Current status of EGS5

- Comparison with experiment on e- backscattering -

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# History of EGS System

<table>
<thead>
<tr>
<th>Period</th>
<th>Program</th>
<th>Language</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1963～1965</td>
<td>SHOWER1</td>
<td>Fortran</td>
<td>Nagel</td>
</tr>
<tr>
<td>1966</td>
<td>SHOWER2</td>
<td>Fortran</td>
<td>Nicoli</td>
</tr>
<tr>
<td>1967～1972</td>
<td>SHOWER3/PREPRO</td>
<td>Fortran</td>
<td>Ryder, Talwar, Nelson</td>
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<tr>
<td>1970～1972</td>
<td>SHOWER4/SHINP</td>
<td>Fortran</td>
<td>Ford</td>
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<tr>
<td>1974</td>
<td>EGS1/PEGS1</td>
<td>Fortran</td>
<td>Ford, Nelson</td>
</tr>
<tr>
<td>1975</td>
<td>EGS2/PEGS2</td>
<td>Mortran 2</td>
<td>Ford, Nelson</td>
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</tbody>
</table>
- Comparison with experiment on e- backscattering – as the benchmark of electron transport
**Benchmark of electron/photon transport calculation code**

<table>
<thead>
<tr>
<th>Incident particle</th>
<th>Transport process</th>
<th>Estimated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(E) Electron, Positron</td>
<td>(i) Backscattering</td>
<td>(a) Coefficient</td>
</tr>
<tr>
<td>(P) Photon</td>
<td></td>
<td>(b) Energy spectrum</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) Angular distribution</td>
</tr>
<tr>
<td>(ii) Transparent</td>
<td>(a) Coefficient</td>
<td>(b) Energy spectrum</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) Angular distribution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(d) Dose</td>
</tr>
<tr>
<td>(iii) Deep penetration</td>
<td>(a) Energy deposition</td>
<td>(b) Charge deposition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) Dose</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(d) Detector response</td>
</tr>
</tbody>
</table>
Benchmark calculation of general purpose electron/photon transport code

• Until now, general purpose electron/photon transport code (EGS, ETRAN, ITS, Penelope, MCNP, Fluka, Geant etc) has been benchmarked for many experiment.

• Among them, electron backscattering* is one of the most severe test, because electron multiple scattering calculation tends to fail for backscattering.

* Electron backscattering coefficient

Electron beam
Score number of electron at half sphere surface
Target Thickness > range/2
BS coefficient from U, Ag target

Calculation condition:
Multiple Scattering angle: Goudsmit-Sauderson theory
Spin relativistic effect is considered.
BS coefficient from Cu, Al target
BS coefficient from C, Be target
Tendency of BS coefficient $\eta$

- Calc. and Exp. values agrees well for U-Al.
- Calc. and Exp. values differ for C and Be.
  - Among calc., ITS is close with exp. at MeV region. why?
- EGS5, EGSnrc and Penelope agreed with 20% for all target/energy.
- We study and re-evaluate Tabata’s exp.
  - Covers wide Z range in MeV region.
  - Experimental condition and analytical method are expressed in detail.
Outline of Tabata’s exp

Tabata used ionization chamber to detect backscattered electron.

\[
I = \int_{E_{\text{cut}}}^{E_0} \frac{d\eta(E)}{dE} R(E) dE
\]

- \( \eta \): Number of back scattered electron
- \( R(E) \): Response function of ion chamber
- \( E_{\text{cut}} \): Electron cut-off energy
- \( I \): Output of ion chamber

Structure of Tabata’s Ion chamber

Question: How do we get \( \eta \) from \( I \)?

Tabata’s solution: \( \eta = \frac{I}{f(E_{\text{av}})} \)

- \( f \) is a multiplication factor of ion chamber which depends on \( E_{\text{av}} \).
- \( E_{\text{av}} \) is average energy of back scattered electron. He assumed that \( E_{\text{av}} \) is a function of the source electron energy and atomic number of the target.
  - \( E_{\text{av}} \) for \( \text{Al, Cu, Pb} \) and 1,2,3 MeV is obtained from other experiment.
  - \( E_{\text{av}} \) for various \( Z \) and \( E \) is obtained by interpolation and extrapolation.
- \( f(E_{\text{av}}) \) for the \( \text{Au} \) target was estimated by \( \eta \) obtained from the Faraday cup.
EGS5 approach 1

• Follow Tabata’s method
  – Calculate response function of Tabata’s IC, R(E)
    – $E_{\text{cut}}$ is set to 1keV
  – Calculate backscattered electron spectrum, $\eta(E)$, and calculate $\eta$ and $E_{\text{av}}$
  – Calculate $I$ by using $\eta(E)$ and $R(E)$
  – Then, calculate $f$

\[ f = I/\eta \]

Response function of Tabata’s IC by EGS5 & ITS 3.0

The value of $R(E)$ below 0.15 MeV is zero due to Al window.
Error of $E_{av}$ and multiplication factor $f$

Comparison of $E_{av}$

Error of $E_{av}$ results in an error of factor 1.7 in $f$ (Be)

E$_{av}$ and $f$ work fine (U)

70%

10%
Reason of large error for Be target

Resonant enhancement of detector response & electron spectrum

Response function of Tabata’s IC
Energy spectrum of backscattered electron

-> Instead of $f(E_{ab})$, $R(E)$ should be employed! Or, $I$ should be compared!
Comparison in $\eta$: Original condition

Comparison in $I$: (Treated $R(E)$)

1 \lt C/E \lt 1.2$ for C, Al, Cu, Ag, Au, U

C/E = 1.5 for Be

Remaining question 1: Why C and E differs? Error in calculation? ...

... New experiment is waited.
• Why was ITS closer to exp?
  – Investigate transport mechanism of ITS.
• Number of substep = 2 for Be. This causes too long path length for electron and too small $\eta$. (Problem A)
• Number of step = 64. This introduces effective cutoff energy (0.028MeV for 6.08MeV electron) which affects $\eta$ largely for Be. (Problem B)
Energy spectrum of backscattered electron by 6.08 MeV electron
MCNP5’s electron transport algorithm

(a) Indexing algorithm (default)
(b) ITS indexing algorithm
(c) New energy and step-specific method

Situation in MCNP5
- $N_{\text{substep}}$ dependence is seen.
- Effective cutoff problem removed.
- Algorithm dependence is seen.

6.08 MeV electron backscattering from Be target

MCNP5-ITS3.0-EGS5 comparison
Summary

• During benchmark activity of egs5 code, we re-evaluated Tabata’s electron backscattering experiment.

• We find BS coefficient $\eta$ was distorted for factor 1.7 by using multiplication factor $f(E_{av})$.
  • We obtained better agreement between egs5 and experiment by comparing ion chamber output.

• We also find incorrect $\eta$ calculated by ITS.
  • This and Tabata’s experiment formed “a good agreement (by chance)”, which has been believed as truth for more than 20y.

• Better experiment data is still needed to verify electron and photon transport calculation code.

• We appreciate Prof. Tabata’s help to understand the exp.

Part of this talk is already published as Kirihara’s PhD thesis at Sokendai and NIMB 268(2010) 2384.
Backup slide for Q and A