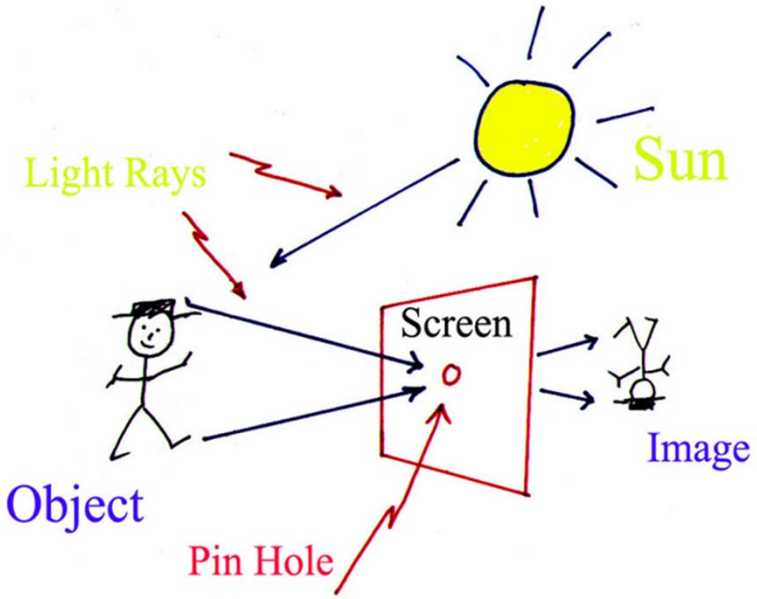
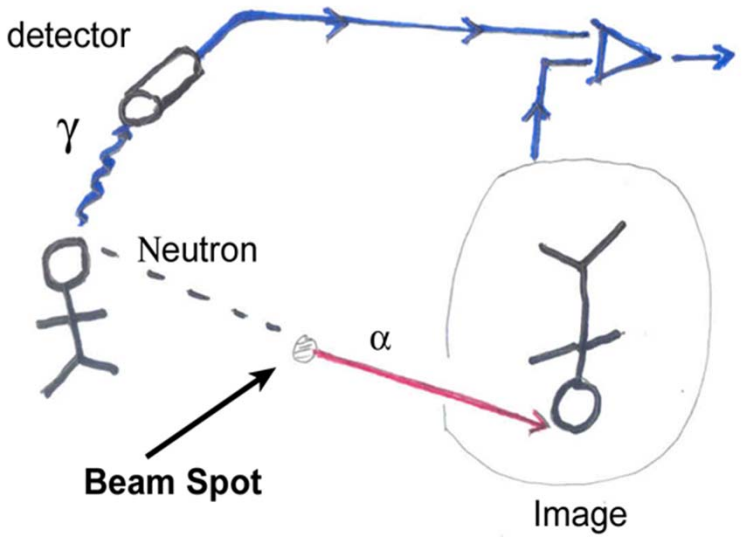
Russell Goff REU work with Dr.Koltick on Neutron Induced Gamma Ray Spectroscopy for Elemental Analysis

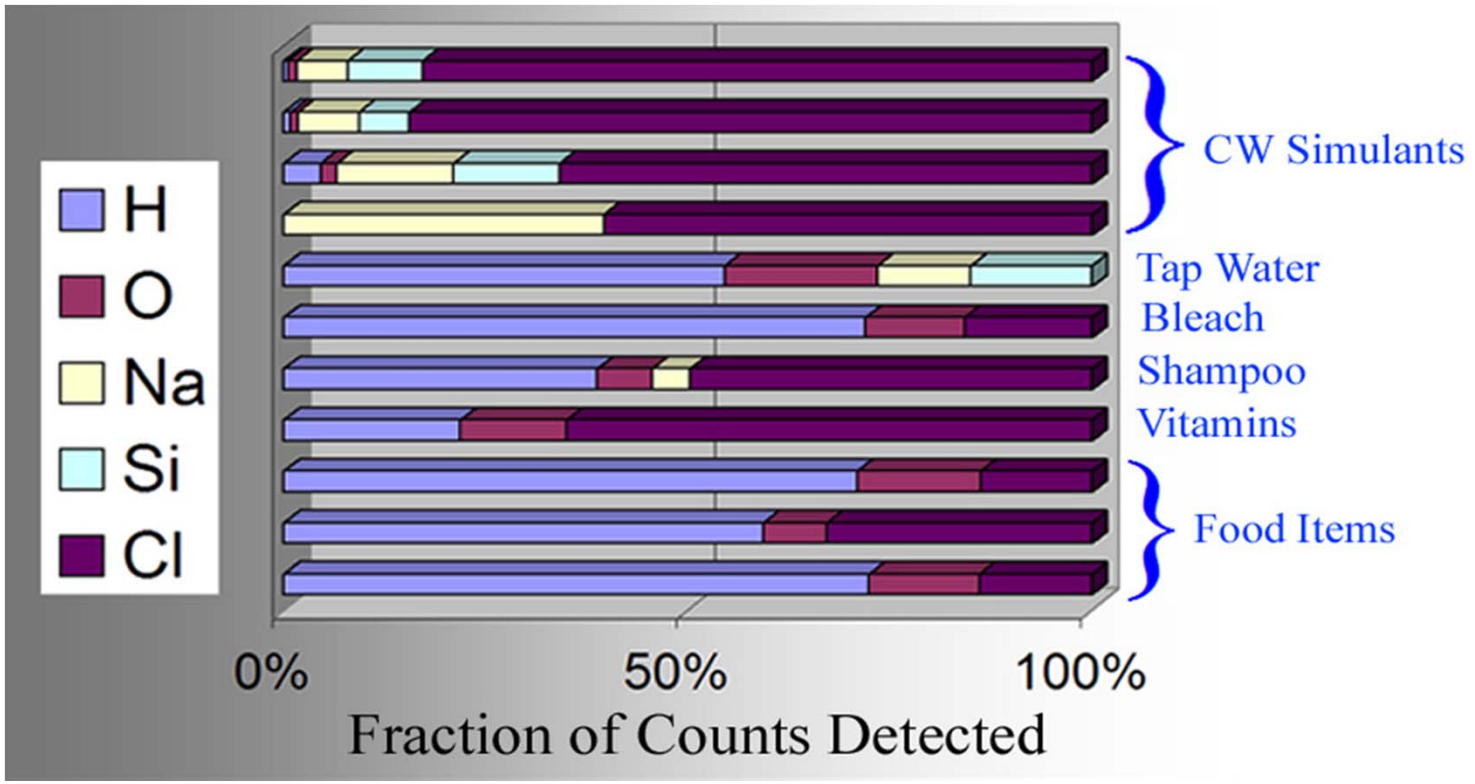
Associated Particle Imaging

- Associated Particle Neutron Elemental Imaging (API)
  - Creates 3-D image of object non-invasively



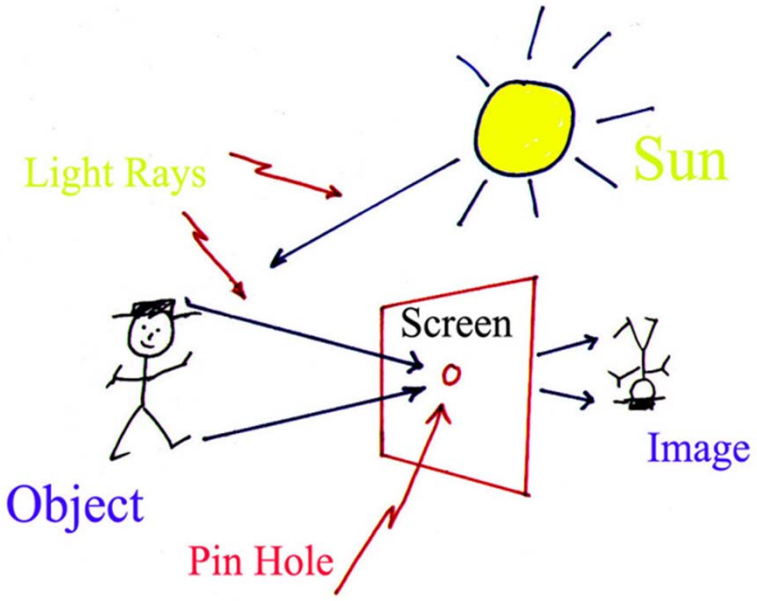


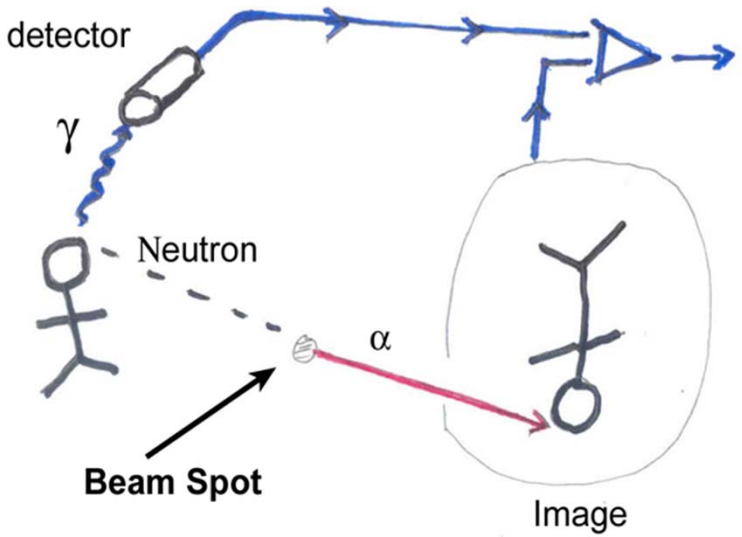
Power of Elemental Analysis



Associated Particle Imaging

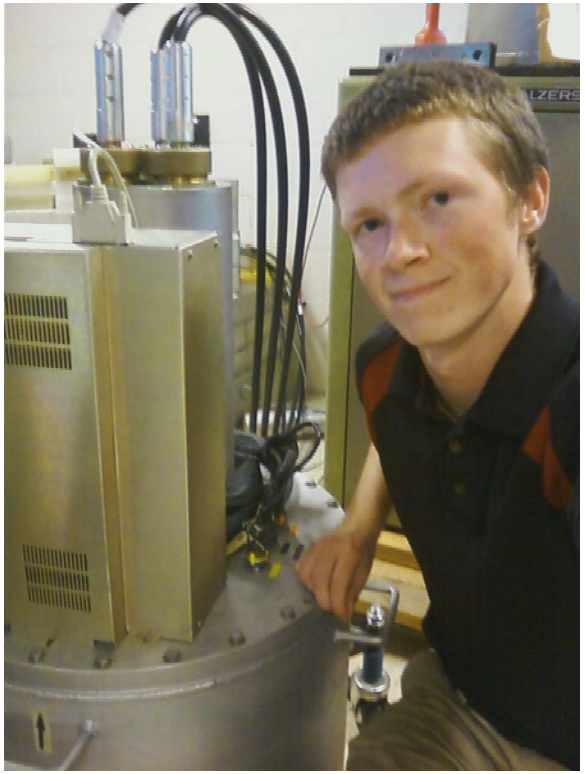
- Associated Particle Neutron Elemental Imaging (API)
  - Creates 3-D image of object non-invasively





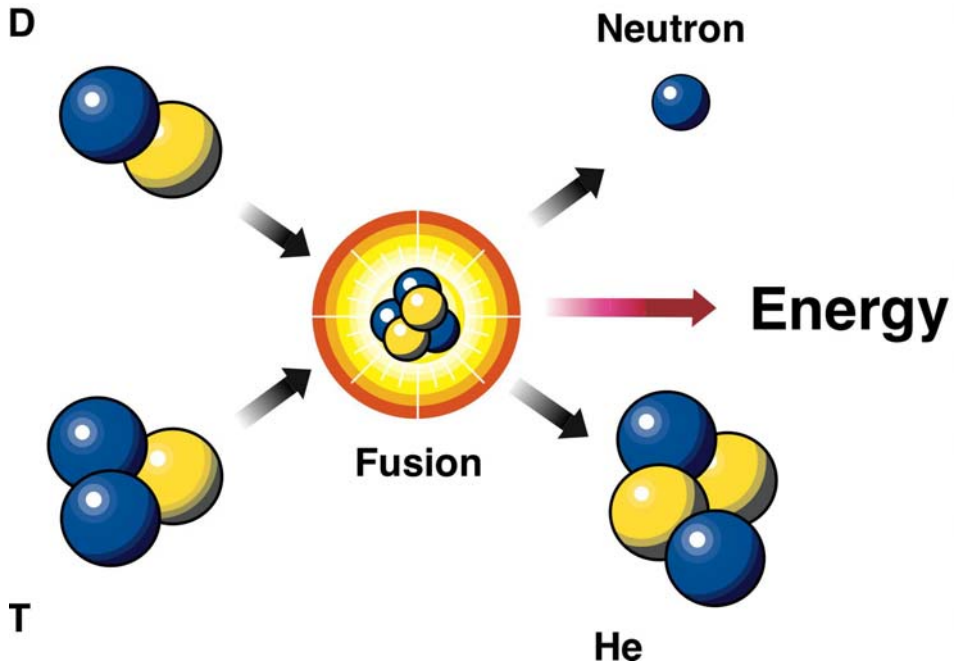
Neutron generator

- Mf Physics- A-920



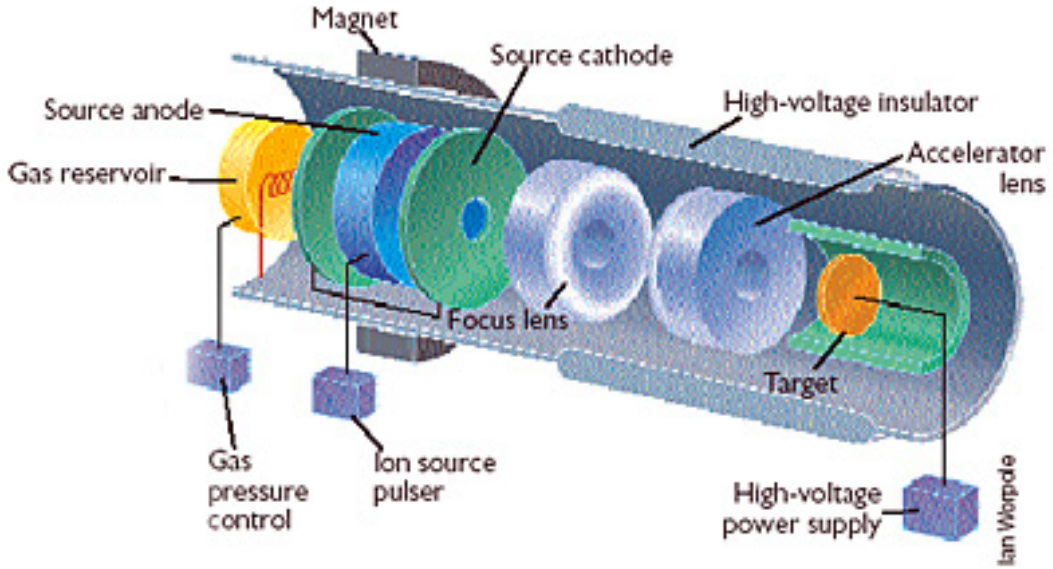
DT Fusion Reaction

100keV D in
14.1 MeV neutron & 3.5 MeV alpha out



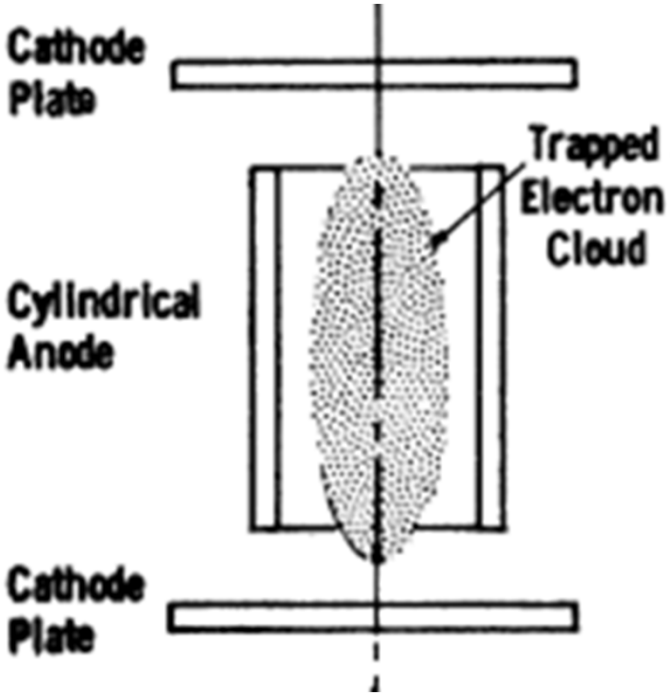
Neutron Generator Specs.

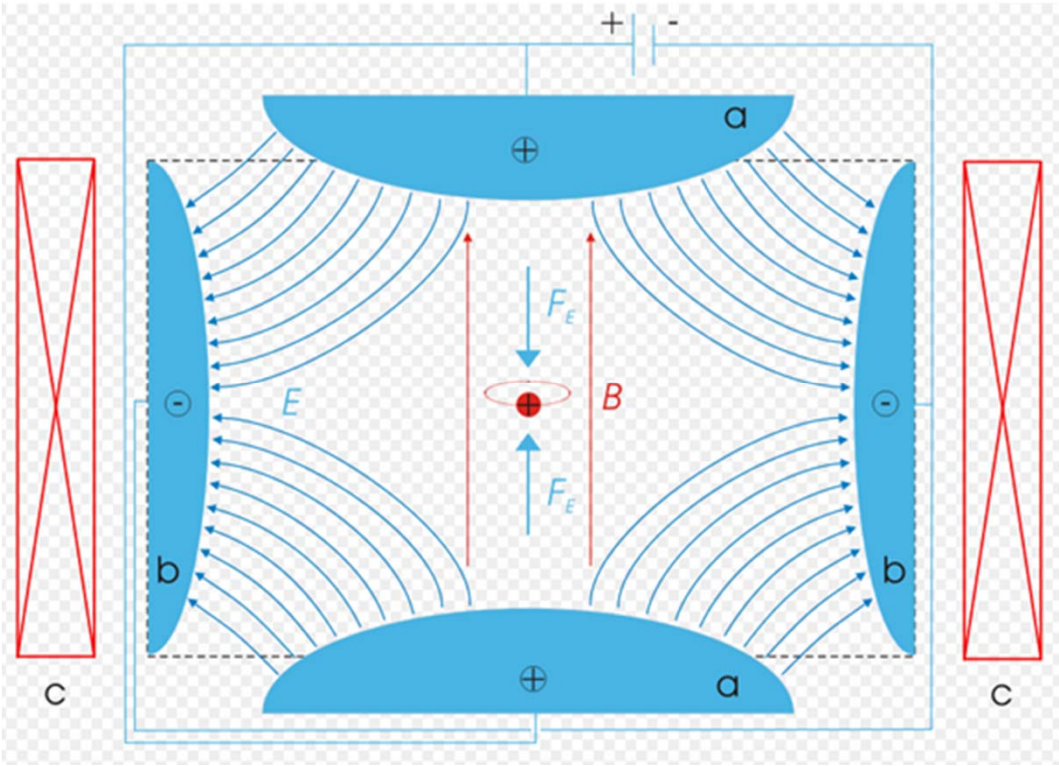
- D + T → α + n
- 14.5 MeV neutrons at around $1x10^8 \frac{\text{nutrons}}{\text{second}}$
- Operator exposed to roughly 0.2 $\frac{mRem}{hour}$ (compared to 0.1 $\frac{Rem}{year}$ NRC general population exposure limit)



Citation 1

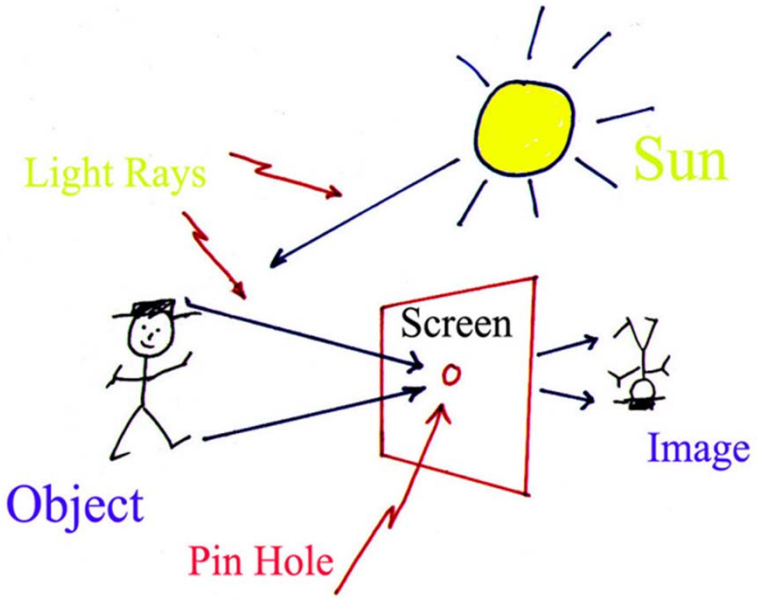
Penning Trap

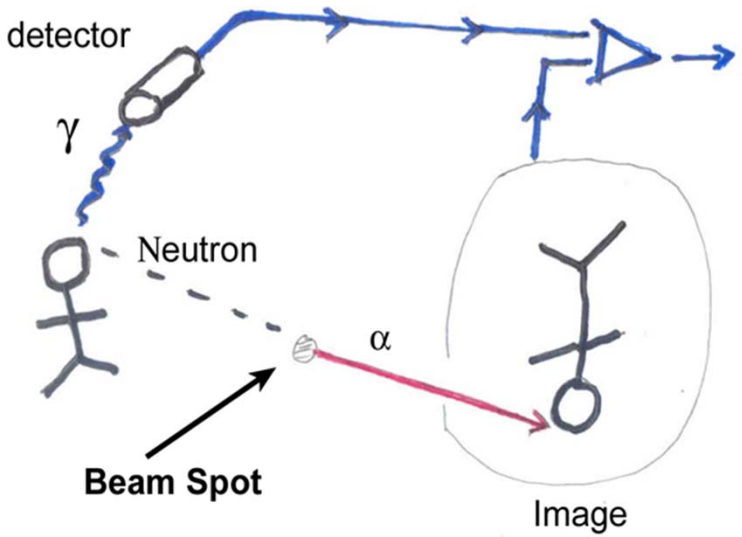




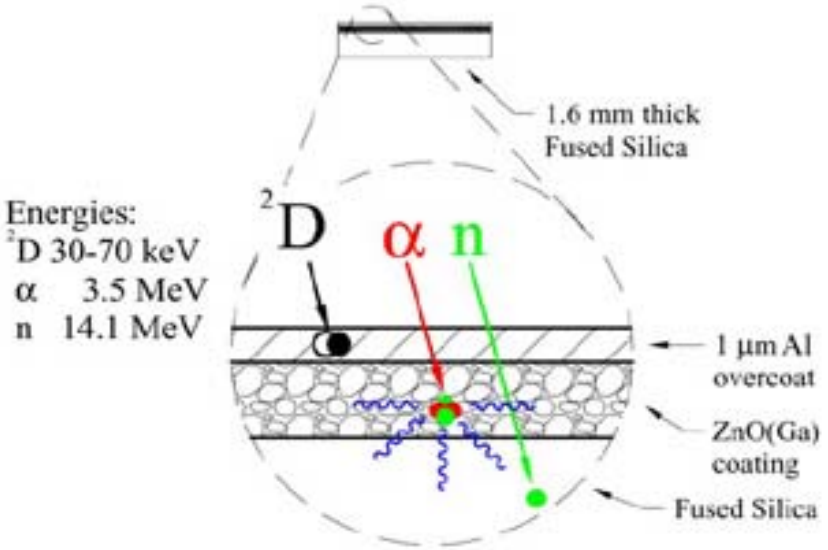
Associated Particle Imaging

- Associated Particle Neutron Elemental Imaging (API)
  - Creates 3-D image of object non-invasively



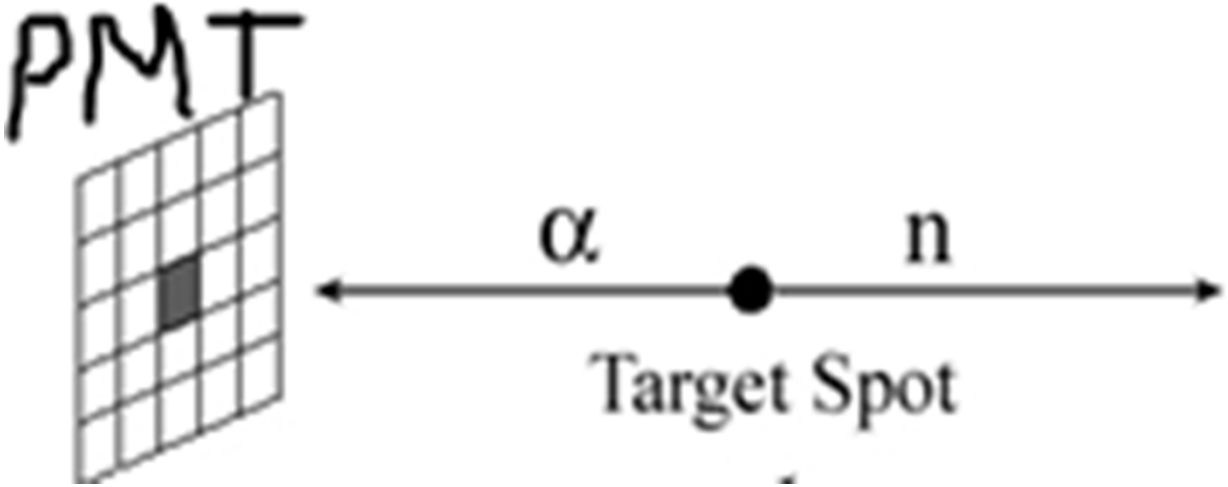


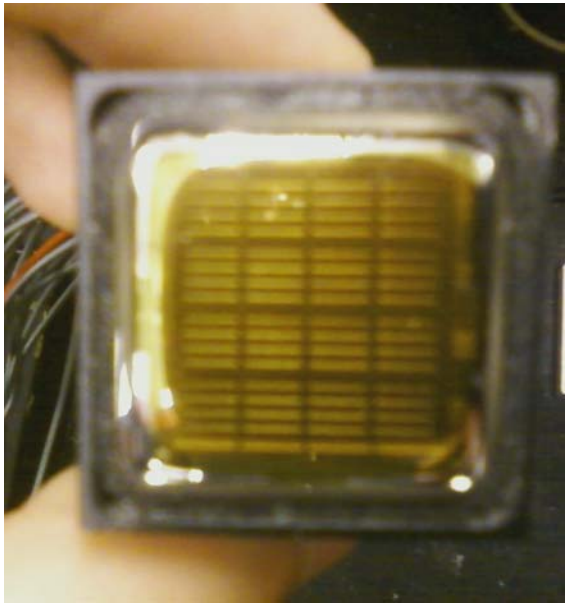
Scintillation Screen



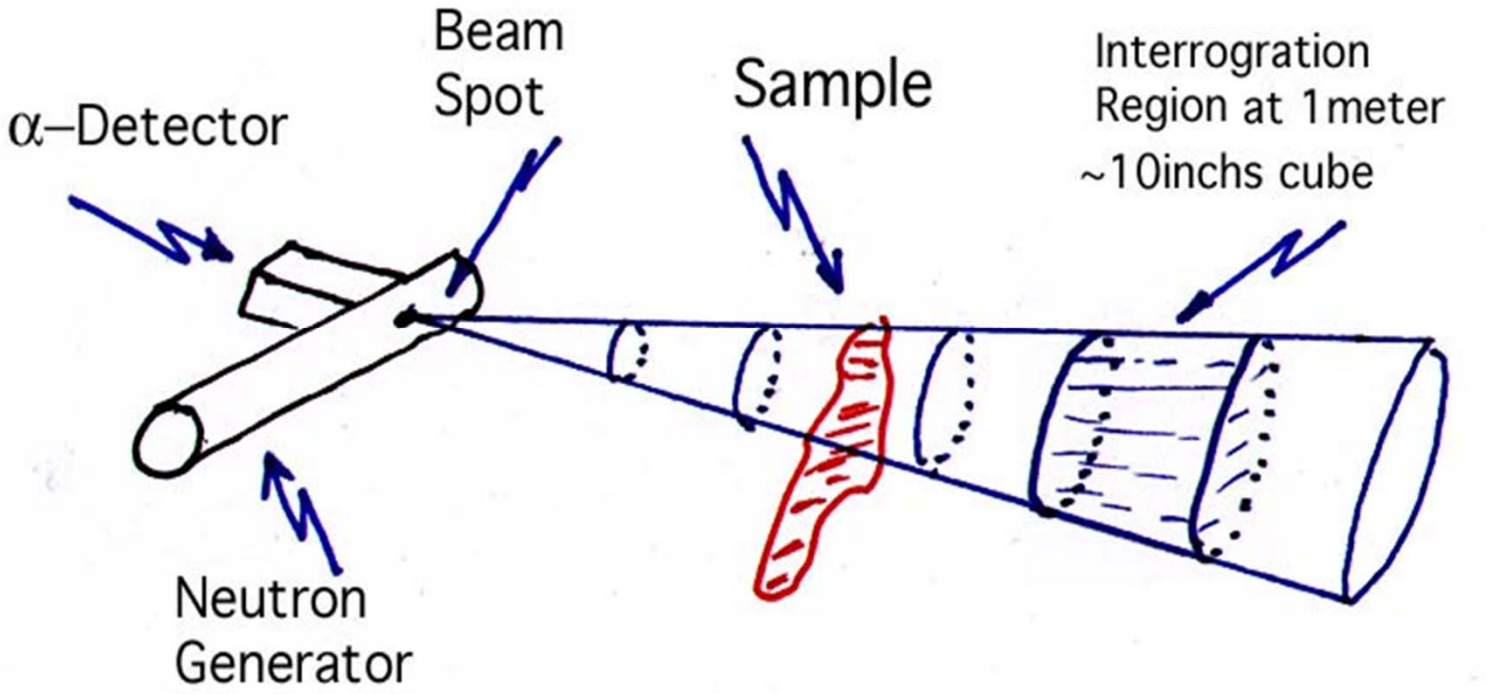
Creation of Elements Location

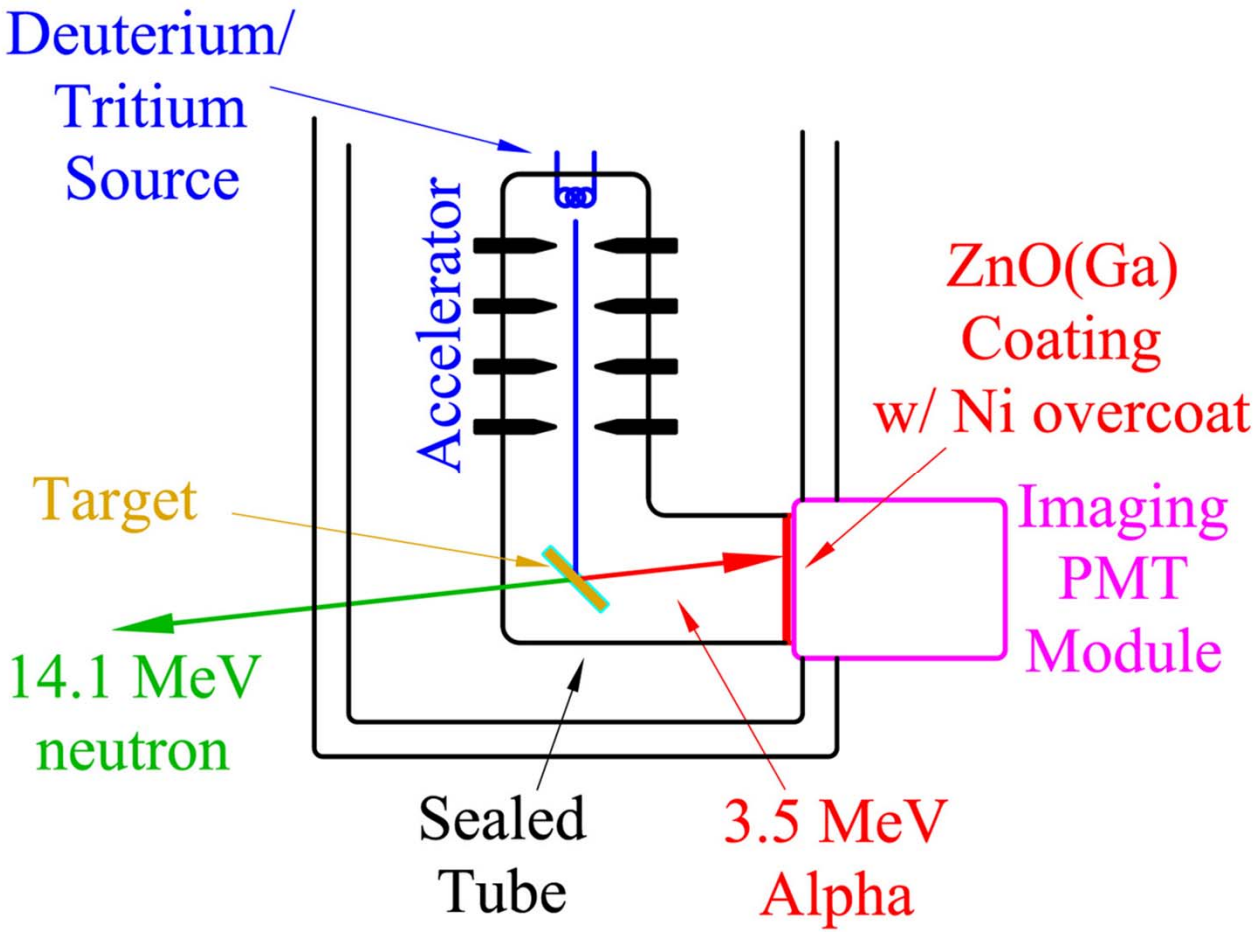
- α particle & neutron from D-T Fusion travel opposite directions
- Time of flight recorded & used to create image. Estimated by time difference between γ detection and start of α particle logic gate. [Neutron=5cm/ns γ=30cm/ns].





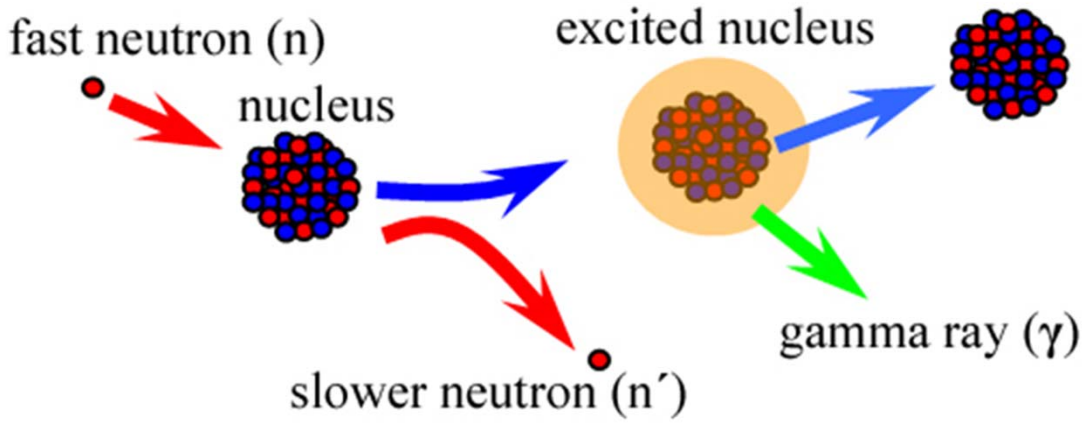
Coupling PMT to A-920


α–Detector
Beam
Spot
Sample
Interrogration
Region at 1meter
~10inchs cube
Neutron
Generator


Deuterium/
Tritium
Source
Accelerator
ZnO(Ga)
Coating
w/ Ni overcoat
Target
Imaging
PMT
Module
14.1 MeV
neutron
Sealed
Tube
3.5 MeV
Alpha

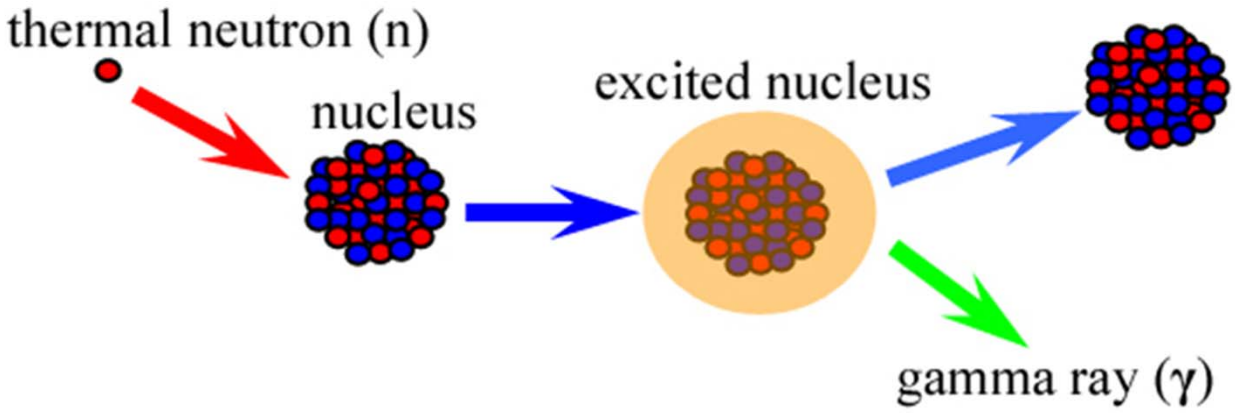
Inducing Gamma Rays

- Inelastic Scattering
  - Lifetime of excited state is in range of picoseconds
  - Incoming neutron must exceed unique threshold



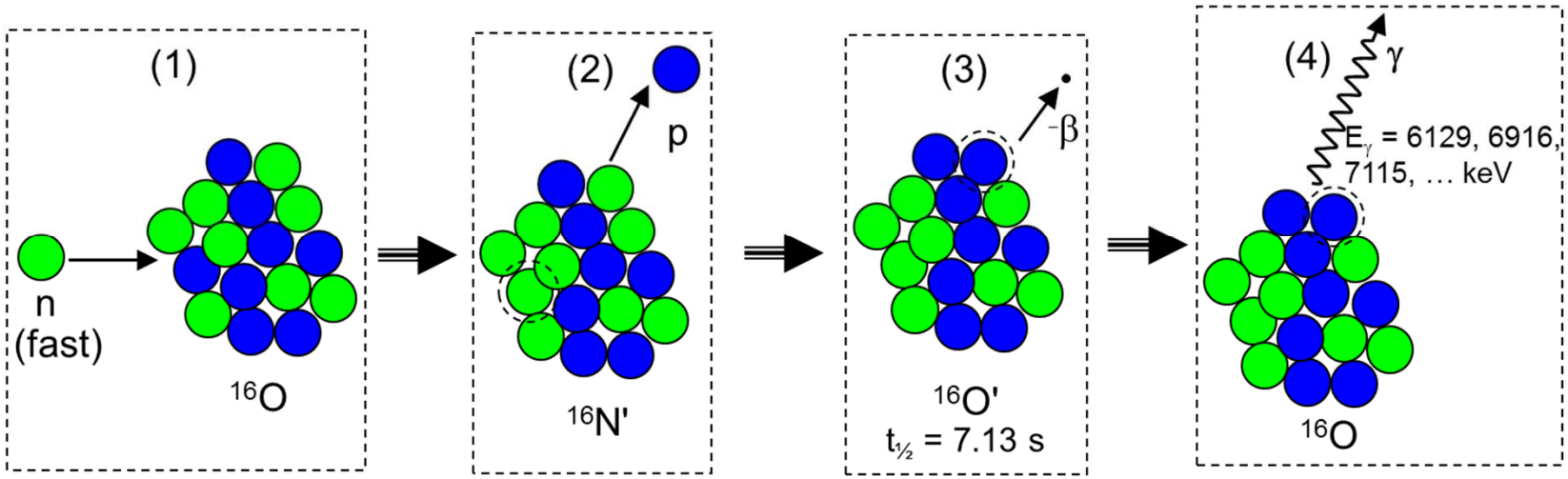
Inducing Gamma Rays

- Thermal Capture
  - De-excitation occurs in picoseconds
  - Cross section increases with decreasing energy



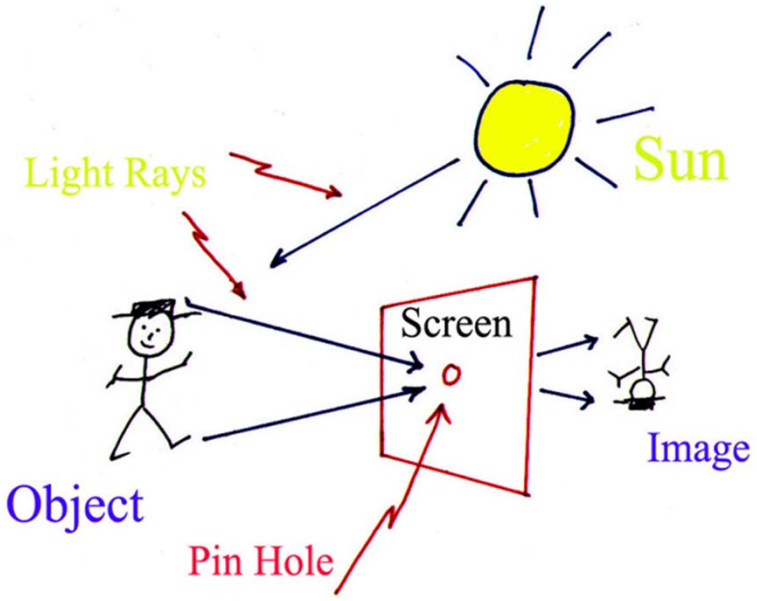
Inducing Gamma Rays

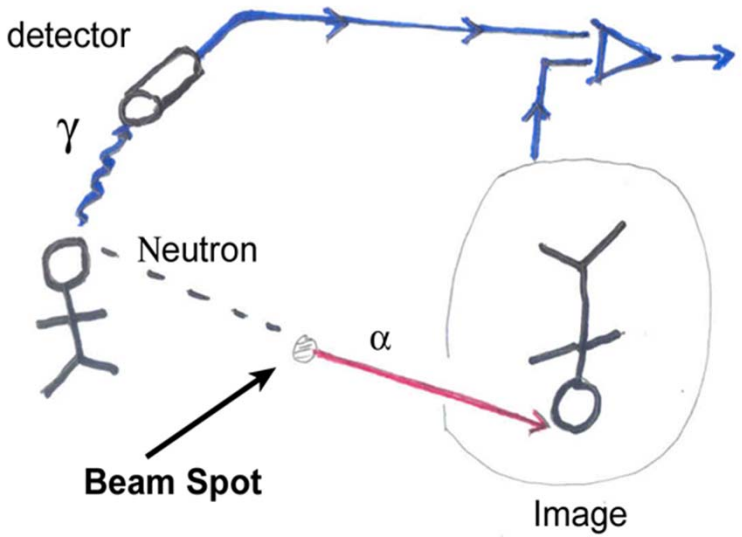
- Activation
  - Not as useful since due to seconds long half lives there can be no alpha gating for imaging.



Associated Particle Imaging

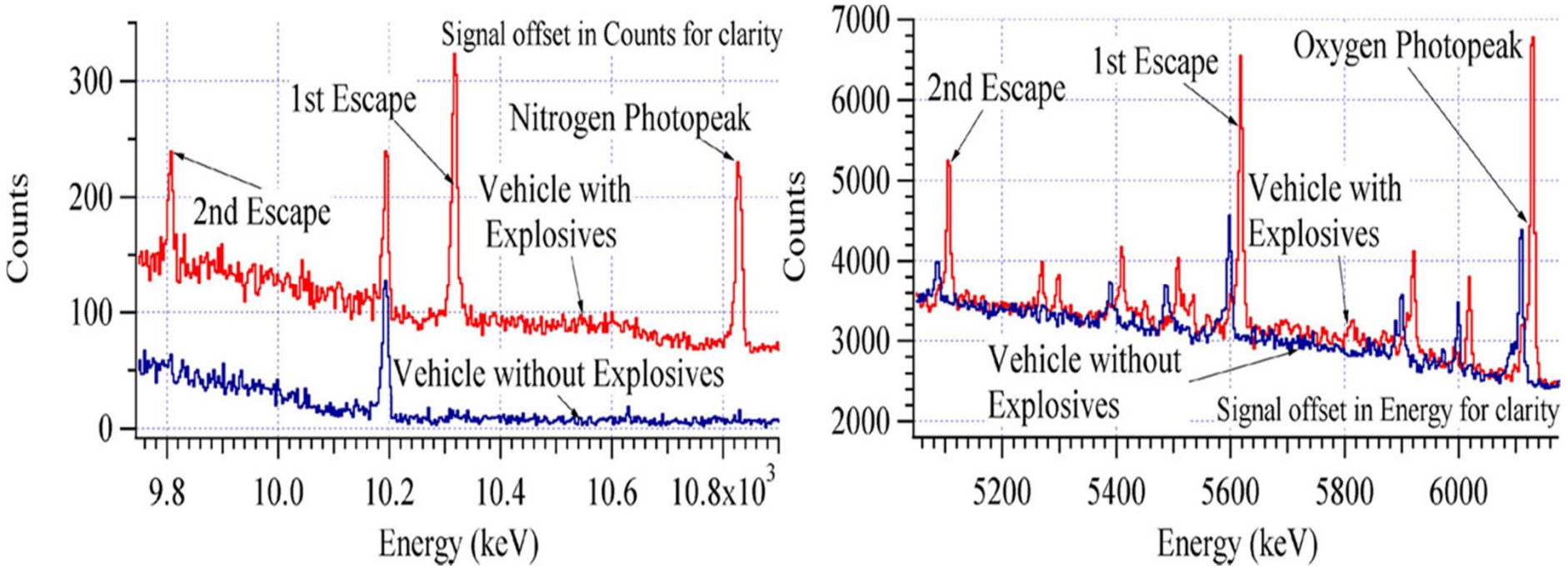
- Associated Particle Neutron Elemental Imaging (API)
  - Creates 3-D image of object non-invasively





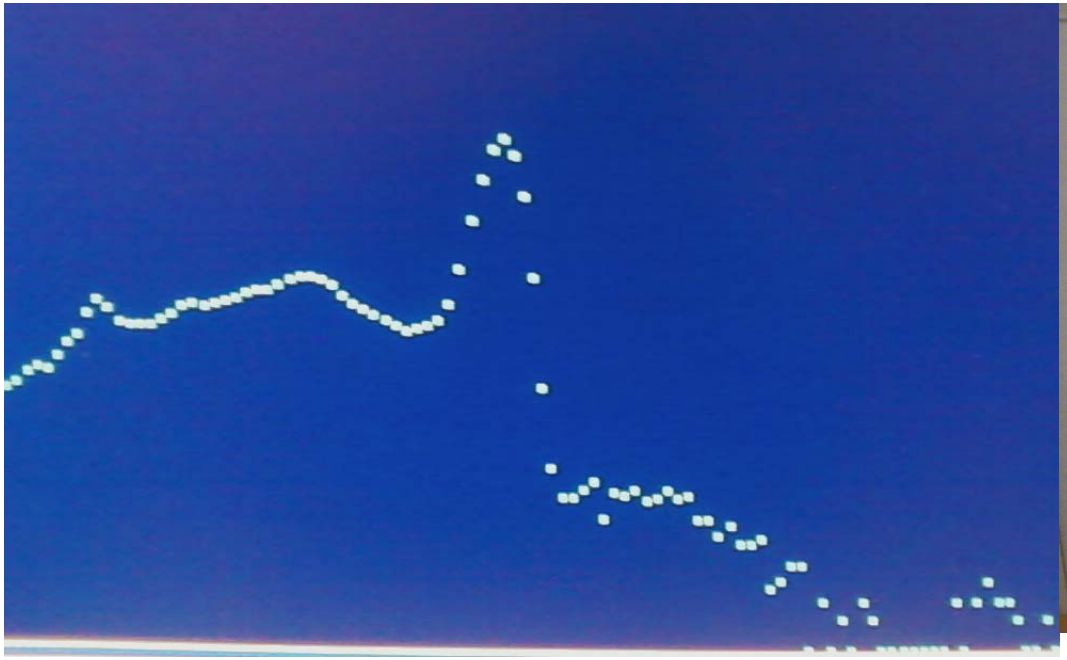
Gamma ray spectroscopy

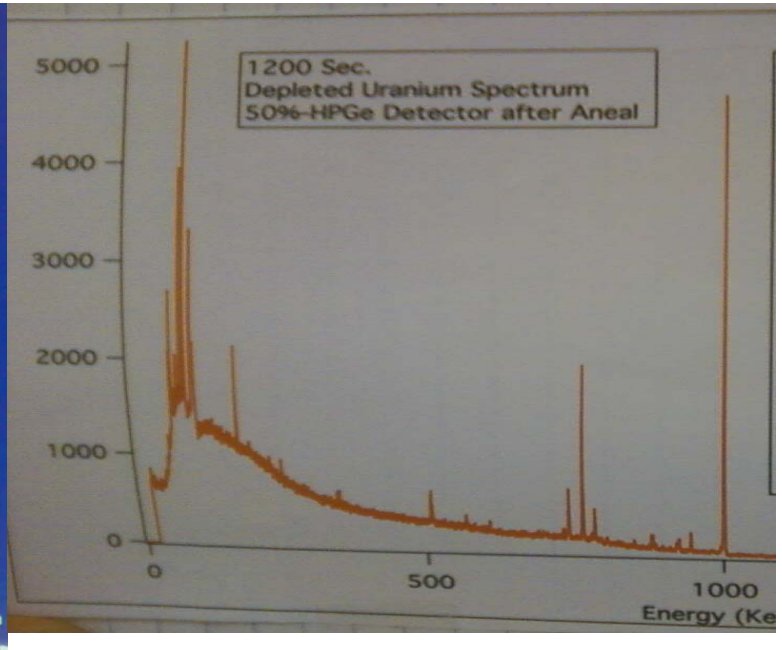
- Different Gamma ray energies are uniquely associated with different isotopes



Need for Good Energy Resolution

- Energy Resolution: FWHM over the mean pulse height of the photopeak
- 10% compared to 0.1%





HPGe Detectors

- Benefit of great energy resolution
  - 1.07keV resolution with 1.173MeV source
- However…
  - High Maintenance
  - Lower counting efficiency
  - Fragile
  - Operate around 100°K
  - Expensive

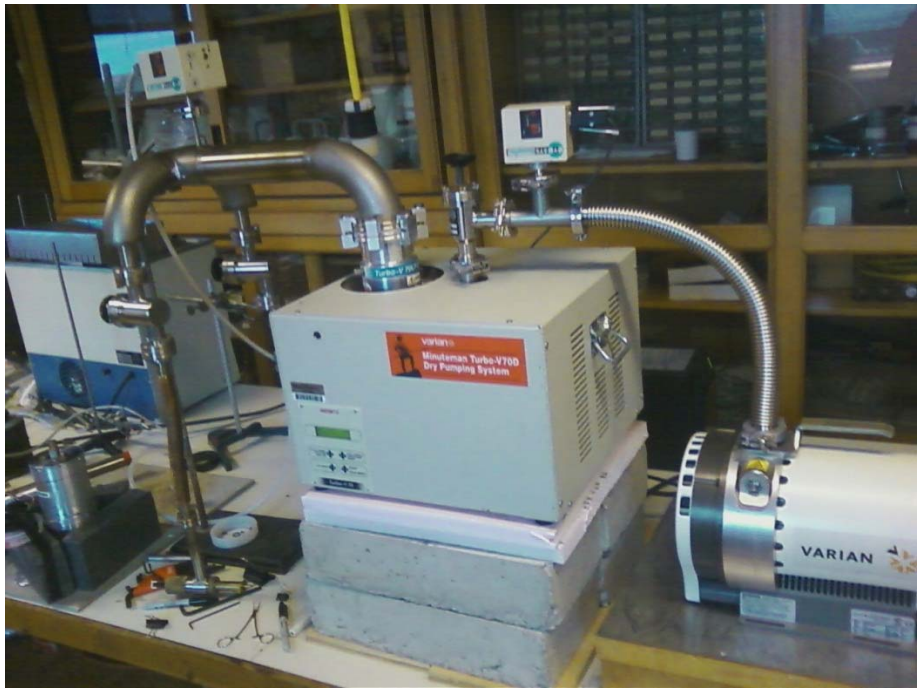
Detector cooling & vacuum systems

- Alternative to liquid nitrogen
- Kept at vacuum

[redacted] Citation 4

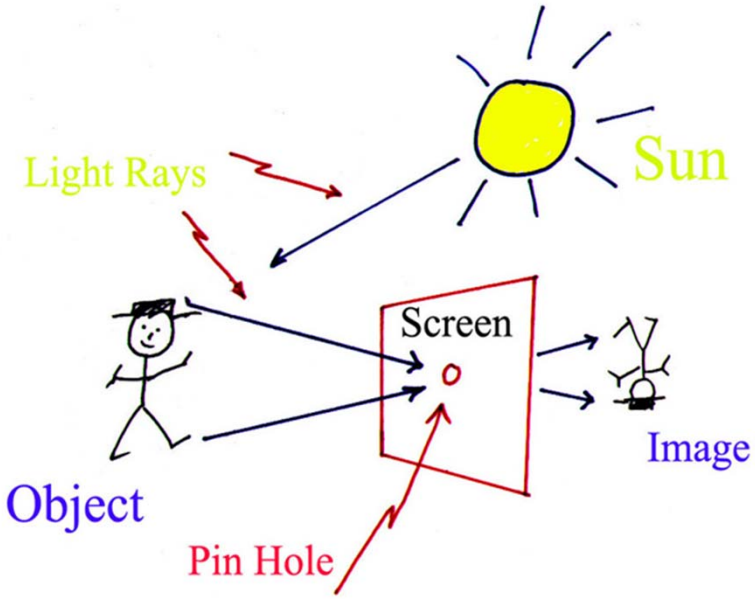
HPGe Detectors

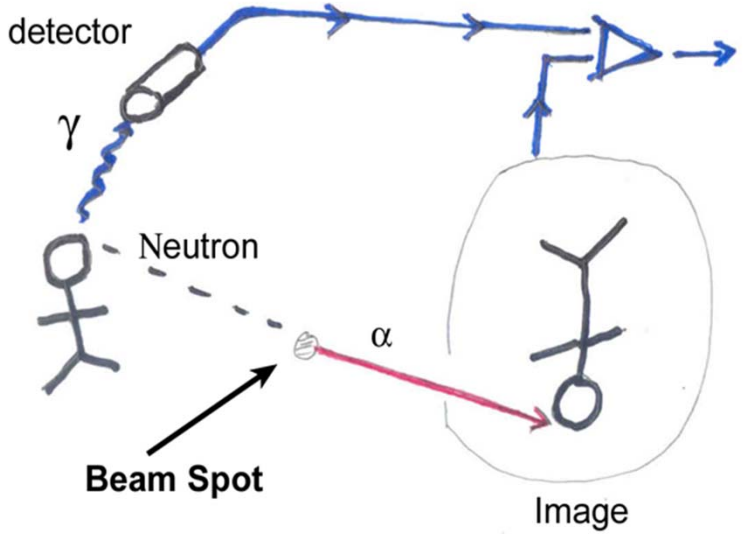
- Must be pumped out and annealed occasionally to "erase" neutron damage and renew vacuum
  - Annealing helps vacancies and interstitials, created from neutron damage, recombine



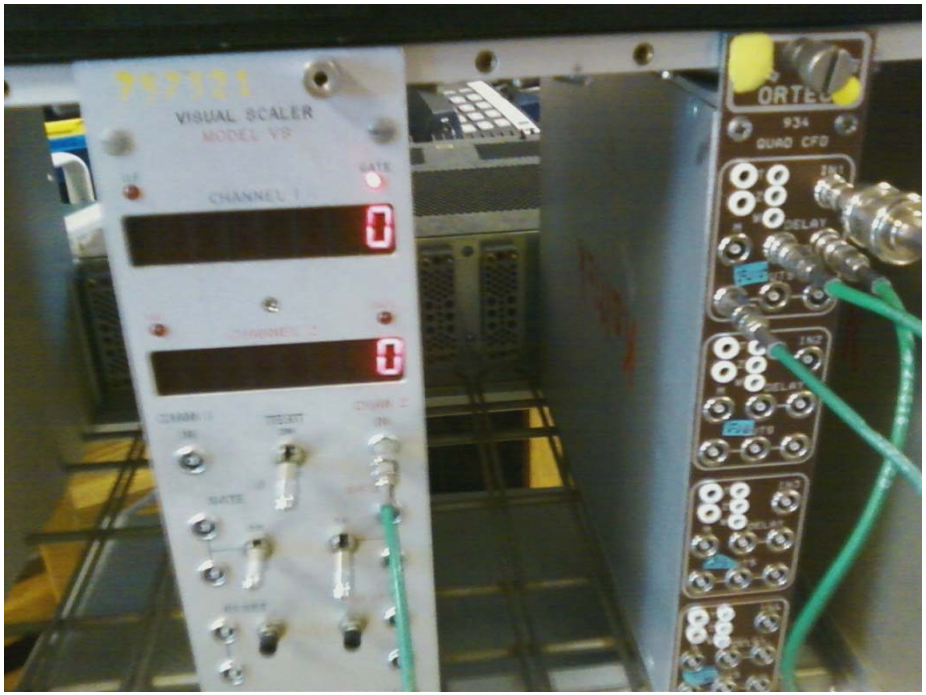
Putting the Pieces Together

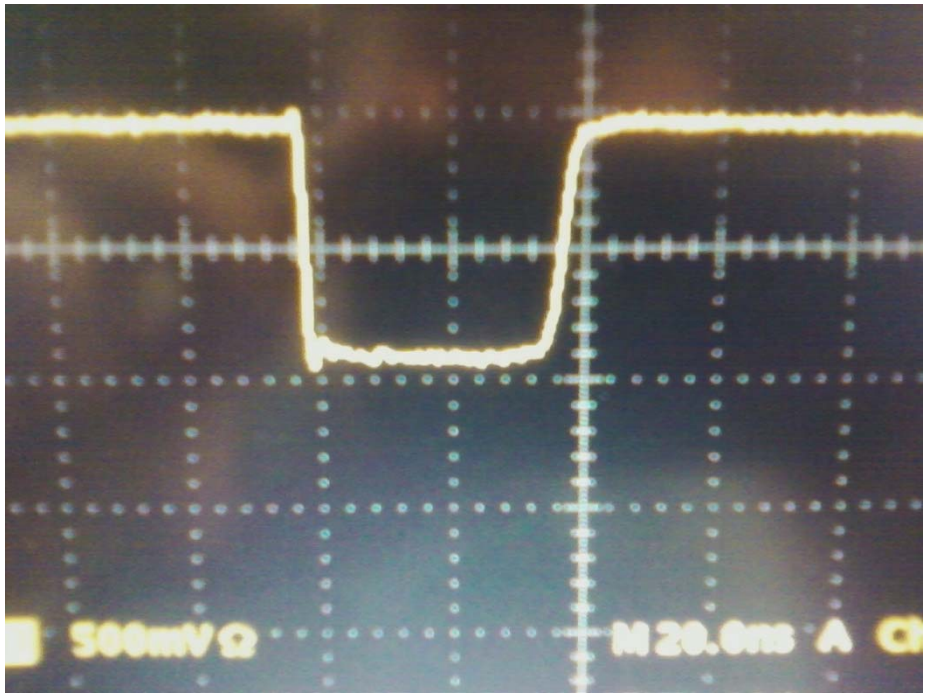
- Used αparticle and beam spot of neutron generator to tell where gamma was born
  - Used gamma ray to deduce what element was at that position



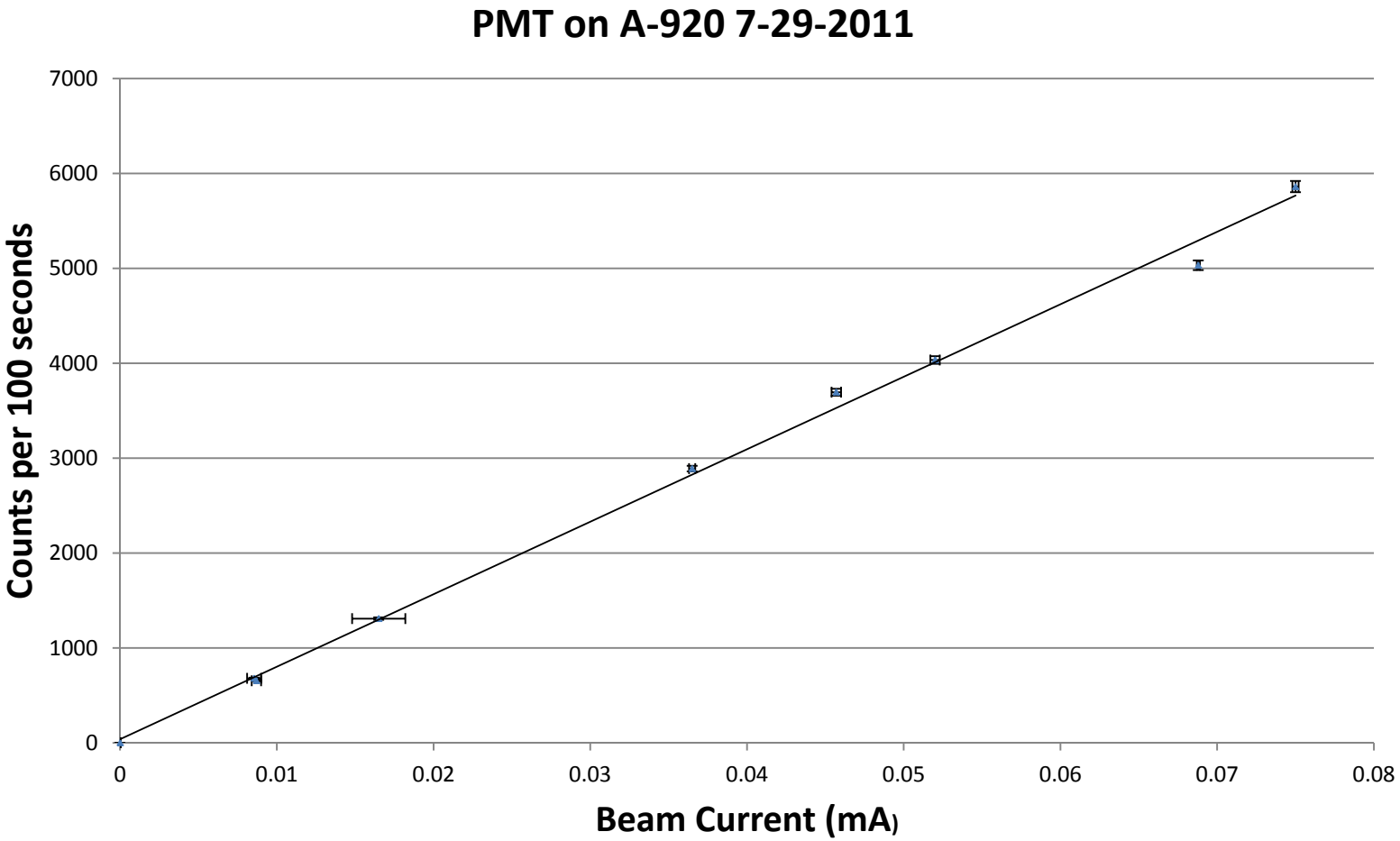


Counting system with Logic pulse

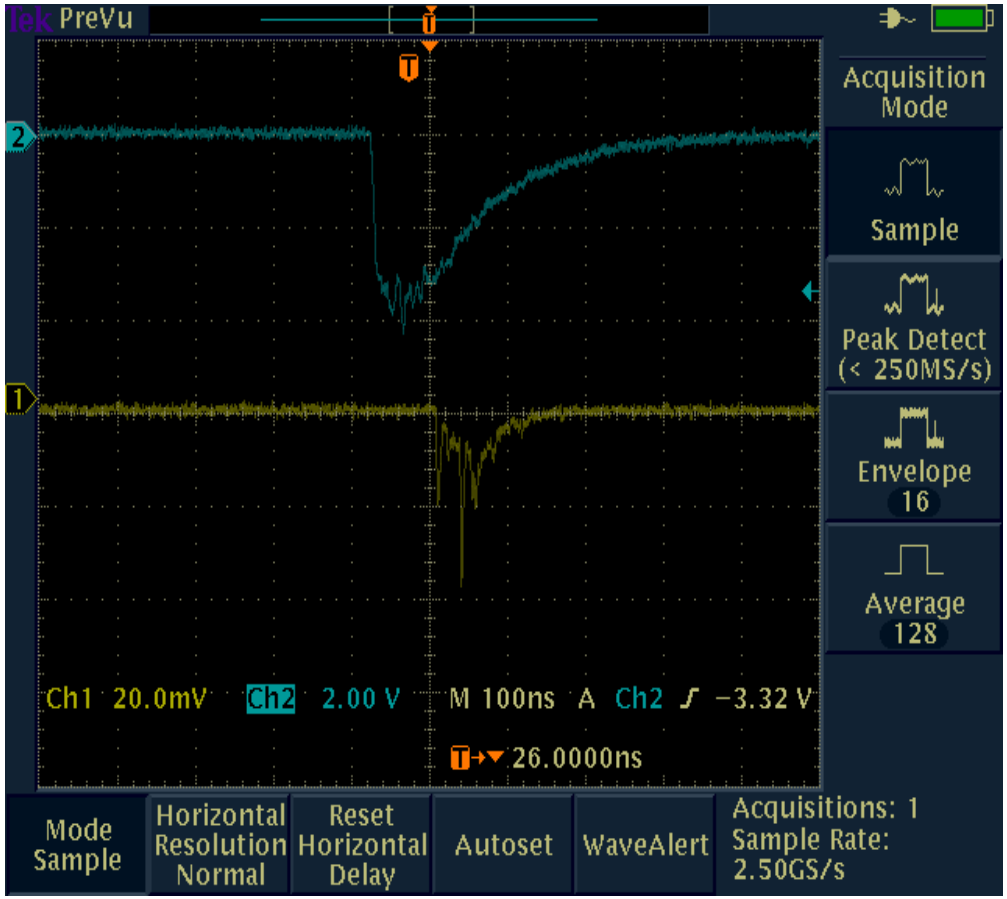




40mV Discriminator Setting Data



Coincidence



Trouble Shooting

- Why didn't that work?
- Where did that piece go?
- This is too expensive to be broken

Writing Manuals

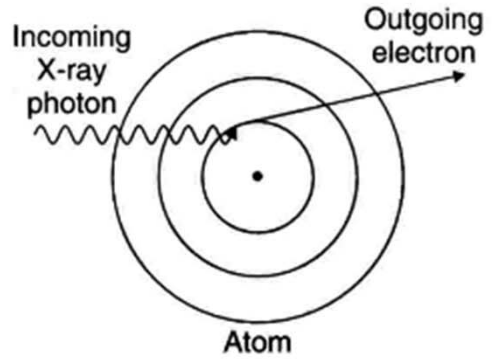
- Creating documentation on
  - Neutron generators
  - HPGe detectors & associated equipment
  - Data processing tools
  - Maintenance Procedures

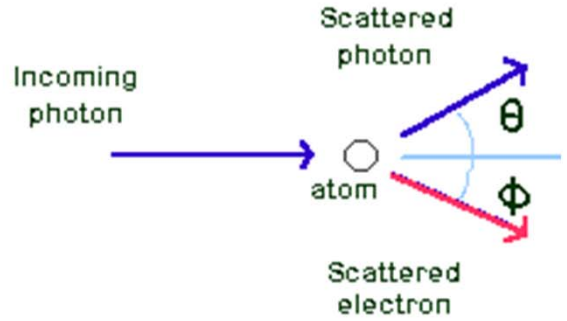
Bibliography

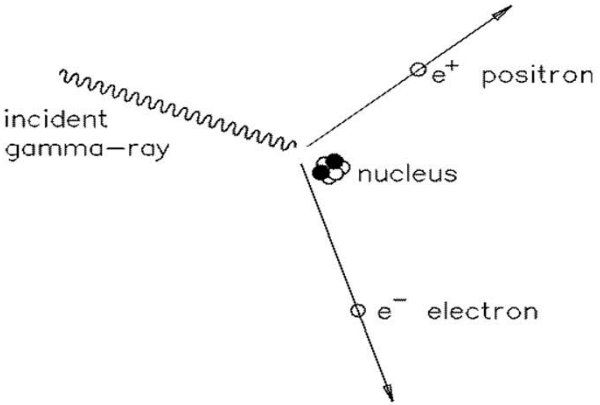
- 1) Simpson, American Institute of Physics "Compact accelerator neutron generators" (2002)
- 2)Thermo-Scientific.com (06/28/11)
- 3) Kane, "Detection of special nuclear materials using prompt gamma-rays from fast and slow neutron induced fission" (2010)
- 4)ORTEC X-Cooler II Owners manual

3 Main Gamma-Ray Interactions

- Photo-Electric Effect (PE)
- Compton Scattering (CS)
- Pair Production (PP)







Appreciation of Time Scale

- A gamma-ray may take multiple interactions to deposit its full energy in a detector
- Photon is traveling speed of light through small distance
- Output response from detector will be same for multiple interactions as it would have been had the photon deposited all its energy in a single interaction due

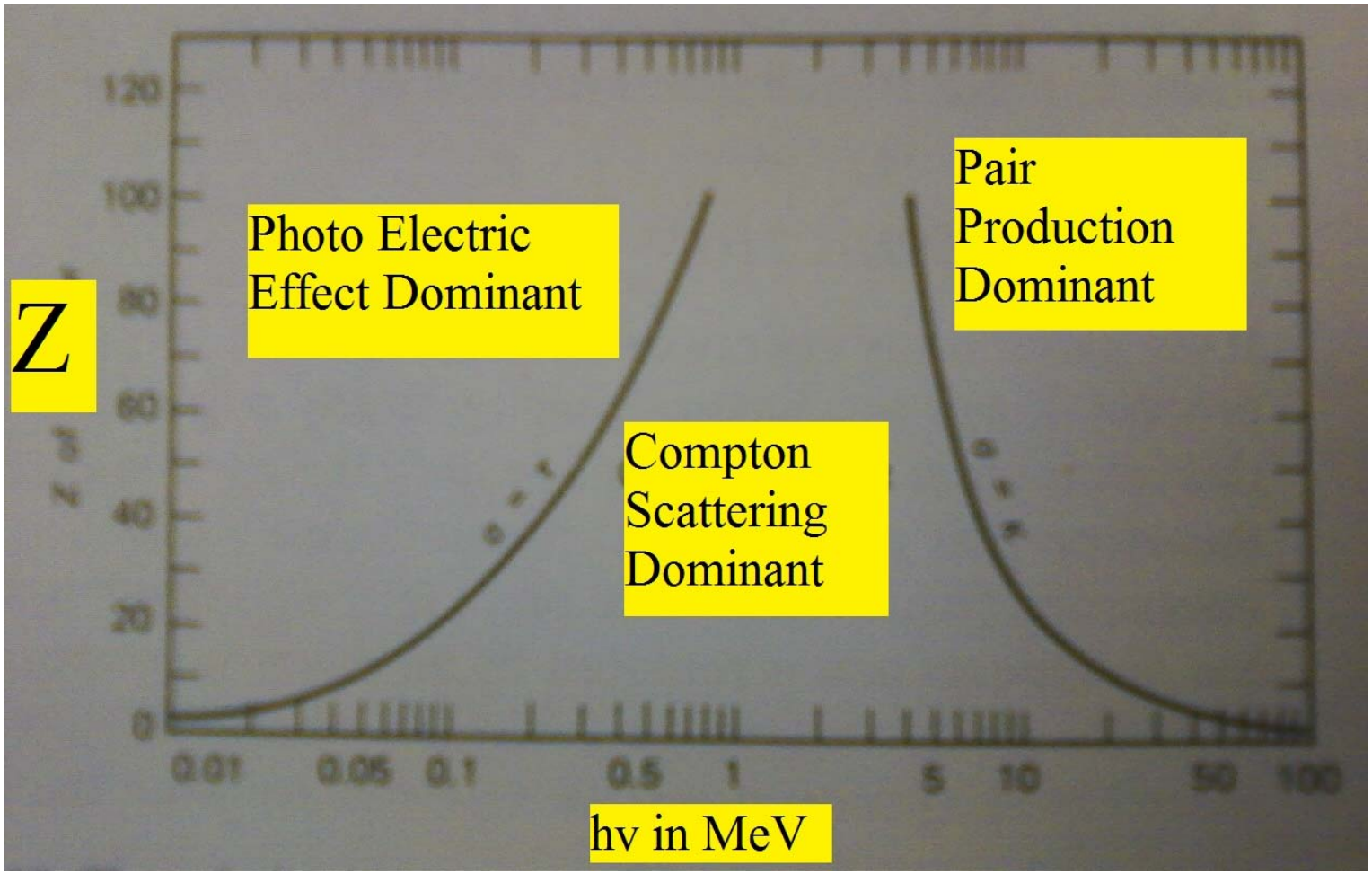
Causes of different peaks

- Escape of x-ray from PE- A few keV
- Annihilation Radiation-Positron and an electron annihilate and send two 511keV photons in opposite directions. This Results in no shift, a single escape peak, or a double escape peak
- Backscatter peak- Compton scattering in surrounding materials before reaching detector. Creates peak around 200keV.

More examples

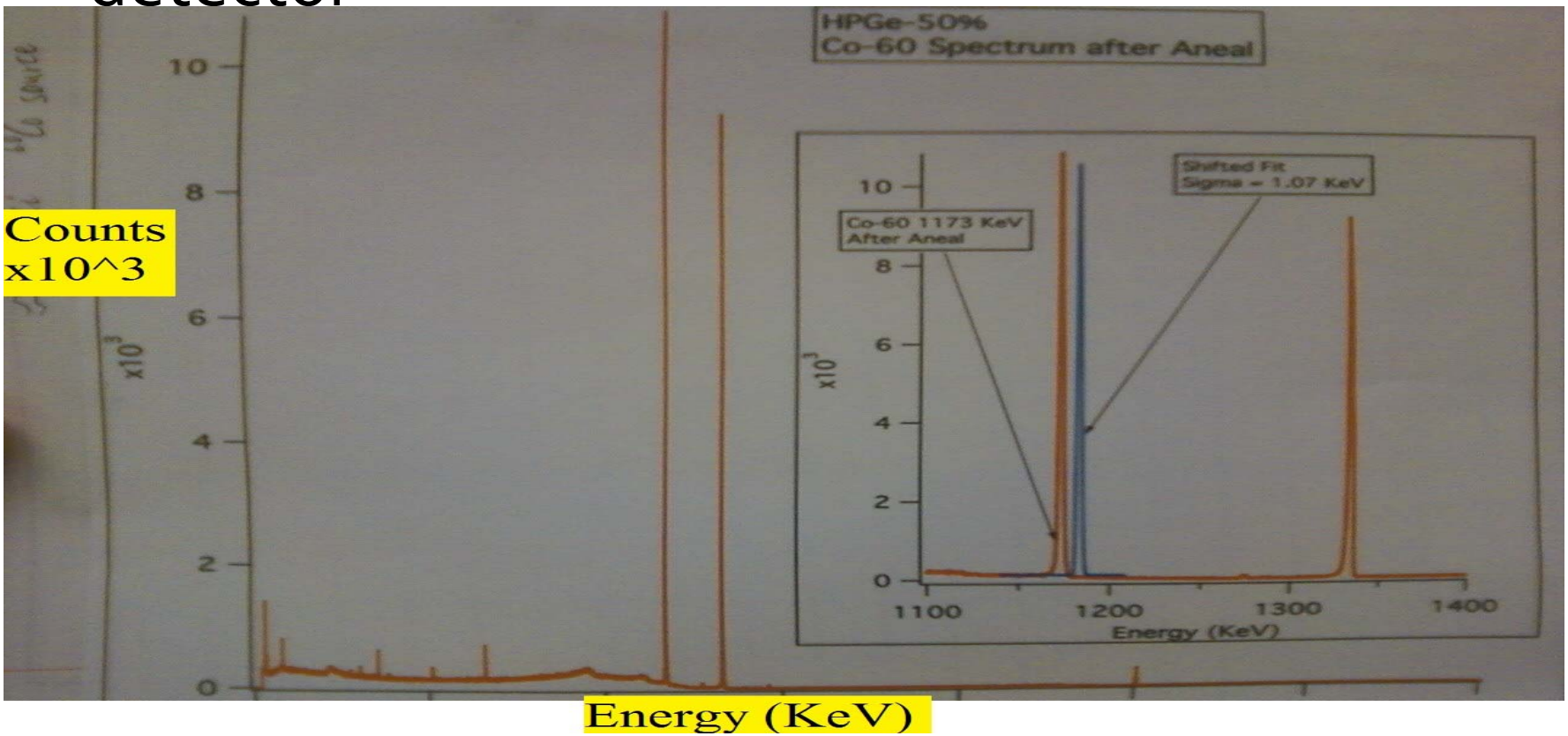
- Pair production in surrounding material: Creates 511keV peak
- $.^{40}K$ in background: Causes 1460keV peak
- Sum peak from pile-up: Two peaks at close enough time that detector system combines them into peak equal to sum of their energies

Likelihood of each Interaction



Shifts in energy peaks

- Occur when energy carrier escapes from detector



Exploring feasibility of API in medical Diagnostics

- Currently in very infant stages of process
- Would require PPM precision
- Cross sections may be too small for prompt gamma's in elements of interest
- Dose to patient must be kept relatively low
  - Currently PET & CT scans give 1-2 REM dose

Potential Future Uses

- Hypoxia-Deficiency of Oxygen in tissue
- Promotes growth of tumors
- Promotes malignancy
- Greater resistance to treatment

Current Diagnosis Procedure

- Biopsies which spread tumors
- Invasive O_2 needle electrode's
  - $pO_2 = 40mmHg\ normal\ cell$
  - $pO_2 < 10mmHg\ generally\ hypoxic$
- Oxygen reduced pharmaceuticals
- Anesthetization & other factors throw results