Semi-Analytical Benchmarks for MCNP6

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Outline

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- **Background**
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  - MCNP history of V&V
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- **Conclusions & Future Work**

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

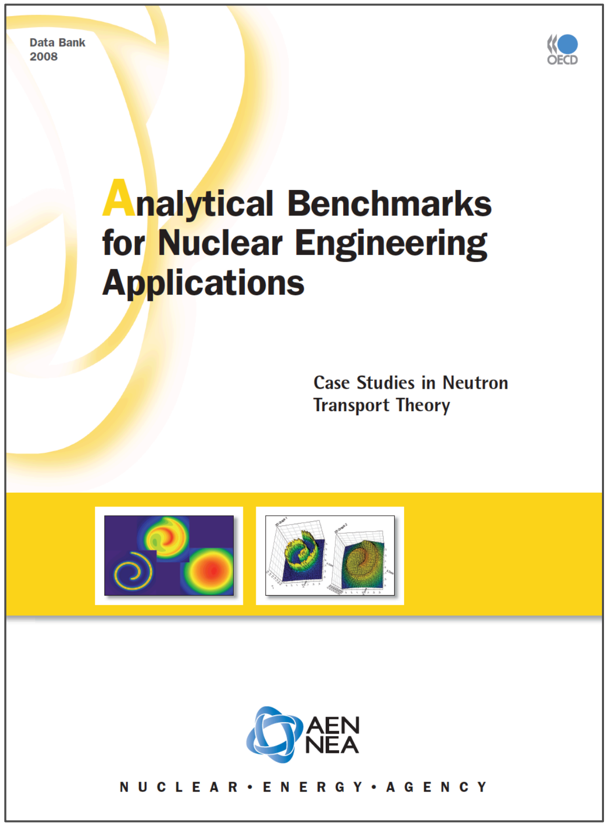
- **MCNP verification suites (and recent efforts*)**
  - Kobayashi
    - Fixed-source
    - Multi-dimensional problems
  - Verification Criticality
    - k-eigenvalue problems
    - Few group problems, simplified physics
  - Gonzales*
    - Heavy gas model
    - Includes free-gas scattering
- **MCNP 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

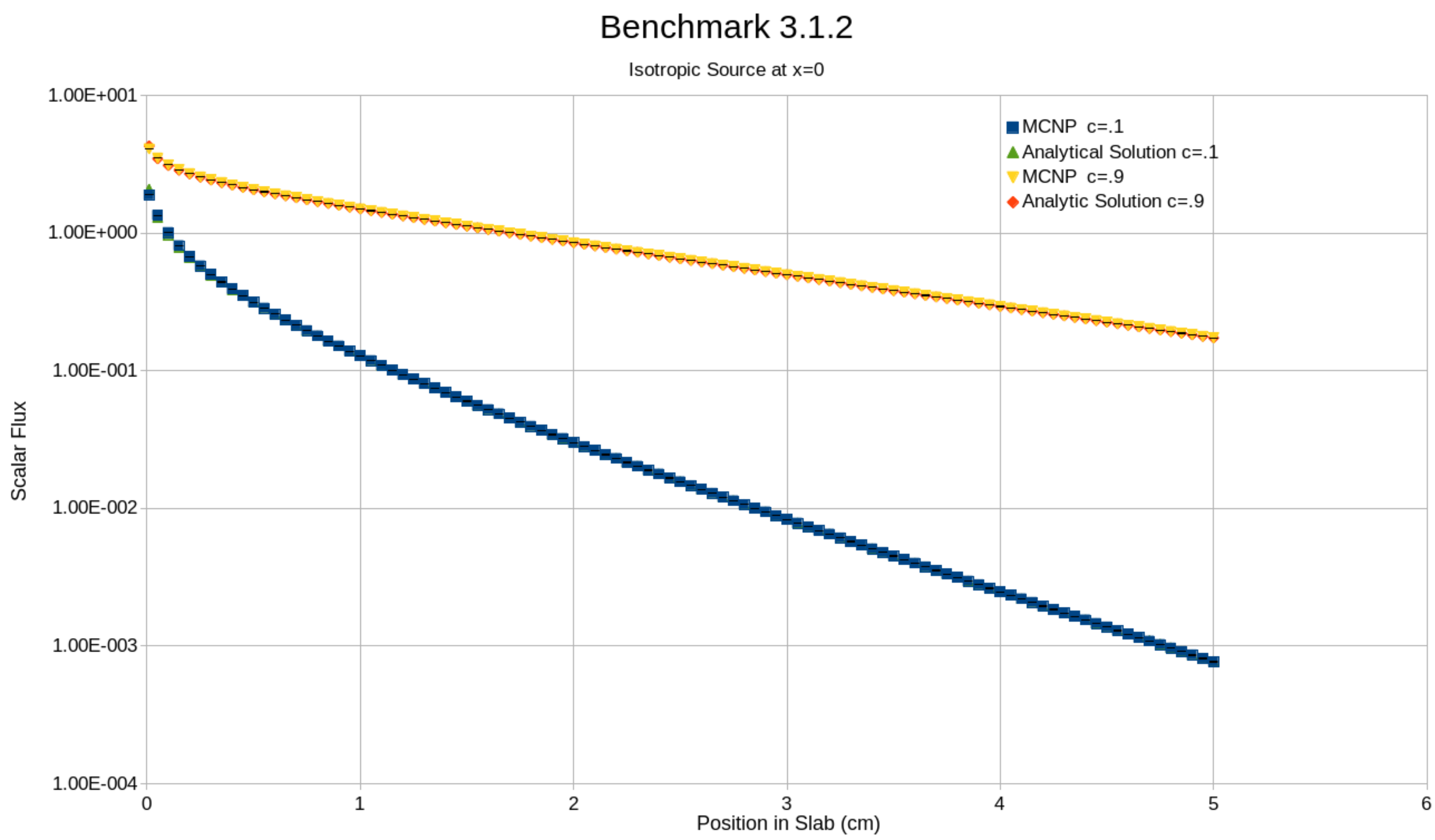
- **"New" benchmarks come from Professor Barry Ganapol's book,** *Analytical Benchmarks for Nuclear Engineering Applications*

- **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

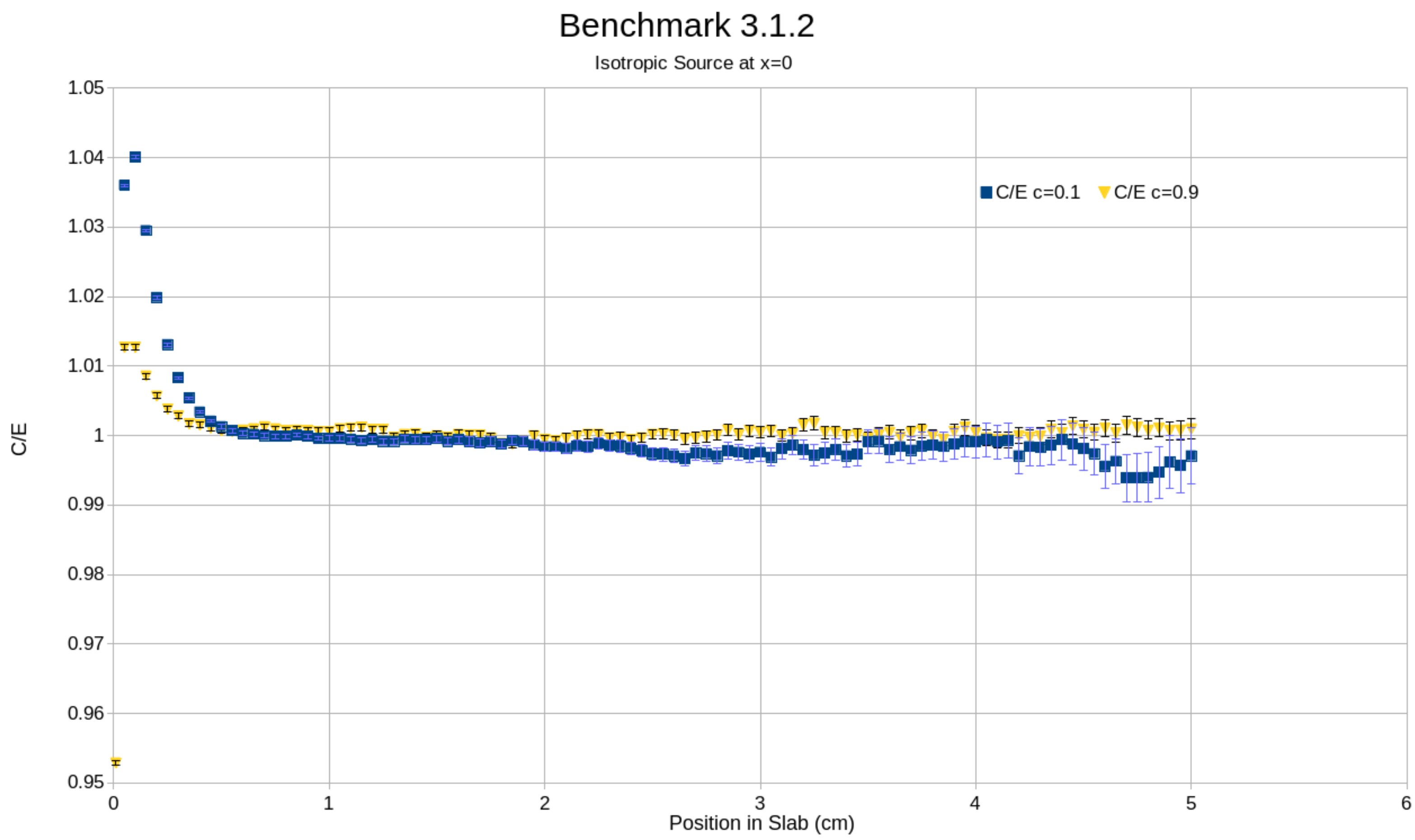


- **Semi-analytic solutions compared to MCNP**

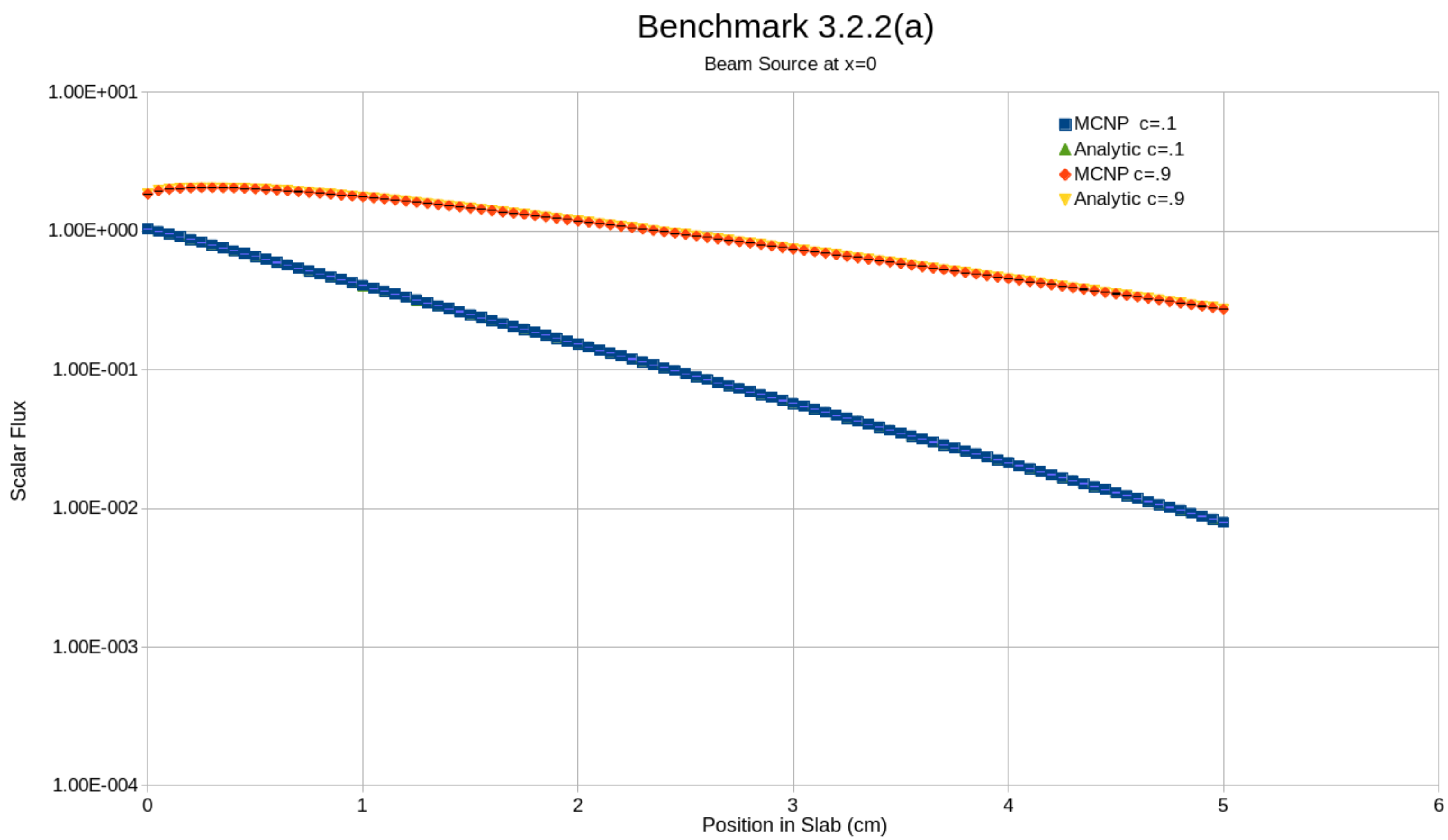
Numerical Results
Comparison of Semi-Analytic to MCNP
Benchmark 3.1



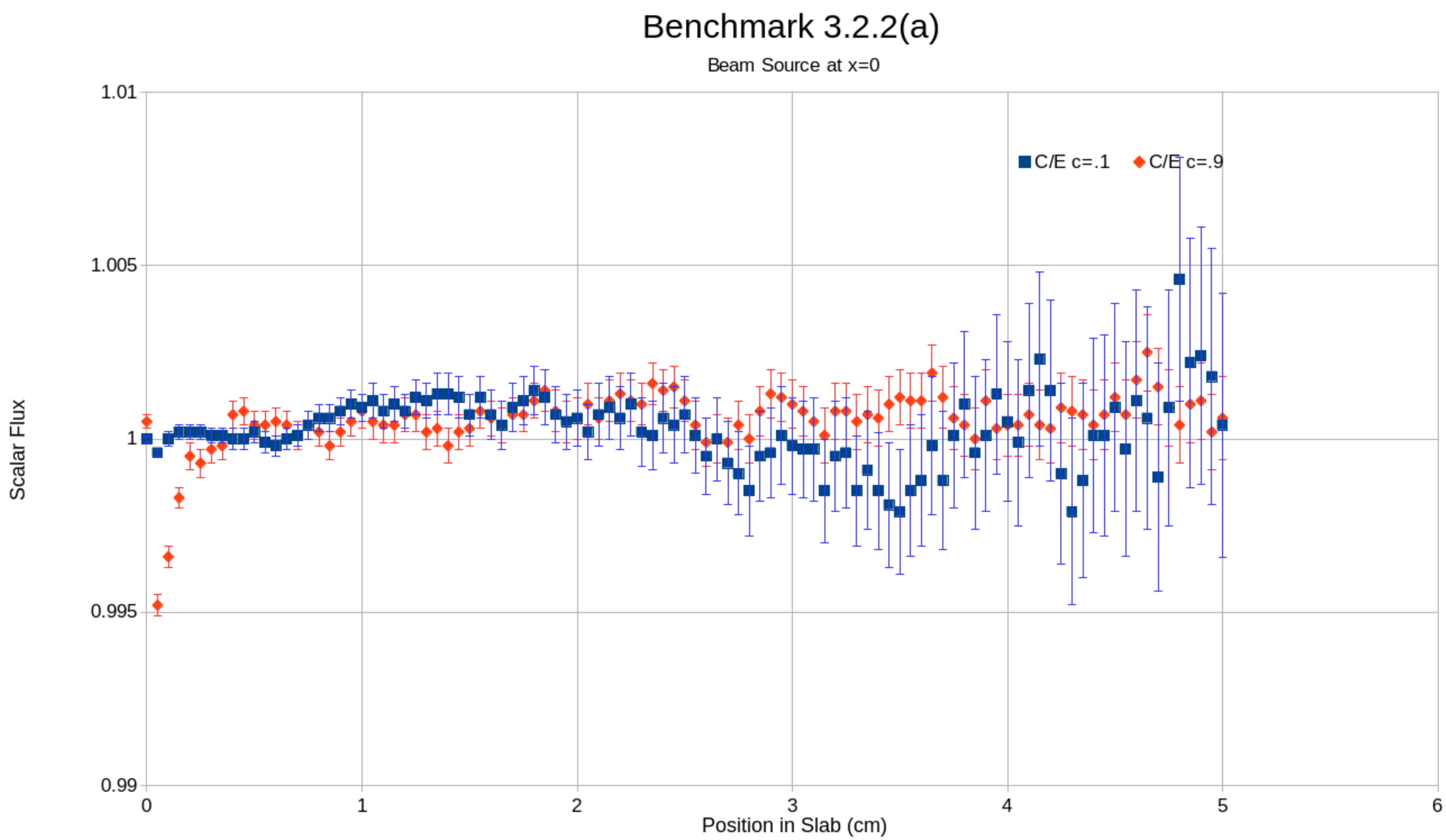
Numerical Results
Comparison of Semi-Analytic to MCNP
Benchmark 3.1



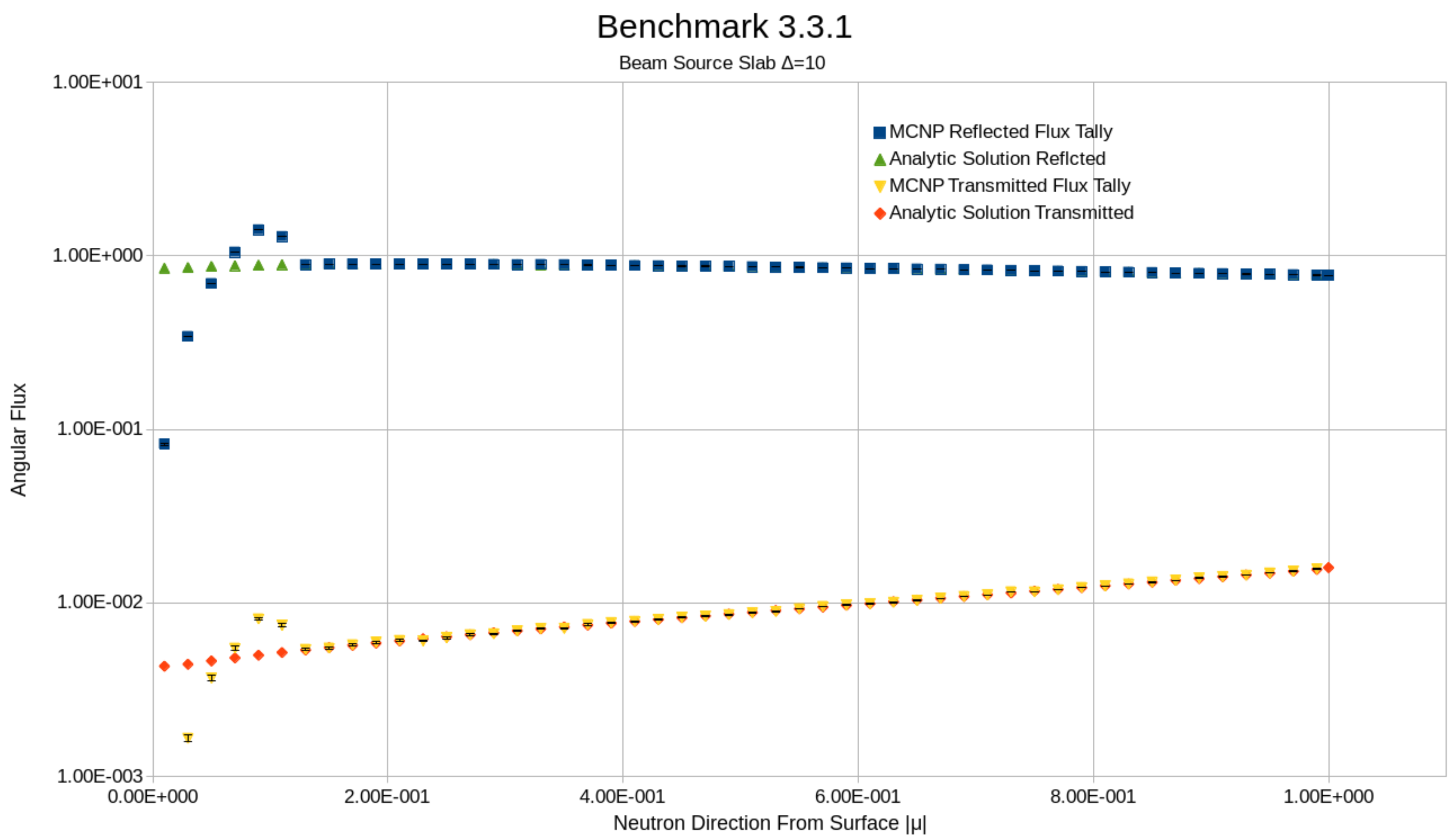
Numerical Results
Comparison of Semi-Analytic to MCNP
Benchmark 3.2



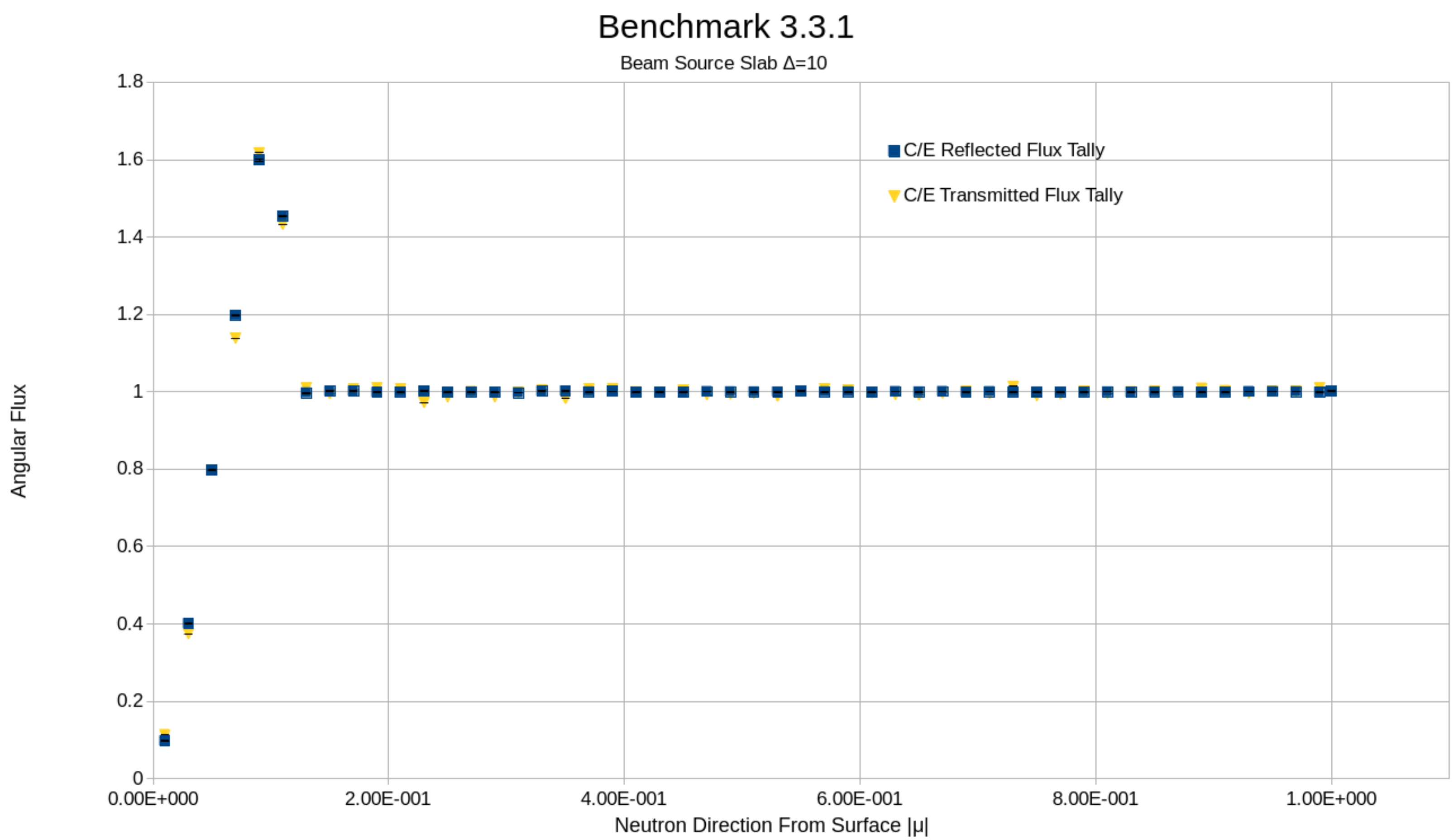
Numerical Results
Comparison of Semi-Analytic to MCNP
Benchmark 3.2



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

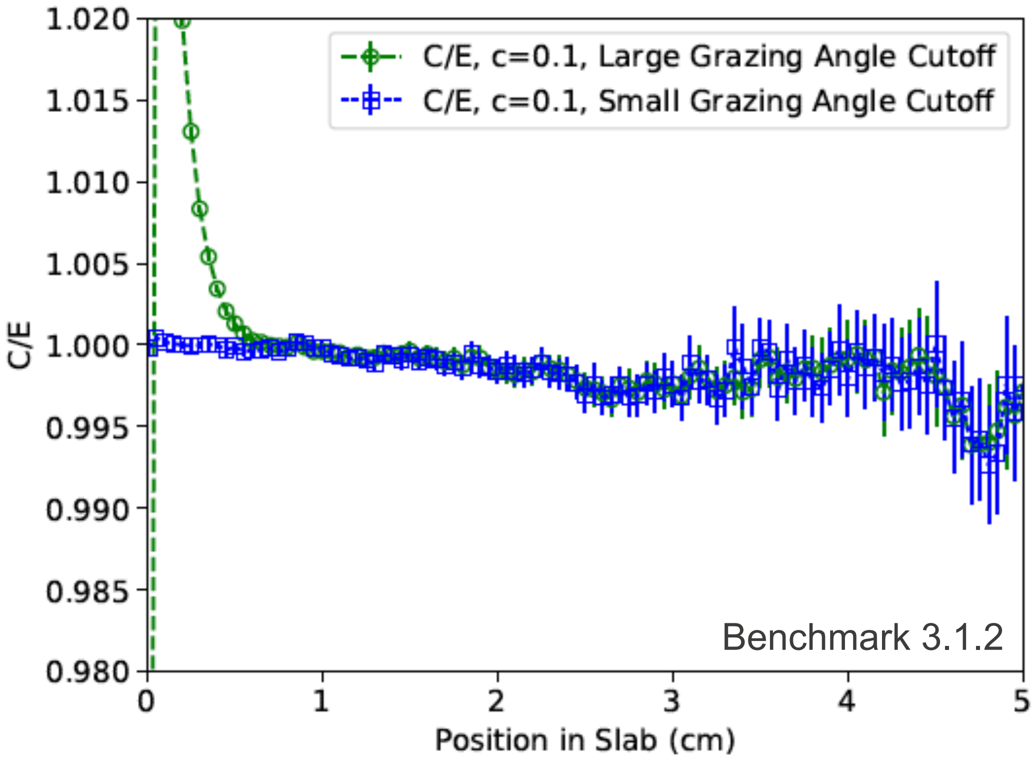
$$\phi = \frac{1}{A * W} \sum \frac{wgt}{|\mu|}$$

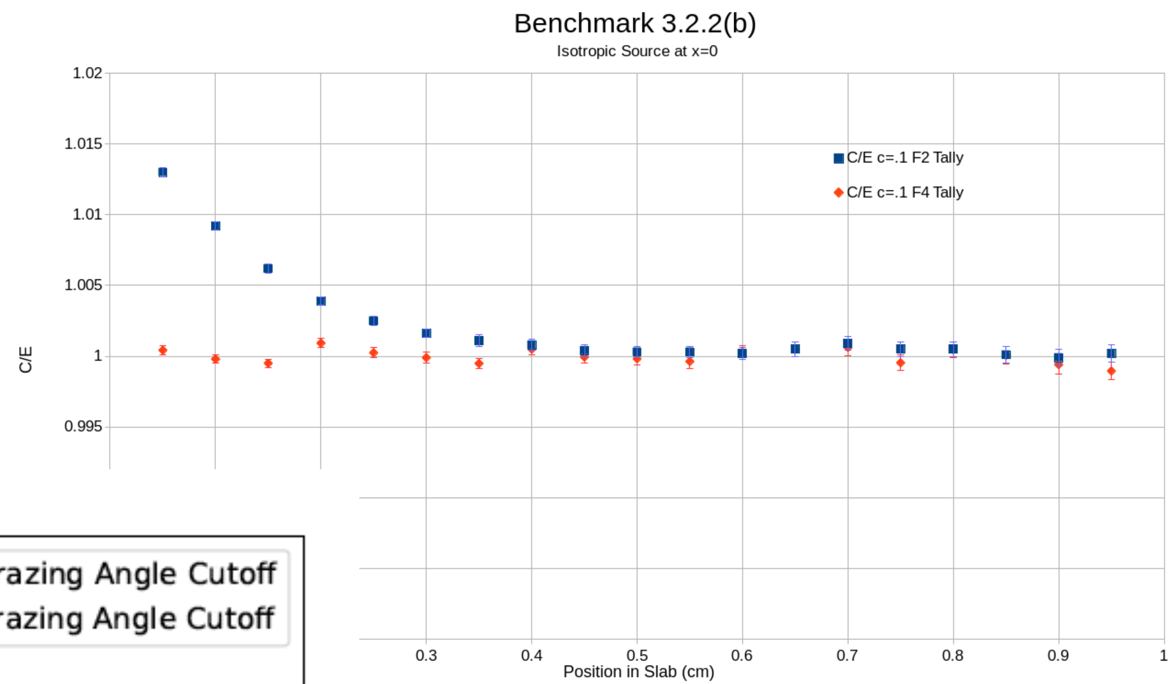
- **For MCNP6.1 and 6.1.1, below** $|\mu|<0.1$ **the F2 tally makes constant flux approximation in this "grazing angle" range**
- **For MCNP6.2, below** $|\mu|<0.001$ **is the new default "grazing angle" cutoff, and the user may now define a preferred cutoff value**

Numerical Results

- Improved solutions

New grazing angle cutoff

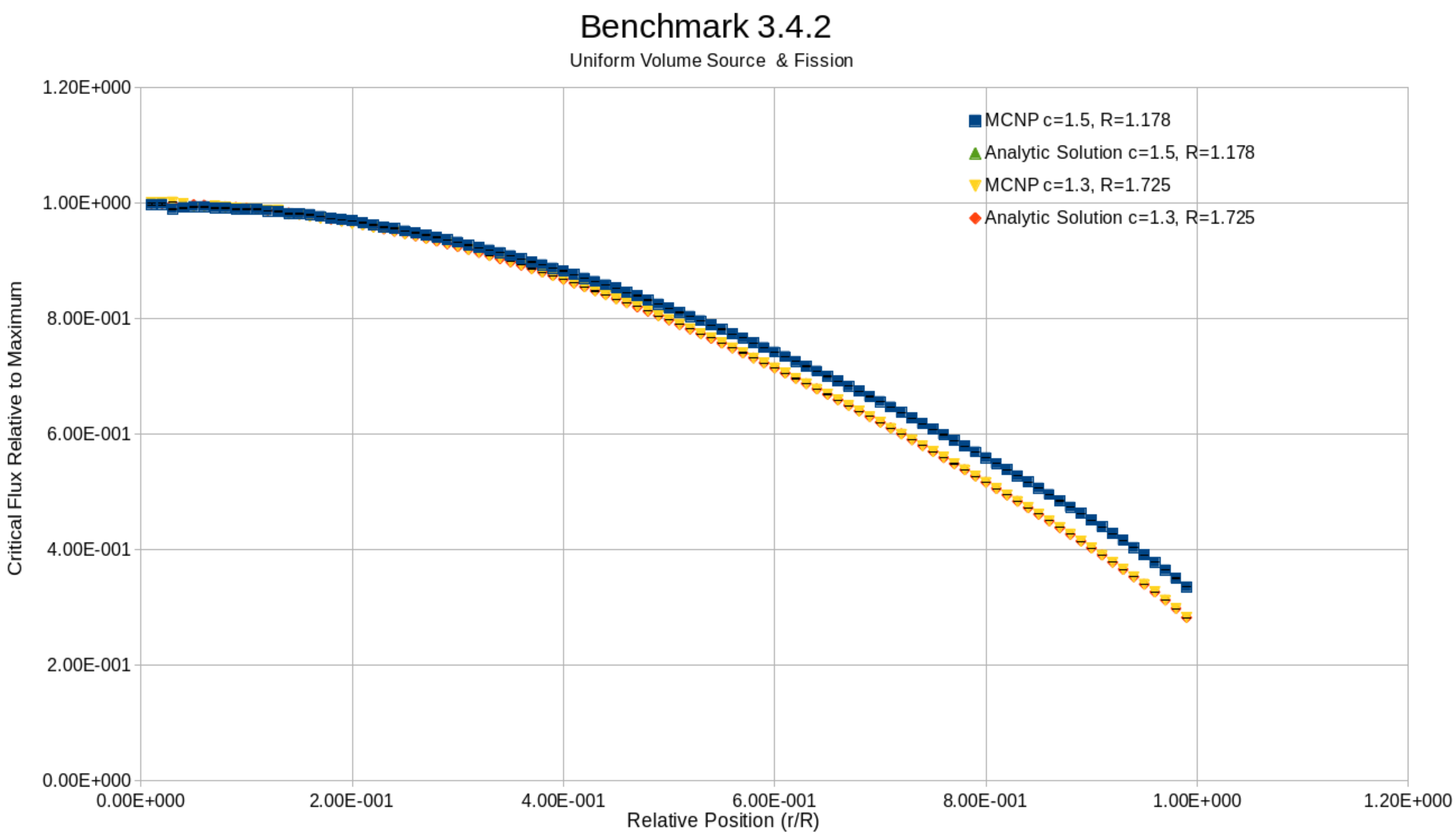




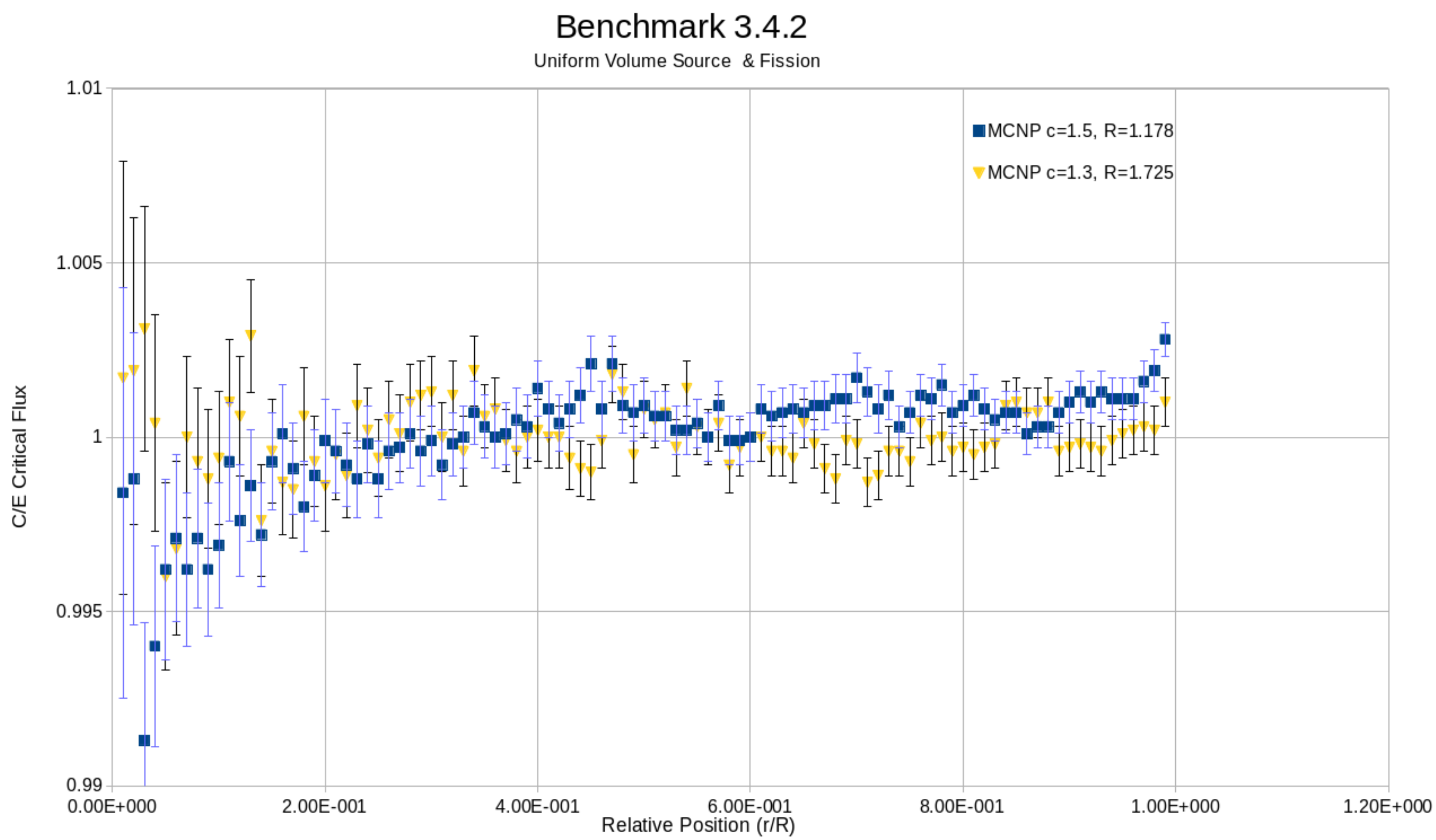
Use F4 type volume tally
(no assumptions)

- 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



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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Thank you!

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