This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

THE IFMIF-DONES TEST BLANKET UNITS

LIBRTI Conference on Breeder Blanket Technology
Culham, Feb 3-5 , 2026

Authors:
D. Rapisarda, F. Arranz, B. Brañas, F. Mota, M.I. Ortiz, P. Arena, F. Castrovinci, A. Serikov, G. Zhou.
Presenter:
F. Arranz. CIEMAT (Spain)

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OUTLINE

- Motivation
- IFMIF-DONES and tritium technologies validation
- DONES Test Blanket Units
- The WCLL-TBU: preliminary results
- The HCPB-TBU: preliminary results
- Summary & Conclusions

MOTIVATION

❑ The Breeding Blanket

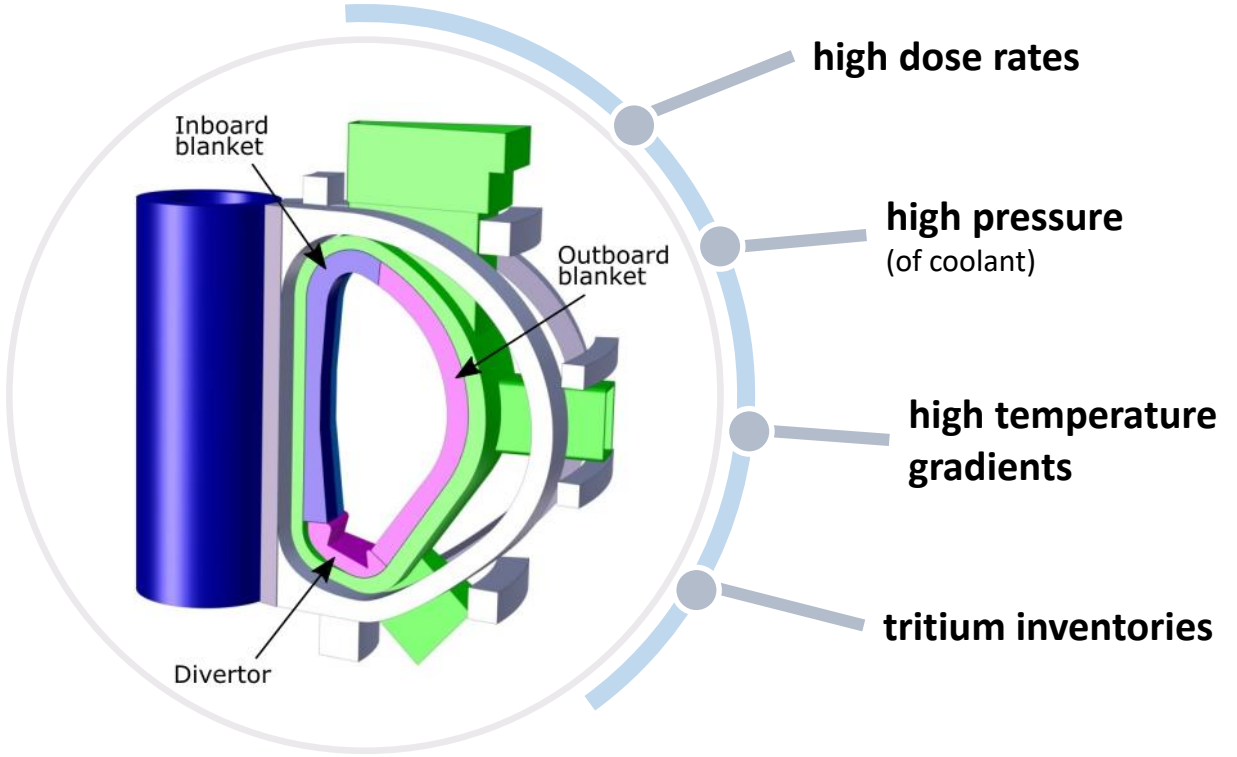
Functions

- Multiplication and extraction of power
- Warrant tritium self-sufficiency
- Radiation shielding for magnetic coils and other elements

Different BB concepts

- Breeding material
- Neutron multipliers
- Power extraction methods (coolants)

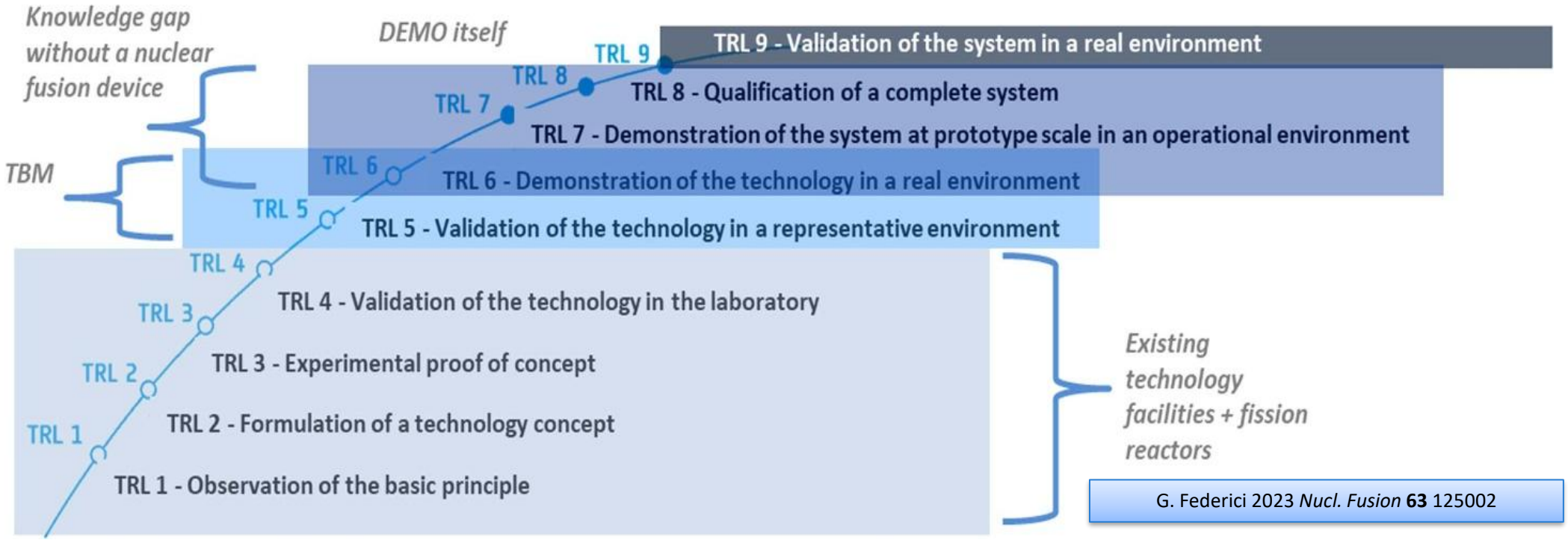
Challenging environment in fusion power plant



MOTIVATION

- Despite the importance of the BB, feasibility concerns and uncertainties exist in all explored concepts.
- Significant research and development are needed to address these issues.

Technology Readiness Level



G. Federici 2023 *Nucl. Fusion* **63** 125002

"independent of the TBM results from ITER, there is still a substantial gap to demonstrate the performance and qualify a breeding blanket for DEMO to increase the TRL from 6 to 8"

MOTIVATION

- Evaluate other alternative neutron sources → Working Group on BB and Fuel Cycle Development (2022)

Some findings of the group:

- Prior to integrated testing and qualification of a breeding blanket, either in a VNS or in DEMO, **single and combined effect characterization** will be necessary, along the timeline of the availability of neutron sources
- The overall need for neutron irradiations, in order to accelerate the development and the informed selection of design choices, is quite huge, and **a wide range of facilities has to be considered** to fulfil the capacity needs
- Focussed pre-qualification campaigns, prior to the availability of either a VNS or DEMO, have to be performed with **high-grade spectrum sources** like IFMIF-DONES (~ 10 years to availability)

MEMBERS:

- Klaus Hesch (KIT) – chair
- Alessandro Spagnuolo (PMU) – secr.
- Alessandro Del Nevo (ENEA)
- Philippe Magaud (CEA)
- Amanda Quadling (UKAEA)
- David Rapisarda (CIEMAT)
- Dmitry Terentyev (SCK-CEN)
- Ladislav Vala (CV Řež)
- Sandor Zoletnik (CER)

DONES Schedule seems compatible with ITER and VNS

- feasible, quick, cheap (meaning it is ready on time), maybe TRL 5-6?

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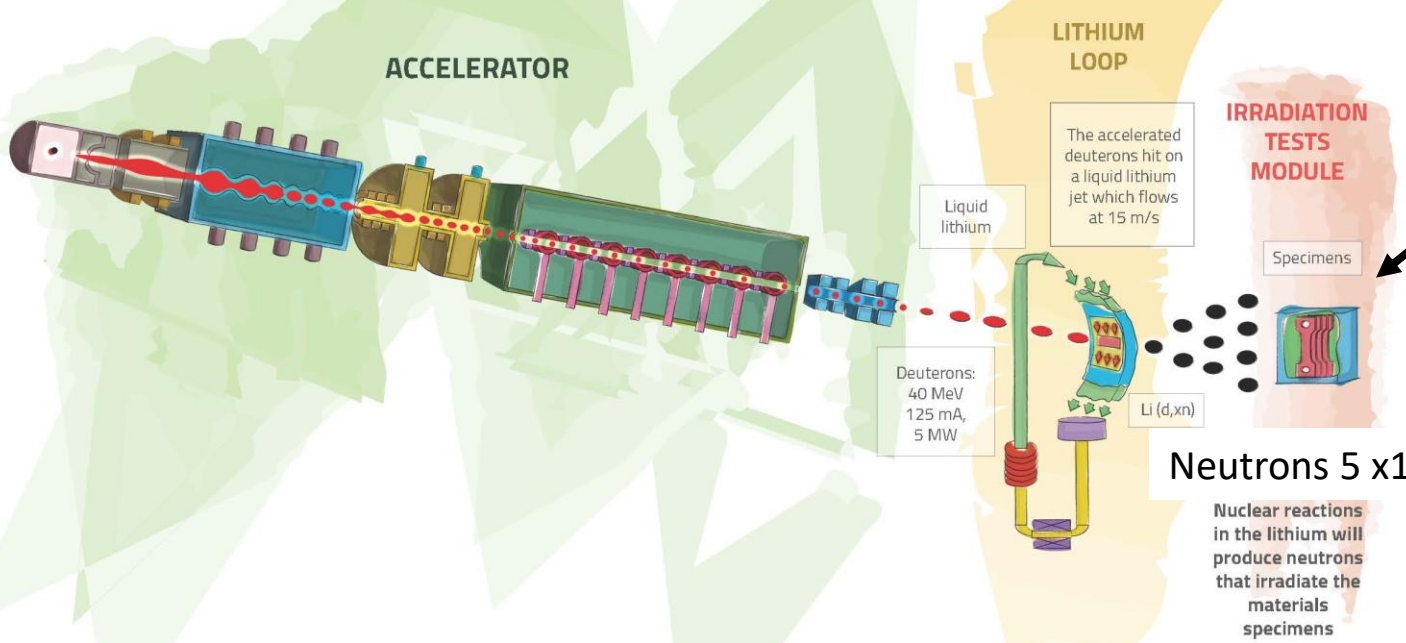
IFMIF-DONES facility

- Main objective → to simulate as closely as possible the irradiation conditions of the structural materials of nuclear fusion reactors.



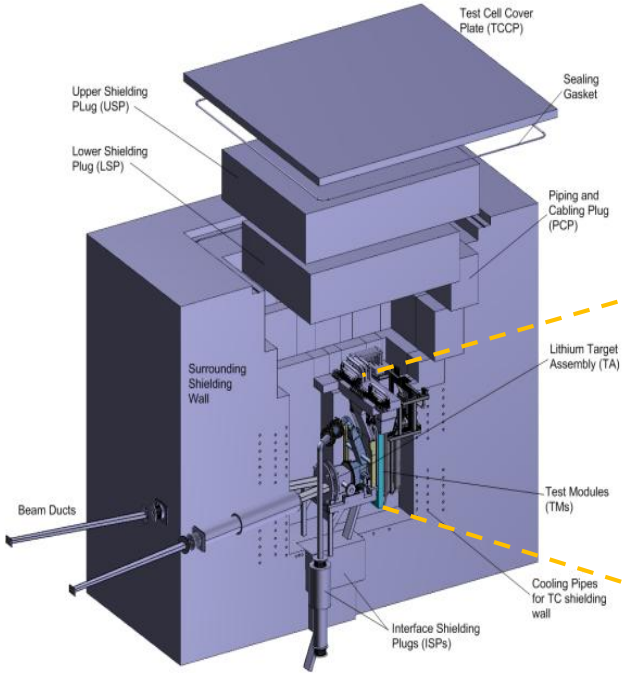
HFTM High Flux Test Module

Neutrons 5 x10^{18} $m^{-2}s^{-1}$ peak at 14,1 MeV stripping reaction

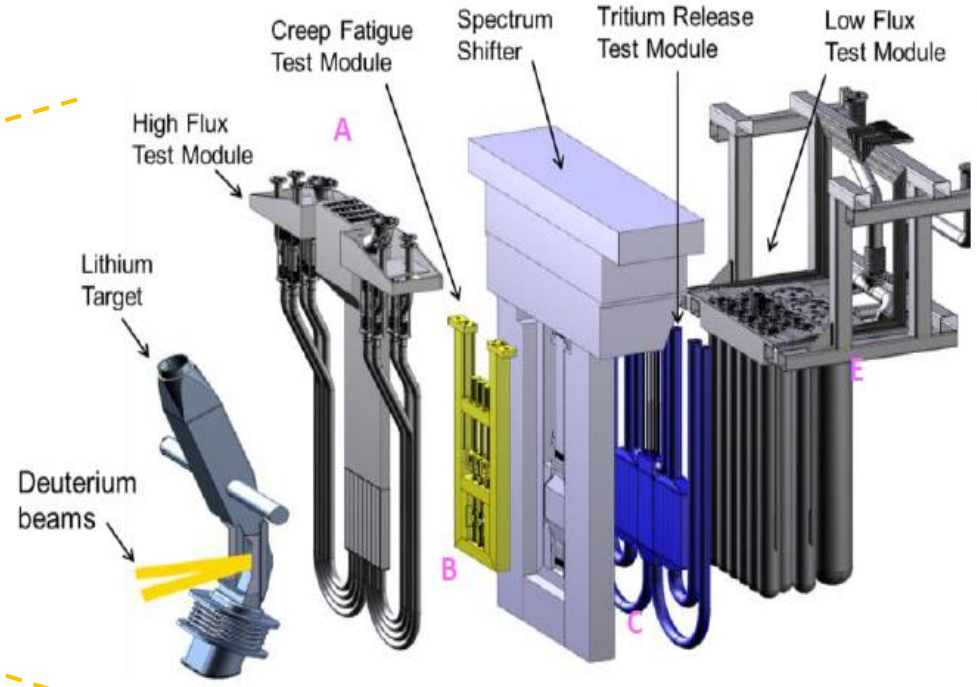
A. Ibarra 2018 *Nucl. Fusion* **63** 105002

IFMIF-DONES: Tritium technologies validation

Previously defined irradiation modules for DONES:
- focused on particular issues
- requiring small volume of actual samples

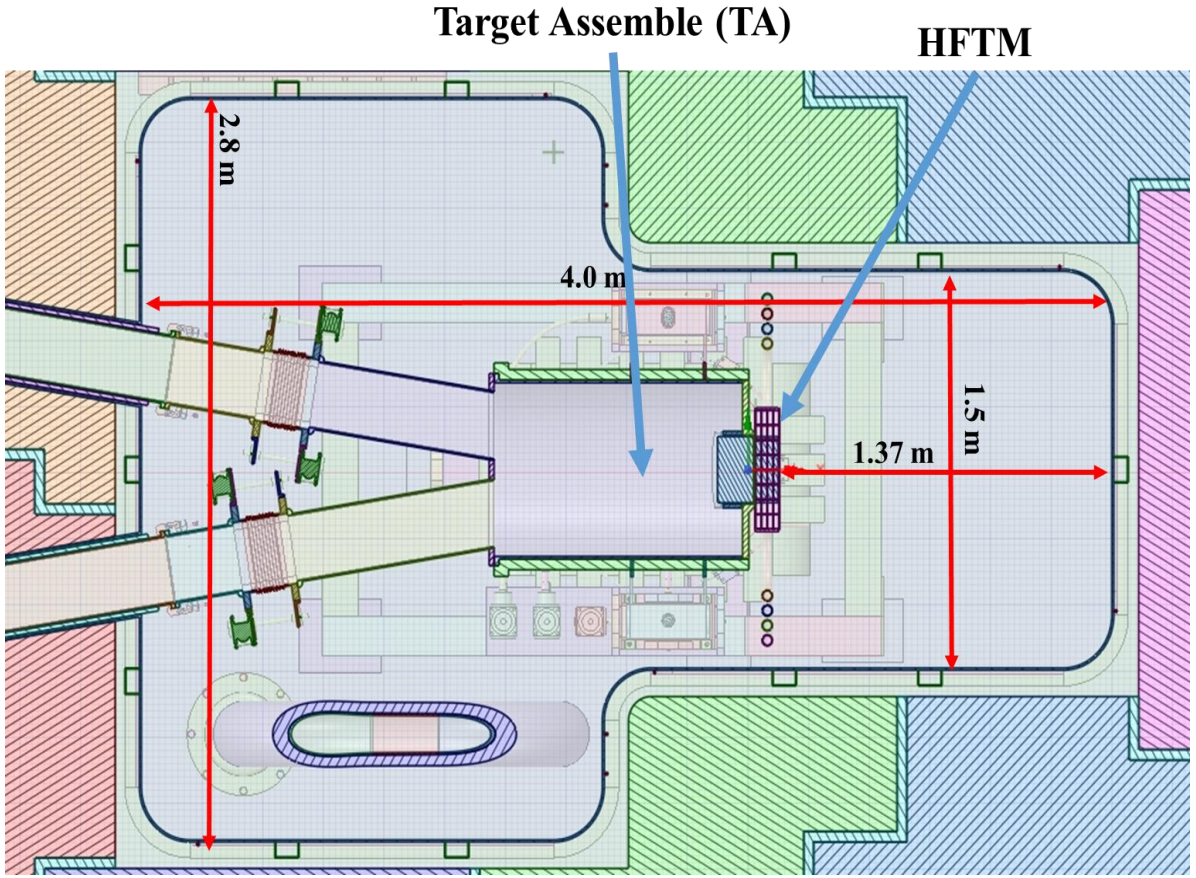


Test Cell



IFMIF-DONES test area

- Available irradiation **volume** in DONES is **large** and represents an important benefit → margin to propose new experiments.



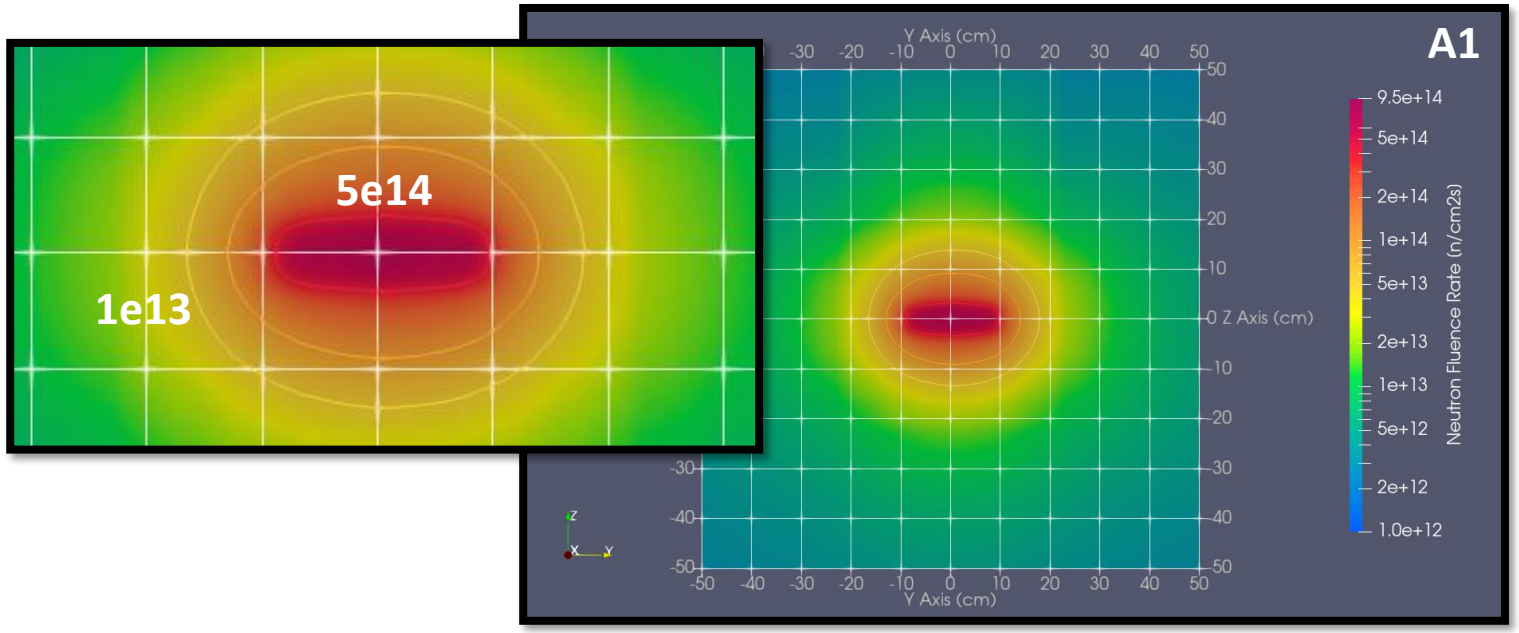
x-axis: 1.37 m in the direction of the beam (excluding the HFTM)
y-axis: 4 m in the vertical direction
z-axis: 1.5 m in the horizontal direction

Effective irradiation volume

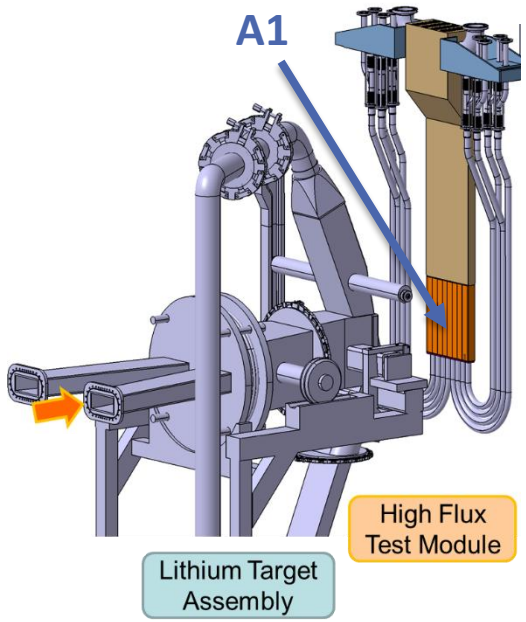
- The volume where the experiments will be relevant (in some way) for the BB qualification
- As in any other neutron source, depending on the used materials and components, the irradiation field could be modified
- **Specific calculations are needed**

IFMIF-DONES test area

- Most of people think on this kind of neutron distribution, but this is the footprint just **immediately behind the Target Assembly** (or the front of the HFTM).

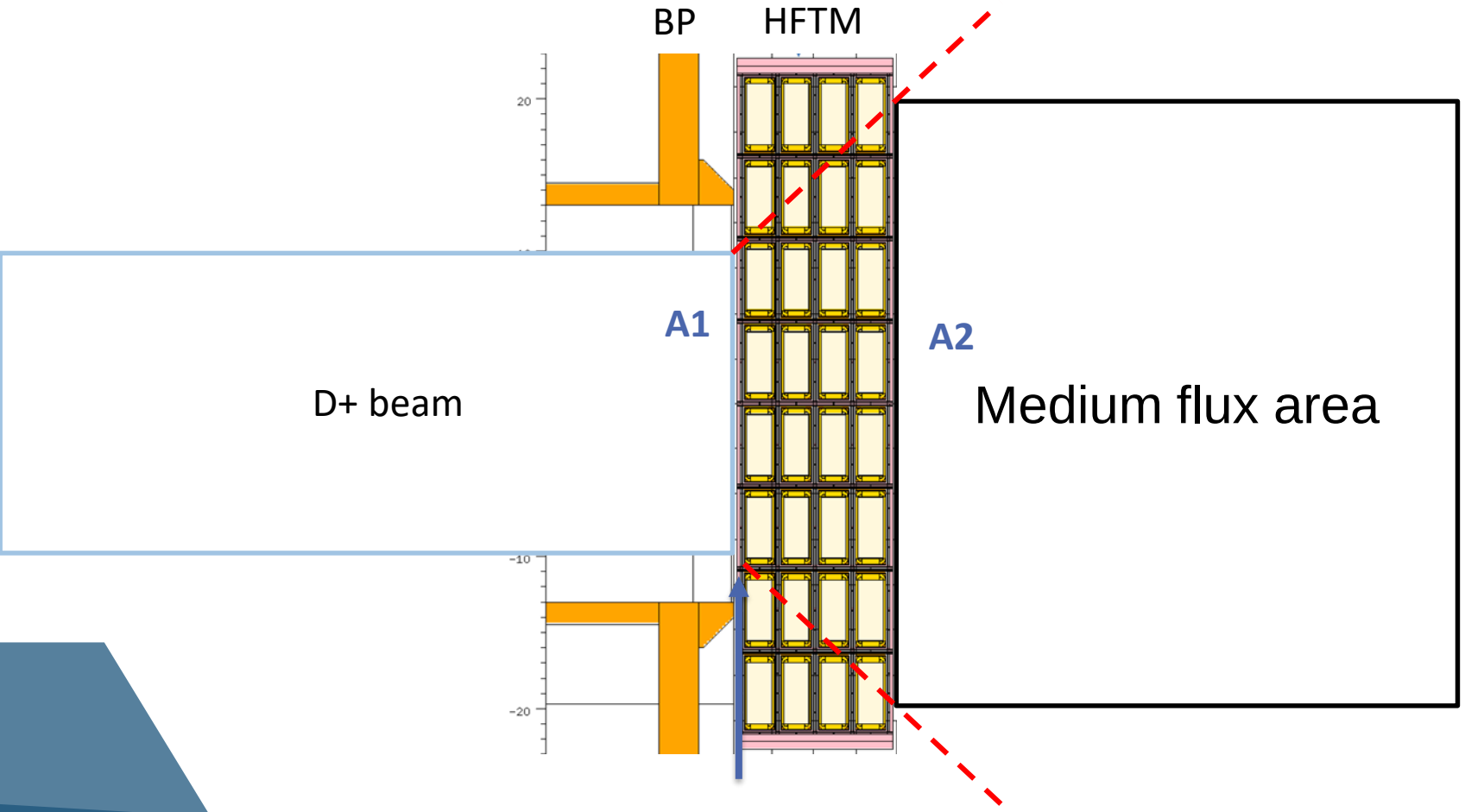


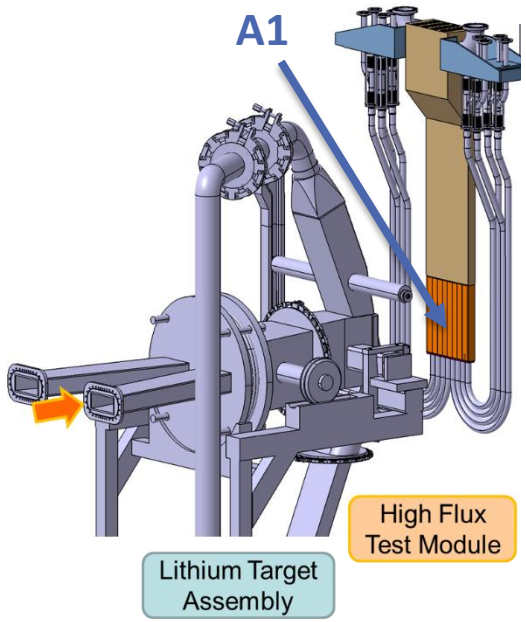
'footprint of beam on lithium curtain'
20 x 5 cm²



IFMIF-DONES test area

- However, the neutron field presents dispersion through the HFTM (distance ~10 cm) that results in a more homogeneous rad field at the beginning of the Medium Flux area





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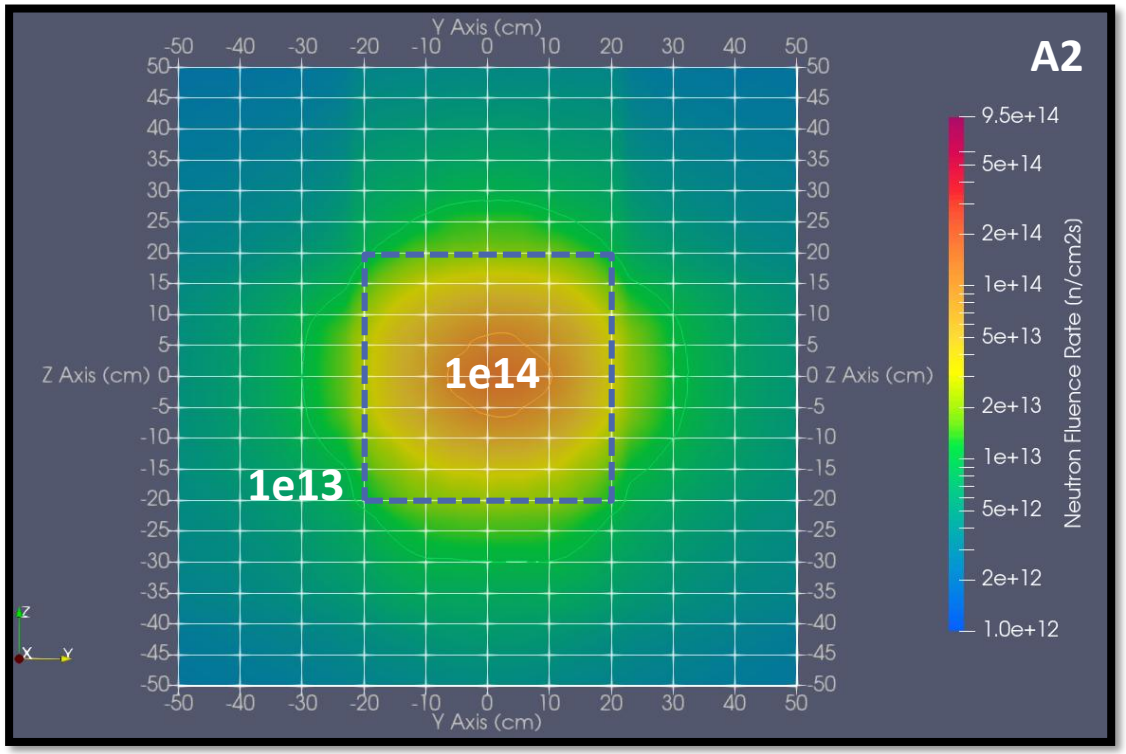
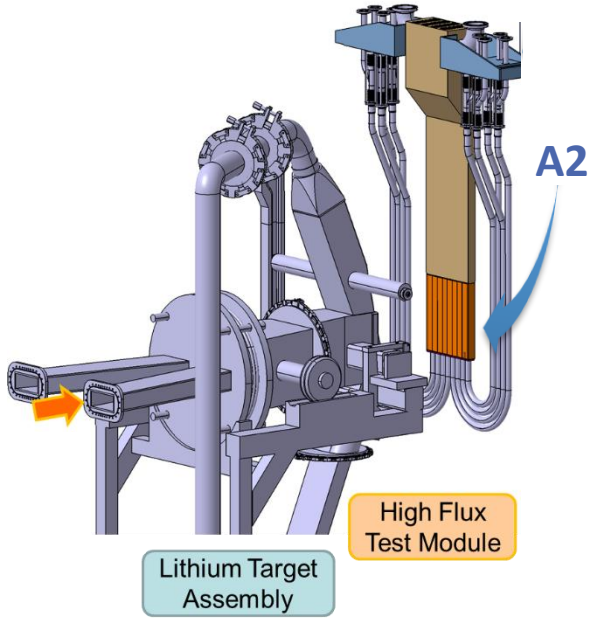


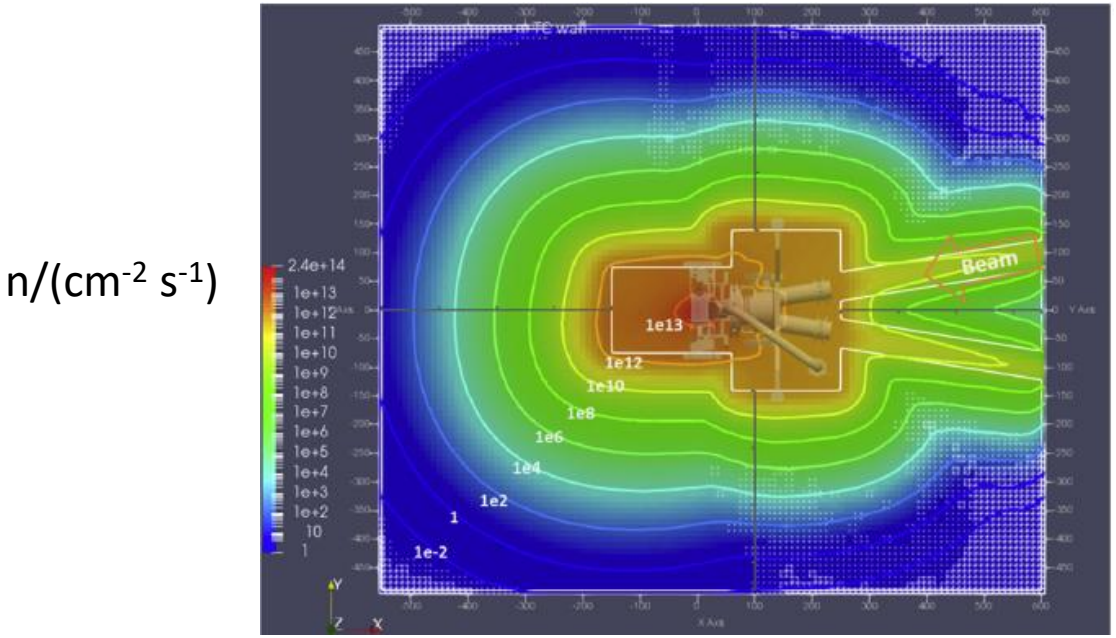
'footprint in the Medium Flux area'
40 x 40 cm²



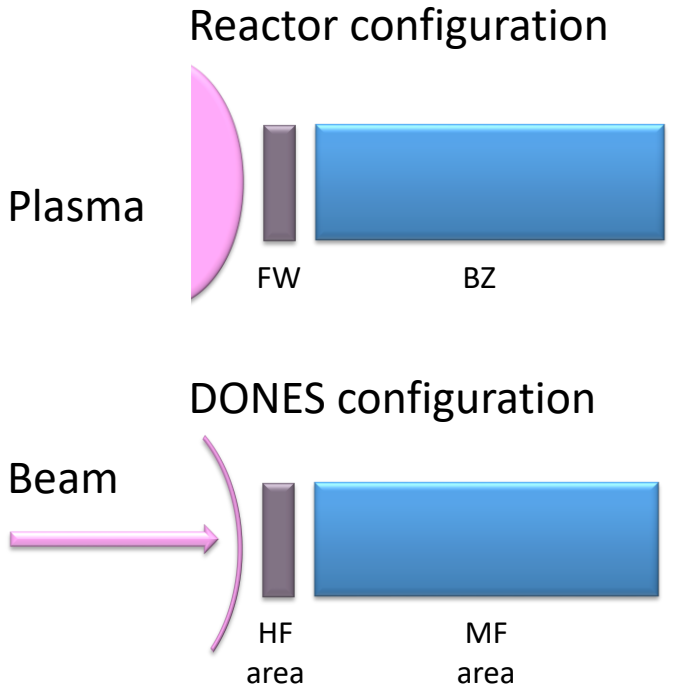
Behind the HFTM → 'effective area' from 100 cm² to **1600 cm²**

IFMIF-DONES test area

- Neutron flux distribution in and around the TC (left: horizontal cut)



U. Fischer et al., 2019 *Fus. Eng. Des.* **146** 1276-1281



- Neutron axial gradient similar to the one in DEMO → TBC (results coming in the next slides)

The DONES medium flux area constitutes a perfect test bench

OUTLINE

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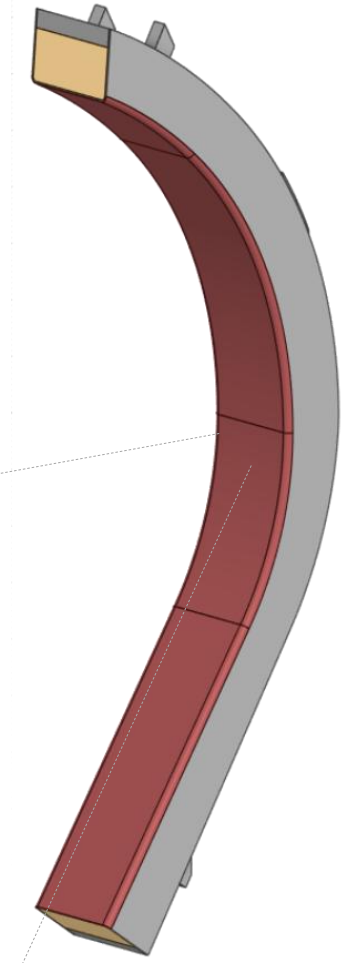
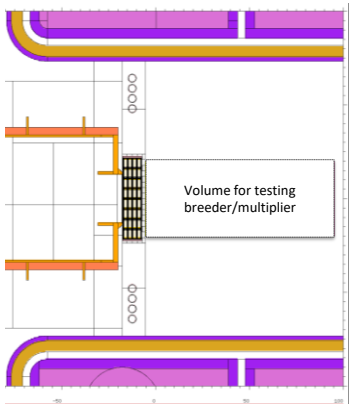
The DONES-TBU

- Tritium technologies validation in IFMIF-DONES
  - Maintain dedicated experiments to test the basic physics → Other Irradiation Modules
  - Scaling up the system to test relevant-sized blanket mock-ups

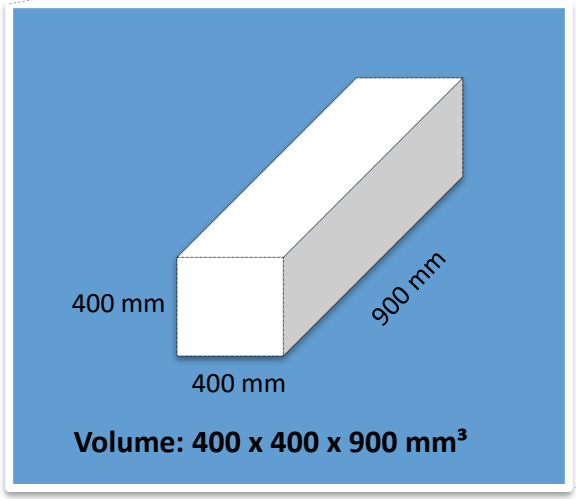
- **Test Blanket Unit** (TBU) → analogy with the ITER-TBM
  - A BB fraction, considered representative (in some way) of a whole segment
  - Medium flux area → effective irradiation volume that can accommodate the TBU



- Activity that involves experts in neutronics, thermal-hydraulics, thermo-mechanics, materials… → BB
- Interesting measures before introducing EM loads complexity

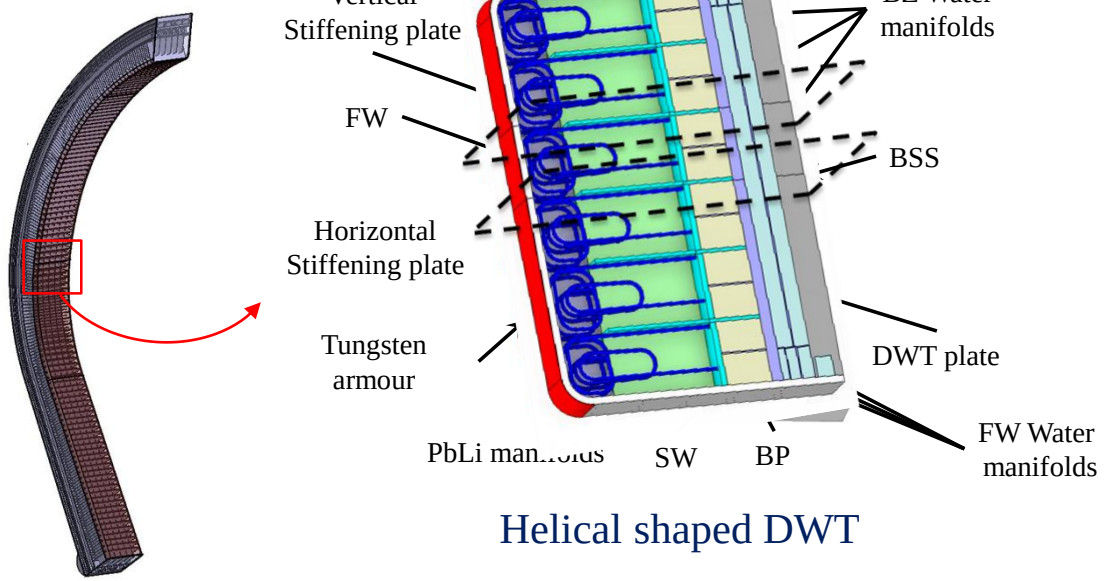


Volume for testing in Test Cell of IFMIF-DONES



EU Breeding Blanket Concepts

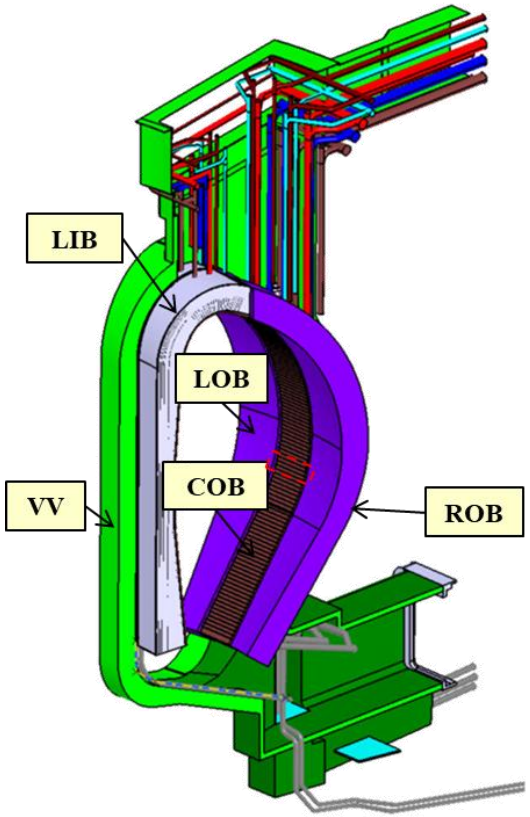
- The **WCLL** (Water Cooled Lead Lithium) breeding blanket



Helical shaped DWT

Main characteristics

- Eurofer as structural material, tungsten coating in plasma facing surfaces
- Water in PWR conditions as coolant: 15.5 MPa, 295-328°C
- Dedicated water coolant circuits for FW (channels) and BZ (Double Walled Tubes)
- Eutectic PbLi alloy as neutron multiplier (Pb), tritium breeder (^{6}Li at 90% enrichment) and tritium carrier
- The structure with elementary cell (slice) is replicated along the polar direction



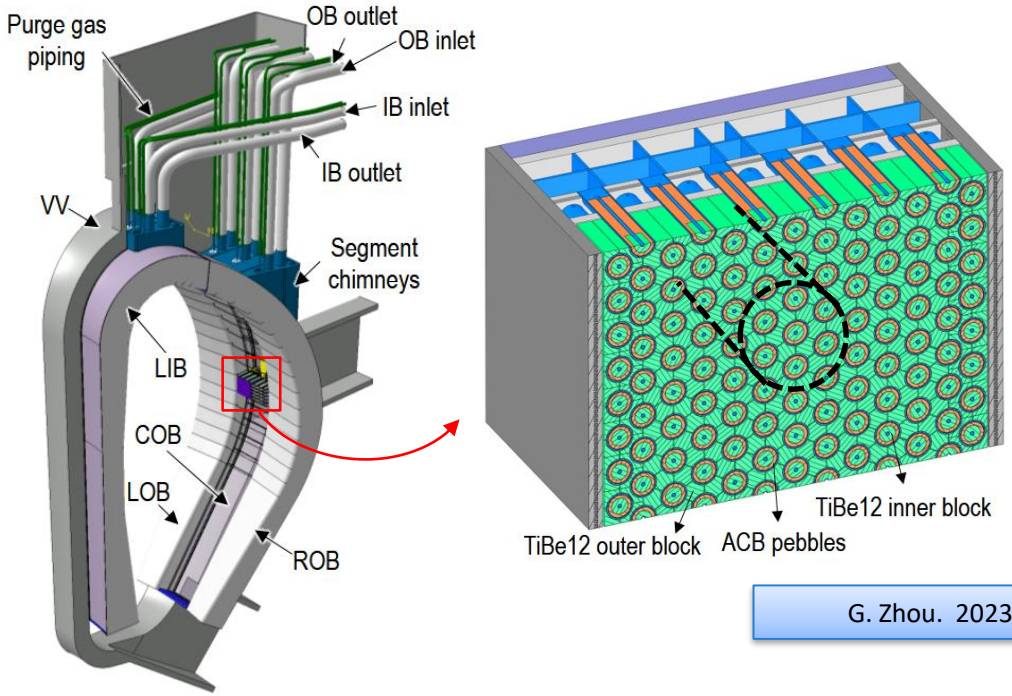
P. Maccari 2018 *Fusion Engineering and Design, (199), 114134*

- A possible WCLL BB test section could be represented by the area enclosed between two consecutive horizontal and vertical stiffening plates

EU Breeding Blanket Concepts

- The **HCPB** (Helium Cooled Pebble Bed) breeding blanket

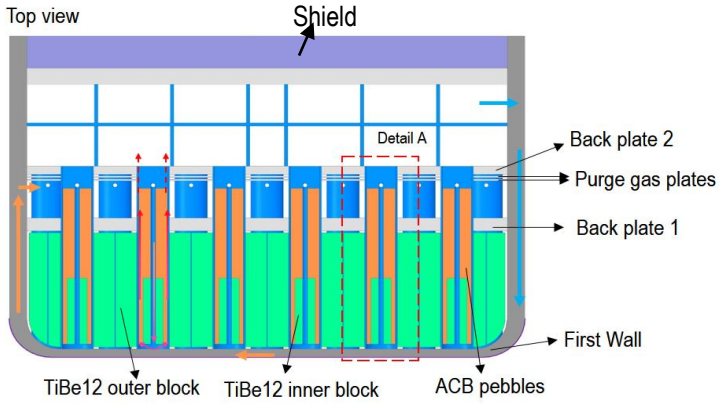
Karlsruher Institut für Technologie



G. Zhou. 2023. *Energies, 16(14) , 5377*

Main characteristics

- Eurofer as structural material
- Coolant: He @80 bar, 300-520°C
- **Fuel-breeder** pins contain **Advanced Ceramic Breeder (ACB)**
- **Beryllide neutron multiplier** of triangular prism with lateral edges filleted
- T-extraction: He + 200 Pa H2 @80 bar
- FW and critical structure thicker + cooled by fresh coolant
- Inner beryllide block inside ACB



- A possible HCPB BB test section could be represented by just one pin, or a set of 7 full-size pins

Note: ACB Advanced Ceramic Breeder:
Lithium orthosilicate: Li_4SiO_4
Lithium metatinate: Li_2TiO_3

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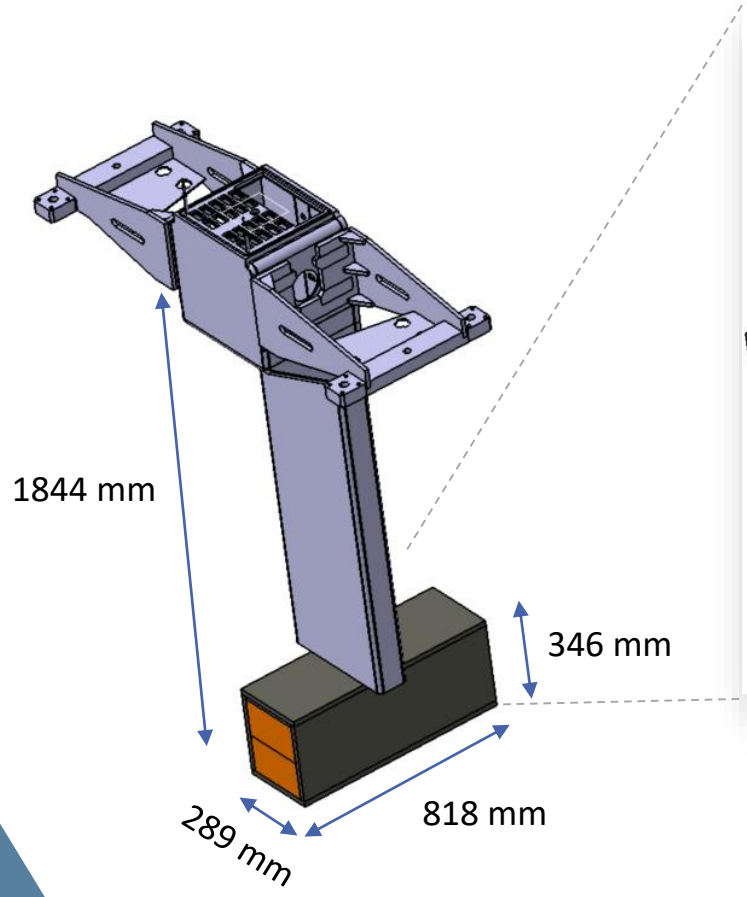
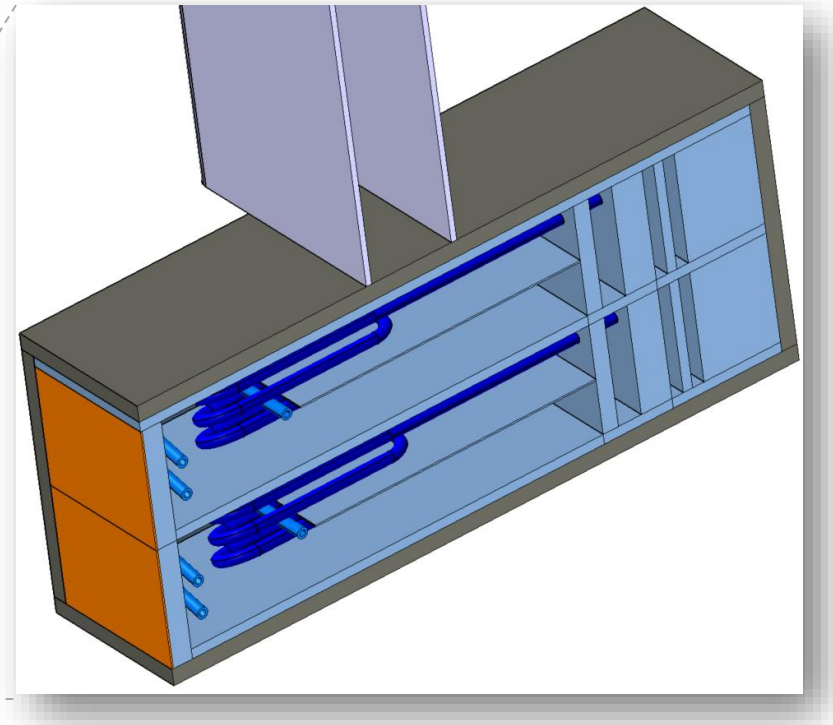
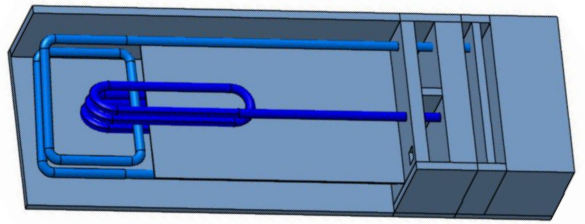
The WCLL-TBU: preliminary results

- Draft design of the WCLL-TBU already available



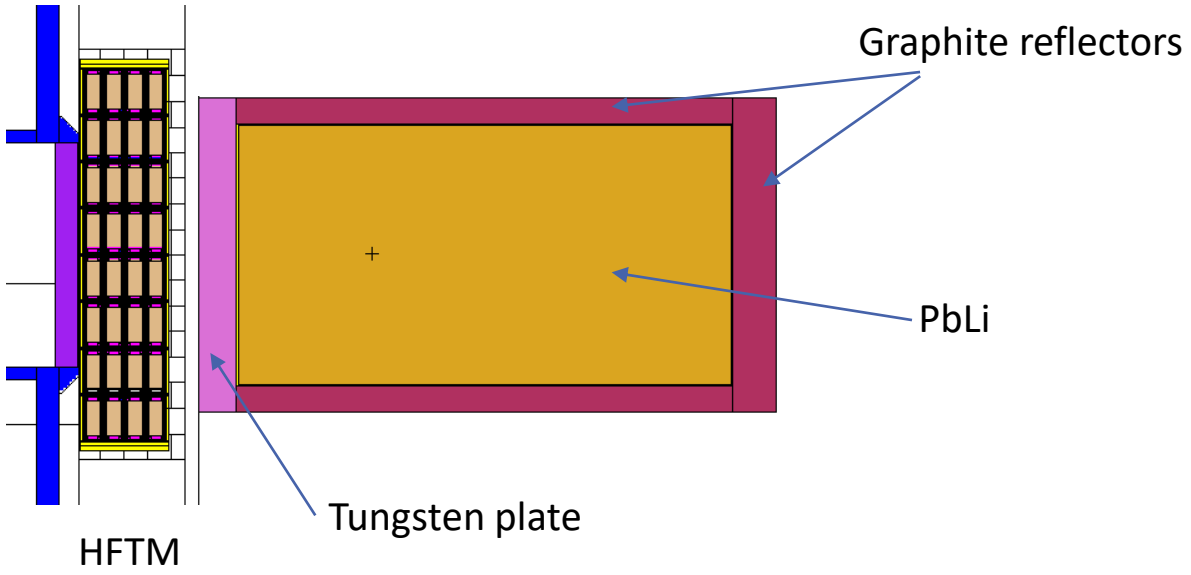


- Tungsten plate
- Graphite reflectors (grey color box)
- 2 cells (one on top of the other)
- Same support than HFTM (first iteration)

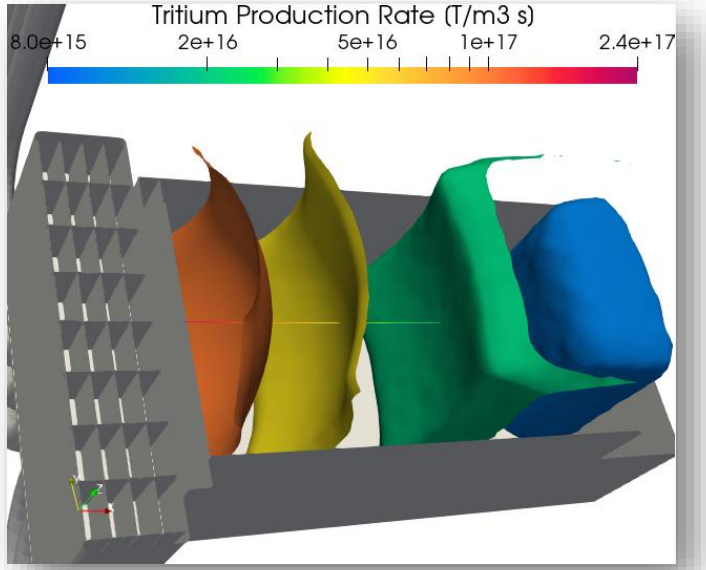


The WCLL-TBU: preliminary results

- Simplified NX model for preliminary estimations



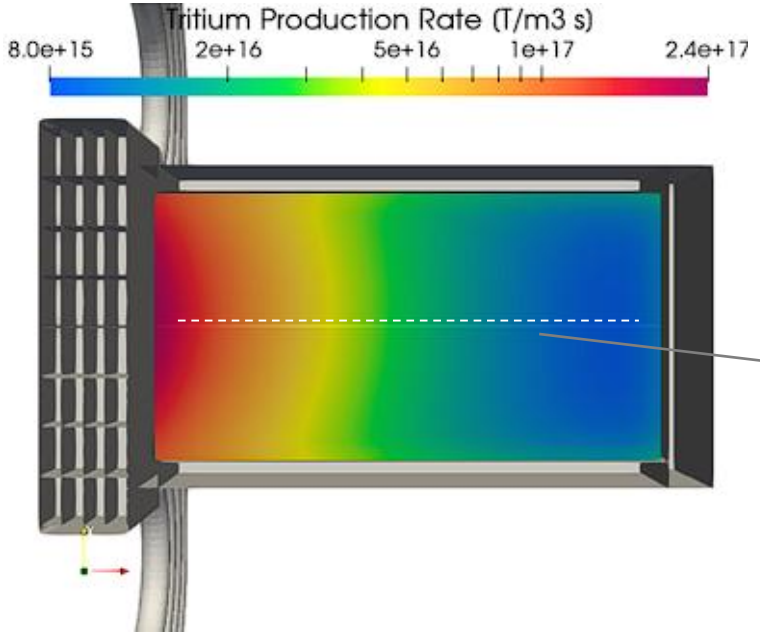
- 1 unique box
- Dimensions: 30x30 cm^2
- 60 cm length
- Stagnant PbLi
- No cooling included yet in NX calculations

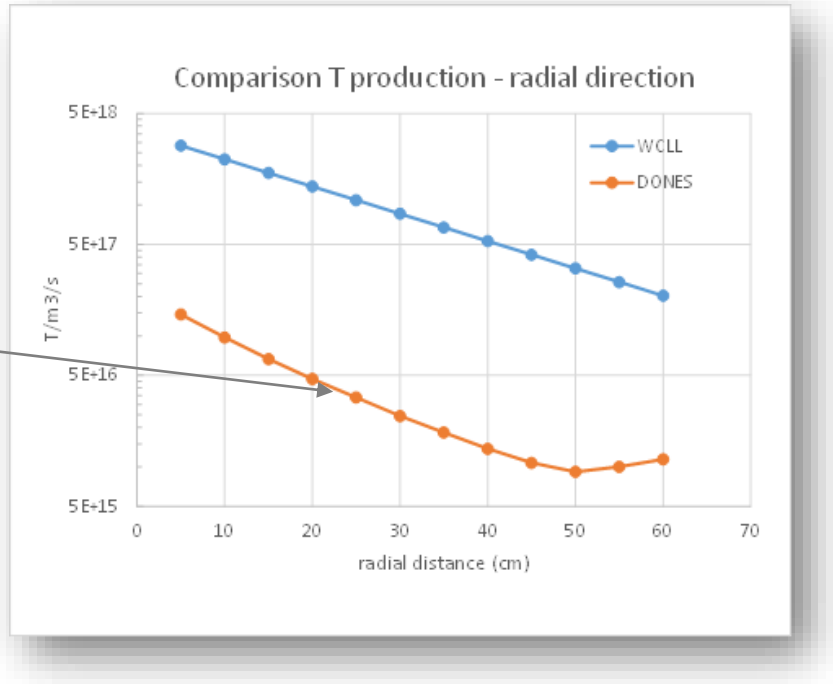


Effect of reflectors:
almost flat profiles in ZY plane

The WCLL-TBU: preliminary results

- Simplified NX model for preliminary estimations: tritium production



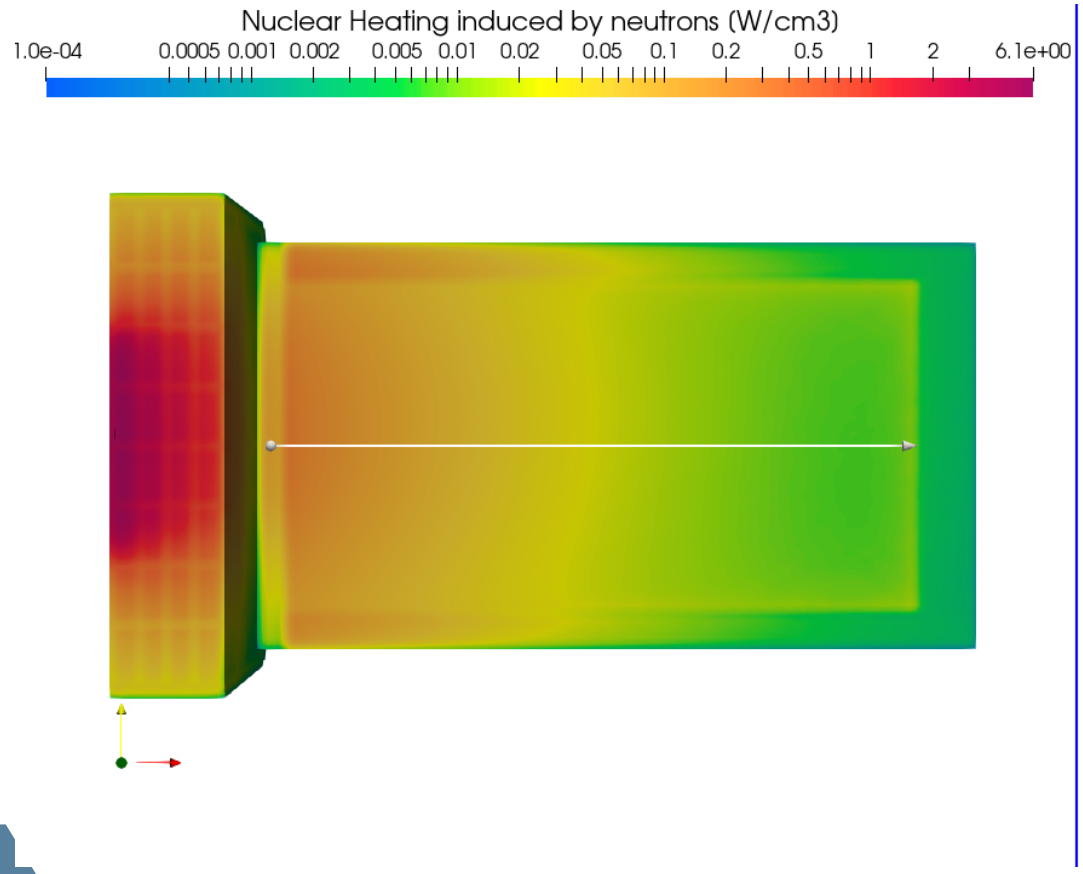


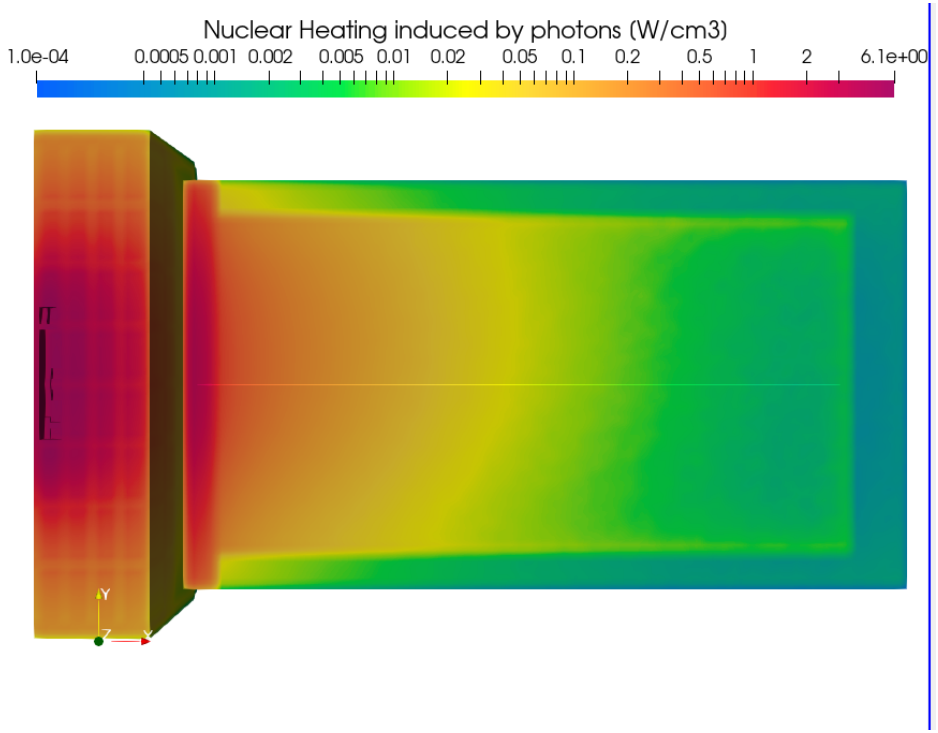
D. Rapisarda 2025 *Nucl. Fusion* **65** 116002

- Tritium production WCLL-TBU ~ 1 mg/day

The WCLL-TBU: preliminary results

- Simplified NX model for preliminary estimations: nuclear heating





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- Nuclear heating WCLL-TBU ~ 0.01 – 5 W/cm^3

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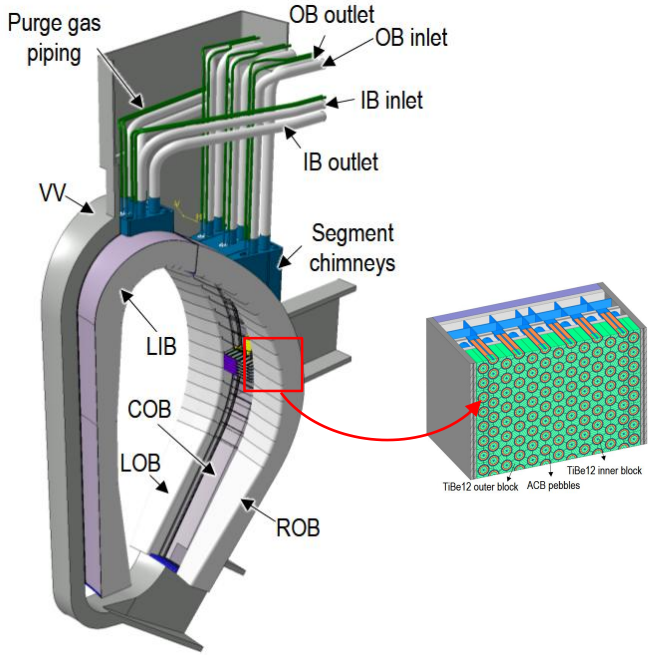
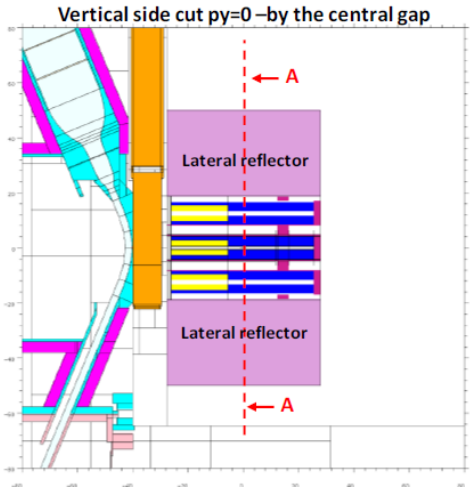
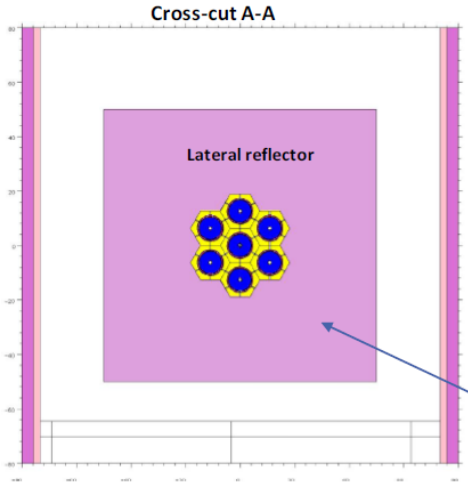
The HCPB-TBU: preliminary results

- Preliminary calculations







Calculated and compared :
1) Neutron fluxes
2) Nuclear heat for the different materials
3) T-production in Li-ceramics ACB
4) Neutron damage (DPA/FPY)

The model includes reflectors surrounding the TBU

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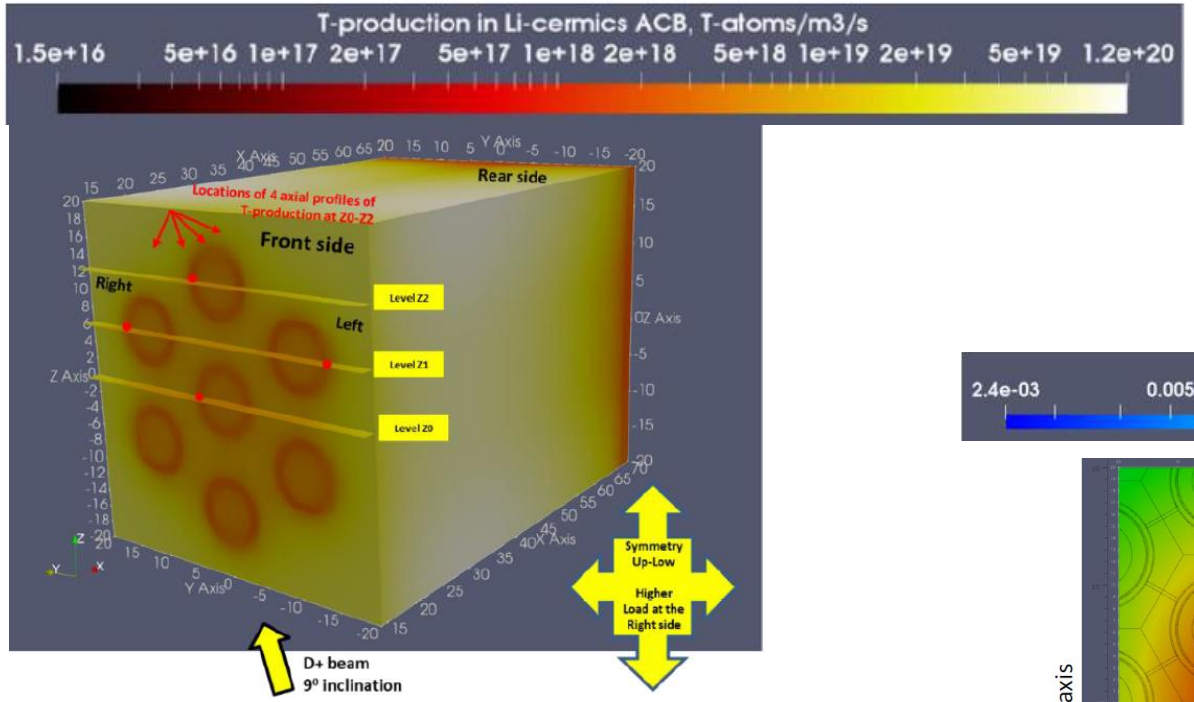
The HCPB-TBU: preliminary results

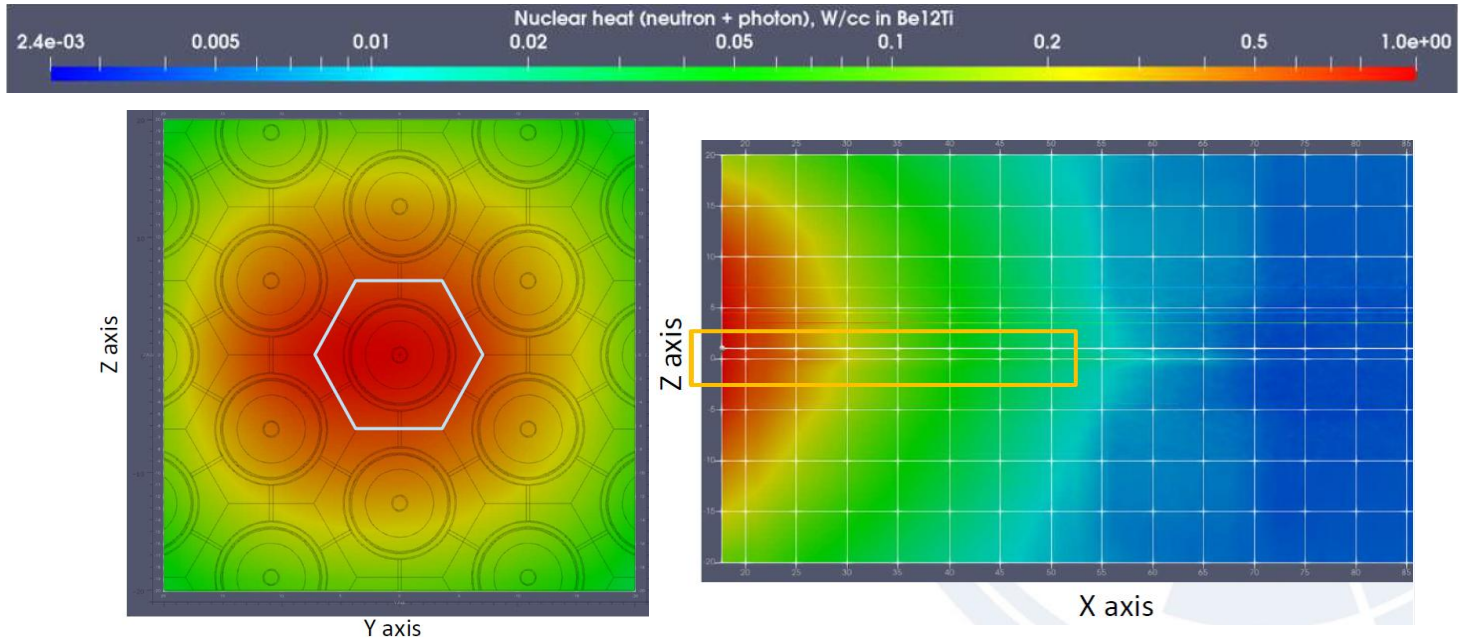
Tritium production



model	Tritium production [per pin]
DEMO HCPB BB	3.3 mg/day
HCPB-TBU-7	0.52 mg/day

3.64 mg/day in 7 pins

Nuclear heating



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SUMMARY & CONCLUSIONS

- The **IFMIF DONES** facility constitutes a perfect scenario for **BB testing**, offering neutrons (and gammas) of high energy and fluence, comparable with the radiation loads to be reached at the future fusion reactors.
- **Preliminary designs of TBU** are proposed for the HCPB/WCLL, and specific calculations show the feasibility of the mock up.
- IFMIF DONES (TBU modular validation) can constitute a **complementary program** to ITER TBM (adding EM loads) and Volumetric Neutron Source (VNS, integrated validation)