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Nuclear analyses of solid breeder blanket options for DEMO: status, challenges and outlook

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Objectives

To support with neutronic analyses the systematic design development of the **HCPB** and alternative **MLCB** blankets

The following nuclear responses were assessed:

- *Tritium breeding ratio (TBR),*
- *Effect of different design modifications on global TBR*
- *Power generation,*
- *Power density distributions in materials,*
- *Shielding performances of the DEMO*

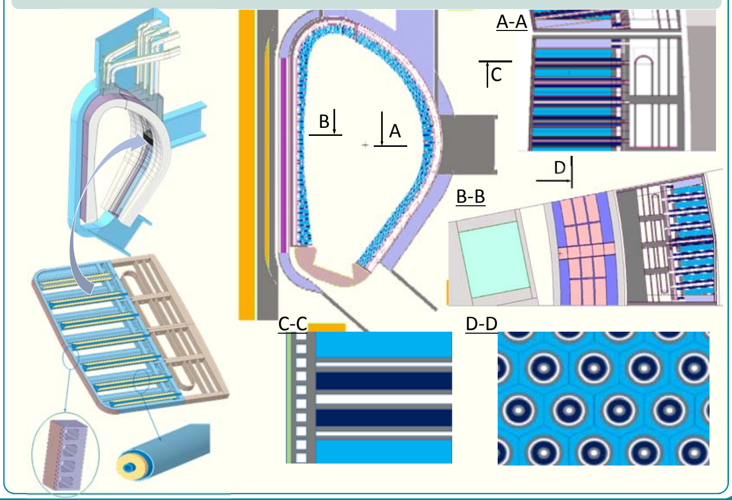
Models

I. Generic MCNP model
   - *CAD model of DEMO baseline 2017*
   - *Full size 3D model of 11,25° torus DEMO segment*
   - *Empty breeder blanket space*

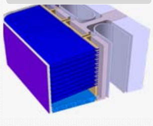
II. SMS blanket MCNP model
   - *Roof shape FW (20 mm) with a W layer (2 mm)*
   - *Faceted FW, empty breeder modules*

III. Breeder module MCNP model
   - *Heterogeneous FW (channels), BZ and BSS*
   - *Hexagonal lattice of the breeder pins*

CAD and MCNP models

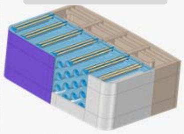


DEMO Baseline 2015



- Breeder zone
  - *Inboard – 22 cm*
  - *Outboard - 51 cm*
- MMS blanket
- Cooling plates
- OB radial thickness of blanket – 130 cm
- **TBR=1.15**

DEMO baseline 2017



- OB radial thickness of blanket – 100 cm
- SMS blanket
- Roof shaped FW
- Fully detailed MCNP blanket model
- Breeder pins instead of cooling plates

HCPB

- Breeder zone
  - *Inboard – 35 cm*
  - *Outboard - 55 cm*
- $Be_{12}Ti$ instead of Be
- Li_4SiO_4 + 30% mol. Li_2TiO_3 instead of Li_4SiO_4
- **TBR=1.16**

MLCB

- HCPB blanket geometry matrix
- Breeder zone
  - *Inboard – 38 cm*
  - *Outboard - 61 cm*
- Pb instead of $Be_{12}Ti$
- No Pb circulation
- **TBR=1.13**

Heterogeneity effects

Geometry modifications applied:

HCPB

- *Flat FW - ΔTBR=+0.03*
- *Homogeneous BZ - ΔTBR=+0.01*
- *Homogeneous FW - ΔTBR=+0.01*

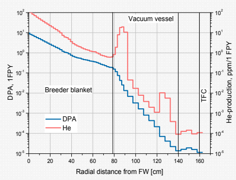
MLCB

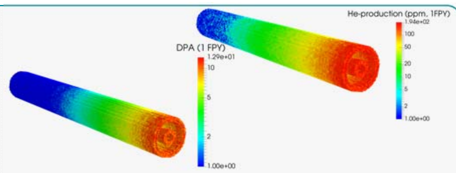
- *Water cooled FW (hom)- ΔTBR=-0.08*
- *Water cooled FW (het) - ΔTBR=-0.10*

Conclusion:

- *Any geometry simplifications in blanket and BZ result in overestimation of TBR*

Damage accumulation



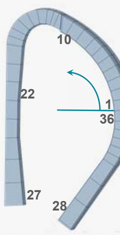


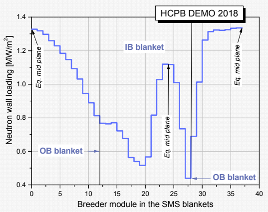
- Peak DPA accumulation is close to the design limit (20dpa/1.57FPY)
- He accumulation behind the blanket is below design limit (1ppm/1.57FPY)
- He accumulation in the VV should be further investigated

FW load

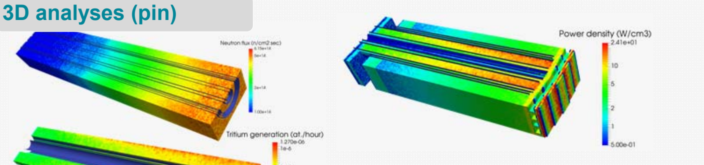
FW neutron wall load:

- *maximum OB – 1.33 MW/m²*
- *maximum IB –1.03 MW/m²*
- *average – 0.93 MW/m²*





3D analyses (pin)

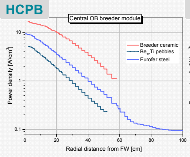


- Neutron streaming through the pin is smaller compared to the one through $Be_{12}Ti$ pebbles
- Tritium generated more intensively in outer region of the ceramic tube
- Power generation in the ceramic is higher in the outer layers close to $Be_{12}Ti$

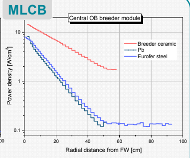
Energy generation

Component	HCPB	MLCB
Blankets	1931	1646
Vacuum vessel	49	77
Divertor	170	197
Total	2150	1920
Energy multiplication factor	1.35	1.20

HCPB

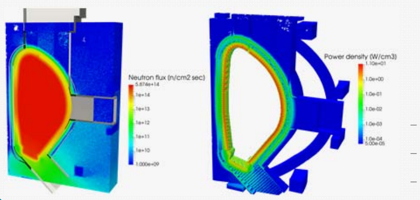


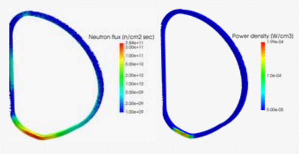
MLCB



- Energy generation in the HCPB is higher compared to the MLCB DEMO
- The highest temperatures in the ceramic and steel are close
- Energy multiplication in the HCPB blanket is higher

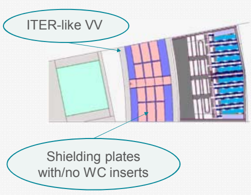
3D analyses (reactor)

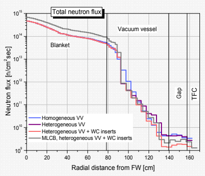


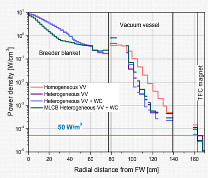


- Neutron streaming through the divertor port is significant due to weak shield
- The power density in the magnet appears to be critical close to the divertor port
- Additional shield is necessary around divertor port

Shielding performances







- Shielding performances in basic case are not sufficient
- Inclusion of WC inserts improves the shielding performances
- Neutron streaming through divertor port must be minimized

Conclusions

- The innovative HCPB SMS blanket design based on the DEMO baseline 2017 was developed and successively optimized by means of coupled particle transport and thermal-hydraulic simulations
- The new HCPB blanket provides sufficient **TBR=1.16** and includes:
  - *Breeder pins instead of cooling plates*
  - *$Be_{12}Ti$ instead of Be*
  - *Li_4SiO_4 + 30% mol. Li_2TiO_3 instead of Li_4SiO_4*
- Alternative MLCB blanket design with Pb neutron multiplier was developed and optimized to provide **TBR=1.13**
- The detailed heterogeneous modelling enables to assess a realistic tritium breeding

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