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

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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.
Validating MCNP Output

- MCNP F8 tally gives the energy deposited in the NaI crystal.
- MCNP output is the probability of a gamma photon depositing a 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.
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.
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 $w_\theta = 1 + \frac{\cos^2\theta}{8} + \frac{\cos^4\theta}{2^4}$
  - 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
\[
p_{ci} = 0.5 \times \left( p_{ai} \cdot p_{b} + p_{bi} \cdot p_{a} + \sum_{j=1,2,...,i-1} p_{aj} \cdot p_{b(i-j)} \right)
\]
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.

\[
(Z_{t}, R_{j}) = \left(0.5 + i, \frac{H}{N_{a} + 1}, \frac{2jR}{2N_{R} + 1}\right)
\]

\[
W_{ij} = \frac{1}{N_{a}} \cdot \left(\frac{2j + 1}{2N_{R} + 1}\right)^{2} - \left(\frac{2j}{2N_{R} + 1}\right)^{2}
\]
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!