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# Benchmark of Serpent-2 with MCNP: application to EU fusion DEMO HCPB breeding blanket

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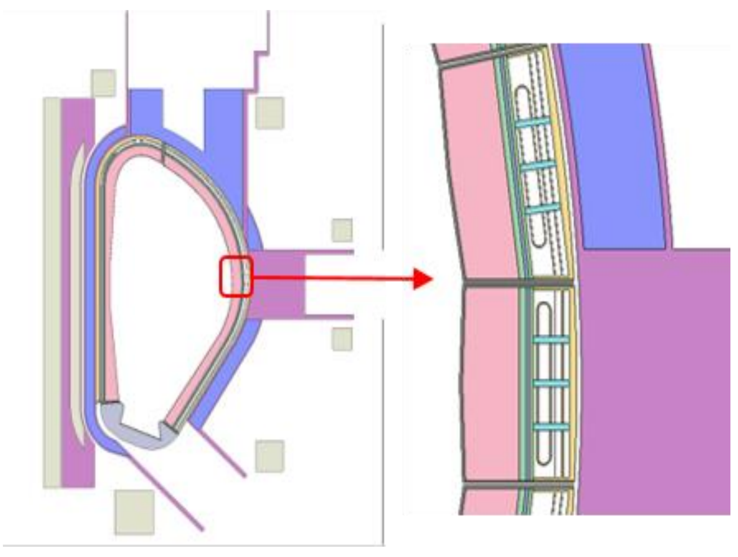
**ABSTRACT：** Magnetic confinement fusion reactors such as the European fusion demonstration reactor (EU DEMO) have a very complex geometry, which makes the modelling of the nuclear analyses rather tedious and time consuming. The Monte Carlo neutron transport code Serpent-2 developed by VTT in Finland, is able to directly import CAD geometry, then is considered an attractive alternative to the Monte Carlo N-Particle Transport code (MCNP) for its application in fusion reactors. A comparison activity is carried out to benchmark the Serpent-2 with MCNP calculations.

## EU-DEMO 2017 Model

The modeling process consists of the following five steps:

- Step 1: Simplify and decompose the reference CAD model and convert it to a CSG model for MCNP using McCad;
- Step 2: Manually fill the back support structure into the blanket;
- Step 3: Check and fix geometric errors in the model.
- Step 4: Translate the MCNP geometry model to the Serpent-2 input file format by utilizing the csg2csg tool.
- Step 5: Set model symmetry, source emissivity, boundary conditions, etc.

- FW: 67.7% Eurofer and 32.3% Helium
- BZ: 12.8% Eurofer, 10.3% mixture of $Li_4SiO_4$ plus 37 mol.% of $Li_2TiO_3$, 40.8% Be12Ti and 36.1% Helium
- BSS: 100% Eurofer



EU-DEMO 2017 Serpent-2 model    horizontal cuts in OB side

## Volume Calculation

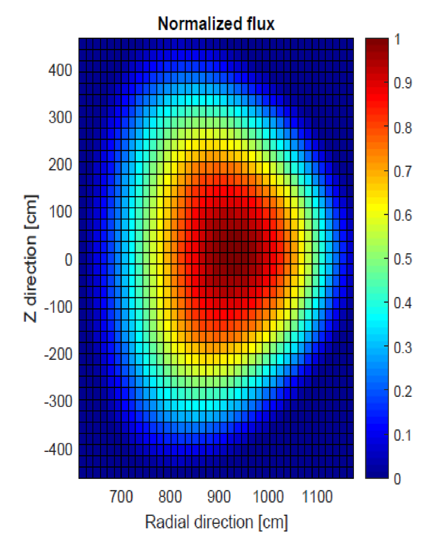
- Serpent-2: Volume checker routine, sample $10^{10}$ points, statistical errors< 0.13%
- MCNP: Track length estimate with a spherical source , sample $10^{10}$ points, statistical errors< 0.02%
- Results: Within 1.1σ of the combined error with a relative difference of less than 0.05%.
- Lost: Particle loss in MCNP and Serpent-2 did not appear----- no undefined regions or overlaps.

| Component | Volume ($cm^3$) | | Difference |
|---|---|---|---|
| | Serpent-2 | MCNP | |
| Blanket | 1.4814E+09 | 1.4819E+09 | -0.033% |
| Dirvertor | 1.5125E+08 | 1.5123E+08 | 0.016% |
| VV | 2.3871E+09 | 2.3879E+09 | -0.031% |
| TF | 1.3261E+09 | 1.3255E+09 | 0.048% |
| CS | 1.0623E+09 | 1.0625E+09 | -0.019% |
| PF | 1.7264E+08 | 1.7272E+08 | -0.044% |

## Neutron Source

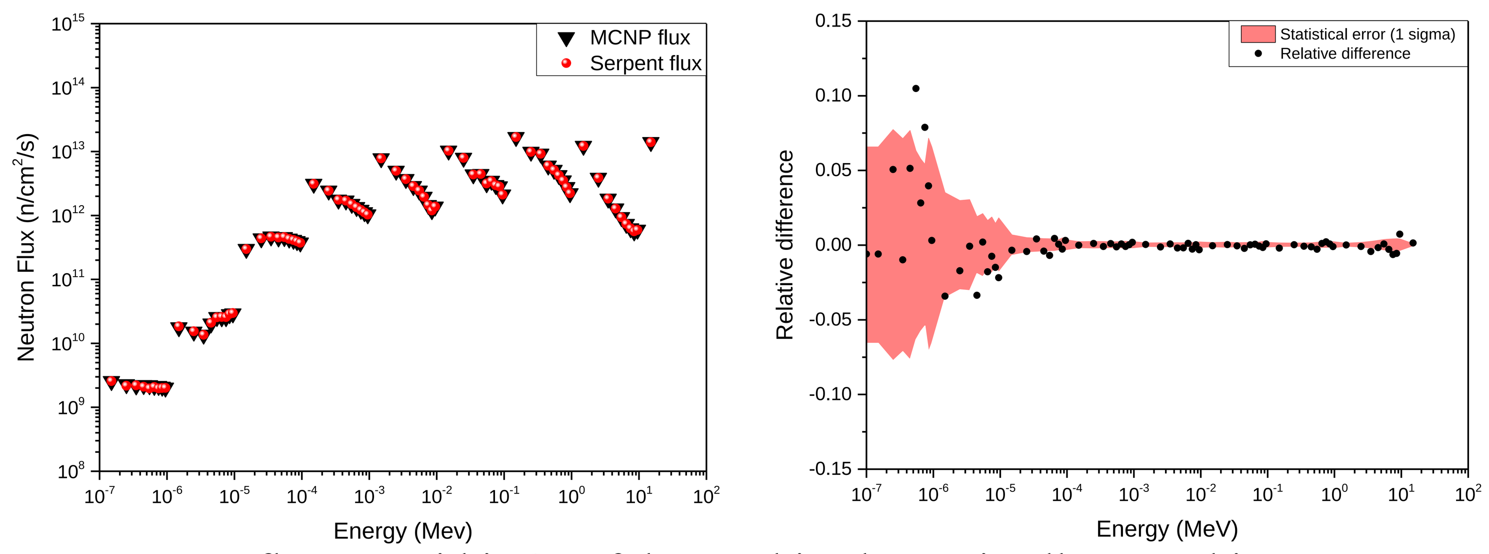
MCNP: 40*40 discrete volume source, Gaussian distribution of 14.1MeV.

Serpent-2: 40*40 source cells, 14 energy bins.

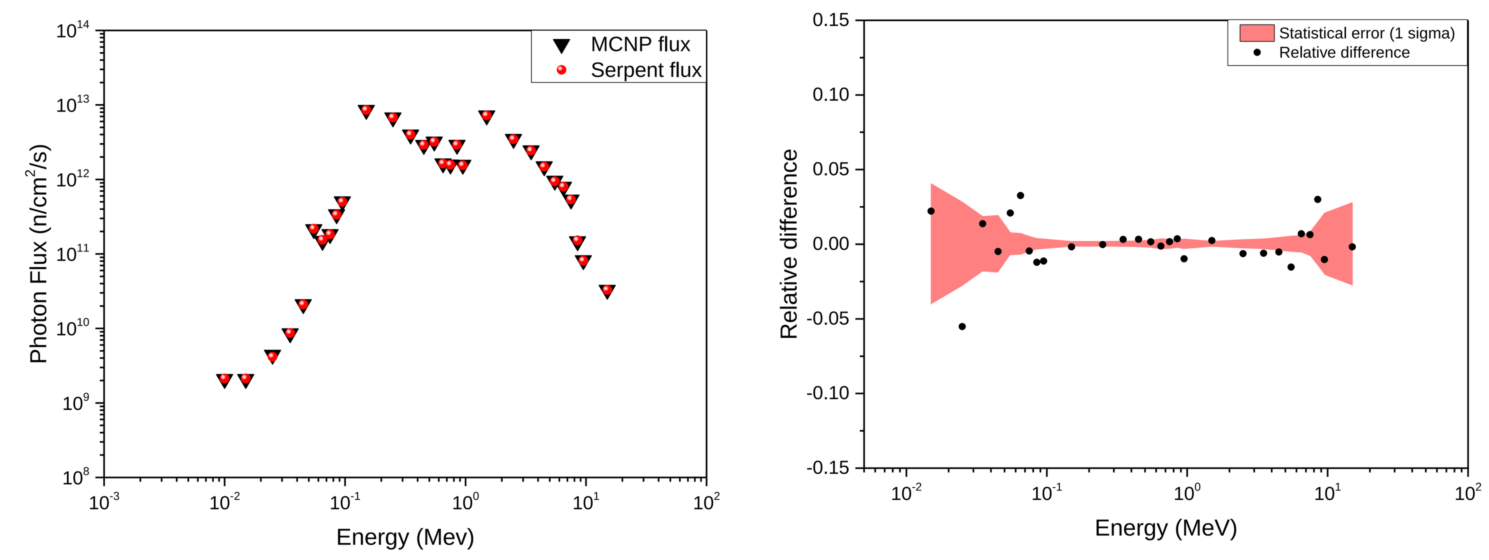



Normalized sources densities distribution

## Neutron and Photon Energy Spectrum

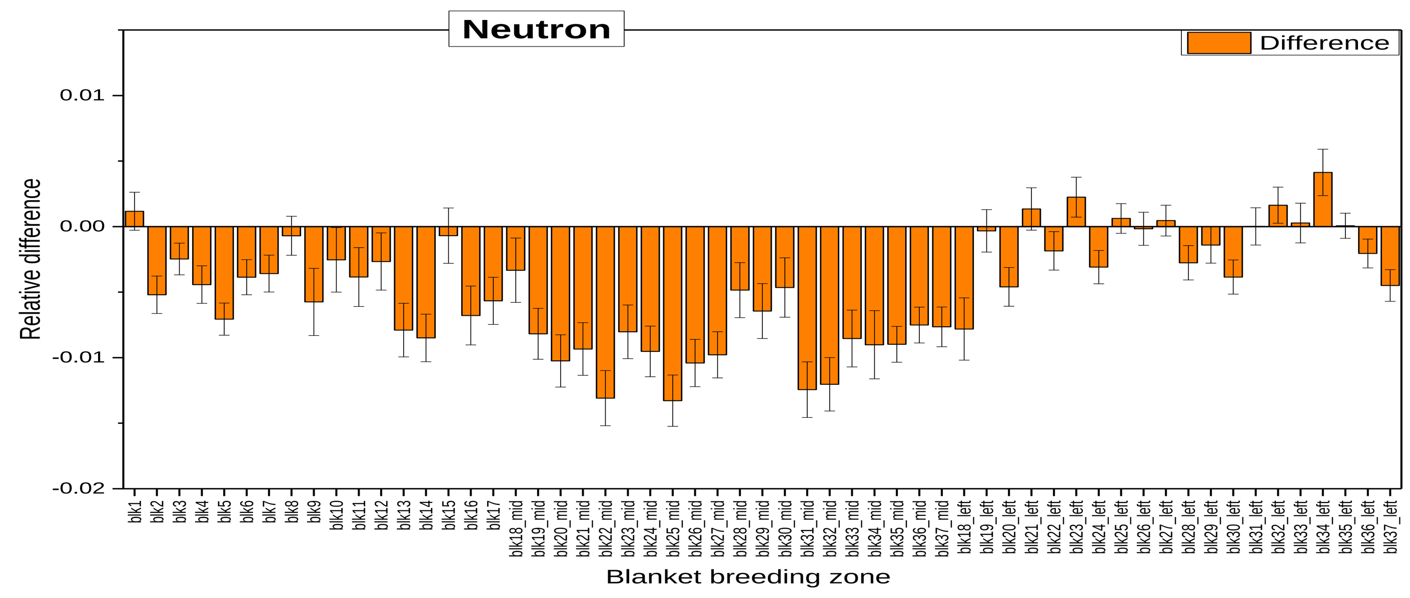


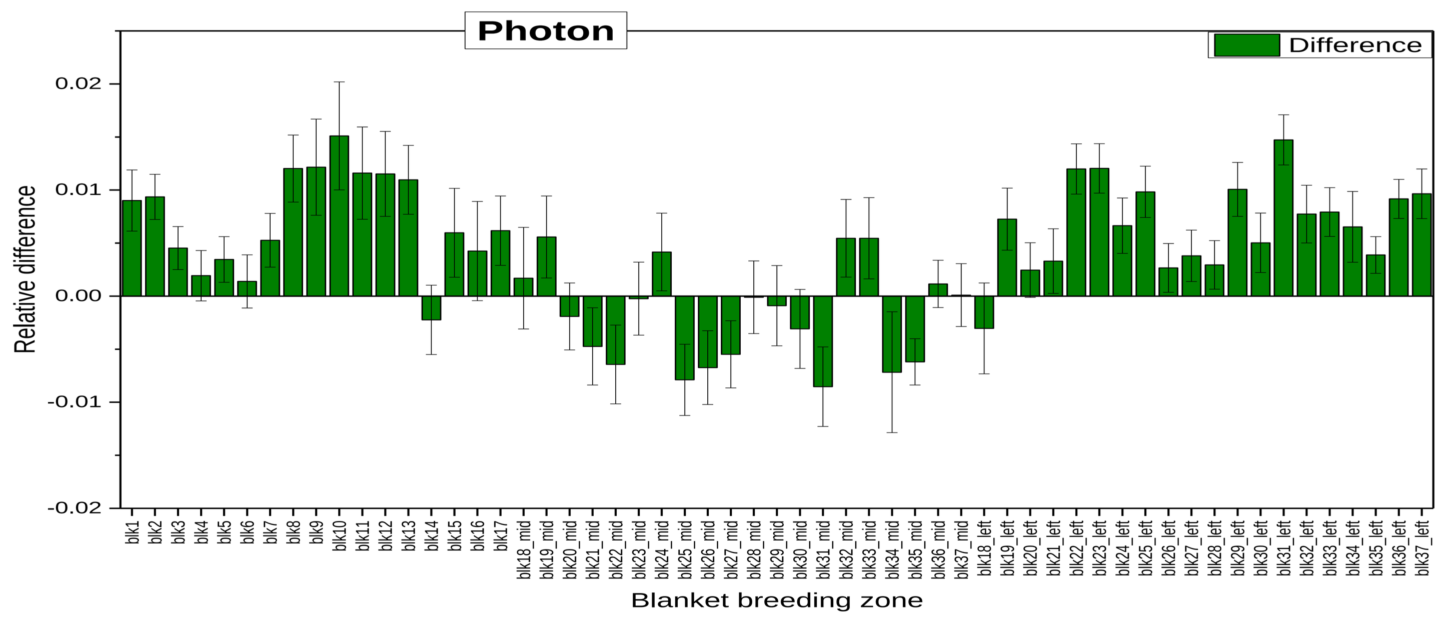

Neutron flux are within 2σ of the combined error in all energy bins, most of which are within 1σ with a relative difference of below 1%.




Photon flux are within 5σ of the combined error in all energy bins, most of which are within 2σ with a relative difference of below 3%.

## Neutron and Photon Heating in Breeder Zone




- Neutron heating: Relative Difference < 1.5%
- Photon heating: Relative Difference < 1.6%

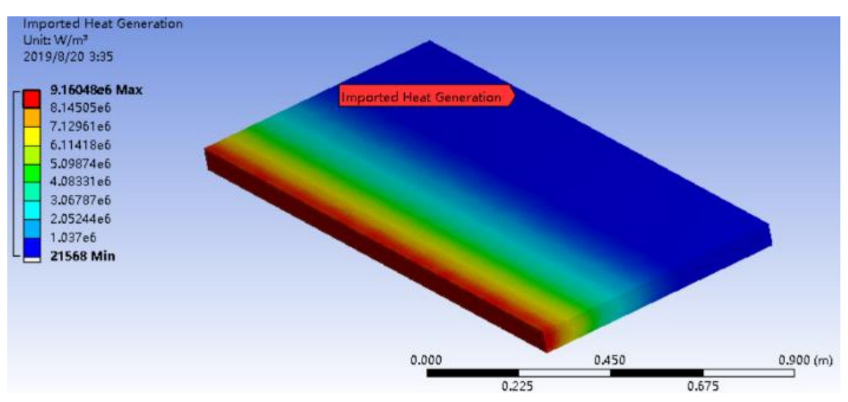
Compared with MCNP, the neutron heating of BZ in Serpent-2 are noted to be 0.38% lower, while the photon heating are 0.44% higher.

Nevertheless, the agreement of the two codes is well

## Nuclear Energy Generation of Various Components

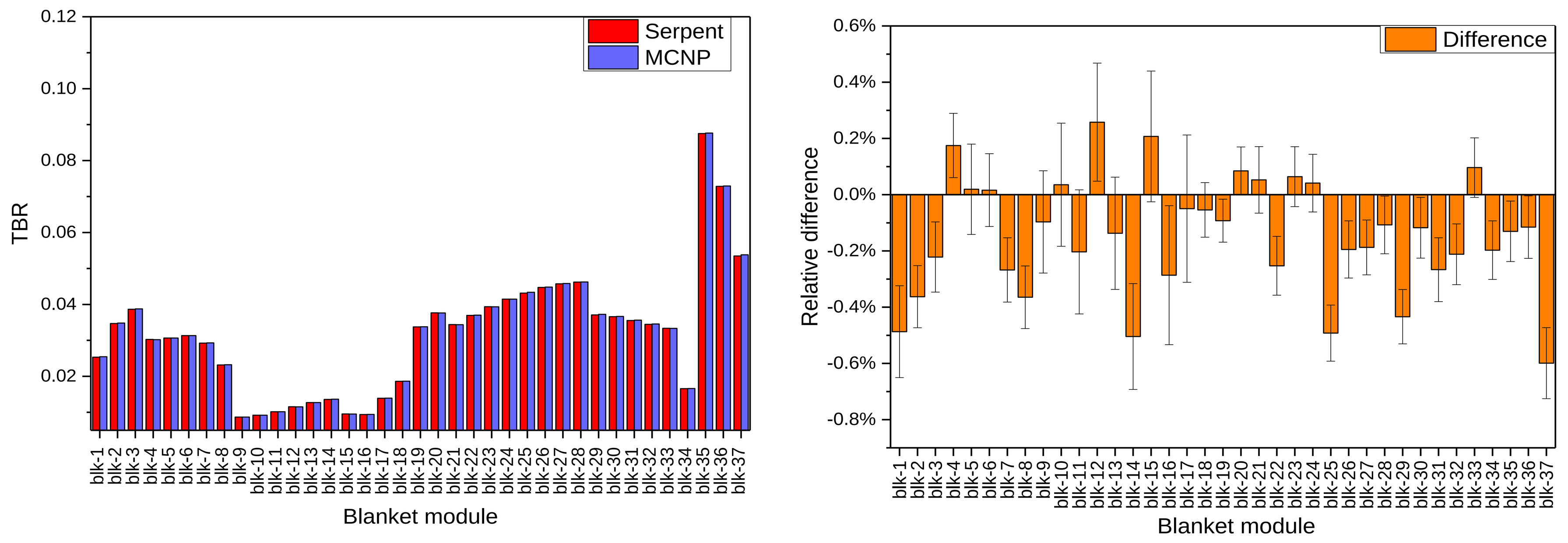
| Component | Neutron Energy generation (MW) | | | Photon Energy generation (MW) | | |
|---|---|---|---|---|---|---|
| | serpent | mcnp | difference | serpent | mcnp | difference |
| Blanket | 1206.1 | 1209.2 | -0.26% | 695.6 | 694.5 | 0.15% |
| Divertor | 29.42 | 29.31 | 0.38% | 139.18 | 139.61 | -0.31% |
| VV | 3.07 | 3.08 | -0.31% | 46.57 | 46.72 | -0.31% |
| Magnet system | 6.46E-03 | 6.36E-03 | 1.65% | 1.04E-01 | 9.93E-02 | 4.40% |

## Nuclear Heating Loading on ANSYS




Serpent-2 mesh detector results were post-processed by Excel containing X, Y, Z coordinates and the corresponding power density.

## Tritium Breeding Ratio




- Relative Difference in each blanket: < 0.6%
- Relative Difference in each nuclide: $^6Li$: -0.18% $^7Li$: -0.037% $^9Be$: negligible
- TBR totel: Serpent: 1.1718; MCNP: 1.1738 ; Relative Difference: -0.18%

## Summary

Neutron and photon flux spectra, neutron heating and photon heating in the breeder zone, nuclear energy generation in blanket, divertor, vacuum vessel and magnet system, tritium breeding ratio were compared, and most results are within 3σ of the combined error with a relative difference of below 1%. Since the variance reduction was not used successfully, magnet system is statistically poor. Besides, nuclear heat was loaded on ANSYS as heat generation by simple post-processing. Notable, the relative errors of Serpent-2 are generally two to five times higher than MCNP for the same model in the simulation. Overall, the Serpent-2 shows excellent agreement against MCNP.

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