

Possible Cross-cutting Applications for EUROfusion High Heat Flux Materials

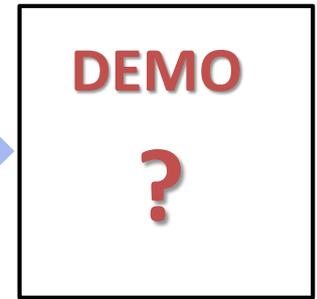
M. Rieth, T. Gräning, A. von Müller, G. Pintsuk, J. Reiser, E. Tejado, J.-H. You



From ITER to DEMO

- Neutron damage has to be taken into account:
 - loss of thermal conductivity
 - embrittlement
 - swelling
- Effect of n-irradiation on CuCrZr and W is uncertain at relevant dose and temperature levels
- CuCrZr has upper temperature limit: 300-350 °C (loss of strength)
- W has lower temperature limit: 800-1000 °C (irrad. embrittlement)

→ Risk Mitigation



Water: 100 °C, 4 MPa
150 °C, 4 MPa

CuCrZr pipes: <0.2 dpa/y
Max. heat: 10-20 MW/m²

3-5 dpa/fpy
10-20 MW/m²



Baseline: ITER-like Divertor Concept



Work Programme

Risk Mitigation: Materials

- W (armour, plasma-facing) Materials
- Interlayer Materials
- Cu (structural, heatsink) Materials

Topics/Strategies

- W-W/fiber composites
- WC & SiC reinforced W
- W alloy development (PIM)
- Cu-W (fiber & particle) comp.
- W/Cu functionally graded
- Self-passivating W alloys

Risk Mitigation: Helium cooled divertor **focus of this presentation**

- Structural Material
- Fabrication Technology

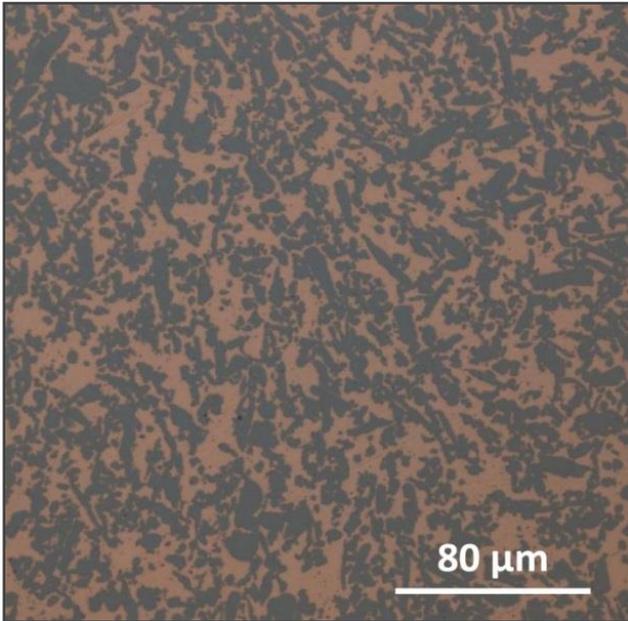
Topics/Strategies

- W-X laminated pipes

Testing & Technology

- Joining Techniques
- Large Facility (HHF) Testing
- Characterization
- Demonstration: Application & Industrial Scale-up

W/Cu(CrZr) Composite Metals



60wt% W / 40wt% Cu



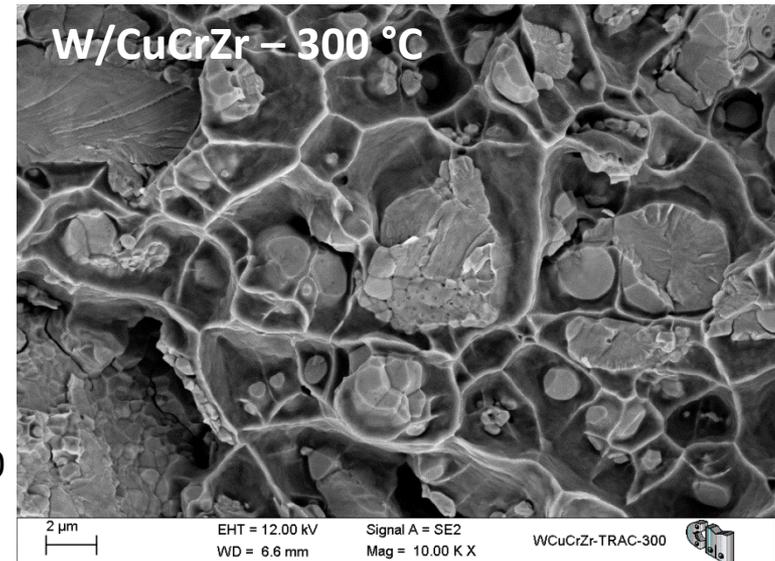
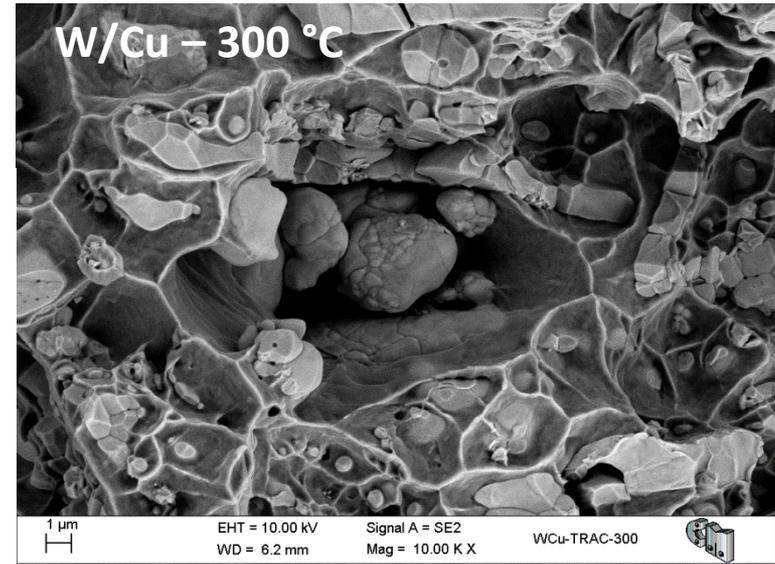
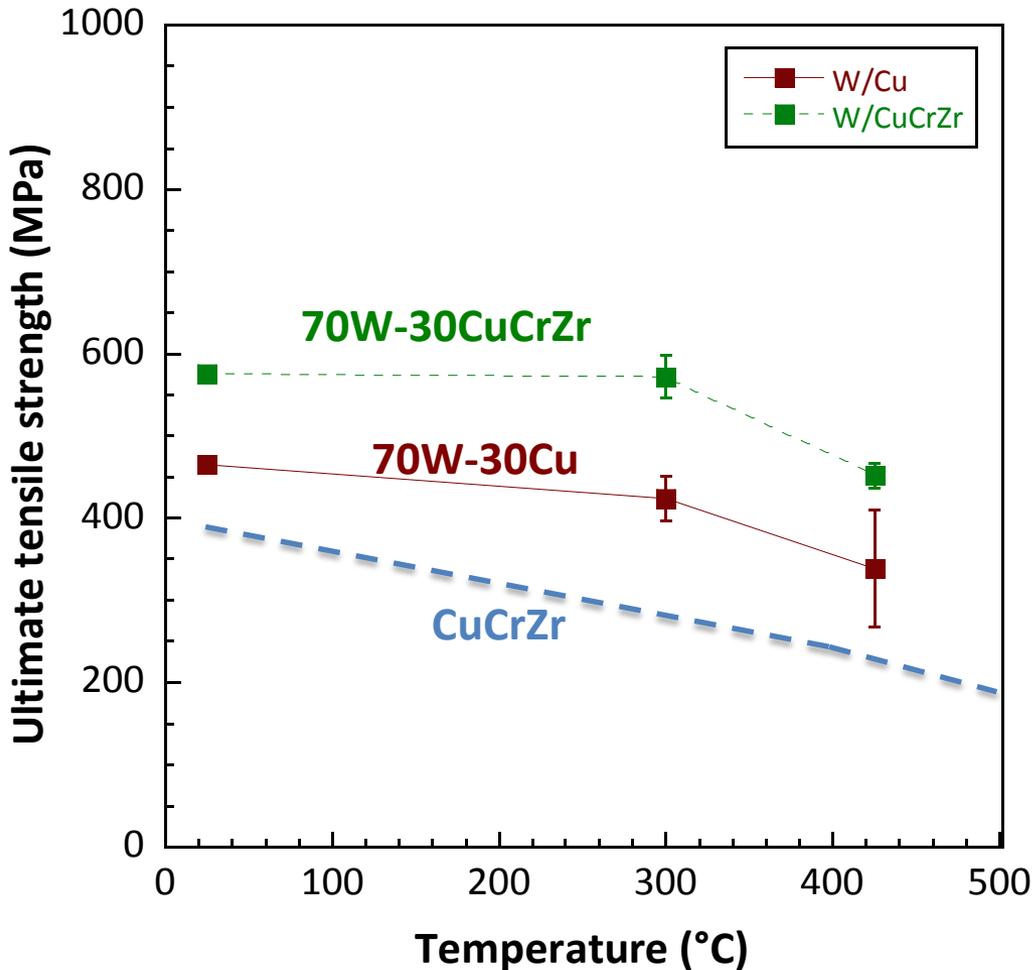
W/Cu composite metal with composition 70wt% W, 30wt% Cu (dimensions: 150 mm x 30 mm x 3 mm)

→ Materials produced

| Composition | | | |
|--------------------|---------------|---------------|----------------|
| wt% W | wt% Cu | vol% W | vol% Cu |
| 85 | 15 | ~ 70 | ~ 30 |
| 75 | 25 | ~ 60 | ~ 40 |
| 70 | 30 | ~ 50 | ~ 50 |
| 60 | 40 | ~ 40 | ~ 60 |



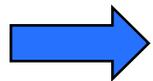
Ultimate strength as function of test temperature in vacuum.





W fibre processing

- Continuous W fibre reinforcement & industrially viable production process



Braiding of cylindrical W fibre preforms



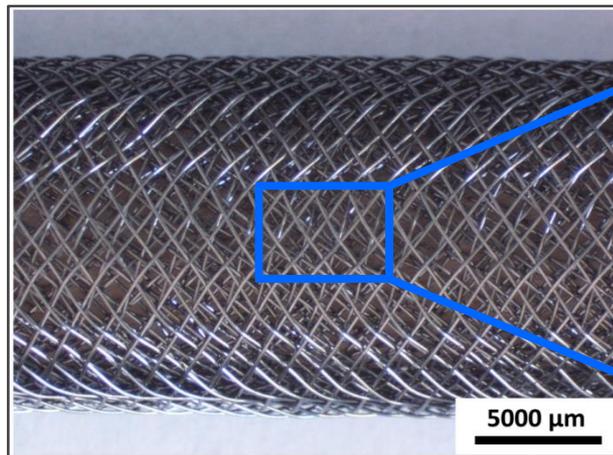
Braiding of W fibres (d = 150 μm)

- Feasibility to process W fibres to cylindrical preforms demonstrated ✓

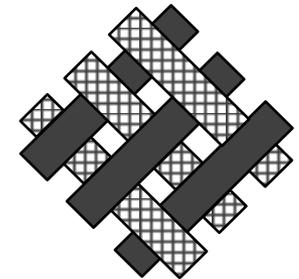
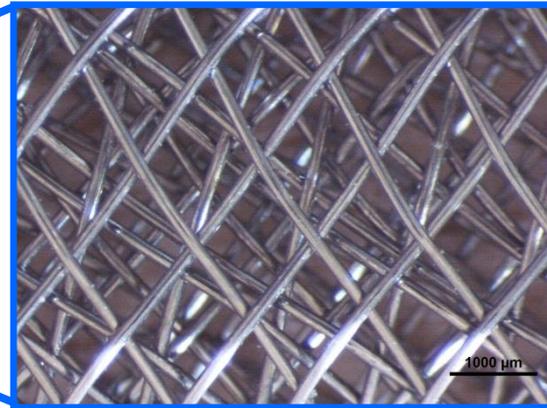


W fibre processing

Multilayer braiding



Fibre diameter: 150 µm



Biaxial regular braid

⇒ High fibre volume fraction (~ 0.3)

⇒ High braiding angles

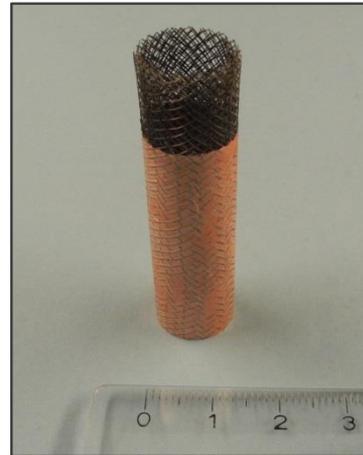
} desired



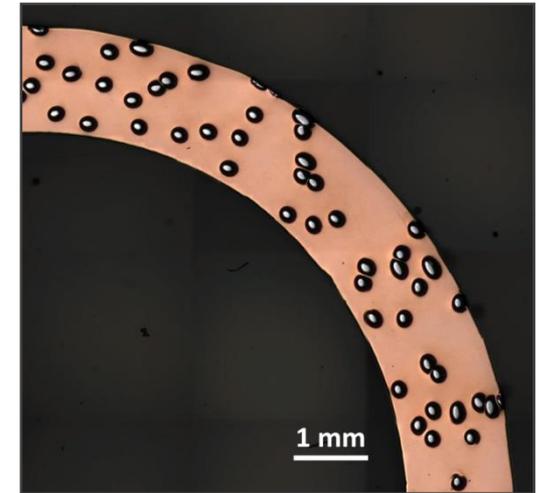
Room for improvement



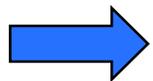
*W fibre reinforced Cu pipes
(length: ~200 mm)*



*W fibre braiding
embedded in Cu
matrix*



*Micrograph of pipe cross
section*



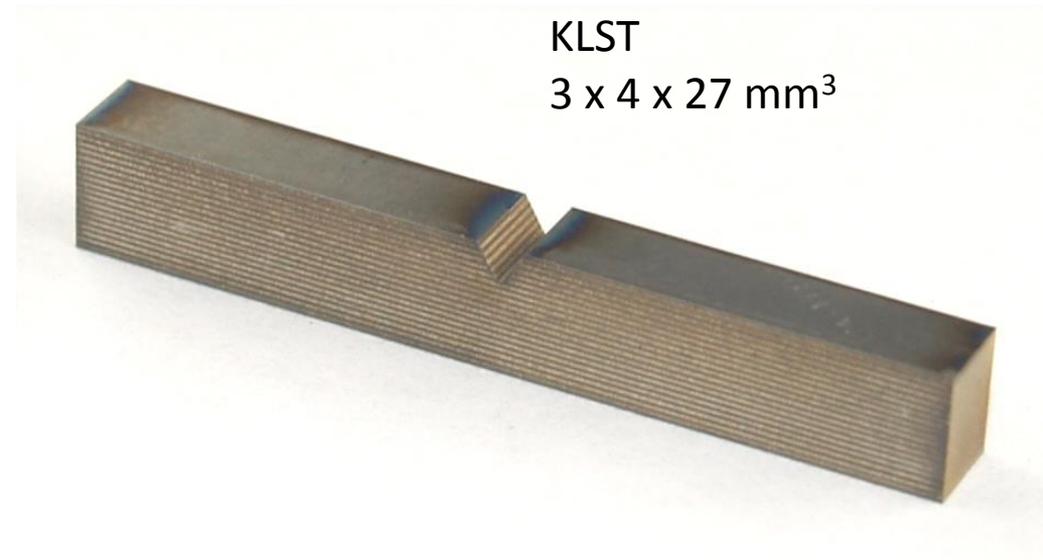
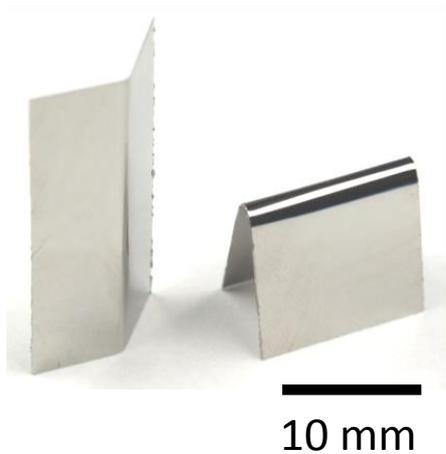
Cu melt infiltration of W fibre preforms a viable manufacturing method



R&D continued

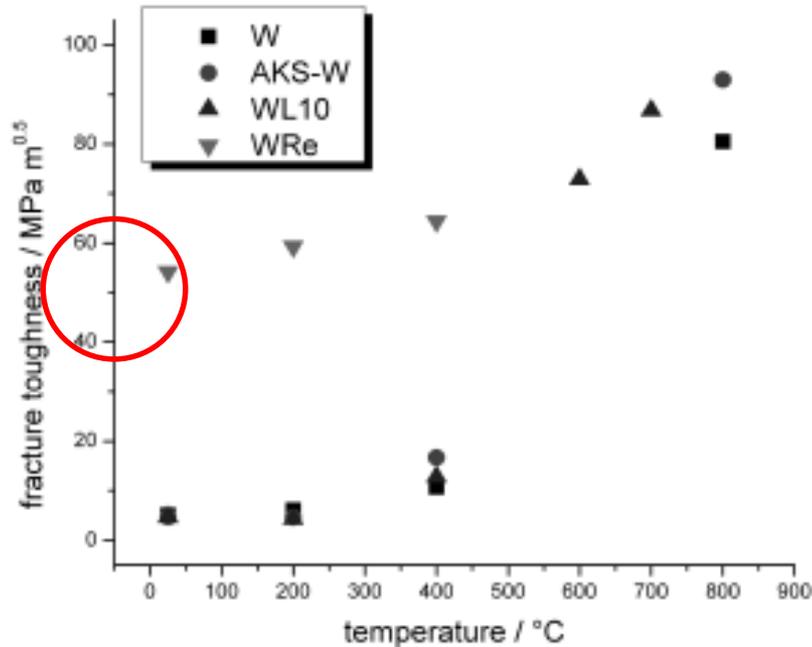


Is it possible to transfer the ductile properties of a W-foil to the bulk?



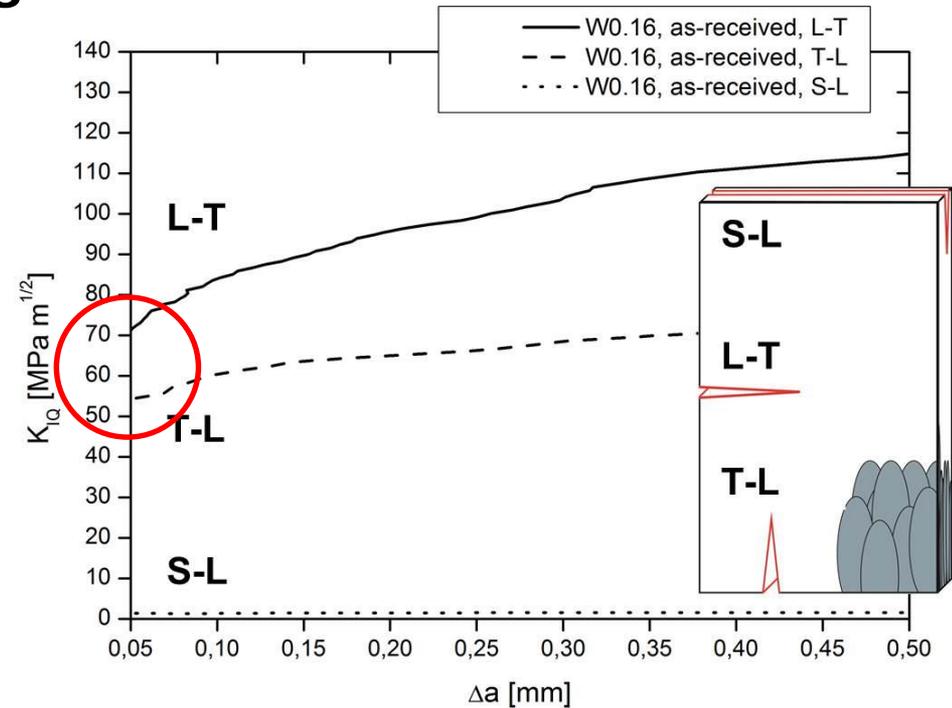


Alloying (W-Re) vs. cold working



B. Gludovatz, S. Wurster, A. Hoffmann, R. Pippan, Int. J. Refract. Met. H., 28 (2010) 674.

K_{IQ} , WRe26wt.%, rolled and stress relieved = 60 MPa(m)^{1/2} (at RT)



R. Pippan, presentation at W-conference, organized by R. Odette, UCLA, Santa Barbara (2011).

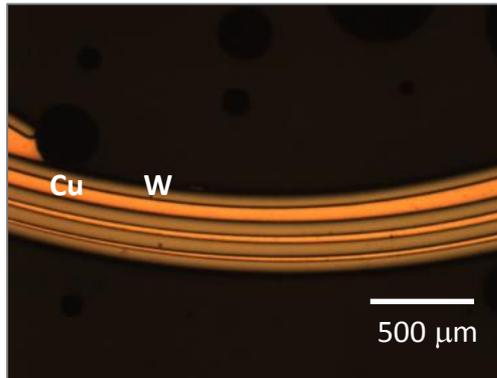
K_{IQ} , pure W foil, 0.16 mm, rolled, as-received



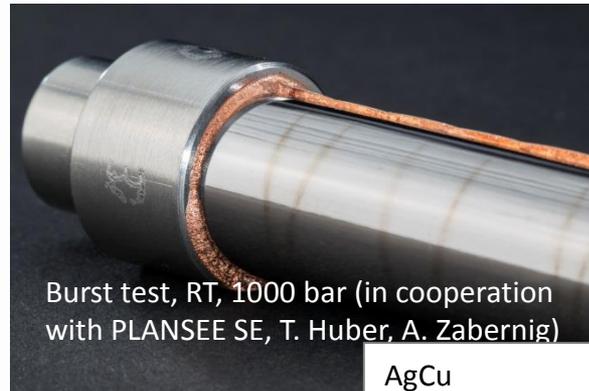
Pressured pipes

- Low cohesion of HAGBs: mitigated by foil orientation
- Fracture toughness (L-T): $K_{I_Q} = 70 \text{ MPa m}^{1/2}$

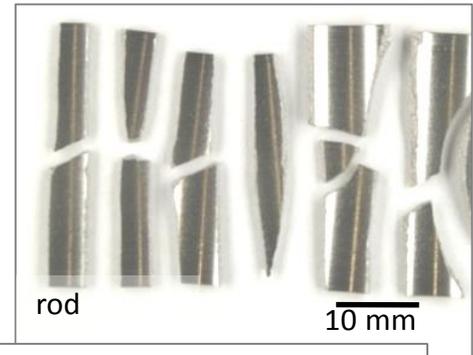
W-laminate pipe



Burst test



Charpy, 300°C



W foil laminates: Possible Interlayers

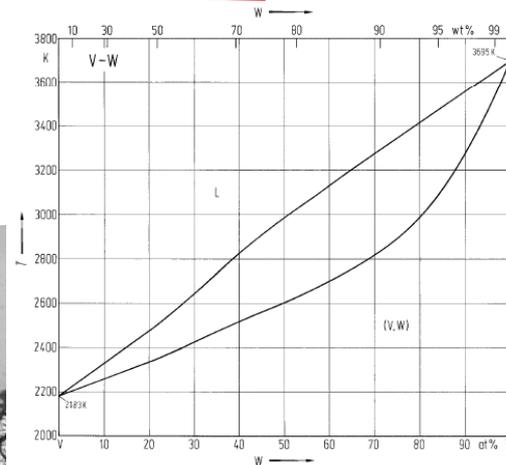
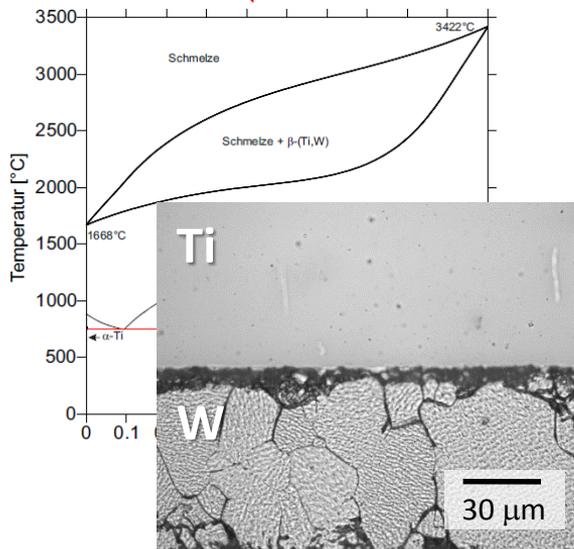
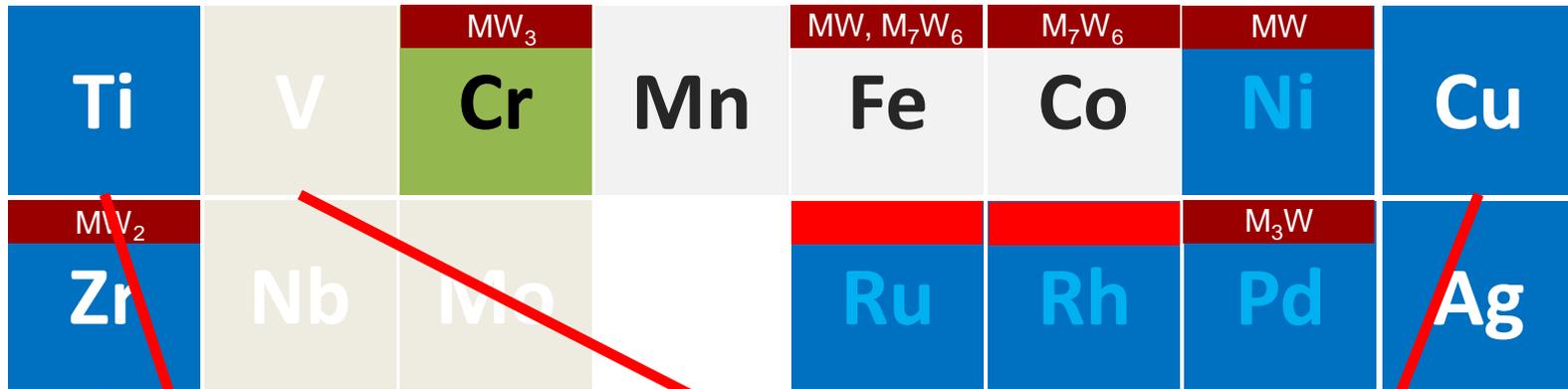


Fig. 1. V-W. Phase diagram.

Landolt-Börnstein, New Series IV/5

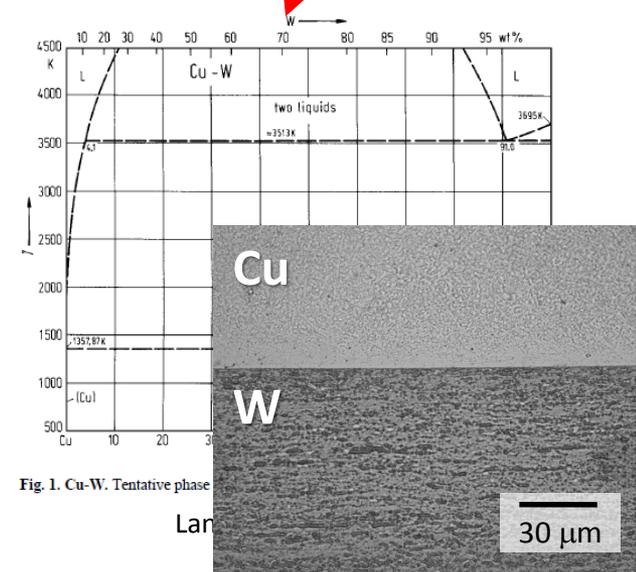


Fig. 1. Cu-W. Tentative phase

Lan



Concentrated solar power (CSP)

CSP, tower

Molten salts, 565°C – 625°C, Ni-base
 → corrosion, temp. gradient, liquid metal



photo: ABENGOA



Heller, DLR (2011)

CSP, Dish-Stirling

Helium, 900°C, Ni-base



photo: DLR, Markus Steur



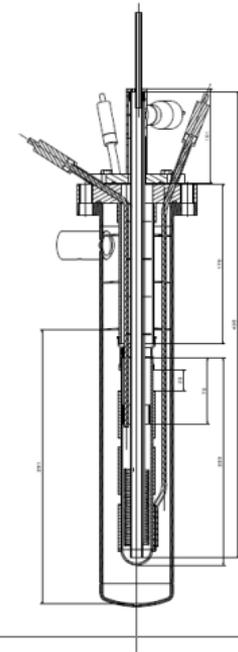
T. Denk, PSA (2013)

AMTEC: alcali metal thermal to electric converter

Topping system, 24/7

β'' -alumina solid electrolyte (BASE)
 Na (liquid) → electron + [Na⁺]BASE

Na, 1000°C
 → corrosion



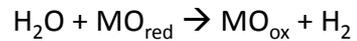
W. Hering, KIT



Solar chemistry

Solar reactor

storable fuels like hydrogen (H₂)
metal oxide (MO) redox system:



T. Denk, PSA (2011)

Fusion

Divertor

Helium, 400°C – 600°C, 20 MW/m²,
neutrons

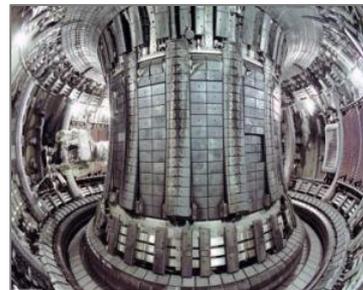
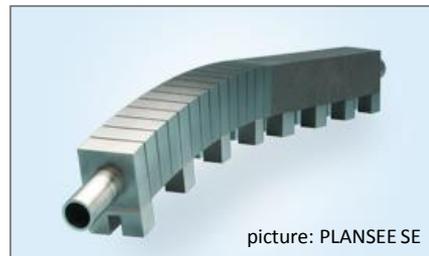


photo: JET



picture: PLANSEE SE

Biomass-to-liquid (BTL)

bioliq® BTL process

gas cleaning and conditioning
80 bar, 500°C – 800°C



photo: KIT

Example: Preliminary Tests with Concentrated Solar Power in Plataforma Solar de Almeria (PSA)

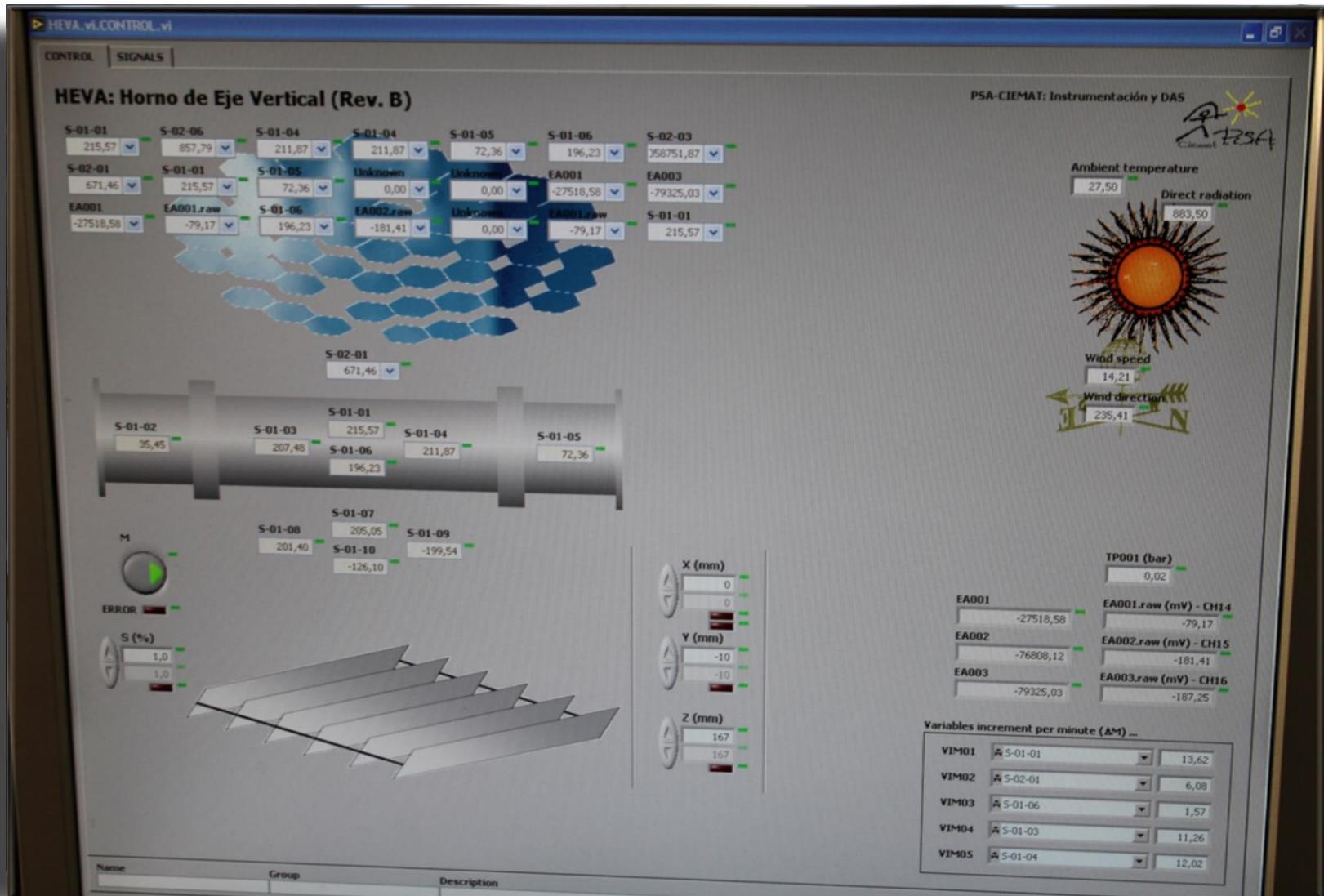


Test Conditions



Solar Tower and Control Center

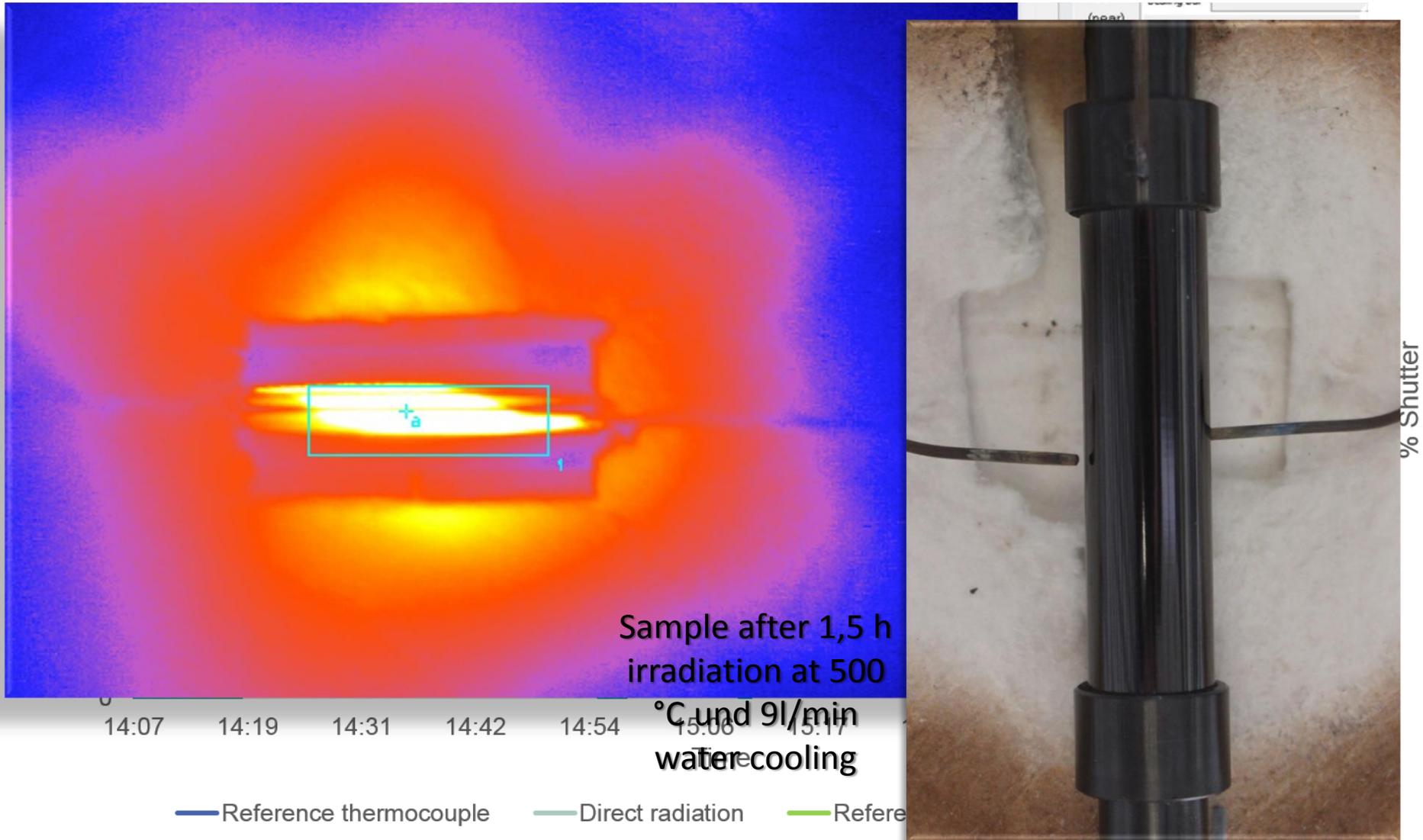
Test Station



Test Matrix

| | Samples | Temperature | Coolant | Fatigue |
|-----|-------------------|-------------|---------------------------|------------|
| 2 d | IV.2 W-Cu | 700°C/ 1h | 50l/ h <i>Helium</i> | NO |
| Mo | III.2 W-Ag-Cu | 400°C/ 1h | <i>~30l/ min</i> water | NO |
| Cu | II.2 W-Ag-Cu | 550°C/ 1,5h | ~9l/ min water | YES |
| | III.1 Mo-Ag-Cu | 550°C/ 1h | ~9l/ min water | NO |
| | II.1 Mo-Ag-Cu | 650°C/ 2h | ~9l/ min water | NO |

Test Data



Sample after 1,5 h
irradiation at 500
°C and 9l/min
water cooling

— Reference thermocouple — Direct radiation — Refere

% Shutter

Results/Summary

-  5 Tests successfully performed
-  3 samples of 7 not leak tight
-  Temperature gradient in laminate
-  Cu as brazing material
-  Ag-Cu as brazing material
-  Performance under “cyclic loading” (clouds)
-  Performance of coating
-  Transition to steel connector



- CCFE
- CEA
- CIEMAT (+ CEIT, URJC, UPM, ...)
- DTU
- ENEA-Frascati
- ENEA-CNR
- FZJ
- Wigner RCP (HAS)
- NCSR (HELLENIC)
- MPG (IPP)
- IPPLM
- IST
- KIT
- ISSP-UL (LATVIA)
- IAP (MEdC)
- JSI (MESCS)
- FOM-DIFFER (NRG)
- OEAW
- RBI
- LPP-ERM-KMS (SCK.CEN)
- UT (TARTU)
- VTT (TEKES)
- VR



Slovenska Fuzijska Asociacija
Slovenian Fusion Association



Vetenskapsrådet