Updates of Helium-Cooled Flat Plate Divertor Design and Analysis

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ARIES Project Meeting
University of Wisconsin, Madison
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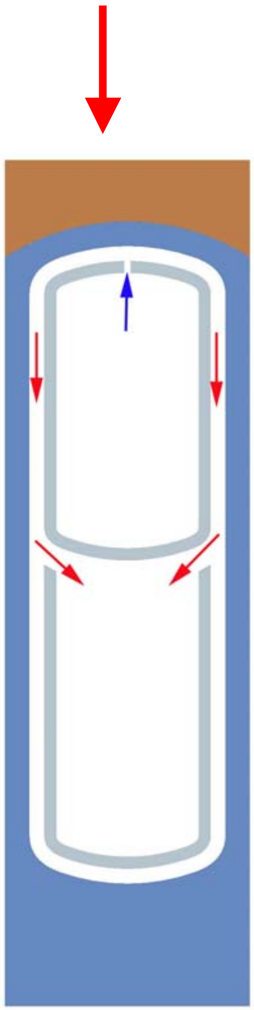
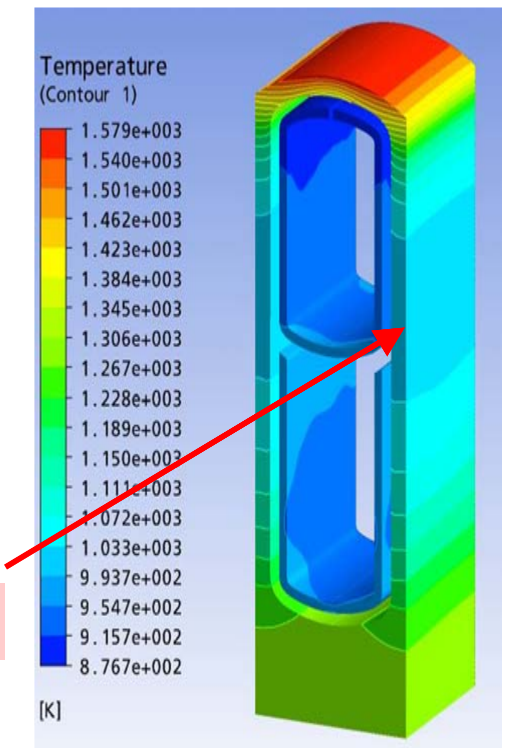
Results Presented at UCSD ARIES Meeting



- The flat plate divertor with slot-jet cooling mechanism was designed to take 10 MW/m^2 heat flux
- Thermo-fluid and thermo-mechanical analyses
  - ✓Heat transfer, HIGH (3.9 x 10^4 W/m^2 K)
  - ✓Pumping power, OK (<10% thermal power)
  - ✓W structure temperature, OK (1300 C, allowable)
  - ✓Stresses, > 3Sm (450 MPa, allowable)



Cold spot at sidewall temperature 800 °C

Is it possible to improve the divertor design to reduce thermal stresses?

Open U-shape Manifold with 1 mm Thermal Insulating Gap to Rise Side Wall Temperature

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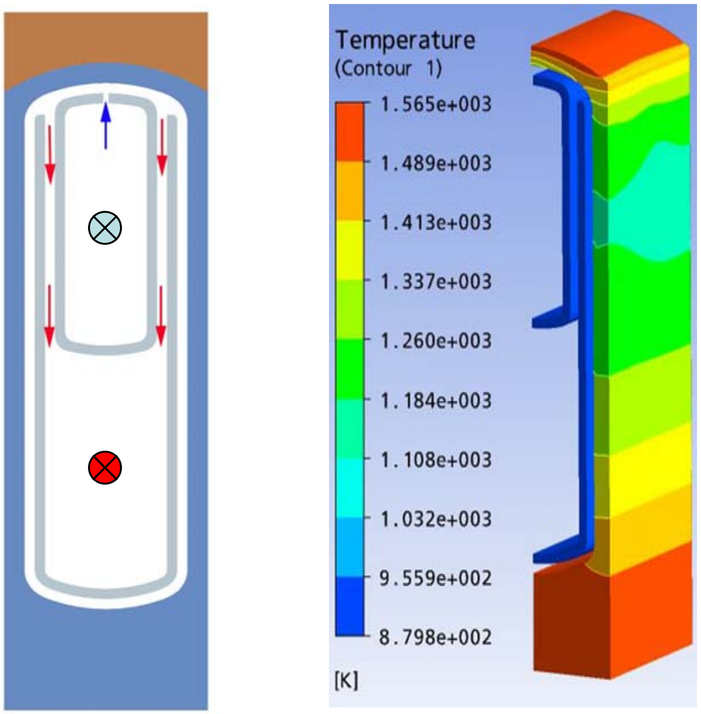

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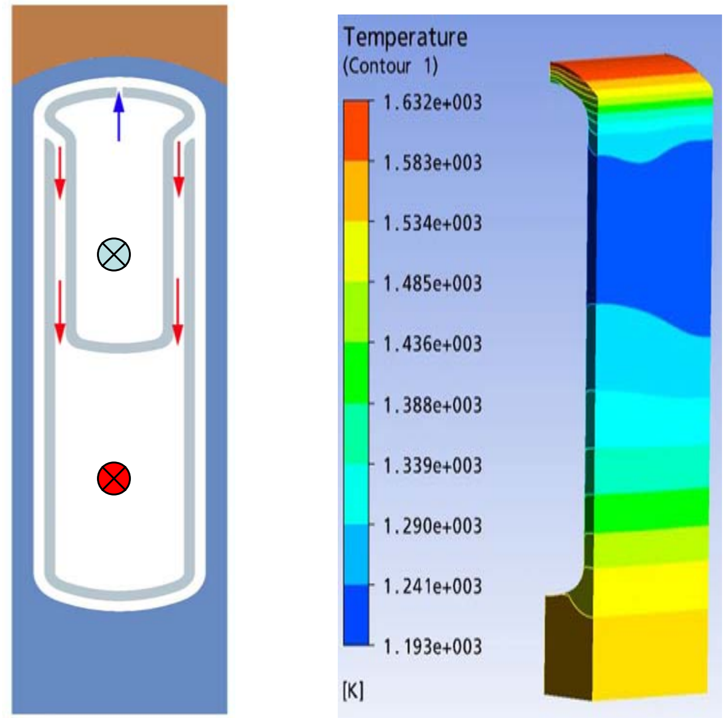
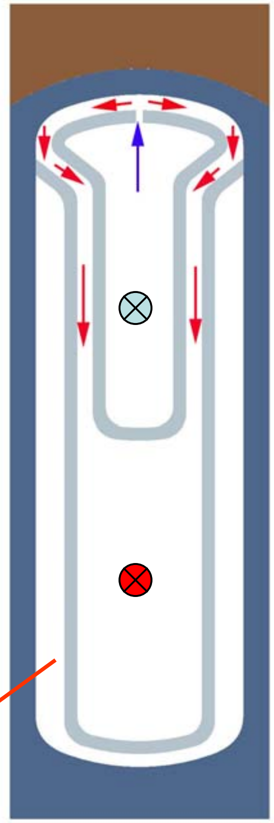


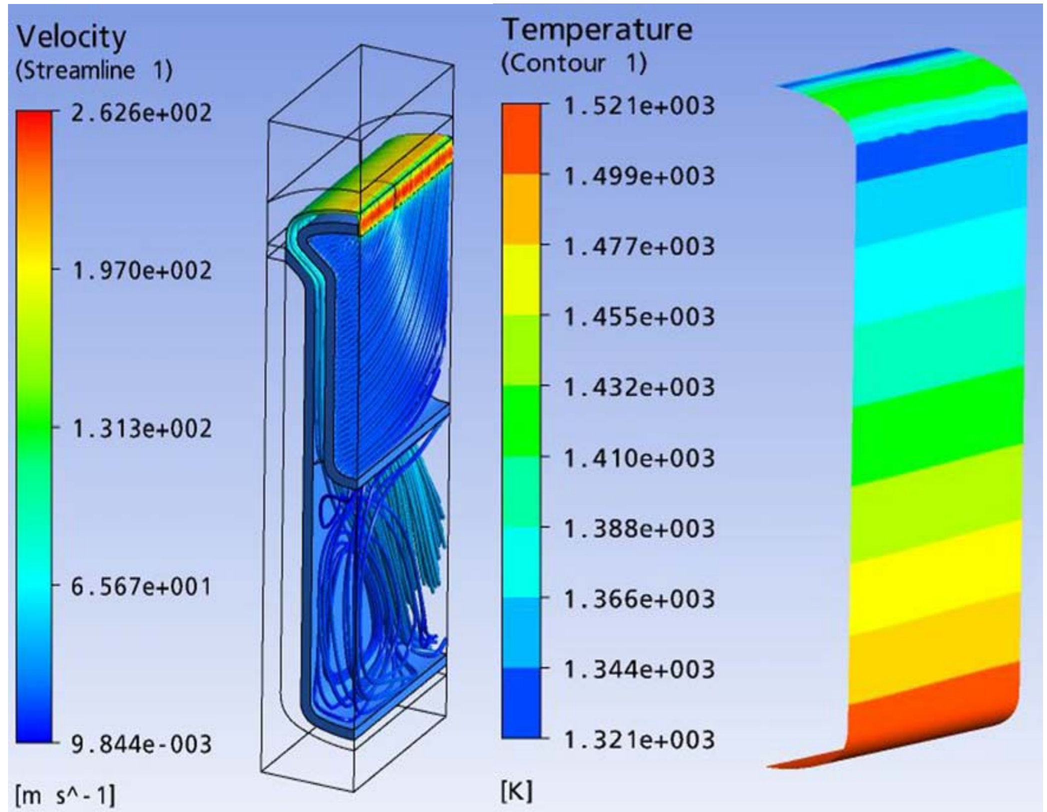
- The basic idea of modification for the plate concept is to employ a thermally insulating gap between the W side walls and the ODS manifold in order to rise temperature at the side wall.
- Thermo-fluid analyses performed by CFX show that the open U-shape manifold with 1 mm thermal insulating gap does not do the job well.
- FEA structure analyses show that the thermal stresses do not improve much.

Closed U-shape Outlet Manifold with 2 mm Thermal Insulating Gap Can Rise Side Wall Temperature ~1100 °C

- Outlet manifold with U-shape
- Added 2 mm stagnant helium gap to the both side of the channel, and 1 mm at the back plate
- Closed the helium gap near the top corner and it has to remain stagnant
- Radiation and conduction in helium gap included in CFX fluid-thermal model

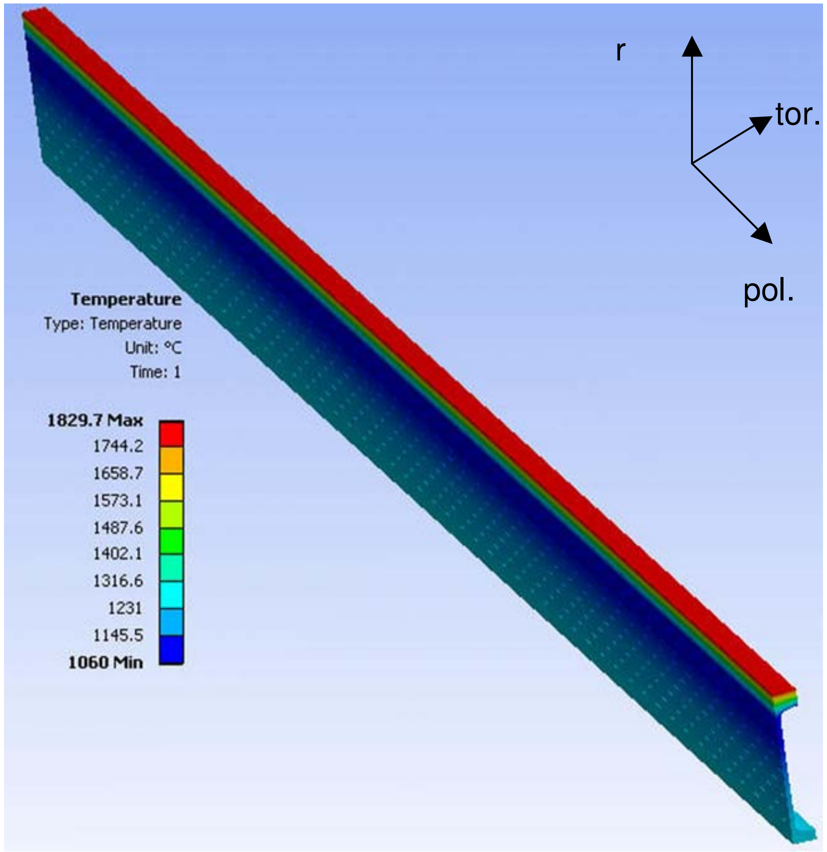
stagnant He

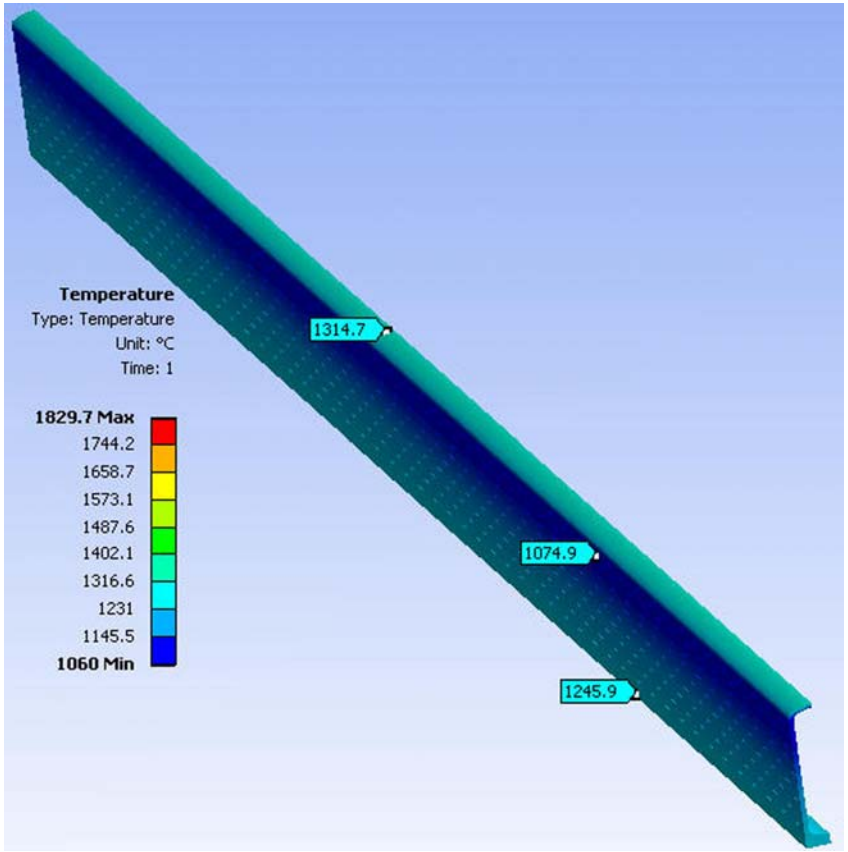




- The Max.temperature at the inner surface of the W back plate is ~ 1248 °C
- The cold spot at the inner surface of W structure temperature is ~ 1074 °C
- Max. jet velocity is about 262.6 m/s
- Max. heat transfer coefficient is about $4.0x10^4$ W/m^2K
- Pumping power, P_p=10.4 % $P_{th.}$

Thermal Results of A Full-size Plate Divertor Channel



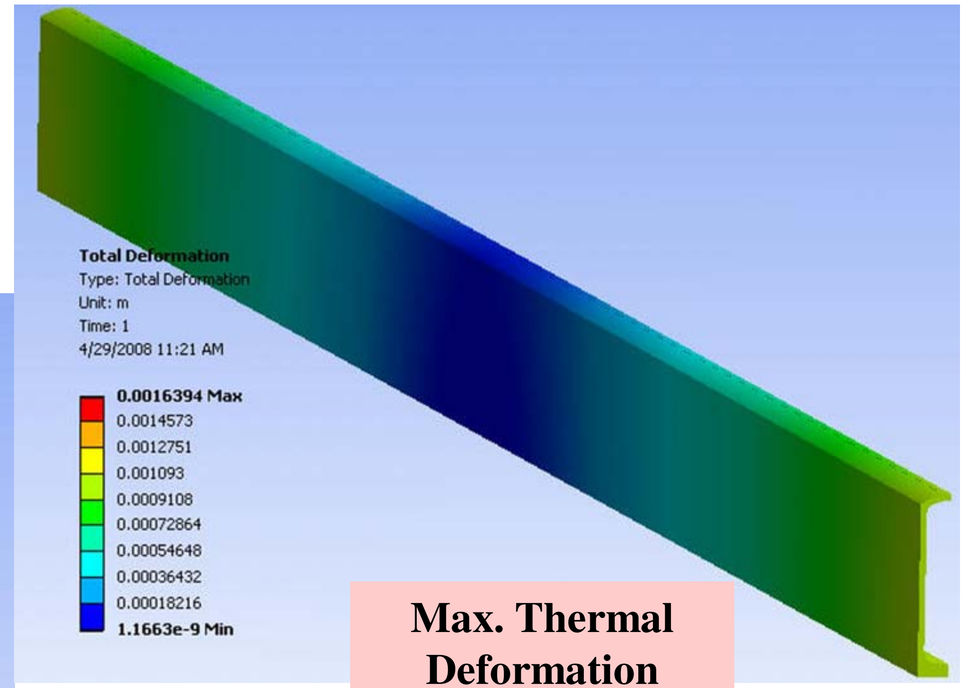


- CFD results from CFX are exported to ANSYS FEA for thermal and stress analysis.
- The max.temperature of the W tile is ~ 1829 °C
- The max. front W structure is about 1315 °C, and cold temperature at side wall rising fro 800 to 1075 ° C
- The max front structure temperature is 15 °C higher than design limit (1300 °C), but it can be easily cooled down by increasing the mass flow or making the diameter of jet nozzle smaller.

Thermal Stress of the Full-size Plate Divertor Channel

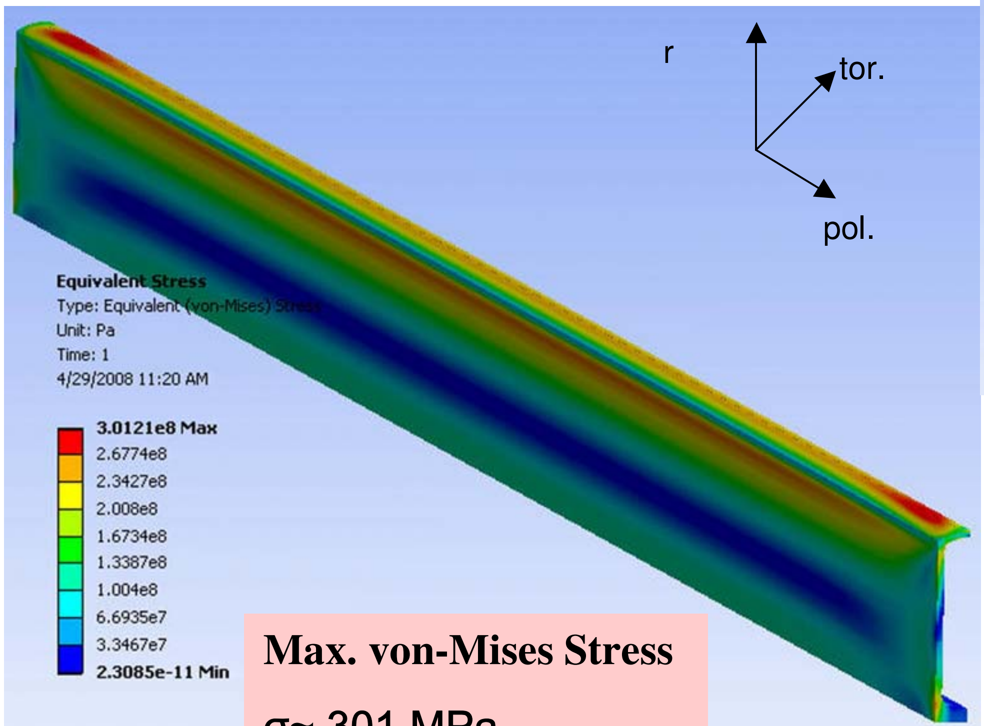
Structural support for thermal stresses analysis:

The plate is not allowed to bend, but free to expand



Max. Thermal Deformation

δ~1.6 mm

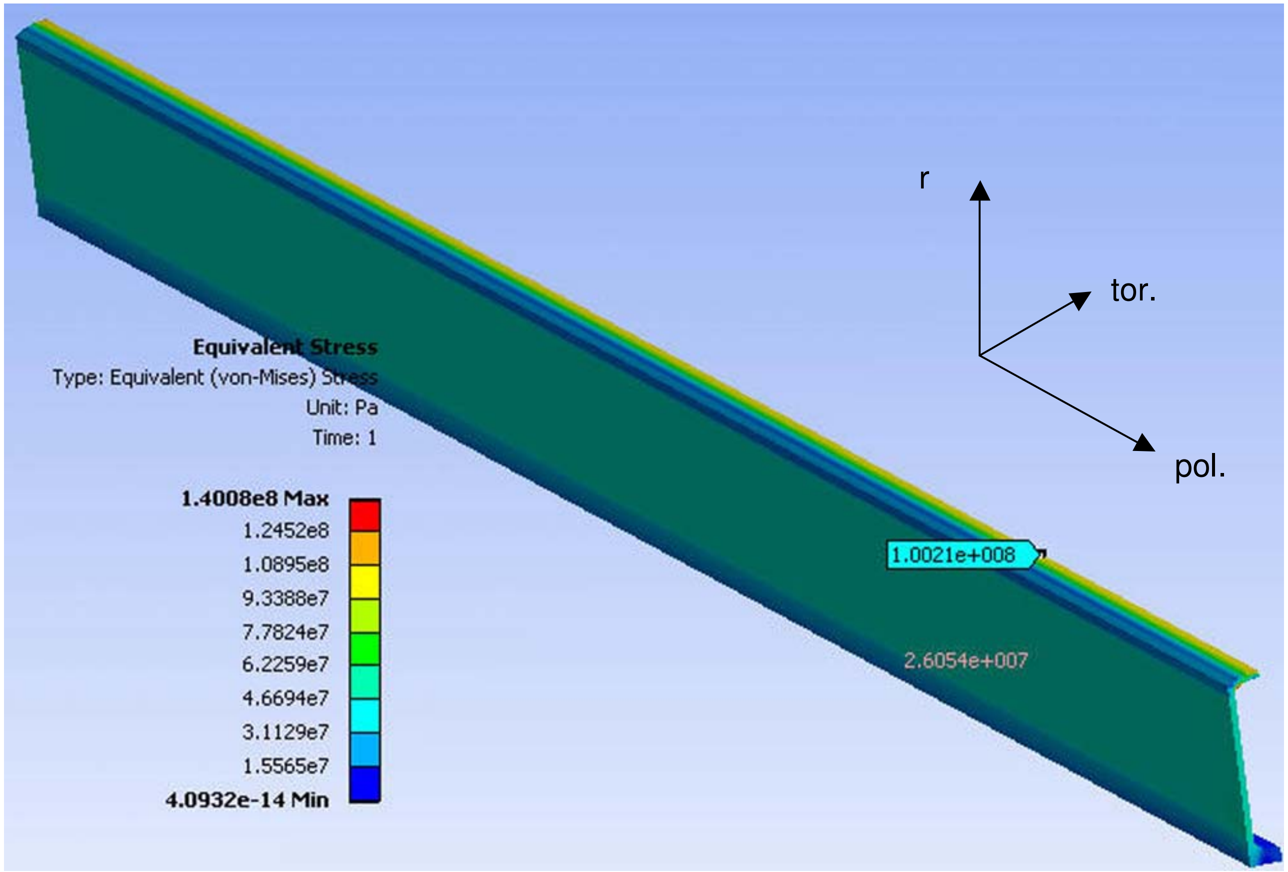


Max. von-Mises Stress

σ~ 301 MPa

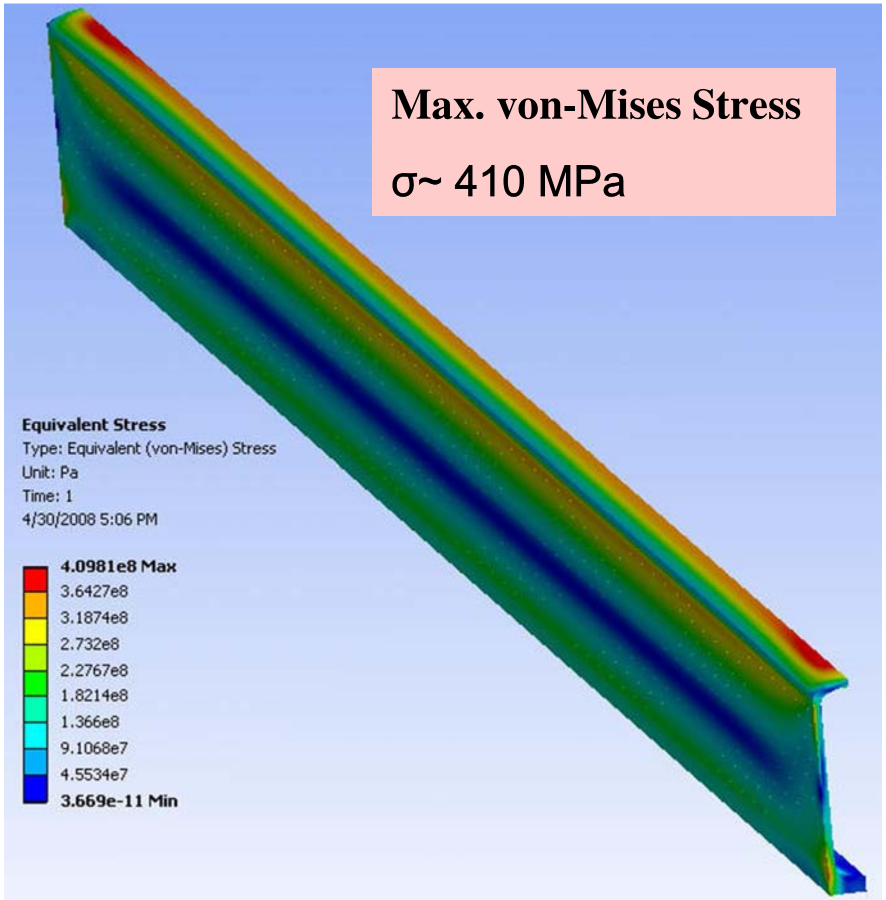
Allowable 3 Sm= 450 MPa

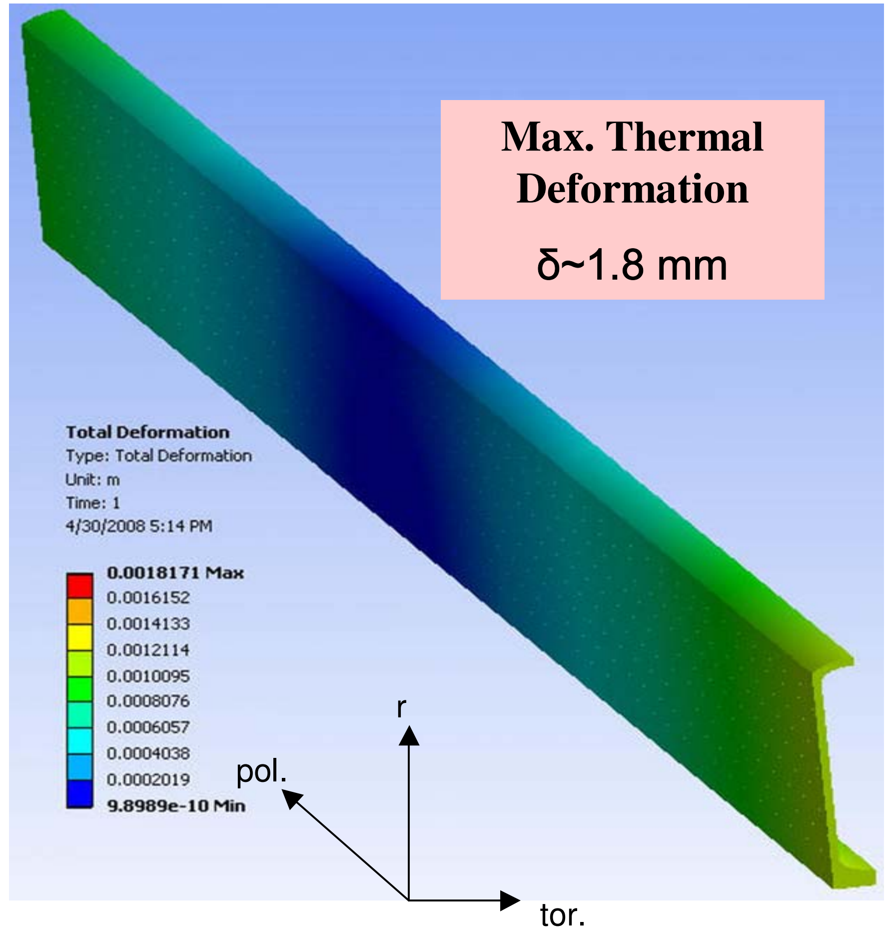
Primary Stress of the Full-size Plate Divertor Channel



- Max local pressure stress at inside of the corner is ~140 MPa
- Max. stress at the front structure is about 100 MPa

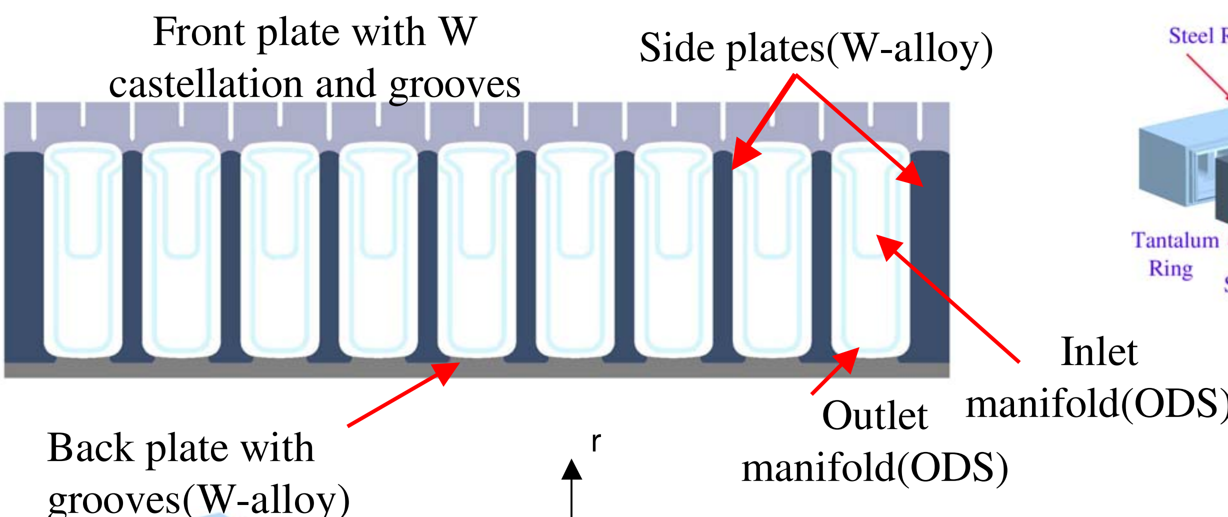
Combination of the Primary and Secondary Stresses of the Full-Size Divertor Channel

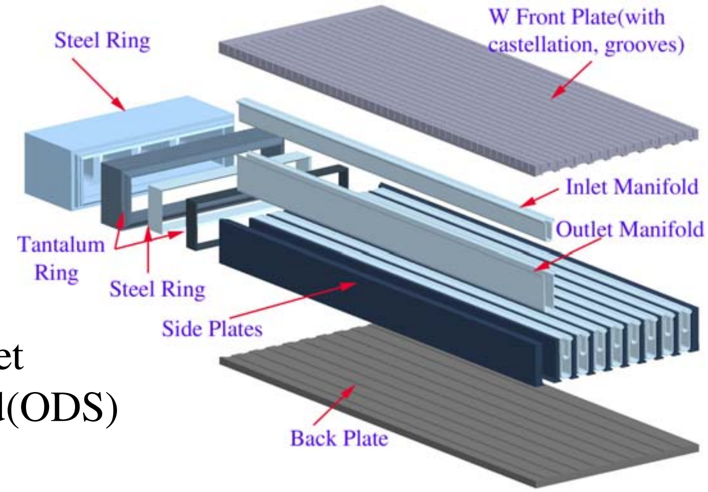


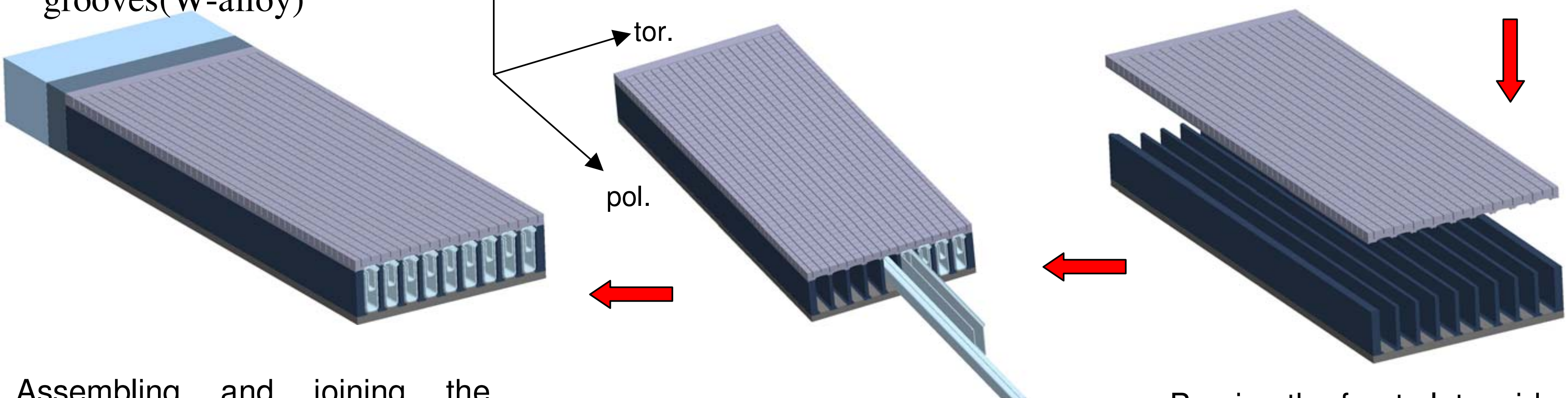


3Sm=450 MPa

Updates of Overall Design, Fabrication and Assembly of the Flat Plate Divertor







Assembling and joining the transition zones at both ends of the plate unit

Inserting the inlet manifold and aligning it to the front plate, then inserting outlet manifold

Brazing the front plate, side plates and back plate together to one unit

Summary and Conclusion

- The He-cooled flat plate divertor with jet cooling method is able to handle the heat flux of 10 MW/m^2
- The flat plate divertor with dimensions of 20 cm(tor.)x100 cm(pol)x 6 cm(thickness)) for each plate has major advantage for a power plant, and only ~750 plates are needed for ARIES-AT like power plant.
- Fabrication complexity and costs can be reduced because the front plate can be fabricated to one piece with the castellation tiles and grooves, and the front plate can be brazed together with the side plates, back plate to one plate unit.

Two Heat Flux Zone Divertor Design

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Center for Energy Research

UC San Diego

General Helium Cooled Divertor Design Concepts

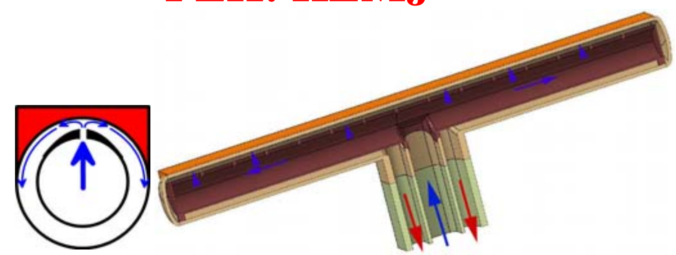
➢HEMJ(He-cooled Modular divertor with Jet cooling), FZK reference divertor concept.

- ✓*Cap D~1.5 cm, Armor ~ 1.8 cm*
- ✓*Multiple-jet cooling, 10 MPa*
- ✓*~535,000 modules for power plant (ARIES-AT)*

FZK: HEMJ

➢He-cooled T-Tube divertor concept for ARIES-CS power plant, T. Ihli and ARIES

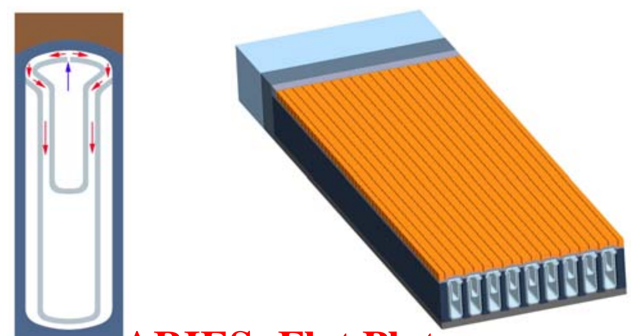
- ✓*Tube D~1.5 cm, L~8.5cm*
- ✓*Slot-jet cooling, 10 MPa*
- ✓*110,000 T-Tube for a power plant*



ARIES: T-Tube

➢He-cooled flat divertor concept for ARIES TNS, proposed by Siegfried

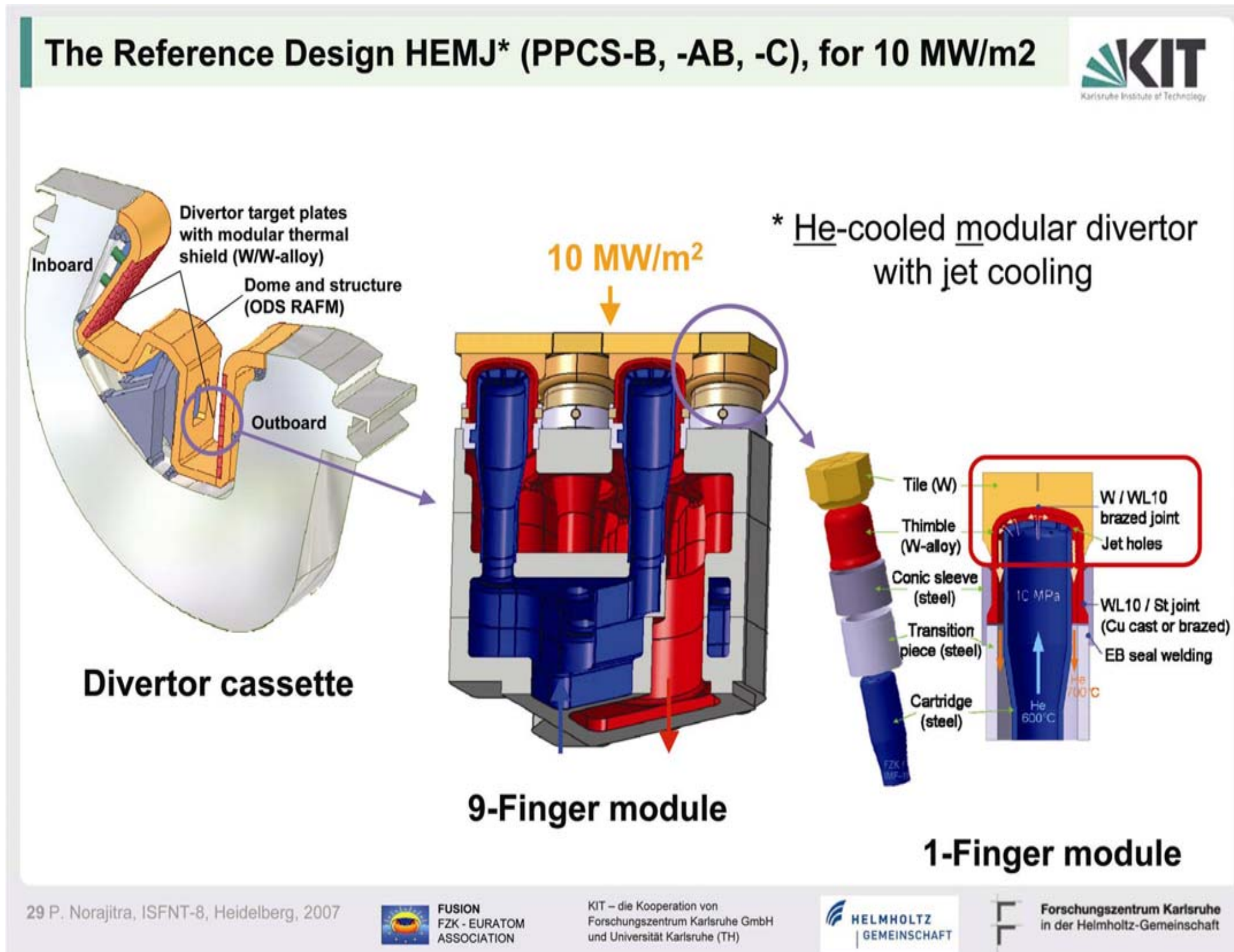
- ✓*Plate with 20 cm (tor.)x 100 cm (pol.)x 6 cm (thickness)*
- ✓*Slot-jet cooling, 10 MPa*
- ✓*~750 flat plates for a power plant*



ARIES: Flat Plate

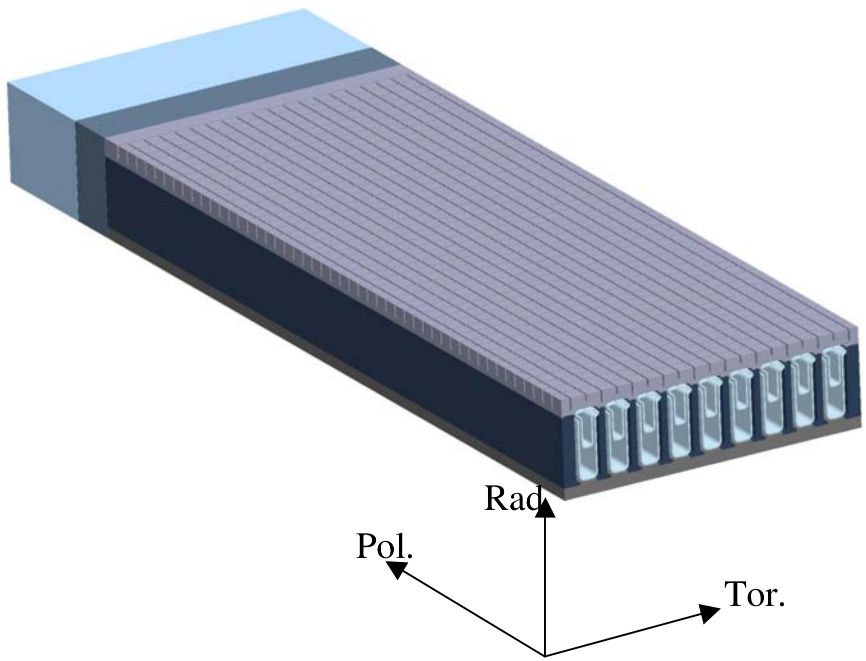
FZK Reference Design HEMJ Shown the Joint and Manifold

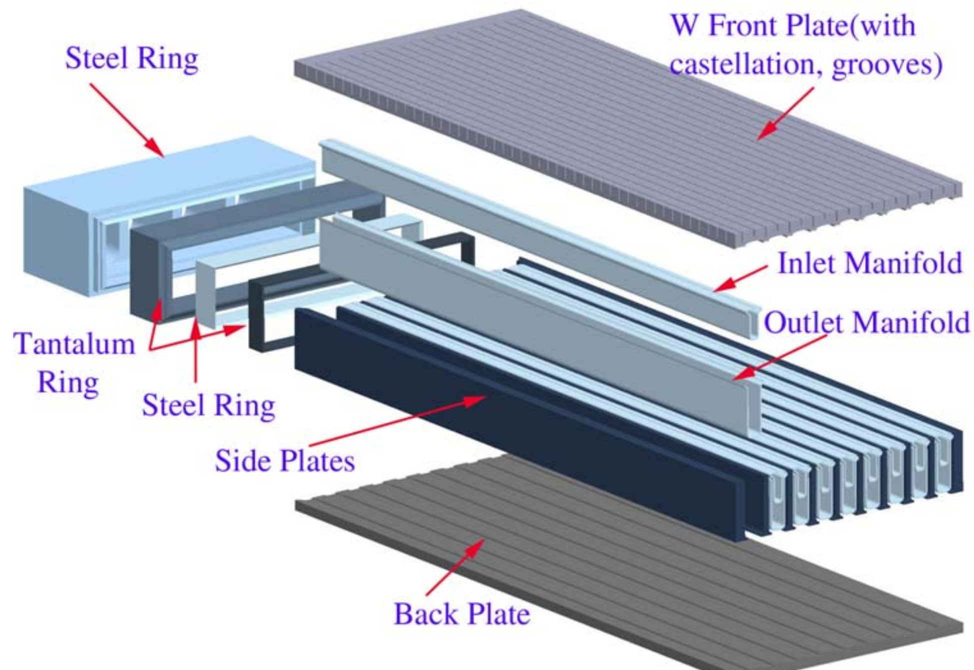
- ➢The HEMJ modular divertor concept is able to accommodate a heat flux of 13 MW/m^2 based on FZK analysis results and Efremov experimental results*.
- ➢The hexagonal tiles are brazed to caps.
- ➢The Caps are connected to the ODS-steel manifold with a joint employing a cast or brazed Cu-layer, conical steel sleeve, and EB seal weld.



*P. Norajitra, He-cooled divertor development for DEMO, Fusion Eng.&Des., 82(2007); also ISFNT-8

He-cooled Flat Plate Divertor for ARIES





- The allowable heat flux is ~10 MW/m^2 for the flat plate divertor concept with small margin in the temperature and stress window.
  - ✓Max. temperature at front structure ~1300 íC (allowable 1300 ° C)
  - ✓Max. stresses ~410 MPa (allowable 3Sm=450 MPa)
  - ✓Pumping power ~10% (allowable < 10% P_{th})

Comparing Three Candidate Divertor Concepts

- For the same temperature and stress windows, the finger-concept (HEMJ) allows the largest surface heat flux(13 MW/m²), and the flat plate design is the lowest one. The limits for T-Tube is somewhere between the two, close to the finger concept.

- For a maximum heat flux in the order of 10 MW/m^2, an extensive development of suitable W-alloy is mandatory for all the three concepts, especially in order to allow for a minimum operating temperature of the W structure down to ~800 °C and maximum allowable structure temperature without re-crystallization of 1300 °C.

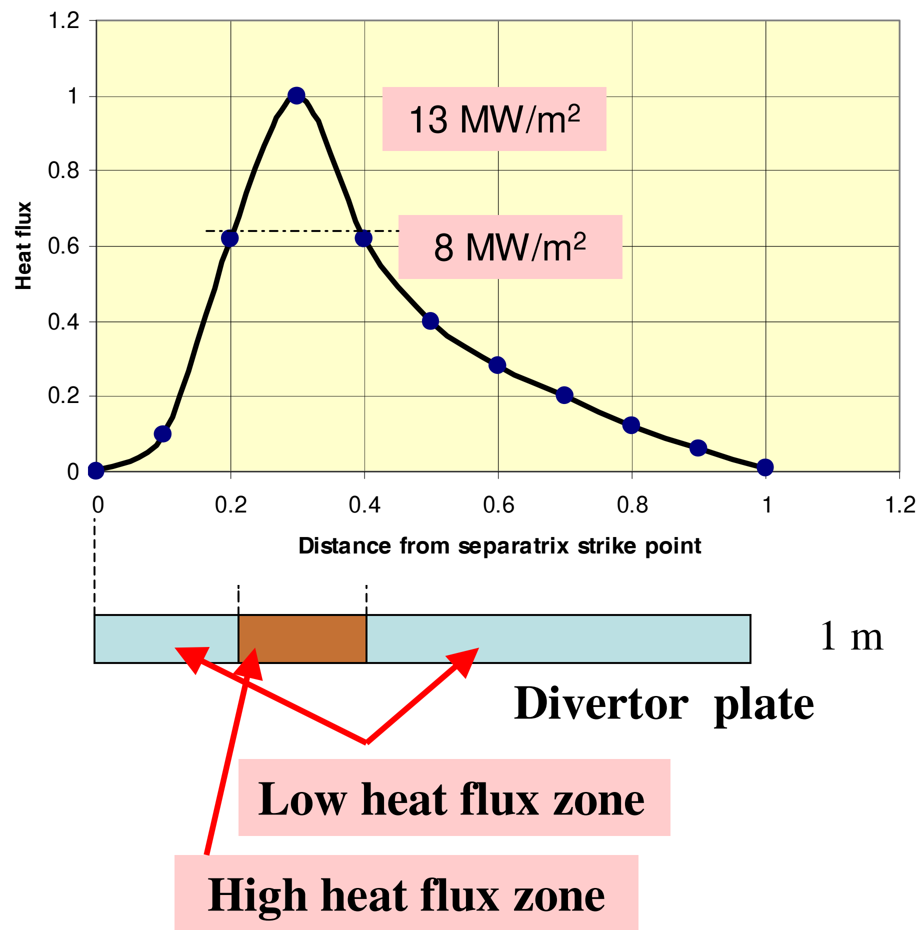
- The development of a highly reliable joint between the high temperature W-zone with the steel structure is very challenging issue since there is a large mismatch in the allowable temperature and the coefficient of the two classes of materials.

Concept of a Two Heat Flux Zone Divertor

- Considering the large variation of the surface heat flux over the poloidal length of the divertor target with the maximum value over 20 to 30 cm only and a peak to average value usually ~ 3, there is an incentive to consider a combination of two concepts:

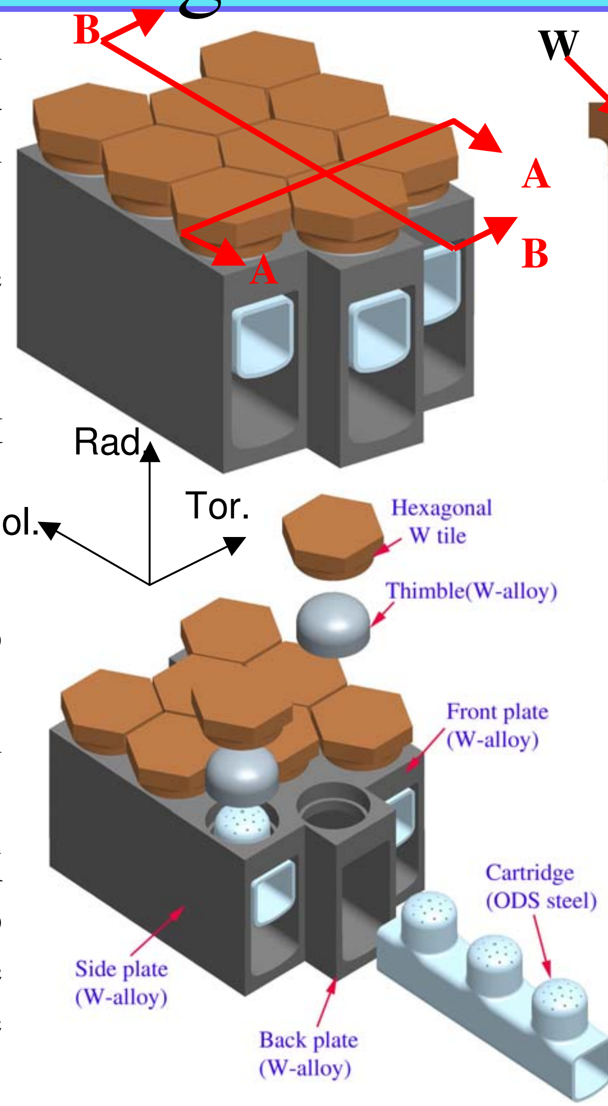
  - ✓Simple and robust plate design for the zone where the heat flux is below a certain value (for example < 8 MW/m^2 over 80 % of the poloidal target length)

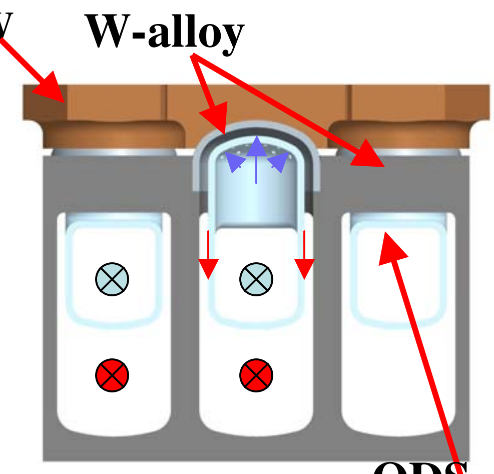
  - ✓Modular concept with maximized load capacity over a small fraction of the target length (for example > 8 MW/m^2 over ~ 20 cm)



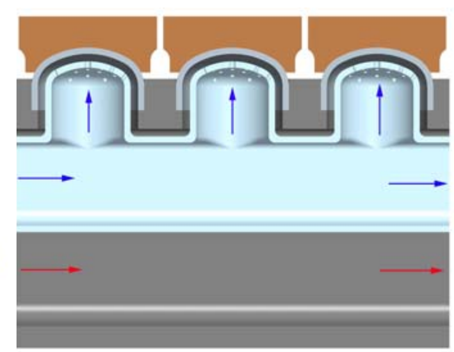
Design of the High Heat Flux Zone in the Divertor Target Plate

- The flat plate concept is replaced by small modules in order to reduce thermal stress, and the high heat flux zone is about 20 cm (pol.) x 20 cm (tor.).
- Castellation will be needed for all the hexagonal tiles in high heat flux zone.
- These modules and their cooling mechanism are very similar to the Finger-like HEMJ concept under development at FZK.
- The sacrificial tiles are brazed to thimble-like caps, and the caps are directly brazed to the front plate by inserting them into holes. There is no connection between high temperature W and ODS manifold.
- The main difference between the FZK HEMJ concept and its application in the two heat flux zone divertor is the attachment to the small module and the manifolding of the helium coolant.





Section A-A



Section B-B

Transition from High Heat Flux Zone to Lower Heat Flux Zone

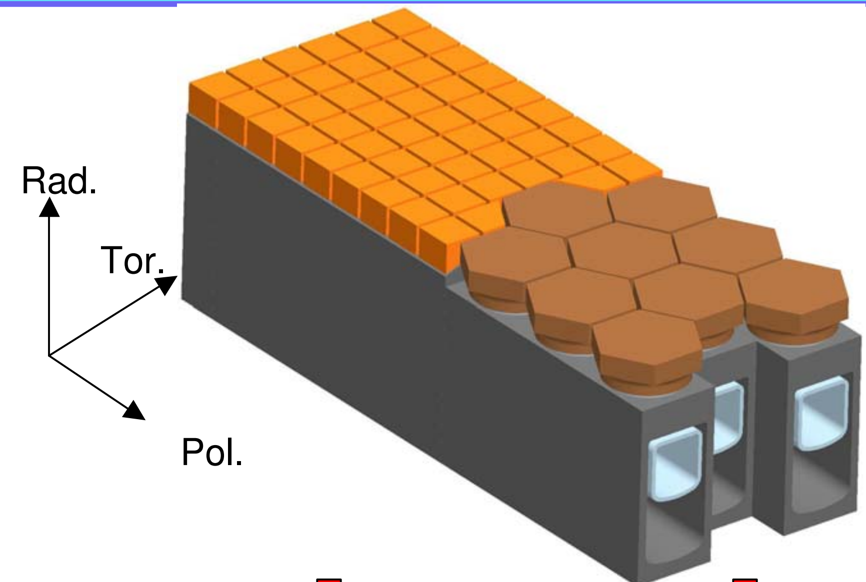
- The two zone divertor plate maintains the same dimension of 20 cm (tor.) x 100 cm (pol.).

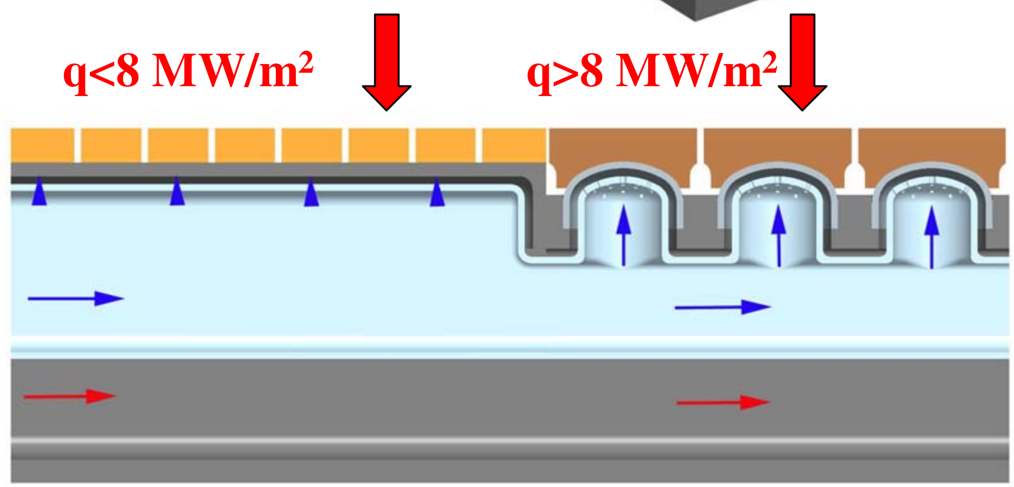
- The plate concept is used in the two zone divertor for zones with the heat flux < 8 MW/m^2. Total poloidal length of the low heat flux zone is about 80 cm.

- The plate is modified to the modular concept, HEMJ (FZK), for the zone with heat flux >8 MW/m^2. The poloidal length of the the high heat flux zone is ~20 cm.

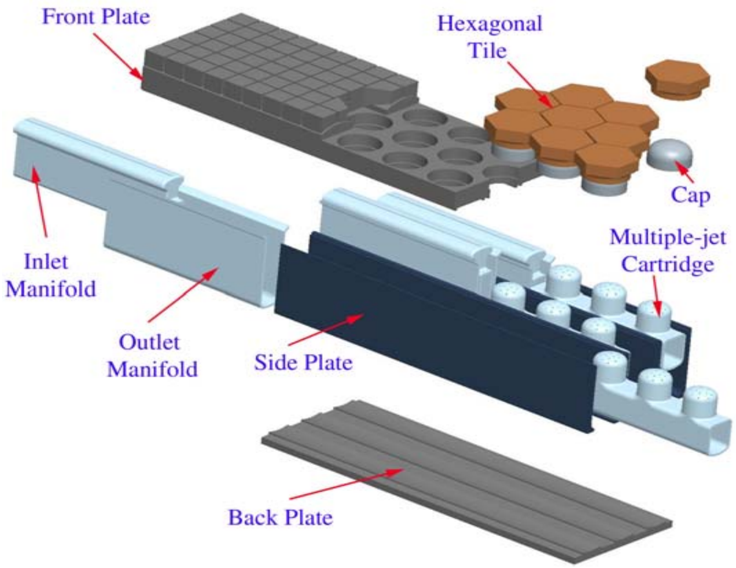
- The plasma facing part of the high heat flux zone and the cooling method employed in the two zone divertor is identical to the HEMJ(FZK).

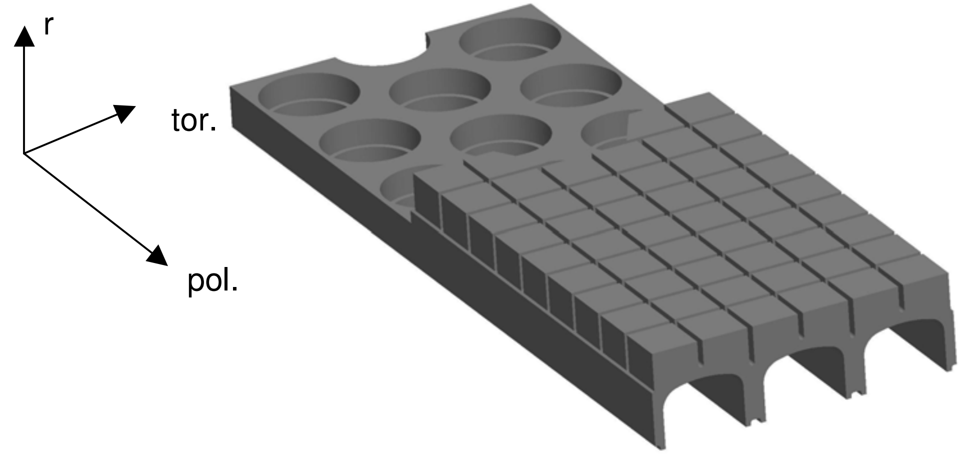
- In the high heat flux zone, any connections between the W-alloy needed for high temperature zone and ODS manifold is avoided



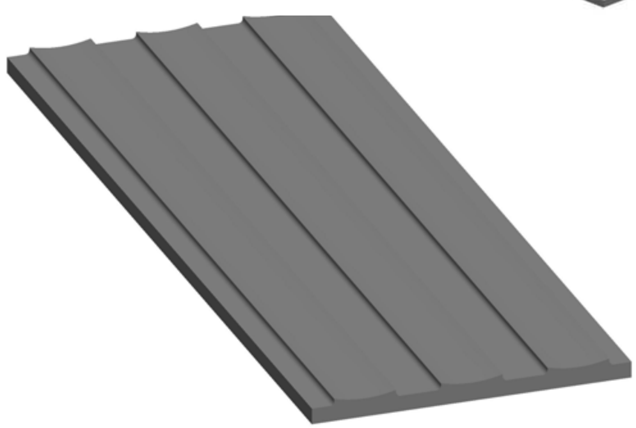


Fabrication and Assembly Sequence of the Two Zone Divertor Target Plate

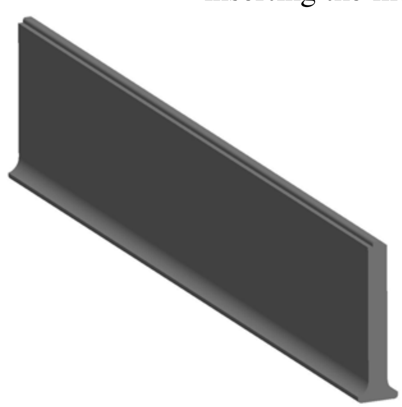




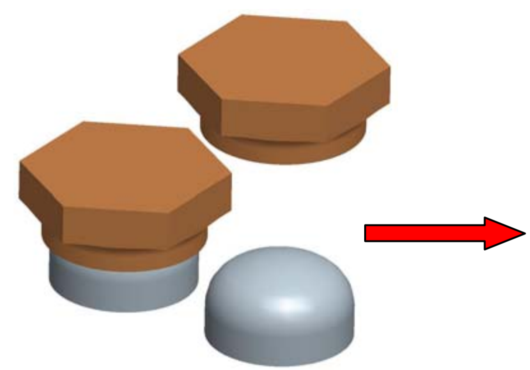
Fabricating the front plate with castellation at low heat flux zone, the grooves for brazing the side walls, and the machining the holes for inserting the modular tiles and caps in high heat flux zone.



Fabricating the back plate with grooves for brazing in the side walls of large helium channels

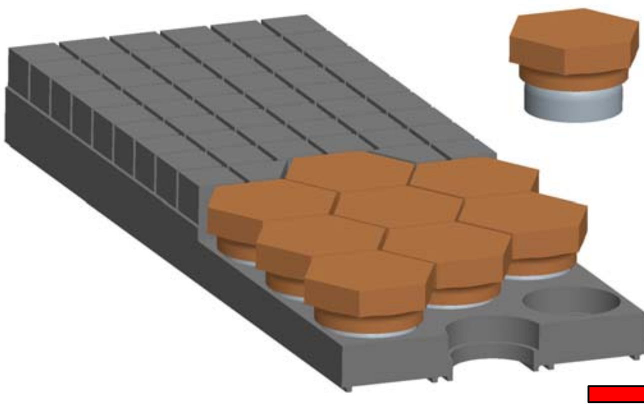


Fabricating the side walls

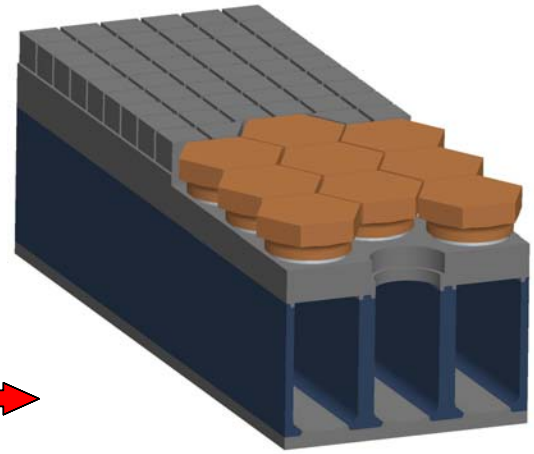


Fabricating the hexagonal tiles and small caps, and brazing them together to be inserted into the front plate in the high heat flux zone

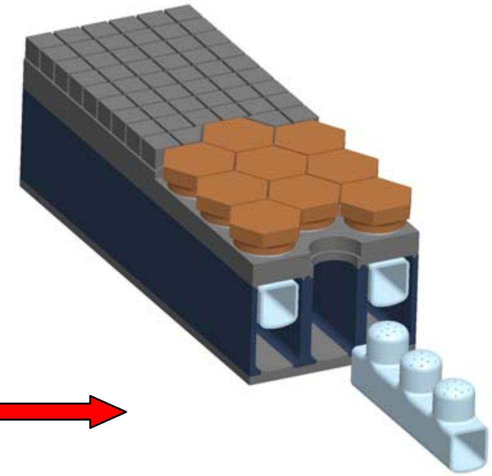
Fabrication and Assembly Sequence of the Two Zone Divertor Target Plate(cont.)



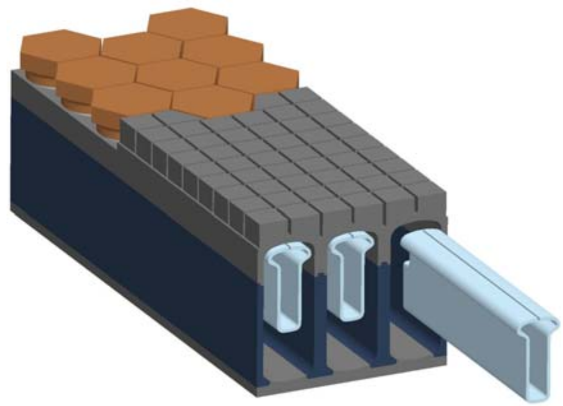
Brazing the small high heat flux modules into the front plate



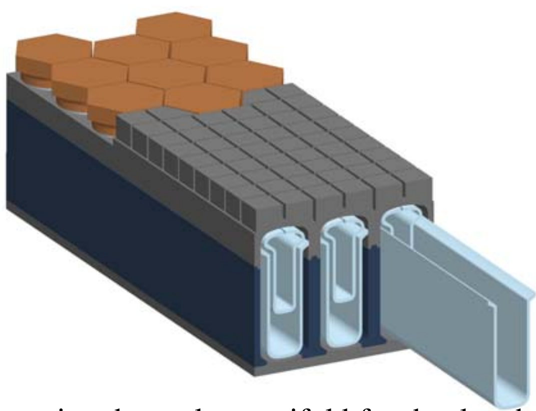
Brazing the front plate, the back plate and all the side plates together to one unit



Inserting the manifold for high heat flux small modules into the plate unit and aligning it to the front plate.



Inserting the inlet manifold for the low heat flux zone from the end of the low heat flux zone and aligning it to the front plate



Inserting the outlet manifold for the low heat flux zone from the end of the low heat flux zone

Summary and Future Work

- Combination of the plate divertor concept for the lower heat flux zone with the modular divertor concept for the high heat flux zone is proposed by Siegfried, and the design of the two zone divertor including fabrication and assembly has explored and analyzed by CAD.
- The simple and robust flat-plate design is used for the zone where the heat flux is < 8 MW/m^2 (~80% of the ploidal target length).
- The modular design with maximized thermal load capacity is used for the zone where the high heat flux is >8 MW/m2 (~20% of the ploidal target length).
- Major difference between FZK HEMJ design and two zone divertor design is that there is no joint or connection in the zone with high heat flux.
- Thermo-fluid and thermo-mechanical analysis for the modular design in high heat flux zone has no performed yet, and will plan to do it in future.