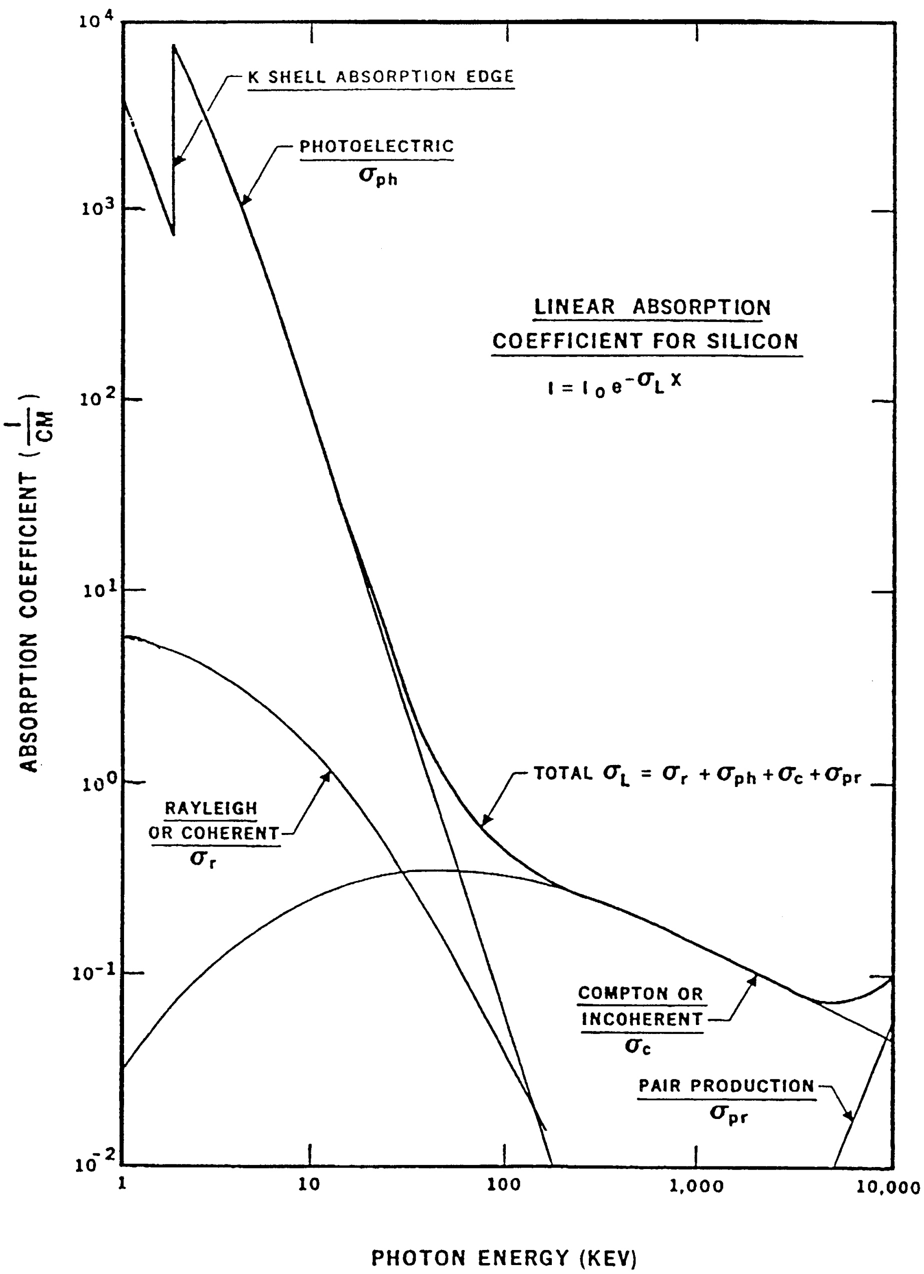
Implications for Required Detector Size

Linear absorption coefficient in Si:

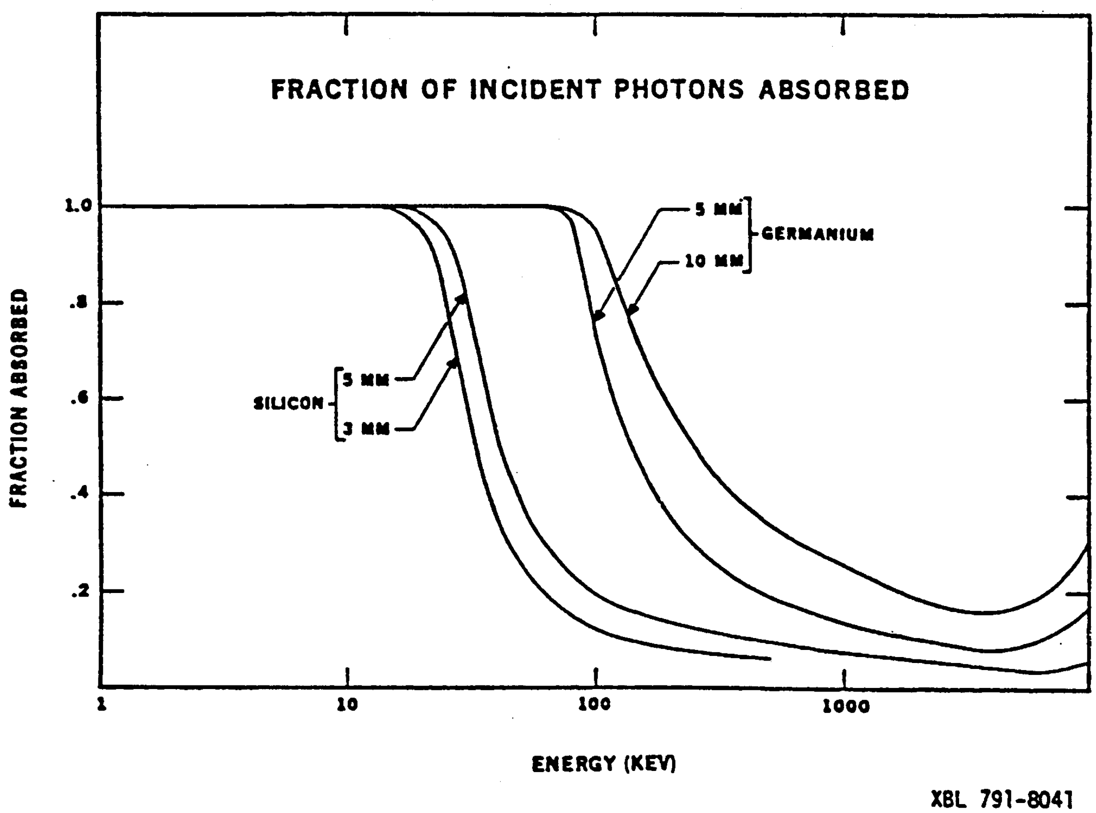
For N_0 incident photons photons impinging on a medium, the number that traverse the length x without interacting is

$$N = N_0 e^{-\sigma_L x}$$



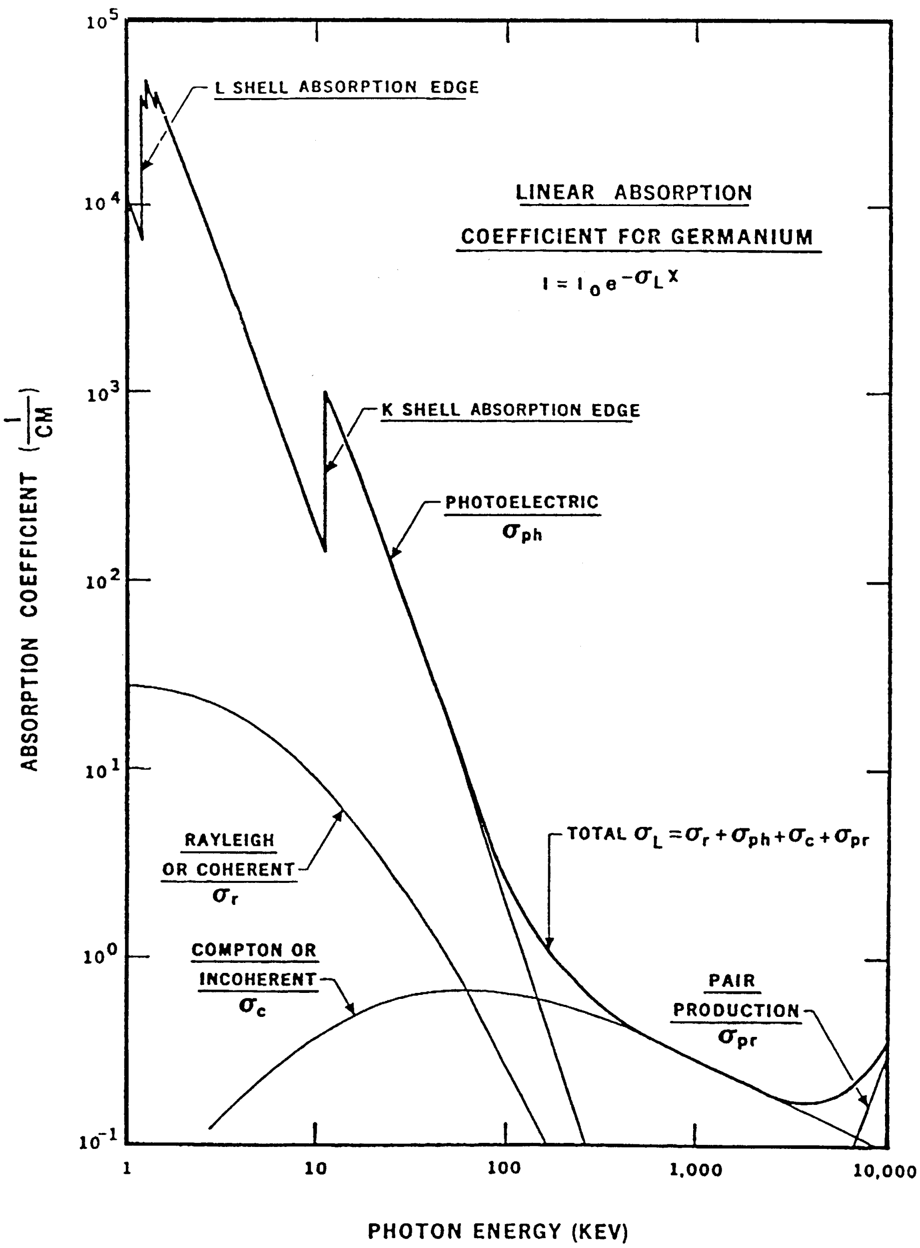
For example, the absorption of 10 keV photons in Si is dominated by the photoelectric effect with $\sigma_{ph} \approx 10^2$ cm^{-1}. If a detector is 300 µm thick, i.e. $\sigma_{ph}\, x \approx 3$, then 95% of the photons will interact in the detector. Since the range of the emitted photoelectron is about 1 µm, all of the primary energy is absorbed in the detector volume.

The absorption coefficient decreases rapidly with energy.



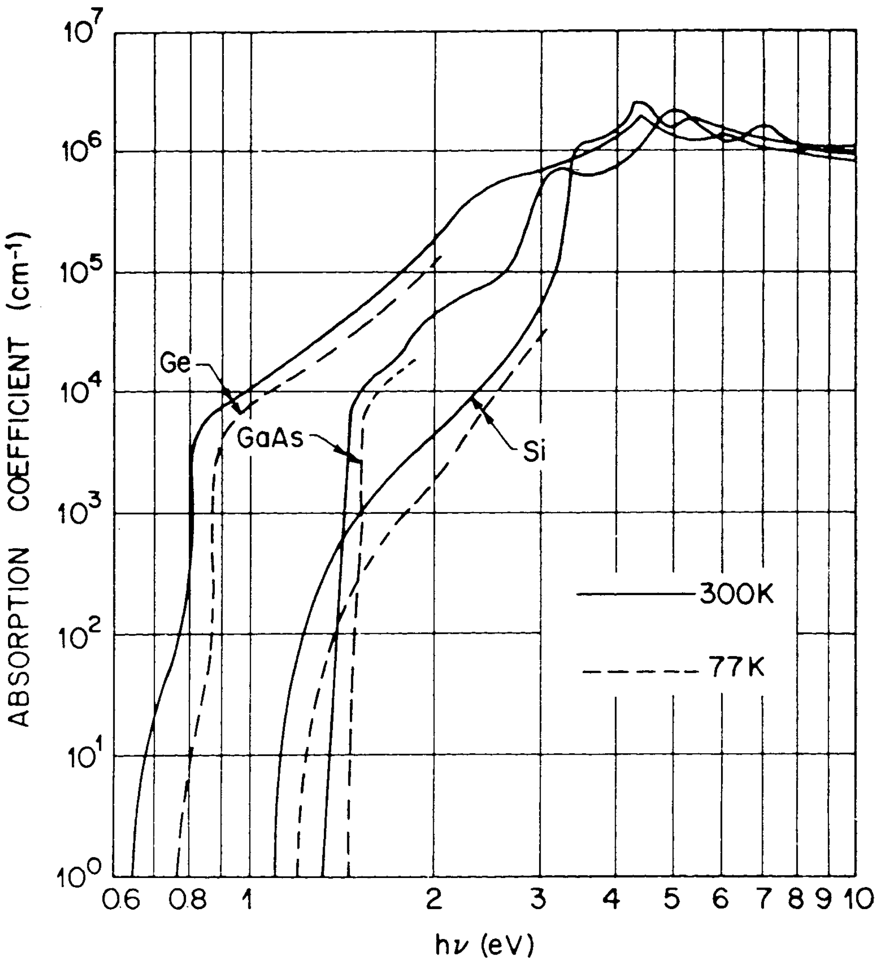
For a photon of 1 MeV, practically all absorption in Si is due to Compton scattering with an absorption coefficient $\sigma_c \approx 10^{-1}$ cm^{-1}. In a 300 µm thick detector, only 0.3% will interact. For 95% absorption, the detector must be 30 mm thick. Even then, the scattered photon may still leave the absorber without further interaction, so only a fraction of the primary photon energy remains in the detector. For full energy absorption with good efficiency the detector would have to be made even larger.

The alternative is to use a material with larger atomic number Z. As shown in the previous graph, Ge maintains high efficiency to higher energies than a Si absorber of the same size.



At higher energies the required crystal volume for Si or Ge becomes impractical or prohibitively expensive, so higher Z materials become attractive, for example NaI(Tl), where iodine (Z= 53) is the primary absorber, or Bismuth-Germinate ($Bi_4Ge_3O_{12}$, “BGO”), where Bismuth (Z= 83) provides even higher absorption efficiency.

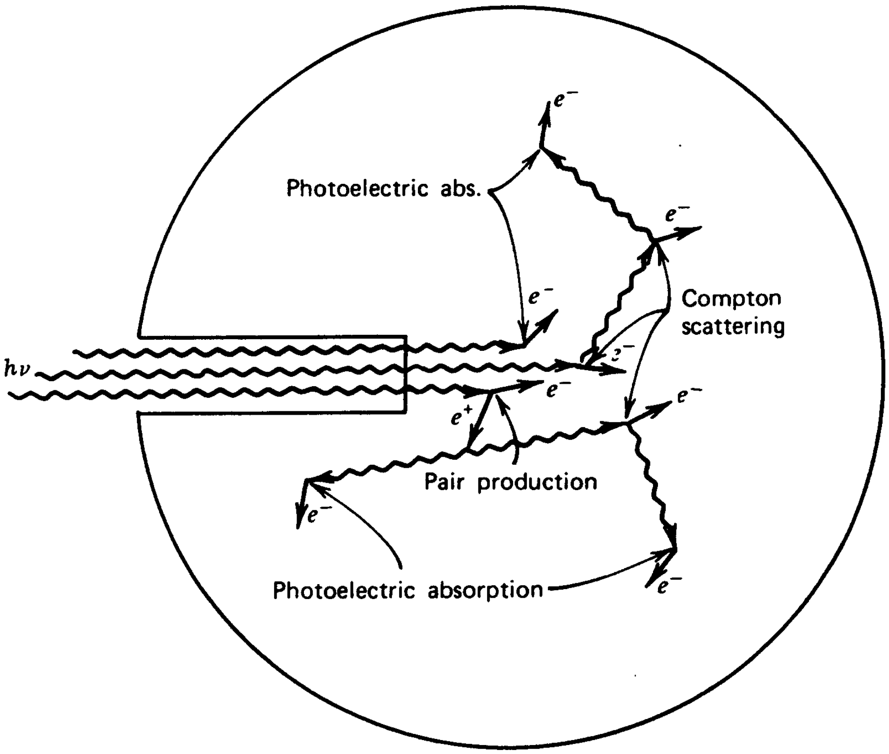
Whenever the energy of the incident photon attains the threshold of an excitation mode, the cross section increases. In the previous graphs this can be seen at the K and L energies. Similar behavior can be observed when the photon energy exceeds the band gap, as shown below for IR to UV photons.

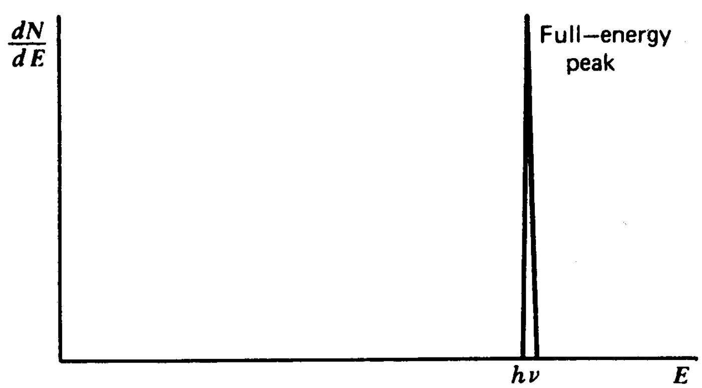


If the absorption coeficient α= 10^4 cm (e.g. visible light in Si), most of the photons are absorbed within about 1 µm of the surface and dead layers must be < 0.1 µm to avoid significant losses (<10%).

Energy Spectra for various Detector Sizes
(adapted from Knoll)

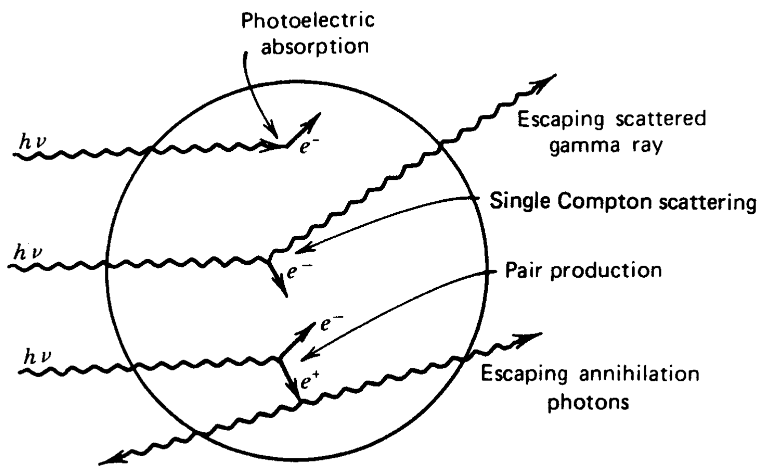
a) Large Detector

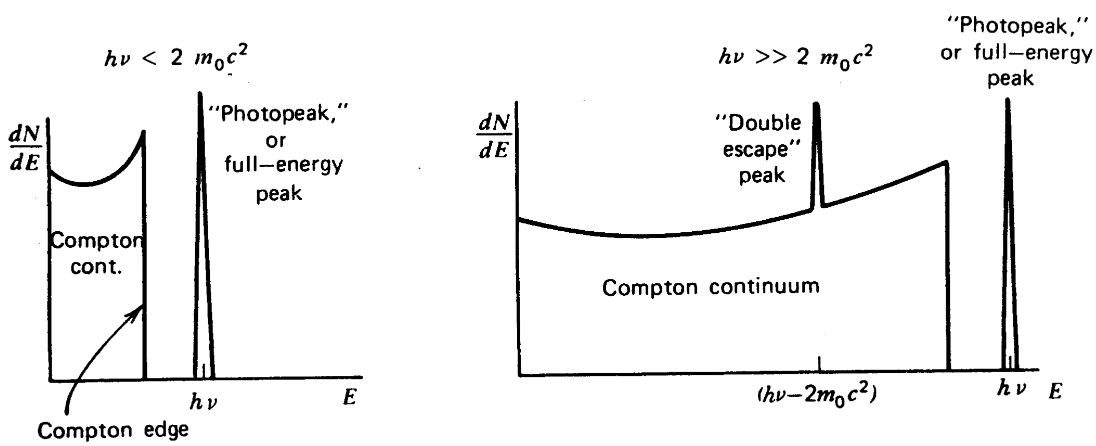




All secondaries absorbed.

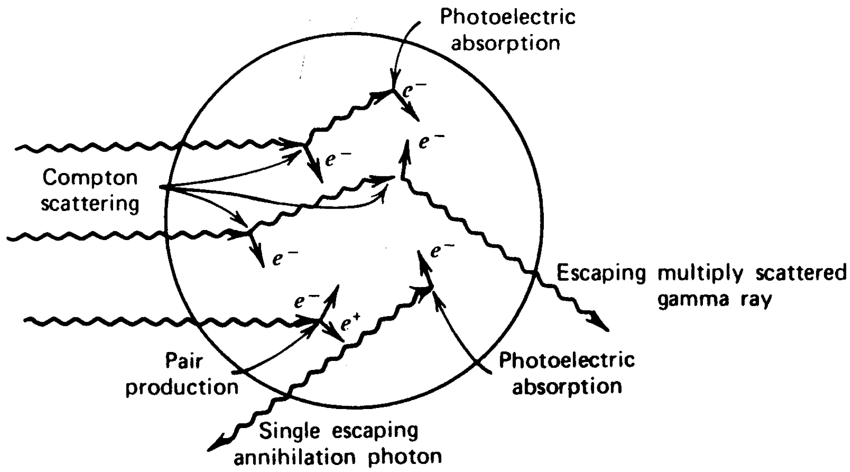
b) Small Detector

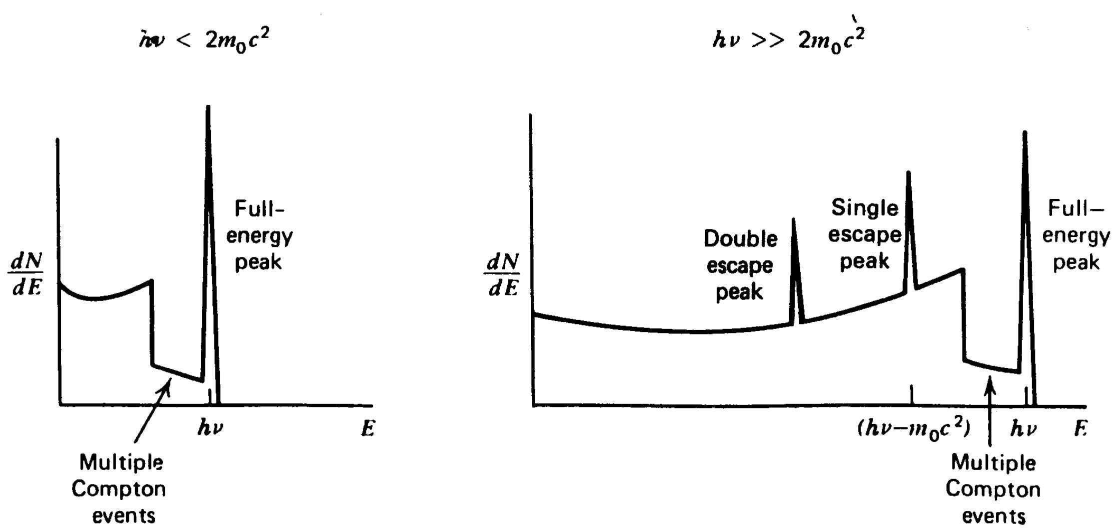




In the small detector there is a substantial probability that neither the Compton scattered gamma nor the two 511 keV annihilation photons from pair production are registered in the detector.

c) Intermediate Volume Detector





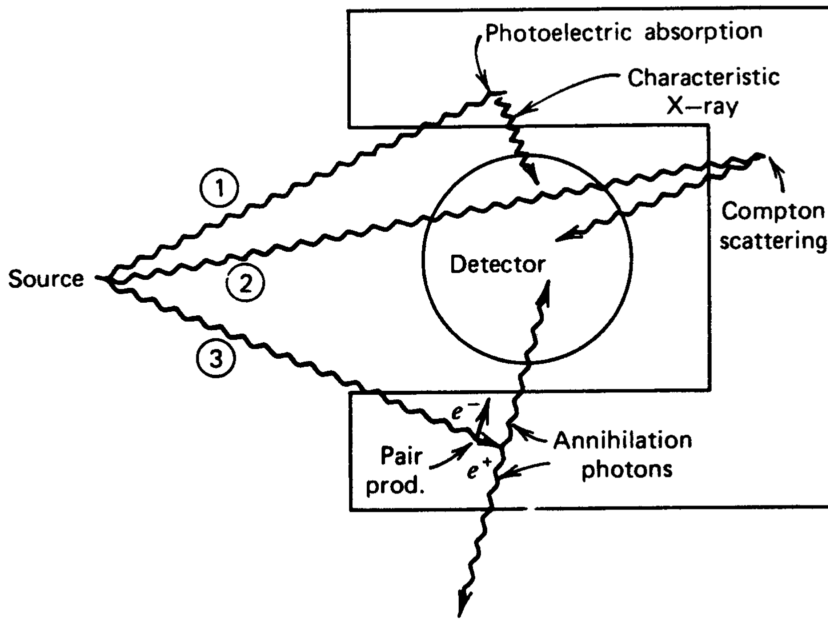
In the intermediate volume detector the initial Compton-scattered photon can scatter again with escape of the final scattered photon.

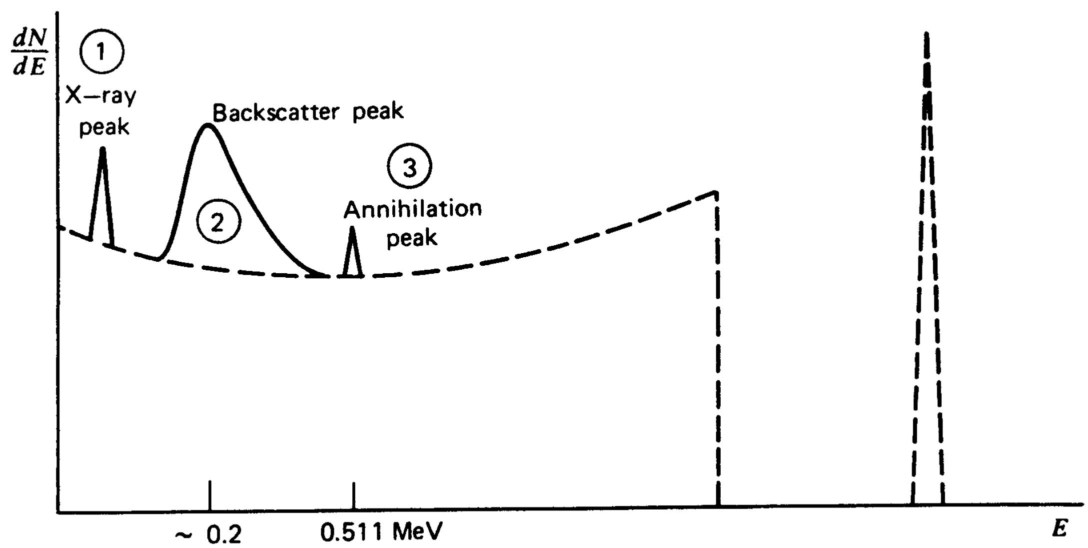
⇒ energy deposition above Compton edge

One annihilation photon from pair-production is absorbed and one escapes

⇒ “single escape peak”

d) Effect of Surrounding Material



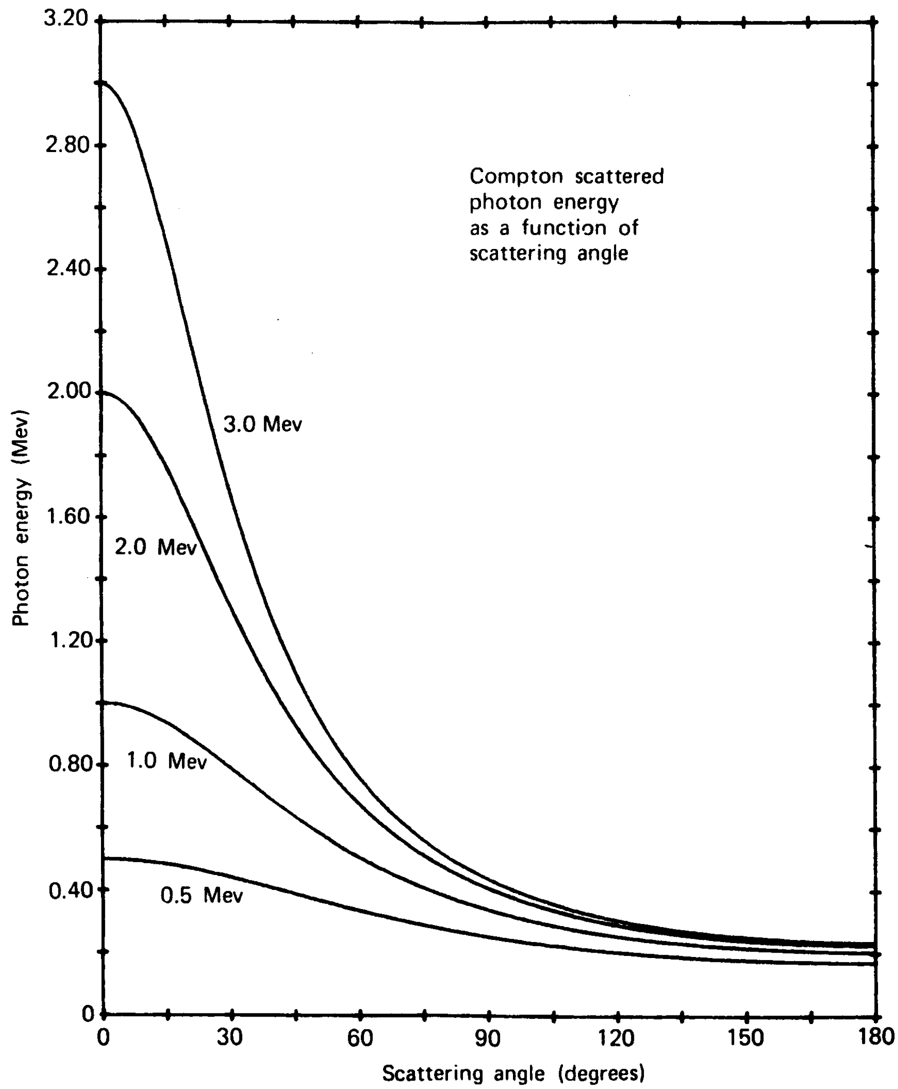


(1) x-ray from photoelectric absorption in external material

(2) Compton backscatter peak (see next page)

(3) Absorption of one 511 keV annihilation photon from pair-production in external material.

Compton Backscattering



At 180° all incident photon energies yield a narrow energy distribution of the scattered photon ("backscatter peak").