Coincidence-Compensation for an MCNP Simulation of a Co-60 Volume Source and Detector

L. Li, K. Klein, Q. Alexander
Presented by B. M. van der Ende

June 17, 2014

AECL EACL

UNRESTRICTED / ILLIMITÉ

Outline

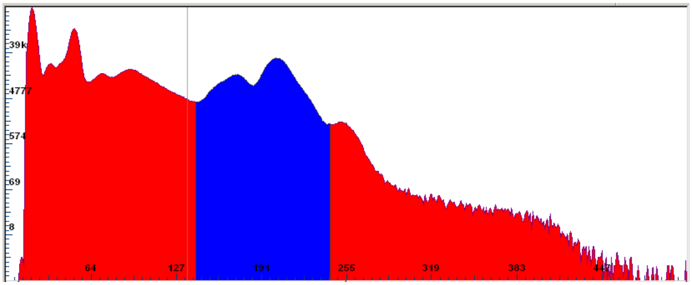
- Introduction to the application
- MCNP used for indirect calibration
- Coincidence compensation
- Extending to volume source
- Result and conclusions

Noble Gas Monitor Introduction

- AECL is a major producer of medical isotopes in the world
- Radioactive noble gases are produced during the production
- They are stored for weeks to let decay
- Then they are released through stack
- The quantity of the radioactive gases released is monitored and reported
- The monitor is mainly composed of
  - Sample chamber
  - NaI scintillator and Photomultiplier (PMT)
  - Amplifier and discriminator

Calibration Methods

- Count rate in the ROI is proportional to the quantity of radioactive concentration in the sample chamber
- The proportional factor can be determined by using calibration source with known quantity
- Direct calibration is not practical
  - Gaseous radioactive sample hard to handle
  - Standard sample decaying away too fast
- Indirect calibration method
  - Simulate the detector with MCNP model
  - Validate the MCNP model with Co-60 measurement
  - Use the validated MCNP model to calculate the calibration factors for radioactive noble gases



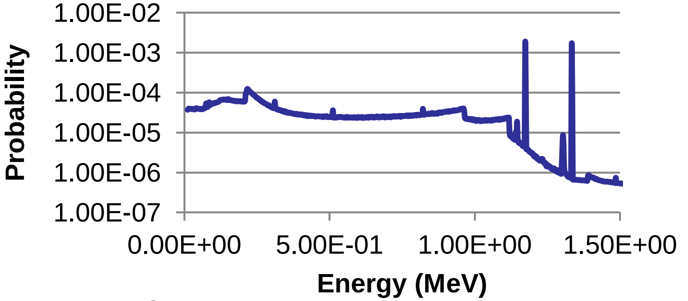
AECL EACL

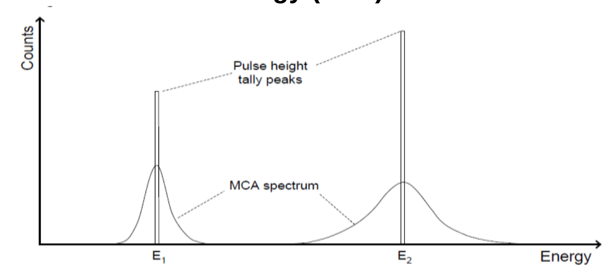
Validating MCNP Output

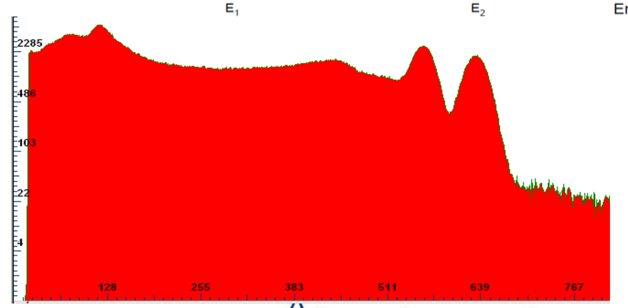
- MCNP F8 tally gives the energy deposited in the NaI crystal
- MCNP output is the probability of a gamma photon depositing certain amount of energy in the scintillator
- Energy will be converted to light by the crystal, and converted to charge signal in PMT
- The signal will be amplified and measured using multichannel analyzer (MCA)
- MCA output is the energy spectrum, counts in the ADC channels
- Gaussian broadening to mimic the limited resolution of the PMT and amplifiers is the key of the validate comparison

```
tally    8            nps =  10000000000
           tally type 8      pulse height distribution.
           tally for   photons

cell  4
      energy
   0.0000E+00     4.84000E-08  0.0455
   2.0000E-03     4.72086E-02  0.0000
   4.0000E-03     3.83122E-05  0.0016
   6.0000E-03     4.10923E-05  0.0016
   8.0000E-03     4.29089E-05  0.0015
   1.0000E-02     4.36692E-05  0.0015
   1.2000E-02     4.42265E-05  0.0015
   1.4000E-02     4.46251E-05  0.0015
   1.6000E-02     4.48966E-05  0.0015
```

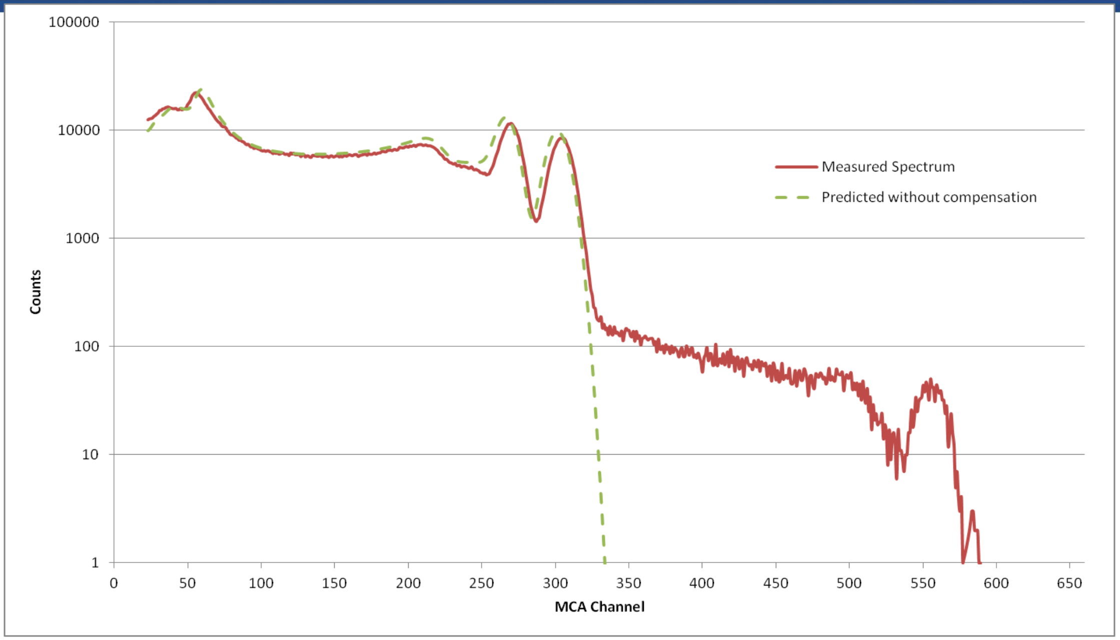


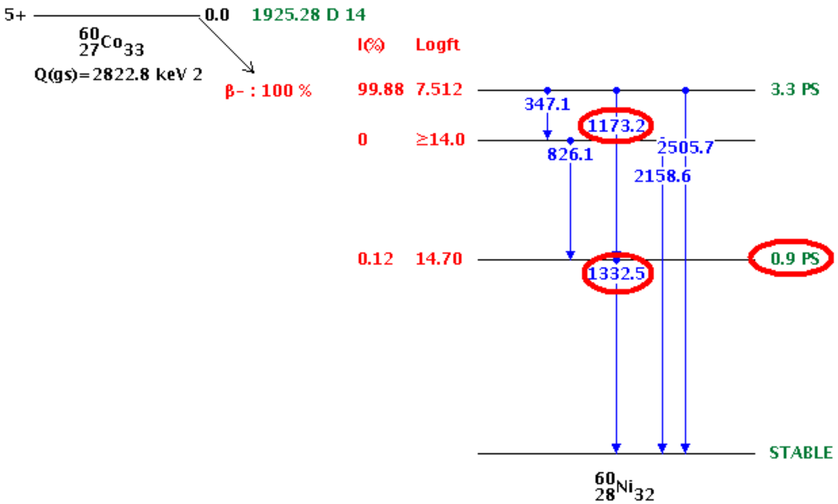




Discrepancy Cause by Coincidence

- There is no data in the MCNP output above 1.33MeV of the Co-60 source
- Co-60 has two main gamma energy peaks: 1.1732MeV and 1.3325MeV
- The two gamma photons are almost always emitted at the same time (>99%, T/2=0.9ps)
- Detector timing resolution is in 10ns order
- Detector will see summing energy peak of 2.5057MeV
- MCNP does not handle coincidence, will not see the summing peak



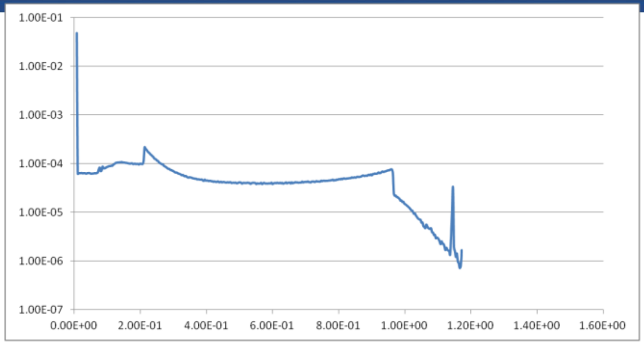


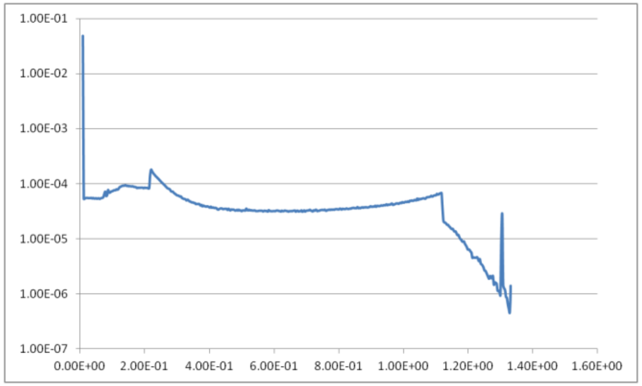
AECL EACL

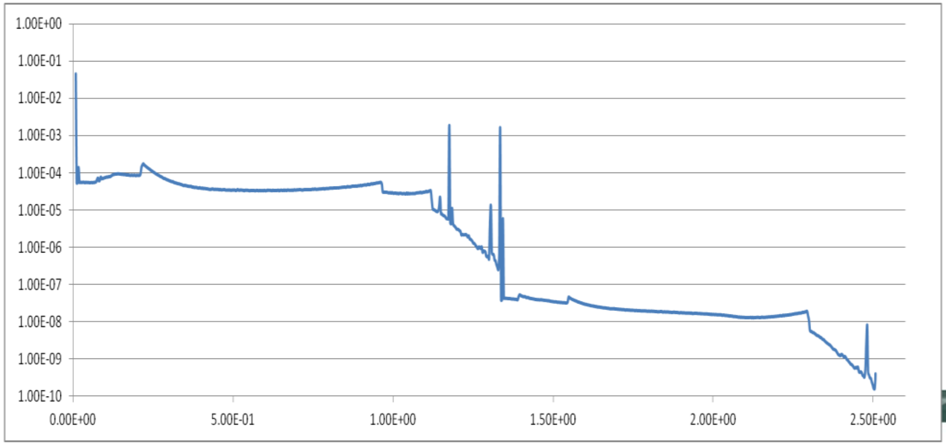
Point Source Coincidence Compensation

- Assume the two coincident gamma photons are independent in their direction
  - According to A.C. Melissinos, the angle between two events are unevenly weighted
  - Weighing factor $w_\theta = 1 + \frac{\cos^2\theta}{8} + \frac{\cos^4\theta}{24}$
  - The maximum/minimum is 1.17
- Make two separate MCNP simulations:
  - a) assuming only 1.1732Mev peak
  - b) assuming only 1.3325MeV peak
- For the two photons of each disintegration there are four possibilities
  - Both miss the detector
  - Only a) hits the detector
  - Only b) hits the detector
  - Both hit the detector
- Combined output, c), will be

$$p_{ci} = 0.5 \times \left(p_{ai} \cdot p_{\bar{B}} + p_{bi} \cdot p_{\bar{A}} + \sum_{j=1,2,\ldots,i-1} p_{aj} \cdot p_{b(i-j)} \right)$$

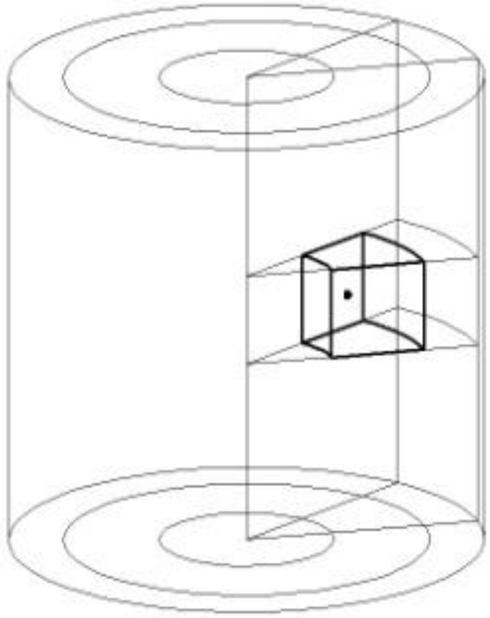






Volume Source

- Coincidence summing is more significant when the detector has a larger solid angle
- Direct volume source MCNP simulation cannot be compensated
- Volume source can be approximately represented by a series of points
- After getting the compensated MCNP output of each point, the total output can be constructed with weighing factors
- Cylindrical symmetric and automatic batch calculation can simplify the work



$$(Z_i, R_j) = \left((0.5 + i)\frac{H}{N_A + 1}, \quad \frac{2jR}{2N_R + 1} \right)$$

$$W_{ij} = \frac{1}{N_A} \cdot \left(\left(\frac{2j+1}{2N_R+1} \right)^2 - \left(\frac{2j}{2N_R+1} \right)^2 \right)$$

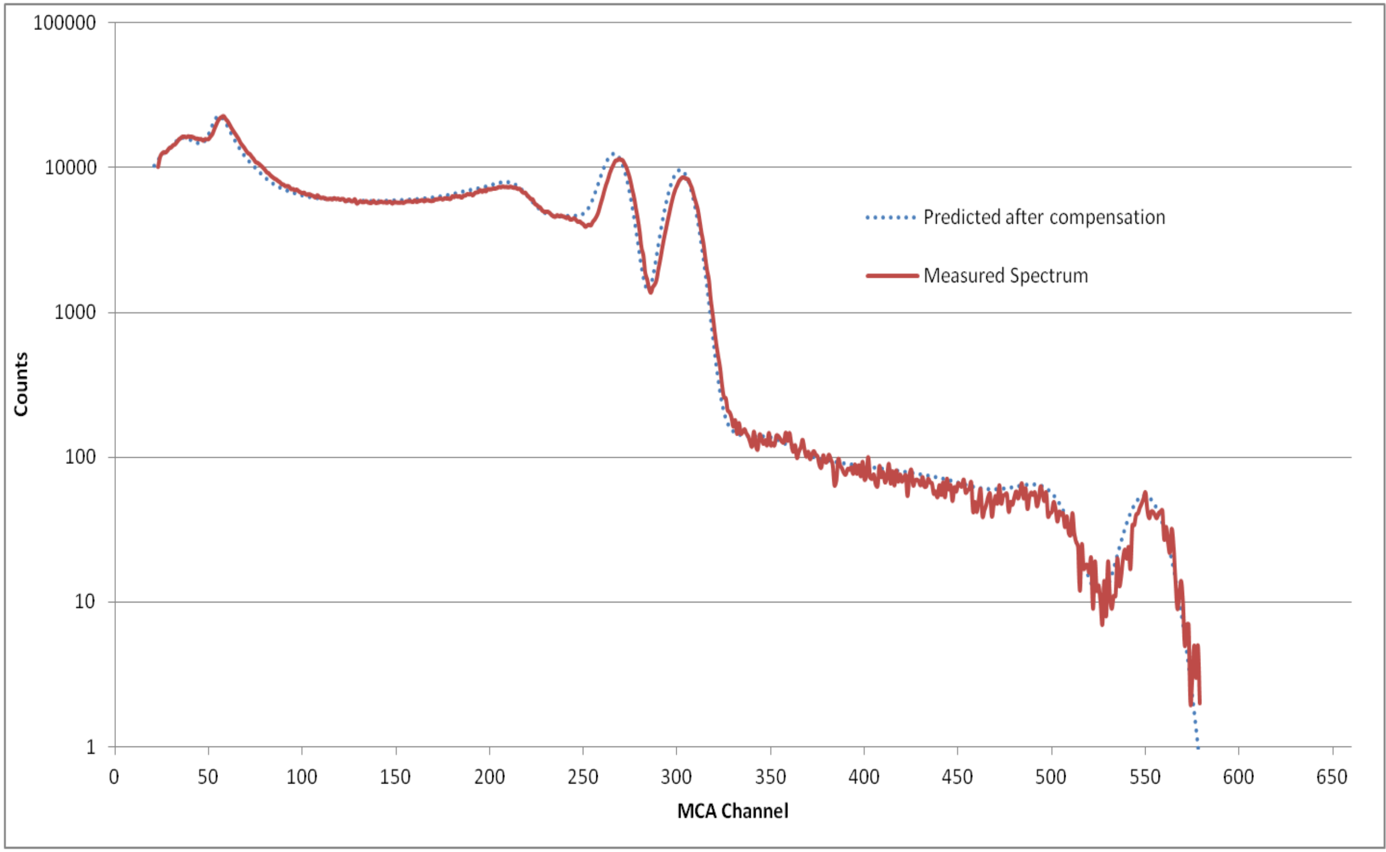
AECL EACL

Result

- Co-60 volume source: 44303Bq
- Measurement time: 1191s

- Vertical 6 sections
- Radial 15 sections
- Total of 180 MCNP simulations
- Total run time on PC: about 46 hours

- Verified that the MCNP model (geometry, material, etc.) is correct



Conclusions

- Indirect calibration with MCNP model can be convenient after being validated
- Co-60 may have coincidence summing in detectors causing discrepancy between measured and MCNP calculated data
- Point source Co-60 coincidence summing can be compensated outside MCNP using probability theory based on assumptions
- Point source method can be extended to volume source case

Thanks!