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BLUME: A blanket functional materials module for the Helium Cooled Pebble Bed breeding blanket in IFMIF-DONES

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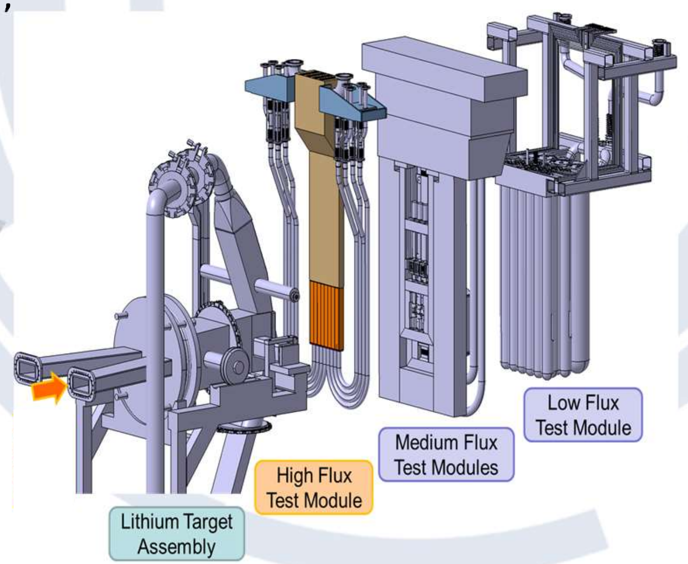

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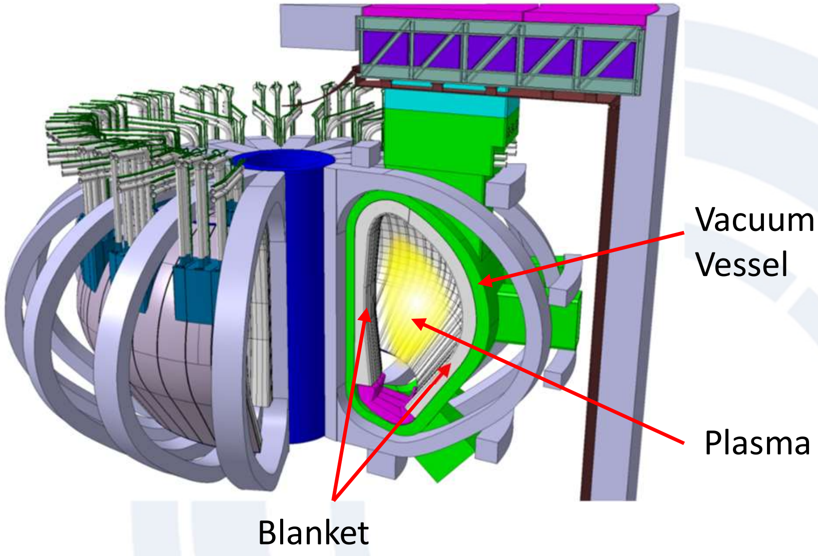
Outline of content

- Why test Breeding Blanket mockup in IFMIF-DONES?
- Testing goals of BLUME
- Initial design of BLUME
- Summary and outlook

Breeding Blanket: a key system in any D-T fusion electricity device

$$ {}^{2}_{1}D + {}^{3}_{1}\boldsymbol{T} \rightarrow {}^{4}_{2}He + \boldsymbol{n} + 17.6\ \mathrm{MeV} $$

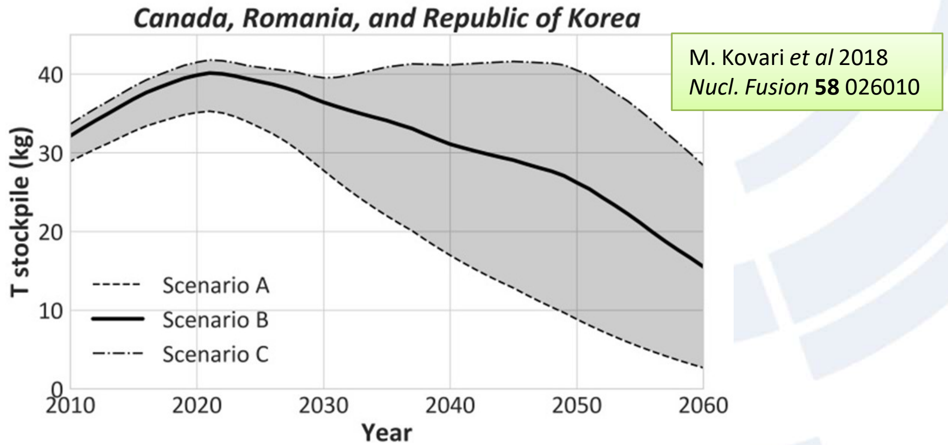
Tritium breeding blanket is a nuclear component within vacuum vessel that surrounds the plasma like a blanket.



Deuterium (*D*) has a large natural abundance in the oceans.

Tritium (*T*) decays and has no natural abundance. About 55 g *T* is lost per year for 1 kg *T*.

1 GW fusion (thermal) power device consumption:
56 kg *T* per full power year (fpy).



Global civil tritium stockpile

Need to produce ***T***, in order to be economically viable!

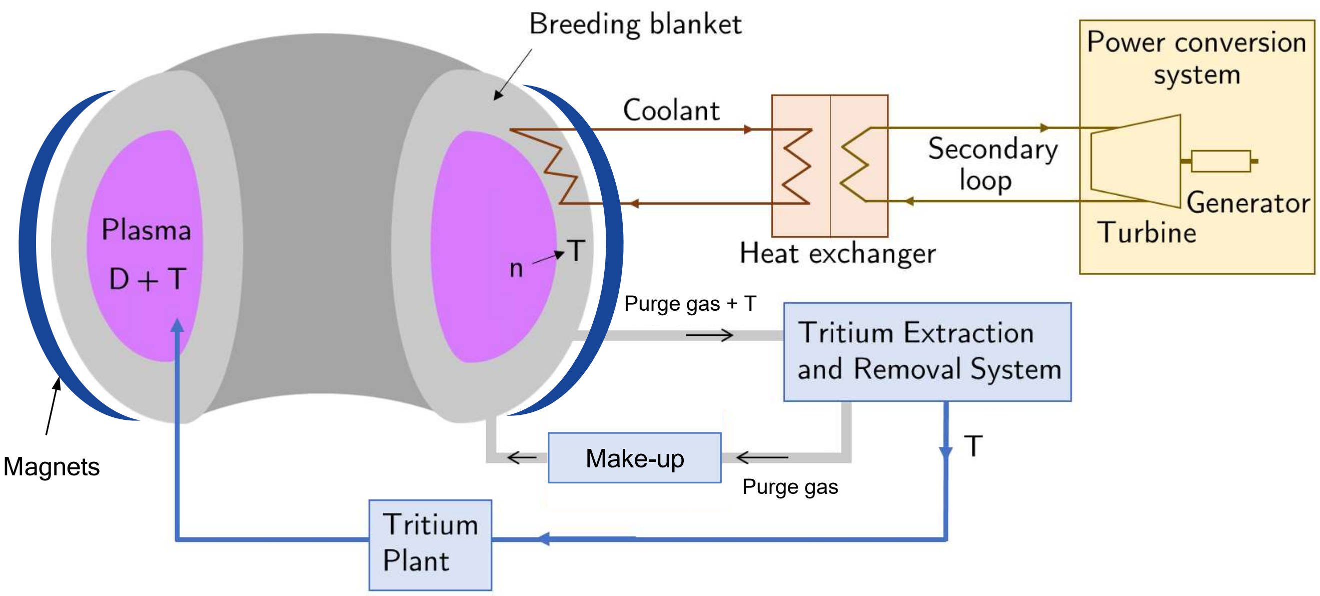
Why Breeding Blanket?

- **Main functions of the Breeding Blanket:**

  - tritium breeding => tritium self-sufficiency
  - heat removal => electricity production
  - shielding => protect magnets

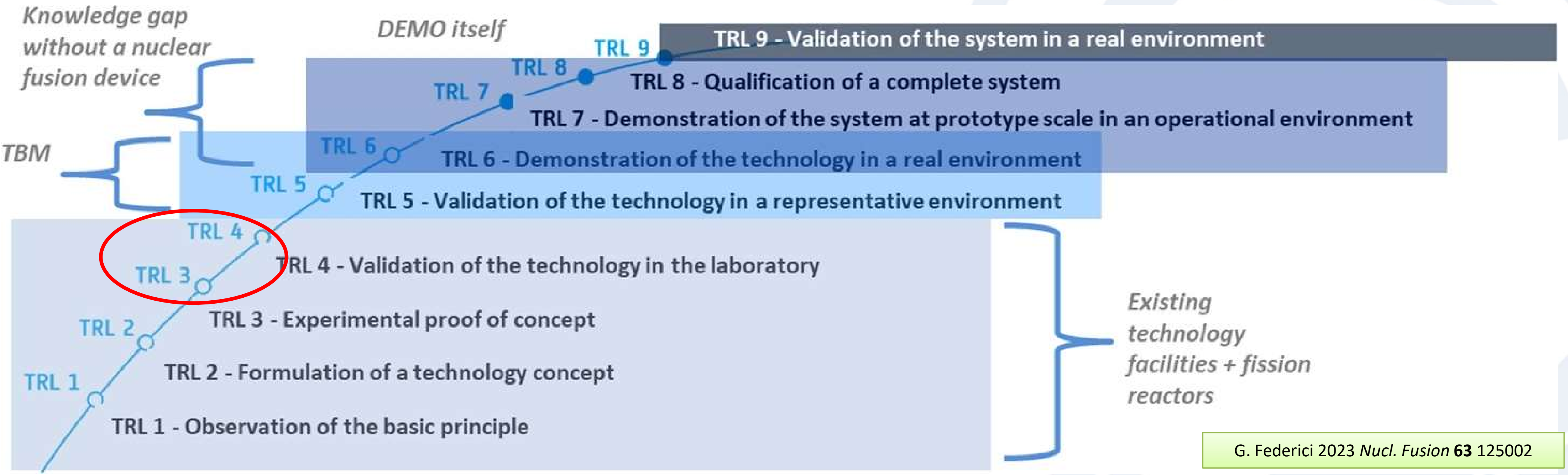
$$^{6}_{3}Li + n \rightarrow \, ^{4}_{2}He + T$$

$$^{3}_{1}T + \, ^{2}_{1}D \rightarrow \, ^{4}_{2}He + n + 17.6 \text{ MeV}$$



Why test Breeding Blanket mockup in IFMIF-DONES?

- Despite the importance of blanket, maturity level of breeding blanket is still very low.
- Feasibility concerns and uncertainties exist in all explored breeding blanket concepts.
- Significant research and development are needed to address these issues.



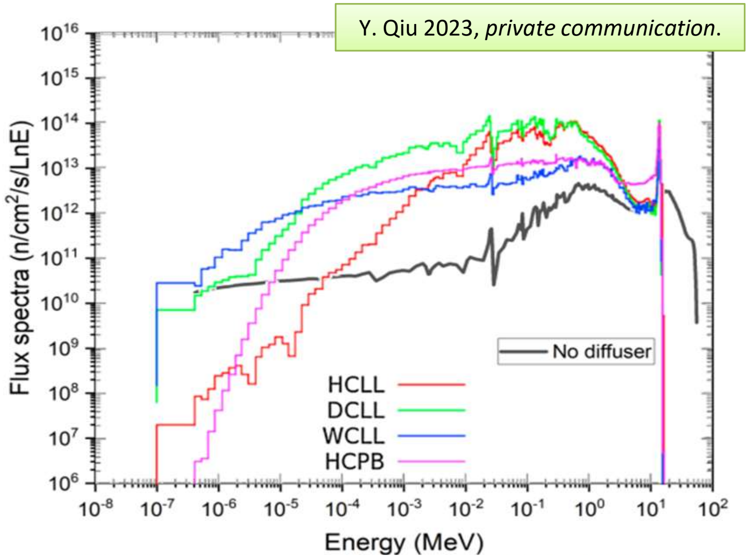
G. Federici 2023 *Nucl. Fusion* **63** 125002

In European DEMO program, Helium Cooled Pebble Bed (HCPB) breeding blanket is under development.

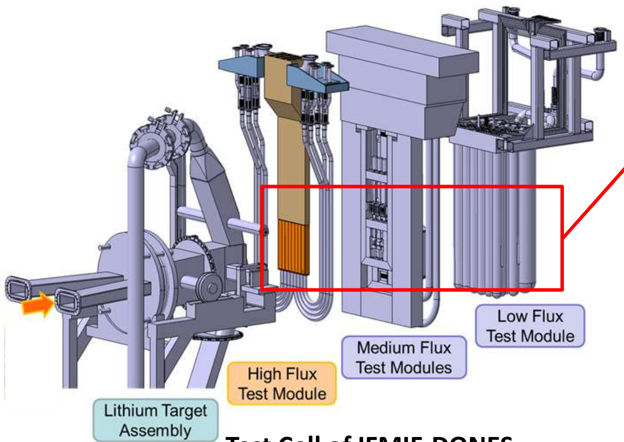
We propose a <u>bl</u>anket f<u>u</u>nctional <u>m</u>aterials modul<u>e</u> (BLUME) for HCPB blanket to be tested in IFMIF-DONES.

Neutron flux spectra and volume for testing in IFMIF-DONES

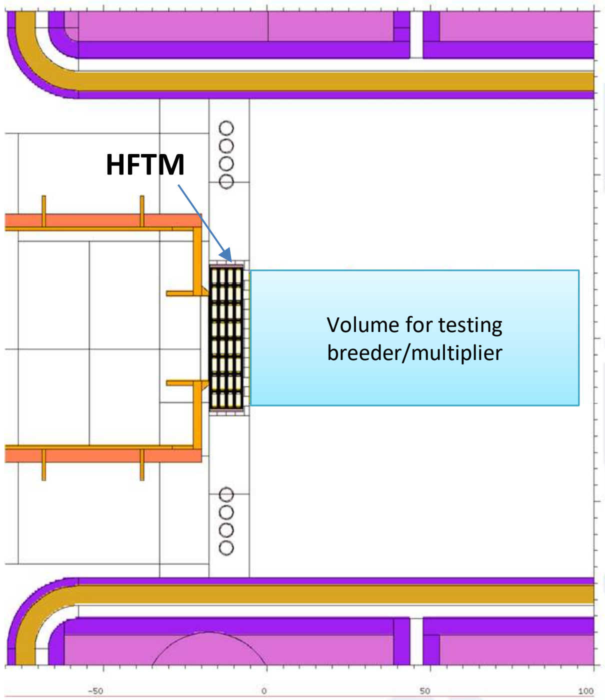
Y. Qiu 2023, *private communication*.



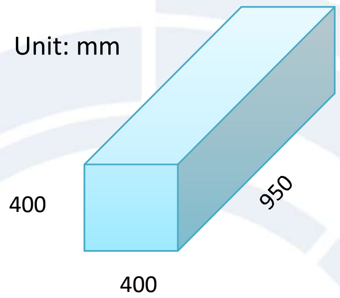
Neutron spectra comparison with EU-DEMO Breeding Blanket



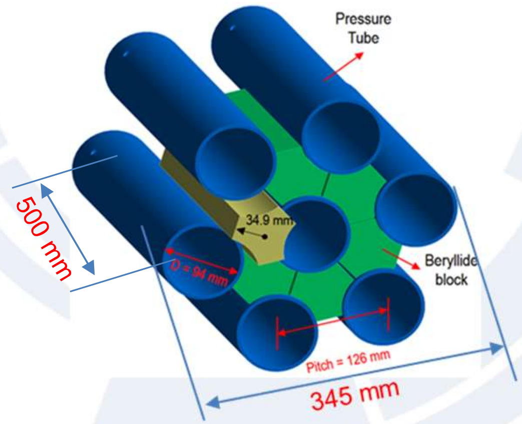
Test Cell of IFMIF-DONES



Volume for testing in Test Cell of IFMIF-DONES

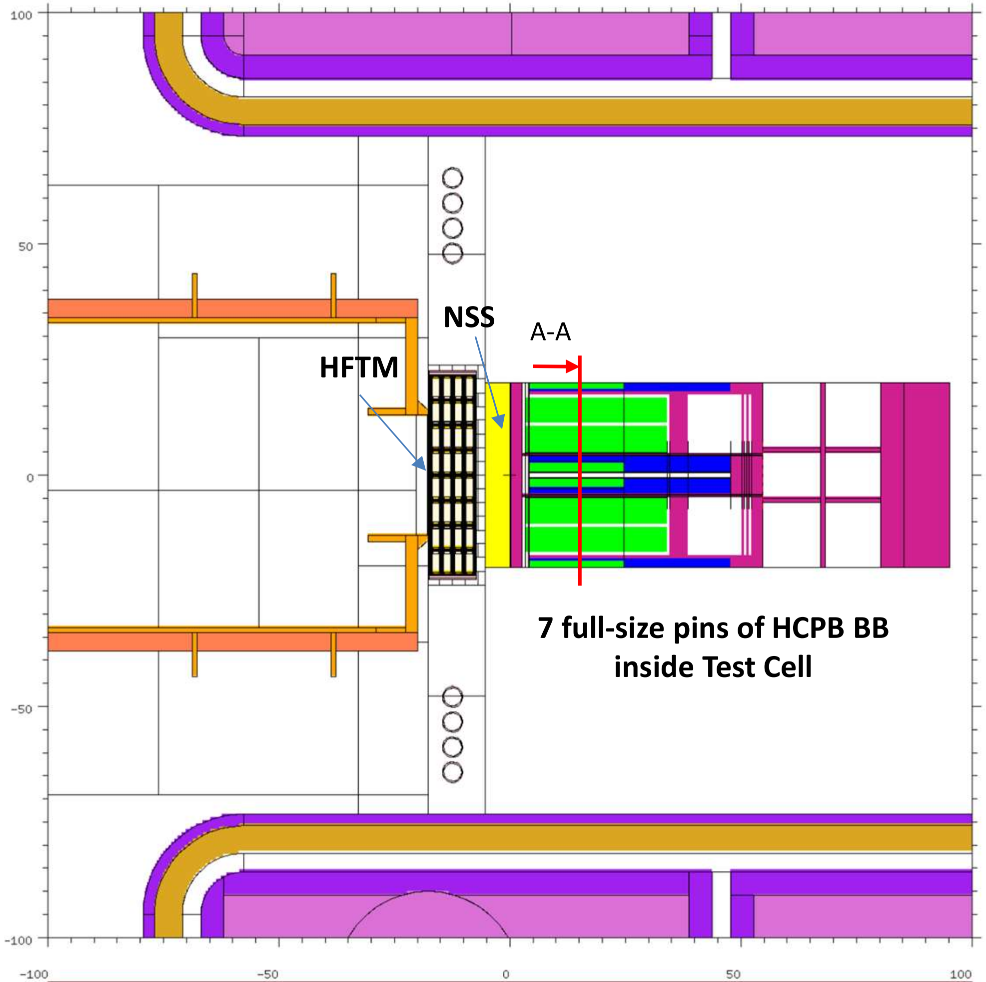


Volume: 400 x 400 x 950 mm³



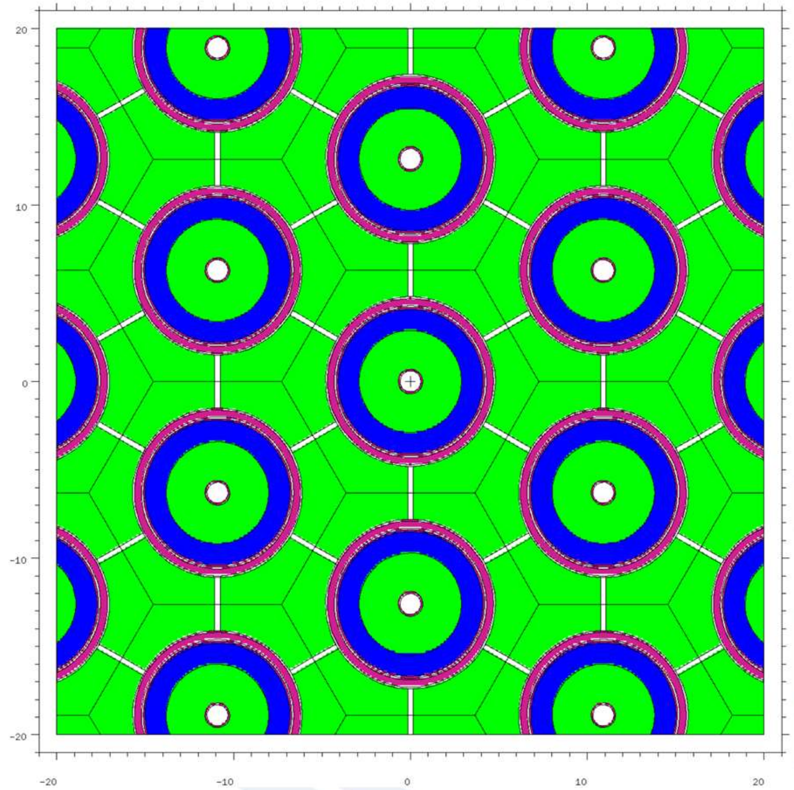
Dimensions of HCPB blanket breeder zone

Preliminary neutronics analyses to check neutron flux relevancy



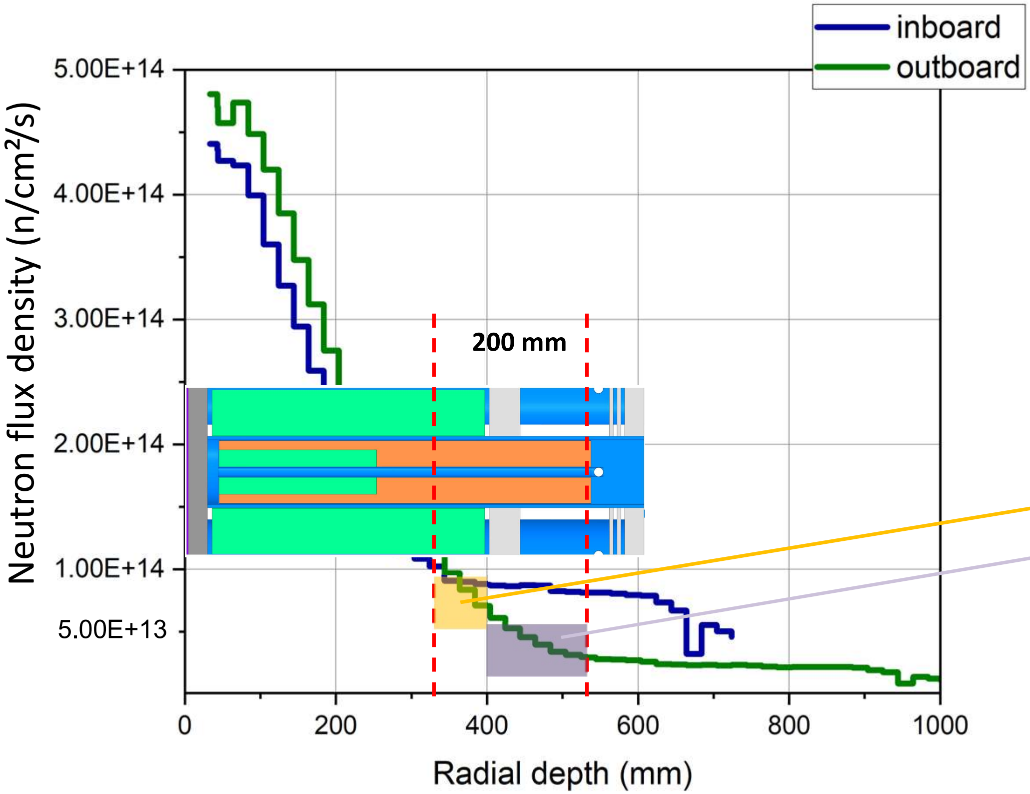
BLUME in Test Cell of IFMIF-DONES

Blue: Advanced ceramic breeder Li-pebbles
Green: Titanium beryllide
Magenta: Eurofer97 steel

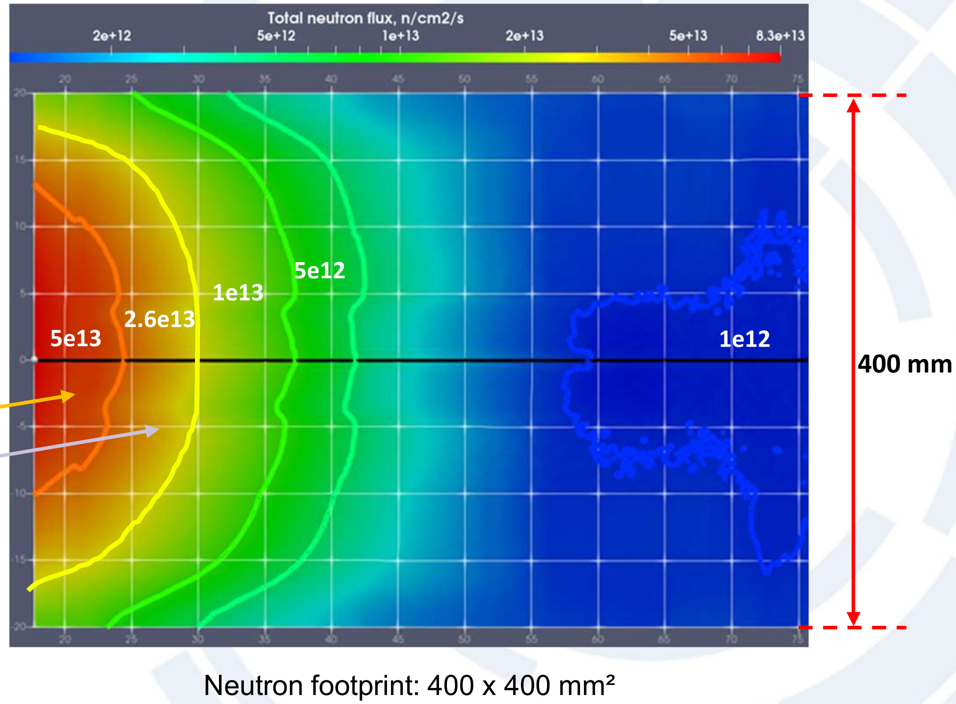


A-A cut-view

Neutron flux DEMO-relevancy



Neutron flux density of HCPB BB in EU-DEMO



Neutron flux density of HCPB mockup in IFMIF-DONES

Testing goals of BLUME (Blanket functional materials module)

1 Heat Transfer Experiments

Goals	To address heat transfer in realistic fuel-breeder pin geometry
Measurements	Temperature (breeder, coolant, and purge), purge pressure drop, and post-test examination of the breeder structure and gap dimensions

2 Neutronics Prediction Validation (Tritium Generation, Nuclear Heating, Activation)

Goals	To verify neutronics predictions for tritium breeding, nuclear heating and activation
Measurements	Post-test examination for activation, tritium inventory, and neutron fluence

3 Breeder/Structure Thermo-Mechanical Interactions

Goals	To study thermomechanical interactive effects on component behavior
Measurements	Temperature, stress, and post-test examination for gap size, cracking, sintering, settling, swelling, and other changes Stress and strain in the structure, cracking and redistribution in the breeder, and overall deformation and failure modes

4 Tritium Behavior in Thermal and Flow Transients

Goals	To investigate the tritium inventory and permeation behavior during thermal and flow transients
Measurements	Measurements include temperature (breeder and coolant), coolant and purge tritium activity, and post-test examination for tritium inventory, cracking, or other changes in the solid breeder

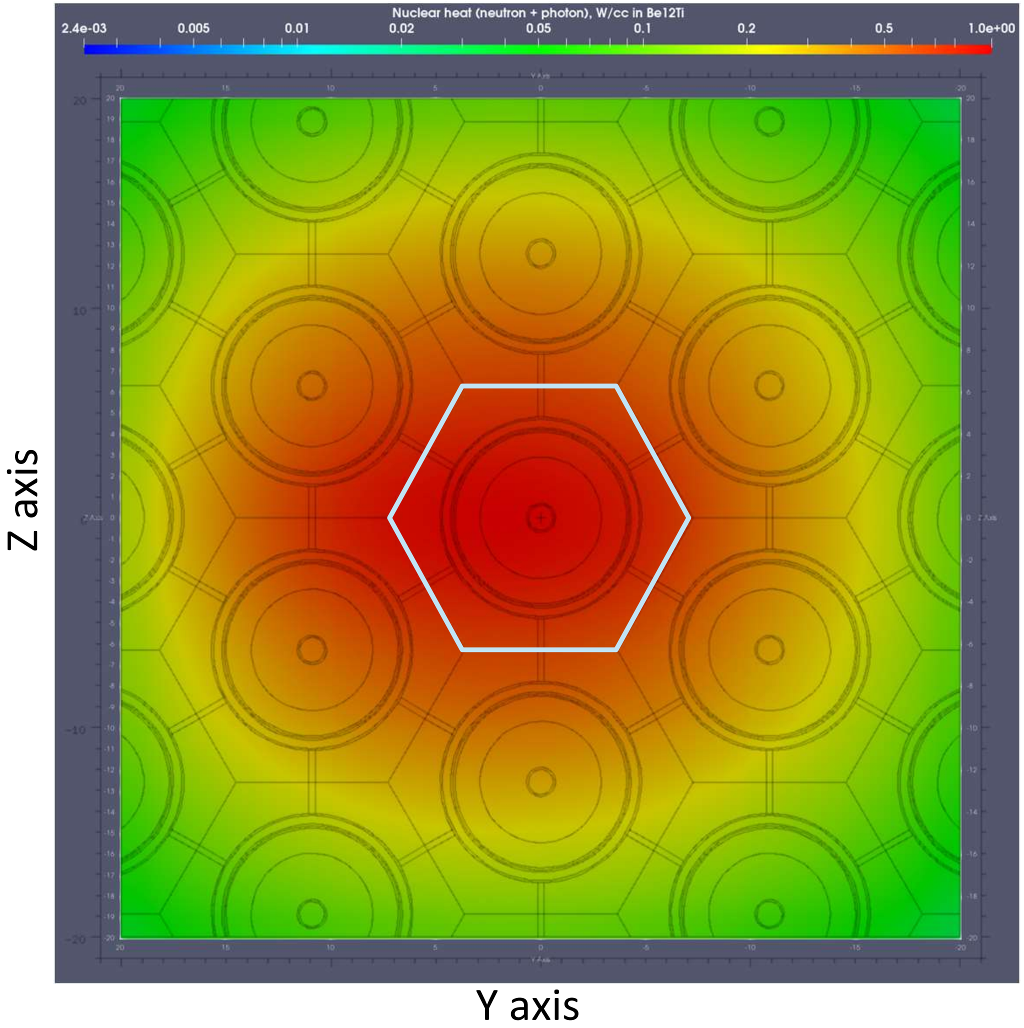
5 Blanket Response to Coolant Transients

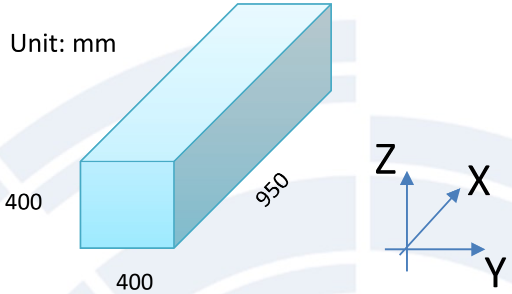
Goals	To assess the effect of loss of flow or loss of coolant conditions on the fuel-breeder pin
Measurements	Measurements include temperature, stress, coolant pressure, flow rate, and post-test examination for deformation and failure

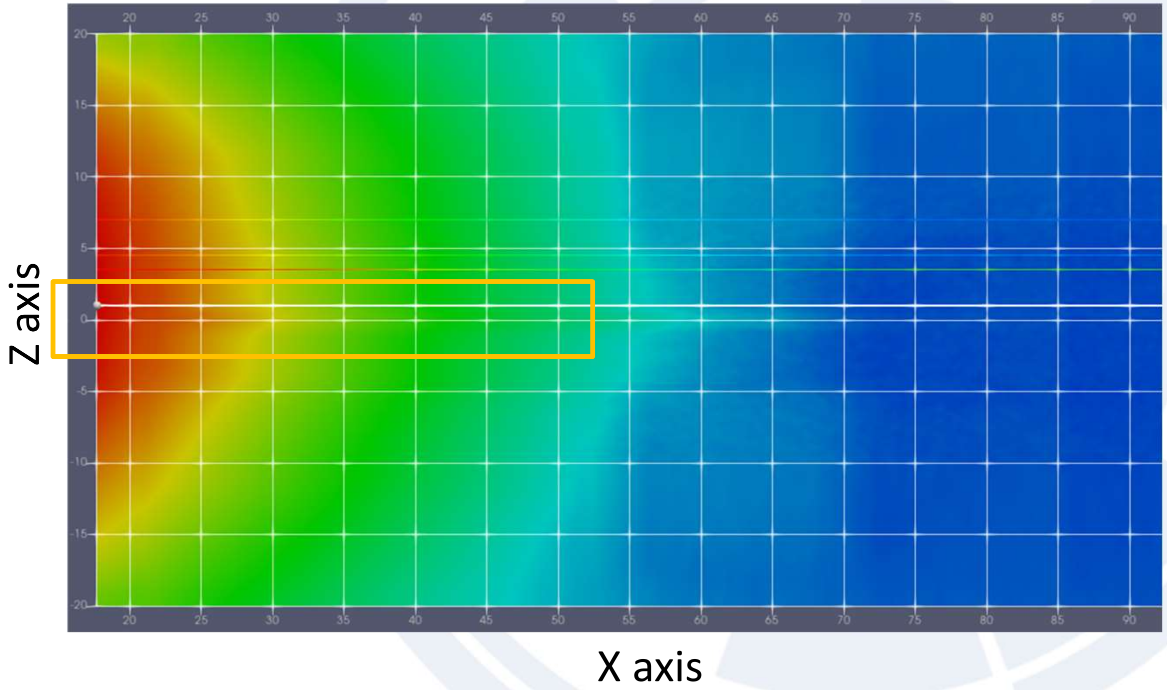
Testing boundary conditions

- Helium coolant at 3.5 bar pressure to avoid pressurization in Test Cell
- To ensure relevant temperature field of HCPB blanket
  - ✓Coolant inlet temperature: 350 – 380 °C
  - ✓Coolant outlet temperature: 500 – 520 °C
  - ✓Eurofer temperature: 300 – 550 °C
  - ✓Advanced ceramic breeder Li-pebble temperature: 400 – 920 °C
  - ✓$TiBe_{12}$ temperature: 300 – 1000 °C
  - ✓Mass flow rate range at 3.5 bar: 1 g/s – 10 g/s

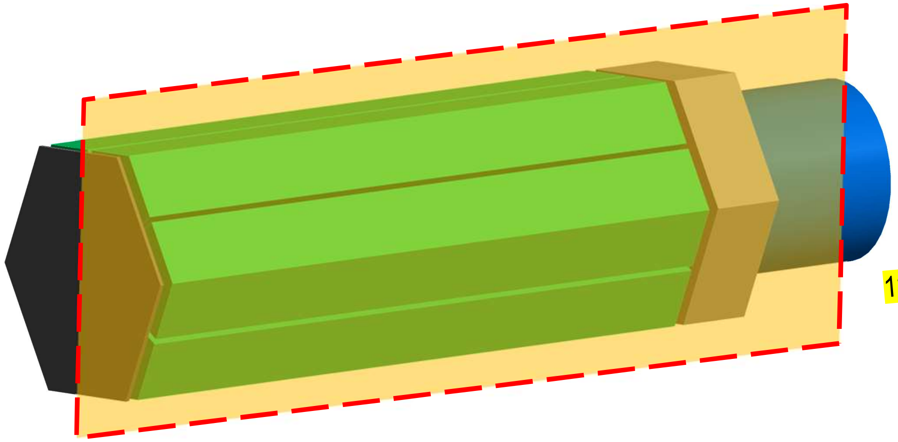
Nuclear heat map of initial design of BLUME

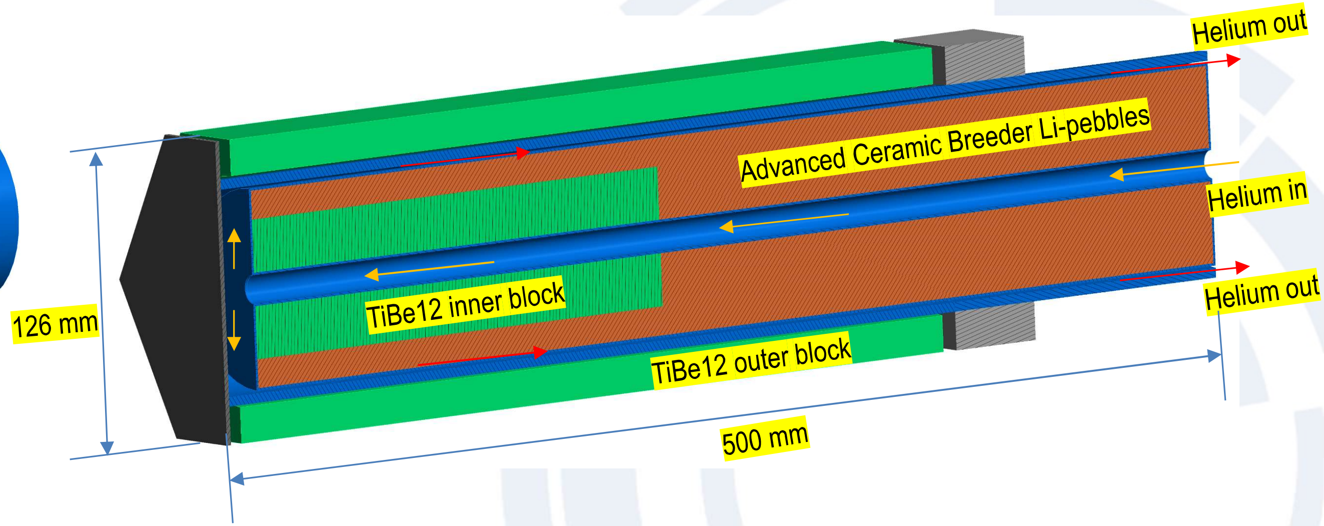




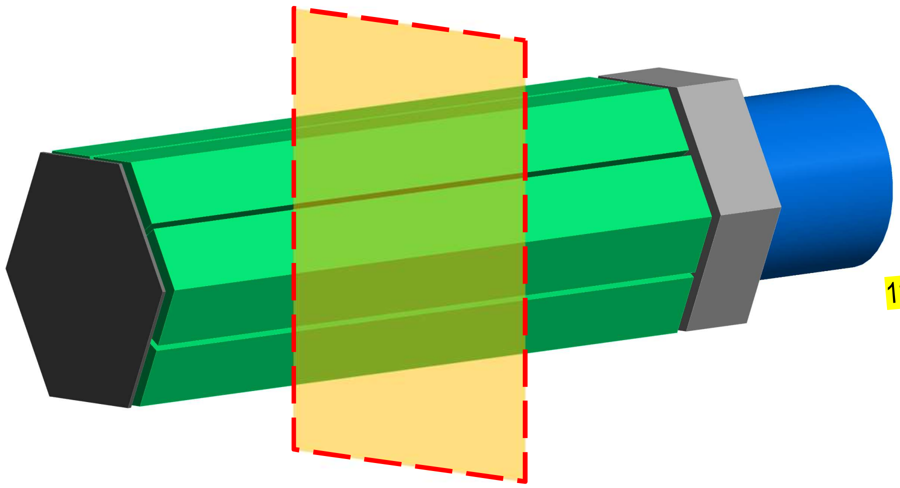


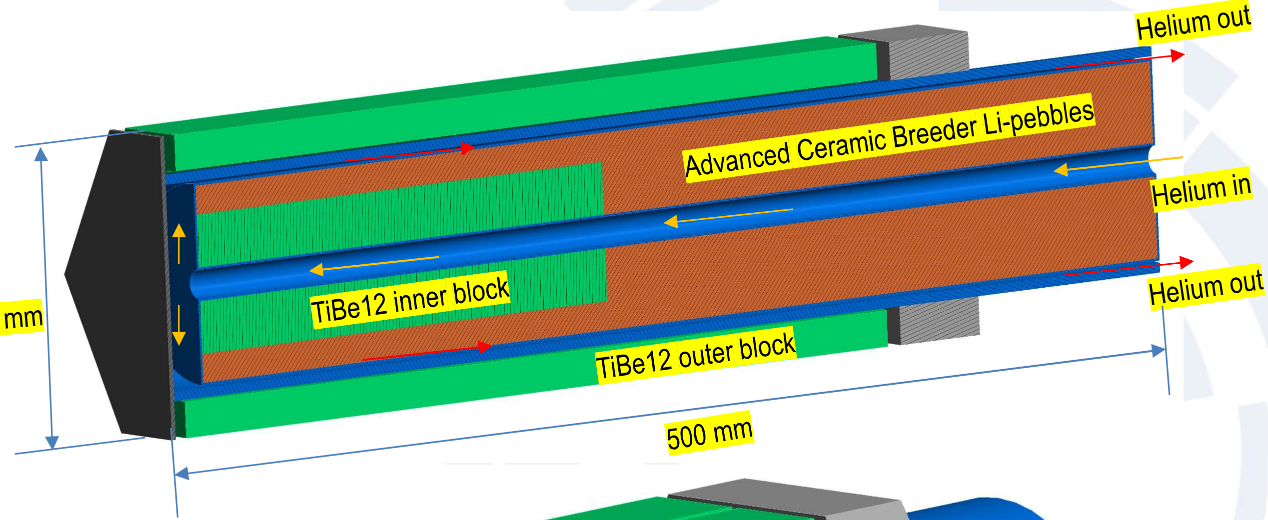
Initial design of BLUME



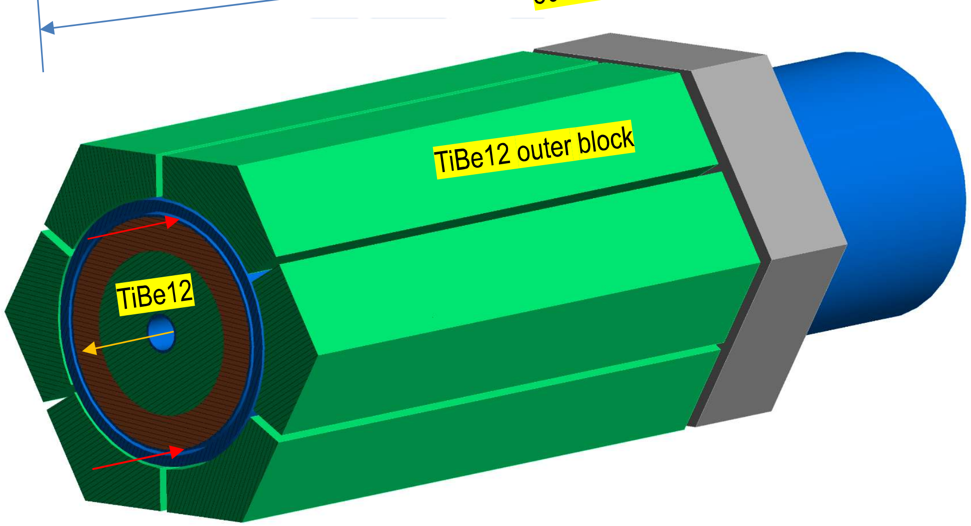


Initial design of BLUME

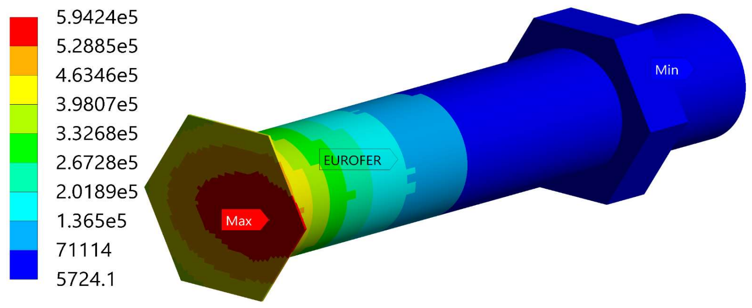




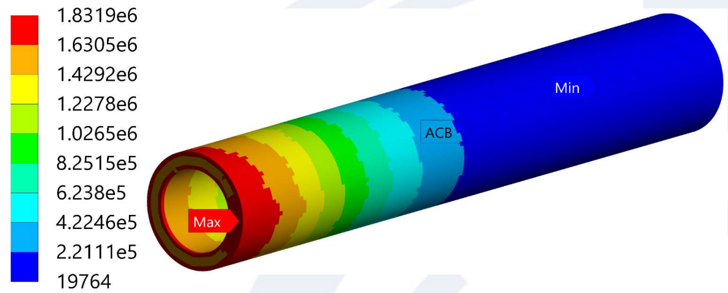
Materials	Total amount
ACB Li-pebbles, g	778
TiBe12, g	6026
Eurofer, g	213
Helium, L	4



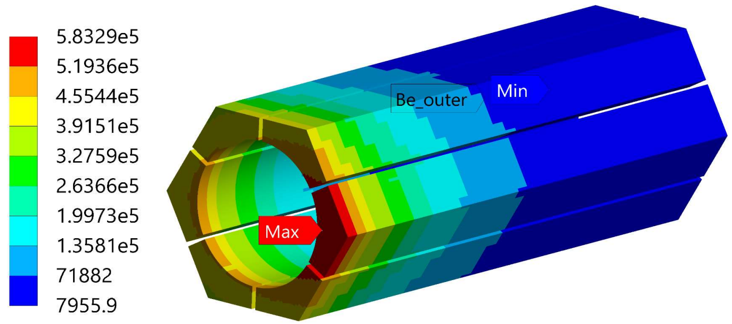
Neutronics analysis: power density [W/cm³]



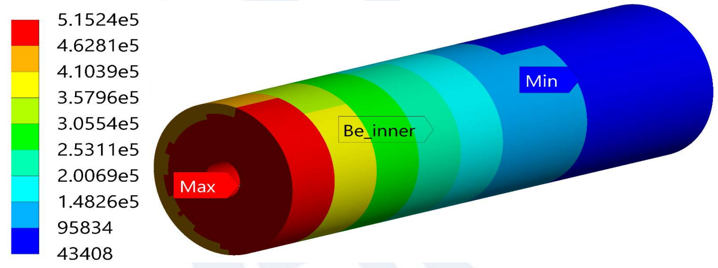
Eurofer



Advanced Ceramic Breeder Li-Pebbles



TiBe12 outer block



TiBe12 inner block

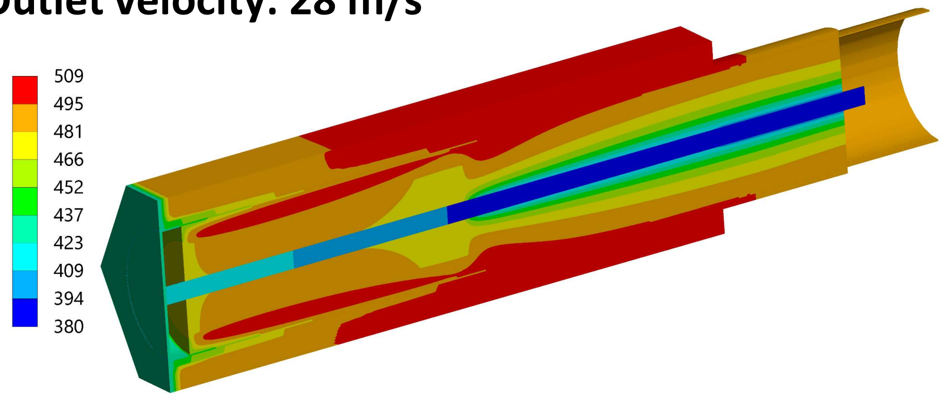
9-degree inclination of deuteron beam causes asymmetry in nuclear heating

Total power: 1044 W

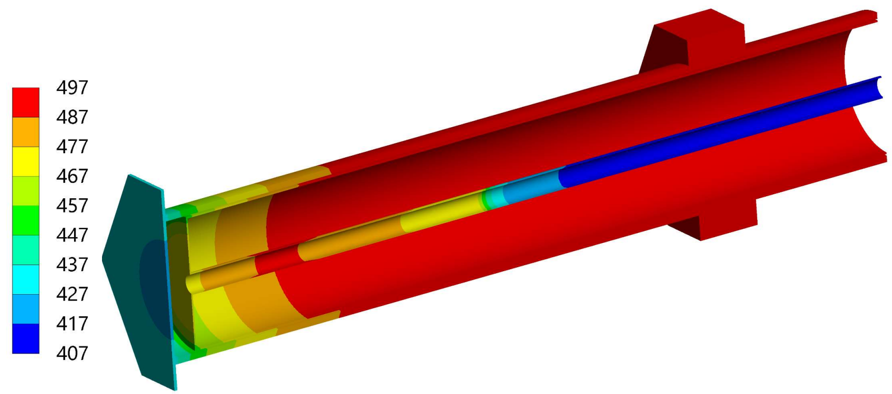
Tritium generation rate: about 4e-06 mg/s, **1 day T-production**: 0.34 mg

Thermal analysis: temperature field [°C]

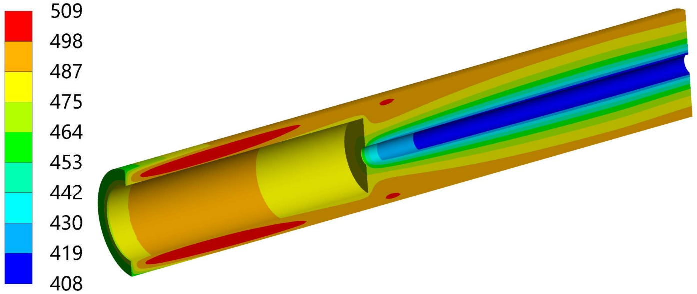
Tin = 380 °C, mass flow rate: 1.7 g/s
Inlet velocity: 57 m/s
Outlet velocity: 28 m/s



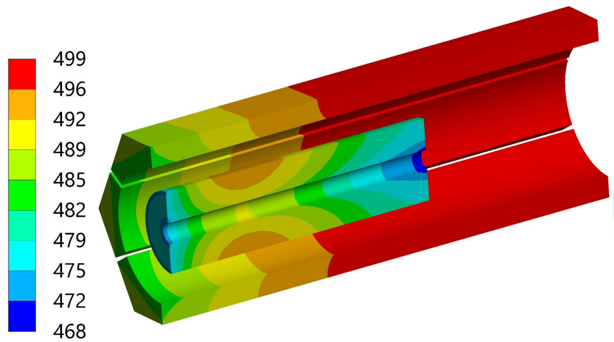
All materials



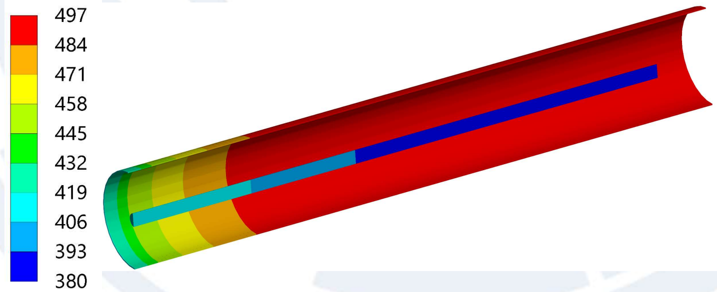
Eurofer



Li-pebbles



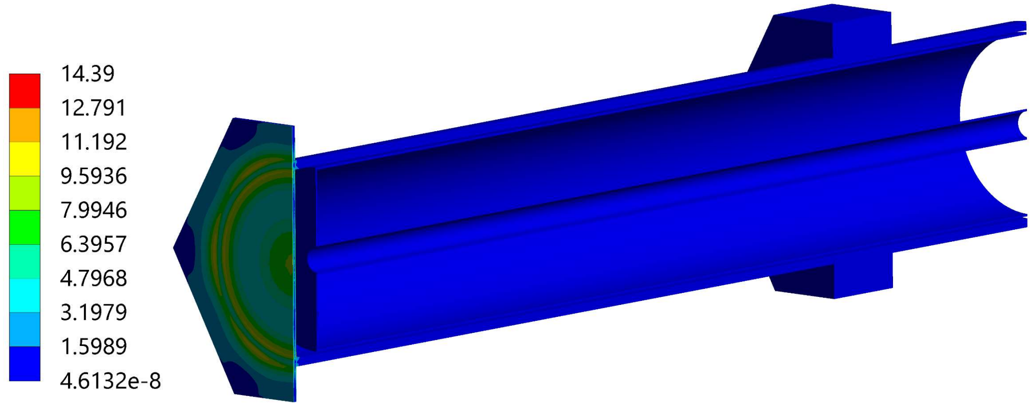
TiBe12



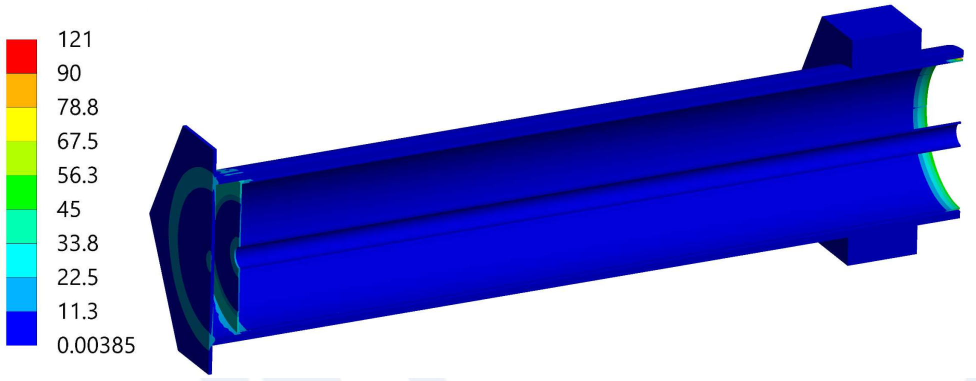
Coolant

Structural analysis: Von-Mises Stress field [MPa]

Coolant-wetted surfaces: 3.5 bar pressure
Body: temperature field
Fixed at rear surfaces of BLUME



Stress with pressure load



Stress with pressure and temperature field

Structure is robust enough to withstand the pressure and thermal stresses.

Summary and outlook

➢ Summary:

- Testing goals of BLUME are presented
- Initial design of BLUME is proposed
- Neutronics, thermal and structural analyses confirm the DEMO-relevancy

➢ Outlook:

- The surroundings of the central pin will be replaced with reflecting materials (TiBe12 or graphite blocks)
- Interface with Test Cell of IFMIF-DONES will be established
- Measurement requirement of different test goals will be defined
- Ancillary systems for BLUME will be defined

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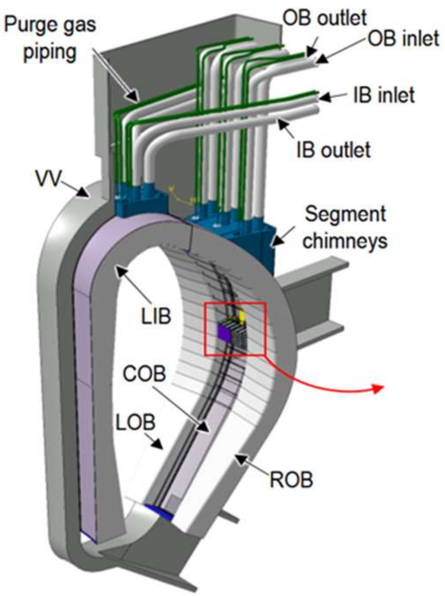
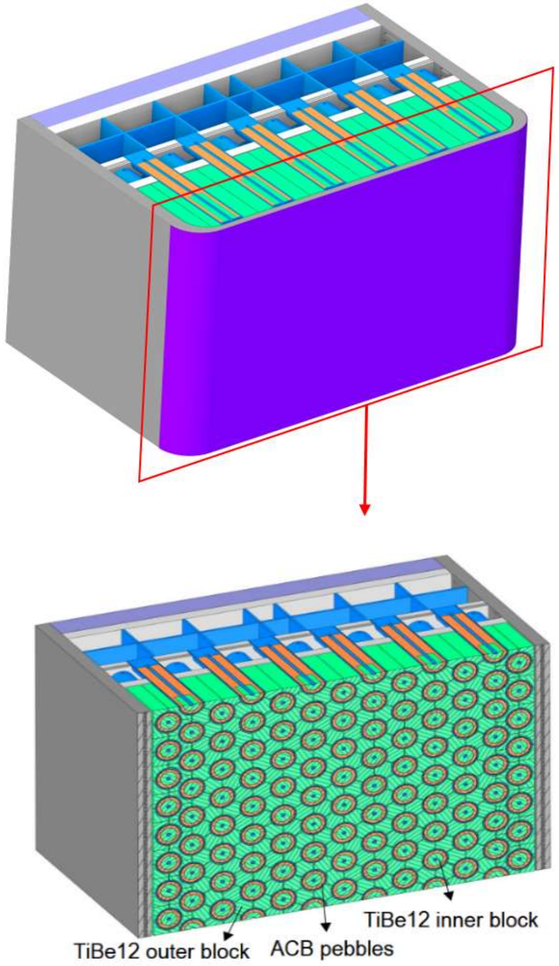
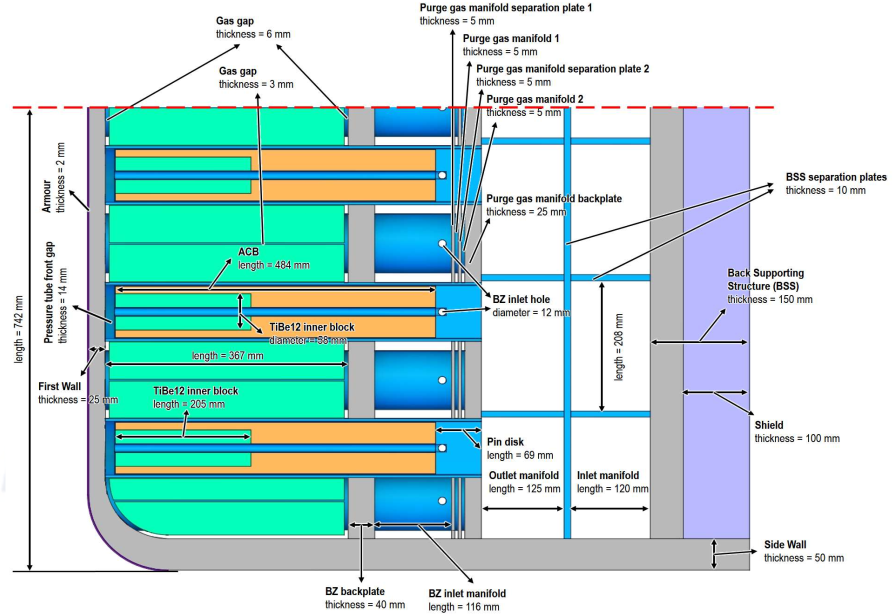
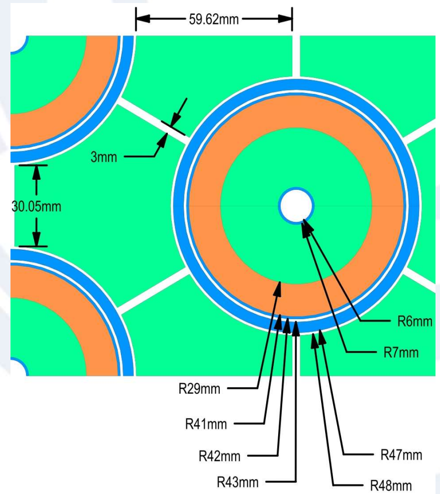
Cooperation
Equal opportunities
Inclusion

Backup: dimensions of HCPB BB









DPA/fpy: Eurofer