Updates on Design and Analyses of the Plate-Type Divertor

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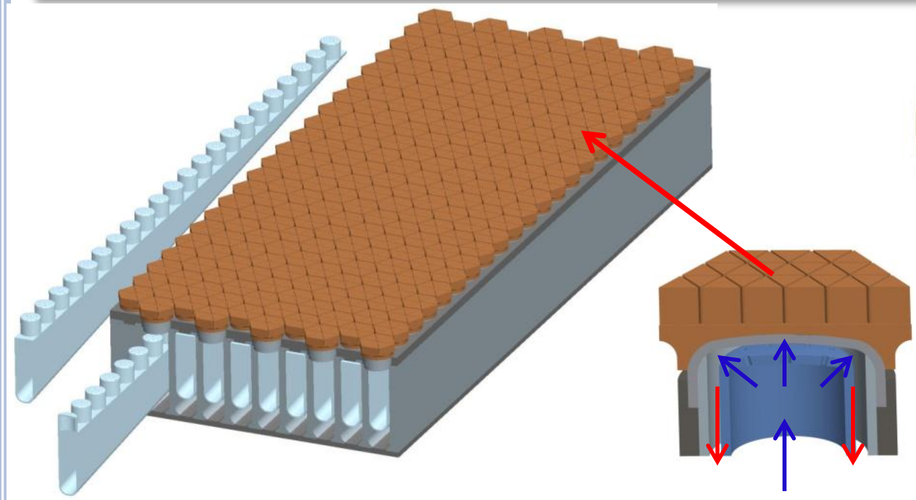
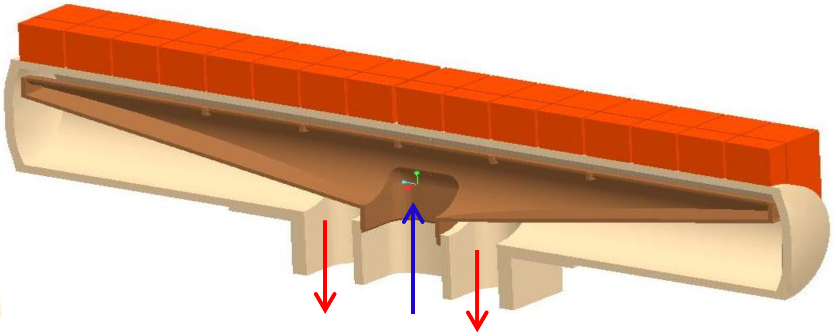
Current Status of ARIES Finger and T-Tube Divertor Concepts



1. HCPF(He-cooled Combined Plate and Finger)*

- ✓ q"=15 MW/m^2
- ✓ P_p /P_{th} <10%
- ✓ 700 °C < T <1300 °C for W structure
- ✓ Allowing yielding, within elastic regime after stress relaxation of plasticity

**With pin-fin array, accommodating ~22 MW/m^2 (without stress verification)



2. HCTT(He-Cooled T-Tube)***

- ✓ Tapered ODS-steel cartridge
- ✓ q"=13 MW/m^2
- ✓ P_p /P_{th} <10%
- ✓ 700 °C < T <1300 °C for W structure
- ✓ Within Elastic regime

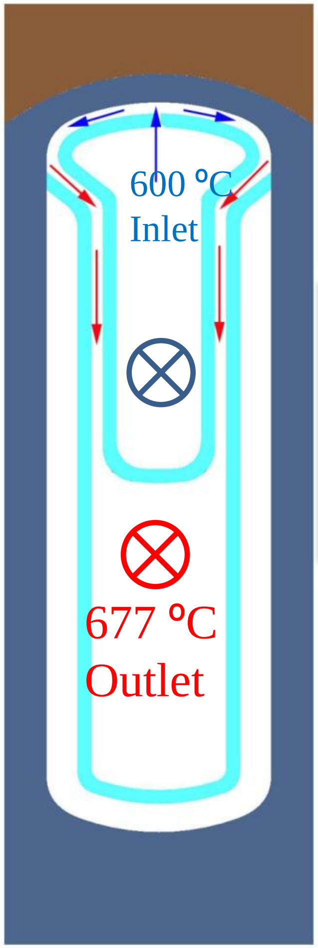
X.R. Wang**, S. Malang and M. S. Tillack, *19th TOFE*, to be published in ***Fusion Science and Technology.

****M. Yoda,** S.I. Abdel-Khalik et. all, ***19th TOFE,*** to be published in ***Fusion Science and Technology.***

*****J. Burke** and et. all, 19th TOFE, to be published in ***Fusion Science and Technology.***

Status of the ARIES Plate-Type Divertor Concept

3. HCFP(Helium-cooled Flat Plate) divertor

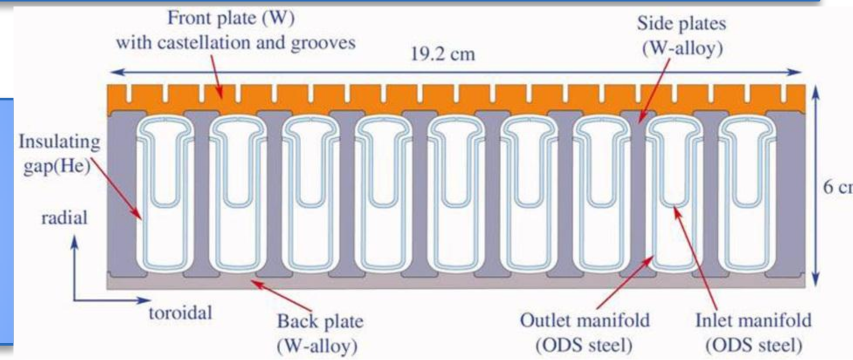


One Channel

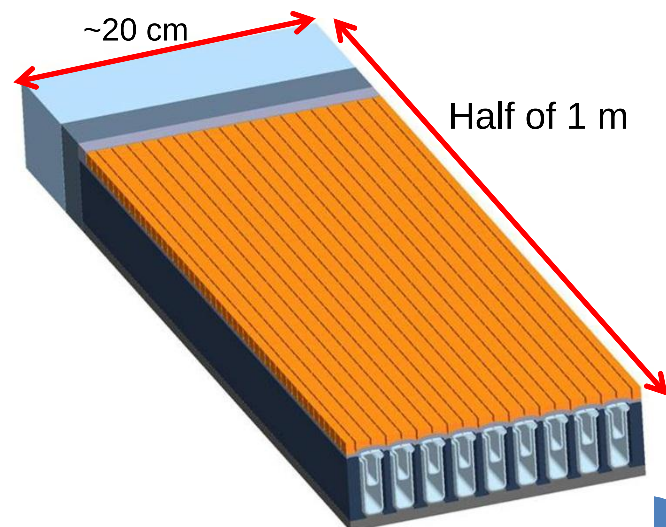
Jet-to-wall distance h=1.2 mm
Jet width D=0.5 mm
Front plate, t_f=2 mm
Side wall, t_s =3 mm
Back plate, t_b =8 mm

2 mm He insulator gap used to makes the cooling duct operating in range of 1075-1300 °C to reduce thermal stresses

q”=10 MW/m^2
q_v=17.5 MW/m^3
P=10 MPa
Tin/Tout=600/677 °C
HTC=~4.822x10^4 W/m^{2}K
T_{thimble}=1295 °C
P_P=9.7% P_{th}
$\sigma_{(p+s)}$ =359 MPa(within elastic regime)



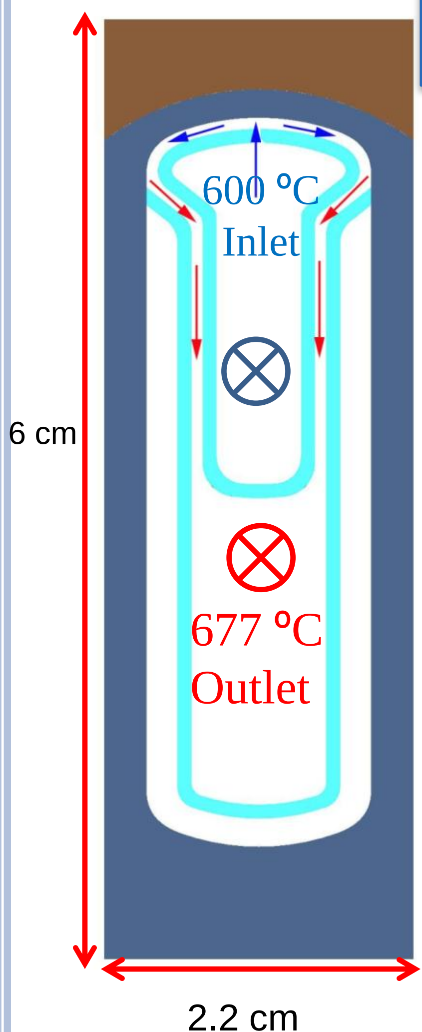
One plate(front view)



One plate(Bird view)

X.R. Wang, S. Malang and R. Raffray, ***Fusion Science and Technology*****, 56,** 1023(2009).

Can the HCFP Concept be Simplified for Pushing to Higher Heat Flux?

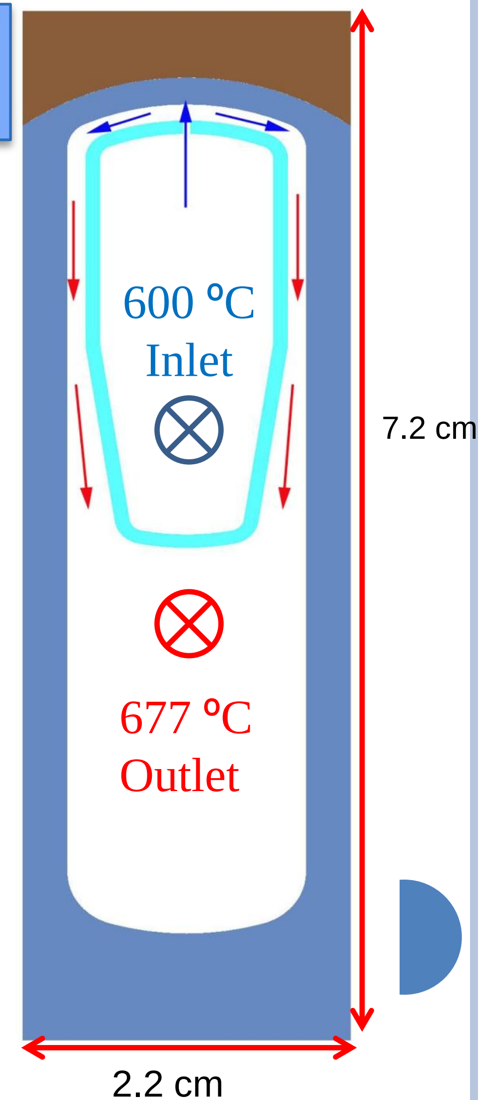


Design Method: Allowing local yield and considering plasticity.

Simplified to

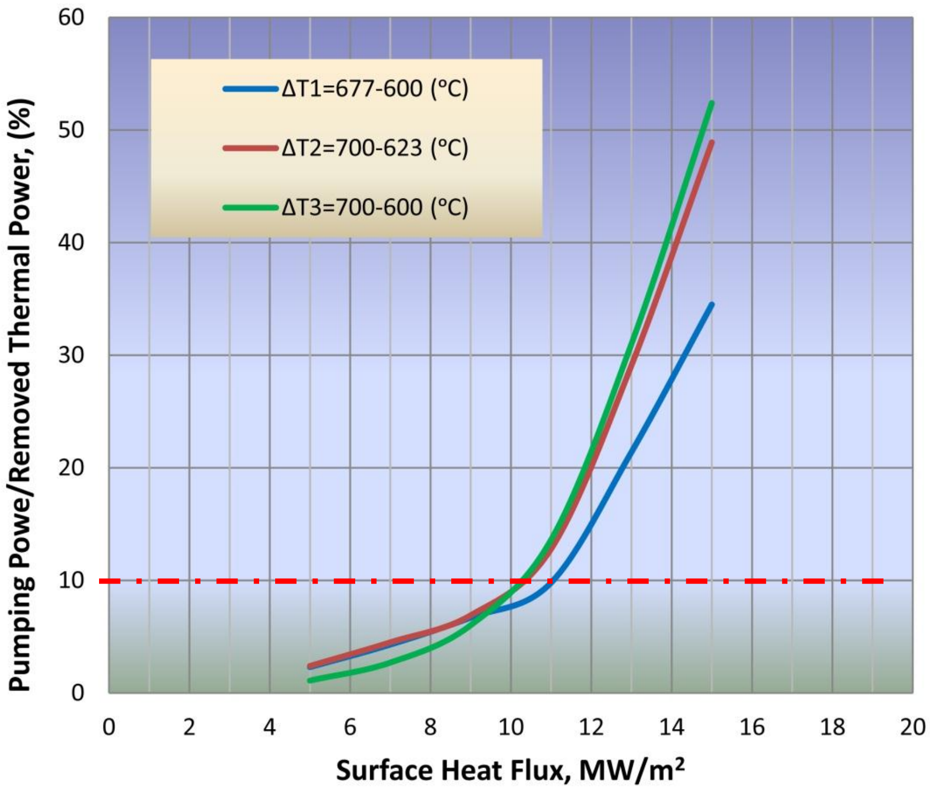
✓Getting rid off the U-shape wall for simplifying the design
✓More space for increasing cross-sections for manifolds and reducing ΔP
✓Increasing temperature design window

Verifications needed:
✓CFD analyses
✓Elasto-plastic analysis
✓Cyclic thermo-mechanics



PARAMETER STUDIES AND OPTIMIZATIONS OF THERMAL PERFORMANCE BY USING CFX

- CFX was used in the parameter studies and optimizations.
- The plate without pin fins are used.
- Different cooling conditions were analyzed
  - ✓ ΔT1=677-600 °C (Original design)
  - ✓ ΔT2=700-623 °C
  - ✓ ΔT3=700-600 °C
- Jet sizes are varying from 0.15 to 0.5 mm
- The plate-type divertor can accommodate the surface heat flux up to 11 MW/m^2 while staying within temperature and pumping power constraints.
  - ✓ T_s<~1300°C (Re-crystallization temperature
  - ✓ P_p< ~10% $P_{\text{removed thermal power}}$
- The plate-type divertor with pin fins can enhance the heat transfer coefficient (it is not included in this plot)**

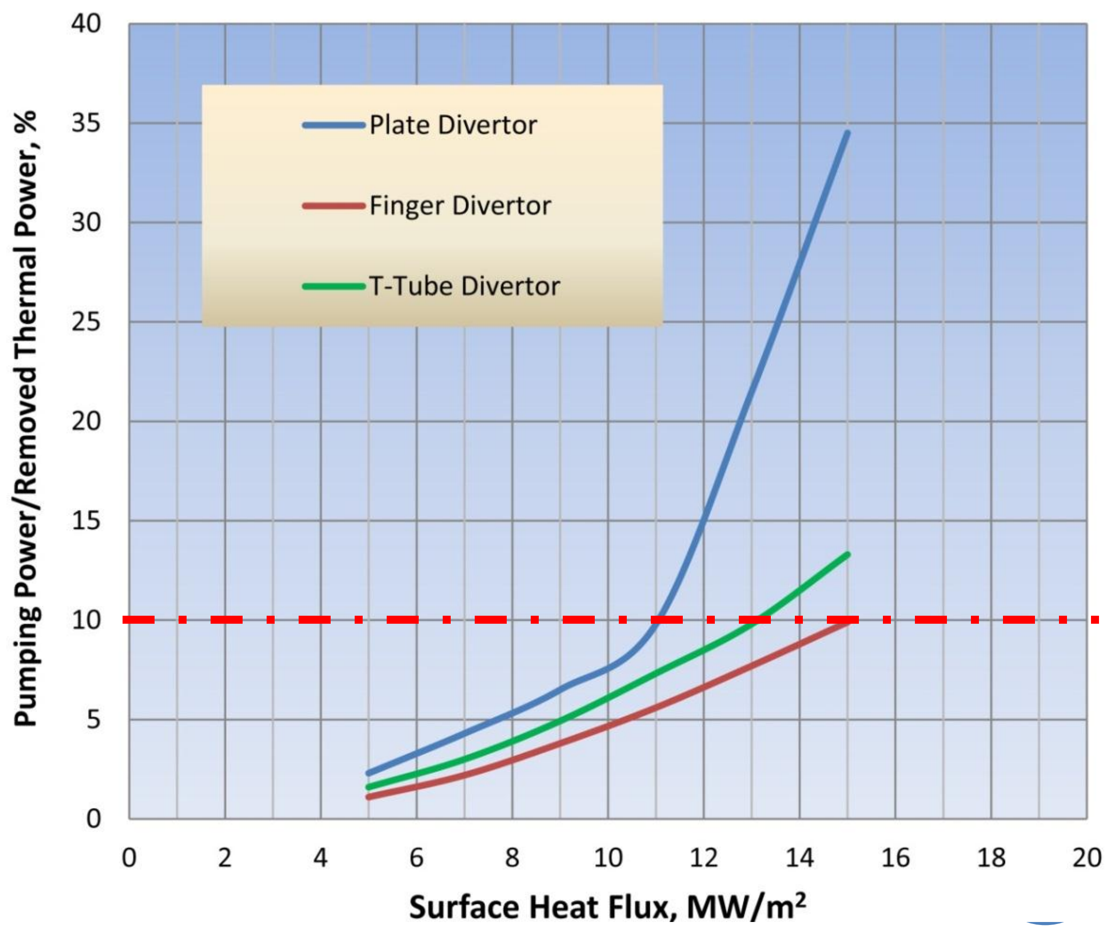


q''<9 MW/m^2, ΔT3 is better option
q''>9 MW/m^2, ΔT1 is better option

**M. Yoda, S.I. Abdel-Khalik et. all, ARIES meeting, May 2010

Comparison of Thermal Performance for Three Concepts

- W structure temperature limit
  700 °C< T_s <1300 °C
- All thermal-hydraulic analyses were performed by CFX
- Finger concept has better thermal performance.
- The finger (HEMJ) with pin fins can handle the heat flux up to 22 MW/m². ** (it is not shown)



**M. Yoda, S.I. Abdel-Khalik et. all, 19th TOFE Meeting, 2010..

Example of CFX Thermal-Fluid Results for HCFP

$q''=11\ MW/m^2$

$q'''=17.5\ MW/m^3$

P=10 MPa

$T_{in}/T_{out}=600/677$ °C

$D_{jet}=0.4$ mm

$V_{jet}=307$ m/s

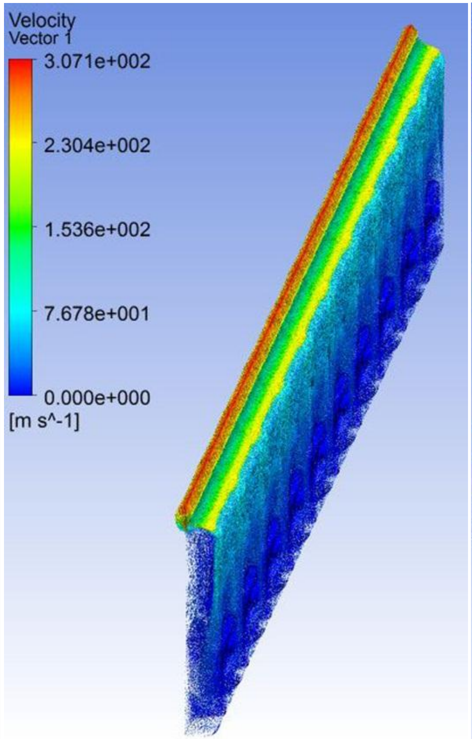
Local H.T.C=$7.64\times10^4\ W/m^2\text{-}K$

$P_p=9.8\%P_{\text{removed thermal power}}$

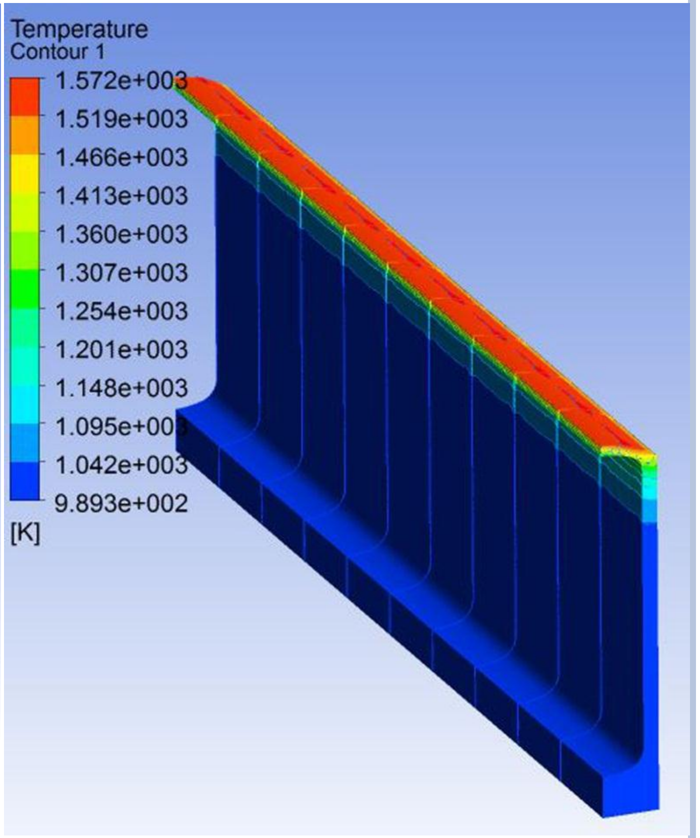
Max. T_{armor}= 1985 °C

Max. $T_{structure}$=1298 °C

Min. $T_{structure}$=716 °C

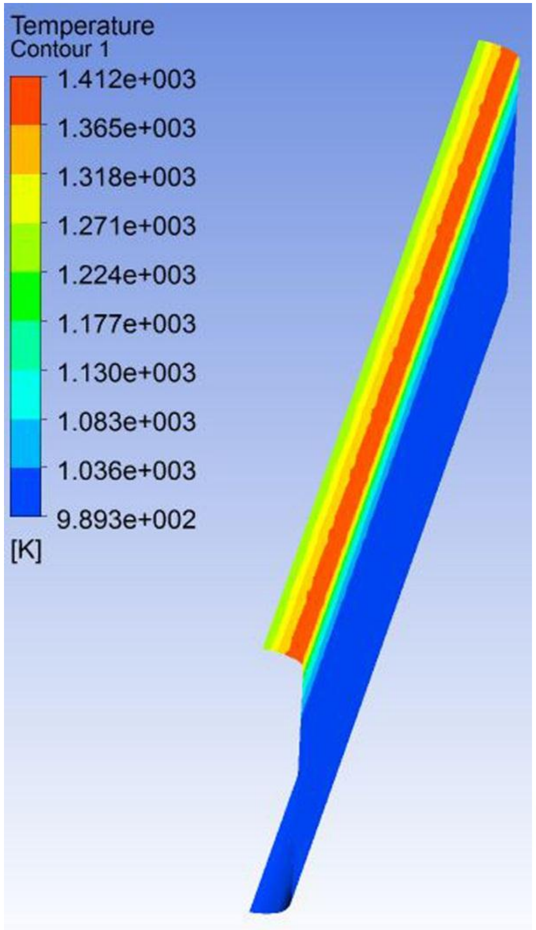


Velocity distribution

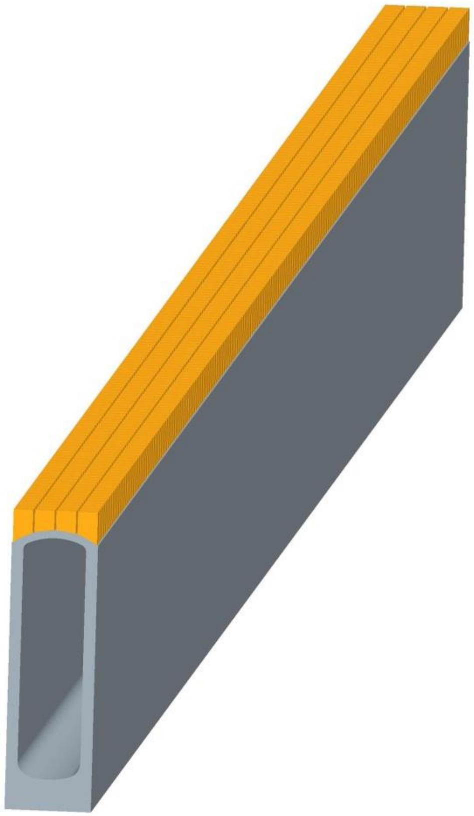


Temperature distribution (W-armor not shown)

THERMO-MECHANICAL ANALYSIS FOR THE HEAT FLUX UP TO 11 MW/m^2



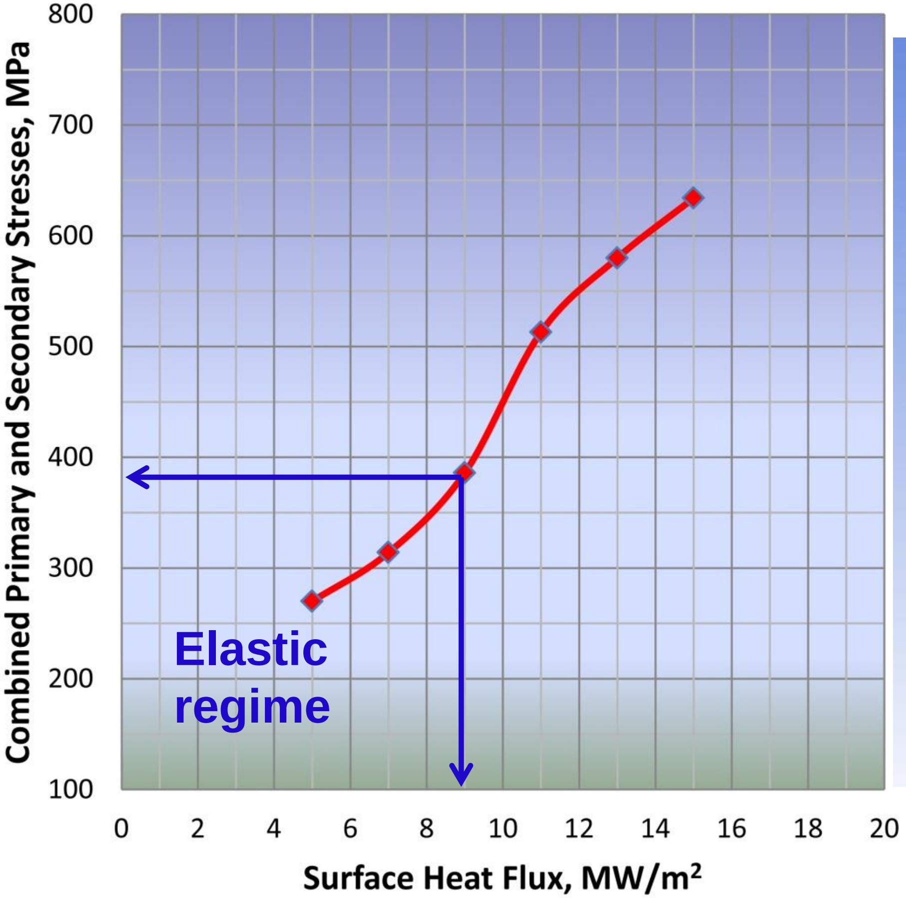
Temperature distribution at interface of the He/W (CFX results)

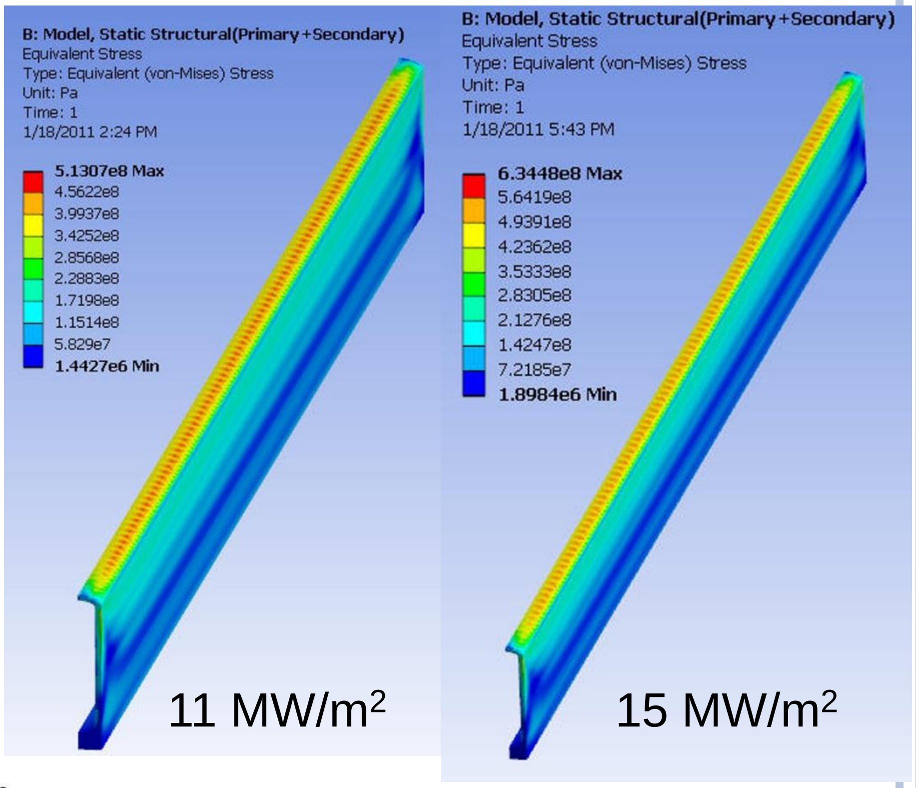


One coolant channel (without manifold)

- Only half of cooling channel is considered in the thermo-mechanical simulation.
- ODS insert manifold is excluded from thermo-mechanical model.
- Thermal boundary conditions and structural supports:
  - ✓ the interface temperature of the He/W is imported from the CFX thermal results
  - ✓ Thermal expansion and bending are free.

Example Results of the Elastic Structural Analysis





Stress distributions

- The plate-type divertor can accommodate the heat flux up to 9 MW/m^2 for maintaining the structure in the elastic regime ($3S_m$=373 MPa at T_s =1300 ºC).

EXAMPLE OF ELSTO-PLASTIC ANALYSES FOR A HEAT FLUX OF 11MW/M²

Design Criteria:

Allowable plastic strain has to be less than 50% of the uniform elongation of the material:

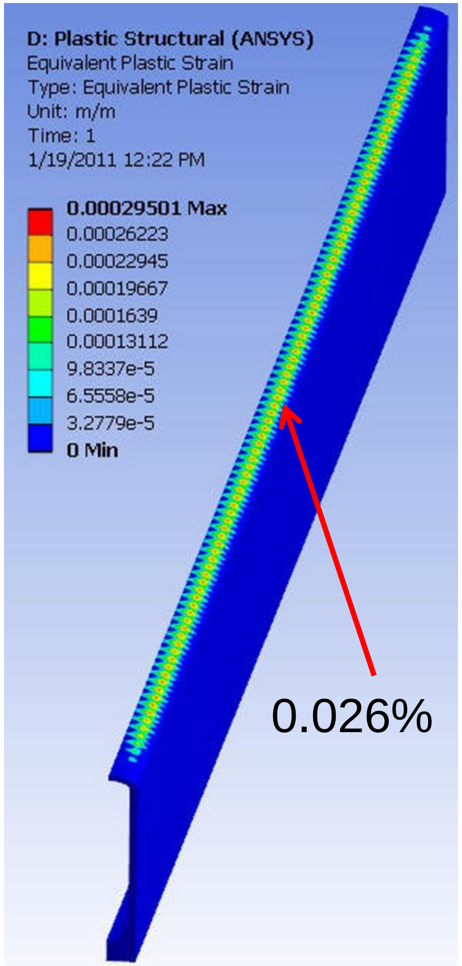
- ✓ **ε_{allow}=~0.8% for W at 270°C**
- ✓ **ε_{allow}=~1.0% for W at 1200 °C**

➢The maximum plastic strains calculated by ANSYS:

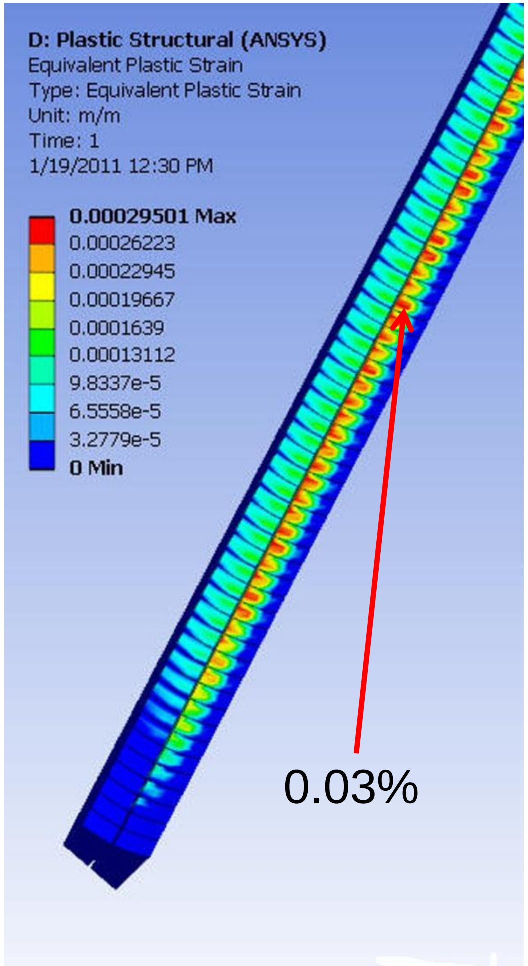
- ✓ ε_{pl}=~0.026% in the channel
- ✓ ε_{pl}=~0.03% in the armor

➢Total deformation is ~3.1 mm (increase of the plate length)

➢**Plastic design criteria are met for the maximum surface up to 11 MW/m².**

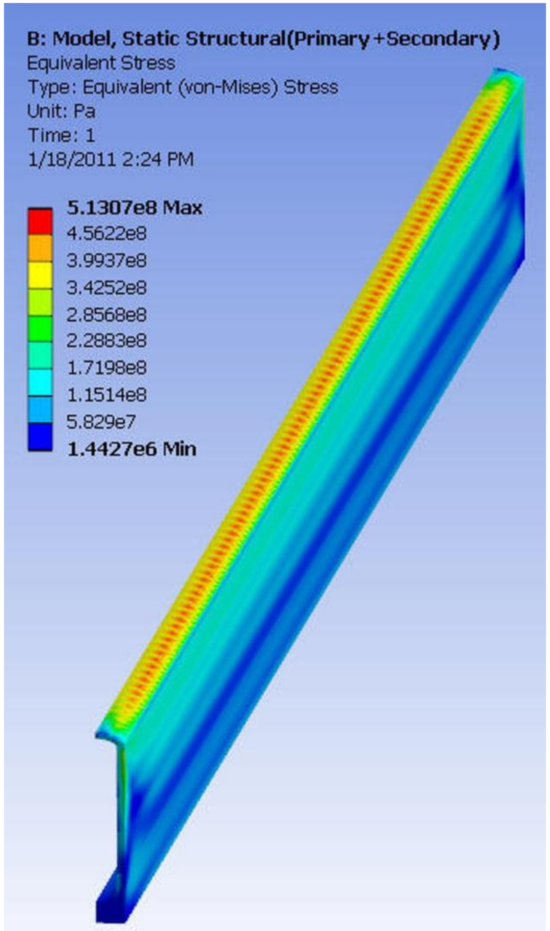


Plastic strain of the cooling channel



Plastic strain of the tiles (on the top of the channel)

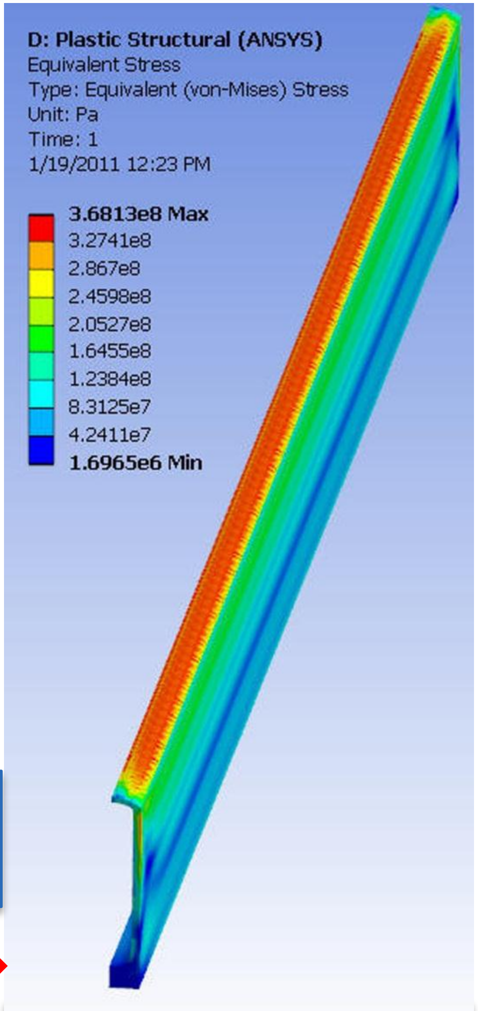
EXAMPLE SHOWING STRESS RELAXATION FOR THE HEAT FLUX OF 11MW/M^2



✓**SF**(safety factor)=3 S_m/Combined primary and secondary stresses
✓SF must be >1

σ_{max} =513 MPa, SF_{min}=0.73
ASME code is not met.

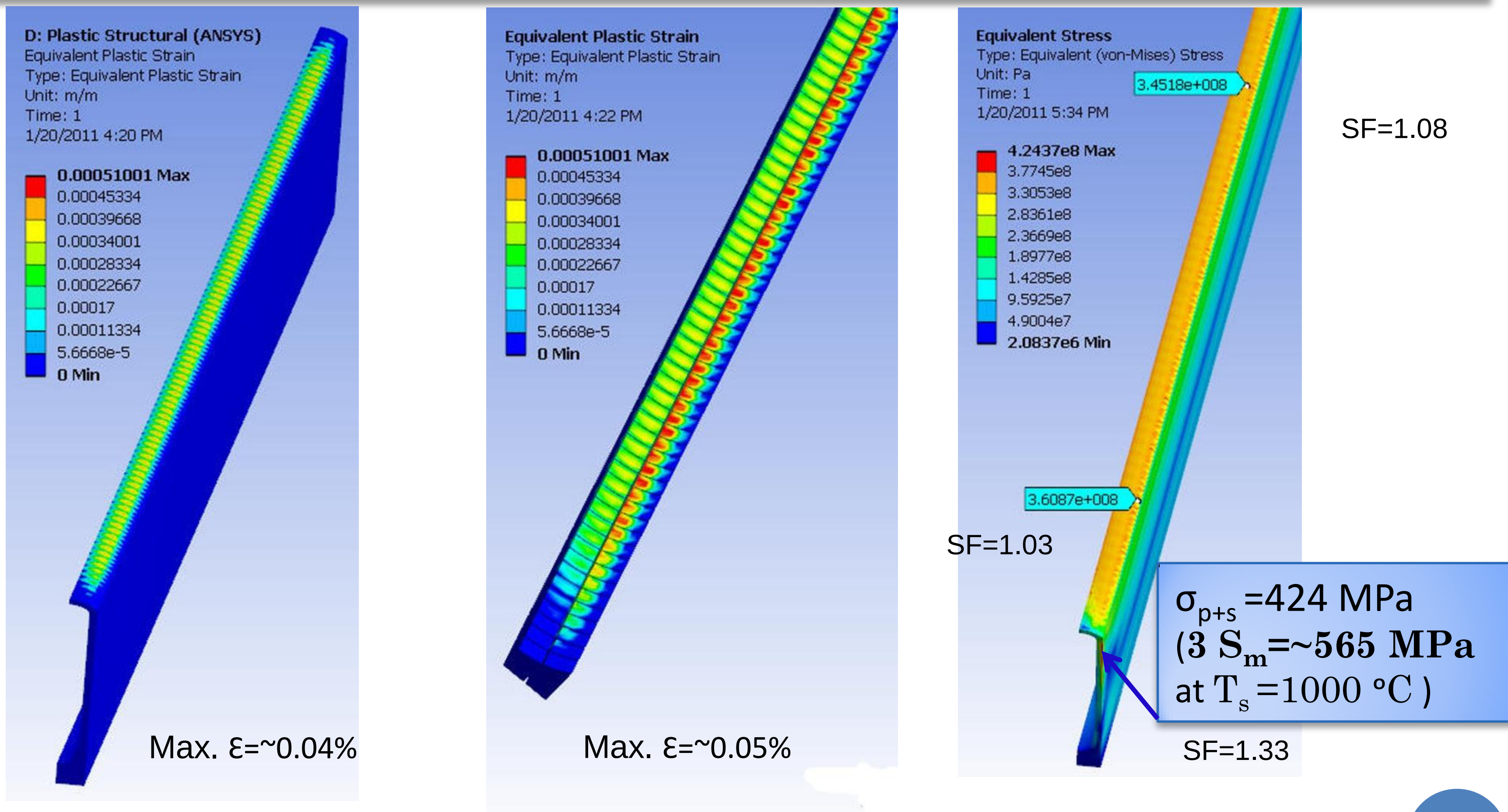
σ_{max} =368 MPa, SF_{min}=1.01
ASME code is met.



Elastic Analysis

Elastic-Plastic Analysis

Elasto-Plastic Analyses for the Heat Flux up to 15MW/m²



- The maximum plastic strains at the channel structure and the armor ~0.04% and 0.05%, respectively **(allowable plastic strain ε_{allow}=~1%).**
- The structural behavior stays in the elastic regime after stress relaxation of the plasticity (**3 S_m=~410 MPa** at T_s =1265 °C). However, the pumping power for the heat flux of 15 MW/m² is too high and the minimum temperature < 700 °C.

Summary and Conclusions

- The HCFP divertor has been re-investigated and simplified by considering “yielding”, stress-relaxation and plasticity, and the U-tube for stagnant helium insulator gap inside of channel can be eliminated.

- Parametric studies have been performed by 3D CFX, and thermal-hydraulic results indicate that:
  - ✓ $\Delta T3 = T_{exit} - T_{inlet} = 700\text{-}600$ °C is better option for the q”<9 MW/m^2
  - ✓ $\Delta T1 = T_{exit} - T_{inlet} = 677\text{-}600$ °C is better option for the q”>9 MW/m^2

- **The simplified HCFP divertor** can accommodate the surface heat flux up to **11 MW/m^2** while staying into the temperature and pumping power limits.

- **Stress is not very important limit constraint** any more comparing to the temperature and pumping power **when the local yielding is allowed**.

- However, it remains to be seen if cyclic loading leads to ratcheting with $\varepsilon_{Pl} > \varepsilon_{allow}$.

- **Modifications for all the divertor concepts are required to increase minimum W temperature from ~720 °C to >800 °C.**