Update on High Performance Divertor Target

Presented by: X.R. Wang
Contributors: S. Malang and M. Tillack

ARIES-Pathway Meeting
GA, San Diego
December 15-16, 2009
Major features of the helium-cooled W target plate with a combination of plate and EU finger concepts has been investigated.

- Multiple-jets cooling
- W-base plate fabricated by brazing together front plate, back plate and side walls.
- Small modules at the plasma side arranged over the entire plate
- No transition between W-alloy and steel at the modules (EU Finger design, joints are between W and steels)
ANALYSES WERE FOCUSED ON THE HIGH TEMPERATURE COMPONENTS

- Each finger and cooling channel of the target plate are identical on the geometry and thermo-fluid and thermo-mechanical behaviors.
- One finger, including the W armor, W thimble, W cylindrical ring and the steel cartridge was simulated during past analyses.
- It is important to confirm the temperature and stresses of the back elements are within design limits.
There are 1.8 million tetrahedral elements in CFX model.
Standard k-\(\varepsilon\) turbulent model is utilized.
Inlet boundary condition is assumed to be identical to the outlet flow of the finger.

CAD model for CFD analysis  FEA Model
THERMO-FLUID RESULTS OF THE COOLING CHANNEL INCLUDING FRONT/BACK PLATES

- Maximum velocity \( v = 47.7 \text{ m/s} \)
- Pressure drop \( \Delta P = 0.01 \text{ MPa} \) (\( \Delta P = 0.13 \text{ MPa} \) for the finger)
- Local heat transfer coefficient \( h = 1.313 \times 10^4 \text{ W/m}^2\text{-K} \)
Half W-base cooling channel (~0.5 m) is considered in the thermo-mechanical model.

Thermal results show the temperature of the cooling channel is uniformly distributed (ΔT~35 °C), and the results will coupled into structural analysis.

Boundary conditions for structural analysis
- Symmetry boundary is applied at both Y-Z planes (x=0 and x=10 mm).
- At one end (X-Y plane, Z=0) is assumed free, and at another end (X-Y plane Z=0.5 m), the symmetry boundary is applied.
- Bending is suppressed at the bottom plane (X-Z)
The maximum combined primary and secondary stresses are 470 MPa (\(<\ 3 \text{Sm} = 752 \text{ MPa for W temperature } T=750 ^\circ \text{C}\))

- Maximum total deformation is about 0.4 mm
Thermal-fluid and thermo-mechanical calculations including both the finger and back elements (beneath of the finger) have been performed, and the results confirm the expected high performance of the concept with a maximum allowable heat flux $> 10 \text{ MW/m}^2$.

As a next step, the nonlinear structural behaviors of the divertor target plates should be investigated, including

- Under thermal cyclic loading condition
- Under anticipated fast transients
- During plant start-up and off-power
**Other Activities on Helium-Cooled Divertor Concepts**

- **Jeremy Burke** is working on expanded T-Tube divertor design to improve performance.
  - T-Tube divertor was designed to accommodate a surface heat flux of 10 MW/m² for ARIES-CS. (by Thomas Ihli)
  - It was expanded to a two heat-flux-zone divertor concept without changing configuration except the thickness of W armors.
  - The coolant cartridge can be tapered to maintain more uniform velocity and heat transfer coefficient, then improve thermal stresses. However, it needs supporting analysis to confirm.

- **Harshit Chitalia** is working on transient analysis of joints with proper accounting of plastic deformation.
  - Transition joints between W and steel is critical for the helium-cooled W-based divertor concepts because thermal expansion of steel is ~2-3 times higher than W and it causes high stresses during operation.
  - The joints were designed using Ta as a transition material between W and Steel. Transition joints for the plate-type divertor were analyzed at UCLA, and a 2-D axis-symmetry model and 3-D cylindrical model were utilized.
  - Detailed non-linear analysis to be performed to include plastic deformation.