Experimental activities in support of the EU-DEMO Helium Cooled Pebble Bed Blanket design and qualification

Karlsruhe Institute of Technology

HCPB-related Experiments

Breeder Unit

- BU-cooling: Pin-mockup
  - HTC in the annular gap
- Breeding material interaction with Eurofer
- Pressure loss coefficients for pebble bed (cm/s velocity range)

First Wall

- Prototypical Mock-up Units
  - Oxide Dispersed Strengthen (ODS) Steel-FW Mock-up
  - W-Functional Graded (FG) coated FW Mock-up
  - First Wall PMU

EUROfusion

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

ODS-FW & FG-FW Experiments

Karlsruhe Institute of Technology

Objective

- feasibility study of industrial fabrication and production processes
- demonstration of material high temperature performance at T=550 ÷ 650°C under high heat loads

ODS-FW Mock-up

- RAFM 9Cr-ODS Steel Plate (**375x167x20.5** mm³)
- Loading cycles (1000) with high heat flux (750kW/m²) loading on the surface: surface temperature **550°C÷650°C**
- **Mock-up:**
  - 8 channels (15x10mm²) with counter-flow cooling
  - Heated surface 375x130mm²
  - ODS to E97 HIP joining
  - Inconel transition piece from E97 to 316L;

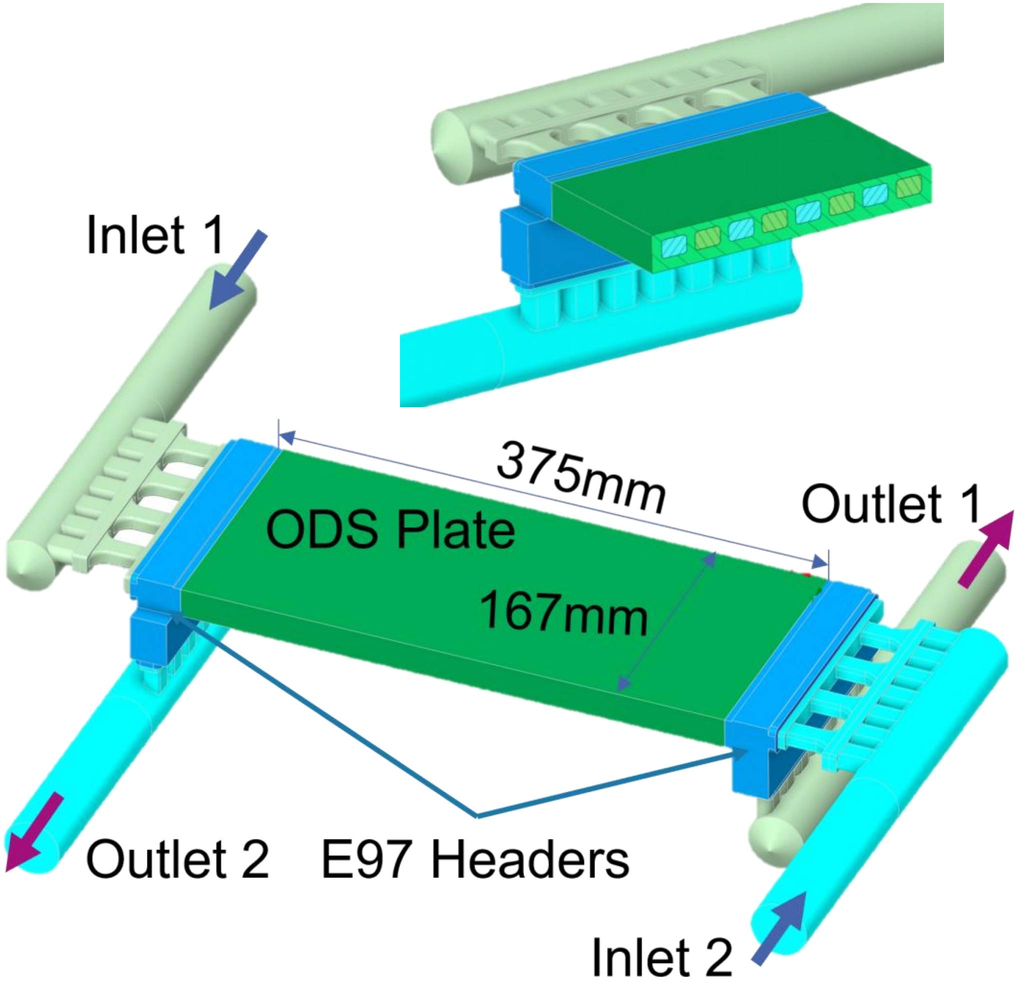
FG-FW Mock-up

- Industrial W FG coating process applied on a **390x247** mm² surface
- Loading cycles (1000) with high heat flux (750kW/m²) loading on the surface: substrate (E97) surface temperature around **550°C**
- **Mock-up:**
  - 12 channels (15x10mm²) with counter-flow cooling
  - Heated surface 350x230mm²
  - Inconel transition piece from E97 to 316L;

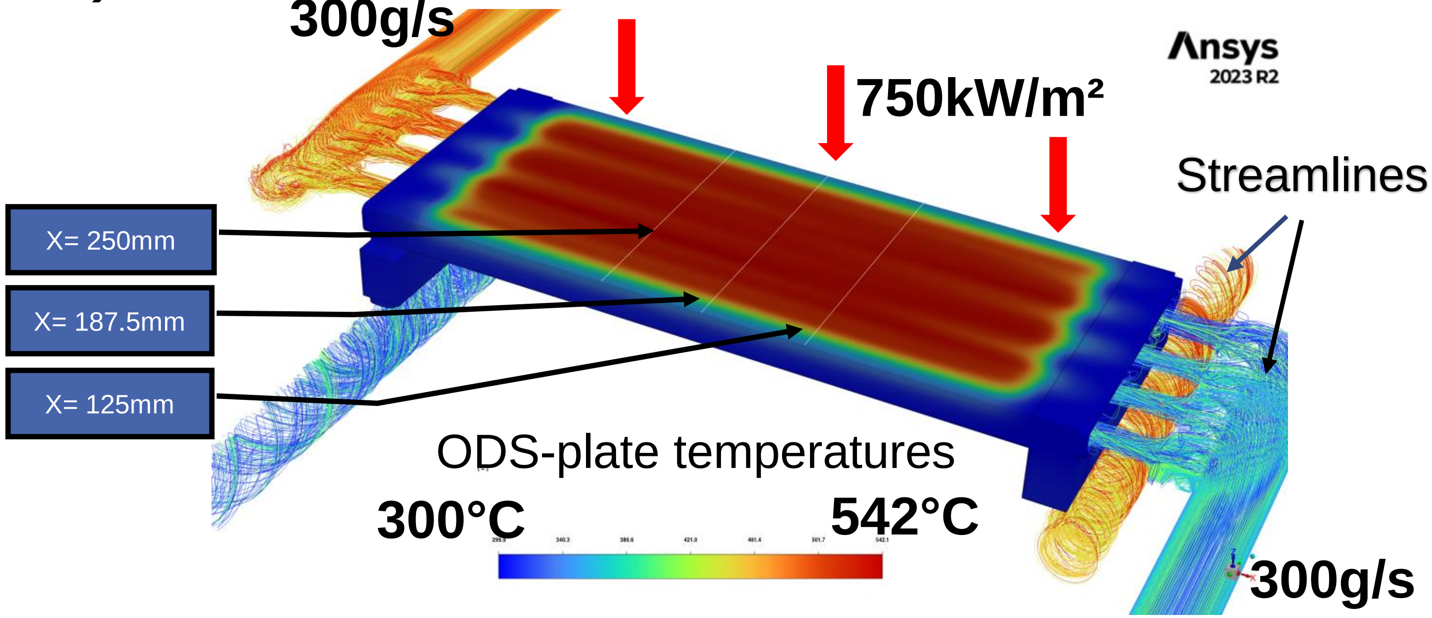
EUROfusion

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Mock-up Design (ODS-FW)

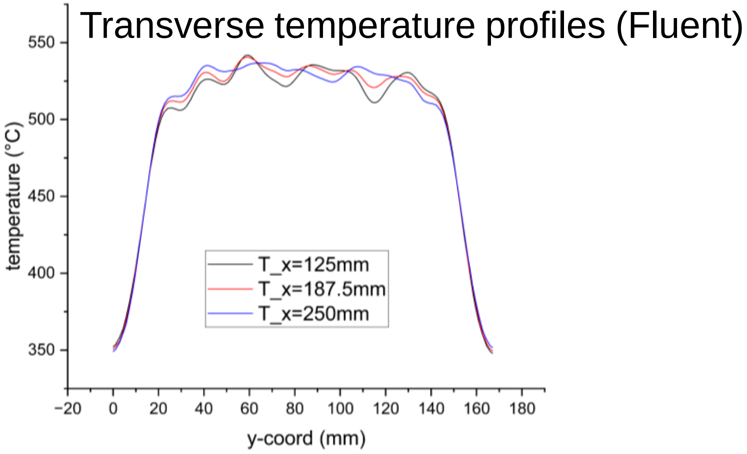


Fluent simulation



Ansys 2023 R2

(raw) ODS plate with headers



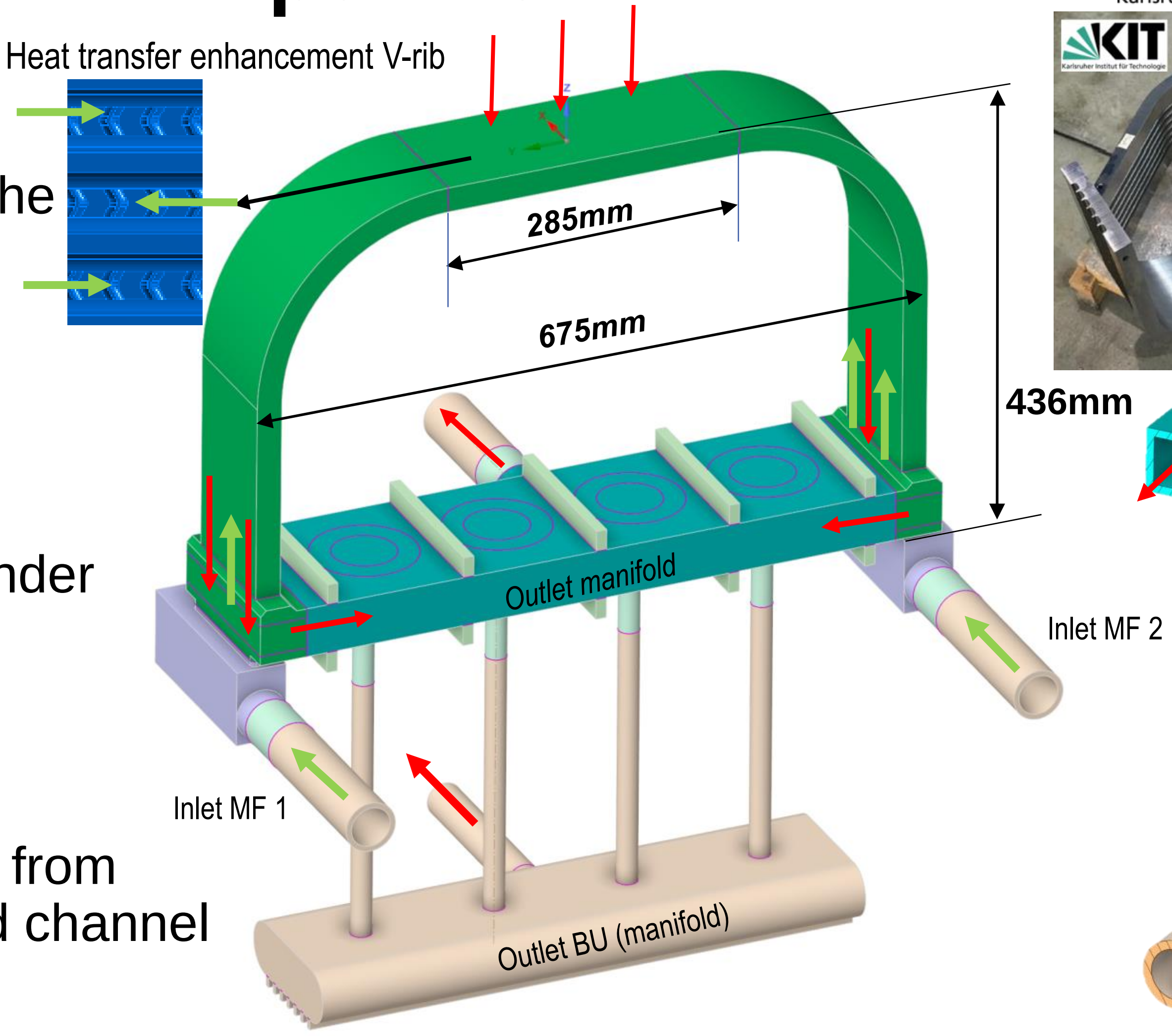
EUROfusion

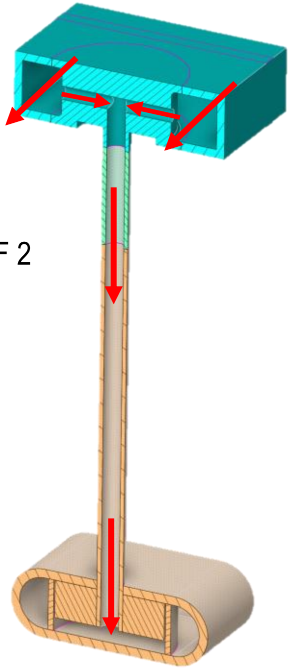
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Karlsruhe Institute of Technology

FW-PMU: Prototypical FW Experiment

- Manufacturing prototype investigating the use of a new technological path
  - U-shaped FW with 6 channels
  - V-rib heat transfer enhancement on the heat loaded side of the channels
- Primary focus on cooling capabilities under high heat flux loadings
- Outlet manifold includes elements of a HCPB BU cooling path
- Test campaign with surface heat fluxes from 280kW/m² up to 1MW/m² (or more) and channel flow rates from 30 g/s up to 150g/s





BU-like cooling path elements

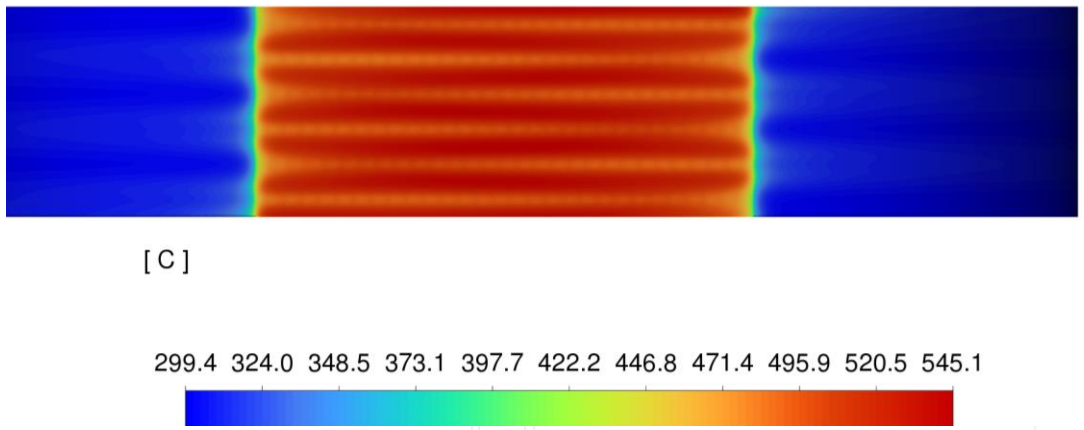
EUROfusion

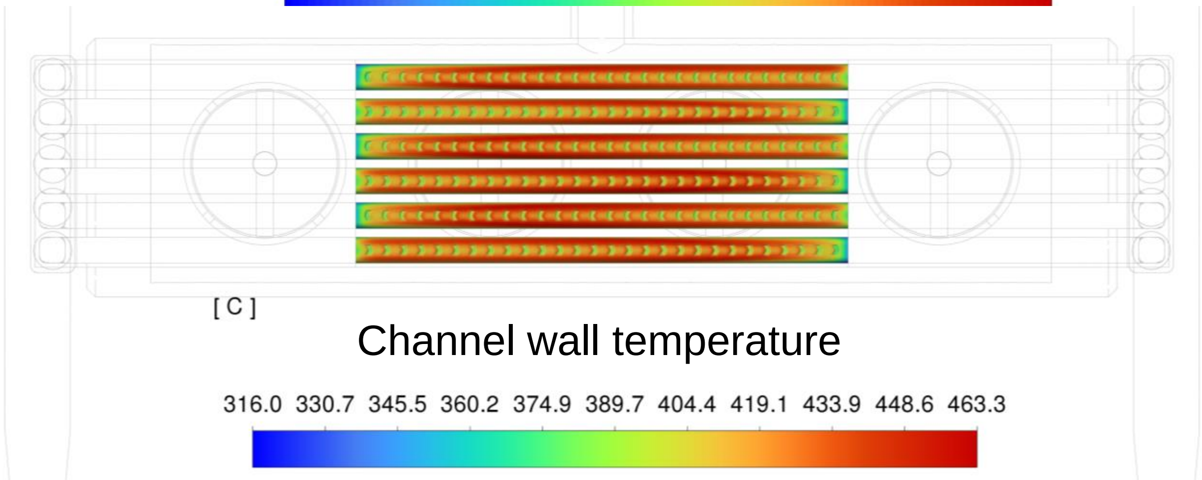
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

FW-PMU: thermal-hydraulic analysis (CFD)

Karlsruhe Institute of Technology

Surface temperature @ 750kW/m² & 70g/s /channel

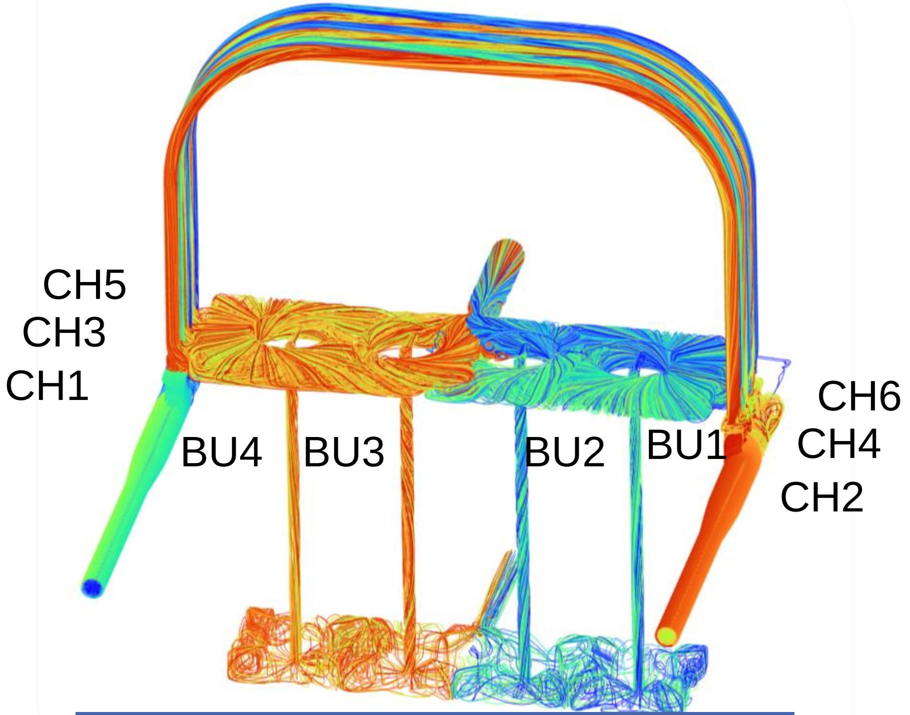




Channel wall temperature

	CH1	CH2	CH3	CH4	CH5	CH6
Flow (g/s)	70.1	69.6	67.99	68.7	72.97	70.7
Deviation to nominal	0%	1%	3%	2%	-4%	-1%

Streamlines: Colours indicate the particle ID



	BU1	BU2	BU3	BU4
Flow (g/s)	15.4	15.3	14.4	14.97
Deviation to mean	-2%	-2%	4%	0%

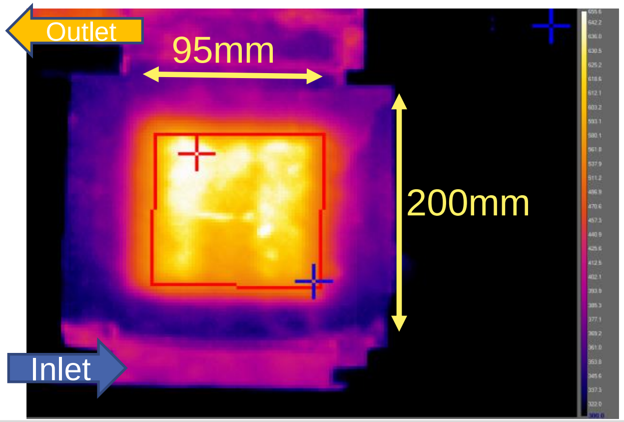
EUROfusion

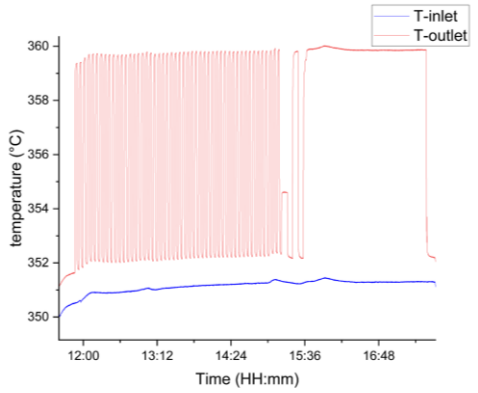
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Validation of computed temperature field

- Widely used methods
  - CFD: fluid-solid coupled simulation (single software tool like CFX or Fluent)
  - Fluid simulation coupled with heat transfer in solids (distinct software tools: CFX or Fluent coupled to ANSYS Thermal)
  - Heat transfer in solids with (simplified) flow and fluid to solid heat transfer models (ANSYS Thermal with fluid lines, for instance)

- Validation case: *2019 (1st) ODS-FW Exp.*
  - 5 channels mock-up with co-curent flow
  - Long (~2h) pulses
  - IR recordings of the surface temperature
  - Reference case: run from 07.10.2019
    - 199.9 ± 0.2g/s
    - 351.3±0.9 °C @ inlet;
    - 7.75±0.9 °C @ outlet;

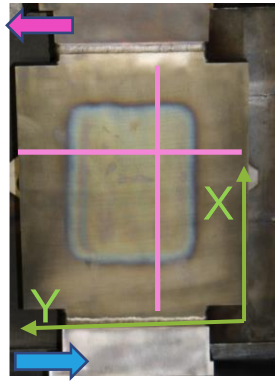


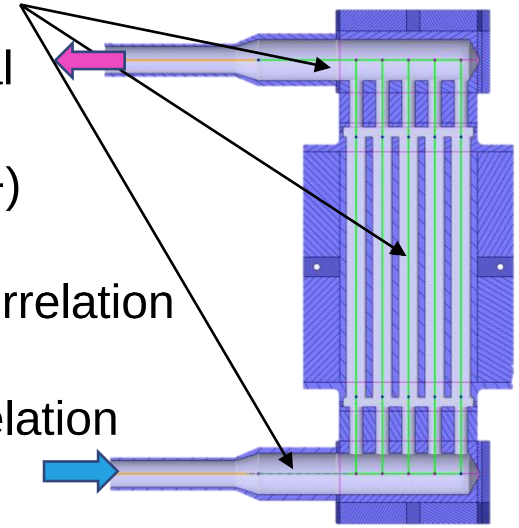


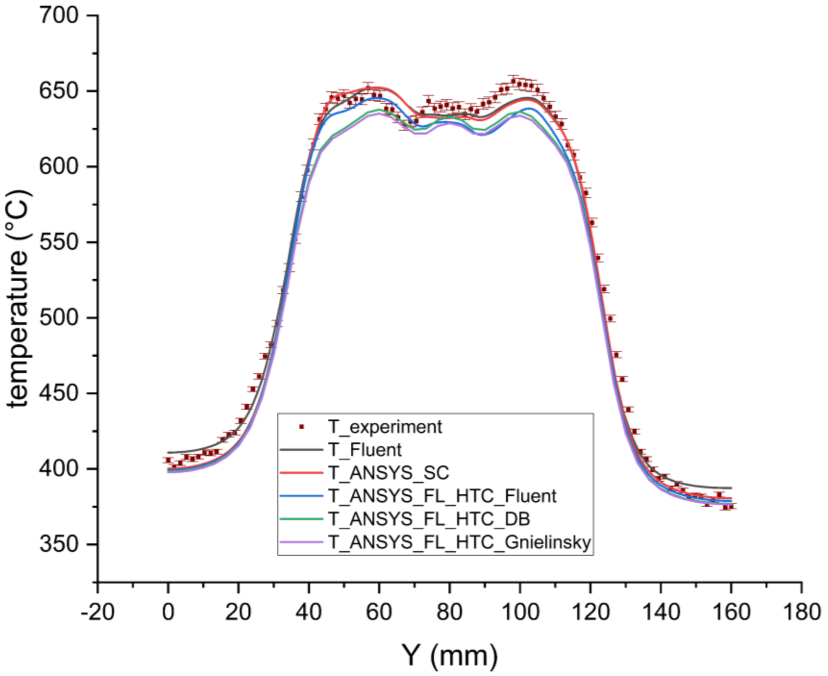
EUROfusion
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Validation of computed temperature field (cont.)

- Heating profile:
  - Power to match the value in experiment: 8894.6W
  - Width& Length from shaded area on the mock-up
- CFD Model: case 1
  - use Fluent (ANSYS 2023R2)
  - Turbulence model SST
- ANSYS Thermal:
  - Case 2: System Coupling Fluent&Thermal
  - Case 3: Thermal with Fluid Lines, HTC from Fluent (Y+)
  - Case 4: Thermal with Fluid Lines, HTC Dittus-Bölter correlation
  - Case 5: Thermal with Fluid Lines, HTC Gnielinski correlation





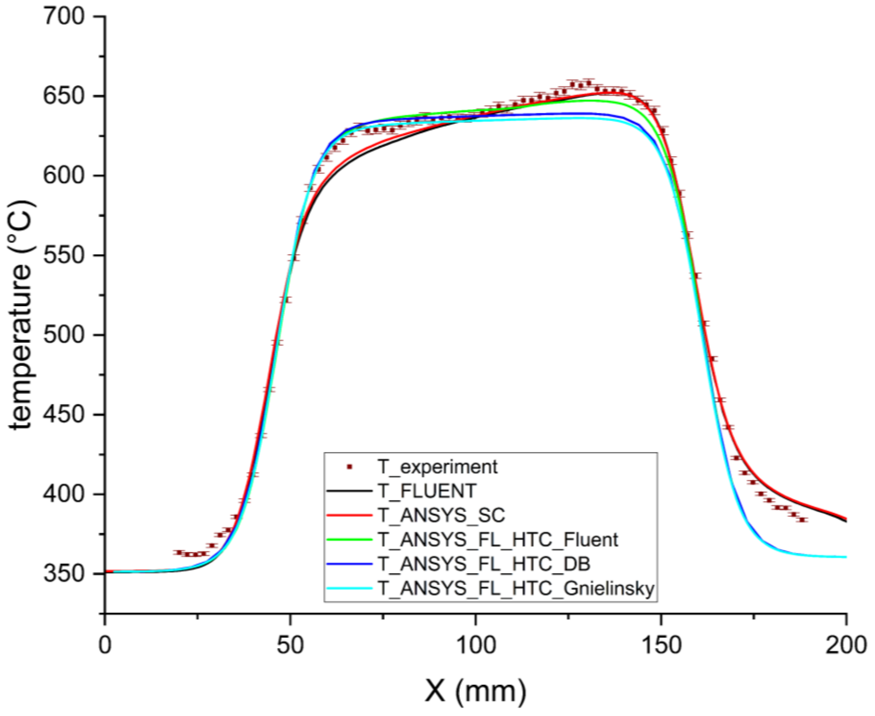


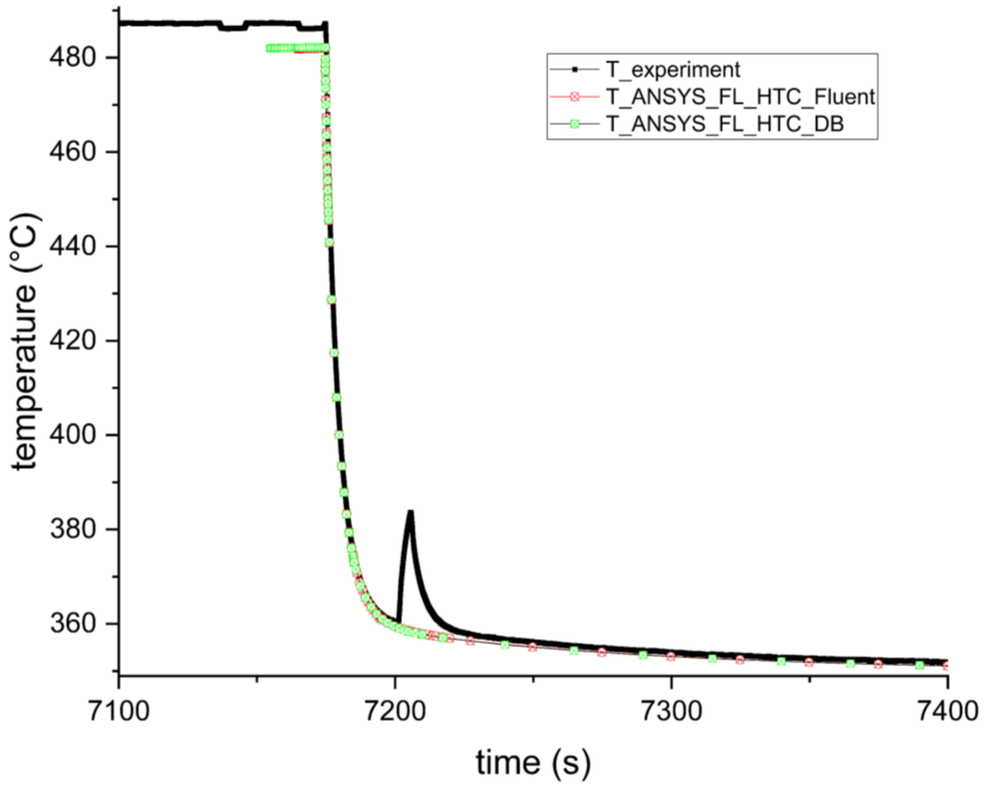
Temperature profiles @ x=136.5 mm (steady state calculation)
Fluent Surface T_{max}@ x=136.5mm;y=57.4mm

* FL mass flow from Fluent
** Dittus-Bölter and Gnielinski only for the channel region
***Gnielinski from VDI Heat Atlas (2010): G1, Section 4

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Validation of computed temperature field (cont.)





Temperature profiles @ y=57.4 mm
(steady state calculation)

Time evolution of the surface mean temperature
HTC-Fluent:0.9% deviation of the simulated values to experiment
HTC-DB: 0.8% deviation of the simulated values to experiment

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Overview & Conclusions

- Wide range of experiments in support of HCPB-BB design
  - **BU**: single effect experiments concerning thermal hydraulic or materials issues
  - **FW**: increased size mock-ups -> prototypical mock-ups
    - Materials: ODS and FG-FW mock-ups with industrially applies technologies
    - Manufacturing: FW-PMU
    - Thermal-hydraulics with channels and flow configurations of relevant sizes
- Model validation
  - Fluid-solid conjugated simulations show good fit with the experimental data
  - (ANSYS Thermal) Models using Fluid Lines and HTC from CFD (either Fluent or Fluent+ANSYS:SC) slightly overpredict the cooling but they are very close to the experimental data both for steady state and transient analysis
  - HTC correlations (HTC versus temperature):
    - Dittus-Bölter show similar performance as the HTC from CFD for both steady state and transient simulations but the temperature profile in the flow direction tends to be rather flat
    - Gnielinski gives similar results as Dittus-Bölter with a slight overestimation of the cooling; the use of a stream-wise dependent correlation is presently investigated

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Thank you for your attention !

Contributors:

- Michael Rieth - material development
- Carsten Bonnekoh – material development and manufacturing
- Jarir Aktaa - material development
- Ashwini Kumar Mishra - material development and manufacturing
- Jörg Rey – manufacturing
- Gaurav Verma – analysis & manufacturing
- Frederik Arbeiter – analysis & instrumentation
- Guangming Zhou – design and management
- Francisco A. Hernandez - design and management

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.