Development of a Monte Carlo model for the Argonne Total Absorption Gamma-ray Spectrometer (TAGS)

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Funding:
Where?
Where?
Where?

Canberra, Australian Capital Territory

Population: 345,000

Australia Map

Australian Flag
Tape irradiated by CARIBU

TAGS with Si
The TAGS detector

Nal(Tl) TAGS detector at Argonne

Original detector used by Greenwood et al @ Idaho.

Greenwood et al. 1992 NIMA 314 pg514-540
The TAGS detector

NaI(Tl) detector dimensions:
25.4 cm diameter x 30.5 cm length

Well Dimensions:
5.1 cm diameter x 20.3 cm length

7 x PMTs
GEANT4: Geometry ANd Tracking 4

International collaboration of programmers organized through CERN, started in 1999

Based on C++, update to Fortran based GEANT3

Originally intended for High Energy Physics simulations

High modularity allowed greater use by the physics community

GEANT4 - NIMA 506 (2007) 250-303
TAGS model

Nal detector constructed in simulation using dimensions both measured and indicated in Greenwood

Dimensions given by Greenwood et al.
TAGS model

- **Under the hood (bonnet)**
  - Simulation resolution
  - Light non-proportionality correction
  - Pile-up
  - Model input
  - Model output
TAGS model

- Under the hood (bonnet)
- **Simulation resolution**
  - Light non-proportionality correction
  - Pile-up
  - Model input
  - Model output
Simulation resolution

$^{60}\text{Co}$

- Idealized response
- Imposed response
TAGS model

- Under the hood (bonnet)
- Simulation resolution

**Light non-proportionality correction**
- Pile-up
- Model input
- Model output
Light non-proportionality correction

Method from Cano-Ott et al. NIMA 430 (1999) pg 333 - 347
Light non-proportionality correction

Method from Cano-Ott et al NIMA 430 (1999) pg 333 - 347

Shift in position of summed peak
More light generated for summed individual events than for a single event of the same energy
**Light non-proportionality correction**

Method from Cano-Ott et al NIMA 430 (1999) pg 333 - 347

**Empirical equation**

\[
\frac{L}{E_e} = \frac{a_1(1 - e^{-a_2 E_e}) + a_3 E_e + a_4 E_e^2}{a_5 + a_6 E_e + a_7 E_e^2}
\]
TAGS model

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TAGS model

- Under the hood (bonnet)
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- **Model input**
- Model output
Model input

Standard particle gun:

Shoots particles
  you define
  - Particle type
  - Direction
  - Energy

One particle per event
Radioactive Decay Module:

Define Co-60 and run.

Decay information controlled by input files, default data from ENSDF
<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>Intensity (counts/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0000</td>
<td>1.6640e+08</td>
</tr>
<tr>
<td>58.5900</td>
<td>6.2800e+02</td>
</tr>
</tbody>
</table>

Decay input file for z27.a60
<table>
<thead>
<tr>
<th>Starting level keV</th>
<th>Transition probability</th>
<th>Angular momentum</th>
<th>Partial Conversion probabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>L1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>L2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>L3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N+</td>
</tr>
</tbody>
</table>
| 3.32518e+03 1.33258e+03 1.00000e+00 | 2.00 1.268e-04 8.968e-01 8.492e-02 | 2.00 9.603e-05 1.159e-04 1.913e-08 3.881e-08 4.286e-03 |}

Photo evaporation file for z28.a60
Greenwood et al. 1992 NIMA 314 pg514-540
$^{60}\text{Co}$

- Greenwood measurement
- Geant4
TAGS model

- Under the hood (bonnet)
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- Pile-up
- Model input

- Model output
Model output

For each event:

- Index1
- Feed1
- Index6
- Feed6
- Energy TAGS total
- Energy TAGS (Feed1)
- Energy TAGS (Feed6)
- Energy TAGS LE correction
- Energy Si Total
- Energy Si-β
- Energy Si-γ
- PMT1
- PMT6

Where Index:

- 0 - error
- 1 - \( e^- \)
- 2 - \( e^+ \)
- 3 - e capture
- 4 - \( \alpha \)
- 5 - \( \gamma \)
Addition of Silicon detector in the simulation

Ability to use in coincidence with TAGS
5 x 10^6 events generated

60Co- Simulation
TAGS Singles

1.04 x 10^5 Si gated hits

4.93 x 10^6 hit singles

60Co- Simulation
Si gated TAGS
Gating with RDM information

$^{60}$Co - Simulation 99.88% branch

$^{60}$Co  

$^{60}$Ni

- 99.88
- 1173
- 1332

- 0.12
- 2505
- 1332
Gating with RDM information

60Co - Simulation
99.88% branch

60Co - Simulation
0.12% branch

60Co

99.88

0.12

1173

1332

2505

60Ni

1332
TAGS Simulation of $^{60}$Co in well

- 1173 keV $\gamma$
- 1332 keV $\gamma$
- 318 keV $\beta$

Total response

Gating on each RDM produced particle
Alternative method

Simulation $^{60}\text{Co}$

- 1173 keV
- 1332 keV

RDM cascade response
Simulation $^{60}$Co

- Using mixing script
- Energy deposition with RDM

$\beta$ component not added here
Meanwhile in the lab.......
TAGS measurement - $^{60}\text{Co}$

Passively summed response
TAGS model

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TAGS model

- Under the hood (bonnet)
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- Optical Photons
Using optical photons
Simulation $^{60}$Co

Summed response
Individual PMT responses
- Central PMT response
- Peripheral tube responses

Summed response
Disadvantage !!

Simulation time \(~1000\) x standard simulation time

This can be overcome by running multiple threads in parallel
Advantage
TAGS model

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- Optical Photons
TAGS model

• Under the hood (bonnet)
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• Optical Photons
Greenwood $^{148}$Ce – $^{148}$Pr

Greenwood et al. 1997 NIMA 390 pg 95-154
Modified decay scheme

Greenwood et al. 1997 NIMA 390 pg 95-154
Not there yet!

- Greenwood $^{148}$Ce-$^{148}$Pr
- Simulation Sum $^{148}$Ce – $^{148}$Pr
Not there yet!

- Greenwood $^{148}\text{Ce} - ^{148}\text{Pr}$
- Simulation Sum $^{148}\text{Ce} - ^{148}\text{Pr}$
- Simulation 2050 keV pseudo level
Summary

• GEANT4 model exists

• ENSDF data as input

• Investigated microscopic behavior - optical photons

To be continued....