Shielding Code Comparison: A Simple Benchmark Problem

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Presentation Summary

• Objective of Study
• Geometry Setup: Ta and Al slabs
• Simulation Status
• Geant4 Physics and Scoring
• Calculations:
  – Aluminum and Tantalum
    ▪ Electron spectrum
    ▪ Photon spectrum
    ▪ Neutron spectrum
• Conclusions
Objectives

• To compare and better understand the predictive capability of commonly used radiation transport tools

• To provide a set of benchmark problems that potential instrument providers can use to validate their own choice of transport tools

• For this initial benchmark study, we are focusing on the high energy electron transport, as they are dominating contributor in the Jovian radiation environment.

• Two codes used: MCNPX and Geant4. For Geant4, two sets of results are given, for a native Geant4 application at JPL and for GRAS (Geant4 Radiation Analysis for Space application)
MCNPX is a general-purpose Monte Carlo radiation transport code for modeling the interaction of radiation with everything. MCNPX stands for Monte Carlo N-Particle xTended. It extends the capabilities of MCNP4C3 to nearly all particles, nearly all energies, and to nearly all applications without an additional computational time penalty. MCNPX is fully three-dimensional and time dependent. It utilizes the latest nuclear cross section libraries and uses physics models for particle types and energies where tabular data are not available. Applications range from outer space (the discovery of water on Mars) to deep underground (where radiation is used to search for oil.) MCNPX is used for nuclear medicine, nuclear safeguards, accelerator applications, homeland security, nuclear criticality, and much more.

MCNPX is written in Fortran 90, runs on PC Windows, Linux, and Unix platforms, and is fully parallel (PVM and MPI). As a superset of MCNP4C3, MCNPX does everything MCNP4C3 does and much more; see the 1-page MCNPX Features Summary: Features.pdf, Features.doc.

MCNPX Beta Release

MCNPX (source code, executables, data) is available from this WWW site to "beta testers" who have access to intermediate code versions. Beta versions of MCNPX are available from "The Code" tab at the left of this web site. Beta Testers are sponsors, collaborators, and those who take MCNPX workshops (see "Classes tab on the left.) For further information on the Beta Test program, contact mcnpx@lanl.gov.

The latest beta test version is MCNPX 2.7.B (June 26, 2009). The principal new capabilities added since the latest RSICC release (MCNPX 2.6.0, April 2008) are described in "MCNPX 2.7B Extensions" LA-UR-09-4150.pdf, LA-UR-09-4150.doc (July 6, 2009).
Geant4

- [http://cern.ch/geant4](http://cern.ch/geant4)
- [http://geant4.esa.int](http://geant4.esa.int) (space users’ community)
GRAS

- [http://space-env.esa.int/index.php/geant4-radiation-analysis-for-space.html](http://space-env.esa.int/index.php/geant4-radiation-analysis-for-space.html)
• Electron, photon, and neutron fluxes at the bottom surface of the slab.
• Energy deposition in the shielding volume is also calculated.
• For GRAS, energy deposition after the shielding also tallied
Simulation Case Summary

Tools

• **MCNPX 2.5**
• **Geant4**
  – Geant4 application @JPL
  – GRAS 2.4.1

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (g/cm²)</th>
<th>Energy (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al and Ta</td>
<td>5, 16.6, and 50</td>
<td>1, 2, 3, 5, 10, 20, 30, 50, and 100</td>
</tr>
</tbody>
</table>

81 cases total, each with ~10M histories
# Geant4 Physics and Scoring

<table>
<thead>
<tr>
<th>Physics</th>
<th>Geant4 @JPL</th>
<th>GRAS (Geant4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrons and Gammas</td>
<td>LowEMPhysics</td>
<td>Standard EM</td>
</tr>
<tr>
<td>Secondary neutrons</td>
<td>G4PhotoNuclearProcess</td>
<td>G4GammaNuclearReaction</td>
</tr>
<tr>
<td>Production cut</td>
<td>1 micron</td>
<td></td>
</tr>
<tr>
<td>Flux for e⁻, γ, n (equiv. to MCNPX F2 Tally)</td>
<td>G4PSFlatSurfaceFlux</td>
<td>GRAS Fluence module (w/ “surf. correction”)</td>
</tr>
<tr>
<td>Dose (all particles) (equiv. to MCNPX +F6 Tally)</td>
<td>G4PSEnergyDeposit</td>
<td>GRAS Dose module</td>
</tr>
</tbody>
</table>
Multiple scattering and Geant4 production cuts

• “Condensed history” for electron transport
  – “Multiple” small angle scatterings -> can not practically follow each individual scatterings: “condensed history” or “condensed random walk”
  – In condensed history modelling of electron transport, the electron paths are broken into many steps in each of which numerous interactions occur

• In Geant4
  – Production cut for secondary e⁻ and γ in ionisation and Bremsstrahlung (to avoid “infrared divergence”)
  – Also affects step length and therefore multiple scattering
Geant4: physics models and production cuts

- LowEM and StandardEM produced similar results for our application.
- Setting up the "cut" value is much more important.
10 MeV input on 5 g/cm² of Al

No Neutron Generated

<table>
<thead>
<tr>
<th>Energy Deposit (MeV)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MCNPX</td>
<td>9.06</td>
</tr>
<tr>
<td>Geant4</td>
<td>9.16</td>
</tr>
</tbody>
</table>
50 MeV input on 5 g/cm² of Al

Electron Integral Spectrum

Energy (MeV)

Integrals flux (cm²)

Energy (MeV)

Gamma Integral Spectrum

Integrals flux (cm²)

Energy (MeV)

Neutron Integral Spectrum

Integrals flux (cm²)

Energy (MeV)

Energy Deposit (MeV)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MCNPX</td>
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<tr>
<td>Geant4</td>
<td>9.16</td>
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</table>
2 MeV input on 5.0 g/cm² of Ta

No Neutron Generated

<table>
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<tr>
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<tbody>
<tr>
<td>MCNPX</td>
<td>1.41</td>
</tr>
<tr>
<td>Geant4</td>
<td>1.45</td>
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</table>
10 MeV input on 16.6 g/cm² of Ta

**Electron Integral Spectrum**

- MCNPX
- Geant4
- GRAS (G4)

**Gamma Integral Spectrum**

- MCNPX
- Geant4
- GRAS (G4)

**Neutron Integral Spectrum**

- MCNPX
- Geant4
- GRAS (G4)

<table>
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<tr>
<td>Geant4</td>
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</table>
Conclusions

• The agreement between the three codes is generally good for all cases
  – However, the selection of correct input parameters is important. For example, the Geant4 results strongly depend on the choice of “cut” value
  – More detailed analyses of differences in preparation
  – Need for experimental coordinated validation programme

• More benchmark cases about to start including
  – Representative detector material (e.g., Silicon or HgCdTe) behind the shielding
  – Representative layered shielding options
2 MeV input on 5 g/cm² of Al

No Neutron Generated

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</tr>
</tbody>
</table>
5 MeV input on 5 g/cm² of Al

No Neutron Generated

<table>
<thead>
<tr>
<th>Energy Deposit (MeV)</th>
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<th>Geant4</th>
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<tbody>
<tr>
<td></td>
<td>4.81</td>
<td>4.80</td>
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</table>
30 MeV input on 5 g/cm² of Al

**Electron Integral Spectrum**

- MCNPX
- Geant4
- GRAS (G4)

**Gamma Integral Spectrum**

- MCNPX
- Geant4
- GRAS (G4)

**Neutron Integral Spectrum**

- Geant4
- MCNPX
- GRAS (G4)

<table>
<thead>
<tr>
<th>Energy Deposit (MeV)</th>
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<td>8.44</td>
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</table>
5 MeV input on 5.0 g/cm² of Ta

No Neutron Generated

<table>
<thead>
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<th>Energy Deposit (MeV)</th>
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<th>Geant4</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>3.76</td>
<td>3.81</td>
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</tbody>
</table>
10 MeV input on 5.0 g/cm² of Ta

**Electron Integral Spectrum**
- MCNPX
- Geant4
- GRAS (G4)

**Gamma Integral Spectrum**
- MCNPX
- Geant4
- GRAS (G4)

**Neutron Integral Spectrum**
- MCNPX
- Geant4
- GRAS (G4)

<table>
<thead>
<tr>
<th>Energy Deposit (MeV)</th>
<th>MCNPX</th>
<th>Geant4</th>
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<tbody>
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<td>7.13</td>
<td>7.23</td>
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30 MeV input on 5.0 g/cm² of Ta

**Electron Integral Spectrum**

- MCNPX
- Geant4
- GRAS (G4)

**Gamma Integral Spectrum**

- MCNPX
- Geant4
- GRAS (G4)

**Neutron Integral Spectrum**

- MCNPX
- Geant4
- GRAS (G4)

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<td>9.87</td>
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50 MeV input on 5.0 g/cm² of Ta

Electron Integral Spectrum

Gamma Integral Spectrum

Neutron Integral Spectrum

<table>
<thead>
<tr>
<th>Energy Deposit (MeV)</th>
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<td>8.75</td>
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<td>Geant4</td>
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<td>8.62</td>
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5 MeV input on 16.6 g/cm² of Ta

No Neutron Generated

<table>
<thead>
<tr>
<th>Energy Deposit (MeV)</th>
<th>MCNPX</th>
<th>Geant4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.96</td>
<td>4.00</td>
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