Karlsruhe Institute of Technology

Institute for Neutron Physics and Reactor Technology (INR)
P.O. Box 3640, D-76021 Karlsruhe, Germany
[a]**Fusion for Energy (F4E)**
Garching, Germany

INR ISFNT14 22-27 September 2019 Budapest, Hungary
EUROfusion

Analyses of the shielding options for HCPB DEMO

Pavel Pereslavtsev, Fabio Cismondi[a], Francisco A. Hernández

Objectives

Assessment of different shielding options to be implemented in the HCPB blanket to demonstrate comparable capabilities as the ones of the WCLL to protect the VV and to reduce its long term activation.

The following nuclear responses have to be assessed:

- *Tritium breeding ratio (TBR),*
- *Effect of different design modifications on DPA accumulation in the vacuum vessel,*
- *Activation of the vacuum vessel*

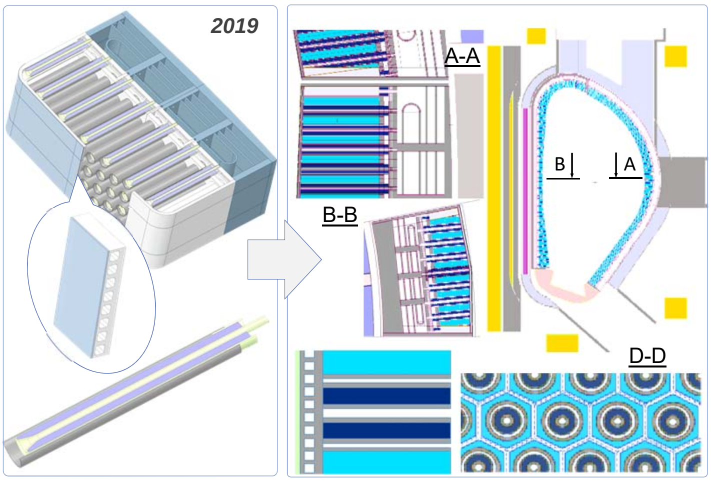
Models

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

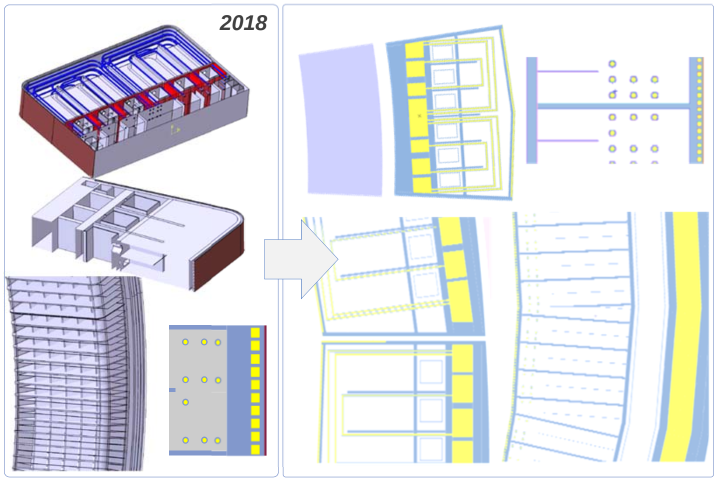
II. SMS blanket MCNP models for HCPB and WCLL DEMOs
   - *Roof-top shape FW with a W layer (2 mm)*
   - *Faceted FW, poloidal segmented empty blanket casing (box)*

III. Breeder element MCNP model
   - *Breeder element geometry universe: hexagonal radial oriented in HCPB, two layer horizontal block in WCLL, fully heterogeneous*
   - *Each blanket segment is filled with breeder elements applying repeated structure function*
   - *FW is filled with cooling channels using repeated structure function*

HCPB: CAD and MCNP models



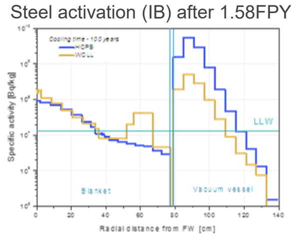
WCLL: CAD and MCNP models



Basic assessments

- Tritium breeding capability
  - *HCPB: TBR=1.20*
  - *WCLL: TBR=1.10*
  - *WCLL (mod. FW): TBR=1.12*
- DPA accumulation in the VV inner shell:
  - *HCPB – 0.130 dpa/FPY*
  - *WCLL – 0.013 dpa/FPY*
- Steel activation in the VV for the HCPB blanket is ~10 times bigger compared to the WCLL one

- Steel activation (IB) after 1.58FPY



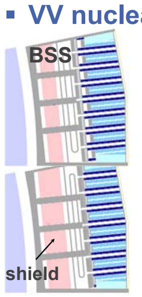
Shielding materials

Compound	Density [g/cm³]	Max. temperature [°C]
WB	15.63	2785
B_4C	2.52	2763
WC	15.63	2785
$YH_{1.6}$	4.32	1200
$YH_{1.75}$	4.31	1130
$ZrH_{1.6}$	5.86	816
LiH	0.78	680
TiH_2	3.76	600
H_2O	0.7*	311

*155 bar, 311 ℃

- HCPB blanket manufacturing processes envisages post-welding heat treatment up to ~1000°C
- Compounds to be used *inside the blanket*: *WB, B_4C, WC, $YH_{1.6}$, $YH_{1.75}$*
- Compounds to be used *outside the blanket*: *$ZrH_{1.6}$, LiH, TiH_2, H_2O*
- Hydrides must be enclosed in a steel cladding
- *WB* and *WC* have a high density resulting in a high blanket weight
- For the arrangement outside the blanket cooling conditions must be checked

VV nuclear damage (I)



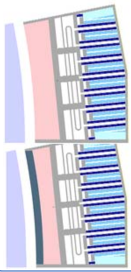
Shield thickness	DPA/FPY							
	B_4C	WB	WC	$YH_{1.6}$	$YH_{1.75}$	$ZrH_{1.6}$	LiH	TiH_2
12 cm	0.043	0.037	0.042	0.036	0.033	0.026	0.035	0.022

- No shield option (12 cm thick block in the BSS) provides dpa accumulation in the VV comparable with WCLL blanket
- The metal hydrides are more preferable

Shield thickness	DPA/FPY							
	B_4C	WB	WC	$YH_{1.6}$	$YH_{1.75}$	$ZrH_{1.6}$	LiH	TiH_2
18 cm	0.024	0.019	0.023	0.023	0.022	0.015	0.024	0.014

- 18 cm thick ZrH1.6 and TiH2 shield blocks arranged in the BSS provide the similar dpa accumulation in the VV as in the WCLL blanket
- The squeeze of the He feeding manifolds results in the additional presser drop that must be assessed

VV nuclear damage (II)



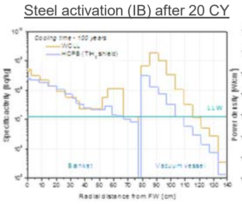
Shield thickness	DPA/FPY							
	B_4C	WB	WC	$YH_{1.6}$	$YH_{1.75}$	$ZrH_{1.6}$	LiH	TiH_2
18 cm	0.015	0.012	0.014	0.015	0.014	0.010	0.014	0.008

- All shielding materials placed behind the BSS appeared to be more efficient for the protection of the VV compared to their integration inside the BSS.
- 18 cm thick pressurized water tank attached behind the BSS ensures damage in the VV inner shell of 0.027 dap/FPY (the least efficient shield)
- Hybrid shield block of two materials (12 cm TiH_2 + 6 cm WB or WC) provides 0.009 dpa/FPY that is higher compared to the pure TiH_2 block
- The cooling options for the shielding blocks attached behind the blanket have to be checked with appropriate thermal-hydraulic analyses.

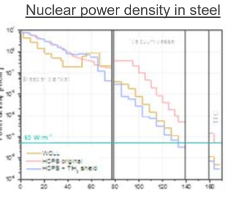
Accompanying analyses

- The significant reduction of the SS-316L(N)-IG steel activation in the VV by implementing of the TiH_2 shield block attached to the BSS
- As ultimate design variation the 25 cm thick TiH_2 shield block was tested being attached behind the BSS in the HCPB blanket resulting in 0.006 dpa/FPY, the TBR≈1.15
- A completely closed gap between blankets provides the decrease of the activity in the VV by 10%

Steel activation (IB) after 20 CY



Nuclear power density in steel



Conclusions

- Fully heterogeneous MCNP DEMO geometry models were developed for the latest designs of the HCPB and WCLL blankets
- The basic nuclear responses were calculated:
  - *Tritium breeding ratio in the HCPB ZBR=1.20, in the WCLL TBR=1.10*
  - *DPA accumulation in the inner shell of the VV: HCPPB – 0.13 dpa/FPY, WCLL – 0.013 dpa/FPY*
- Arrangement of the 18 cm thick shield (metal hydrides *$ZrH_{1.6}$*, *TiH_2* or *WB* and *WC* compounds) behind the BSS in the HCPB results in decrease of the dpa accumulation in the VV by the factor ~20.
- The inventory calculations show:
  - *The deficiency of both blanket concepts to achieve VV activation below LLW*
  - *Implementation of the plug shield behind the BSS in the HCPB results in ~10 times lower activation of the VV compared to the WCLL blanket but still above LLW*

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.