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EUROfusion

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

# Increasing irradiation and thermo-hydraulic performance of breeding blankets by ODS steel plating

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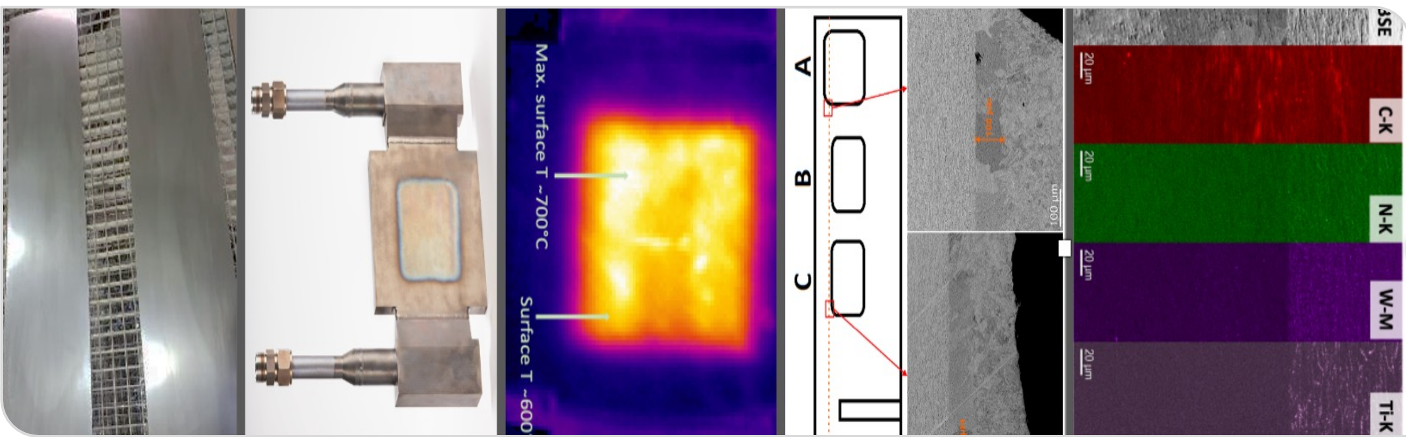
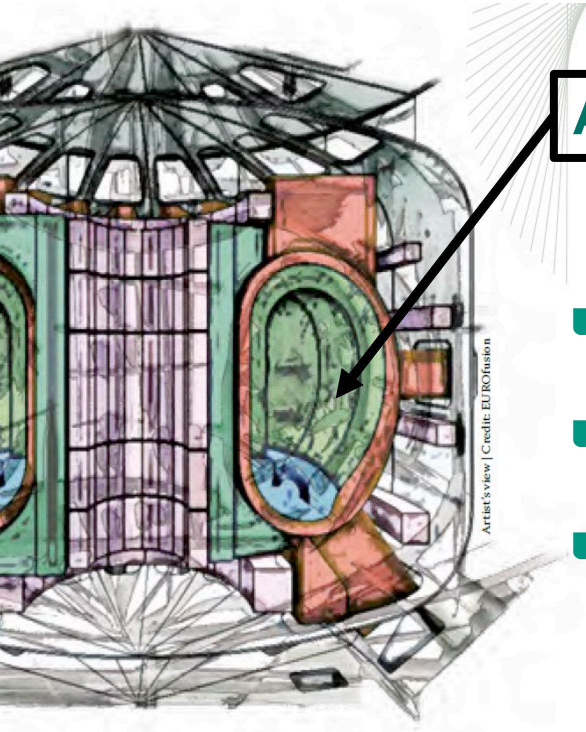


# Introduction



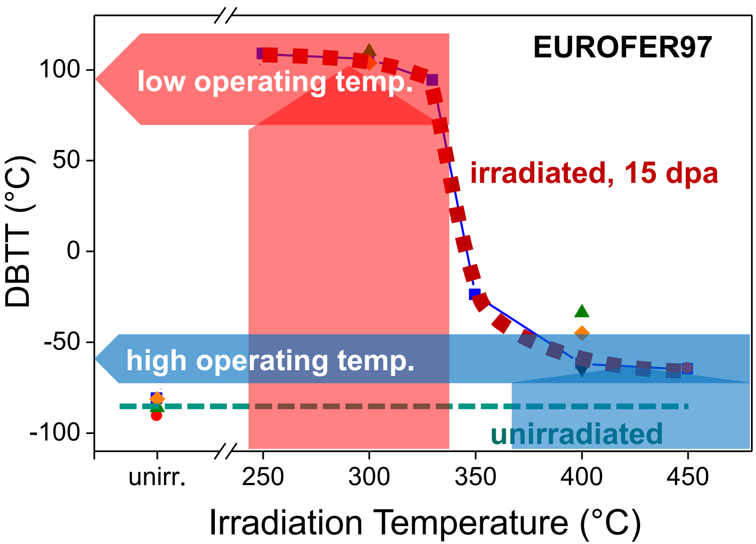

**Advanced DEMO blanket: 50 dpa**

- **Hardening** and **embrittlement** due to high neutron dose
- **Helium bubbles** due to transmutation
- **Fatigue** due to pulsed high heat flux load

# Mitigation of hardening and embrittlement

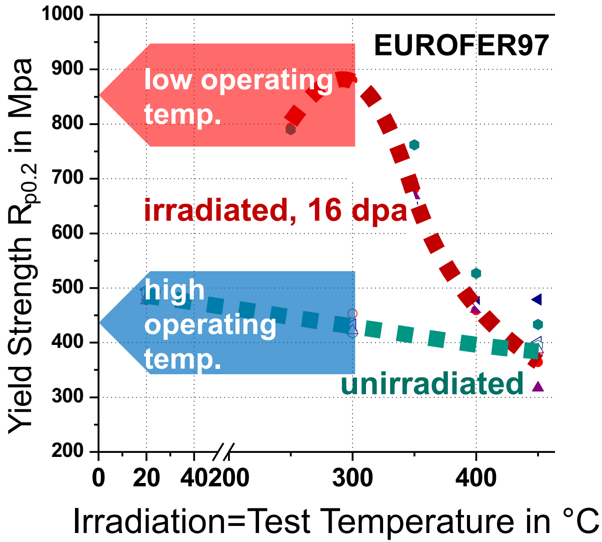
High operating temperature

## Embrittlement




E. Gaganidze et al., KIT

## Hardening



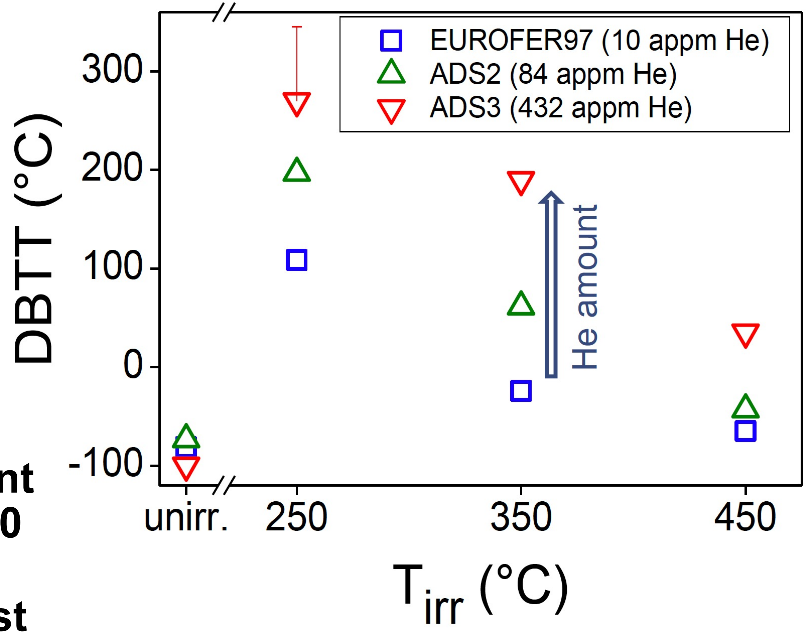

E. Materna-Morris et al., KIT

# Helium embrittlement

## What do we know?

- At temperatures >0.5 $T_m$, stress and transmutation lead to He migration to grain boundaries.
- At grain boundaries, the formation of large intergranular bubbles significantly degrade strength and toughness.
- **The critical helium amount is estimated to be 200-500 appm, corresponding to 20-50 dpa for a DEMO first wall**
  **➔ Proof by IFMIF/DONES**

*Gaganidze, et al., Fus. Eng. Des. 2008*

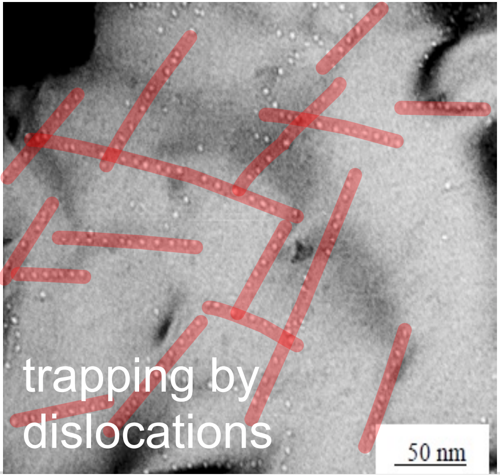


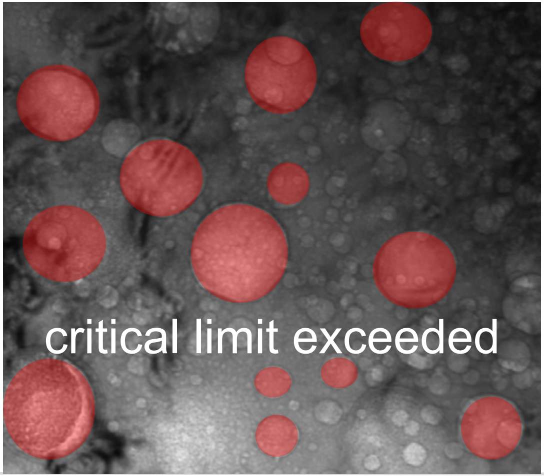

Neutron irradiation experiments with boron-doped EUROFER

# Mitigation of helium embrittlement

## High density of effective helium sinks

- Finely distributed oxide dispersoids in ODS steels can trap helium and prevent the formation of critical big bubbles.



# ODS vs. standard EUROFER

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## ups

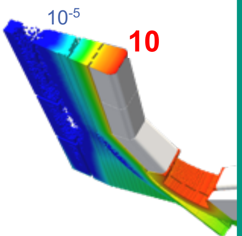
- 👍 Better irradiation performance
- 👍 Higher fatigue lifetime
- 👍 Higher creep strength

## downs

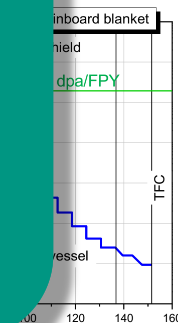
- 👎 High fabrication costs
- 👎 Reduced production capacities
- 👎 Limited welding processes: only diffusion bonding or friction welding

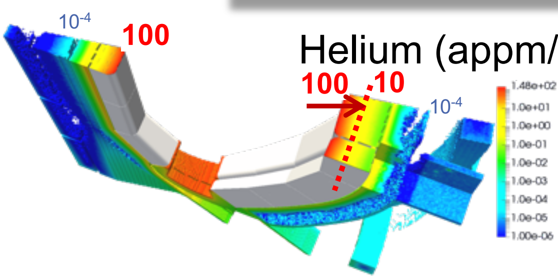
# Reduction of material needs

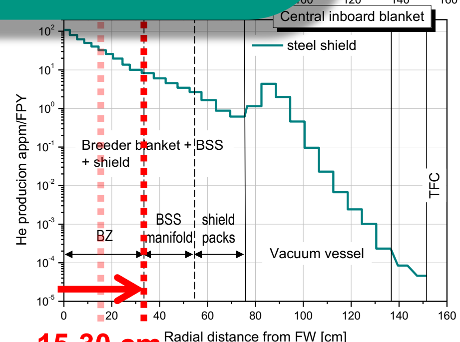
## ODS s... rst wall




A volume of about 0.3 m depth from the surface of the first wall would require an amount of ODS steel in the order of **several 100 tons.**
➔ important long-term goal (not followed in this study)




15-30 cm

U. Fischer, KIT

# Objectives of this project

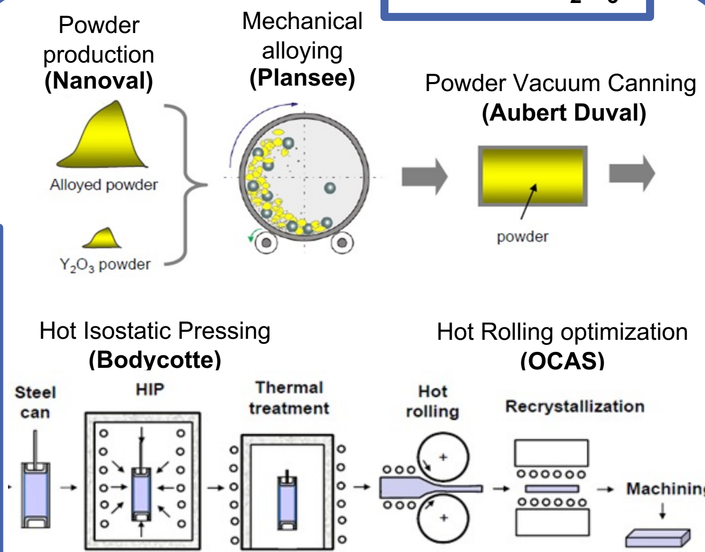
- **Design** an advanced blanket first wall mock-up with superior thermo-mechanical properties and potentially higher irradiation resistance for longer component operating-times by the use of **ODS steel plating**.
- Select, optimize, apply **industrial fabrication processes** for the mock-up manufacturing.
- **Demonstrate the performance** of the mock-up by cyclic high heat-flux tests in a helium cooling loop.
- **Analyze** the highest loaded areas of the mock-up after the tests.

# ODS steel production

## Production of thin plates (2-3 mm) from a ~100 kg batch of ferritic ODS steel powder

**109 kg Fe-13.5Cr-1W-0.16Ti-0.2$Y_2O_3$**

**150 kg Fe-13.5Cr-1W-0.16Ti**

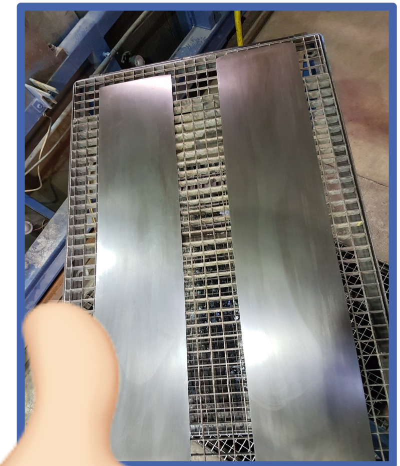



# ODS steel plates

## More than 0.5 m² plates produced from 2 consolidated blocks of 15 kg each

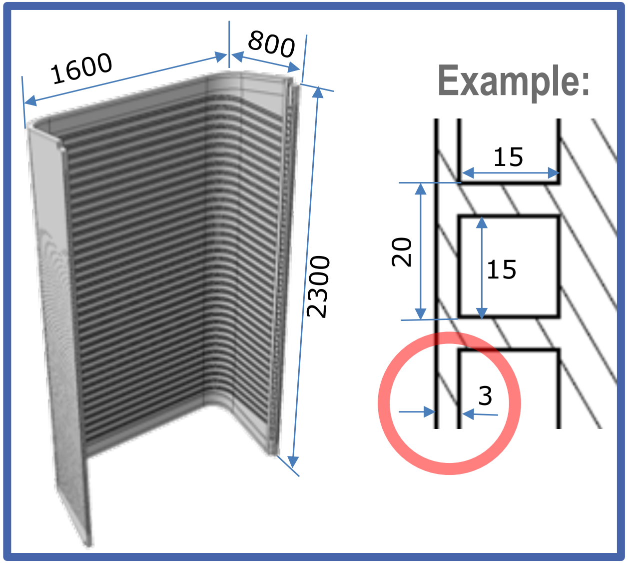
→ 2 plates: 1200 mm x 230 mm x 2 mm
→ 2 plates: 1000 mm x 100 mm x 3 mm
→ 2 plates: 1300 mm x 100 mm x 2 mm

**One advanced DEMO blanket module → 100-400 kg**
**Complete DEMO blanket first wall → 20 to 40 tons**

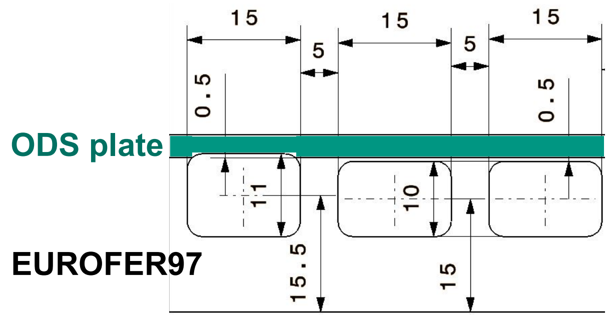


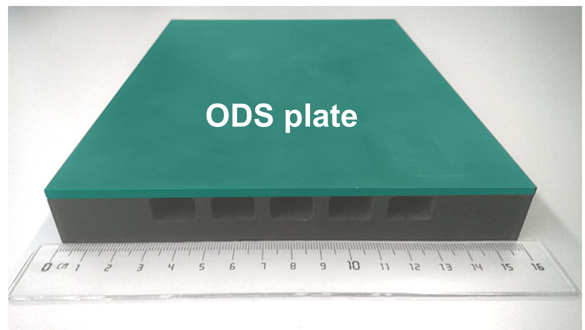
- Verification of **100 kg** ODS steel production route **successful**
- **Several 10-ton ranges feasible**

# Mockup design




**U-shaped first wall of a HCPB blanket**
Note: the distance of the channels from the plasma is only **3 mm**.

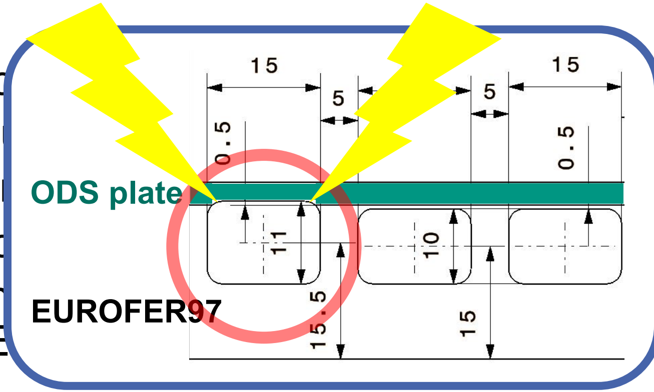


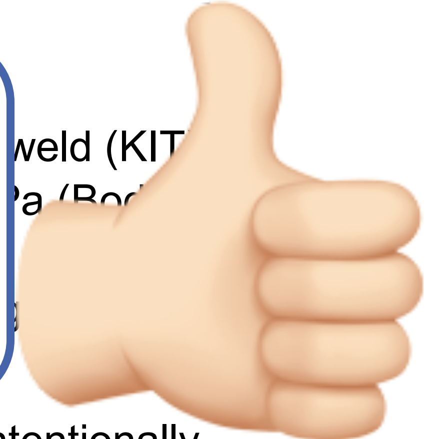




**Mockup** after ODS steel plating and fabrication of cooling channels

# Mockup fabrication

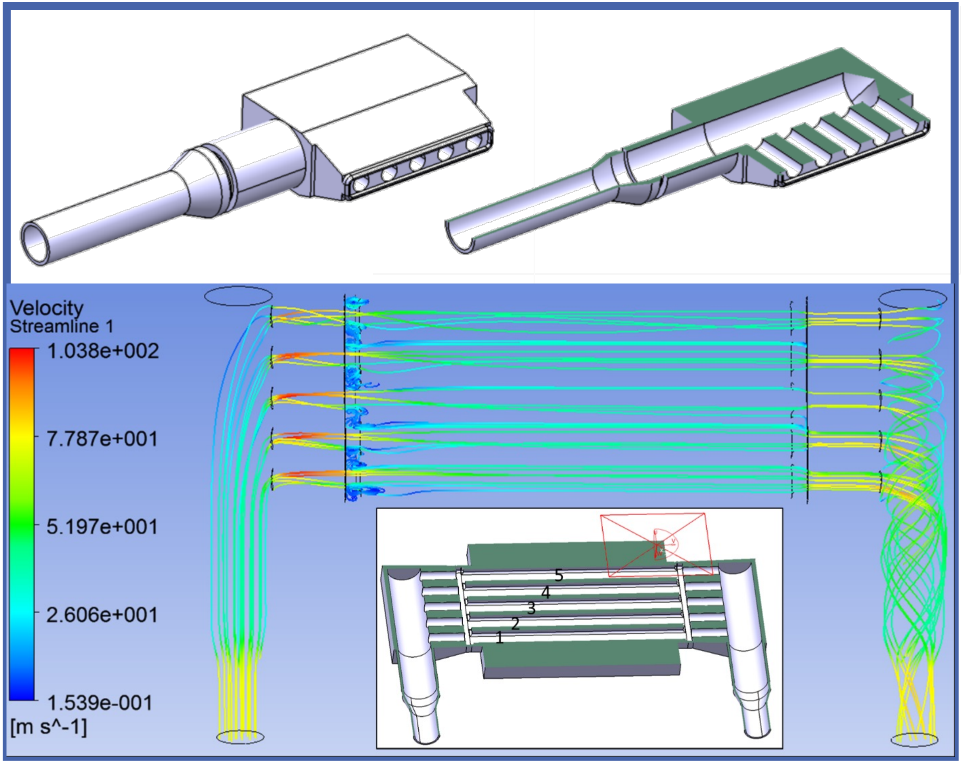
- ODS plating
  - Milling c
  - Encaps ... weld (KIT
  - Diffusio ... Pa (Bo
  - Milling c
- Cooling chan
  ERODIERTE



- **NOTE**: The height of the middle channel was intentionally increased to 11 mm, so that the upper part runs into the ODS steel plate. Therefore, the middle channel includes **two weld seams** along both upper corners. Since the corners are the highest stressed regions in the mockup plate, we have produced **artificial crack initiators**, which we expected to **develop cracks or even fracture** during the high heat flux tests.

# Installation layout




- helium distributors

- mass flow rate
- CFD simulations
- velocity profiles

# Connections

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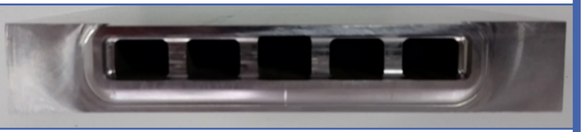
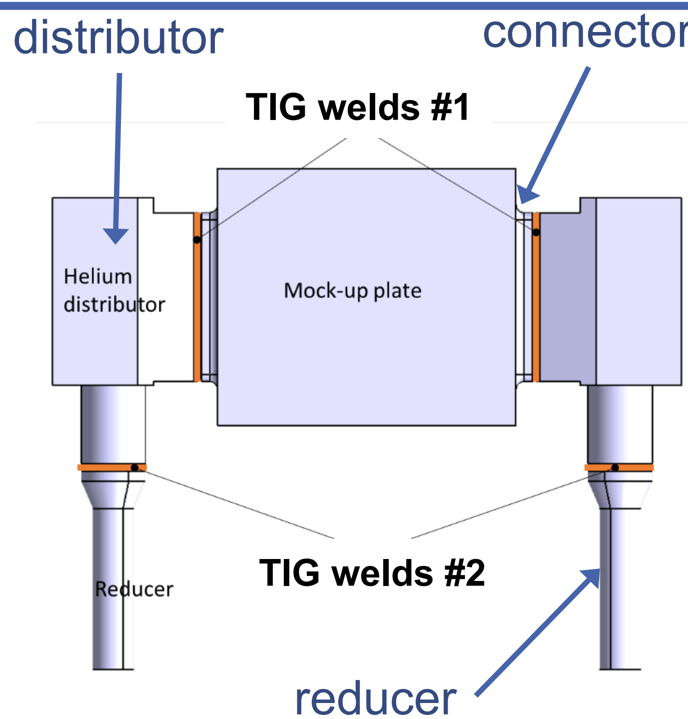
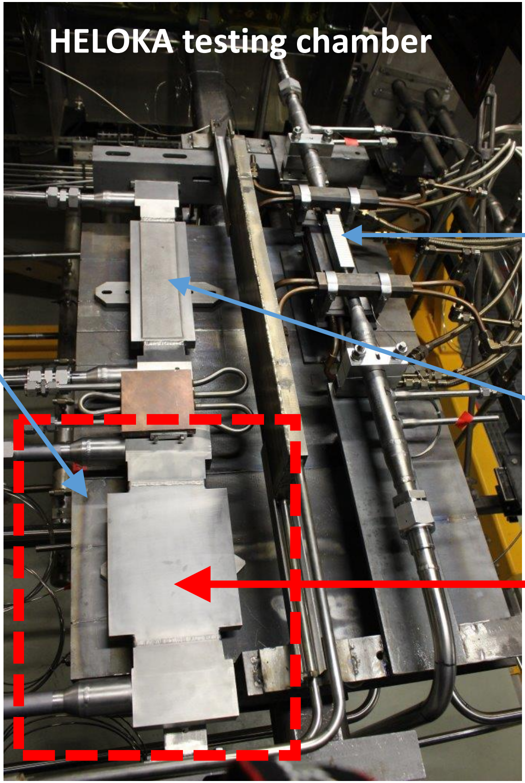
Connectors at both ends of the mock-up plate



- TIG welds performed
- post-welding heat treatment (PWHT)
- 980 °C/1 hour + quenching + 750 °C/2 hours
- liquid penetration tests
- ultra-sonic tests



# Installation in the Helium Loop Karlsruhe (HELOKA)

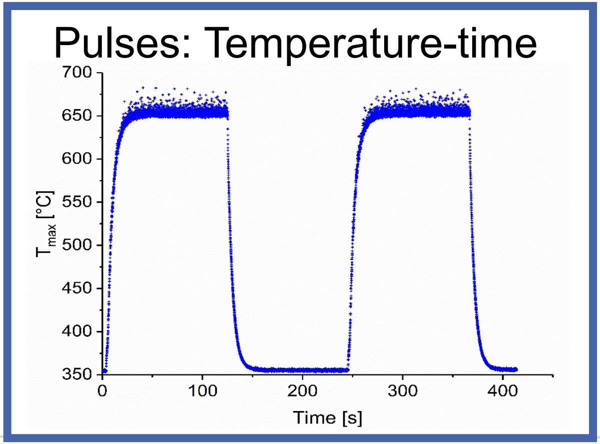


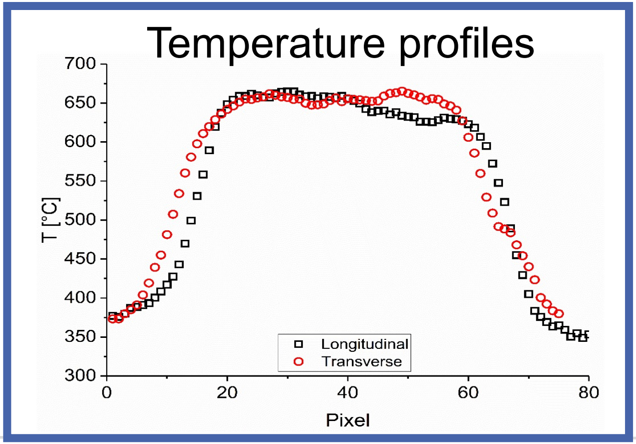

## Instrumentation

- Surface temperature (IR-camera)
- Inlet temperature
- Outlet temperature
- Total mass flow
- Inlet pressure
- Outlet pressure

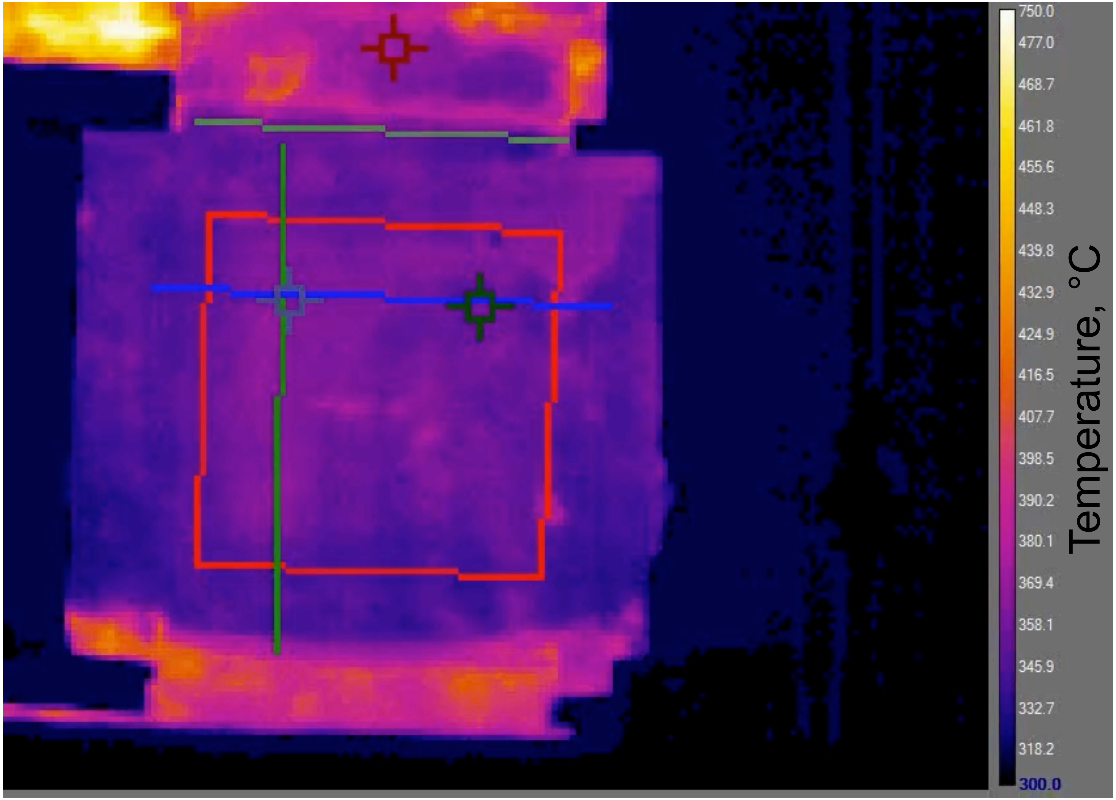
# High heat flux tests

| Test sequence | No. of cycles performed | Heat flux | Puls length (on/off) | Surface temperature |
|---|---|---|---|---|
| #1 | 100 | 0.7 $MW/m^2$ | 2 min / 2 min | ~550 °C |
| #2 | 100 | 0.8 $MW/m^2$ | 2 min / 2 min | ~600 °C |
| #3 | 100 | 0.9 $MW/m^2$ | 2 min / 2 min | ~650 °C |
| #4 | 7 | 0.9 $MW/m^2$ | 2 hours / >2 min | ~650 °C |

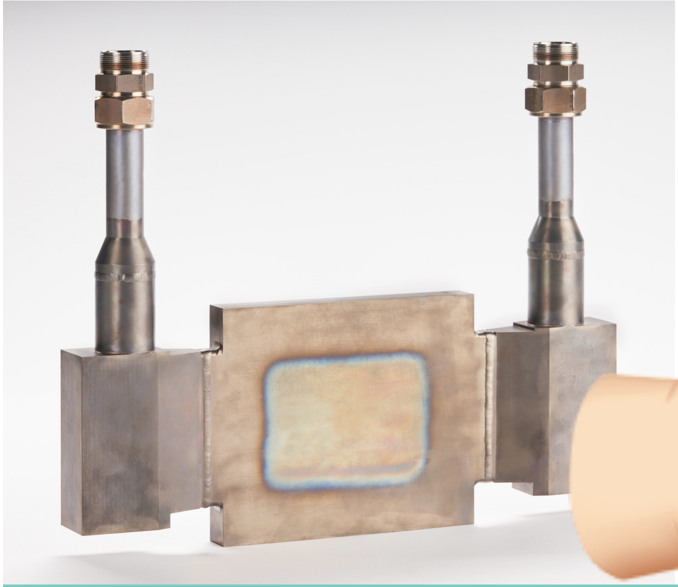


# High heat flux tests

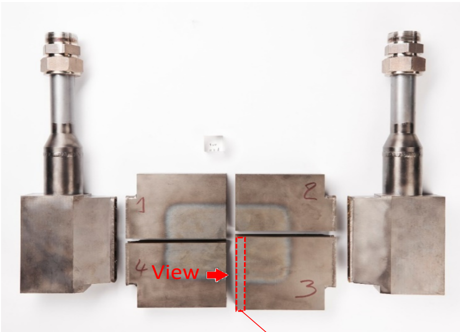


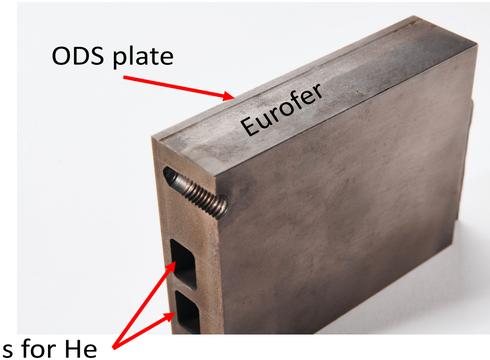
# Experimental results

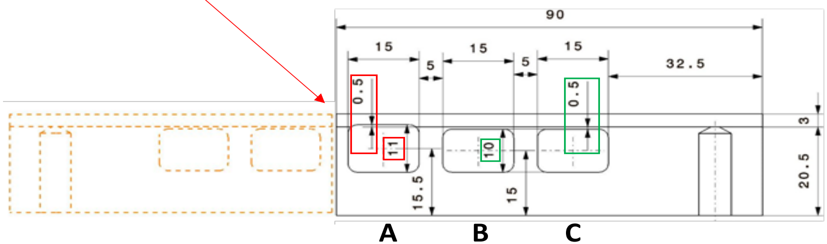


- No peculiar changes in the operating parameters.
- This indicated that the structural integrity was most probably not affected.

# Post testing examination

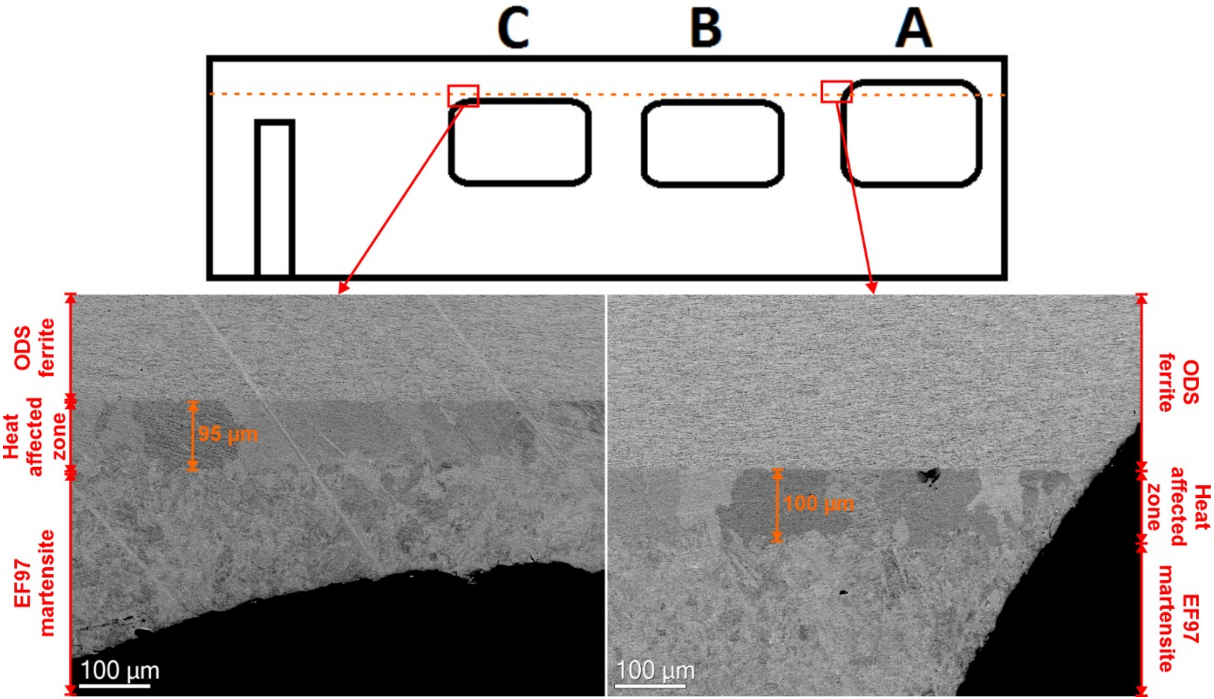


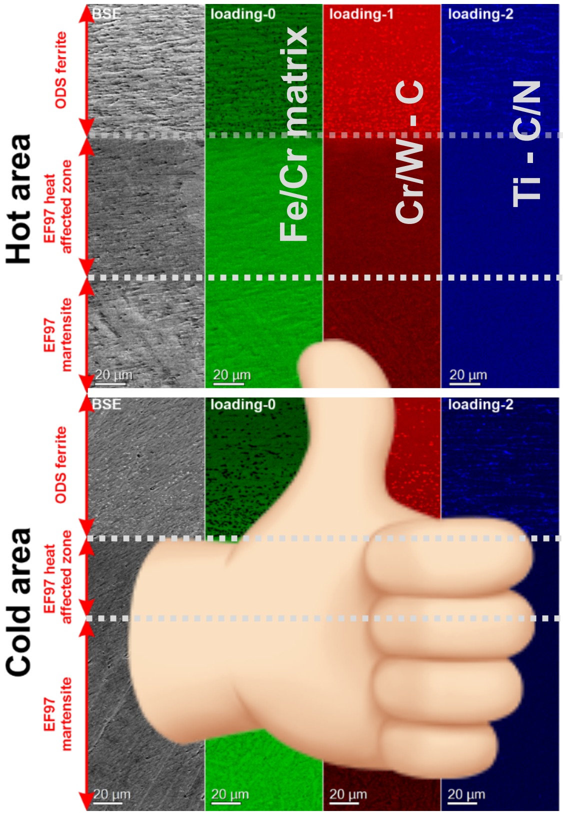

Mockup pieces with labels 1-4 in top-down view (upper left). Sideview of piece #3 from which the SEM sample was cut (upper right). Technical drawing and identification of the cooling channel cross-sections A, B, C (lower part).

# Post testing examination




Comparison of the BSE images acquired in the ODS/EUROFER97 interfacial region close to channel C (left) and channel A (right).

# Post testing examination




In both areas, three phases were found: **Fe/Cr matrix**, **(Cr/W) carbides**, and **Ti carbo-nitrides**.

- Heat affected zones formed at the EUROFER/ODS-steel interface in cold and hot areas as well.
- Coarser Cr carbide precipitates are located in the ODS steel part of the interface.
- Effect: carbon diffusion from EUROFER into the ODS steel.
- Cracks, “Kirkendall bubbles”, or other obvious defects not observed.

# Conclusions

- **Production route of 100 kg ODS steel powder** and **plate fabrication** verified
- Up-scaling to the **several 10-ton ranges** feasible
- Industrial fabrication processes with **very high tolerances against manufacturing imperfections** for advanced

The mockup **did not develop cracks or show tendencies to fail**. **Even at intentionally introduced weak points** (i.e., the weld seams that were placed in one of the five cooling channels), **crack formation did not occur**.

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