Gamma – Ray Spectrometry

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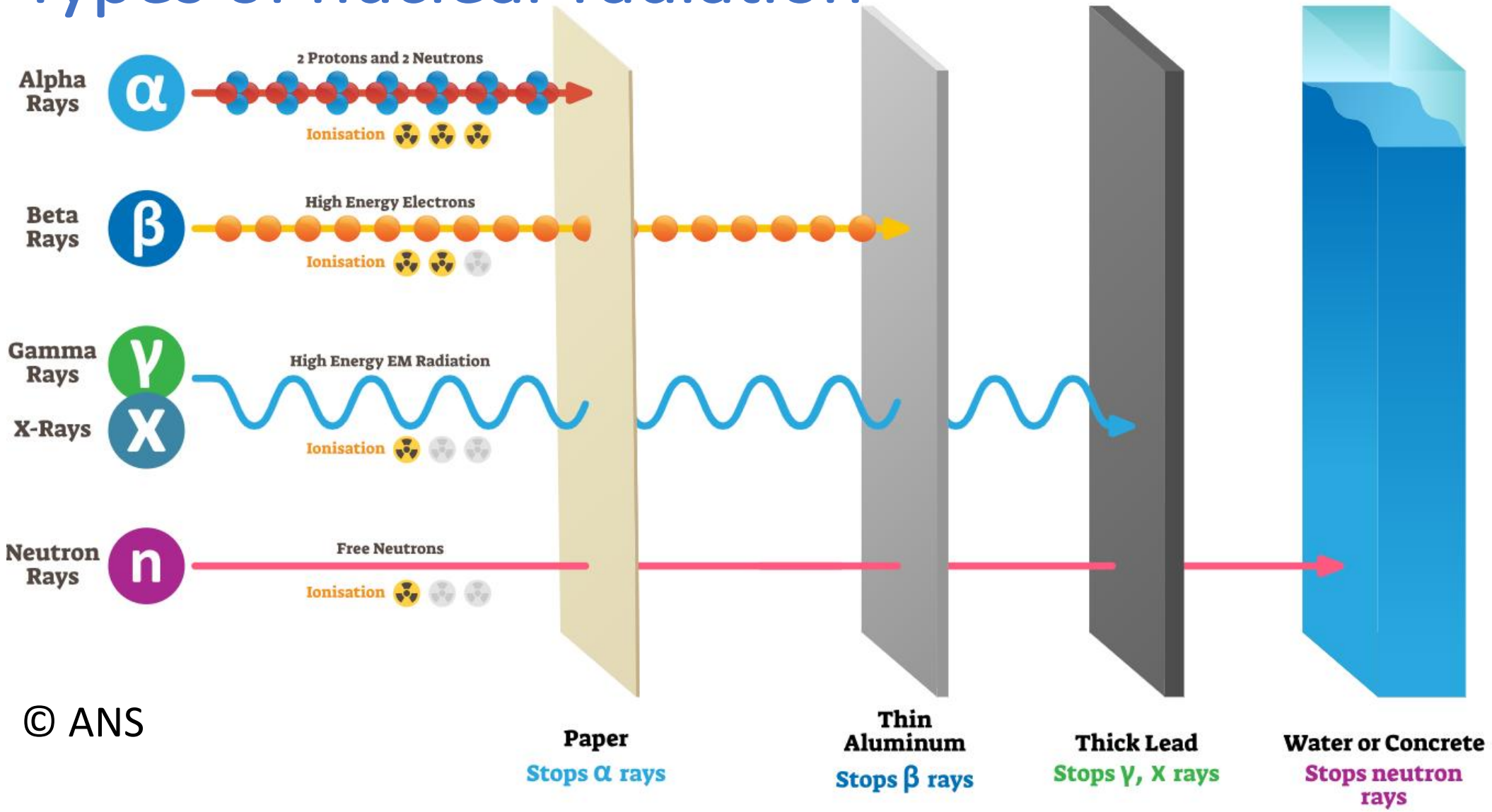
Learning Outcomes

By the end of this session the learner should be able to:

- ❑ describe the nature and properties of nuclear radiation
- ❑ describe the interaction of photons with matter
- ❑ perform calibration of detectors for nuclear radiation
- ❑ describe the gamma-ray spectrum from a source
- ❑ perform spectral data analysis

Types of nuclear radiation



Photon Interactions

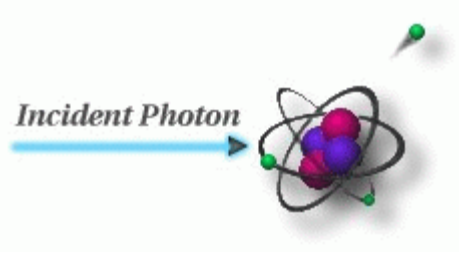
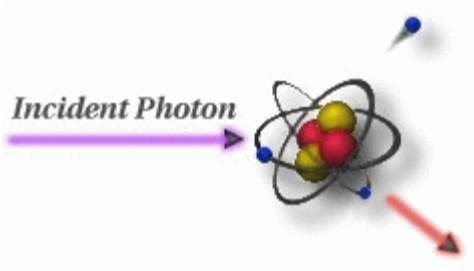
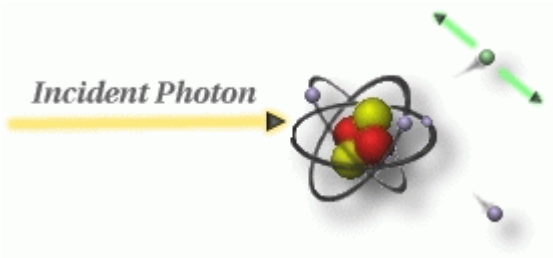


Photo electric effect (PE)



Compton scattering (C)

Rayleigh scattering (R)



Pair production (PP)

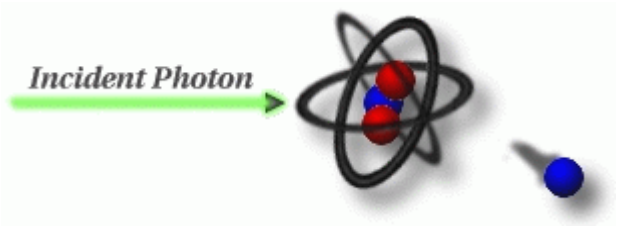
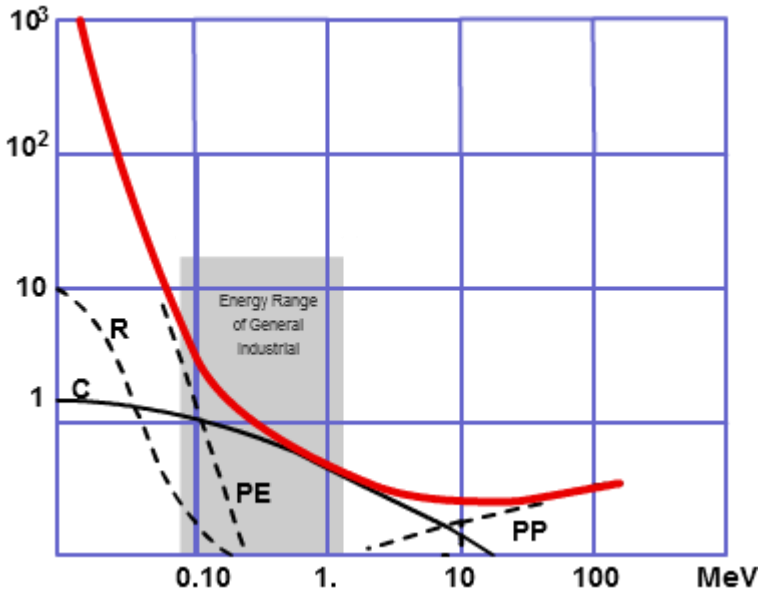
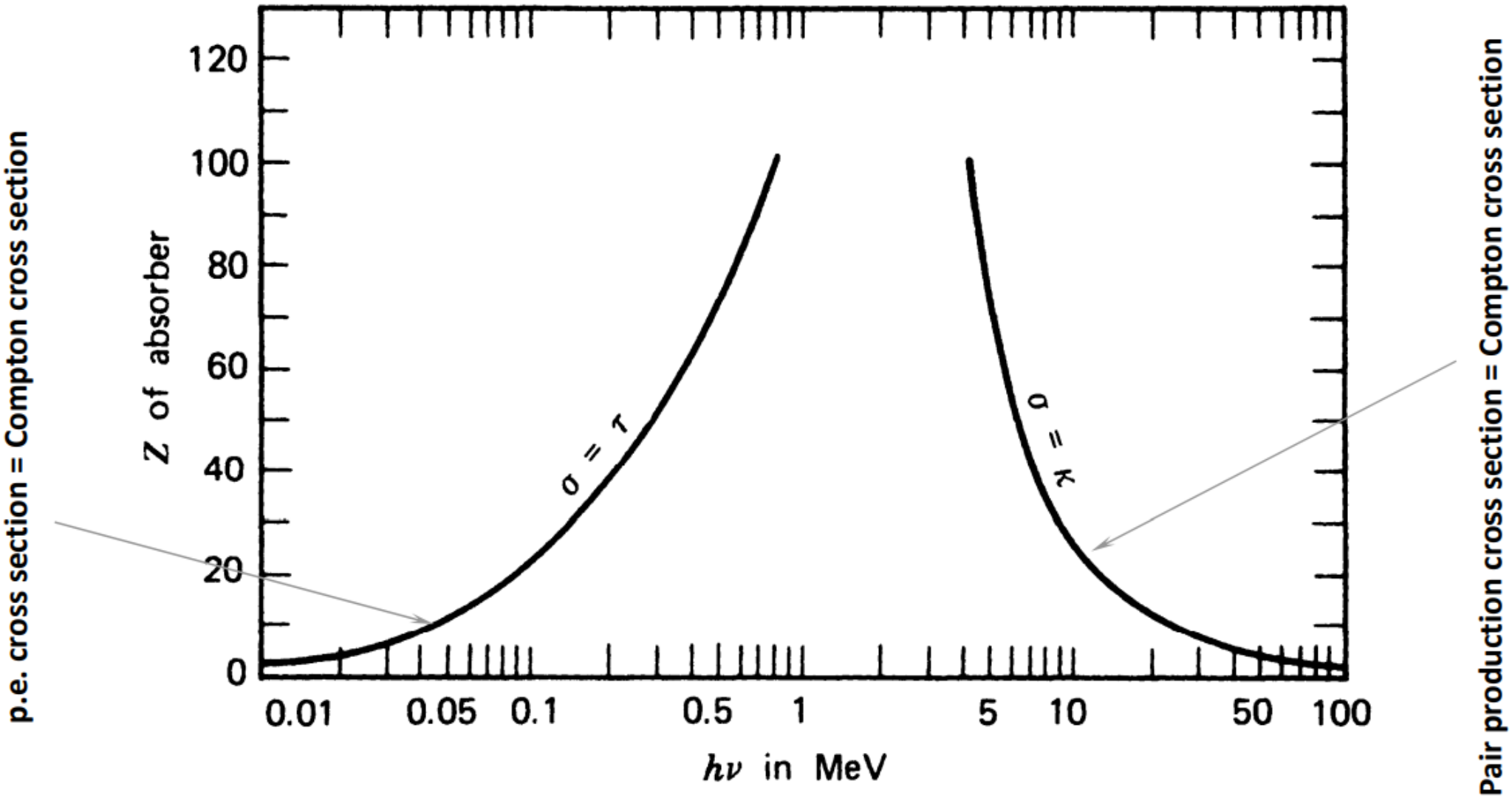


Photo disintegration (PD)



Absorption

Interaction of ionizing photons with matter



Page 52, Chapter 2 in Radiation Detection and Measurements, Third Edition, G. F. Knoll, John Wiley & Sons, 1999.

Introduction to gamma-ray spectroscopy

Physics basis:

- Interaction of photons with matter – photo-electric effect, Compton scattering, pair production

Detectors used:

- Scintillators – NaI(Tl) – low energy resolution, high counting efficiency, operated at room temperature
- Semiconductors – HpGe – high energy resolution, low counting efficiency, requires liquid nitrogen for cooling

Gamma-ray spectra:

- Provide “finger prints” of radionuclides
- Energy resolution determines ability to identify close peaks
- Area under the peak indicates activity of the source

Detectors used in gamma-ray spectroscopy

NaI(Tl):

- low energy resolution (7-8% at 662 keV), high counting efficiency
- operated at room temperature

HPGe:

- high energy resolution (0.2 – 1.2% at 662 keV), low counting efficiency
- requires liquid nitrogen for cooling

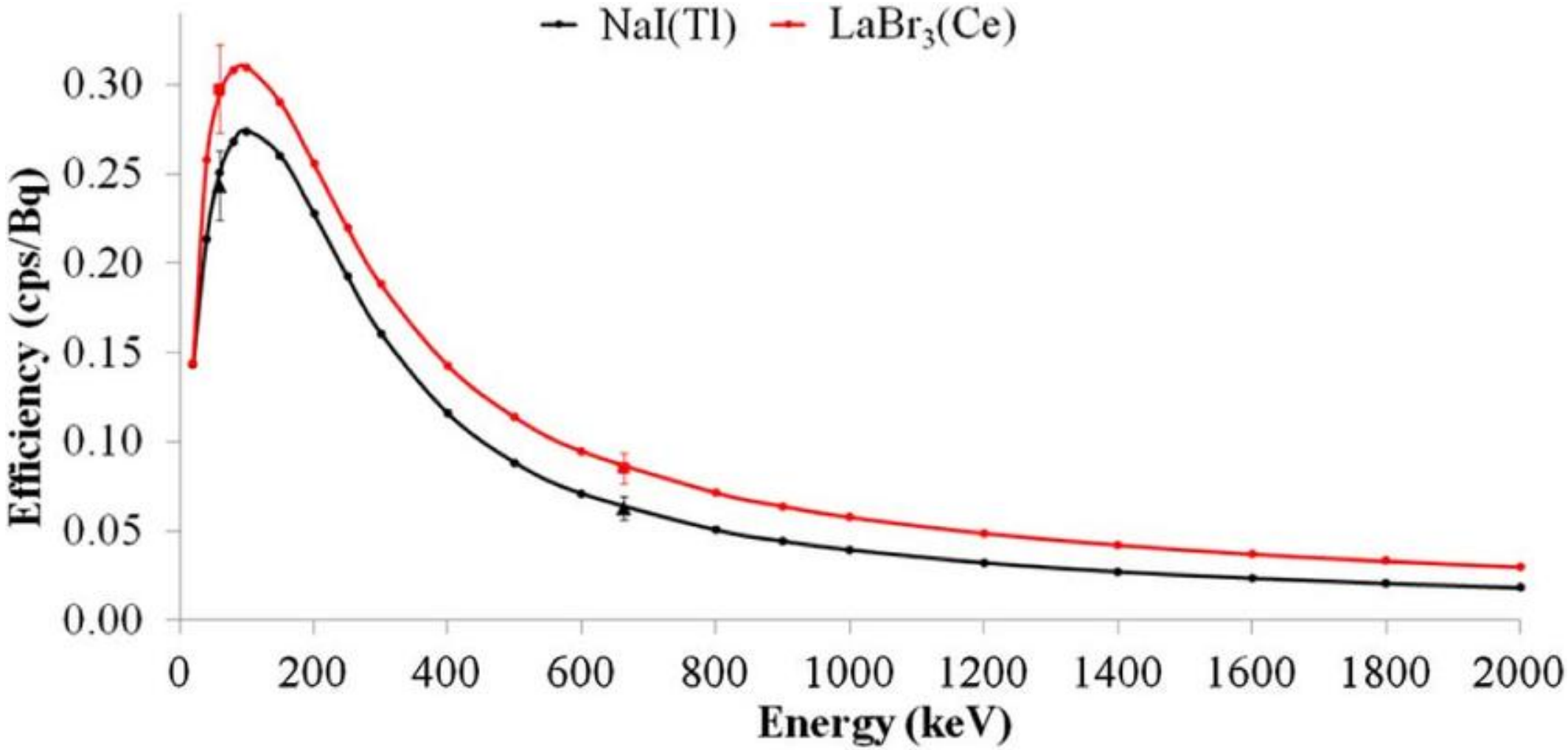
CdZnTe:

- Moderate energy resolution (2% at 662 keV),
- high efficiency, very compact

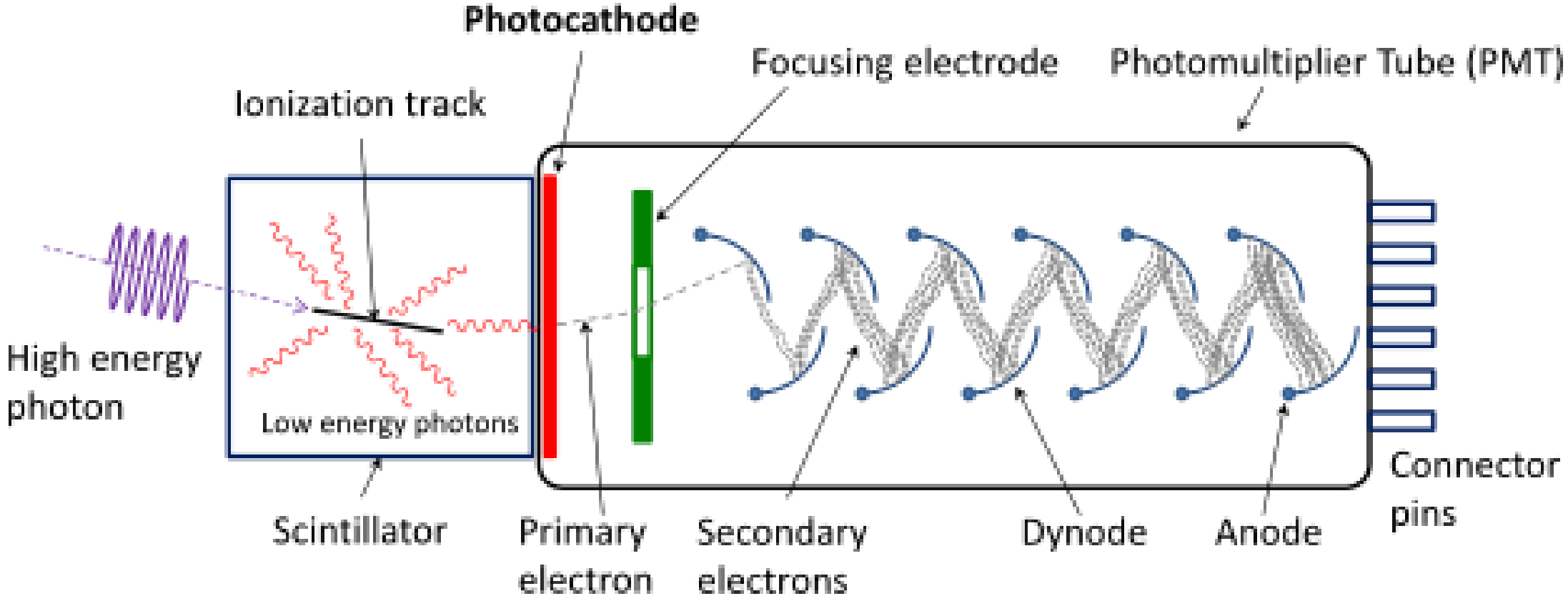
$LaBr_3$:

Low energy resolution (2.80-4% at 662 keV), high efficiency

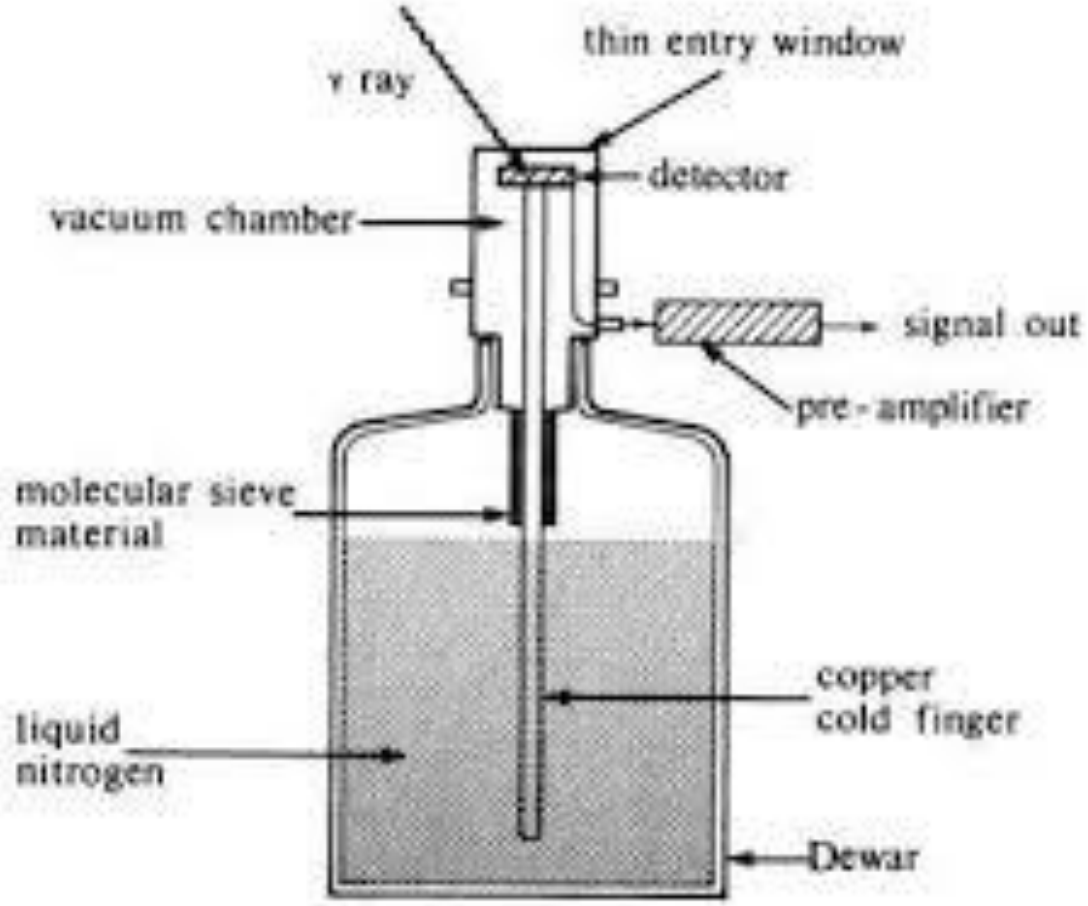
Typical Detector Efficiency Curves



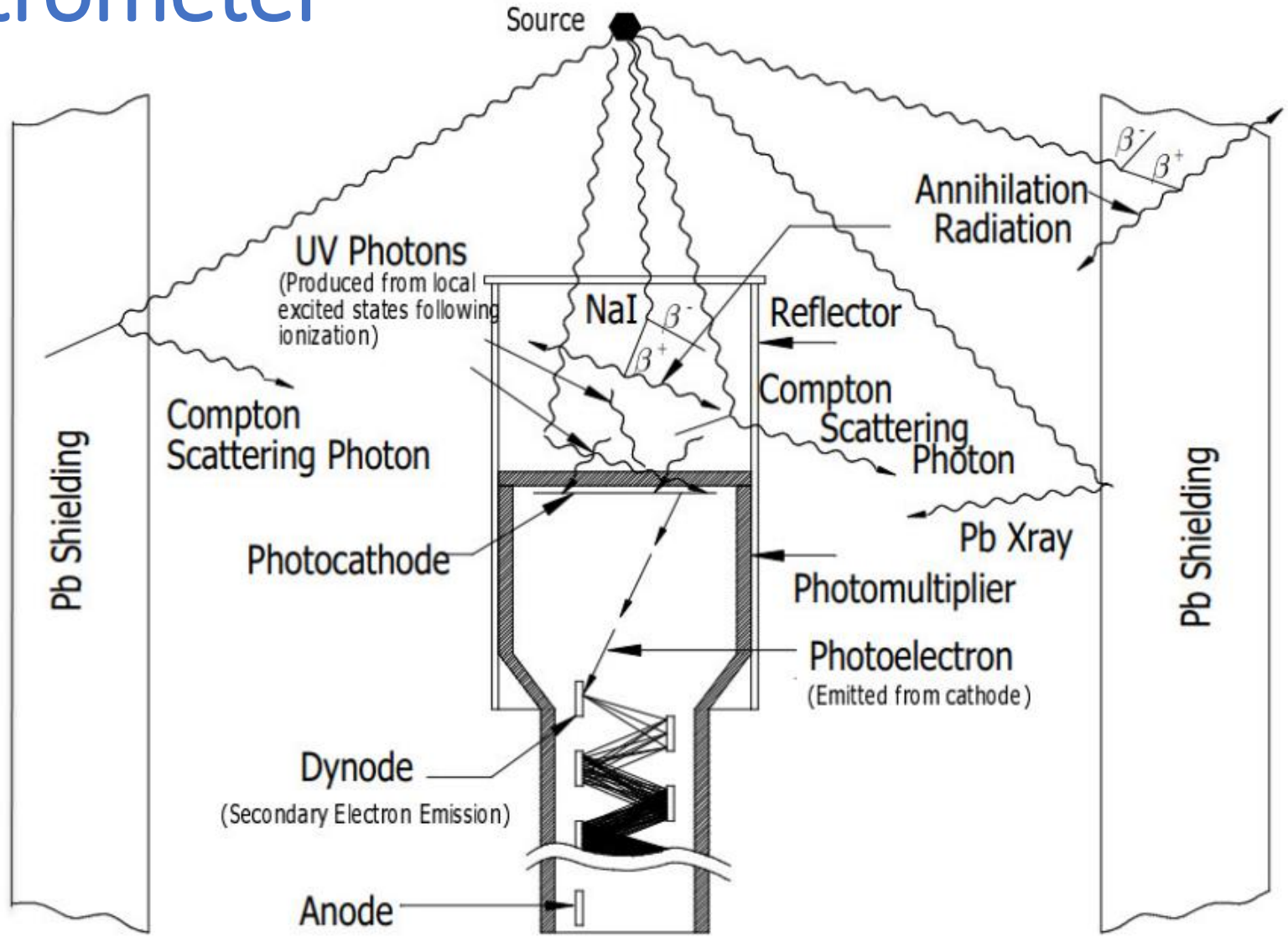
NaI(Tl) detector ad Photo-Multiplier Tube (PMT)



HPGe Detector



Interaction of gamma-ray photons in the spectrometer



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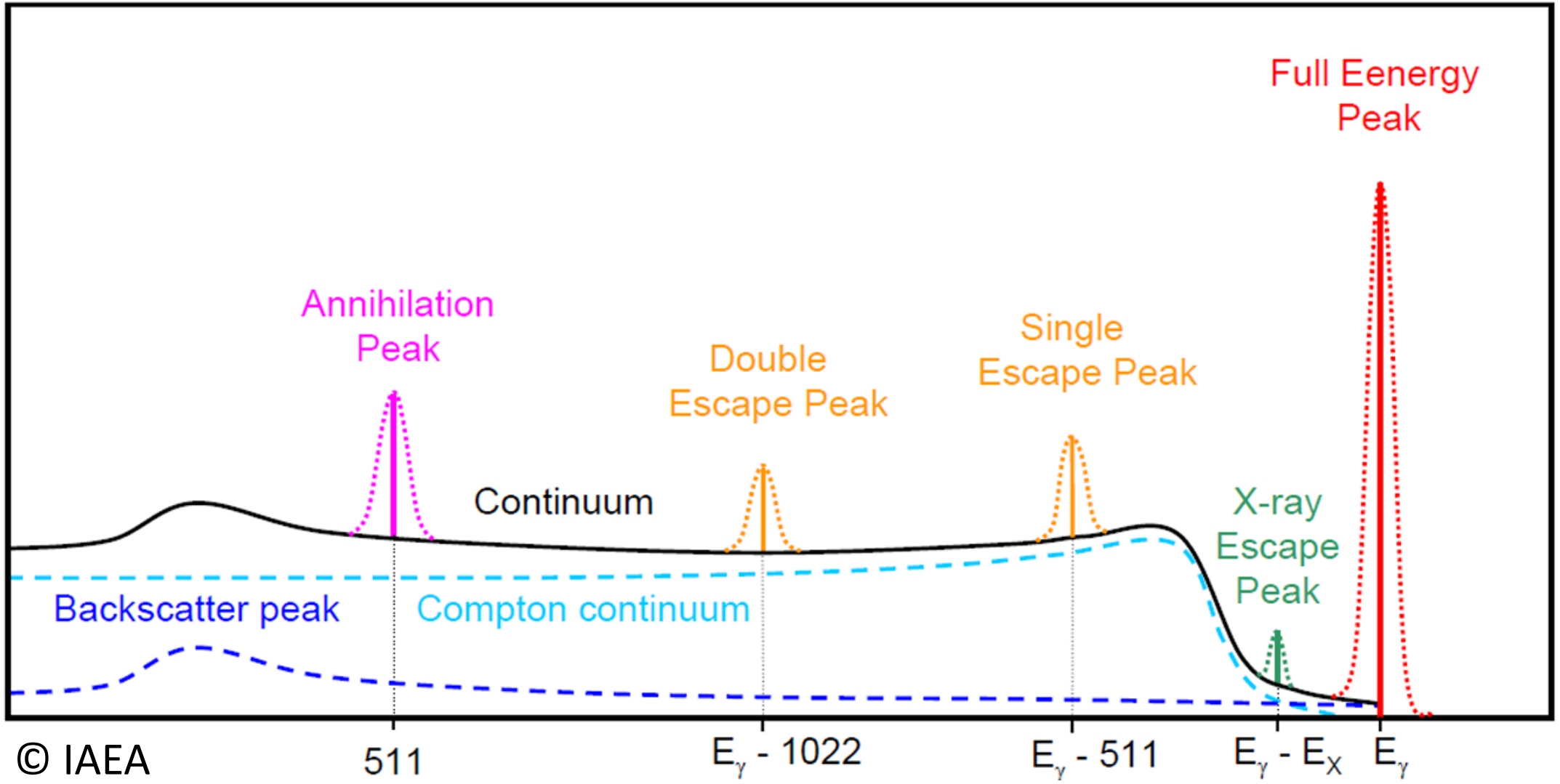
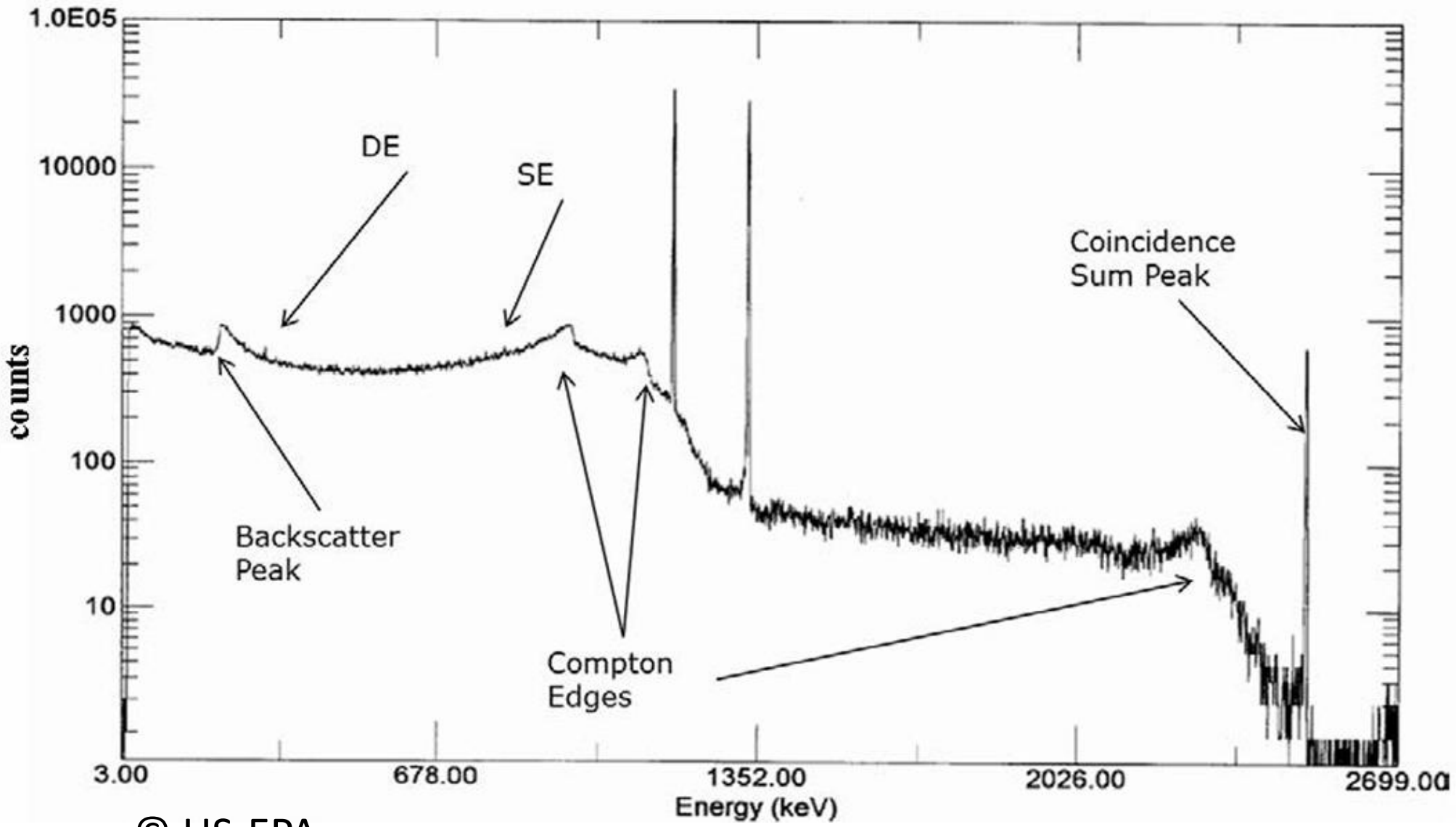
Components of the Gamma-ray Spectrum



Components of the Gamma-ray Spectrum ^{60}Co



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Components of the Gamma-ray Spectrum

Table 3. Commonly Encountered Radionuclides with True Coincidence Sum Effects

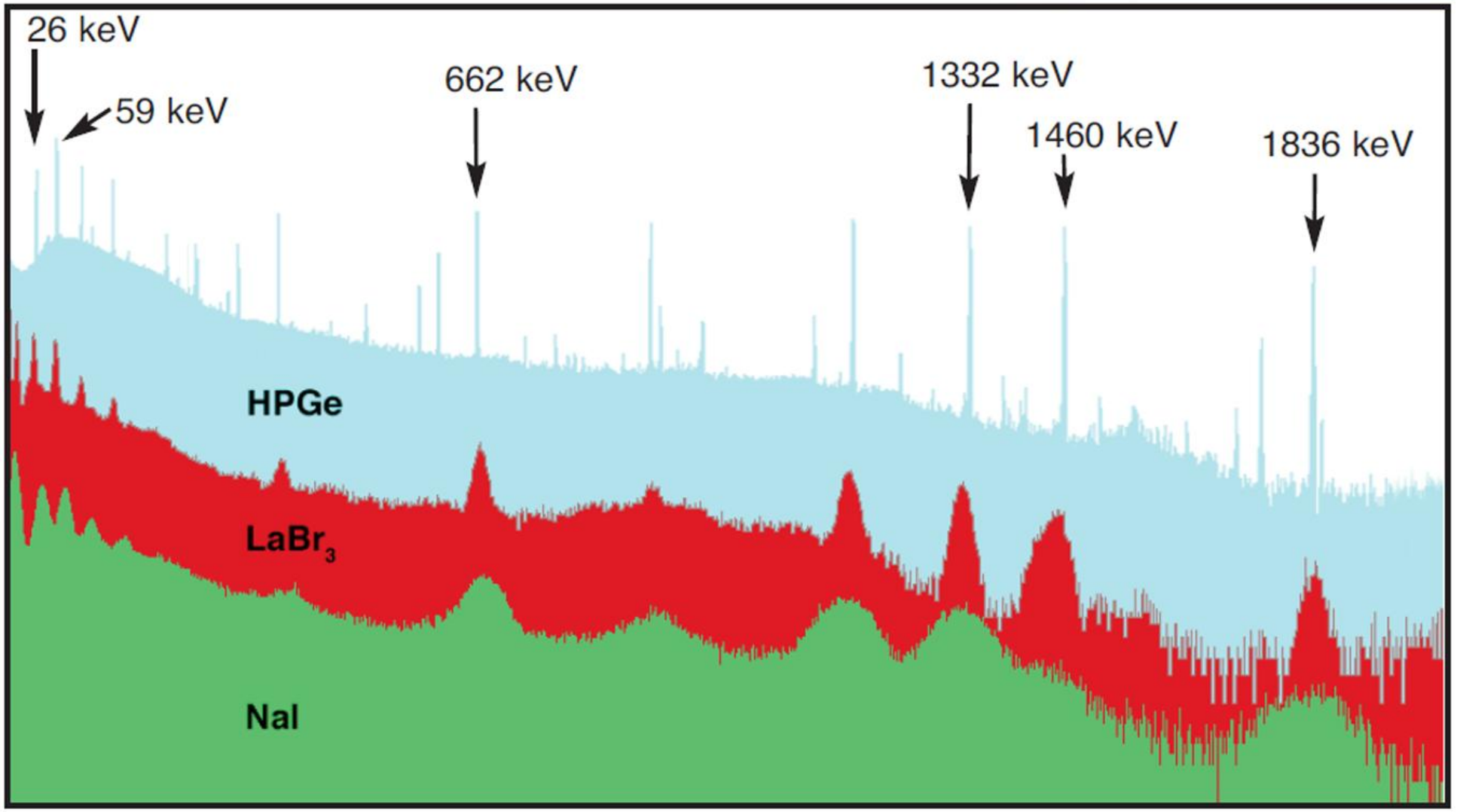
Radionuclide	Gamma 1, keV	Gamma 2, keV	Sum Peak, keV
^{60}Co	1173.2	1332.5	2505.7 [1]
^{134}Cs	604	796	1400
^{154}Eu	58.4	1274	1332.8
	123.1	1047.2	1170.3
^{88}Y	1836	898	2734 [2]

Notes:

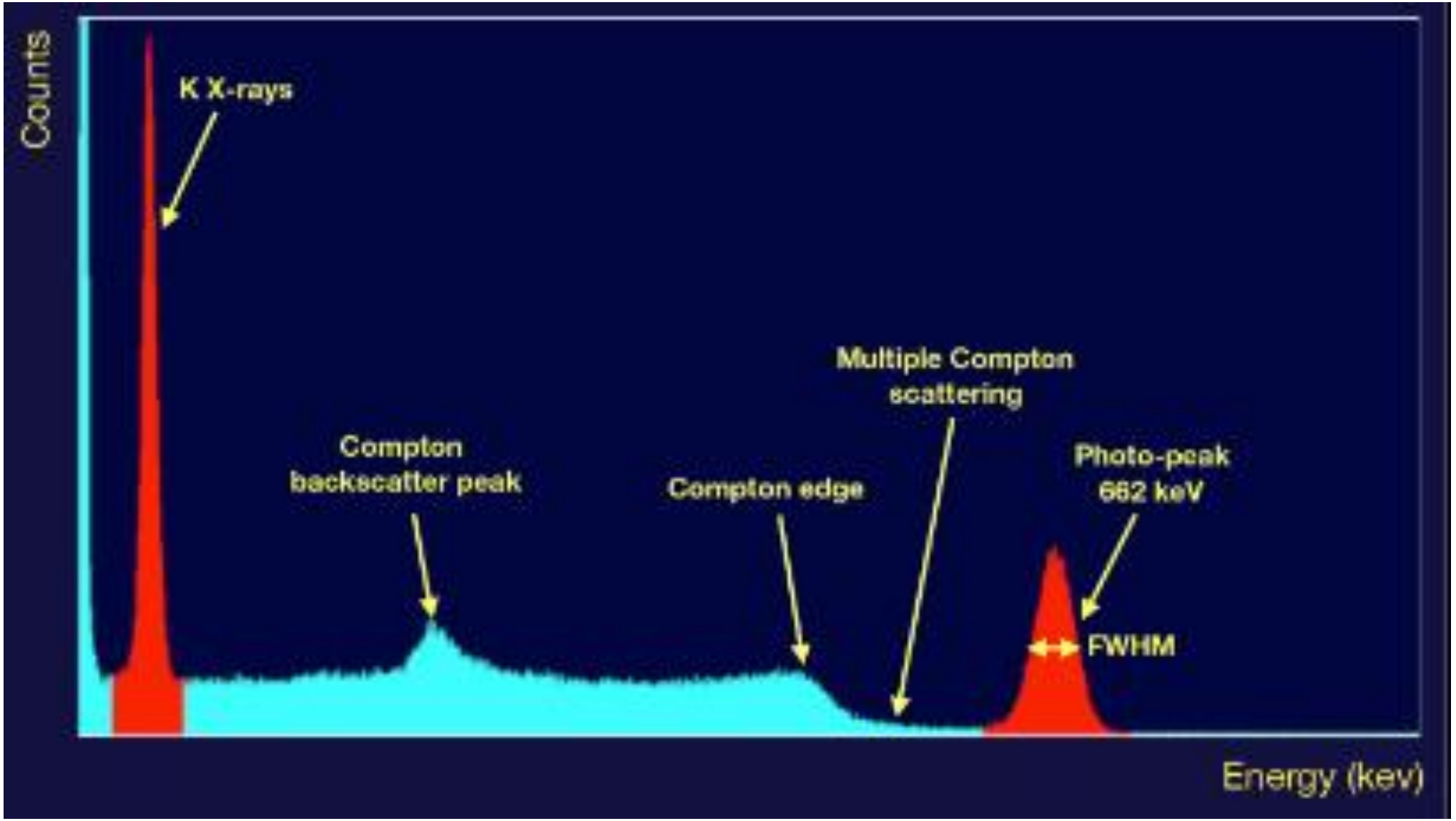
[1] Non-coincidence abundance is 2.0×10^{-6}%

[2] Non-coincidence abundance is 7.10×10^{-1}%

Gamma-ray spectra from different detectors



Gamma – ray spectroscopy: NaI(Tl) detector



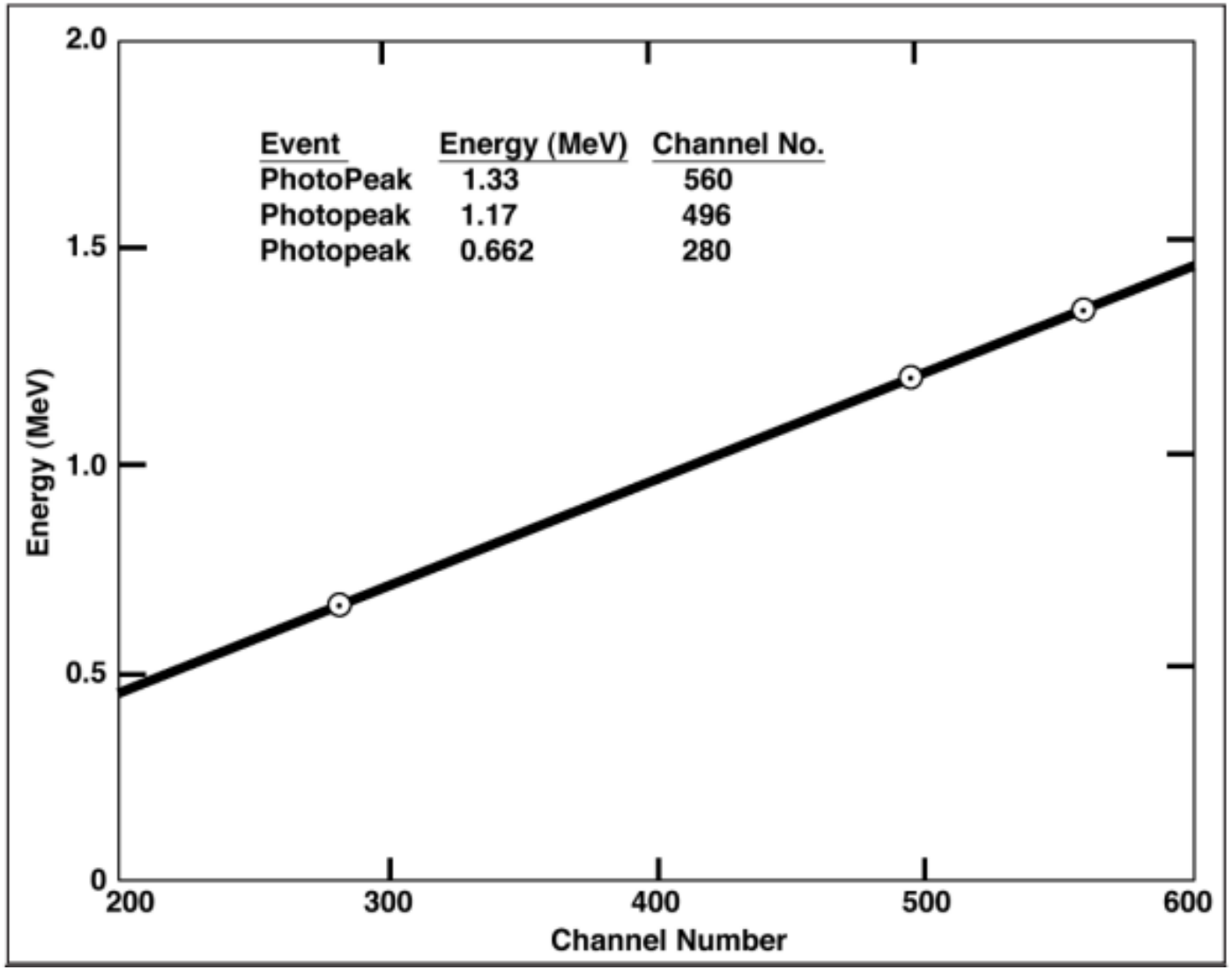
Evaluation of gamma-ray spectra

The following steps are taken in order to allow the identification and quantification of the gamma emitting radionuclides in a sample:

- ❑ Identification of peaks
- ❑ Determination of the energy of the peaks
- ❑ Identification of radionuclides
- ❑ Estimation of background
- ❑ Calculation of net peak area
- ❑ Determination of activities and uncertainties

Using the relevant multi-channel analyser and software

Gamma – ray spectrum energy calibration



Exercise:

Use Cs-137 and Co-60 sources and NaI(Tl) detector to determine the following:

- full-energy peaks
- Compton edge
- Backscatter
- Energy resolution
- Energy calibration

Gamma – ray spectrum energy calibration

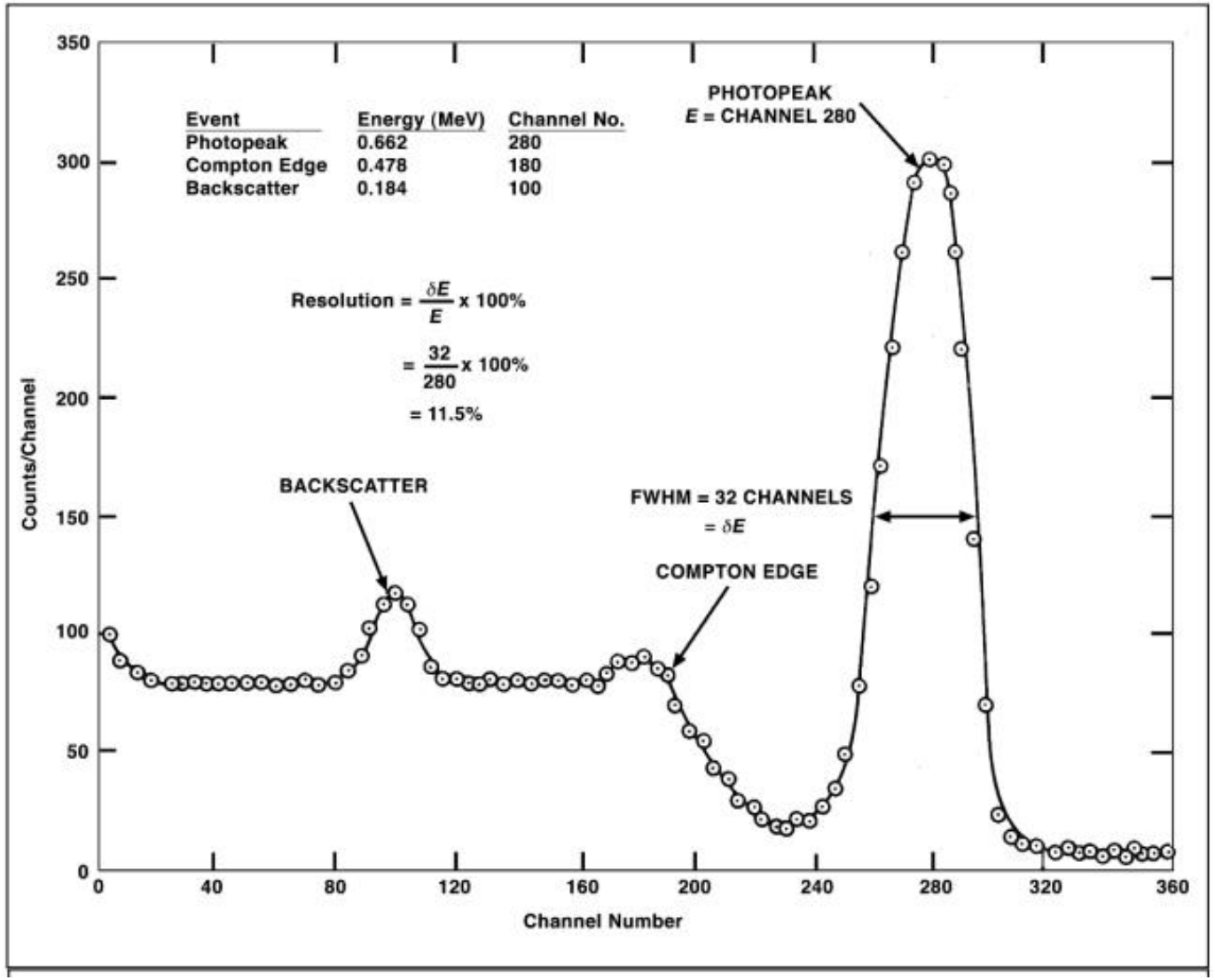
	Item	Energy (MeV)	Channel No.
1.	0.662-MeV photopeak	0.662	
2.	1.17-MeV photopeak	1.17	
3.	1.33-MeV photopeak	1.33	
4.	Compton Edge ^{137}Cs		
5.	Backscatter ^{137}Cs		
6.	Compton edge for ^{60}Co 1.33-MeV gamma ray		
7.	Backscatter ^{60}Co for 1.33-MeV gamma ray		
8.	Backscatter ^{60}CO for 1.17-MeV gamma ray		

Exercise:

Use Cs-137 and Co-60 sources and NaI(Tl) detector to determine the following:

- full-energy peaks
- Compton edge
- Backscatter
- Energy resolution
- Energy calibration

Gamma – ray spectroscopy: NaI(Tl) detector



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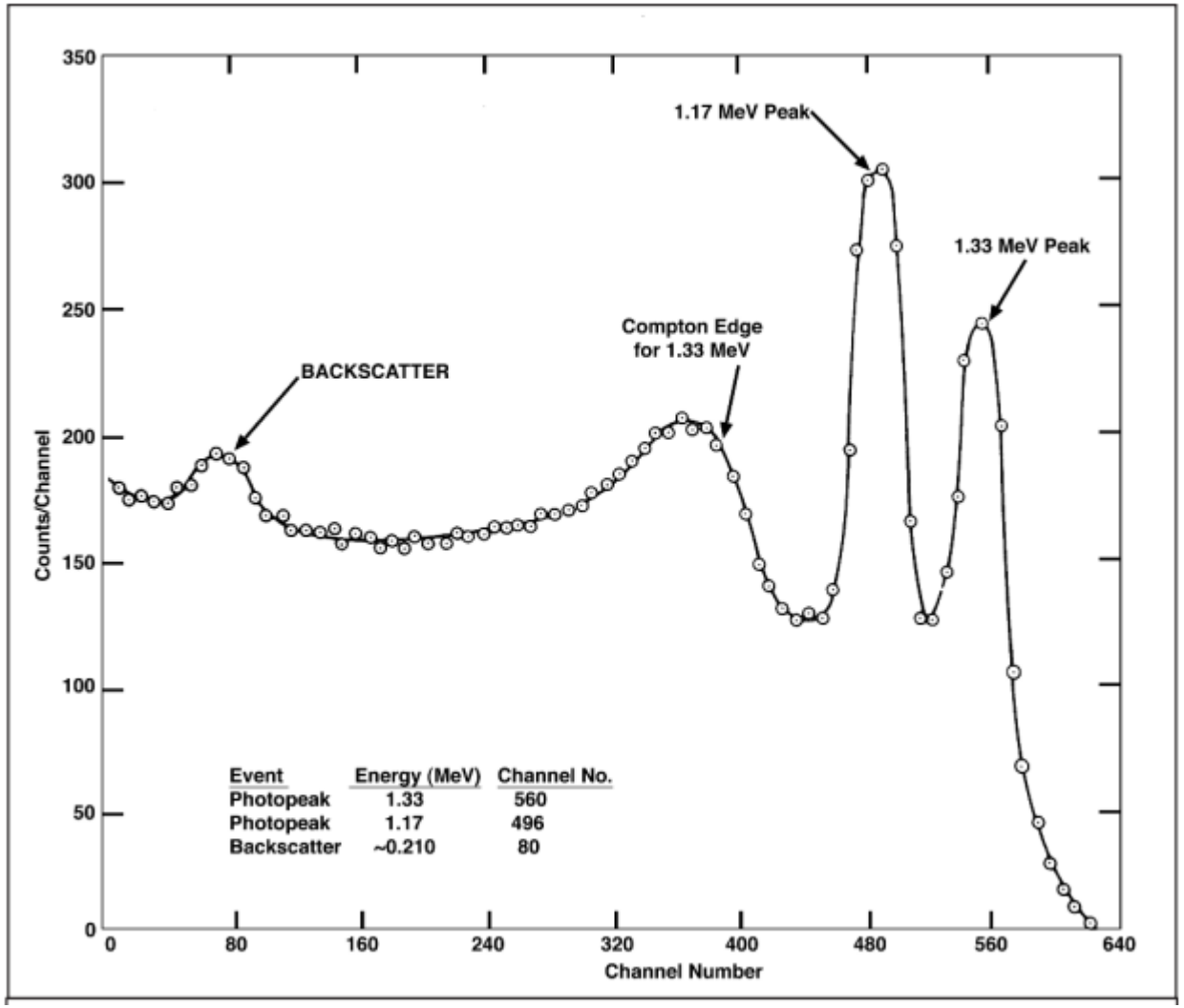
Exercise:

Use a Cs-137 source and NaI(Tl) detector to determine the following:

- full-energy peak
- Energy resolution
- Compton edge
- Backscatter

Gamma – ray spectroscopy: NaI(Tl) detector



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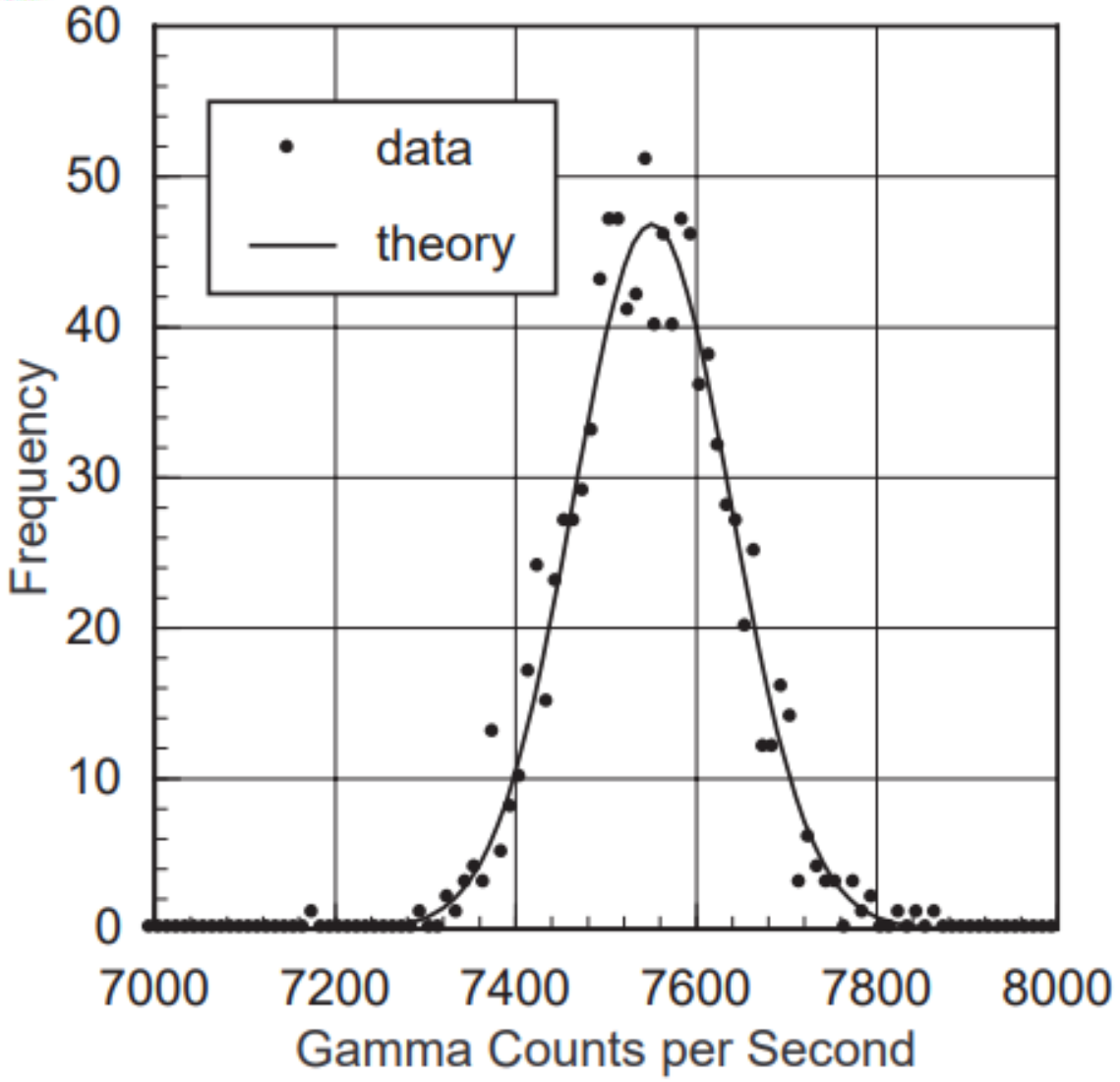
Exercise:

Use a Co-60 source and NaI(Tl) detector to determine the following:

- full-energy peak
- Compton edge
- Backscatter

Gamma – ray spectroscopy: NaI(Tl) detector



Exercise:

Use a Cs-137 or Co-60 source and NaI(Tl) detector to determine the following:

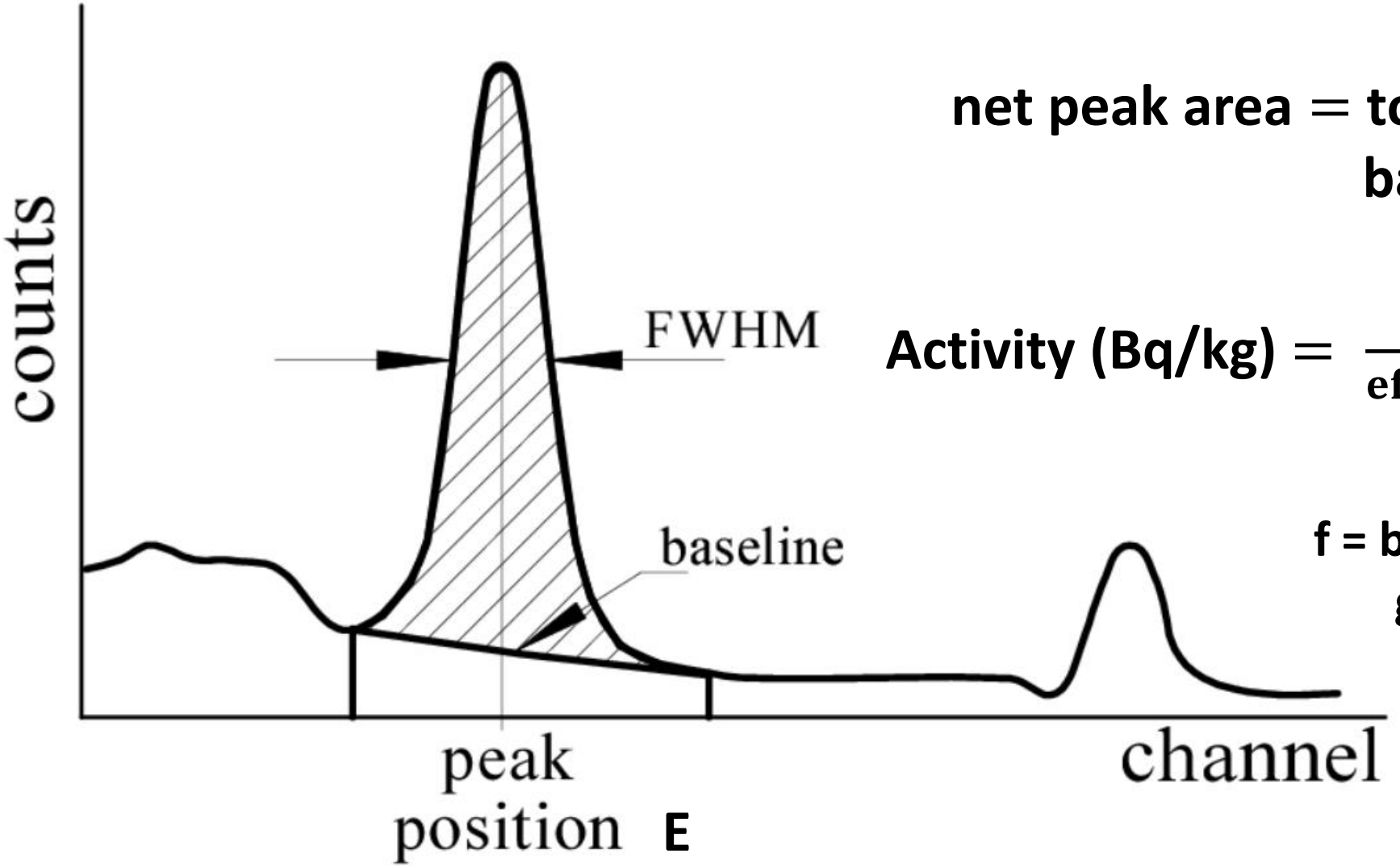
- Average count rate
- Gaussian fit to the count rate

$$P(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(x-\mu)^2 / 2\sigma^2}$$

Peak analysis

$$\text{energy resolution} = \frac{\text{FWHM}}{\text{E}}$$

net peak area = total counts – background counts



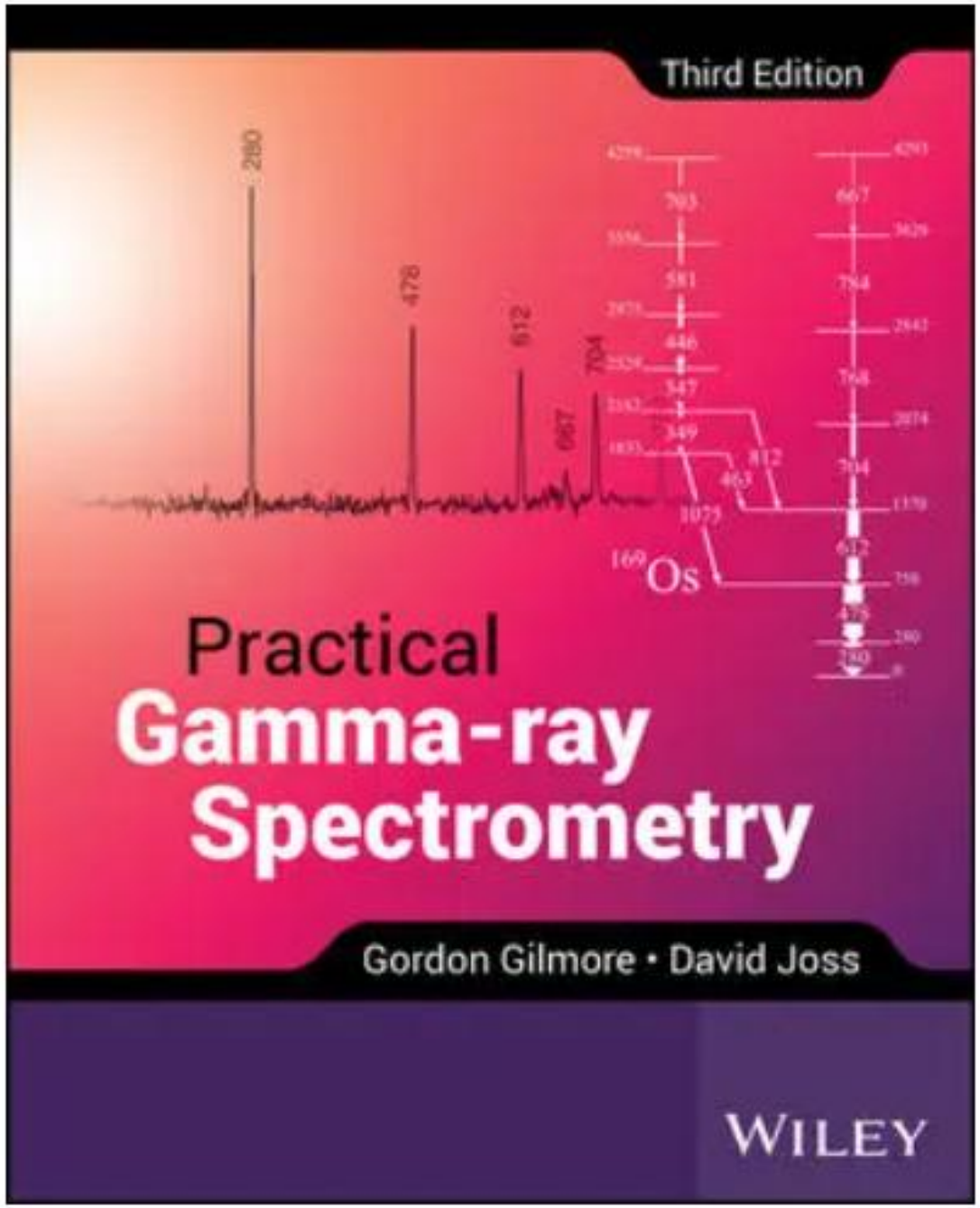
$$\text{Activity (Bq/kg)} = \frac{\text{net peak area (counts)}}{\text{efficiency} \times \text{mass} \times \text{time} \times \text{f}}$$

f = branching fraction of the gamma-ray line

Summary

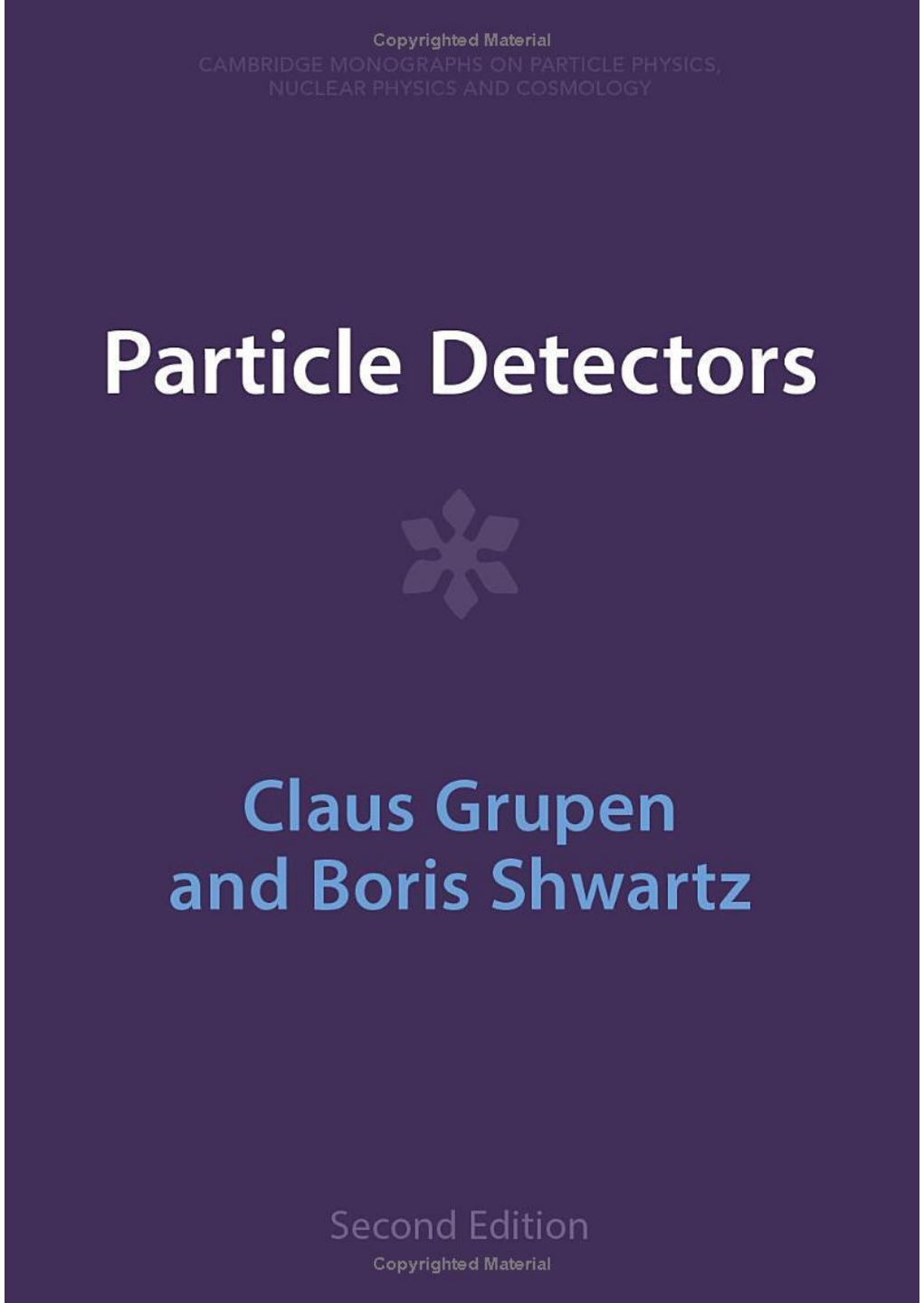
The following was discussed during this lesson:

- ✓ Ionizing radiation – nature and interactions
- ✓ Gamma-ray spectrometry
  - ❖ Physics basis
  - ❖ Common types of detectors used
  - ❖ Calibration of spectrometer
  - ❖ Components of spectral data
  - ❖ Analysis of spectral data



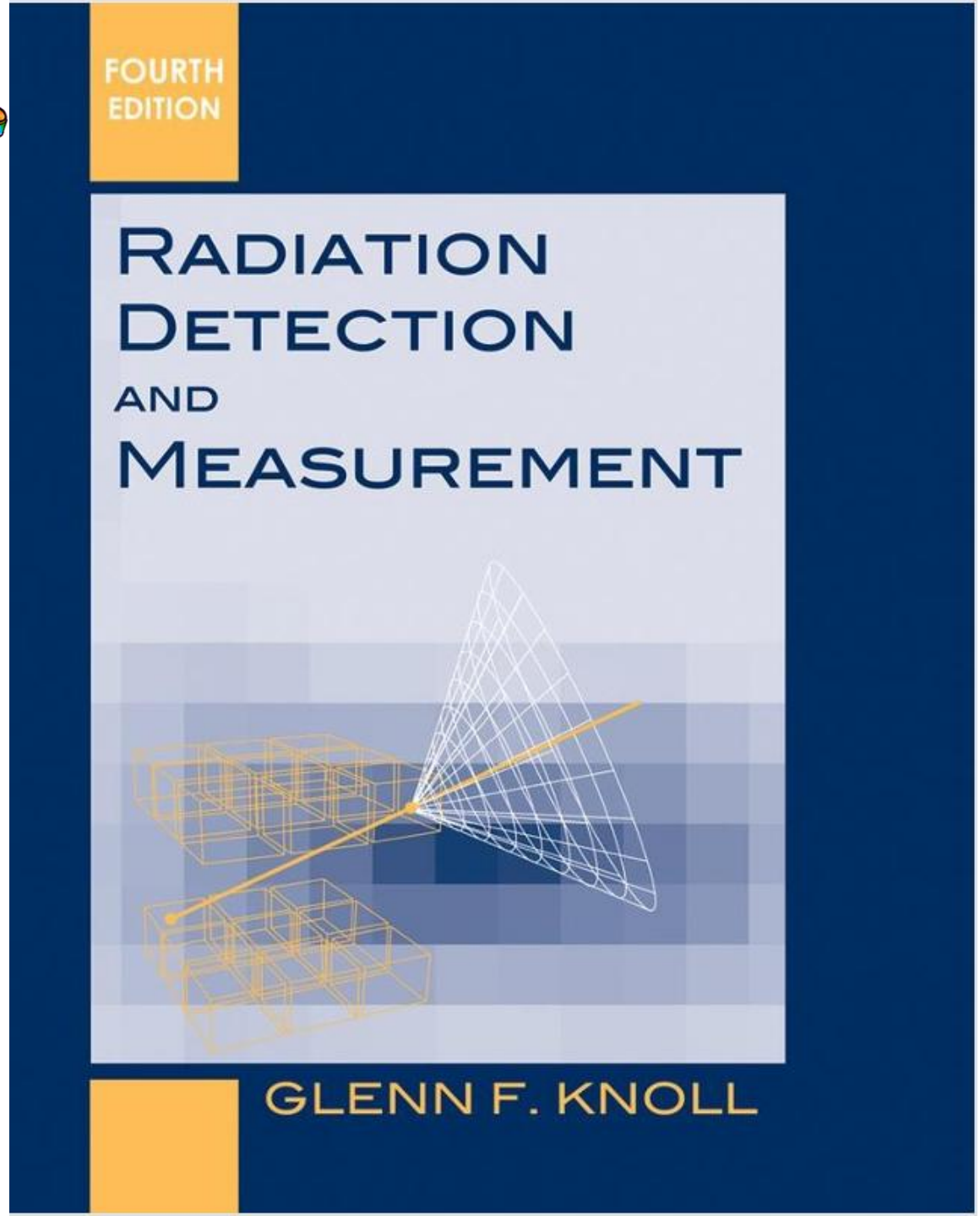
Further reading

Gordon Gilmore, David Joss (2024). Practical Gamma-ray Spectrometry, 3rd Edition. Wiley
ISBN: 978-1-119-89608-1



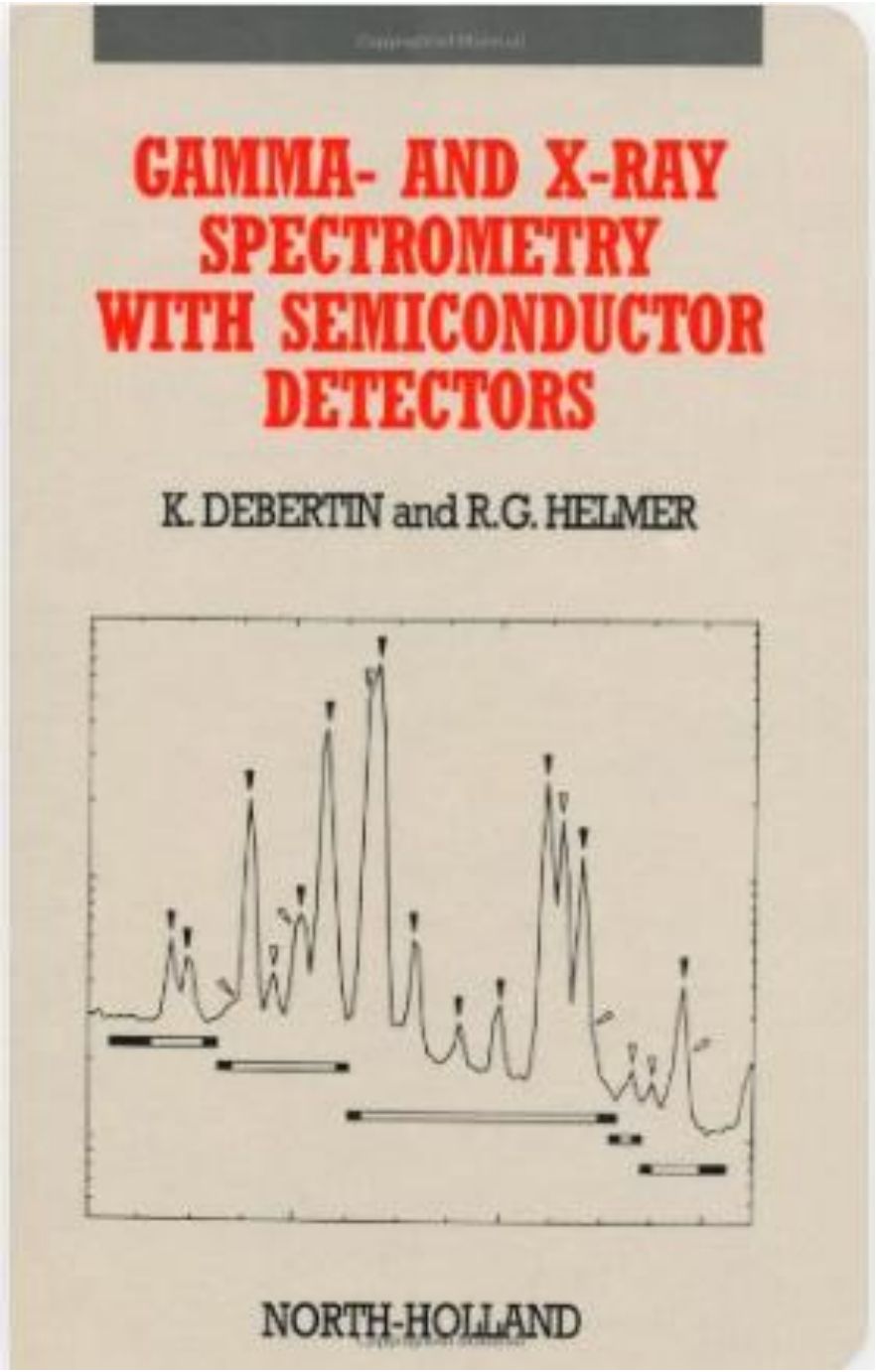
Further reading

Claus Grupen and Boris Shwartz (2023). Particle Detectors (Cambridge Monographs on Particle Physics, Nuclear Physics and Cosmology). Cambridge University Press.
ISBN-10 : 1009401513
ISBN-13 : 978-1009401517



Further reading

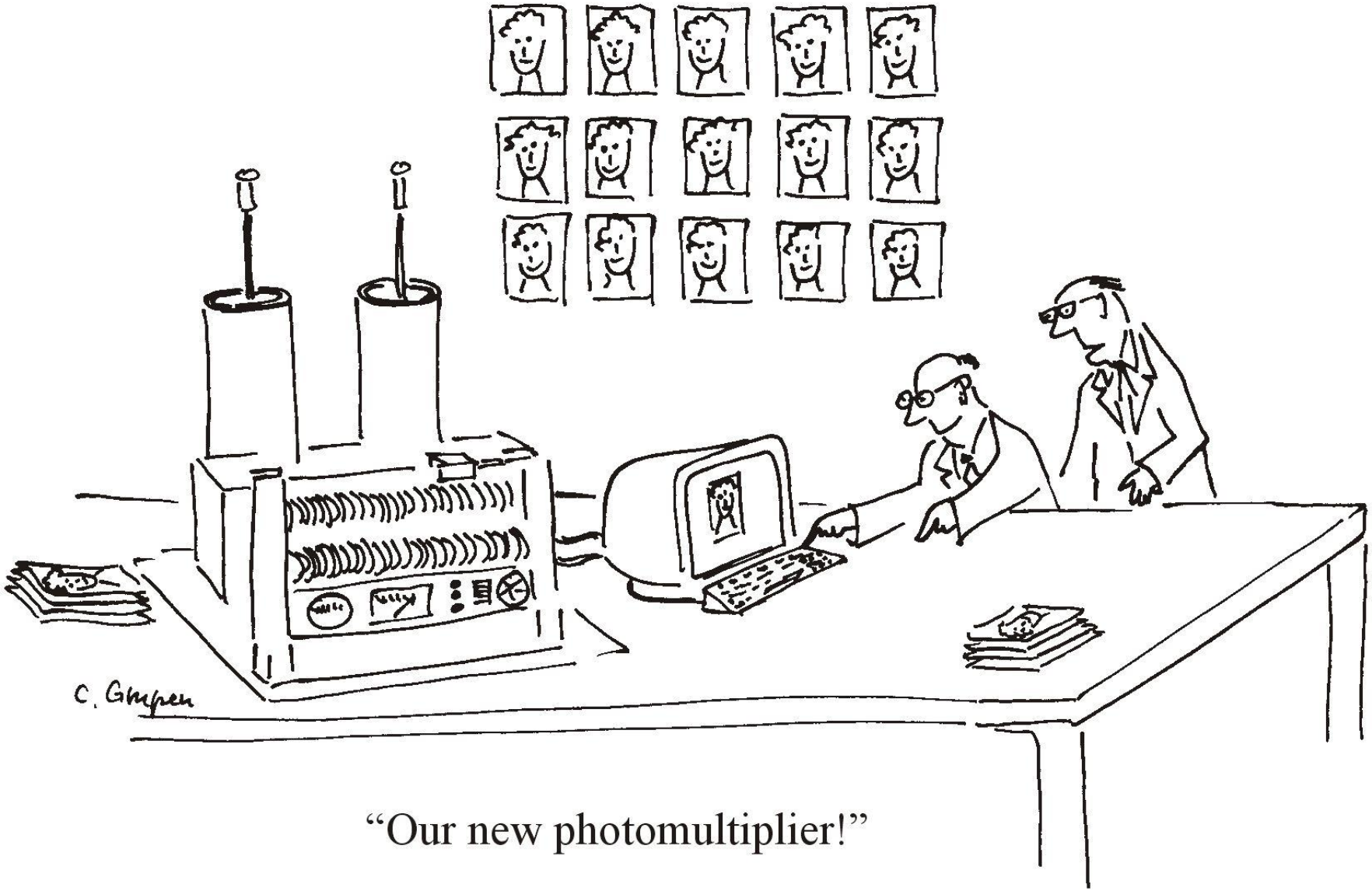
Glenn F. Knoll (2010). Radiation Detection and Measurement 4th Edition. Wiley.
ISBN-10 : 9780470131480
ISBN-13 : 978-0470131480



Further reading

K. Debertin and R.G. Helmer (1988). Gamma- and X-Ray Spectrometry with Semiconductor Detectors. North-Holland.
ISBN-10 : 0444871071
ISBN-13 : 978-0444871077

Thank you for the attention … so far



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