1.7 $\pm$ 0.3 mg/cm^2 mica
Sensitivity: ~ 3,300 cpm/mR/hr (^{137}Cs)
Beta Efficiency (4π): ~ 22% ^{90}Sr/Y; 19% ^{99}Tc; 5% ^{14}C; 32% ^{32}P
Alpha Efficiency (4π): ~ 15% ^{239}Pu

Micro-R Meter

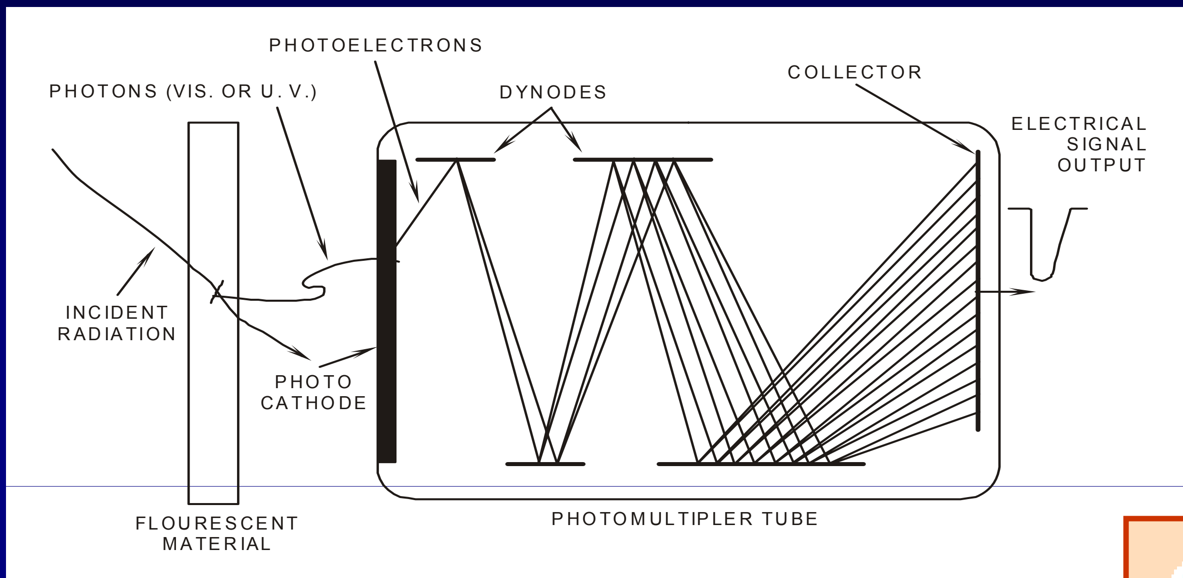
- Use - measure local gamma dose rates in environment
- Display units – microR/hr (μR/hr)
- Sensitivity – NaI over-responds (plastic scintillator microrem detector does not)

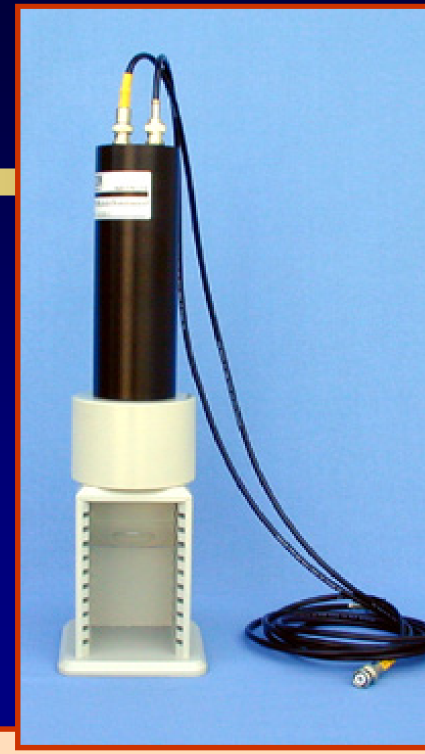
Micro-R Meter

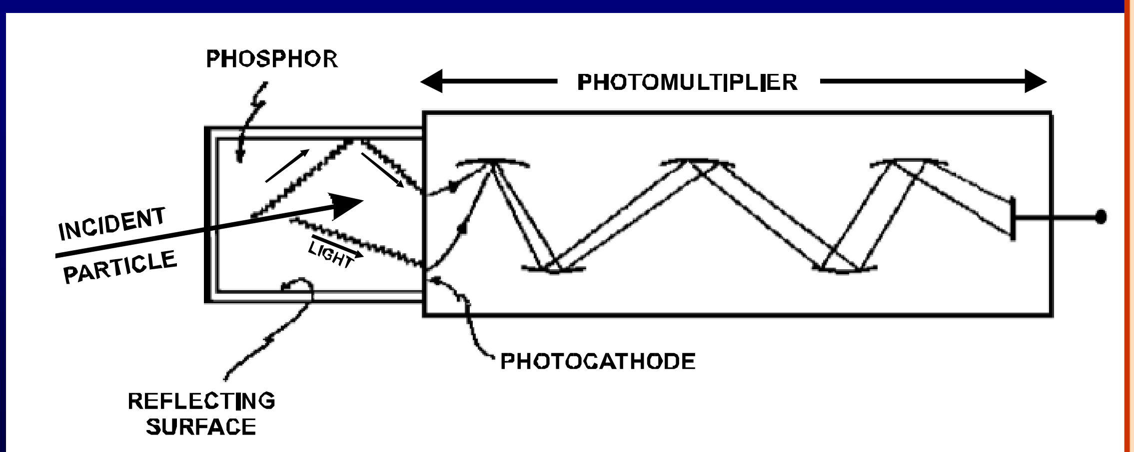
NaI Scintillation Detector

- Use - search for surface and subsurface gamma-emitting radionuclides
- Display units - counts/minute (cpm)
- Sensitivity - very good for environmental applications

Scintillation Detector (gamma)



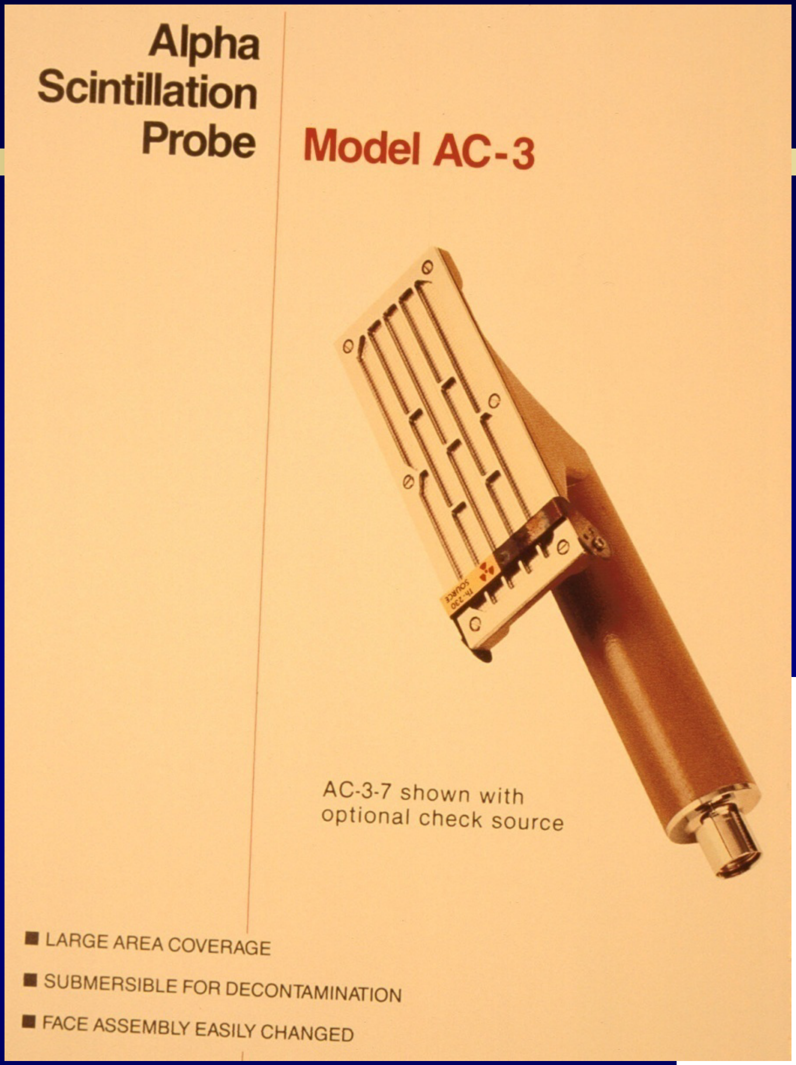


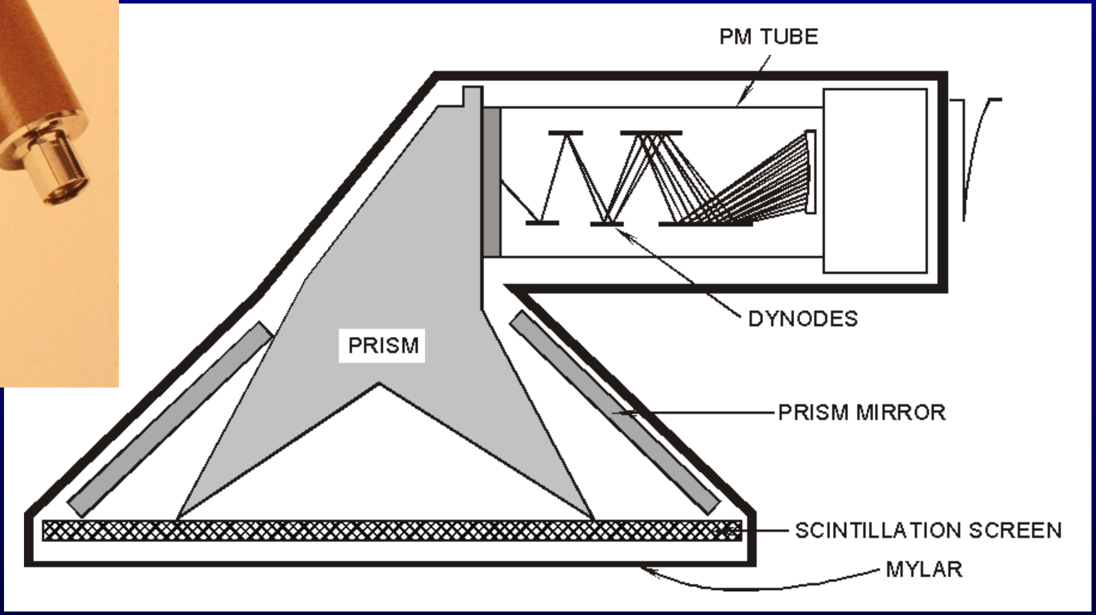


Alpha Scintillation Detector

- Use - general surface and personnel frisking
- Display units - counts/minute (cpm)
- Sensitivity - very good for alphas with no gamma detection

Alpha Scintillation Detector

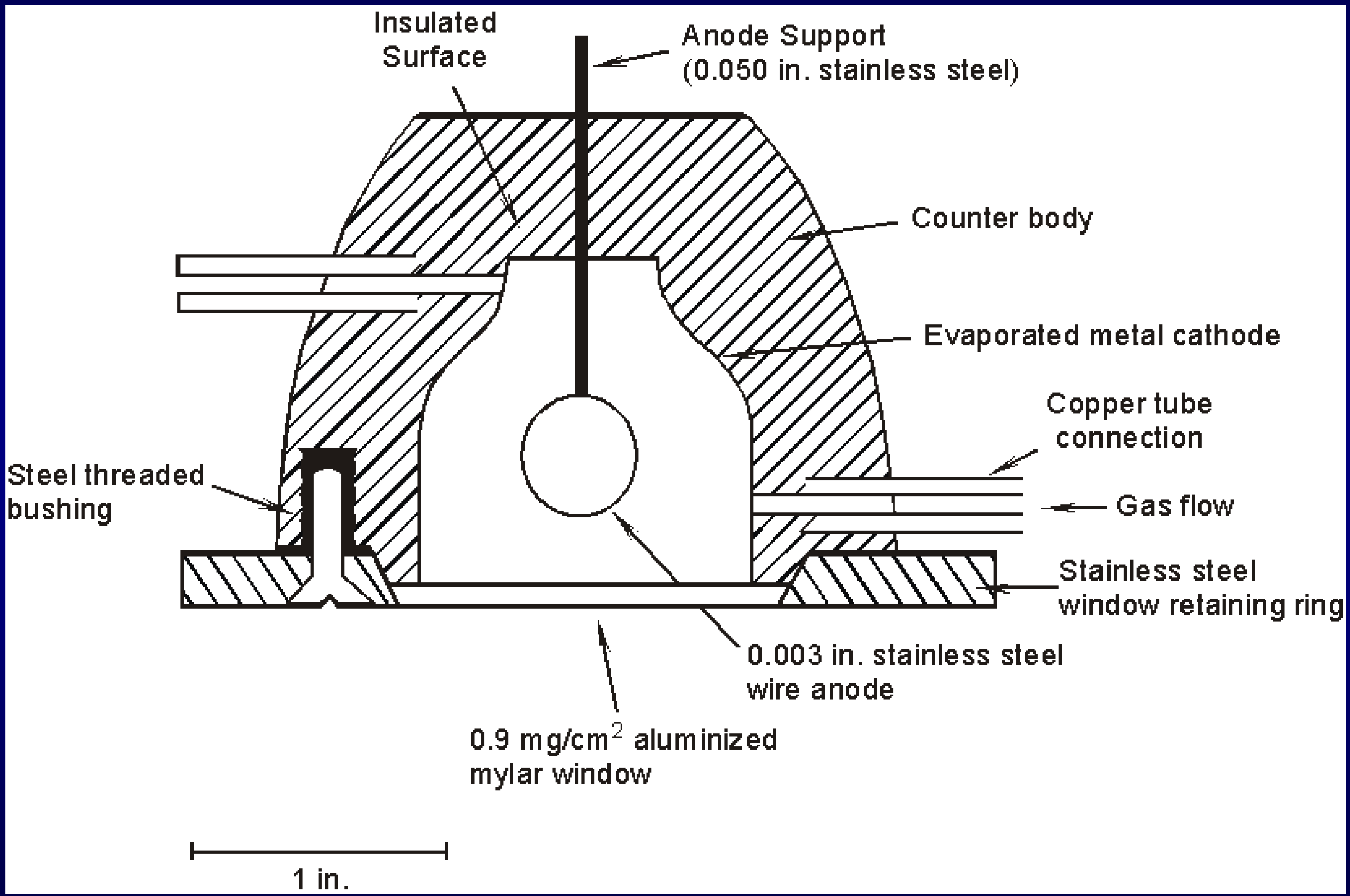




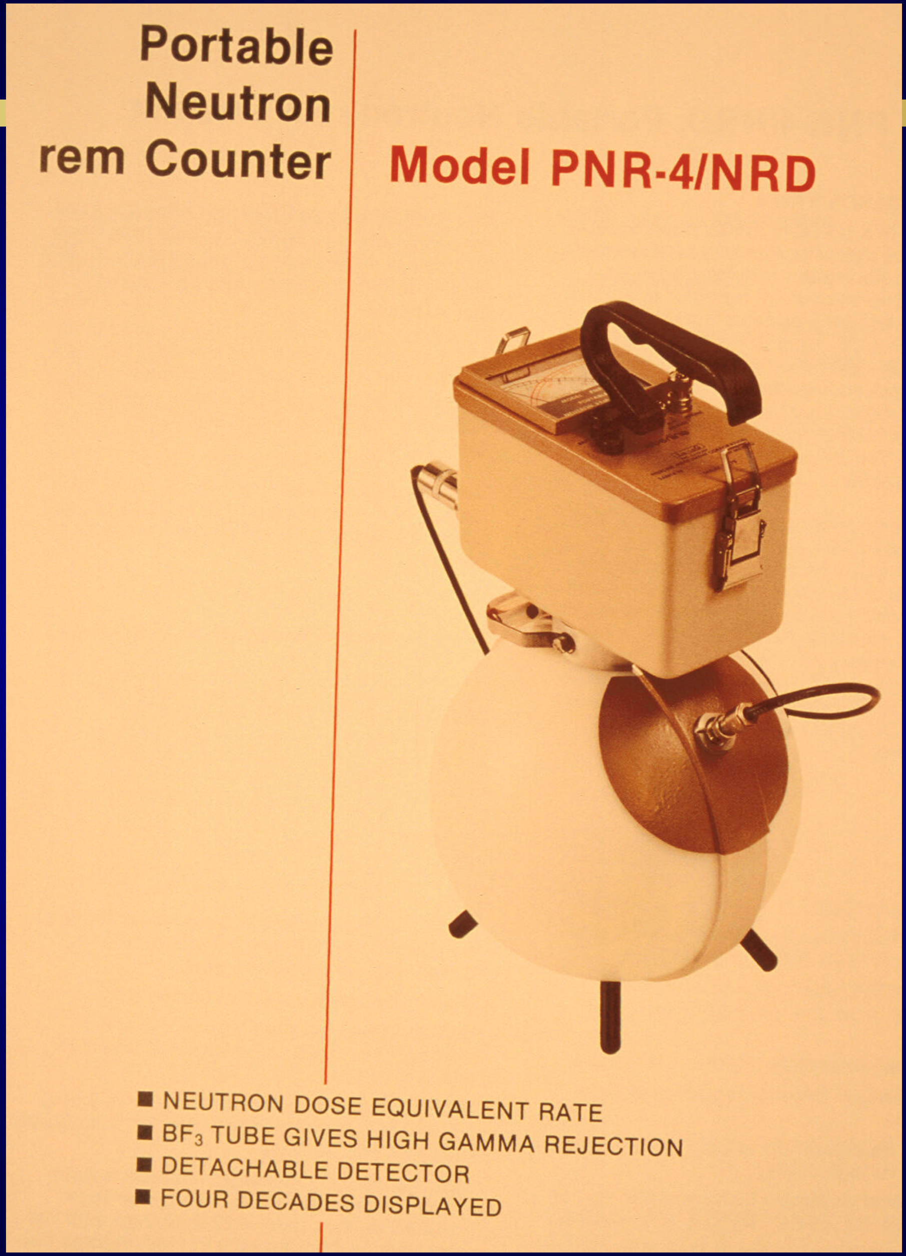
Gas Proportional Detector

- Use - general surface surveying of large areas
- Display units - counts/minute (cpm)
- Sensitivity - very good with capability of discriminating between alpha and beta radiations

Gas Flow Proportional Chamber



Neutron Detectors



Eberline E600 Survey Meter + NRD Detector

FEATURES

Measures Thermal and Fast Neutrons
Gamma Rejection Up To 500 R/h
Direction Independent Measurements

GENERAL DESCRIPTION

The model E600/NRD combines E-600 Survey Meter with NRD neutron REM detector

- nine-inch-diameter,
- cadmium-loaded polyethylene sphere with a BF_3 tube in the center
- energy range from 0.025 eV thermal to about 10 MeV

COMBINED DETECTOR/METER

Weight: 18 lbs (8.16 Kg)

Eberline E600 Survey Meter + NRD Detector

Detector: BF_3 Tube in nine inch, cadmium loaded polyethylene sphere
Plateau: Approximately 200 V with a slope of 5% per 100 V
Operating Voltage: Dependant on sensitivity of counter and cable length; typically 1,600 to 2,000 V.
Directional Response: Within ±10%
Energy Range: Thermal to approximately 10 MeV
Gamma Rejection: Up to 500 R/h. Rejection is dependant on voltage selected. Factory default is 10 mR/h.
Sensitivity: Approximately 45 cpm/mrem/h (3,000 counts per mrem)

SURVEY METER (E-600)
Count Range: 1 to 1.3 million cpm
Response Times: Slow, Medium, Fast (each setting programmable up to 255 sec)
Audible Alarm: 85 dB @ 30 cm
Dead Time Correction: 0 to 255 μsec
Operating Modes: Ratemeter, Scaler, Integration, Peak Trap, Background Accumulation.
Controls: Check mode, 5 operating modes, speaker on/off, gross/net counts display, display back light, multi-function soft key and channel select.

Ludlum Model 15 (α-β-γ-η)

End Window GM Detector for Alpha, Beta, and Gamma
BF_3 Proportional Detector with Moderator for Neutron
4 Ranges - Total Counting Range from 0 - 500,000 cpm

INDICATED USE: neutron, alpha, beta-gamma survey
DETECTORS: Controlled by selector switch
NEUTRON: Model 42-9 BF_3 proportional detector with 3"(7.6 cm) diameter cadmium lined moderator for fast neutrons (remove detector from moderator for thermal neutrons)
ENERGY RESPONSE: Count response is not linear throughout energy spectrum (0.025 - 8 MeV)
SENSITIVITY: Typically 60 cpm/mrem/hr (AmBe fast neutrons)
GAMMA REJECTION: Less than 10 cpm through 10 R/hr
ALPHA BETA-GAMMA: Model 44-7 thin end window GM detector
WINDOW: 1.7 $\pm$0.3 mg/cm2 mica
WINDOW AREA: Active - 6.4 cm^2 Open - 5.2 cm^2
EFFICIENCY(2π geometry): Typically 5% - ^{14}C; 20% - $^{90}Sr/^{90}Y$; 15% - ^{239}Pu
SENSITIVITY: Typically 2100 cpm/mR/hr (^{137}Cs gamma)

Ludlum Model 44-110

The Model 44-110 is a windowless 100 cm^2 gas proportional detector for tritium detection

INDICATED USE: Tritium surface survey

WINDOW AREA: Active - 126 cm^2 Open - 100 cm^2

EFFICIENCY (4π): Typically 25% - H^3

BACKGROUND: Typically 400 cpm

RECOMMENDED COUNTING GAS: P-10 (10% methane, 90% argon)

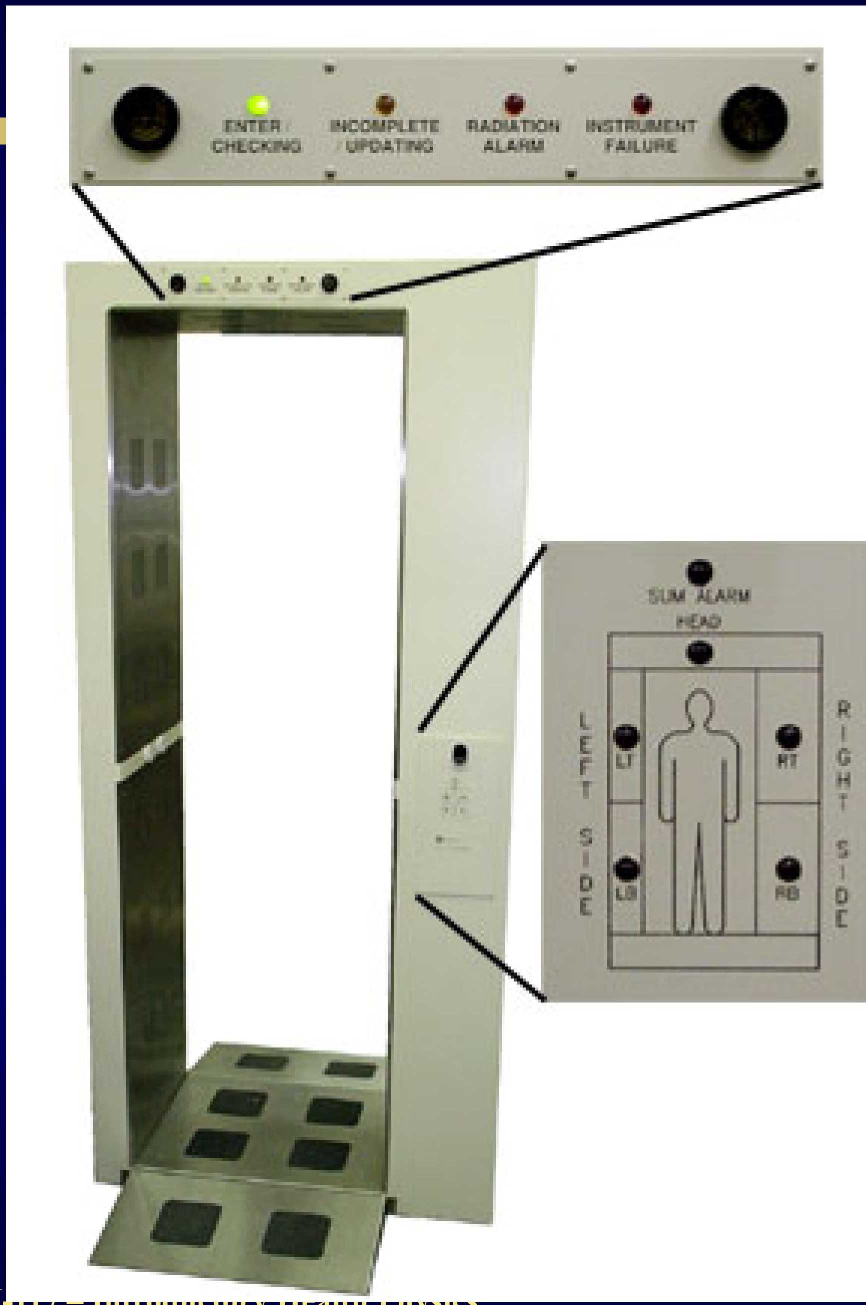
GAS PURGE TIME: Approximately 20 seconds

TEMPERATURE RANGE: -4° F(-20° C) to 122° F(50° C)

SIZE: 4.9"(12.4cm)H X 4.6"(11.7cm)W X 9"(22.9cm)L)

Portal Monitor
(Multiple GM or Scintillation detectors)

- Use - quick scan of personnel entering and exiting controlled areas
- Display units - counts/minute (cpm)
- Sensitivity
  - 100 nCi - Cs-137 in dynamic (walk through) mode
  - 50 nCi - Cs-137 in a 2 second count (static mode)
- Calibration - once or twice per year



Portal Monitor

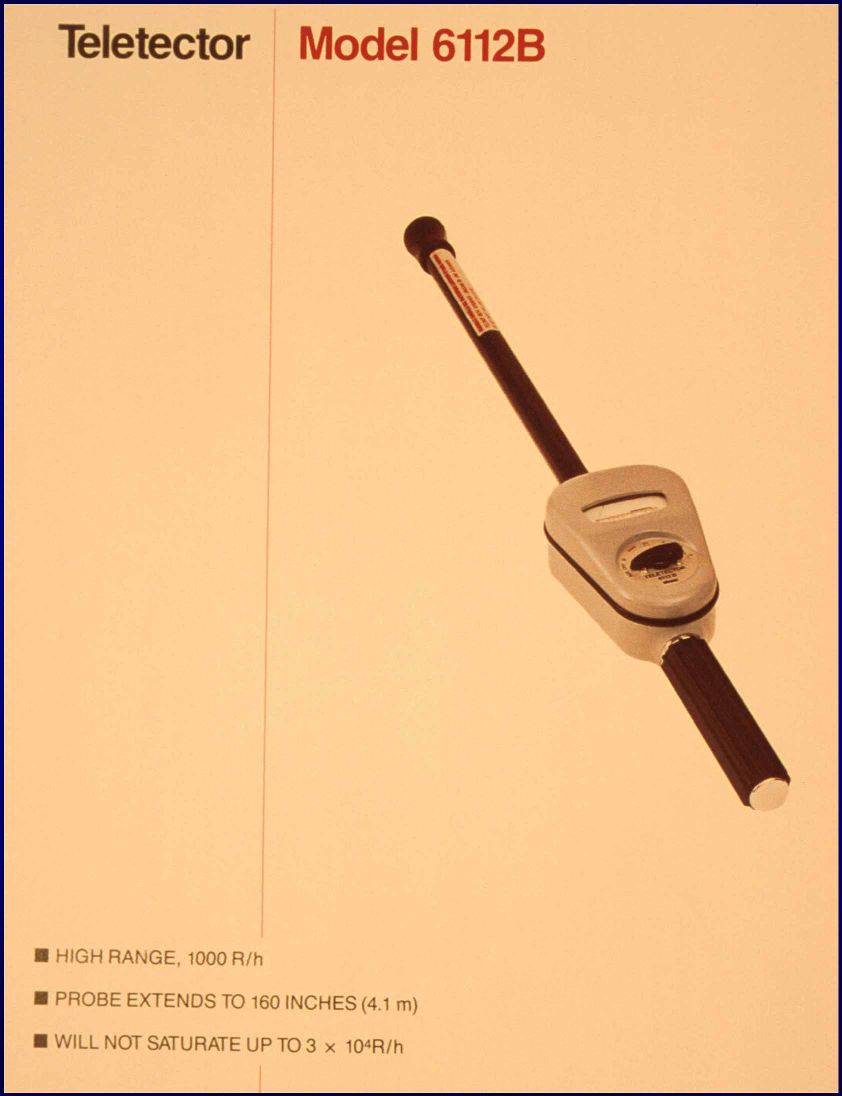
Waste/Laundry/Tool Monitors (multiple GM or scintillation detectors)

- Use - quick scan of items exiting controlled areas
- Detectors – 4-6 plastic scintillation detectors
- Sensitivity – e.g. detects 5000 dpm activity within 10 seconds (4 detectors, 1 in. shield)
- Calibration - once or twice per year

Small Article Monitor (SAM)

Bag Monitor

High Dose Rate Gamma Survey Instrument

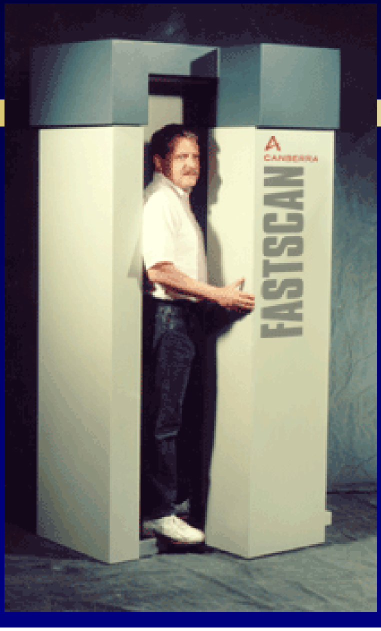


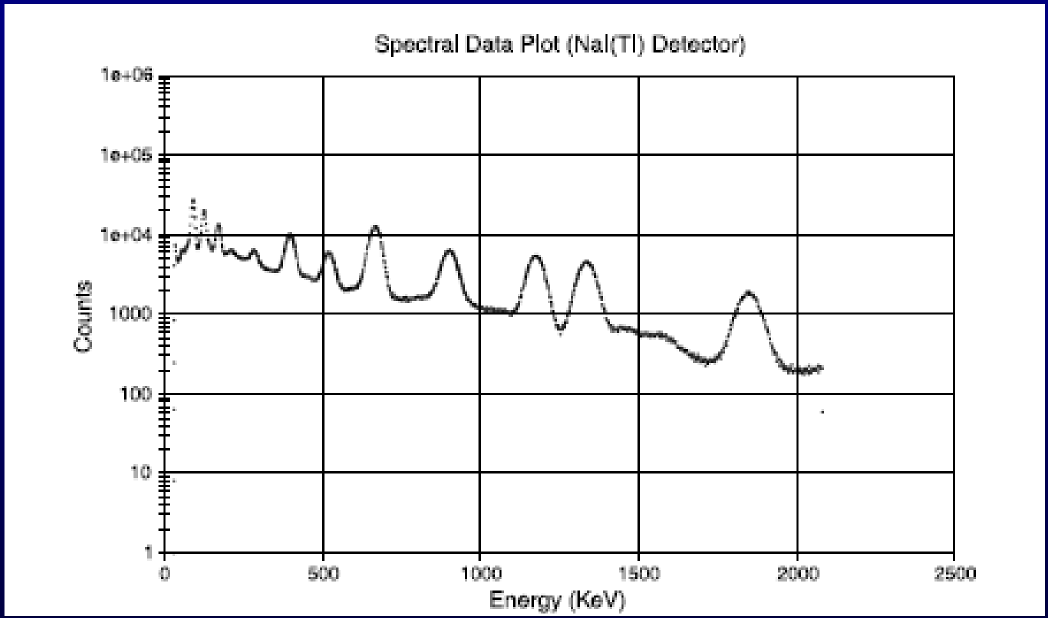
Guide to Selecting Portable Radiation Detection Instrumentation

Radiation Type	Desirable Detector Qualities	Example Detectors
Alpha	Gas detection volume with minimal window thickness.	Proportional counter, ZnS(Ag) scintillation counter.
Beta	Gas detection volume with minimal window thickness. Solid detection volume but thin.	Proportional counter, GM counter. Plastic scintillator.
X-ray	Gas detection volume. Solid detection volume but thin.	GM counter, ionization chamber. NaI(Tl) scintillator, plastic scintillator.
Gamma	Gas detection volume. Solid detection volume that's thick.	GM counter, ionization chamber. NaI(Tl) scintillator, plastic scintillator.
Neutron	Use hydrogen containing moderator to slow fast neutrons. Fast neutron detection without moderation. No moderator for slow neutrons.	Slow neutron detector surrounded with hydrogenous material. Recoil proton detector. BF_3 proportional gas tube, Helium proportional gas tube, lithium crystal scintillation detector.

Whole Body Counters

- The peak energy is determined from a WBC spectrum which corresponds to a photon energy allowing identification of the nuclide.
- Activity of the nuclide is then determined to calculate a dose.
- A NaI spectrum is shown. The Canberra "FASTSCAN" uses two large NaI detectors.
- Count time can be as short as one minute.



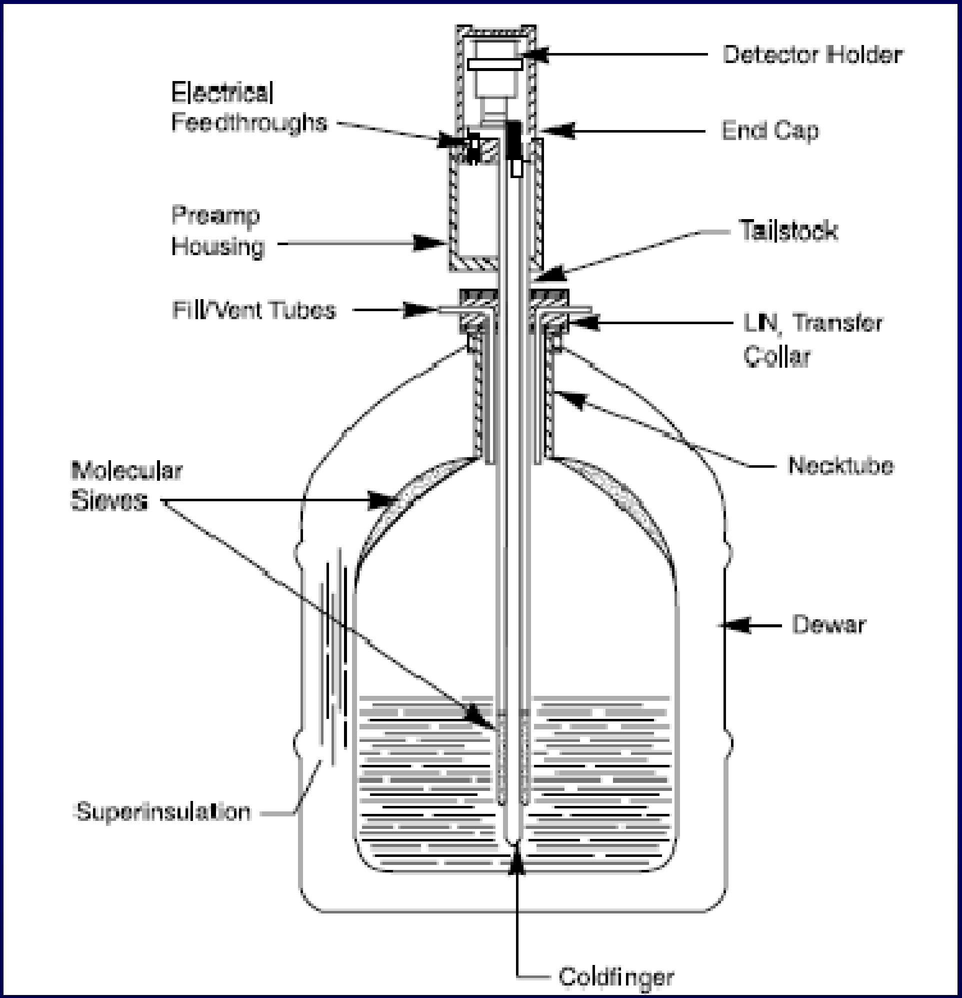


Lung Counting

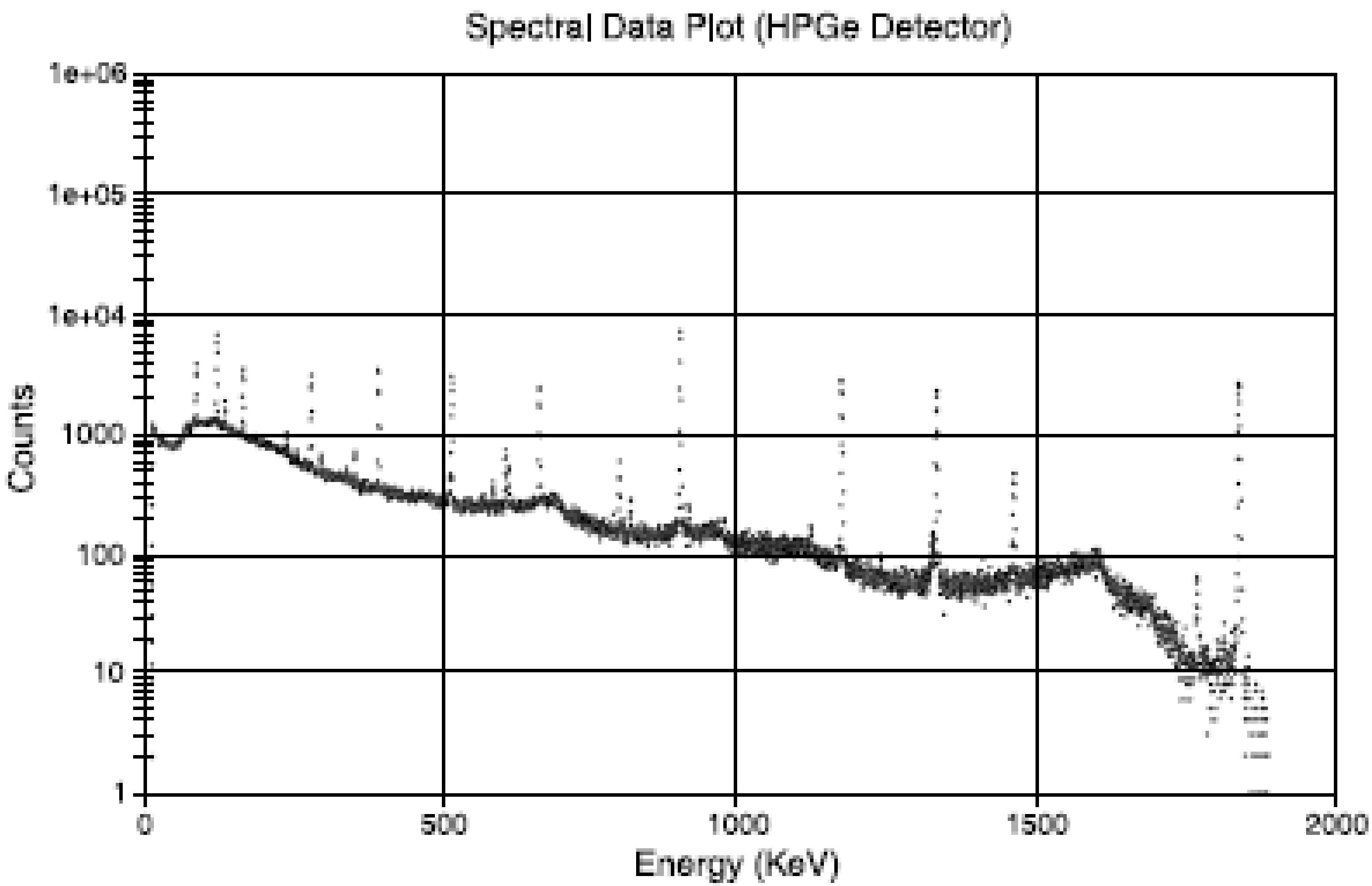
- A germanium (Ge) semiconductor detector is used for very sensitive analysis.
- A Ge spectrum has a much better resolution than a NaI detector; however, Ge detectors are less efficient.
- Ge detectors have to be cooled with liquid nitrogen.
- Lung counters are used to measure nuclides like plutonium. The count time may be much longer than a WBC, e.g. several hours.

Germanium Detectors

- Germanium detectors are crystal semiconductors that are sensitive to X-rays and gamma rays.
- Ionizations created by photons interacting with the semiconductor produce a charge that is proportional to the energy of the incoming photon.
- These detectors must be cooled with liquid nitrogen to reduce thermally generated charge in the semiconductor.



Whole Body Counters



QUESTIONS?

END OF INSTRUMENTATION

Review Questions

- Zinc sulfide scintillation detectors have thin _______ windows and are commonly used _________ detectors.
- Name two types of detectors that can be used for beta detection
- Name two types of gamma ray detectors

Review Questions

- Name one type of portable dose rate meter that would be suitable for measuring gamma dose rates
- Which type of radiation typically has lower energy: X-rays or gamma rays?
- Name two types of detectors that are good for detecting slow neutrons

Review Questions

- Name two methods for detecting fast neutrons
- In a $^{10}B(n,\alpha)^{7}Li$ reaction, what particle is being used to determine the presence of neutrons?
- Name three high-voltage regions in which gas-filled detectors operate

Review Questions

- A GM detector is a type of ____________ detector, which operates through collection of electrons formed during the ionization process
- What type of portable detector is typically used for measuring dose rates?
- Detectors operating in the _____________ region or in the _______________ region can differentiate between alpha, beta, or gamma radiation

Review Questions

- Detectors operating in the ____________ region cannot discriminate between various energies or types of incident radiation.

- What type of detector is typically used for detection and quantification of contamination (beta-emitting radioactive material)?

- What is the term to describe the inadequate response of a GM detector at high count rates?

Review Questions

- What type of detector is typically used for detecting the presence of skin contamination (alpha-emitting radioactive material)?
- What type of counting method would be used for low-energy beta emitting isotopes such as H-3 and C-14?
- What is a check source used for?

Review Questions

- Scintillation crystals such as NaI(Tl) have high detection efficiencies for __________.
- What is different about a pressurized ion chamber compared to other ion chambers?
- What two detector types are used in whole body counters?
- How do whole body counters determine which nuclide is in the body?

Review Questions

- Which whole body counter type has a better resolution?
- Which whole body counter type has a better efficiency?

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