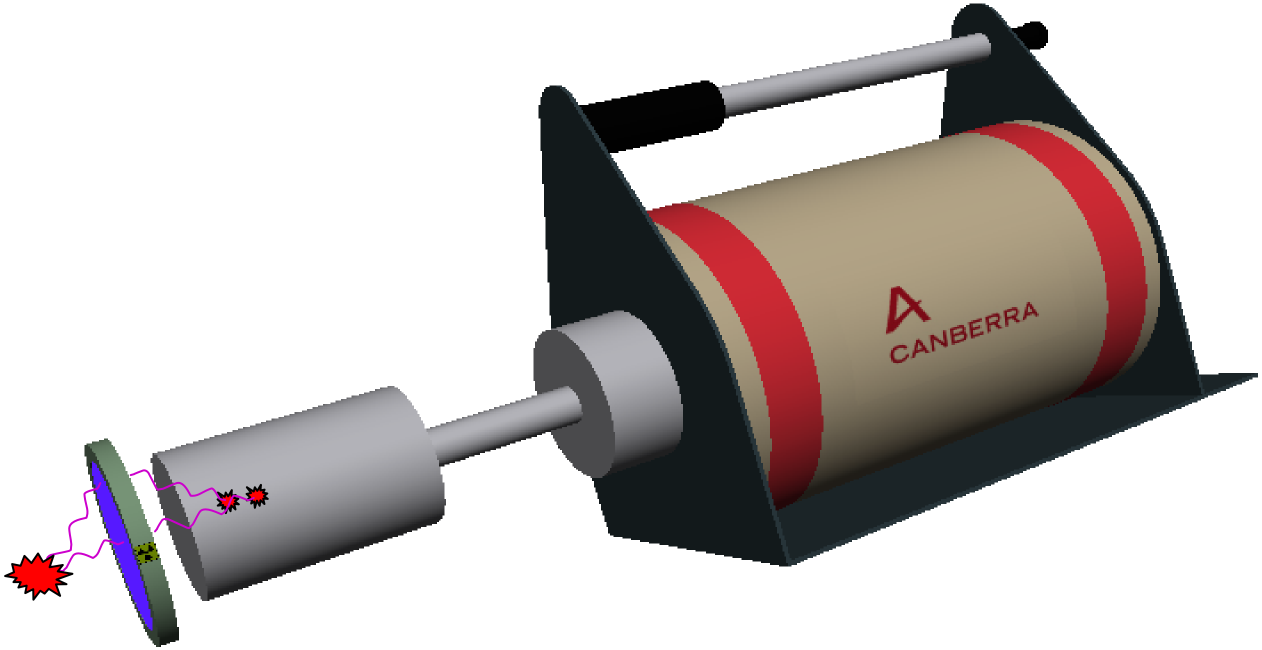
Coincidence summing correction in Genie-2000

Henrik Jäderström
Canberra Solutions AB
GammaSem-2010

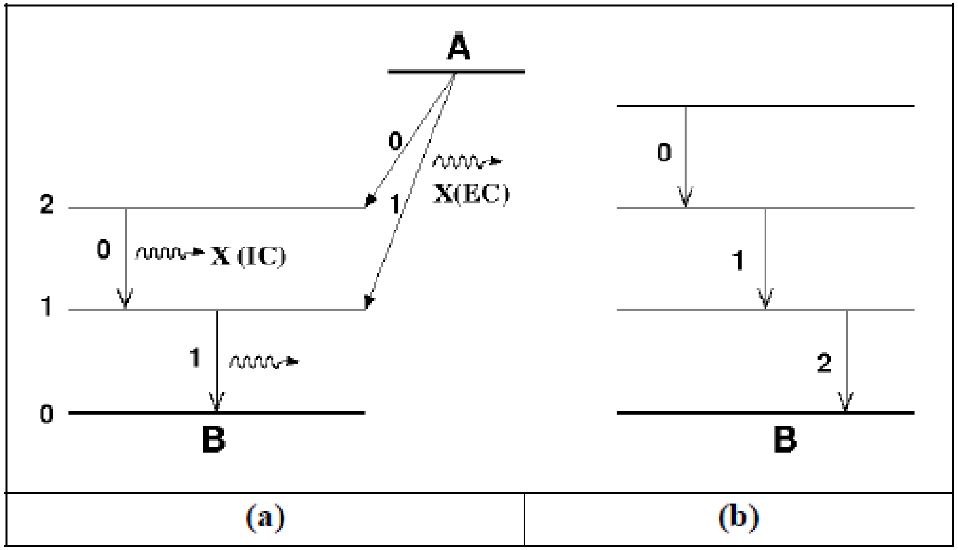
Outline

- Introduction
- Coincidence summing algorithm
- Geometry description with LabSOCS
- Validation
- Summary



Introduction

- Genie-2000 is Canberra's software for gamma spectroscopy
- Coincidence summing correction first introduced in 2001
- Major upgrade in 2009, included summation with X-rays and annihilation photons
- Database updated and expanded



CANBERRA

Algorithm

- **Coincidence summing correction factor (COI)**

$$COI_A = (1 - L^{\gamma-\gamma}{}_A - L^{\gamma-X,511}{}_A)(1 + S^{\gamma-\gamma}{}_A)$$

- **$L^{\gamma\text{-}\gamma}{}_A$ and $S^{\gamma\text{-}\gamma}{}_A$ is the summing out and summing in probability for γ-γ coincidences**
- **$L^{\gamma\text{-}X,511}{}_A$ is the summing out probability for γ and EC X-ray and annihilation photons**
- **L and S are the sum of the partial decay chains for the gamma ray of interest**

CANBERRA

Summing in probability

- **Summing in probabilty for a gamma chain with 3 gammas A= $\gamma_1 + \gamma_2 + \gamma_3$**

$$S_A = \frac{\gamma_1}{\gamma_A} a_2 c_2 a_3 c_3 \frac{\varepsilon_{p,1}\varepsilon_{p,2}\varepsilon_{p,3}}{\varepsilon_{p,A}}$$

- **γ is the absolute gamma yield, the number of photons of emitted per decay for the energy of interest.**
- **a is the branching ratio, the probability of particular transition from given nuclear state.**
- **c is the internal conversion factor, defined as the 1/(1+α) where α is the ratio between the number of gammas and electrons emitted from a nuclear state.**
- **Summing in from more than 3 gammas can be neglected**

CANBERRA

Summing out probability

- More complicated than summing in
- Depends on the position of the transition of the decay chain
- Genie-2000 uses maximum 5 transitions in cascade
- For a cascade with 5 transitions and the transition of interest is the third the correction is, as given by de Corte

$$
\begin{aligned}
&\gamma_0/\gamma_2 \cdot a_1 \cdot a_2 \cdot c_1 \cdot c_2 \cdot \Sigma_0 + \gamma_1/\gamma_2 \cdot a_2 \cdot c_2 \cdot \Sigma_1 + a_3 \cdot c_3 \cdot \Sigma_3 + a_3 \cdot a_4 \cdot c_4 \cdot \Sigma_4 - \qquad \text{(c)}\\
&\gamma_0/\gamma_2 \cdot a_1 \cdot a_2 \cdot c_1 \cdot c_2 \cdot \Sigma_0 \cdot \Sigma_2 - \gamma_0/\gamma_2 \cdot a_1 \cdot a_2 \cdot a_3 \cdot c_2 \cdot c_3 \cdot \Sigma_0 \cdot \Sigma_3 - \gamma_0/\gamma_1 \cdot a_1 \cdot a_2 \cdot a_3 \cdot a_4 \cdot c_2 \cdot c_4 \cdot \Sigma_0 \cdot \Sigma_4 - \\
&\gamma_1/\gamma_2 \cdot a_2 \cdot a_3 \cdot c_2 \cdot c_3 \cdot \Sigma_1 \cdot \Sigma_3 - \gamma_1/\gamma_2 \cdot a_2 \cdot a_3 \cdot a_4 \cdot c_2 \cdot c_4 \cdot \Sigma_1 \cdot \Sigma_4 - a_3 \cdot a_4 \cdot c_3 \cdot c_4 \cdot \Sigma_3 \cdot \Sigma_4 + \\
&\gamma_0/\gamma_2 \cdot a_1 \cdot a_2 \cdot a_3 \cdot c_1 \cdot c_2 \cdot c_3 \cdot \Sigma_0 \cdot \Sigma_1 \cdot \Sigma_3 + \gamma_0/\gamma_2 \cdot a_1 \cdot a_2 \cdot a_3 \cdot a_4 \cdot c_1 c_2 \cdot c_4 \cdot \Sigma_0 \cdot \Sigma_1 \cdot \Sigma_4 + \\
&\gamma_0/\gamma_2 \cdot a_1 \cdot a_2 \cdot a_3 \cdot a_4 \cdot c_2 \cdot c_3 \cdot c_4 \cdot \Sigma_0 \cdot \Sigma_3 \cdot \Sigma_4 + \gamma_1/\gamma_2 \cdot a_2 \cdot a_3 \cdot a_4 \cdot c_2 \cdot c_3 \cdot c_4 \cdot \Sigma_1 \cdot \Sigma_3 \cdot \Sigma_4 - \\
&\gamma_0/\gamma_2 \cdot a_1 \cdot a_2 \cdot a_3 \cdot a_4 \cdot c_1 \cdot c_2 \cdot c_3 \cdot c_4 \cdot \Sigma_0 \cdot \Sigma_1 \cdot \Sigma_3 \cdot \Sigma_4
\end{aligned}
$$

- The total efficiency can be expressed as to account for coincidences with IC x-rays

CANBERRA

IC and EC x-rays

- The total efficiency can be expressed as to account for coincidences with IC x-rays

$$\sum_i = \varepsilon_{t,i} + \alpha_K \omega_K \sum_j k_j \varepsilon_{t,k_j}$$

- α_K is the K-electron internal conversion factor, ω_K is the K-shell flourescence yield, k_j is the KX-ray relative intensity
- For EC X-rays substitute in de Cortes formula

$$a_1 a_2 c_2 \frac{\gamma_0}{\gamma_2} \rightarrow \frac{\beta_0 a_0}{\beta_0 a_0 + \beta_1} = \frac{\beta_0 a_0}{T} = B_0, \quad \text{and} \quad \Sigma_0 \rightarrow P_{K,0} \omega_K \sum_i k_i \varepsilon_{t,k_i}$$

- c = 1(1+α_T) where α_T is the total internal converstion coefficient, β_i is the i-th decay branching ratio and $P_{K,j}$ is the K-electron capture probability of the EC decay

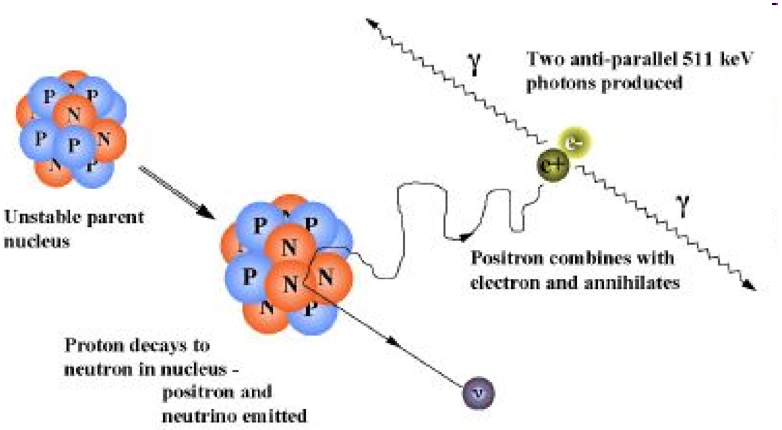
CANBERRA

Annihilation photons

- Similar to EC x-ray correction but substitute

$$\beta_i \rightarrow \beta_i^{B+}, \quad \text{and} \quad P_{K,i}\omega_K \sum_i k_j \varepsilon_{t,k_j} \rightarrow 2 \times \varepsilon_{t,511},$$

- β_i^{B+} is the relative positron emisson branching ratio and $\varepsilon_{i,511}$ is the total efficiency of the 511 keV photon and the 2 is for the two photons emitted from the positron annihilation



CANBERRA

Subcascades

- Several nuclides contains more than one cascade and a partucular transition may be part of more than one of these subcascades
- 244 keV + 122 keV decay chain from Eu-152 is a part of seven subcascades
- In order not to overestimate the summing out probability it is necessary to reduce the total summing out probability for six subcascades involving this transition
- The total summing out probability can be expressed as

$$L_{244} = \sum_{i=1}^{7} L_i - 6L_{244 \to 122}$$

CANBERRA

Voluminous sources

- **Activity calculated as $A=N_p/(\varepsilon\gamma)$**
- **Dividing the source into n subsources gives the count rate from each subsource as $N_{p,i}=(N_p\varepsilon_i)/(\varepsilon n)$**
- **For a gamma line the coincidence corrected count rate is**

$$N'_{p,g} = \frac{N_p}{\varepsilon \cdot n} \sum_{i=1}^{n} \frac{\varepsilon_i}{COI_i}$$

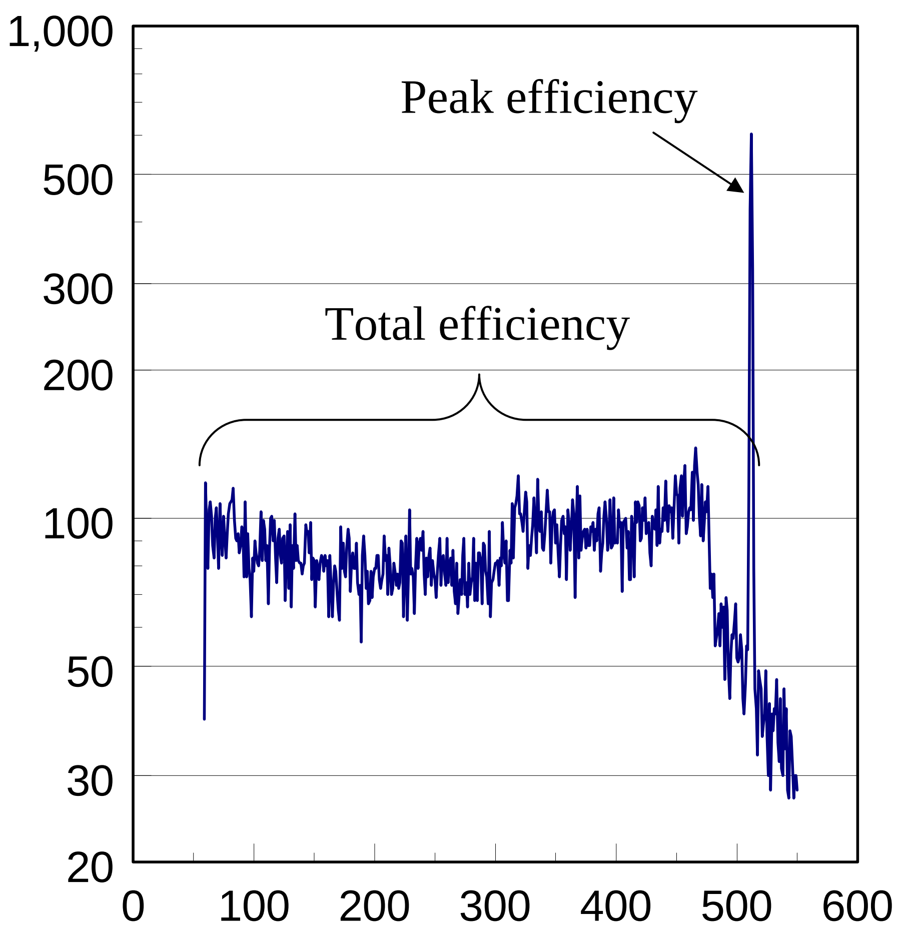
- **The coincidence correction is then calculated as**

$$COI = \frac{N_p}{N'_p} = \frac{\varepsilon \cdot n}{\sum_{i=1}^{n} \frac{\varepsilon_i}{COI_i}}$$

CANBERRA

Total Efficiency

- **In the calculations presented it is necessary to know the total efficiency for the gamma lines**
- **Genie offers two way of calculating the total efficiency**
- **Peak-To-Total calibrations (old way)**
- **Mathematical calculations with LabSOCS (prefered way)**

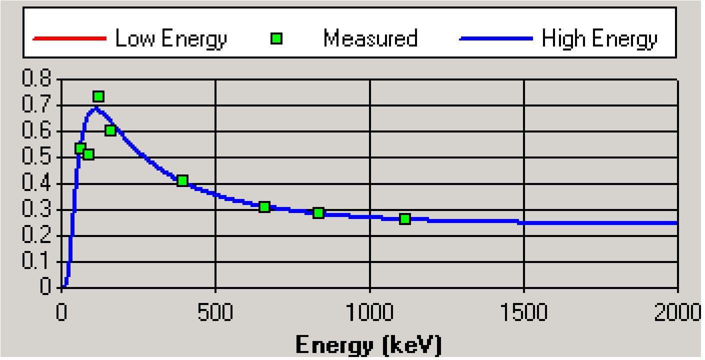


CANBERRA

Peak-To-Total Calibration

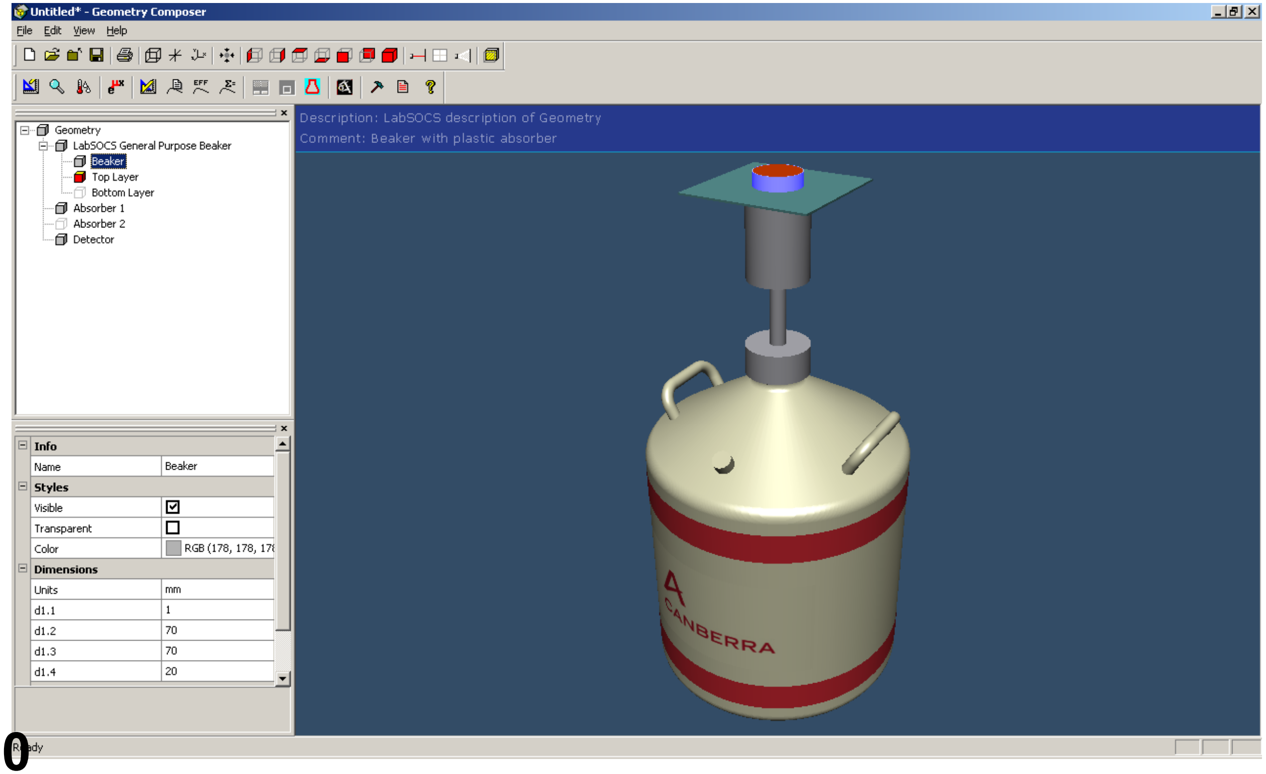
- Peak Efficiency is normally already done
- Measure the number of counts in the full energy peak and the number of counts in the Compton continuum
- Usually extrapolated for the lowest energy
- Use mono-energetic sources
- From the interpolated curve and the peak efficiency the total efficiency can be calculated

P/T calibration curve



Geometry description

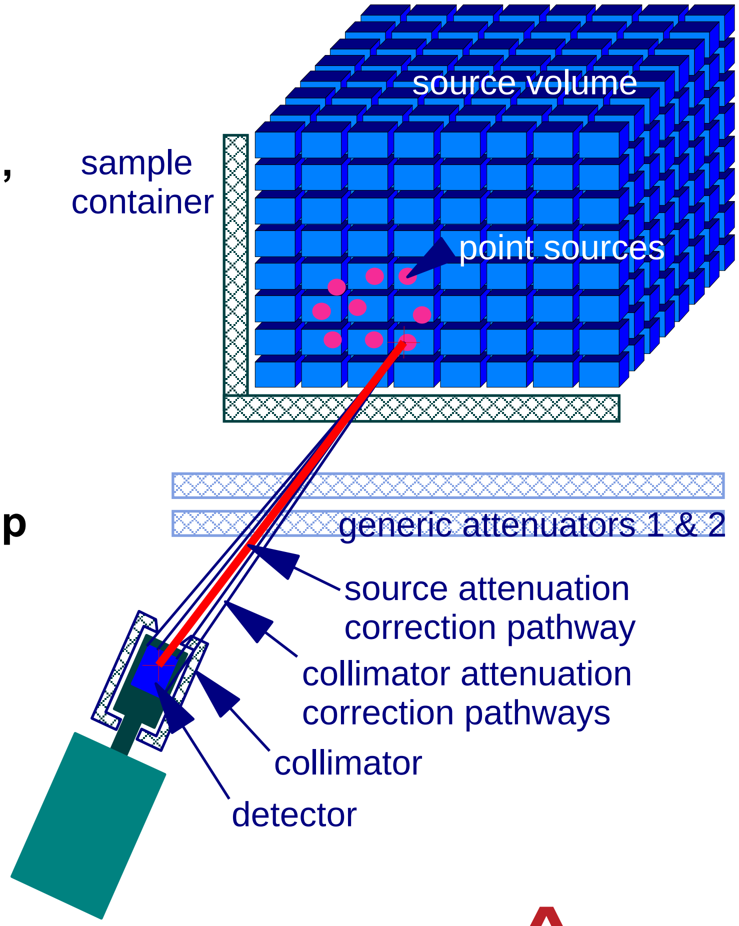
- 3D geometry composer
- Efficiency calculations with LabSOCS/ISOCS algorithm
- 12 LabSOCS templates
- Customizable complex beaker template
- Energy range from 10 keV to 7000 keV
- Accuracy from 20% at 10 kev to 4 % at 2000 kev



CANBERRA

Efficiency calculations

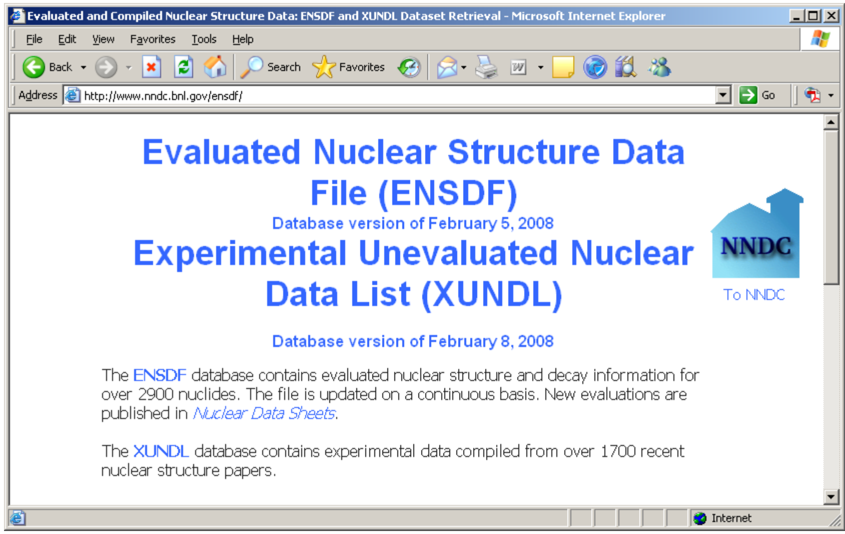
- Divide the geometry into 2^n voxels
- Place a point source in a random position in each voxel
- Calculate the efficiency for that point in space, including material attenuation
- Calculate efficiency for whole volume and all energies of interest
- Divide into 2^{n+1} voxels and redo calculations
- Repeat until convergence is reached
- Total efficiency is corrected for photon-buildup (scattering in attenuators) and albedo effects (scattering in surrounding materials)
- The build-up is based on MCNP simulations and is parameterized as a function of energy, material and geometry



CANBERRA

Database used

- **Data for the coincidence summing correction taken from ENSDF**
- **Atomic X-ray data**
- **Nuclides and gamma lines that are free from or subject to coincidence summing and their decay parameters**
- **Energies of gamma lines in summing-out chains**
- **Energies of gamma lines in summing-in chains**
- **Energies of gamma lines in sub-cascade chains**
- **Summarized in one database file containing 205 nuclides**



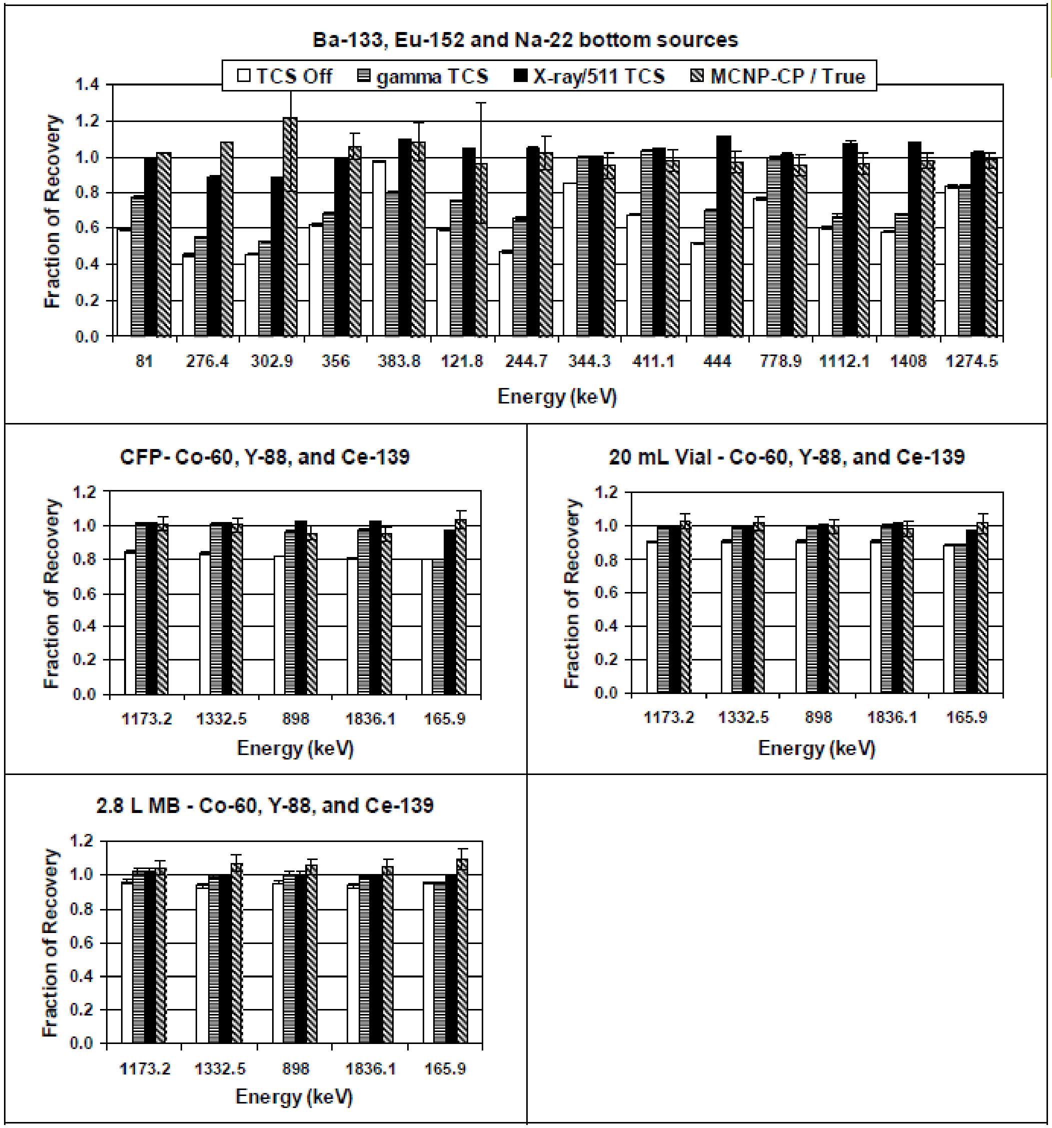
J.K. Tuli, BNL-NCS051655-01/02-Rev

Validation

- **Extensive validation of the methods with different sources (all NIST traceable 1-2% uncertainty) and geometries**
- **Co-60, Y-88 and Ce-139 in three geometries: Close filter paper, 20 ml liquid vial and 2.8 l Marinelli beaker**
- **Ba-133, Eu-152 and Na-22 all disc sources**
- **All 205 nuclides and more than 2000 lines contained in the coincidence library compared to MCNP calculations**

Validation

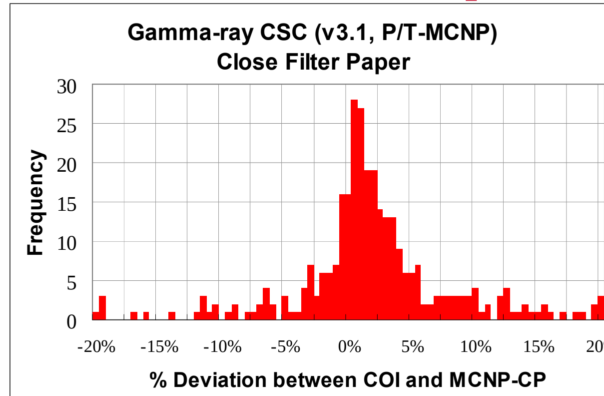
- *Top: disc Na-22, Ba-133 and Eu-152 source*
- *Bottom: common mixed gamma calibration source with Ce-139, Y-88 and Co-60 shown*
- *Result*
  - *Gamma OK for Co-60 since no X-rays*
  - *Y-88, Ba-133 and Eu-152 are all better with X+g than with gamma only*



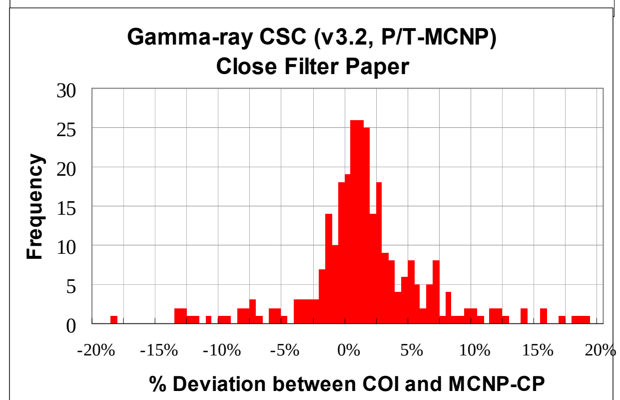
CANBERRA

Gamma-ray CSC Regression Test
to v3.1

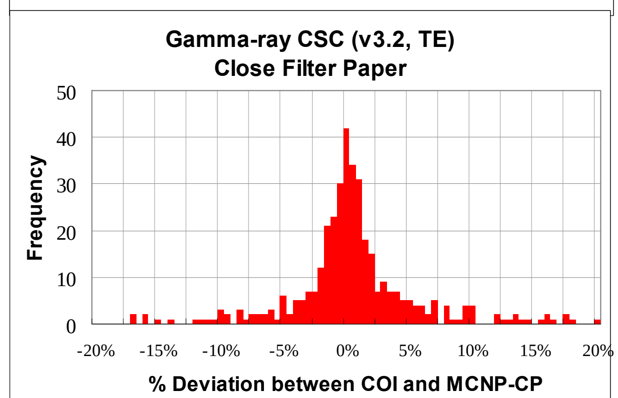
- ***Results from 32 common cascading nuclides for close filter paper geometry.***
  - *~400 lines with CSC*
- ***Analysis performed for a BE5030 detector.***
- ***MCNP-CP used as reference***
- ***Top = 3.1 with P/T***
- ***Middle = 3.2 with P/T***
- ***Bottom = 3.2 with internal TE***
- ***3.2 better than 3.1***
  - *fewer outliers, better library*
- ***TE better than P/T***
  - *Smaller bias and SD, TE calculated for each voxel*



V3.1 with P/T
Mean: 1.0%
SD: 1.6%
%>±5%: 28%
%>±10%: 13%



V3.2 with P/T
Mean: 1.0%
SD: 1.6%
%>±5%: 23%
%>±10%: 8%



V3.2 with G2K TE
Mean: 0.1%
SD: 1.3%
%>±5%: 20%
%>±10%: 7%

CANBERRA

X-ray Cascade Summing Correction of Gammas v3.2

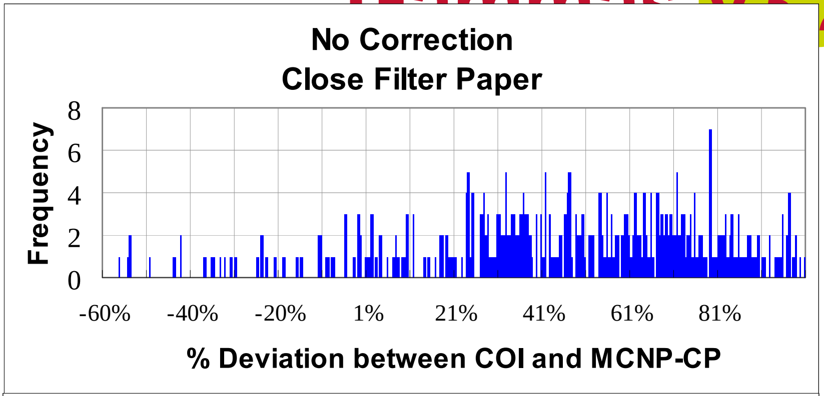
- *Data are for Close Filter Paper (59 nuclides)*
- *Analysis using ISOCS TE for BE5030 [wide energy range detector]*
- *MCNP-CP used as reference*
- *Top – no CSC*
- *Middle – gamma only CSC*
- *Bottom – gamma & X-ray CSC*
- *Results: no bias, 2%sd slightly larger than for Gammas where there are no X-rays*
- *Similar results for 20 ml vial (15 nuclides) and Marinelli beaker (12 nuclides).*

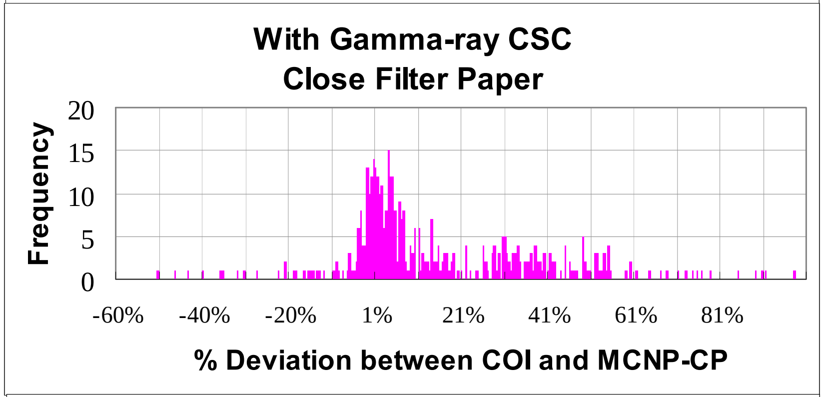
Mean: 0.5%

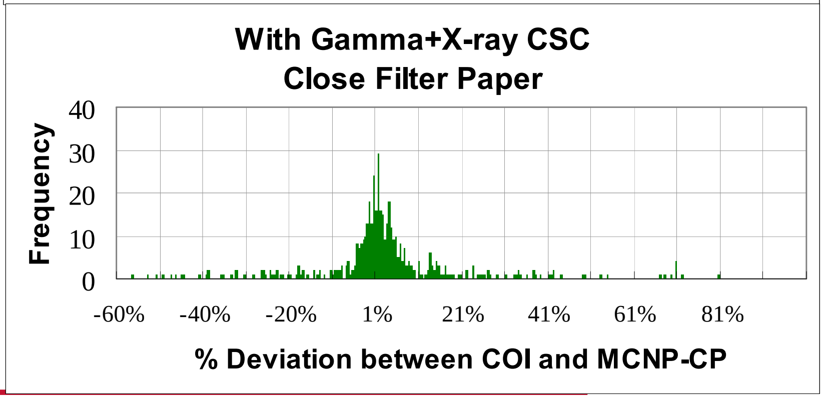
SD: 2.0%

%>±5%: 30%

%>±10%: 14%







Summary

- Canberra has developed an algorithm to correct for coincidence summing in the software Genie-2000
- Can correct for gamma-gamma coincidences and gamma-x-ray/511 coincidences
- Does not require any sources for calibration
- Uses the LabSOCS code to calculate the both the peak and total efficiency (preferred way)
- Has undergone extensive validation which have shown that the systematic uncertainty from the correction is 5%

CANBERRA