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Thermal hydraulics activities for the consolidated HCPB breeding blanket of EU DEMO

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1. Features of Design

- A-A, B-B, C-C, Detail 1
- BZ backplate, Front ribs, BSS outlet piping, Back ribs
- Fuel-breeder pin
- BSS backplate (+shielding)
- BSS FW separator plate
- FW manifold
- FW, N-armor
- Purge gas manifold front plate, Purge gas manifold mid plate, Purge gas manifold back plate
- BZ manifold
- Pressure tube, Purge gas flow in NMM, Outer cladding, Outlet coolant, Purge gas flow in pin, Inlet coolant
- NMM (Be$_{12}$Ti block), KALOS CB, Inner cladding, Backplate, Coolant outlet plenum, Purge gas manifolds
- KALOS breeder ceramics, Pin inner cladding, NMM (Be$_{12}$Ti block), Pressure tube, Inlet coolant channel, Outlet coolant annular channel, Pin outer cladding

HCPB integrated in EU DEMO BL2017 sector

3. CFD analysis of Blanket Unit-Slices

- Unit-slices at IB and OB equatorial position were analyzed and optimized by CFX calculations.
- Max. Temp. at IB/OB = 947.5/986.0 °C, on Be12Ti (IB) and KALOS (OB)

Temp. of IB blanket unit-slice [°C]

Temp. of OB blanket unit-slice [°C]

Velocity of IB blanket unit-slice [m/s]

Velocity of OB blanket unit-slice [m/s]

2. TH of Blanket Segment

[W/cm²] 125.666, 112.146, 98.626, 85.1062, 71.5864, 58.0665, 44.5467, 31.0268, 17.507, 3.98714

[W/cm²] 31.224, 27.9607, 24.6974, 21.4341, 18.1708, 14.9075, 11.6442, 8.38087, 5.11757, 1.85428

- A script has been written to extract heat flux data from PWI code
- Nuclear Heating on FW
- Power coming from BZ to FW
- Convection heat transfer coefficient calculated using correlations on all channels (FW, BZ, Backplate, BSS)
- Lumped fluid lines technique to get coolant temperature
- Thermal radiation from BSS to Vacuum Vessel

Heat flux on IB and OB FW

550, 522, 495, 467, 439, 412, 384, 356, 328, 301

533.9, 508, 482, 456.1, 430.1, 404.2, 378.2, 352.3, 326.3, 300.4

Temp. of IB and OB Blanket Seg. [°C]

FW outlet temp.

Region name	Temperature [°C]
IB-1 / OB-1	388.5 / 360.0
IB-2 / OB-2	392.9 / 365.1
IB-3 / OB-3	397.5 / 368.1
IB-4 / OB-4	385.6 / 370.1
IB-5 / OB-5	389.9 / 372.2
IB-6 / OB-6	383.6 / 374.0
IB-7 / OB-7	368.1 / 375.6
IB-8 / OB-8	359.5 / 376.8
IB-9 / OB-9	362.9 / 376.2
IB-10 / OB-10	366.1 / 381.1
IB-11 / OB-11	369.5 / 382.2
IB-12 / OB-12	365.9 / 381.8
IB-13 / OB-13	346.3 / 381.7
IB-14 / OB-14	338.2 / 376.1
IB-15 / OB-15	338.5 / 379.8
IB-16 / OB-16	385.2 / 379.6
IB-17 / OB-17	390.8 / 355.0

4. Hydraulics of Blanket Segment

- Porous media approach was used to simplify the model/reduce elements.
- Characterized by two main parameters: porosity and permeability

Region I, Region II, Region III, Region IV, Region V, Region VI, Region VII, Region VIII, Region IX, Region X, Region XI, Region XII, Region XIII, Region XIV, Region XV, Region XVI, Region XVII

COB Segment: Regions Identification

Naming and CFD model

Velocity: 8.646e+01, 7.685e+01, 6.724e+01, 5.764e+01, 4.803e+01, 3.842e+01, 2.882e+01, 1.921e+01, 9.606e+00, 1.366e-05 [m s^-1]

Streamlines of coolant

FW mass flow rate

Region No.	FW G [kg/s] @Design	FW G [kg/s] @Calculated	Deviation [%]
1	1.104E+00	1.125E+00	1.893%
2	1.553E+00	1.689E+00	8.797%
3	1.553E+00	1.689E+00	8.764%
4	1.311E+00	1.408E+00	7.435%
5	1.311E+00	1.409E+00	7.473%
6	1.311E+00	1.406E+00	7.256%
7	1.311E+00	1.413E+00	7.753%
8	1.311E+00	1.372E+00	4.618%
9	1.311E+00	1.368E+00	4.367%
10	1.311E+00	1.368E+00	4.348%
11	1.311E+00	1.367E+00	4.297%
12	1.035E+00	1.093E+00	5.612%
13	1.035E+00	1.093E+00	5.559%
14	1.035E+00	1.091E+00	5.448%
15	1.035E+00	1.091E+00	5.440%
16	1.035E+00	1.089E+00	5.208%
17	1.180E+01	1.061E+01	-10.115%
Total value =	3.167E+01	3.168E+01	-0.017%

Average mass flow rate at diff. regions

Region #1, Region #2, Region #3, Region #10, Region #15, Region #16, Region #17

Toroidal distribution of mass flow rate

2.187E-01 6.095E-02 1.882E-02 3.906E-01 1.100E-01 bar bar bar bar bar

OUTLET — ΔP$_{BZtoOut}$ ΔP$_{BZ}$ ΔP$_{FWtoBZ}$ ΔP$_{FW}$ ΔP$_{IntoFW}$ — INLET

ΔP$_{Tot}$ 0.799 bar

OB Pressure drop

5. Conclusions

- 3D thermal hydraulics analysis of HCPB blanket segment taking into account the spatially variable heat fluxes coming from plasma to FW were conducted, confirming the soundness of the current design to cope peak heat fluxes.
- Thermal hydraulic analyses and optimization of typical IB and OB blanket unit-slices were performed to obtain the temperature fields, which were within limits.
- 3D CFD analyses using porous medium approach of the blanket segment were performed, showing good agreement between the calculated flow distribution and design values. The obtained pressure drops of OB and IB blanket segment were 0.799 bar and 0.55 bar, which can be optimized further.