Status of He-cooled Divertor Design

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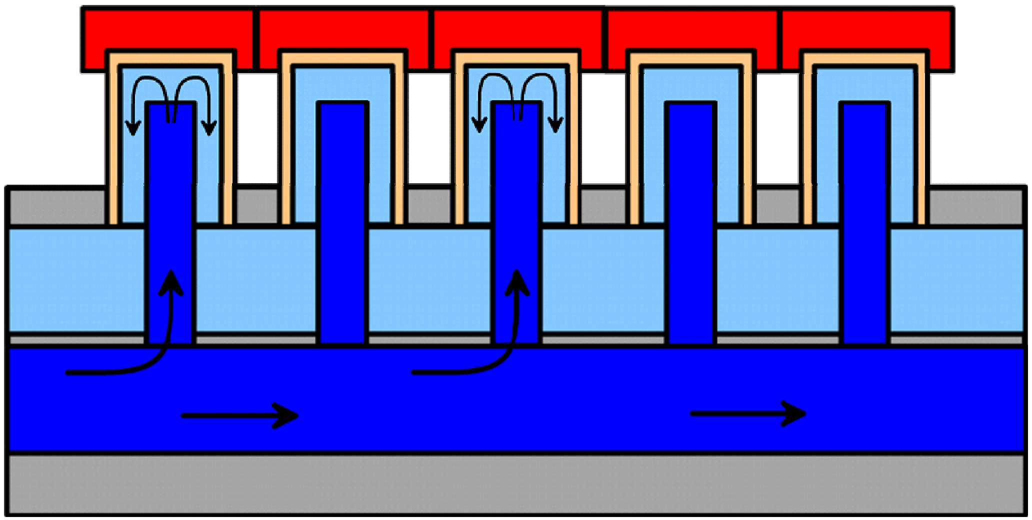
Basic divertor concept

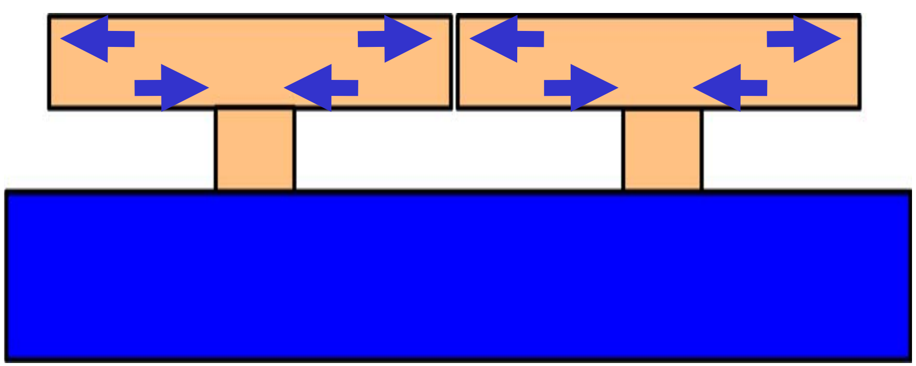
Caps in parallel



heat exchange part:
tungsten alloy

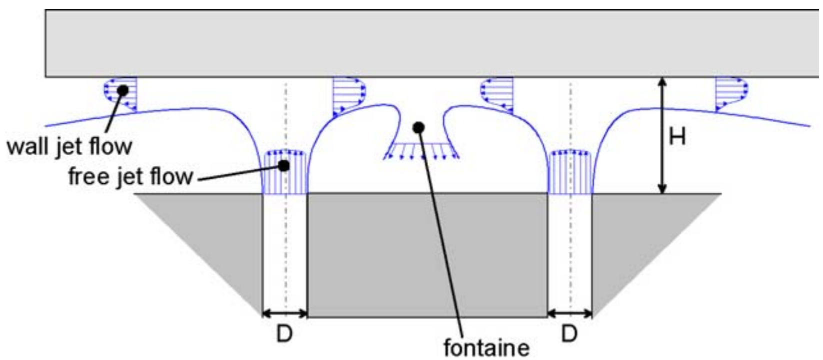
target main structure:
ODS ferritic steel

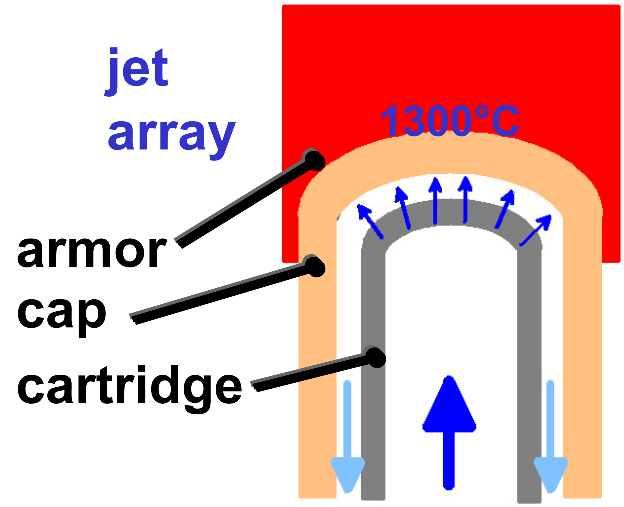
T-Tubes in parallel



+ reduced number of single parts
+ single parts can be tested before assemb
+ simplified manifold possible (more space)

Cooling concept

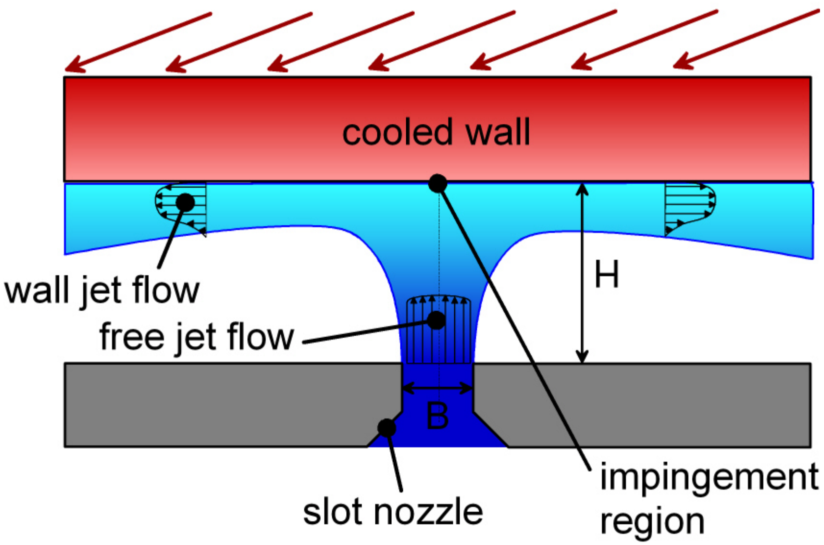




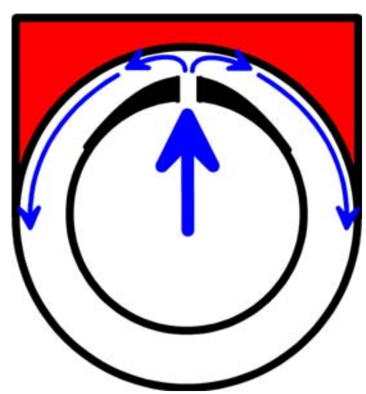
Multijet

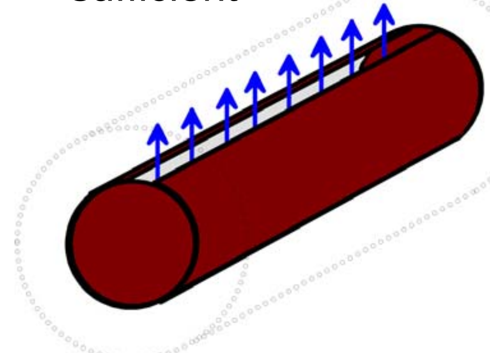
↓

Slot Jet

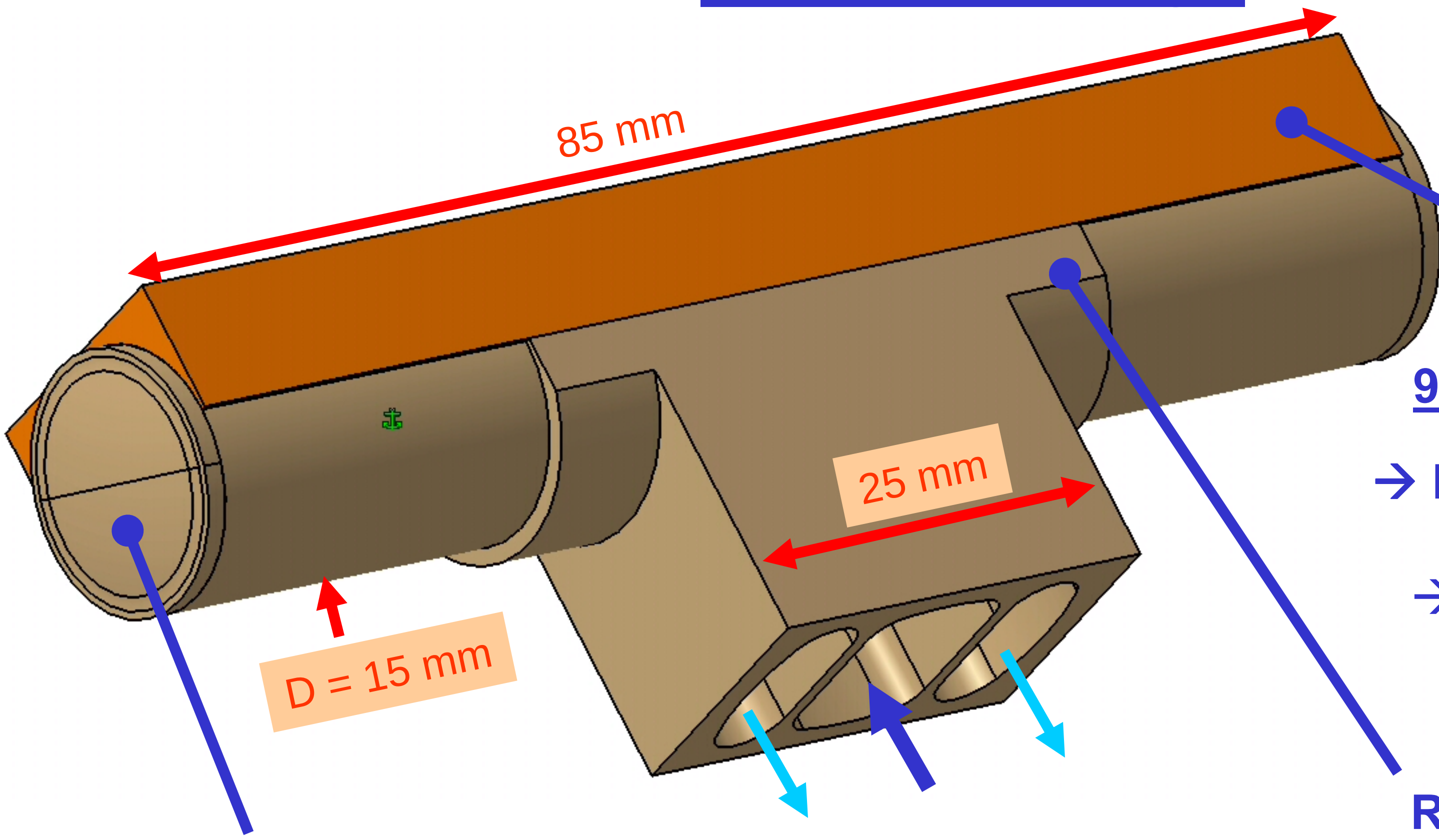


+ larger cooling area
  → lower averaged
  heat transfer coefficien
  sufficient





Refined Design



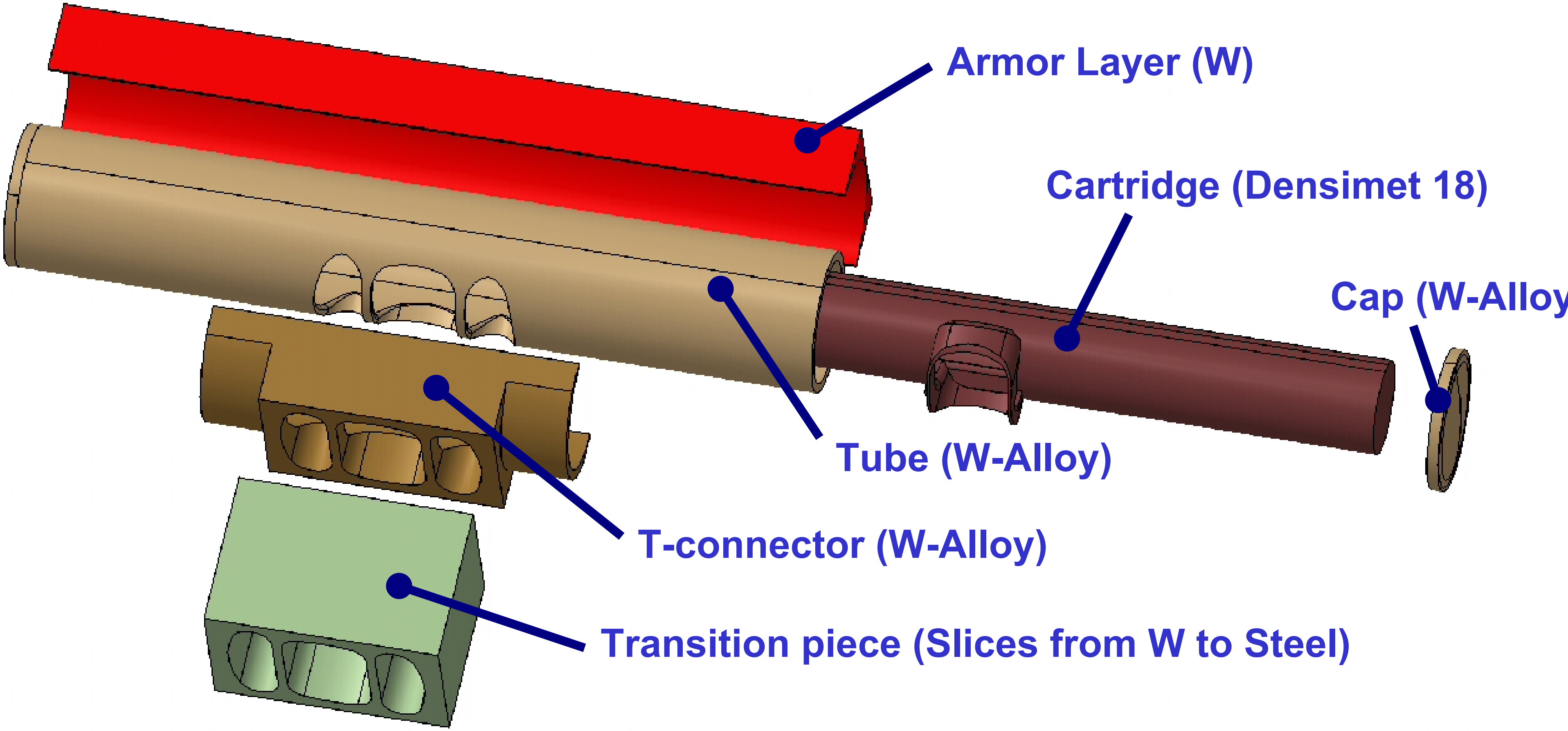
Total unit length:
90 mm for 10 MW/m^2

→ better flow uniformity
→ stronger parts
→ small deformation

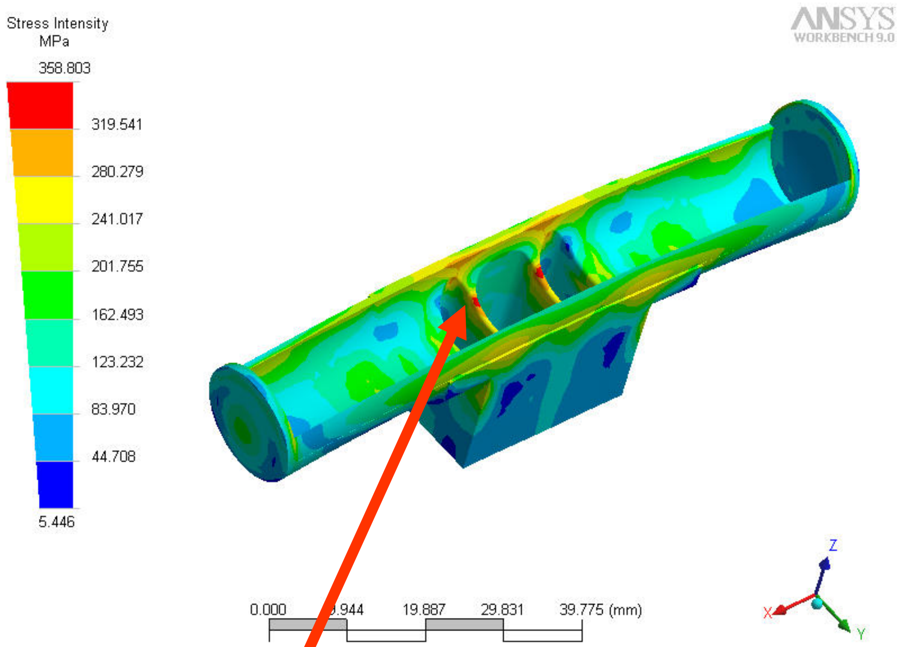
Reinforcement
+
improved assembly
of tube and connector

Caps less curved
→ reduced tube-tube distance

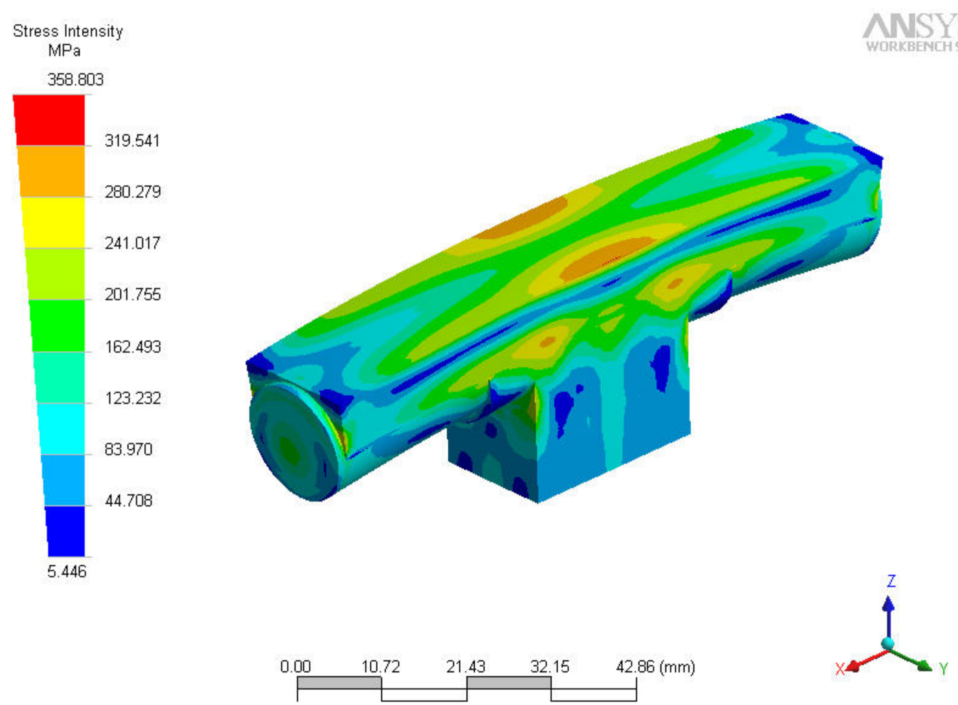
Parts of T-Tube Design



Stress Intensities for basic geometry



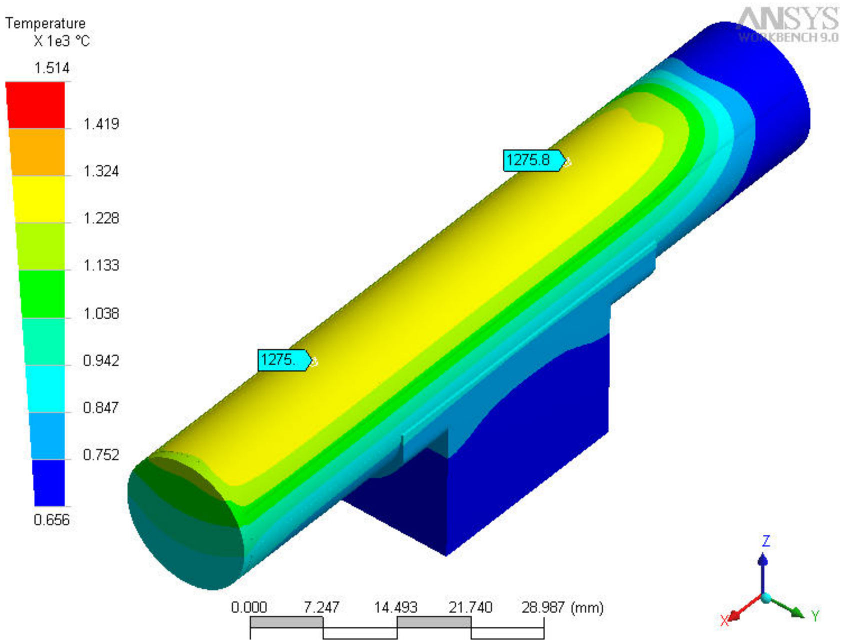
maximum of stress intensities
(~ 360 MPa) within design limits

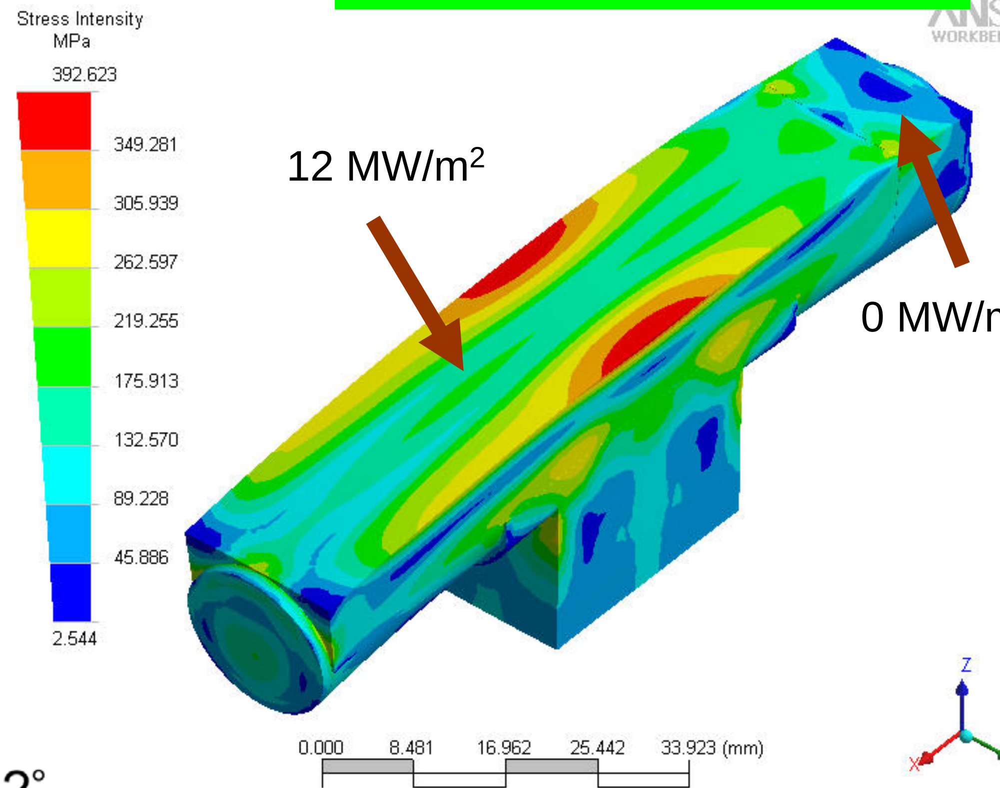


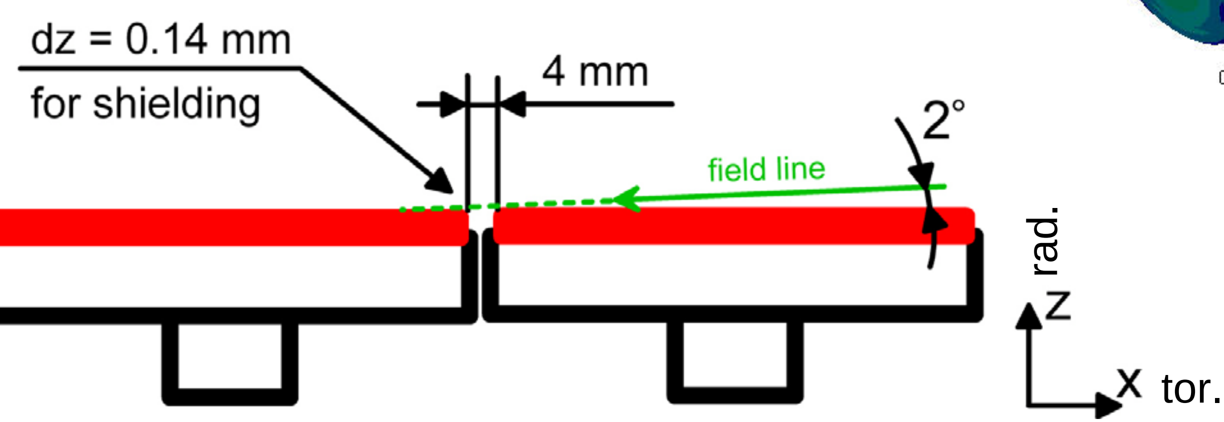
acceptable total stress
at flow channels

Shielding

asymmetric heat load

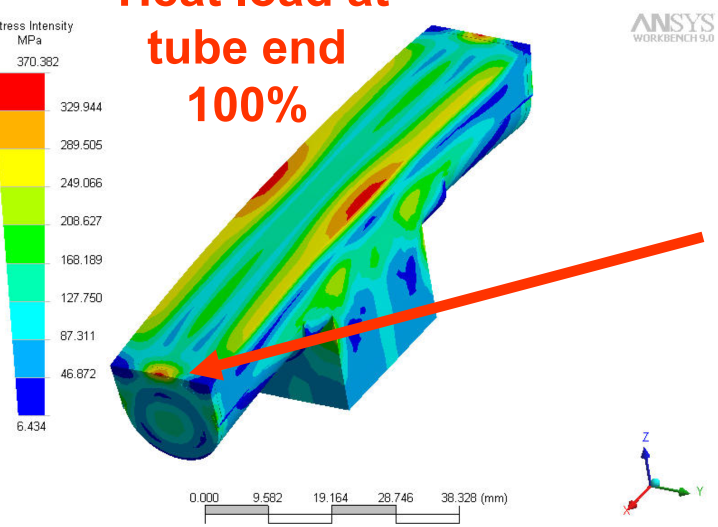




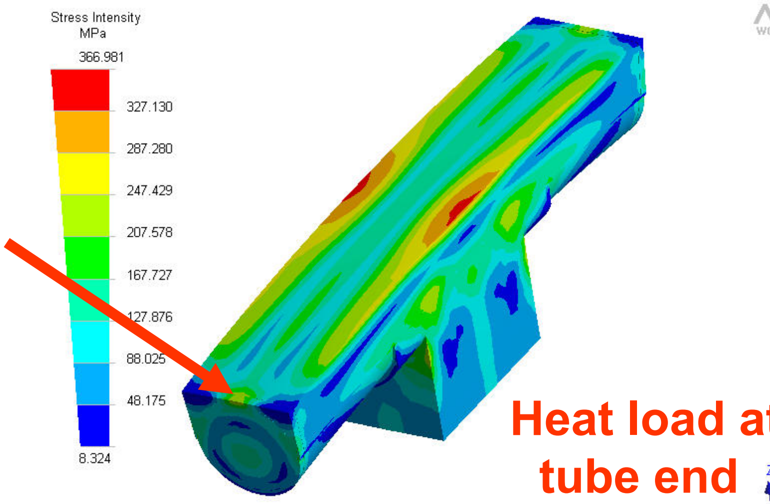


Heat load on caps (by radiation)

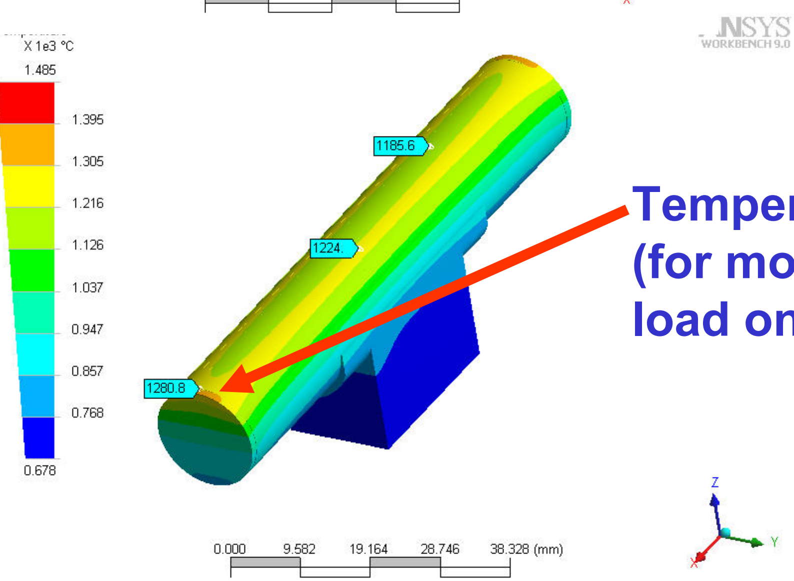
Heat load at tube end 100%



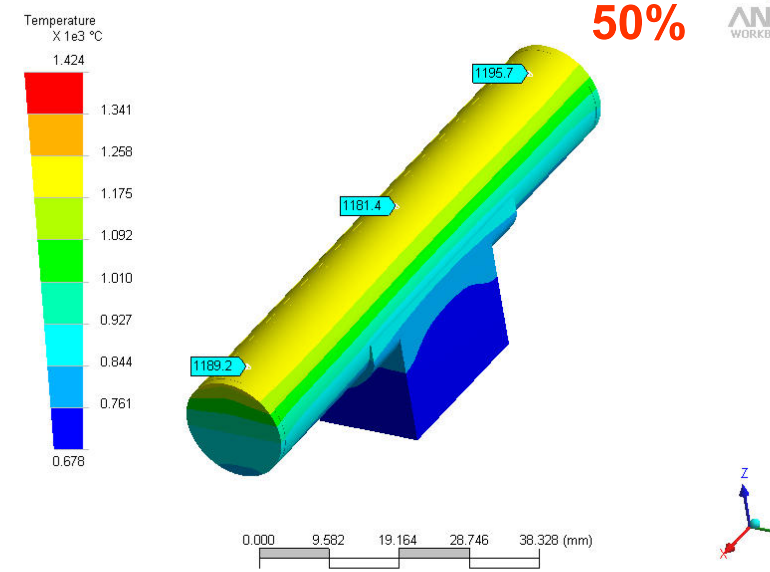
stress intensities at tube end o.k.



Heat load at tube end 50%



Temperature peak (for more than 50 % load on tube ends)

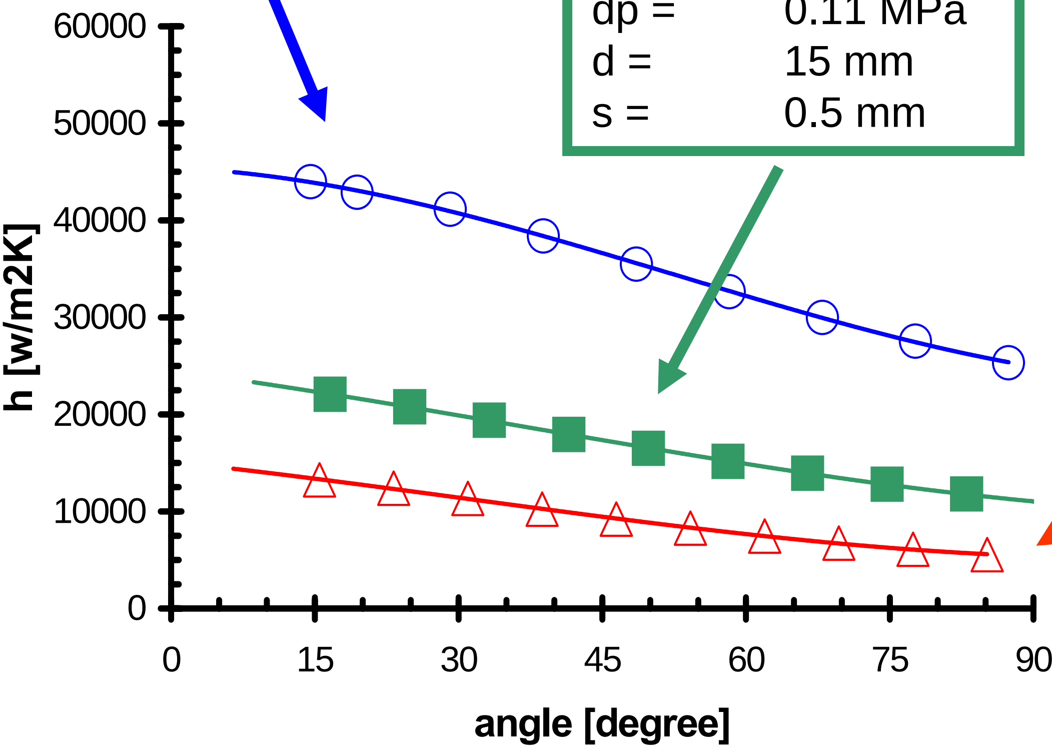


Heat transfer coefficient

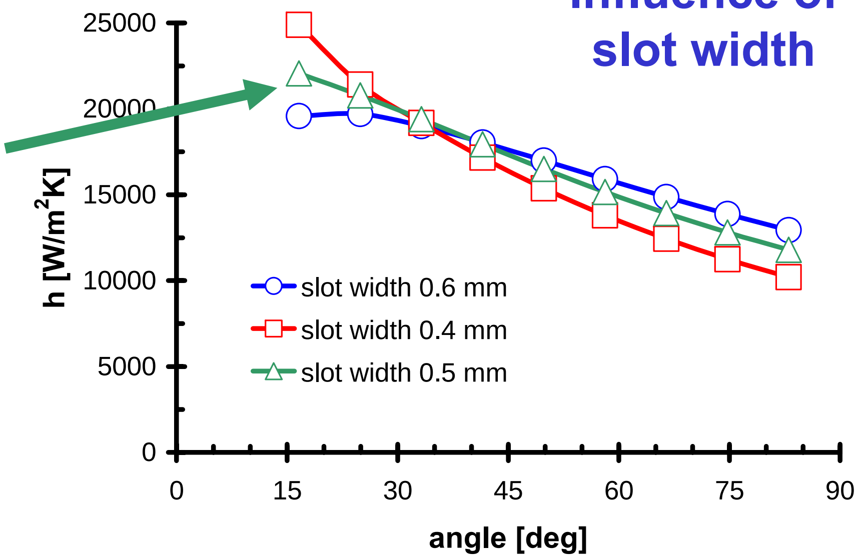
q' = 20 MW/m²
G/A = 48 kg/m²
dp = 0.28 MPa
d = 7.5 mm
s = 0.25 mm

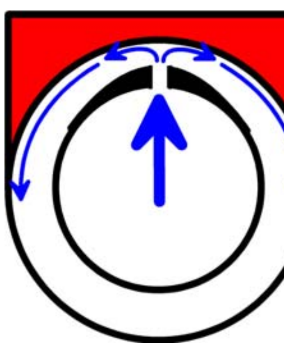
q' = 10 MW/m²
G/A = 24 kg/m²
dp = 0.11 MPa
d = 15 mm
s = 0.5 mm

q' = 5 MW/m²
G/A = 12 kg/m²
dp = 0.027 MPa
d = 30 mm
s = 0.8 mm



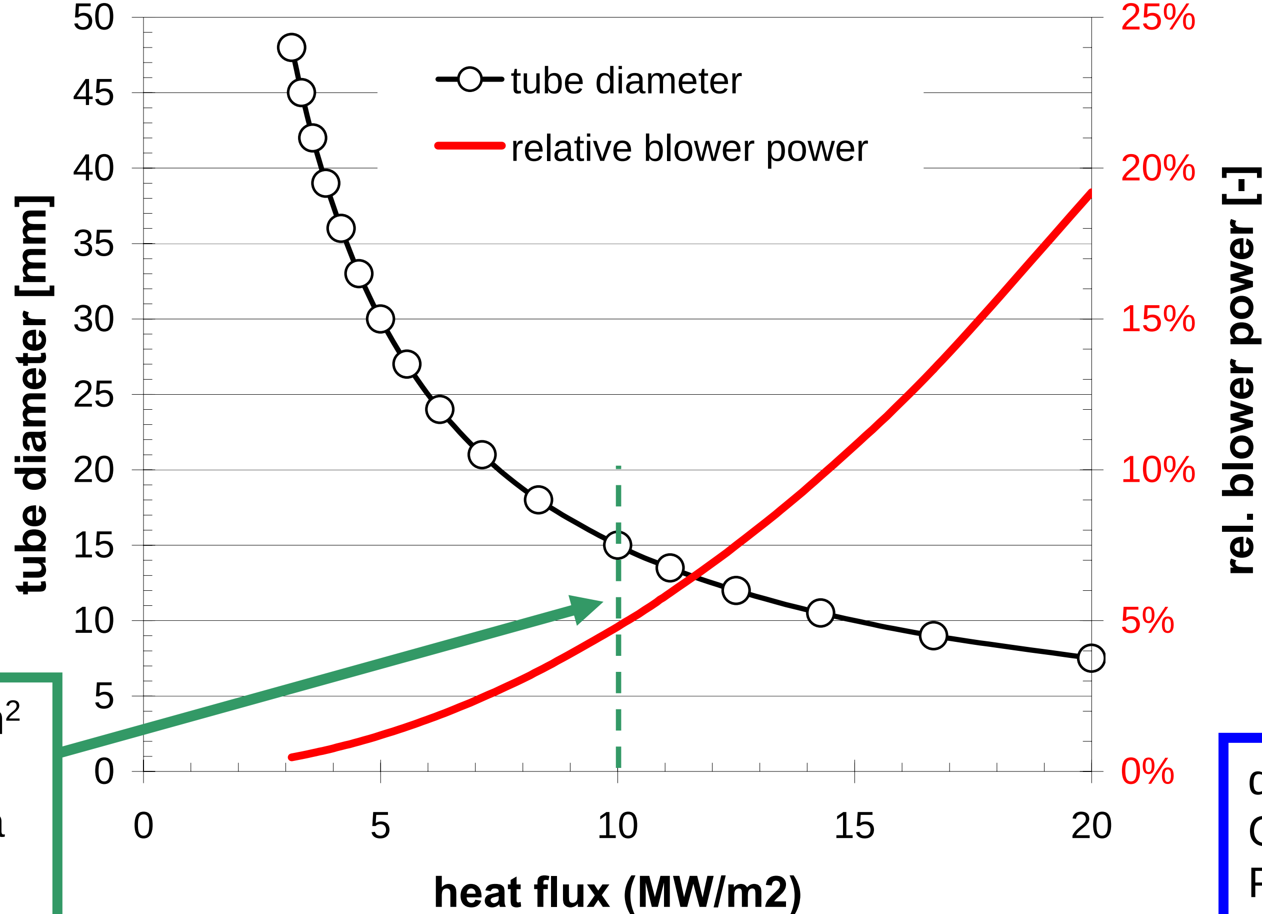
Influence of slot width





Adjustment to various loads by scaling

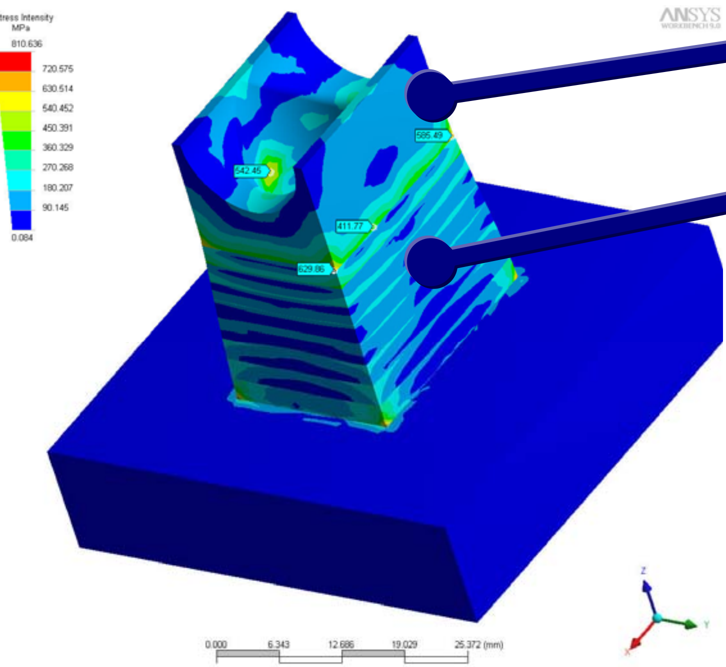
stress
ntensities
~ const.

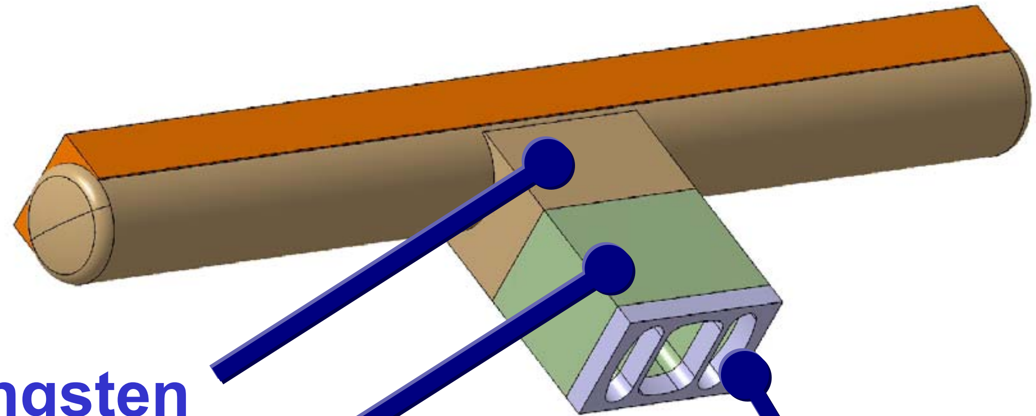


q' = 10 MW/m²
G/A = 24 kg/m²
dp = 0.11 MPa
d = 15 mm
s = 0.5 mm

d,b,l ~ 1/q'
G/A ~ q'
P/Q' ~ q'²

W – Fe transition





Tungsten

W-Fe Gradient

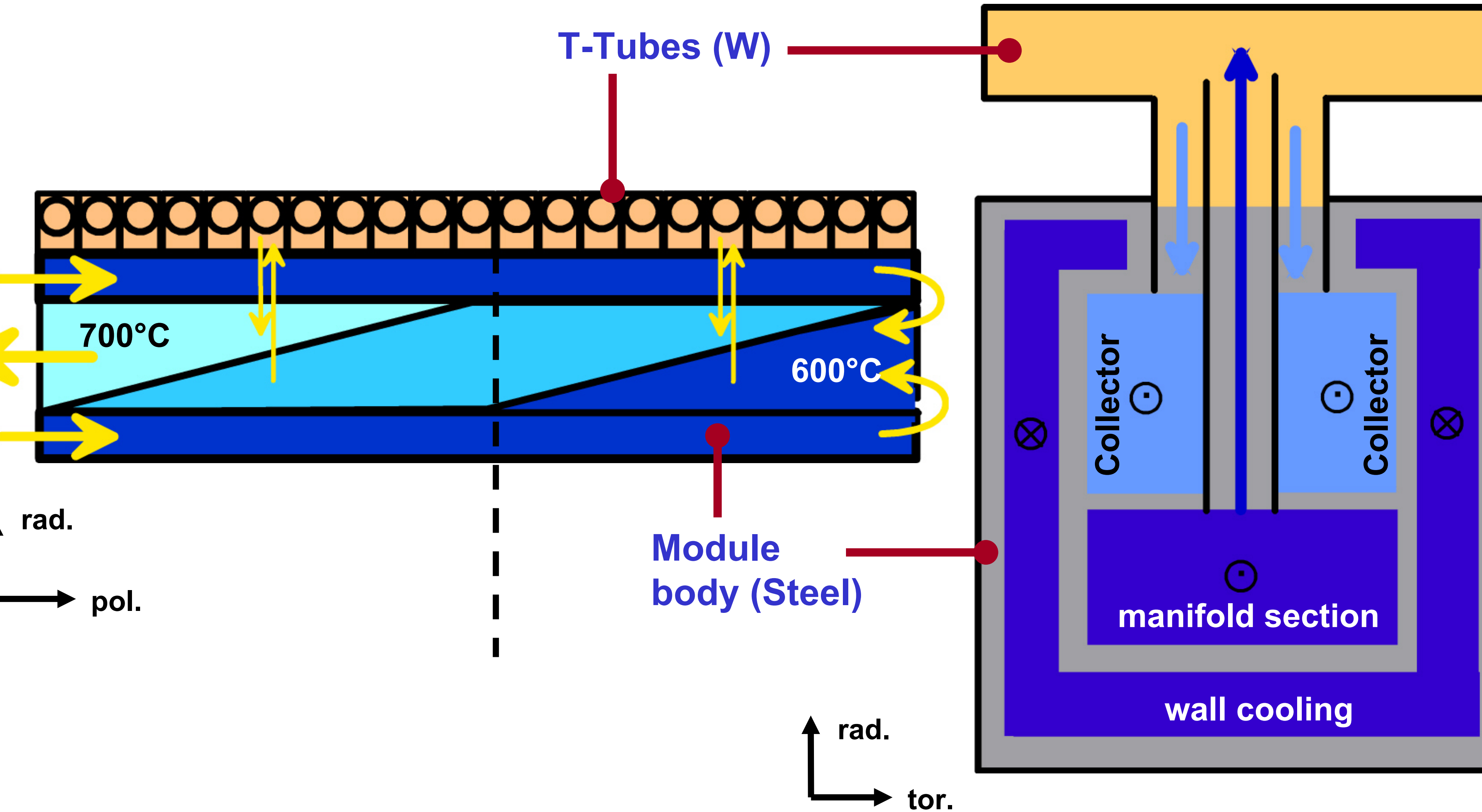
Steel anchor

W-FE gradient transition:

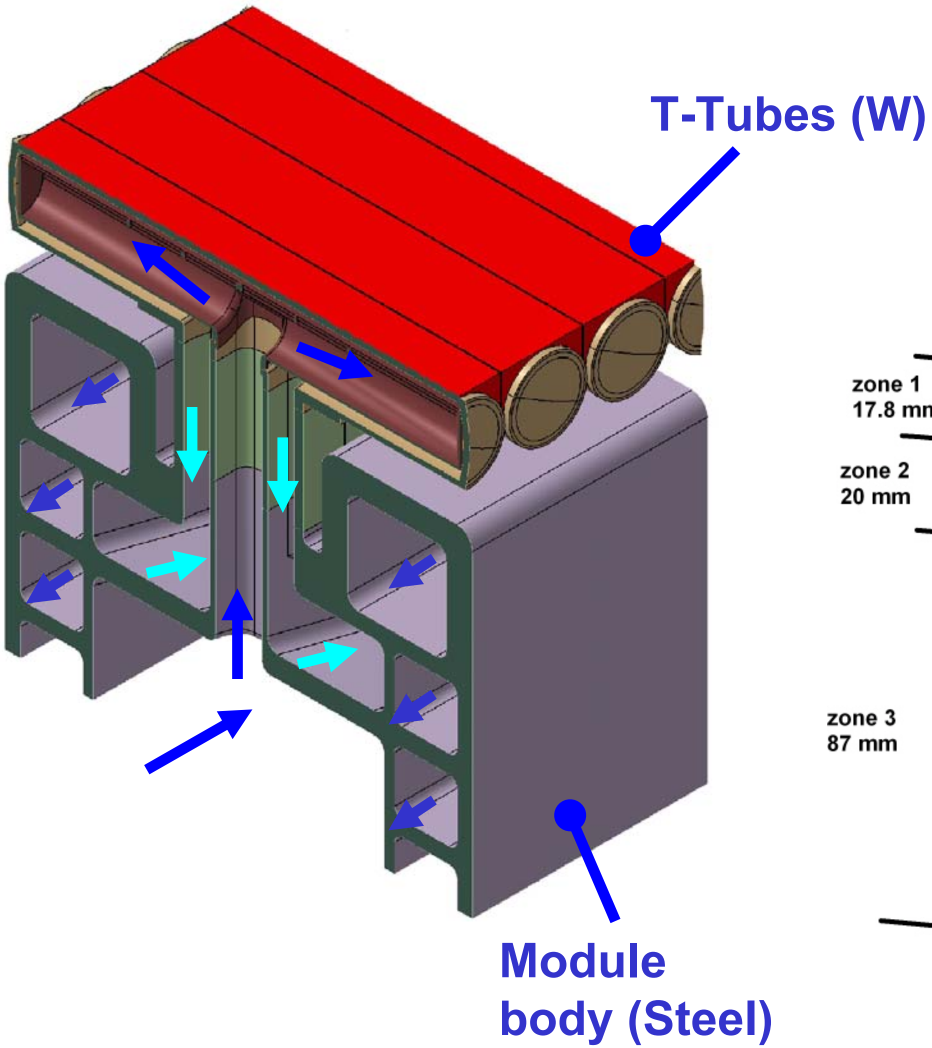
Slices for stepwise adjusting of thermal expansion,

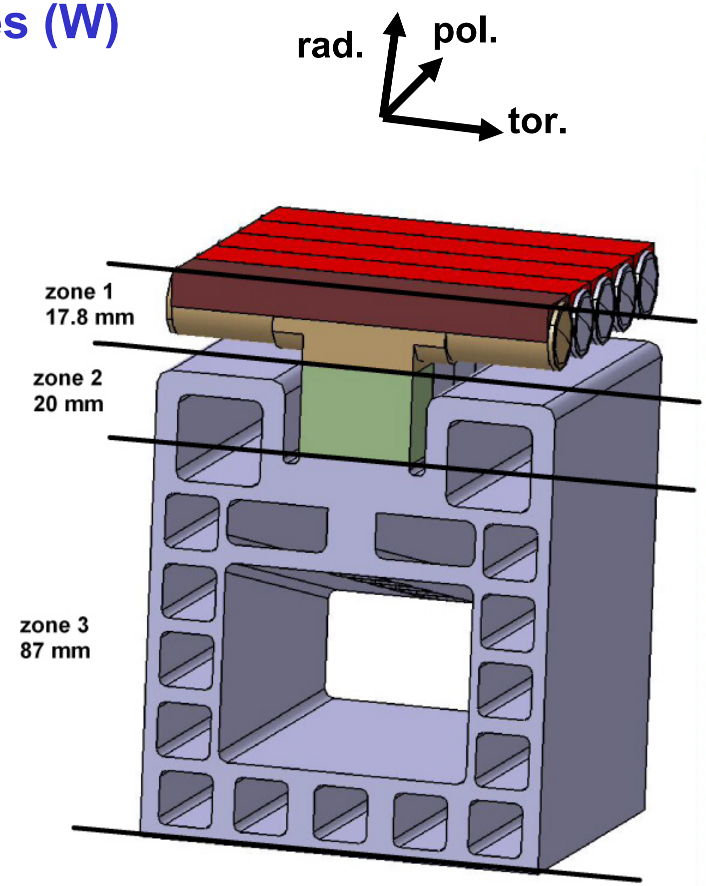
Brazed and/or HIPped

Schematic Divertor Module Design



Divertor Module Design





zone1: Tungsten parts, h = 17.8 mm

	V	
	m3	%
sum W	9.540E-06	37.69%
Helium	1.07E-05	42.27%
space	5.07E-06	20.04%
total	2.53E-05	

zone2: W-FS-Gradient zone, h = 20 mm

	V	
	m3	%
sum W	1.919E-06	6.75%
sum FS	9.909E-06	34.84%
Helium	1.05E-05	36.96%
space	6.10E-06	21.45%
total	2.84E-05	

zone3: Manifolds, h = 87 mm

	V	
	m3	%
sum FS	4.000E-05	32.34%
Helium	8.35E-05	67.50%
space	2.08E-07	0.17%
total	1.24E-04	

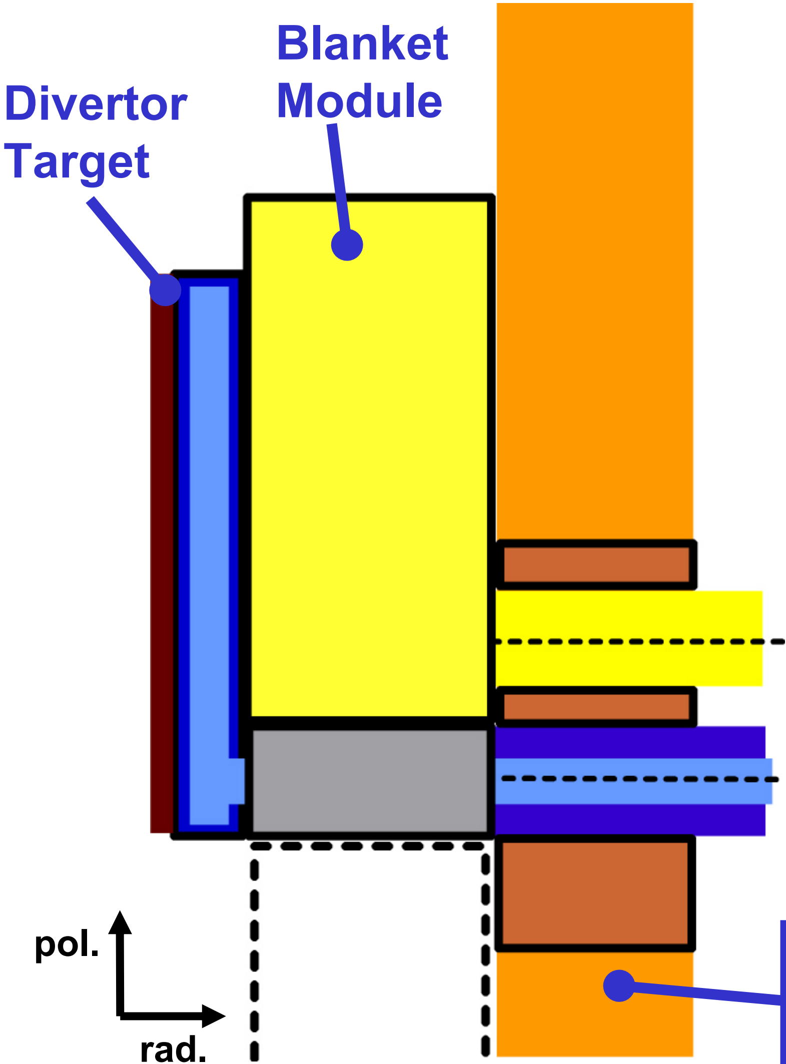
Divertor Integration:

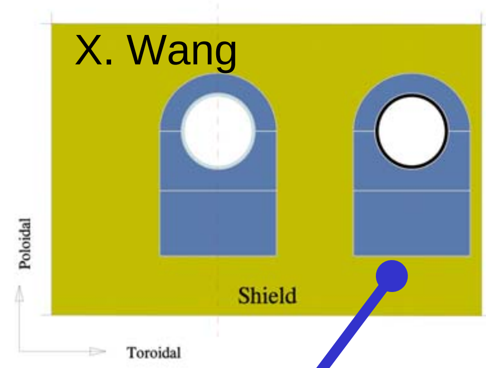
Independent Blanket/Divertor
(if remaining breeding zone is still sufficient)

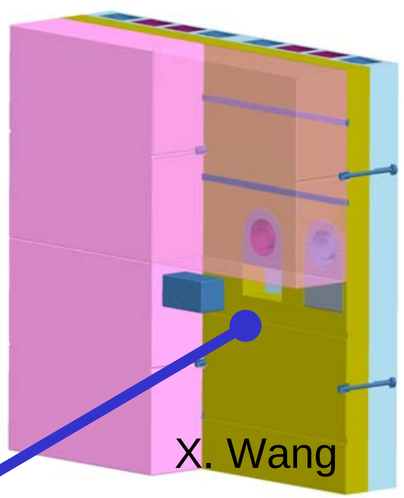
A1) Divertor Manifold box below Blanket module

+ Access to blanket pipes from below
  → same cutting/welding scheme for divertor
+ Simple shape for blanket

- Large cooled divertor manifold necessary
- reduced breeding zone
- divertor has to be disassembled from blanket

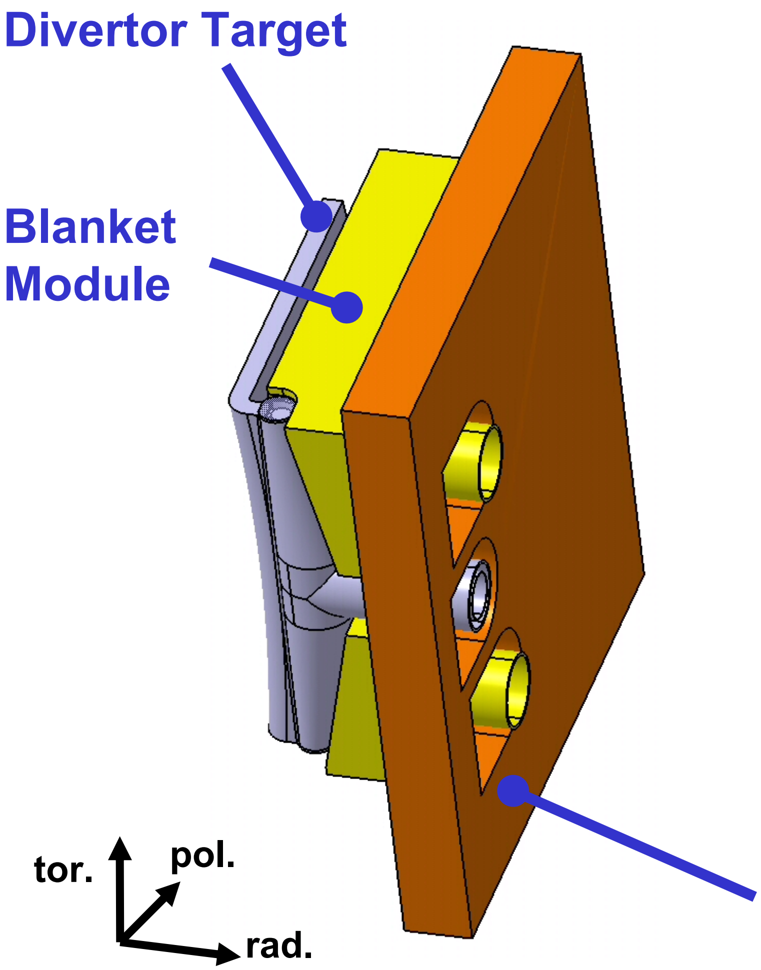






HT Shield with cut-outs for front access maintenance

Divertor Integration



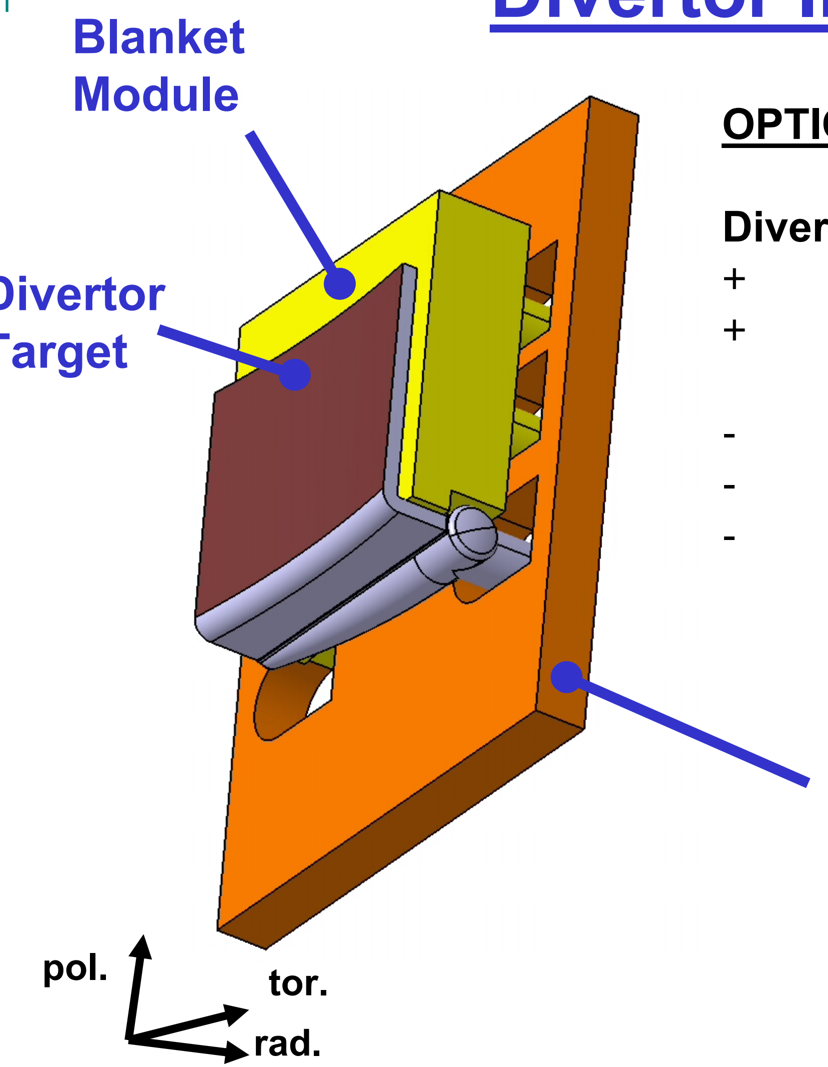
Independent Blanket/Divertor
(if remaining breeding zone still sufficient)

A2) Divertor Manifold fits into cut-out in Blanket module

+ Divertor may be removed with Blanket
+ Access to blanket pipes from below
+ Smaller divertor manifold

- Very complicated shape for blanket
- Cooled divertor manifold necessary
- Reduced shielding in manifold/tube area

Divertor Integration Options



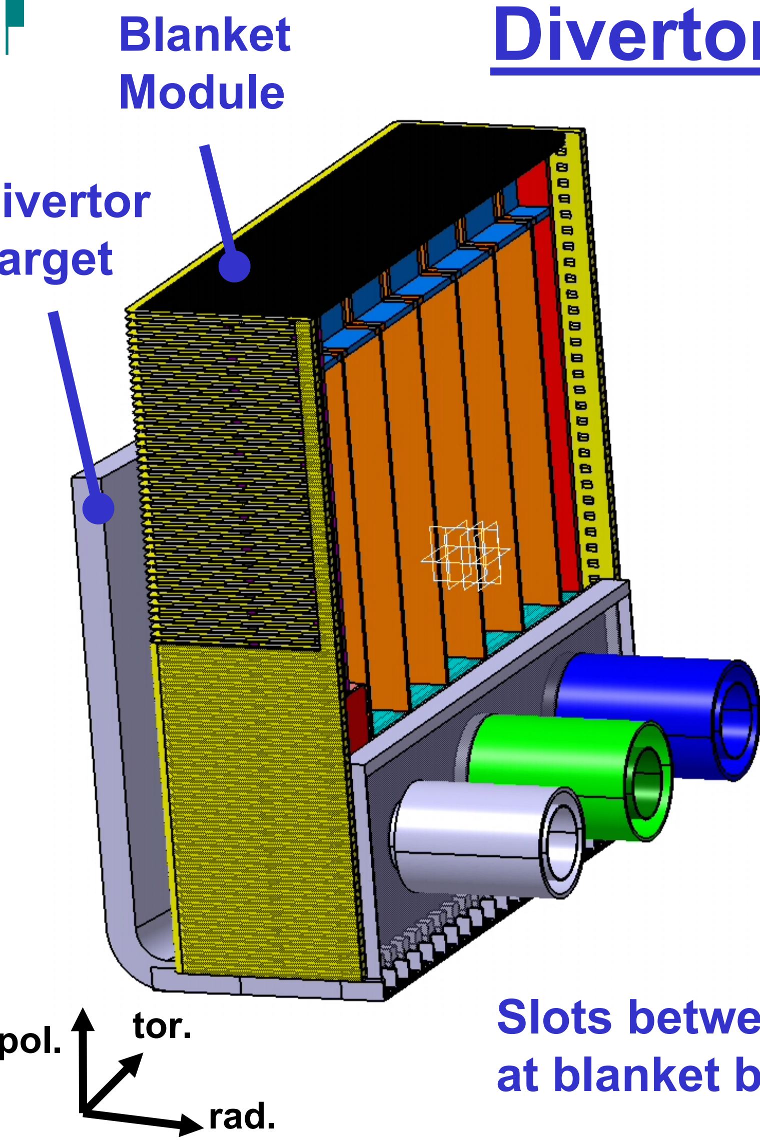
OPTION B:

Divertor Manifold fits into cut-out in Blanket module

+ Independent Blanket/Divertor
+ Less neutron heating for divertor manifold

- Complicated shape for blanket
- Access of blanket pipes limited (tor.)
- Divertor cannot be removed without the Blanket

Divertor Integration Options

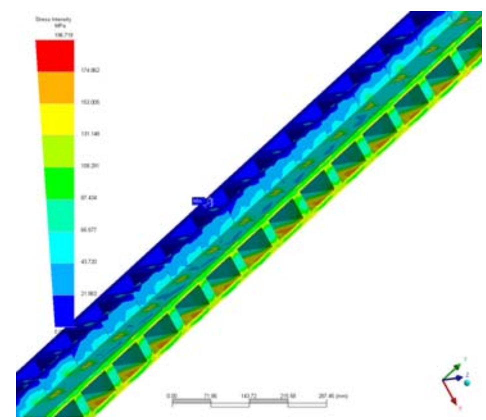


OPTION C: Divertor Manifold in Blanket box

+ Lower neutron heating for divertor manifold
+ No additional cooling for divertor manifold
+ Thin manifold as included in blanket box
+ Uncomplicated shape for blanket
+ Better shielding than option A & B
+ Access to blanket pipes from below

- Fix point at blanket back side
- Divertor part of blanket

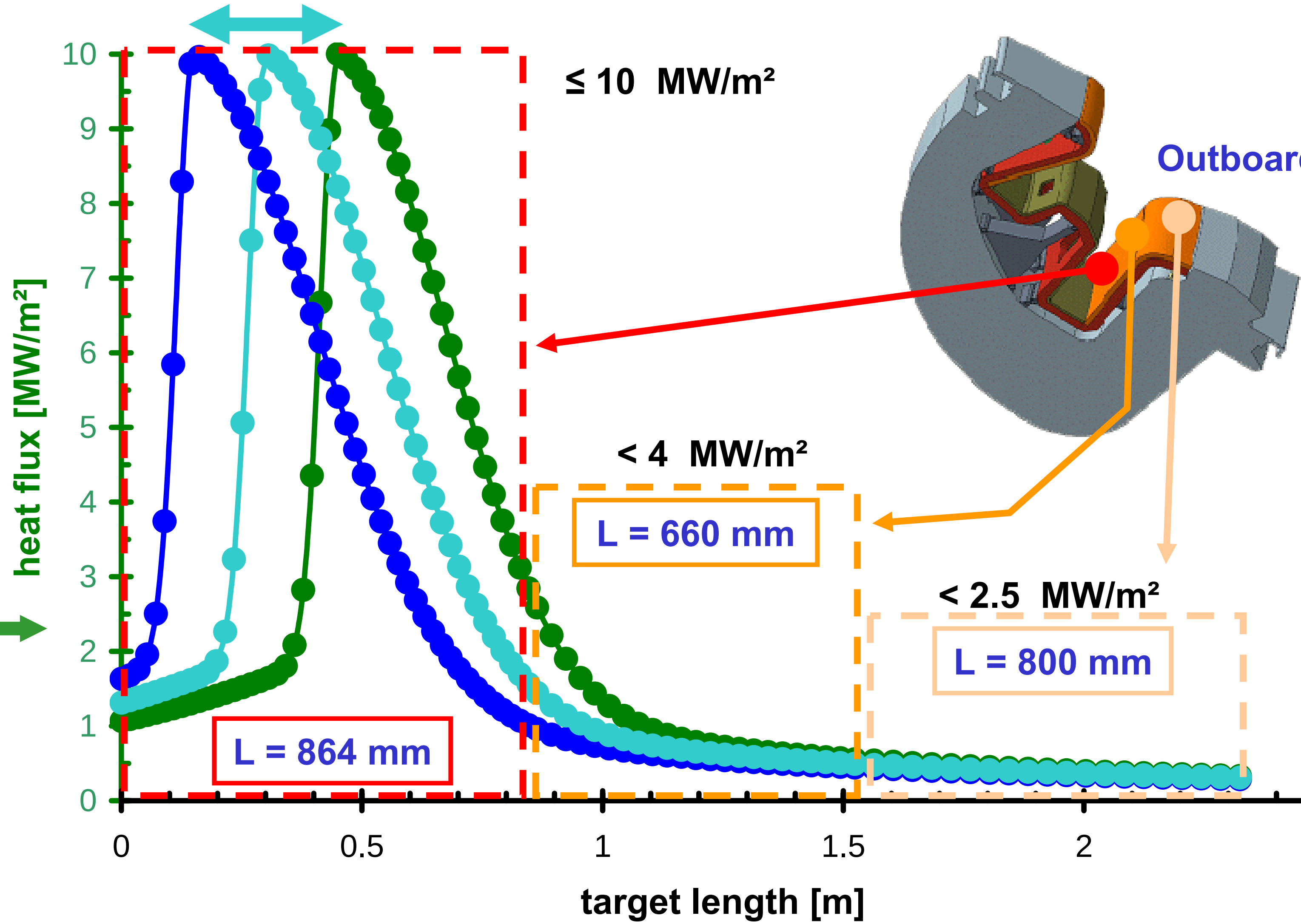
Slots between divertor channels at blanket box passage → stress ok.



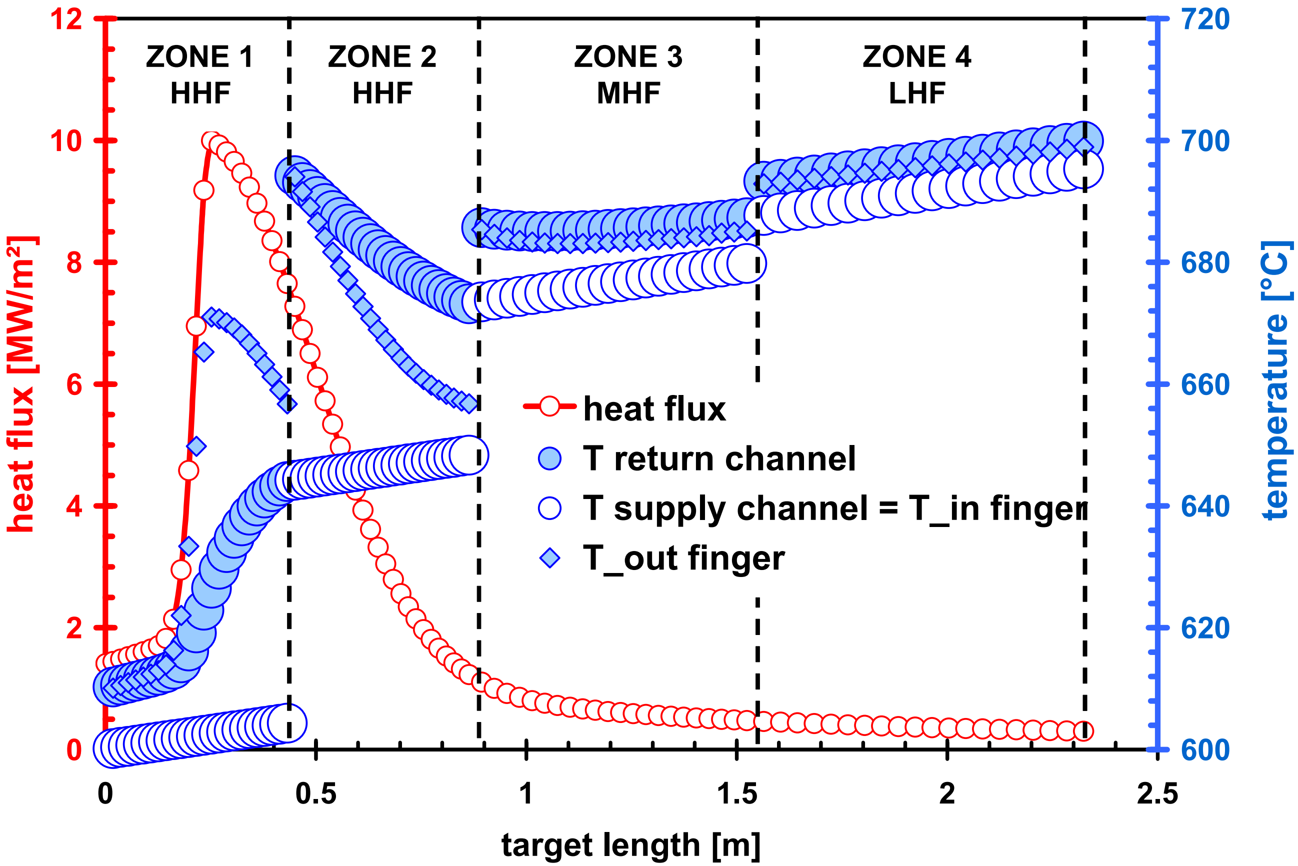
TOKAMAK Outboard target: cooling zones

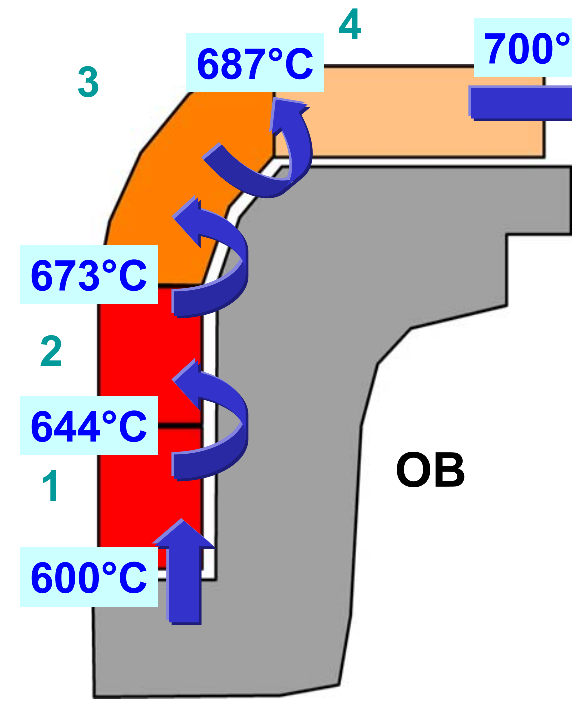
livertor power load
<u>685 MW</u>
8 % neutron power
2 % surface power

max. 80 % of
surface power
on outboard
→ 230 MW



LAYOUT EXAMPLE TOKAMAK: thermo-hydraulic layout ΔT = 100 K





SUMMARY

Divertor Design Concept for ARIES CS has been developed

- New T-tube heat exchanger design
- New manifold concept for rel. high neutron load (vol. heating)
- Slot based jet impingement adapted
- Good therohydraulic performance (Said & Regina FZK)
- Thermal stress within design limits for 10 MW/m^2

- Different Integration concepts can be chosen
- Detailed target layout possible, when distribution data available