IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Use of Monte Carlo codes in gamma ray spectrometry in an **environmental radioactivity** metrology laboratory

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ICRM GS WG Meeting

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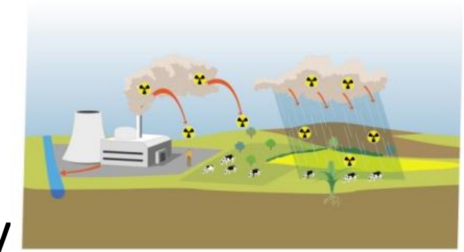
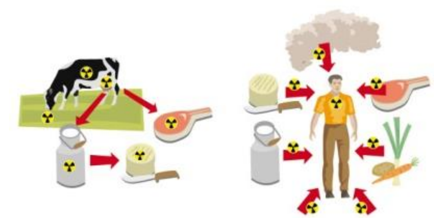
Paris

LMRE

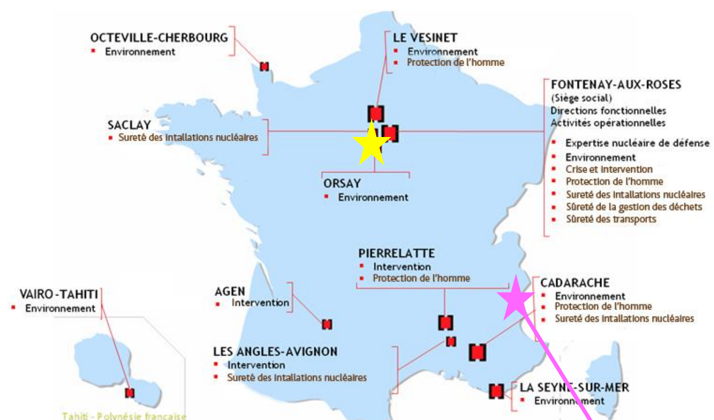
- Institute of Radiation Protection and Nuclear Safety



- Laboratory of Environmental Radioactivity Metrology
  - Environment **monitoring** program
  - **Radioecology** studies
  - **Emergency** preparedness

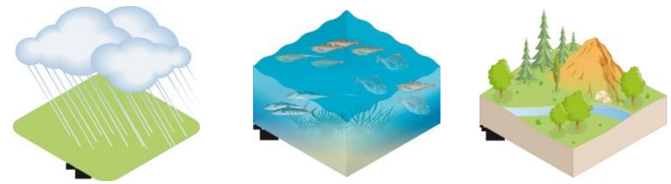


- Gamma ray spectrometry
  - 22 HPGe detectors (3 in Modane)
  - 1500-2000 measurements / year
  - Accreditation
  - Counting time : 1 day → 1 week
  - **Specificity**: **wide range** of measurements
    - Samples: Matrices (i.e. sample material) and counting geometries
    - Radionuclides
    - Detectors



Deep underground laboratory

Which samples ?



Matrices

- All the environment compartments: atmospheric, marine, terrestrial…
- Various media : waters, soils, air (aerosol filters)
- Various organisms : biological matrices

➔ Various **chemical compositions**

➔ Various **densities** (generally 0.5 → 1.5)

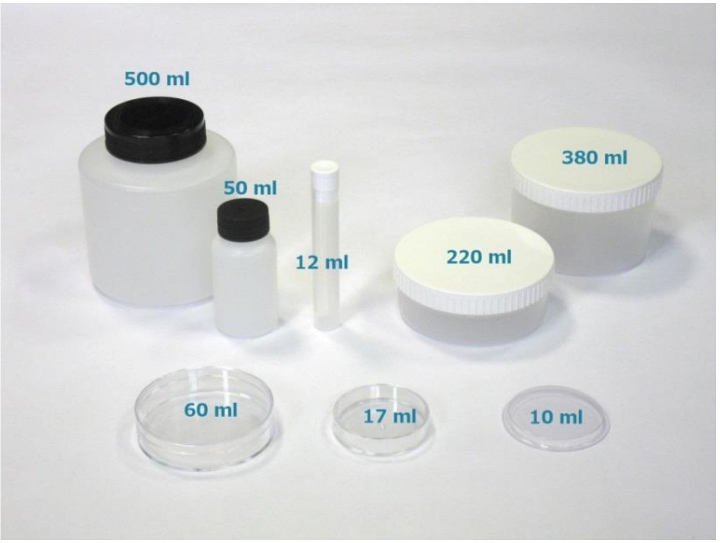
Counting geometries

- Measurements on the endcap
- Depending on :
  - the sample type
  - The availability of the sample
- **7** cylindrical geometries

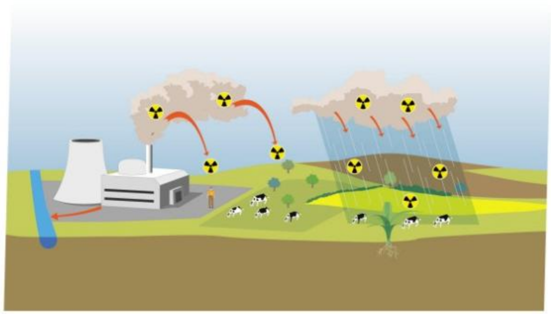
From 10 mL to 500 mL ➔ Variable **thickness**

- **Tubes** for well-type detectors

➔Variable **filling height** !



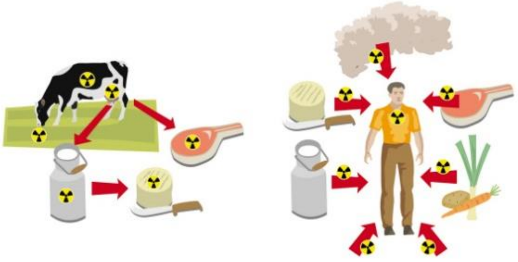
Which radionuclides ?



Naturally occurring radionuclides

- Cosmogenic : ^{7}Be, ^{22}Na…
- Telluric : ^{40}K, ^{235}U, ^{238}U and ^{232}Th natural decay chains…

Artificial radionuclides

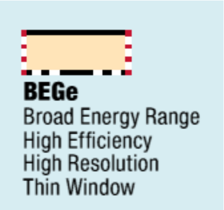


- Present at trace levels in the French environment
  - Global fallout (nuclear weapon tests, Chernobyl…)
  - Nuclear facilities discharges
  - ^{58}Co, ^{60}Co, ^{110m}Ag, ^{137}Cs, ^{129}I…
  - → **Low level measurement**
- Potentially released in case of incident or accident : ^{131}I, ^{134}Cs…
  - → **Rapid measurement**

Issues

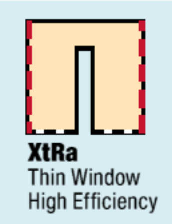
- Not all available in **standard sources**
- **Coincidence** emissions

Which detectors ?



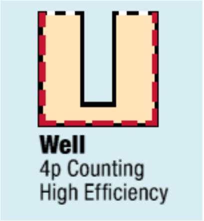
In Orsay

- 10 m w.e.
- « Classic »
  - **Low background**
  - **Relative efficiency > 50%**
  - **Good resolution** : 0.6 keV @ 46 keV (^{210}Pb) ; 1.7 keV @1460 keV (^{40}K)
    - 6 BEGe5030 + 1 BEGe6530 (Canberra) and 5 Profile-FX (Ortec)
      - » 6 with **anti-cosmic** devices
- Anti-Compton system : 1 HPGe XtRa (Canberra) + NaI(Tl)
- Multi-detector **Léda** : 2 BEGe5030 (Canberra) + NaI(Tl)
- 1 planar detector for transmission measurement
- 1 SAGe well type detector (Canberra)

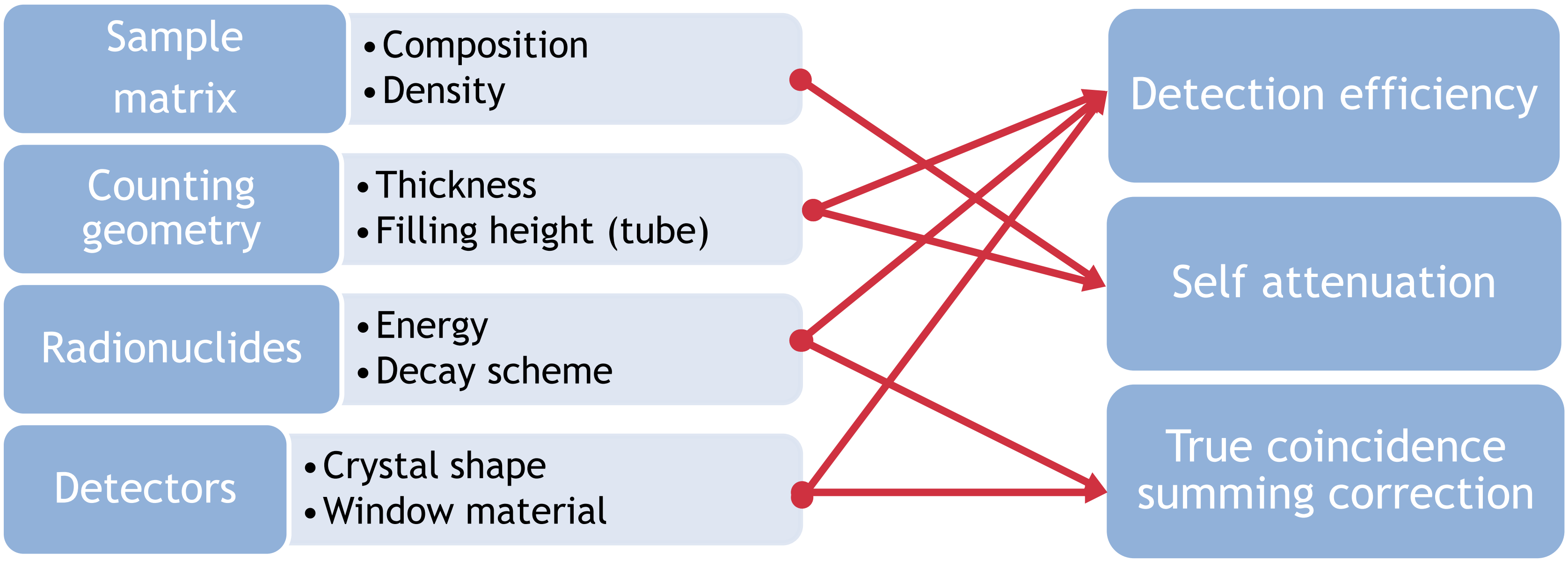


In the Laboratoire Souterrain de Modane (LSM)

- 1700 m w.e.
- **ultra low background** :1 coaxial + 2 well type detectors



Complexity



→needs of simulations

Detection efficiency corrections

True coincidence summing effect (1/3)

Detection efficiency calibrations using standard sources

- All the counting geometries
- Mixture of gamma emitting radionuclides:

^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{54}Mn, ^{88}Y, ^{65}Zn, ^{60}Co + **^{210}Pb**

Correction factors

- calculated with GeSpeCor (Version 4.1)
  - 4 detector types :
    - Coaxial with carbon window
    - Coaxial with aluminum window
    - BEGE5030 (Canberra)/Profile-FX (Ortec)
    - BEGE6530 (Canberra)
  - 7 counting geometries
  - 48 radionuclides
- Applied since 2008 to the calibration measurements (^{57}Co, ^{60}Co, ^{88}Y…)

AND the sample measurements (^{22}Na, ^{214}Bi, ^{110m}Ag…)

- Record value : ^{108m}Ag in 10 mL on BEGe6530 : **0.49** ➔ factor 2 in activity !

True coincidence summing effect (2/3)

MCNPX

- = ideal efficiency
- depending only on the energy

MCNP-CP

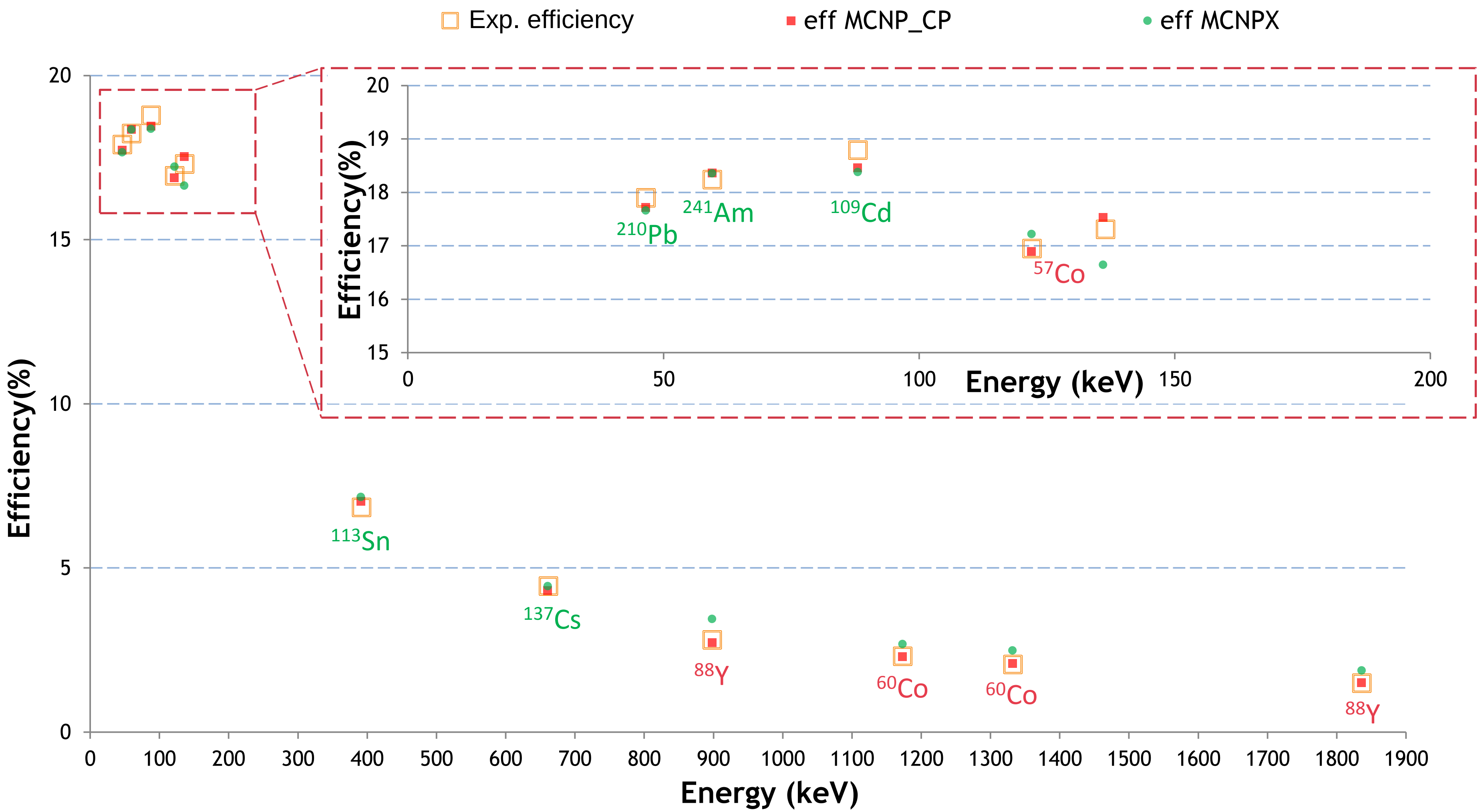
- Extension of MNCPX (A. Berlizov)
- ENSDF decay data
- = real efficiency depending on the decay scheme → taking into account the True Coincidence Summing effect
- Comparable to the experimental detection efficiency (via the emission intensity)

Calculations with MCNP

- Combinations of detection efficiencies calculated by MCNPX and MCNP-CP
- Correction factor on efficiency =

$$C_{sum\ (E,geo)} = \frac{\varepsilon_{real}}{\varepsilon_{ideal}} = \frac{\varepsilon_{MCNP\_CP\ (E,geo)}}{\varepsilon_{MCNPX(E,geo)}}$$

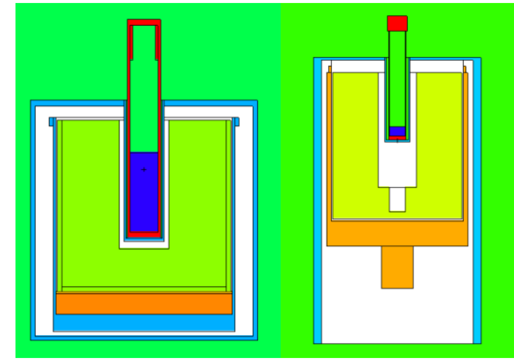
True coincidence summing effect (3/3)



Experimental and simulated efficiency of the detector

Detection efficiencies

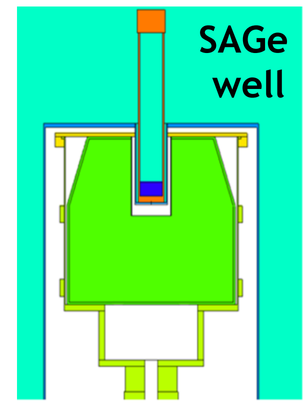
Well type detectors



- **Why ?** Each sample is unique : material AND volume
- **How ?**
  - 3 well type detectors (844, 450 and 487 cm^3) simulated with MCNP-CP : extension of MNCPX + ENSDF decay data
  - Simulated models fitted with standard sources:
    - Water equivalent epoxy resin in tubes with 4 filling heights
    - 3 contents : ❶ ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{54}Mn, ^{88}Y, ^{65}Zn, ^{60}Co + **^{210}Pb** ❷ ^{134}Cs ❸ ^{129}I
  - Efficiency calculation calculated for each sample :

efficiency = f(Sample material, Filling height, Sample mass)

  - Automatically done in routine for 61 photon energies characterizing 32 radionuclides and 6 predefined sample materials
  - Any radionuclide, any sample material !



Multi-detector systems (1/2)

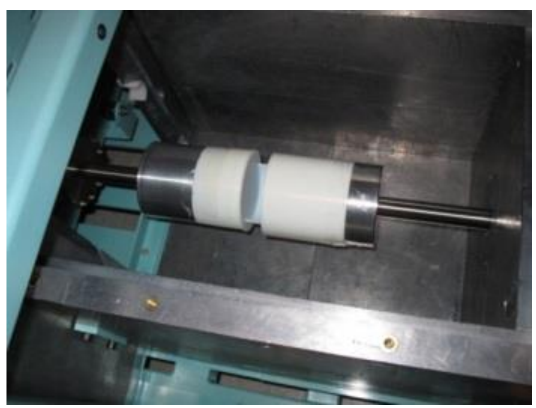
Anti-Compton device

- 55 % XtRa Ge (Canberra)
- NaI (Tl)

H. Paradis (2016) Appl. Rad. Isot. 109 487-492

Leda system :

- 2 BEGe5030 (Canberra)
- NaI(Tl)

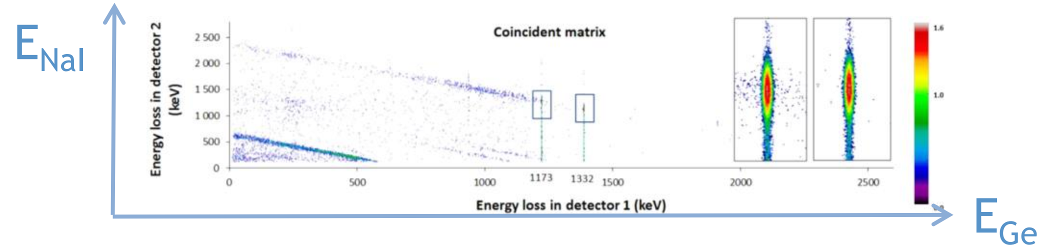


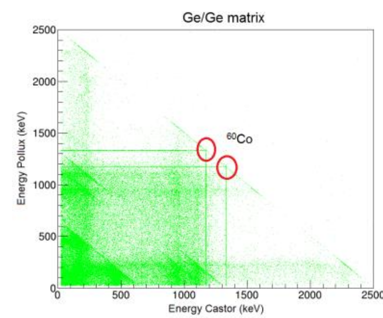
H. Paradis (2017) Appl. Rad. Isot. 126 179-184

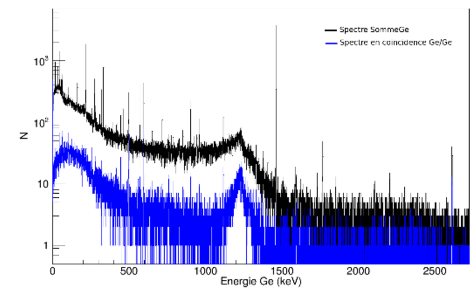
Multi-detector systems (2/2)

Digital electronics

- **List mode** file
- Time and energy information
- **Multiple analysis channels** :
  - Spectra (peaks)
  - Matrices (fingerprints)
  - Coincidence
  - Anti-coincidence

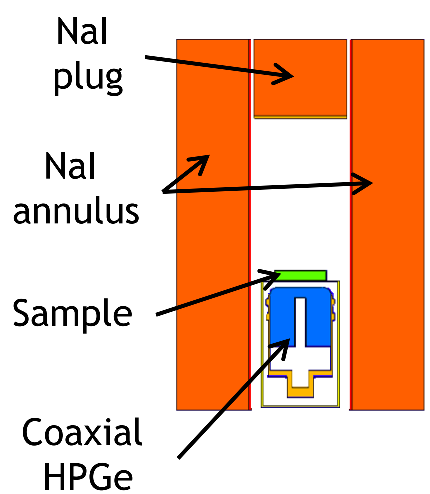


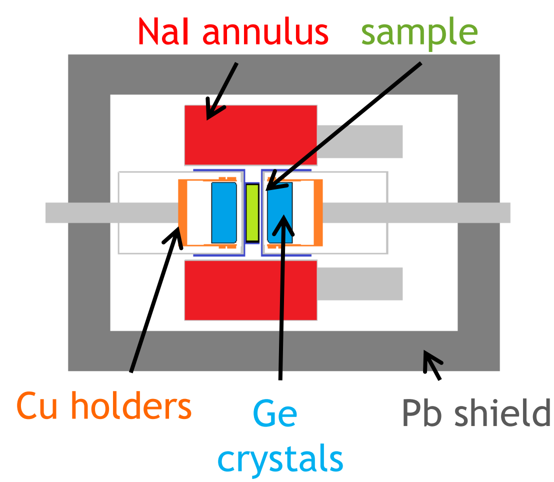




Efficiency calibration

- Models fitted with standard sources measurements
- Geometries : 10, 17 and 60 mL
- **MCNP-CP** : extension of MNCPX
  - ENSDF decay data
  - List mode





Conclusion

Environment radioactivity → Wide range of measurements

Needs of Monte Carlo simulations

- Detection efficiency corrections
- Detection efficiency calibrations

Validated by

- Standard sources measurements
- Reference materials measurements
- Proficiency tests, International comparisons, Intracomparisons…

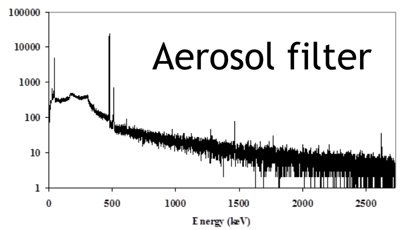
Codes

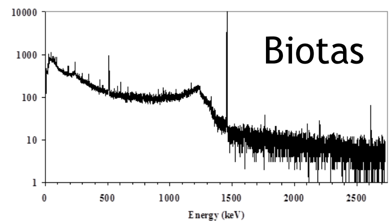
- MCNP-CP : more versatile, more precise + mode list
  - e.g. need for coincidence measurement !
- GeSpeCor : more integrated : less flexible but more sure !
  - e.g. in case of emergency : use of GeSpeCor !

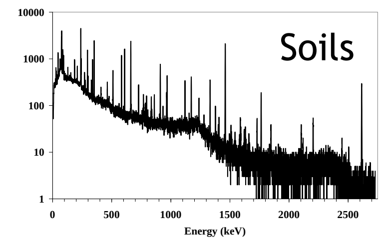
Outlook

Environment radioactivity → Wide range of spectra

- More or less complex, presence of dominant Compton continuum, interferences…

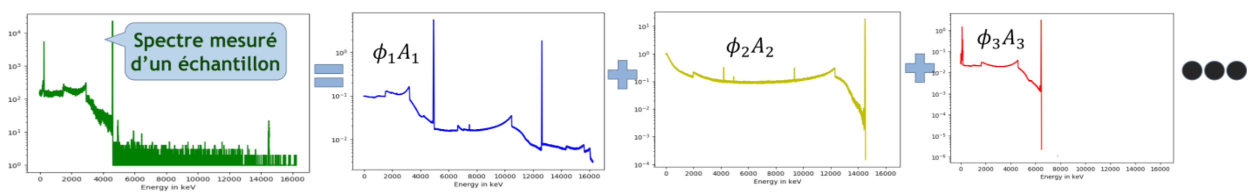






New need of Monte Carlo simulations : **spectra**

- Since October 2017, **PhD thesis** on "Development on tools to help expertise in gamma ray spectrometry" in collaboration with CEA and LNHB
  - **Deep learning** : lab data base 2000 (spectrum, activities per RN)/year
  - **Spectral unmixing** based on the mathematic model of the physical process



- Algorithms tested at first on simulated spectra (**MCNP-CP**) from individual spectra
- More details in Salamanca, May 2019, during ICRM 2019…

Thank you for your attention

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