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SELF-EVALUATION OF COINCIDENCE SUMMING FACTOR OF RADIONUCLIDES USING MCNP-CP AND PENNUC CODES

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CONTENT

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- ✓ Introduction
- ✓ Monte Carlo simulation
- ✓ Results and discussions
- ✓ Conclusions

Introduction

- Gamma ray spectrometry: detection efficiency calibration, radionuclide activity, and gamma emission intensity.
- However, ANSI N42.14-1999 shows that:

Uncertainty contribution	Typical magnitude (%)[a]
Activity of standard source	0.1—2.0
Source aliquots	0.1—3.0
Peak-area measurement	0.1—30.0
Background peak-area variations	0.0—100.0
Variations in sample attenuation	0.0—50.0
Source-detector geometry	0.1—10.0
ADC live timer	0.0—0.5
Pulse pileup (high counting rate)	0.0—30.0
Coincidence summing	0.0—100.0
Decay of radionuclide	0.0—5.0
Gamma-ray emission probability	0.1—20.0
Full-energy peak efficiency	0.5—15.0

Source-to-detector

Decay scheme

Solid angle

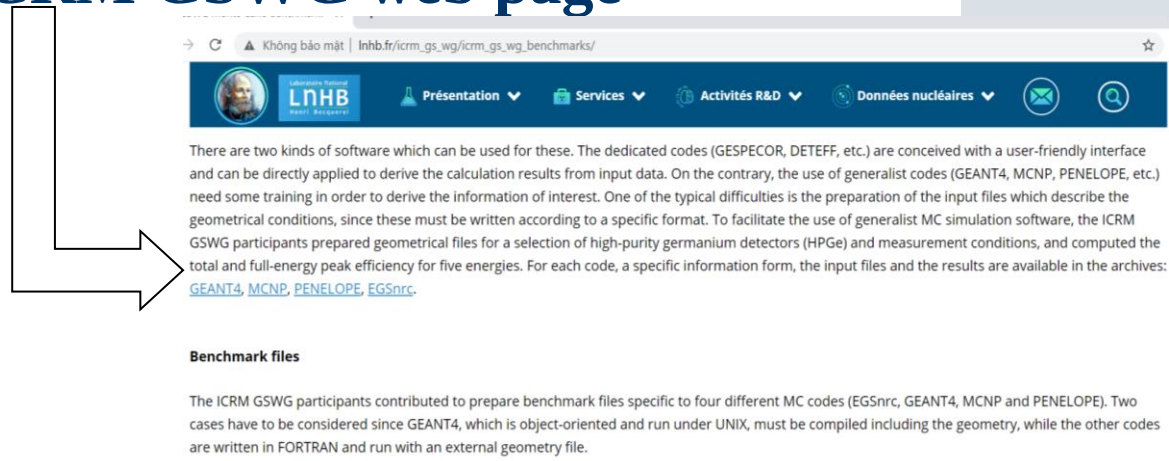
Introduction (cont)

- The goal of this work validated the coincidence summing correction factor by Monte Carlo method.

  - MCNP-CP (**M**onte **C**arlo **N**-**P**article version 6 with **C**orrelated nuclear **P**articles version 3.2)

  - PENNUC (**PEN**ELOPE2014 and **NUC**LEIDE?)

- Geometrical parameters for the simulation are based on the benchmark geometry of **ICRM GSWG web page**



MONTE CARLO SIMULATION

Monte carlo simulation

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- **MCNP-CP** and **PENNUC** codes simulate decay scheme of radionuclides.
- **Energy**: 1keV – 3000keV
- **Channel**: 1000
- **NPS**: 1E7
- **Cutoff**: photon (1keV), and electron (1keV)

Monte Carlo simulation

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- **Radionuclides: Na-22, Co-60, Ba-133, Cs-134, and Bi-214.**
- **Data for MCNP-CP (ENSDF) and PENNUC (NUCLIDE)**

Properties of electromagnetic transitions

Transition ##	E,keV	Level indexes init	-> fin	Multipolarity ENSDF2	Taken as	Mixing ratio	Gammas *
1	1332.492	2	1	E2	E2	0.00000	9.9983e+001
2	826.100	3	2	D+Q	M1	0.00000	7.6000e-003
3	2158.570	3	1		E2	0.00000	1.2000e-003
4	347.140	4	3		E2	0.00000	7.5000e-003
5	1173.228	4	2	E2(+M3)	E2+M3	-0.00250	9.9850e+001
6	2505.692	4	1	E4	E4	0.00000	2.0000e-006

* Intensities per 100 decays of a parent nucleus.

True gamma-gamma coincidence table*.

##	E, keV	Ten the most intense coinciding gamma-rays, keV
1	347.14	1332.51 826.10 2158.61
2	826.10	1332.51 347.14
3	1173.24	1332.51
4	1332.51	1173.24 826.10 347.14
5	2158.61	347.14
6	2505.75	*** single gamma-ray ***

* 500.000 ns resolution time was assumed.

Transitions from level 3

3 --> 0 ICL1 , E = 2.504836E+06 eV, PR = 1.520000E-13
3 --> 0 ICK , E = 2.497415E+06 eV, PR = 1.560000E-12
3 --> 0 GAMMA , E = 2.505692E+06 eV, PR = 2.000000E-08
3 --> 1 ICL1 , E = 1.172328E+06 eV, PR = 1.478000E-05
3 --> 1 ICK , E = 1.164907E+06 eV, PR = 1.510000E-04
3 --> 1 GAMMA , E = 1.173228E+06 eV, PR = 9.985000E-01
3 --> 2 ICL1 , E = 3.462300E+05 eV, PR = 3.770000E-08
3 --> 2 ICK , E = 3.388100E+05 eV, PR = 3.740000E-07
3 --> 2 GAMMA , E = 3.471400E+05 eV, PR = 7.500000E-05

Transitions from level 2

2 --> 0 ICL1 , E = 2.157698E+06 eV, PR = 5.200000E-11
2 --> 0 ICK , E = 2.150277E+06 eV, PR = 5.300000E-10
2 --> 0 GAMMA , E = 2.158570E+06 eV, PR = 1.200000E-05
2 --> 1 ICL1 , E = 8.251880E+05 eV, PR = 2.210000E-09
2 --> 1 ICK , E = 8.177670E+05 eV, PR = 2.280000E-08
2 --> 1 GAMMA , E = 8.261000E+05 eV, PR = 7.600000E-05

Transitions from level 1

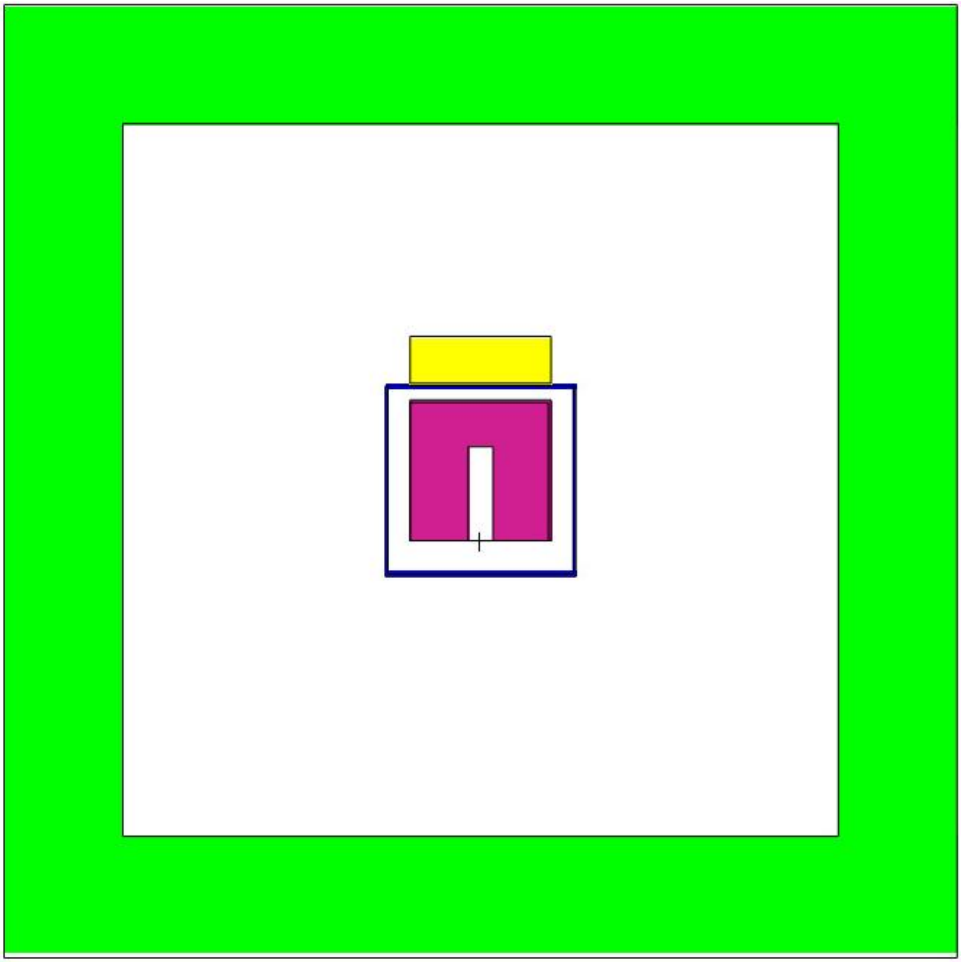
1 --> 0 ICL1 , E = 1.331596E+06 eV, PR = 1.130000E-05
1 --> 0 ICK , E = 1.324175E+06 eV, PR = 1.150000E-04
1 --> 0 GAMMA , E = 1.332492E+06 eV, PR = 9.998260E-01

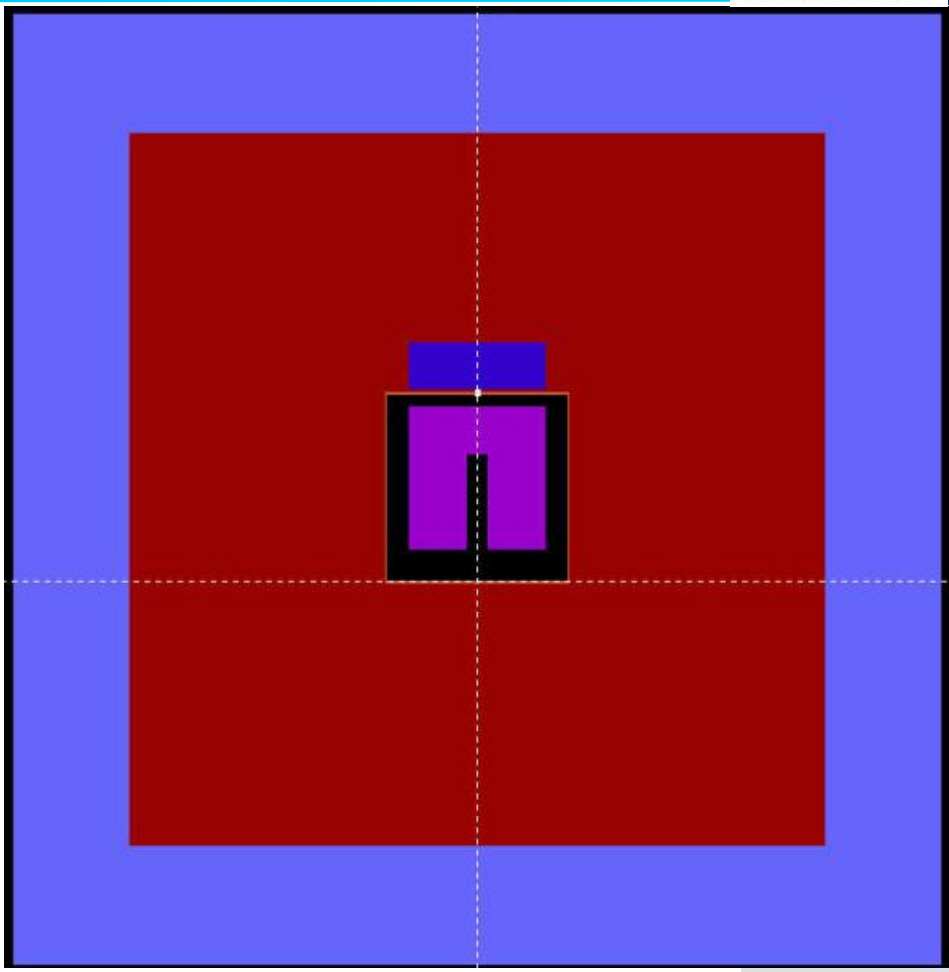
Monte Carlo simulation

Radionuclide	Energy (keV)	I(E) (%)		Relative deviation (%)
		ENSDF	NUCLIDE	
Na-22	**511**		**180.7**	
Na-22	**1274**	**99.944**	**99.94**	**0.00**
Cs-134	**K alpha 32 keV**	**0.4451**	**0.438**	**1.60**
Cs-134	**K beta 36 keV**	**0.08051**	**0.129**	**60.10**
Cs-134	**475**	**1.486**	**1.479**	**0.47**
Ba-133	**K alpha 30 keV**	**70.38**	**62.400**	**11.34**
Ba-133	**K beta 35 keV**	**12.61**	**18.240**	**44.65**
Ba-133	79-80	36.68	35.940	2.02
Bi-214	**609.31**	**46.1**	**45.490**	**1.32**
Bi-214	**934.06**	**3.03**	**3.100**	**2.31**
Bi-214	**2204.21**	**5.08**	**4.913**	**3.29**
Bi-214	**1729.6**	**2.92**	**2.844**	**2.60**

- **The discrepancies are only in X-ray regions**. The maximum relative deviation of intensities is 60%.
- The t-test shows that was not statistically significant (p = 0.67)

Monte Carlo simulation





MCNP plot

PENELOPE plot

Figure 1: Geometrical plot for detector A with soil sample

Results and discussions

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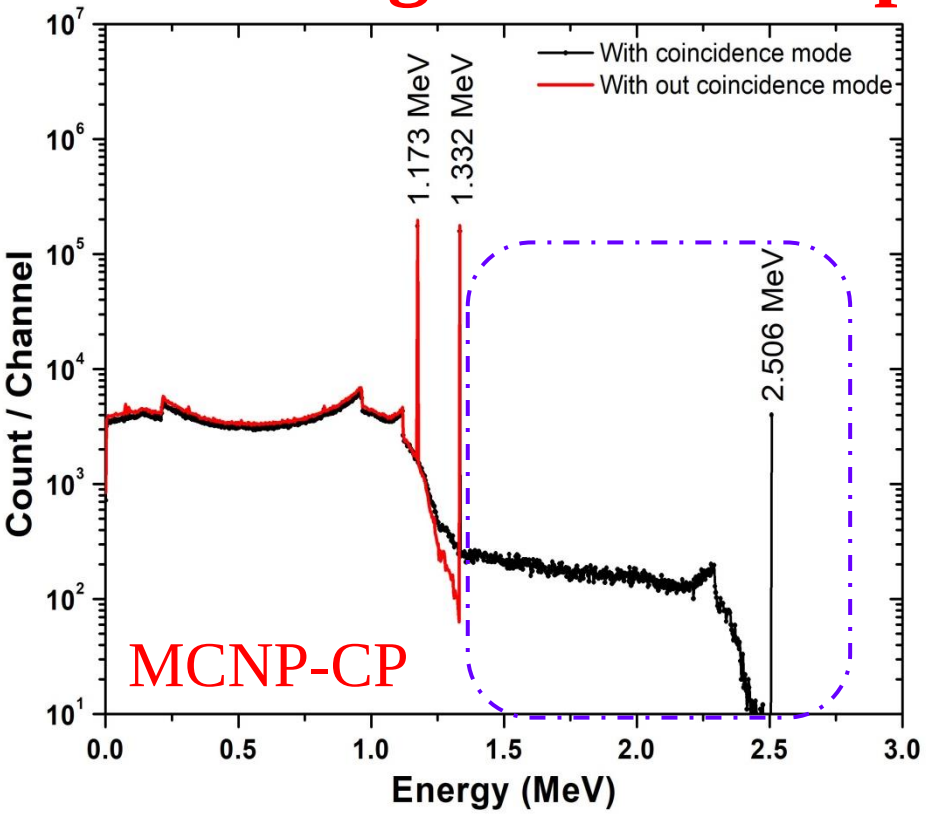
- Comparison of MCNP-CP and PENNUC codes

→ Good agreement of spectra for both codes



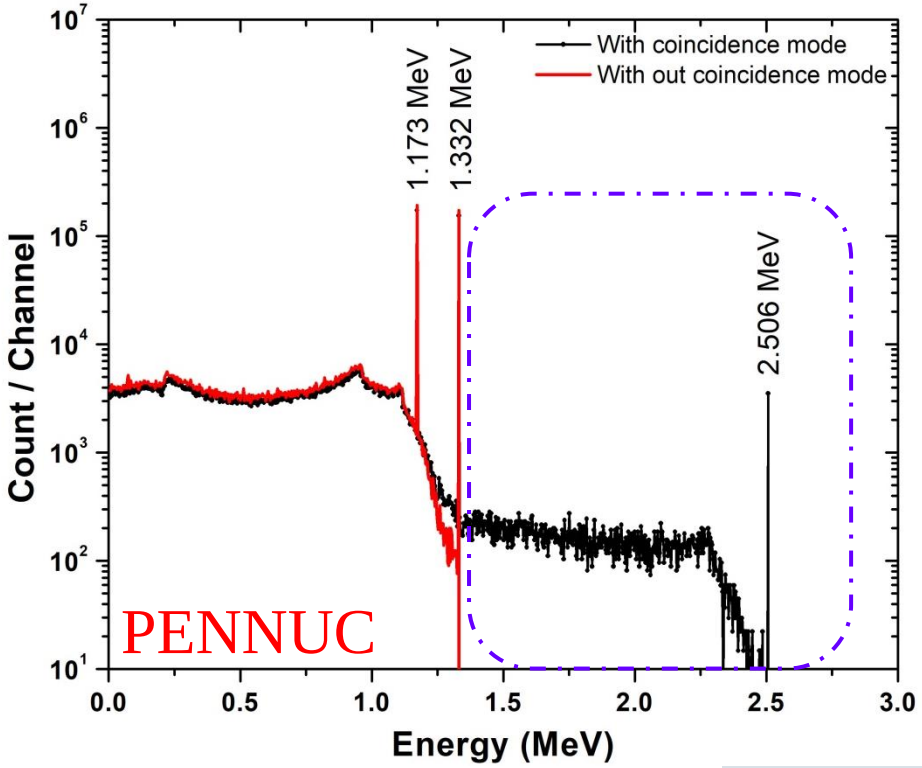


Figure 2: The simulated spectra are with (black line-point) and with out (red line) coincidence summing mode for Co-60.

Results and discussions

The coincidence summing factor (CSF) is a ratio of FEP efficiencies.

$$CSF = \frac{\varepsilon_{Wo}(E)}{\varepsilon_{W}(E)}$$

Without coincidence mode

With coincidence mode

MCNP-CP code has gamma-gamma angular correlations.

In PENNUC code, ACs are disregarded.

Results and discussions

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- **The good agreement between both codes for gamma-gamma coincidence summing factors.**

E(keV)	Detector	Source	MCNP-CP	Unc (%)	PENNUC	Unc (%)	Ratio (M/P)
1173	A	**Point**	**1.219**	**0.23**	**1.213**	**0.22**	**1.00**
		Water	1.085	0.43	1.074	0.43	1.01
		Filter	1.136	0.29	1.135	0.30	1.00
		Soil	1.126	0.33	1.112	0.88	1.01
	B	**Point**	**1.252**	**0.21**	**1.246**	**0.21**	**1.00**
		Water	1.086	0.39	1.084	0.39	1.00
		Filter	1.150	0.27	1.157	0.27	0.99
		Soil	1.129	0.30	1.136	0.79	0.99
1332	A	**Point**	**1.230**	**0.24**	**1.226**	**0.24**	**1.00**
		Water	1.087	0.45	1.082	0.45	1.00
		Filter	1.145	0.31	1.139	0.31	1.01
		Soil	1.126	0.35	1.124	0.93	1.00
	B	**Point**	**1.259**	**0.23**	**1.252**	**0.22**	**1.01**
		Water	1.092	0.42	1.095	0.41	1.00
		Filter	1.154	0.28	1.159	0.29	1.00
		Soil	1.140	0.32	1.151	0.83	0.99

Results and discussions

ICRM GSWG

E(keV)	Detector	Source	MCNP-CP	Unc (%)	PENNUC	Unc (%)	Ratio (M/P)
511	A	**Point**	**1.219**	**0.20**	**1.224**	**0.18**	**1.00**
		Water	1.081	0.24	1.085	0.24	1.00
		Filter	1.132	0.16	1.139	0.16	0.99
		Soil	1.120	0.17	1.118	0.46	1.00
	B	**Point**	**1.254**	**0.18**	**1.250**	**0.17**	**1.00**
		Water	1.092	0.22	1.099	0.22	0.99
		Filter	1.153	0.15	1.158	0.14	1.00
		Soil	1.133	0.16	1.132	0.41	1.00
1274	A	**Point**	**1.176**	**0.23**	**1.208**	**0.23**	**0.97**
		Water	1.186	0.45	1.200	0.45	0.99
		Filter	1.294	0.32	1.348	0.32	0.96
		Soil	1.310	0.35	1.314	0.93	1.00
	B	**Point**	**1.202**	**0.21**	**1.245**	**0.22**	**0.97**
		Water	1.227	0.42	1.220	0.42	1.01
		Filter	**1.354**	**0.29**	**1.413**	**0.30**	**0.96**
		Soil	1.355	0.33	1.343	0.84	1.01

Results and discussions

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E(keV)	Detector	Source	MCNP-CP	Unc (%)	PENNUC	Unc (%)	Ratio (M/P)
30.9	A	**Point**	**1.066**	**1.17**	**1.071**	**1.14**	**1.00**
		Water	1.060	2.16	1.048	2.12	1.01
		Filter	1.053	1.59	1.088	1.84	0.97
		Soil	1.027	1.65	1.059	1.64	0.97
	B	**Point**	**1.832**	**0.09**	**1.823**	**0.10**	**1.00**
		Water	1.279	0.20	1.279	0.20	1.00
		Filter	1.468	0.12	1.468	0.13	1.00
		Soil	1.413	0.19	1.411	0.20	1.00
35	A	**Point**	**1.094**	**1.14**	**1.095**	**1.13**	**1.00**
		Water	1.014	2.11	1.018	2.11	1.00
		Filter	1.059	1.55	1.041	1.83	1.02
		Soil	1.078	1.61	1.043	1.61	1.03
	B	**Point**	**1.812**	**0.20**	**1.795**	**0.21**	**1.01**
		Water	1.266	0.41	1.275	0.43	0.99
		Filter	1.450	0.26	1.455	0.26	1.00
		Soil	1.378	0.35	1.374	0.37	1.00
53.1	A	**Point**	**1.195**	**0.99**	**1.126**	**0.99**	**1.06**
		Water	1.045	1.72	1.043	1.72	1.00
		Filter	1.085	1.33	1.126	1.54	0.96
		Soil	1.086	1.33	1.104	1.33	0.98
	B	**Point**	**1.710**	**0.56**	**1.573**	**0.55**	**1.09**
		Water	1.204	0.92	1.178	0.91	1.02
		Filter	1.393	0.70	1.357	0.69	1.03
		Soil	1.309	0.77	1.276	0.76	1.03

Results and discussions

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E(keV)	Detector	Source	MCNP-CP	Unc (%)	PENNUC	Unc (%)	Ratio (M/P)
32.1	A	**Point**	**1.344**	**1.21**	**1.367**	**1.20**	**0.98**
		Water	1.114	2.02	1.128	2.01	0.99
		Filter	1.215	1.58	1.228	1.70	0.99
		Soil	1.170	1.58	1.187	1.58	0.99
	B	**Point**	**1.419**	**1.14**	**1.442**	**1.15**	**0.98**
		Water	1.138	1.75	1.154	1.77	0.99
		Filter	1.258	1.47	1.234	1.54	1.02
		Soil	1.227	1.45	1.188	1.45	1.03
36.6	A	**Point**	**1.372**	**1.21**	**1.363**	**1.20**	**1.01**
		Water	1.126	2.02	1.061	1.99	1.06
		Filter	1.214	1.58	1.196	1.69	1.02
		Soil	1.220	1.58	1.174	1.58	1.04
	B	**Point**	**1.410**	**1.05**	**1.421**	**1.06**	**0.99**
		Water	1.148	1.77	1.103	1.76	1.04
		Filter	1.244	1.36	1.229	1.43	1.01
		Soil	1.217	1.40	1.198	1.41	1.02

Results and discussions

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- The maximum relative deviation is about 9%.
- The T-test was used for evaluating CSF taking into account from MCNP-CP and PENNUC codes.
- There were not statistically significant for Co-60, Cs-134, and Bi-214 (p value > 0.05)
- However, the results showed that there were differences in the CSF values of Ba-133 and Na-22 between the MCNP-CP and PENNUC data (The p-value of the mean comparison tests is significant with $p < 0.05$).

Conclusion

- Good agreement of response functions of the dectector.
- Good agreement between two codes for calculating CSF.
- Gamma-gamma angular correlations.
- Decay data parameters especially for X-ray regions.

CẢM ƠN - THANK YOU – MERCI

Questions or comments?

References

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