Neutronics for DEMO Fusion Power Plant:

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

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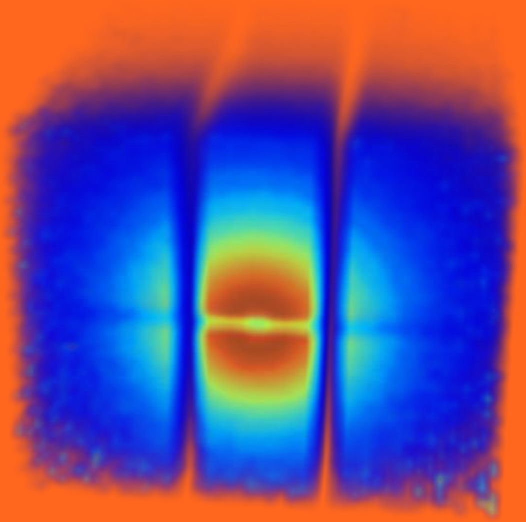


Outline

- **Introduction**
- **WCLL Tritium Breeding Experiment**
    - Neutron studies with serpent
    - Benchmark with MCNP and validation
- **Tungsten Shielding Experiment**
    - Neutron studies with serpent
    - Benchmark with MCNP
- **Summary**

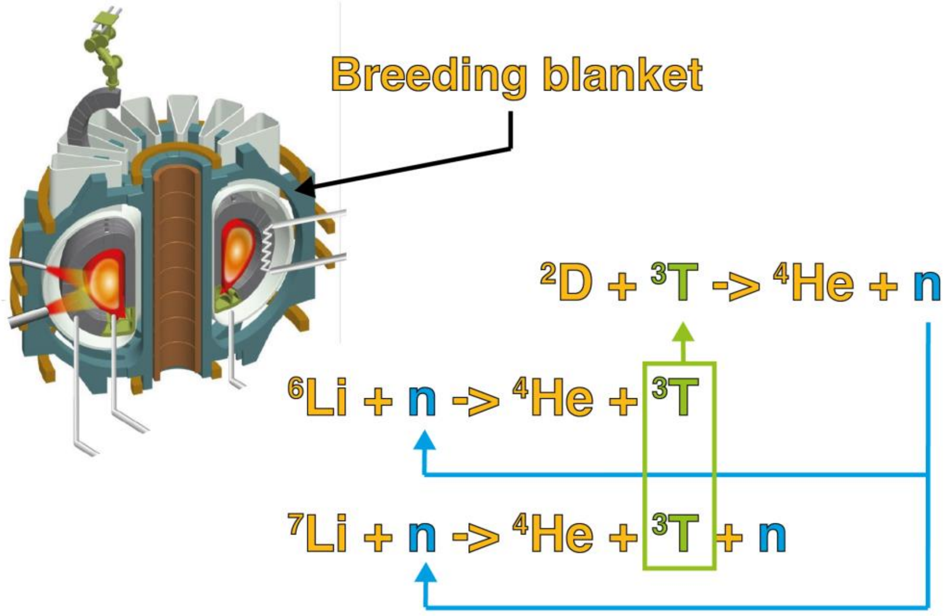
Neutrons: A key component to fuel self-sufficiency of DEMO

- 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

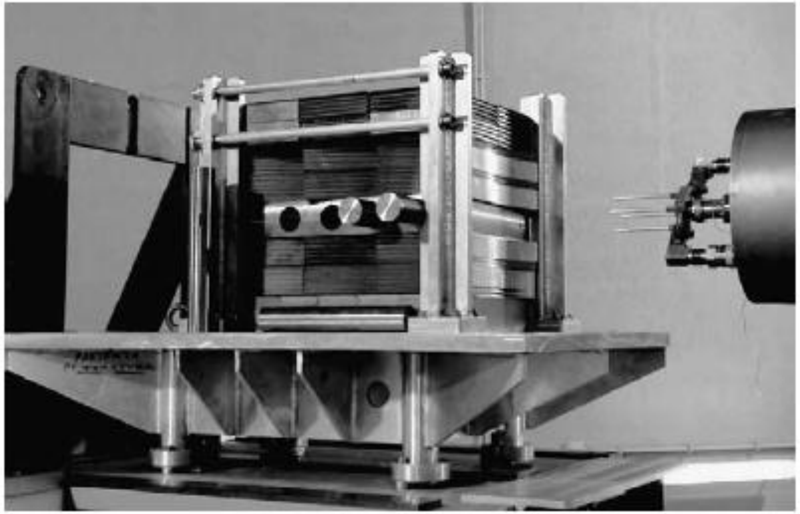


Laboratory experiments: WCLL breeding blanket and W shielding mock-ups

- 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]

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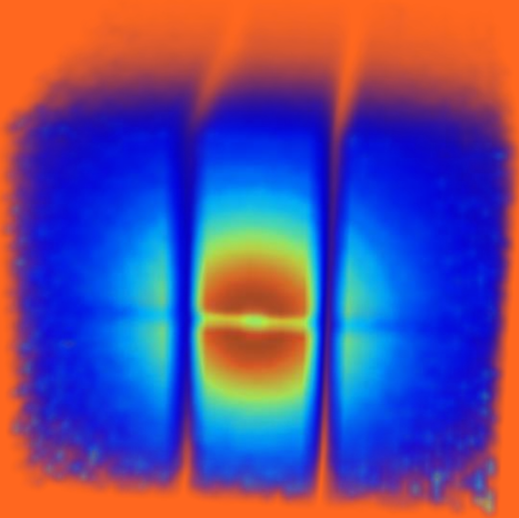

Water-cooled Litium Lead (WCLL) Tritium Breeding Experiment

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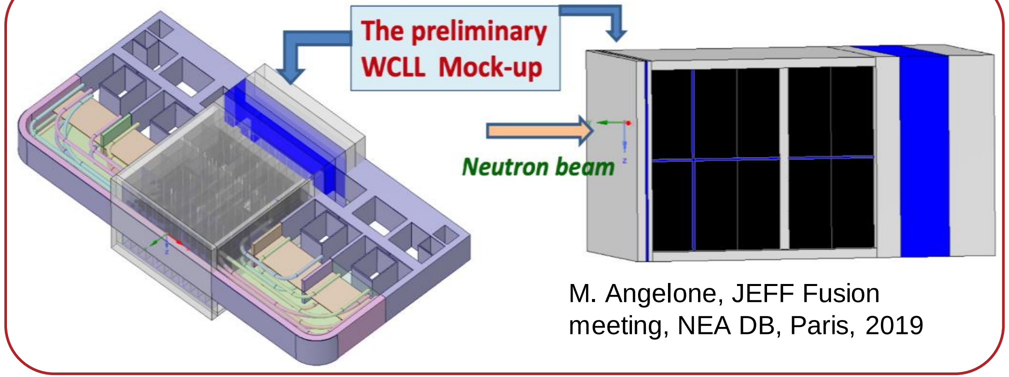
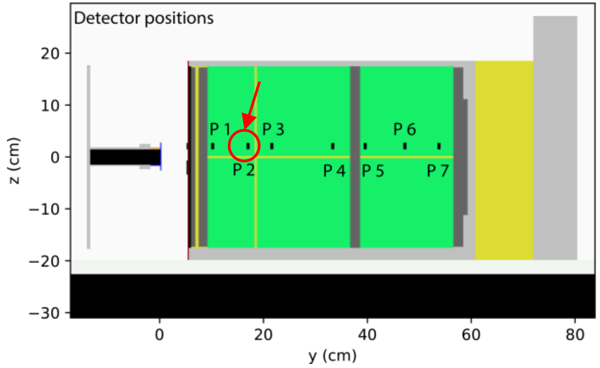
Water Cooled Lithium Lead (WCLL) breeding blanket mock-up

- 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

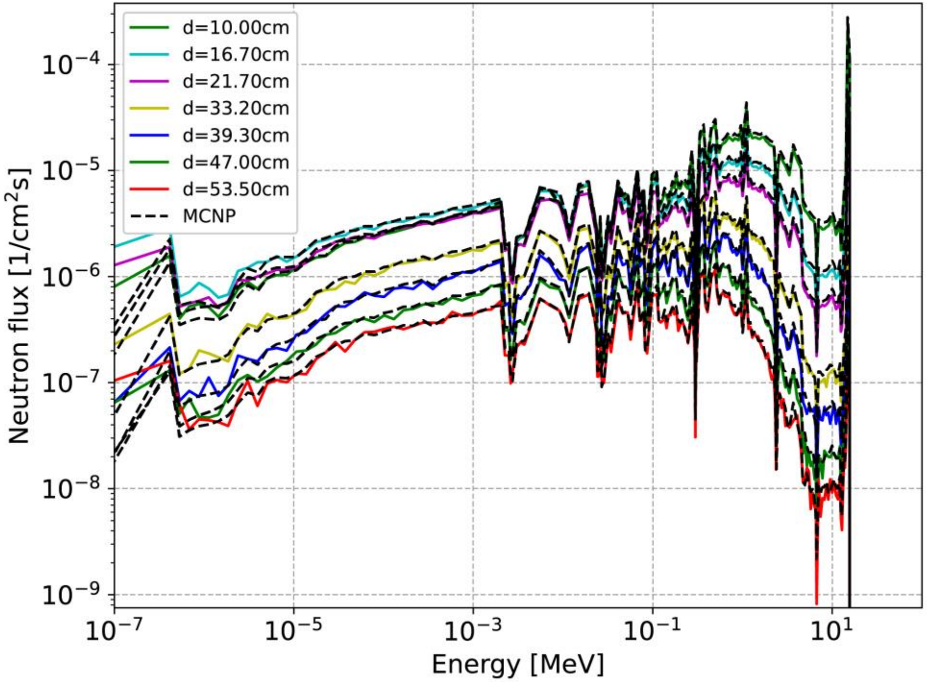


Serpent-calculated neutron flux vs. MCNP

- Neutron flux in the WCLL mock-up calculated at the 7 detector locations and compared to the MCNP results

- Libraries JEFF3.3 and IRDF-II were used

- Difference between Serpent and MCNP results remains below 10% for most of the energy range



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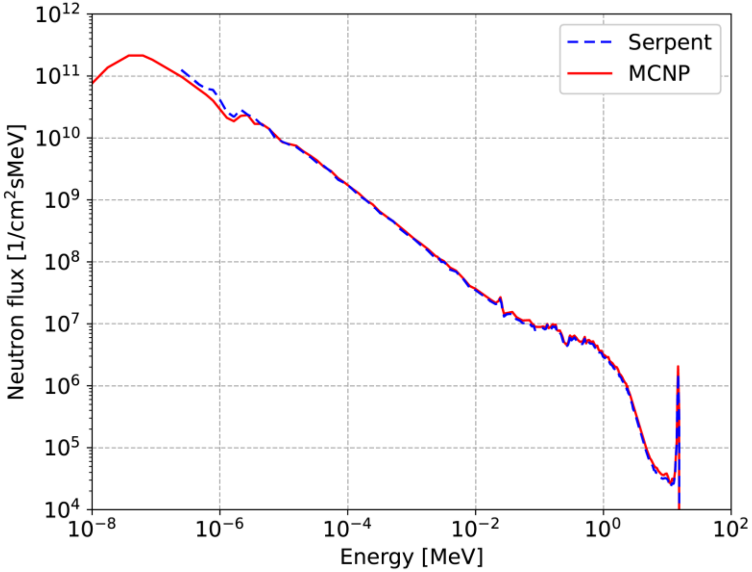
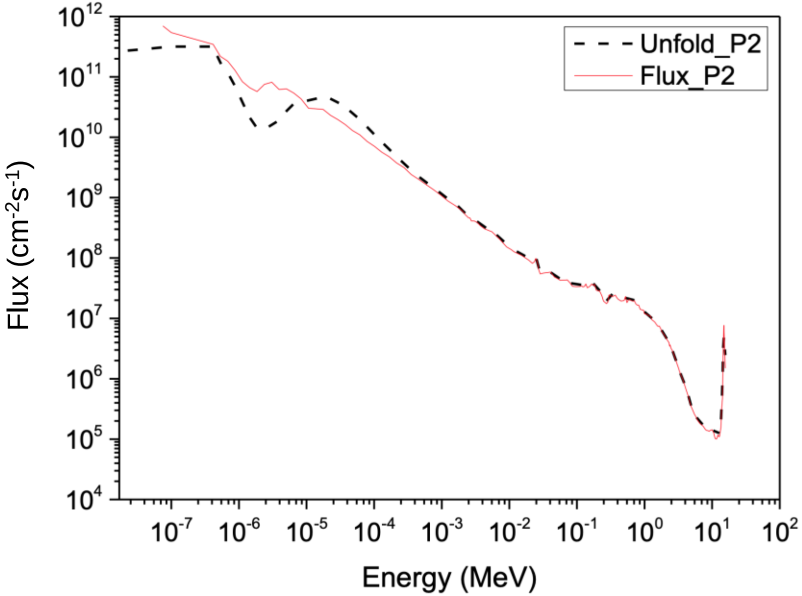
Serpent and MCNP agree well with experiment

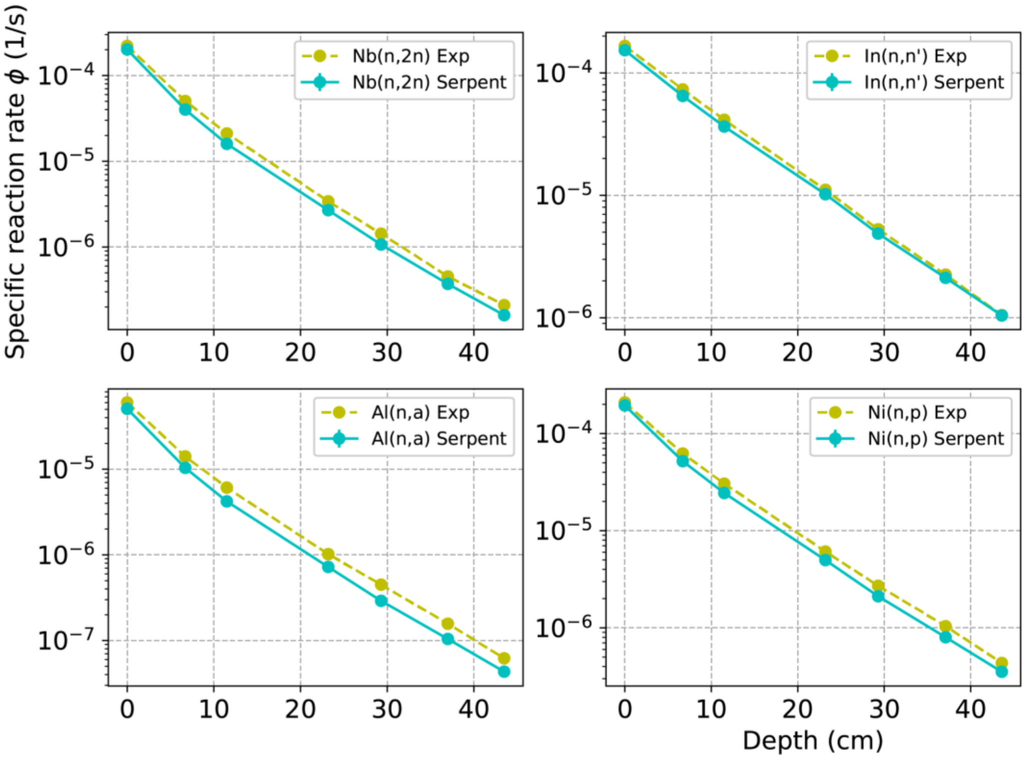




- The differential neutron flux as a function of the energy was calculated at position P2 and compared with MCNP and experimental data

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



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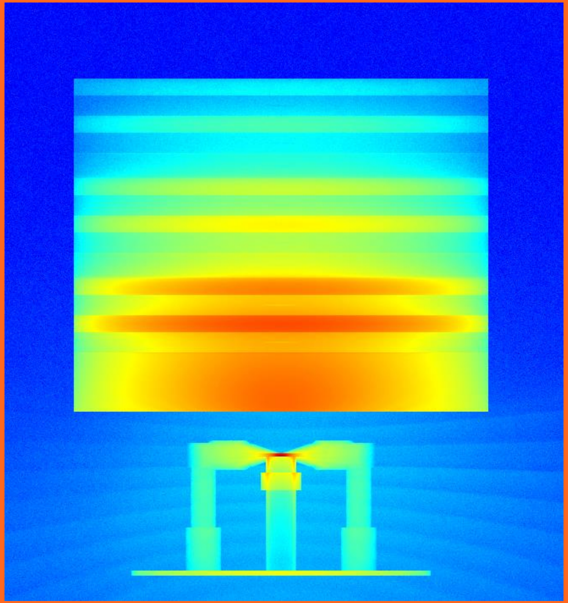

Tungsten Shielding Experiment

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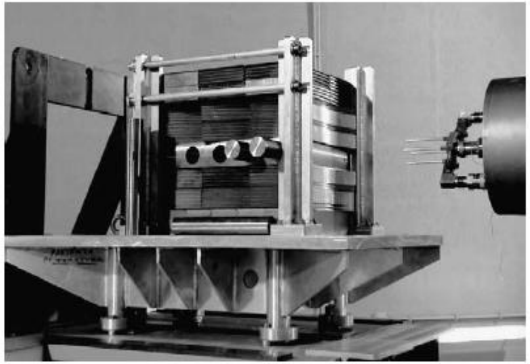
Studying the neutron transport in a reactor-like tungsten shield

- W mock-up mimics the composition of a shielding element 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



Tungsten block in front of the FNG.
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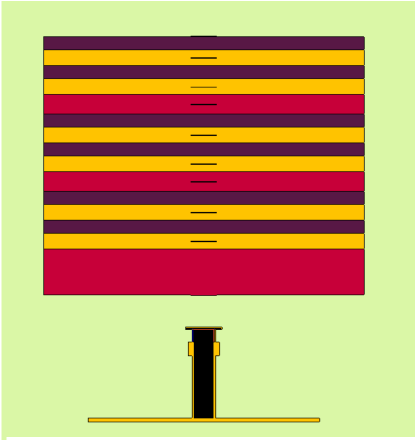

Serpent model. Top view

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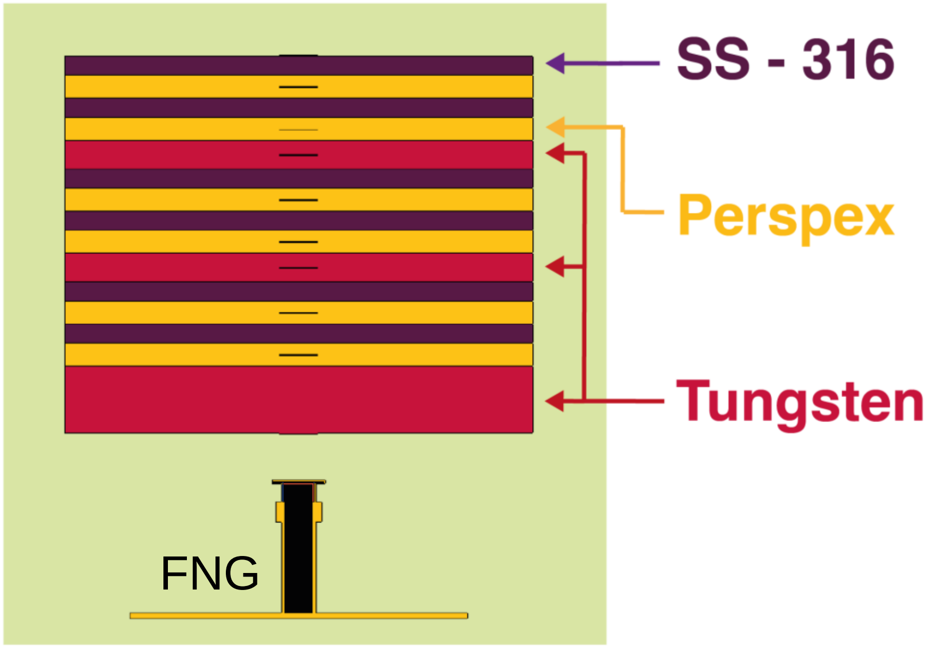
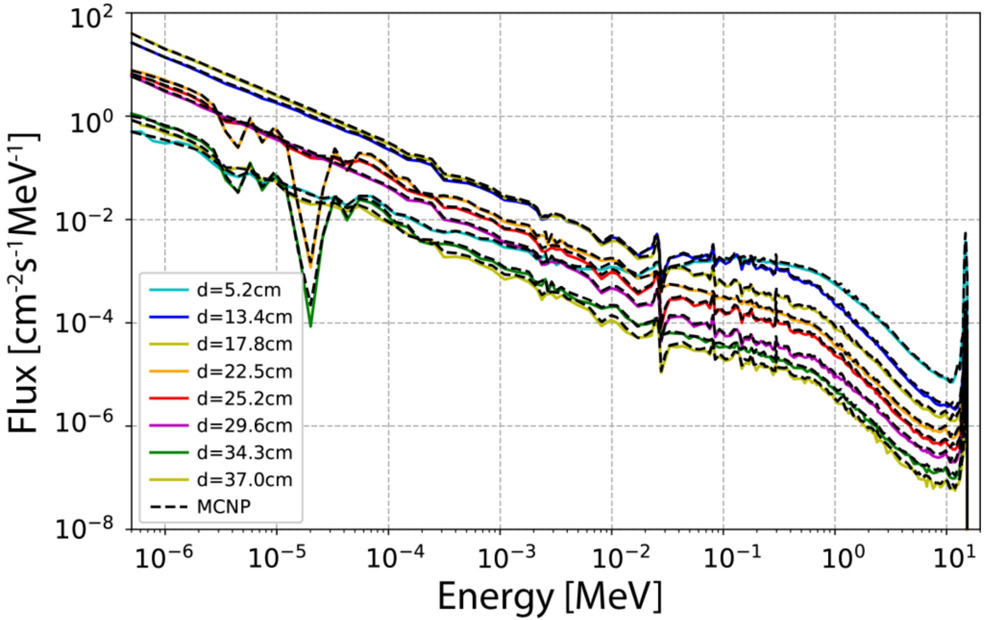
Geometry and material composition of the mock-up

- 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 IRDF-II
- Absorption peak at 20 keV due to (n,γ) reaction
- Difference between Serpent and MCNP results remains below 10%



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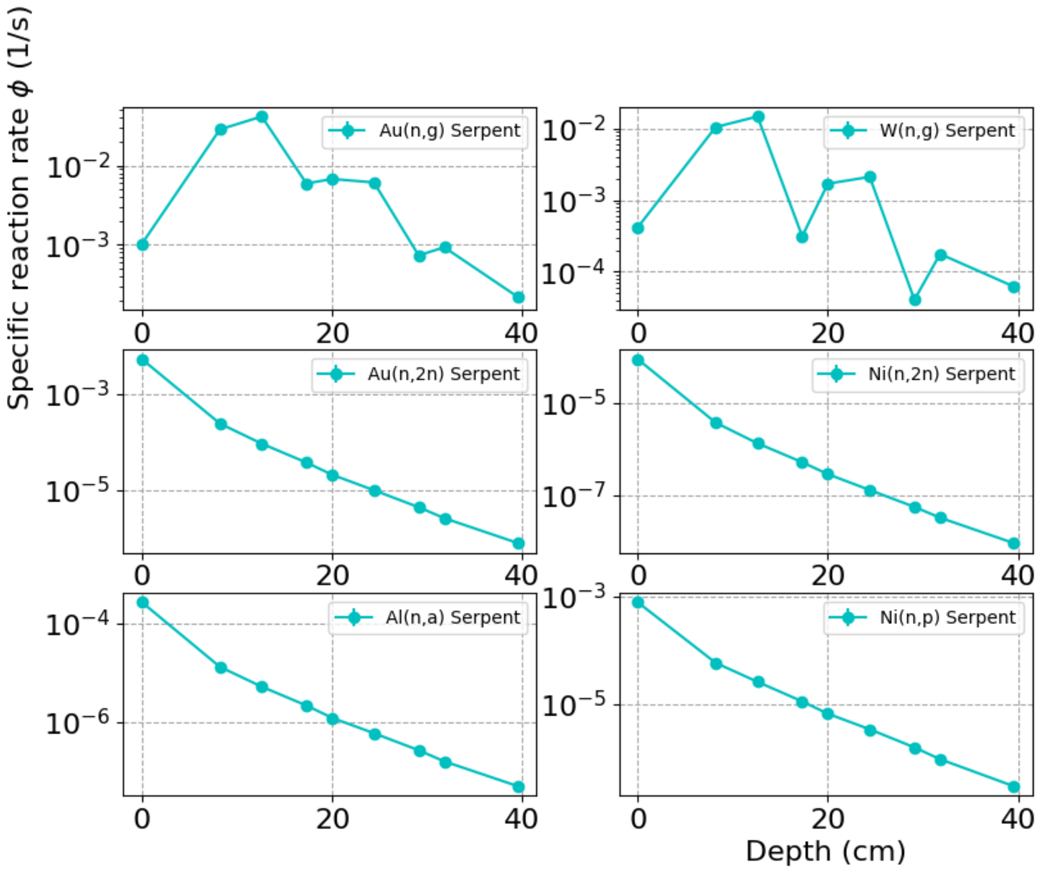
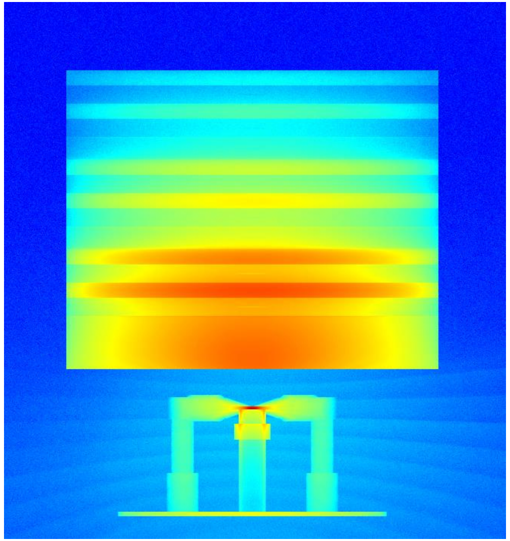
Serpent-calculated reaction rates at the 9 detector locations

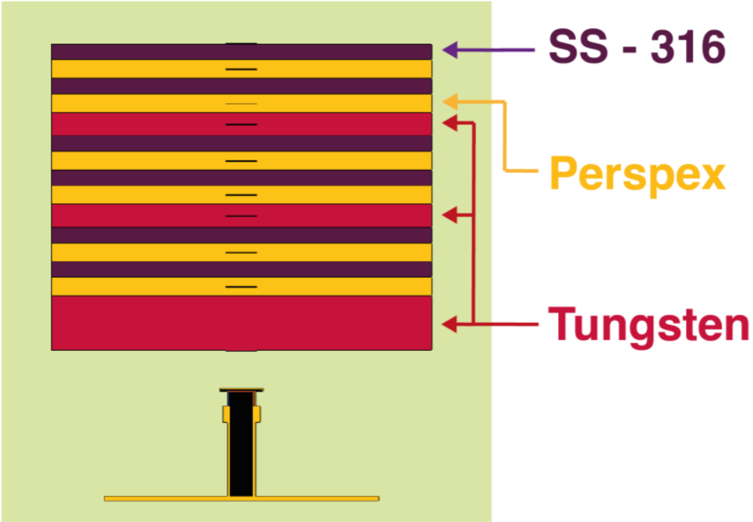
- γ reactions: Au(n,γ), W(n,γ)
- n multiplier reactions: Au(n,2n), Ni(n,2n)
- α reactions: Al(n,α), Ni(n,p)
- Serpent analysis ready to be compared against MCNP and experimental data



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 conclusions

- WCLL mock-up was used to benchmark and validate Serpent through the calculation of neutron fluxes and RRs

- A maximum of 10% discrepancy with MCNP was found in the neutron fluxes and C/E is within 0.88-0.99 in the RRs 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

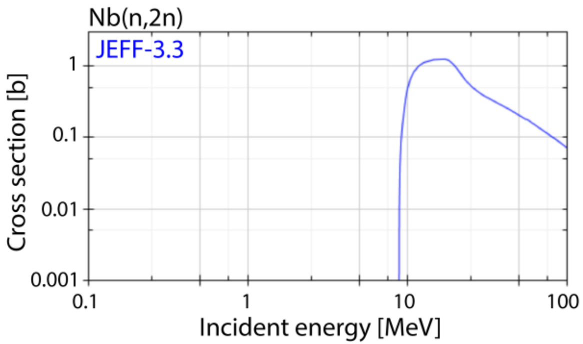
- Two possible sources of error:

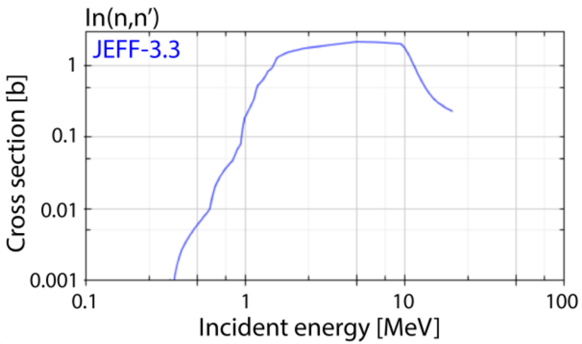
  - JEFF3.3 and IRDFFv2 were used in Serpent while MCNP used JEFF3.3 and IRDFF (v1.05 and v2), which could have affected the detector dosimetric data → Plan to install IRDFF v1.05

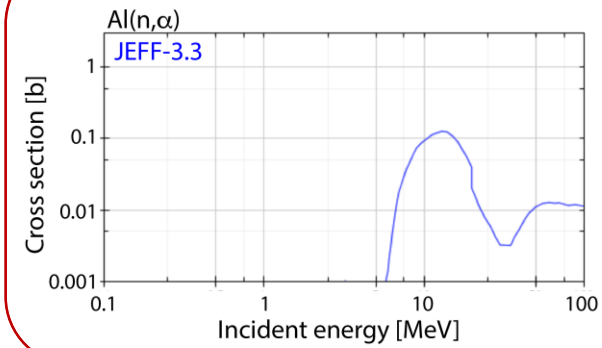
  - Low statistics achieved in some of the activation foils (e.g. gold foils are only 25μm thick) → Use variance reduction method or move to a bigger HPC cluster

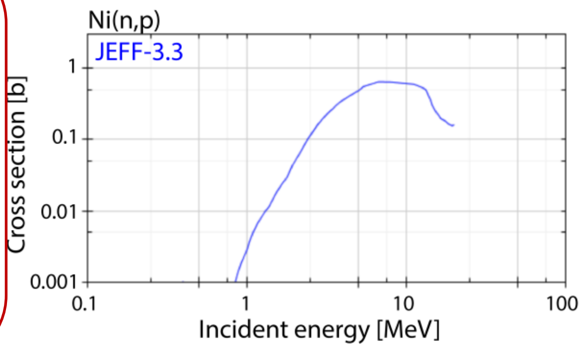
Back-up slides

RR cross sections (WCLL)









Calculated/Experiment

	RR Nb(n,2n)	RR Nb(n,2n)	C/E	RR In(n,n')	RR In(n,n')	C/E
Pos	Serpent ($1/cm^3s$)	Measured ($1/cm^3s$)		Serpent ($1/cm^3s$)	Measured ($1/cm^3s$)	
1	$2.01 \cdot 10^{-4}$ (0.06%)	$2.21 \cdot 10^{-4}$(5.0%)	0.91	$1.53 \cdot 10^{-4}$(0.10%)	$1.66 \cdot 10^{-4}$(4.8%)	0.92
2	$4.00 \cdot 10^{-5}$ (0.13%)	$5.04 \cdot 10^{-5}$(5.1%)	0.80	$6.48 \cdot 10^{-5}$(0.16%)	$7.33 \cdot 10^{-5}$(4.7%)	0.88
3	$1.60 \cdot 10^{-5}$ (0.23%)	$2.11 \cdot 10^{-5}$(5.1%)	0.75	$3.65 \cdot 10^{-5}$(0.20%)	$4.14 \cdot 10^{-5}$(4.2%)	0.88
4	$2.69 \cdot 10^{-6}$ (0.56%)	$3.41 \cdot 10^{-6}$(5.2%)	0.78	$1.02 \cdot 10^{-5}$(0.39%)	$1.11 \cdot 10^{-5}$(5.0%)	0.92
5	$1.07 \cdot 10^{-6}$ (0.95%)	$1.43 \cdot 10^{-6}$(5.1%)	0.72	$4.87 \cdot 10^{-6}$(0.51 %)	$5.28 \cdot 10^{-6}$(5.8%)	0.92
6	$3.71 \cdot 10^{-7}$ (1.50%)	$4.53 \cdot 10^{-7}$(5.1%)	0.80	$2.12 \cdot 10^{-6}$(0.70%)	$2.25 \cdot 10^{-6}$(6.7%)	0.94
7	$1.60 \cdot 10^{-7}$ (2.20%)	$2.10 \cdot 10^{-7}$(6.7%)	0.80	$1.04 \cdot 10^{-6}$(0.96%)	$1.05 \cdot 10^{-6}$(7.6%)	0.99

	RR Al(n,α)	RR Al(n,α)	C/E	RR Ni(n,p)	RR Ni(n,p)	C/E
Pos	Serpent ($1/cm^3s$)	Measured ($1/cm^3s$)		Serpent ($1/cm^3s$)	Measured ($1/cm^3s$)	
1	$5.08 \cdot 10^{-5}$(0.06%)	$6.02 \cdot 10^{-5}$(4.8%)	0.84	$1.95 \cdot 10^{-4}$(0.07%)	$2.09 \cdot 10^{-4}$(5.0%)	0.93
2	$1.04 \cdot 10^{-5}$(0.13%)	$1.41 \cdot 10^{-5}$(4.8%)	0.74	$5.19 \cdot 10^{-5}$(0.15%)	$6.23 \cdot 10^{-5}$(5.1%)	0.83
3	$4.21 \cdot 10^{-6}$(0.22%)	$6.10 \cdot 10^{-6}$(4.7%)	0.69	$2.44 \cdot 10^{-5}$(0.22%)	$3.05 \cdot 10^{-5}$(5.1%)	0.80
4	$7.22 \cdot 10^{-7}$(0.54%)	$1.02 \cdot 10^{-6}$(5.0%)	0.71	$4.98 \cdot 10^{-6}$(0.51%)	$6.10 \cdot 10^{-6}$(5.2%)	0.82
5	$2.91 \cdot 10^{-7}$(0.88%)	$4.49 \cdot 10^{-7}$(4.9%)	0.65	$2.12 \cdot 10^{-6}$(0.76%)	$2.71 \cdot 10^{-6}$(5.1%)	0.78
6	$1.04 \cdot 10^{-7}$(1.45%)	$1.57 \cdot 10^{-7}$(5.6%)	0.66	$8.01 \cdot 10^{-7}$(1.13%)	$1.04 \cdot 10^{-6}$(5.1%)	0.77
7	$4.33 \cdot 10^{-8}$(2.23%)	$6.20 \cdot 10^{-8}$(5.1%)	0.70	$3.53 \cdot 10^{-7}$(1.70%)	$4.35 \cdot 10^{-7}$(6.7%)	0.81