Applied Nuclear Physics

Efficiency of Gamma Ray Detectors

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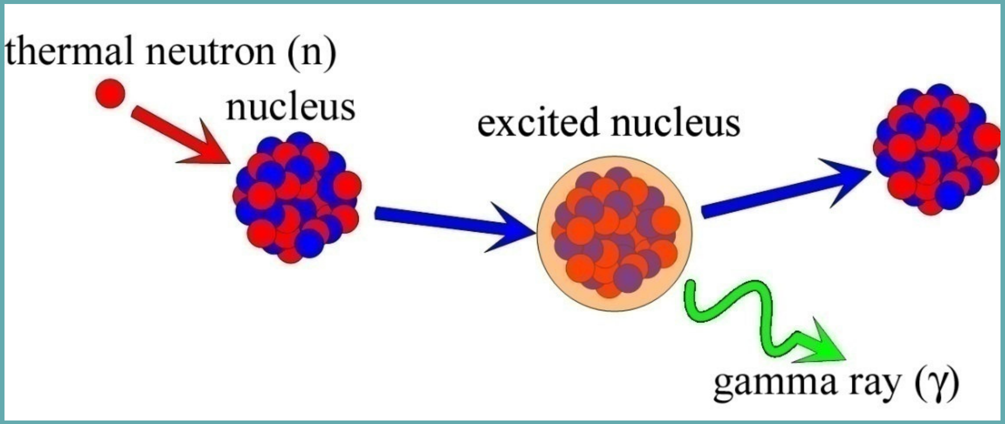
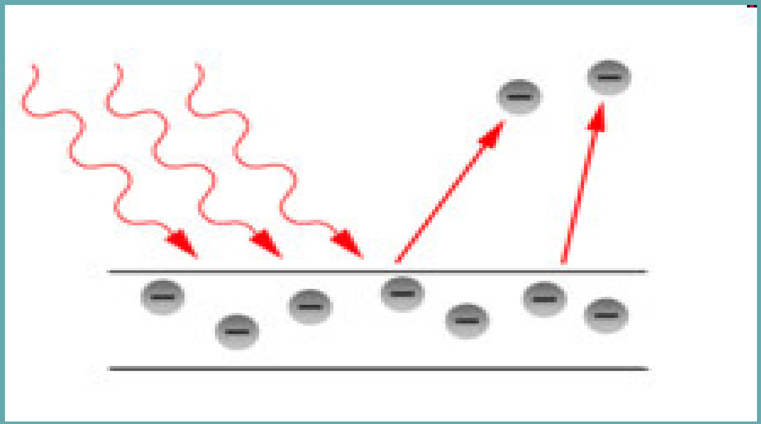
Nuclear Physics

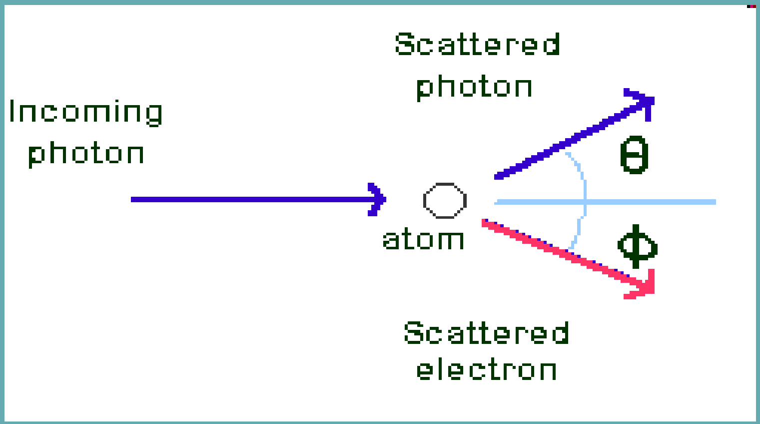


- Neutron source, Cf-252
- Neutrons captured in nucleus
- Unstable nucleus created
- Nucleus decays (in picoseconds)
- Gamma ray emitted
- Energy spectrum unique to isotope

Gamma Ray Interactions

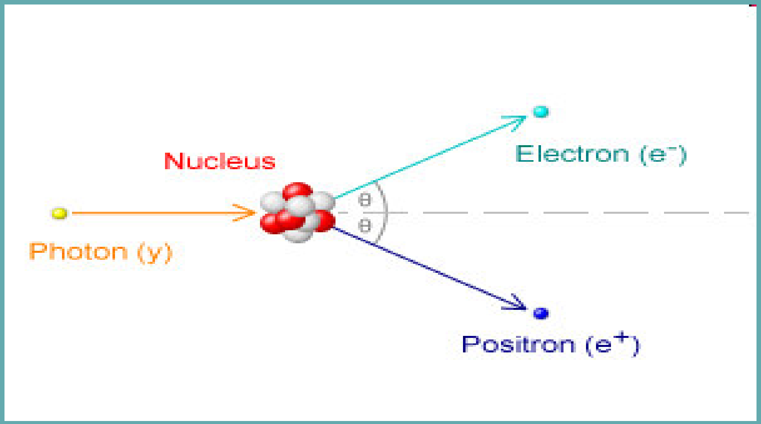


Photoelectric Effect



Compton Scattering

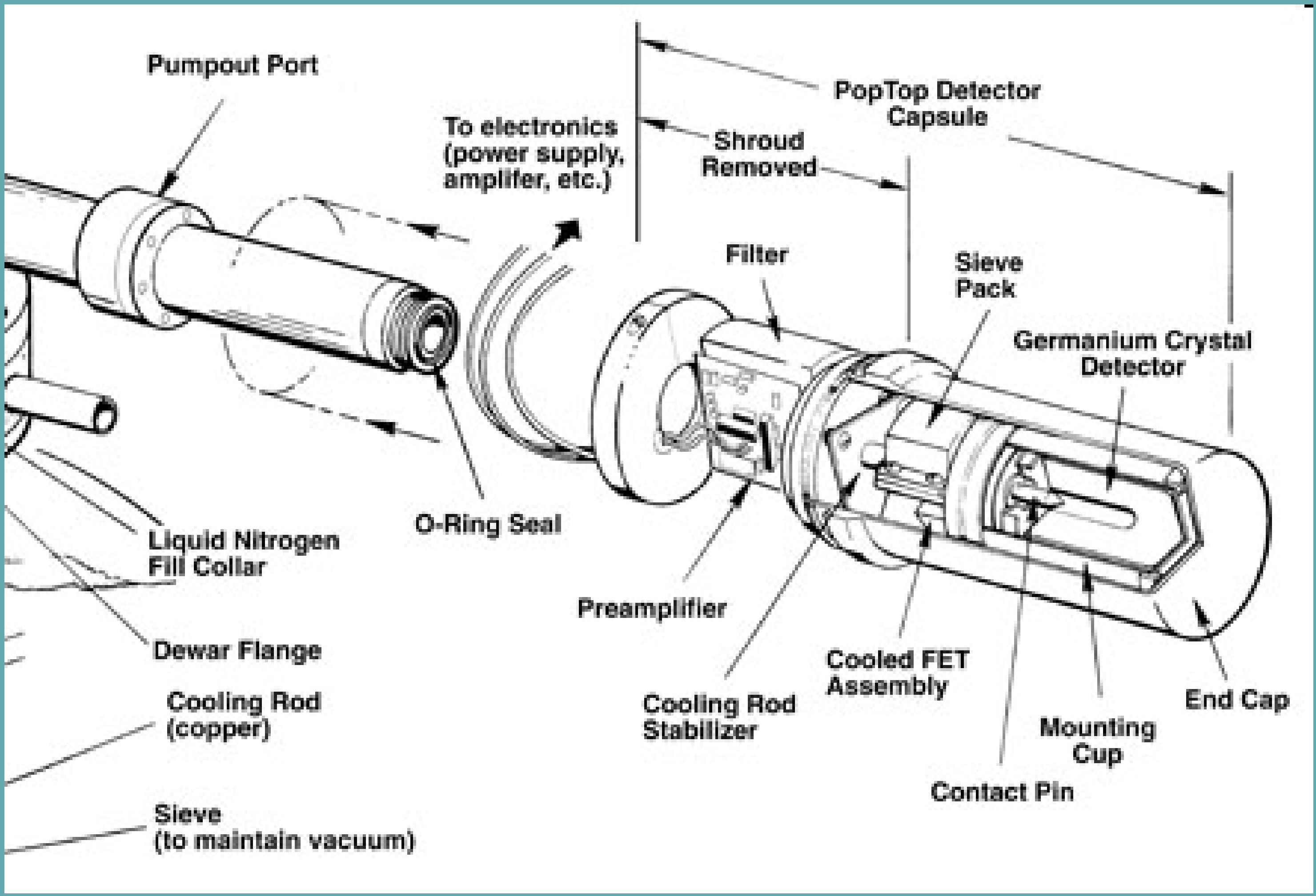
Pair Production



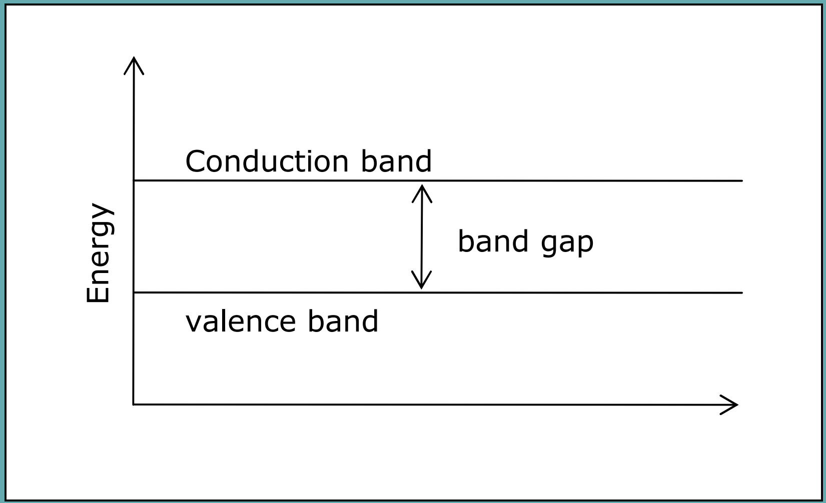
High-Purity Germanium Detectors

- Ge crystal – semiconductor
- X-cooler

HPGe Detectors



How Semiconductor Detectors Work



- Crystal lattice with electron band structure
- Charge Carriers
  - Charge is carried via electrons and holes
  - Electrons are promoted from the valence band to the conduction band
  - Holes are electron vacancies in the crystal lattice, behave similarly to electrons

How Semiconductor Detectors Work

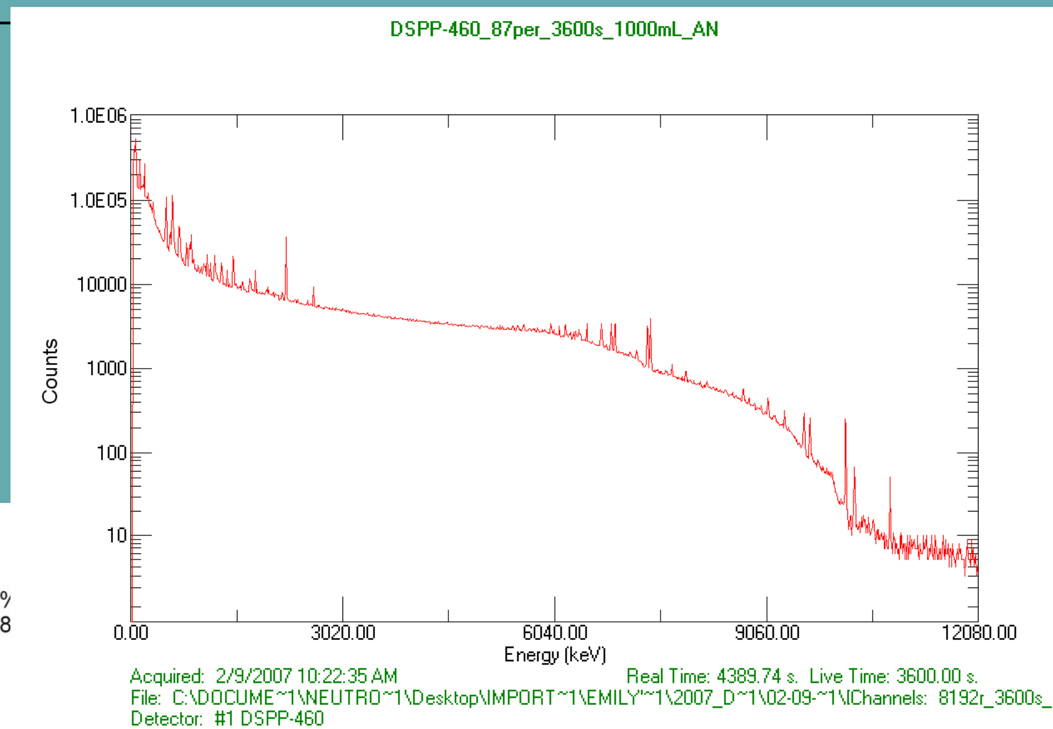
- Thermal Excitation
  - Probability of promoting an electron to the conduction band

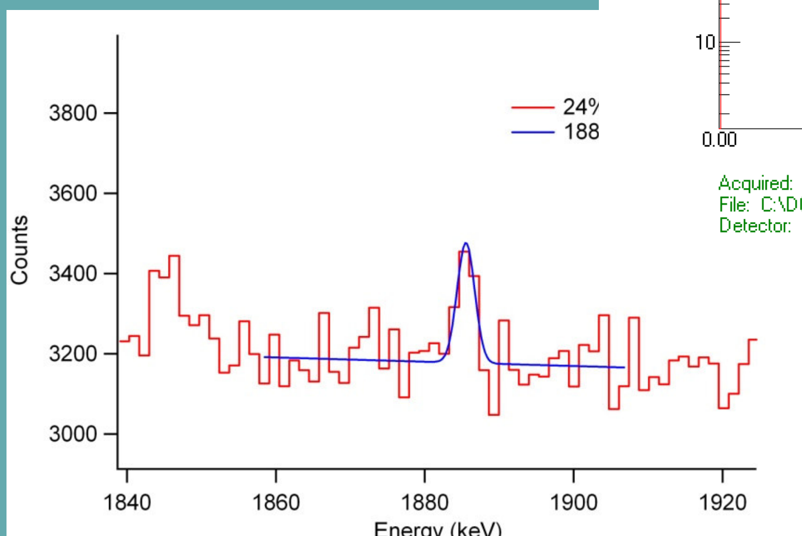
$$p(T) = CT^{3/2} e^{\left(-\frac{E_g}{kT}\right)}$$

  - Reduced by cooling crystal
  - $p(100K)/p(300K) \sim 10^{-24}$, cooling to 100K reduces noise by 24 orders of magnitude

- Drawbacks
  - Cooling necessary
  - More costly than other detectors
  - Radiation damage
    - Particle bombardment causes dislocations in lattice
    - Dislocations degrade detector performance by capturing charge carriers before they are collected

Sample Spectra





What Peaks are Seen

- **Energy varies based on Isotope**
- **Photoelectric Absorption**
  - Dominates up to 150keV in Ge
  - All photon energy deposited
  - Electron promoted to the conduction band
  - Electron deposits energy, creating additional electrons and holes
- **Compton Scattering**
  - Dominates from 150keV to 8MeV
  - Photon loses energy, changes direction
  - Electron promoted to conduction band
  - This process may continue until...
    - Photon loses enough energy for photoelectric absorption
    - Photon escapes the crystal before depositing all of its energy
- **Pair Production**
  - Dominates at greater than 8MeV
  - Photon creates electron-positron pair
  - Electron loses energy by creating additional electrons and holes
  - Positron annihilates with electron
  - Annihilation creates two 511keV photons
    - Both Absorbed: full photopeak energy recorded
    - One Absorbed: photopeak energy minus 511 keV (1^{st} escape peak)
    - Neither Absorbed: photopeak energy minus 1022 keV (2^{nd} escape peak)

Efficiency Study Setup

- Neutron Guide
- NH_4NO_3, $MgCl_2$
- Cf-252
- HPGe detectors

Efficiency

$$\varepsilon(E) = \frac{S_{Obs}(E)}{N_{\gamma,Incident}(E)}$$

$$\varepsilon = \frac{S}{N_{sim} R_{Cf} t_{live}} f_{\phi}$$

where:

S = photopeak signal from experiment

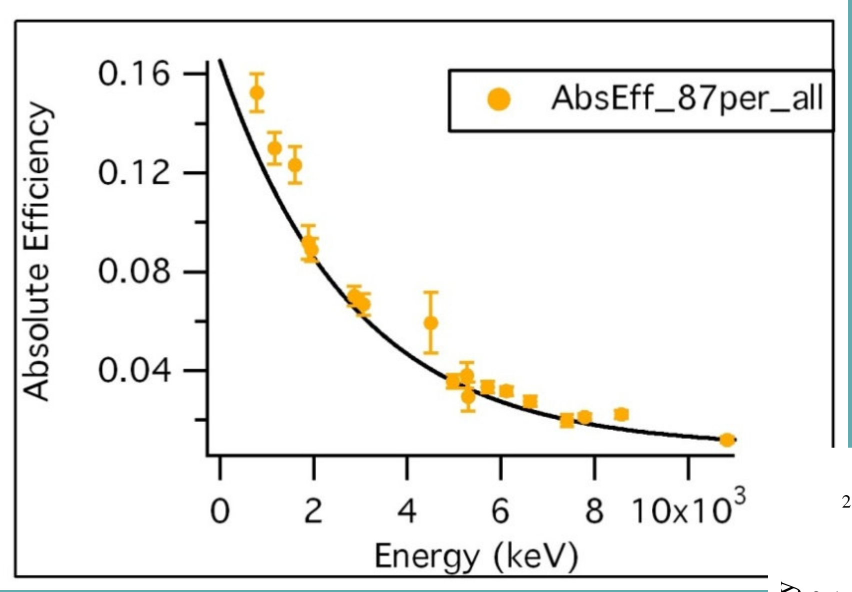
N_{sim} = the number of gamma's crossing the detector from simulation normalized per starting neutron

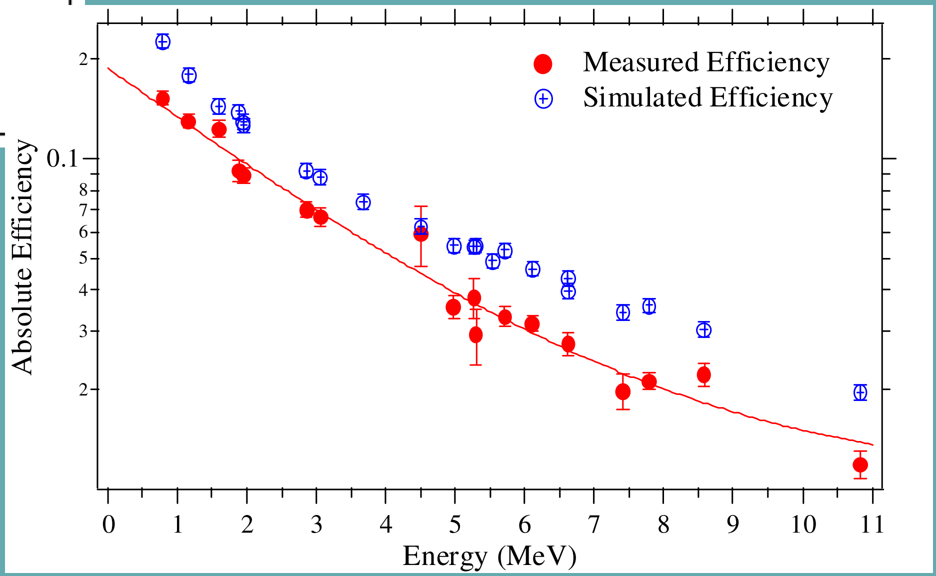
R_{Cf} = neutron emission rate from Cf source

t_{live} = detector live time

f_{ϕ} = scaling factor which accounts for inaccuracies in placing Cf source

Efficiency Study Results

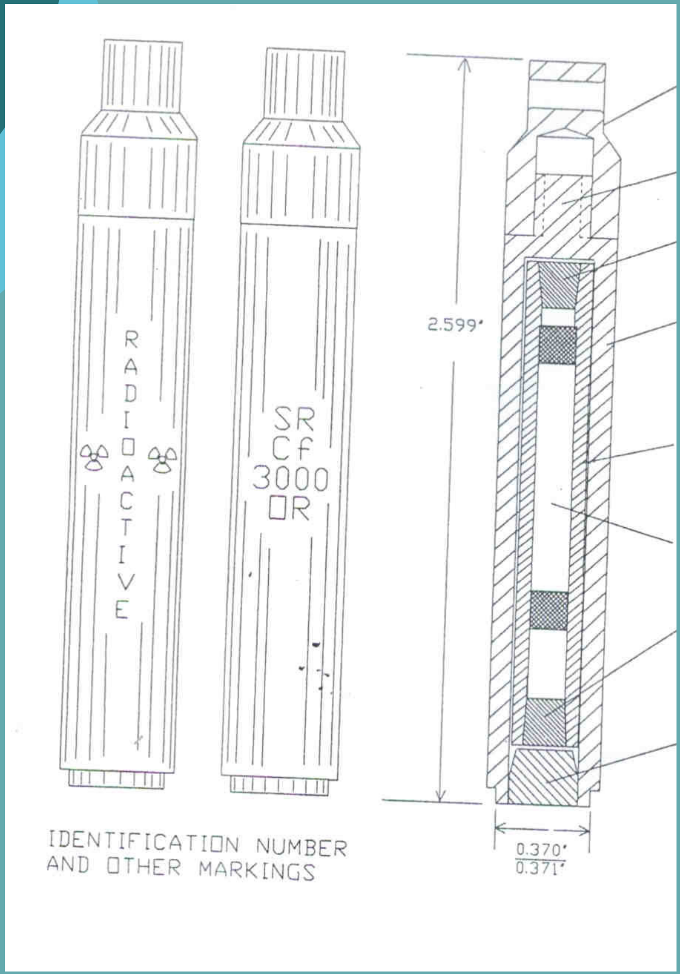




Efficiency Study Paper

- Found Correction Factors
  - Volume/ Density
  - Plastic Skin
  - Cf Placement
  - Sample Placement

Tasks



- Locate relevant files
- Interpret files
- Contact grad students
- Verify calculations

To Complete the Paper

- New Data
  - 87% Detector
  - Exact Cf placement
- MCNP simulations
- Writing
  - Organize Results
  - Make conclusions
- Publish in NIM

Sandbox Update

- Purpose: Detect IED’s
- Progress:
  - Sand!
  - Waiting for funding

Basic Concept

- Send neutrons into ground
- Excite material underground
- Measure emitted gamma rays
- Examine spectrum to determine if material is explosive

- Device must be
  - Fast
  - Accurate
  - Durable

Future Work

- Explosives
- Track system over sandbox for generator, detectors
- Computer Program

Acknowledgments

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