

Reactor Instrumentation – Gamma Detectors

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Overview

- Gas Filled Detectors
- Gamma Detectors
- Neutron Detectors
- Applications

Purpose of Detectors

Is there something there?

What is it?

How much is there?

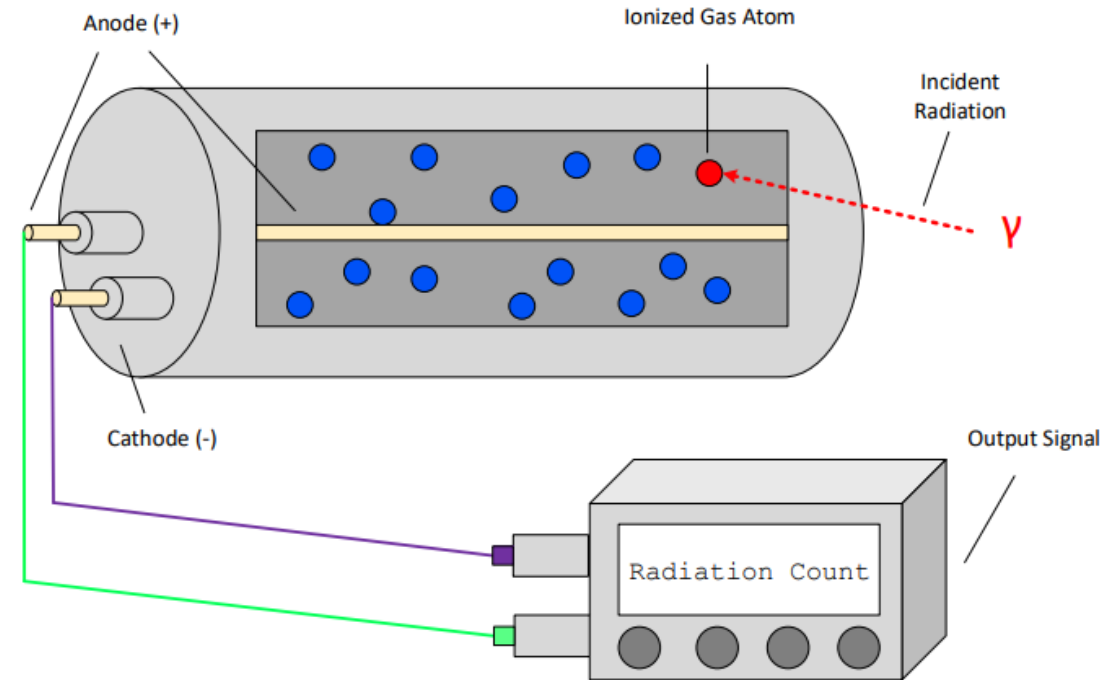
How They Measure Radiation

Detectors Turn Radiation into An Electrical Signal

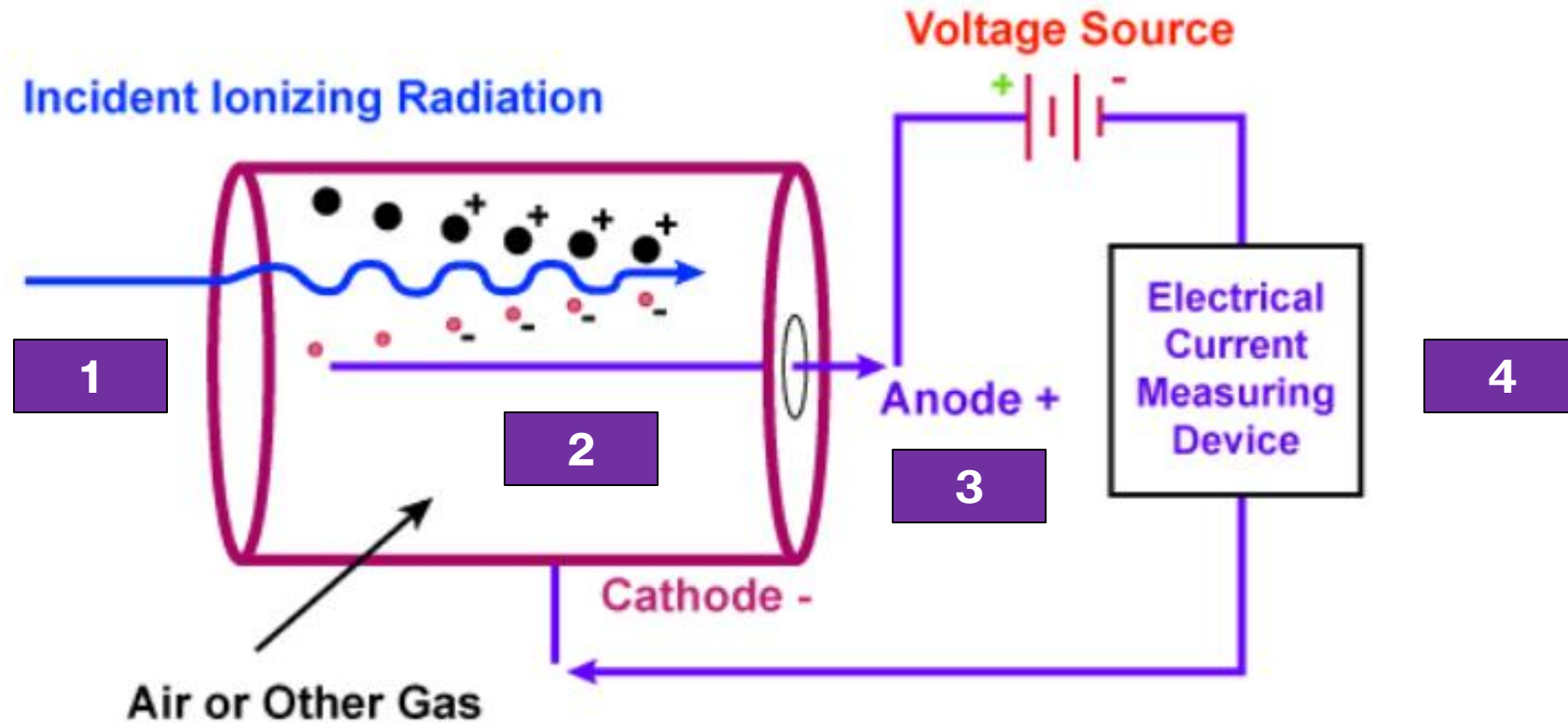


Gas-Filled Detector Operation

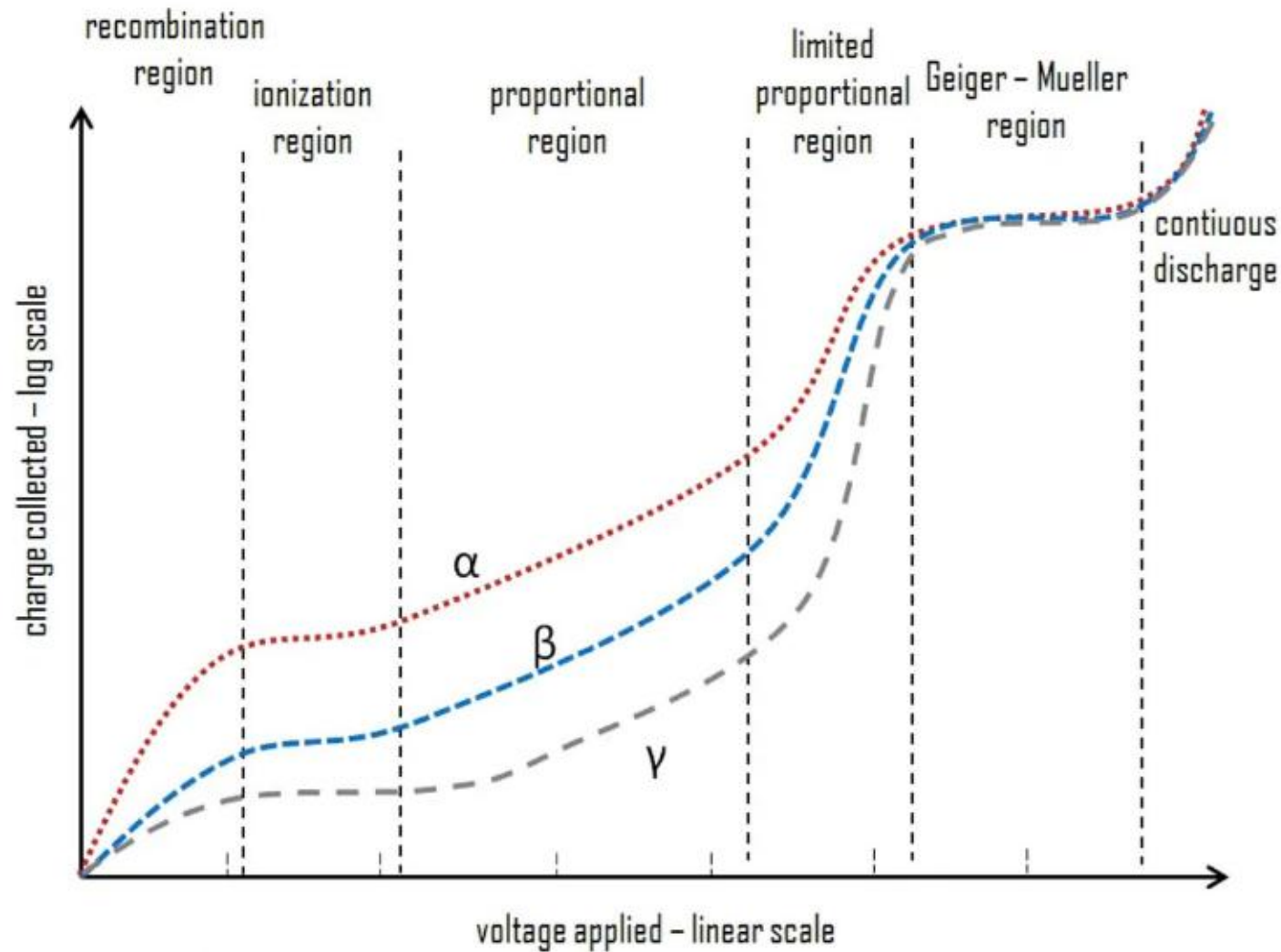
1. Ionizing radiation interacts with the gas in the detector
2. Ionization of the gas creates electrons and positive ions
3. Electrons are accelerated towards the anode
4. While moving, they continue to interact with the gas and create an electron avalanche
5. Charge collection at the anode creates an electrical signal



Gas-Filled Detector Operation



Operating Regimes



<https://www.nuclear-power.com/nuclear-engineering/radiation-detection/gaseous-ionization-detector/operating-regions-of-ionizing-detectors-detector-voltage/>

Operating Regimes and Detector Types

Ionization Detectors

- Noble gases and air
- Weak Signal
- Energy Differentiation

Proportional Detectors

- Noble gasses with a quenching gas
- Amplified Signal
- Energy Differentiation

GM Detectors

- Noble gasses with a quenching gas
- Strong Signal
- No Energy Differentiation

Quenching Gas

- Without a quenching gas, positive ions traveling to the cathode could liberate an electron, restarting the electron avalanche, producing multiple pulses.
- Quenching gasses neutralize the positive ions through charge-transfer collisions.
- Quenching gases gain a positive charge from the positive ions without releasing additional electrons.
- Halogens (chlorine or bromine), ethyl alcohol, ethyl formate, heavy polyatomic molecules (methane)

Gamma Detectors

Geiger Mueller Detectors

Survey Meters

- Handheld Survey Meters
- Measure the amount of gamma radiation present in an area



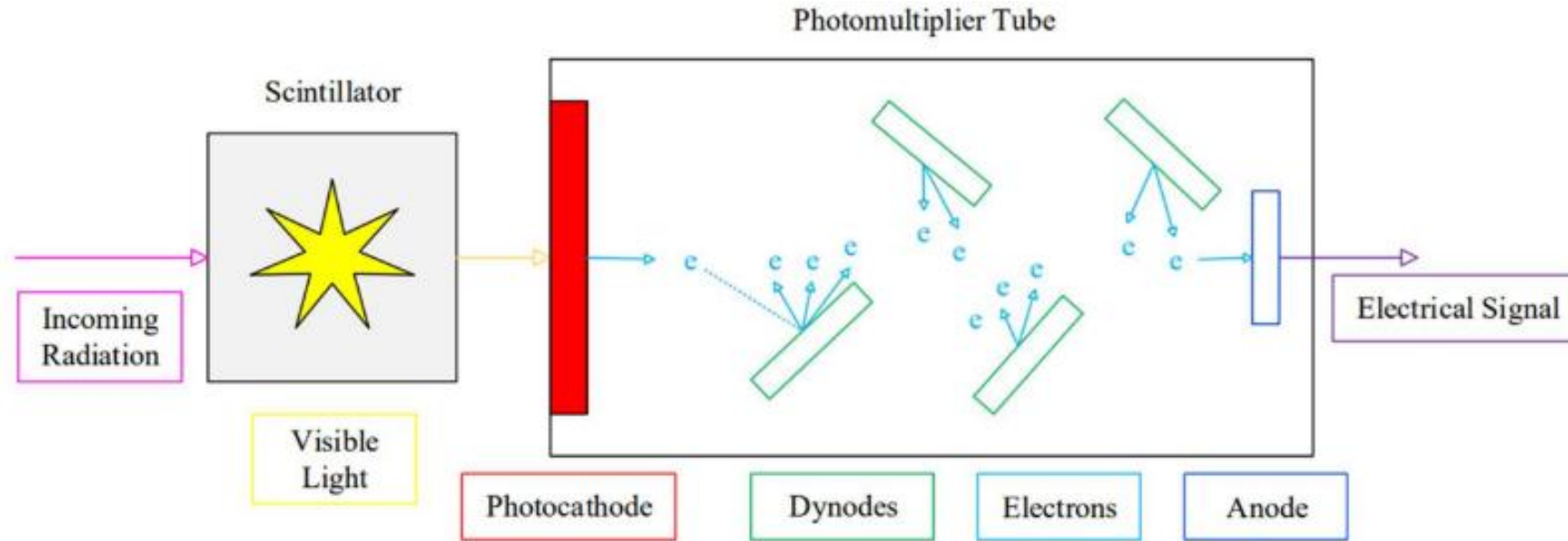
<https://www.orau.org/health-physics-museum/collection/geiger-mueller-tubes/index.html>

Counters

- Counting Detector
- A source is placed in the detector
- Detector records the number of radiation counts from the source
- Uses a nuclear electronics set up



Scintillation Detectors



Scintillator

Material that converts a radiation interaction into visible light

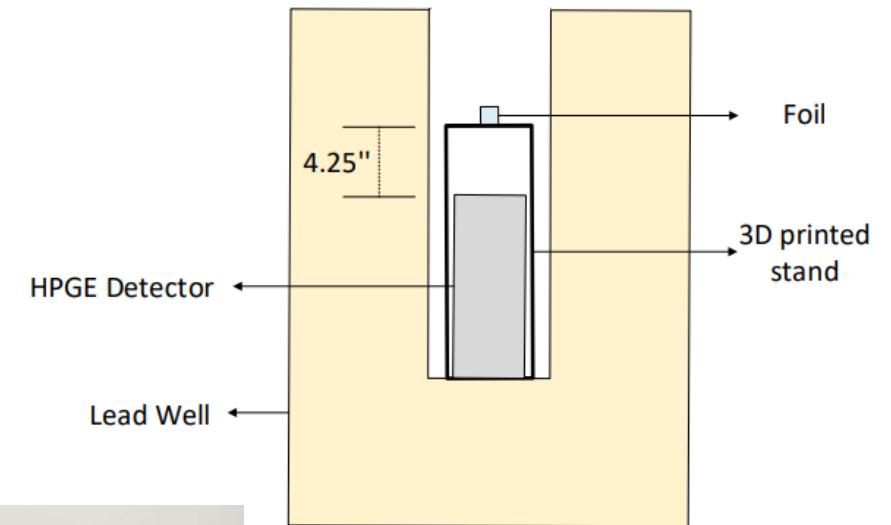


Photomultiplier Tube

- Light knocks electrons from the photocathode
- Electrons interact with dynodes to produce and avalanche.
- Charge is collected at the anode, outputting a signal

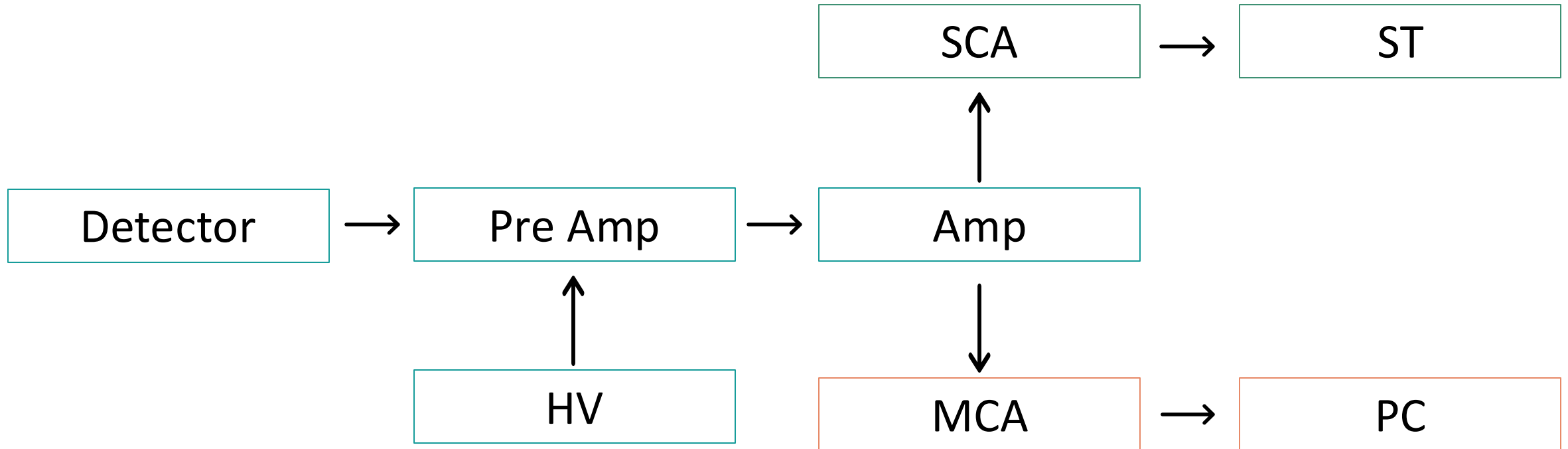
Solid-State Detectors

- Use semi-conductor materials
- An applied voltage leads electrons and holes to move apart.
- Radiation interacts with the material to form electron-hole pairs .
- Pairs are collected at electrodes, creating a signal.
- Require an external cooling source



Nuclear Electronics

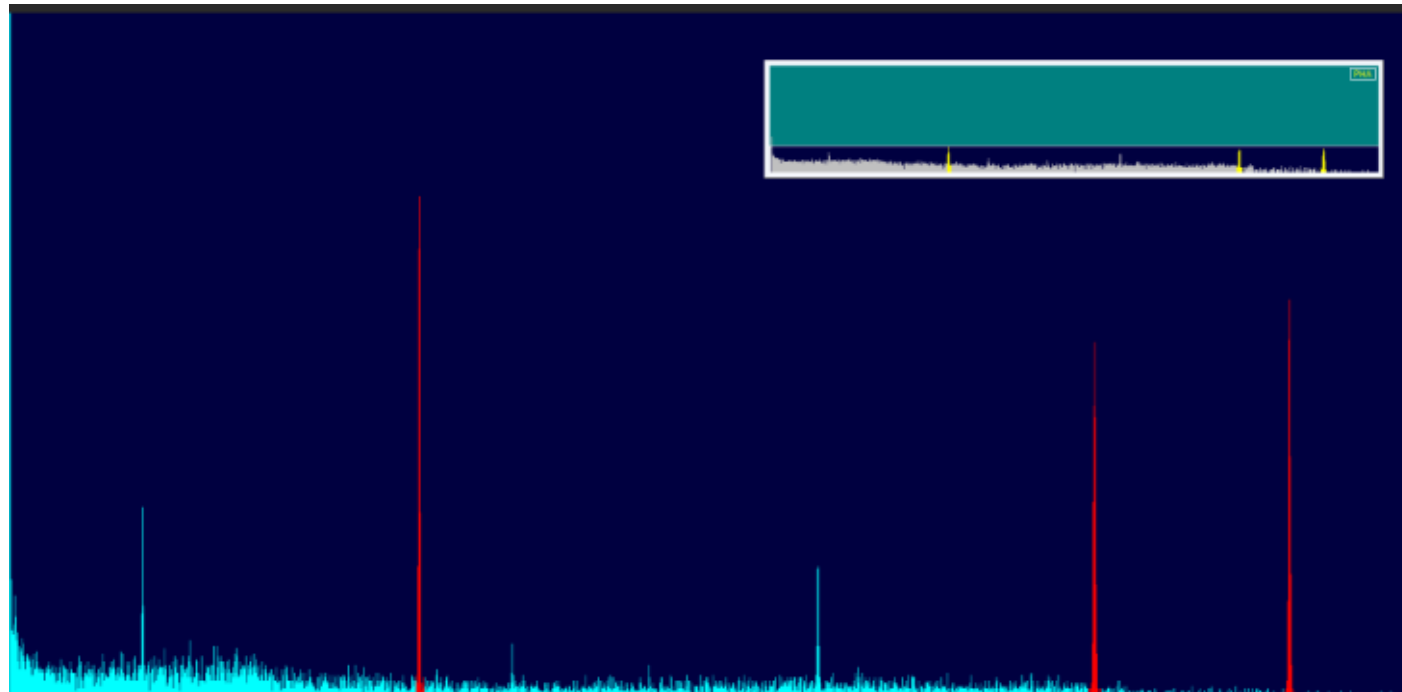
GM Counters



Scintillation or Solid-State Detector

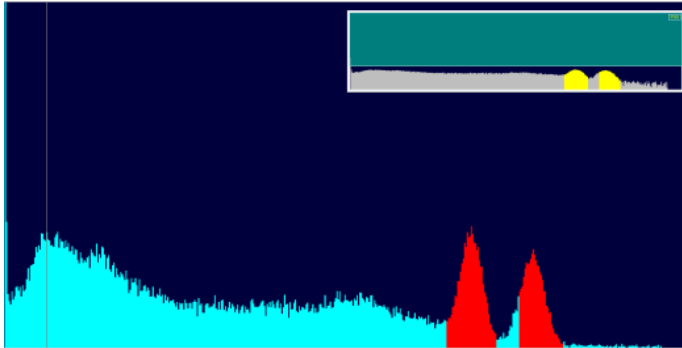
Detector Outputs

- GM detectors = a signal reading (radiation survey or a count)
- Scintillation and Solid-State = Energy Spectrum (energy differentiation)



Resolution

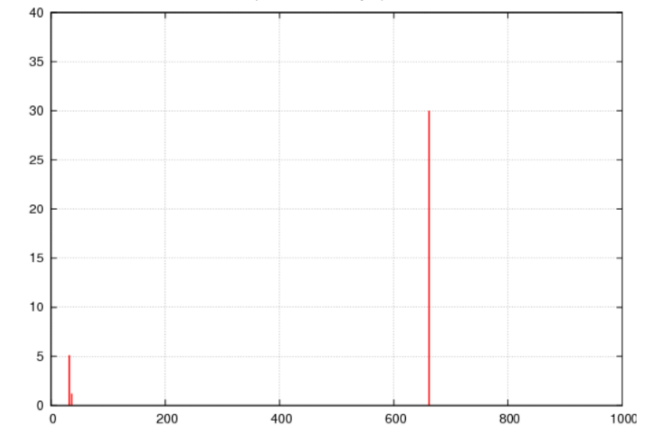
- Measure of the clarity of an energy spectrum
- $\text{Resolution} = \text{FWHM} / \text{Energy of the Peak}$



Scintillation Detector



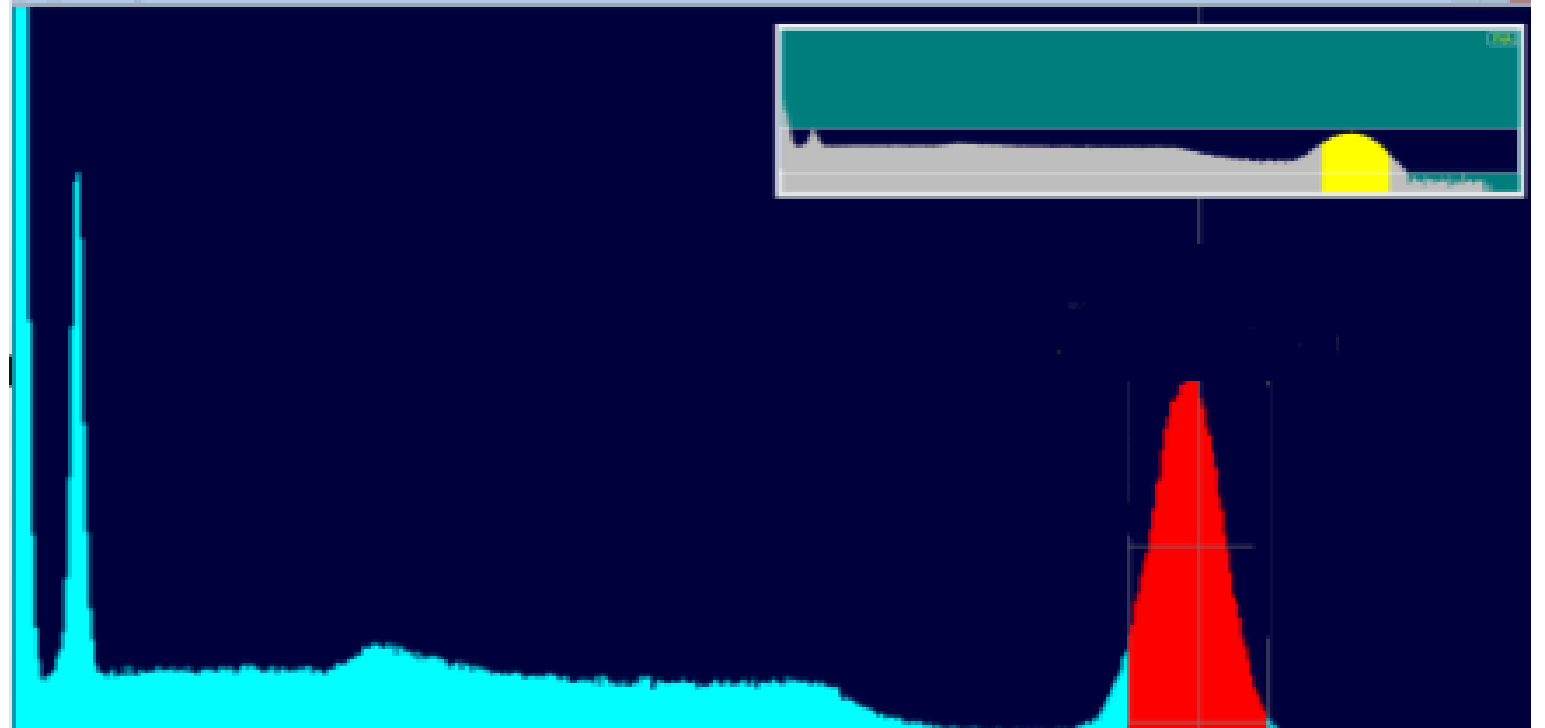
Solid State Detector



Source Spectrum

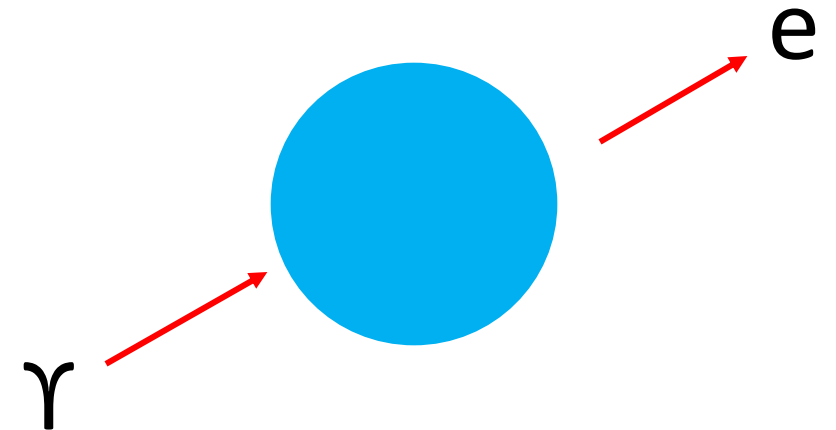
Energy Differentiation - Radiation Spectroscopy

- Backscatter
- X-ray
- Annihilation
- Photopeak
- Compton Edge and Continuum
- Single and Double Escape Peaks



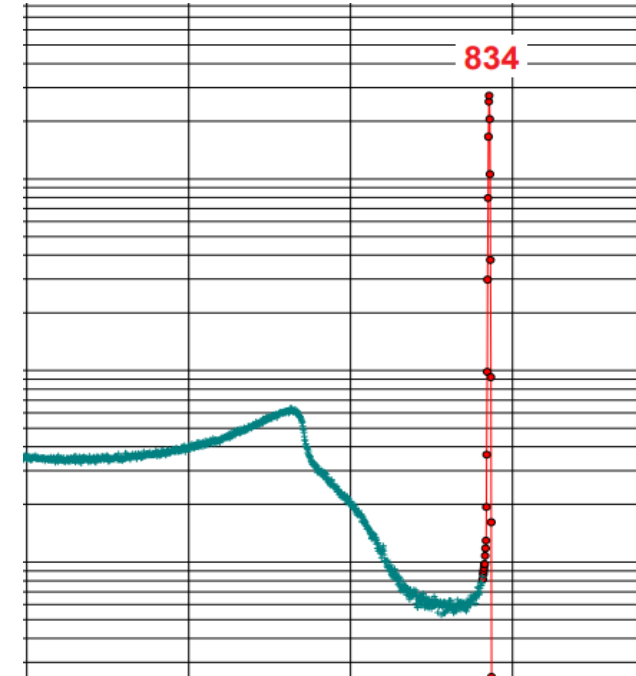
Energy Differentiation - Photopeak

- Products of the Photoelectric Effect
 - Gamma rays are absorbed by the atom
 - Gives energy to an electron, knocking it from the atom
 - Gamma ray energies 100 – 2000 keV
 - Can be thought of as a full energy event

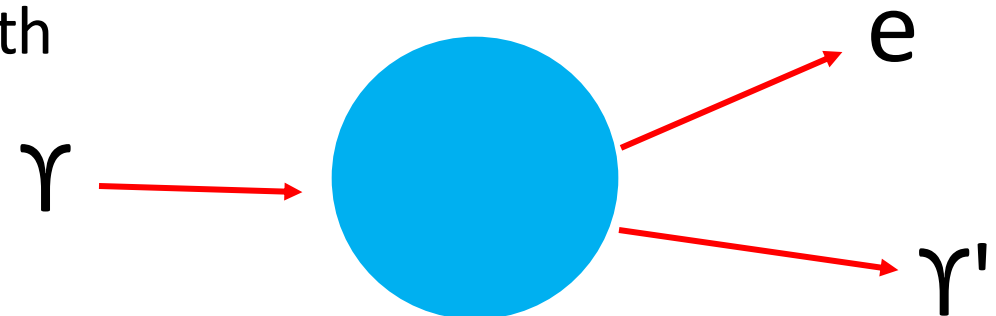


Energy Differentiation - Compton Edge and Continuum

- Product of Compton Scattering
 - Gammas rays interact with an atom and transfers a portion of its energy, but not all
 - Energy is transferred to an electron, knocking it from the atom
 - Results in an electron and a gamma with less energy than the original

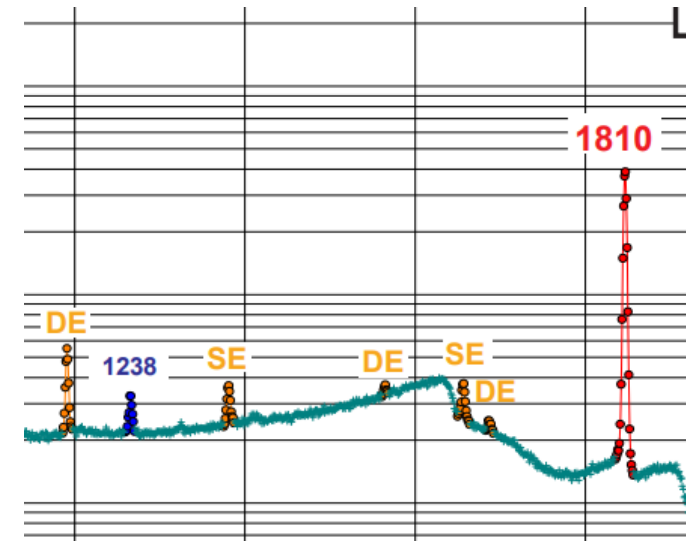


<https://inl.gov/content/uploads/2023/07/mn54.pdf>

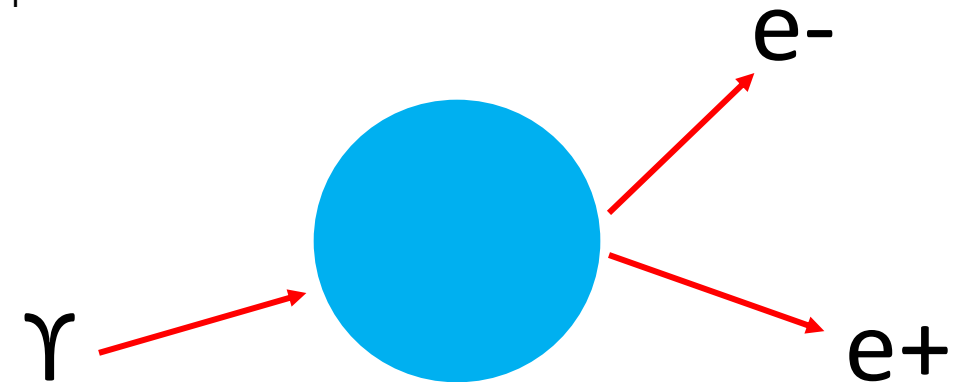


Energy Differentiation - Single and Double Escape Peaks

- Product of Pair Production
 - Gamma rays interact with an atom
 - Gives energy to the atom, releasing an electron and a positron
- Positron annihilates and emits two 0.511 MeV (511 keV) gammas
- Gamma energy must be greater than 1.022 MeV
- Single = one 0.511 MeV gamma escapes
- Double = both escape

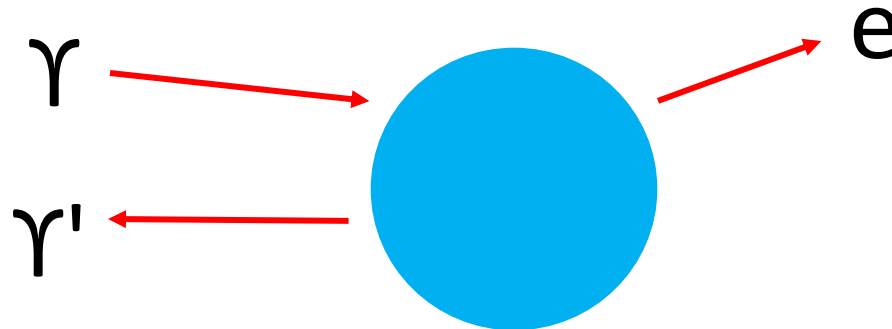
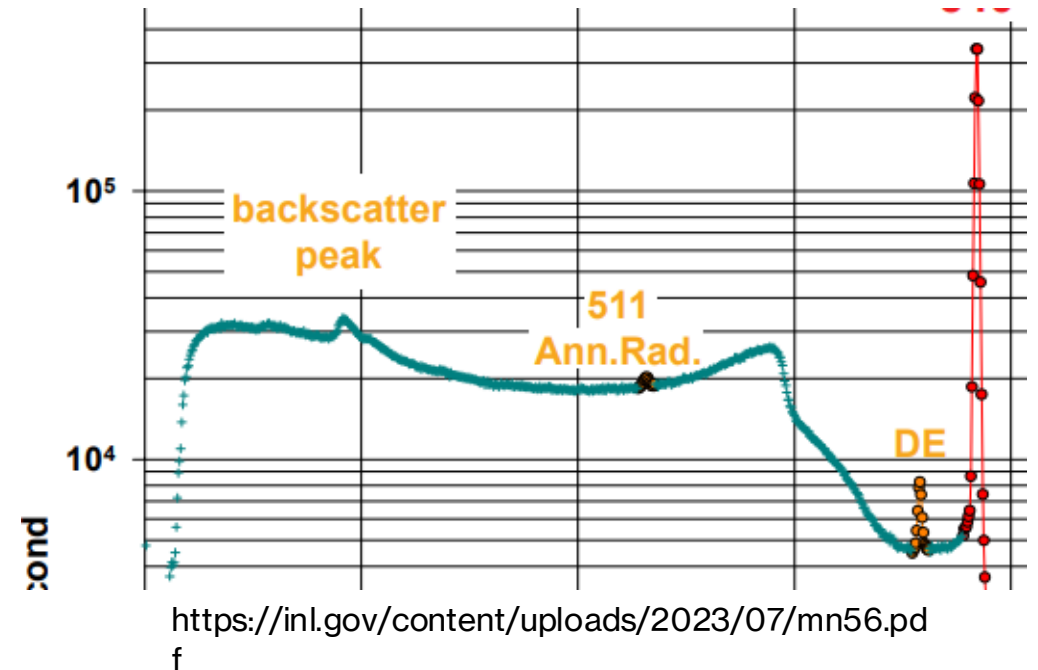


<https://inl.gov/content/uploads/2023/07/in116m.pdf>



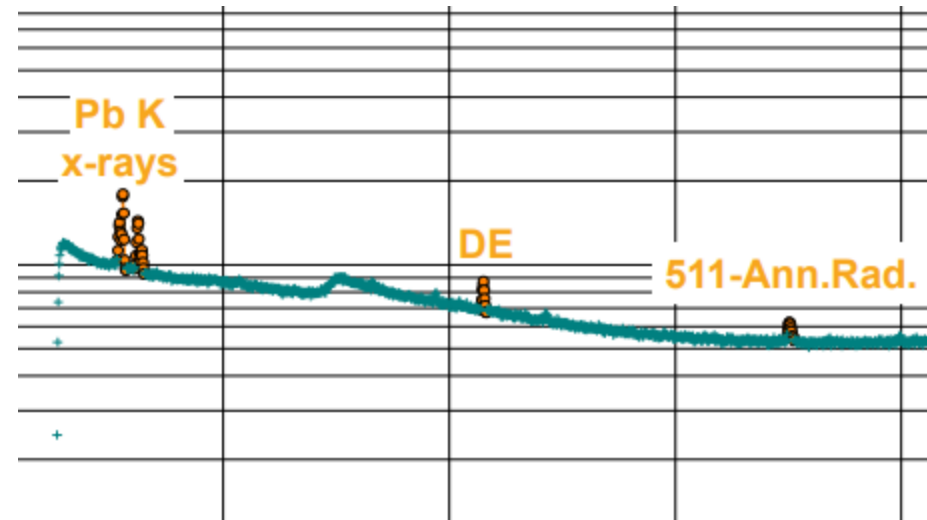
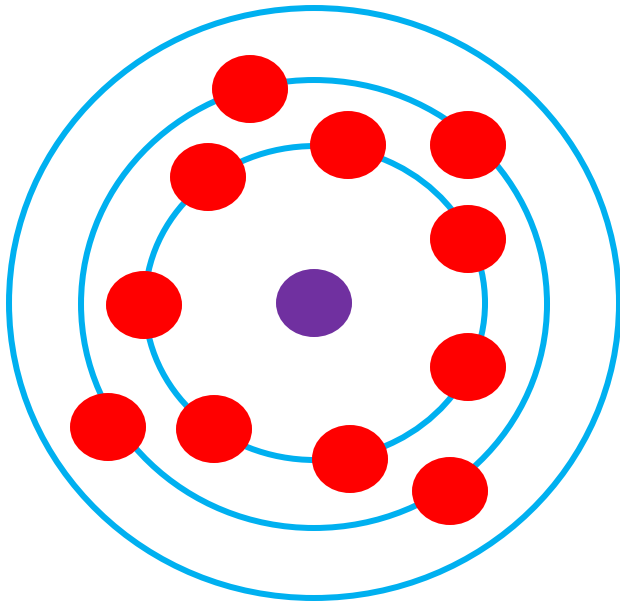
Energy Differentiation - Backscatter

- Result of large angle deflections of particles
- Gammas entering the detector can undergo Compton scattering, and scatter at an ~ 180 degree angle (backwards) before being detected.
- Low energies



Energy Differentiation - X-ray

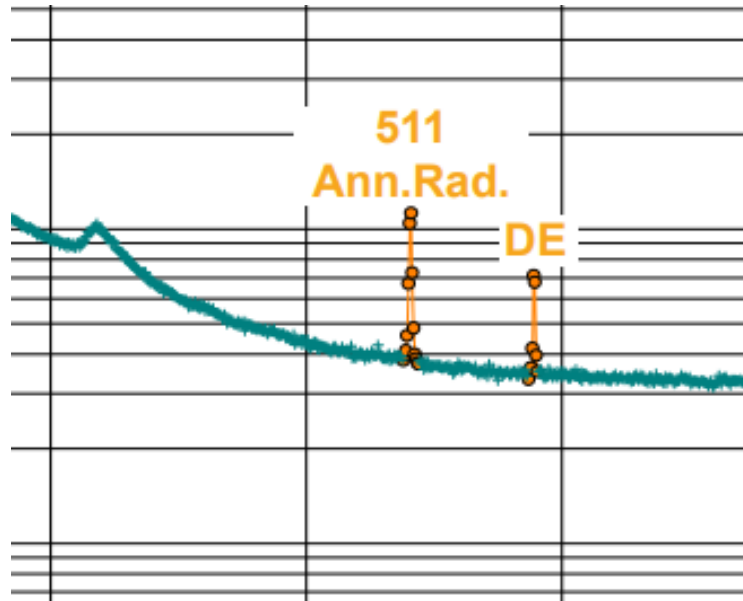
- Result of electrons moving to fill vacancies in the K-shell of an atom



<https://inl.gov/content/uploads/2023/07/co60.pdf>

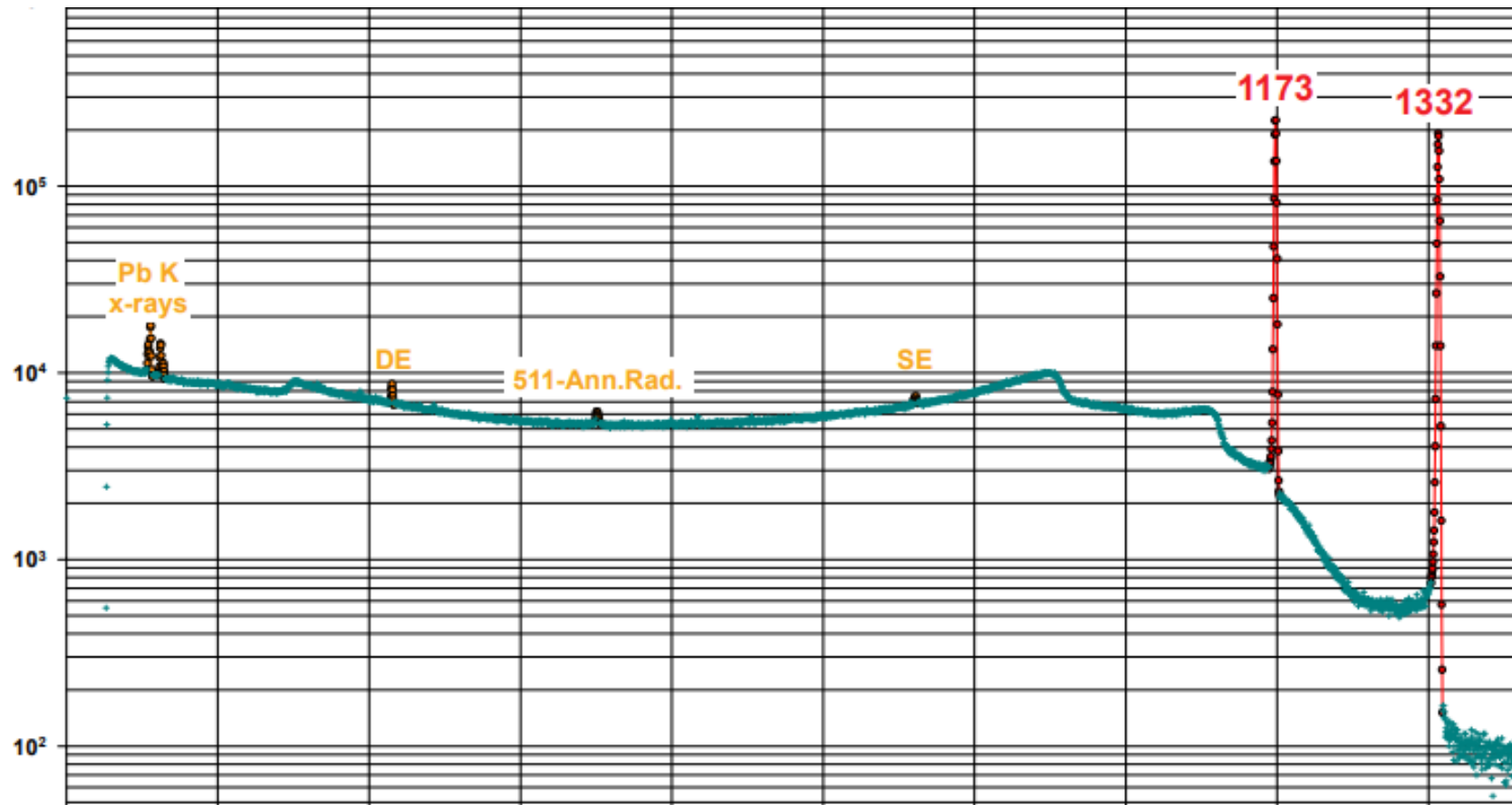
Energy Differentiation - Annihilation

- Small energy peak at 0.511 MeV
- Photons resulting from the annihilation of a positron



<https://inl.gov/content/uploads/2023/07/cl38.pdf>

Energy Differentiation - Full Spectrum

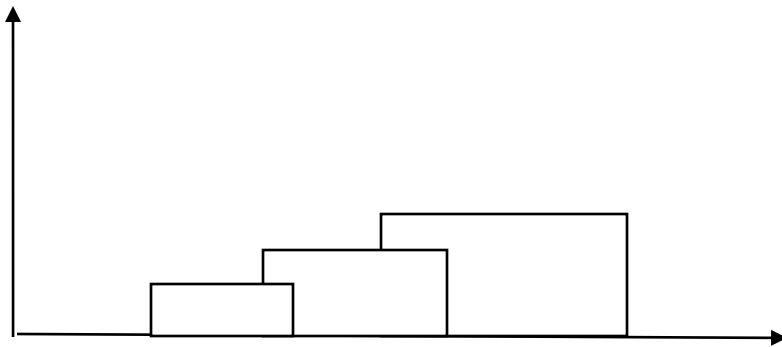


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Deadtime

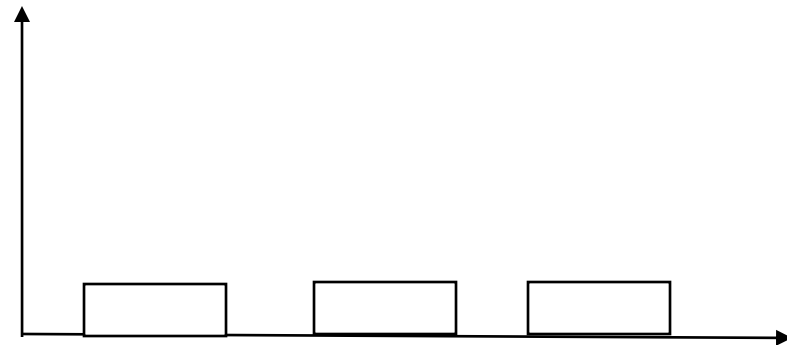
A reset period for a detector between radiation interactions

Paralyzable



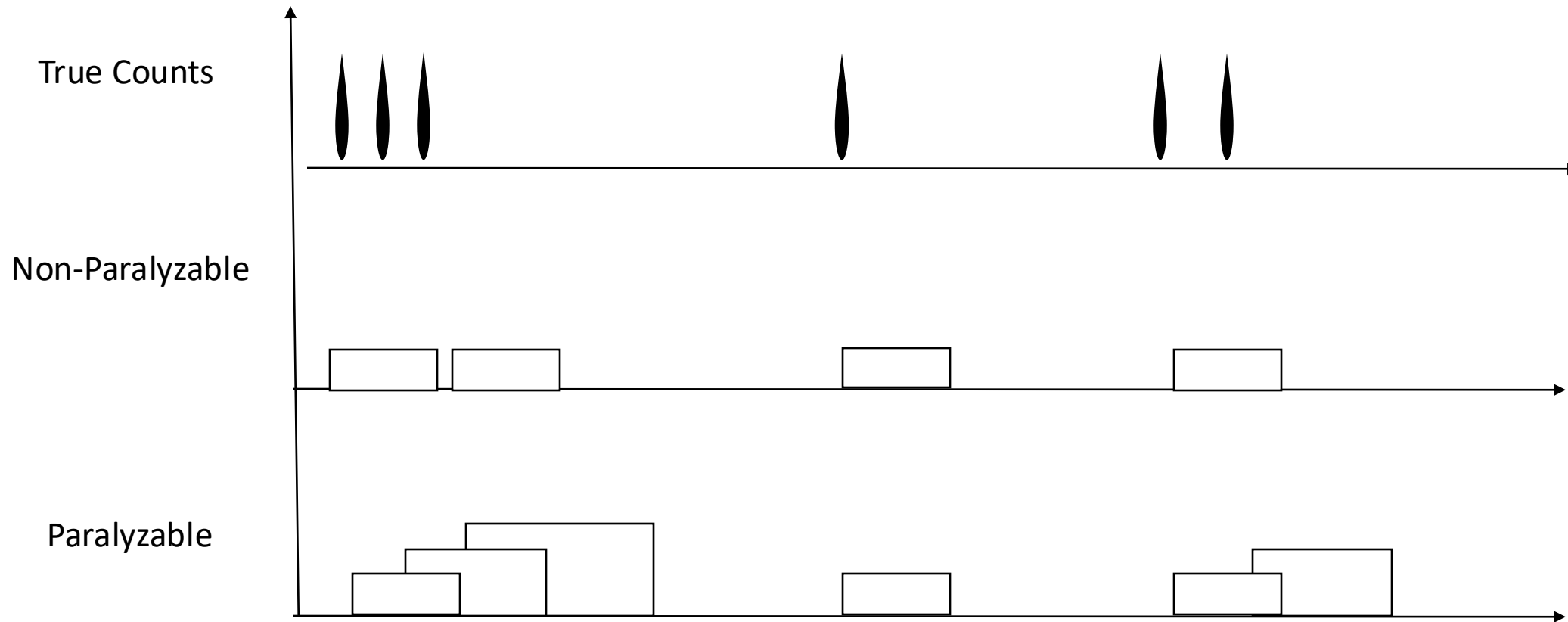
$$\dot{n} \approx \frac{\dot{m}}{e^{-\dot{n}\tau}} \approx \frac{\dot{m}}{e^{-\dot{m}\tau}}$$

Non-Paralyzable



$$\dot{n} \approx \frac{\dot{m}}{1 - \dot{m}\tau}$$

Deadtime



Practice Problem – Realistic Case

Calculate your corrected counting rate for a count of 900,000 cps if your deadtime is 0.2 microseconds (0.0000002 seconds) for both detectors.

$$\dot{n} \approx \frac{\dot{m}}{1 - \dot{m}\tau} \qquad \dot{n} \approx \frac{\dot{m}}{e^{-\dot{n}\tau}} \approx \frac{\dot{m}}{e^{-\dot{m}\tau}}$$

$\dot{n}$ = corrected counting rate

$\dot{m}$ = original count

τ = deadtime

Practice Problem – Realistic Case

Calculate your corrected counting rate for a count of 900,000 cps if your deadtime is 0.2 microseconds (0.0000002 seconds) for both detectors.

$$\dot{n} \approx \frac{\dot{m}}{1 - \dot{m}\tau}$$

$$n = 1097560.9$$

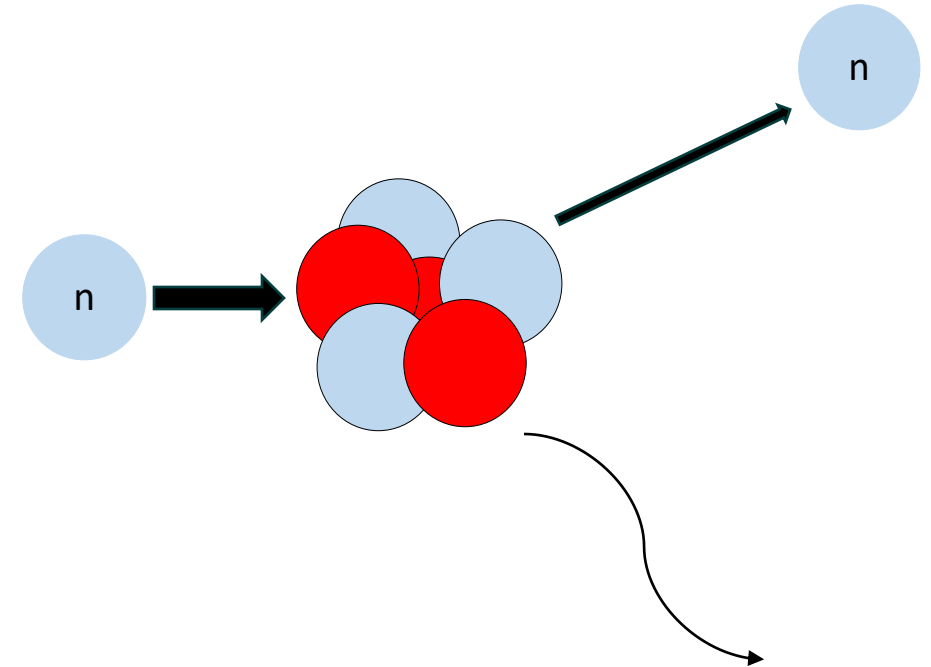
$$\dot{n} \approx \frac{\dot{m}}{e^{-\dot{m}\tau}} \approx \frac{\dot{m}}{e^{-\dot{m}\tau}}$$

$$n = 10774956.3$$

Neutron Detectors

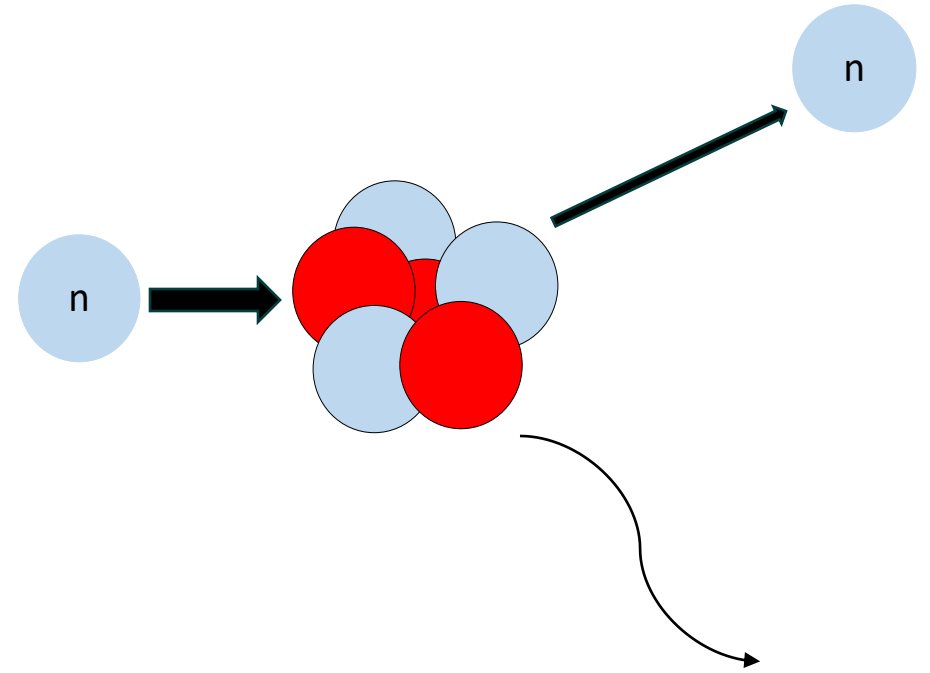
Why?

- Chargeless → Not detected by standard surveying equipment
- Damage → Fast moving particles with mass can emit high energy gammas when interacting with matter
- Penetrating → Most elements have low neutron cross-sections
- Activation → Neutrons can activate materials, turning them radioactive



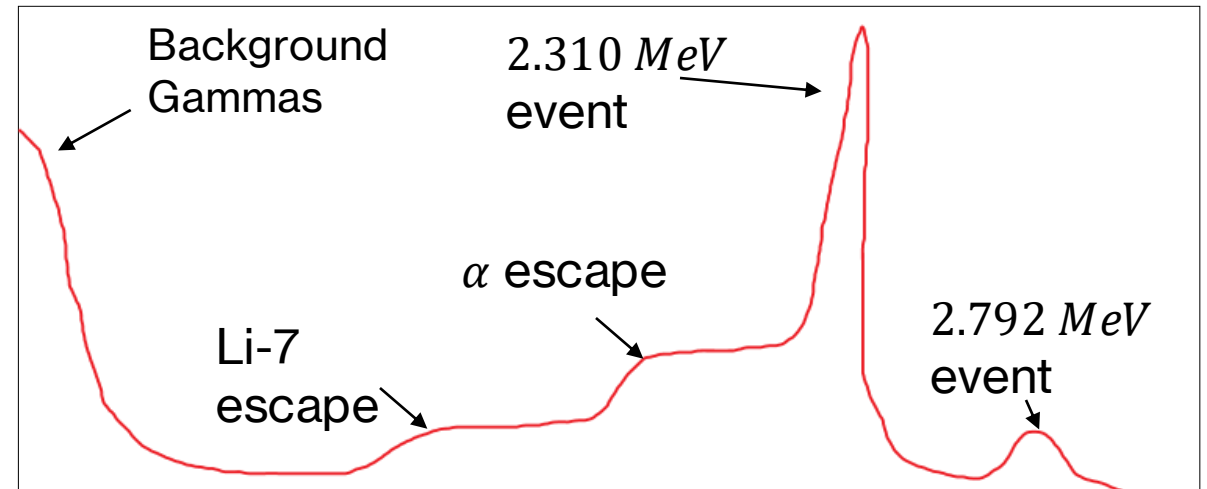
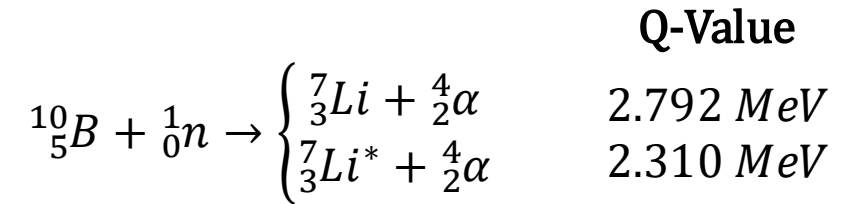
Neutron Detectors

- Chargeless → Standard detectors will not work
- Detect neutron interactions
- Neutrons interact with gas
- Produces gammas and charged particles
- Products ionize gas
- Detection!
- Examples: BF₃ or He-3



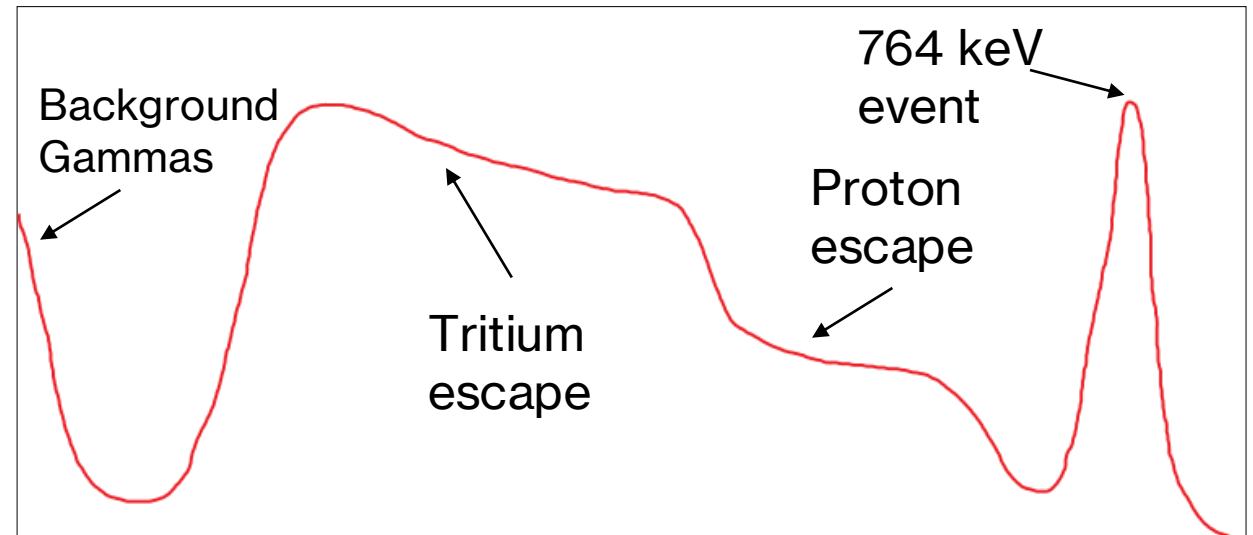
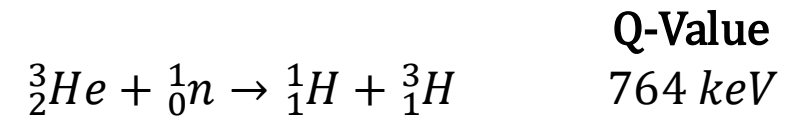
BF3 Detectors

- Fast neutrons – Very few interactions
- Thermal neutrons – Interact with boron through the given interaction
- Full energy events – 2.792 MeV or 2.310 MeV deposited in detector
- Partial energy events – Alpha particles or Li-7 escape



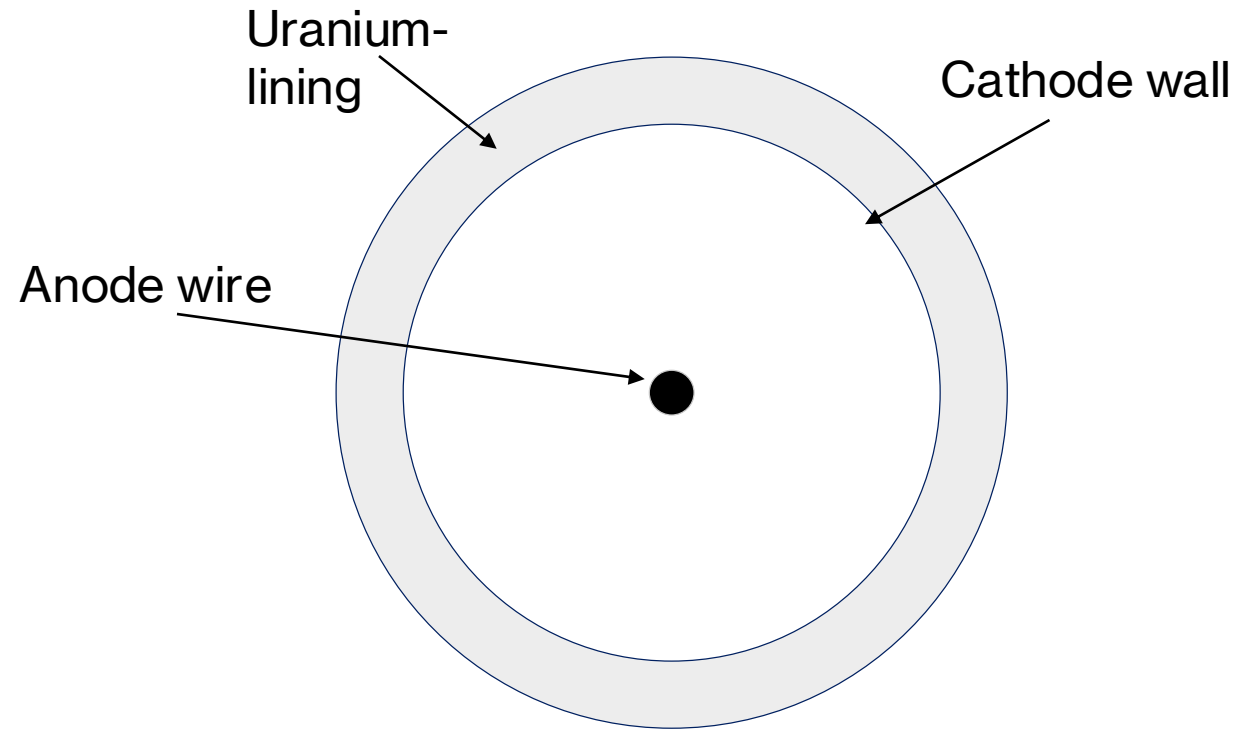
He-3 Detectors

- Fast neutrons – Very few interactions
- Thermal neutrons – Interact with boron through the given interaction
- Full energy events – 2.792 MeV or 2.310 MeV deposited in detector
- Partial energy events – Alpha particles or Li-7 escape



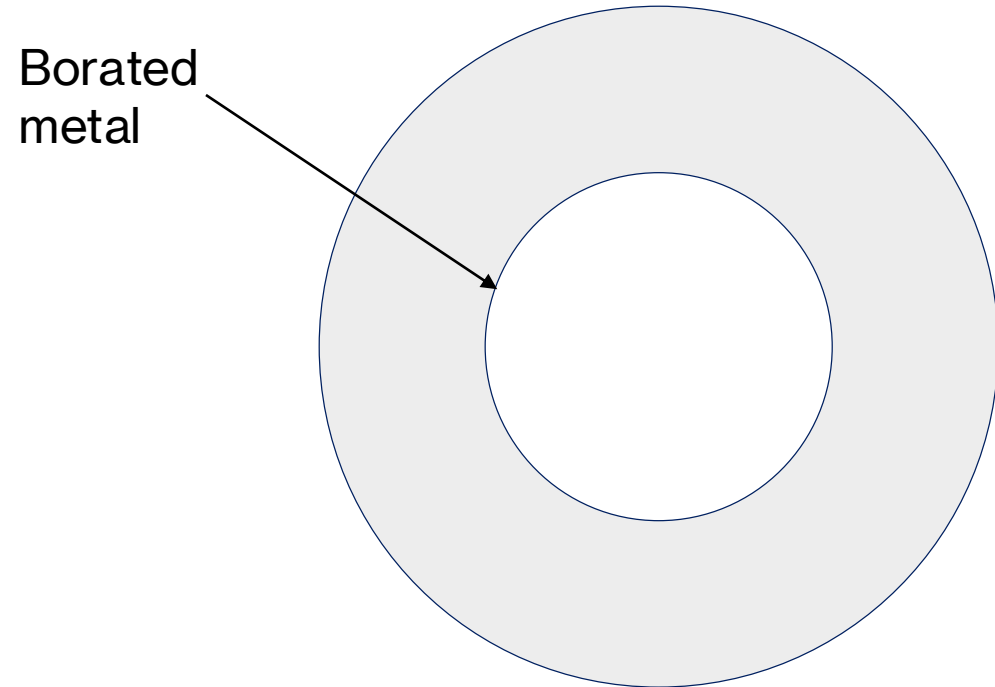
Fission Chambers

- Neutrons are tough to detect, but fission products are easy!
- Uranium-lined walls cause fission in ionization chamber
- Fission products create electron-ion pairs → counts

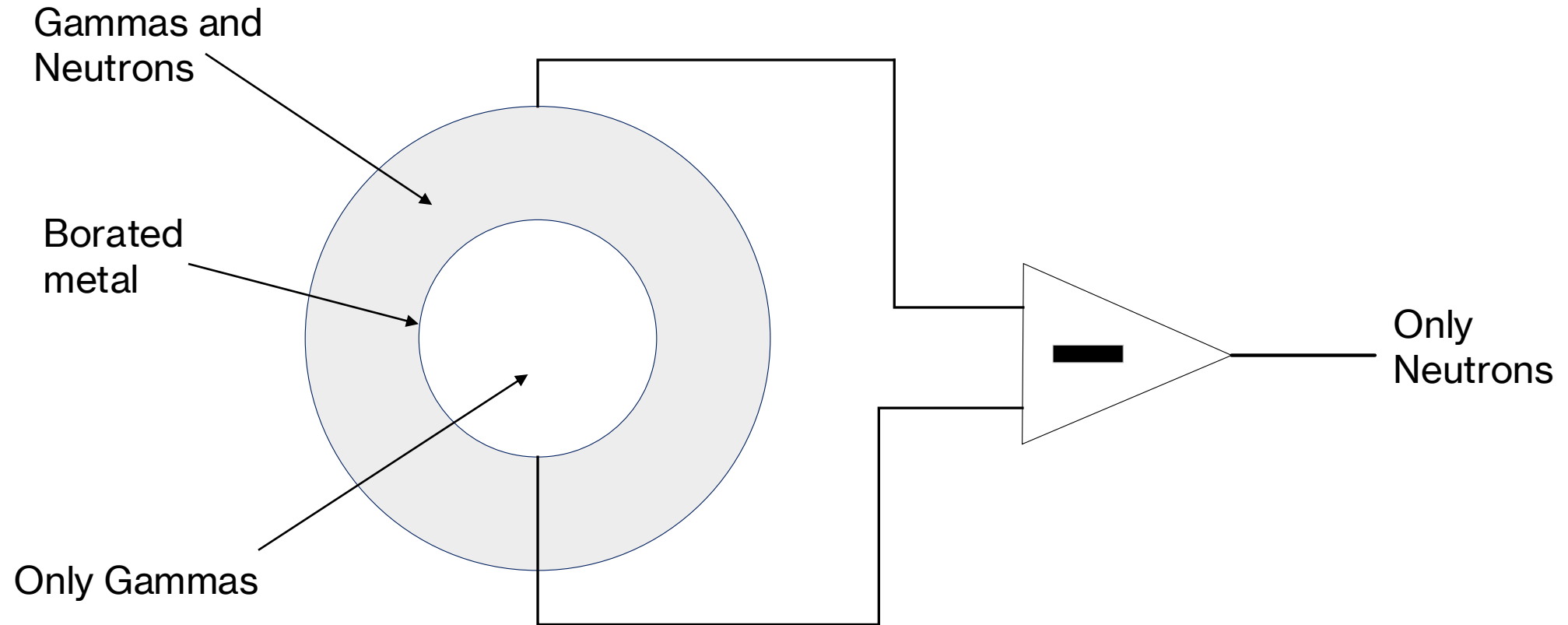


Compensated Ion Chambers (CIC)

- With lots of neutrons, there are lots of gammas
 - Produced by fission
 - Produced through decay of fission products
- Current type detector
- Two concentric chambers, inner chamber lined with Boron



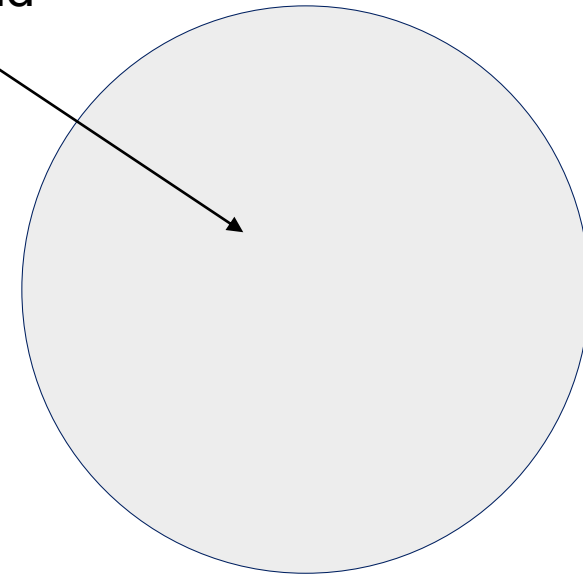
Compensated Ion Chambers (CIC) Diagram



Uncompensated Ion Chambers (UIC)

- Similar to a CIC detector, but without inner chamber
- Detects both gammas and neutrons
- Current type detector
- At high power levels, gamma flux and neutron flux are proportional

Gammas and
Neutrons

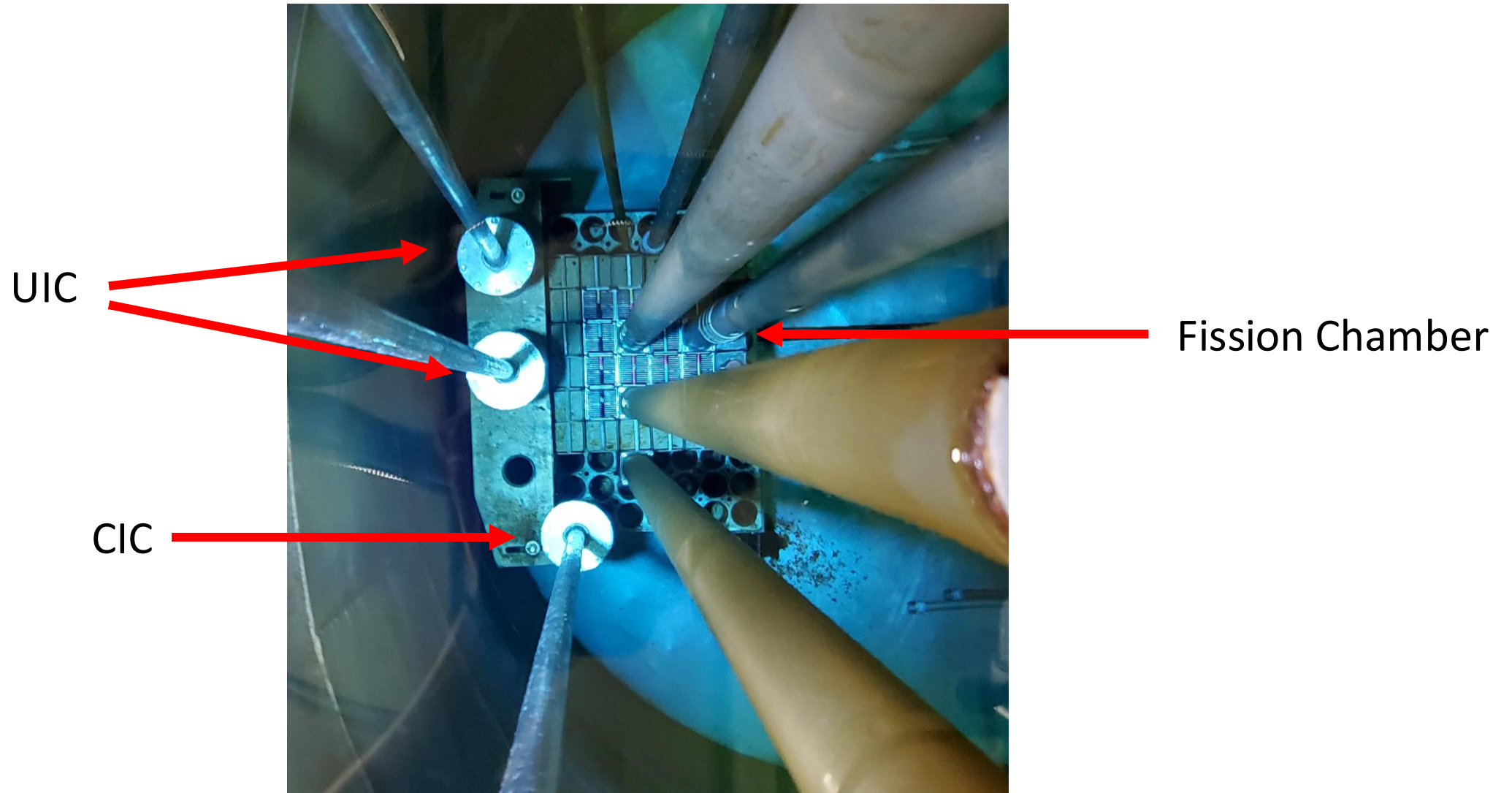


Applications

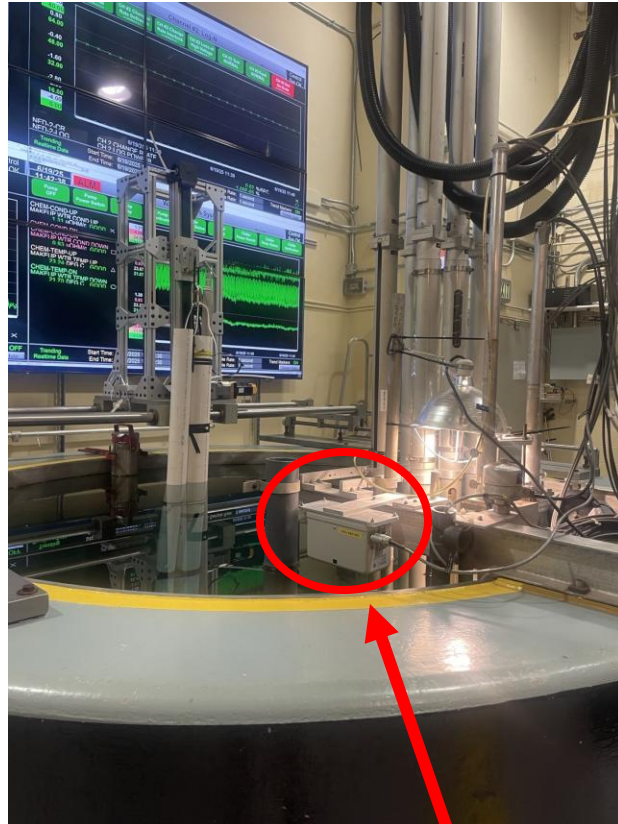
Applications

- Radiation Safety
- Waste Monitoring
- Neutron Flux Monitoring
- Neutron Activation Experiments and Research
- Material Characterization

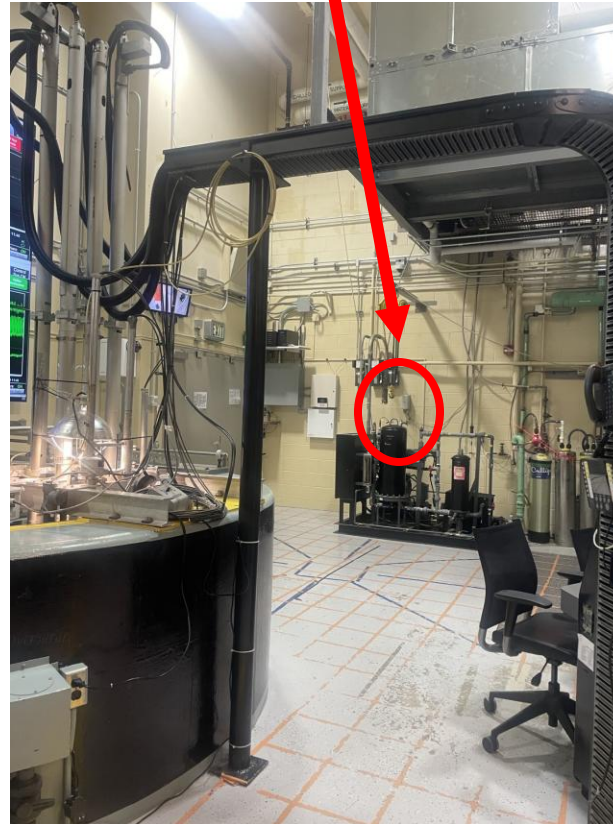
PUR-1 Examples



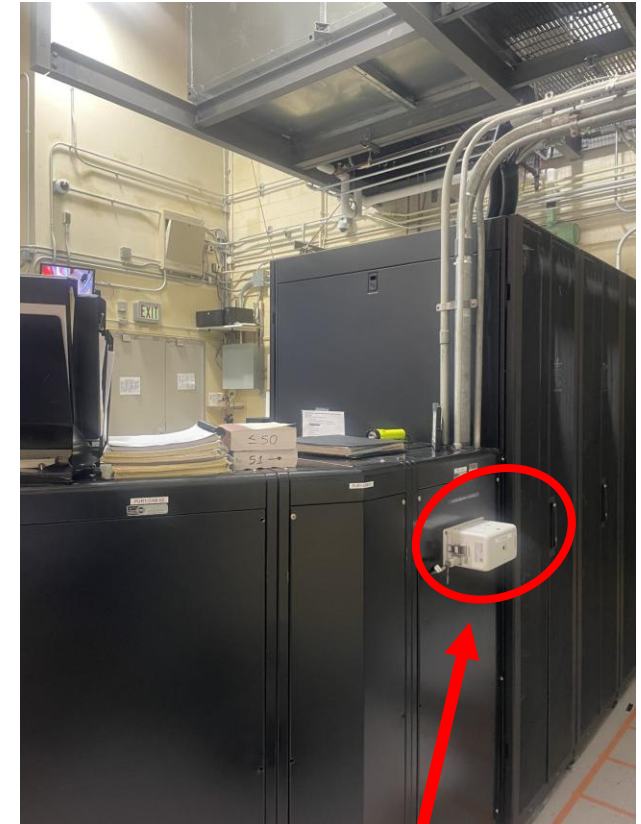
PUR-1 Examples



RAM 1



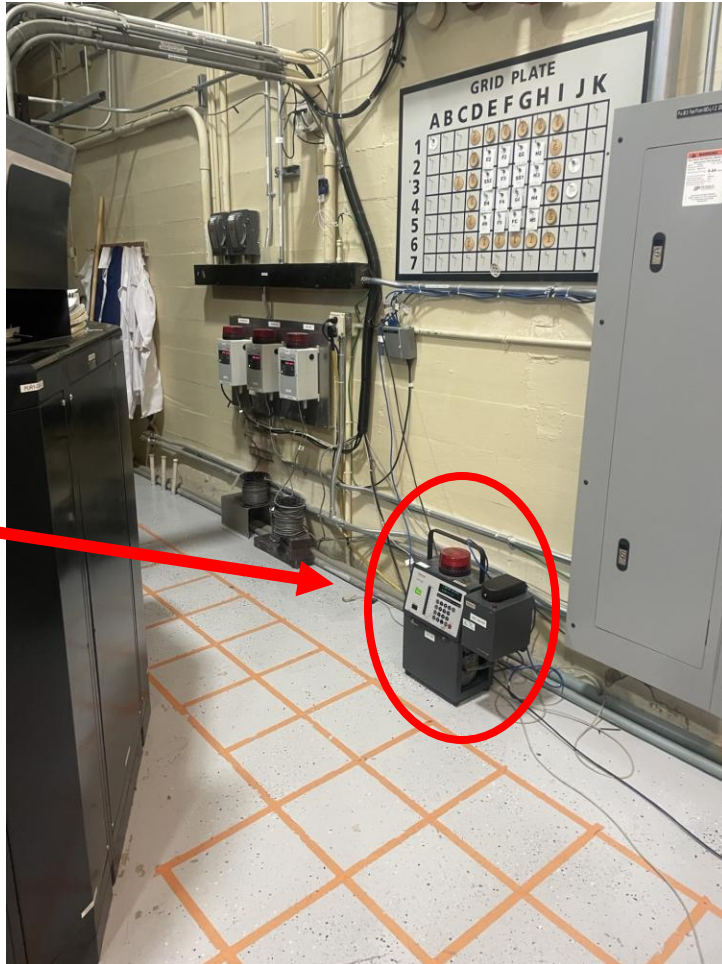
RAM 2



RAM 3

PUR-1 Examples

CAM



GM Survey Meter

Summary

- Gas filled detectors
- Gamma detectors
 - GM, scintillation detectors, solid-state detectors
- Neutron detectors
 - BF₃, He-3
 - Fission Chambers, UIC, CIC
- Applications
 - PUR-1



Questions and Discussion