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V&V Analyses of the GEANT4 Monte Carlo Code Toolkit with Computational and Experimental Fusion Neutronics Benchmarks

In the plasma of fusion reactors, tritium and deuterium react to create helium and a 14.1MeV neutron, which escapes the magnetic containment. For defining and verifying requirements and boundary conditions for fusion reactor systems, the neutron transport through reactor components and the interactions of neutrons with the encountered materials has to be assessed. To this end, 3D Monte Carlo particle transport codes are employed.

The current reference code for fusion neutronics calculations is the Monte Carlo N-Particle (MCNP) code developed by Los Alamos National Laboratory. Due to restrictions on the distribution of MCNP, there is a European effort to find alternative open-source codes. One potential alternative is the high-energy particle physics Monte Carlo code toolkit GEANT4. It has been expanded for fusion energy-range neutron transport simulations based on evaluated nuclear cross-section libraries and offers the potential to represent complex geometries and volumetric neutron sources. The aim of this work is to investigate the suitability of GEANT4 for fusion neutronics requirements and to expand the code where necessary. On this poster, the steps undertaken so far will be presented.

First, the basic neutron transport behaviour of GEANT4.10.3 was evaluated on the basis of two simple geometries filled with the most fusion-relevant isotopes in comparison with MCNP5-1.6. For this, nuclear data from the ENDF/B-VII.0 and the JEFF-3.1 library was used. The differential computational benchmark assumes a neutron beam with isolethargic energy distribution along the axis of a cylinder with length 2m and radius 1µm. After a single material interaction, the scattered or secondary neutrons passing through the cylinder side surface are recorded. The average relative deviation between GEANT4 and MCNP throughout the energy spectrum is <1% for all isotopes and libraries. The integral computational benchmark is a 30cm radius sphere with an isotropic 14.1MeV neutron source in the centre. The neutron flux averaged over the sphere volume is recorded. The total flux deviation between GEANT4 and MCNP is <1% for all isotopes and libraries with some larger deviations in individual energy groups for some isotopes.

Second, the consistency of GEANT4 calculations with experimental results was tested with geometry and source descriptions of the benchmark experiment "IPPE (Institute of Physics and Power Engineering) neutron transmission through iron shells"processed from the Shielding Integral Benchmark Archive and Database (SINBAD). Geometry and source description were converted for GEANT4 from MCNP input files. It consists of spherical iron shells of five different thicknesses between 2.5—28cm, the experimental setup for the creation of the 14.1MeV neutron source in the centre of the shells and the detector at a distance of 679cm. The Calculation/Experiment is acceptable for most of the energy spectrum with larger deviations in the range of 4—10.5MeV.

Third, another experimental benchmark from SINBAD was chosen: the "FNG (Frascati Neutron Generator) HCPB (Helium Cooled Pebble Bed) Tritium Breeder Mock-up". Here, the more complex geometry description made it necessary to convert the MCNP input via CAD to GDML for GEANT4. At the time of abstract submission, this work was still ongoing.

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