High Performance Divertor Target Plate, a Combination of Plate and Finger Concepts

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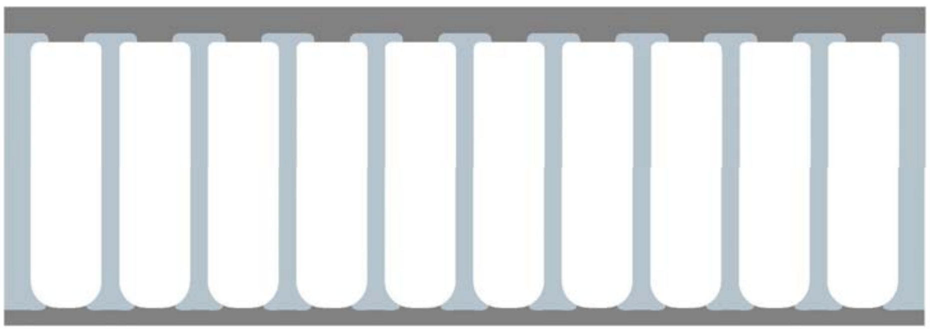
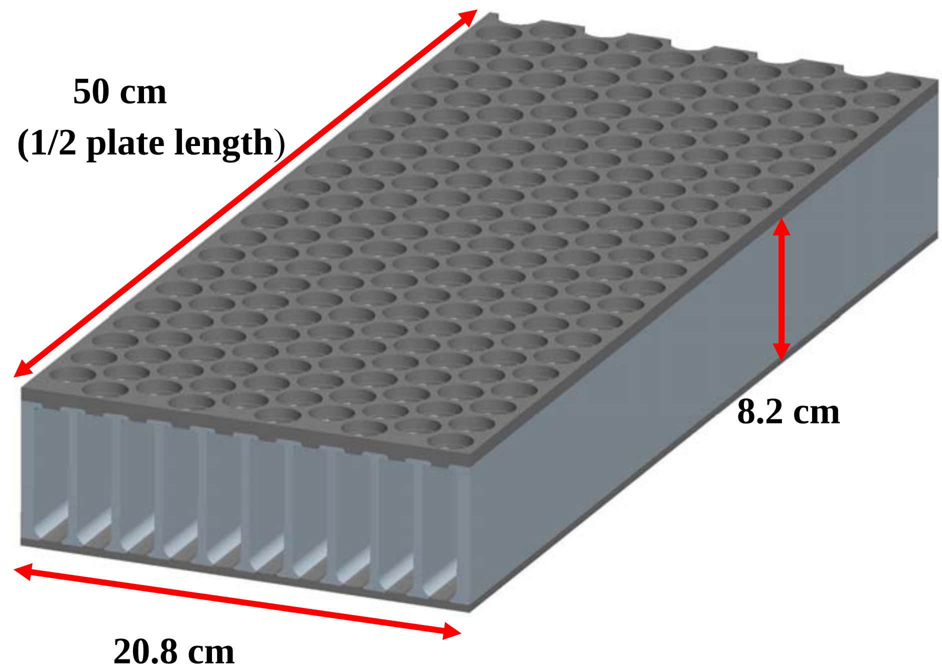
Characteristic features of the concept

- *W-base plate fabricated by brazing together front plate, back plate, and side walls*





Main reasons for this fabrication method:

✓Better mechanical properties obtained for W-alloys if plate thickness is < 20 mm

✓Machining of the long parallel channels in a thicker plate would be difficult

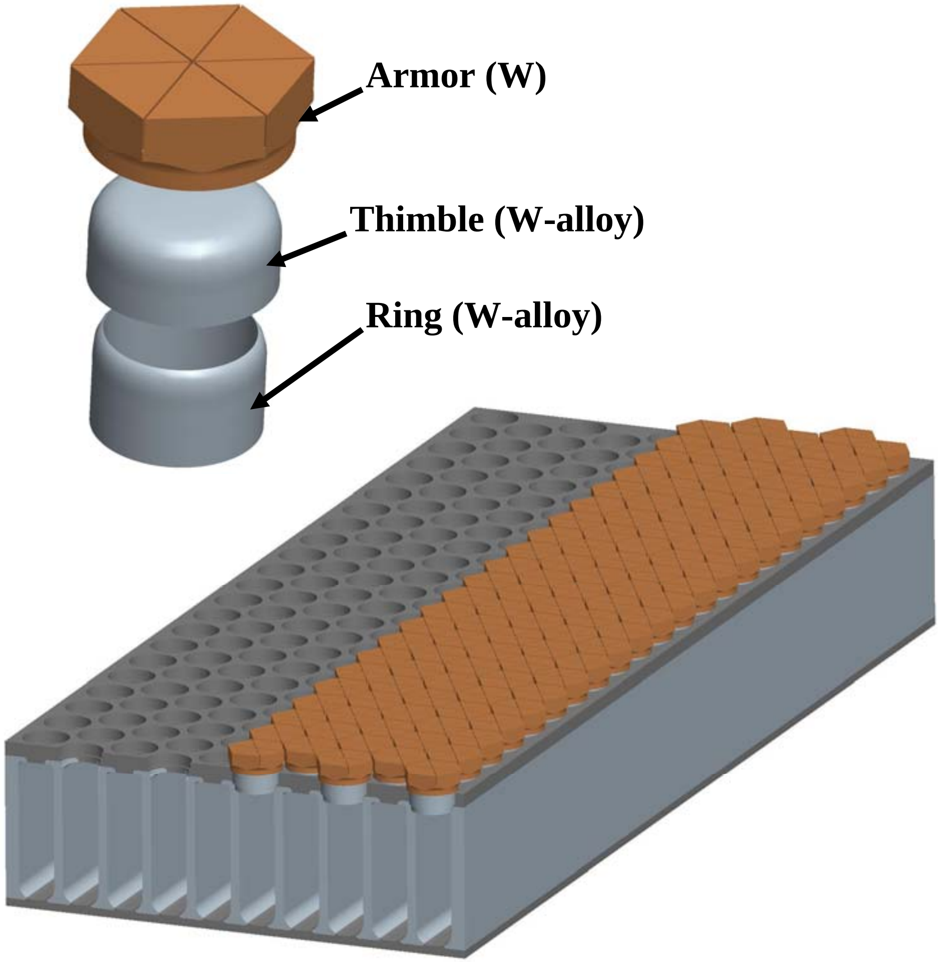
✓All the brazes in the entire plate can be done in a furnace in a single step

Characteristic features of the concept

- *Small modules at the plasma facing side arranged over the entire plate*

Main reasons for this design:

- ✓Subdividing the plasma facing surface into small units reduces thermal stresses,
- ✓Adjustment of the cooling conditions to the local surface heat flux easy by varying the number of cooling jets and there diameter,
- ✓No thermal insulation of side walls and back walls necessary since all parts of the plate are kept by the coolant flow at a temperature slightly above the Helium exit temperature,
- ✓Maximum cross section of the poloidal helium channels for a given plate thickness.



Characteristic features of the concept

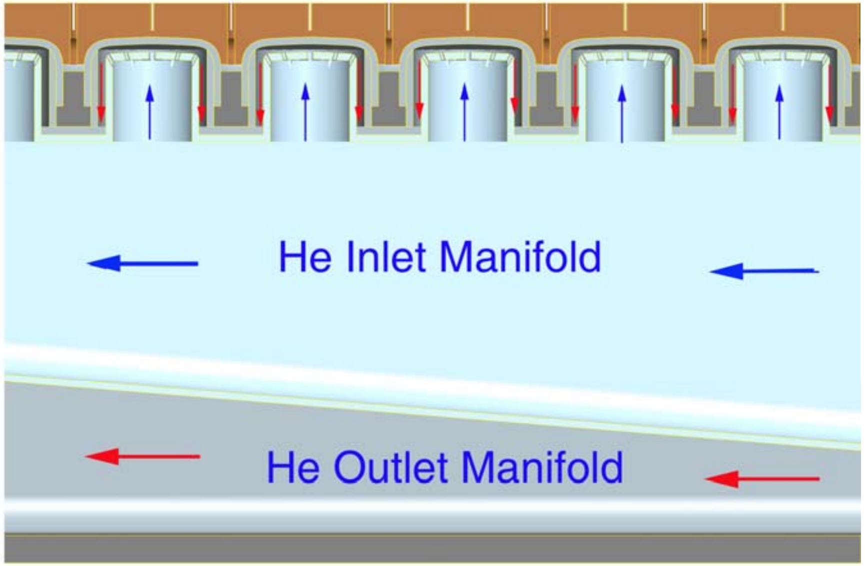
- ***No transition between W-alloy and steel at the modules, double containment of the high pressure Helium in the most critical region***

Advantages of this design compared to the EU concept:

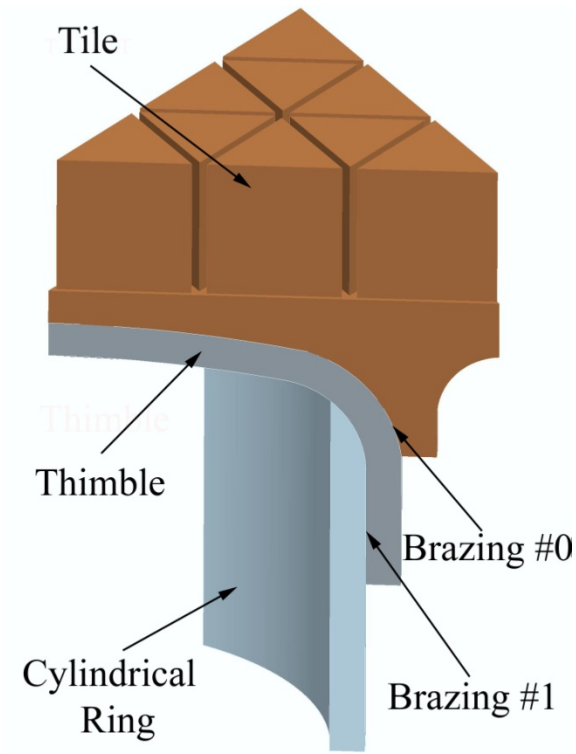
✓In the EU concept the joining of the W-alloys of the thimbles to the ODS-steel of the manifold as necessary in each of the ~ 500,000 finger-modules is a very difficult issue (small temperature window, thermal expansion coeff. of W about 2.5 times larger than the one for ferritic steel).

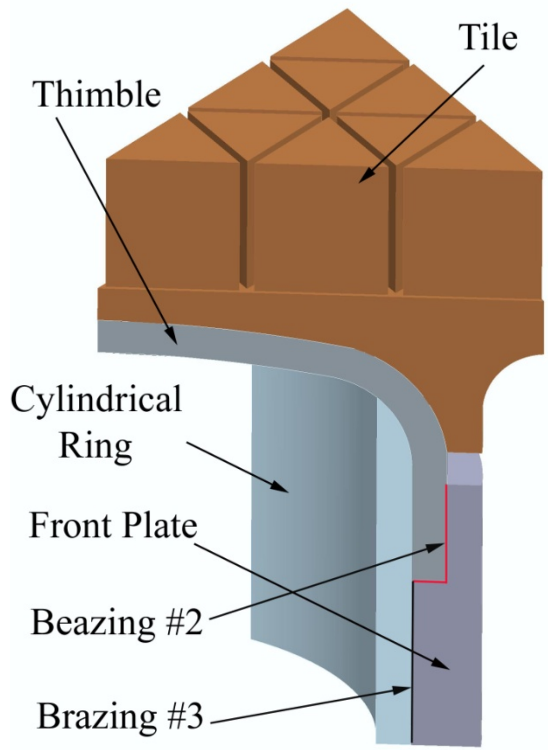
✓Fabrication of such complicated fingers difficult and expensive,

✓Double containment in the critical region decreases the potential for coolant leaks decisively.



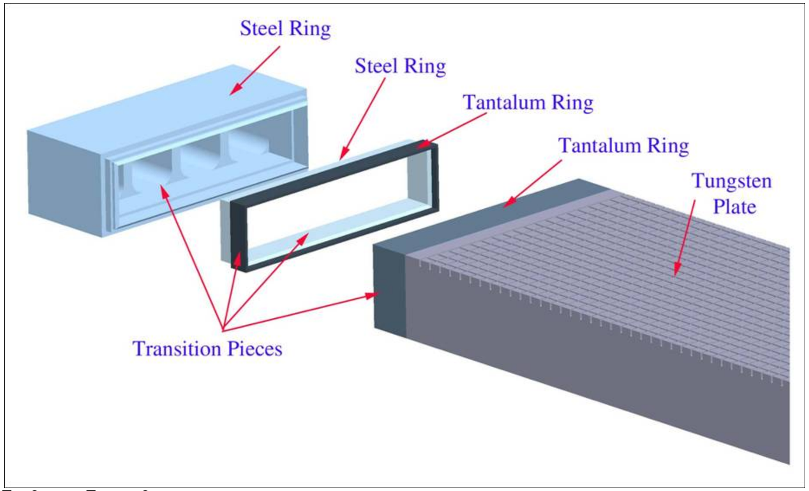
Assembly of the finger module and brazing it into the plate





- ✓ **Brazing of the tile to the thimble and the ring into the thimble (Brazing # 0 and # 1)**
- ✓ **Brazing of thimble and the ring into the front plate (brazing # 2 and # 3). This brazing can be made for the entire plate in a furnace in a single step.**

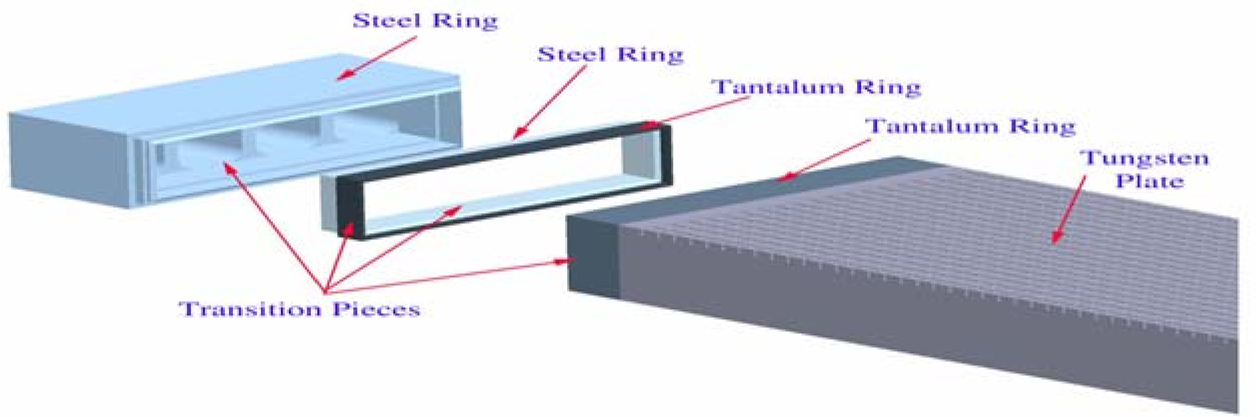
Transition zone between the W-plate and the steel manifold located at both ends of the plate with a Ta transition piece between W and steel

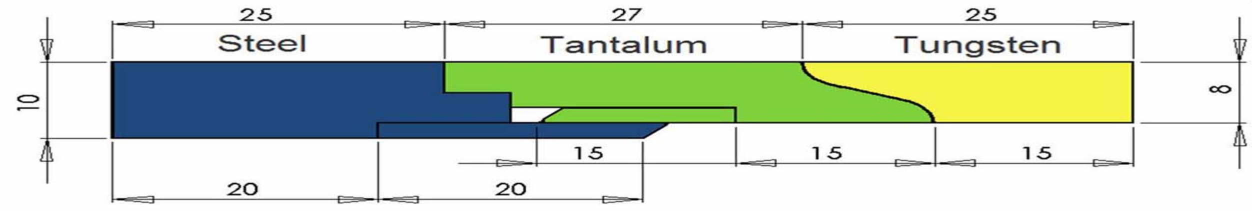


Main reasons for this design:

- ✓ Number of transitions between the dissimilar materials reduced by a large factor,
- ✓ Locating the transitions into a region with minimal surface heat flux facilitates the design,
- ✓ Using of Ta-transition pieces between the W-plate and the ODS-manifold reduces cyclic thermal stresses since the thermal expansion coefficient of Ta is in the middle of the coeff. for W and ferritic steels,
- ✓ Geometry of the transition zone enables jointing with proven methods**.**

Steps for the assembly of the transition region at both ends of the plate

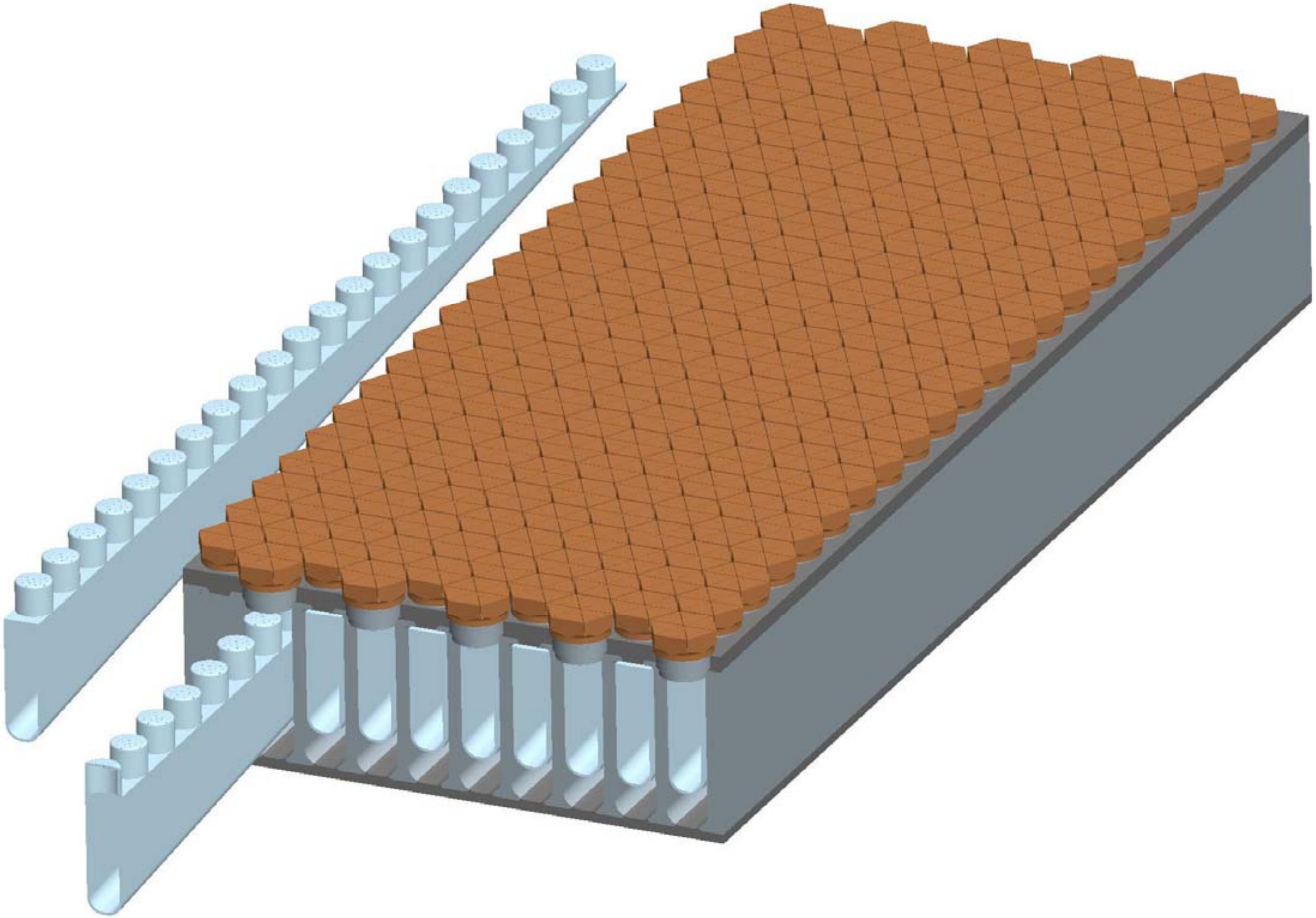




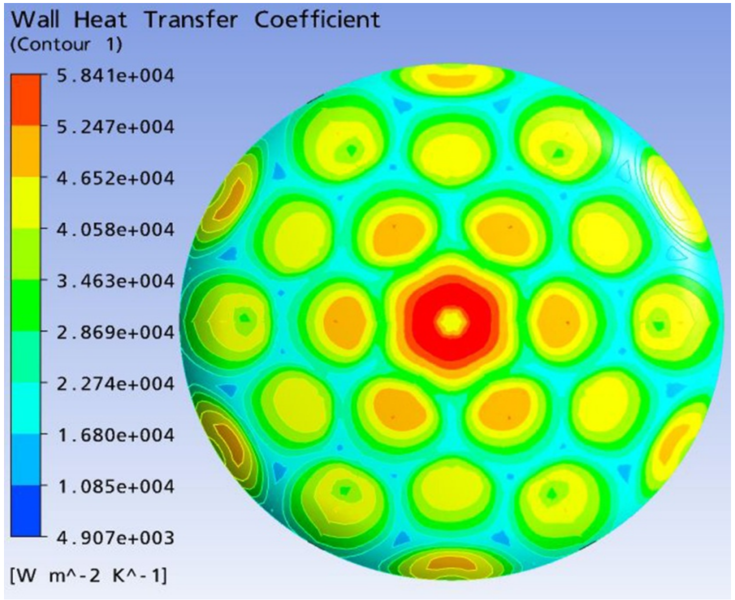
At both ends of the plate:

- Thick Ta-ring to W-plate : brazing
- Thin Ta-ring to thin steel ring: explosion welding
- Composite thin Ta/steel rings to thick steel ring: diffusion welding in HIP facility
- Thin Ta ring to thick Ta ring: Laser or TIG welding

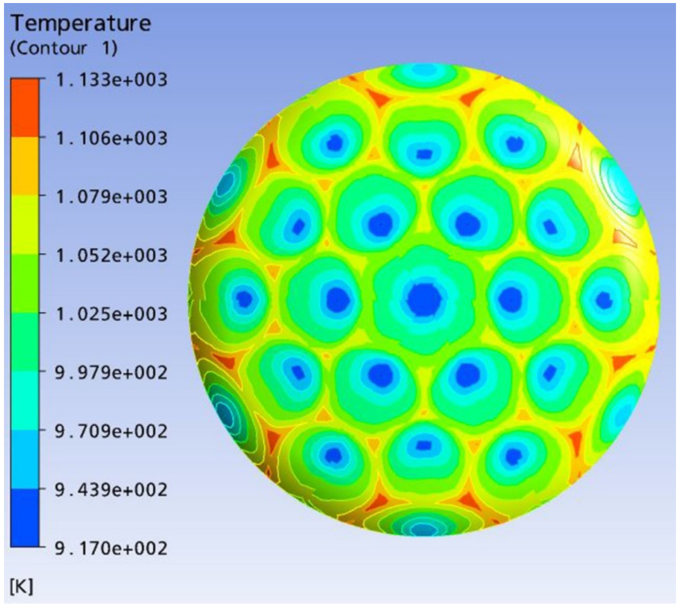
Inlet Manifold (Steel Cartridge) Inserted Into the Plate



Thermo-fluid Analysis Results of the Modified Finger Module



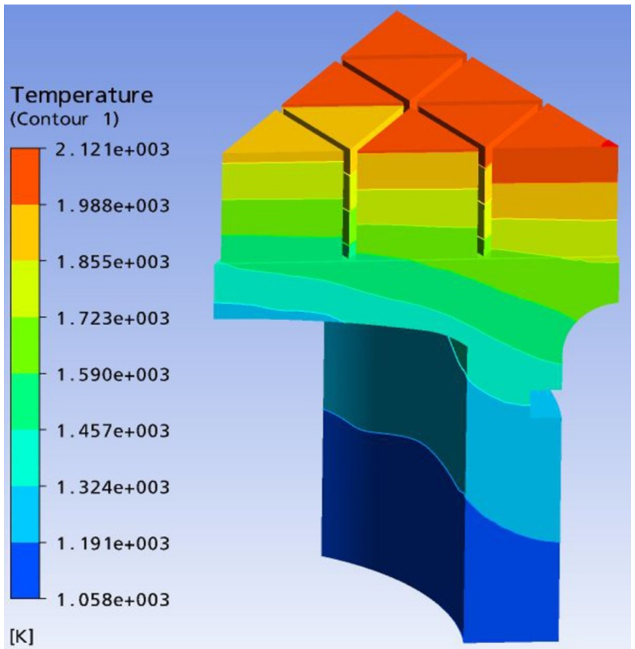
Heat transfer coefficient



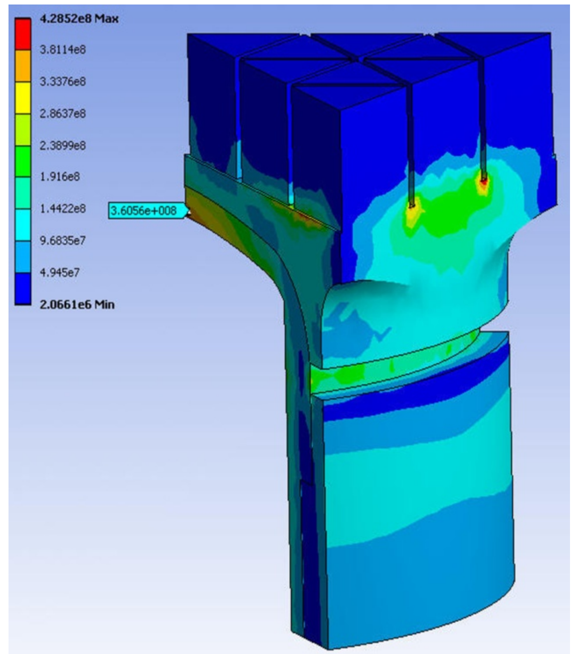
Temperature distribution of the fluid

- ✓ARIES-DB thermal loads are assumed in the analysis, incident q"=10 MW/m^2, neutron volumetric heat generation=17.5 MW/m^3
- ✓~1.35 million tetrahedral elements, temperature dependant material properties, k-ε turbulent model
- ✓He inlet/outlet temperature=600/700 °C, He pressure=10 MPa
- ✓Max. jet velocity=~250 m/s; Max. H.T.C=~5.84x 104 W/m^2K
- ✓$P_{pumping/Pthermal}$~7.5% (<design limit of 10%)

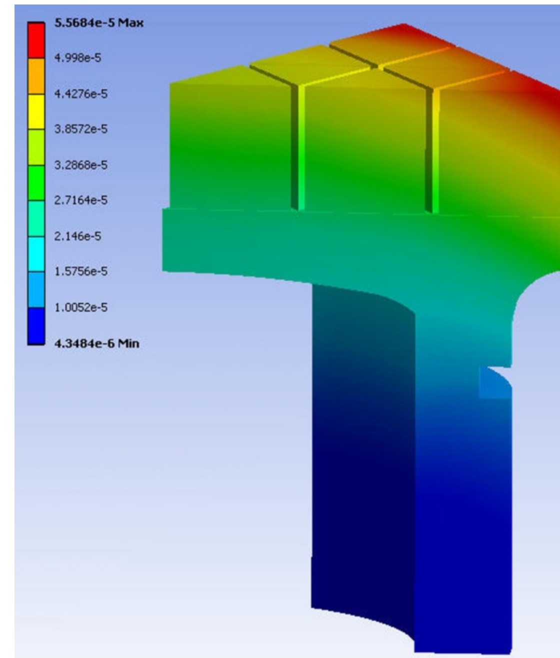
Thermo-Mechanical Results of the Modified Finger Module



Temperature



Stress



Deformation

- ✓W armor is assumed to be castellated with small triangle, 0.25 mm gap and 4 mm deep.
- ✓Max. Armor temperature=1848 °C
- ✓Max. Thimble temperature=1222 °C (<1300 °C recrystallization temperature)
- ✓Max. σ_{p+s}(primary+thermal stresses)=429 MPa, (Max. thimble stresses σ_{p+s} =360 MPa)
- ✓Max. σ_p(pressure stress)=90 MPa; Max. Displacement=0.06 mm

Material considerations

- The compatibility with the plasma as well as the high heat flux density to the target makes the use of tungsten for the tiles mandatory. These tiles operate in a temperature range of roughly 1000 ^{o}C to 2000 ^{o}C, and there are no high requirements on the mechanical strength. Probably the most economic way to fabricate these tiles is by power hipping of tungsten powder.

- The cup-shaped thimbles between tile and plate are the most difficult elements of the entire concept. There is a very attractive material for this application, called vacuum metalized W (WVM). This is pure W doped with 0.005 wt. % K, offering after an extremely large reduction of the thickness excellent mechanical properties and a high re-crystallization temperature. WVM is obtainable as thin wires and sheets up to a few mm thickness. An interesting aspect is the relationship between thickness and mechanical properties: As thinner as better! Since the wall thickness of our thimbles is 1 mm, we can take benefit of this relationship and fabricate them by deep drawing of a thin sheet, and obtain excellent material properties!

- The plate itself is constructed by brazing together the front und back plates with the side plates between the parallel helium channels. All the plates have a thickness of < 10 mm and operate in a small temperature range between 750 ^{o}C and 850 ^{o}C. The material requirements are relatively moderate, and it should be possible to fabricate them from standard Tungsten plates.

Summary and conclusions:

- The concept of a helium cooled divertor target plate is a combination of the European modular finger concept and a design with helium coolant channels in a thick plate. Jet-cooling at the back side of the plasma facing surface is employed in all these concepts.
- In the concept described here the plasma facing surface is subdivided into a large number of small hexagonal modules, similar to the EU finger concept. Such a modularization reduces the thermal stresses and allow therefore maximum surface heat fluxes of 10 MW/m^2 at least.
- A solution has been found allowing brazing the fingers made of a W-alloy directly into the W-plate, avoiding in this way the connection of di-similar materials with largely different thermal expansion coefficients.
- For an increase in reliability, double walled thimbles are used in the most critical region, providing an additional barrier against leaks of the high pressure helium.
- Splitting the entire plate into three different elements (tile, thimble, and plate) allows the use of different W-alloys and fabrication methods for the three elements.
- Thermal-mechanical calculations confirmed the expected high performance of the concept with a maximum allowable heat flux > 10 MW/m^2.
- As a next step, the behavior of the divertor target plate under cyclic loading condition and fast transients will be investigated.