Selected divertor studies and experiments

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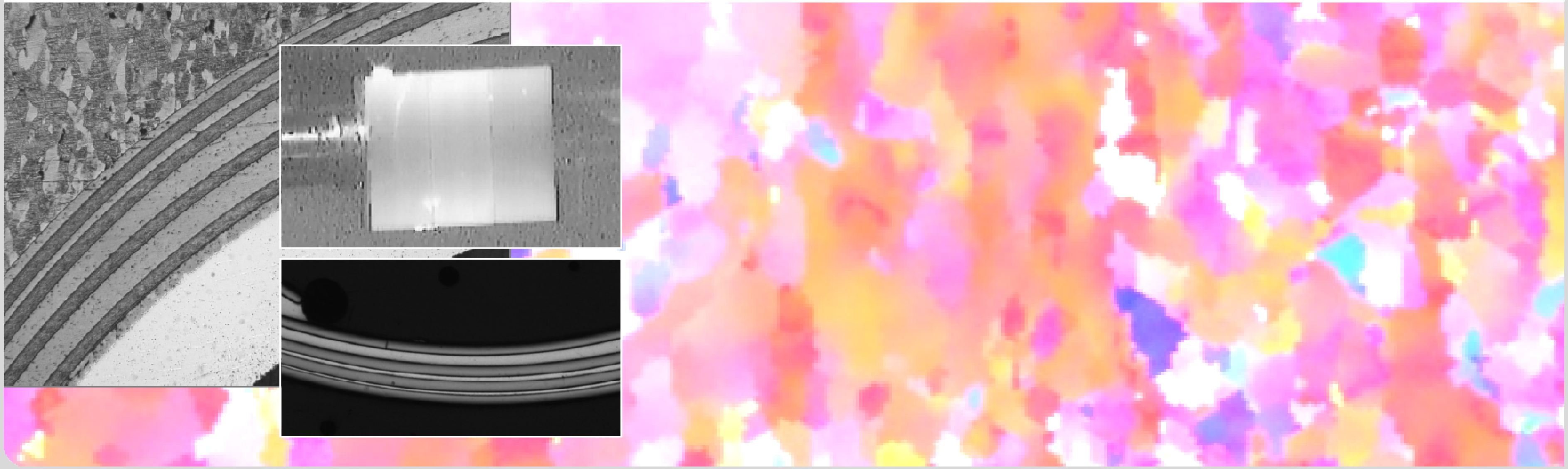
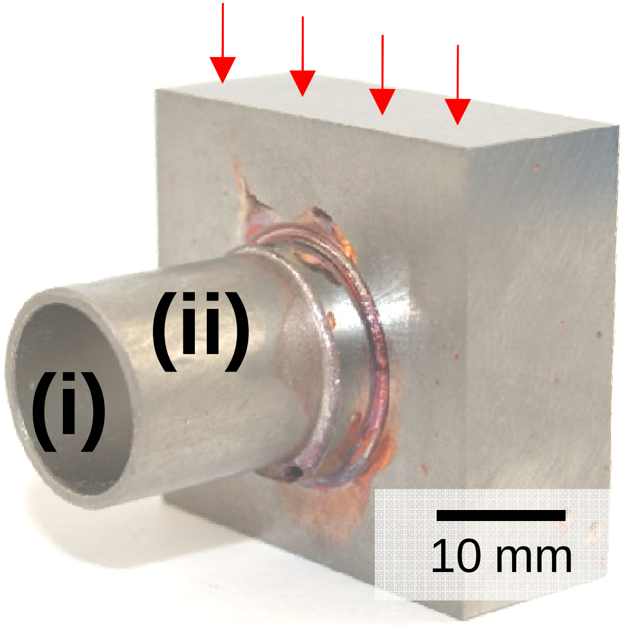
INSTITUTE FOR APPLIED MATERIALS, APPLIED MATERIALS PHYSICS



Aims

- Aim of our work:
  - DEMO divertor: What is the right combination of (i) coolant, and (ii) structural material?
- Aim of this presentation:
  - Presentation of the results of 2 major experiments.

picture: PLANSEE SE



Content

- Introduction
- Experiment 1: HHF tests, austenitic steel, water
- Experiment 2: Burst test, Charpy impact tests on W-laminate pipes

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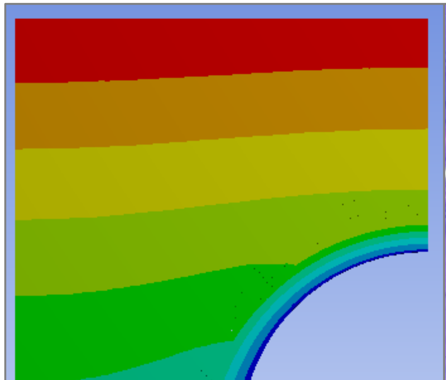
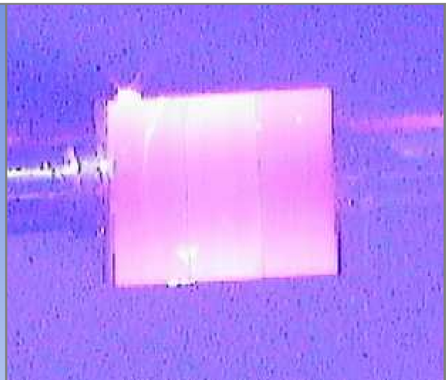
- Appendix (material issues)

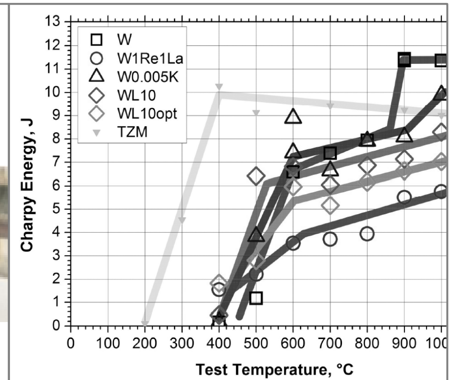


introduction



experiment 1

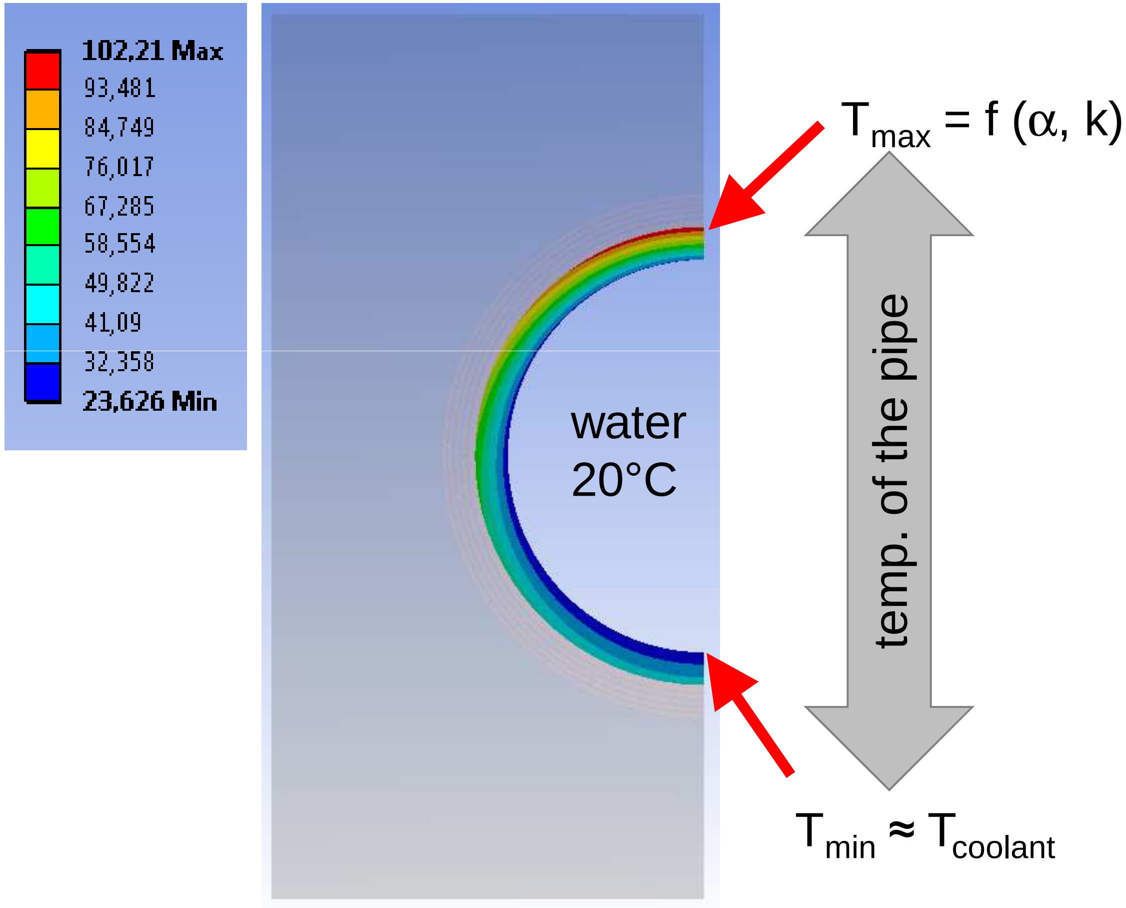
experiment 2



appendix

Introduction

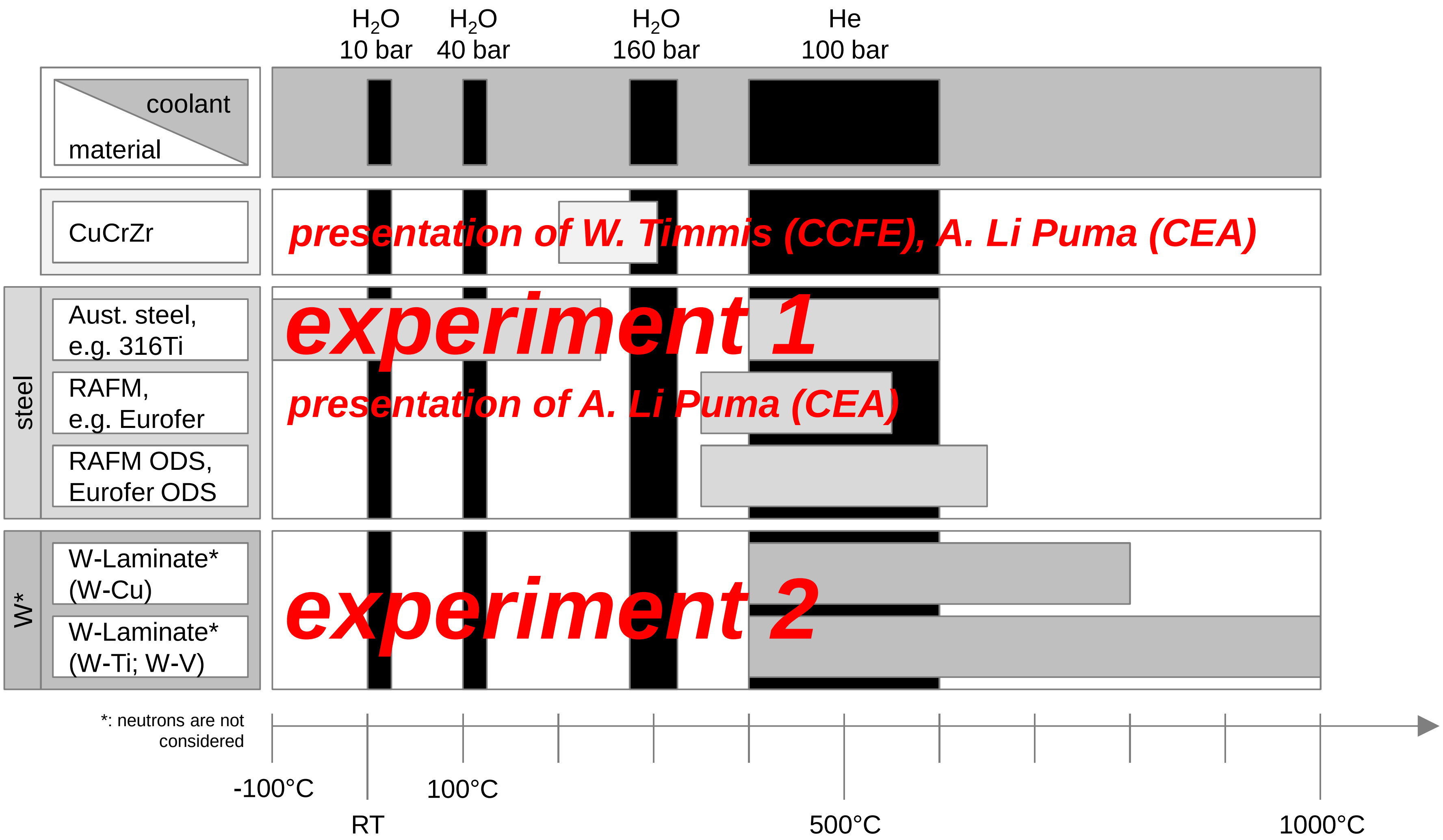
- thermal conductivity, operation window, and heat transfer coefficient



k: therm. cond. [W/(m*K)]	op. window [°C]
CuCrZr: 305	200 - 300
316Ti: 15	0 – 250; 400
RAFM: 30	350 – 550
W: 180	

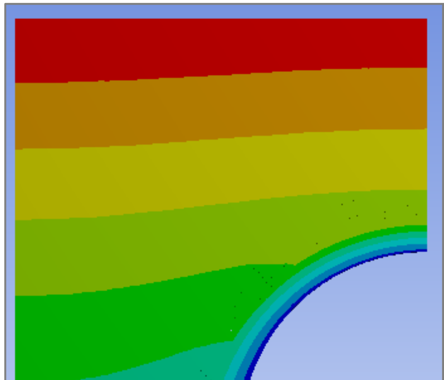
α: heat transfer coefficient, [kW/(m²*K)]	
water:	100 swirl, hyperv.
helium:	30 jet impingement

Introduction: matrix of coolant and material

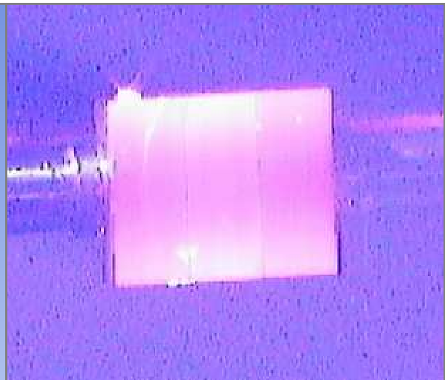


Content

- Introduction
- Experiment 1: HHF tests, austenitic steel, water
  - Mockup, tests, results
  - 10 MW/m^2 and austenitic steel?
  - Austenitic steel and water at 250°C
  - Remarks on thermal stresses
- Experiment 2: Burst test, Charpy impact tests on W-laminate pipes

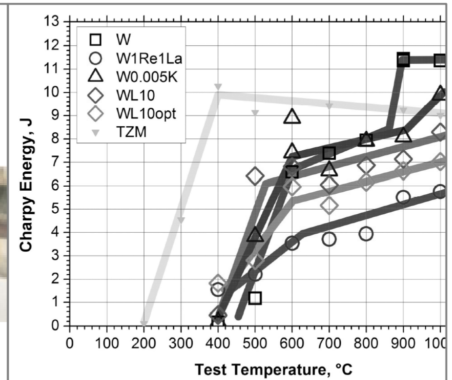


introduction



experiment 1

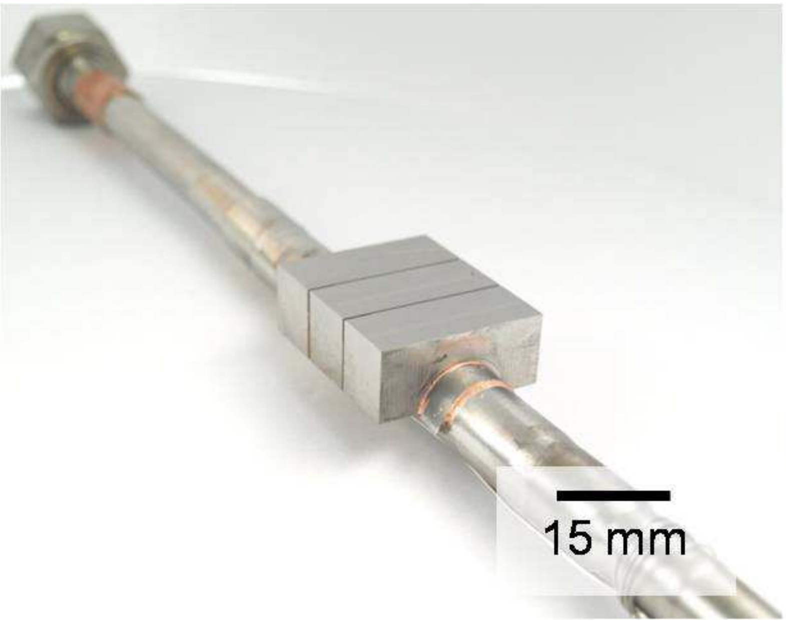
experiment 2

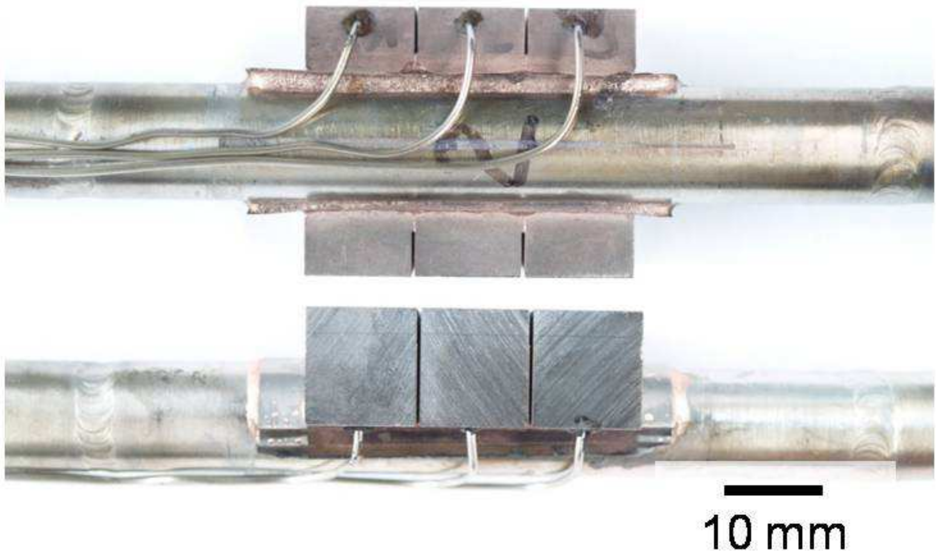


appendix

Experiment 1: HHF tests, austenitic steel, water

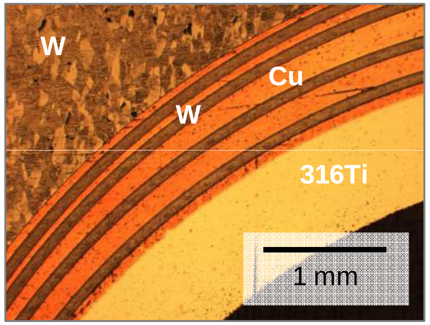
- Mockup, tests, results
  - pipe: austenitic steel (316Ti, 1.4571)
  - coolant: water, 20°C, 10 bar, 10 m/s, 1.13 l/s
  - beam: 20 s on, 40 s off



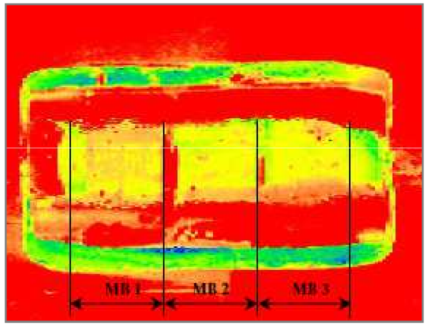


Experiment 1: HHF tests, austenitic steel, water

- Mockup, tests, results
  - **results: 100 cycles, 6 MW/m², no residual damage**



W-laminate as a transition piece

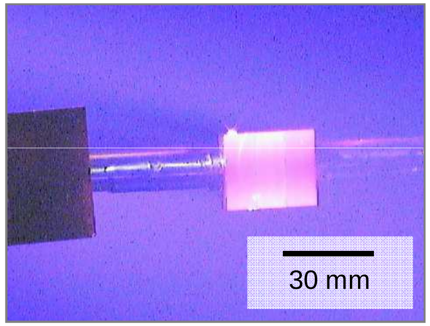


non-destructive testing, PLANSEE SE

T. Huber, A. Zabernig

GLADIS, IPP, Garching

H. Greuner, B. Böswirth

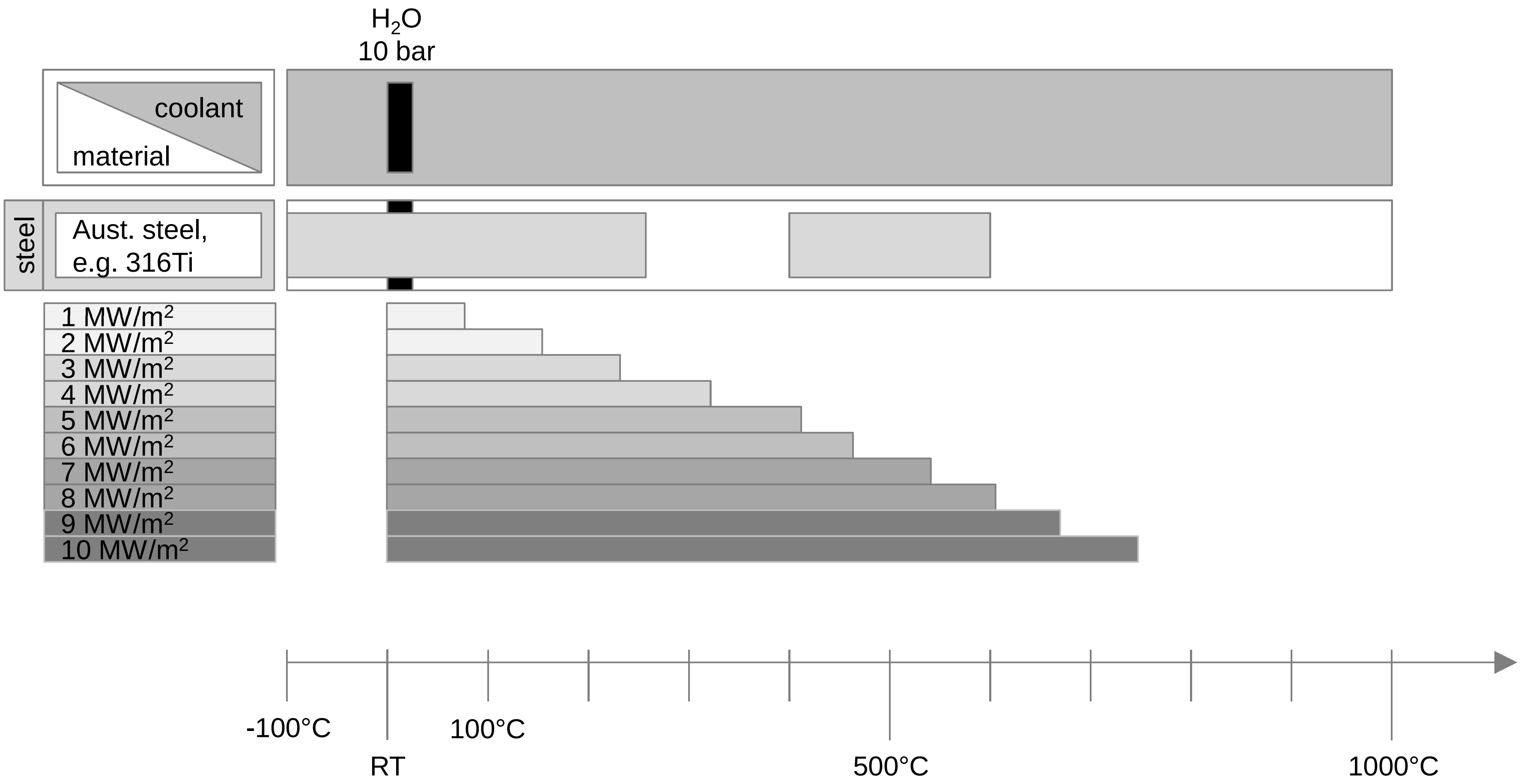


Test: 100 Zyklen, 6 MW/m²

H. Greuner, B. Böswirth

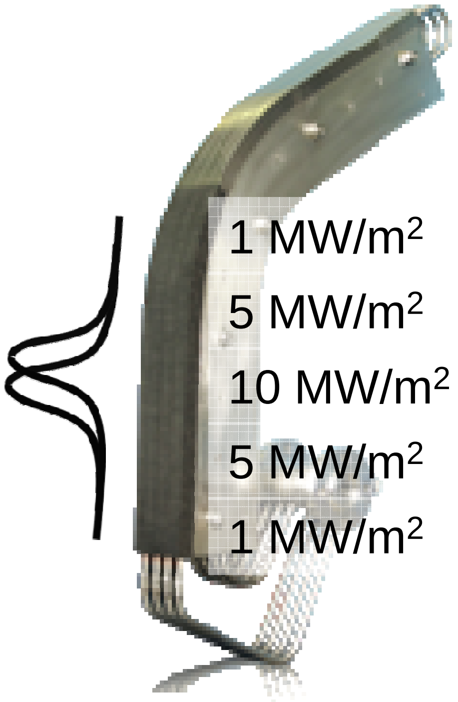
Experiment 1: HHF tests, austenitic steel, water

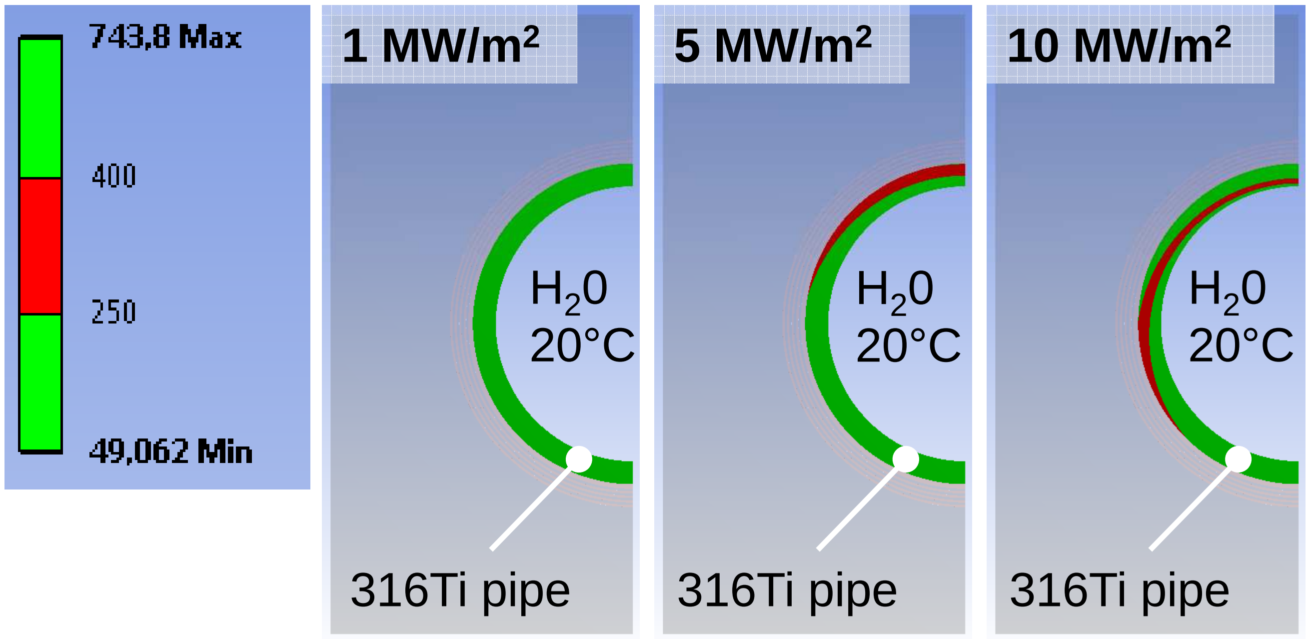
- 10 MW/m² and austenitic steel?



Experiment 1: HHF tests, austenitic steel, water

- 10 MW/m² and austenitic steel?

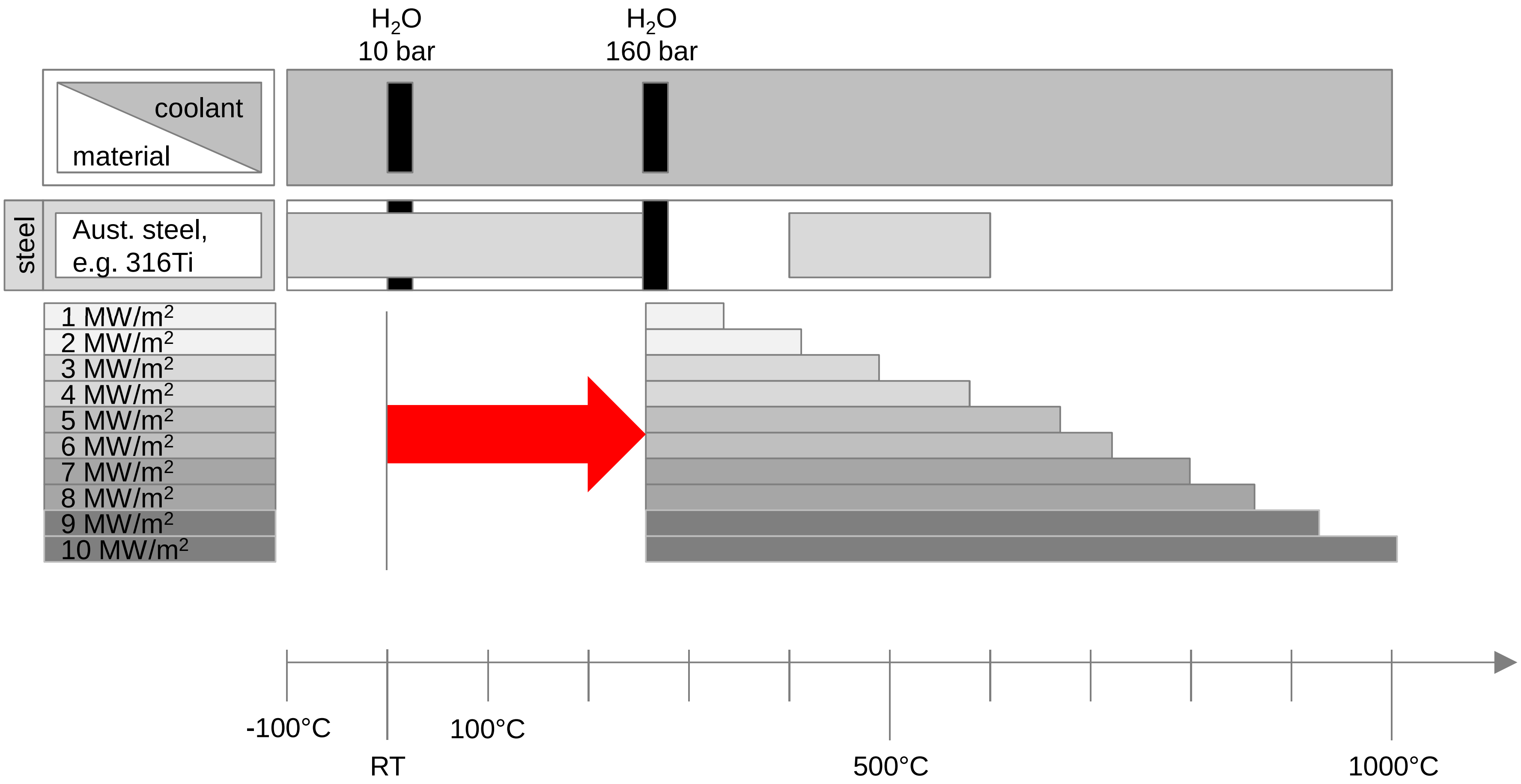




picture: PLANSEE SE

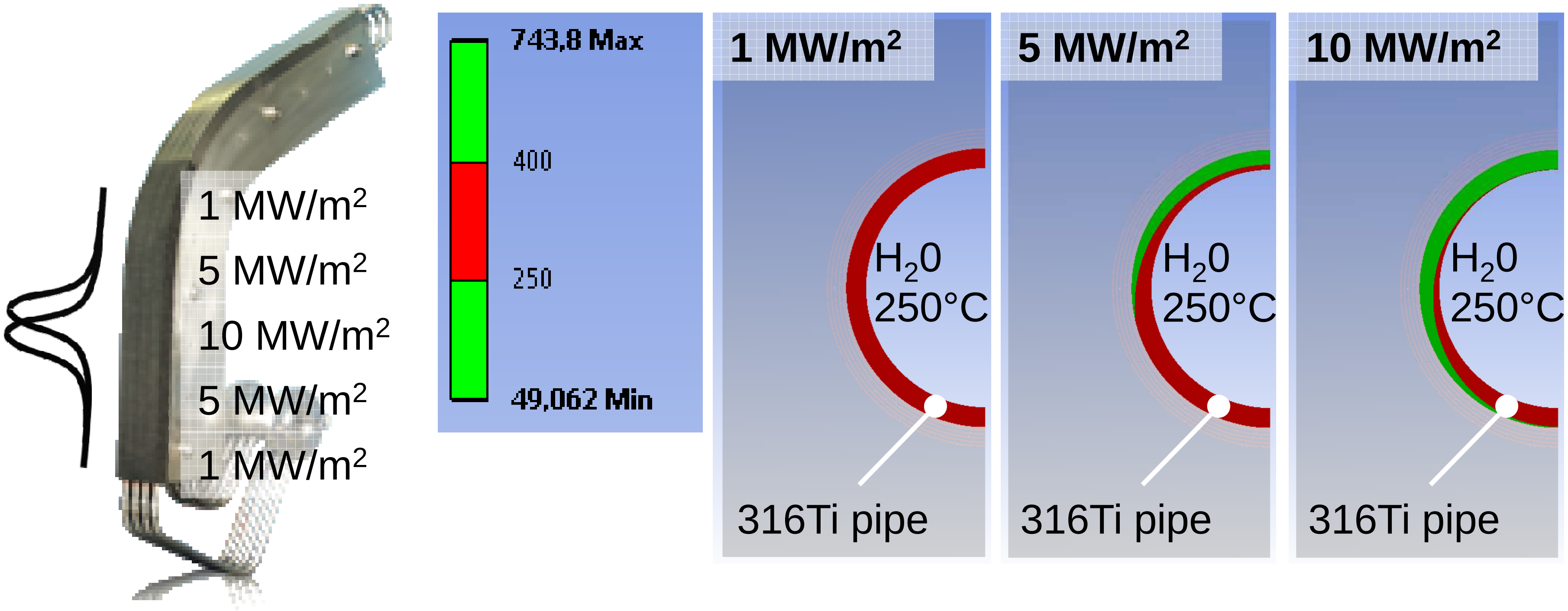
Experiment 1: HHF tests, austenitic steel, water

- Austenitic steel and water at 250°C?



Experiment 1: HHF tests, austenitic steel, water

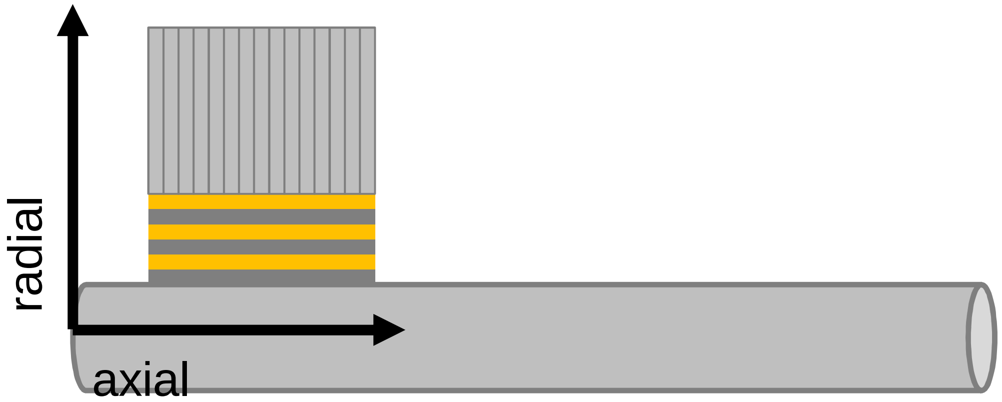
- Austenitic steel and water at 250°C?

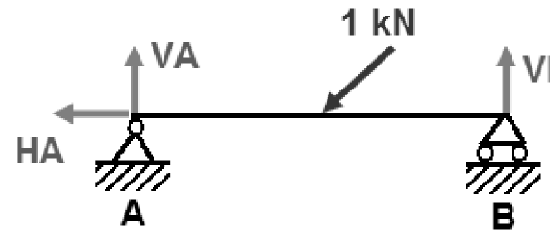


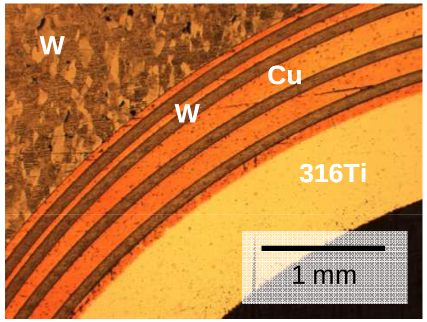
picture: PLANSEE SE

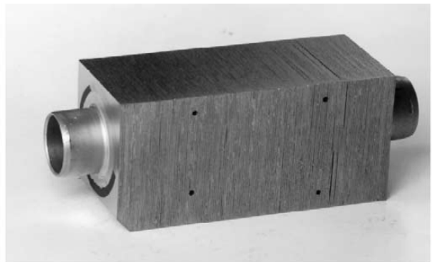
Experiment 1: HHF tests, austenitic steel, water

- Remarks on thermal stresses:
  - minimum bearing → no thermal stresses
- Radial: W-laminate
- Axial: lamellar monoblocks







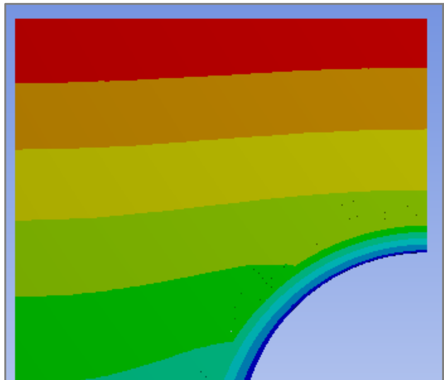
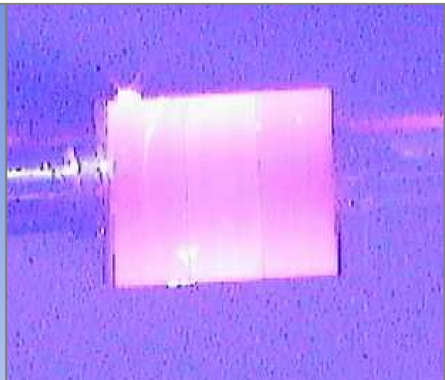


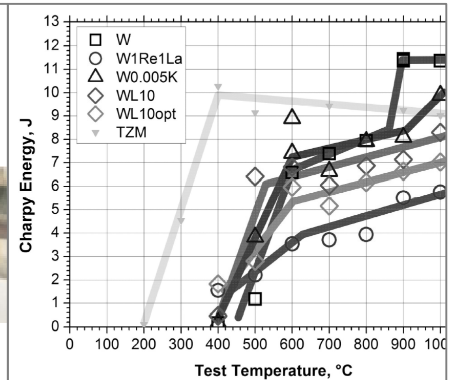
b) W Monoblock (Lamellae Type)

M. Roedig, Fus. Eng. Des. (2002).

Content

- Introduction
- Experiment 1: HHF tests, austenitic steel, water
- Experiment 2: Burst test, Charpy impact tests on W-laminate pipes
  - The tungsten laminate project
  - Test results
  - Proposal: He-cooled divertor made of a W-laminate pipe

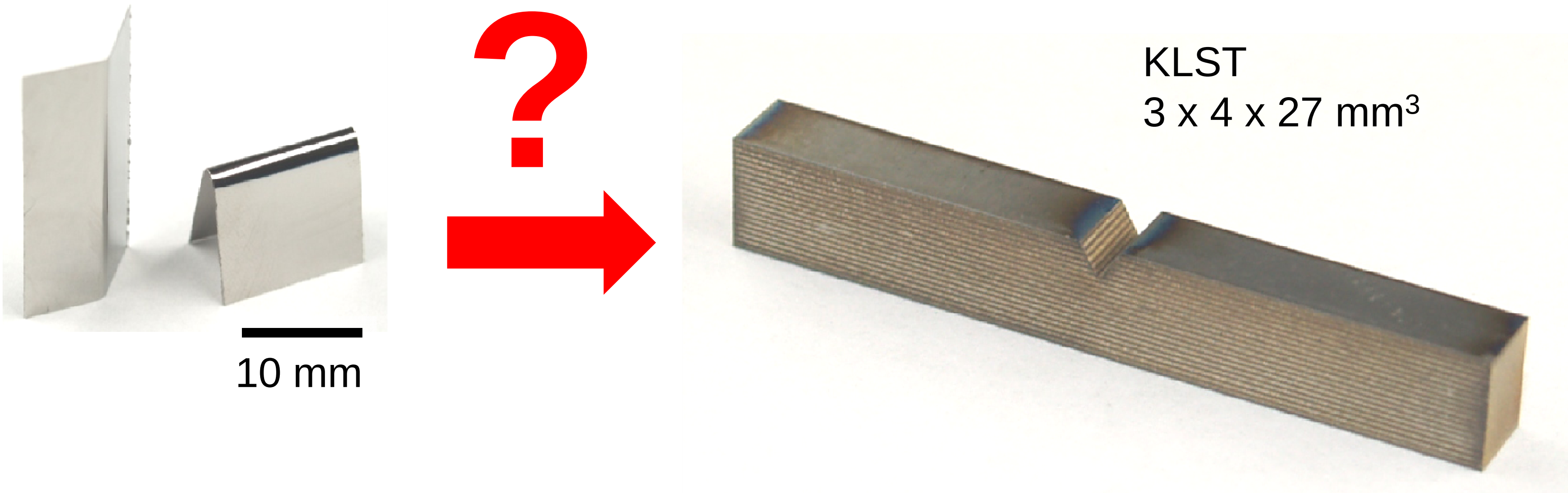





introduction	experiment 1	experiment 2	appendix

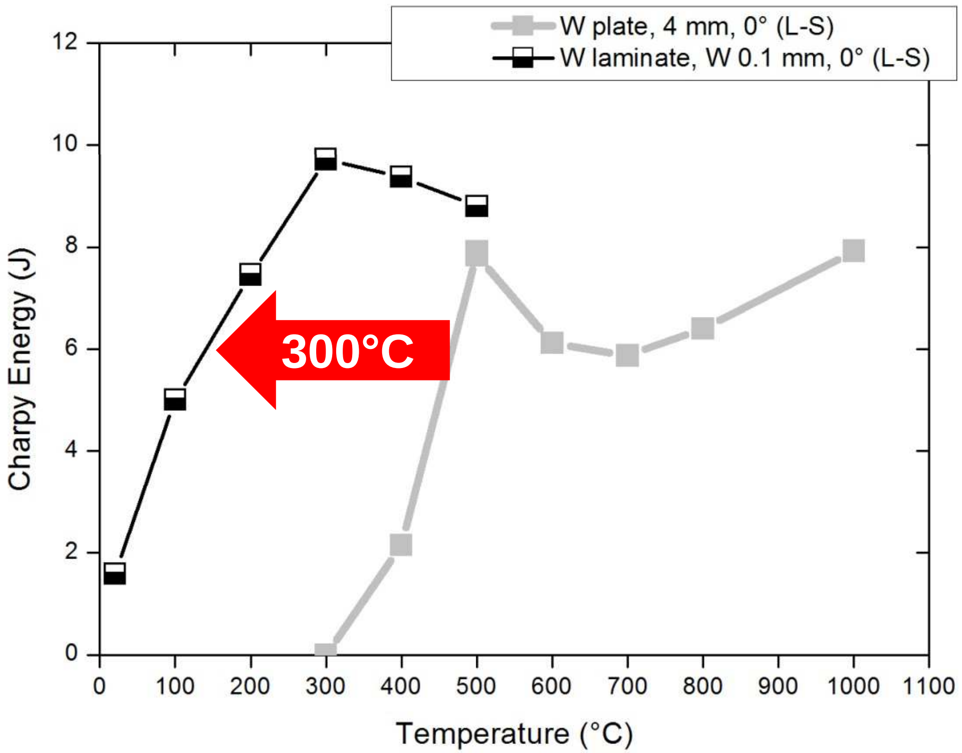
Experiment 2: Tests on W-laminate pipes

- The W-laminate project: Is it possible to expand the ductile properties of a W foil to the bulk?



Experiment 2: Tests on W-laminate pipes

- The W-laminate project: Charpy impact tests
  - as-received condition: improvement of 300°C

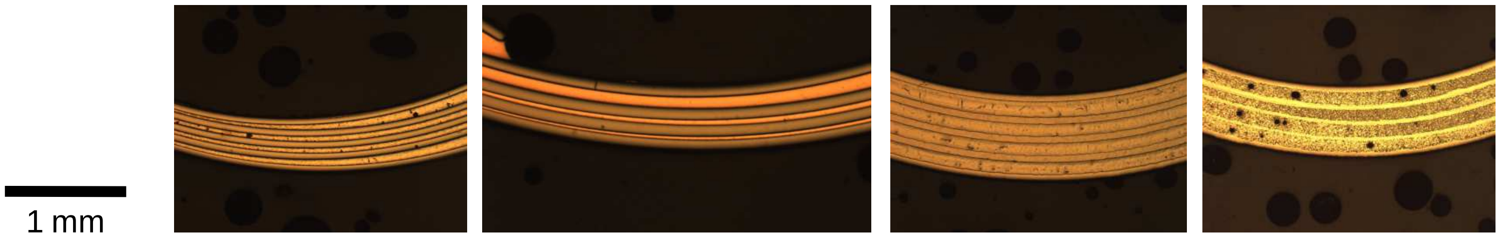


W-laminate made of Cu-alloy

Experiment 2: Tests on W-laminate pipes

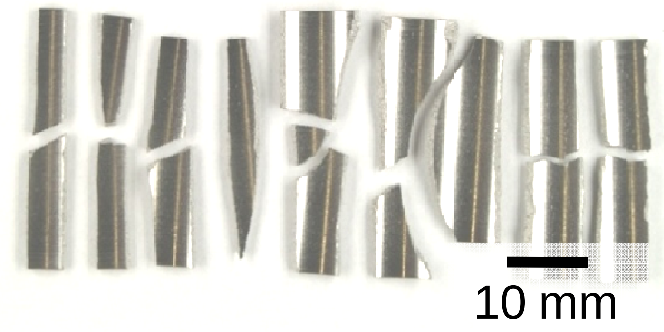
- The W-laminate project: W-laminate pipes

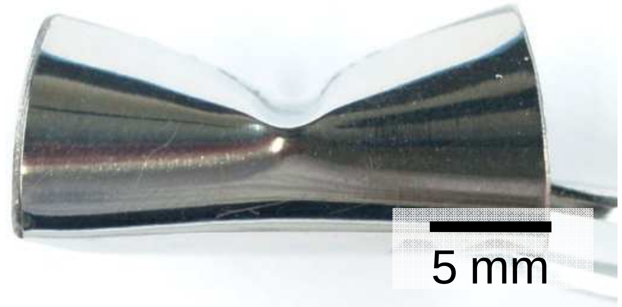
rod | AgCu, 780°C | Cu, 1085°C | Ti, 1670°C | Zr, 1855°C



Experiment 2: Tests on W-laminate pipes

- Test results
  - Charpy impact tests at 300°C

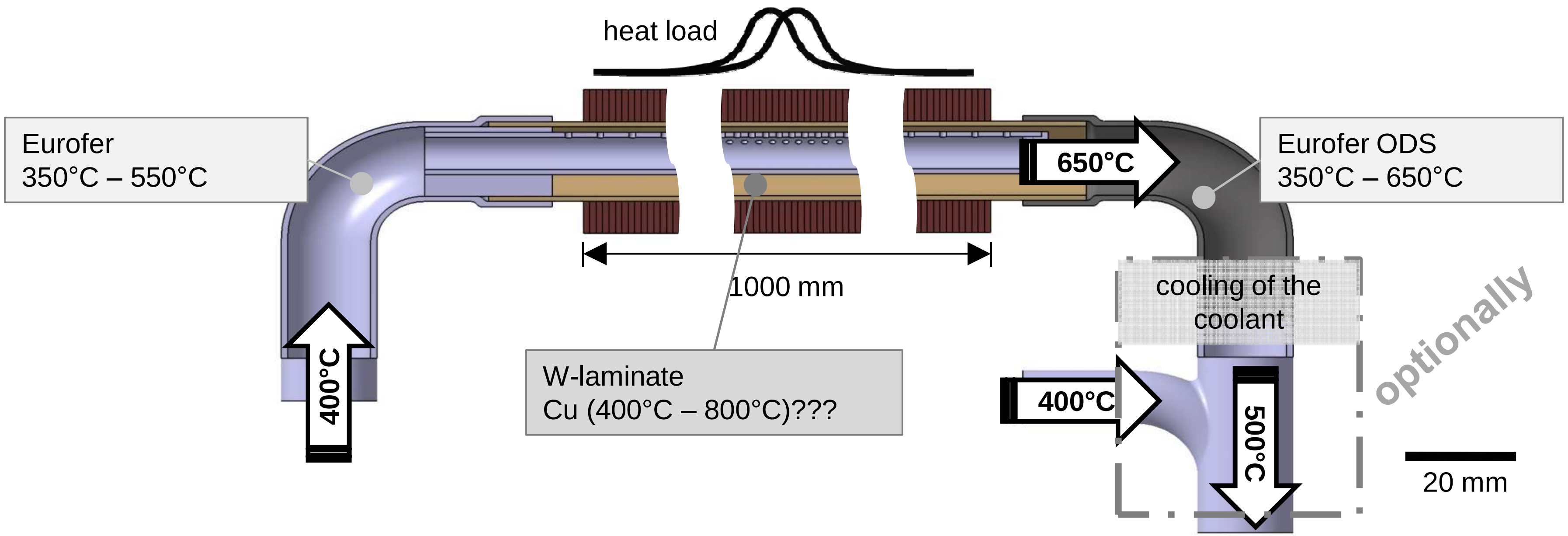




  - Burst test at RT, 1000 bar, no residual damage
    (in cooperation with PLANSEE SE, T. Huber, A. Zabernig)

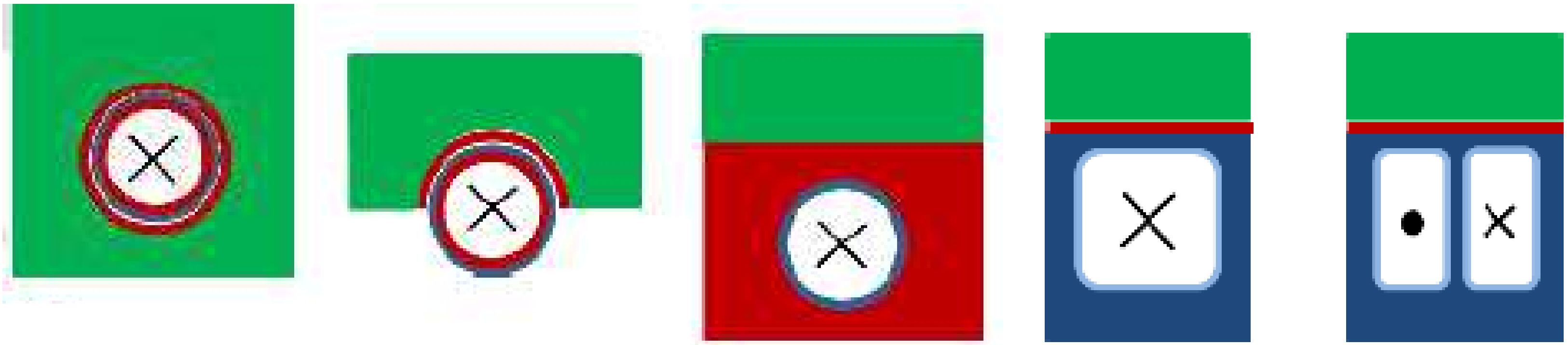
Experiment 2: Tests on W-laminate pipes

- Proposal: He-cooled divertor made of a W-laminate pipe



Outlook (I/II)

- KIT-CCFE cooperation:
  E. Surrey, T. Barrett, W. Timmis, C. Waldon, M. Porton,…
- Workshop on water cooled divertors:
  - Mai 2012: CCFE
  - August 2012: KIT
  - next: March 2013: CCFE
- Plans and ideas: e.g. double-walled pipes



Summary

- **Experiment 1: austenitic steel, water:**
  - 6 MW/m^2 have been tested in HHF tests *(H. Greuner, GLADIS, IPP)*
  - 10 MW/m^2 will be tested next *(H. Greuner, GLADIS, IPP)*
  - Use water at RT, not at 250°C
  - Realize a minimum bearing

  → **Calculation using design rules required**

- **Experiment 2: W-laminate pipes:**
  - Charpy impact tests look promising
  - Burst test looks promising *(PLANSEE SE, T. Huber, A. Zabernig)*

  → **Irradiation data required *(Y. Katoh, L. Snead, Oak Ridge National Laboratory)***

Thank you for your attention

The authors are grateful to:

Plansee Metall GmbH,
University of Oxford,
Culham Centre for Fusion Energy,
Oak Ridge National Laboratory,
IPP in Garching, and
our colleagues from IAM (KIT).

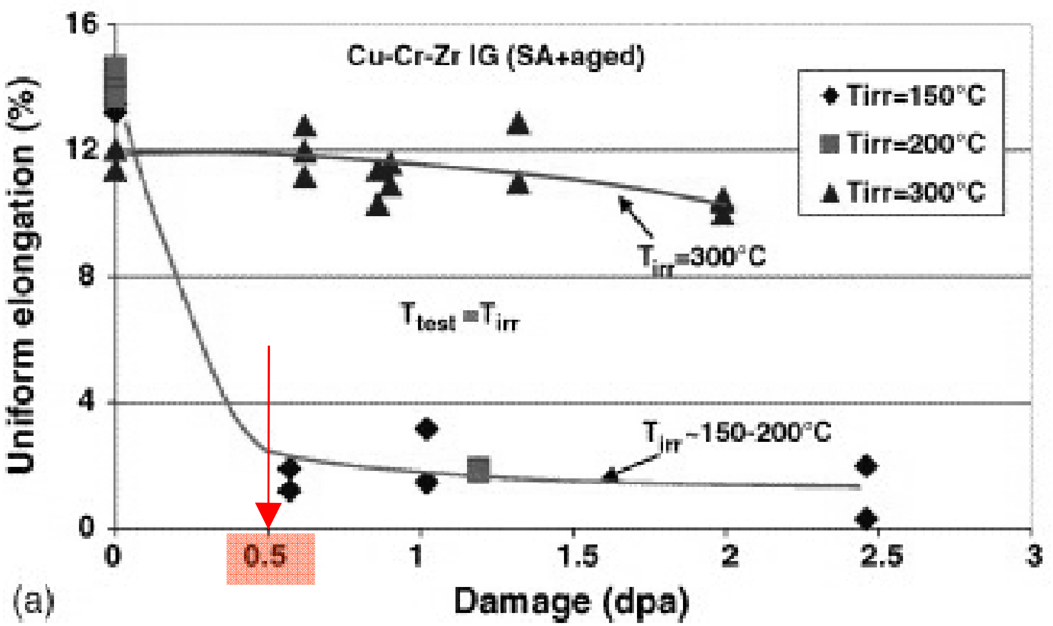
Appendix

Appendix

CuCrZr

Structural material: material for the pipe (II)

- CuCrZr (precipitation hardened: Cu, 0.5 – 1.2 wt.% Cr and 0.03 – 0.3 wt.% Zr):
  - k_{RT} = 305 [W/(m*K)]
  - operation window: 180°C – 280°C



S.A. Fabritsiev, A.S. Pokrovsky, Fusion Engineering and Design 73 (2005) 19–34

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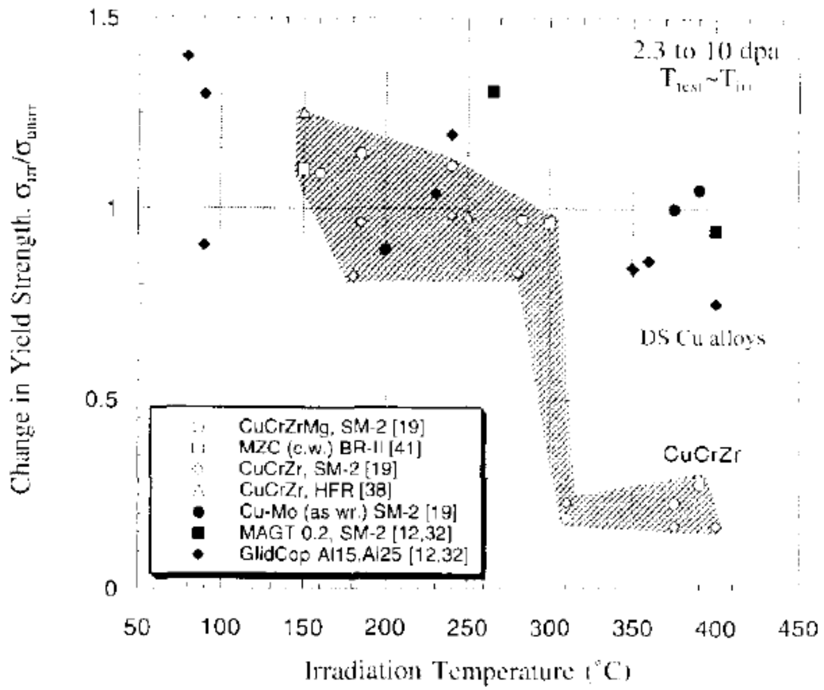

S. A. Fabritsiev, S. J. Zinkle and B. Singh J. Nucl. Mat. (1996)

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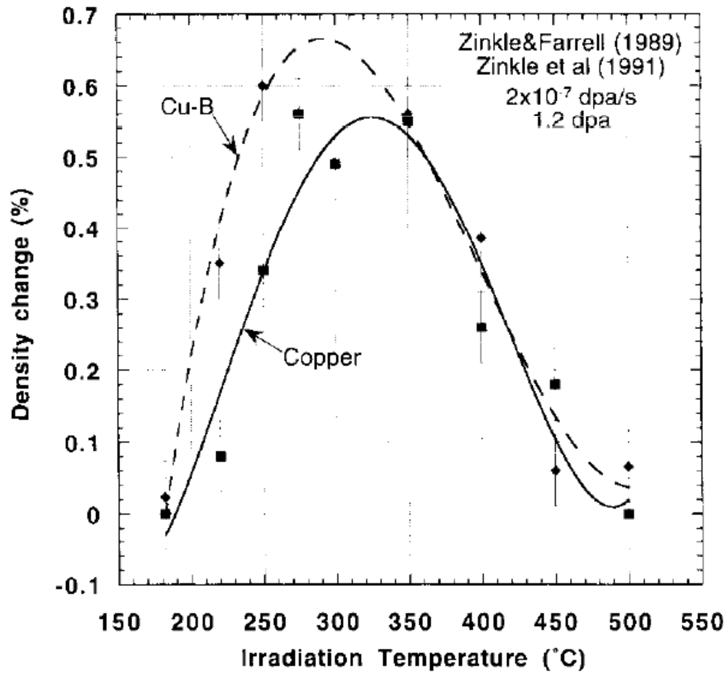

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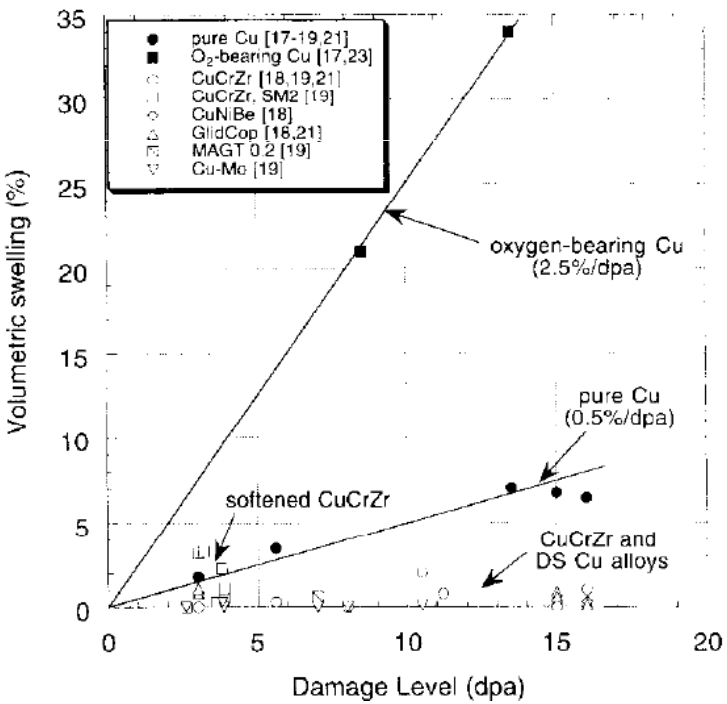


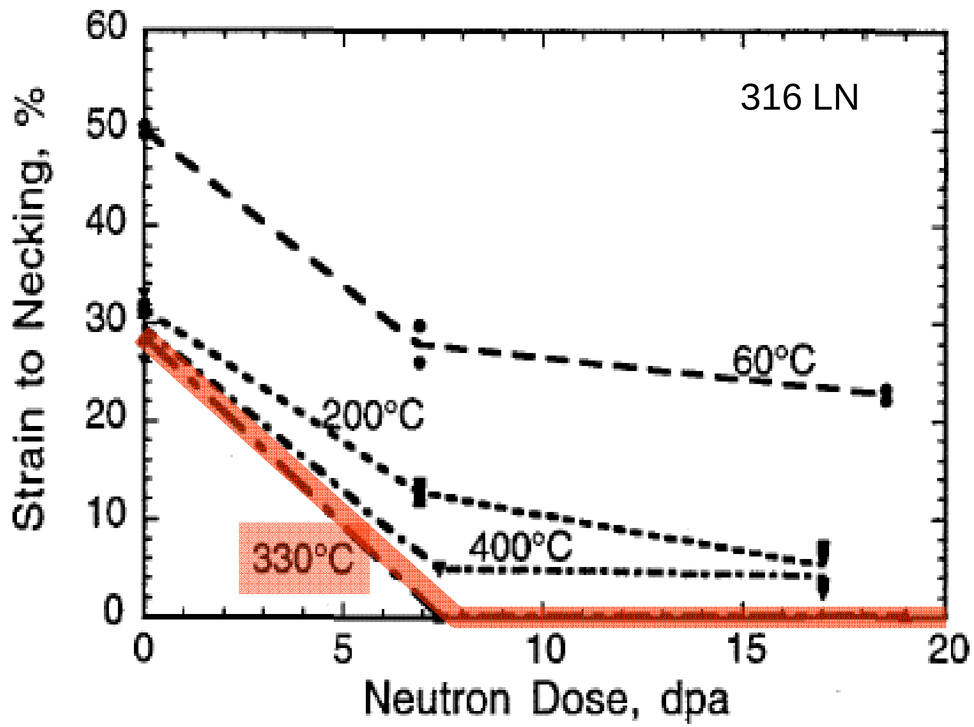
S. A. Fabritsiev, S. J. Zinkle and B. Singh J. Nucl. Mat. (1996)

Appendix

316Ti, austenitic steel

Structural material: material for the pipe (II)

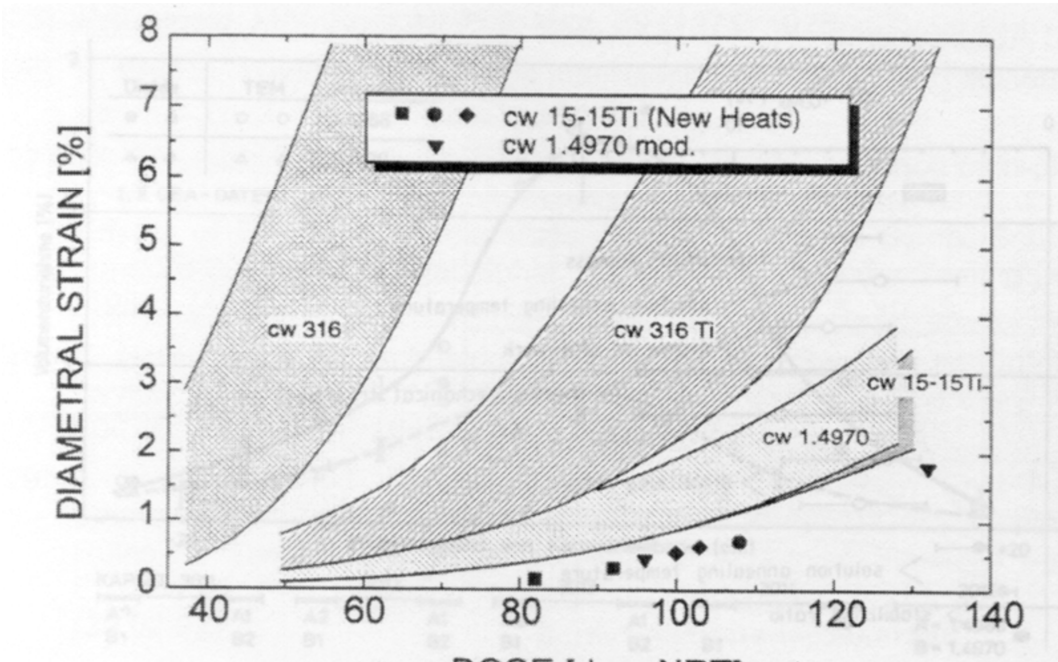
- austenitic steel (e.g. 316):
  - k_{RT} = 15 [W/(m*K)]
  - operation window: up to 250°C and from 400°C – 600°C



J. P. Robertson

Structural material: material for the pipe (II)

- austenitic steel (e.g. 316):
  - k_{RT} = 15 [W/(m*K)]
  - operation window: up to 250°C and from 400°C – 600°C



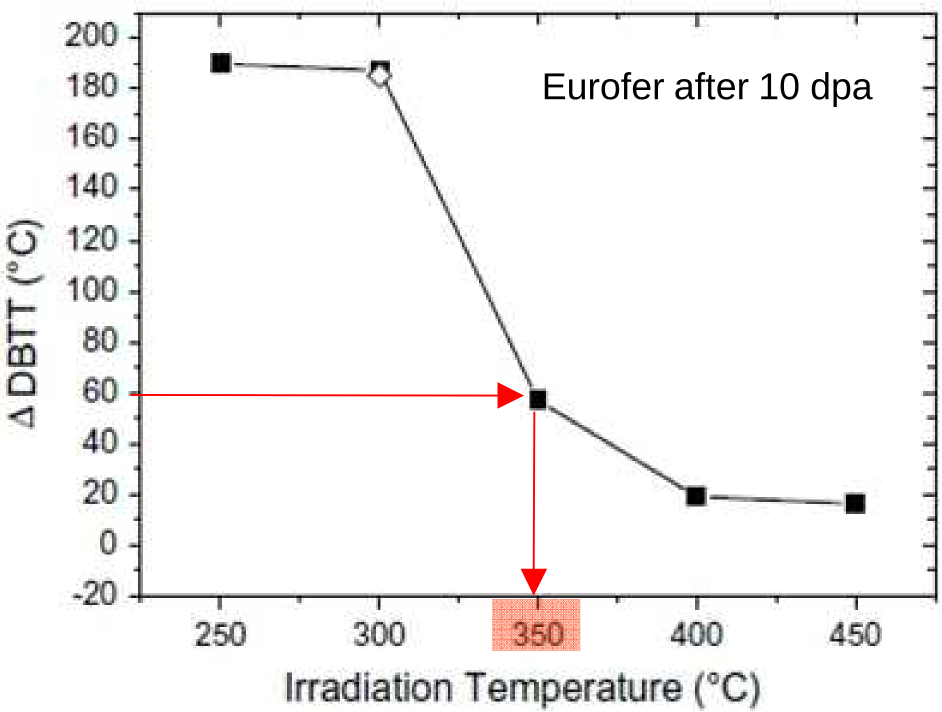
FZK, IMF I

Appendix

RAFM, Eurofer

Structural material: material for the pipe (II)

- RAFM steel e.g. Eurofer, F82H,
  - $k_{500°C}$ = 30 [W/(m*K)]
  - operation window: 350°C – 550°C (Eurofer)
  - operation window: 350°C – 650°C (Eurofer ODS)

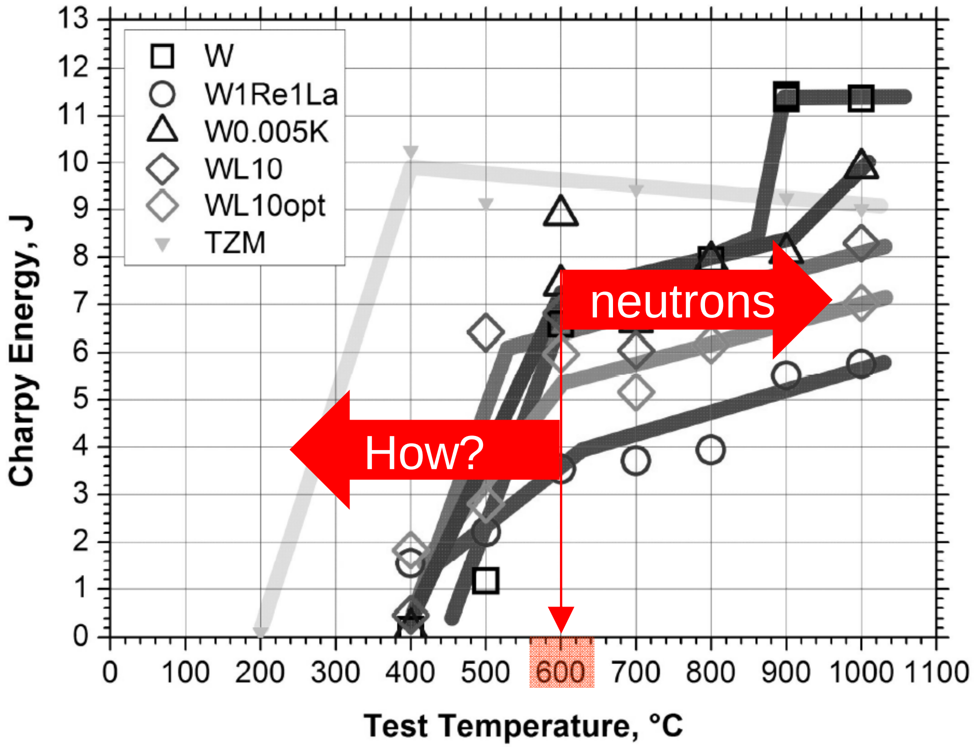


E. Gaganidze et al., KIT

Tungsten

Structural material: material for the pipe (II)

- tungsten:
  - $k_{180°C}$ = 180 [W/(m*K)]
  - optimistic operation window: 600°C – 1200°C (no neutrons)
  - conservative operation window: 900°C – 1100°C (pure W, no neutrons)

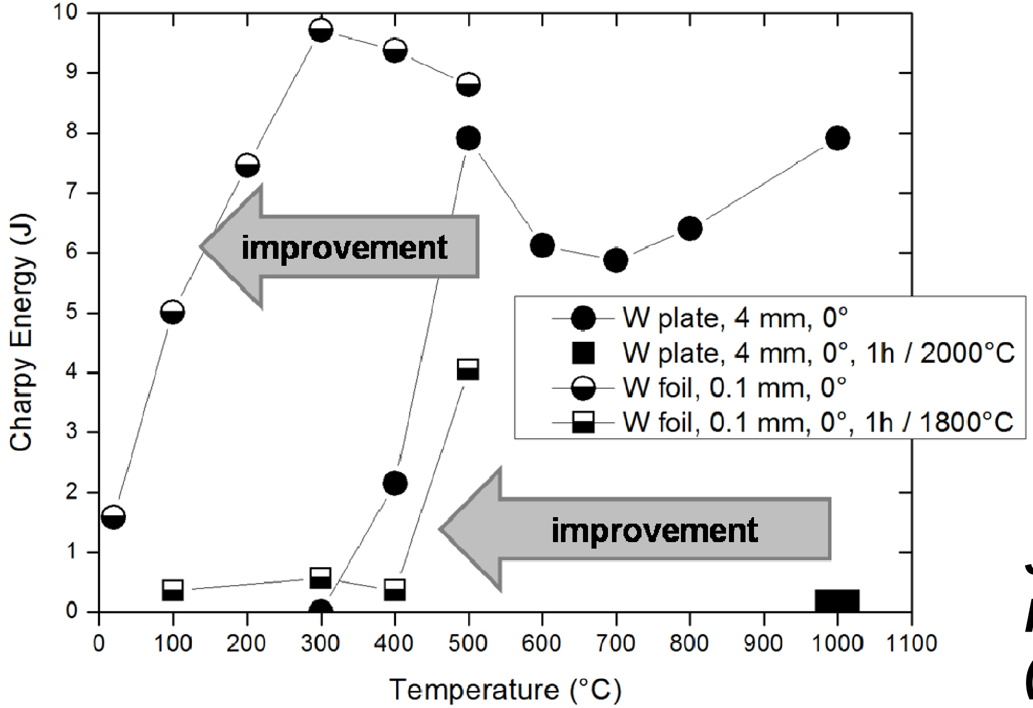


M. Rieth, A. Hoffmann, Adv. Mater. Res. 59 (2009) 101.

W-laminate

Structural material: material for the pipe (II)

- tungsten:
  - $k_{180°C}$ = 235 [W/(m*K)]
  - optimistic operation window: xxx (no neutrons)
  - conservative operation window: xxx (pure W, no neutrons)



J. Reiser, M. Rieth, A. Hoffmann, et al. J. Nucl. Mater (2012).