Workshop
Metodi avanzati di spettrometria gamma
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Coincidence-summing corrections in high resolution gamma-ray spectrometry: simplified analytical expressions

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Introduction

The spectrometric analysis of a gamma-emitter sample measured in "close geometry" can be affected by errors due to coincidence-summing effects that can occur when two or more coincident photons (real coincidences) are emitted within the resolution time of the spectrometric system.

L'analisi spettrometrica gamma di un campione misurato in "geometria vicina" può essere affetta da errori dovuti ad effetti di coincidenza-somma che possono avvenire quando due o più fotoni sono emessi in coincidenza (stessa disintegrazione), ossia entro il tempo di risoluzione dello spettrometro.

Introduction

If a photon releases all its energy in the detector and another coinciding photon will issue only one part of its energy, a reduction in the area of full-energy peaks related to both photon energies occurs (*summing-out effect*). If the energy of the two photons in coincidence is fully released into the detector, the counting related to peak-sum of photon energies increases (*summing-in effect*).

Se un fotone rilascia tutta la sua energia nel rivelatore e un secondo fotone in coincidenza ne rilascia solo una parte, l'impulso che ne deriva non viene classificato nè in corrispondenza dell'energia del primo fotone, nè in quella del secondo, bensì in una zona diversa dello spettro (summing- out). Se invece viene rilasciata l'intera energia dei due fotoni, il conteggio del picco somma corrispondente si incrementa (summing-in).

Introduction

The basic theory on coincidence-summing phenomena is widely reported in many works. For example : …

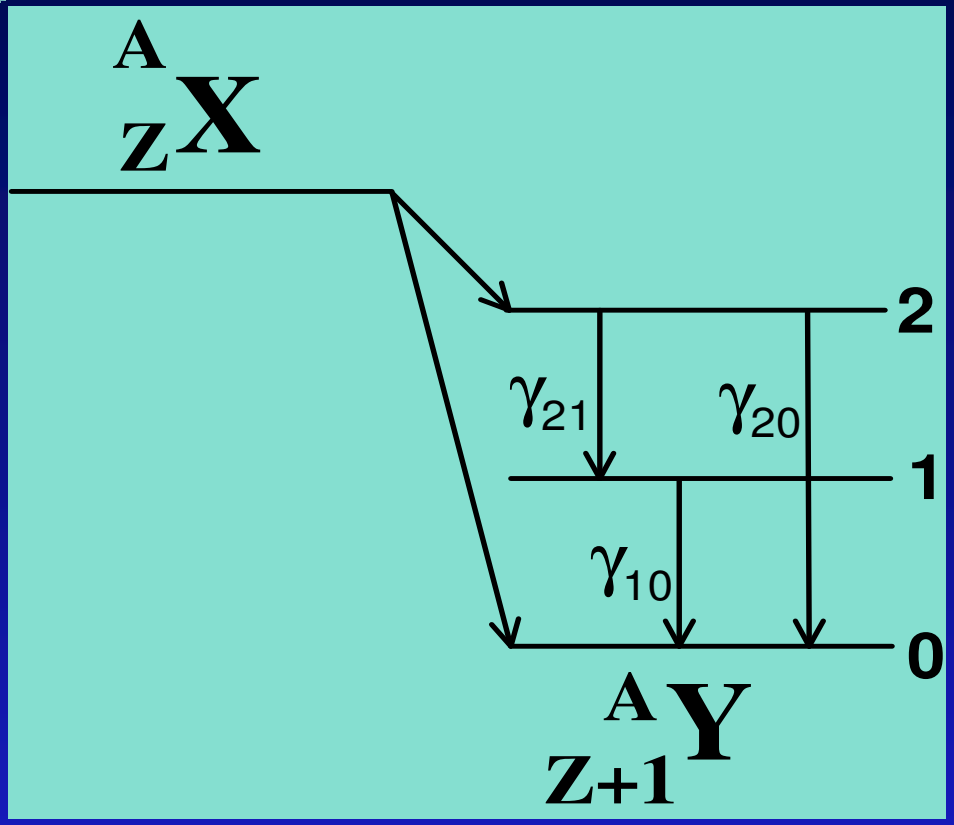
L'*evoluzione storica della metodologia di approccio al problema delle coincidenze è data in molti lavori, ad esempio:*

Debertin, K. and Schötzig U. (1979). *Coincidence summing corrections in Ge(Li)-spectrometry at low source-to-detector distances,* Nuclear Instruments and Methods **158**, 471-477.

Debertin, K. and Helmer R.G. (1988). *Gamma- and X-ray spectrometry with semiconductor detectors*. North-Holland, ISBN: 0444871071, 1988.

Debertin K. (1990). *Corrections in gamma-ray spectrometry with Germanium detectors*. Proceedings of the 2th International Summer School, La Rabida, Huelva, Spain, June-July 1990, World Scientific.

Gilmore G. (2008). *Practical Gamma-ray Spectrometry*. 2th edition , John Wiley &Sons, 2008. ISBN 978-0-470-86196-7. and others



Basic expressions

With reference to the simple 2-level decay scheme (es. ^{60}Co), if we can neglect correction for decay, angular correlations, internal conversion, for the counting of a photopeak related to γ_{10} transition we can write the form

Con riferimento a un semplice schema a 2-livelli (tipo ^{60}Co, due emissioni in coincidenza, probabilità di emissione ~ 100%), se possiamo trascurare le correzioni per decadimento, correlazioni angolari, X di conversione interna, etc., per il conteggio relativo alla transizione γ_{10} possiamo scrivere:

$$C_{10} = A\ \varepsilon_{10}^{P}\ T_C$$

Basic expressions

However, the presence of a coincident transition from level 2 to level 1, can be lead to a non-zero probability to detect simultaneously the photons with a loss in photopeak counting of γ_{10}. This probability is associated to the probability ε^{T}_{21} that the energy of γ_{21} is fully or in part released in the detector.

$$C^{*}_{10} = A\, T_C\, \varepsilon^{P}_{10}\, (1 - \varepsilon^{T}_{21})$$

Tuttavia, la transizione dal livello 2 al livello 1 ha una probabilità non nulla di essere rivelata in coincidenza, con perdita di conteggio in γ_{10}. Questa probabilità è associata alla efficienza totale $\varepsilon^{T}_{21,}$ probabilità che l'energia del fotone γ_{21} sia tutta o in parte depositata nel rivelatore.

$$F^{S}_{10} = C_{10}/C^{*}_{10} = (1 - \varepsilon^{T}_{21})^{-1}$$

$$A(\gamma_{10}) = \frac{C^{*}_{10}}{I_{10}\, \varepsilon^{P}_{10}\, T_C} F^{S}_{10}$$

Basic expressions

If we would consider only the effects of Internal Conversion (IC), we come easily to the expressions.

Una modifica delle espressioni, considerando la sola conversione interna, conduce a

$$F_{10}^{s} = \left(1 - \frac{Y_{21}}{T_1}\frac{\varepsilon_{21}^{T}}{1+\alpha_{21}^{T}}\right)^{-1}$$

$$F_{21}^{s} = \left(1 - \frac{Y_{10}}{T_1}\frac{\varepsilon_{10}^{T}}{1+\alpha_{10}^{T}}\right)^{-1}$$

$$F_{20}^{s} = \left(1 + \frac{Y_{10}Y_{21}}{T_1 Y_{20}}\frac{1+\alpha_{20}^{T}}{(1+\alpha_{10}^{T})(1+\alpha_{21}^{T})}\frac{\varepsilon_{21}^{P}\varepsilon_{10}^{P}}{\varepsilon_{20}^{P}}\right)^{-1}$$

Basic expressions

Taking into account the coincidences γ-X_K following IC, the relations become

Prendendo in considerazione le coincidenze con i raggi X che seguono la conversione interna, si ha

$$F_{10}^{s} = \left(1 - \frac{Y_{21}}{T_1}\frac{\varepsilon_{21}^{T}}{1+\alpha_{21}^{T}}\right)^{-1}\left(1 - \frac{Y_{21}}{T_1}\alpha_{21}^{K}\,\omega_K\frac{\varepsilon_{X_K}^{T}}{1+\alpha_{21}^{T}}\right)^{-1}$$

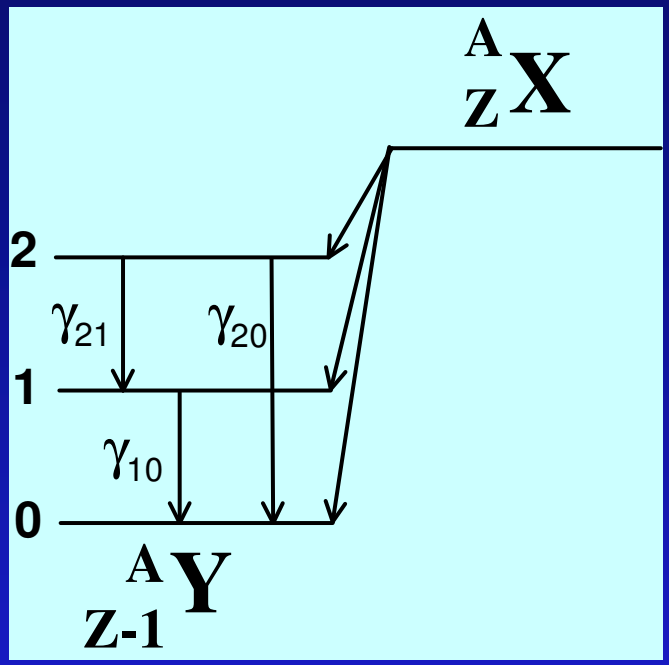
$$F_{21}^{s} = \left(1 - \frac{Y_{10}}{T_1}\frac{\varepsilon_{10}^{T}}{1+\alpha_{10}^{T}}\right)^{-1}\left(1 - \frac{Y_{10}}{T_1}\alpha_{10}^{K}\,\omega_K\frac{\varepsilon_{X_K}^{T}}{1+\alpha_{10}^{T}}\right)^{-1}$$

$$F_{20}^{s} = \left(1 + \frac{Y_{10}\,Y_{21}}{T_1 Y_{20}}\frac{1+\alpha_{20}^{T}}{(1+\alpha_{10}^{T})(1+\alpha_{21}^{T})}\frac{\varepsilon_{21}^{P}\,\varepsilon_{10}^{P}}{\varepsilon_{20}^{P}}\right)^{-1}$$

- For EC decay , the relations become:
- *Per il decadimento EC (cattura elettronica), si ha :*

$$F_{10}^{s} = \left(1-\frac{Y_{21}}{T_1}\frac{\varepsilon_{21}^{T}}{1+\alpha_{21}^{T}}\right)^{-1}\left(1-\frac{Y_{21}}{T_1}\alpha_{21}^{K}\,\omega_K\frac{\varepsilon_{X_K}^{T}}{1+\alpha_{21}^{T}}\right)^{-1}\times$$

$$\times\left(1-\frac{Y_{21}}{T_1}\frac{Y_{32}\,(P_K)_{32}}{T_2}\,\omega_K\,\varepsilon_{X_K}^{T}\right)^{-1}\left(1-\frac{Y_{31}\,(P_K)_{31}}{T_1}\,\omega_K\,\varepsilon_{X_K}^{T}\right)^{-1}$$



$$F_{21}^{s} = \left(1-\frac{Y_{10}}{T_1}\frac{\varepsilon_{10}^{T}}{1+\alpha_{10}^{T}}\right)^{-1}\left(1-\frac{Y_{10}}{T_1}\alpha_{10}^{K}\,\omega_K\frac{\varepsilon_{X_K}^{T}}{1+\alpha_{10}^{T}}\right)^{-1}\times$$

$$\times\left(1-\frac{Y_{32}\,(P_K)_{32}}{T_2}\,\omega_K\varepsilon_{X_K}^{T}\right)^{-1}$$

$$F_{20}^{s} = \left(1+\frac{Y_{10}\,Y_{21}}{T_1\,Y_{20}}\,\frac{1+\alpha_{20}^{T}}{(1+\alpha_{10}^{T})\,(1+\alpha_{21}^{T})}\,\frac{\varepsilon_{21}^{P}\;\varepsilon_{10}^{P}}{\varepsilon_{20}^{P}}\right)^{-1}\times$$

$$\times\left(1-\frac{Y_{32}\,(P_K)_{32}}{T_2}\,\omega_K\,\varepsilon_{X_K}^{T}\right)^{-1}$$

Basic expressions

For the sake of simplicity, the relations do not take into account bremmstrahlung radiation, angular correlations, shielding presence as well as other X-rays (X_L, X_M, …) and electrons are considered removed by absorbers between source and detector (cap, dead layers and so on). This statement is generally correct for p-type detectors but is not strictly applicable to n-type or well-type detector based measurements.

Per semplicità, non sono presi in considerazione gli effetti di bremmstrahlung, correlazioni angolari, fotoni X relativi ai livelli L,M,.... e degli elettroni in quanto ritenuti rimossi dagli assorbitori (cap, strato-morto, etc.) interposti tra sorgente e cristallo di Ge; ciò può essere corretto per rivelatori tipo p mentre per rivelatori tipo n o a pozzetto non è strettamente applicabile.

Mathematical formulation

As a generalization of the previous formulations, for a decay scheme with *n* levels, numbered from 0 (ground state) to *n*-1, the expression to compute the correction factor F^{S}_{ij} is derived from the one reported in:

Generalizzando le espressioni precedenti, per uno schema di decadimento a n livelli, numerati da 0 (stato finale del nucleo) ad n-1, l'espressione per il calcolo del fattore di correzione F^{S}_{ij} relativo a una transizione γ_{ij} (i>j) tra due livelli è stata dedotta da quella riportata in :

Morel, J., Chauvenet, B., Kadachi, A. (1983). *Coincidence-summing corrections in gamma-ray spectrometry for normalized geometries,* The Intern.J. of Applied Radiation and Isotopes **34** ,1115-1122.

Lepy, M.C., Morel, J., Chauvenet, B. (1986). *Correction des pertes de comptage dues aux coïncidences gamma-gamma, gamma-X et X-X dans un spectre de photons.* **Rapport CEA-R-5356**.

Mathematical formulation

$$F_{ij}^{s} = \underbrace{\prod_{l=i}^{n-2}\prod_{k=l+1}^{n-1}\left(A_{kl}^{\gamma}\right)^{-1}}_{A}\ \underbrace{\prod_{p=1}^{j}\prod_{m=0}^{p-1}\left(B_{pm}^{\gamma}\right)^{-1}}_{B}\ \underbrace{\prod_{g=j+1}^{i-1}\left(C_{gj}^{\gamma}\right)^{-1}}_{C}$$

$$\times\ \underbrace{\prod_{l=i}^{n-2}\prod_{k=l+1}^{n-1}\left(A_{kl}^{X}\right)^{-1}}_{D}\ \underbrace{\prod_{p=1}^{j}\prod_{m=0}^{p-1}\left(B_{pm}^{X}\right)^{-1}}_{E}\ \cdot\ \underbrace{\prod_{l=i}^{n-1}\left(C_{nl}^{X}\right)^{-1}}_{F}$$

$$A_{kl}^{\gamma} = 1-\frac{Y_{kl}}{T_l}\frac{\varepsilon_{kl}^{T}}{1+\alpha_{kl}^{T}}\ M_{li}$$

$$A_{kl}^{X} = 1-\frac{Y_{kl}}{T_l}\,\alpha_{kl}^{K}\,\omega_K\,\frac{\varepsilon_{X_K}^{T}}{1+\alpha_{kl}^{T}}\ M_{li}$$

$$B_{pm}^{\gamma} = 1-\frac{Y_{pm}}{T_p}\frac{\varepsilon_{pm}^{T}}{1+\alpha_{pm}^{T}}\ Njp$$

$$B_{pm}^{X} = 1-\frac{Y_{pm}}{T_p}\,\alpha_{pm}^{K}\,\omega_K\,\frac{\varepsilon_{X_K}^{T}}{1+\alpha_{pm}^{T}}\ Njp$$

$$C_{gj}^{\gamma} = 1+\frac{Y_{gj}\ Y_{ig}}{T_g\ Y_{ij}}\ \frac{1+\alpha_{ij}^{T}}{(1+\alpha_{ig}^{T})\ (1+\alpha_{gj}^{T})}\ \frac{\varepsilon_{ig}^{P}\ \varepsilon_{gj}^{P}}{\varepsilon_{ij}^{P}}$$

$$C_{nl}^{X} = 1-\frac{Y_{nl}}{T_l}(P_K)_{nl}\,\omega_K\,\varepsilon_{X_K}^{T}\ M_{li}$$

Mathematical formulation

The terms A,D are related to "*summing-out*" effects due to gamma transitions originating from levels above *i*, the terms B,E are related to transitions originating from levels lower than *j*, term C is associated to "*summing-in*" effects and, F represents "*summing-out*" contribution of X-ray from EC-decay of the parent nucleus.

I termini A,D sono correlati all'effetto di summing-out dovuto a transizioni gamma che si originano da livelli superiori a quello di riferimento (i), mentre B,E sono relativi a transizioni che si originano da livelli inferiori a j, C è associato al summing-in, F rappresenta il termine di summing-out con radiazioni X originati dal decadimento EC.

Mathematical formulation

$$M_{li} = \begin{cases} 1 & (l=i) \\ \dfrac{Y_{li}}{T_i} & (l=i+1) \\ \dfrac{Y_{li}}{T_i} + \displaystyle\sum_{b=i+1}^{l-1} \dfrac{Y_{lb}}{T_b} M_{bi} & (i+2 \le l \le n-2) \end{cases}$$

$$N_{jp} = \begin{cases} 1 & (p = j) \\ \dfrac{Y_{jp}}{T_j} & (p=j-1) \\ \dfrac{Y_{jp}}{T_j} + \displaystyle\sum_{q=p+1}^{j-1} \dfrac{Y_{jq}}{T_j} N_{qp} & (1 \le p \le j-2) \end{cases}$$

The quantities M_{li} and N_{jp} represent the probabilities that a transition cascade starting from level *l* will reach the level *i* and from level *j* down to level *p*, respectively.

Le quantità M e N rappresentano le probabilità che una transizione che parte da un livello l possa raggiungere il livello i e che, partendo al livello j, arrivi al livello p, rispettivamente.

MATRIX REPRESENTATION OF A DECAY SCHEME

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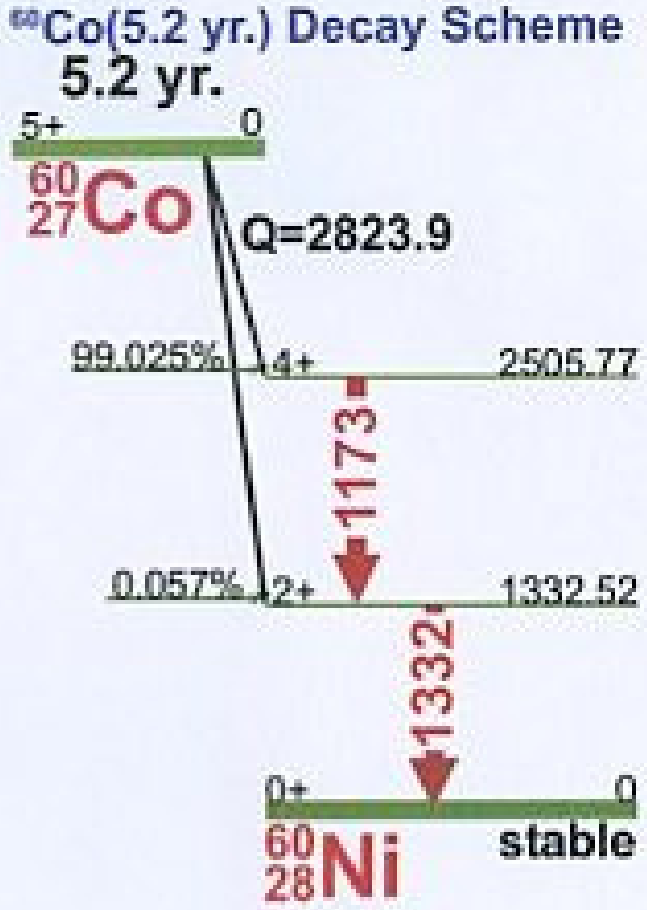


GAMMA-RAY ENERGIES AND INTENSITIES

Nuclide: ^{60}Co — Half Life: 5.2714(5) yr.
Detector: 55 cm³ coaxial Ge (Li) — Method of Production: ^{59}Co(n,γ)

E_γ (keV)	σE_γ	I_γ (rel)	I_γ (%)	σI_γ	S
346.93	0.07		0.0076	0.0006	4
826.28	0.09		0.0076	0.0008	4
1173.237	0.004	100	99.9736	0.0007	1
1332.501	0.005	100	99.9856	0.0004	1
2158.77	0.09		0.0011	0.0002	4
2505					4

E_γ, σE_γ, I_γ, σI_γ - 1998 ENSDF Data

Very intuitive but insufficient as regards decay data

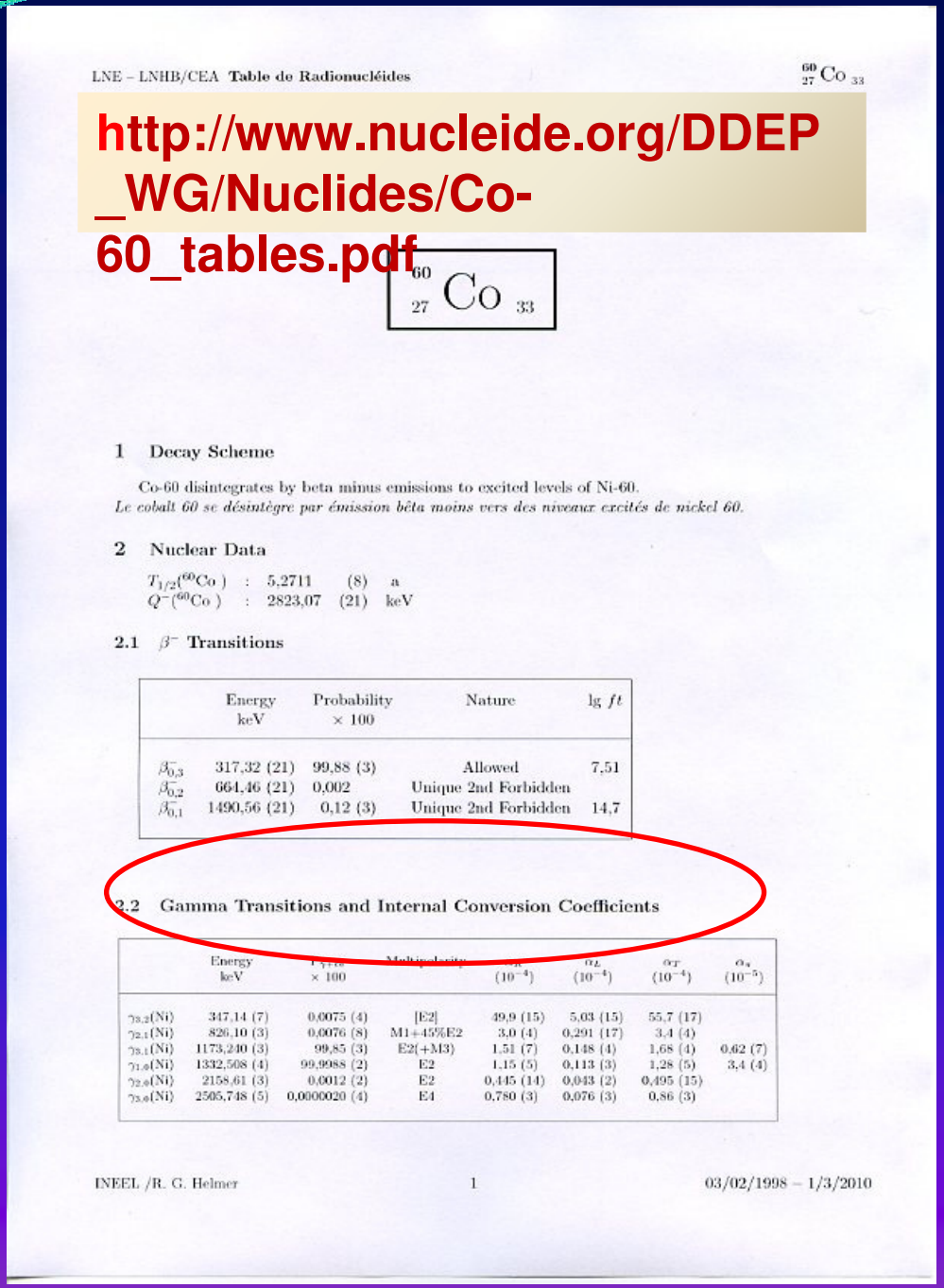
Intuitivo ma insufficiente per quanto riguarda i dati presentati

Gamma-ray spectrum catalogue –
(*Helmer et al., Idaho National Engineering & Environmental Laboratory)*

```
60NI     60CO B- DECAY (5.2711 Y)
60NI C  References: 2002Ba85
60NI T  Auger electrons and ^X ray energies and emission intensities:
60NI T       {U Energy (keV)}     {U Intensity }      {U Line  }
60NI T
60NI T        7.46097           0.00334 12      XKA2
60NI T        7.47824           0.0065 3        XKA1
60NI T
60NI T        8.2647         |]                  XKB3
60NI T                       |]  0.00136 5       XKB1
60NI T        8.3287         |]                  XKB5II
60NI T
60NI T
60NI T        0.74-0.94         0.0002          XL (total)
60NI T        0.74                              XLL
60NI T         -0.94                            XLG
60NI T
60NI T        6.26-6.54      |]                  KLL AUGER
60NI T        7.2-7.47       |]  0.0154 5       ^KLX AUGER
60NI T        8.1-8.32       |]                  KXY AUGER
60NI T        0.7-0.9           0.0392 12       L AUGER
60NI  N 1.0         1.0       1         1.0
60CO  P 0.0         5+                5.2711 Y  8              2823.07   21 60NI  L 0          0+                  STABLE
60NI  L 1332.508  4 2+                0.713 PS  11
60NI  B 1490.56   210.12    3           14.7                                 2U
60NIS B EAV=625.6 1 60NI  G 1332.492  4 99.9826 6 E2                       0.000125
60NI2 G KC=0.000115 5$LC=11.3E-6 3$MC=
60NI  L 2158.61   3 2+                0.59 PS   17
60NI  B 664.46    210.002                                                  2U
60NIS B EAV=274.8 1 60NI  G 826.10    3 0.0076  8 M1+E2     0.9     3     0.000344
60NI2 G KC=0.0003 4$LC=29.1E-6 17$MC=
60NI  G 2158.57   3 0.0012  2 E2                      49.5E-615
60NI2 G KC=44.5E-6 14$LC=43.E-7 2$MC=
60NI  L 2505.748  5 4+                0.30 PS   9
60NI  B 317.32    2199.88   3           7.51
60NIS B EAV=95.6 1 60NI  G 347.14    7 0.0075  4 [E2]                     0.0055717
60NI2 G KC=0.00499 15$LC=0.000503 15$MC=
60NI  G 1173.228  3 99.85   3 E2(+M3)                0.000164
60NI2 G KC=0.000151 7$LC=14.8E-6 4$MC=
60NI  G 2505.692  5 20.E-7   4 E4                     0.000083
60NI2 G KC=0.000078 3$LC=76.E-7 3$MC=
```

MATRIX REPRESENTATION OF A DECAY SCHEME

ENSDF Format



LNE – LNHB/CEA **Table de Radionucléides** $^{60}_{27}Co_{33}$

http://www.nucleide.org/DDEP_WG/Nuclides/Co-60_tables.pdf

$^{60}_{27}Co_{33}$

1 Decay Scheme

Co-60 disintegrates by beta minus emissions to excited levels of Ni-60.
Le cobalt 60 se désintègre par émission bêta moins vers des niveaux excités de nickel 60.

2 Nuclear Data

$T_{1/2}(^{60}Co)$: 5,2711 (8) a
$Q^-(^{60}Co)$: 2823,07 (21) keV

2.1 β^- Transitions

	Energy keV	Probability × 100	Nature	lg *ft*
$\beta^-_{0,3}$	317,32 (21)	99,88 (3)	Allowed	7,51
$\beta^-_{0,2}$	664,46 (21)	0,002	Unique 2nd Forbidden	
$\beta^-_{0,1}$	1490,56 (21)	0,12 (3)	Unique 2nd Forbidden	14,7

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$I_{\gamma+ce}$ × 100	Multipolarity	α_K (10^{-4})	α_L (10^{-4})	α_T (10^{-4})	α_π (10^{-5})
$\gamma_{3,2}$(Ni)	347,14 (7)	0,0075 (4)	[E2]	49,9 (15)	5,03 (15)	55,7 (17)	
$\gamma_{2,1}$(Ni)	826,10 (3)	0,0076 (8)	M1+45%E2	3,0 (4)	0,291 (17)	3,4 (4)	
$\gamma_{3,1}$(Ni)	1173,240 (3)	99,85 (3)	E2(+M3)	1,51 (7)	0,148 (4)	1,68 (4)	0,62 (7)
$\gamma_{1,0}$(Ni)	1332,508 (4)	99,9988 (2)	E2	1,15 (5)	0,113 (3)	1,28 (5)	3,4 (4)
$\gamma_{2,0}$(Ni)	2158,61 (3)	0,0012 (2)	E2	0,445 (14)	0,043 (2)	0,495 (15)	
$\gamma_{3,0}$(Ni)	2505,748 (5)	0,0000020 (4)	E1	0,780 (3)	0,076 (3)	0,86 (3)	

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MATRIX REPRESENTATION OF A DECAY SCHEME

More suitable, because the formulation was chosen to use the data provided in the database,
www.nucleide.org/DDEP_WG/DDEPdata.htm
***Molto più adatti, anche perché la formulazione è stata appositamente scelta; i dati forniti nel database sono* ormai disponibili su web**
*www.**nucleide.org/DDEP_WG**/DDEPdata.htm*

MATRIX REPRESENTATION OF A DECAY SCHEME

LNE – LNHB/CEA Table de Radionucléides $^{60}_{27}Co_{33}$

3 Atomic Data

3.1 Ni

ω_K : 0,421 (4)
$\bar{\omega}_L$: 0,0084 (4)
n_{KL} : 1,388 (4)

3.1.1 X Radiations

	Energy keV		Relative probability
X_K			
$K\alpha_2$	7,46097		51,24
$K\alpha_1$	7,47824		100
$K\beta_3$	8,2647	}	
$K\beta_5''$	8,3287	}	20,84
X_L			
$L\ell$	0,74		
$L\gamma$	– 0,94		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	6,26 – 6,54	100
KLX	7,20 – 7,47	27,6
KXY	8,10 – 8,32	1,9
Auger L	0,7 – 0,9	329

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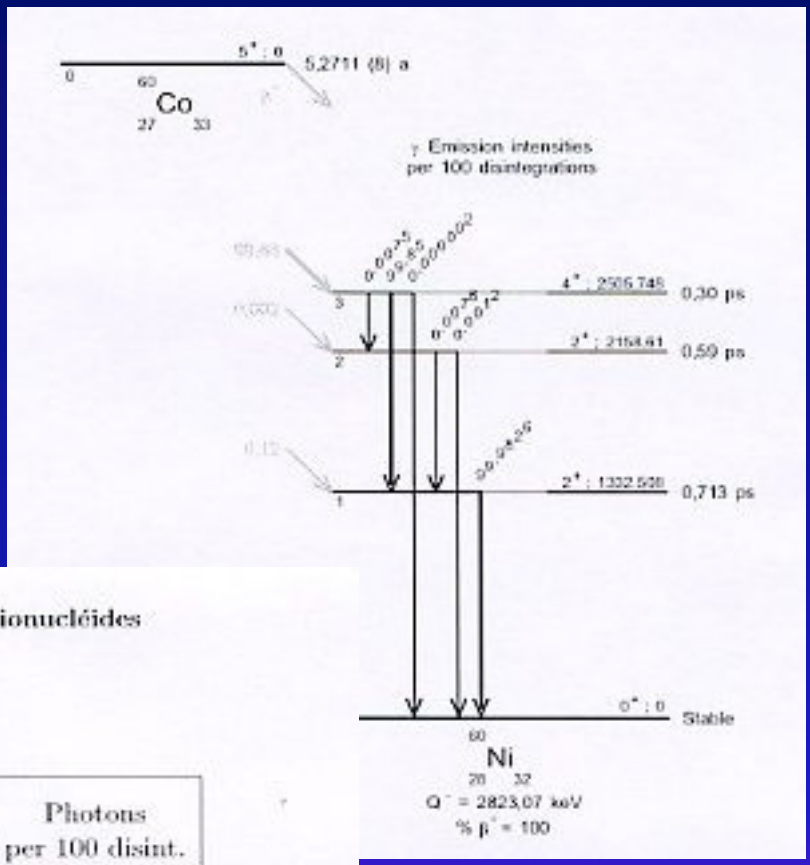
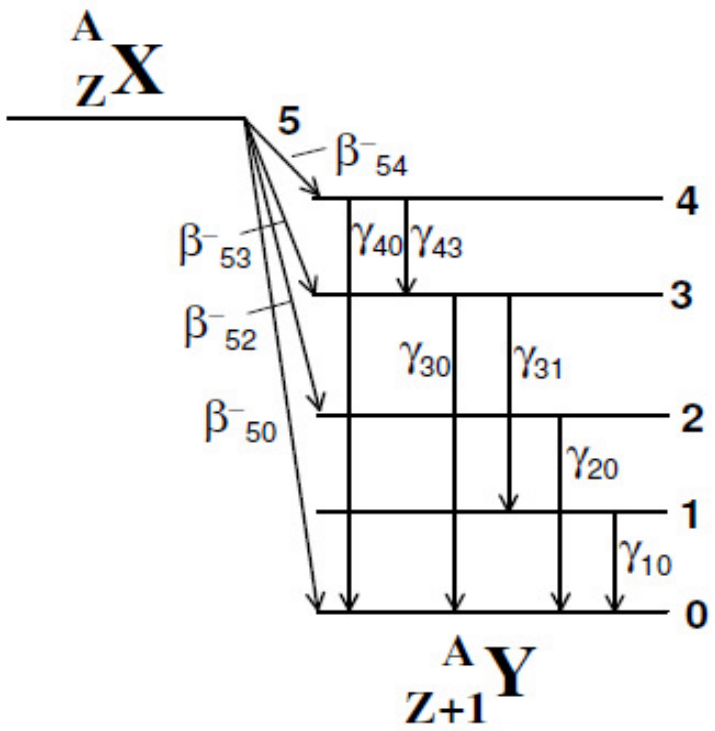


LNE – LNHB/CEA Table de Radionucléides

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{3,2}(Ni)$	347,14 (7)	0,0075 (4)
$\gamma_{2,1}(Ni)$	826,10 (3)	0,0076 (8)
$\gamma_{3,1}(Ni)$	1173,228 (3)	99,85 (3)
$\gamma_{1,0}(Ni)$	1332,492 (4)	99,9826 (6)
$\gamma_{2,0}(Ni)$	2158,57 (3)	0,0012 (2)
$\gamma_{3,0}(Ni)$	2505,692 (5)	0,0000020 (4)

MATRIX REPRESENTATION OF A DECAY SCHEME



I)

	0	1	2	3	4	5
0	E_0	I_{10}	I_{20}	I_{30}	I_{40}	T_0
1	Y_{10}	E_1	0	I_{31}	0	T_1
2	Y_{20}	0	E_2	0	0	T_2
3	Y_{30}	Y_{31}	0	E_3	I_{43}	T_3
4	Y_{40}	0	0	Y_{43}	E_4	T_4
5	Y_{50}	0	Y_{52}	Y_{53}	Y_{54}	

II)

	0	1	2	3	4	5
0		E_{10}	E_{20}	E_{30}	E_{40}	
1	α^K_{10}		0	E_{31}	0	
2	α^K_{20}	0		0	0	
3	α^K_{30}	α^K_{31}	0		E_{43}	
4	α^K_{40}	0	0	α^K_{43}		
5						$T_{½}$

III)

	0	1	2	3	4	5
0		ε^T_{10}	ε^T_{20}	ε^T_{30}	ε^T_{40}	
1	ε^P_{10}		0	ε^T_{31}	0	
2	ε^P_{20}	0		0	0	
3	ε^P_{30}	ε^P_{31}	0		ε^T_{43}	
4	ε^P_{40}	0	0	ε^P_{43}		$\varepsilon^T_{X_K}$
5	0	0	0	0	0	ω_K

CORRECTION EQUATIONS

Equations to compute coincidence-summing correction factor can be obtained for each nuclide taking into account decay data taken mainly from *DDEP/BIPM-5 database (CEA-LMRI, 2004-2008).*

Le equazioni per il calcolo di correzione del fattore di coincidenza-somma possono ottenersi tenendo conto dei dati dal database DDEP/BIPM-5 (CEA-LMRI, 2004-2008).

Equation terms are easy to compute because they are related to transition energy E and not to levels *i* and *j* from which originates.

I termini dell'equazione sono facili da calcolare perché legati all'energia E della transizione e ai livelli i e j.

CORRECTION EQUATIONS

So, information about the decay layout are unnecessary. Each term of equations appears as [1 ± h·ε], where h is a numerical coefficient which depends only on the decay data and ε is an efficiency value (FEPE=Full-Energy_peak efficiency or TE= Total efficiency)

Quindi, le informazioni relative allo schema di decadimento non sono necessari . Ogni fattore dell'equazione si può scrivere come [1 ± h ε], dove h è un coefficiente numerico che dipende soltanto dai dati di decadimento ed ε è un valore di efficienza.

It should point out here that the correction factor, to avoid errors, must be assessed by calculating each term within the brackets and then working the product of various terms.

Si deve precisare che il fattore di correzione, al fine di evitare errori, deve essere valutato calcolando ogni termine entro le parentesi e poi operando il prodotto dei vari termini.

CORRECTION EQUATIONS

To better explain this point, we take as reference an expression whose coefficients are given either in *Schima and Hoppes* (1983) or in *Dryak et al.* (2009), namely the one refers to 604 keV of ^{134}Cs.

Per spiegare meglio questo punto, si prenda come riferimento una espressione i cui coefficienti sono forniti sia in Schima e Hoppes (1983) sia in Dryak et al. (2009), vale a dire l'equazione per l'energia 604 keV del ^{134}Cs.

As efficiency values, we adopt the evaluations referring to "0 cm" efficiency curve, as determined in the next example. *Per le efficienze, saranno adottate le valutazioni riferite alla geometria "0 cm" , le cui curve di efficienza sono riportate nell'esempio appresso riportato.*

CORRECTION EQUATIONS

Schima- Hoppes (1983)

$1/Fs\ (604\ keV\ ^{134}Cs) = [1 - 0.004\ \varepsilon^T(K_X) - 0.074\ \varepsilon^T(563) - 0.160\ \varepsilon^T(569) - 0.890\ \varepsilon^T(796) - 0.075\ \varepsilon^T(802) - 0.032\ \varepsilon^T(1365)] \rightarrow 1.479$

Dryák, *et al. (2009)*

$1/Fs = [1 - 0.004\ \varepsilon^T(L_X) - 0.0032\ \varepsilon^T(K_\alpha) - 0.0008\ \varepsilon^T(K_\beta) - 0.0125\ \varepsilon^T(475) - 0.0854\ \varepsilon^T(563) - 0.1563\ \varepsilon^T(569) - 0.8705\ \varepsilon^T(796) - 0.0728\ \varepsilon^T(802) - 0.0307\ \varepsilon^T(1365) - 0.010\ \varepsilon^T(1038)] \rightarrow 1.4245$

(But if we add a quadratic term $+0.8705 \times 0.1563 \times \varepsilon^T(569\ keV) \times \varepsilon^T(795 keV)$) → 1.407.

Present work

$1/Fs\ (604 keV, ^{134}Cs) = [1 - 0.8706\ \varepsilon^T(795)][1 - 0.1567\ \varepsilon^T(569)][1 - 0.0853\ \varepsilon^T(563)][1 - 0.0726\ \varepsilon^T(802)][1 - 0.0307\ \varepsilon^T(1365)][1 - 0.01257\ \varepsilon^T(475)][1 - 0.0101\ \varepsilon^T(1038)] \rightarrow 1.383$

The results are quite different. However, if the coefficients reported by both authors are composed in the formulation above suggested, i.e a series of products, the results practically coincide.

I risultati sono diversi. Tuttavia, se i coefficienti riportati da entrambi gli autori sono utilizzati nella formulazione suggerita, una serie di prodotti, i risultati praticamente coincidono.

With coefficients of Schima and Hoppes:

$$1/Fs\ (604\ keV\ ^{134}Cs) = [1-0.074\ \varepsilon^T(563)]\ [1-0.160\ \varepsilon^T(569)]\ [1-0.890\ \varepsilon^T(796\ keV)]\ [1-0.075\ \varepsilon^T(802\ keV)]\ [1-0.032\ \varepsilon^T(1365\ keV)]\ [1-0.004\varepsilon^T(K_X)] \rightarrow 1.381.$$

With coefficients of Dryak :

$$1/Fs\ (604keV,^{134}Cs) = [1-0.0854\ \varepsilon^T(563\ keV)]\ [1-0.1563\varepsilon^T(569\ keV)]\ [1-0.8705\varepsilon^T(796\ keV)]\ [1-0.0728\ \varepsilon^T(802\ keV)]\ [1-0.0307\ \varepsilon^T(1365\ keV)]\ [1-0.0125\ \varepsilon^T(475keV)]\ )]\ [1-0.01\ \varepsilon^T(1038\ keV)]\ [1-0.0004\varepsilon^T(L_X)]\ [1-0.0032\ \varepsilon^T(K_\alpha)]\ [1-0.0008\ \varepsilon^T(K_\beta)] \rightarrow 1.383.$$

Therefore, it is confirmed that the differences are related mostly to the different degree of approximation of the relation and only in less part to differences in the characteristic data of decay scheme. As a suggestion, it seems suitable to use a form similar to the one here proposed and the numerical coefficients can be obtained from *Schima and Hoppes* (1983) or *Dryak et al.* (2009) besides those provided by us and included in the cited article in press on "Radiation Physics and Chemistry".

Ciò conferma, pertanto, che le differenze sono dovute principalmente al tipo di formulazione (e diverso grado di approssimazione) e solo in minima parte a differenze nei dati di decadimento.

Come suggerimento, sembra utile utilizzare una formulazione tipo serie di prodotti, i cui coefficienti numerici possono essere ottenuti sia da Schima e Hoppes (1983), sia da Dryak et al. (2009), o utilizzare quelli dati nel presente lavoro e riportati più diffusamente in un articolo in stampa su "Radiation Physics and Chemistry".

Table 1
Expressions of coincidence-summing correction factor for the most intense gamma emissions of a selected set of nuclides. The $[1 \pm h\varepsilon]$ factor with h less than 0.005 are not reported with the exception of γ–X_K terms.

Nuclide	Energy (keV)	I (%)	$F^s(E)$
^{110m}Ag	657.8	94.38	$[1-0.7716\varepsilon^T(884.7)]\,[1-0.3638\,\varepsilon^T(937.5)]\,[1-0.2603\,\varepsilon^T(1384.3)]\,[1-0.2090\,\varepsilon^T(763.9)]\,[1-0.1557\,\varepsilon^T(706.7)]\,[1-0.1372\,\varepsilon^T(1505.0)]\,[1-0.1113\,\varepsilon^T(677.6)]\,[1-0.0764\,\varepsilon^T(818.0)]\,[1-0.0438\,\varepsilon^T(687.0)]\,[1-0.0384\,\varepsilon^T(446.8)]\,[1-0.0320\,\varepsilon^T(744.3)]\,[1-0.0287\,\varepsilon^T(620.4)]\,[1-0.0126\,\varepsilon^T(1562.3)]\,[1-0.0029\,\varepsilon^T_{XK}(23.7)]$
	937.5	34.51	$[1-1.0095\,\varepsilon^T(884.7)]\,[1-0.9948\,\varepsilon^T(657.8)]\,[1-0.1055\,\varepsilon^T(446.8)]\,[1-0.0041\,\varepsilon^T_{XK}(23.7)]$
	1384.3	24.70	$[1-1.0095\,\varepsilon^T(884.7)]\,[1-0.9948\,\varepsilon^T(657.8)]\,[1+0.4258\,\varepsilon^P(677.6)\,\varepsilon^P(706.7)/\varepsilon^P(1384.3)]\,[1+0.1473\,\varepsilon^P(937.5)\,\varepsilon^P(446.8)/\varepsilon^P(1384.3)][1+0.1096\,\varepsilon^P(620.4)\,\varepsilon^P(763.9)/\varepsilon^P(1384.3)]\,[1-0.0034\,\varepsilon^T_{XK}(23.7)]$
^{198}Au	411.8	95.54	$[1-0.0081\,\varepsilon^T(675.9)]$
^{133}Ba	81.0	32.90	$[1-0.6831\,\varepsilon^T(356.0)]\,[1-0.2019\,\varepsilon^T(302.9)]\,[1-0.0691\,\varepsilon^T(276.4)]\,[1-0.0292\,\varepsilon^T(79.6)]\,[1-0.0161\,\varepsilon^T(53.2)]\,[1-0.7507\,\varepsilon^T_{XK}(31.7)]$
	302.9	18.34	$[1-0.3622\,\varepsilon^T(81.0)]\,[1-0.0746\,\varepsilon^T(53.2)]\,[1+0.0078\,\varepsilon^P(79.6)\,\varepsilon^P(223.2)/\varepsilon^P(302.9)]\,[1-1.4541\,\varepsilon^T_{XK}(31.7)]$
	356.0	62.05	$[1-0.3622\,\varepsilon^T(81.0)]\,[1+0.0365\,\varepsilon^P(79.6)\,\varepsilon^P(276.4)/\varepsilon^P(356.0)]\,[1+0.0220\,\varepsilon^P(302.9)\,\varepsilon^P(53.2)/\varepsilon^P(356.0)]\,[1-1.0887\,\varepsilon^T_{XK}(31.7)]$
^{140}Ba	162.7	6.26	$[1-0.5107\,\varepsilon^T(304.9)]\,[1-0.0092\,\varepsilon^T(113.5)]\,[1+0.005\,\varepsilon^P(30.0)\,\varepsilon^P(132.7)/\varepsilon^P(162.7)]\,[1-0.0260\,\varepsilon^T_{XK}(34.2)]$
	537.3	24.39	$[1-0.1548\,\varepsilon^T(30.0)]\,[1-0.0172\,\varepsilon^T(13.9)]$
^{207}Bi	569.7	97.76	$[1-0.7465\,\varepsilon^T(1063.7)]\,[1-0.0688\,\varepsilon^T(1770.2)]\,[1-0.7305\,\varepsilon^T_{XK}(76.6)]$
	1063.7	74.58	$[1-0.9785\,\varepsilon^T(569.7)]\,[1-0.7205\,\varepsilon^T_{XK}(76.6)]$
^{212}Bi	727.7	6.64	$[1-0.1625\,\varepsilon^T(785.5)]\,[1-0.0805\,\varepsilon^T(1078.6)]\,[1-0.0556\,\varepsilon^T(893.4)]\,[1-0.0205\,\varepsilon^T(952.3)]\,[1-0.0081\,\varepsilon^T_{XK}(81.9)]$
^{214}Bi	609.3	45.49	$[1-0.3269\,\varepsilon^T(1120.3)]\,[1-0.1278\,\varepsilon^T(1238.1)]\,[1-0.1073\,\varepsilon^T(768.4)]\,[1-0.068\,\varepsilon^T(934.1)]\,[1-0.0524\varepsilon^T(1408.0)]\,[1-0.0467\,\varepsilon^T(1509.2)]\,[1-0.0358\,\varepsilon^T(1155.2)]\,[1-0.0335\,\varepsilon^T(665.4)]\,[1-0.0315\,\varepsilon^T(1281.0)]\,[1-0.0292\,\varepsilon^T(1401.5)]\,[1-0.0277\varepsilon^T(806.1)]\,[1-0.0174\,\varepsilon^T(1385.3)]\,[1-0.0155\varepsilon^T(1583.2)]\,[1-0.0134\varepsilon^T(1207.6)]\,[1-0.0133\varepsilon^T(703.2)]\,[1-0.0116\varepsilon^T(719.9)]\,[1-0.0088\varepsilon^T(1538.5)]\,[1-0.0085\varepsilon^T(454.8)]\,[1-0.0075\varepsilon^T(1838.4)]\,[1-0.0074\varepsilon^T(388.9)]\,[1-.0071\varepsilon^T(1052.0)]\,[1-0.0071\varepsilon^T(1599.3)]\,[1-0.0060\varepsilon^T(1594.8)][1-0.0056\,\varepsilon^T(1133.7)]\,[1-0.0126\,\varepsilon^T_{XK}(81.0)]$
	1120.3	14.91	$[1-0.9973\,\varepsilon^T(609.3)]\,[1-0.02164\,\varepsilon^T(388.9)]\,[1-0.0069\,\varepsilon^T(752.8)][1-0.0051\,\varepsilon^T(474.5)]\,[1+0.0258\,\varepsilon^P(665.4)\,\varepsilon^P(454.8)/\varepsilon^P(1120.3)]\,[1-0.0191\,\varepsilon^T_{XK}(81.0)]$
	1764.5	15.31	$[1-0.0208\,\varepsilon^T(964.1)]\,[1+0.1065\,\varepsilon^P(609.3)\,\varepsilon^P(1155.2)/\varepsilon^P(1764.5)]\,[1+0.0091\,\varepsilon^P(1377.7)\,\varepsilon^P(386.8)/\varepsilon^P(1764.5)]$
^{82}Br	554.4	70.60	$[1-0.7833\,\varepsilon^T(776.5)]\,[1-0.6133\,\varepsilon^T(619.1)]\,[1-0.3925\,\varepsilon^T(698.4)]\,[1-0.3824\,\varepsilon^T(1317.5)]\,[1-0.2267\,\varepsilon^T(1474.9)]\,[1-0.0116\,\varepsilon^T(1044.0)]\,[1-0.0115\,\varepsilon^T(273.5)]\,[1-0.0015\,\varepsilon^T_{XK}(12.8)]$
	776.5	83.40	$[1-0.6631\varepsilon^T(554.3)]\,[1-0.3384\,\varepsilon^T(698.4)]\,[1-0.3294\,\varepsilon^T(619.1)][1-0.3277\,\varepsilon^T(1044.0)]\,[1-0.3217\varepsilon^T(1317.5)]\,[1-0.2869\varepsilon^T(827.8)]\,[1-0.0253\,\varepsilon^T(221.5)]\,[1-0.0151\,\varepsilon^T(1007.5)]\,[1-0.0149\,\varepsilon^T(606.3)]\,[1-0.0096\,\varepsilon^T(273.5)]\,[1-0.0089\,\varepsilon^T(1650.3)]\,[1-0.0068\,\varepsilon^T(92.2)]\,[1-0.0012\,\varepsilon^T_{XK}(12.8)]$

E. Tomarchio and S. Rizzo - Coincidence-summing correction equations in gamma-ray spectrometry with p-type HPGe detectors . In press on Radiation Physics and Chemistry, available on-line from 30 September 2010.

Table 1. True summing probability Pc and Ps

Na-22 : coincidence of the E0 with E1

E0=1274.6

E1	Pc
LX(Ne)	0.0000
KXα(Ne)	0.0014
KXβ(Ne)	0.0000
511.0	0.8987

Na-24 : coincidence of the E0 with E1

E0=1368.6		E0=2754.0	
E1	Pc	E1	Pc
LX(Mg)	0.0000	0.1	0.0000
KXα(Mg)	0.0000	1.2	0.0000
KXβ(Mg)	0.0000	1.3	0.0000
2754.0	0.9994	1368.6	1.0000

Sc-46 : coincidence of the E0 with E1

E0=889.3		E0=1120.6	
E1	Pc	E1	Pc
LX(Ti)	0.0000	0.5	0.0000
KXα(Ti)	0.0000	4.5	0.0000
KXβ(Ti)	0.0000	4.9	0.0000
1120.6	0.9997	889.3	0.9998

Cr-51 : coincidence of the E0 with E1

E0=320.1

E1	Pc
LX(V)	0.0050
KXα(V)	0.2011
KXβ(V)	0.0269

Fe-52 : coincidence of the E0 with E1

E0=168.7		E0=1434.1	
E1	Pc	E1	Pc
LX(Mn)	0.0029	LX(Cr)	0.0001
KXα(Mn)	0.1100	KXα(Cr)	0.0039
KXβ(Mn)	0.0149	KXβ(Cr)	0.0006
511.0	0.5596	511.0	0.9842

Ce-139 : coincidence of the E0 with E1

E0=165.9

E1	Pc
LX(La)	0.0706
KXα(La)	0.5721
KXβ(La)	0.1287

Eu-152 : coincidence of the E0 with E1

E0=121.8		E0=244.7	
E1	Pc	E1	Pc
LX(Sm)	0.1283	5.6	0.1941
KXα(Sm)	0.6181	39.9	0.8445
KXβ(Sm)	0.1546	45.6	0.2112
244.7	0.1232	121.8	0.4620
444.0	0.0271	295.9	0.0126
688.7	0.0136	444.0	0.0381
867.4	0.0691	488.7	0.0141
964.1	0.2337	656.5	0.0172
1005.2	0.0108	674.6	0.0205
1112.1	0.2183	719.4	0.0317
1212.9	0.0231	867.4	0.5061
1408.0	0.3397	926.3	0.0344
		1005.2	0.0793
		1212.9	0.1692

E0=344.3		E0=778.9	
E1	Pc	E1	Pc
LX(Gd)	0.0007	LX(Gd)	0.0054
KXα(Gd)	0.0031	KXα(Gd)	0.0222
KXβ(Gd)	0.0008	KXβ(Gd)	0.0057
411.1	0.0815	344.3	0.9616
503.5	0.0049	520.2	0.0039
520.2	0.0019		
586.3	0.0169		
678.6	0.0171		
764.8	0.0067		
778.9	0.4680		
989.7	0.0011		
1089.7	0.0626		
1299.1	0.0590		

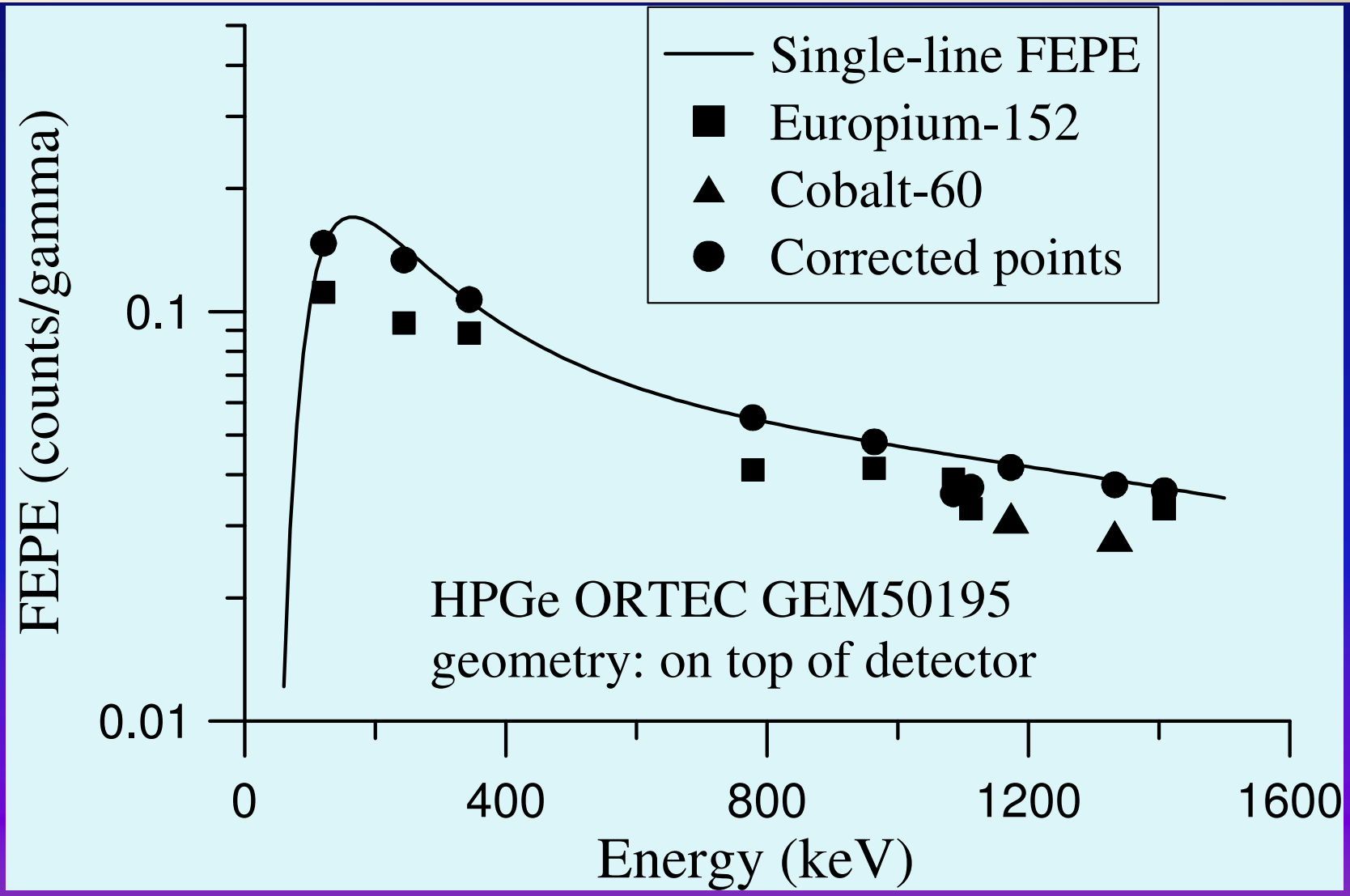
P. Dryak, P. Kovar (2009) – Table for true summation effect in gamma-ray spectrometry – *Journal of Radionalytical and Nuclear Chemistry*, 279 (2) , 385-394

Present work

Energy (keV)	Intensity (%)	Coincident with Energy (keV)	Summing Coefficient	Coincident with Energy (keV)	Summing Coefficient	Coincident with Energy (keV)	Summing Coefficient
657.8	94.38	*884.7*	0.7716	*937.5*	0.3638	*1384.3*	0.2603
		763.9	0.2090	*706.7*	0.1557	*1505.0*	0.1372
		677.6	0.1113	*818.0*	0.0764	*687.0*	0.0438
		446.8	0.0384	*744.3*	0.0320	*620.4*	0.0287
		1562.3	0.0126				
937.5	34.51	*884.7*	1.0095	*657.8*	0.9948	*446.8*	0.1055
1384.3	24.70	*884.7*	1.0095	*657.8*	0.9948	*677.6; 706.7*	0.4258
		937.5; 446.8	0.1473	*620.4; 763.9*	0.1096		

EXPERIMENTAL VALIDATION OF COINCIDENCE EQUATIONS

Corrected efficiency values for ^{60}Co and ^{152}Eu are almost equal to the ones of the "single-line" efficiency curve.



Application of equations

To use equations for *point sources* is needed to introduce, for a given measurement geometry and for each energy, point source FEPE or TE values. The last values can be derived from suitable calibration curves $\varepsilon^T(E)$ and $\varepsilon^P(E)$ obtained through a proper fit of spectrometric measurement data of "single-line" radionuclide.

L'impiego delle equazioni per sorgenti puntiformi è immediato, basta introdurre, per una geometria di misura, i rispettivi valori di efficienza FEPE o TE, relativi all'energia specificata. Questi valori possono essere ricavati da adatte curve di calibrazione di $\varepsilon^T(E)$ and $\varepsilon^P(E)$ *ottenute tramite misure spettrometriche di radionuclidi "single-line" .*

Application of equations

The equations cannot be applied to *extended volume sources*, as the effect of coincidence is related to coincident photons emitted from a point on the source. The average efficiency over the entire volume can not be used. However, any source volume can be considered composed of many volumes *dV* located at a distance r.

Le equazioni non possono essere applicate alle sorgenti di volume perché l'effetto di coincidenza è collegato a fotoni emessi in coincidenza da uno stesso punto della sorgente.

*Non possono quindi essere impiegate le efficienze mediate sull'intero volume. Tuttavia, qualsiasi volume può essere considerato composto da molti volumi piccoli (dV) posti a distanza **r** .*

Application of equations

The relations return to be valid for each elementary volume, considered as a point source, with the condition to know $\varepsilon^T(E,\mathbf{r})$ and $\varepsilon^P(E,\mathbf{r})$ efficiency behaviours as function of position besides that of the attenuation factor as function of energy and sample matrix composition, if required. Unfortunately, the experimental determination of $\varepsilon^T(E,\mathbf{r})$ and $\varepsilon^P(E,\mathbf{r})$ is a difficult and tedious task, and with a rather complex data analysis.

Le relazioni possono essere considerate valide per ogni volume elementare, considerato come una sorgente puntiforme, con la condizione di conoscere gli andamenti $\varepsilon^T(E,\mathbf{r})$ and $\varepsilon^P(E,\mathbf{r})$, oltre che i fattori di attenuazione in funzione della composizione di energia e matrice del campione, se necessario. Purtroppo, la determinazione sperimentale degli andamenti $\varepsilon^T(E,\mathbf{r})$ and $\varepsilon^P(E,\mathbf{r})$ è un compito difficile e noioso, e con una analisi piuttosto complessa dei dati.

Application of equations

The assessment of efficiency behaviours performed with efficiency transfer, Monte Carlo methods or others, lets we to propose the use of equations for volume sources by substituting FEPE and TE with the corresponding "effective FEPE" and "effective TE" as defined in (*Arnold and Sima*, 2001).

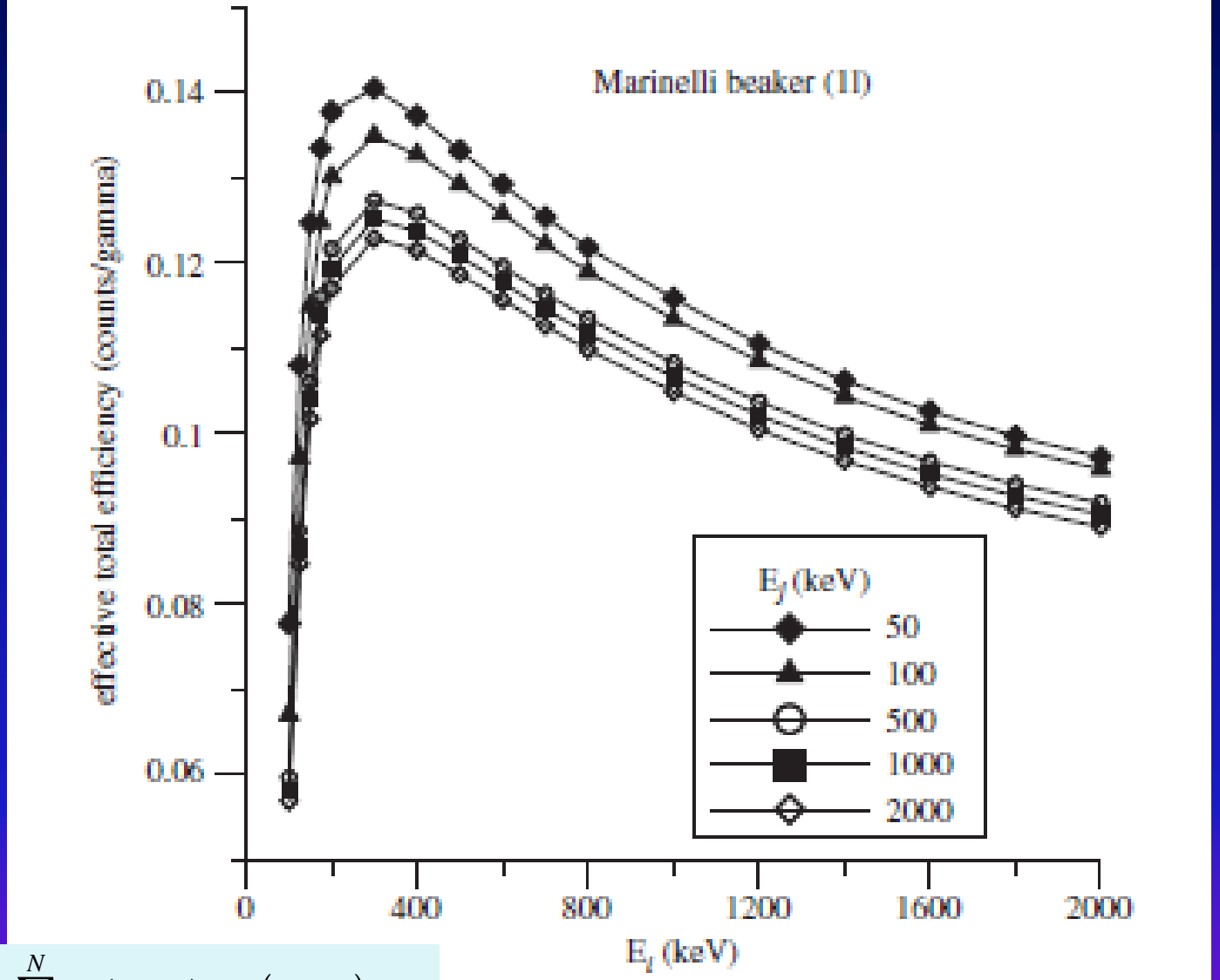
La valutazione degli andamenti delle efficienze, effettuata con codici Monte carlo o di trasferimento di efficienza, ci ha indotti a usare le equazioni sostituendo FEPE e TE con il corrispondente "FEPE efficace" e "TE efficace" come definito nella (Arnold e Sima, 2001).

$$\varepsilon_T^{eff}\left(E_i,E_j,V\right)=\frac{\int\varepsilon_p\left(E_i,\vec{r}\right)\cdot\varepsilon_T\left(E_j,\vec{r}\right)dV}{\int\varepsilon_p\left(E_i,\vec{r}\right)dV}\approx\frac{\sum_{i=1}^{N}\varepsilon_p\left(E_i,\vec{r}_i\right)\cdot\varepsilon_T\left(E_j,\vec{r}_i\right)\Delta V_i}{\sum_{i=1}^{N}\varepsilon_p\left(E_i,\vec{r}_i\right)\Delta V_i}$$

$$\varepsilon_p^{eff}\left(E_p,E_q,V\right)=\frac{\int\varepsilon_p\left(E_p,\vec{r}\right)\cdot\varepsilon_p\left(E_q,\vec{r}\right)dV}{\int\varepsilon_p\left(E_p+E_q,\vec{r}\right)dV}\approx\frac{\sum_{i=1}^{N}\varepsilon_p\left(E_p,\vec{r}_i\right)\cdot\varepsilon_p\left(E_q,\vec{r}_i\right)\Delta V_i}{\sum_{i=1}^{N}\varepsilon_p\left(E_p+E_q,\vec{r}_i\right)\Delta V_i}$$

Application of equations

S. Rizzo, E. Tomarchio Applied Radiation and Isotopes, 68 (2010), 555-560.



$$\varepsilon_T^{eff}\left(E_i,E_j,V\right)=\frac{\int\varepsilon_p\left(E_i,\vec{r}\right)\cdot\varepsilon_T\left(E_j,\vec{r}\right)dV}{\int\varepsilon_p\left(E_i,\vec{r}\right)dV}\approx\frac{\sum_{i=1}^{N}\varepsilon_p\left(E_i,\vec{r}_i\right)\cdot\varepsilon_T\left(E_j,\vec{r}_i\right)\Delta V_i}{\sum_{i=1}^{N}\varepsilon_p\left(E_i,\vec{r}_i\right)\Delta V_i}$$

Application of equations

As *Gelsema* (2001) well stated, this approach is generally not valid because the whole equation must be weighted volume-averaged or a different approach may be used (i.e. Monte Carlo simulation code, an efficiency transfer method and so on).

Come Gelsema (2001) ha giustamente affermato, questo approccio non è generalmente valido perché si deve mediare l'intera equazione sul volume o deve essere usato un approccio diverso (un codice Monte Carlo, un metodo di trasferimento di efficienza, etc.).

Although in some cases the relations may still be used, the most meaningful way of determining correction factors for extended sources seems to be obtain them directly from MC simulation using existing efficiency transfer or others commercially available codes.

Anche se in alcuni casi abbastanza semplici le relazioni possono essere ancora utilizzate, sembra più significativo determinare i fattori di correzione per sorgenti estese direttamente da una simulazione MC o altri codici disponibili in commercio.

A case study – Determination of correction factor trends as a function of distance

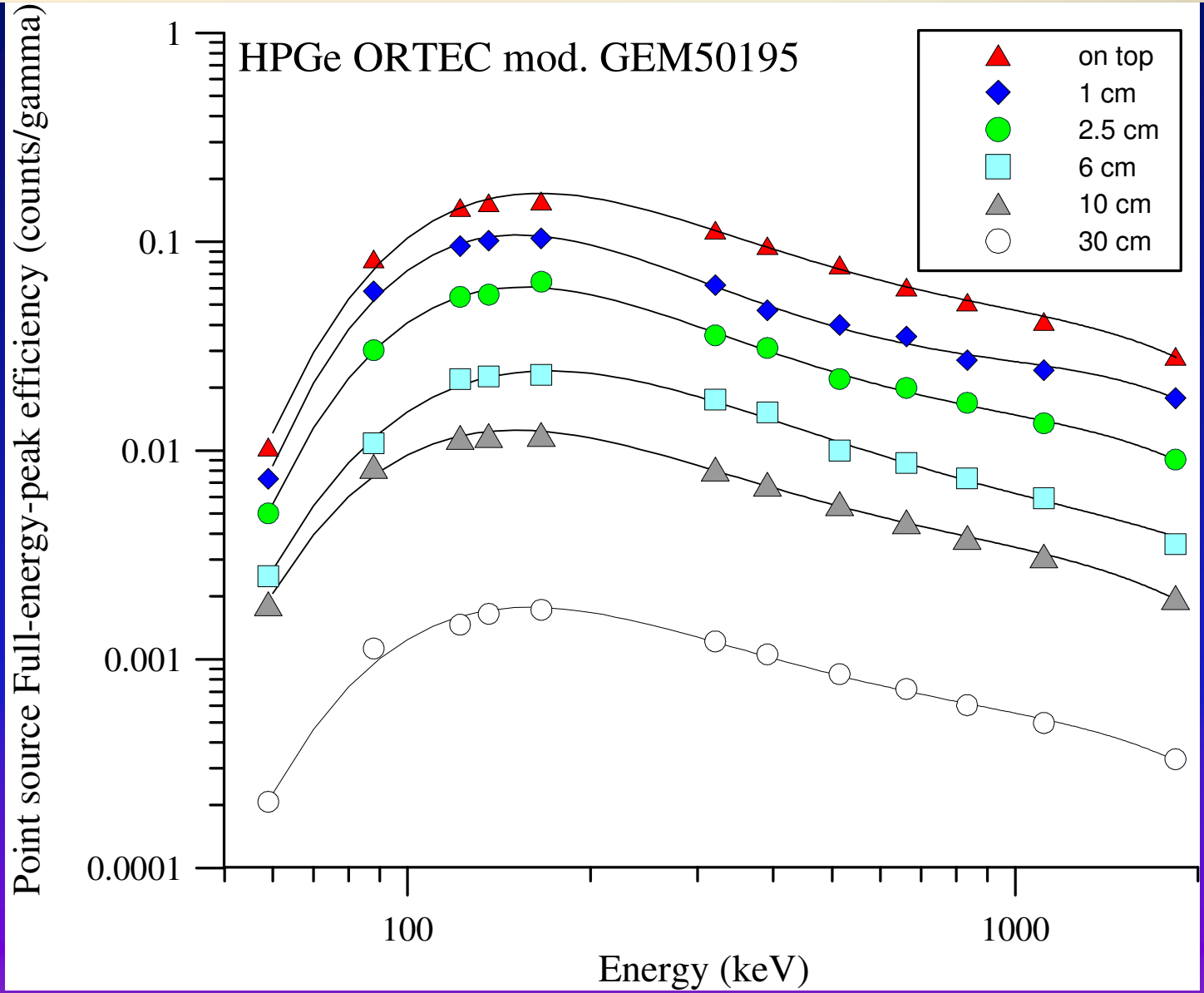
POINT SOURCES

FEPE and TE calibration parameters for HPGe detectors can be determined through spectrometric measurements of "single-line" point sources whose activity value was adequate to close geometry measurements.

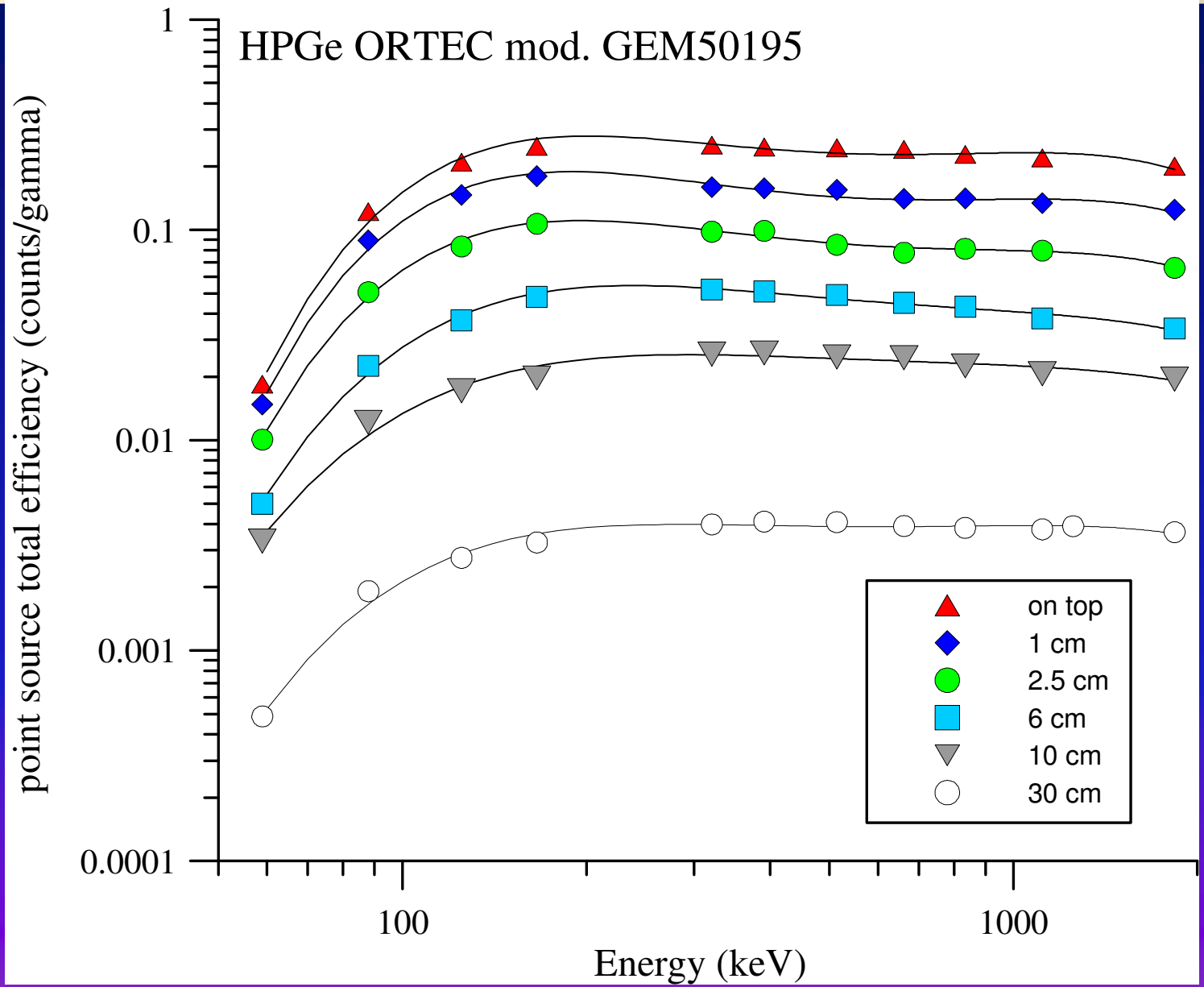
Experimental determination of FEPE and TE can be performed by using, for example, a sources kit provided by CEA, code 9CH04-EGEA10, composed of the following sources: ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{113}Sn, ^{137}Cs, ^{54}Mn, ^{65}Zn.

In addition, to extend the energy range, can be also used a source of ^{88}Y of the same type.

FEPE calibration curve



TE calibration curve



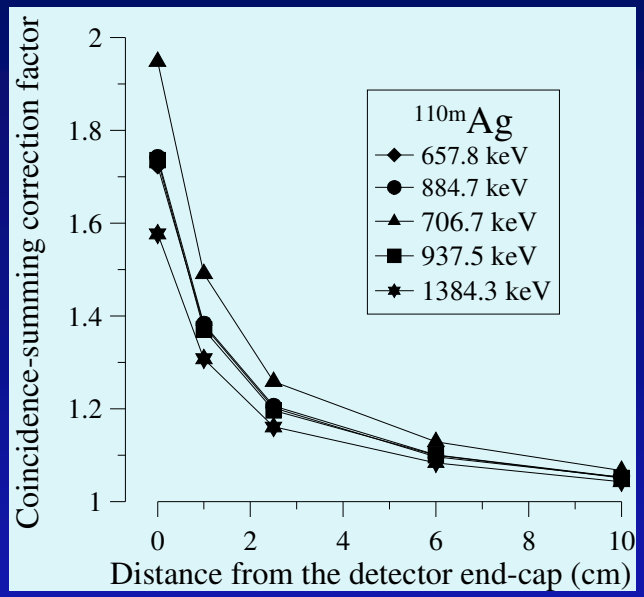
Coincidence correction factor trends

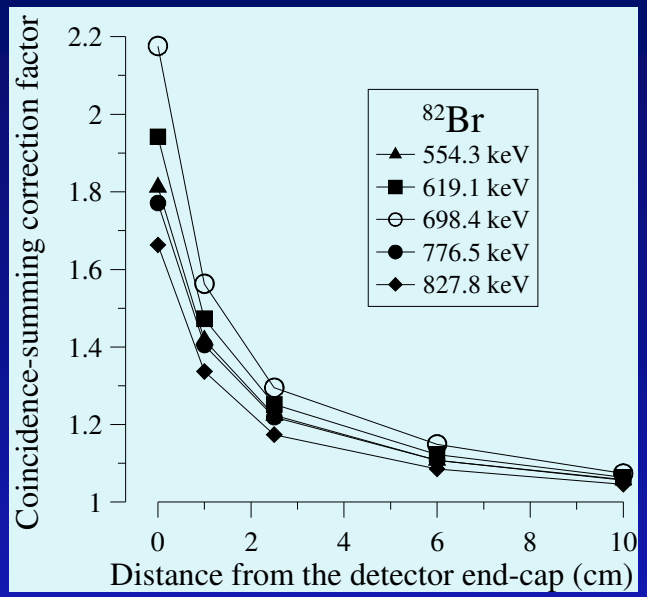
POINT SOURCES

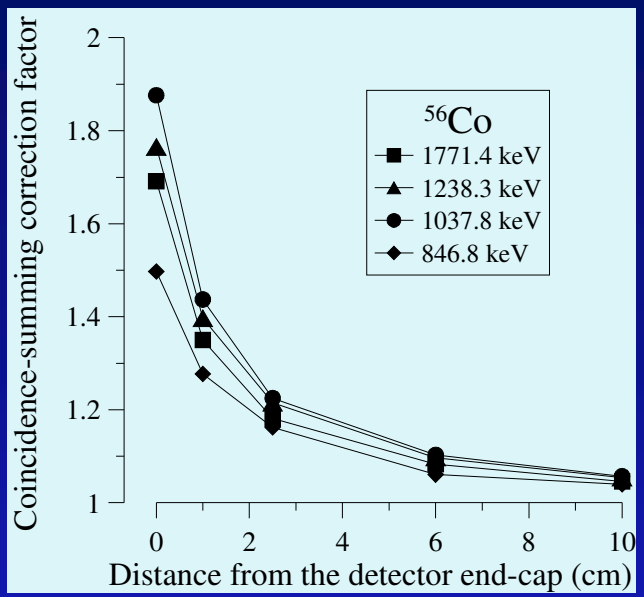
With the FEPE and TE efficiency trends it is easy to assess the correction factors by using the relations and determine a possible variation with distance. In this way, some curves can be obtained as those shown in the figures below for some nuclides

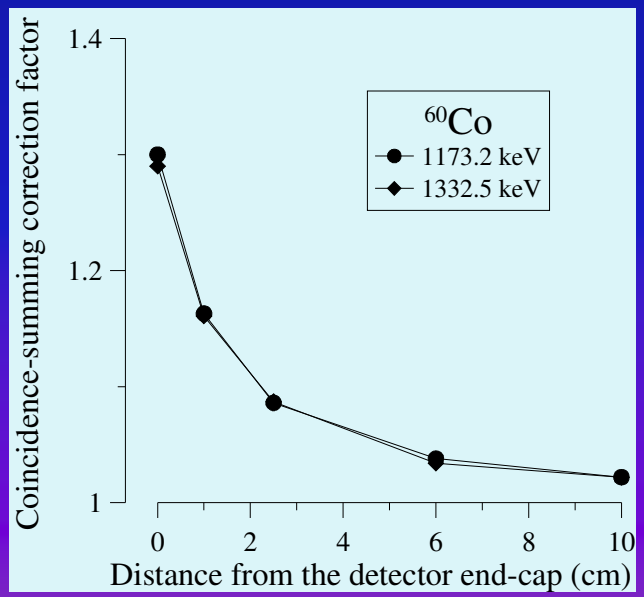
Determinate le efficience FEPE e TE in funzione dell'energia, tramite le equazioni è facile valutare i coefficienti di correzione e determinare una loro variazione con la distanza. In questo modo sono state ricavate alcune curve come quelle riportate nelle seguenti figure per alcuni radionuclidi .

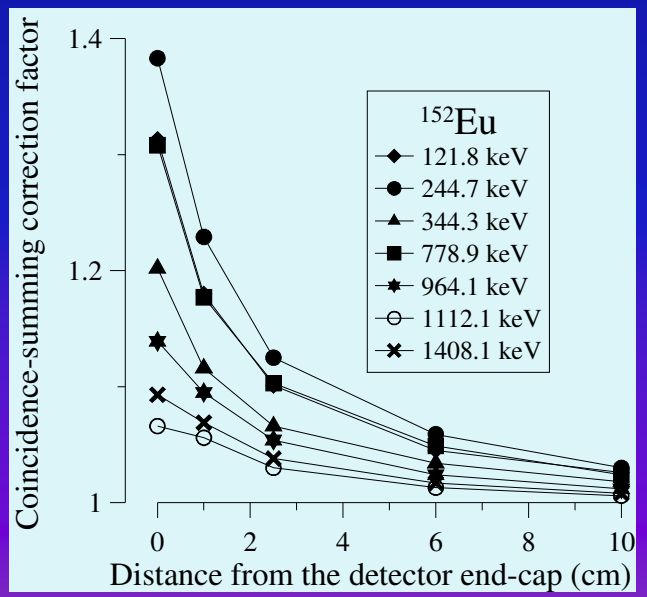
Correction factor trends as a function of distance

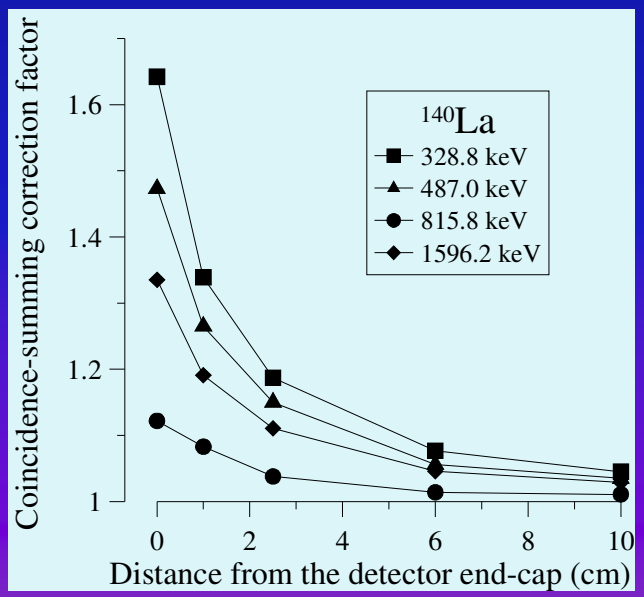






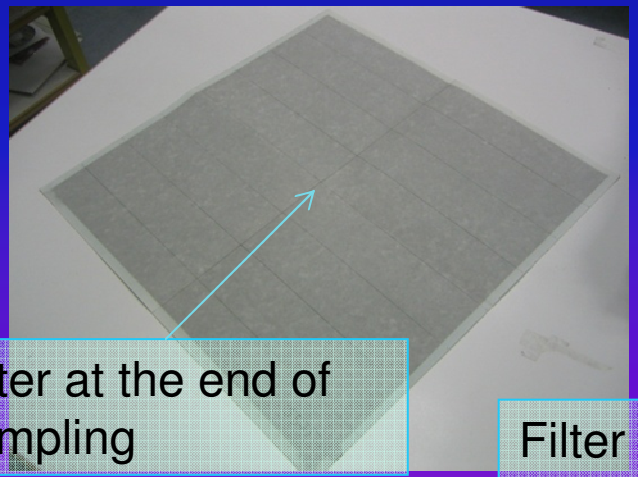




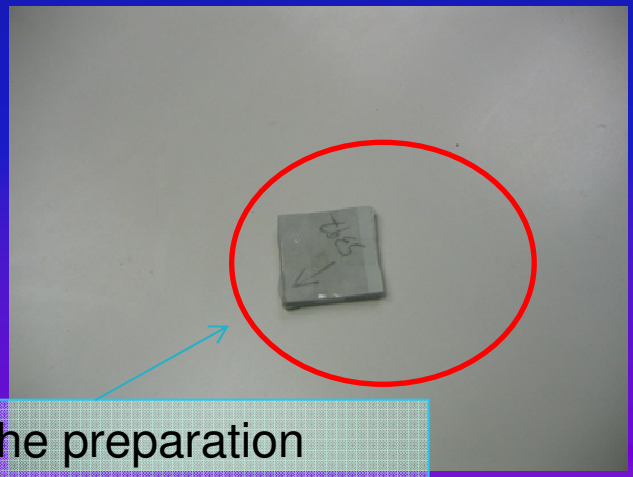


A case study - Volume source

One of more difficult problem to be solved is the determination of a "single-line" efficiency curve for an extended volume sample. In this example, we consider a measurement geometry largely used in a research activity carried out for many years and concerning air particulate radioactivity sampling and measurement, in particular during the days following the Chernobyl accident. The measurement geometry was identified as **"packet-sample"** in our works (e.g. *Cannizzaro et al.*, 1994; *Rizzo et al.*, 2010)



Filter at the end of sampling



Filter after the preparation (packet-sample)

Volume source

To derive an efficiency curve at the distance of 2 cm, it was decided to use activity data of some radionuclides retained like "single-line" and identified in a filter measured at 25 cm distance. With reference to their gamma emissions, the radionuclides considered are: ^{141}Ce (133 keV), ^{144}Ce (145 keV), ^{132}Te (228 keV), ^{131}I (364 keV), ^{103} Ru(497 keV), ^{140}Ba (537 keV), ^{137}Cs (662 keV), ^{95}Nb(765 keV).

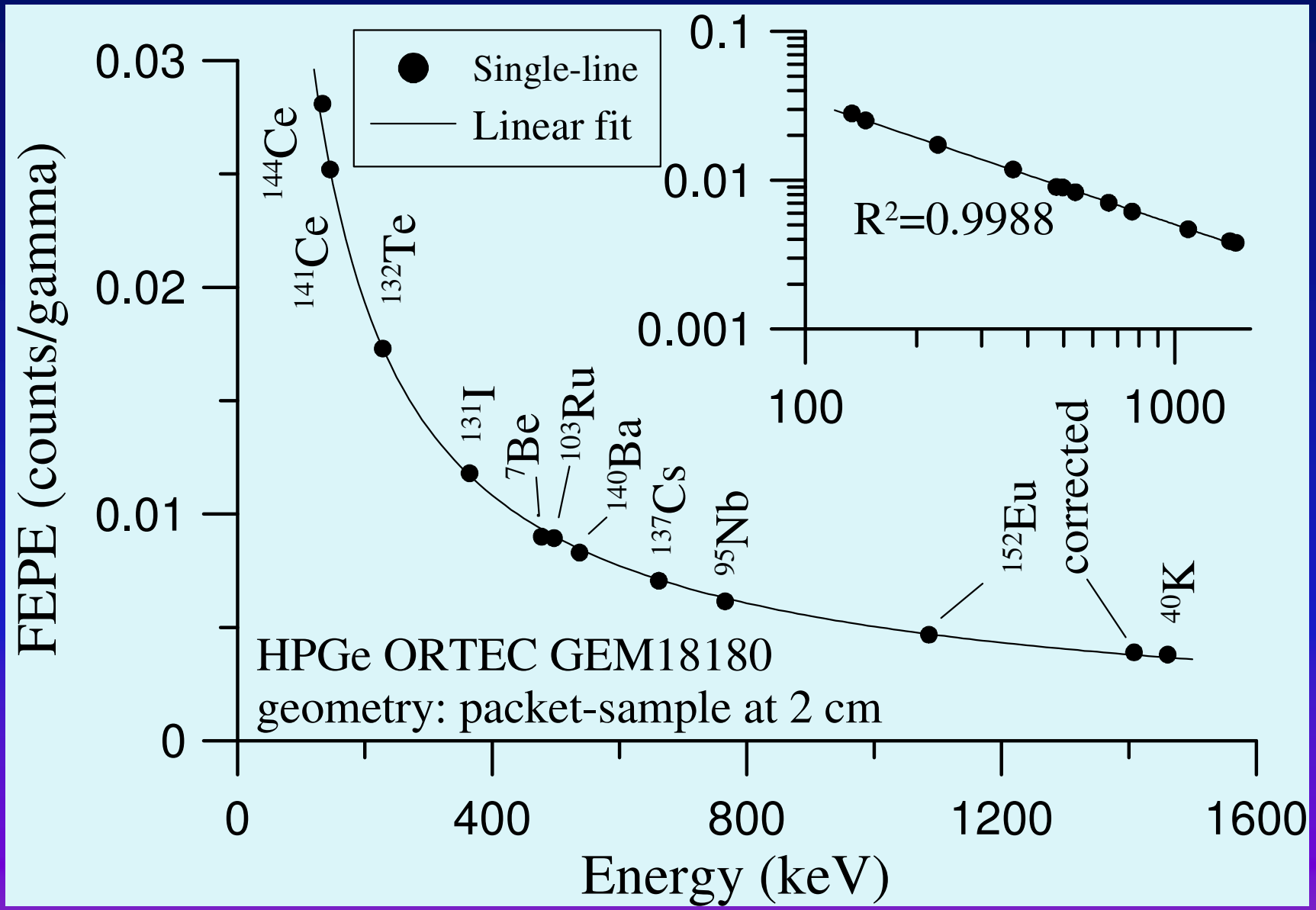
Per ottenere una curva di efficienza alla distanza di 2 cm, si è deciso di utilizzare dati relativi all'attività di alcuni radionuclidi da considerare "single-line" quantificati in un filtro misurato a 25 cm di distanza. Con riferimento alle loro emissioni gamma, i radionuclidi considerati sono: ^{141}Ce (133 keV), ^{144}Ce (145 keV), ^{132}Te (228 keV), ^{131}I (364 keV), ^{103}Ru(497 keV), ^{140}Ba (537 keV), ^{137}Cs (662 keV), ^{95}Nb(765 keV).

Volume source

To these was successfully added ^{7}Be (477 keV) previously determined and ^{40}K (1460 keV) by measuring a second standard set up adding a small quantity of KCl to a blank filter. Other two values were also considered from the $^{152\text{-}154}$Eu standard, at 1112 and 1408 keV energies. Suitable corrections for the last values were obtained by using CORCO program (*Lepy et al.*, 1987) and considering an equivalent cylindrical geometry.

A questi è stato aggiunta la determinazione precedente di ^{7}Be(477 keV) e quella di ^{40}K (1460 keV) misurando un secondo standard realizzato aggiungendo una piccola quantità di KCl a un filtro in bianco. Altri due valori sono stati considerati da uno standard $^{152\text{-}154}$Eu, a 1112 e 1408 keV energie. Le correzioni per gli ultimi valori sono stati ottenuti utilizzando il programma CORCO (Lepy et al., 1987) e considerando una geometria cilindrica equivalente.

A case study – packet-sample single-line efficiency



Thank you for your attention !

Grazie per l'attenzione!

Coincidence-summing corrections in high resolution gamma-ray spectrometry: simplified analytical expressions

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