Hands-on session: Radioactivity Laboratory

Spectrometry with NaI(Tl)

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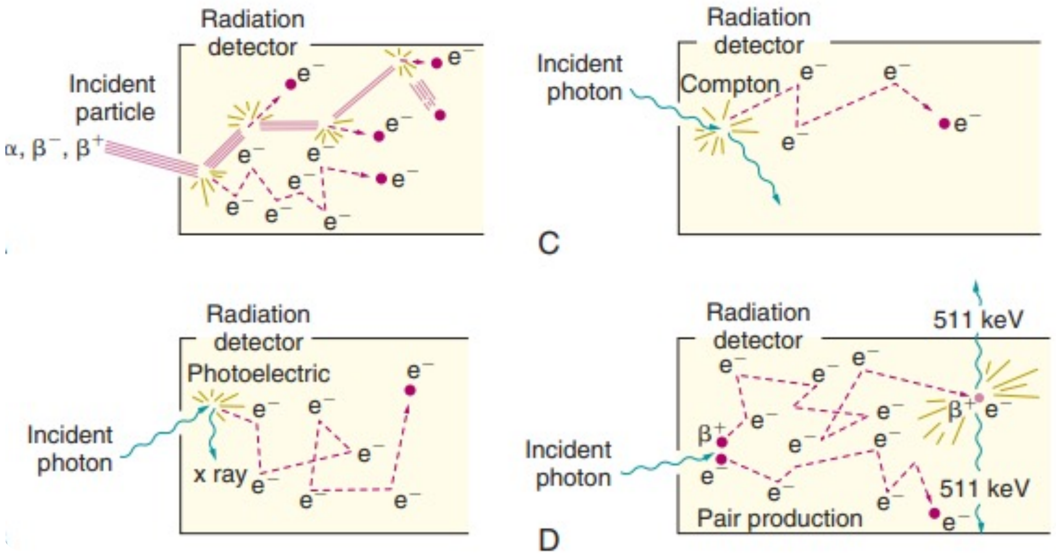
Gamma Spectrometry

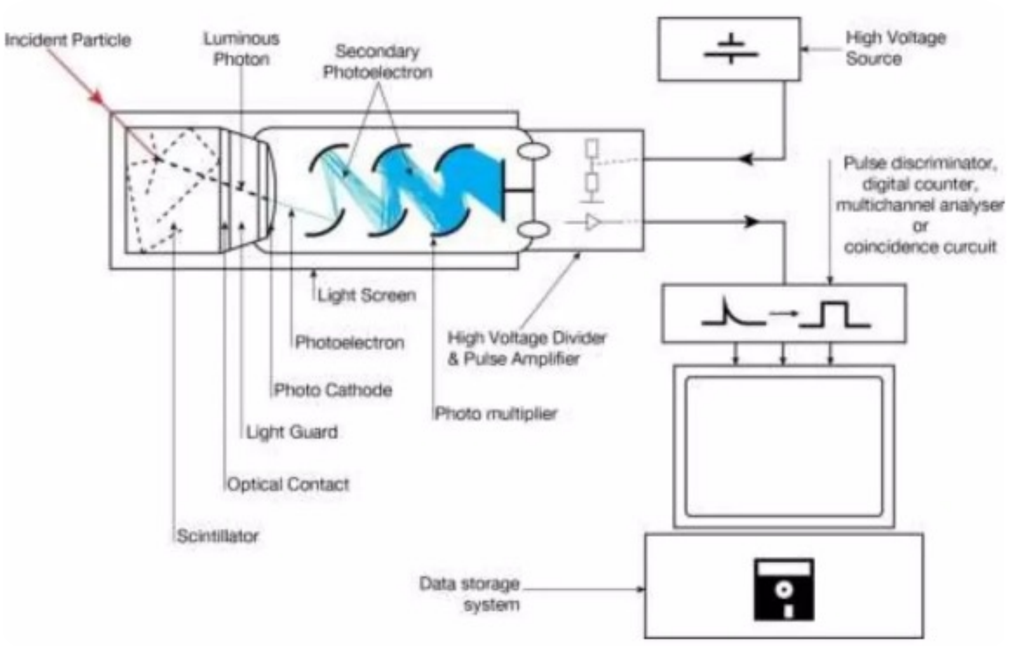
- Introduction to spectrometry
- NaI(Tl) photopeak detection
- Detection response
- Multi-Channel-Analysis
- Measurements

Basics of Pulse-Height Spectrometry

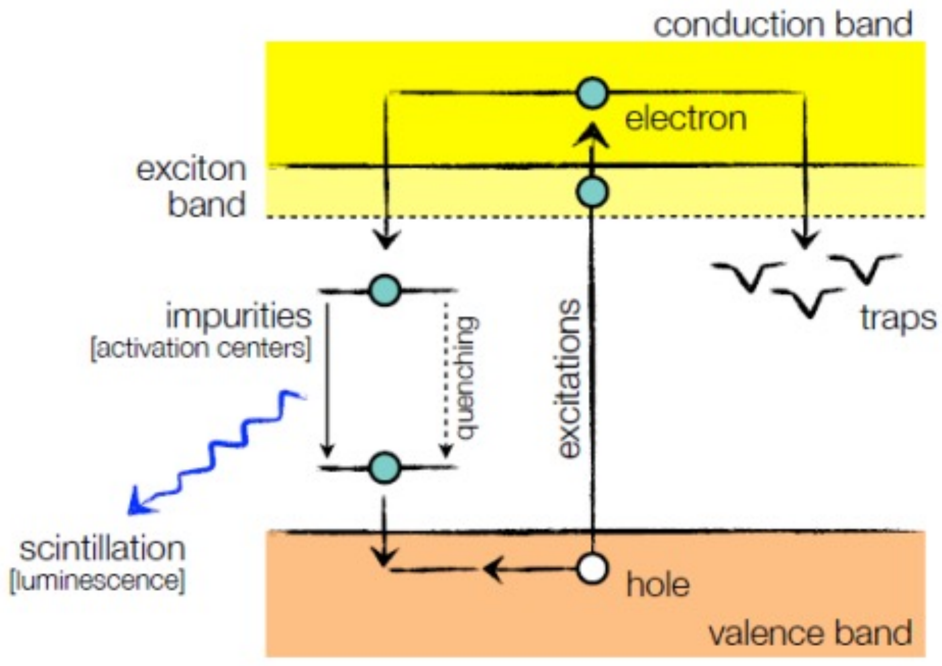


- Particles deposit energy into sensitive volume of detector
- Signal output proportional to particle energy
- Energy deposited outside the detector is not registered

Spectrometry with NaI(Tl)



- In inorganic scintillator there is an electron-hole creation and deexcitation on impurities intermediate states able to collect all the energy inside, because range in solid is very short.
- Very good performance-to-cost ratio
- Good coupling with PMT or APD

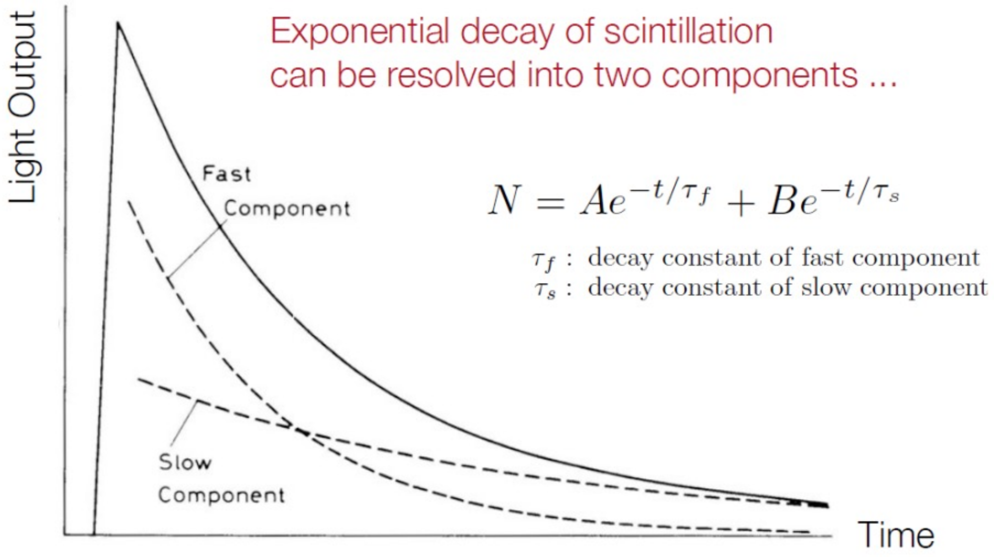


Energy bands in impurity activated crystal
showing excitation, luminescence, quenching and trapping

Spectrometry with NaI(Tl)

- Inorganic scintillators are lab grown crystals.
- Pure crystals make bad scintillators:
  - the defined energy bands between valence band and excitation band means that energy emitted by the crystal get reabsorbed by the same lattice
  - There are only definite energy quanta allowing for the excitation of molecules
  - Adding impurity improves the behavior
  - There are more intermediate states between valence and excitation band that can be reached by the excited electron
  - The emitted light is not completely reabsorbed by the crystal lattice

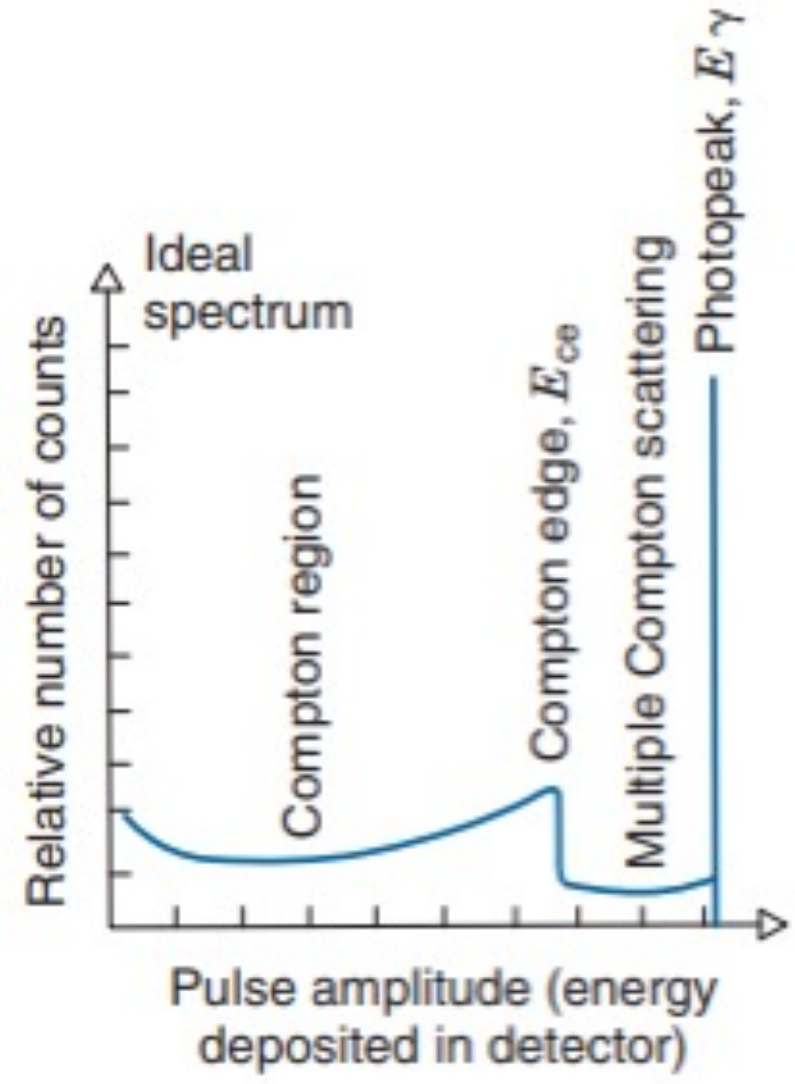
Spectrometry with NaI(Tl)



Light output characterized by two time constants:

- 1. Fast (or prompt) component, due to activated centers
- 2. Slow (or non-prompt) component, mainly due to trapping

Usually the fast component dominates, but the ratio between A and B depends on the scintillating material



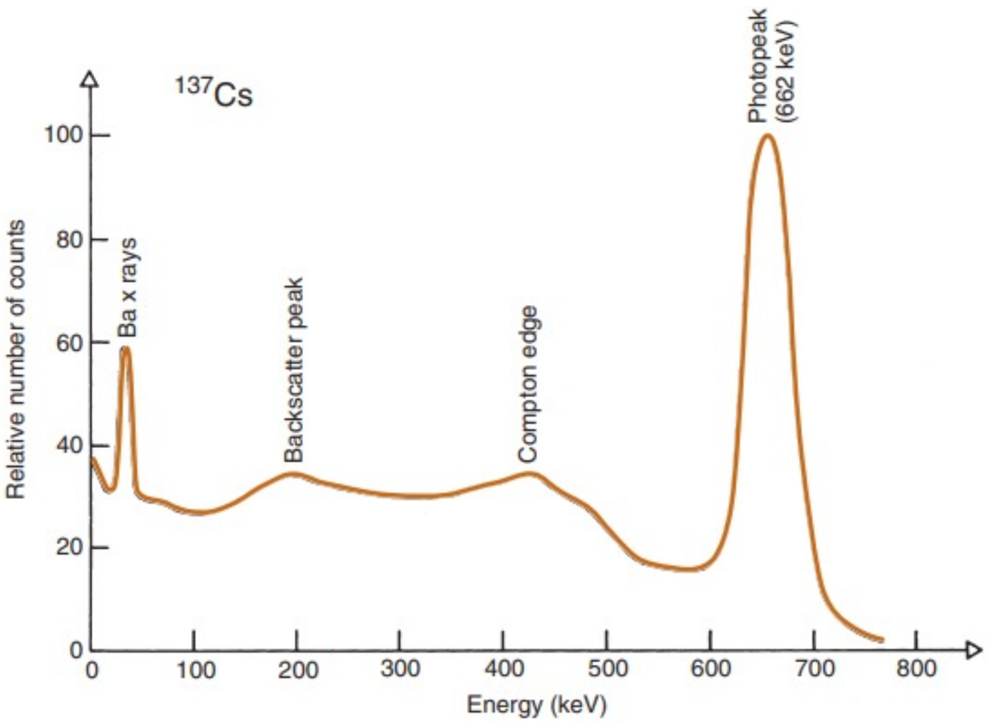
Spectrometry with NaI(Tl)

- Compton region
- Compton edge:

$$E_{re} = \frac{E_p^2}{E_p + 0.255}$$

- Multiple Compton scattering
- Photopeak

Spectrometry with NaI(Tl)

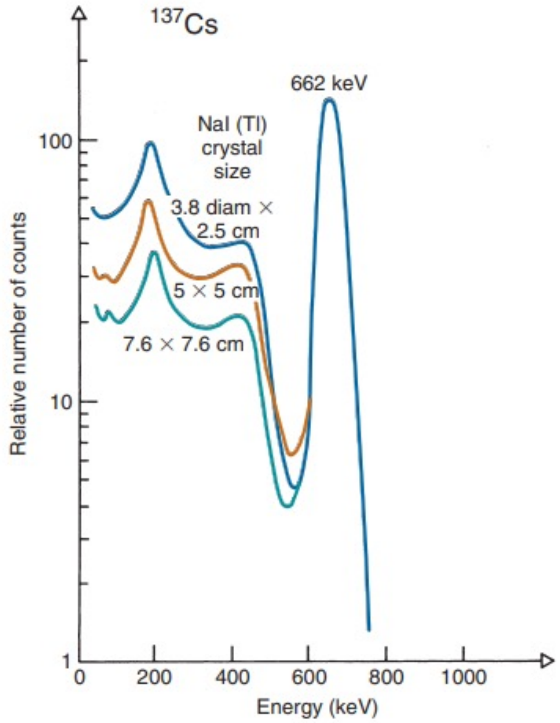


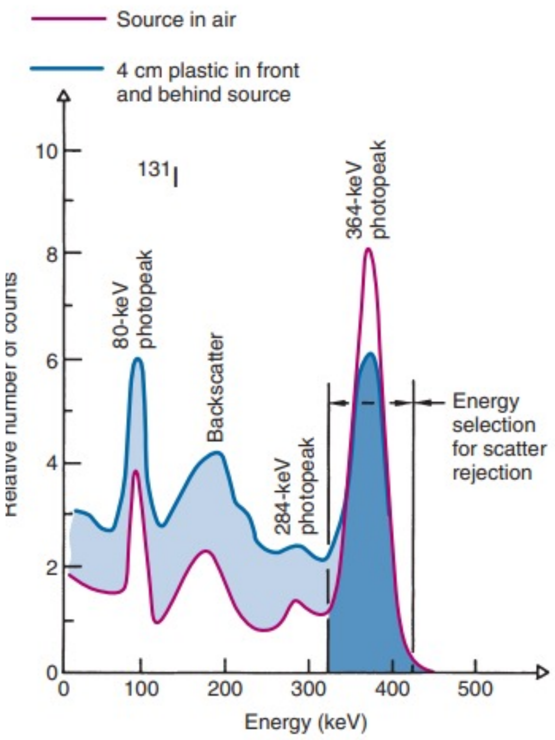
- ^{136}Cs decay emitting 662 keV gamma rays
- Photopeak
- X-rays of Ba
- Backscattered peak

Spectrometry with NaI(Tl)

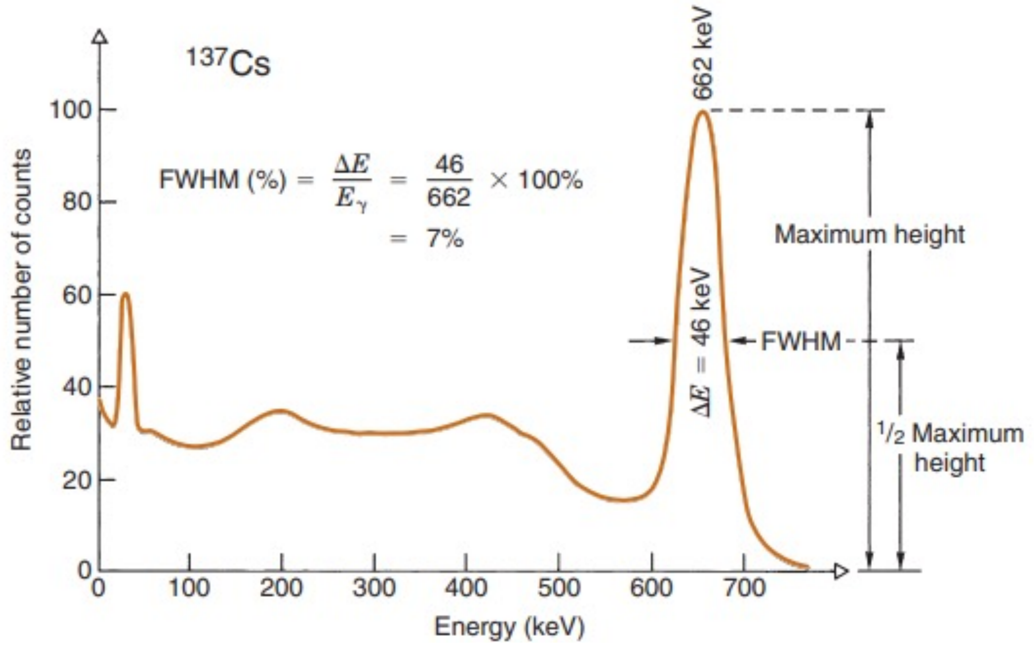
- Effect of detector size: more events in lower-energy spectra, and also in photopeak due to increase in detection efficiency

- Effect of scattering material around the source: more events in lower-energy spectra





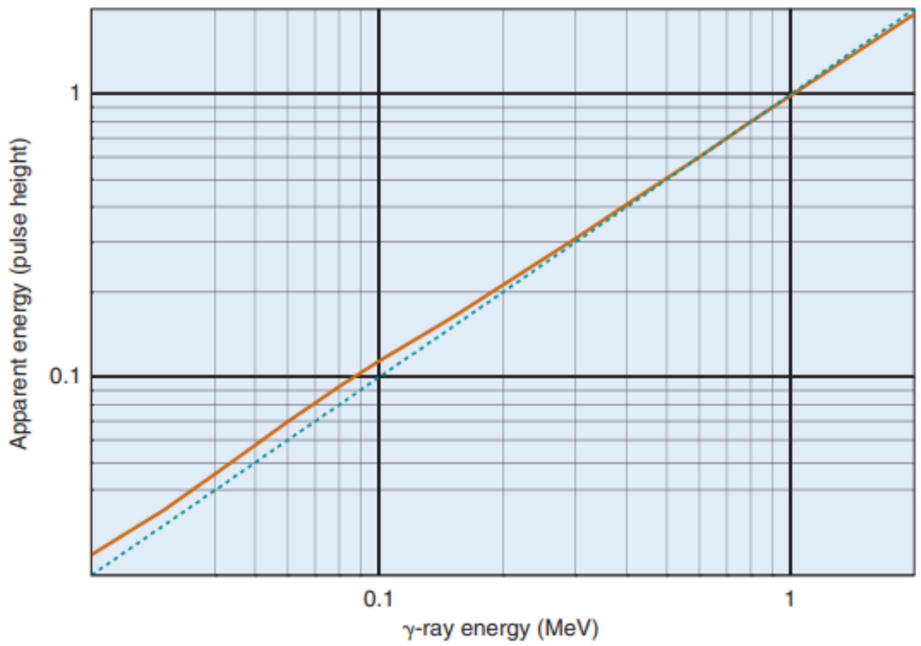
Spectrometry with NaI(Tl)



- Gaussian shape peak, instead of narrow-line.
- The width of the photopeak, ΔE, measured across its points of half-maximum amplitude is the energy resolution. This is referred to as the full width at half maximum.

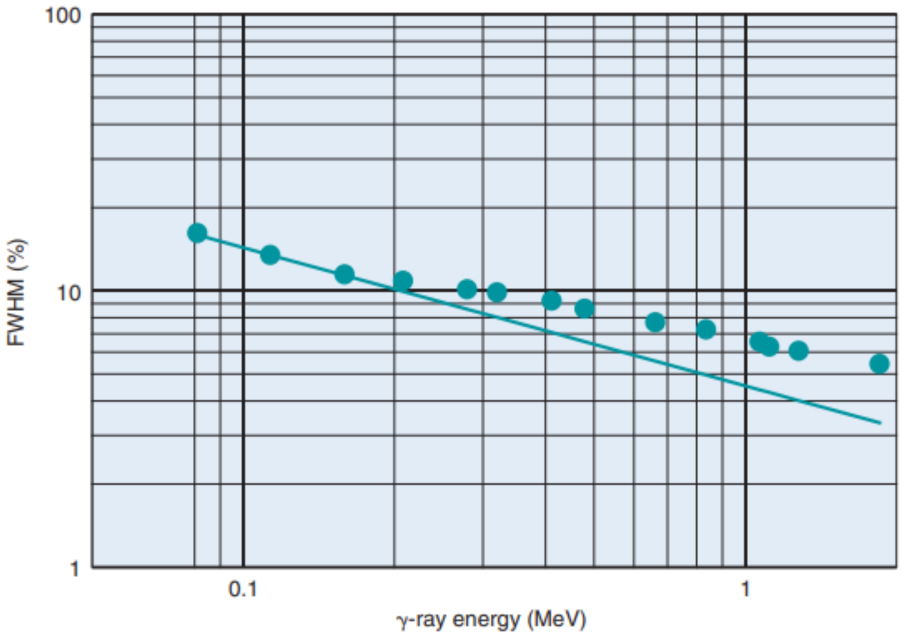
$$FWHM(\%) = \frac{\Delta E}{E_\gamma} * 100\%$$

Spectrometry with NaI(Tl)



- Energy linearity
- Proportionality between output pulse amplitude and energy absorbed in the detector
- Apparently non-linearities of 10-15 % for $E_\gamma < 0.2\ MeV$
- Problems in calibrating with high energy sources and measuring lower-energy sources

Spectrometry with NaI(Tl)



- Theoretical dependence of energy resolution :
- $\frac{\Delta E}{E_\gamma} = \frac{1}{\sqrt{E}}$
- Factors that raises energy resolution:

1. Integration time:
   $1\ \mu sec$ for imaging SPECT
   $100\ nsec$ for PET
2. Poor light coupling between scintillator and PMT

Energy resolution versus γ-ray energy for a 7.5-cm-diameter ~ 7.5-cm-thick NaI(Tl) scintillation detector.

Solid line indicates theoretical $\frac{1}{\sqrt{E}}$ behaviour, fitted to low-energy data points.

Detector efficiency

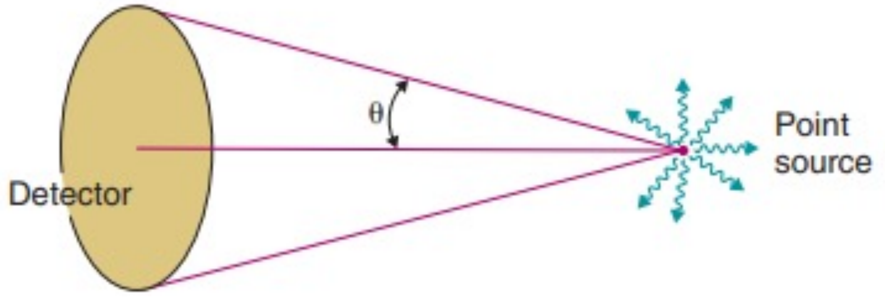
Efficiency with which detectors converts emission of a source into signal

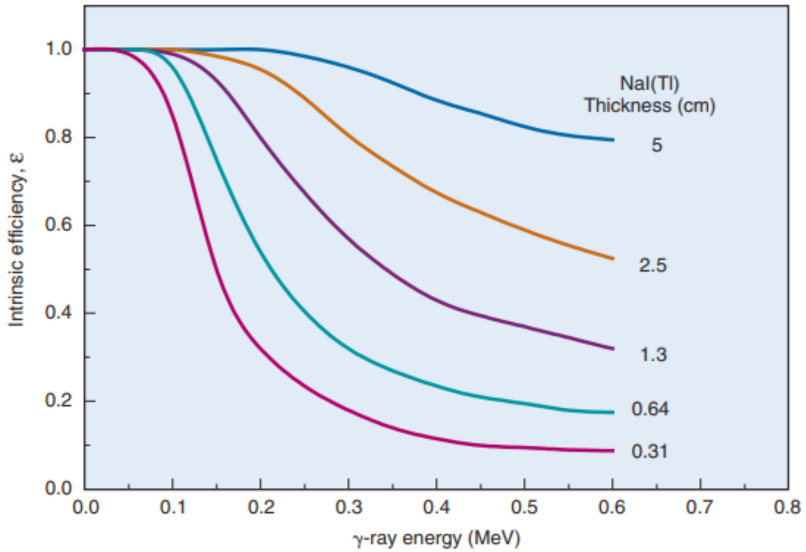
$$\xi\left(\frac{\gamma\ rays}{sec}\right) = A\left(\frac{dis}{sec}\right) * \ \eta\left(\frac{\gamma\ rays}{dis}\right)$$

$$R = D\ \xi$$

- Parameters
- ξ rate of emission
- A activity
- η gamma per disintegration
- R rate of counts
- D efficiency

Detector efficiency





- **Geometric (g)**: efficiency of geometric interception of radiation
- **Intrinsic (ε)**: efficiency of absorption and conversion, depends on thickness, composition and type of particles
- **Energy selective (f)**: efficiency of selection of amplitude

- **Absorption and scattering (F)**: efficiency of materials between detectors and source

- $D = g * \varepsilon * f * F$

$$\varepsilon = 1 - e^{-\mu_l(E)x}$$

$\mu_l(E)$ is linear attenuation coefficient

Multi-channel analyzer

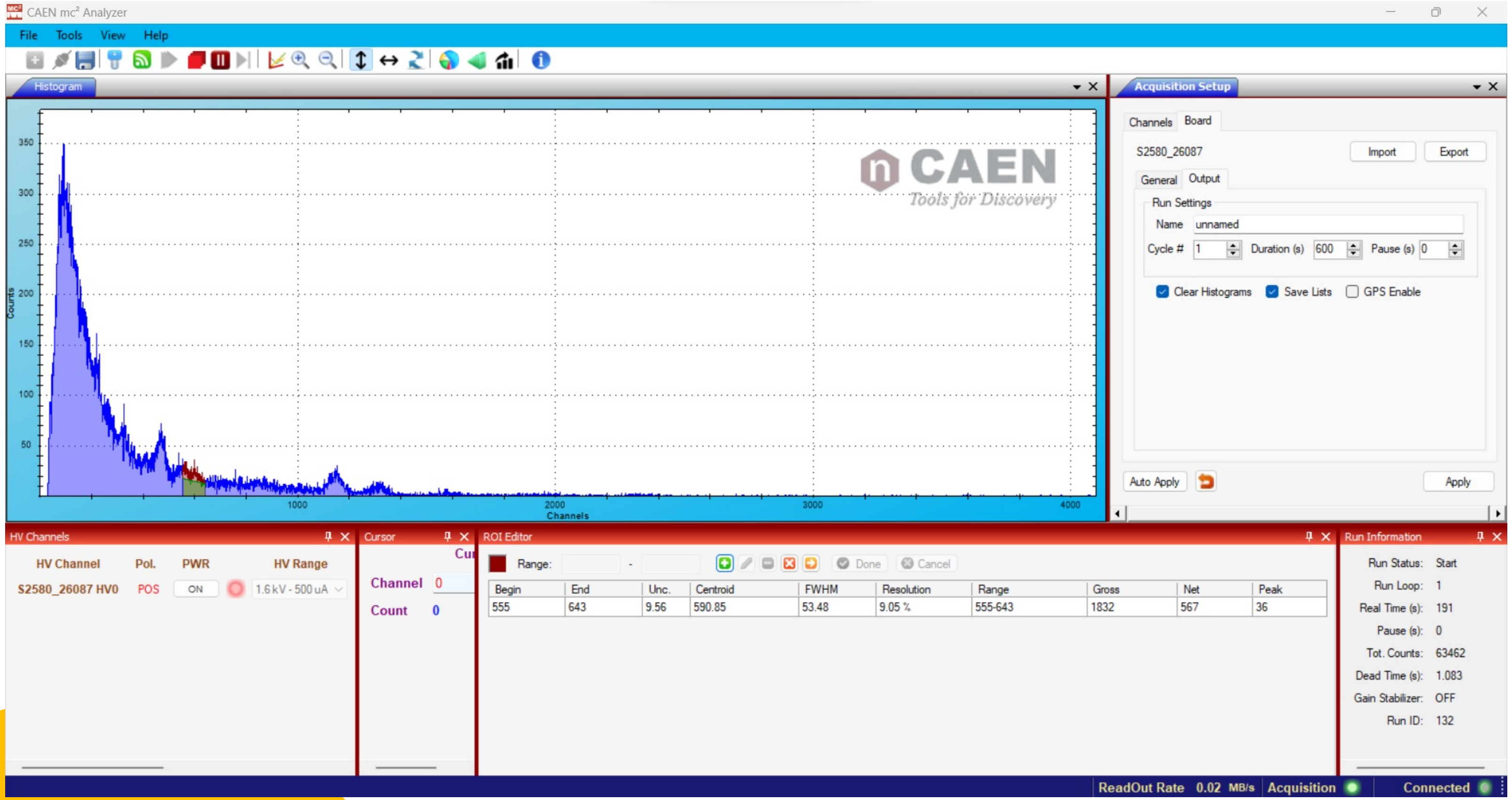
Energy selection is made by multichannel analyser, allowing the entire spectrum to be analysed

- Multi Channel Analyzer:

1. Receives in input PMT output signals
2. ADC digitizes the signals
3. Produces the pulse-height histogram = plot of number of events from the PMTs as function of output amplitude

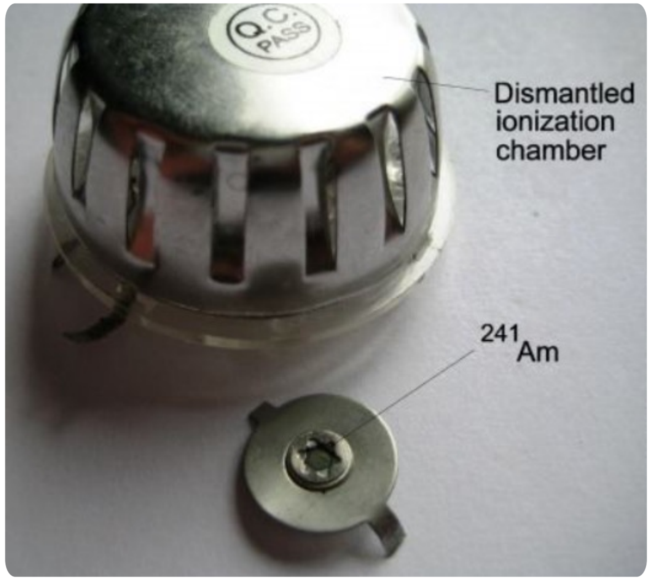
Channel = specific energy range → number of channels can be >1000 → complete energy spectra produced

Gamma laboratory with MCA



1. Calibrate MCA with sources
2. Measure ^{241}Am activity
3. Attenuation coefficient measure

Source

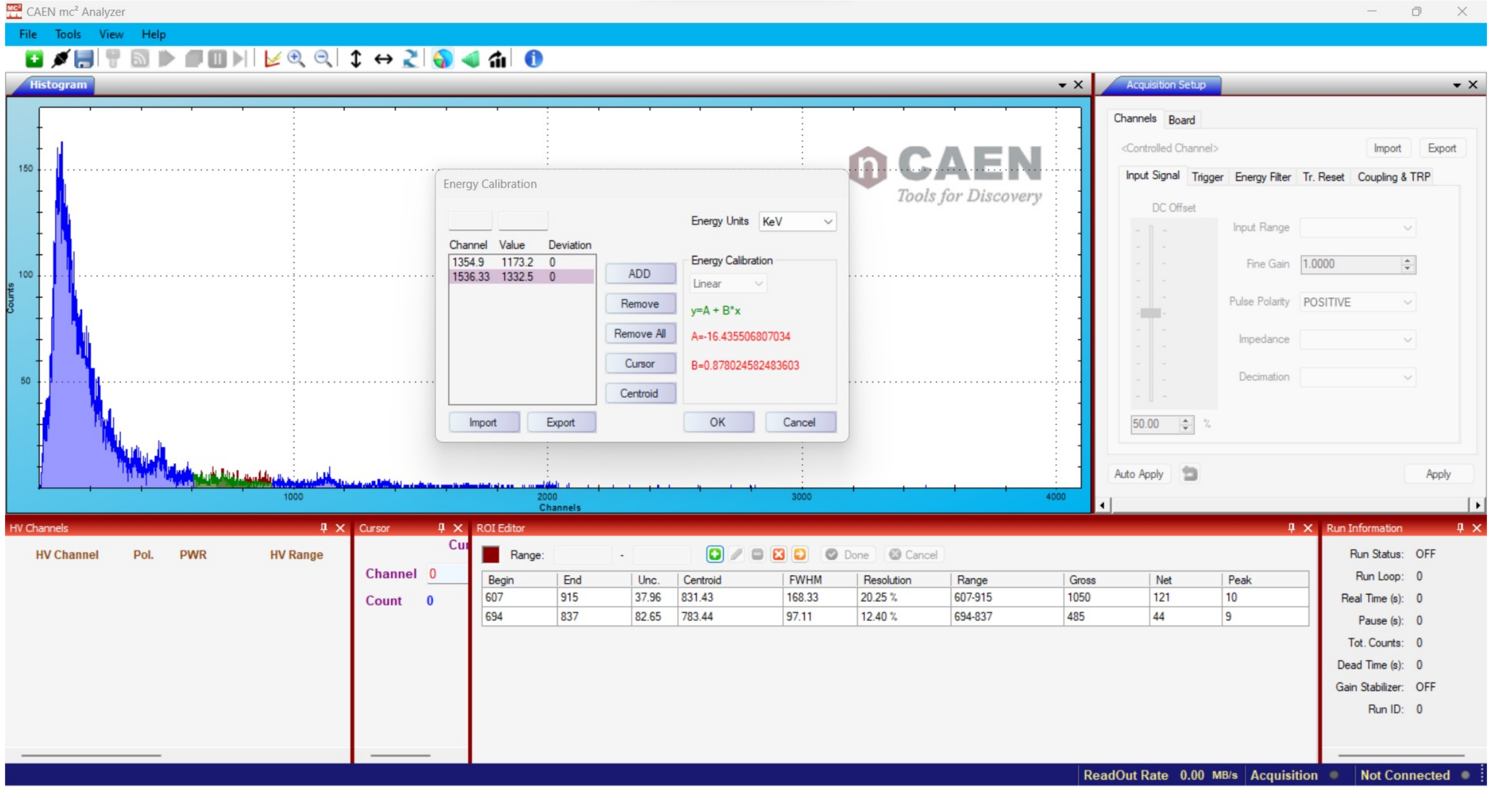


- **^{241}Am**

- Americium-241 is the most important radioisotope of americium from the point of view of the occurrence in environment. The other long-lived isotope ^{243}Am is produced in nuclear reactors in smaller activity compared to ^{241}Am. The activity of ^{242m}Am (half-life 160 years) that originated in nuclear weapons tests was nearly six orders of magnitude lower in comparison with ^{241}Pu activity from which ^{241}Am in-grows. Americium-241 is produced in nuclear power plants during activation of ^{239}Pu and ^{240}Pu by neutrons, which is followed by beta decay of ^{241}Pu ($T_{1/2}$ = 14.35 years).

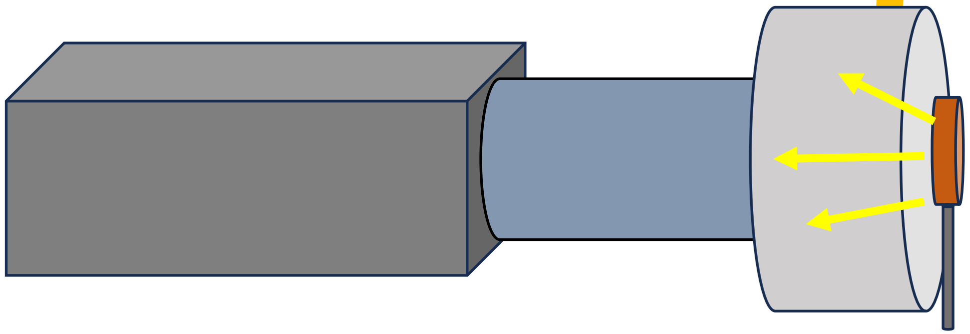
- Americium -241 is used in many smoke detectors for homes and business, for measure levels of toxic lead in dried paint samples, to ensure uniform thickness in rolling processes like steel and paper production, and to help determine where oil wells should be drilled.

Calibration setup



Open calibration setup and set ^{60}Co peaks channels

Activity measure



$$R = D\,\mathrm{A}$$

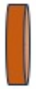
$$\mathrm{N} = D\,\mathrm{A}\Delta t$$

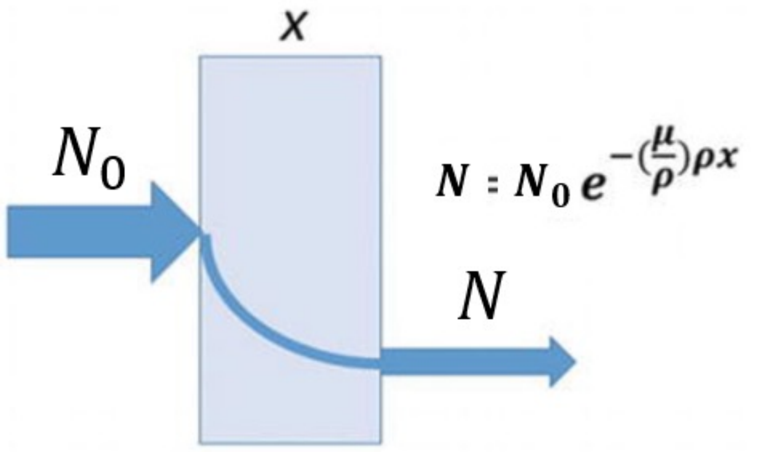
$$\frac{\mathrm{N}}{D\Delta t} = A$$

If we assume D is equal to 50% because of geometry, obtain A

Theory

Lambert-Beer Law

Source 



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

$$N = \#gamma\ trasmitted$$

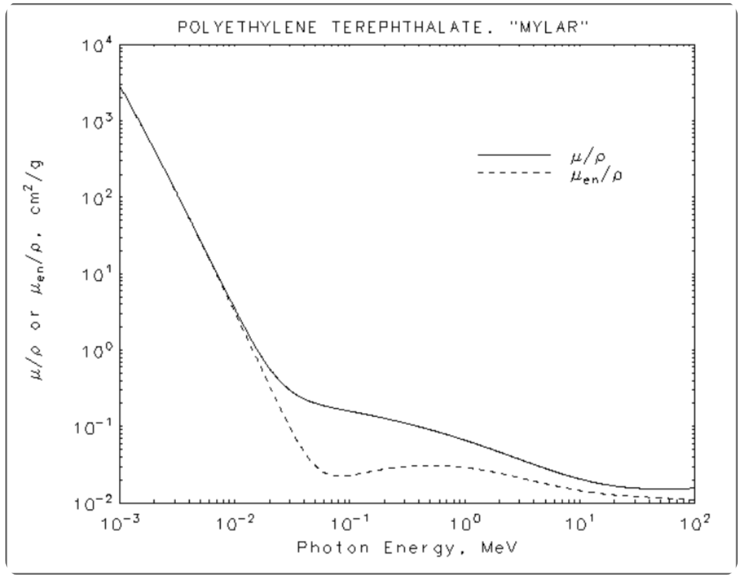
$$N_0 = \#gamma\ from\ source$$

$$x = thickness \qquad \mu = attenuation\ coefficient$$

The attenuation coefficient

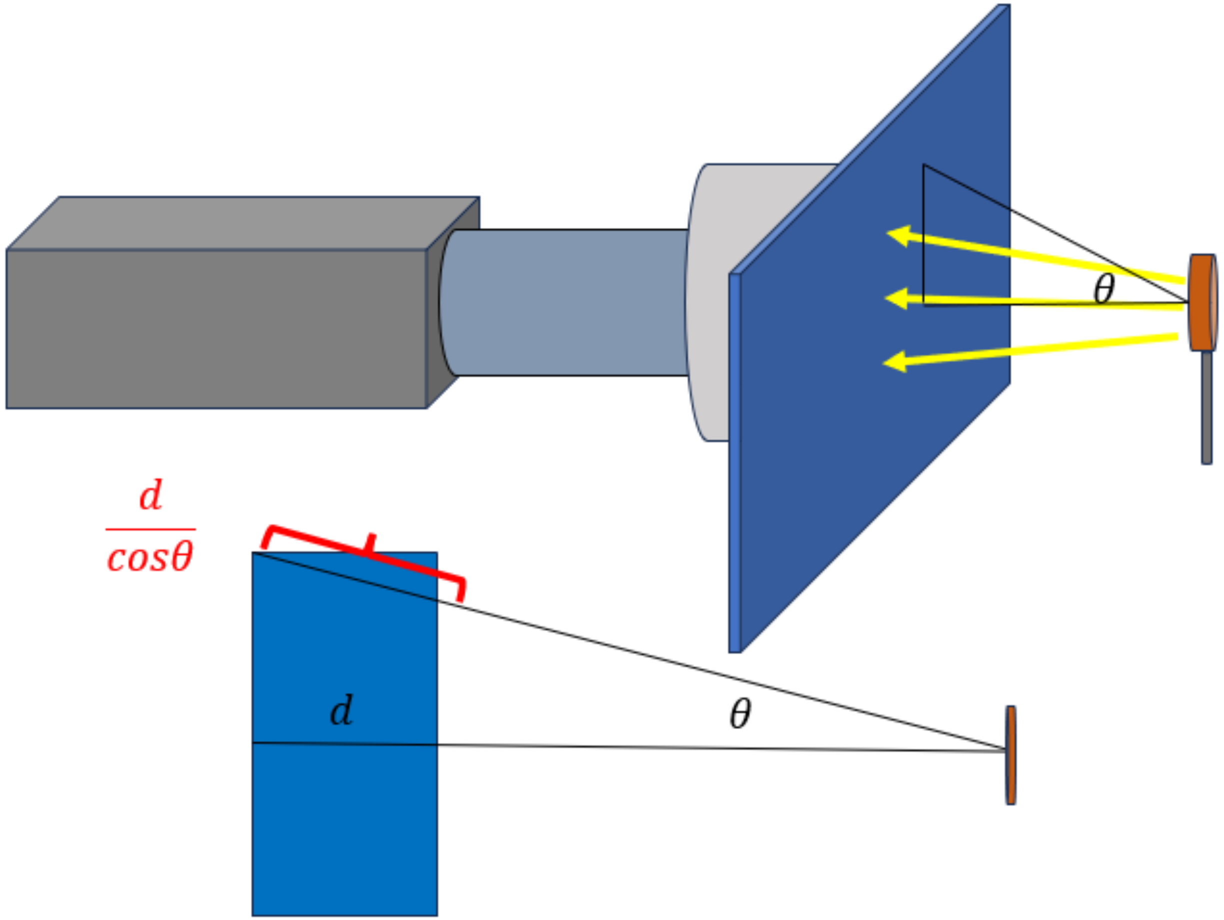
Energy (MeV)	μ/ρ (cm^2/g)	μ_{en}/ρ (cm^2/g)
1.00000E-03	2.911E+03	2.905E+03
1.50000E-03	9.536E+02	9.513E+02
2.00000E-03	4.206E+02	4.192E+02
3.00000E-03	1.288E+02	1.279E+02
4.00000E-03	5.466E+01	5.398E+01
5.00000E-03	2.792E+01	2.737E+01
6.00000E-03	1.608E+01	1.561E+01
8.00000E-03	6.750E+00	6.370E+00
1.00000E-02	3.481E+00	3.153E+00
1.50000E-02	1.132E+00	8.668E-01
2.00000E-02	5.798E-01	3.462E-01
3.00000E-02	3.009E-01	9.972E-02
4.00000E-02	2.304E-01	4.695E-02
5.00000E-02	2.020E-01	3.082E-02
6.00000E-02	1.868E-01	2.508E-02
8.00000E-02	1.695E-01	2.247E-02
1.00000E-01	1.586E-01	2.297E-02
1.50000E-01	1.406E-01	2.567E-02
2.00000E-01	1.282E-01	2.772E-02
3.00000E-01	1.111E-01	2.990E-02
4.00000E-01	9.947E-02	3.073E-02
5.00000E-01	9.079E-02	3.093E-02
6.00000E-01	8.395E-02	3.079E-02
8.00000E-01	7.372E-02	3.005E-02
1.00000E+00	6.628E-02	2.909E-02
1.25000E+00	5.927E-02	2.780E-02
1.50000E+00	5.395E-02	2.657E-02
2.00000E+00	4.630E-02	2.444E-02
3.00000E+00	3.715E-02	2.135E-02

- Table shows mass attenuation coefficient at different energy for the polyethylene terephthalate



- Density=1.38 g/cm^3

Measurements



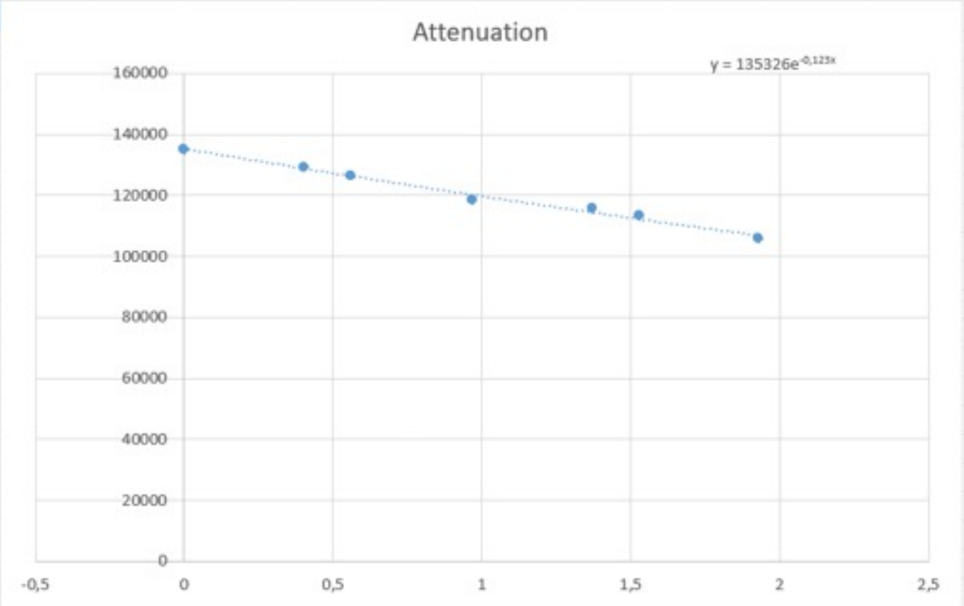
Measure the distance from the source to the detector, measure the thickness of the slice, position the slice in front of the detector

Measure the angle between the source and the edge of the detector, like in figure.

$$\langle d \rangle = \frac{1}{2}\left(1 + \frac{1}{cos\theta}\right)$$

Analysis

MEASURE OF ATTENUATION COEFFICIENT								
Shield	I	x (cm)	x corrected (cm)	sigma I	sigma x (cm)		distance (cm)	
no shield	134978	0	0	367,3935	0,001		10	
shield1	129355	0,387	0,402196473	359,6596	0,001			
shield2	126537	0,539	0,560165113	355,7204	0,001		theta	22
shield3	118536	0,931	0,967557923	344,2906	0,001		correction	1,039267
shield1+shield3	115643	1,318	1,369754395	340,0632	0,001			
shield2+shield3	113298	1,47	1,527723036	336,5977	0,001			
shield1+shield2+shield3	105802	1,857	1,929919509	325,2722	0,001			
polyethylene therephtalate (mylar)								
0,1158								
polymethyl methacrylate								
0,1035								
polyvynil chloride								
0,1166								



Try with and without correction factor equal $\langle d \rangle = \frac{1}{2}\left(1 + \frac{1}{cos\theta}\right)$