A benchmark for Monte Carlo simulations in gamma-ray spectrometry

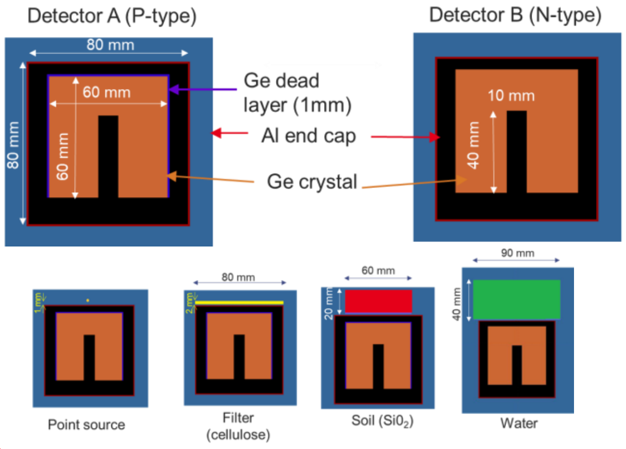
M.-C. Lépy[1], C. Thiam[1], M. Anagnostakis[2], C. Cosar[3], A. De Blas del Oyo[4], H. Dikmen[5], M.A. Duch[4], R. Galea[6], M.L. Ganea[3], S. Hurtado[8], K. Karfopoulos[9], A. Luca[3], G. Lutter[7], I. Mitsios[2], H. Persson[9], C. Potiriadis[10], S. Röttger[11], N. Salpadimos[10], M.I. Savva[12], O. Sima[3,13], T.T. Thanh[14], R. Townson[6], A. Vargas[4], T. Vasilopoulou[12], L. Verheyen[15], T. Vidmar[15]

[1]LNE-LNHB, France, [2]NTUA, Greece, [3]IFIN-HH, Romania, [4]UPC, Spain, [5]TENMAK, Turkey, [6]NRC, Canada, [7]JRC-Geel, Belgium and DTU, Denmark, [8]U-Sevilla, Spain, [9]Mirion Technologies, Inc, USA, [10]EEAE, Greece, [11]PTB, Germany, [12]NCSR "Demokritos", Greece, [13]U. Bucharest, Romania, [14]VNUHCM, Vietnam, [15]SCK·CEN, Belgium

Motivation: Monte Carlo simulation codes are now widely used in many different fields of application. In gamma-ray spectrometry, they can be applied for the optimization of experimental geometrical conditions and to compute the detection efficiencies and corrective factors for self-attenuation and coincidence summing effects. However, reliable results depend on the configuration files and/or exploitation of resulting data.
To help new users, a benchmark has been conceived, as a **learning tool** for the use of Monte Carlo codes applied to gamma-ray spectrometry.

Approach: In the frame of the gamma-ray spectrometry working group (GSWG) of the International Committee for Radionuclide Metrology (ICRM), different users ran several Monte Carlo codes for study cases based on simple geometries, to mimic eight typical measurement conditions. The individual results were compared and causes of discrepancies were discussed between the participants, leading to recommendations for harmonized calculation conditions.

Eight geometries

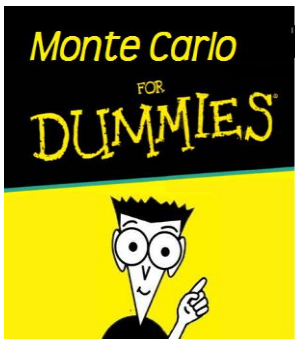


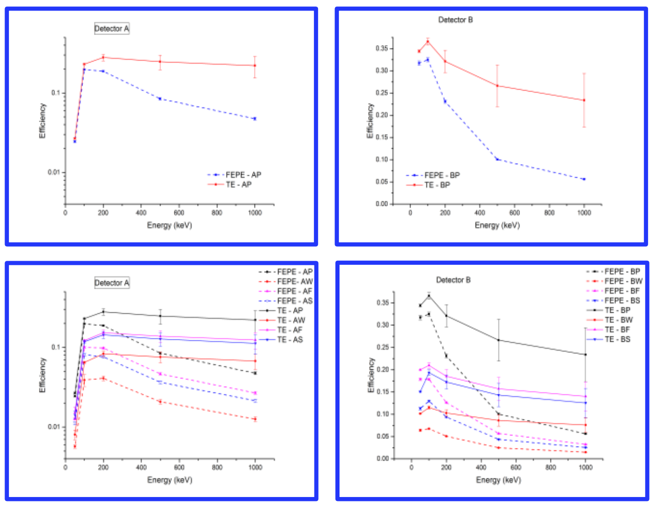
Step 1

Full-energy peak **efficiency**

Total efficiency

Five energies





19 datasets

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Two types of codes

Dedicated to gamma-ray spectrometry:

EFFTRAN, GESPECOR
Specific user-friendly interface

General purpose:

EGSnrc, GEANT4, MCNP-CP, PENELOPE
Training required to prepare input files (description of geometries, calculation parameters)

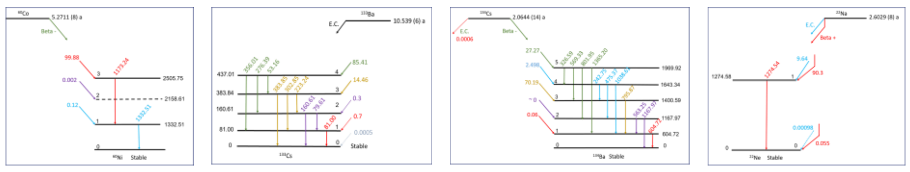
Comparison of results for each gamma-ray

- Mean value of individual results (i = participant number) $$M(E) = \frac{\sum_i C(E,i)}{N}$$
- Relative differences of individual results compared to the mean value (%) $$R(E,i) = \frac{C(E,i) - M(E)}{M(E)} \cdot 100$$
- Mean value per code (k = code number) $$M_k(E) = \frac{\sum_j C(E,j)}{N_k N}$$
- Relative differences between codes (%) $$R_k(E) = \frac{M_k(E) - M(E)}{M(E)} \cdot 100$$
- Relative differences within code k (%) $$R_p(E,i) = \frac{C(E,i) - M_k(E)}{M_k(E)} \cdot 100$$

Step 2

Coincidence summing corrective factors for four radionuclides with typical decay schemes

Depends on the efficiency and radionuclide decay scheme



^{60}Co Energy (keV)	Detector A				Detector B			
	Point	Water	Filter	Soil	Point	Water	Filter	Soil
1173	1.215 (10)	1.079 (6)	1.130 (6)	1.116 (8)	1.242 (7)	1.088 (5)	1.147 (6)	1.130 (5)
1332	1.225 (10)	1.083 (11)	1.134 (9)	1.120 (7)	1.251 (8)	1.094 (8)	1.154 (6)	1.135 (9)

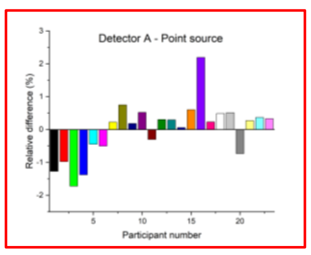
^{133}Ba Energy (keV)	Detector A				Detector B			
	Point	Water	Filter	Soil	Point	Water	Filter	Soil
53.1	1.360 (26)	1.127 (32)	1.223 (20)	1.191 (19)	1.94 (8)	1.307 (25)	1.522 (40)	1.396 (26)
79.6	1.391 (19)	1.144 (19)	1.230 (15)	1.205 (18)	2.16 (12)	1.353 (30)	1.62 (6)	1.444 (32)
81	1.304 (12)	1.111 (11)	1.178 (13)	1.162 (10)	1.686 (38)	1.226 (17)	1.389 (23)	1.287 (14)
160.6	1.118 (13)	1.054 (10)	1.062 (15)	1.068 (10)	1.006 (26)	1.024 (16)	0.972 (20)	0.986 (14)
223.2	1.153 (18)	1.055 (36)	1.089 (20)	1.088 (33)	2.24 (25)	1.33 (7)	1.64 (15)	1.40 (8)
276.4	1.148 (22)	1.055 (16)	1.087 (18)	1.085 (16)	1.97 (28)	1.27 (7)	1.51 (15)	1.33 (9)
302.8	1.068 (13)	1.023 (10)	1.040 (10)	1.038 (9)	1.75 (14)	1.214 (37)	1.41 (7)	1.241 (36)
356	1.056 (11)	1.020 (9)	1.033 (11)	1.032 (10)	1.52 (8)	1.161 (23)	1.299 (43)	1.179 (24)
383.8	0.875 0(9)	0.956 (9)	0.921 (10)	0.933 (10)	1.007 (39)	1.007 (18)	1.002 (26)	0.961 (17)

^{134}Cs Energy (keV)	Detector A				Detector B			
	Point	Water	Filter	Soil	Point	Water	Filter	Soil
475.3	1.52 (6)	1.180 (25)	1.301 (34)	1.268 (32)	1.60 (6)	1.202 (25)	1.344 (35)	1.309 (32)
563.2	1.593 (32)	1.189 (19)	1.327 (15)	1.296 (16)	1.684 (30)	1.224 (14)	1.380 (14)	1.344 (16)
569.3	1.589 (25)	1.200 (11)	1.331 (18)	1.299 (14)	1.682 (23)	1.225 (9)	1.382 (13)	1.346 (14)
604.7	1.320 (12)	1.115 (6)	1.187 (8)	1.172 (9)	1.365 (10)	1.131 (5)	1.216 (5)	1.197 (7)
795.8	1.324 (12)	1.116 (11)	1.188 (9)	1.171 (10)	1.372 (10)	1.132 (5)	1.221 (20)	1.197 (6)
801.9	1.521 (37)	1.174 (21)	1.297 (20)	1.267 (20)	1.608 (40)	1.202 (17)	1.344 (29)	1.308 (21)
1038.6	1.05 (9)	1.04 (6)	1.01 (8)	1.03 (6)	1.05 (8)	1.037 (47)	1.02 (7)	1.04 (6)
1167.9	0.77 (4)	0.919 (33)	0.841 (28)	0.883 (20)	0.741 (38)	0.895 (23)	0.815 (29)	0.862 (23)
1365.2	0.676 (8)	0.866 (20)	0.764 (10)	0.814 (15)	0.638 (9)	0.838 (16)	0.727 (6)	0.784 (16)

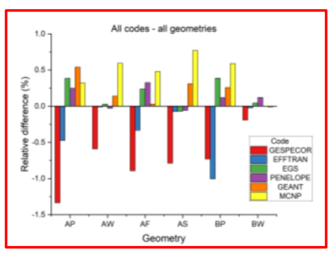
^{22}Na Energy (keV)	Detector A				Detector B			
	Point	Water	Filter	Soil	Point	Water	Filter	Soil
1274	1.35 (22)	1.19 (5)	1.31 (7)	1.29 (7)	1.42 (27)	1.22 (6)	1.36 (8)	1.34 (8)

23 datasets – Discussion between participants to examine discrepancies and harmonise calculation conditions

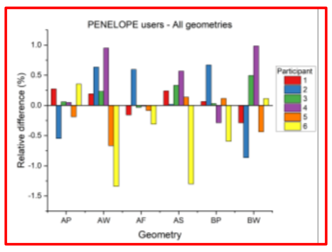
Analysis of coincidence corrective factors for ^{60}Co - 1173 keV



Relative differences of individual results
$R(E,i) = 1\% - 2\%$



Relative differences between codes
$R_k(E) = 1\% - 2\%$



Relative differences within code PENELOPE
$R_p(E,i) = 1\% - 1.5\%$

Output: The action results are made available on a the ICRM GSWG webpage: http://www.lnhb.fr/icrm_gs_wg/icrm_gs_wg_benchmarks/.

For each Monte Carlo code, these include **input files** and efficiency and coincidence summing **calculation results**, including **practical recommendations** for new users.

Some lessons learned

Influence of binning size, peak area definition
Importance of the decay scheme and of X-rays (^{133}Ba)
Case of positrons (^{22}Na): results strongly depend on the annihilation position

Laboratoire National LNHB Henri Becquerel