European Commission

Gamma-ray Spectrometry

Training Workshop on Applications of Gamma-ray Spectrometry to Environmental Samples

Coincidence Summing

Tim Vidmar, PhD

SCK.CEN, Belgian Nuclear Research Centre, Boeretang 200, Mol, Belgium

Tim.Vidmar@sckcen.be

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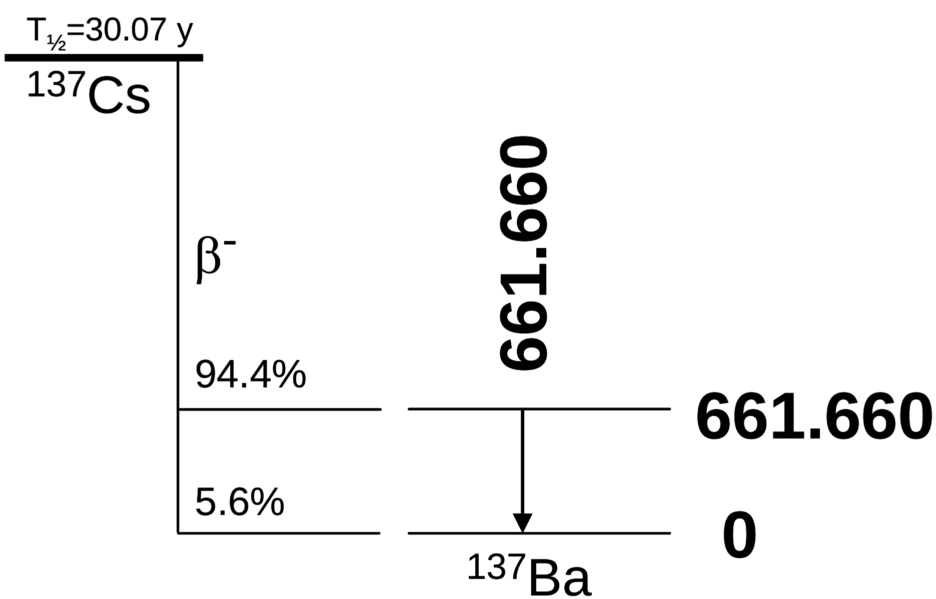
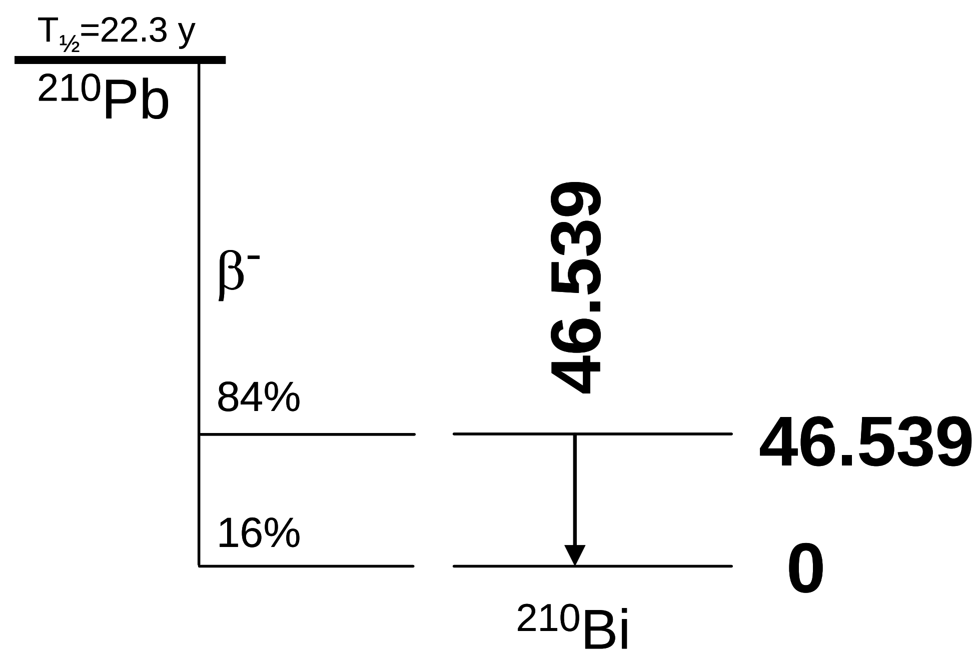
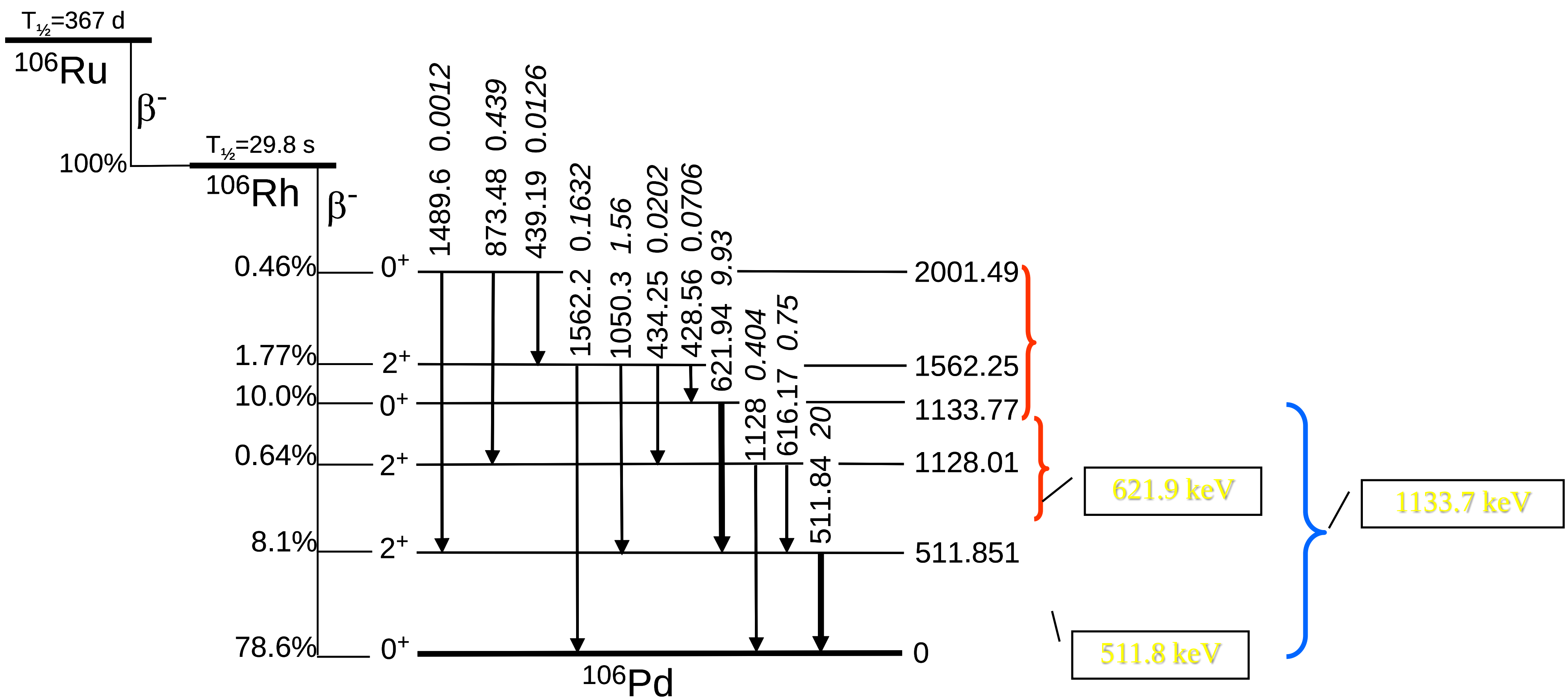
Mono-energetic gamma-ray emitters

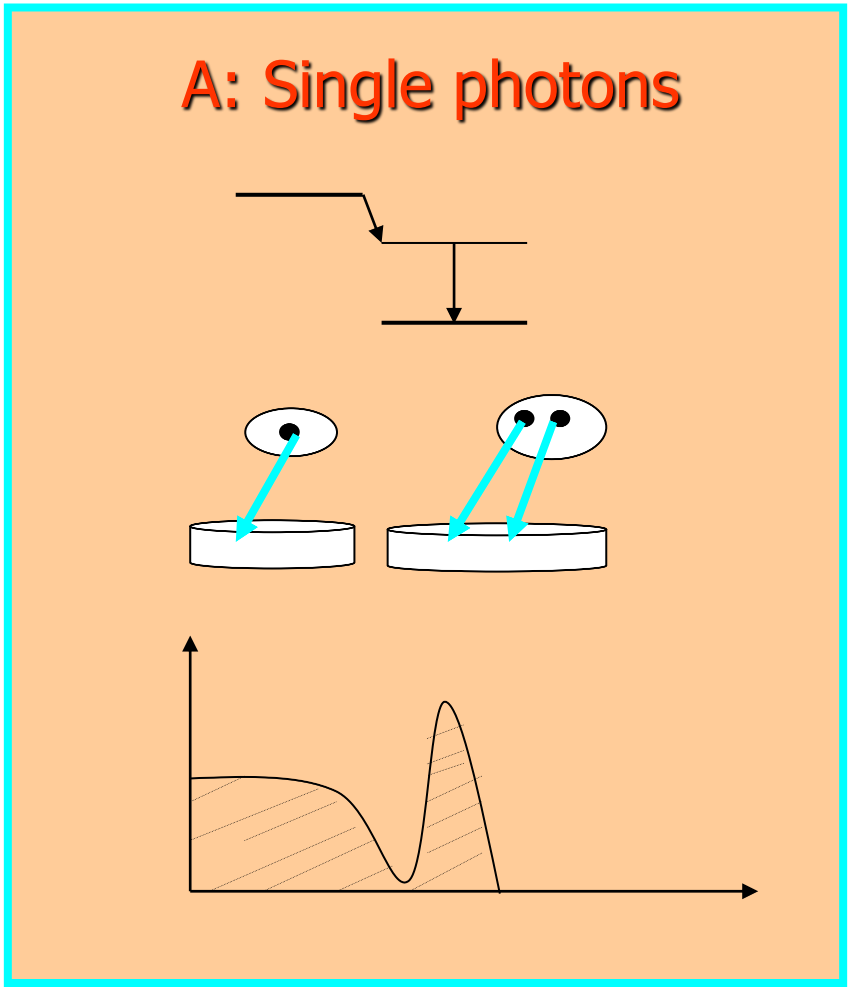


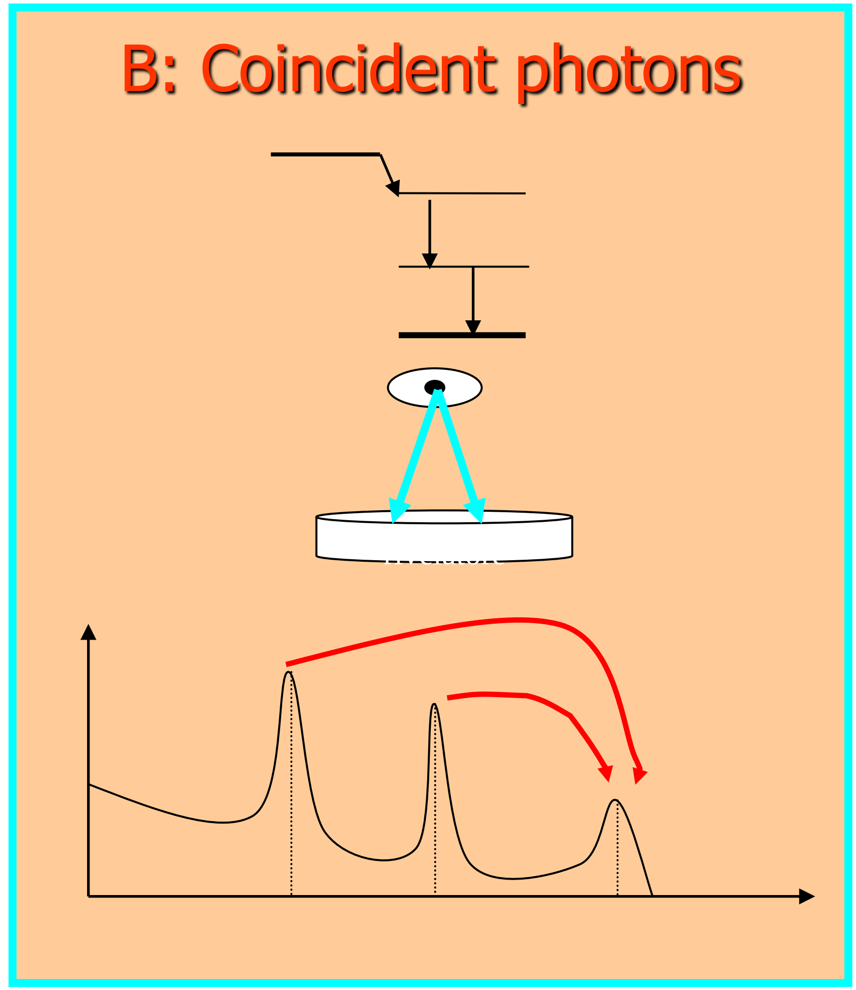


Coincidence summing

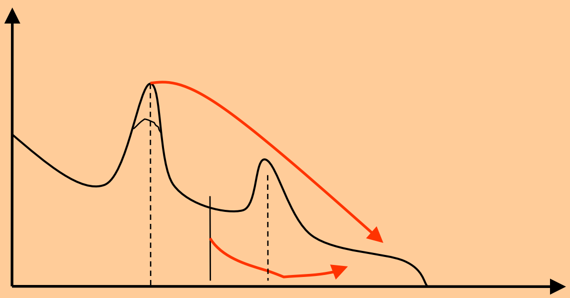


COINCIDENCE-SUMMING
occurs for radionuclides emitting two or more photons within the spectrometer resolving time



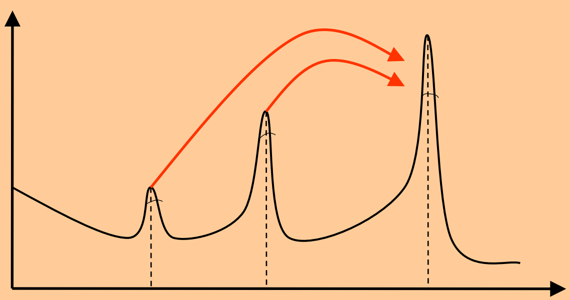


Spectrum deformation due to coincidence summing



a) Photoelectric-Compton: summing out

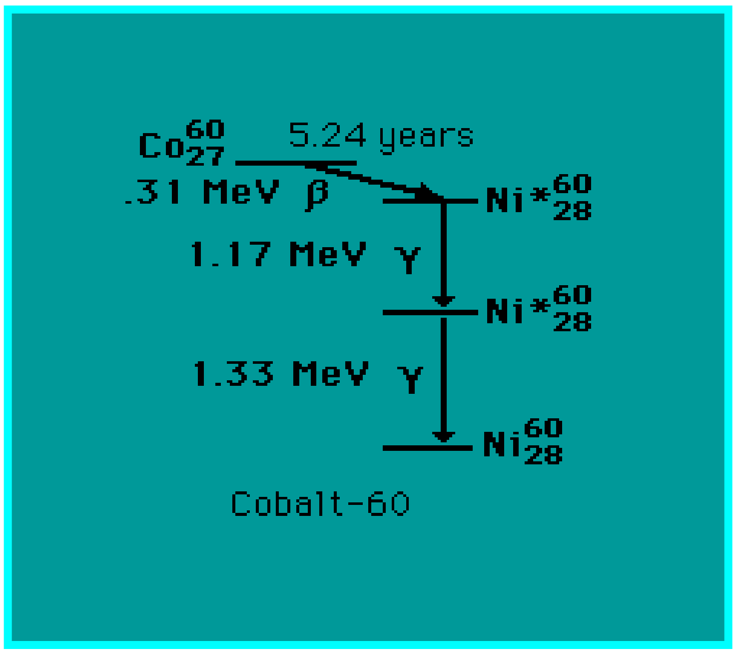
$$n_1 = AI_{\gamma_1}\varepsilon_1 - Ak_{12}\varepsilon_1\varepsilon_{t2}$$

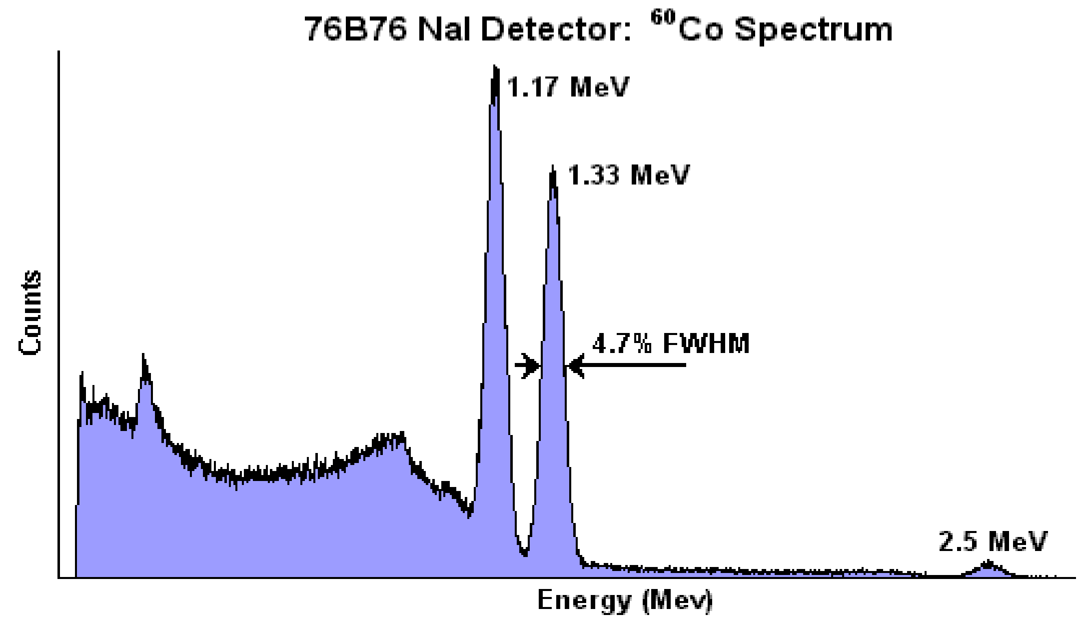


b) Photoelectric-photoelectric: summing in

$$n_{12} = Ak'_{12}\varepsilon_1\varepsilon_2$$

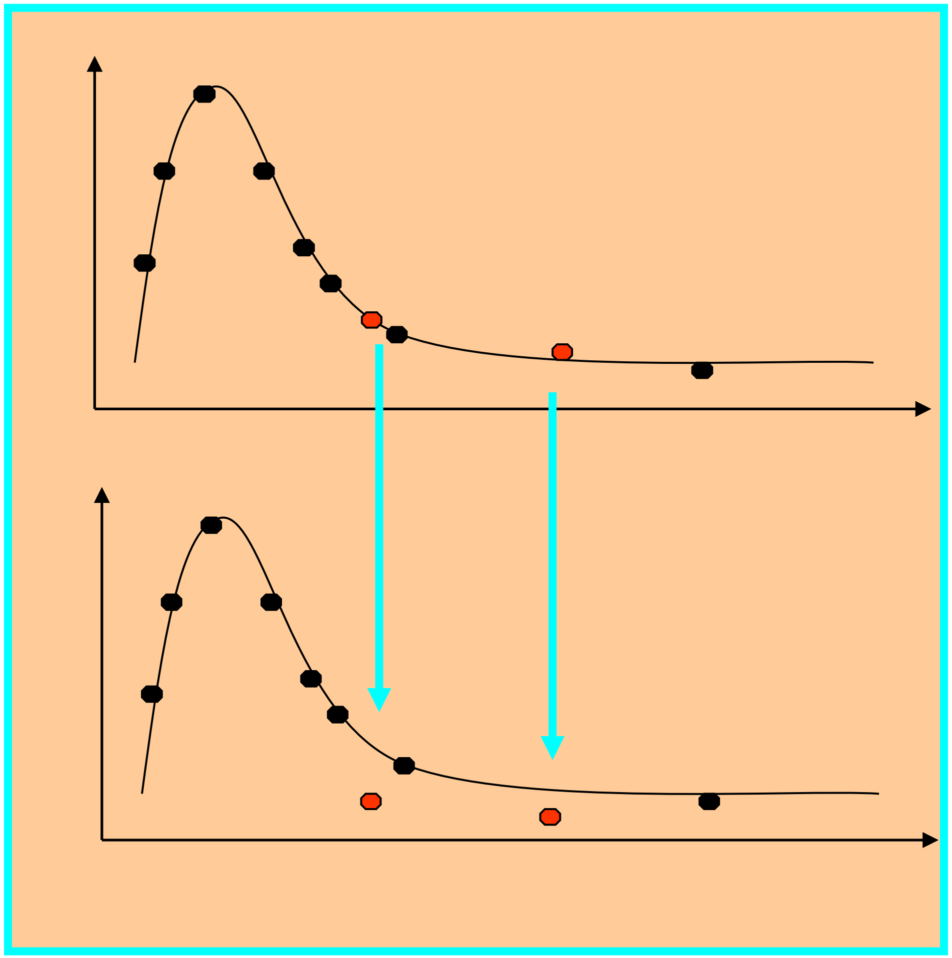
Coincidence summing correction for Co-60





$n_1 = A\varepsilon_1(1-\varepsilon_{t2})$
$n_2 = A\varepsilon_2(1-\varepsilon_{t1})$
$A = Cn_1/\varepsilon_1$
$C = 1/(1-\varepsilon_{t2})$

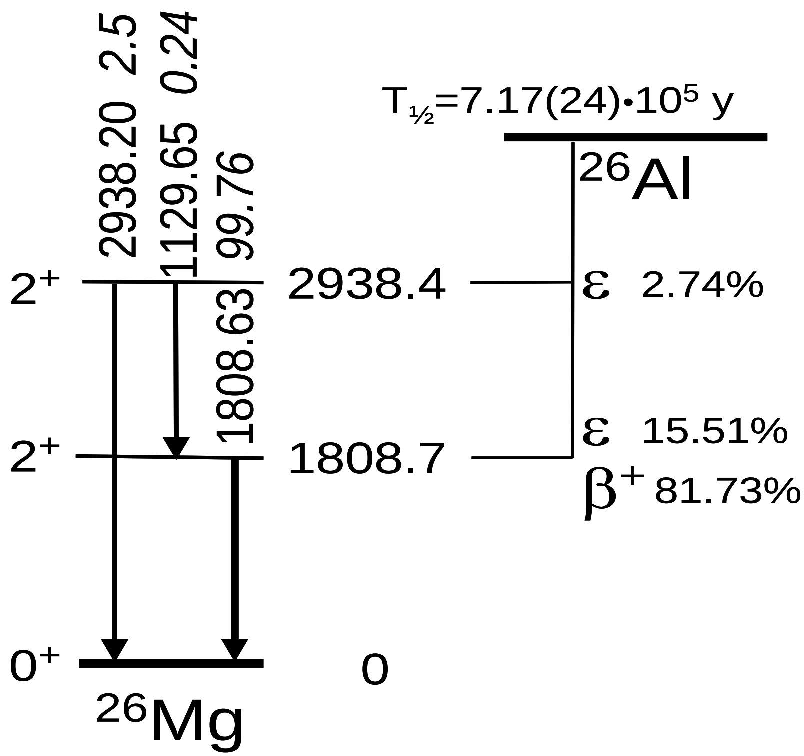
Loss of events from the full-energy peak



A: Single photons

B: Coincident photons

Coincidence summing with the 511 keV gamma ray

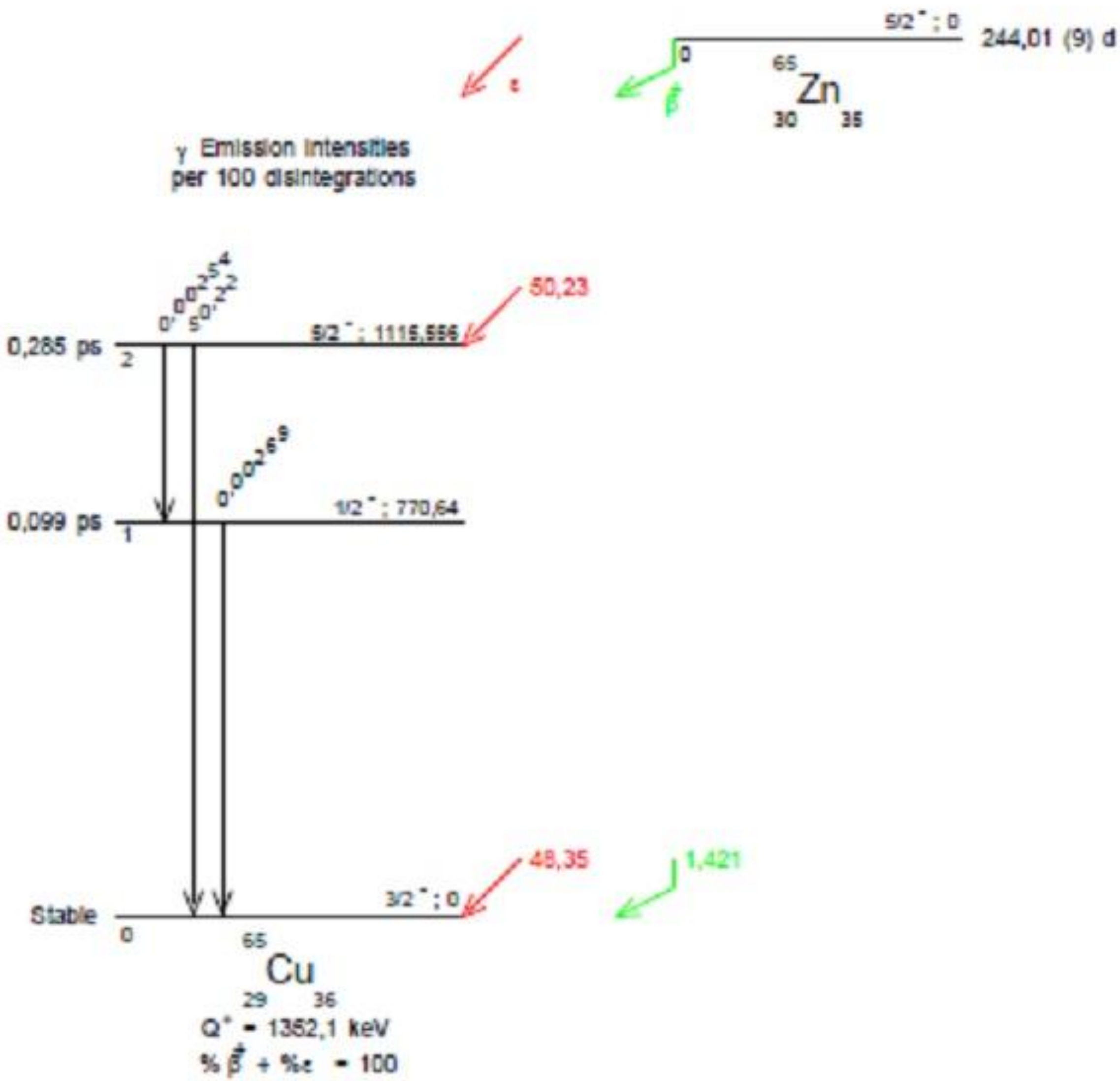


β^+ decay $\Rightarrow$

summing with annihilation quanta

511+1809 = 2320 keV

Coincidence summing with X-rays



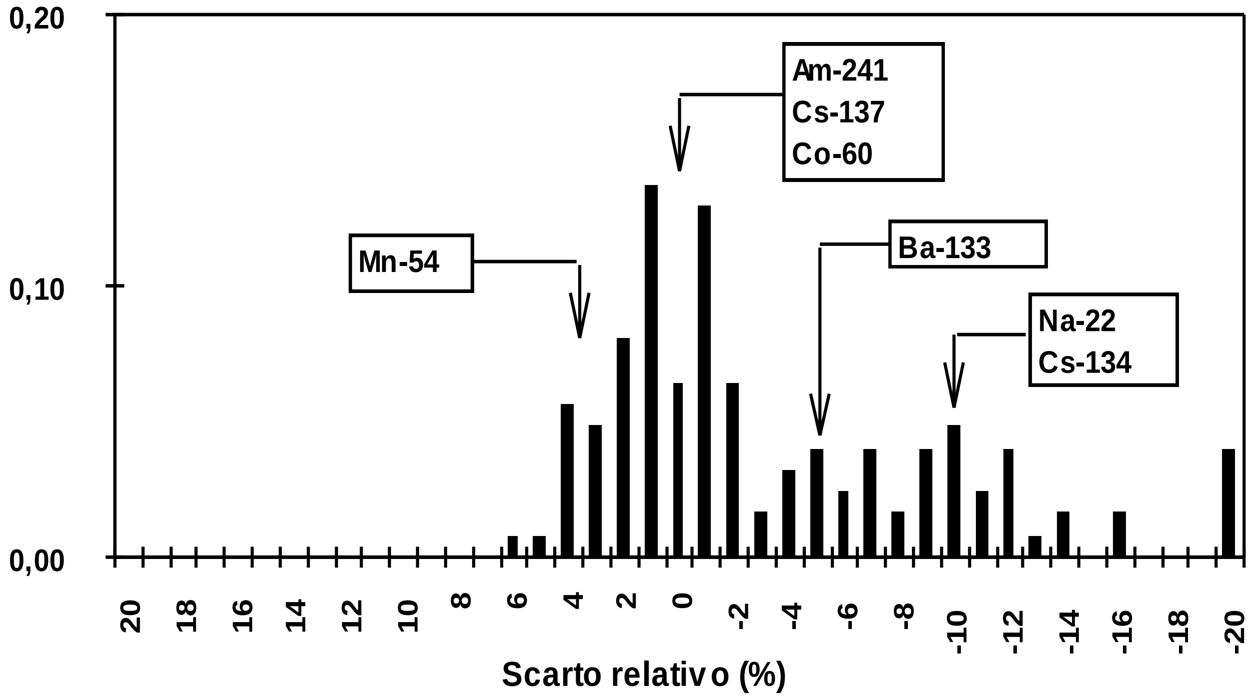
Electron capture ⇒

summing with X-rays

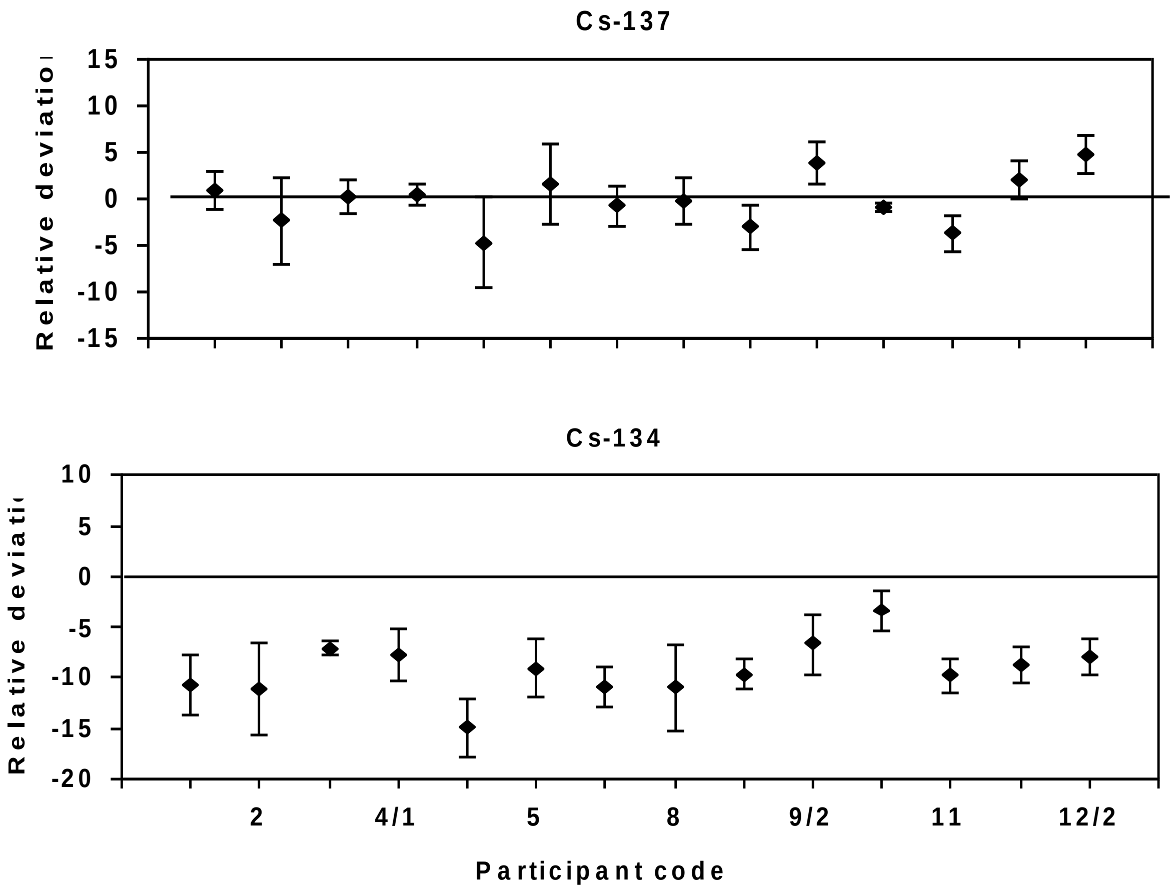
8+1809 = 1817 keV,

8+1130 = 1138 keV

Experimental evidence of coincidence-summing effect -- Results of a gamma-spectrometry proficiency test



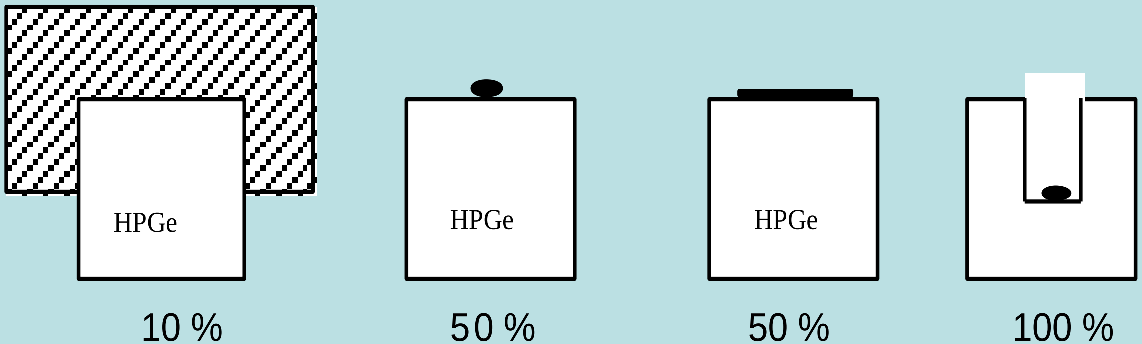
Coincidence-summing is a common source of systematic errors in gamma-spectrometry



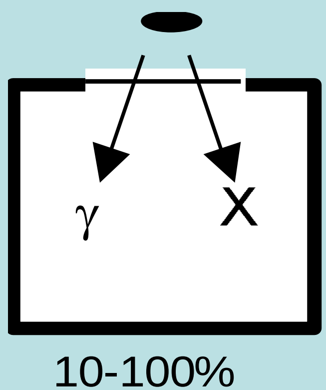
Example:

Italian gamma-spectrometry proficiency test (1998)

Magnitude of coincidence-summing effect



a) p-type detectors



b) n-type detectors

Magnitude of coincidence-summing effects

50% planar detector

		Water in TEFLON container height: 4 cm diameter: 5 cm	Point source
For ^{106}Ru	622 keV	20%	45%
For ^{60}Co	1174 keV	14%	31%
For ^{133}Ba	356 keV	15%	32%
	304 keV	23%	52%
	82 keV	30%	61%

Coincidence summing …

- Is **also called** "cascade summing", "true summing", "…
- Does **NOT** depend on the activity of the source
- **Depends** on the decay scheme (cascading gamma-rays)
- **Depends** on the geometry
- Is **only important** for close distance between source and detector
- Is **less important** for smaller detectors
- Well-type detectors **suffer most** coincidence summing
- Summing with **X-rays** can be very important (**n-type** detectors) – use an absorber
- Generally results in a **lower detection efficiency** for a specific peak (summing-out)
- Sometimes results in a **higher detection efficiency** for a specific peak (summing-in)
- Is the main reason for **errors of 10-50%** in gamma-ray spectrometry
- Is almost always present with **complex decay schemes**
- **Affects calibration**, as well as sample analysis

Methods for calculation of coincidence-summing corrections

- Standard replicating the conditions of the sample
- Analytical expression [Hoppes, 1983], [Blawn, 1993]
- Precompiled tables
- Monte Carlo Methods [Sima, 1996]
- Simplified semi-empirical methods [De Felice, 2000]
- Software tools
    - **Commercial gamma spectrometry packages**
    - **Freely available codes**

Standard of the same radionuclide in the same geometry as the sample

Advantage

Gives correct results while requiring no corrections for coincidence summing

Drawback

It is necessary to have a standard for each radionuclide and geometry measured

Analytical expressions

Advantage

For radionuclide with simple decay schemes it is easy to implement and it gives accurate results

Drawback

Intractable for radionuclides with complex decay schemes and with different types of interactions

Simulation methods

- Based on Monte Carlo calculations
- Accuracy level increased to a tenths of a per cent
- Need dedicated software
- Easily available nowadays

Commercial tools

- Canberra's LABSOCS and ISOCS
  - no additional measurements required
  - detector characterization
  - generic detector models
- Ortec's GammaVision
  - method of Blaauw
  - calibrated standard with Cs-134 for each sample geometry
  - correction for density and composition still needed
  - calculation-only approach under development

Which correction method to choose

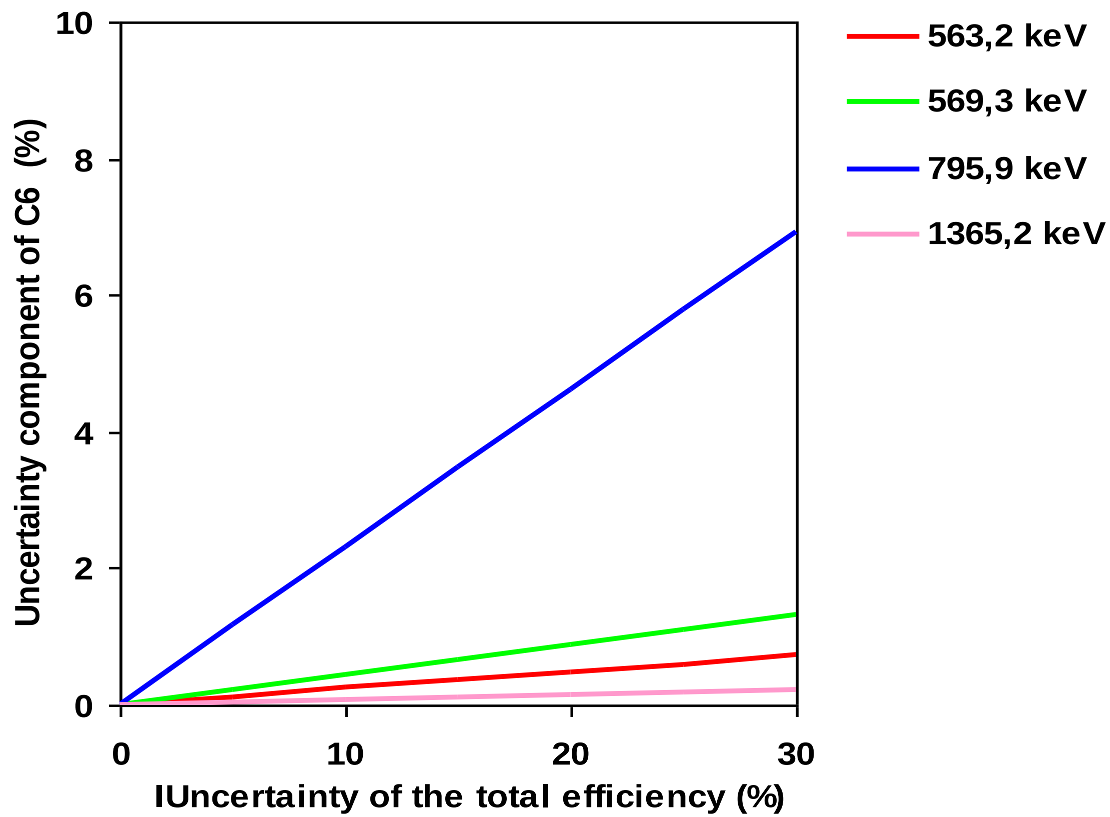
The « best method » depends on what you would like to achieve:

Routine measurements	→ Standard with same geometry
Samples with different geometries	→ Monte Carlo method
Low activity samples	→ Most practical method
Qualitative analysis	→ No correction or Table of correction factors

Uncertainty propagation

The uncertainty of the total efficiency ε_t is propagated to the correction factor C by the usual error propagation law

Input uncertainties are "compressed" by partial derivatives and the output uncertainties of C are notably reduced



Uncertainty propagation – Co-60

$$A = C\frac{N_1}{t\,\varepsilon_1}$$

$$C = 1/(1-\varepsilon_{t2})$$

$$\Delta C = (dC/d\varepsilon_{t2})\Delta\varepsilon_{t2} = 1/(1-\varepsilon_{t2})^2\Delta\,\varepsilon_{t2} = C^2\Delta\varepsilon_{t2}$$

$$\frac{\Delta C}{C} = C\Delta\varepsilon_{t2} = (C\varepsilon_{t2})\frac{\Delta\varepsilon_{t2}}{\varepsilon_{t2}}$$

$$\varepsilon_{t2} = 0.1, \Delta\varepsilon_{t2}/\varepsilon_{t2} = 0.1 \xrightarrow{\text{yields}} \Delta C/C = 0.01$$

Literature on Uncertainties in Monte Carlo simulations

P.N. Johnston, M. Hult, J. Gasparro, "Cascade Summing Effects in Close Geometry Gamma-ray Spectrometry", Appl. Radiat. Isot. 64 (2006) 1323 1328.

J. Gasparro, M. Hult, P.N. Johnston, H. Tagziria, "The effect of uncertainties in nuclear decay data on coincidence summing calculations for gamma-ray spectrometry", Czech.J.Phys. 56, Suppl. D, (2006), 203-210.

T. Vidmar, et al. "An intercomparison of Monte Carlo codes used in gamma-ray spectrometry", Applied Radiation and Isotopes 66 (2008) 764–768.

J. Gasparro, M. Hult, P.N. Johnston, H. Tagziria "Monte-Carlo modeling of germanium crystals that are tilted and have rounded front edges", Accepted for publication in Nucl. Instr. And Meth A.

Avoiding (routine) coincidence corrections

- The main trick is to increase the distance between your sample and the detector
- Significant loss in efficiency and increase in MDA possible
- Estimation of the remaining coincidence effect must still be made!
- This estimate should be included into the uncertainty budget!