Week 14, Lecture 1 – Radiation Detectors – 2

MICHIGAN STATE UNIVERSITY

Radiation Detectors

- Gas-filled Devices

-- Ion Chambers

-- Geiger Counters

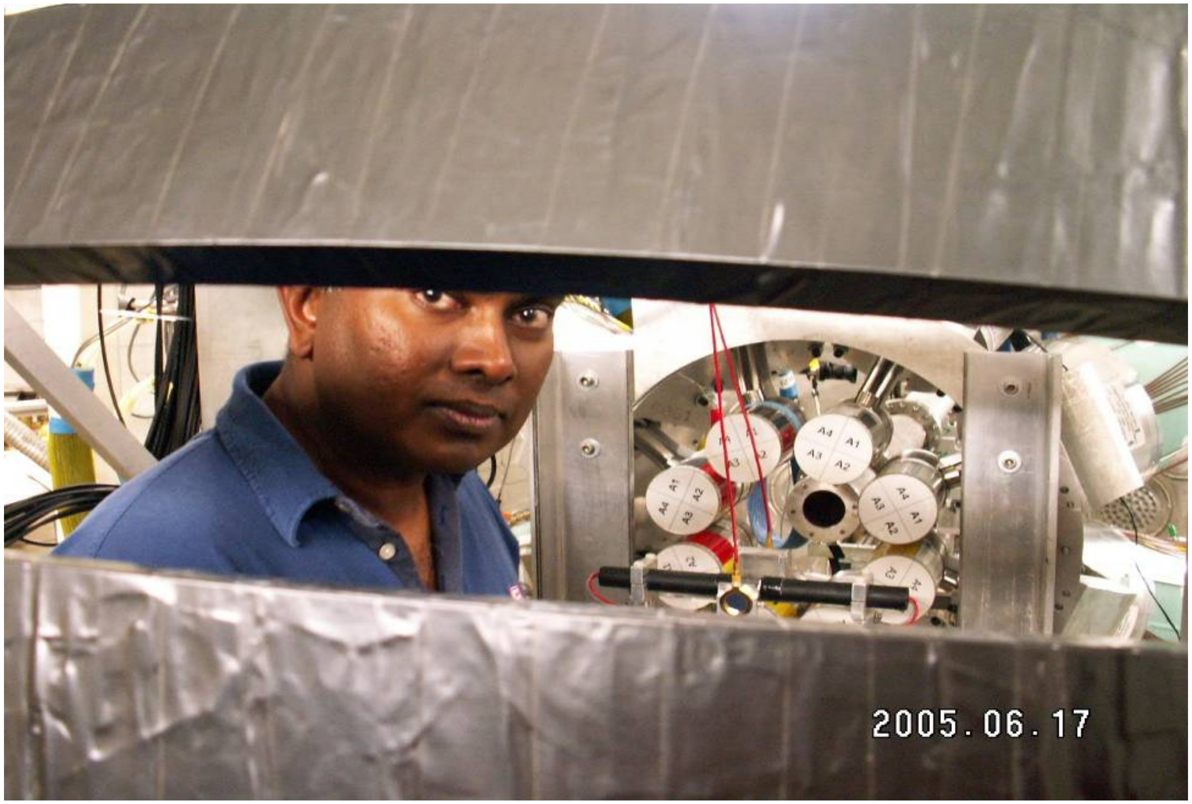
-Solid state detectors

-- semiconductor devices

-Background radiation

-Homeland security detectors

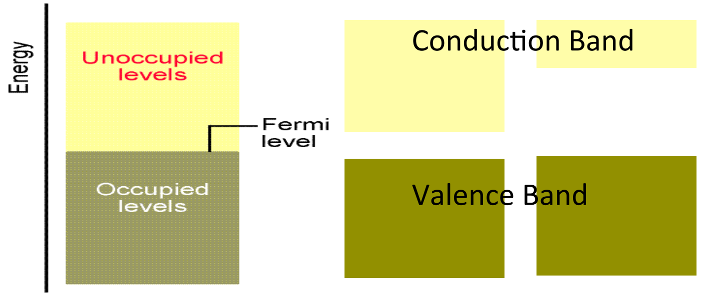
Many people's view of detectors



Chandana Sumithrarachchi (grad student) with detectors sensitive to four different types of radiation (Heavy-CP, Beta's, Gamma's and Neutrons).

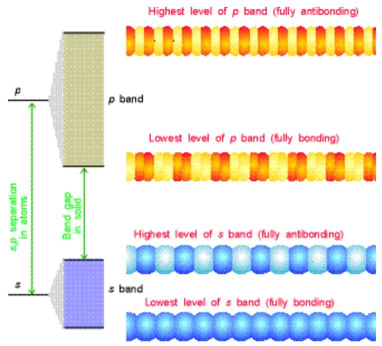
Semiconductor Detector Materials

The band theory of solid materials in one sentence: the regular structure of the solid lattice and close proximity of atoms allows formation of "molecular" orbitals that extend over the entire lattice. There are so many individual orbitals (N_A) will nearly the same energy that they merge into bands that preserve the underlying atomic orbital energy pattern.



Metal

Insulator



A semiconductor is an insulator with a small band gap, ~1.2eV for silicon. Generally want smallest band gap *but* thermal excitation across the gap provides a leakage current (noise). N.B. the actual band gap depends on the direction relative to the lattice (Si and Ge do not crystallize in cubic lattices) and the gap decreases slowly with temperature but the thermal noise increases rapidly.

The ratio of 'w' to band gap is approximately constant for a wide range of materials – division of excitation energy between e/h pair and phonons, etc. is ~ constant.

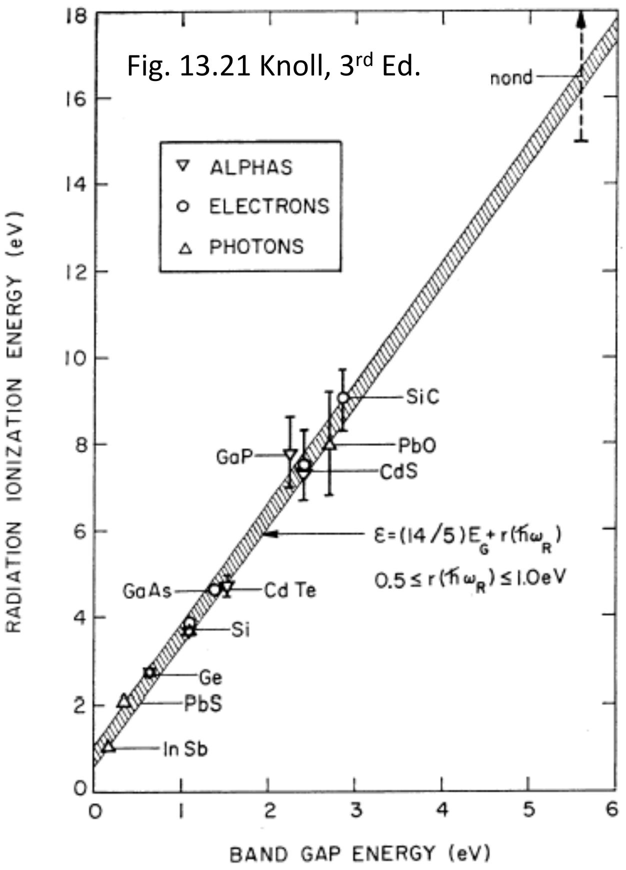
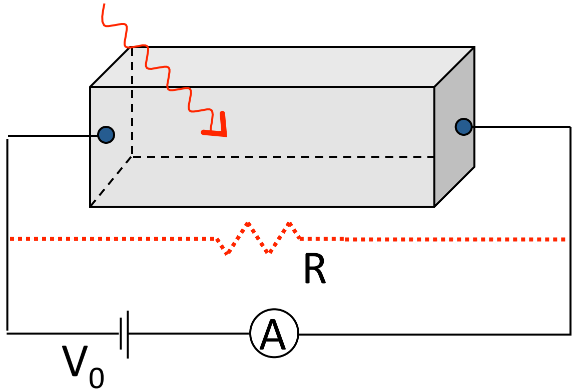


Fig. 13.21 Knoll, 3rd Ed.

C.A.Klein, J.App. Phys. 39 (1968) 2029

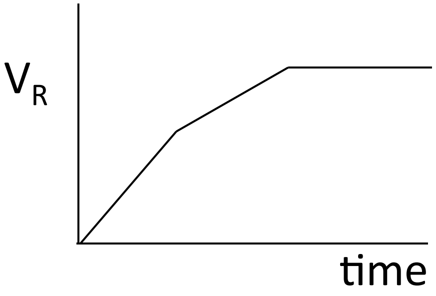
Semiconductor – Ion Chamber?



Imagine constructing a simple block of intrinsic semiconductor and trying to use it as an ion chamber … The block has a length, "L" and a cross sectional area, "A" with a resistivity of ρ = 60k ohm-cm (high quality silicon).

1 MeV energy into material creates ~ $3x10^5$ e/h in ~10 ps … limiting drift velocity ~ 10^7

$$i_{signal} \sim \frac{\Delta Q}{\Delta t} = \frac{3x10^5\left(1.6x10^{-19}\right)}{\left(L\,cm/10^7\,cm/s\right)} = \frac{5}{L}10^{-7}\,\mathrm{Amps\ \ for\ \ L\ \ in\ \ cm}$$

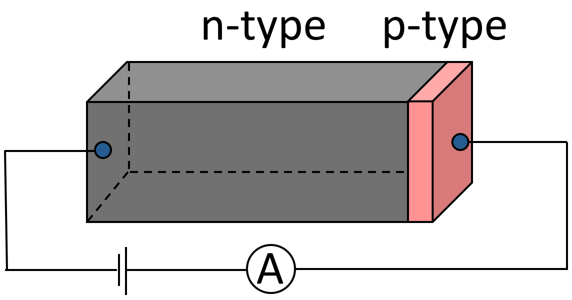


$$I_{Leakage} = \frac{V_0}{R} \quad where \quad R = \rho\frac{L}{A}$$

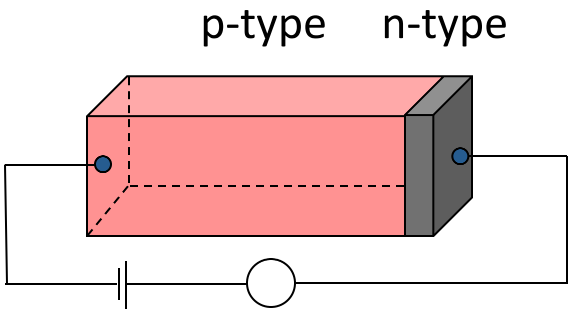
$$I_{Leakage} = \frac{V_0 A}{\rho L} \quad \rightarrow \quad \frac{60A}{60{,}000L} = \frac{A}{L}10^{-3}\,\mathrm{Amps\ \ for\ \ A/L\ \ in\ \ cm}$$

Thus, $I_{Leakage} >> i_{Signal}$ so we need a trick to kill the leakage current.

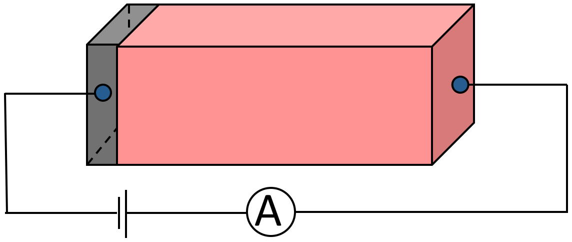
Semiconductor Diodes



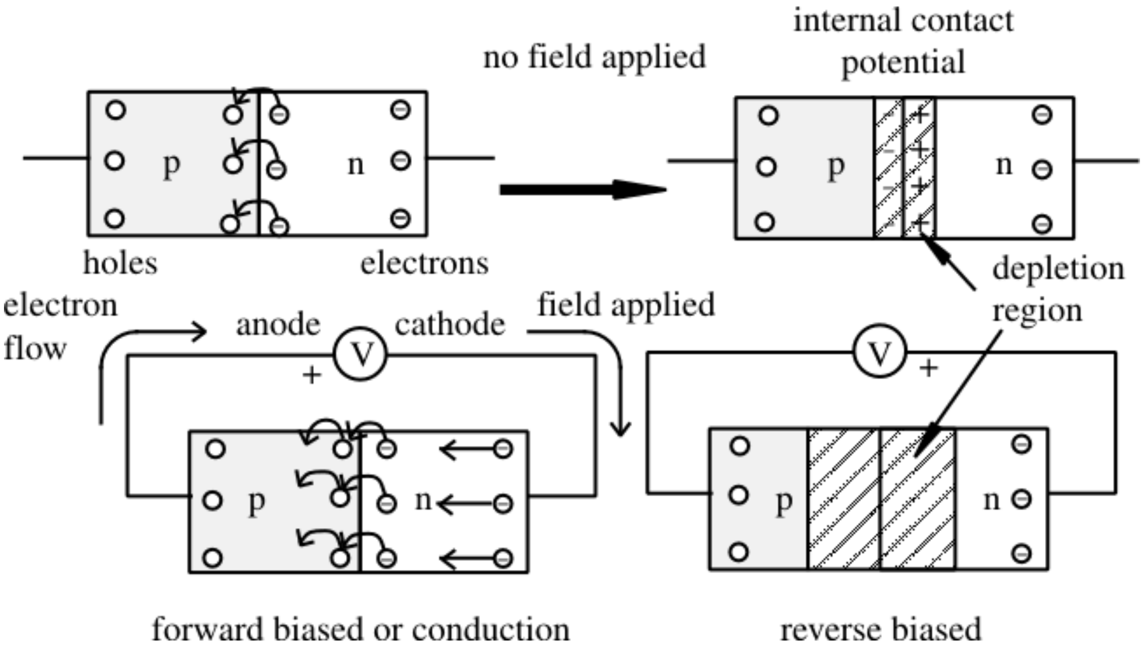
“Forward” bias – normal flow of current



“Reverse” bias – no nominal current

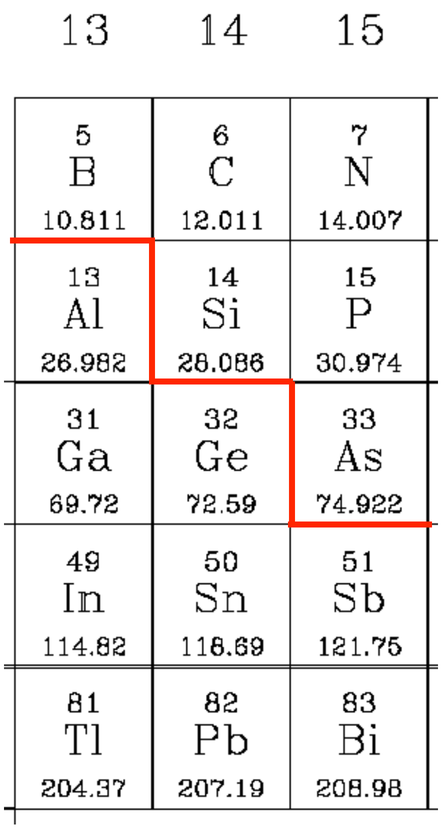


The “type” is determined by the implanted atoms .. Different atoms can be put into a single piece of semiconductor, then an internal field will form due to migration of charges.



Semiconductor Detectors – options

The semiconductors provide the lowest value of “w” and thus the highest resolution for the energy, Silicon has become widely available in thin disks but the low atomic number (14) limits its use for photon detection – a higher Z is needed.



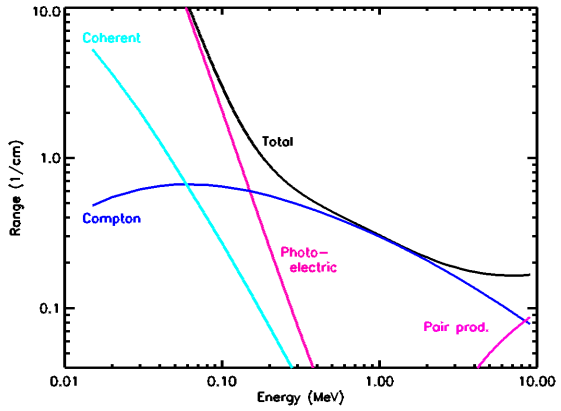
13	14	15
5 B 10.811	6 C 12.011	7 N 14.007
13 Al 26.982	14 Si 28.086	15 P 30.974
31 Ga 69.72	32 Ge 72.59	33 As 74.922
49 In 114.82	50 Sn 118.69	51 Sb 121.75
81 Tl 204.37	82 Pb 207.19	83 Bi 208.98

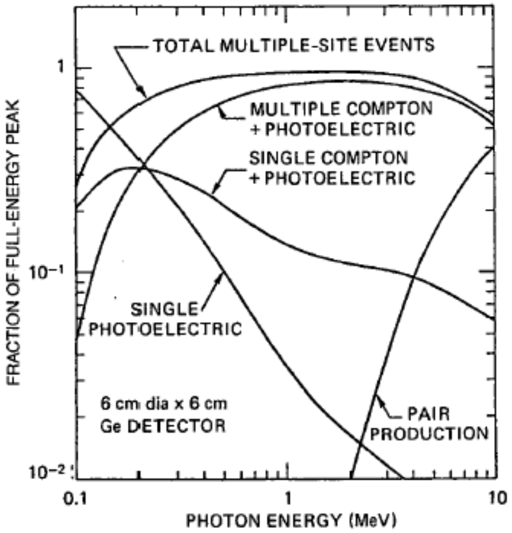
- Sn & Pb are “metallic”
- Ge is only elemental option
- GaAs, InSb are used somewhat
- CdZnTe is a “new” material

Germanium is more metallic than silicon – band gap is lower, higher signals, higher thermal noise, easier to purify, donor/acceptor level must be lower

Large volumes are available (~1 L) from zone refining n-type usually has Oxygen in the matrix
p-type usually has Aluminum in the matrix
“hyperpure” material is readily available .. Intrinsic.

Germanium Based Detectors – contacts





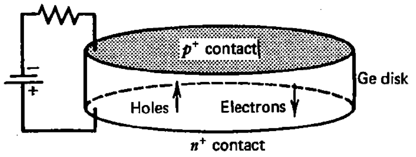
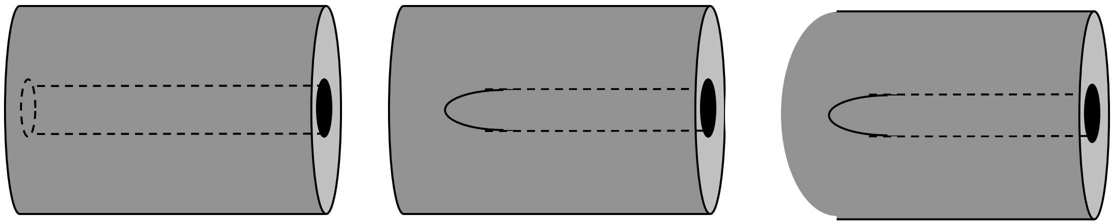


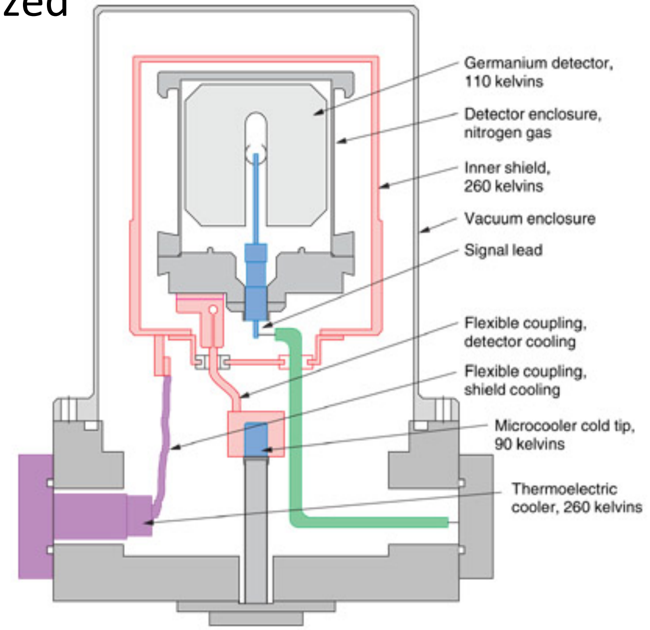
Fig. 12.2 Knoll, 3rd Ed.

Multiple Compton Scattering is most likely process in “nuclear regime”
Planar devices: low energy photons.

6cm x 6cm Fig. 12.16 Knoll, 3rd Ed.

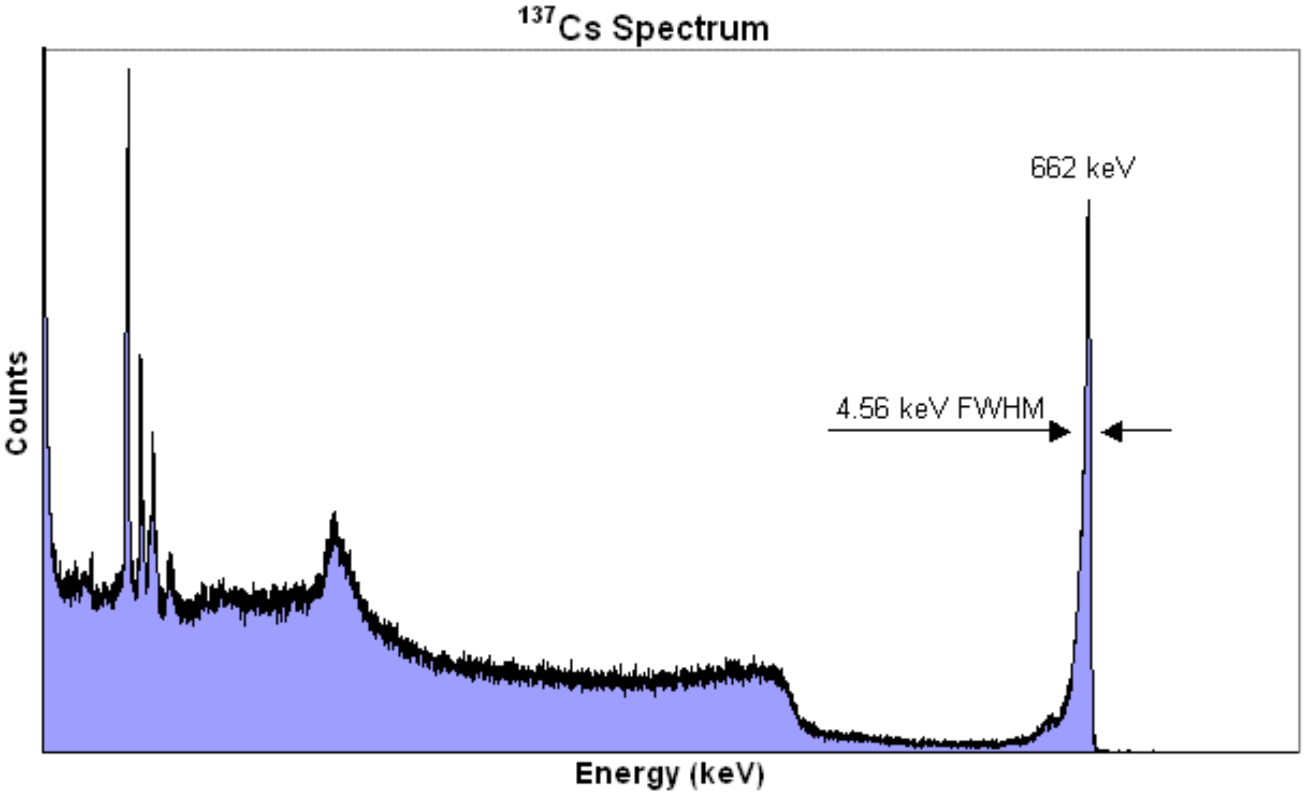
Intrinsic or high purity germanium can be formed into coaxial shapes with radial electric fields but end-caps are often left on and they are often “bulletized”

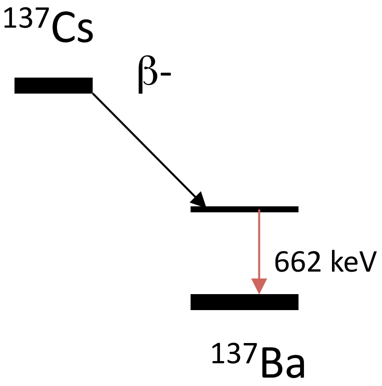




N.B. Germanium-based detectors have to be held at liquid nitrogen temperature to attain an acceptable noise level !!!

Gamma-ray Detectors – Spectrum – 1

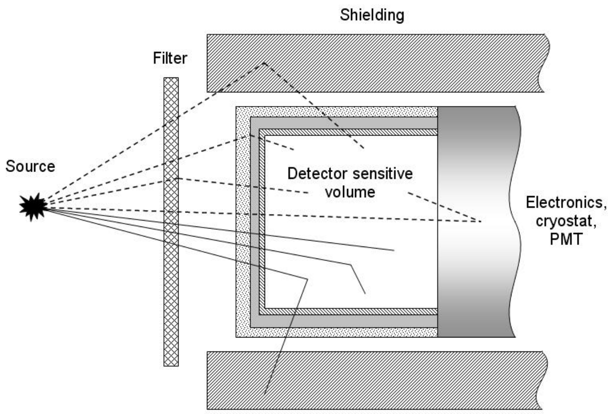


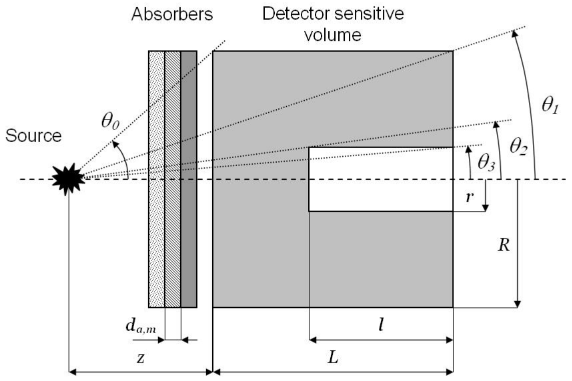


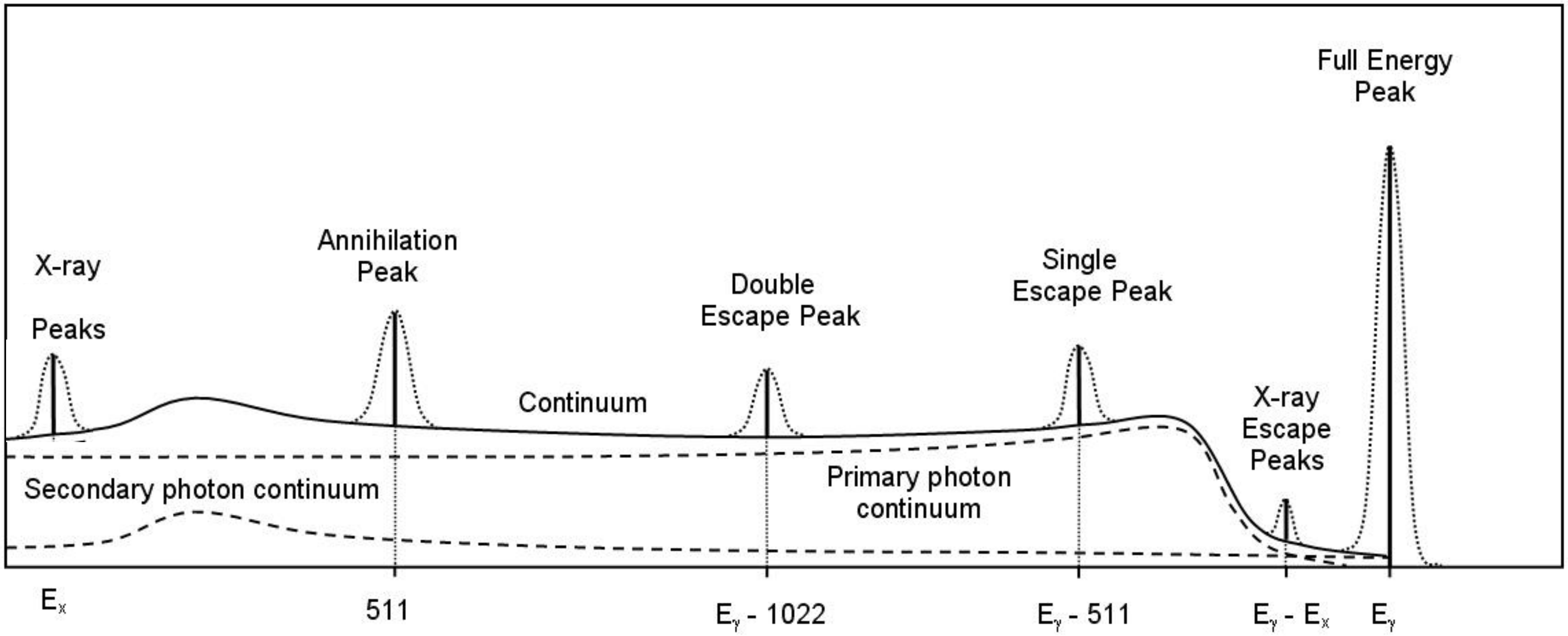
http://www.amptek.com/ cdtestack.html

Features include:
Full energy peak from individual gamma ray.
X-rays (from Ba) due to disruption of atomic electrons during decay.
Large underlying background from Compton Scattering of photons.
Backscattering “peak” (electron at ~0^{o} and photon at 180^{o})

Gamma-ray Detectors – Spectrum Components

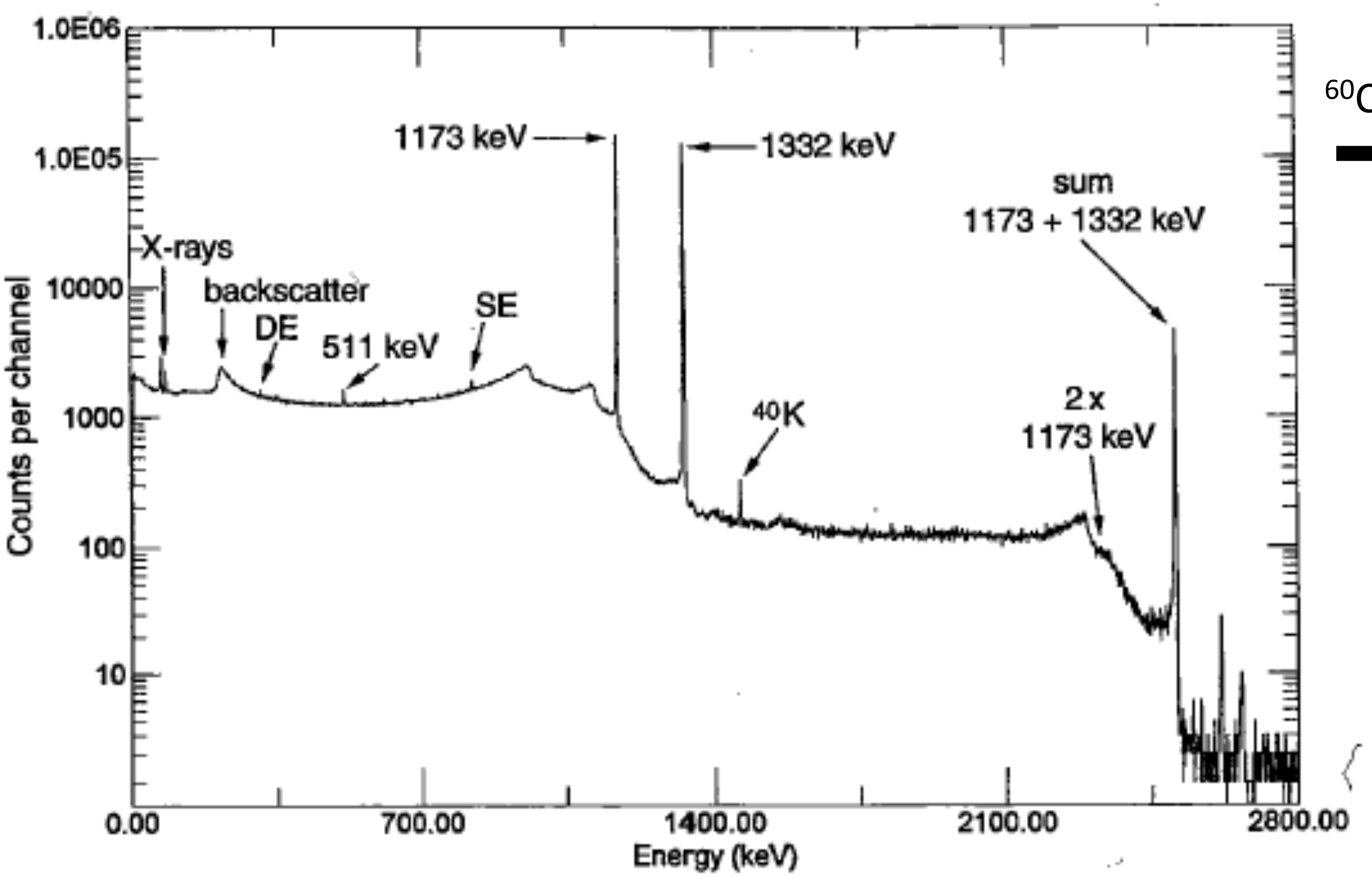


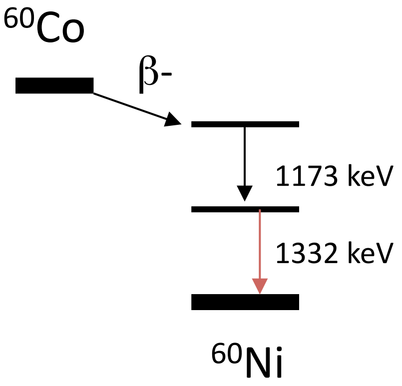




http://www.nucleonica.net/wiki/index.php/Help:Gamma_Spectrum_Generator

Gamma-ray Detectors – Spectrum – 2




^{60}Co

β-

1173 keV

1332 keV

^{60}Ni

Additional features include:

Full energy peaks from individual gamma's and coinindence sum.

Escape peaks from pair production ($E_\gamma > 1.022$ MeV)

Background Radiation - local

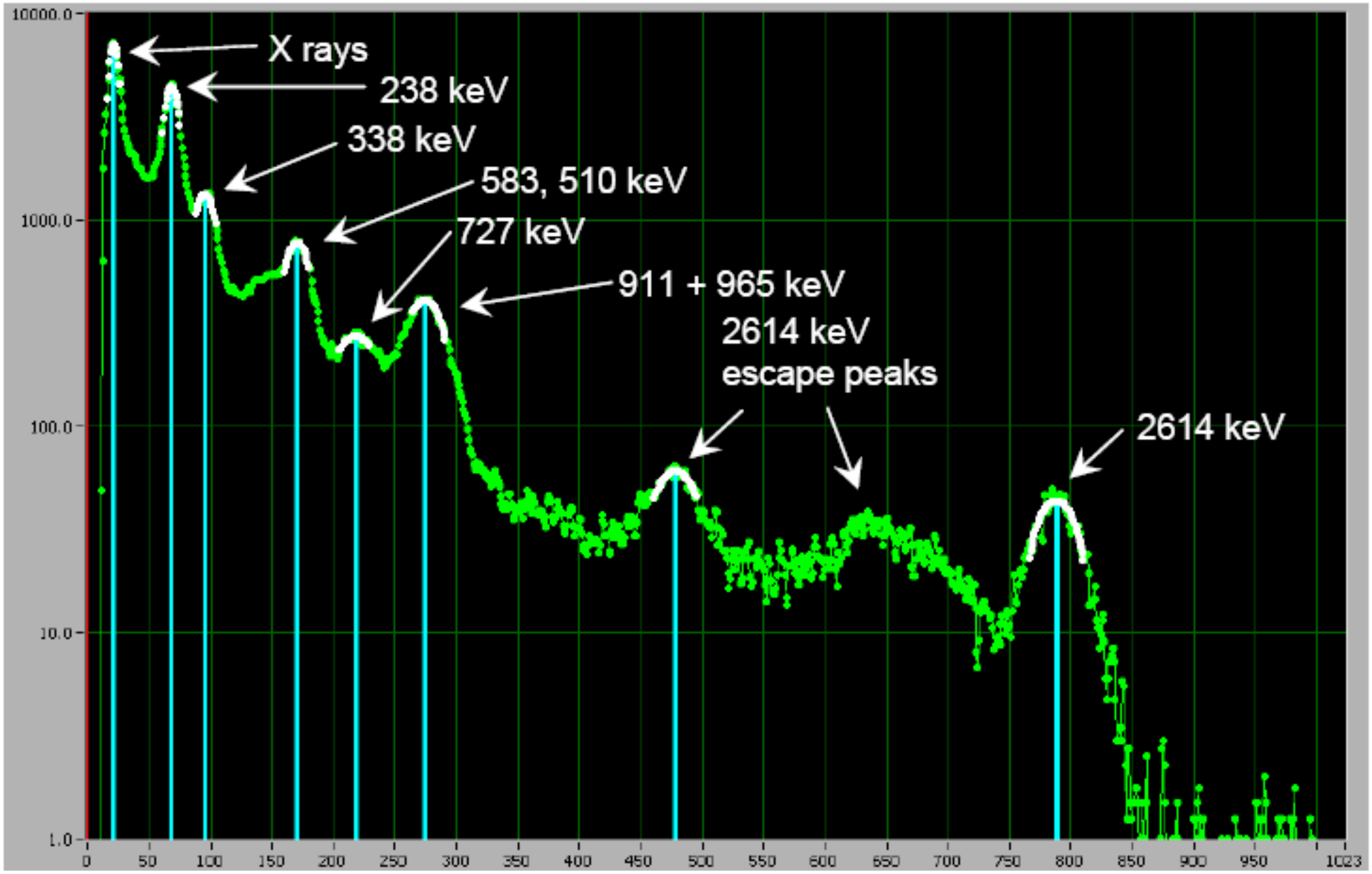
Nuclide	T ½	Source
^{235}U	7x10^{8} yr	0.72% of all natural uranium
^{238}U	4x10^{9} yr	99.2745% of all natural uranium; 0.5 to 4.7 ppm total uranium in the common rock types
^{232}Th	1.41 x 10^{10} y	1.6 to 20 ppm in the common rock types with a crustal average of 10.7 ppm
^{226}Ra	1.60 x 10^{3} yr	0.42 pCi/g (16 Bq/kg) in limestone and 1.3 pCi/g (48 Bq/kg) in igneous rock
^{222}Rn	3.82 days	Noble Gas; annual average air concentrations in the US from 0.016 pCi/L (0.6 Bq/m^{3}) to 0.75 pCi/L (28Bq/m^{3})
^{40}K	1.28 x 10^{9} yr	soil - 1-30 pCi/g (0.037-1.1 Bq/g)
^{14}C	5730 yr	Cosmic-ray interactions, ^{14}N(n,p)^{14}C , 6 pCi/g (0.22 Bq/g) in organic material
^{3}H	12.3 yr	Cosmic-ray interactions with N and O, spallation from cosmic-rays, ^{6}Li(n, alpha)^{3}H , 0.032 pCi/kg (1.2 x 10^{-3} Bq/kg)

e.g., 70 kg person

Nuclide	Activity
U : 90 µg	1.1 Bq
Th : 30 µg	0.11 Bq
Ra : 31 pg	1.1 Bq
^{40}K : 17 mg	4.4 kBq
^{14}C : 22 ng	3.7 kBq
^{3}H : 60 fg	37 Bq

http://www.physics.isu.edu/radinf/natural.htm

Background ^{232}Th spectrum .. The ^{208}Pb line



^{232}Th spectrum in a small $CdWO_4$ survey device

Background & Shielding: Singles

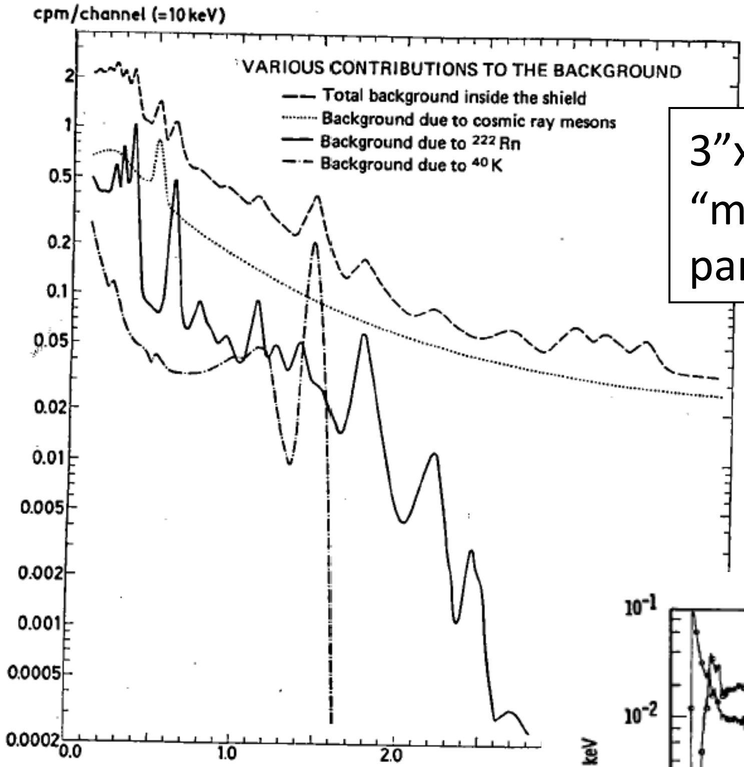


Fig. 20.2 Knoll, 3rd Ed.

3"x3" NaI(Tl) inside a "massive" lead/borated-parafin shield

85 cm^3 Ge in a laboratory shield

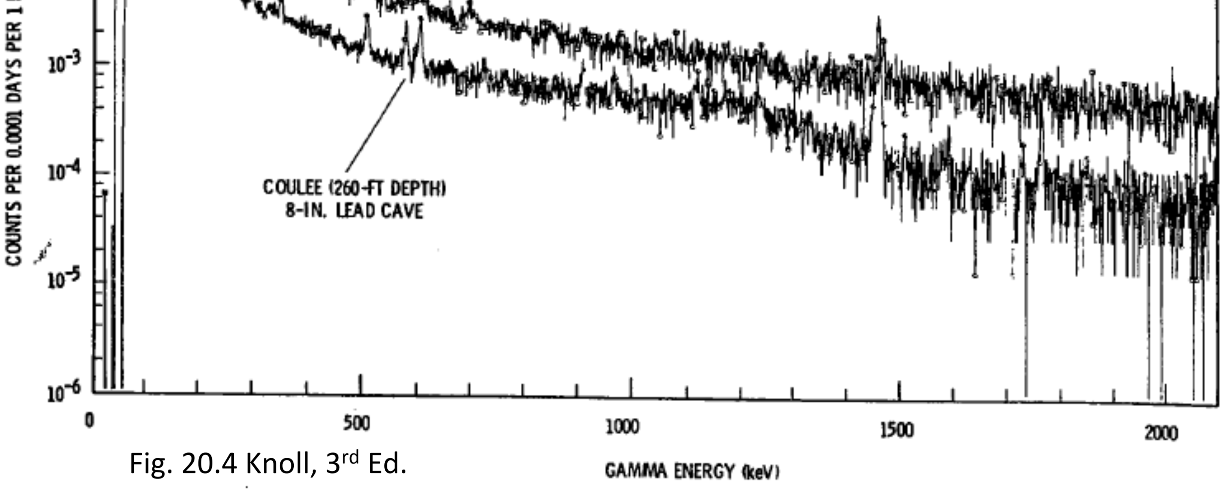


Fig. 20.4 Knoll, 3rd Ed.