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Title: Verification and validation testing and tools: comparison between MCNP code versions and nuclear data libraries

Author(s): Clark, Alexander Rich
Rising, Michael Evan
Josey, Colin James
Kulesza, Joel A.

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Verification and validation testing and tools: comparison between MCNP code versions and nuclear data libraries

Alexander R. Clark, *Michael E. Rising, Colin J. Josey, and Joel A. Kulesza*

Monte Carlo Codes Group (XCP-3)

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Overview

- Primary goal of software testing
- Results for individual suites
  - Validation
    - Expanded criticality
    - Pulsed spheres
    - Rossi-α
  - Verification
    - k_{eff}
    - Kobayashi

Primary goal of software testing

- Test the code for *correctness*
- Correctness is defined with respect to some standard
  - Comparison to another code (version)
  - Comparison to (semi-)analytic results
  - Comparison to experiment measurements

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    - Behavioral testing done for every code change during development
    - Full end-to-end testing attempting to isolate behaviors / features
  - Comparison to (semi-)analytic results
    - Ensuring the algorithms indeed solve the transport equation
    - Simplified problems and mock data used to isolate code / algorithm implementation
  - Comparison to experiment measurements
    - Ensuring the combination of algorithms and data compare well to nature / reality
    - Applies only to application area being tested and compared

Current MCNP6 Testing Practices

Primary goal of software testing

Current MCNP6
Testing Practices

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REGRESSION

  - Comparison to (semi-)analytic results
    - Ensuring the algorithms indeed solve the transport equation
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VERIFICATION

  - Comparison to experiment measurements
    - Ensuring the combination of algorithms and data compare well to nature / reality
    - Applies only to application area being tested and compared

VALIDATION

Role of Verification and Validation

- Verification
  - Where analytical and semi-analytical solutions to the transport equation may exist, we want to ensure that MCNP is solving the correct equations
- Validation
  - Combination of code (MCNP) and nuclear data (ENDF/NJOY/ACE) work together to produce results comparable to reality
- Full end-to-end tests exercising many separate features

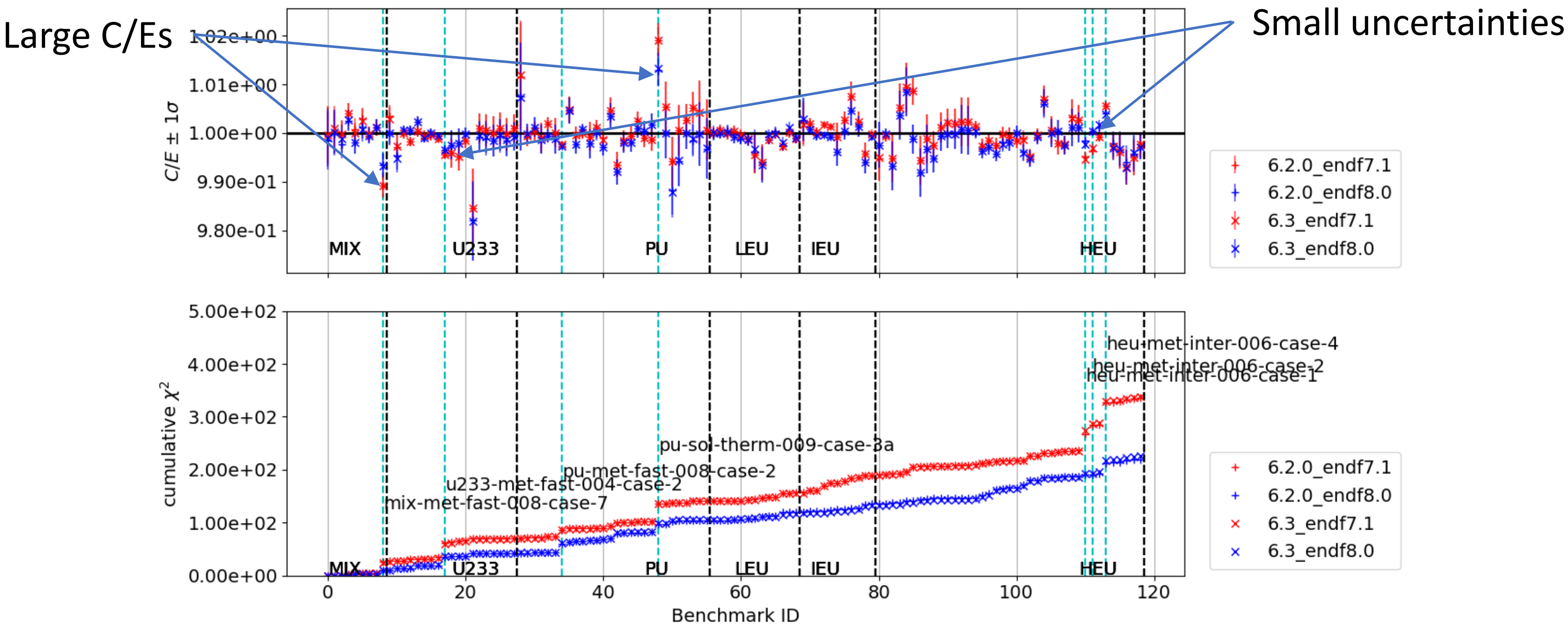
  (input parsing, problem setup, nuclear data usage & collision physics, transport & random walk algorithm, tallying, dose/response functions, output, etc.)
- Long-standing reputation can be linked to extensive and robust V&V

Results: Validation: Expanded criticality

- 119 criticality benchmarks selected from the ICSBEP handbook[1]
- Includes systems with a variety of characteristics[2]
  - Fast, intermediate, and thermal spectra
  - Light, heavy, or no reflectors
  - Lattices of fuel pins and liquid solutions
  - Low-, intermediate-, and highly-enriched uranium (LEU, IEU, HEU), mixed uranium and plutonium (MIX), U-233, and plutonium (PU) systems

1. "International Criticality Safety Benchmark Evaluation Project Handbook 2015," OECD Nuclear Energy Agency, Paris, France
2. R. D. Mosteller, F. B. Brown, and B. C. Kiedrowski, "An Expanded Criticality Validation Suite for MCNP," in American Nuclear Society Summer Meeting, Hollywood, FL, USA, Jun. 2011

Results: Validation: Expanded criticality



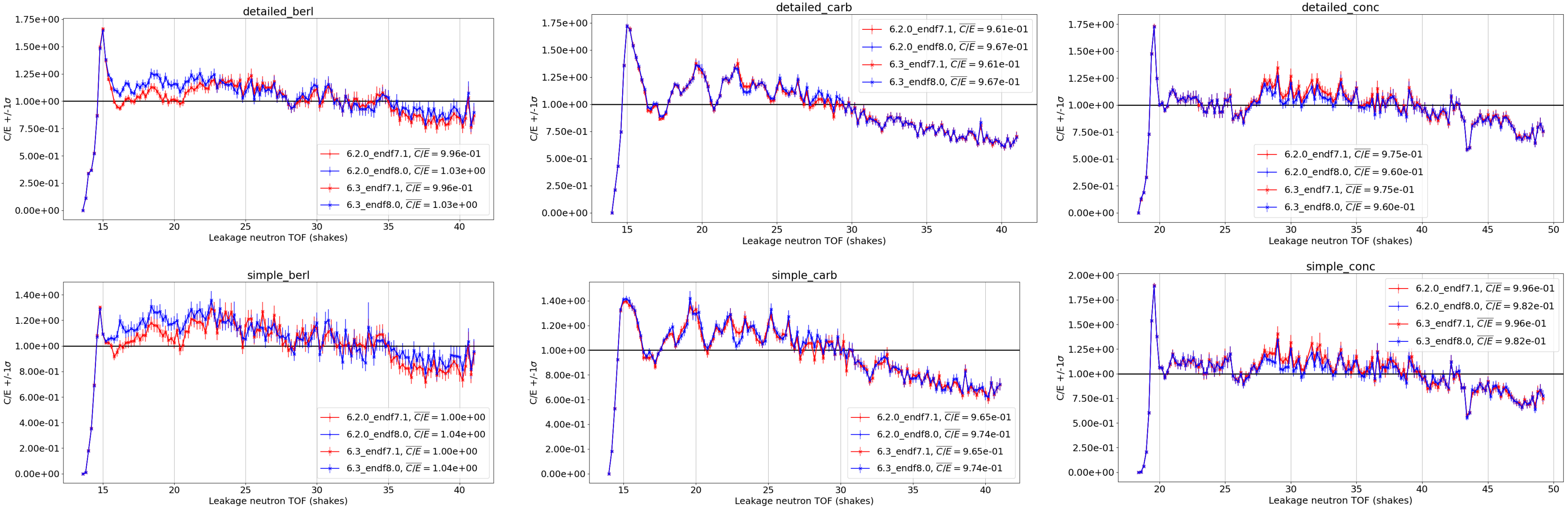
Expanded criticality suite comparison between MCNP code versions 6.2.0 and 6.3 using ENDF/B-VII.1 and ENDF/B-VIII.0 nuclear data libraries. Plots are grouped by principal nuclide. Highlighted in the bottom plot are benchmarks that contributed significantly to the cumulative chi-squared.

Results: Validation: Pulsed spheres

- 6 LLNL pulsed sphere measurements[1]
  - Spherical shell of material (beryllium, carbon, concrete, iron, lithium, and water)
  - Nominally 14-MeV (D,T) source
  - Leakage neutron time-of-flight (TOF) spectrum
- Two model types
  - Constructive solid geometry (CSG) modeling of only the pulsed sphere
  - Detailed CSG modeling the pulsed sphere, neutron source, and surroundings

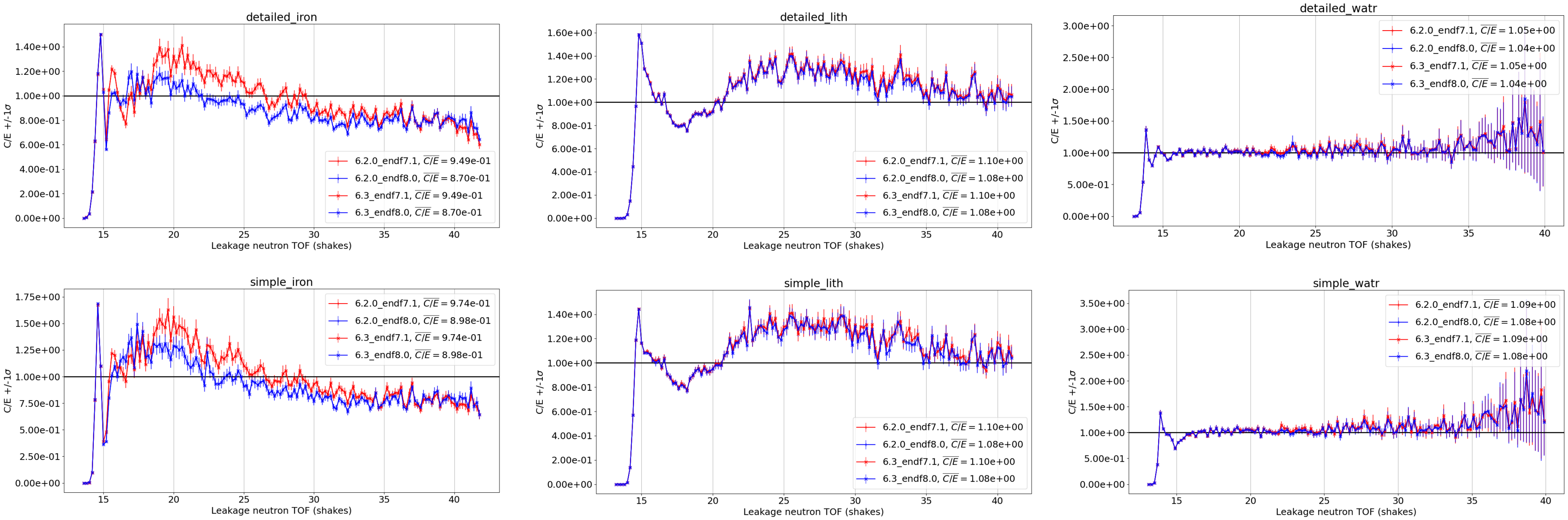
1. C. Wong et al., “Livermore Pulsed Sphere Program: Program Summary through July 1971,” Lawrence Livermore National Laboratory, Livermore, CA

Results: Validation: Pulsed spheres



Pulsed spheres suite comparison between MCNP code versions 6.2.0 and 6.3 using ENDF/B-VII.1 and ENDF/B-VIII.0 nuclear data libraries. From left to right; beryllium, carbon, and concrete. Top and bottom plots are “detailed” and “simple” geometries, respectively.

Results: Validation: Pulsed spheres



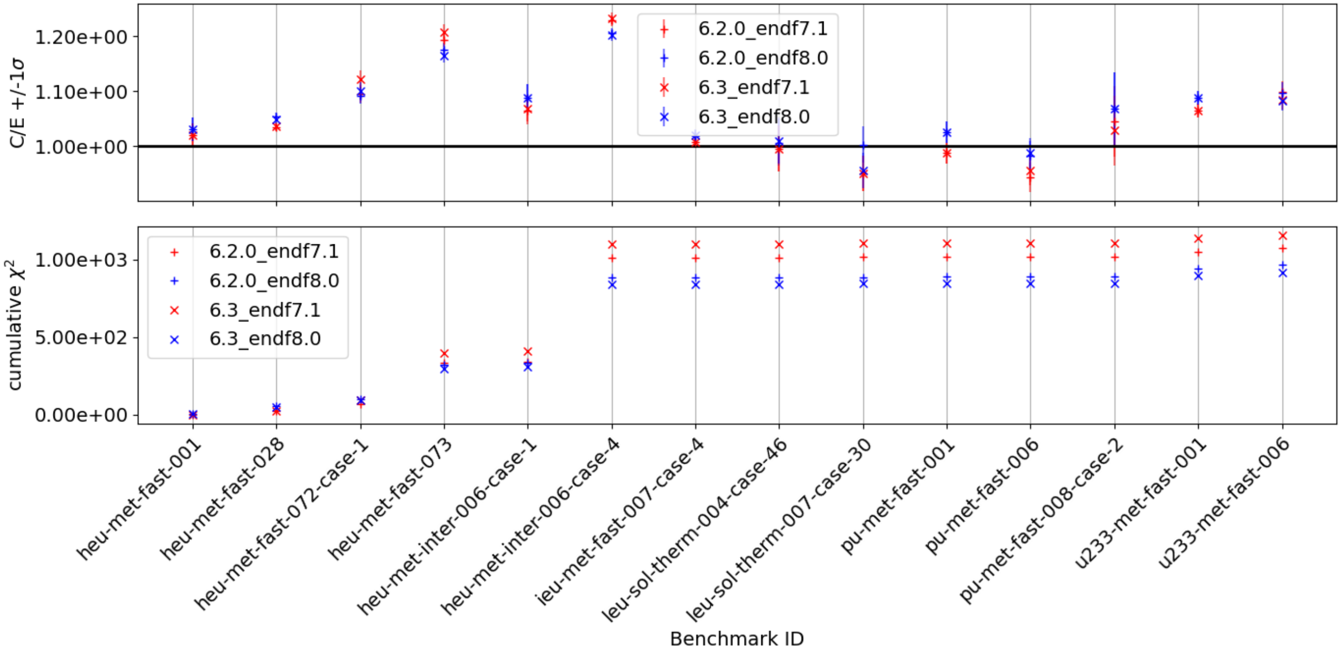
Pulsed spheres suite comparison between MCNP code versions 6.2.0 and 6.3 using ENDF/B-VII.1 and ENDF/B-VIII.0 nuclear data libraries. From left to right; iron, lithium, and water. Top and bottom plots are "detailed" and "simple" geometries, respectively.

Results: Validation: Rossi-α

- 14 criticality benchmarks selected from the ICSBEP handbook[1]
- α-eigenvalue is calculated via KOPTS card ("kinetics=yes")
- Includes systems with a variety of characteristics[2]
  - Fast, intermediate, and thermal spectra
  - Light, heavy, or no reflectors
  - Lattices of fuel pins and liquid solutions
  - Low-, intermediate-, and highly-enriched uranium, mixed uranium and plutonium, U-233, and plutonium systems

1. "International Criticality Safety Benchmark Evaluation Project Handbook 2015," OECD Nuclear Energy Agency, Paris, France
2. R. D. Mosteller and B. C. Kiedrowski, "A Rossi Alpha Validation Suite for MCNP," in International Conference on Nuclear Criticality, 2011

Results: Validation: Rossi-α



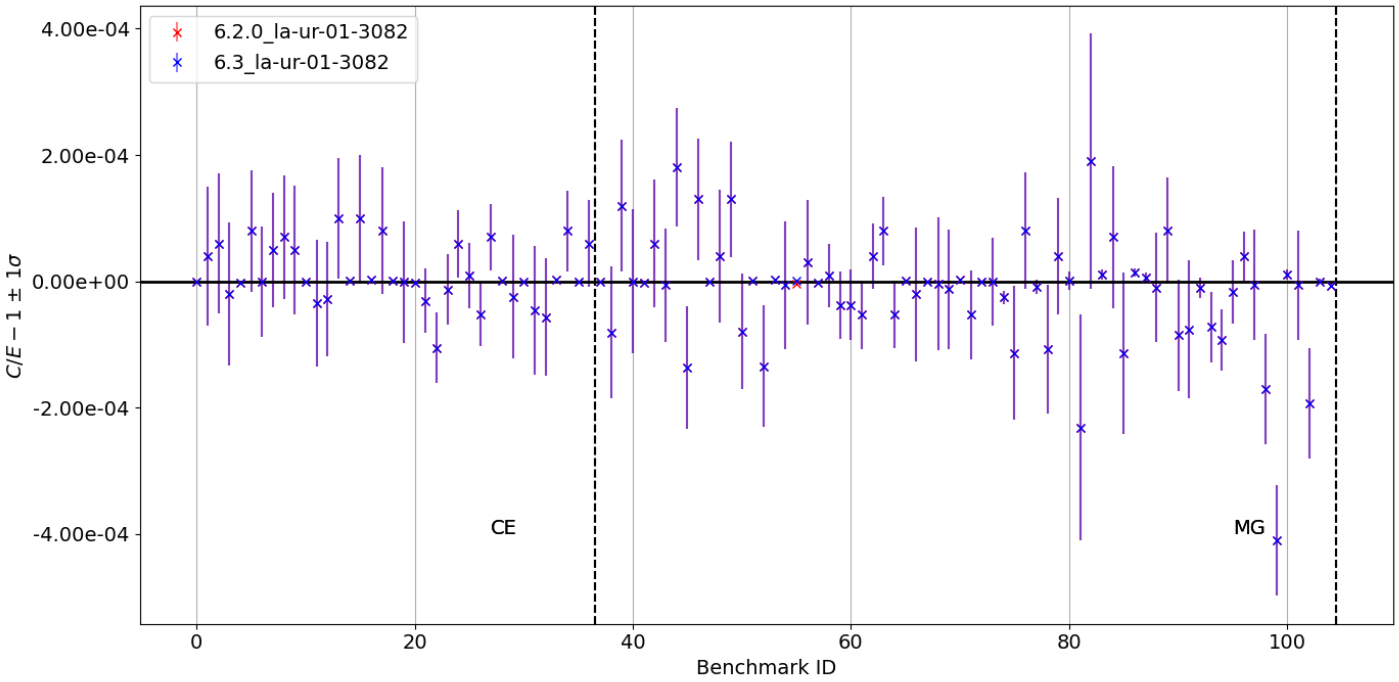
Rossi-α suite comparison between MCNP code versions 6.2.0 and 6.3 using ENDF/B-VII.1 and ENDF/B-VIII.0 nuclear data libraries.

Results: Verification: k_{eff}

- 37 continuous energy (CE) and 68 multigroup (MG) k-eigenvalue analytic benchmarks[1]
- These simple models include k_{∞}, infinite slab, infinite cylinder, sphere, and two medium-reflected infinite slab problems

1. A. Sood, R. A. Forster, and D. K. Parsons, "Analytical Benchmark Test Set for Criticality Code Verification," Progress in Nuclear Energy, vol. 42, no. 1, pp. 55–106, 2003

Results: Verification: k_{eff}

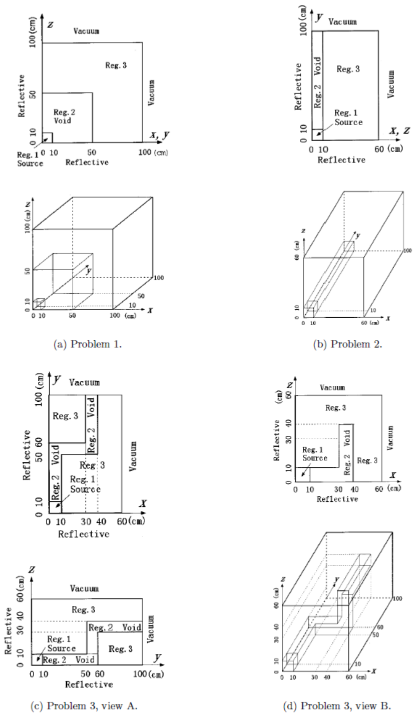


k_{eff} suite comparison between MCNP code versions 6.2.0 and 6.3 using a fictitious nuclear data library. Plots are grouped by energy representation.

Results: Verification: Kobayashi

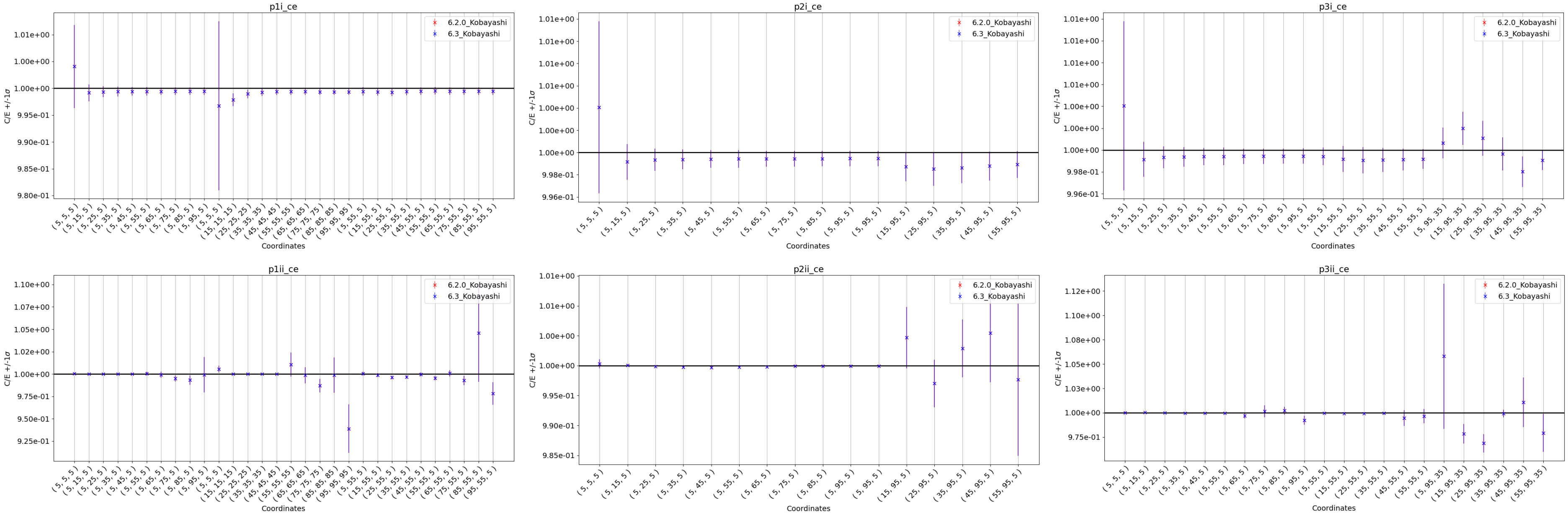
- 6 analytic benchmarks with 3 distinct geometries[1]
- Designed to test how 3D discrete ordinates codes deal with ray effects in problems with void and shield regions.
- Neutron source
  - Monoenergetic and isotropic
  - Uniformly distributed throughout a cube
  - Bounded by void and shield material regions
- Shielding
  - Pure absorber
  - 50% absorbing, 50% scattering

1. K. Kobayashi, N. Sugimura, and Y. Nagaya, “3D radiation transport benchmark problems and results for simple geometries with void region,” Progress in Nuclear Energy, vol. 39, no. 2, pp. 119–144, 2001.



Kobayashi problem geometries (reproduced from [1]).

Results: Verification: Kobayashi



Kobayashi suite comparison between MCNP code versions 6.2.0 and 6.3 using a fictitious nuclear data library. From left to right; problems 1, 2, and 3. Top plots are pure absorbers and bottom plots are 50% absorbing, 50% scattering.

Summary

- V&V framework enables easy comparison between calculations performed with different code versions and/or nuclear data libraries
  - Expanded criticality: cumulative chi-squared is generally lower for ENDF/B-VIII.0
  - Pulsed spheres: some improvement in C/E vs TOF using ENDF/B-VIII.0
  - Rossi-α: cumulative chi-squared is generally lower for ENDF/B-VIII.0
  - k_{eff}: little difference between code versions (same "fictitious" nuclear data)
  - Kobayashi: little difference between code versions (same "fictitious" nuclear data)
- This entire framework will be distributed with the upcoming MCNP6.3 release
- V&V test suites shown and several that were not (Criticality, LAQGSM, Lockwood) will be distributed in new framework

Questions?

Contact: arclark@lanl.gov