Neutronics for DEMO Fusion Power Plant:

Serpent2 Modelling of 14.1 MeV Neutrons in Reactor Mock-Up Components

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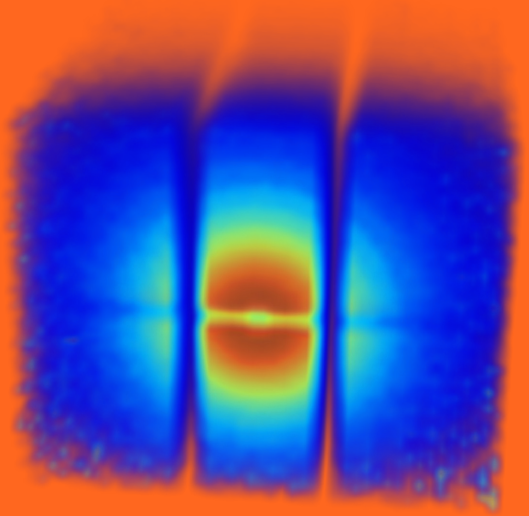
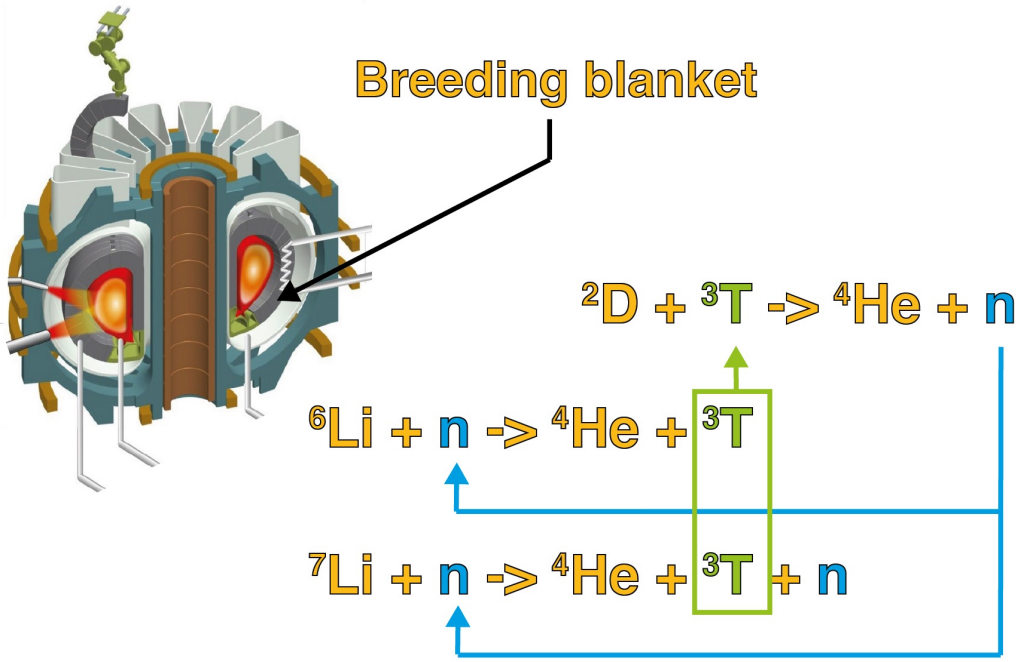


Outline

- **Introduction**
- **WCLL breeding blanket mock-up experiment**
  - Neutron studies with serpent
  - Benchmark with MCNP and validation
- **Tungsten shield mock-up experiment**
  - Neutron studies with serpent
  - Benchmark with MCNP
- **Summary**

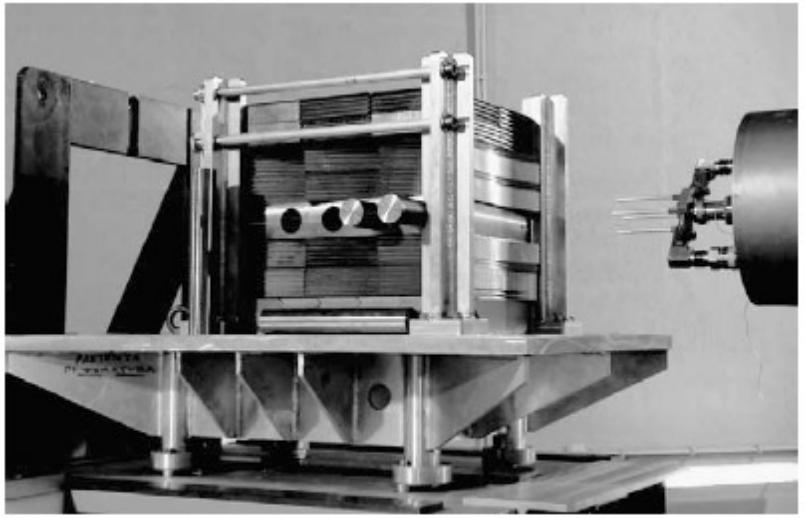
Neutrons: A key component to fuel self-sufficiency of DEMO

- Neutrons to produce fuel (T) from Li in the wall blankets
  - ↳ Fuel self-sufficiency
- ITER will not be ready in time to provide crucial information about fusion neutrons in reactor conditions
  - ↳ Experiments and modelling necessary to assess Tritium Breeding Ratio (TBR) and W shielding capabilities

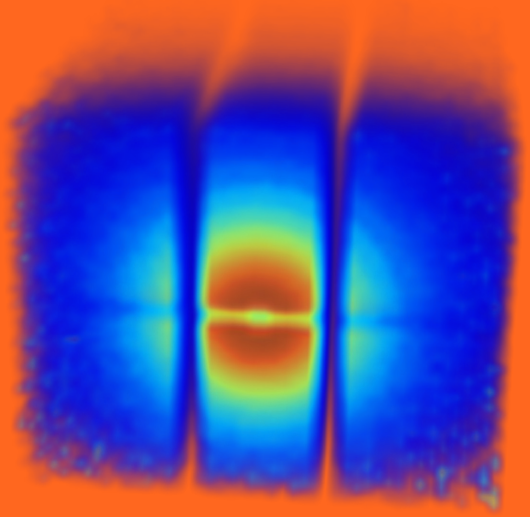


Laboratory experiments: WCLL breeding blanket and W shielding mock-ups

- Two experiments to test: the breeding efficiency of the Water-Cooled Lithium Lead (WCLL) BB and the shielding capabilities of Tungsten
- Neutron irradiations experiments carried out in mock-ups with simplified geometry
- Both experiments are provided at ENEA, Frascati, using the the Frascati Neutron Generator (FNG)



Tungsten block in front of the FNG.
[P. Batistoni et al., Neutronics benchmark experiment on tungsten, Journal of Nuclear Materials, Vol. 329-333, Part A, (2004) pp. 683-686]



Water-cooled Litium Lead (WCLL) mock-up experiment

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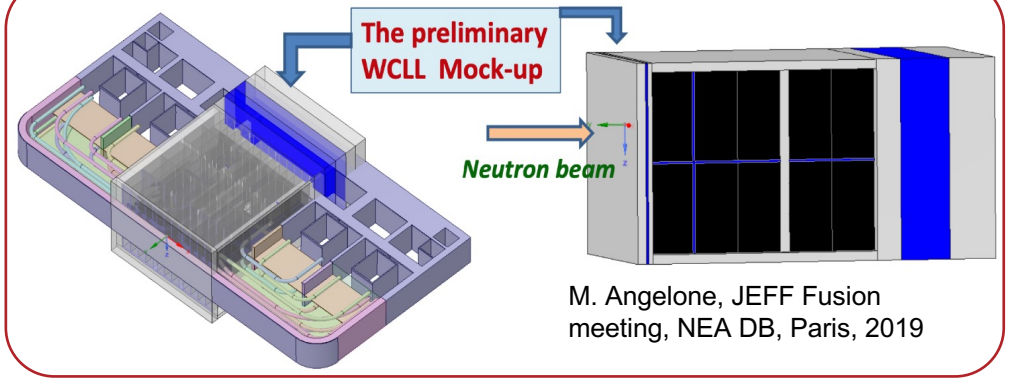
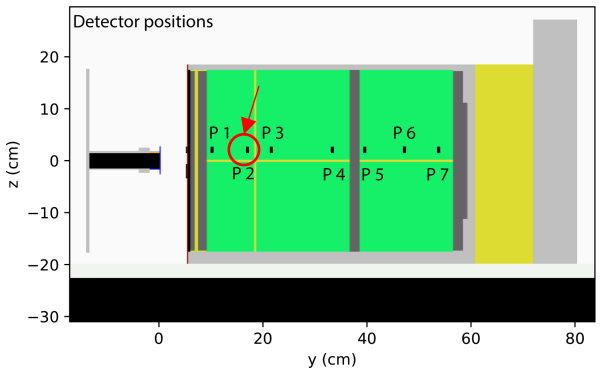
Water Cooled Lithium Lead (WCLL) breeding blanket mock-up

- WCLL mock-up at the Frascati Neutron Generator represents the European DEMO design
- Serpent model (from MCNP model) includes the realistic geometry and material composition of the mock-up
- Seven detectors lined up at different distances (P1-P7)



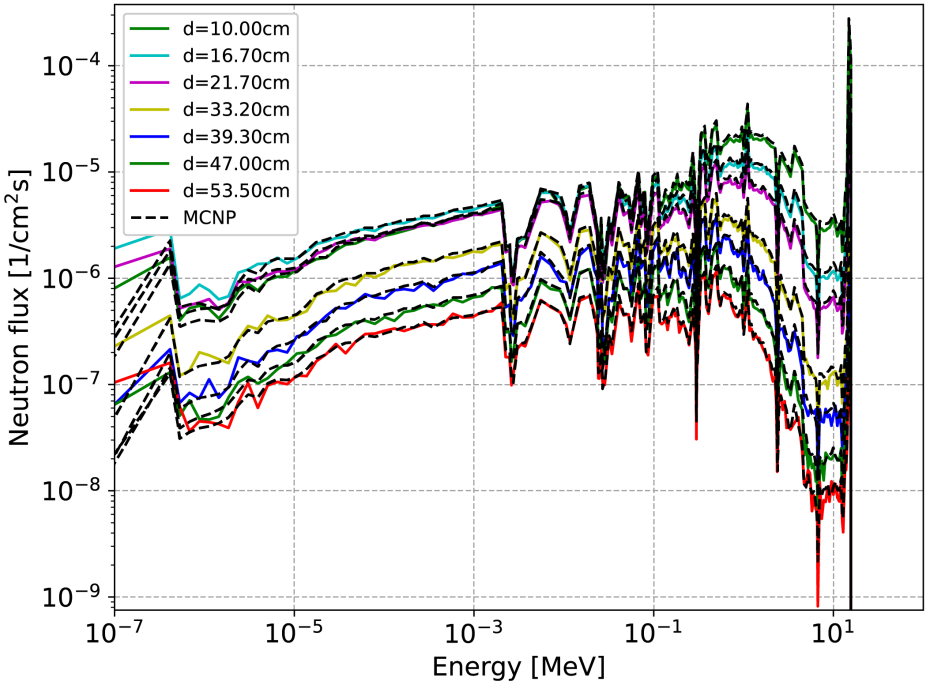
M. Angelone, JEFF Fusion meeting, NEA DB, Paris, 2019

WCLL Mock-up in Serpent

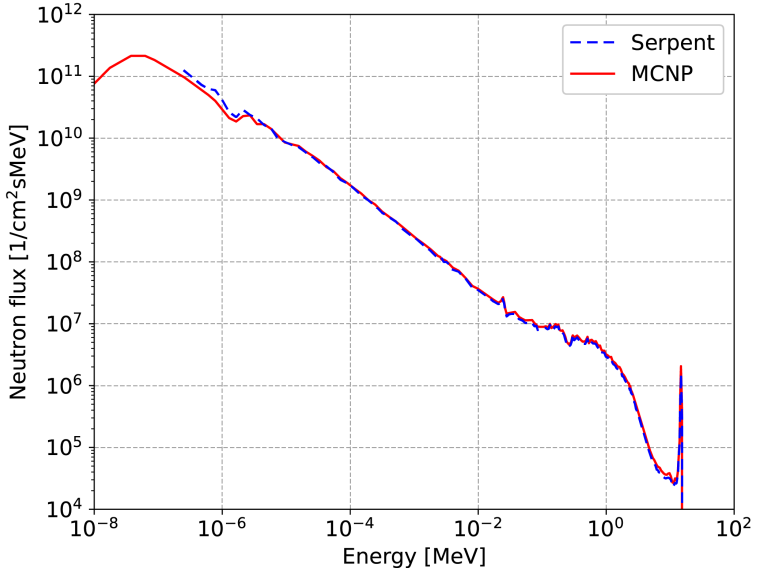


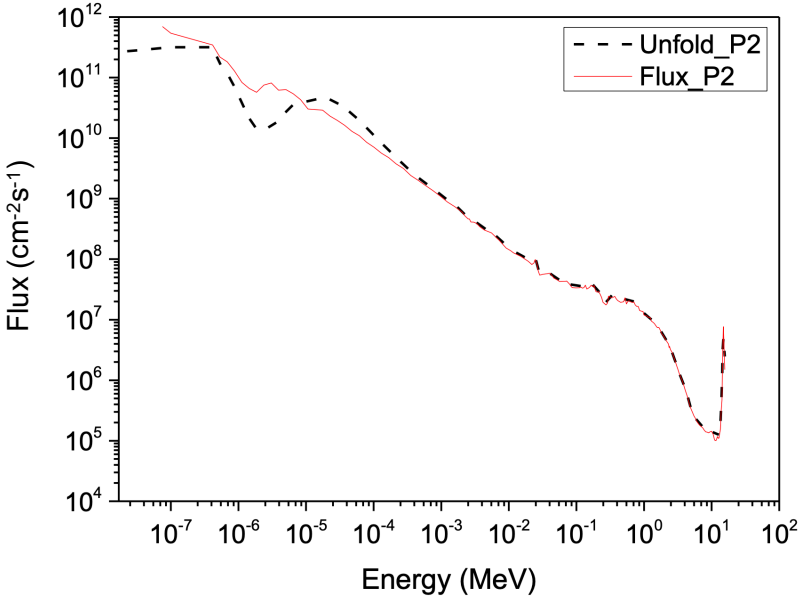
Serpent-calculated neutron flux vs. MCNP

- Neutron flux in the WCLL mock-up calculated at the 7 detector locations and compared to the MCNP results
- Libraries JEFF3.3 and IRDFF-II were used
- Difference between Serpent and MCNP results remains below 10% for most of the energy range



Serpent and MCNP agree well with experiment

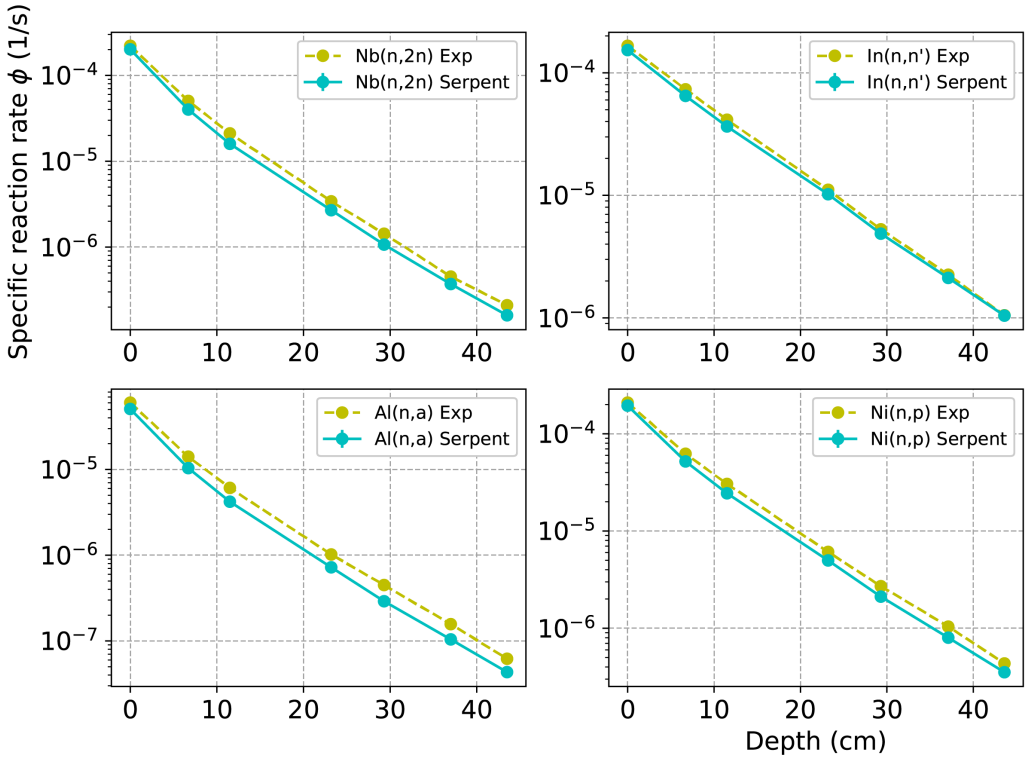


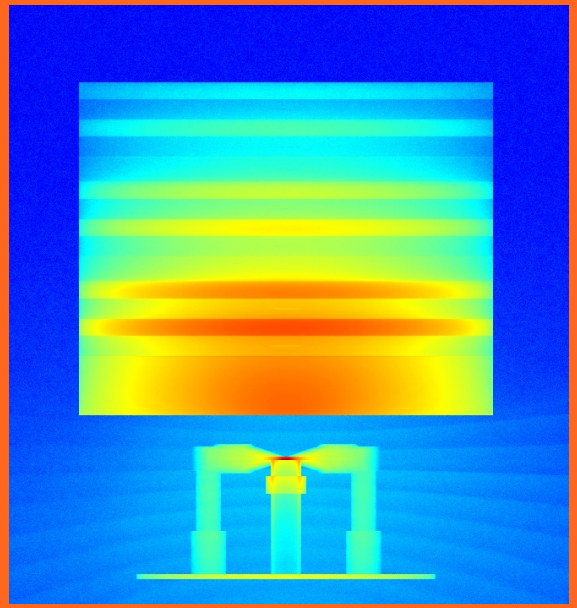


- The differential neutron flux as a function of the energy was calculated at position P2 and compared with MCNP and experimental data

Agreement with experiments best at high cross section

- Four reaction rates were compared at each detector location with experimental data
- Reaction rates obtained from $5 \cdot 10^9$ neutron histories
- The highest C/E ratio, 0.88-0.99, for In(n,n') due to high cross-section





Tungsten shield mock-up Experiment

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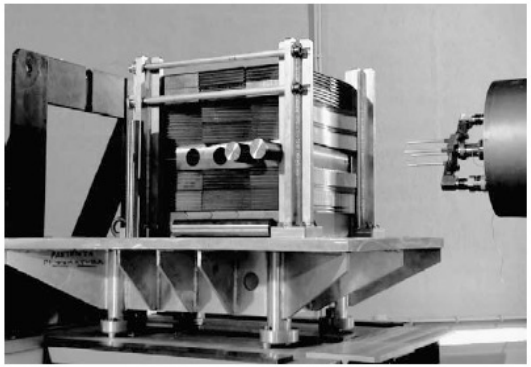
Studying the neutron transport in a reactor-like tungsten shield

- W mock-up mimics a shielding component in a reactor containing tungsten, SS and water
- Water is replaced by Perspex
- Serpent model (from MCNP model) includes the realistic geometry and material composition of the mock-up



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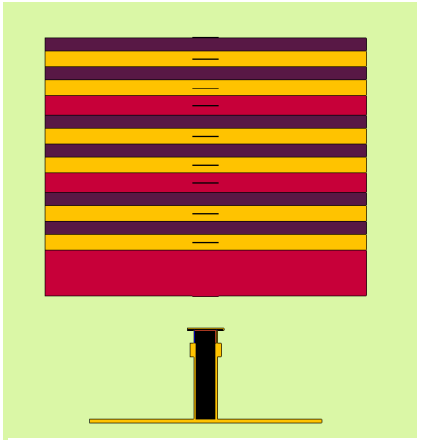
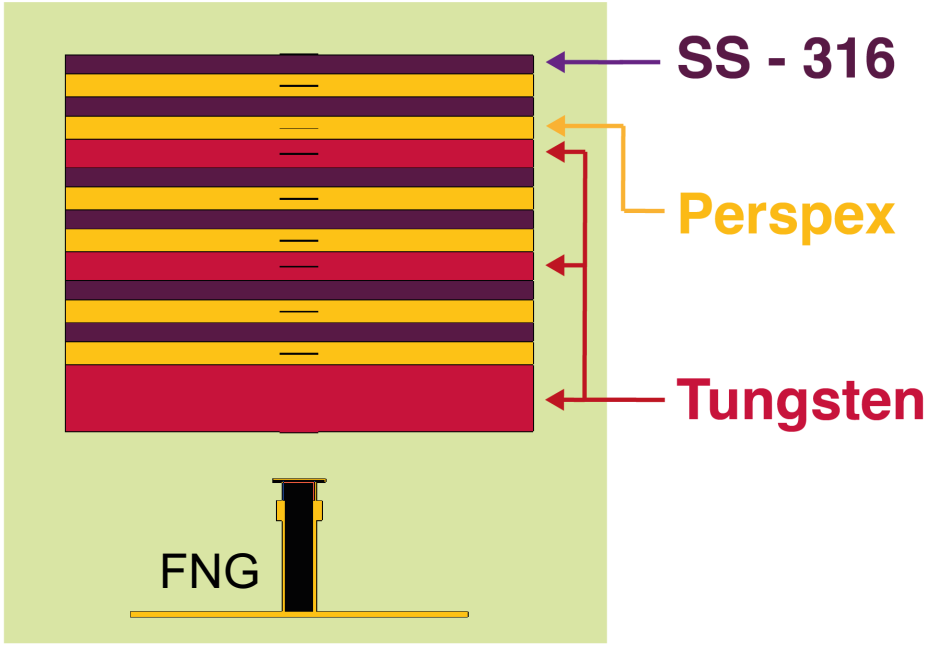


Serpent model. Top view

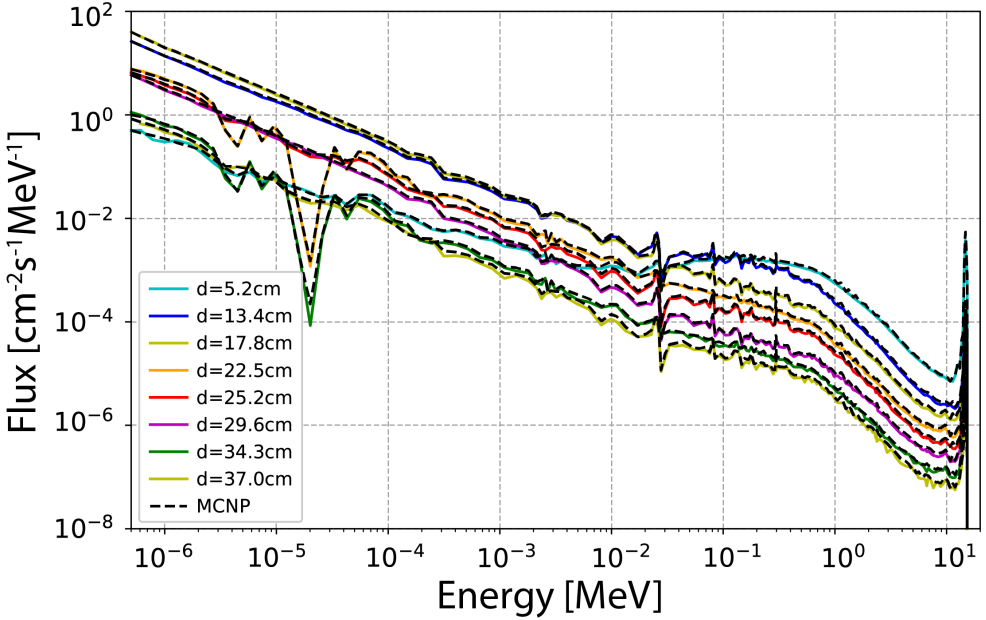
Geometry and material composition of the mock-up

- MCNP5 was used to optimise the experimental set-up
- Final set-up includes slabs of W, SS-316 and Perspex
- Nine detectors lined up at different distances from the source



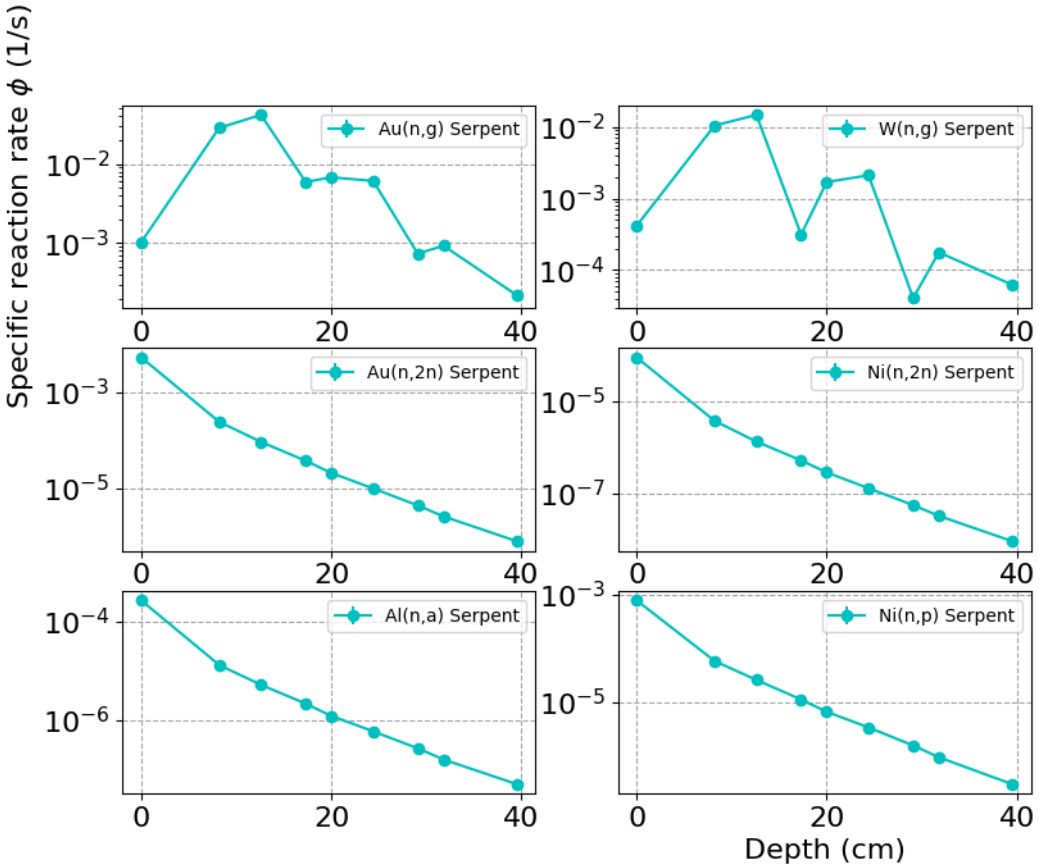
Serpent-calculated neutron flux vs. MCNP

- Neutron flux in the W-shielding mock-up calculated at the 9 detector locations
- Neutron histories: $2 \cdot 10^9$
- Libraries: JEFF3.3 and IRDFF-II
- Absorption peak at 20 keV due to (n,γ) reaction
- Difference between Serpent and MCNP results remains below 10%

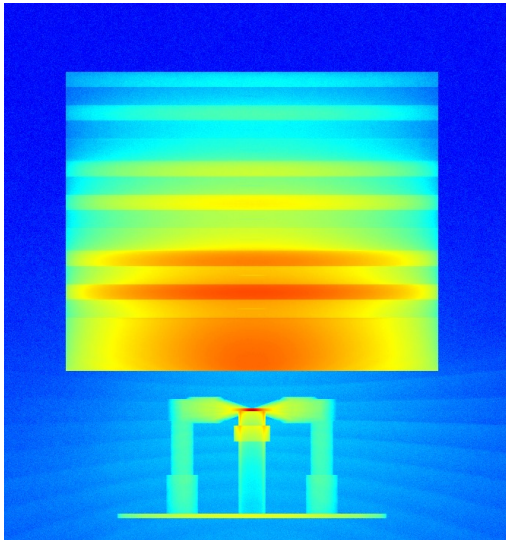


Serpent-calculated reaction rates at the 9 detector locations

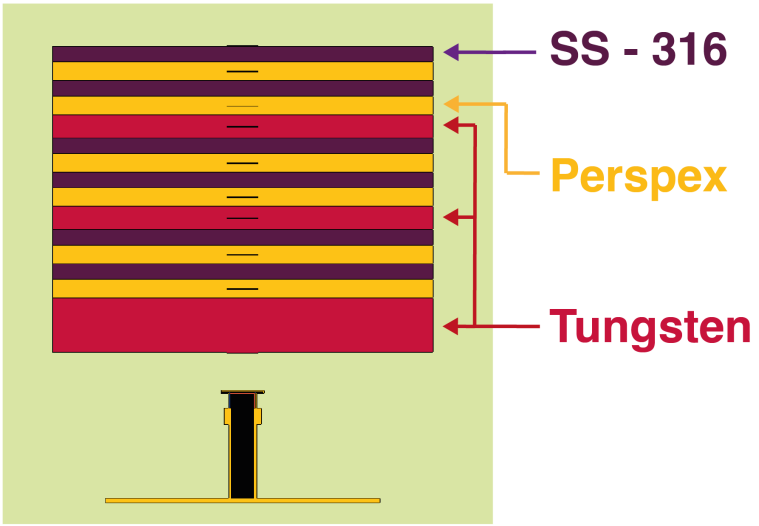
- γ reactions: Au(n,γ), W(n,γ)
- n multiplier reactions: Au(n,2n), Ni(n,2n)
- α reactions: Al(n,α), Ni(n,p)
- Serpent analysis ready to be compared against MCNP and experimental data



Serpent-calculated neutron flux in all slabs



Serpent-calculated flux
(Mock-up top view)



Serpent geometry model
(Mock-up top view)

- The effect of neutron multiplication due to Ni inside SS is visible in the flux analysis

Summary and outlook

- WCLL mock-up was used to benchmark and validate Serpent through the calculation of the neutron fluxes and RRs
- A maximum of 10% discrepancy with MCNP was found in the neutron fluxes calculated and C/E is within 0.88-0.99 in the reaction rates for the case with better statistics

- For W-shield mock-up, geometry was implemented and neutron fluxes and RRs were calculated with Serpent.
- The neutron flux was compared with that from MCNP, showing differences within 10%
- Results will be validated by the end of the year when the experimental data become available

Summary and conclusions

- Two possible sources of error:
  - JEFF3.3 and IRDFFv2 were used in Serpent while MCNP used JEFF3.3 and IRDFF (v1.05 and v2), which could have affected the detector dosimetric data → Plan to install IRDFF v1.05
  - Low statistics achieved in some of the activation foils (e.g. gold foils are only 25μm thick) → Use variance reduction method or move to a bigger HPC cluster