Semi-Analytical Benchmarks for MCNP6

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Introduction

• The neutron Boltzmann transport equation is complicated
  • There are many forms of this equation
  • And there are many ways to solve it

• Should you assume the “black box” just works?
  No.

• There should be some way to prove that the computer code works as expected…
Background
Verification and Validation

- In the context of radiation transport codes

- **Verification**
  - Proof that the transport codes actually solve the transport equation
  - Code-to-analytical comparison

- **Validation**
  - Proof that the transport codes actually reflect what happens in nature
  - Code-to-experimental comparison

- **This presentation will focus only on recent verification efforts**
Background
MCNP History of V&V

• **MCNP verification suites (and recent efforts*)**
  • Kobayashi
    • Fixed-source
    • Multi-dimensional problems
  • Verification Criticality
    • k-eigenvalue problems
    • Few group problems, simplified physics
  • Gonzales*
    • Heavy gas model
    • Includes free-gas scattering
• **MCNP validation suites**
  • Validation Criticality + Expanded
  • Validation Shielding
  • Validation Electron / Photon*
• **Others**

V&V reports for criticality safety applications are regularly issued from MCNP developers with continued support from the DOE NCSP
Background
Semi-Analytic Benchmarks

• “New” benchmarks come from Professor Barry Ganapol’s book, *Analytical Benchmarks for Nuclear Engineering Applications*

• Sections
  • Neutron slowing down and thermalization
  • One-group neutron transport in one-dimension
    • Infinite medium (3.1)
    • Infinite half-space (3.2)
    • Finite slab (3.3)
    • Infinite cylinder (3.4)
  • One-dimensional multigroup neutron transport
  • Multidimensional neutron transport in semi-infinite and infinite media

• Semi-analytic solutions compared to MCNP
Numerical Results
Comparison of Semi-Analytic to MCNP
Benchmark 3.1

Benchmark 3.1.2
Isotropic Source at x=0

- MCNP c=1
- Analytical Solution c=1
- MCNP c=9
- Analytical Solution c=9

Scalar Flux vs. Position in Slab (cm)
Numerical Results
Comparison of Semi-Analytic to MCNP Benchmark 3.1

Benchmark 3.1.2
Isotropic Source at x=0
Numerical Results
Comparison of Semi-Analytic to MCNP Benchmark 3.2

Benchmark 3.2.2(a)
Beam Source at x=0

Scalar Flux

Position in Slab (cm)
Numerical Results
Comparison of Semi-Analytic to MCNP Benchmark 3.2
Numerical Results
Comparison of Semi-Analytic to MCNP Benchmark 3.3
Numerical Results
Comparison of Semi-Analytic to MCNP
Benchmark 3.3
Numerical Results

• What is going on?

• When comparing the semi-analytical solutions to the MCNP simulations, the F2 surface flux tally can be used
  • Provides the solution at a point for one-dimensional problems making it easy to compare with the semi-analytic benchmark solutions
  • F2 type tallies have assumptions to maintain finite variance

\[
\phi = \frac{1}{A \ast W} \sum \frac{wgt}{|\mu|}
\]

• For MCNP6.1 and 6.1.1, below $|\mu|<0.1$ the F2 tally makes constant flux approximation in this “grazing angle” range
• For MCNP6.2, below $|\mu|<0.001$ is the new default “grazing angle” cutoff, and the user may now define a preferred cutoff value
Numerical Results

- Improved solutions

- New grazing angle cutoff

Benchmark 3.1.2

- Use F4 type volume tally (no assumptions)

- Errors due to F2-type tally assumptions
Numerical Results
Comparison of Semi-Analytic to MCNP Benchmark 3.4
Numerical Results
Comparison of Semi-Analytic to MCNP Benchmark 3.4

Benchmark 3.4.2
Uniform Volume Source & Fission

- MCNP $c=1.5$, $R=1.178$
- MCNP $c=1.3$, $R=1.725$
Numerical Results

Tips for Proper Comparisons

• **Remember F2 tallies have assumptions**
  - To maintain finite variance in flux tally
  - Small grazing angles can cause discrepancies

• **Use F4 or FMESH tallies for cell/volume-based track-length flux tallies**
  - No assumptions
  - Comparison to point-wise solutions is difficult

• **Use lower grazing angle threshold to minimize discrepancies**
  - MCNP6.2 includes lower default grazing angle cutoff ($|\mu|<0.001$)
  - User can define cutoff value from input file
Conclusions & Future Work

Conclusions

• **MCNP6 appears to correctly calculate these semi-analytic benchmarks**
  • Continuous energy and multigroup cross sections give same results
  • For improved accuracy when comparing solutions using the F2 flux tally
    • Using small grazing angle cutoff (now default in MCNP6.2)
    • Using cell/volume-based tallies

Future Work

• **Implement more of Ganapol’s benchmarks**
  • Slowing down, multigroup, and multidimensions
• **Create and release a new verification suite**
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