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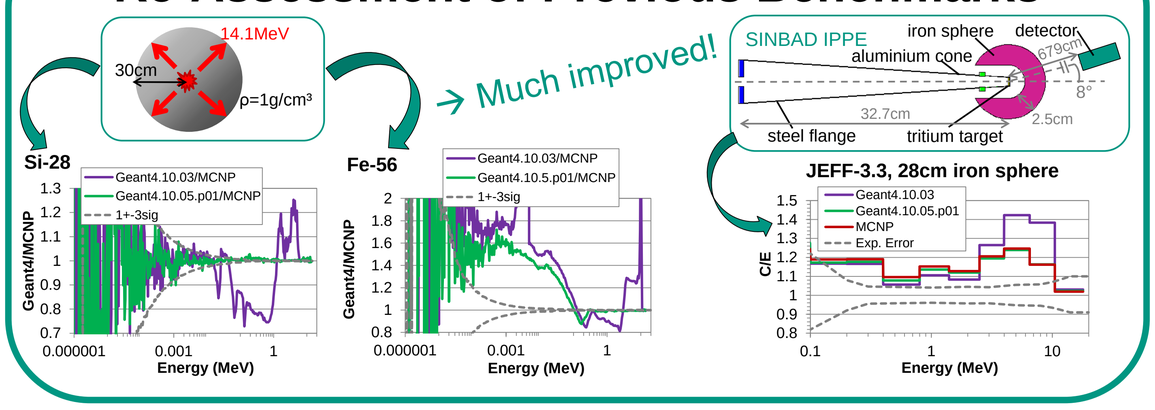
Verification and Validation of the Geant4 Monte Carlo Code Toolkit for DEMO Neutronics Applications

Motivation and Objective

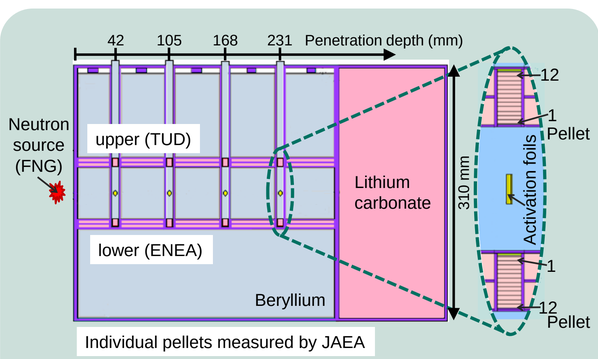
- Search for open-source alternative to MCNP for long-term future fusion neutronics applications like DEMO
- Geant4 potential option
  - Fusion evaluated libraries available
  - Open-source, object-oriented toolkit allows adaptation
- Validation of Geant4: Benchmarks vs. MCNP and experiments
- Extension of Geant4
  - Neutron source & CAD geometry conversion
  - Reflective Boundaries and Tally Multiplication

→ DEMO nuclear design analyses compared to MCNP

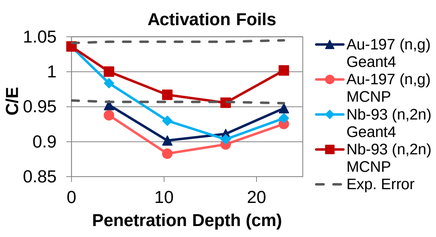
Re-Assessment of Previous Benchmarks



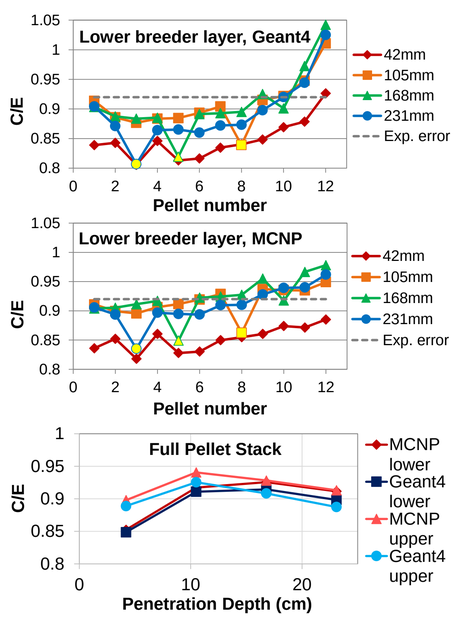
Experimental Benchmark: HCPB Mock Up



- Converted with SuperMC, McCad to GDML
- Neutron source converted from SDEF
- New tally multiplication function used



- >1MeV neutrons: Geant4 increasingly underestimates with penetration depth
- Low energy neutrons: Geant4 is consistent with MCNP

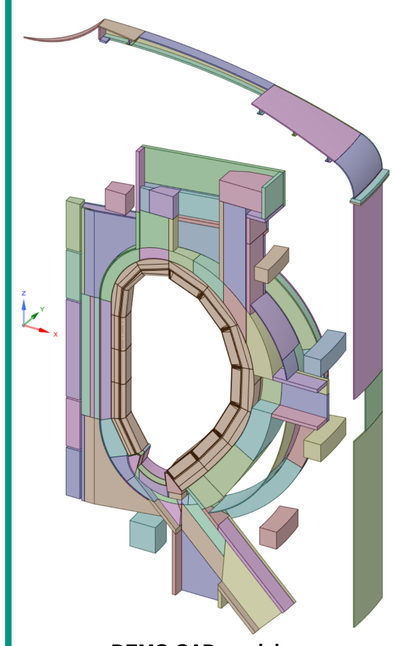


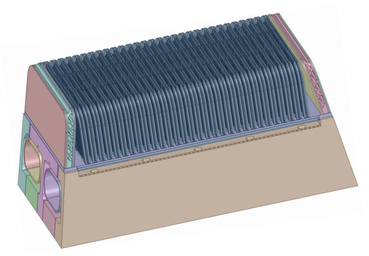
- Experimental T activity mostly underestimated for both codes
- Strong overestimation in 12th pellet of lower breeder layer by Geant4 mostly caused by 0.1MeV energy bin
- Deviation to MCNP otherwise <5%; increasing underestimation with penetration depth
- For full pellet stack: same increasing underestimation, but only up to 2.6%
- Total tritium activity: Geant4 results deviate only by -1.3% towards MCNP

→ Thermal neutron treatment should be investigated

→ Geant4 produces close agreement with MCNP for tritium production

DEMO with HCPB Blanket

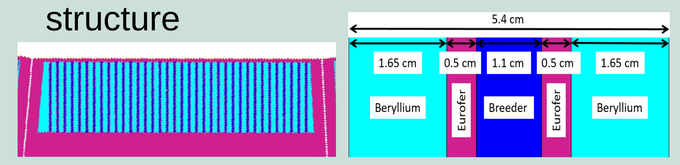




- Most of geometry converted with McCAD
- Reflective Boundary function developed for Geant4
- Fortran90 MCNP plasma neutron source converted into C++ for Geant4

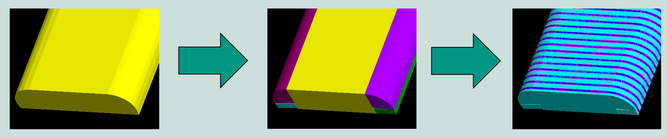
HCPB breeder internal structure

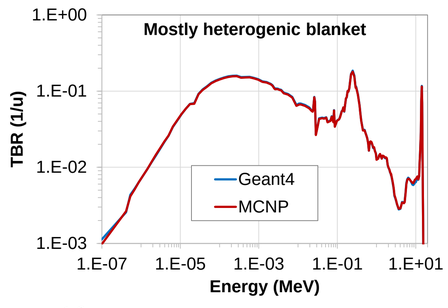
- MCNP Boundary Representation of geometry allows easy repeated internal structure



- Geant4 Constructive Solid Representation allows replication only within basic shapes

→ Split into basic shapes; homogenized material for left-over 8.4% of volume





homogenized	MCNP	Geant4	Deviation
Li6	1.380	1.367	-0.99%
Li7	0.014	0.014	-0.82%
total	1.394	1.380	-0.98%
heterogenic	MCNP	Geant4	Deviation
Li6	1.152	1.169	1.46%
Li7	0.013	0.013	-0.24%
total	1.165	1.181	1.44%

- Homogenization causes overestimation of TBR
- Good agreement between Geant4 and MCNP for both homogenized and mostly heterogenic blanket
- Deviations in TBR spectrum mostly at ~1Mev and ~0.1MeV

→ Thermal neutron treatment and better repeated structure method should be investigated

→ Already good TBR agreement between Geant4 and MCNP

Conclusions and Outlook

- Improved basic neutron transport agreement with MCNP for newest version Geant4.10.05.p01
- McCAD to GDML geometry conversion successful
- Newly developed tally multiplication and reflective boundaries successfully used
- *HCPB:* slightly different volumetric distribution of T breeding, but good total agreement
- *DEMO:* good TBR agreement

→ **Geant4's suitability for fusion neutronics demonstrated**

- Thermal neutron treatment should be investigated
- Better repeated structure representation method needs to be developed, possibly based on HalfSpaceSolid
- DEMO nuclear analyses other than TBR

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.