Thermal-hydraulic experiments in support of the Helium Cooled Pebble Bed Blanket design within the EU-DEMO project

HELOKA (Helium Loop Karlsruhe) Technology Hub

- Three helium-cooled loops:
  - **HELOKA-HP**: 4-9.2MPa, 70-550°C, 1.3kg/s (HCPB-TBM)
  - **KATHELO**: 4-10MPa, 70-650°C, 250g/s
  - **HEMAT**: 0.1-0.6MPa, 20-650°C, 15g/s
- High-heat flux testing rig: **HELOKA-HHF**
  - EB-gun 800kW
  - 24.4m³ vacuum chamber (3m diameter)
  - Capable of testing mock-ups connected to either HELOKA-HP or KATHELO
  - Low pressure, low temperature water cooling capabilities also available

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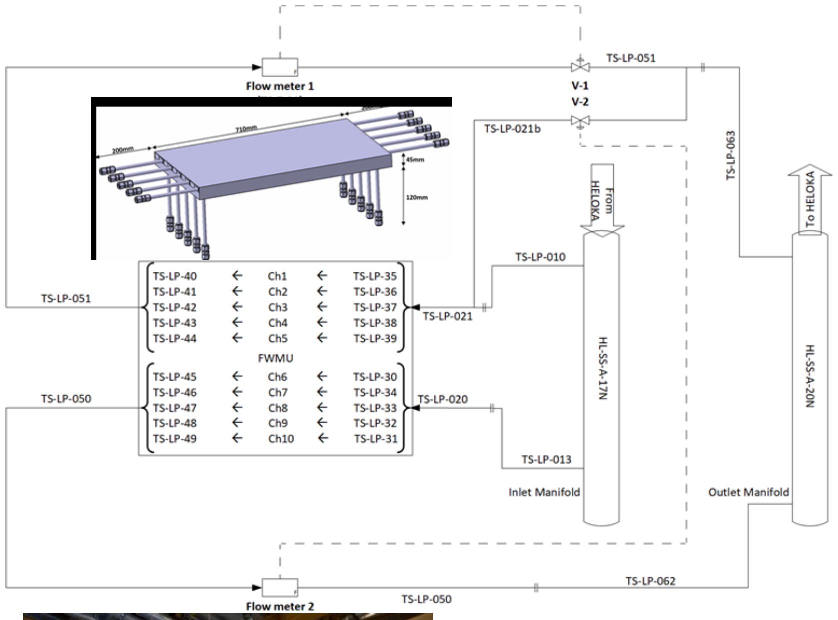
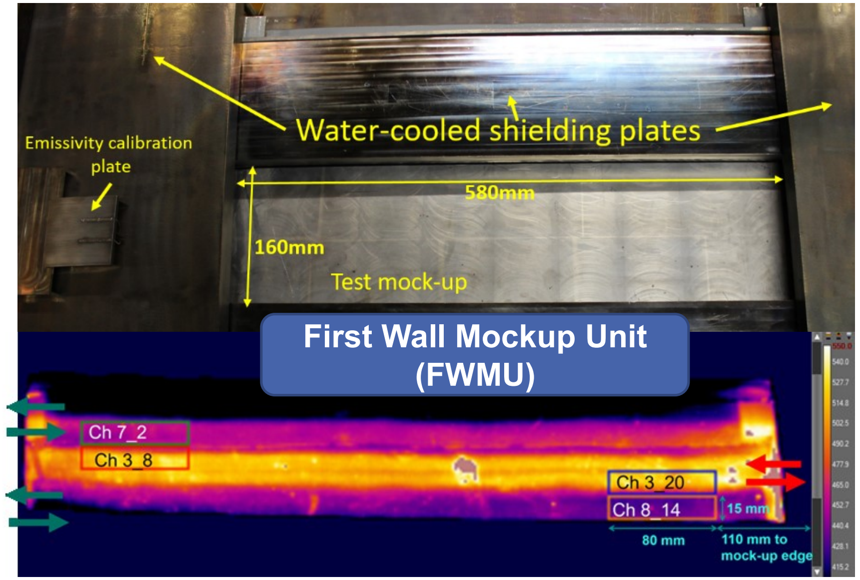
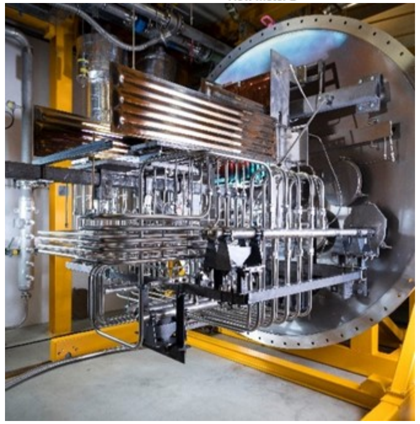
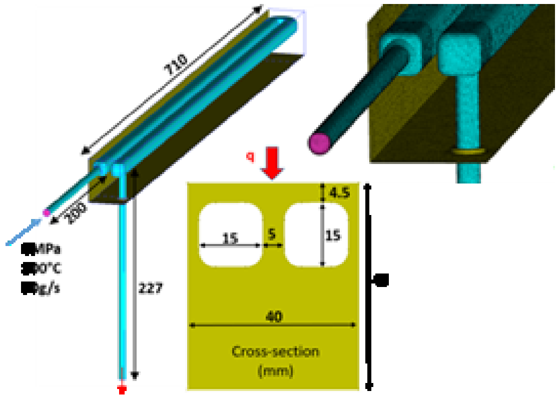
HCPB First Wall LOFA Experiment

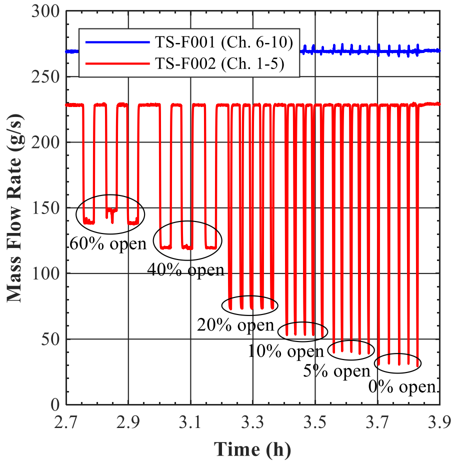


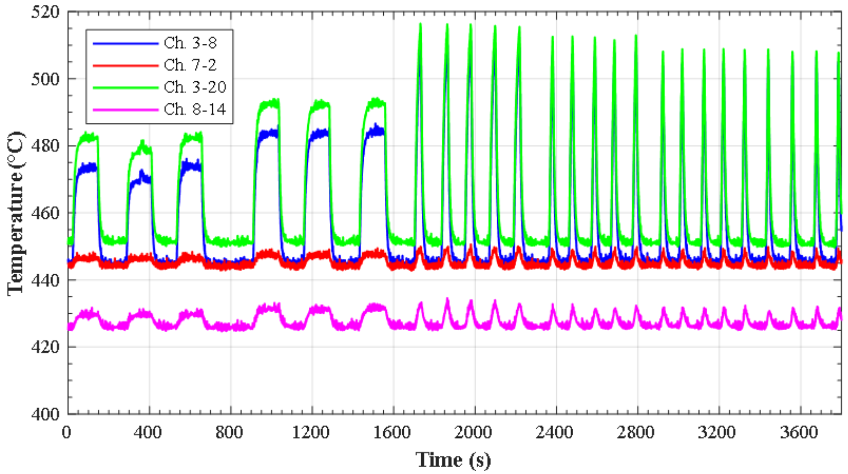
- **Scope**: investigate the ability of the used thermal-hydraulic models (RELAP-3D) of simulating first wall fast transients
- **Best-Estimate methodology** used for assimilating all available experimental data and computational uncertainty-afflicted results to provide best-estimate calibrated model parameters and responses together with their uncertainties











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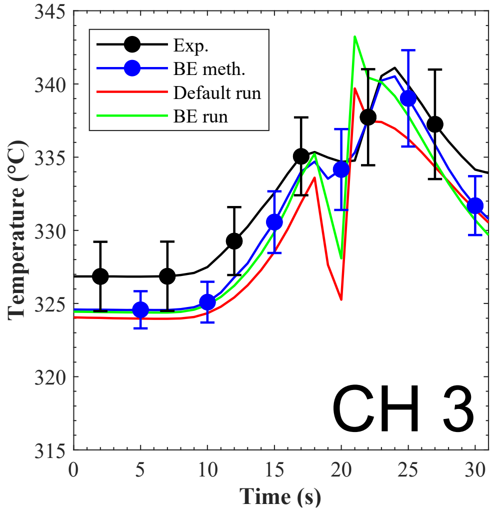
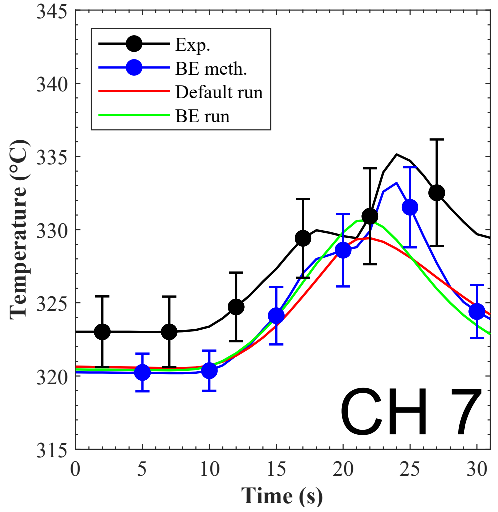
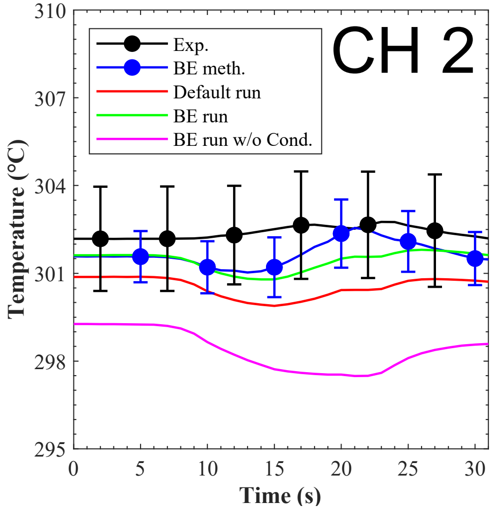
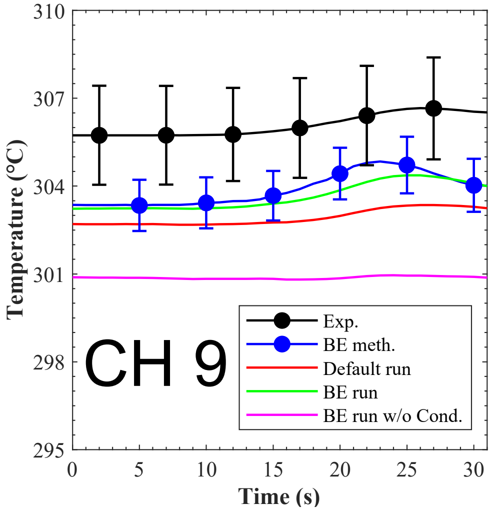
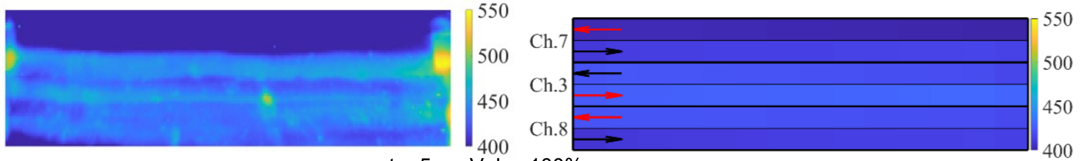
HCPB First Wall LOFA Experiment (cont.)



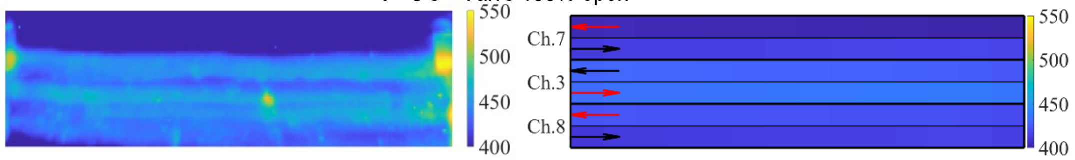




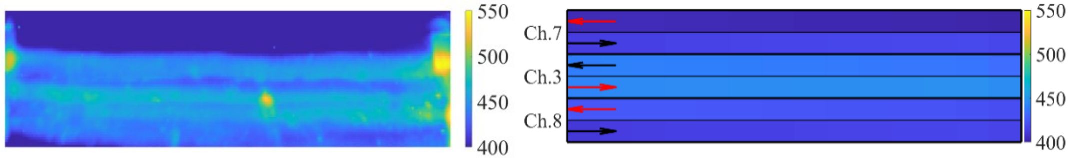




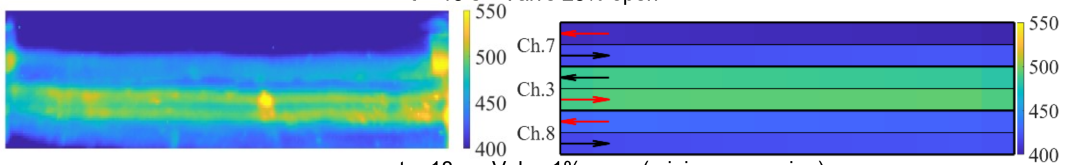
t = 5 s—Valve 100% open



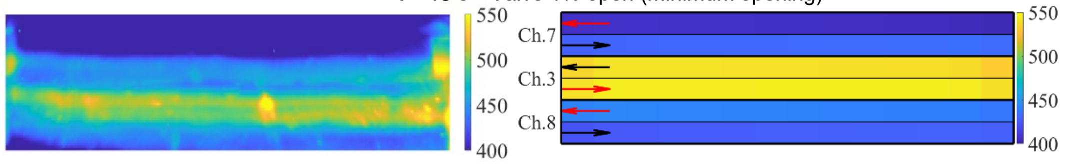
t = 11 s—Valve 50% open



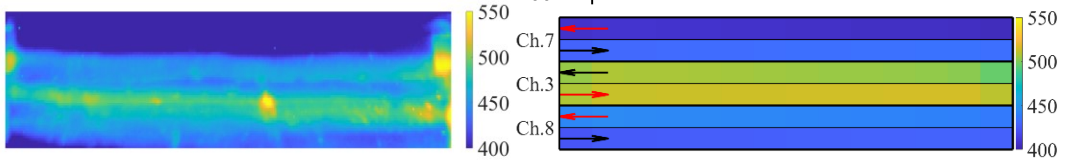
t = 13 s—Valve 25% open



t = 18 s—Valve 1% open (minimum opening)



t = 22 s—Valve 60% open



t = 25 s—Valve 100% open

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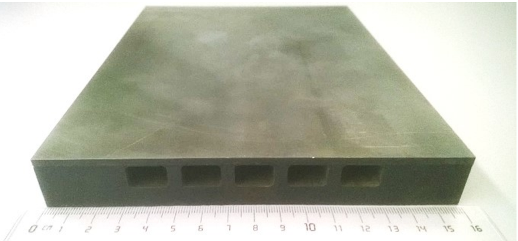
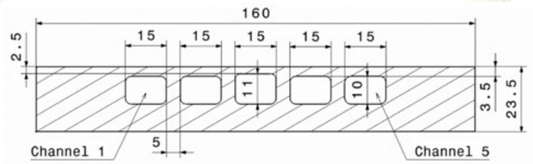
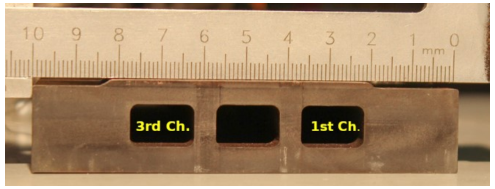
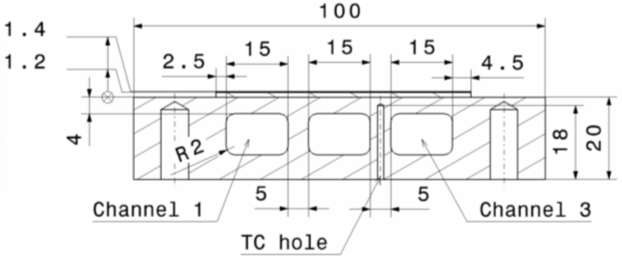
ODS-FW and Functional Graded FW-Coating

- **Oxide Dispersed Steel** Mock-up
  - 2.5mm ODS layer
  - **Scope**: High heat flux & High temperature behavior





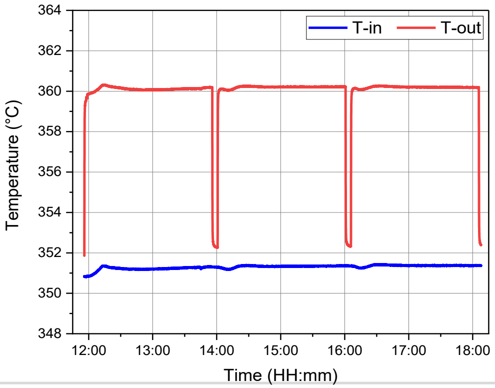


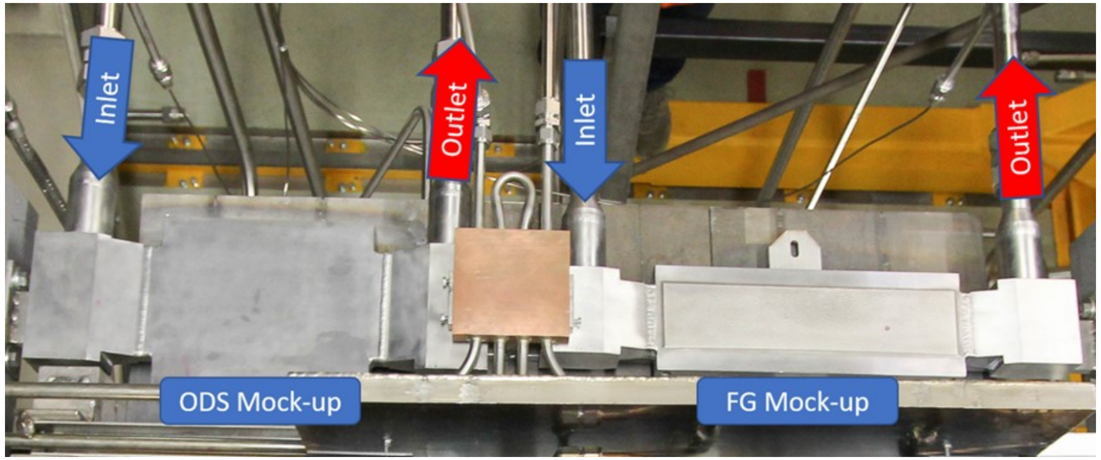


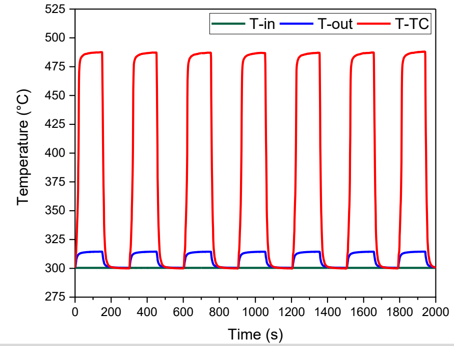
- **Functional Graded** Mock-up
  - 1.4mm Tungsten-Eurofer graded protection layer
  - **Scope**: FG-layer stability under specific cyclic loading

Cycles	He Inlet T	Surface T	Heat on/off Time	Est. Heat flux
100	300 °C	550 °C	120 s/120 s	700 kW/m^2
100	300 °C	600 °C	120 s/120 s	800 kW/m^2
100	350 °C	650 °C	120 s/120 s	900 kW/m^2
7	350 °C	650 °C	2 h /5 min	900 kW/m^2

Helium Mass Flow Rate	170 g/s
Helium inlet temperature	300 °C
Helium pressure	8 MPa
Maximum heat flux	700 kW/m^2
Substrate temperature limit	<520 °C
Heating on/off time	150 s/150 s
Number of cycles	1000







Ghidersa et al, Energies, **2021**, 14, 7580. https://doi.org/10.3390/en14227580

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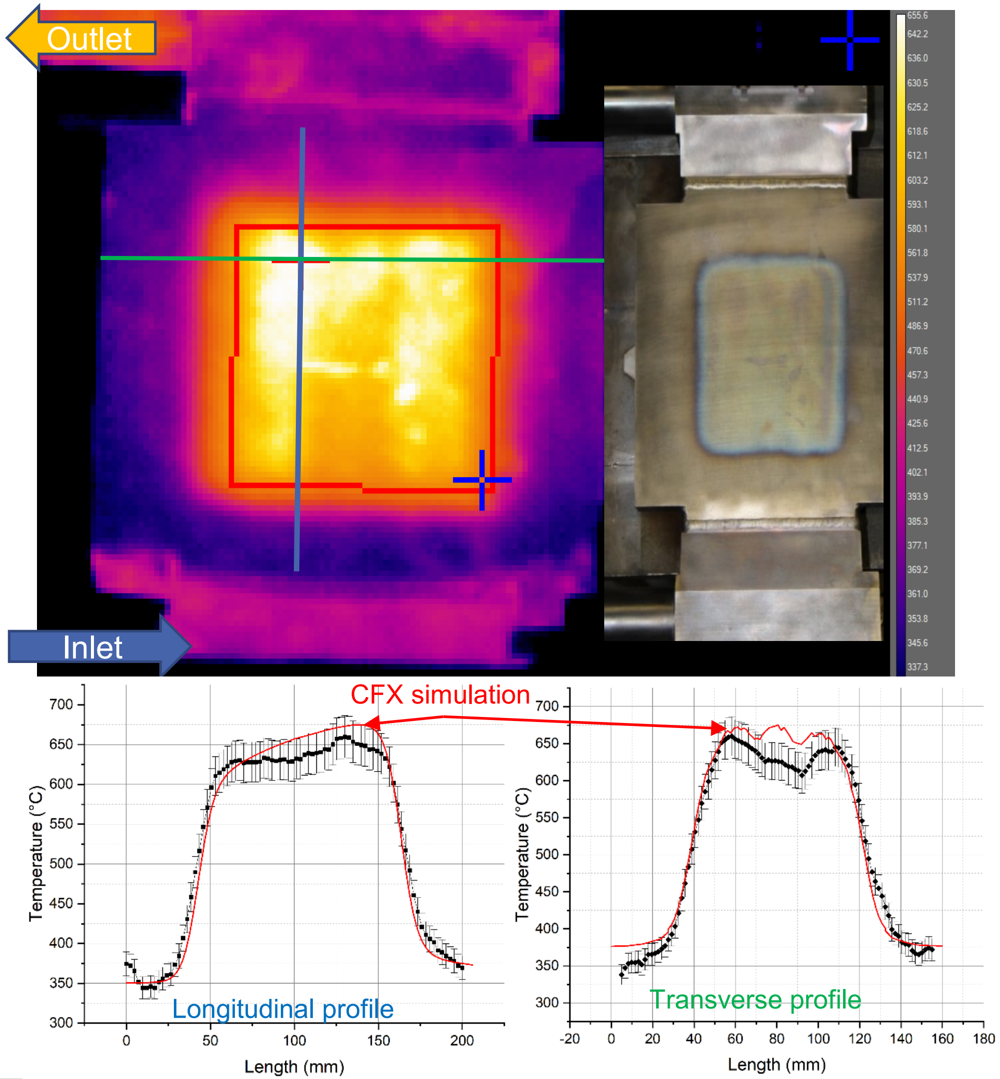
ODS Mock-up results



- Challenging experiment due to limited knowledge of the material (ODS) and the impact of the manufacturing steps
- CFD and stress analysis using ANSYS
  - ANSYS-CFX simulations indicate a uniform flow distribution (+4% for CH1 and -3.5% for CH3)
  - Stress analysis:
    - Heat load applied on a 110x90 mm² surface to avoid high stresses near the welding seams between manifolds and plate (P91xE97xODS)
    - At high heat fluxes (900kW/m²) the stresses exceed locally (ODS region) the E97 allowable values (120% from RCC-MRx limits)
- Experimental campaign concluded without any visible geometrical or mechanical damages of the mock-up

Rieth et al, Appl. Sci. **2021**, 11, 11653. https://doi.org/10.3390/app112411653
Ghidersa et al, Energies, **2021**, 14, 7580. https://doi.org/10.3390/en14227580

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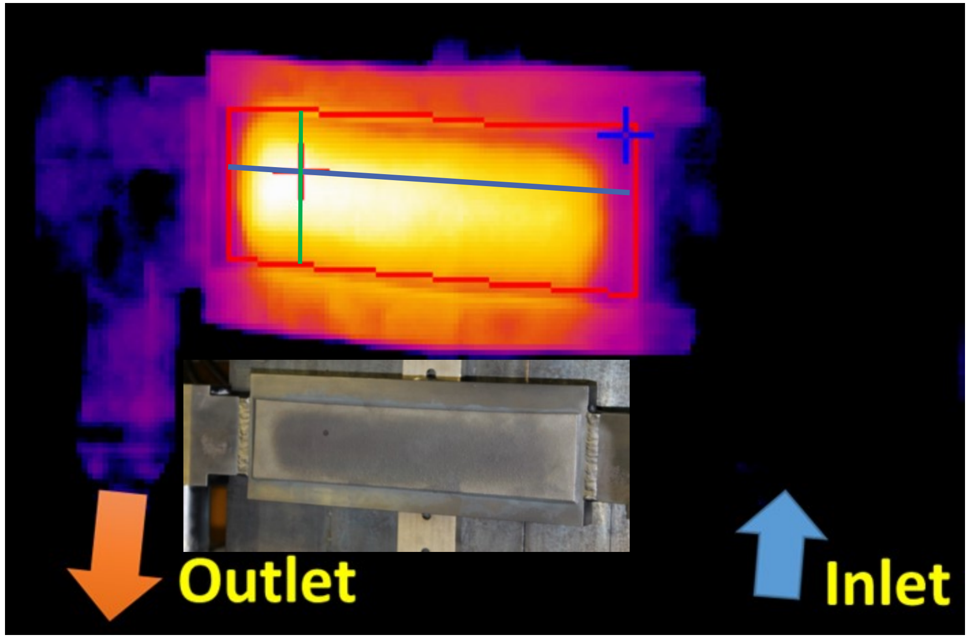
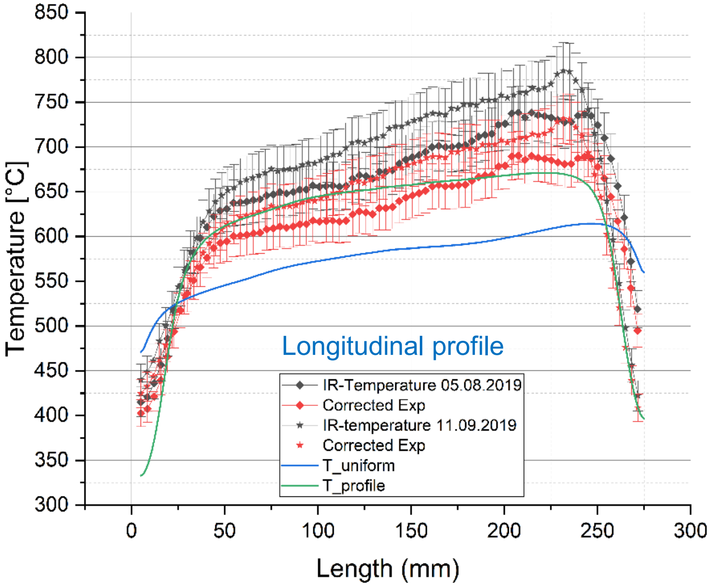
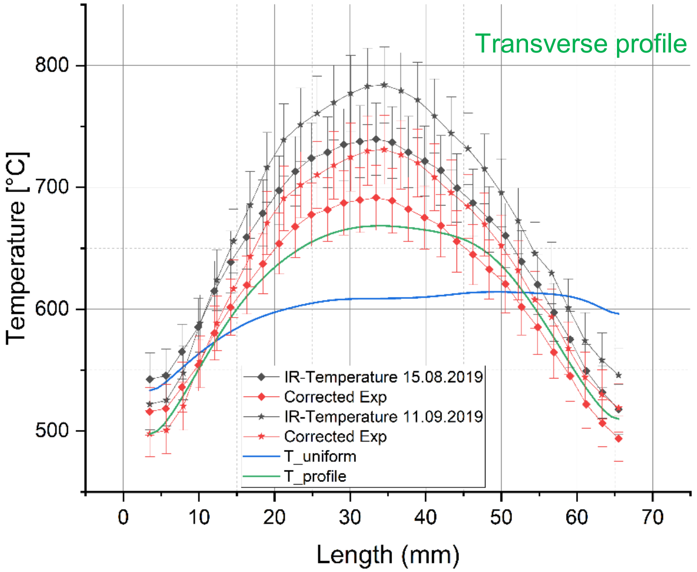
FG Mock-up



- Back-up unit tested due to complications during the manufacturing of the mock-up:
  - Smaller coated area (275x65 as compared to 275x115mm²)
  - Only one thermocouple monitoring the substrate temperature (mid distance between inlet and outlet, 2mm below steel surface)
- IR-camera readings of the W-coating temperature show overestimated values during loading:
  - temperatures corrected using a dedicated correlation (separate experiment)
- No apparent damages or changes of the coating after the test campaign





- ANSYS-CFX simulations:
  - Careful tuning of the surface heating profile required
  - Relatively good agreement with experimental data

Emmerich et al, Nucl. Fusion 2020, 60, 126004.

Ghidersa et al, Energies, **2021**, 14, 7580. https://doi.org/10.3390/en14227580

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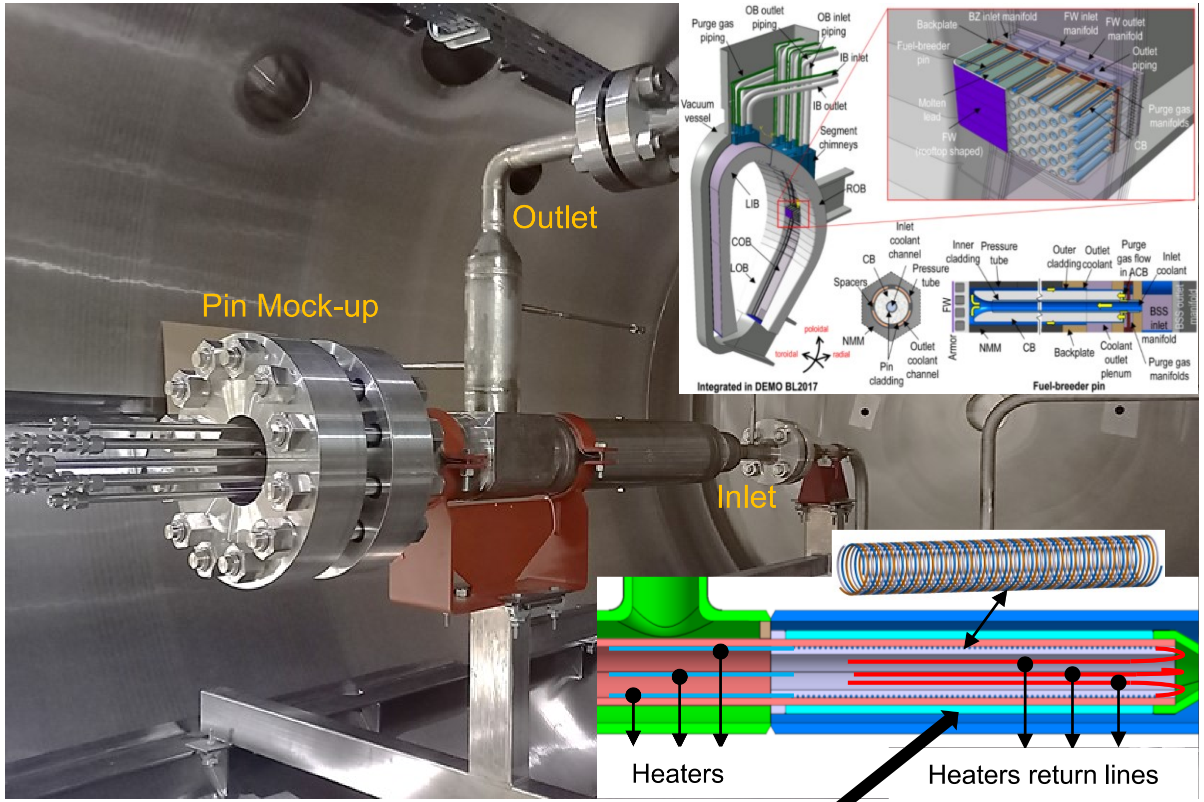
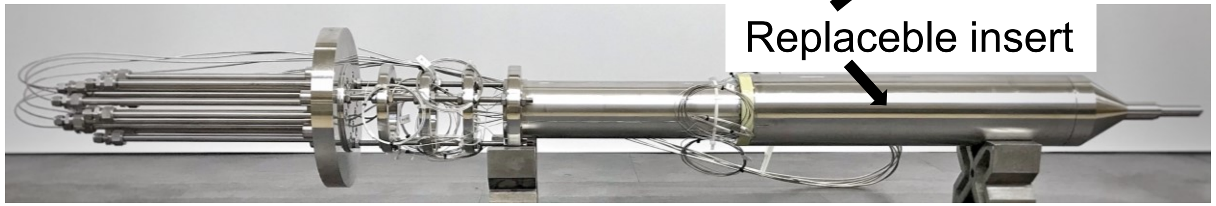
HCPB Breeder zone experiment – Pin Mockup

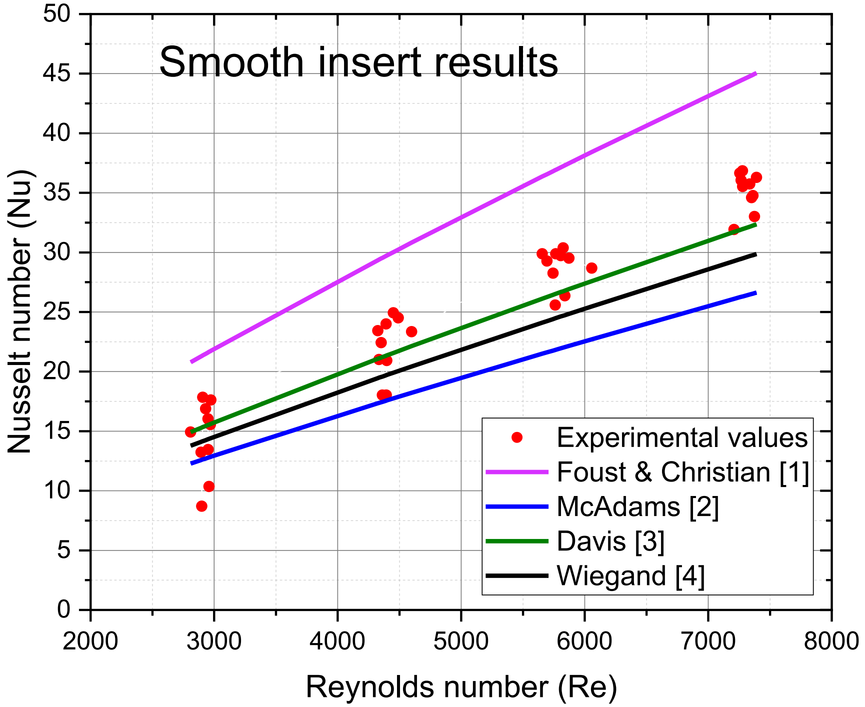
G. Zhou, poster **# 477** in poster session 3

A. Abousena: poster **# 416** in poster session 3





Scope: HTC for the cooling gap between BZ and multiplyer and HTC improvement (surface roughness and turbulence promoters)



[1] Foust A.S., Christian G.A., American Institute of Chemical Engineers, 36, p. 541-554, (1940).
[2] McAdams W.H., Heat Transmissions 3rd ed., p. 241-244, (1954).
[3] Davis E.S.,Transactions of ASME, p. 755-760, (1943).
[4] Wiegand J.H. et al, American Institute of Chemical Engineers, 41, p. 147-153, (1945).

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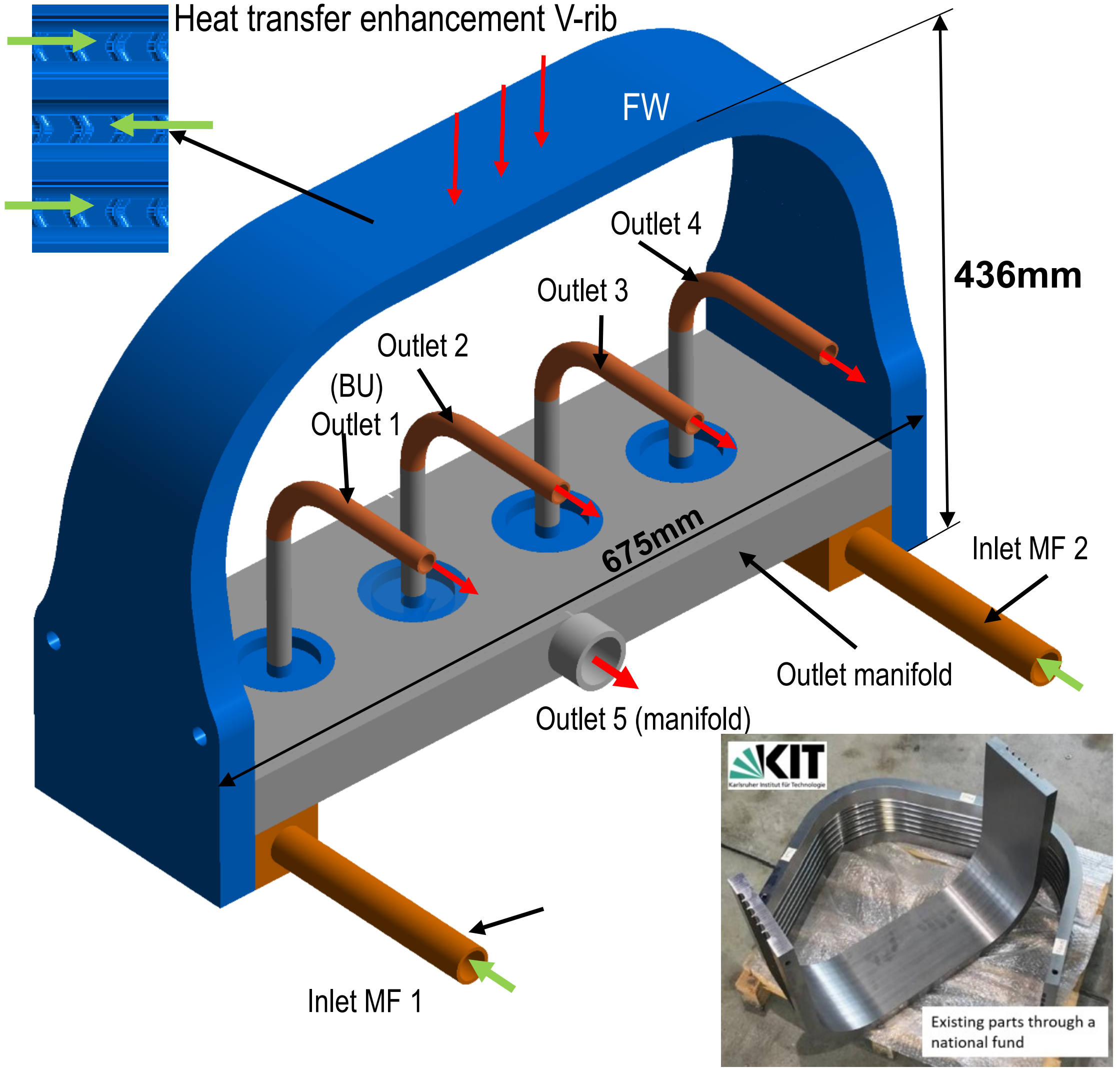
Future plans: Prototypical FW Experiment

- **2021-2023:** on-going demonstration of relevant manufacturing procedure of FW including V-shaped heat transfer enhancement ribs
  - First Wall Prototypical Mockup Unit (FW-PMU) with 6 cooling channels and representative manifold (FW to BU)
- **2023-2024**: FW-PMU testing campaign in HELOKA:
  - Evaluation/Demonstration of high heat flux operational capabilities at DEMO relevant conditions
  - Investigate the flow distribution in the breeding zone
- **2024-2025**: thermal-hydraulic investigations of a FW mock-up in support of the ITER-TBM (EU-HCPB) using a modified FWMU (LOFA-Experiment)



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