He-cooled Divertor Development in the EU:

The Helium Jet cooled Divertor HEMJ

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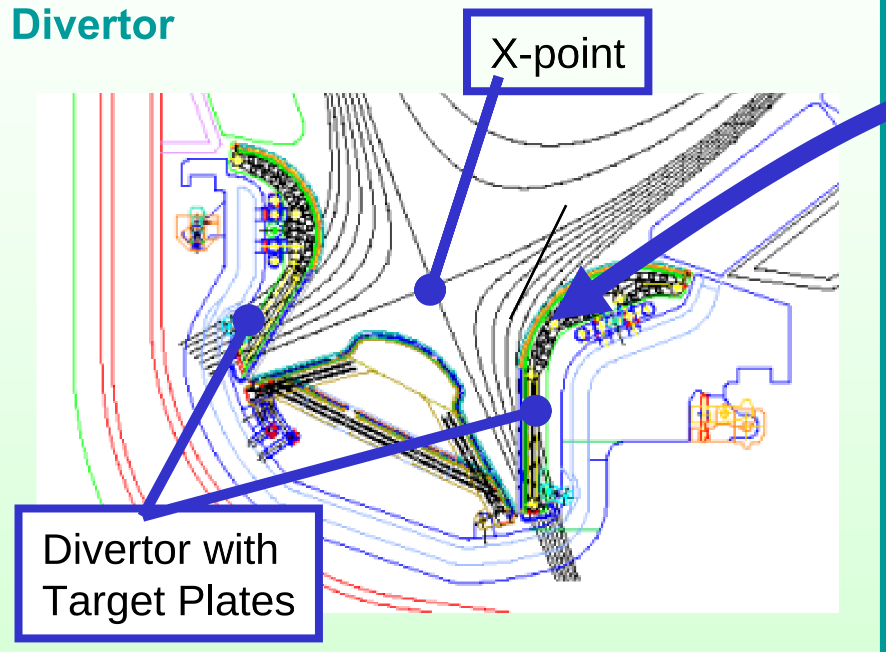
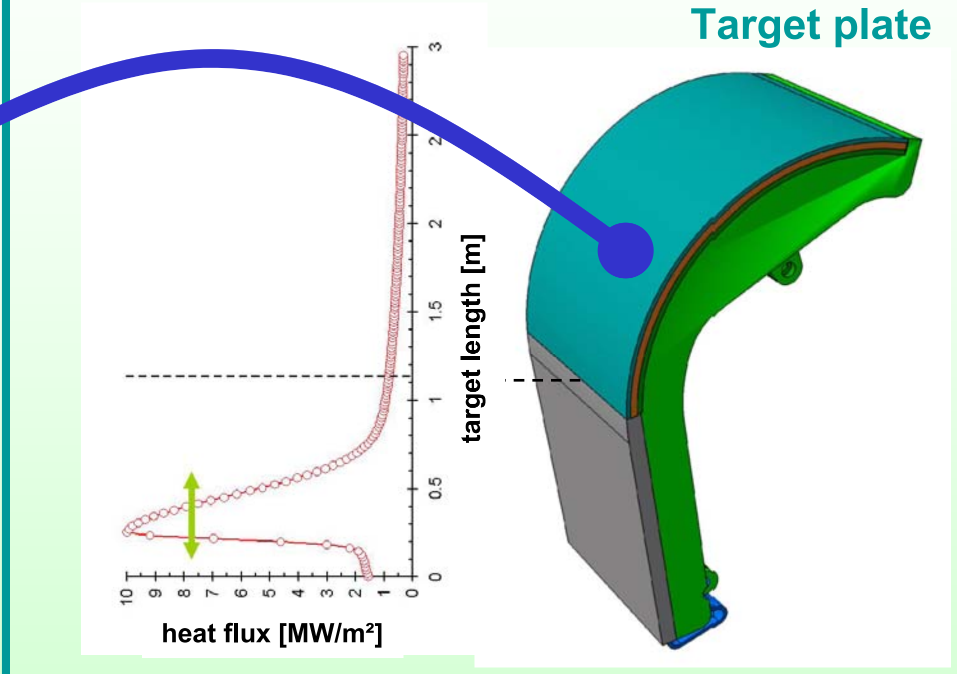
Introduction: Divertor Requirements

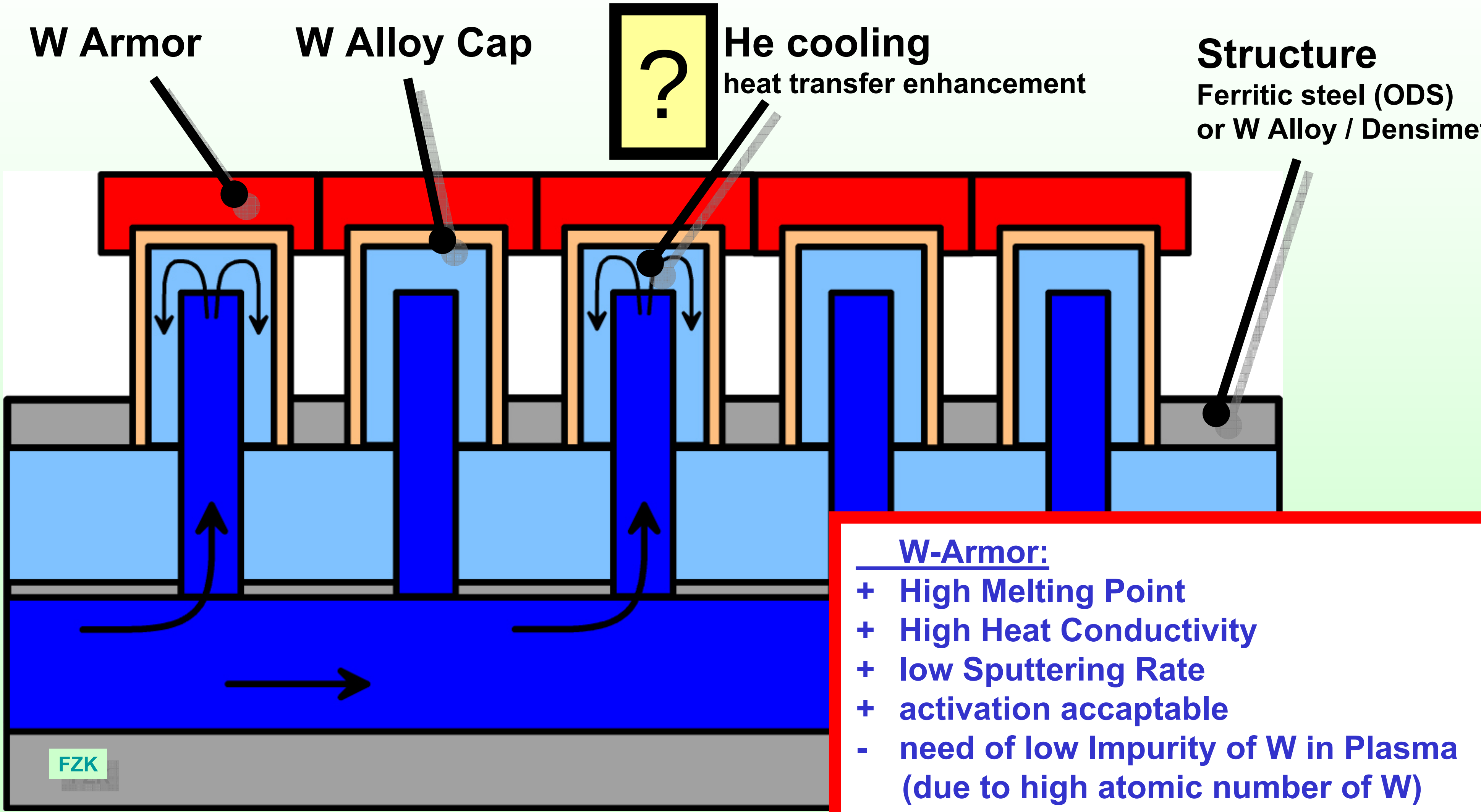




DEMO Divertor main requirements:

- **Heat load up to at least 10 MW/m² & strike point movements**
- **Withstand erosive particle flux for several years (low sputtering rate)**
- **He-cooling, high He-pressure ≈ 100 bars & vacuum leak tightness**

EU Tungsten Divertor: General Design

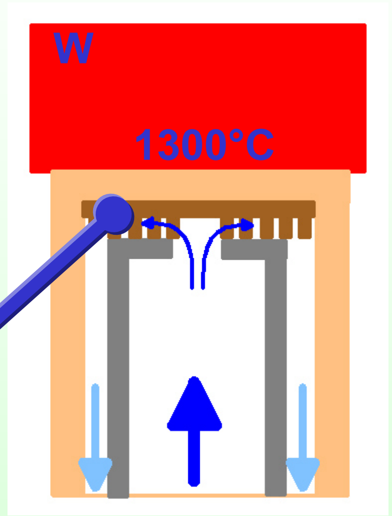


W-Armor:

- \+ High Melting Point
- \+ High Heat Conductivity
- \+ low Sputtering Rate
- \+ activation accaptable
- \- need of low Impurity of W in Plasma (due to high atomic number of W)

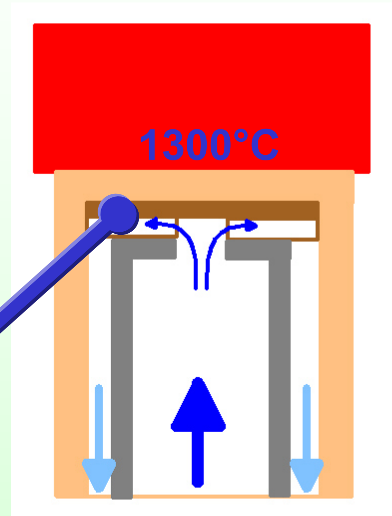
Evolution of FZK Heat Transfer Design

HEM P



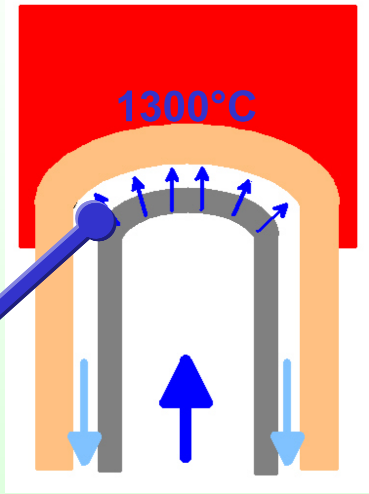
pin array

HEM S



slot array

HEM J



jet array

back-up

reference

simple fabrication

max. heat flux

COOLING TECHNOLOGY: Jet Impingement

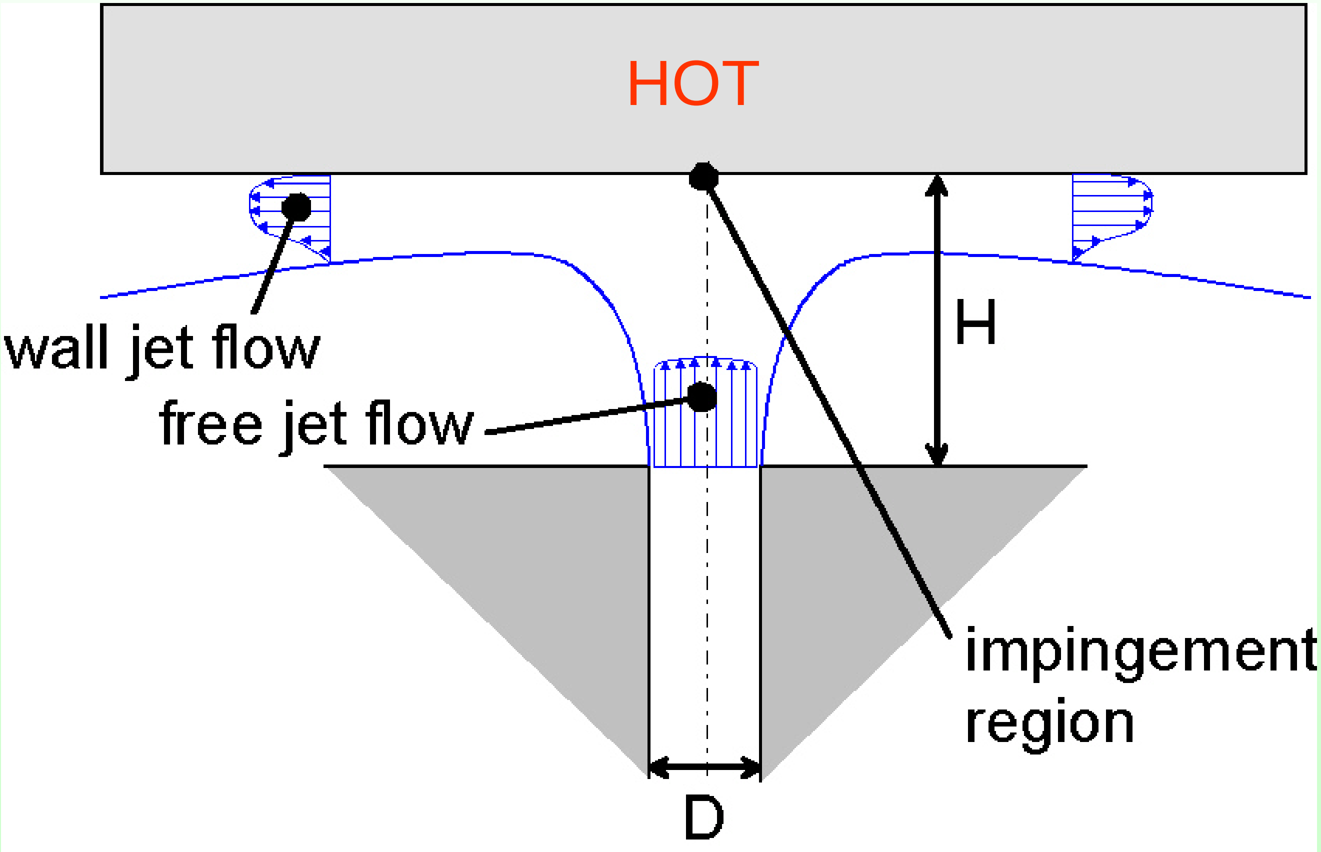
Cooling technology applied in the fields of:

- **Aircraft Engines**
- **Gas Turbines**
- **Burners**

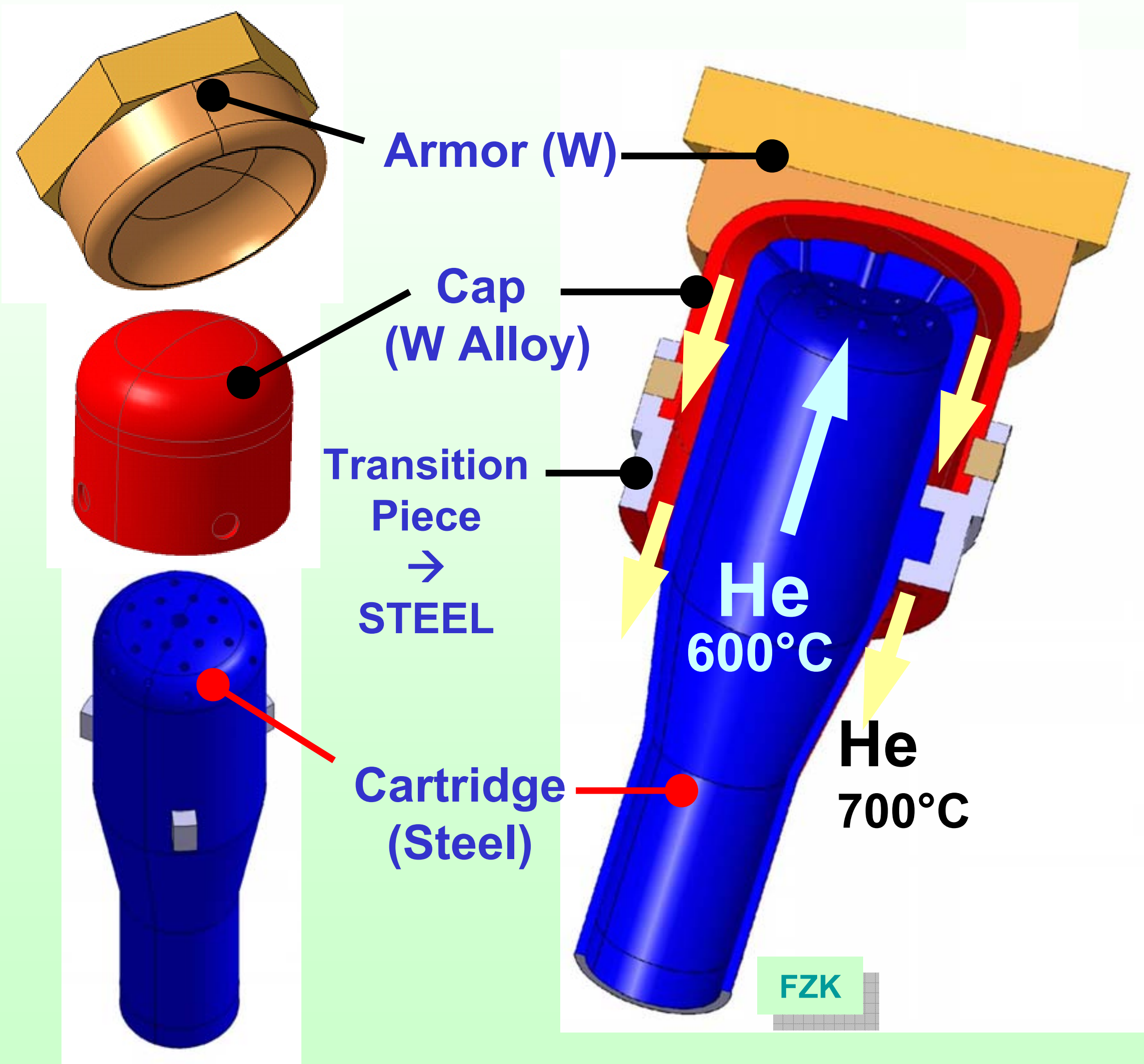
…

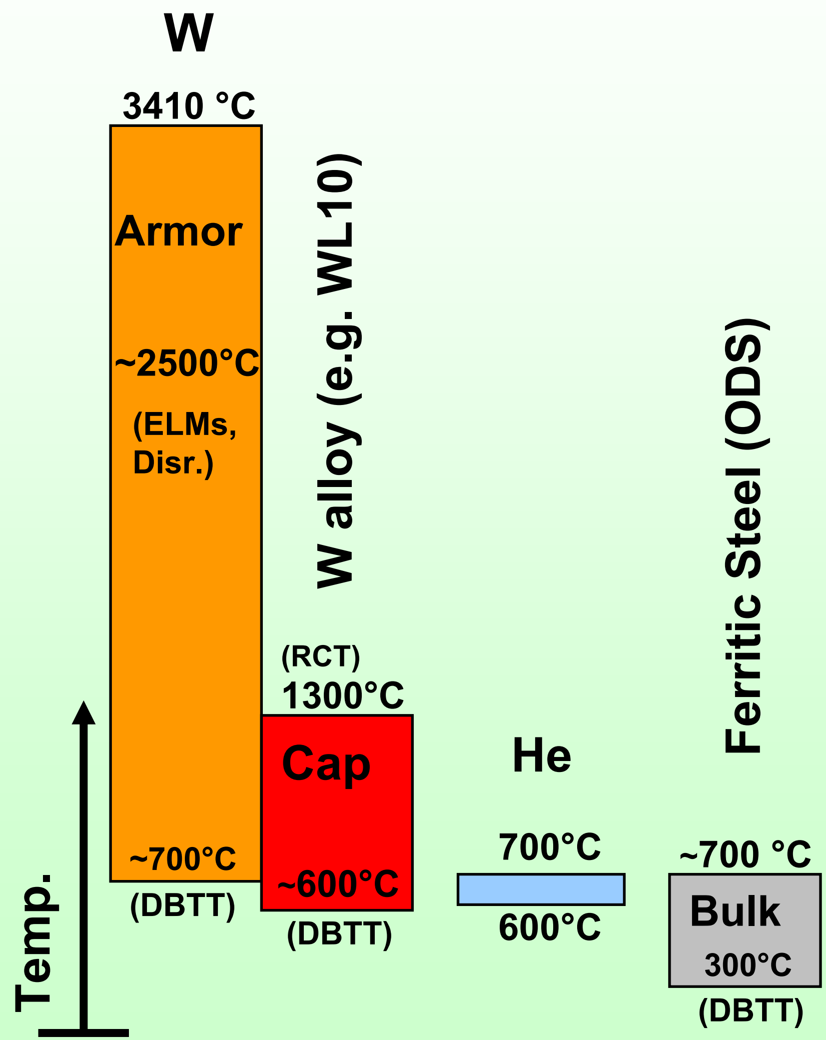
→ **DEMO Divertor**

Jet Impingement



HEMJ Cooling Finger: Design & Materials

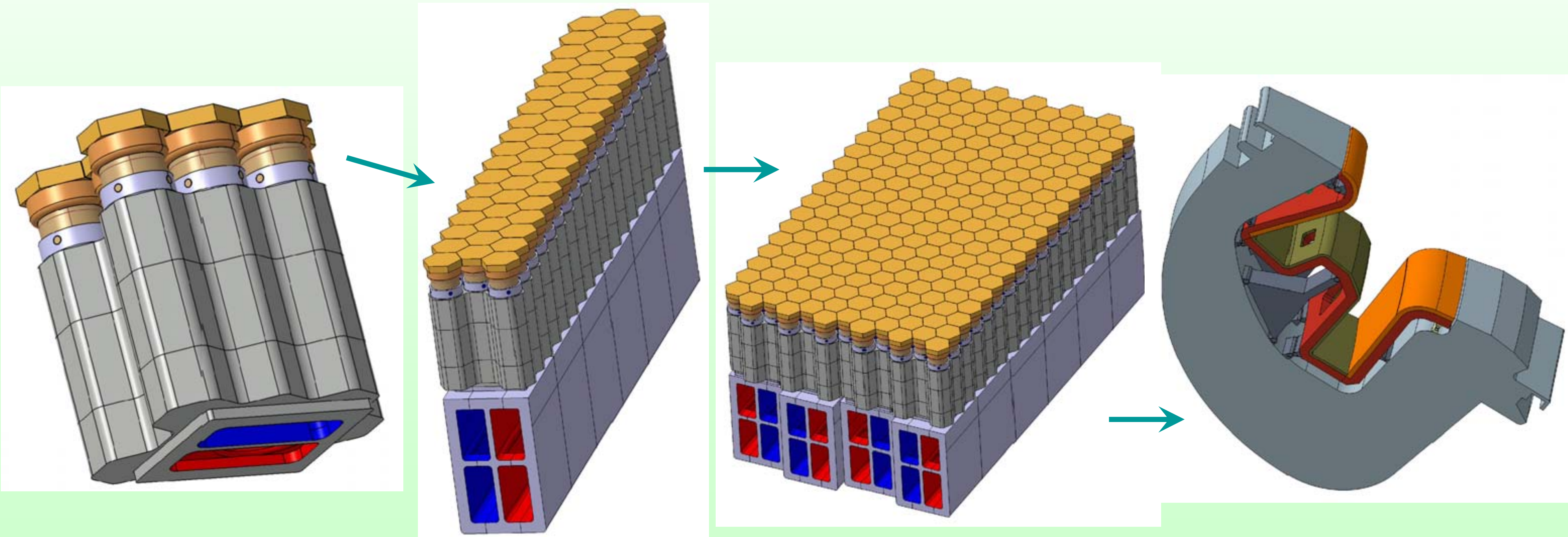




High reliability, low waste during fabrication

Construction Kit Principle:
Small Units advantageous for R&D progress
Small Units can be tested before assembling

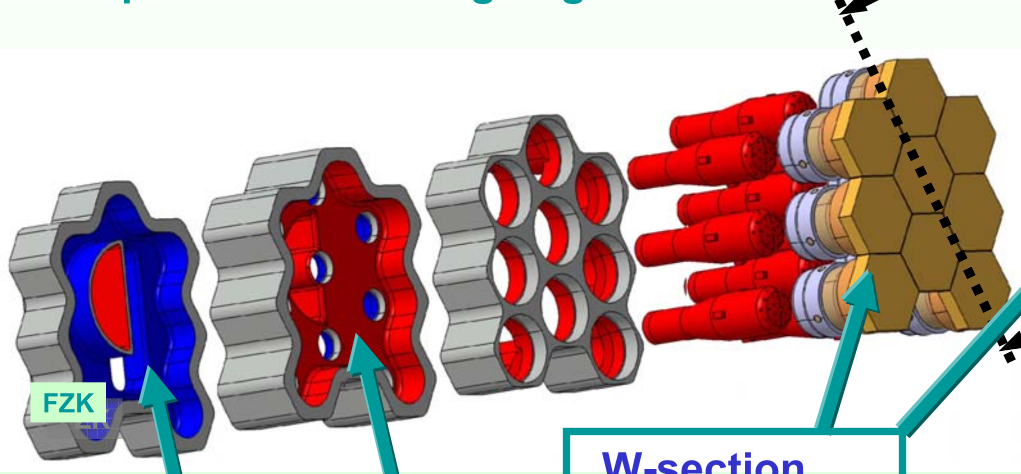
9-Finger Unit | **Stripe-Unit** | **Target Plate** | **Divertor Cassette**



Test, Assembly → Test, Assembly → Test, Assembly → …

Details of 9-Finger module

Steel-plates and cooling fingers



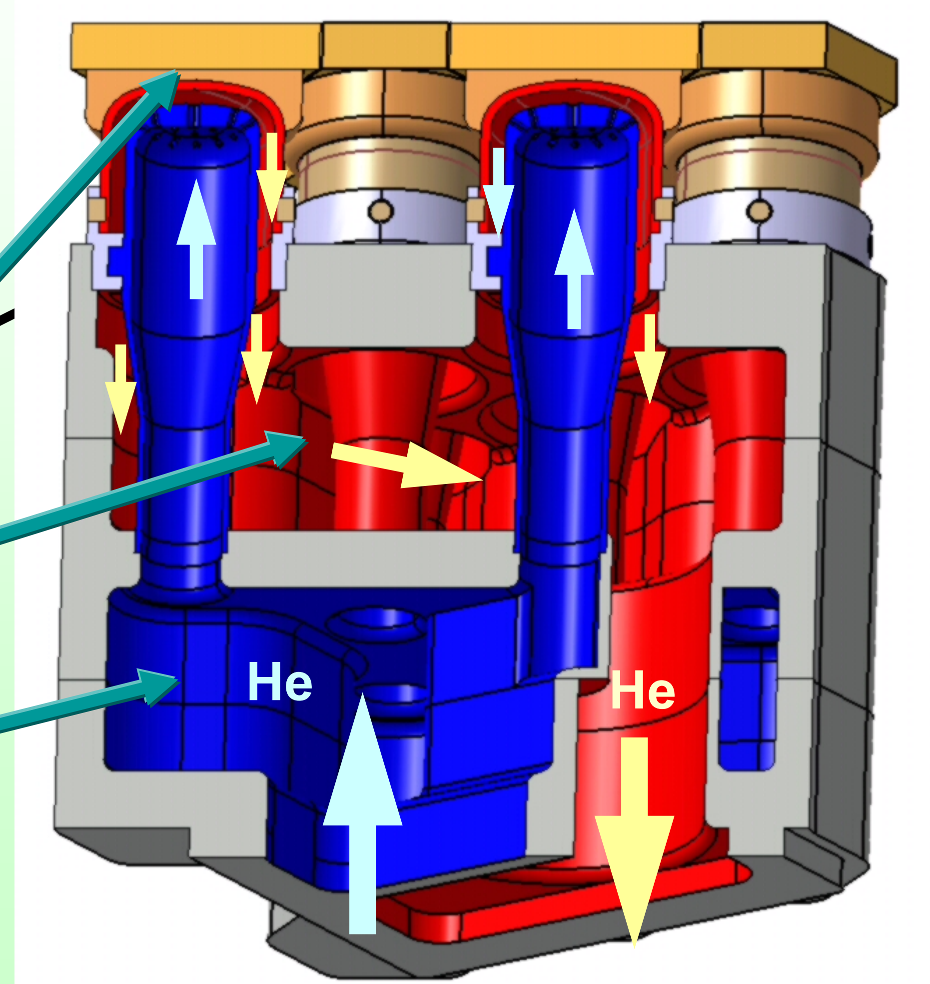
W-section,
600 to 2000°C

Collector section
He, Steel: 600 to 700°C

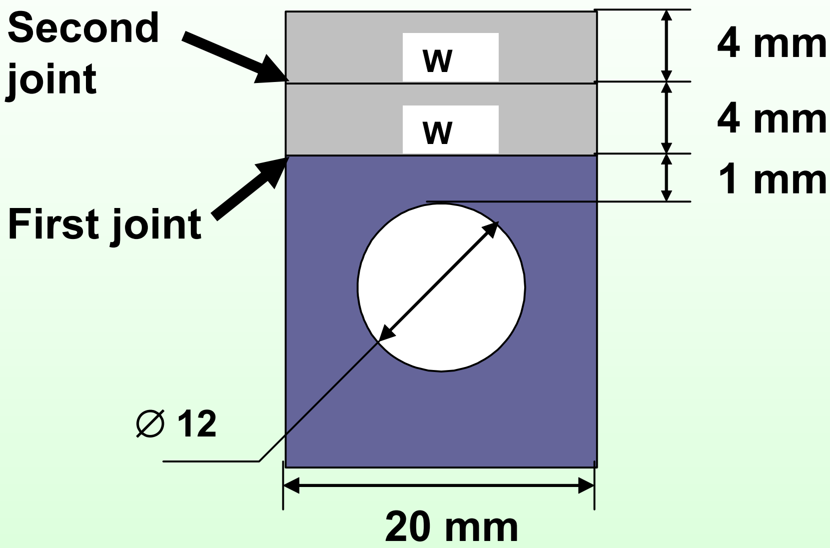
Manifold section
He, Steel: 600 to 700°C

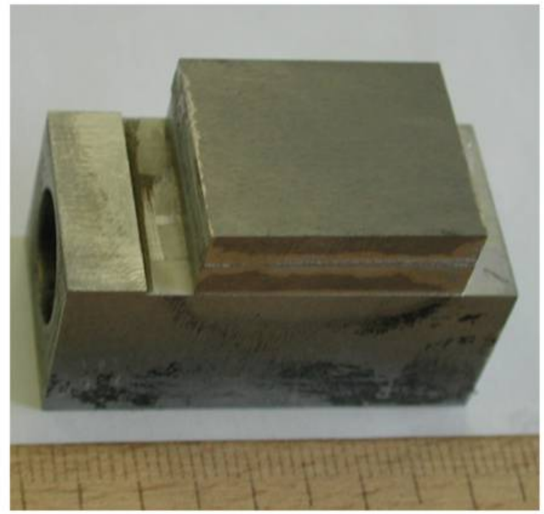
(Welding: Laser, E-Beam, diffusion welding or HIP)

9-finger-module



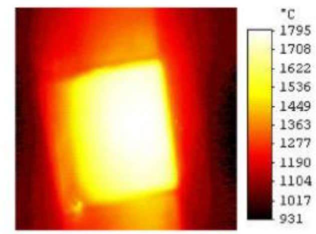
R&D on fabrication technologies: high temperature W-joint



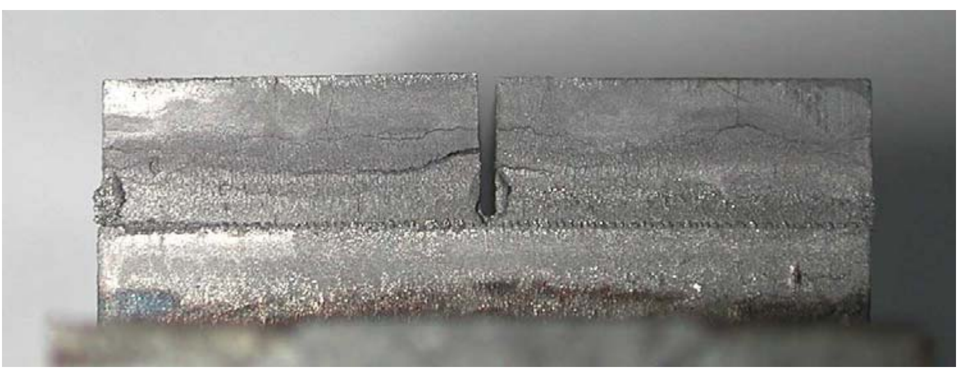


Screening test :

10 MW/m²	100 cycles	OK
12 MW/m²	100 cycles	OK
14 MW/m²	100 cycles	OK
15 MW/m²	100 cycles	OK
16 MW/m²	100 cycles	OK



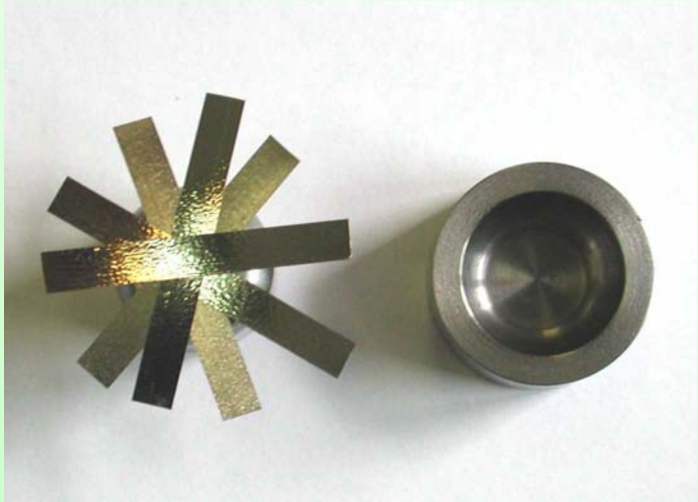
Mock-up brazed with STEMET 1311 filler metal undergone successfully HHF screening tests

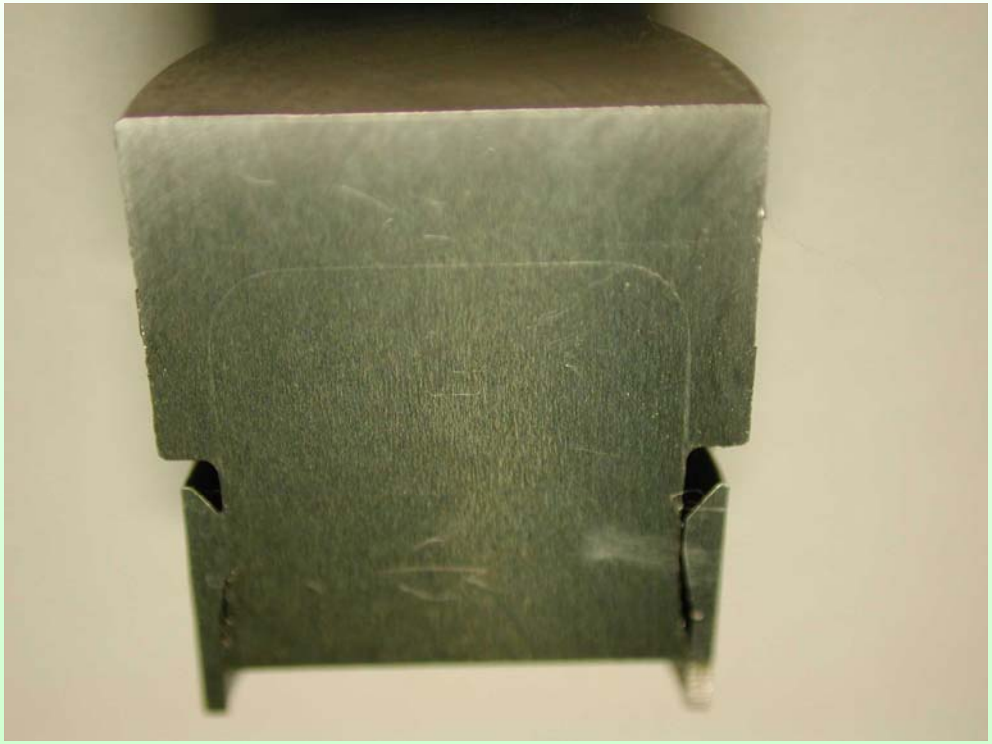


Upper W layer with castellation (10x10 mm)
15 MW/m^2 700 cycles OK
defect after add. 50 cycles at 16 MW/m^2

EFREMOV under FZK contract

R&D on fabrication technologies: high temperature curved W-joint





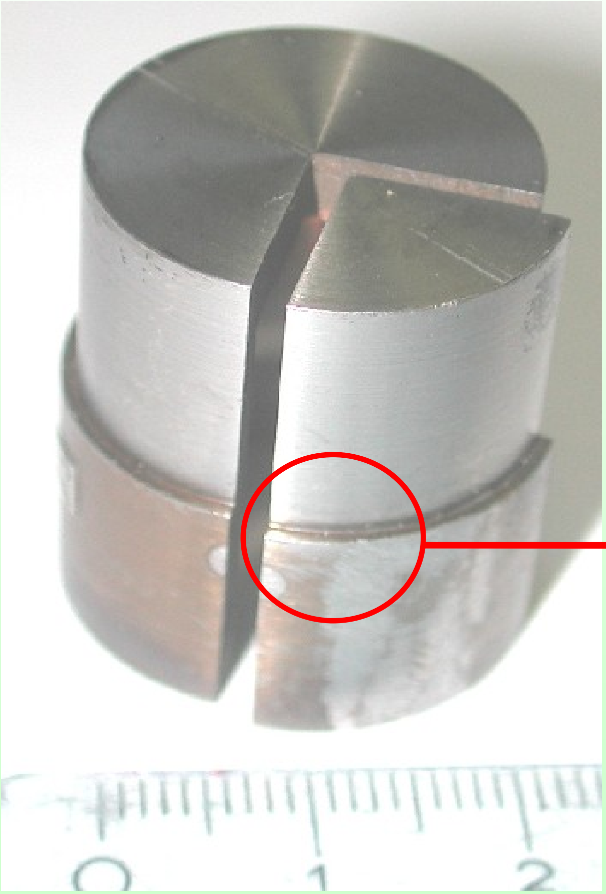
Brazing successful,

survived up to 100 temperature cycles at 14 MW/m2

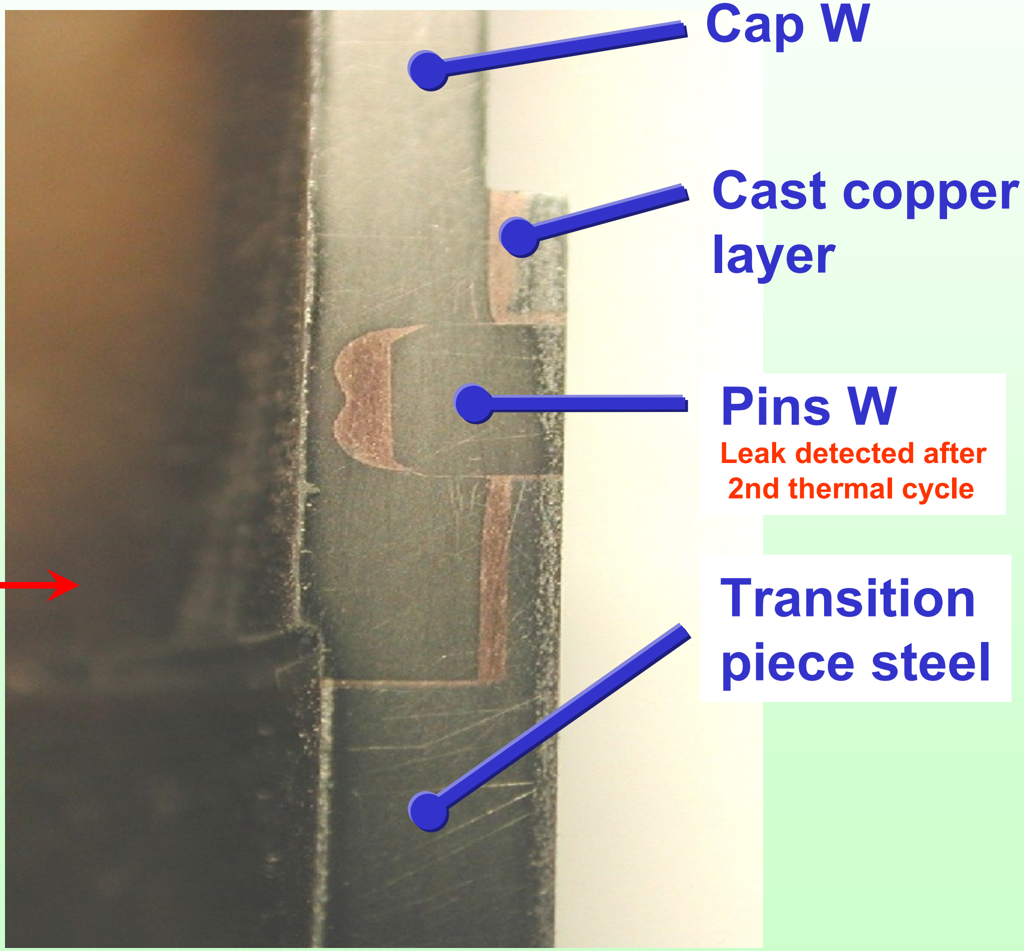
EFREMOV under FZK contract

W-Cap – Steel Joint (Efremov Inst.)

W-Cap – Steel-Tube Joint MOCKUP



Cross-section of lock-area



R&D on fabrication technologies: W-steel joint

Main elements for W-Steel joint with new (conic) lock

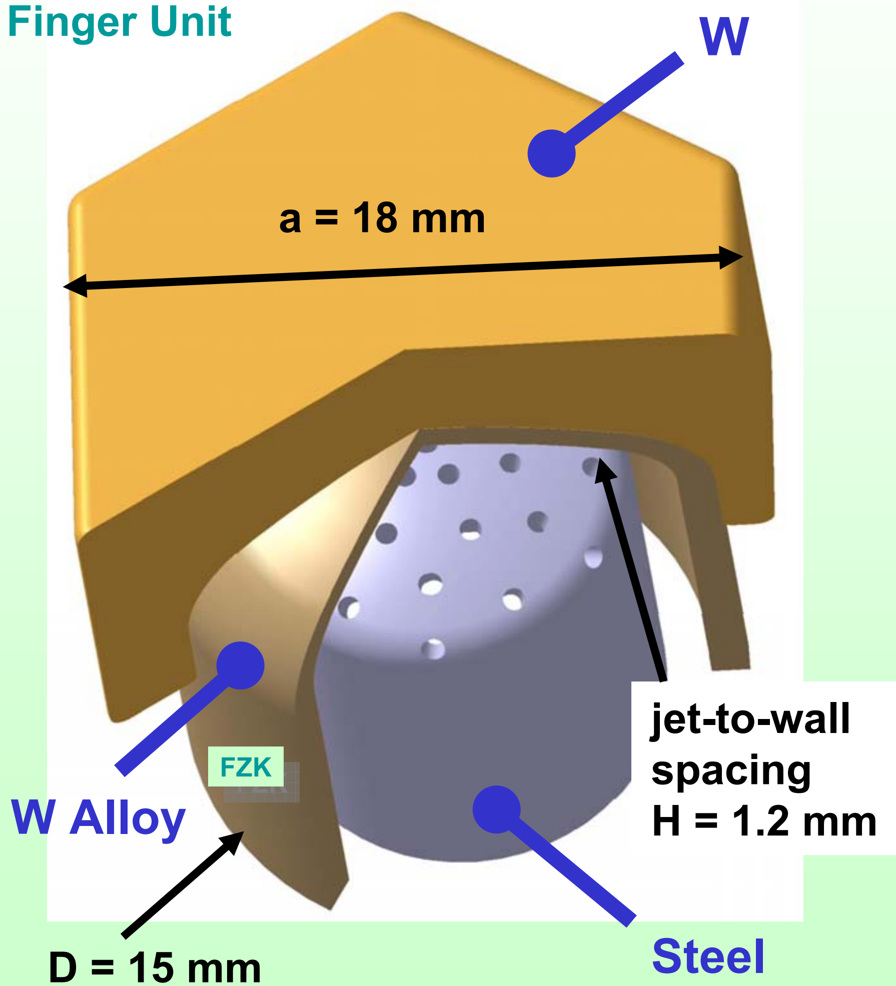
EFREMOV under FZK contract

Finger mockup (without armour tile) after casting (left) and after post-testing examination (right).

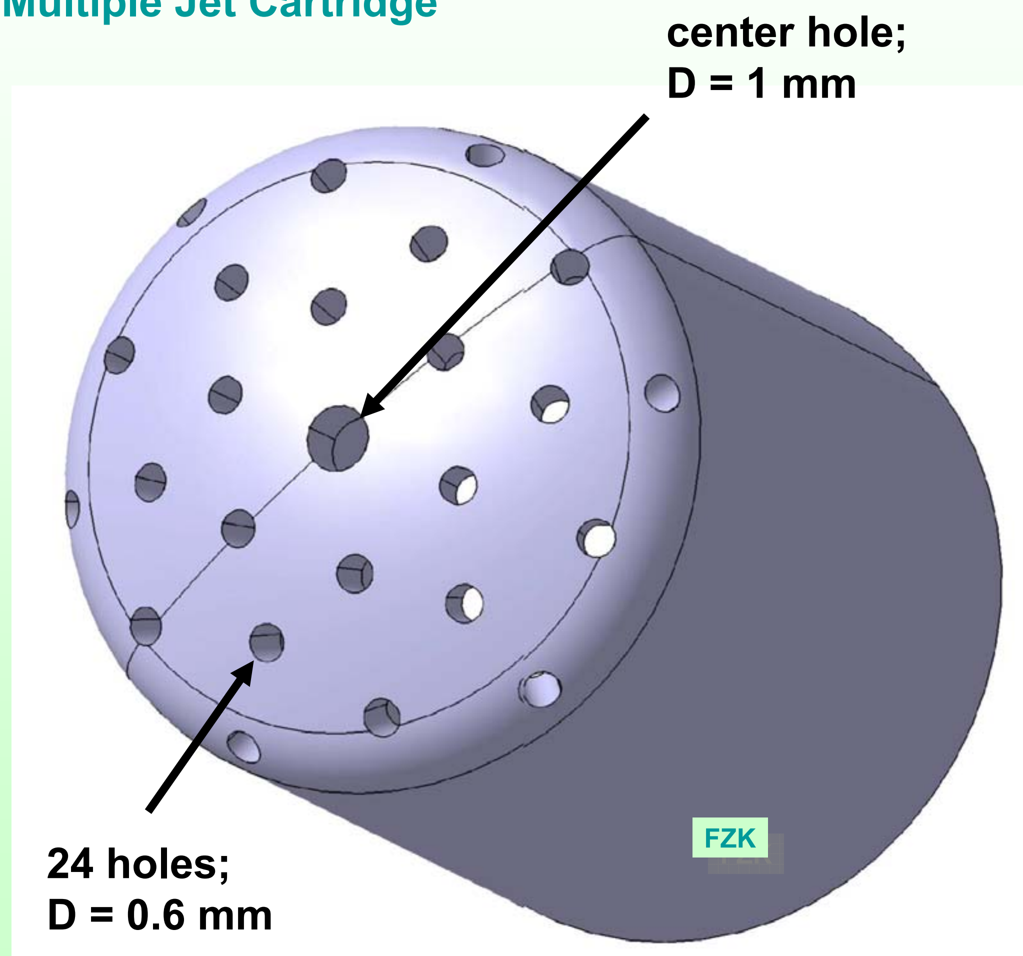
100 thermocycles (p_{in}=10 MPa) ok

Layout example for Multiple-He-Jet-Cooled Divertor

Finger Unit



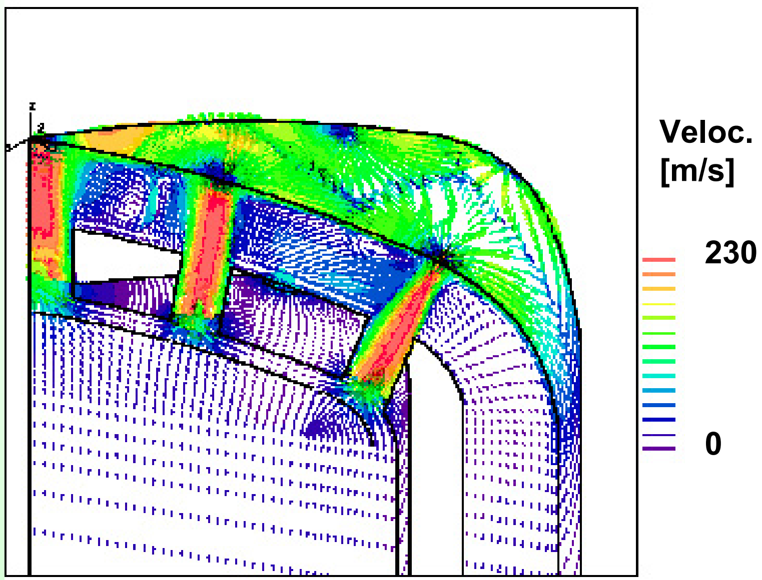
Multiple Jet Cartridge



CFD-Results for layout example

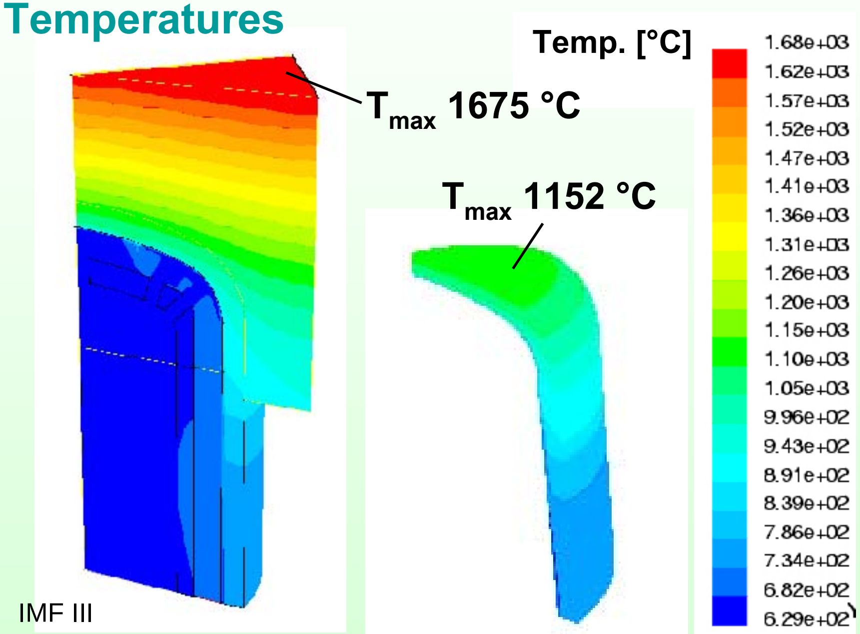
Flow Velocities

$Ma_{max} = 0.13$
$a = 1770$ m/s



IRS

Temperatures



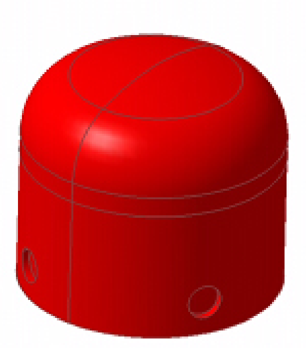
IMF III

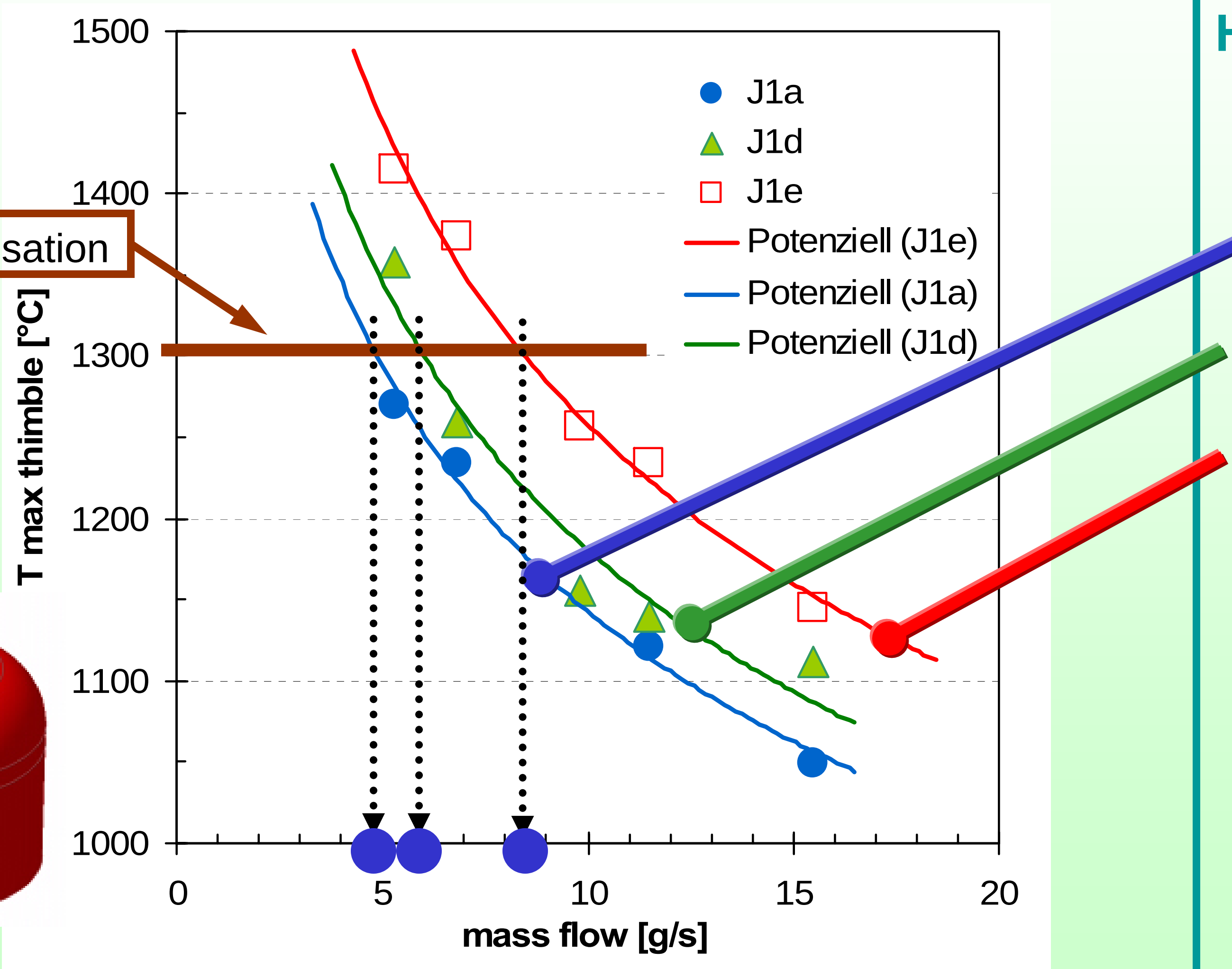
B.C.: **Helium, 10 MPa, T in 630 °C, heat load: 10 MW/m²:**

Results:

- **max. Temperature in W-Cap: 1152°C (< 1300°C)**
- **Pressure drop: 0.14 MPa**
- **Mass flow per finger: 6.8 g/s**

Minimal He mass flow for different jet hole diameters





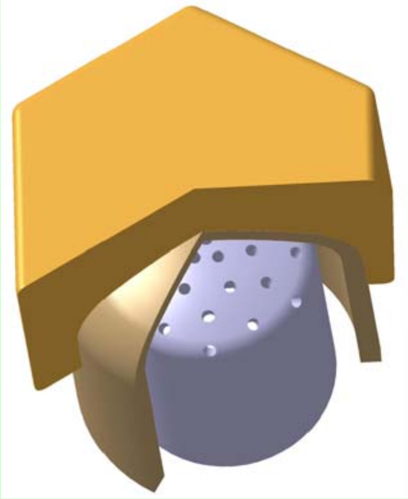
HEM J

heat flux: 10 MW/m²

J1a: D = 0.6 mm

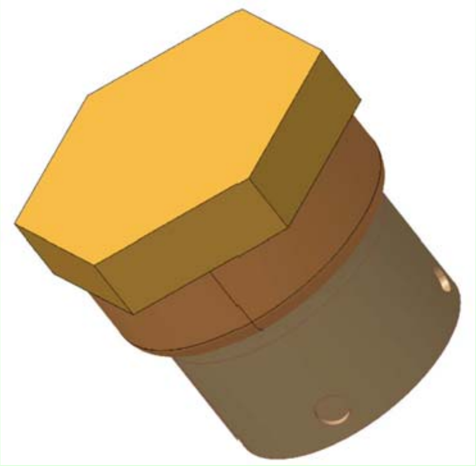
J1d: D = 0.7 mm

J1e: D = 0.85 mm



Armor – Cap Joint

Improved Finger Design

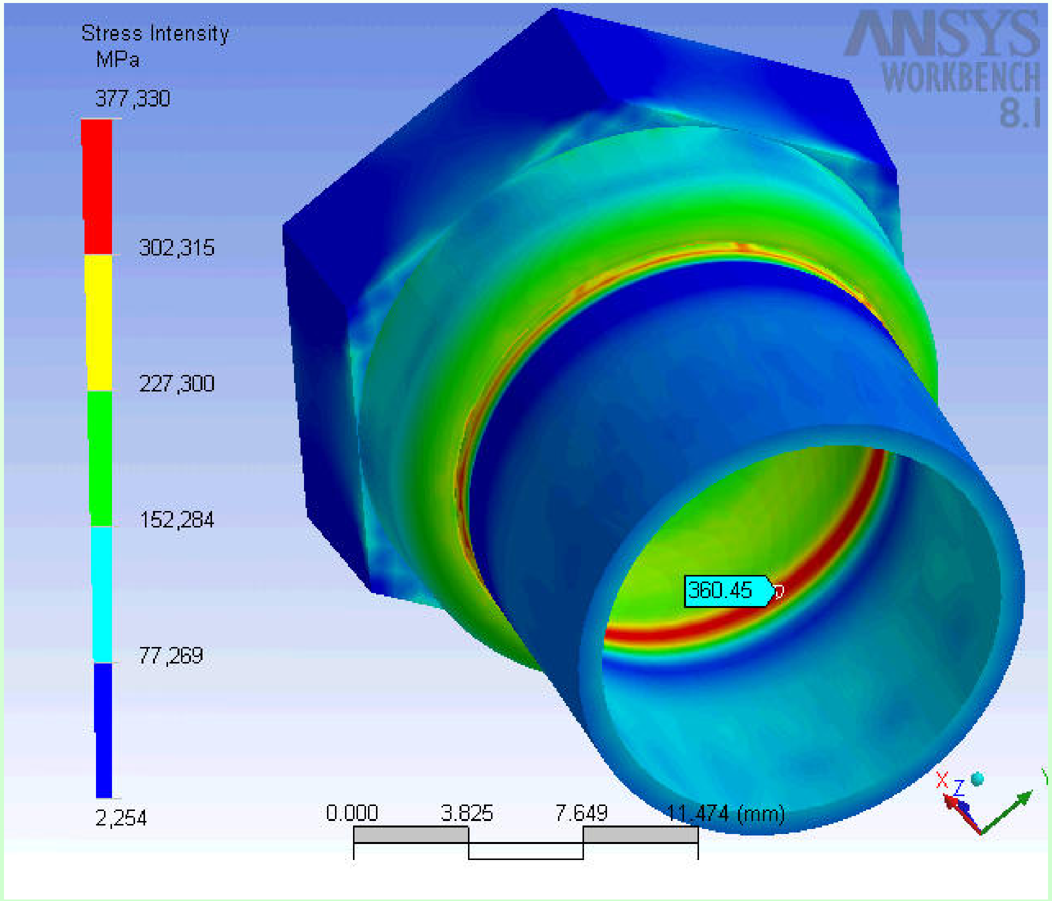


Stress intensities depending on cap interface treatment and heat flux:

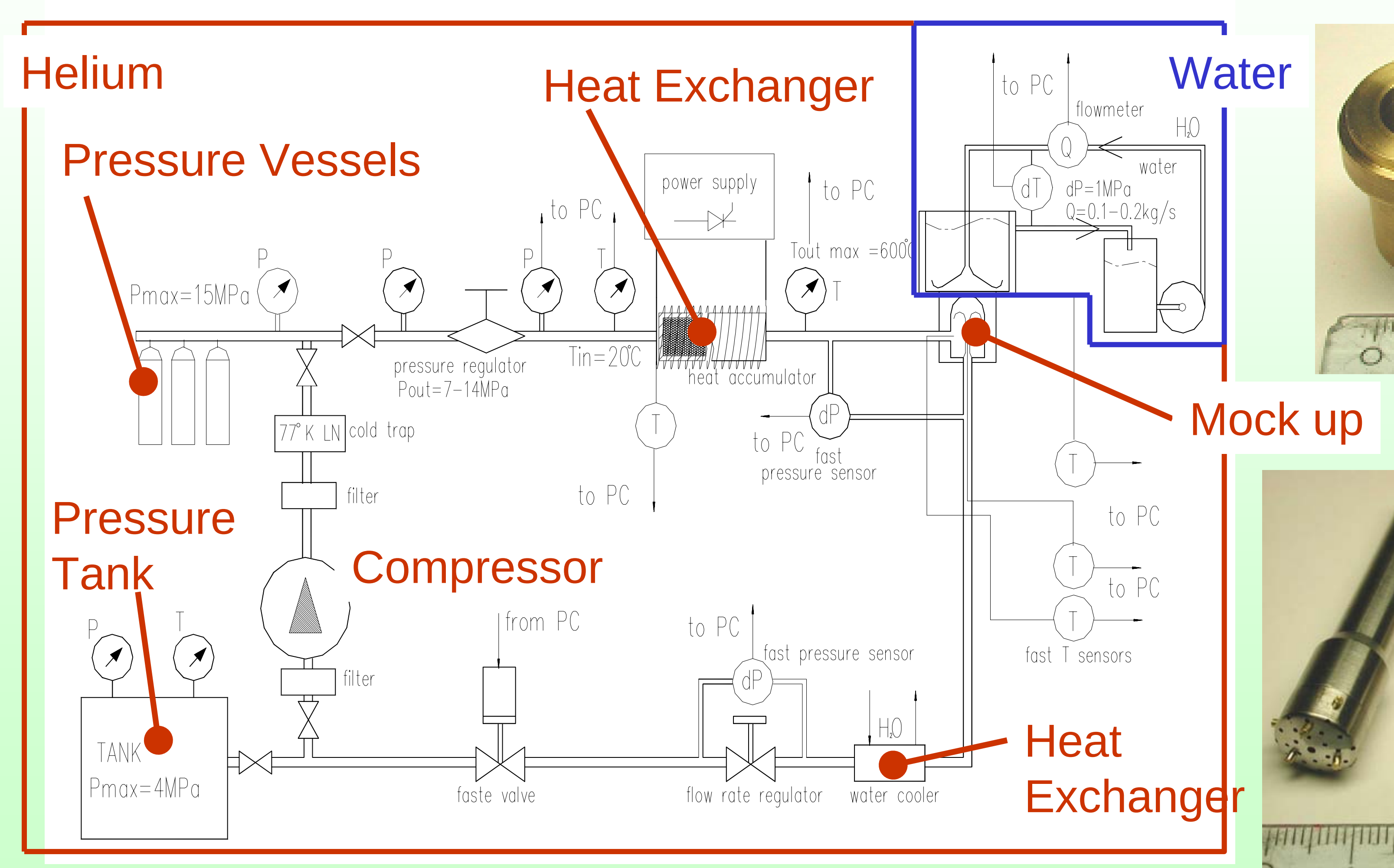
ANSYS FE Connection	“Bonded”	“No separation”
Stress Intensity	377 MPa	228 MPa

3Sm at 1100°C ~ 460 MPa
at 850°C ~ 580 MPa

Stress intensity for bonded armor, 10 MW/m², 10 MPa



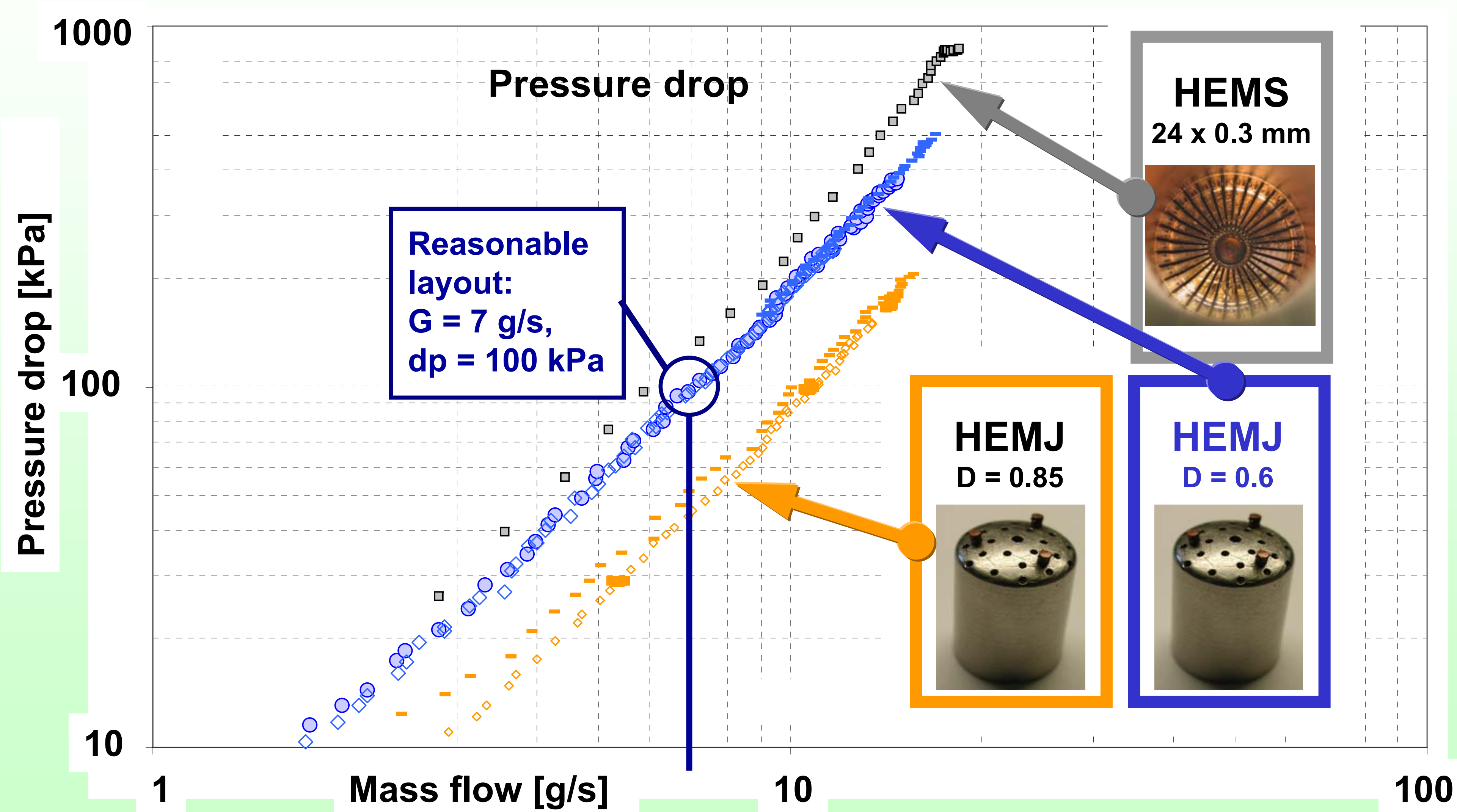
Efremov GPF2: Scheme & Mock-ups



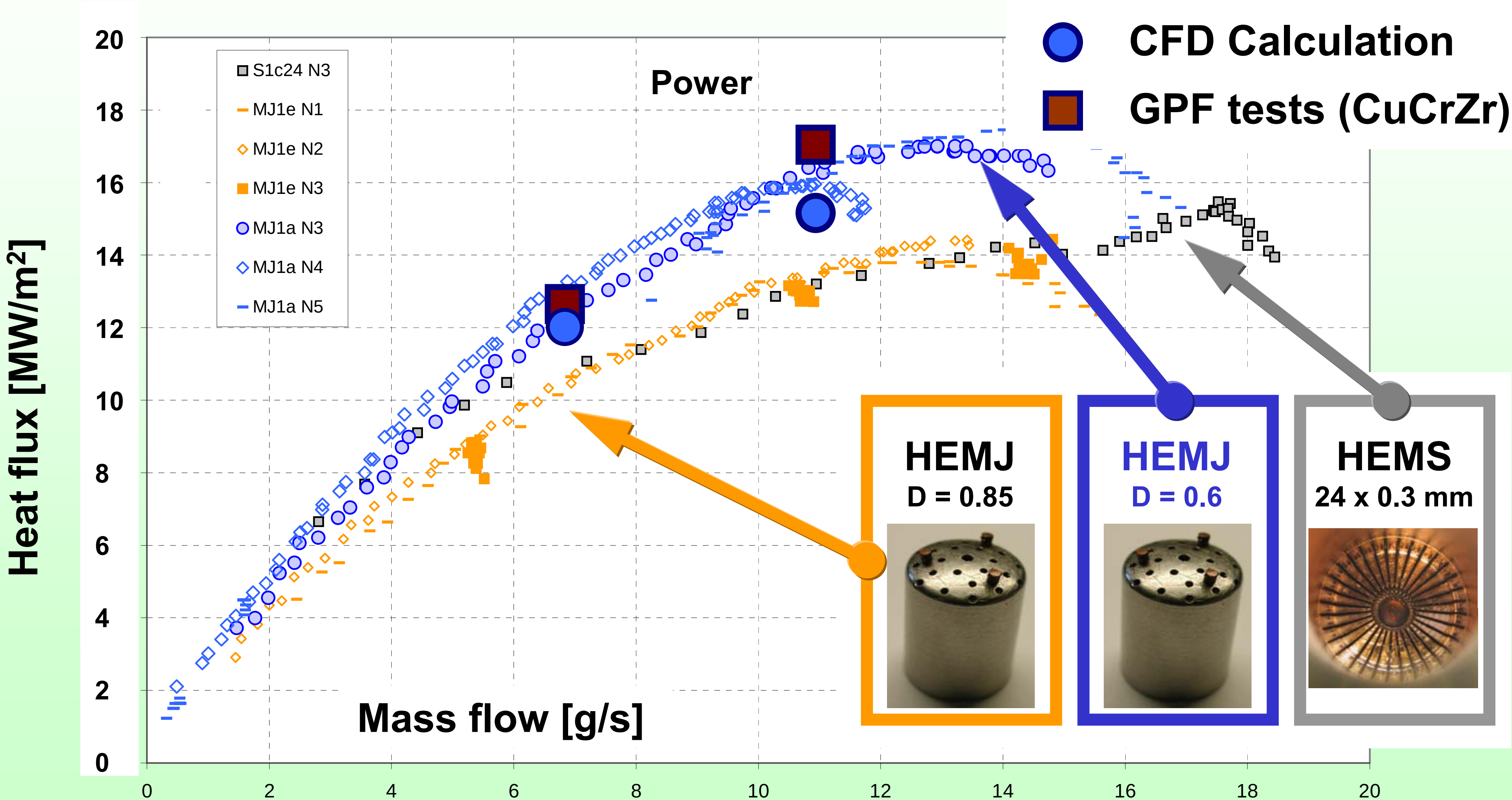
Caps (brass)

Cartridges (steel)

GPF 2 RESULTS (Δp) for 2004 brass mock-ups



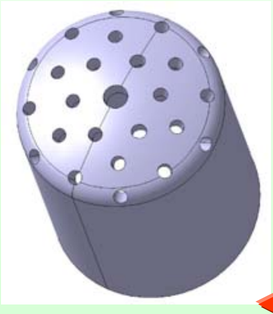
GPF 2 RESULTS for 2004 brass mock-ups



HEMJ Layout for OB target (PPCS Model B)

Zone 1 & 2

24 fingers zone length in parallel 432 mm



HEXAGONAL TILE
mass flow: 7.9 g/s
dp: 103 kPa (76%)
heat flux: 11.61 MW/m²
holes: 24 x 0.71 mm, 1 x 1.47 mm

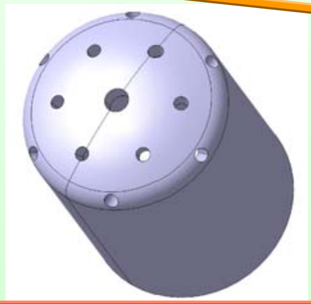
Zone 3

38 fingers zone length in parallel 684 mm

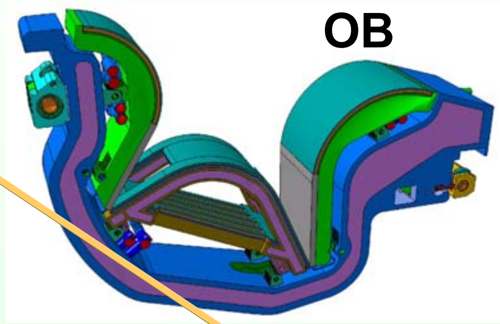
SQUARE TILE
mass flow: 5.4 g/s
dp: 55 kPa (69%)
heat flux: 7 MW/m²
holes: 24 x 0.7 mm, 1 x 1.47 mm

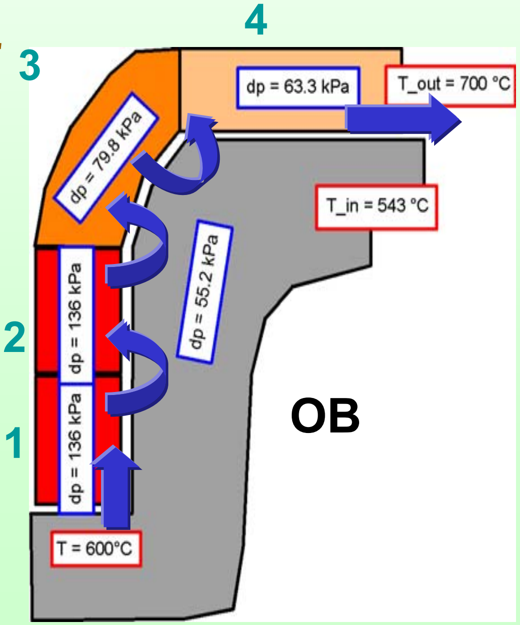
Zone 4

78 fingers zone length in parallel 1404 mm



SQUARE TILE
mass flow: 2.46 g/s
dp: 37 kPa (60%)
heat flux: 3.2 MW/m²
holes: 12 x 0.7 mm, 1 x 1.47 mm





Objectives: He-cooled Divertor on the way to ITER & DEMO