# Ongoing Serpent 2 neutronics studies of Jules Horowitz Reactor

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07/11/2022 VTT – beyond the obvious

# Topics of the presentation

- Introducing JHR project, VTT's collaboration and secondment project
- JHR Serpent 2 neutronics benchmark (2021)
- Dosimetric and spectral analyses of OCCITANE test device (2021)
- Reflector block modelling (2021)
- RCC-MRx material studies (2022)
- Study on poisoning of reflector beryllium blocks (2022-2023)

# Jules Horowitz Reactor

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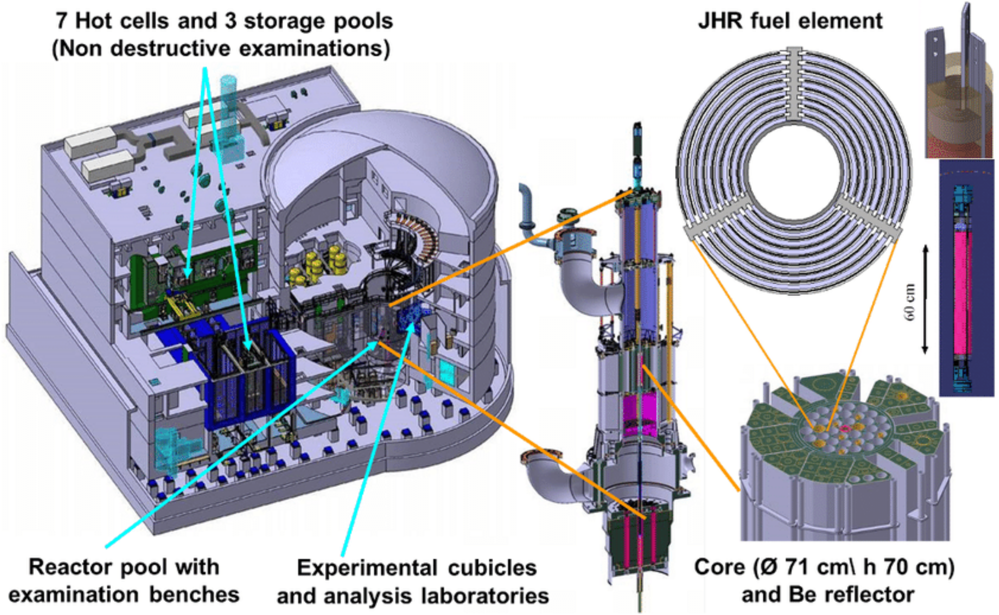
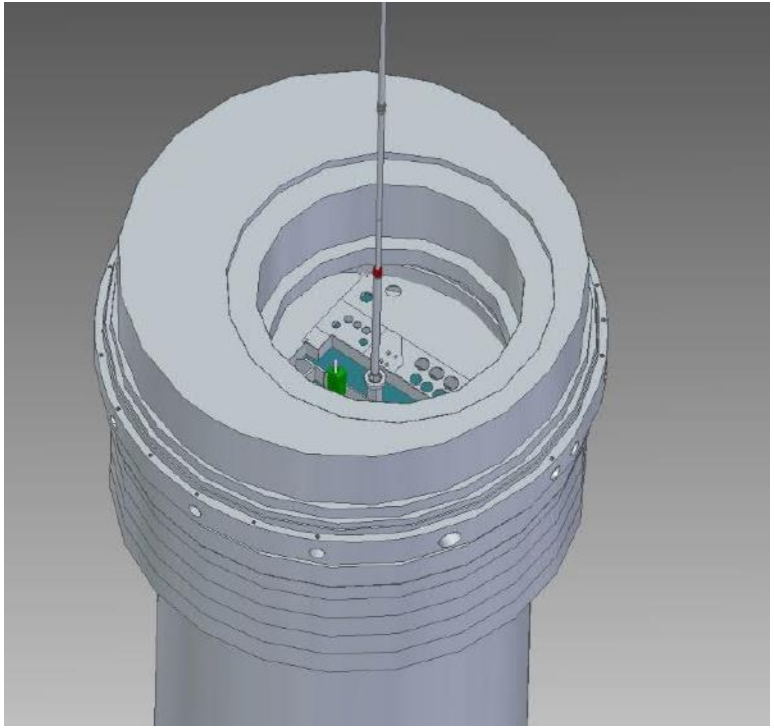
- Under construction in CEA Cadarache, southern France.
- European material testing reactor currently scheduled to start operation in early 2030s.
- Supports the pre-existing power plants via lifetime extension and safety improvements
- Enables the optimization of the generation III power plants and development and qualification of advanced fuel materials.



# VTT's participation in Jules Horowitz Reactor project

VTT

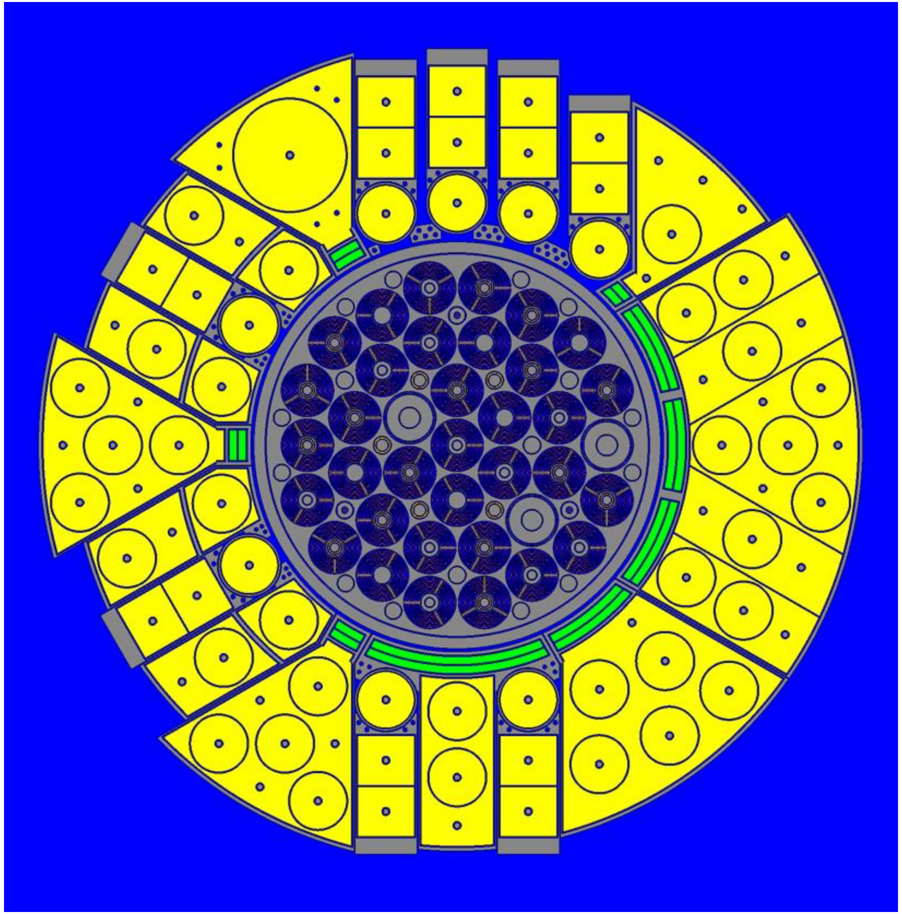
- The initiative behind JHR is run by a consortium consisting of research institutes from several European Member States, including VTT Technical Research Centre of Finland.
- Finland participates in the construction of the JHR test reactor via VTT's in-kind deliveries, such as MeLoDie II test device.
- Past participation was funded by SAFIR programmes. The project applied for SAFER excellence project funding last month.



MeLoDie II (Mechanical Loading Device for Irradiation Experiment) test equipment.

# Neutronics analyses of JHR as a secondment work

- A year ago, a complete computational model of JHR was created for Finnish Monte Carlo neutronics code Serpent 2 and benchmarked against CEA's TRIPOLI-4 code during a secondment visit to CEA Cadarache.
- The results were published in a conference article of PHYSOR2022 organized 15.-20.5.2022 in Pittsburgh, Pennsylvania in USA.



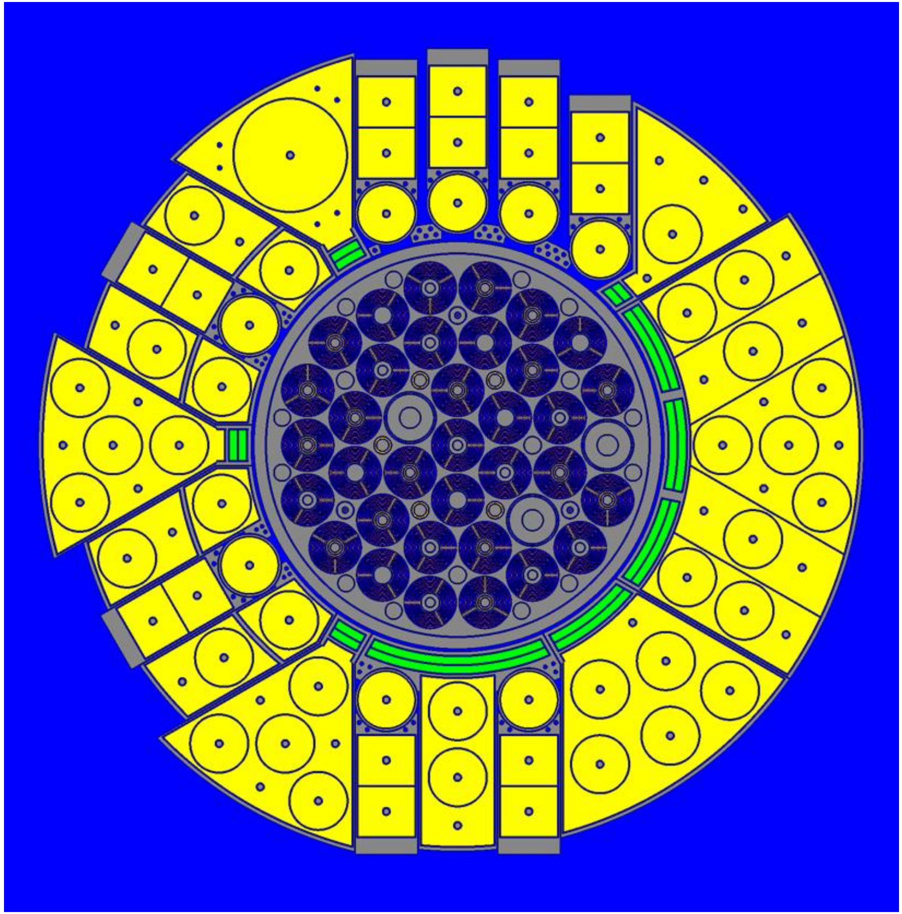
# JHR benchmarking of SERPENT 2

# Fresh core at the beginning of life

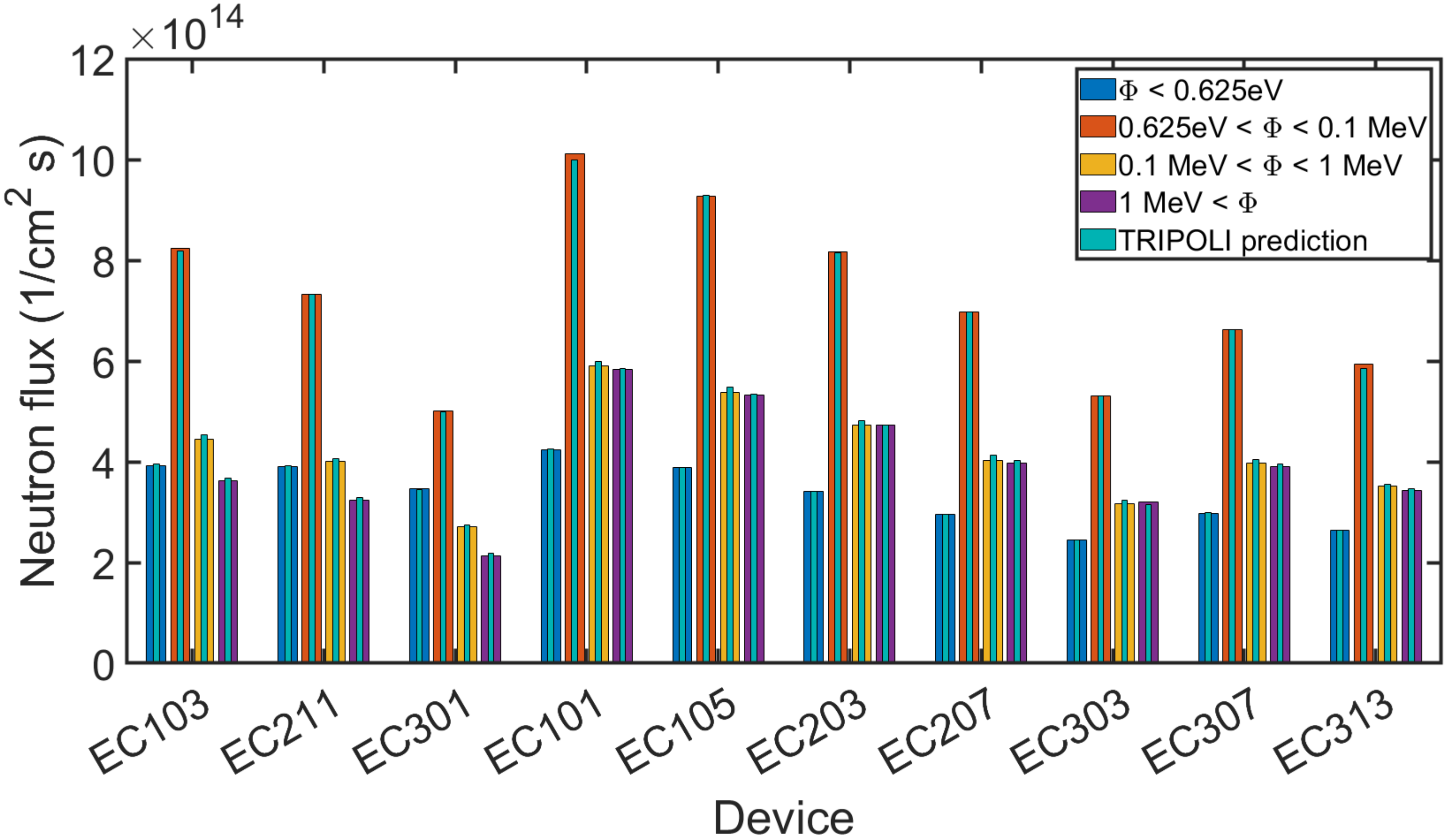
- JHR was modelled with two configurations: fresh core at the beginning of life and reference core at end-of-cycle in equilibrium conditions.

- The criticality calculation solves the neutronic conditions of the reactor by simulating the behaviour of $10^8$ neutrons. Properties such as neutron energy spectra and material heating can then be calculated statistically.

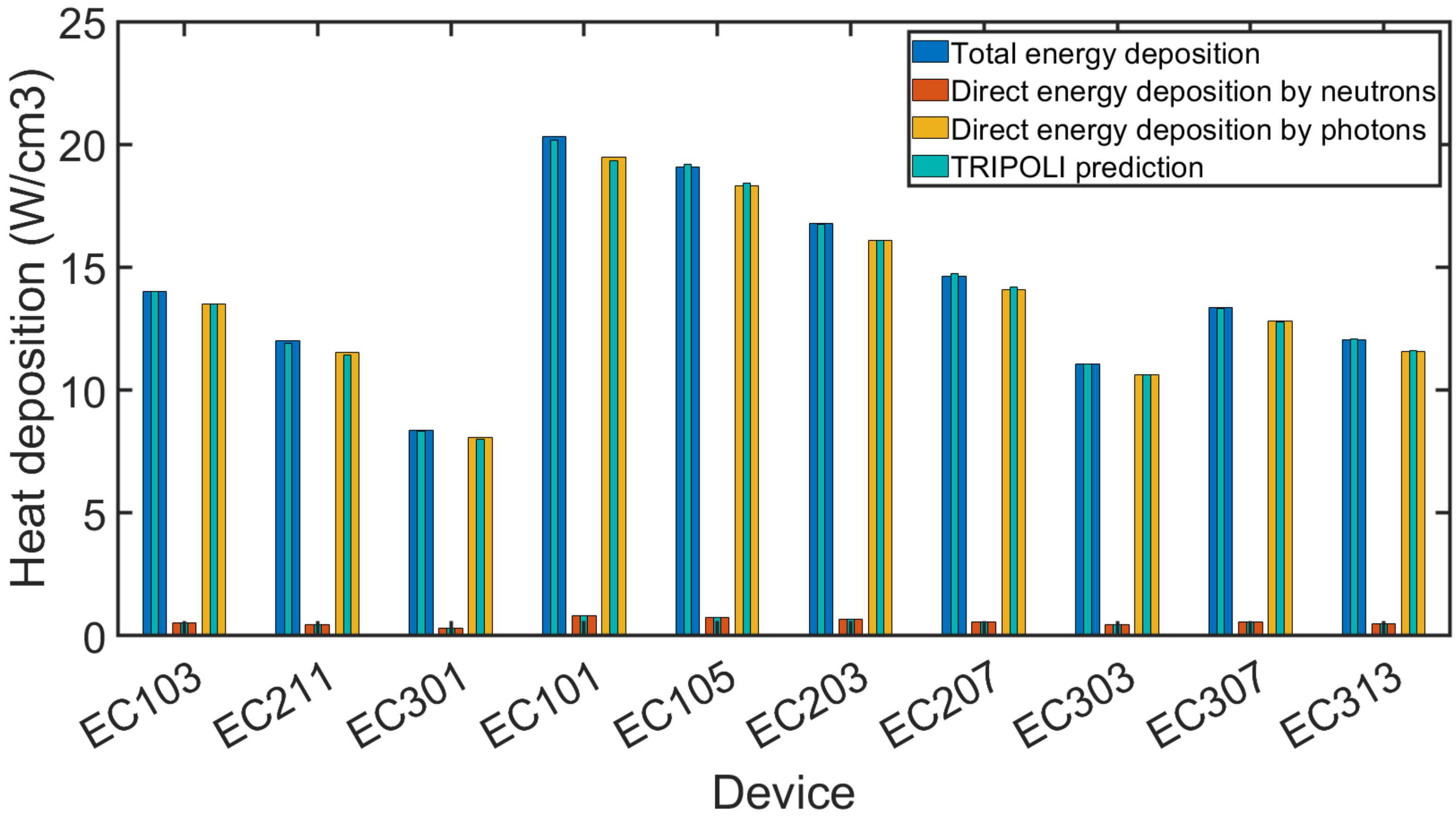
- The results were compared to a respective TRIPOLI-4 calculation.



# Neutron fluxes at in-core experimental positions



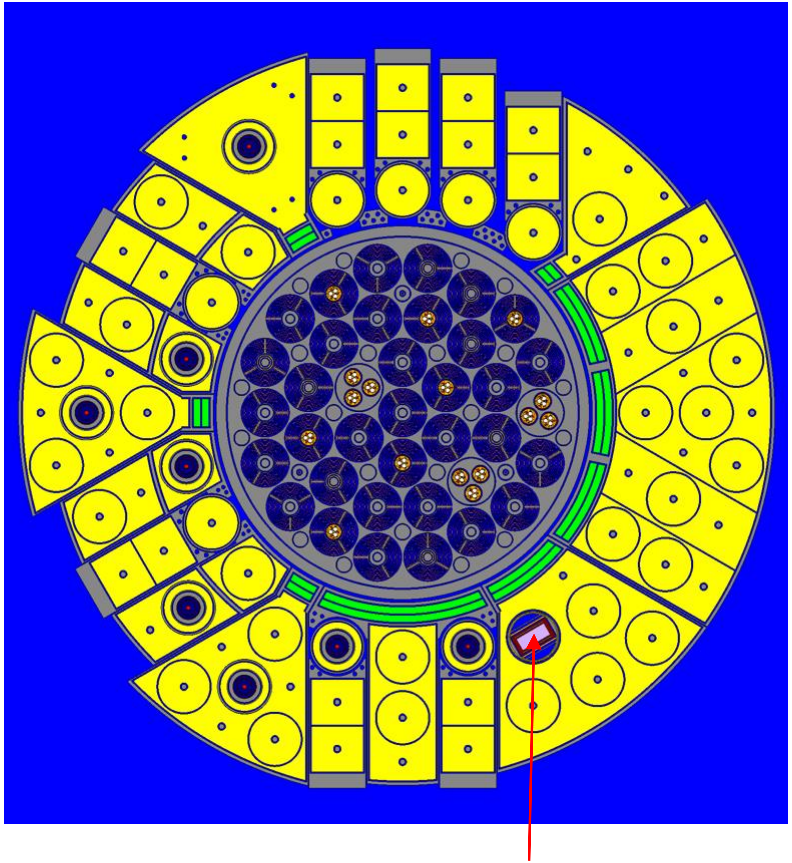
# Heat deposition at in-core experimental positions



# Dosimetric and spectral analyses of OCCITANE test device

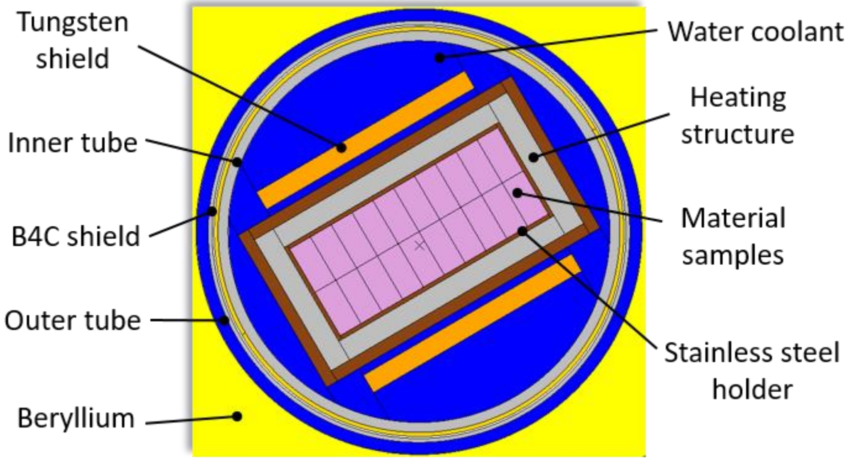
# Modelling test device OCCITANE in JHR middle-of-cycle core

- High-enriched (27% U-235) fuel operated at total power of 70 MW in nominal temperature conditions.
- OCCITANE (Out-of-Core Capsule for Irradiation Testing of Ageing by Neutrons) is based on IRMA device of OSIRIS (CEA Saclay).
- OCCITANE will be implemented in JHR reflector to study the ageing of pressure vessel steel at low DPA (displacements per atom) rate.



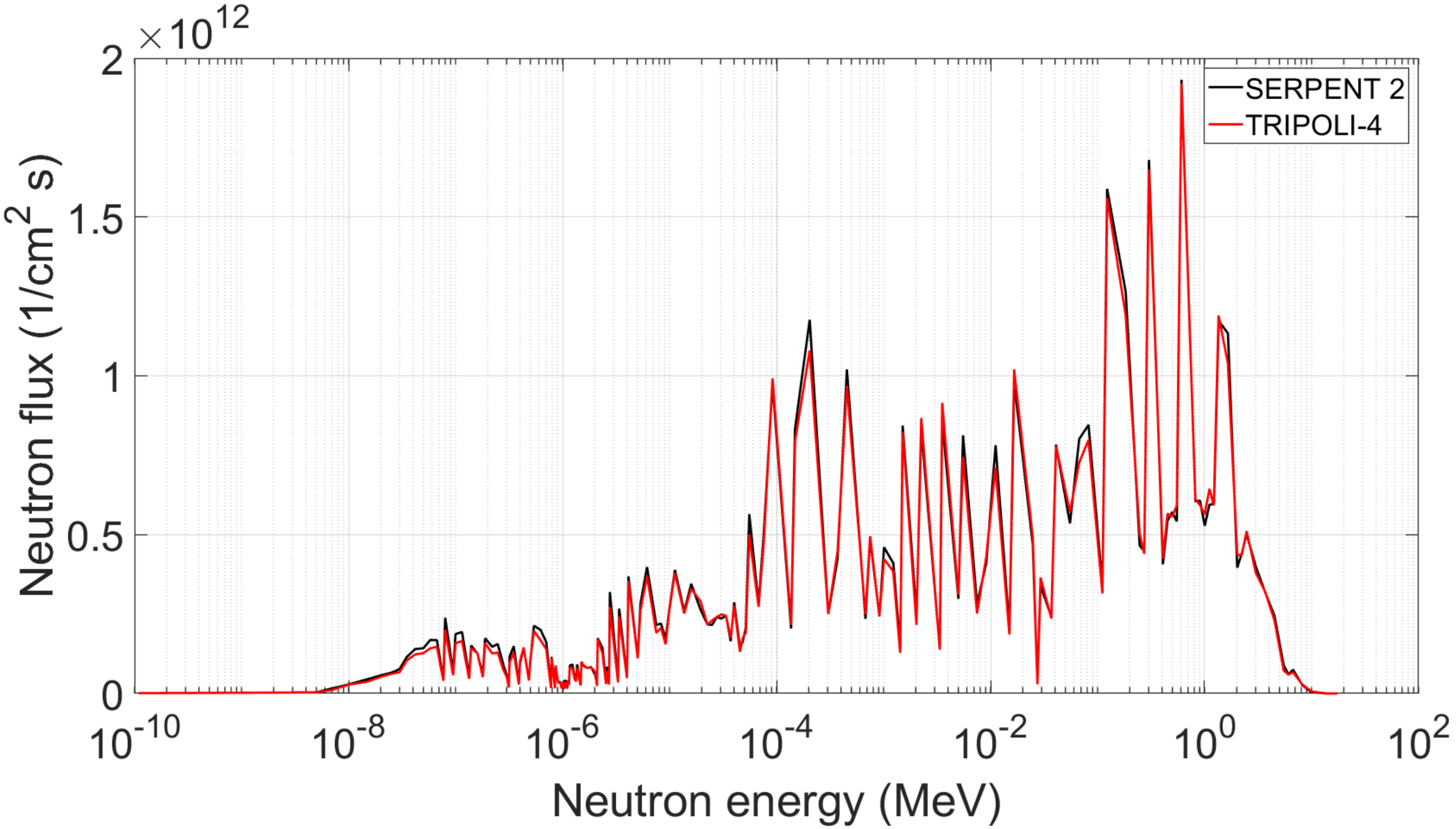
# OCCITANE

- $3 \cdot 10^{12} \leq \varphi > 1$ MeV $\leq 5 \cdot 10^{12}$ $n.cm^{-2}.s^{-1}$ to obtain a total dose 0.1-0.2 dpa in around 150 days of irradiation
- The nuclear heating must be limited to < 0.5 W/g in order to prevent a temperature gradient.
- The device will be rotated 180° halfway into the experiment to prevent irradiation gradient.
- Optimized spectrum ratio Rs = ($\Phi \geq 0.1$ MeV) / ($\Phi \geq 1$ MeV) at around 2.4

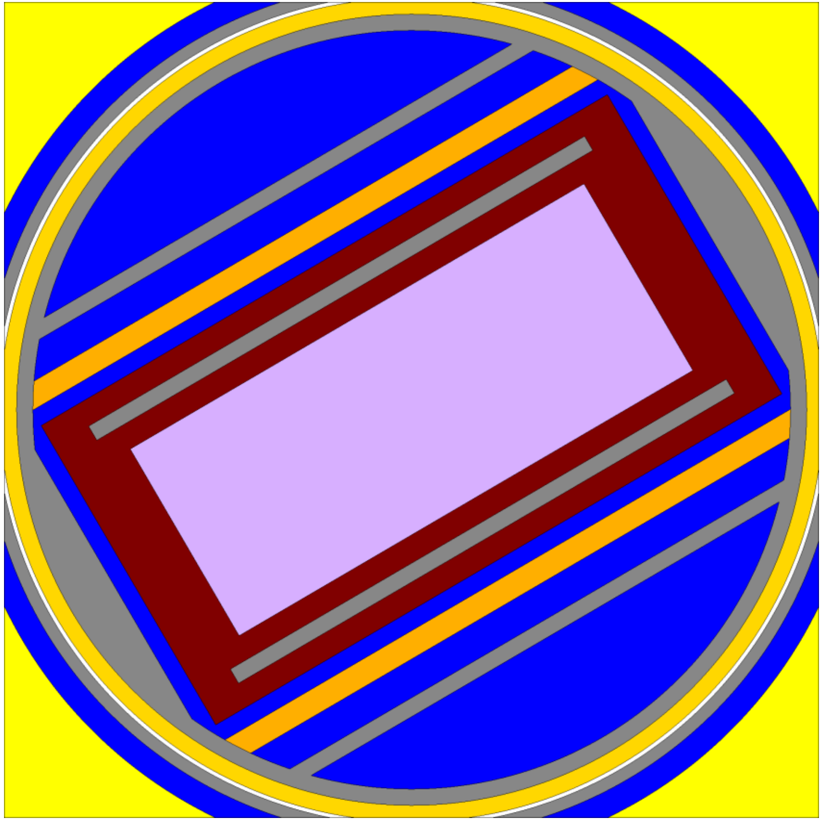


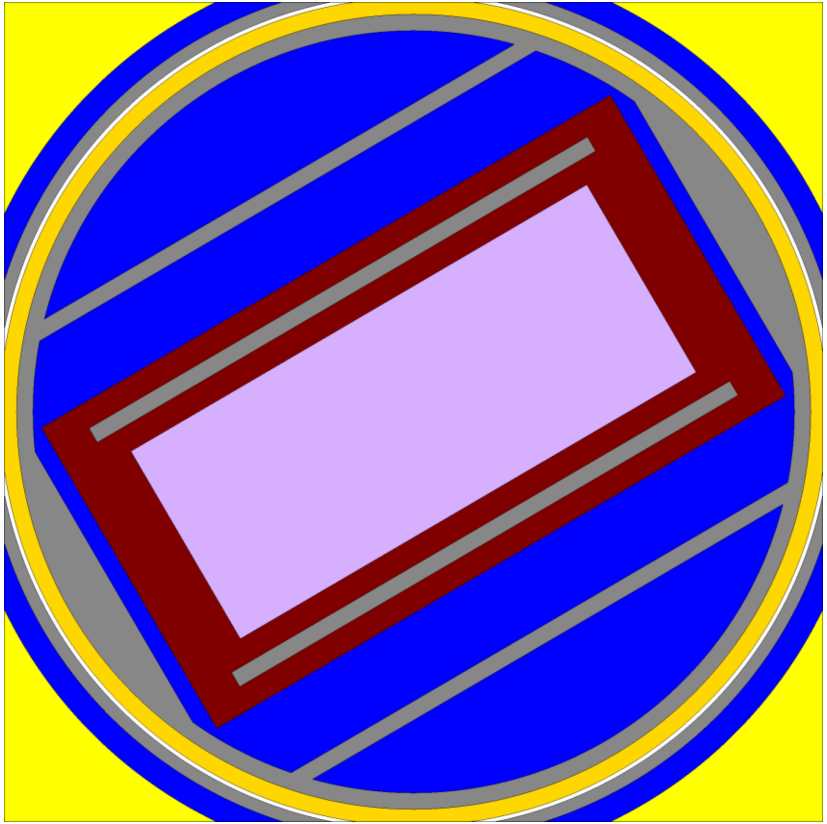

OCCITANE

# OCCITANE flux spectra comparison

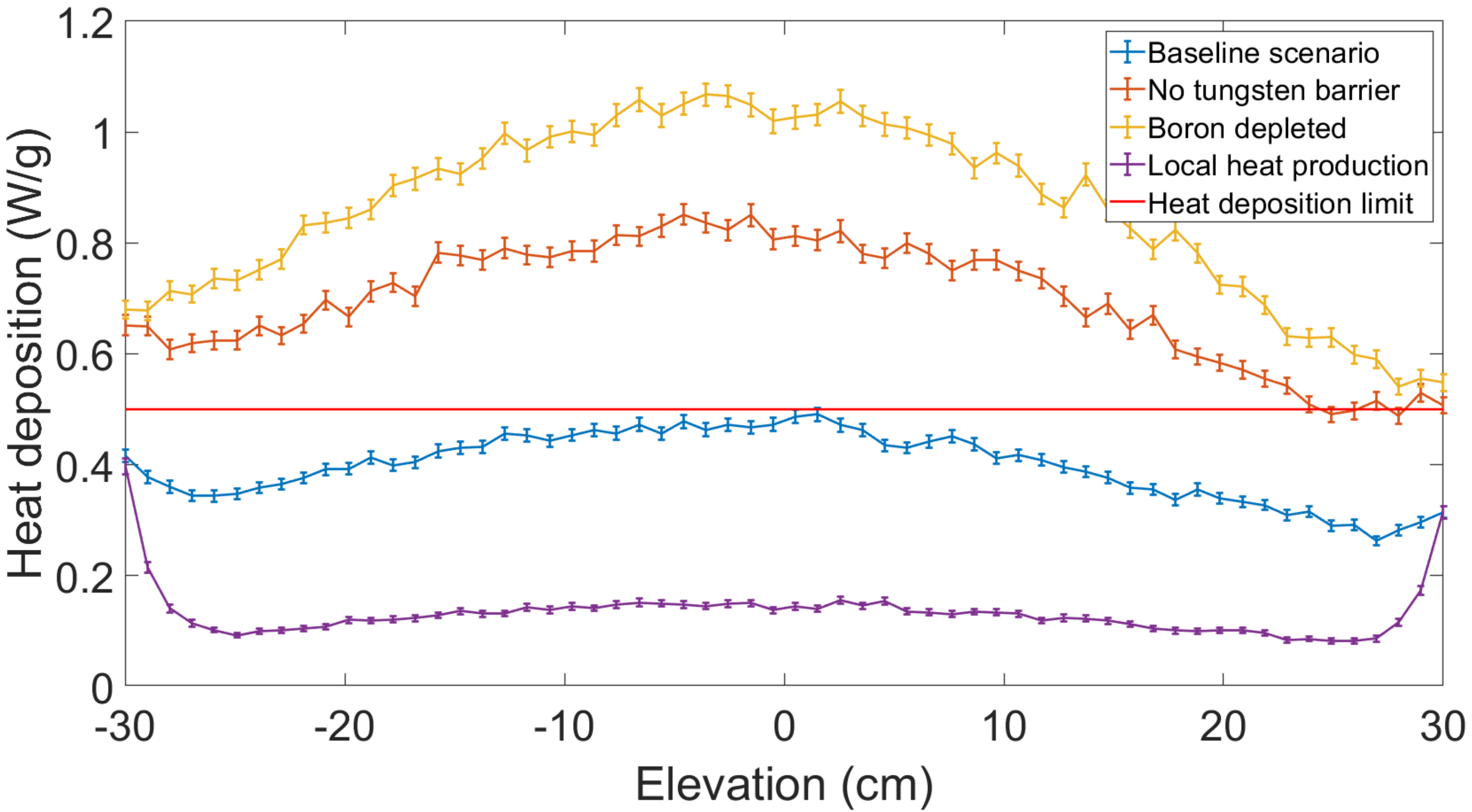


# Impact of tungsten shield and boron depletion?

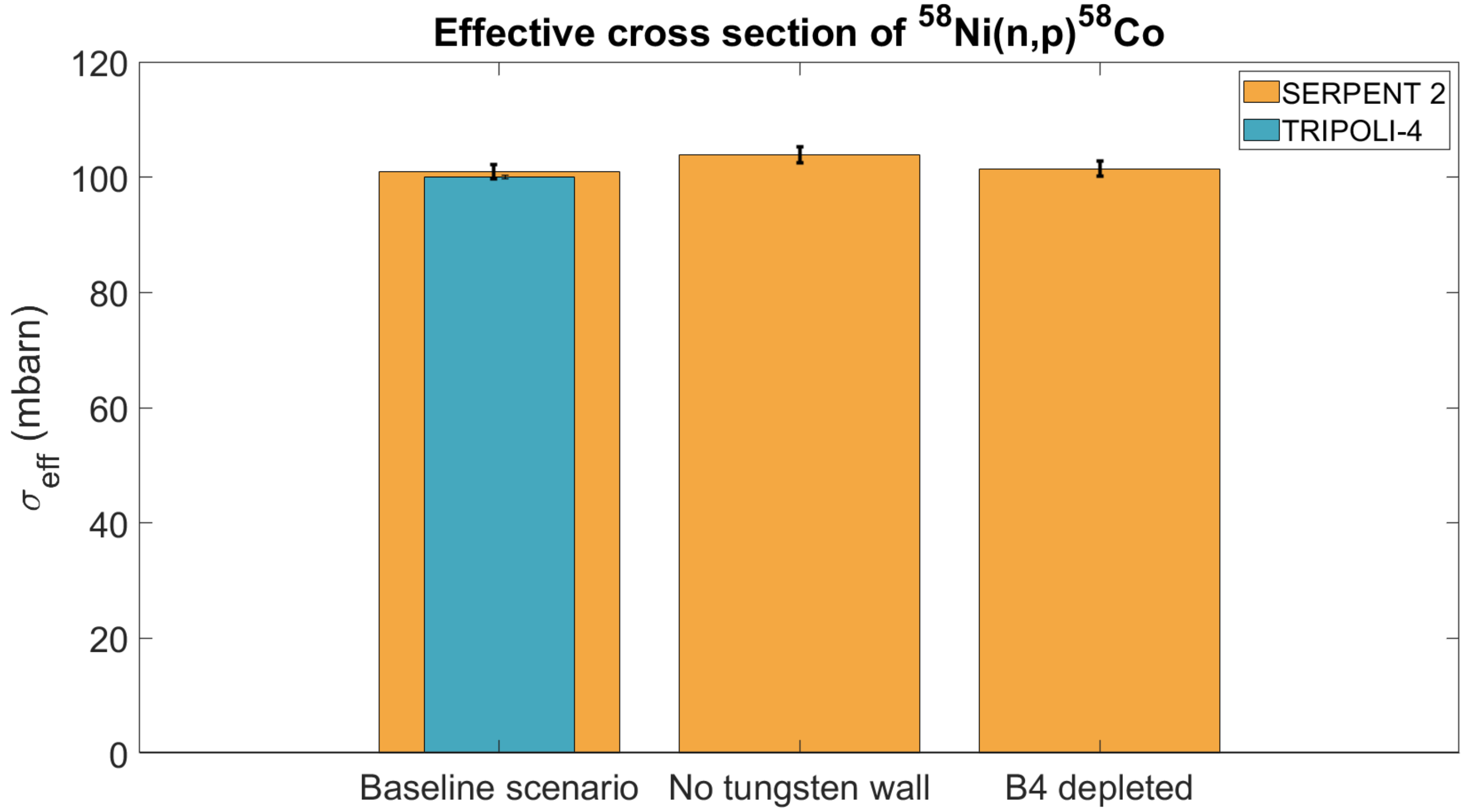




# OCCITANE heat deposition at different setups

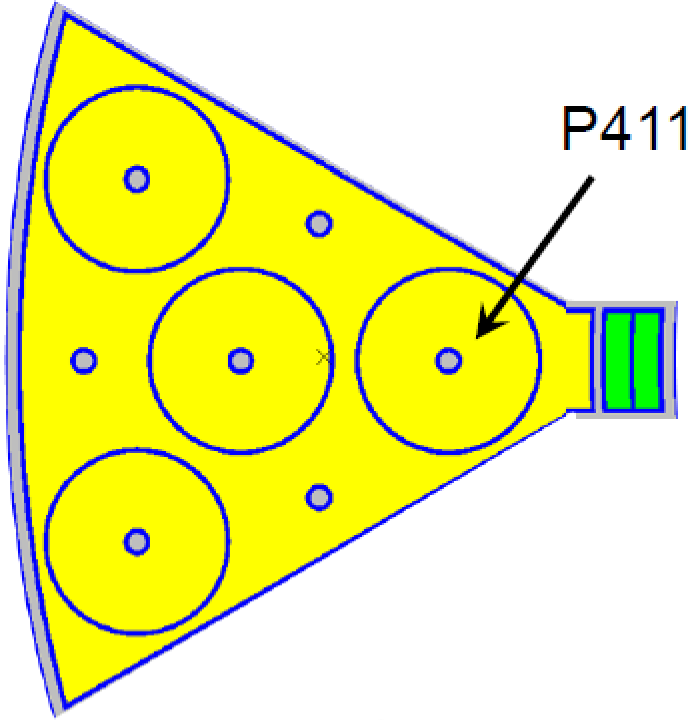


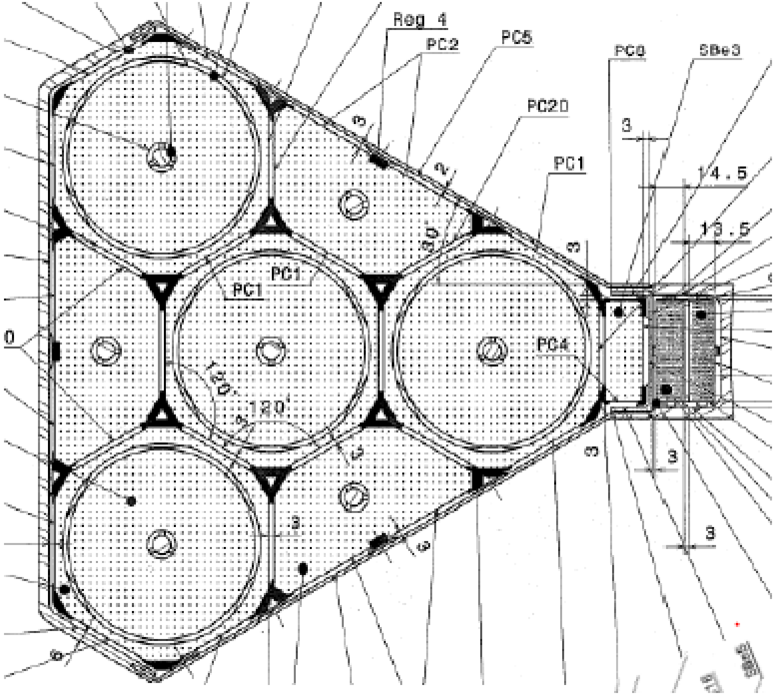
# OCCITANE dosimetric reaction rates at different setups



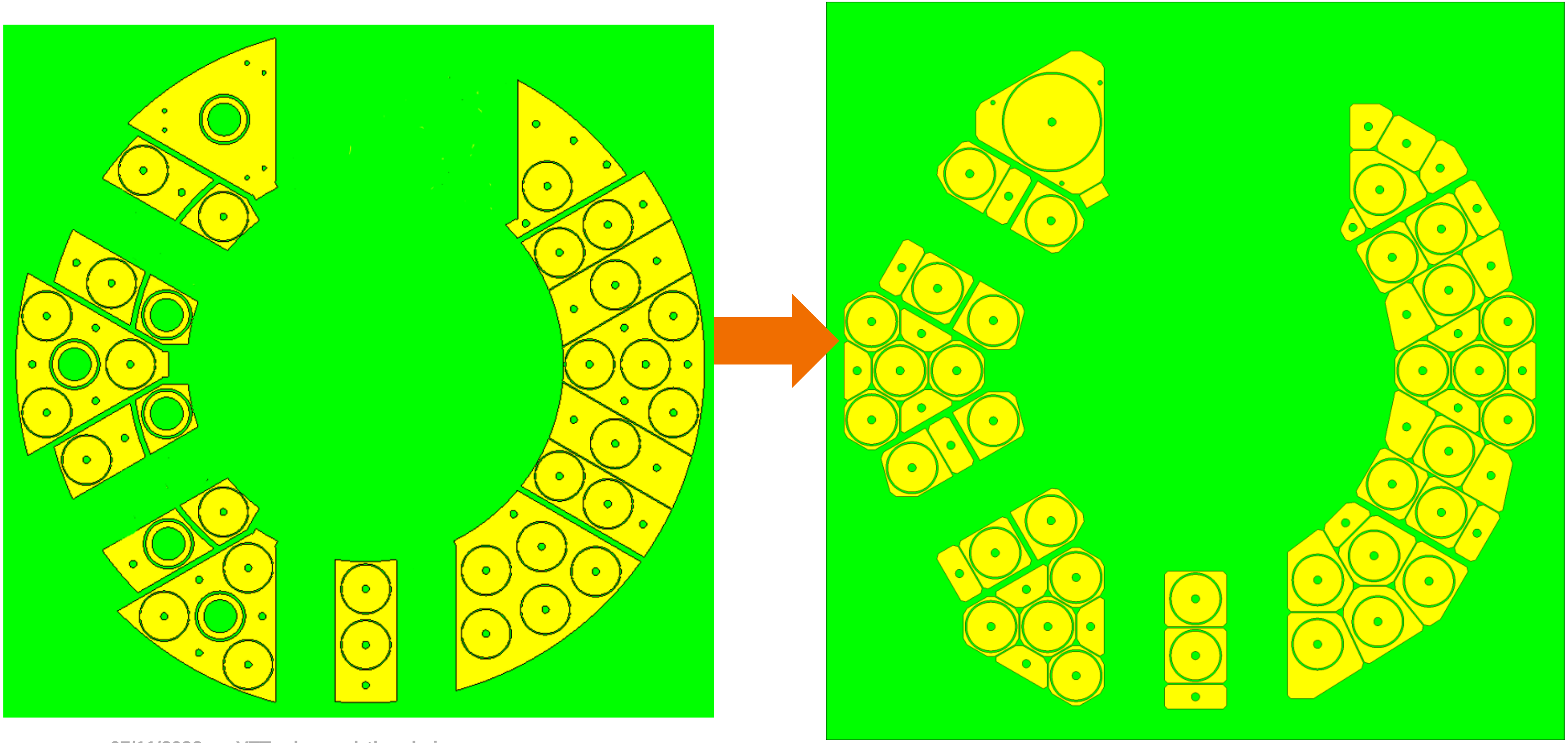
# Improvements in the reflector block modelling

# Improving the reflector models

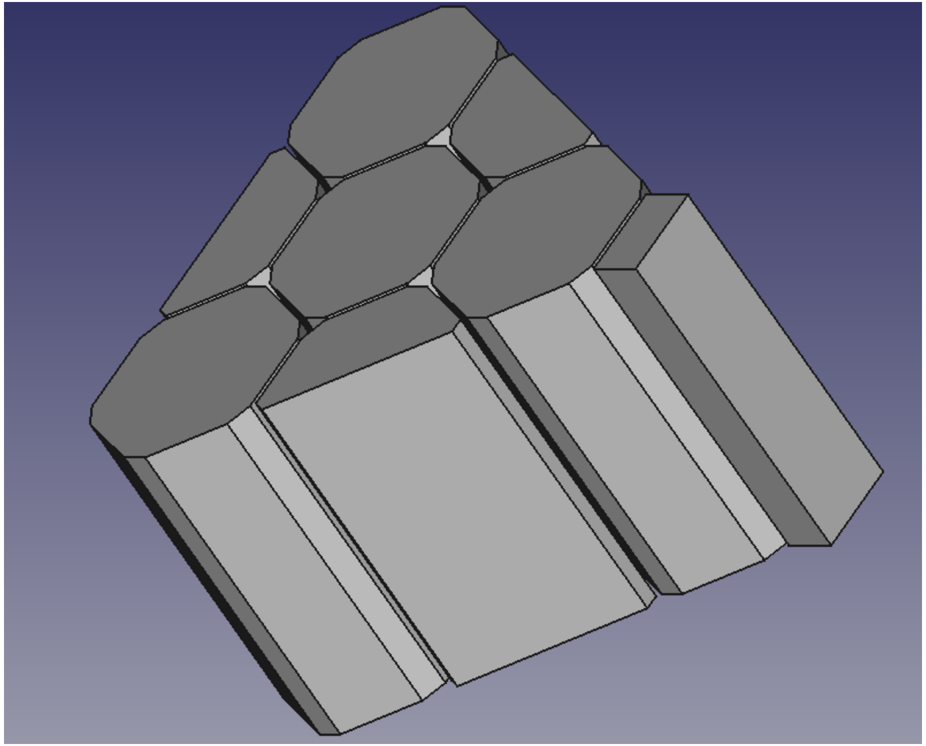


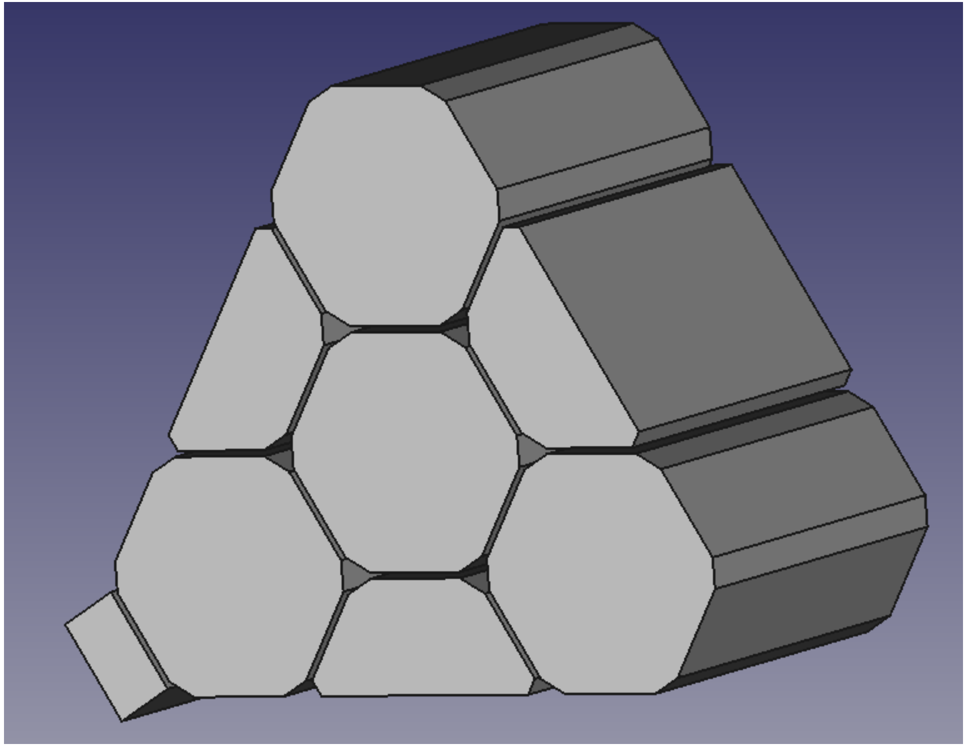



# Improving the reflector models



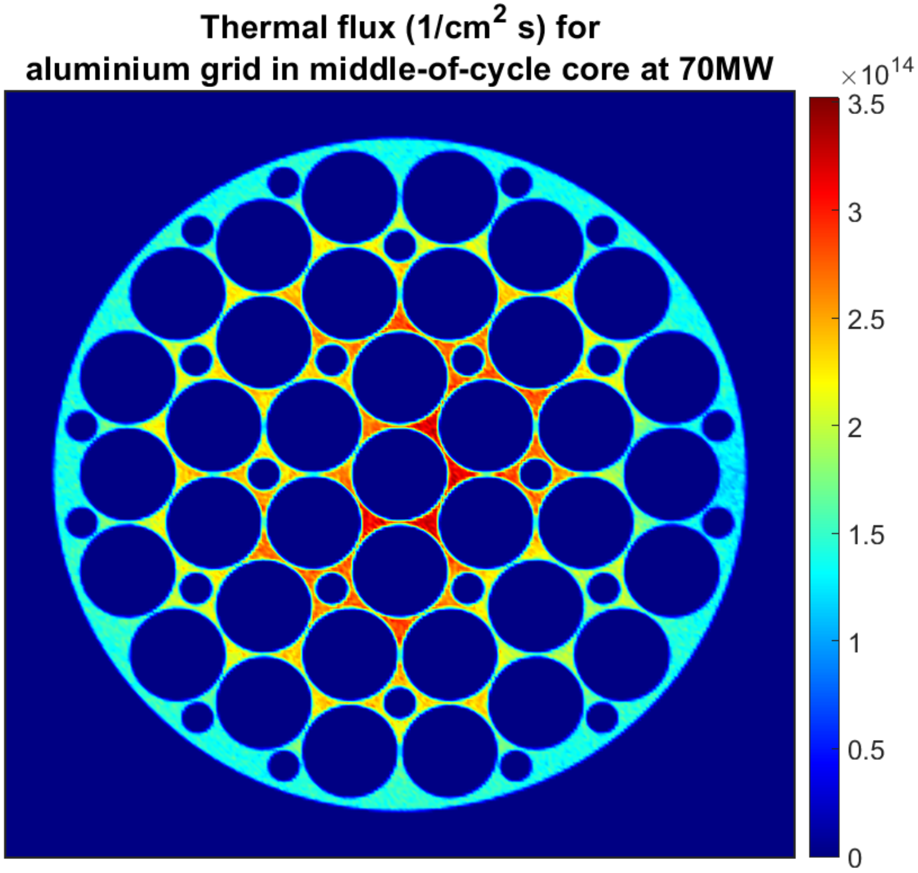
# CAD models of the reflector blocks



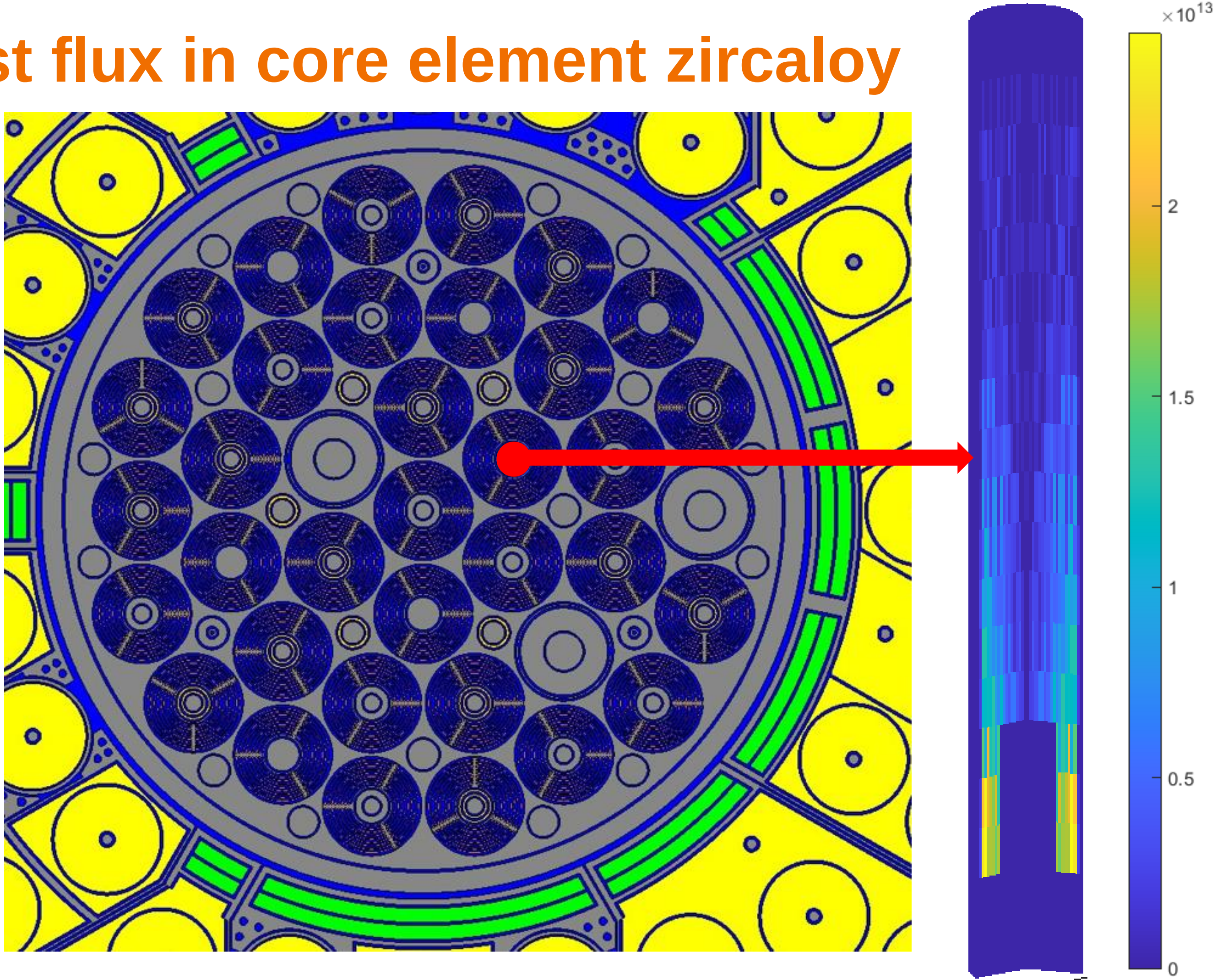


# RCC-MRx material lifetime analyses

- Structural components in French sodium-cooled fast reactors, fusion reactors and research reactors are subject to the RCC-MRx design code.
- According to the code, reactor materials, such as aluminum, zircaloy and stainless steel have defined maximum tolerable fluences over lifetime.
- Computational estimates of the lifetime fluences on components can be calculated based on the standard irradiation cycle fluxes of JHR.



# Fast flux in core element zircaloy



# Methodological study on beryllium poisoning

# Poisoning of beryllium reflector blocks

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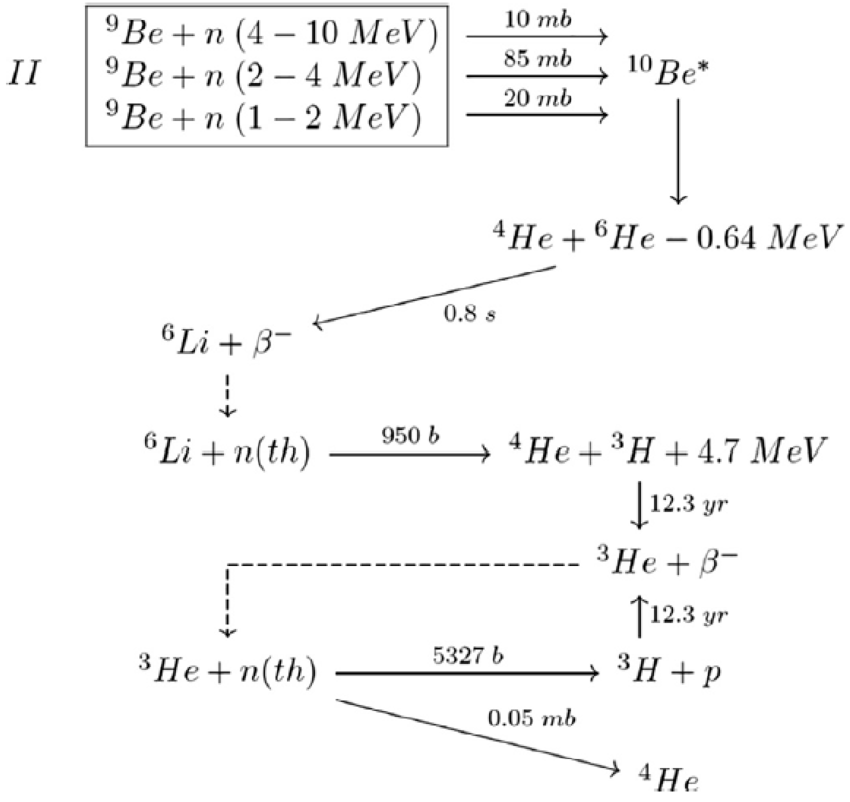
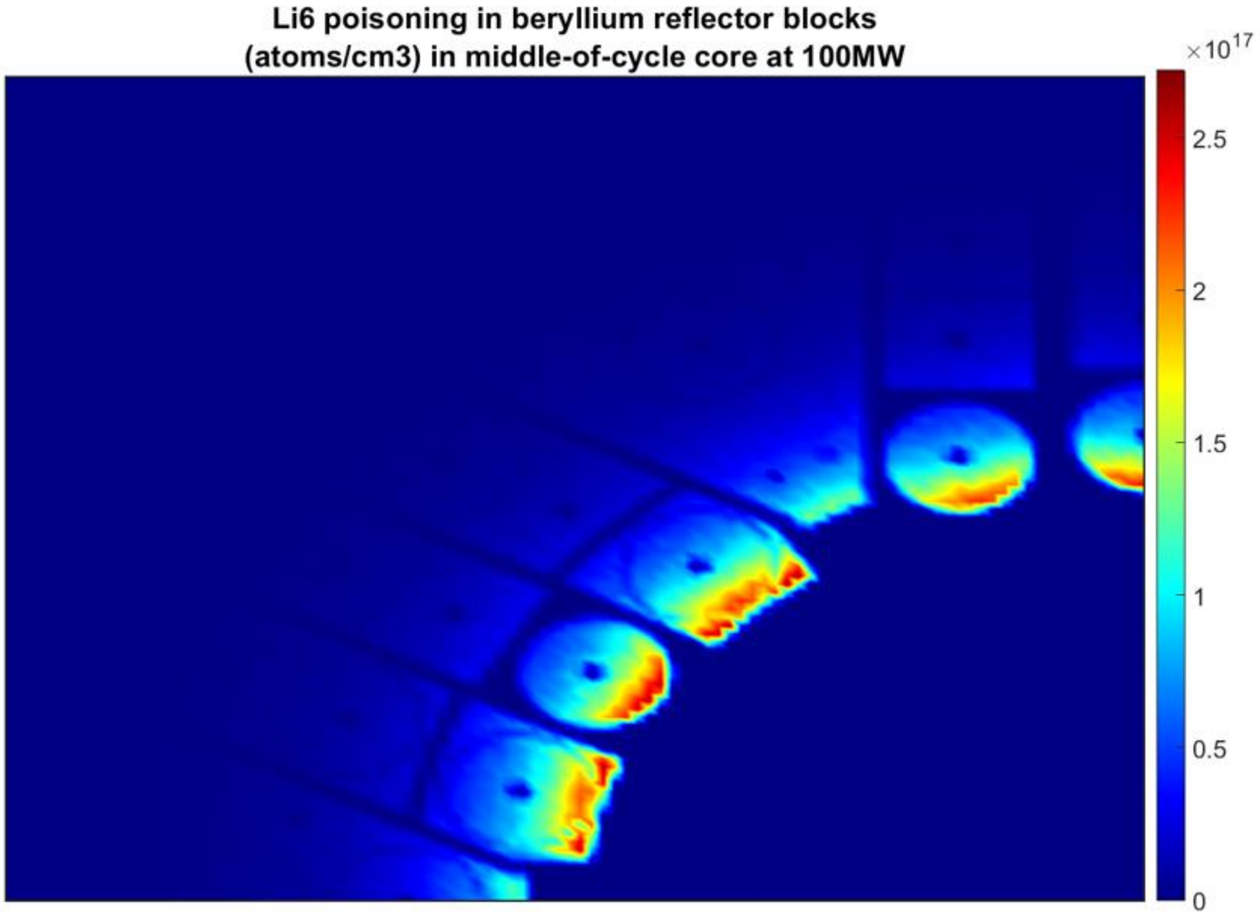
- In co-operation with University of Cambridge, two different methods are being studied for analyzing the impact of the beryllium poisoning (6Li, 3He and 3H) on the criticality and neutronic properties of the reactor.
- The first method (by Wróblewska et al.) obtains the flux distribution in a standard JHR middle-of-cycle scenario in the reflector area with Serpent 2 and calculates the analytic solution to the poison accumulation based on the known time-dependent differential equations.
- The second solution calculates the poison accumulation directly with a Serpent 2 burnup calculation.




Małgorzata Wróblewska, David Blanchet,.., 'A review and analysis of the state of the art on beryllium poisoning in research reactors, Annals of Nuclear Energy, Volume 163, 2021,108540

# Poison distribution based on the analytic solution



# Thank you!

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