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Evaluation and Extension of the MC Code Toolkit GEANT4 for Fusion Nuclear Analyses of DEMO

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Motivation and Objective

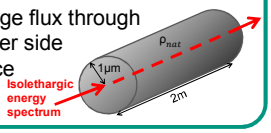
- Search for open-source alternative to MCNP for long-term future fusion neutronics applications like DEMO
- GEANT4 potential option
  - Fusion evaluated libraries available
  - Open-source, object-oriented toolkit allows adaptation
- Validation of GEANT4
  - Benchmarks vs. MCNP and experiments
- Extension of GEANT4
  - DEMO neutron source & CAD geometry conversion

→ DEMO nuclear design analyses compared to MCNP

Benchmarking GEANT4 vs. MCNP

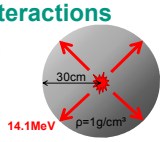
Differential problem, single interaction

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; 1e8 – 1e9 histories

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

→ ***Integral:*** total flux deviation <1% everywhere; for isotopes from O-16 and heavier individual energy groups >>5 % dev.

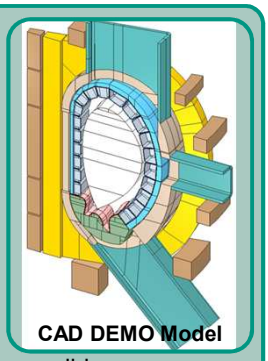
Source Conversion

- Simple basic sources for computational benchmarks
- Translation of specific MCNP SDEF sources (IPPE and Frascati Neutron Generator for HCPB Mock-Up)
- Translation of MCNP Fortran90 subroutine for DEMO plasma neutron source

→ Access to modular code allows flexibility for defining complex volumetric particle sources

Geometry Conversion

- Manually for basic geometries of computational benchmarks and SINBAD IPPE exp. benchmark
- Automated conversion from CAD to GDML with McCad software using tesselated solids and new half space solid add-on for ongoing SINBAD HCPB Mock-Up experiment and DEMO geometry

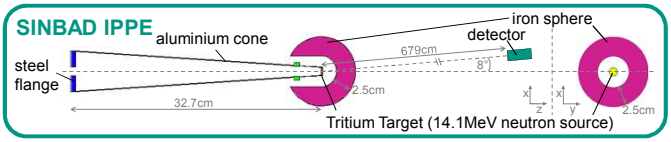


→ Representation of complex geometries possible

Qiu Y, Lu L, Fischer U. A new Geant4 modeling solution based on CAD geometries[C]//2016 IEEE Nuclear Science Symposium, Medical Imaging Conference and Room-Temperature Semiconductor Detector Workshop (NSS/MIC/RTSD). IEEE, 2016: 1-5.
Qiu Y. Development of a coupling approach for multi-physics analyses of fusion reactors[D]. Karlsruhe Institute of Technology, 2016

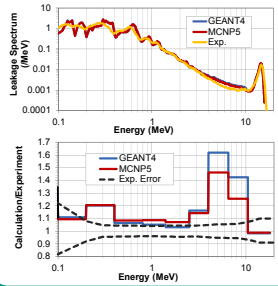
Experimental Benchmarks

SINBAD IPPE

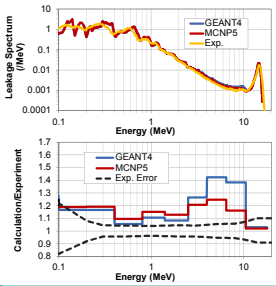


- 5 iron sphere shell thicknesses: 2.5 – 28.0 cm
- MCNP: 5e7–2e8 histories (point detector)
- GEANT4: 2e10–7e10 histories (no standard point detector)

28cm, ENDF/B-VII.0



28cm, JEFF-3.1



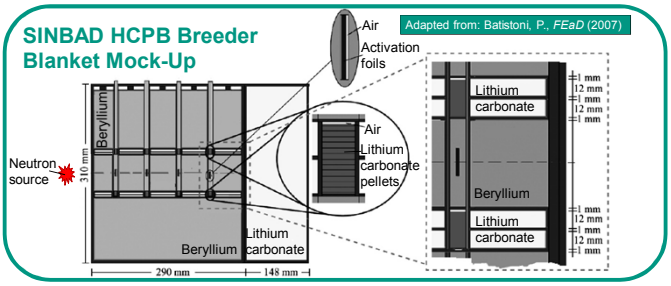
→ ***4–10.5 MeV:*** Large deviation for both, but GEANT4 worse than MCNP; GEANT4's additional deviation increases with material thickness

→ ***Other energies:*** GEANT4 closer to MCNP / experiment

To be published: Nunnenmann, E., et al. "V&V Analyses of the GEANT4 Monte Carlo Code Toolkit with Computational and Experimental Fusion Neutronics Benchmarks" *Fusion Engineering and Design* (2019)

SINBAD HCPB Breeder Blanket Mock-Up

Adapted from: Batistoni, P., *FEaD* (2007)



- Many detector volumes with many energy bins: problem with GEANT4 standard detector
- MCNP tally multiplier card function missing

→ New track length sensitive detector classes: both support multiple energy bins and one also supports multipliers

Conclusions and Outlook

→ ***GEANT4 vs. MCNP:*** good differential agreement; for integral good total flux agreement, but deviations in energy spectra

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

→ ***Developments:*** CAD to GDML conversion, various neutron source configurations, sensitive detectors with multiple energy bins

- HCPB Breeder Blanket Mock-Up analysis almost finished
- DEMO nuclear design analyses to be done