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Consolidated Design of the HCPB Breeding Blanket for the Pre-Conceptual Design Phase of the EU DEMO and Harmonization with the ITER HCPB TBM Program

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20th International Workshop on Ceramic Breeder Blanket Interactions, Karlsruhe, 18-20 September 2019

Outline

1. HCPB BL2017 v1: Design Architecture
2. Performance: Neutronics, Thermo-hydraulics, Thermo-mechanics
3. Plant Integration: HCPB TER and HCPB PHTS & BoP
4. DEMO Relevancy of the ITER HCPB-TBS
5. Summary and Outlook Towards the CD Phase

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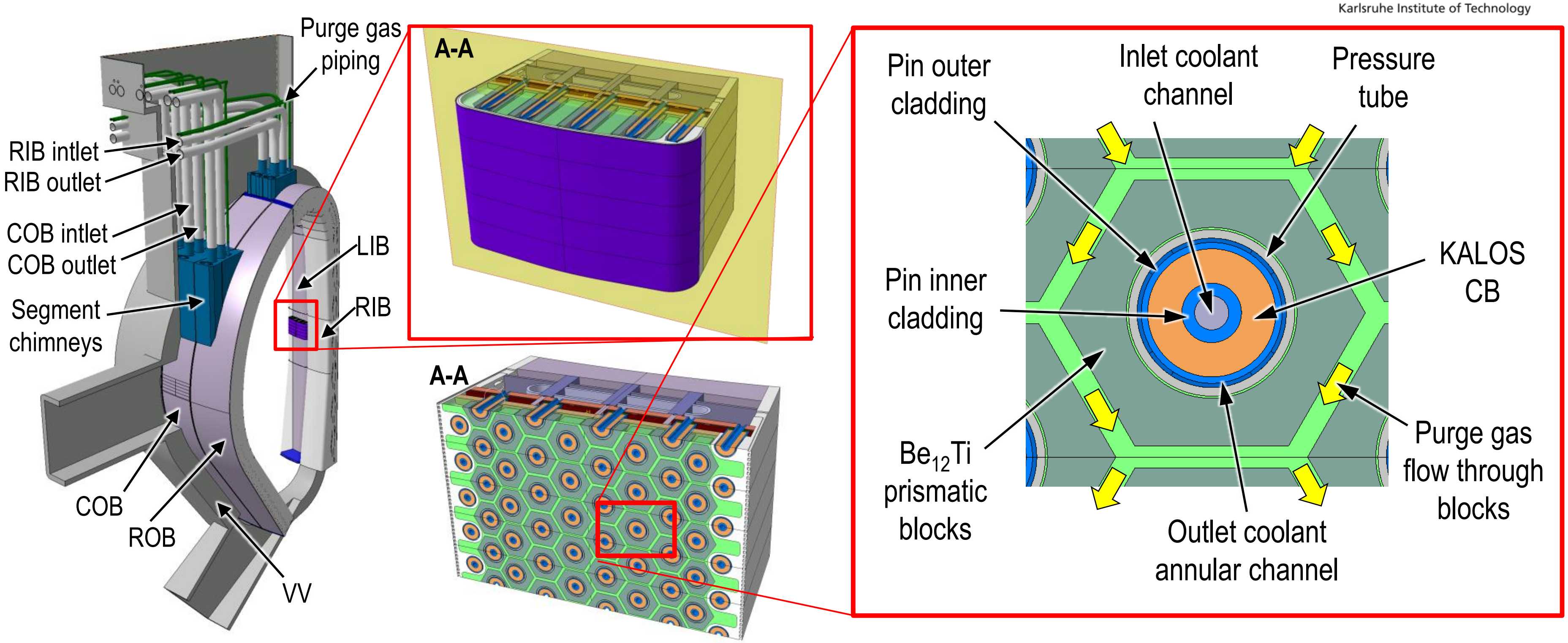
2. HCPB BL2017 v1: Design Architecture



- HCPB integrated into DEMO1 BL2017 (16 sectors, R_0=9m, A=3.1, P_{fus}≈2GW)
- 1 sector = 3 outboard (OB) + 2 inboard (IB) (single module) segments
- Arrangement of fuel-breeder pins containing KALOS CB (Li_4SiO_4 + 35mol% Li_2TiO_3)
- Pins inserted into hexagonal prismatic blocks of $Be_{12}Ti$ neutron multiplier
- Structural steel: EUROFER97

2. HCPB BL2017 v1: Design Architecture

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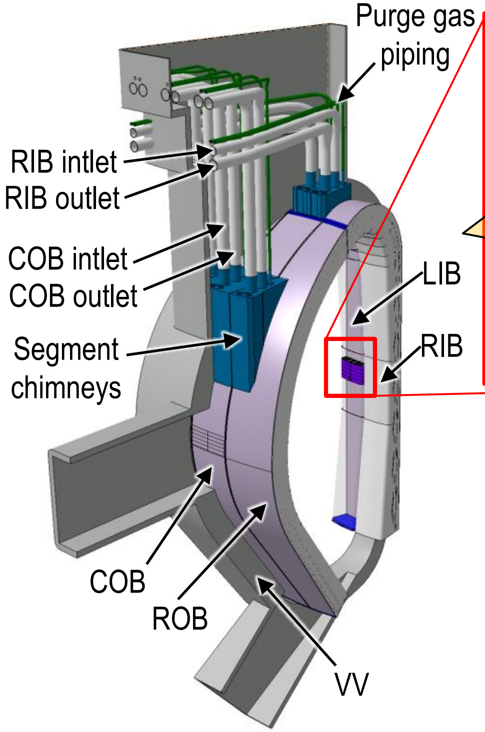

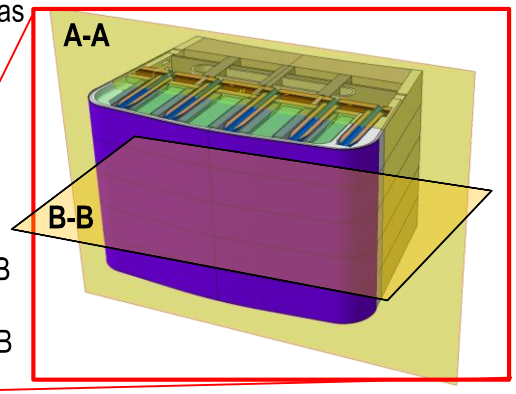

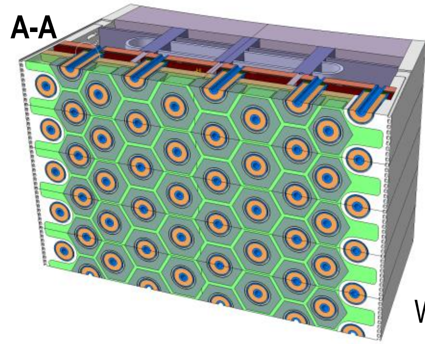

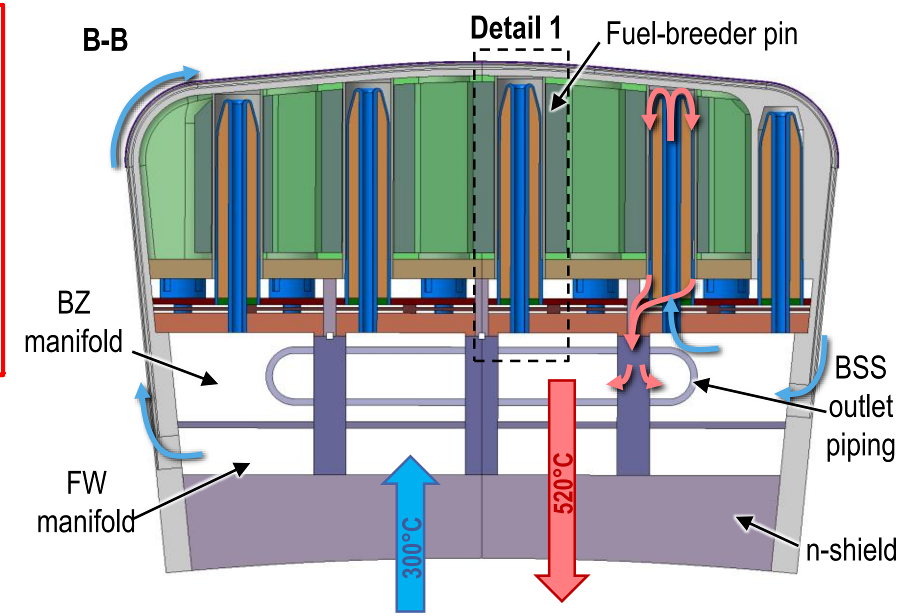

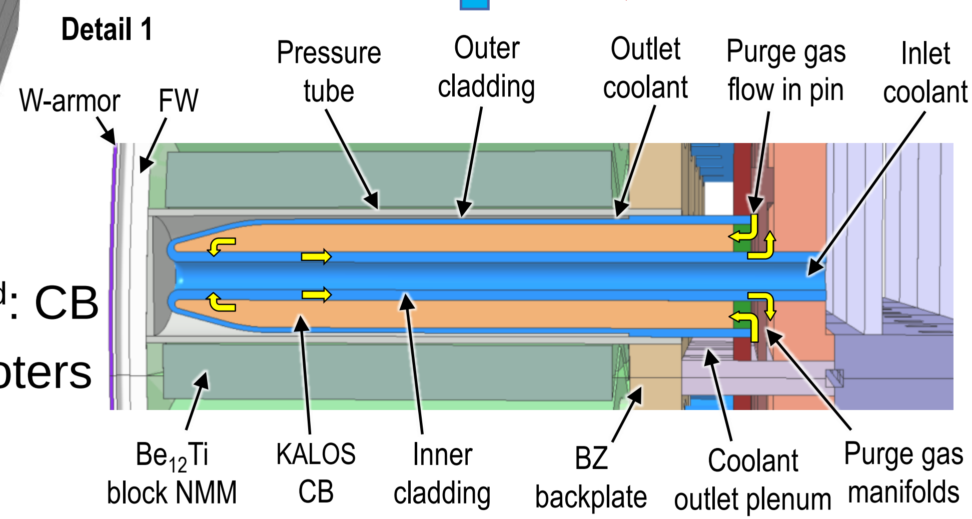

- Coolant: He @80bar, 300°C-520°C
- Purge gas: He + 0.1vol% H_2 @2bar ($He+H_2O$ as alternative); 1st: NMM, 2nd: CB
- FW roof-top shaped, turbulence promoters in FW and BZ
- Easier filling of functional materials

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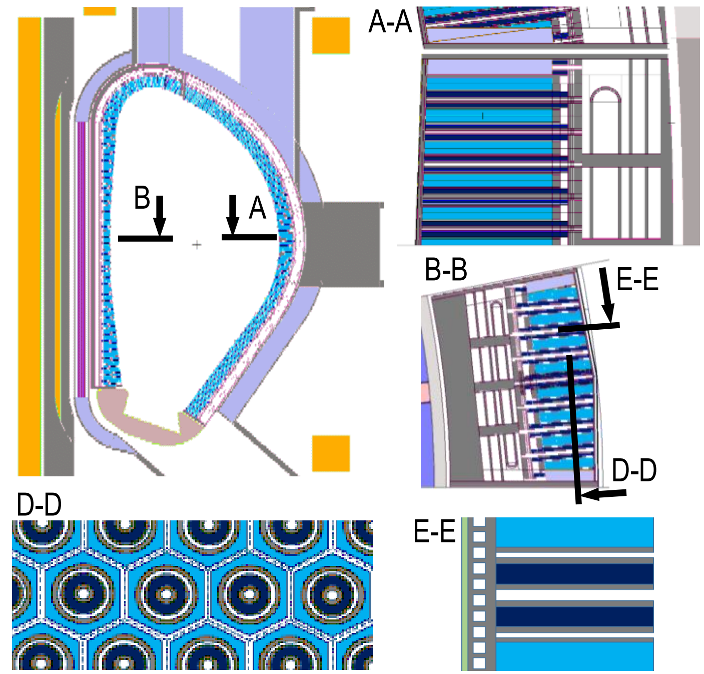
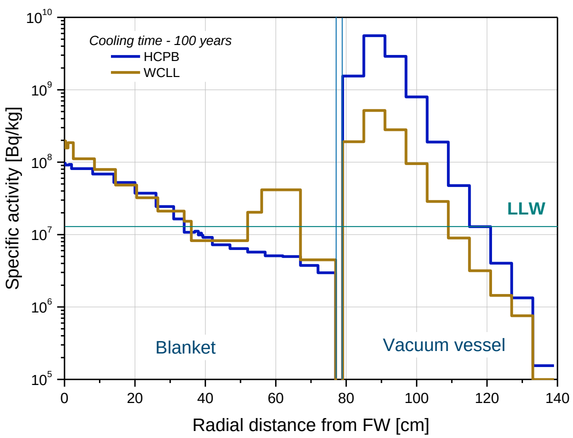
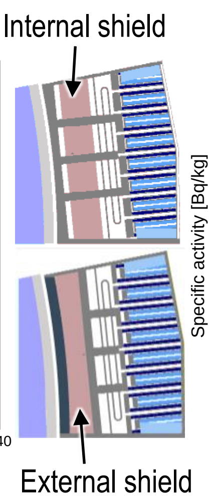
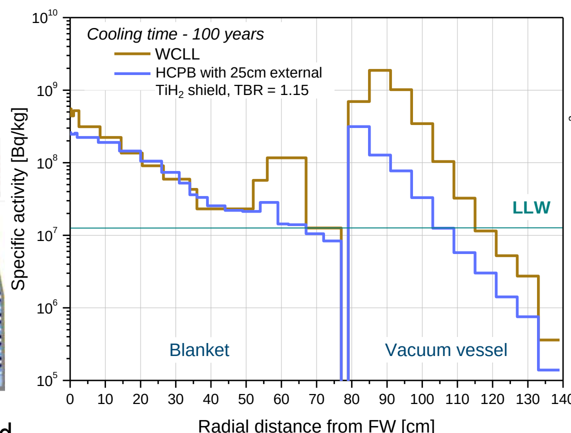
3. Performance: Neutronics

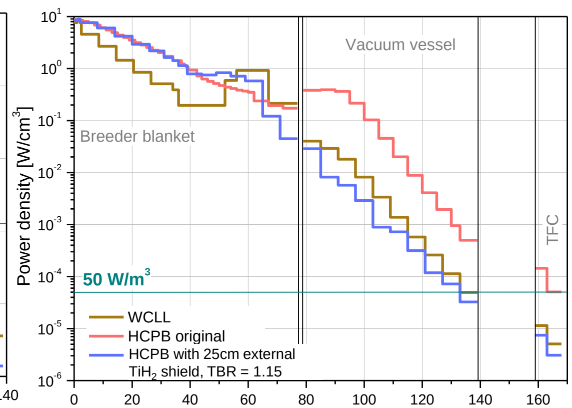
- Fully heterogeneous MCNP model
- Tritium Breeding:
  - ^{6}Li 60%: TBR ≈ 1.20, ^{6}Li 40%: TBR ≈ 1.16
- Neutron shielding:
  - Increased concern on VV activation: BB should contribute to ALARA-activate VV
  - dpa_{VV} ≈ 0.130dpa/fpy (WCLL ≈ 1/10 HCPB)
  - Best mats.: TiH_2, $ZrH_{1.6}$, $YH_{1.75}$, WC, B_4C
  - 18cm external shield => WCLL-like dpa_{VV}











3. Performance: Thermo-hydraulics (TH)

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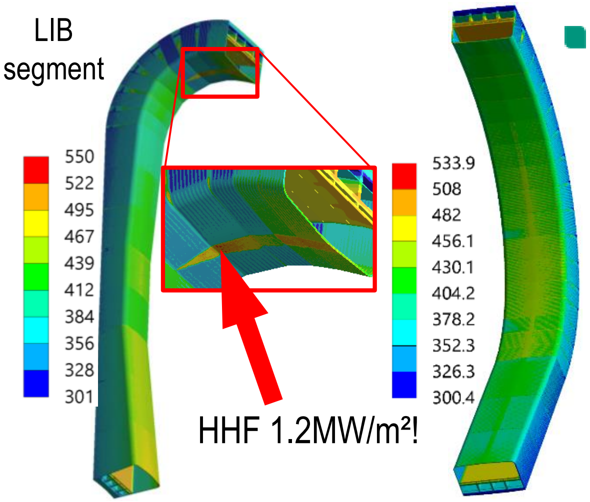
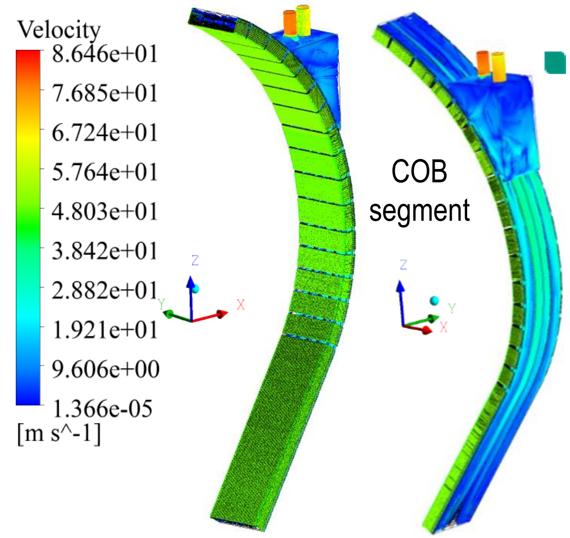
Global FEM TH analyses



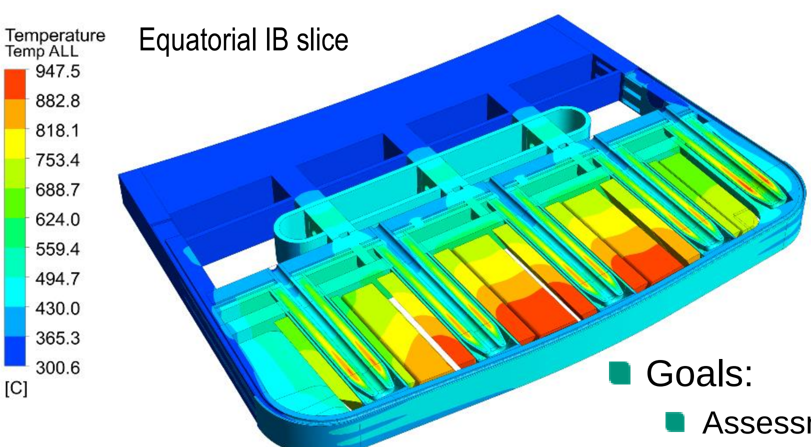
- Goals:
  - Assessment on adequacy of coolant parameters, even under HHF laods
  - Input for further global TM analyses

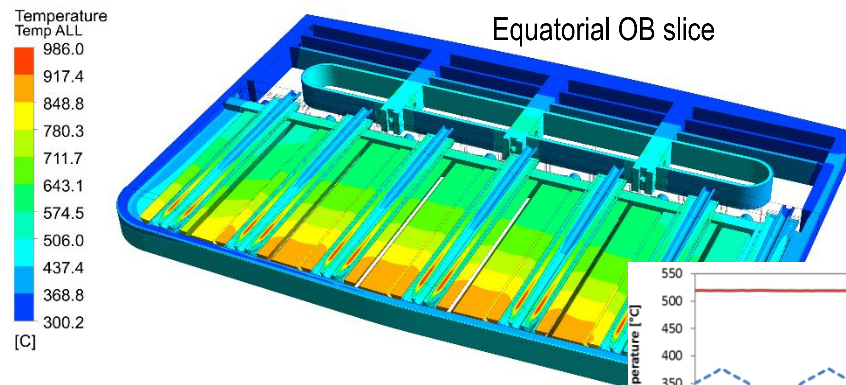
Global CFD hydraulic analyses



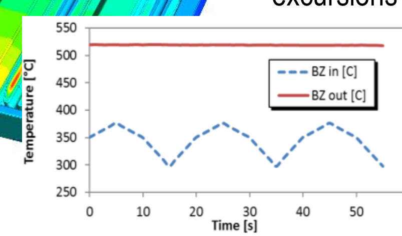
- Goals:
  - Assessment of total BB pressure drops (0.8 bar!)
  - Benchmark and calibration of global TH models with RELAP5 for WPBOP and WPSAE

Detailed local CFD TH analyses





Transient: Power excursions



- Goals:
  - Assessment of temperature limits compliance
  - Input for further local TM analyses

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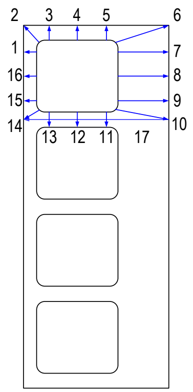
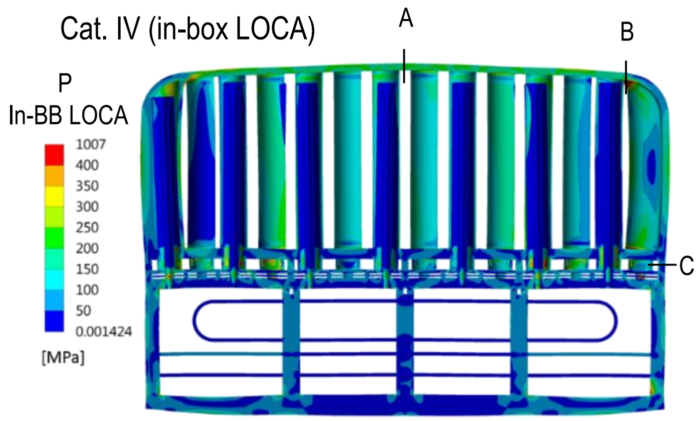
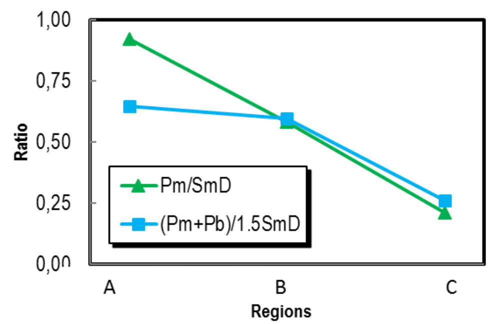
3. Performance: Thermo-mechanics (TM)

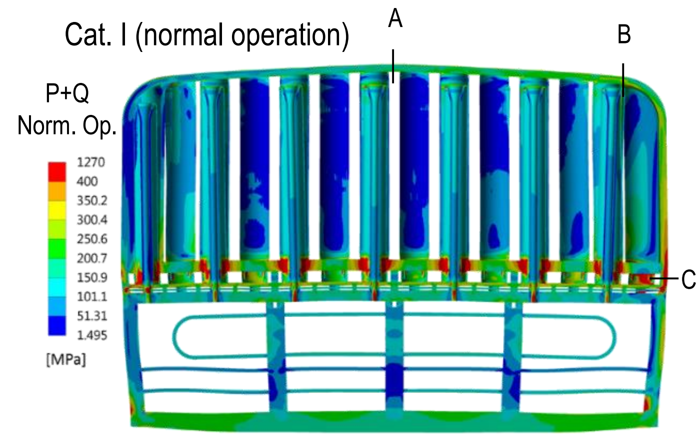
- Local FEM TM analyses (Cat. I & IV)

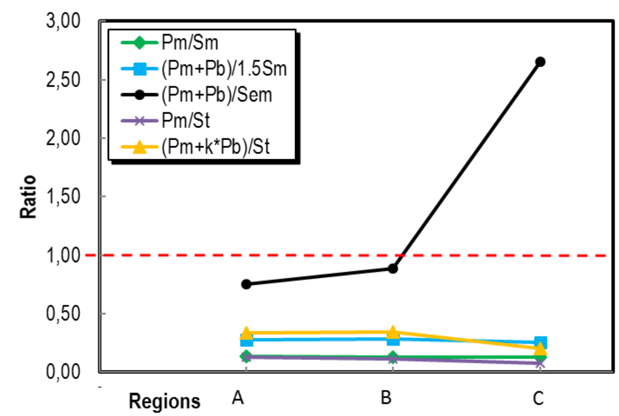


Display of paths for stress linearization









- Global FEM TM analyses (Cat. II & III)
  - Analyses involving VDE scenarios
  - EM inputs recently finished; Ongoing work with focus on BB attachment

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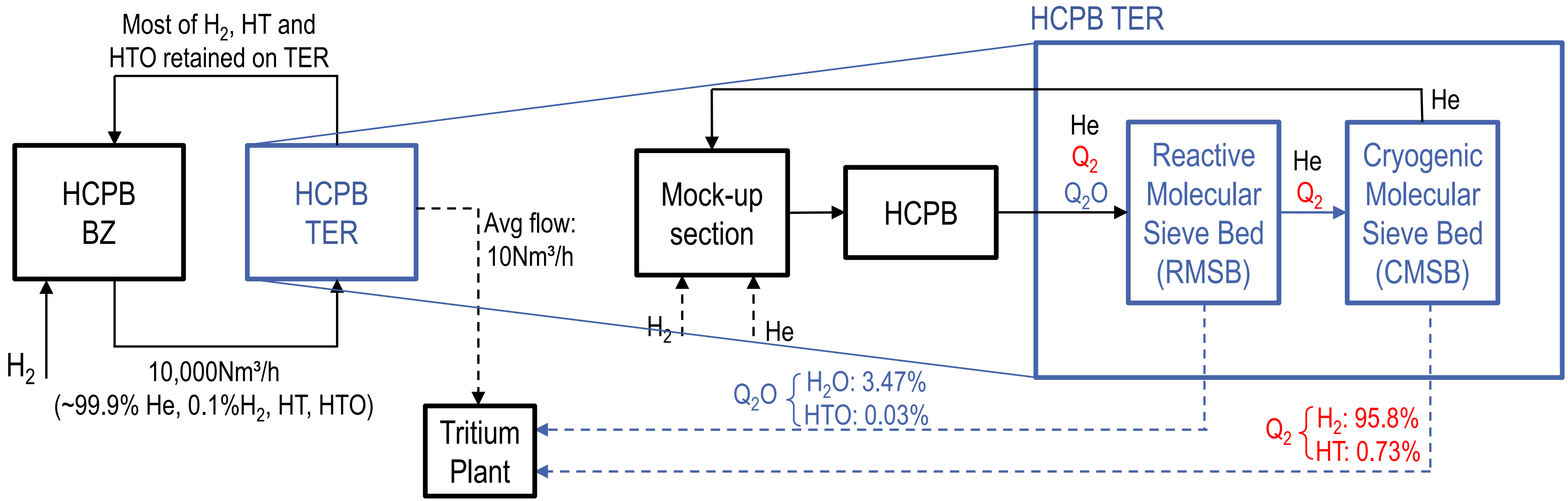
4. Plant Integration: HCPB TER System



- Selected TER technology: cryogenic approach (higher TRL)
- Purge gas chemistry: He + 0.1%H_2 => permeating Q_2 species => T permeation
- Alternative chemistry: He + x% H_2O (“wet” purge gas) => non-permeating Q_2O species => T permeation reduced orders of magnitude, but fast corrosion of EUROFER97 and safe use with beryllides to be assessed
- TER technology for wet purge gas can also be based on RMSB

4. Plant Integration: HCPB PHTS and BoP

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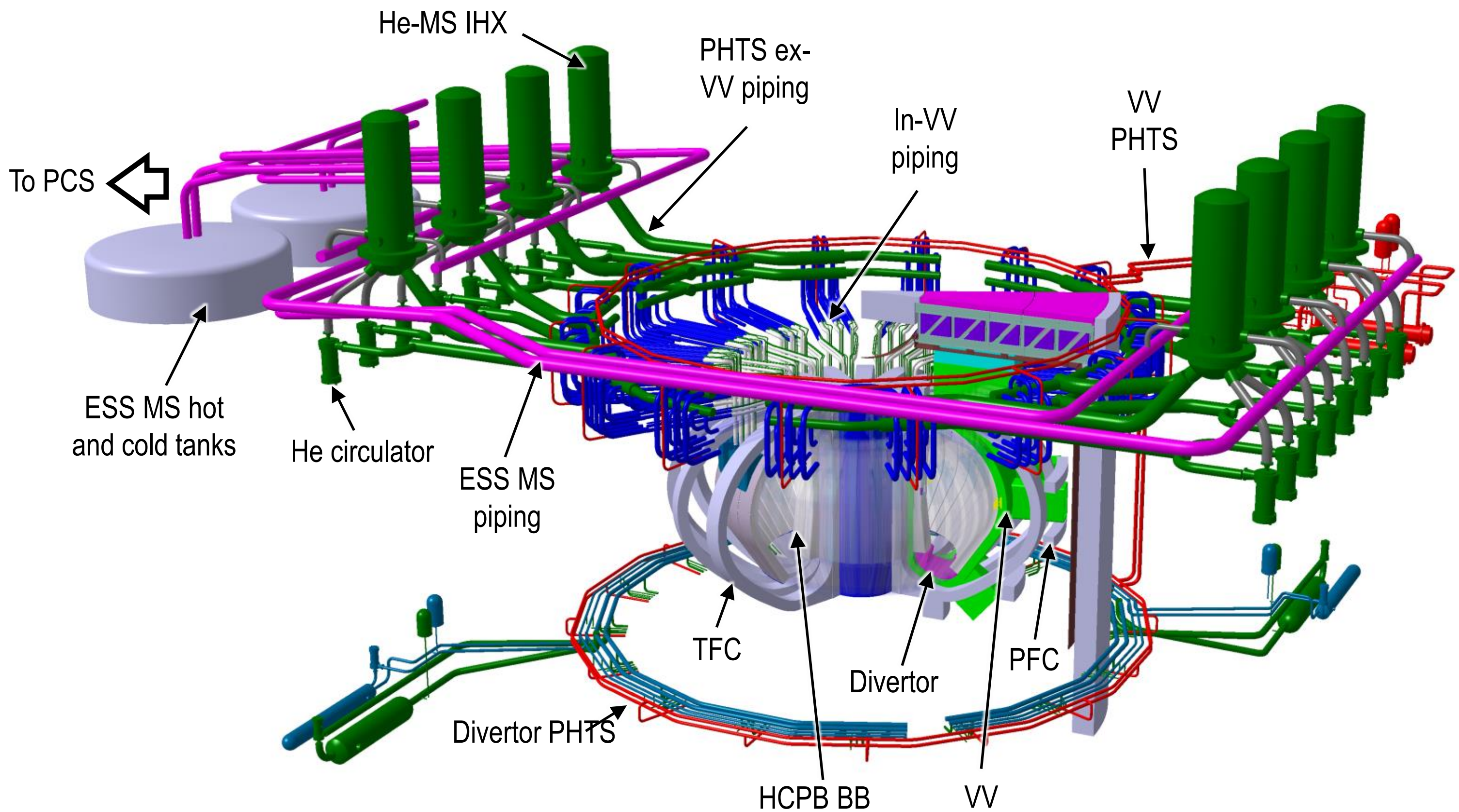

- BoP = PHTS + IHTS(ESS) + PCS ; PHTS: 8 loops ; 1 loop = 1 IHX + 2 circulators
- High BoP TRL ⬄ $P_{1circ,el}$ <6MW ⬄ Δp_{PHTS} <3 bar (for P_{fus}≈2GW)
- Δp_{inVV}≈0.8 bar; Δp_{exVV}≈1.9 bar; Δp_{PHTS}≈2.7 bar => **$P_{pump,el}$ ≈90MW ($P_{1circ,el}$ ≈5MW)**

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Outline

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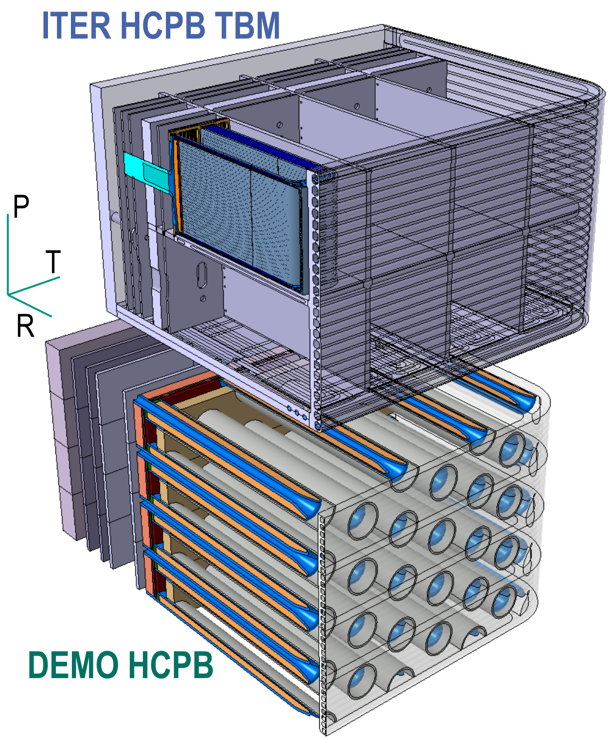
5. DEMO Relevancy of the ITER HCPB-TBS

- Technical Performance Assessment EU DEMO through ITER TBM:



	ITER CDR HCPB TBM	DEMO PCD HCPB
Coolant	He	He
• Pressure / Tin / T_{out}	80 bar / 300°C / 500°C	80 bar / 300°C / 520°C
Steel		
• Type	EUROFER97	EUROFER97
BFMs		
• CB / Li6	Li_4SiO_4 / 90%	Li_4SiO_4+Li_2TiO_3 / 60%
• T_{max} CB / PF	920 °C / ~63%	920 °C / ~63%
• NMM	Be	$Be_{12}Ti$
• T_{max} NMM / PF	650 °C / ~63%	- / blocks
Purge gas		
• Chemistry / Pressure	He + 0.1%H_2 / 4 bar	He + 0.1%H_2 / 2 bar
FW		
• Length x thickness	3m x 29mm	~3m x 20mm
• Channels section	(15 x 15)mm	~(12 x12)mm, variable
• Mass flow / speed	100 g/s / 80 m/s	~50 g/s / ~50m/s
• HTC / augmentation	6400 W/m²K / no	8000 W/m²K / yes
BU / Pin		
• T x P x R | Ø / pitch	(205 x 205 x 480)mm	Ø80mm / 130mm
• Mass flow per unit	~50 g/s	~20 g/s
Stiffening grids		
• Channel section	(6 x 10)mm	-
• HTC / Δp	4400 W/m²K / 0.24 bar	-

- Functionality ("act-alike" philosophy) is maintained
- Expected that EU TBM RoX to DEMO will still be very relevant despite changes

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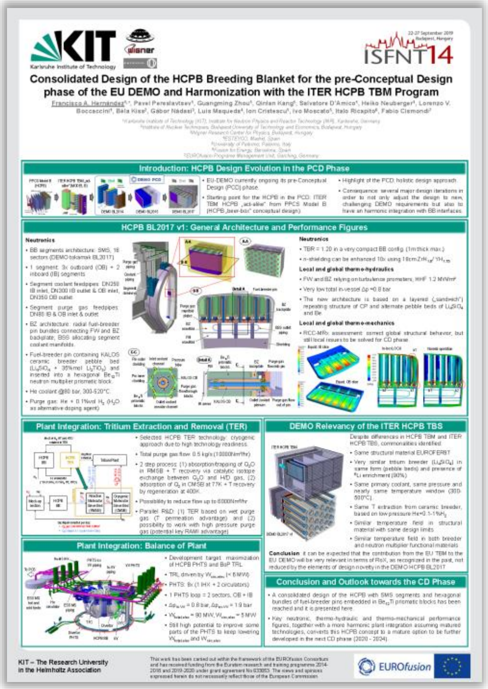
6. Summary and Outlook Towards CD Phase

- Current reference design: fuel-breeder pin in hexagonal prismatic $Be_{12}Ti$ blocks
- Basic key performance indicators (neutronics, thermo-hydraulics, thermo-mechanics) show promising results
- “Interface-friendly” design => helps to keep high TRL of key interfacing systems (TER and BoP)
- Design to be presented at the PCD phase Gate Review => starting point for CD phase



- You’re welcomed for a further discussion at ISFNT (Poster P1-083, Monday 23rd)!

Back up slides

Outline

1. Introduction: HCPB Design Evolution

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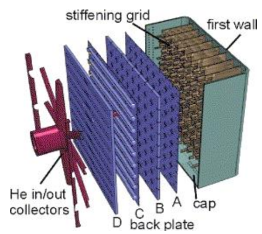
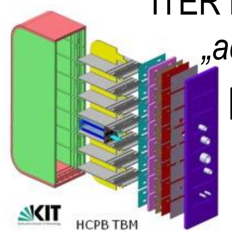
- Design iterations to meet new, very challenging DEMO requirements



PPCS Model B (HCPB)

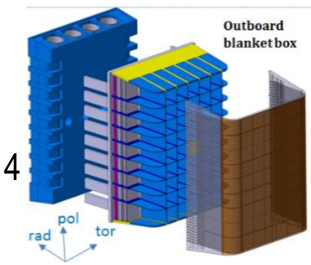
ITER HCPB TBM
„act-alike“



- New paradigm: Stakeholder focus on near-term, high TRL solutions

2014

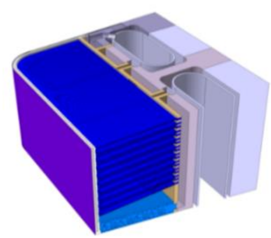
DEMO baseline 2014



\+ ↑↑ Robustness (in-box LOCA)
– ↓↓ TBR (1.06)
– ↑↑ Fabrication & assembly complexity
– ↑↑ Δp (P_{pump}≈250MW, low TRL BoP)

2015
2016

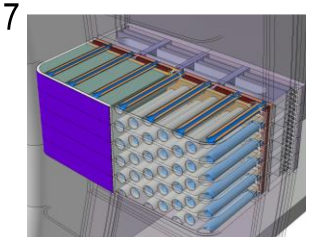
DEMO baseline 2015



\+ ↑ Robustness (in-box LOCA)
\+ ↑ TBR (1.15)
– ↑ Fabrication & assembly complexity
– ↑ Δp (P_{pump}≈150MW, low TRL BoP)

2017
2018
2019
2020

DEMO baseline 2017



\+ ↑ Robustness (in-box LOCA)
\+ ↑ TBR (1.20)
\+ ↓ Fabrication & assembly complexity
\+ ↓ Δp (P_{pump}≈ 90MW, high TRL BoP)
– RAMI

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