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Verification and Validation Analyses of the GEANT4 Monte Carlo Code with Computational and Experimental Fusion Neutronics Benchmarks

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Motivation and Objective

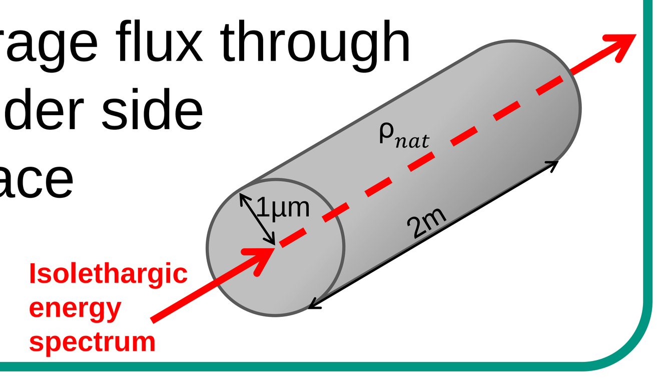
- For long-term future neutronics applications like DEMO, open-source alternative to MCNP is considered
- Potential option: GEANT4
  - High-energy particle physics code, fusion evaluated libraries available
  - Open-source, object-oriented toolkit allows adaptation

→ Verification &Validation of GEANT4's basic neutron transport behaviour by comparing GEANT4.10.3 to MCNP5-1.6

Benchmarking GEANT4 versus MCNP

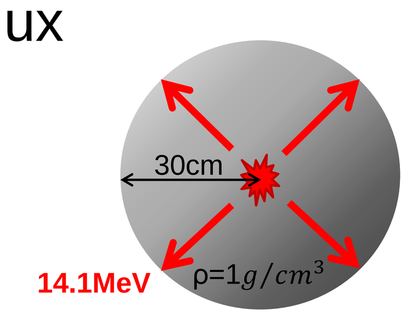
Differential problem, single interaction

Average flux through cylinder side surface



Integral problem, multiple interactions

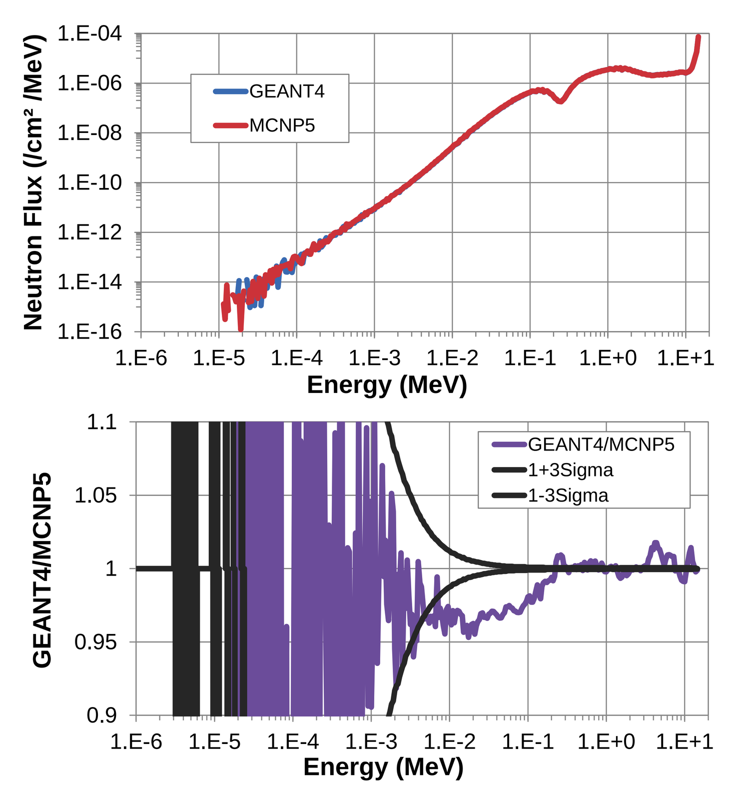
Average flux in sphere volume



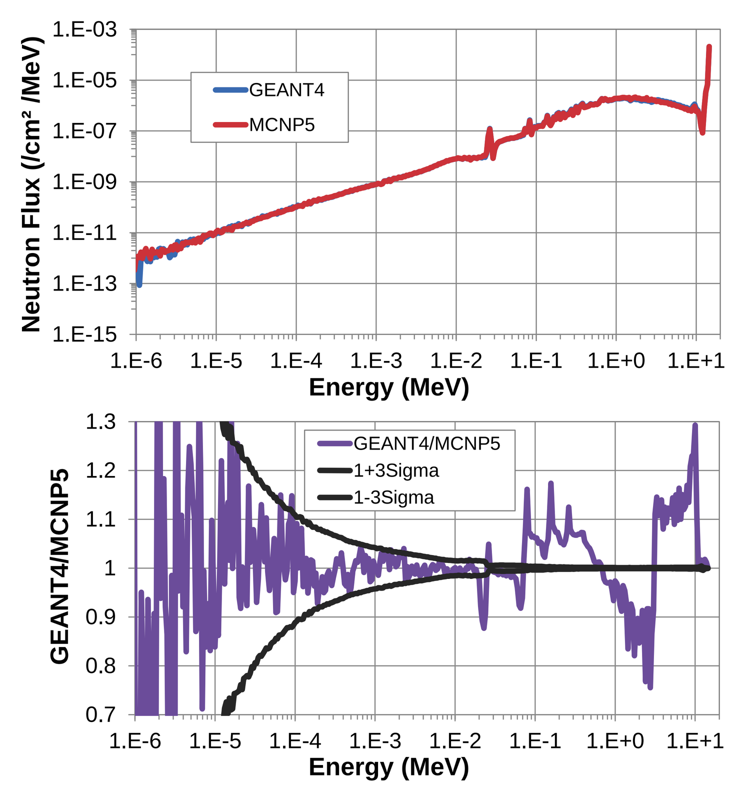
- Volume filled with one fusion-relevant isotope at a time: ^{1}H, ^{6}Li, ^{7}Li, ^{9}Be, ^{nat}C, ^{16}O, ^{28}Si, ^{52}Cr, ^{56}Fe, ^{184}W, ^{208}Pb
- ENDF/B-VII.0 and JEFF-3.1 library
- $10^8 - 10^9$ particle histories
- Accumulative deviation $d = \frac{1}{N}\sum_i |\Phi_i^{GEANT4} - \Phi_i^{MCNP}| / \Phi_i^{MCNP}$ summed over energy bins i for individual isotopes

Integral problem results

Li-6, ENDF/B-VII, 10^9 histories



Fe-56, ENDF/B-VII, 10^9 histories



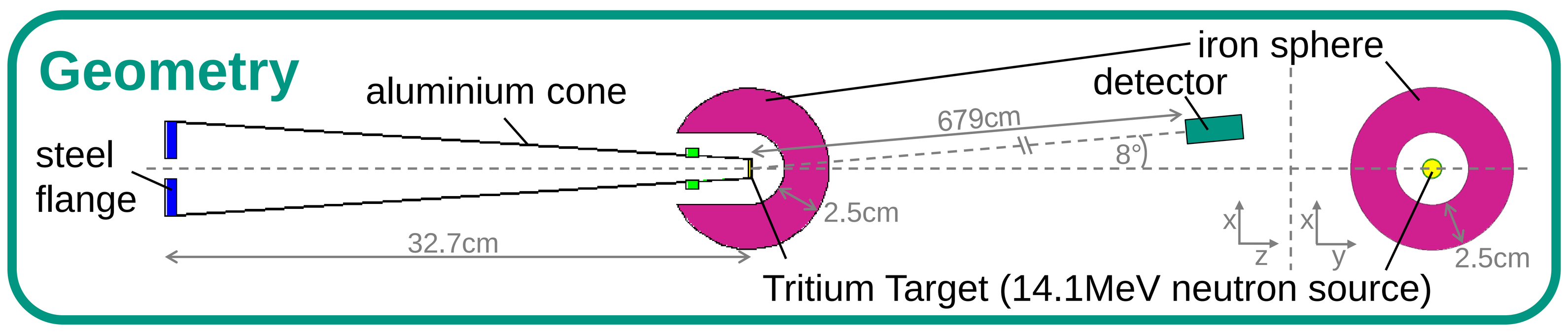
→ ***Differential***: accumulative deviation <1% everywhere

→ ***Integral***: integral deviation <1% everywhere; for heavier isotopes many individual energy groups >>5% dev.

→ ***Differences between libraries***

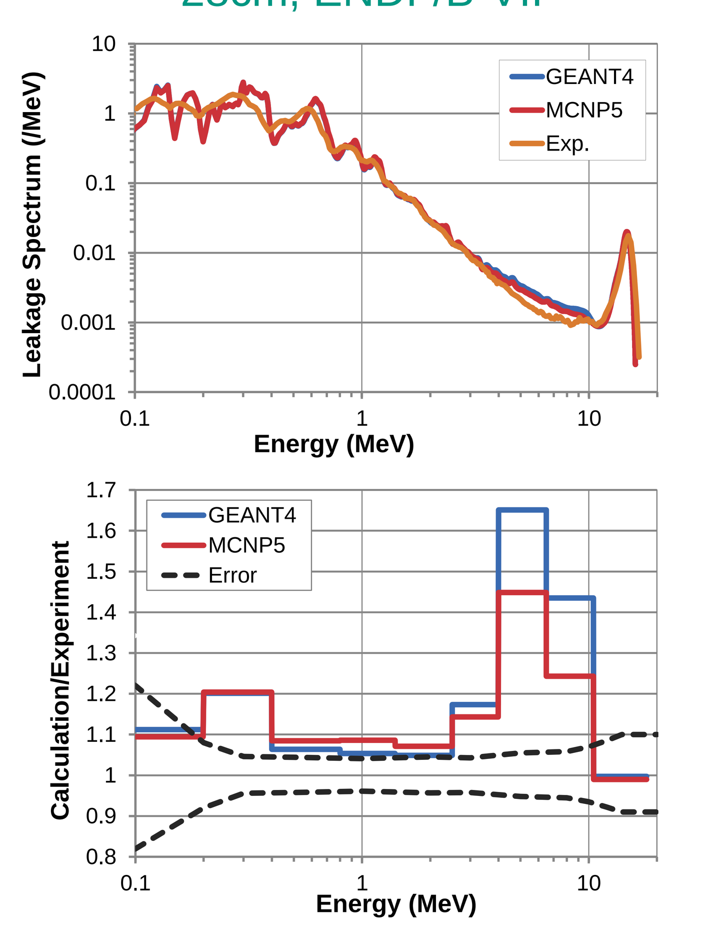
Experimental Benchmark SINBAD-IPPE-Fe

Geometry

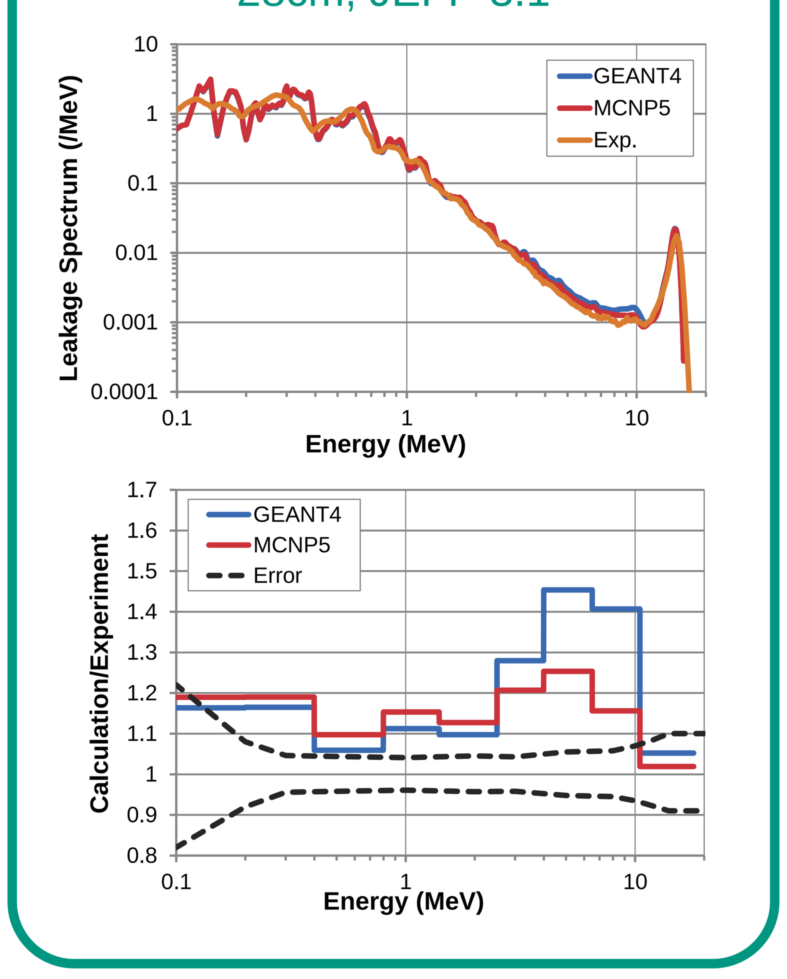


- 5 iron sphere shell thicknesses: 2.5–28.0cm
- ENDF/B-VII.0 and JEFF-3.1 library
- MCNP5: $1 \cdot 10^8 - 2 \cdot 10^8$ histories (point detector)
- GEANT4: $5 \cdot 10^9 - 2 \cdot 10^{10}$ histories (no point detector)
- Flux spectrum folded with spectrometer response function with original processing code

28cm, ENDF/B-VII



28cm, JEFF-3.1



→ ***4–10.5MeV:*** Large deviation for MCNP and GEANT4
  - GEANT4 worse than MCNP
  - Less deviation for 2.5–18.1cm shells

→ ***<4MeV:*** GEANT4 closer to MCNP
  - 2.5–18.1cm shells: GEANT4 often closer to experiment
  - 2.5cm shell: GEANT4 C/E mostly <1

Conclusions

→ ***Benchmarks GEANT4 vs. MCNP:*** good diff. agreement; for integral good tot. flux agreement, but dev. in energy spectra

→ ***Experimental Benchmark:*** larger GEANT4 deviations in 4–10.5MeV range, otherwise mostly similar to MCNP

→ ***Suitable for fusion neutronics***

Outlook

- CAD to GDML conversion for GEANT4
- Further SINBAD benchmarks: HCPB, ITER bulk shield
- DEMO plasma neutron source conversion
- Application to DEMO nuclear design analysis