Improvement of gamma efficiency curves by maximizing the number of data-points

András KOCSONYA
HUN-REN Centre for Energy Research (earlier KFKI)
Budapest, Hungary

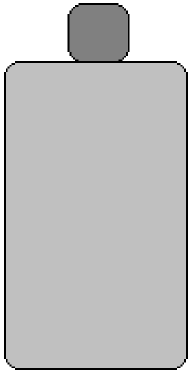
Agenda

- physical ↔ computational calibration
- physical calibration with radionuclide standards
- relative efficiency curve with natural uranium ore
- distance scaling and angular dependence
- analytical fit of efficiency curve

Physical calibration

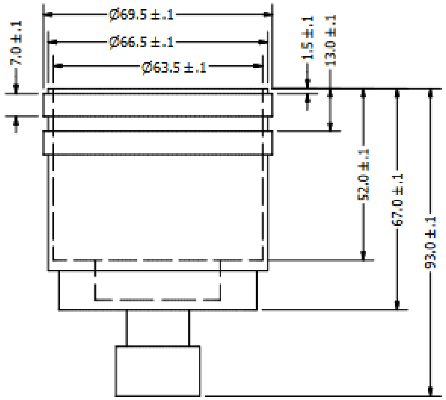
Certified calibration standard is needed
for all sample geometries
preferably with similar composition and density
Standard activities should be selected as:
- satisfactory counting statistics in reasonable acquisition time
- not too high dead time

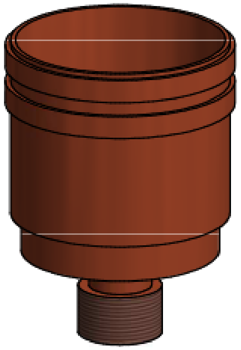
Special sample geometries:
dedicated calibration standard should be prepared



Computational calibration

Detector characterisation is needed
+ exact model of the measurement geometry
with dimensions, composition and density of
all layers between / around the sample and
the detector





Computational calibration is quick, flexible,
new sample geometries can be easily added
No radioactive sources are needed
-> no licences are needed

Several computer codes are available:
LabSOCS, EFFTran, Geant4, GESPECOR, DECCA

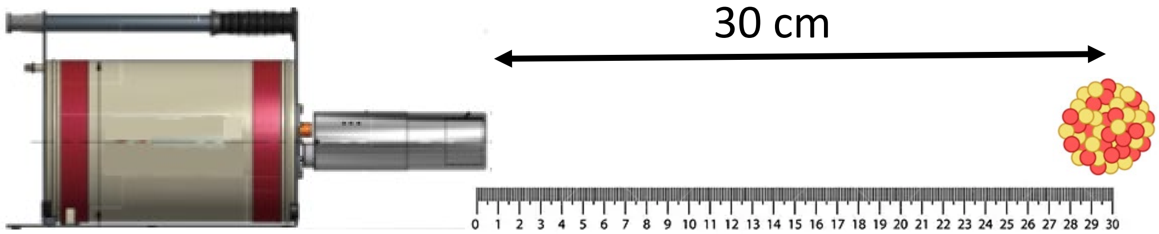
Physical calibration with certified reference standards

Due to the limitations of computational calibration, physical calibration is still inevitably neeed:

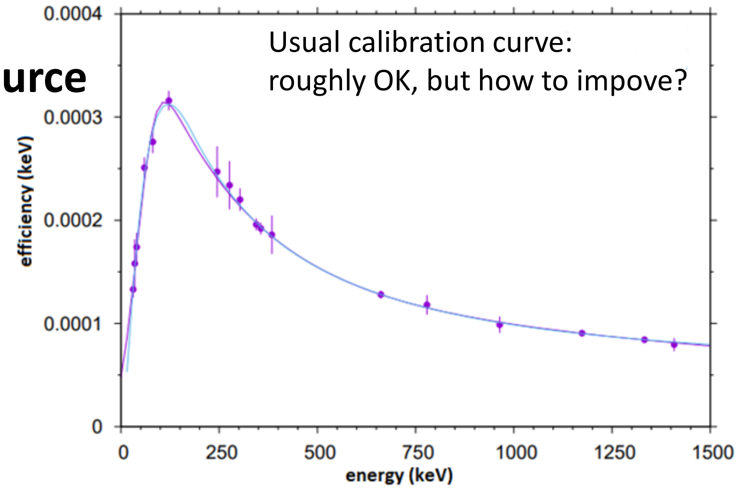
- as starting point for calculations
- to verify the calculated efficiencies

Purpose of current work:

to establish a reliable efficiency calibration curve with point source



point-like standard from 30 cm distance



Usual calibration curve:
roughly OK, but how to impove?

- as **many energy-efficiency data-points** as possible:
  - short energy-steps, mainly in energy regions where the efficiency curve changes rapidly
    - low energy region (below the maximum)
    - just over the maximum (significant slope of the efficiency curve)
    - near to the maximum, to prevent to overstep the maximum
- **wide energy range**: modern thin window gamma-detectors can detect downto few keV energies
  - gamma- and X-ray lines are mixed

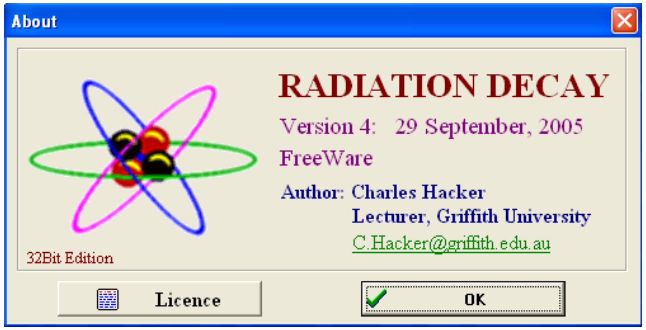
more direct experimental data – less interpolation / extrapolation

Gamma efficiency curve with radionuclide standards

Typical radionuclide standards for calibration purposes: certificates of activities are needed

Nuclide	$T_{1/2}$	decay mode
^{152}Eu	13.537 y	β^-, EC
^{133}Ba	10.51 y	EC
^{60}Co	5.27 y	β^-
^{137}Cs	30.07 y	β^-
^{241}Am	432.2 y	α, SF
^{57}Co	0.744 y	EC
^{22}Na	2.602 y	β^+, EC
^{88}Y	106.65 d	β^+, EC
^{109}Cd	462.6 d	EC

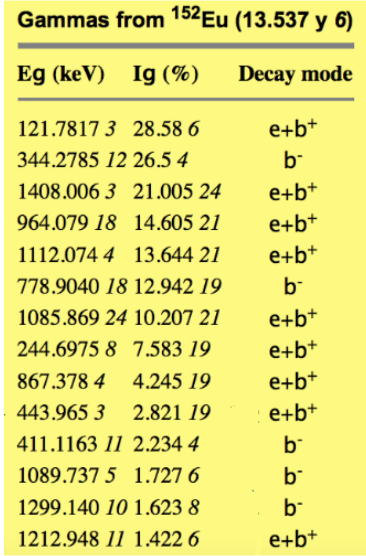
Nuclide
activity ± uncertainty
Reference date



RADIATION DECAY
Version 4: 29 September, 2005
FreeWare
Author: Charles Hacker
Lecturer, Griffith University
C.Hacker@griffith.edu.au
32Bit Edition

nucleide.org
Laboratorie National Henri Becquerel

The Lund / LBNL Nuclear Data Search



Gammas from ^{152}Eu (13.537 y *6*)

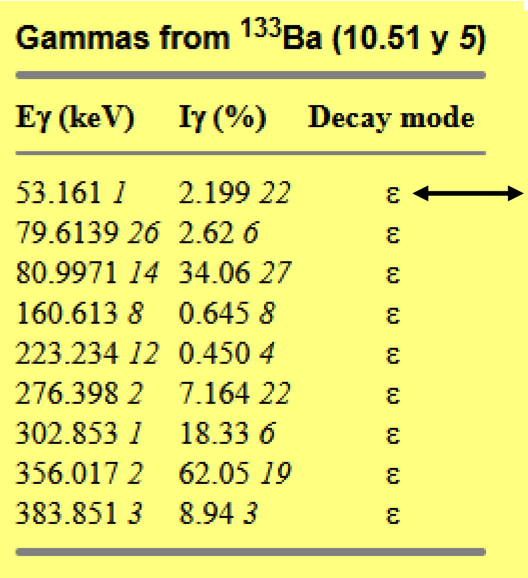
Eg (keV)	Ig (%)	Decay mode
121.7817 *3*	28.58 *6*	e+b$^+$
344.2785 *12*	26.5 *4*	b$^-$
1408.006 *3*	21.005 *24*	e+b$^+$
964.079 *18*	14.605 *21*	e+b$^+$
1112.074 *4*	13.644 *21*	e+b$^+$
778.9040 *18*	12.942 *19*	b$^-$
1085.869 *24*	10.207 *21*	e+b$^+$
244.6975 *8*	7.583 *19*	e+b$^+$
867.378 *4*	4.245 *19*	e+b$^+$
443.965 *3*	2.821 *19*	e+b$^+$
411.1163 *11*	2.234 *4*	b$^-$
1089.737 *5*	1.727 *6*	b$^-$
1299.140 *10*	1.623 *8*	b$^-$
1212.948 *11*	1.422 *6*	e+b$^+$

Emission energies and branching ratios are available from databases, but attantion is needed:

- line overlaps can occur (mainly in the low-energy region)
- inconsistencies between databases for weaker lines

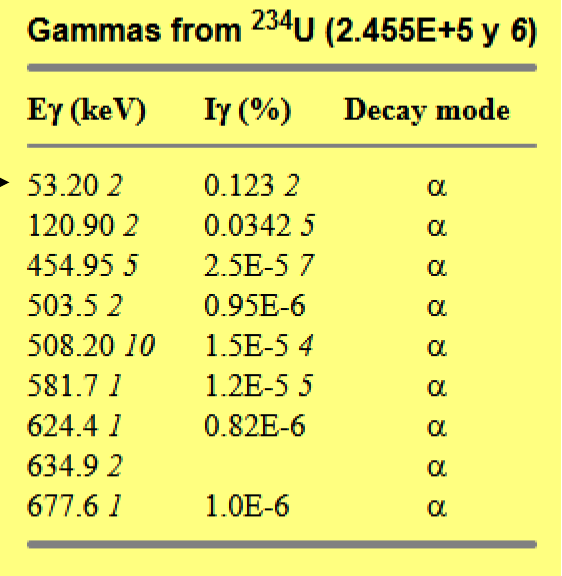
Single-nuclide & mixed sources are available.
In these experiments we used single-nuclide sources to prevent line overlaps.
More measurement – simpler evaluation.

Attention to line overlaps



Gammas from ^{133}Ba (10.51 y 5)

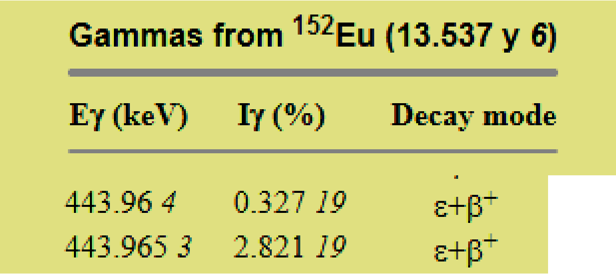
Eγ (keV)	Iγ (%)	Decay mode
53.161 *1*	2.199 *22*	ε
79.6139 *26*	2.62 *6*	ε
80.9971 *14*	34.06 *27*	ε
160.613 *8*	0.645 *8*	ε
223.234 *12*	0.450 *4*	ε
276.398 *2*	7.164 *22*	ε
302.853 *1*	18.33 *6*	ε
356.017 *2*	62.05 *19*	ε
383.851 *3*	8.94 *3*	ε



Gammas from ^{234}U (2.455E+5 y 6)

Eγ (keV)	Iγ (%)	Decay mode
53.20 *2*	0.123 *2*	α
120.90 *2*	0.0342 *5*	α
454.95 *5*	2.5E-5 *7*	α
503.5 *2*	0.95E-6	α
508.20 *10*	1.5E-5 *4*	α
581.7 *1*	1.2E-5 *5*	α
624.4 *1*	0.82E-6	α
634.9 *2*		α
677.6 *1*	1.0E-6	α

two close lying gamma-lines of ^{152}Eu



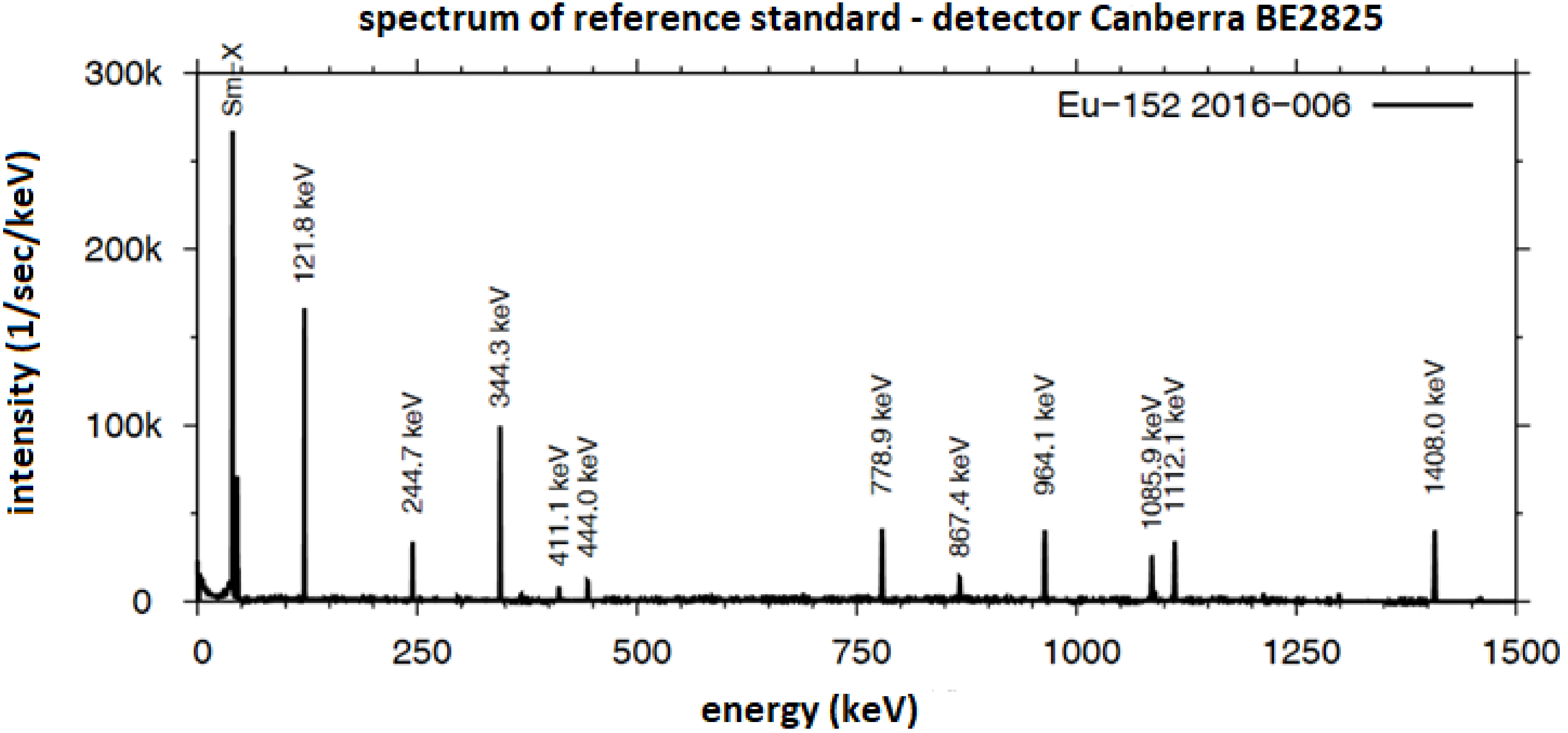
Gammas from ^{152}Eu (13.537 y 6)

Eγ (keV)	Iγ (%)	Decay mode
443.96 *4*	0.327 *19*	$\varepsilon+\beta^+$
443.965 *3*	2.821 *19*	$\varepsilon+\beta^+$

Σ 3.148 %   practically one line

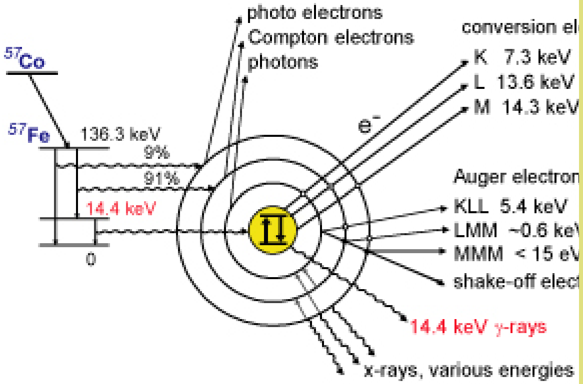
Characteristic X-ray lines in gamma-spectra

decay by electron capture (EC) -> emission of characteristic X-ray lines of the daughter element
^{55}Fe: Mn X-rays, ^{57}Co: Fe X-rays, ^{133}Ba: Cs X-rays, ^{152}Eu: Sm X-rays – characteristic to the element



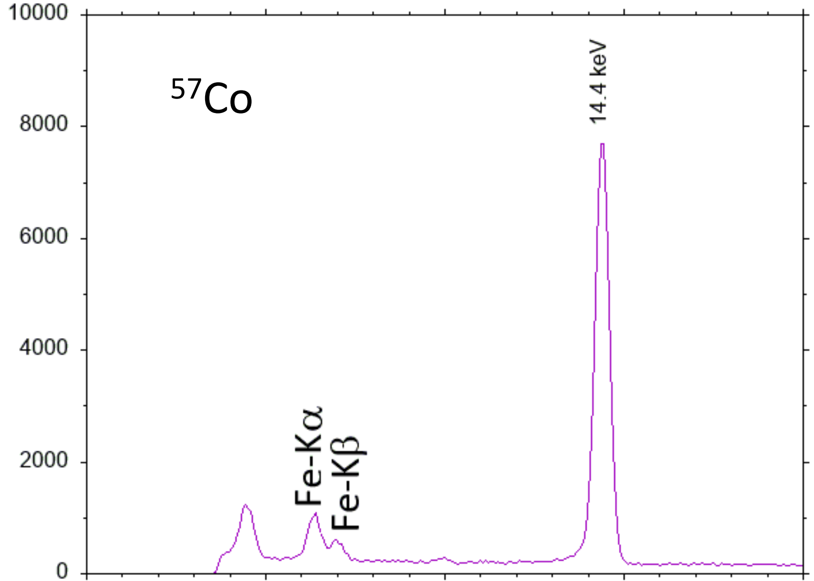
Characteristic X-ray lines in gamma-spectra

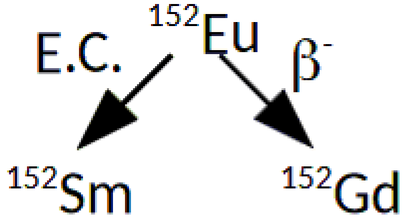
X-ray lines are multiplets and their peak-shapes are different from gamma-lines



X-rays from ^{57}Co (271.79 d *9*)

E (keV)	I (%)	Assignment	
6.266	1.69E-05 *9*	Fe $K_{\alpha3}$	
6.391	16.4 *8*	Fe $K_{\alpha2}$	Fe K_{α}
6.404	32.6 *16*	Fe $K_{\alpha1}$	
7.058	1.99 *10*	Fe $K_{\beta3}$	Fe K_{β}
7.058	3.88 *19*	Fe $K_{\beta1}$	
7.108	0.00206 *12*	Fe $K_{\beta5}$	
7.112	2.20E-07 *13*	Fe $K_{\beta4}$	

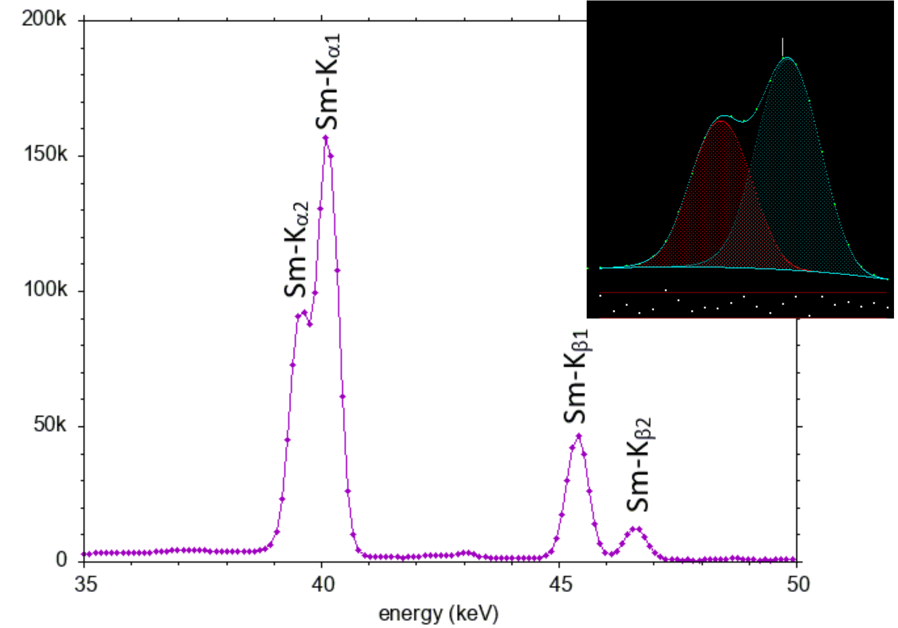




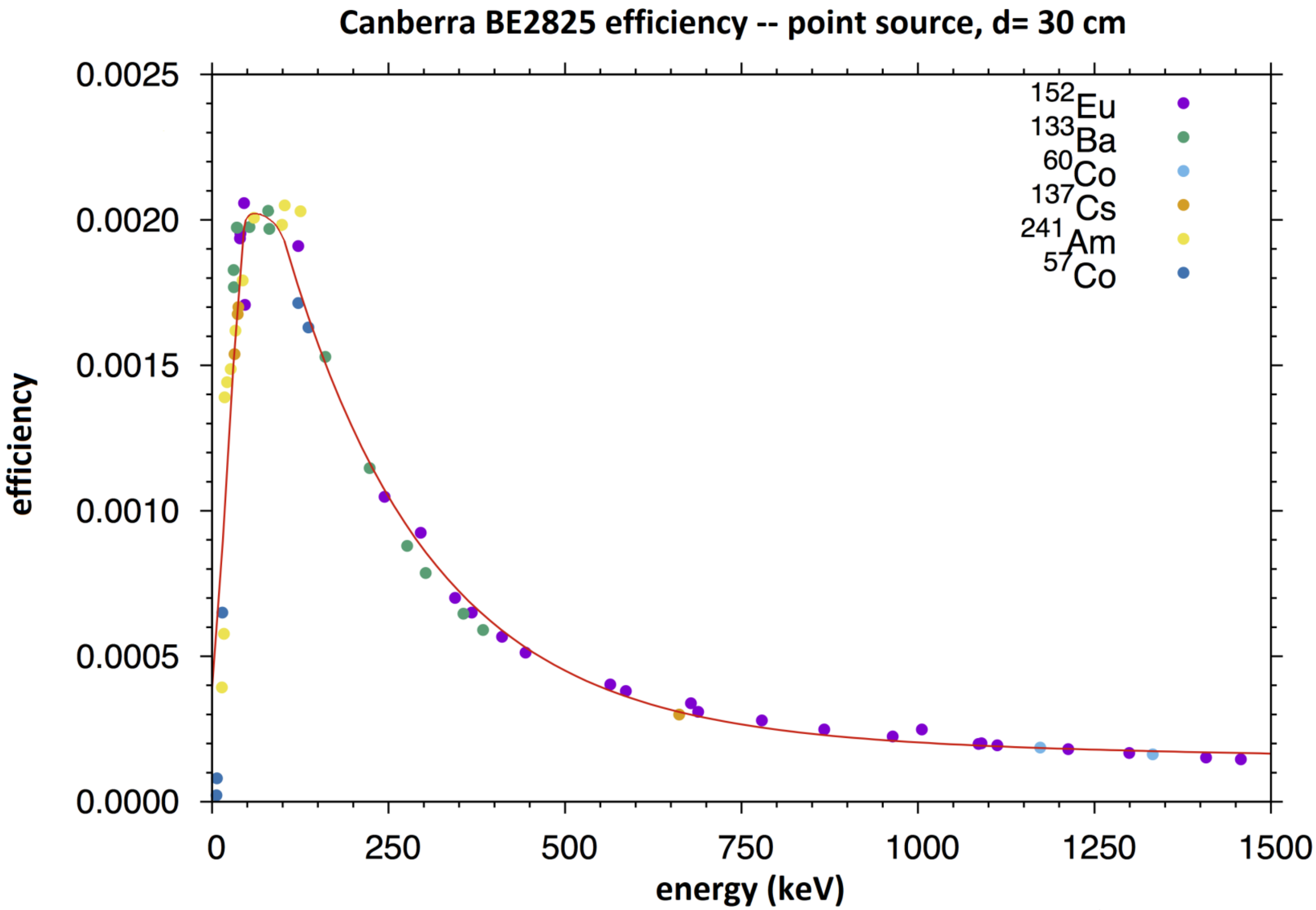
X-rays from ^{152}Eu (13.537 y *6*)

E (keV)	I (%)	Assignment	
39.097	0.00536 *18*	Sm $K_{\alpha3}$	<<<
39.522	21.1 *5*	Sm $K_{\alpha2}$	
40.118	38.3 *10*	Sm $K_{\alpha1}$	
45.294	3.74 *10*	Sm $K_{\beta3}$	
45.414	7.24 *19*	Sm $K_{\beta1}$	
45.741	0.107 *5*	Sm $K_{\beta5}$	
46.578	2.39 *6*	Sm $K_{\beta2}$	
46.705	0.91 *4*	Sm $K_{\beta4}$	

spectrum analysis
by dedicated
computer codes: QXAS



Gamma efficiency curve with radionuclide standards: the result



6 nuclides

61 data-points:

^{152}Eu: 26
^{133}Ba: 13
^{60}Co: 2
^{137}Cs: 4
^{241}Am: 11
^{57}Co: 5

Energy-range: 6.4 keV – 1457.6 keV

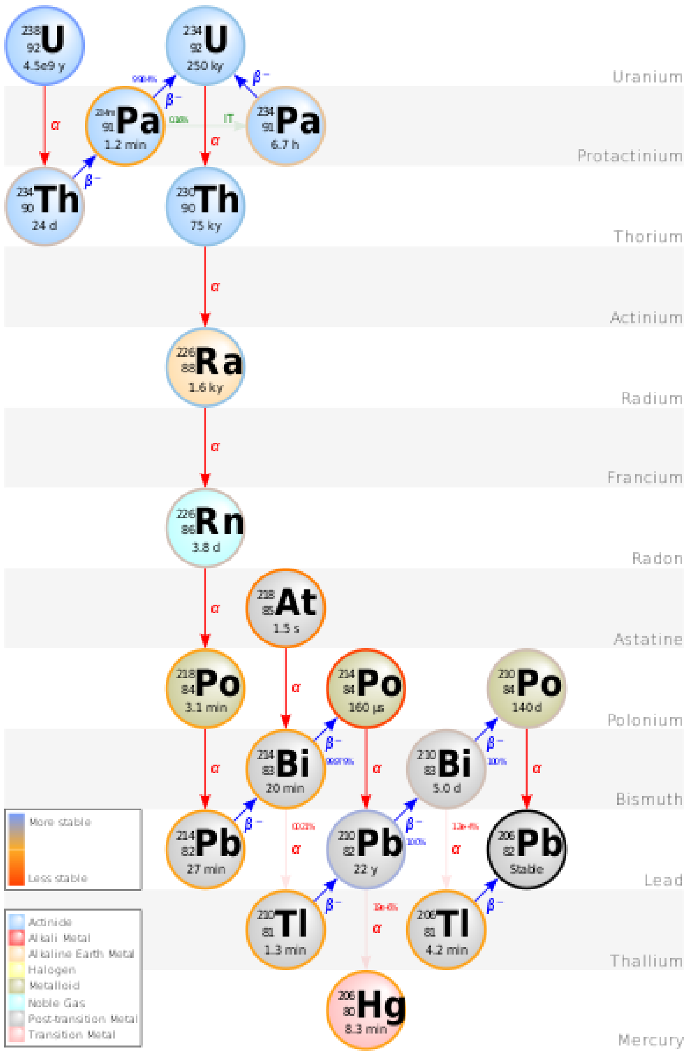
All available gamma-lines with branching ratio >0.5% were used.

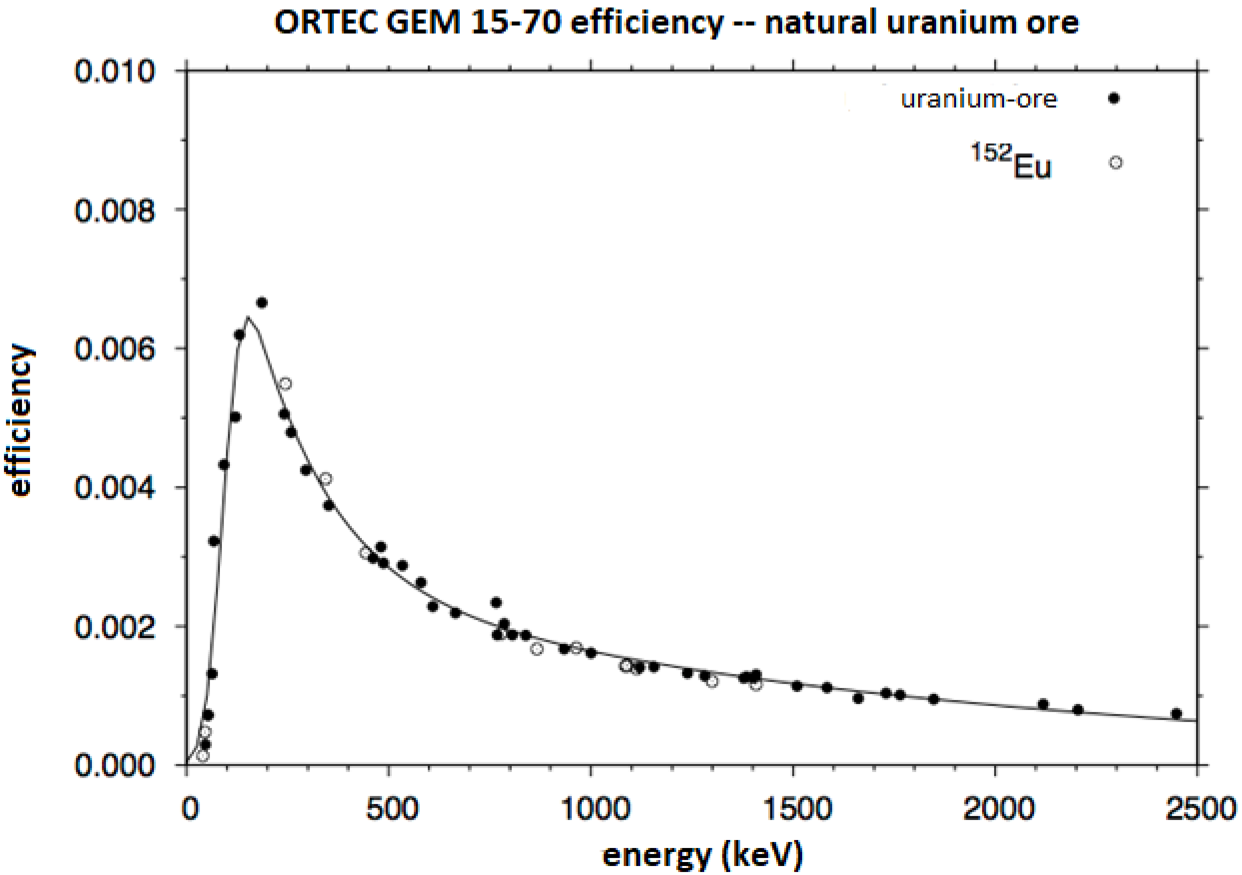
Acquisition time: 60 000 – 120 000 s / source
except for ^{60}Co: ~ 2000 s (only 2 lines)
<1% counting statistics even for weaker gamma-lines

The used reference standard sources double-checks each-other.
If one activity does not match to the certificate,
the data points does not fit to the curve.

Efficiency calibration with natural Uranium-ore: the whole ^{238}U decay chain in secular equilibrium

+^{235}U in natural abundance (0.71%)





42 data points: ^{234}Th: 3, ^{234m}Pa: 2: ^{234}U:2, ^{230}Th: 1, ^{226}Ra: 1, ^{214}Pb: 5, ^{214}Bi: 14

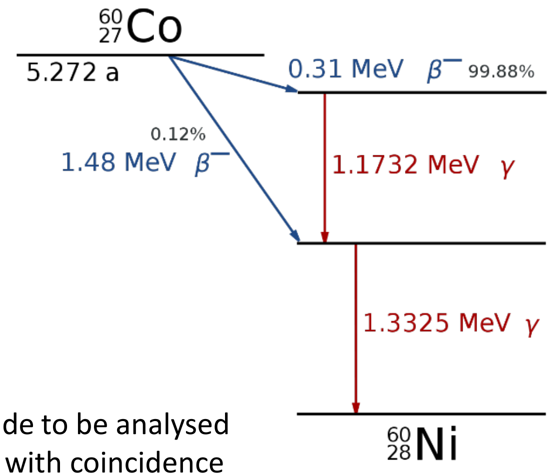
efficiency-curve can be extended toward higher energies, up to 2447.9 keV (^{214}Bi)

without exact uranium-mass: relative effieciency curve:

extended to absolute by an additional standard (^{152}Eu)

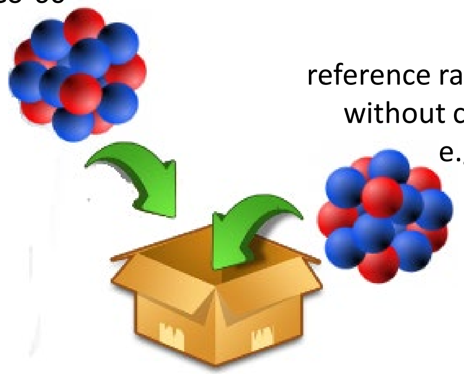
known line overlap: ^{226}Ra 186.2 keV <-> ^{235}U 185.7 keV

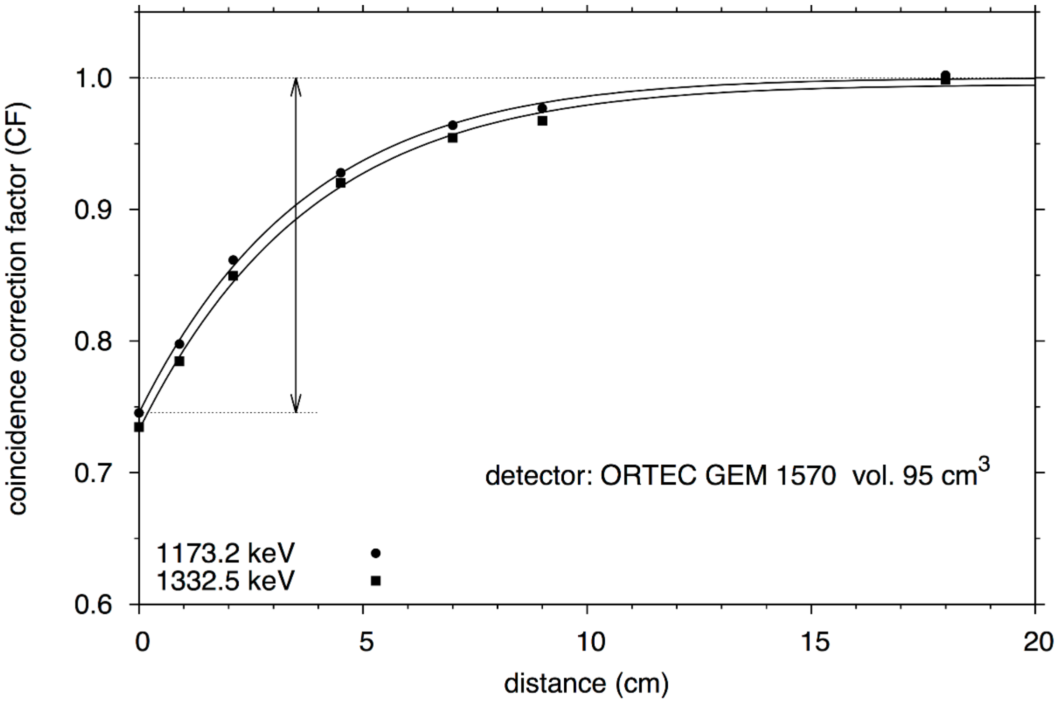
True gamma-gamma coincidence – direct experimental method

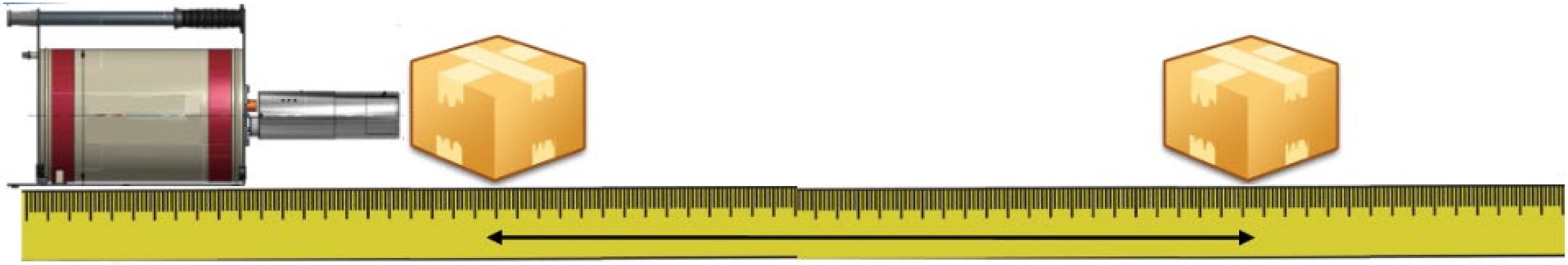


radionuclide to be analysed
with coincidence
e.g. Co-60

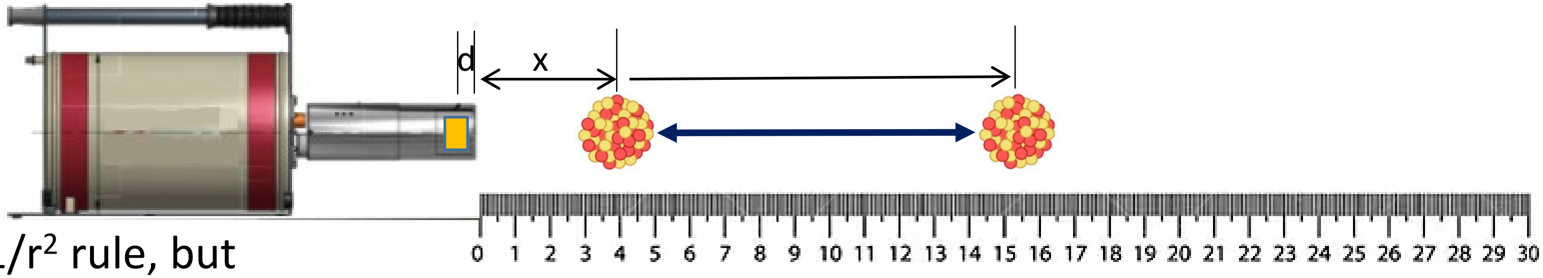
reference radionuclide
without coincidence
e.g. Cs-137





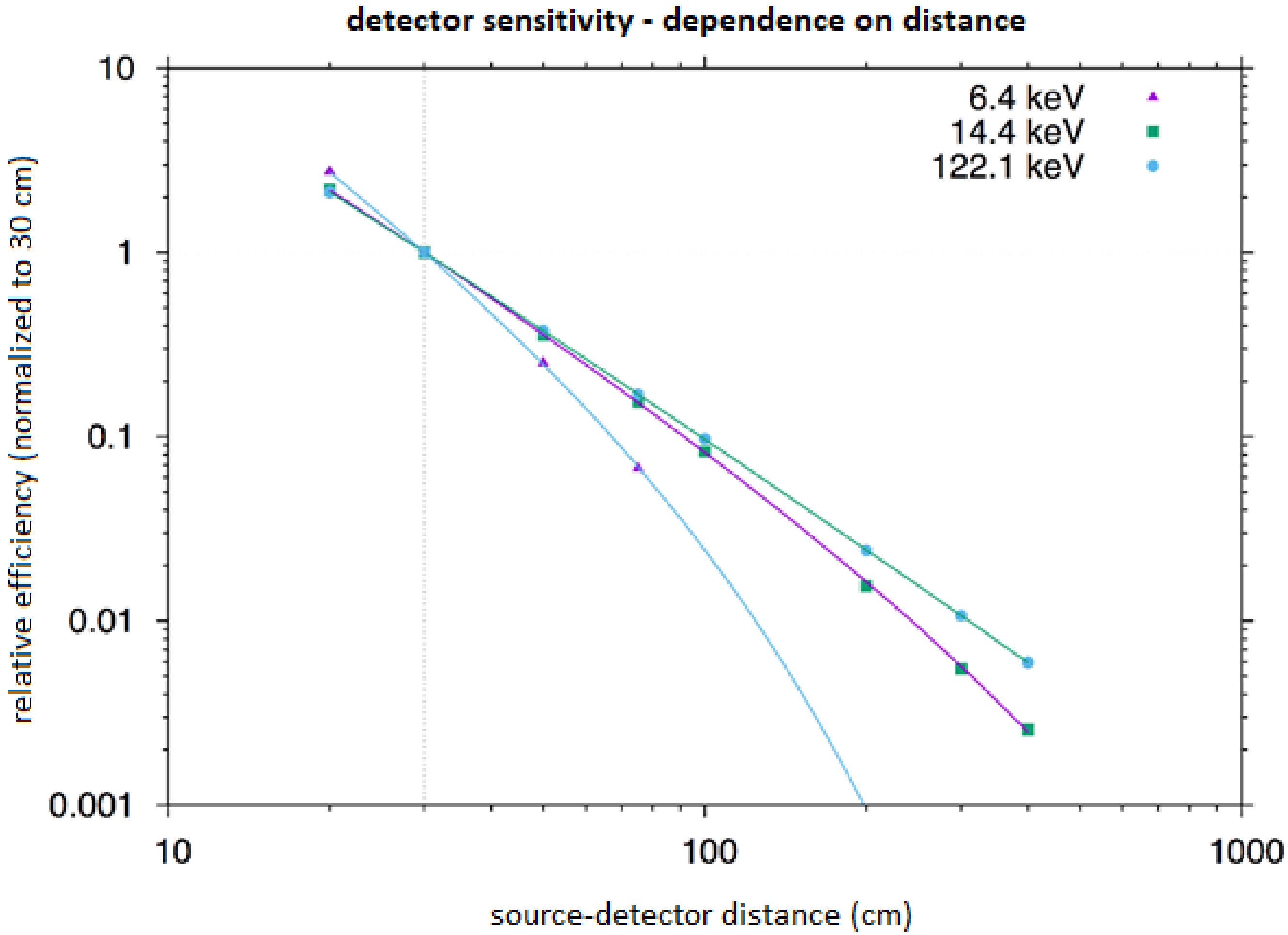


Distance scaling

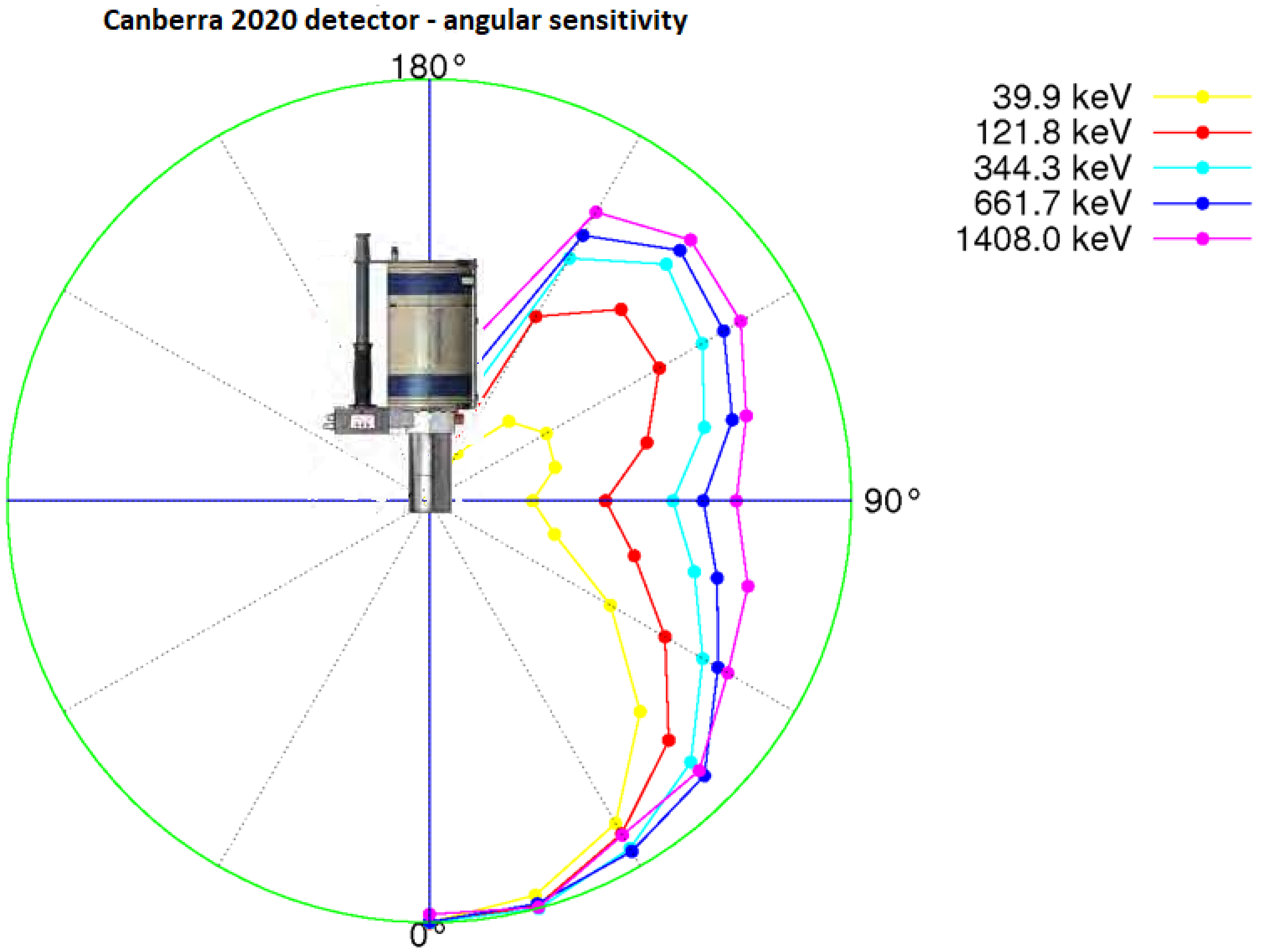


Principally follows the $1/r^2$ rule, but

- where is the 0-point: $I(x) = I_0 / (d+x)^2$ – the effective center of the crystal is behind the front window
- at lower gamma / X-ray energies the absorption can be significant



Angular dependence of detector sensitivity



How to use the efficiency data by spectrum evaluation computer codes?

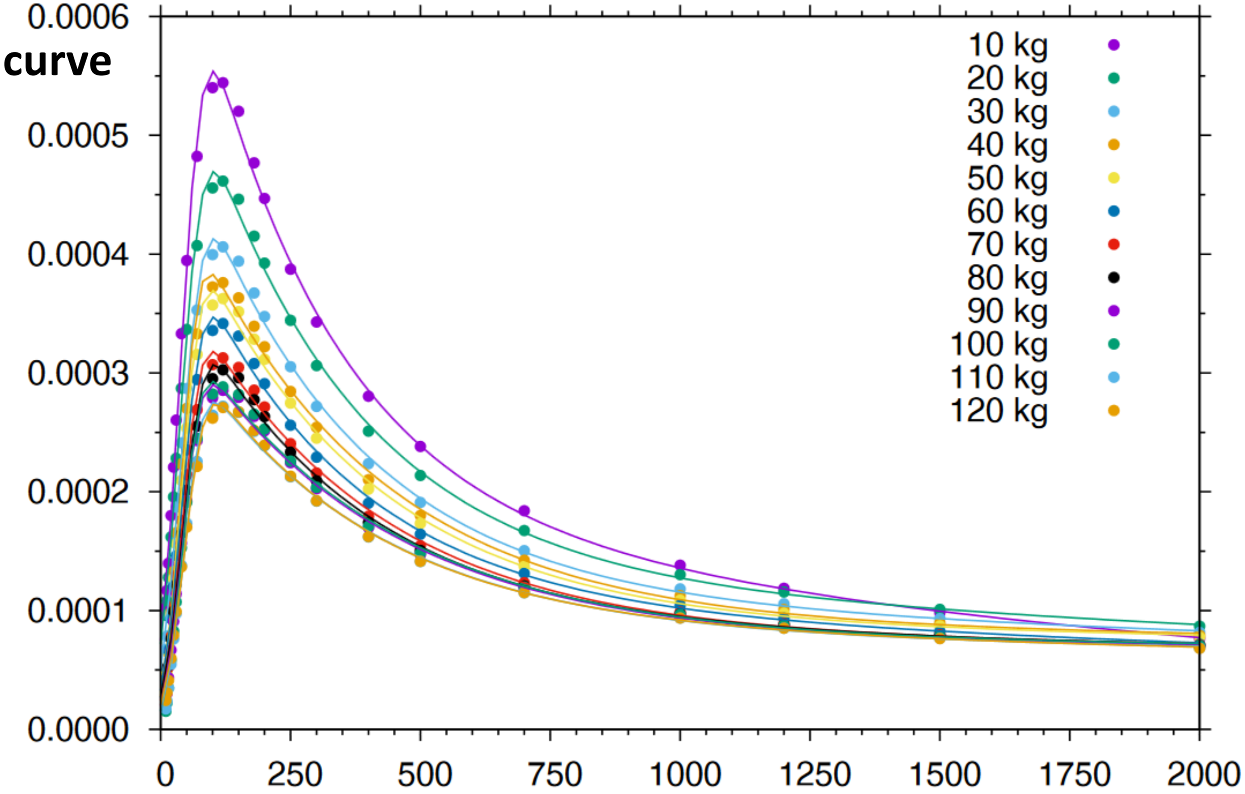
Mathematical model to fit the efficiency curve

Dual exponential polynom

- used by sevaral computer codes

$$\varepsilon(E) = \begin{cases} \exp\left(\sum_{i=0}^{n} P_{\mathrm{L},i} \cdot (\ln E)^i\right) & \text{if } E < E_{\mathrm{CO}} \\ \exp\left(\sum_{i=0}^{n} P_{\mathrm{H},i} \cdot (\ln E)^i\right) & \text{if } E > E_{\mathrm{CO}} \end{cases}$$

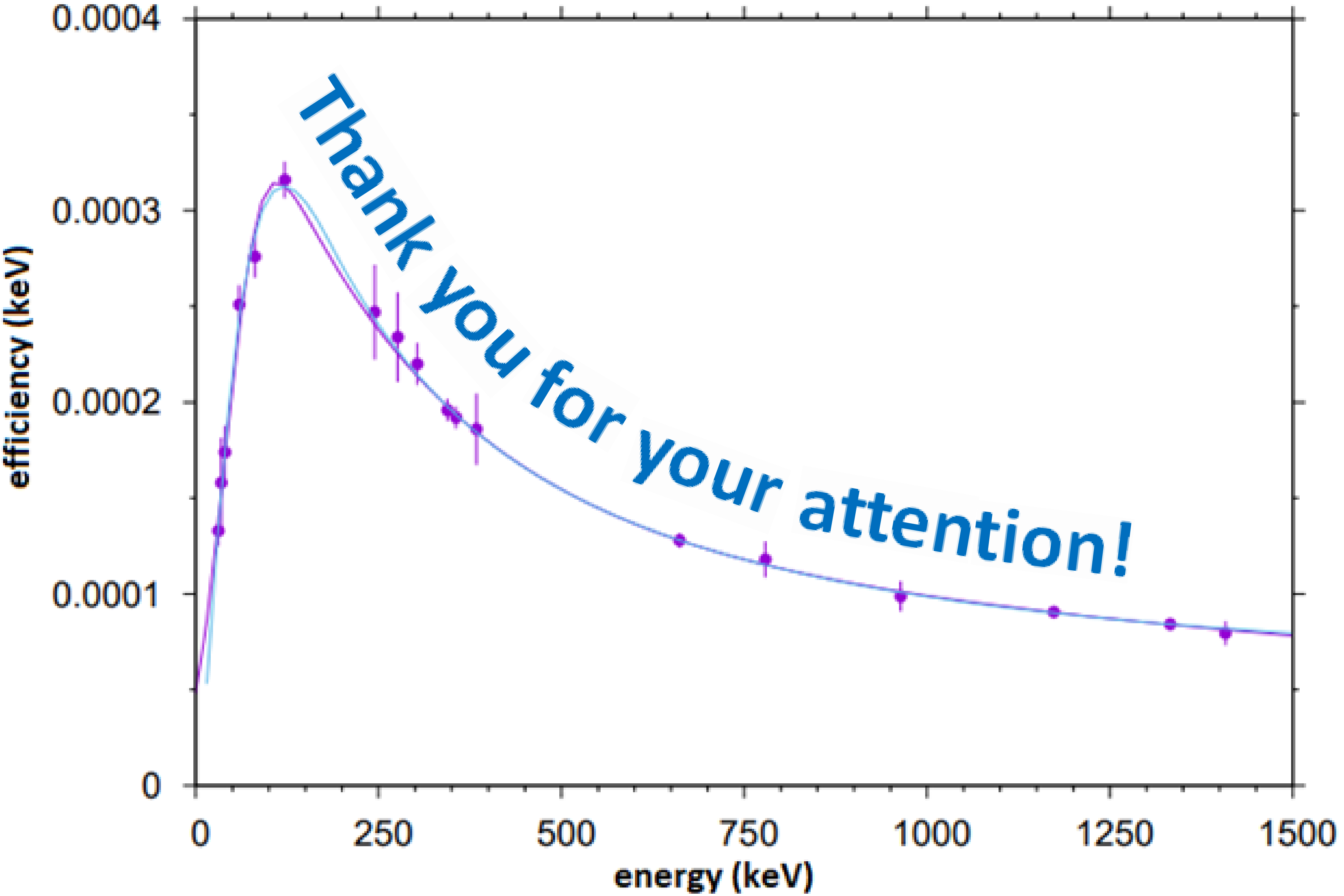
E_{CO}: crossover energy



→ can be directly used by spectrum evaluation computer codes

→ input -> efficiency transfer codes efficiency for other geometries can be calculated

To create a good calibration curve is a time consuming process, significant work of skilled personnel, but it is a long-lasting investment, since a good calibration can be used for long time, while the configuration or the measurement circumstances are unchanged.



Thank you for your attention!