UCLA Efforts on PFC
(with High Heat Flux Heat Removal Emphasis)

Presented by

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PFC Meeting
Aug. 10-12, 2011
Oak Ridge, TN, USA

Scopes of UCLA PFC Efforts

- Joining technique development for Be/F82H (Ph. D. dissertation- near completion)
- ITER FW/shield blanket thermofluid and structural design analysis (supplemented by SNL US ITER FW/shield design work)

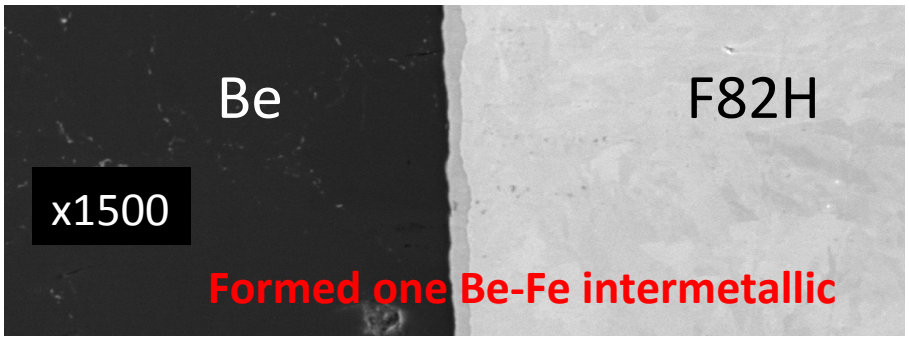
- Exploratory study of He Impinging jet for FW High Heat Load Removal (Master thesis)
- Revisiting liquid metal free surface flow and heat transfer (Modeling)

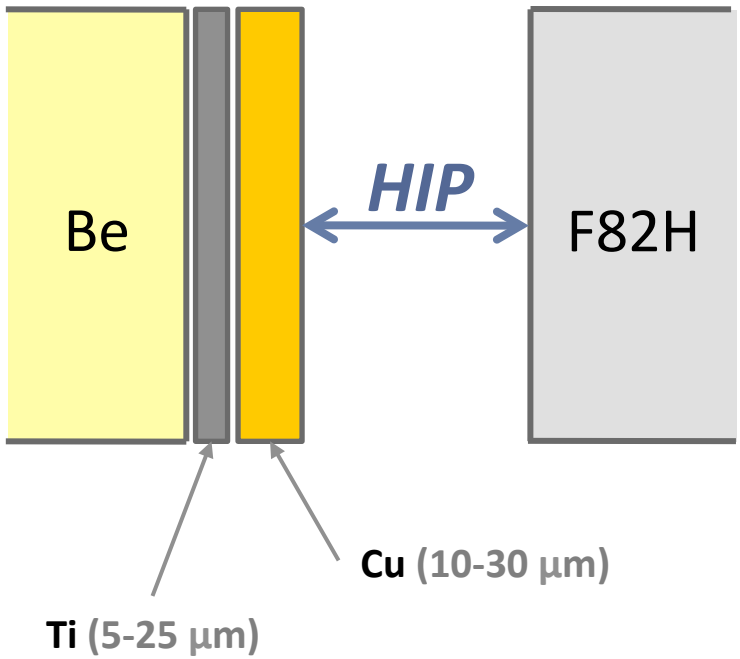
UCLA

A Cu interlayer to increase ductility and Ti to block diffusion, Be bonded to F82H with a shear strength of *168 MPa*

Three challenges must be overcome to bond Be/F82H

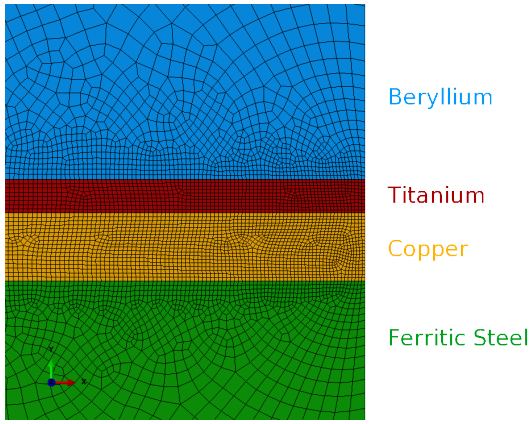
- **HIP temperature, if too high, affects material properties**
- **Differential thermal expansion causes significant residual stress**
- **Be forms brittle intermetallics with most elements**





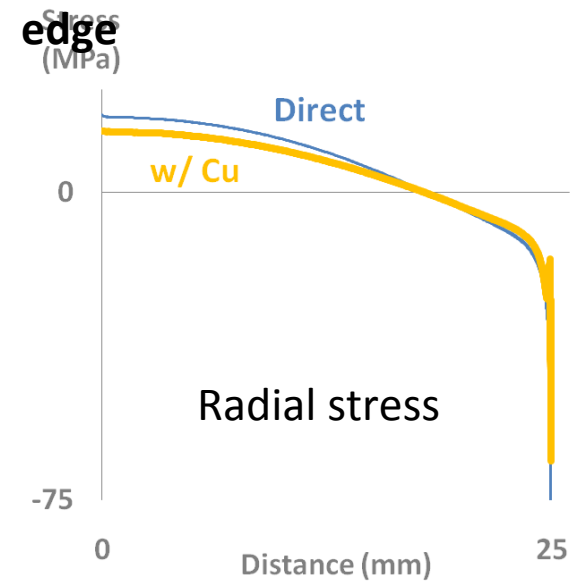
- **Impede Be diffusion with a diffusion barrier and controlled fabrication temperature**
- **Insert a ductile interlayer between substrates to absorb differential thermal expansion**

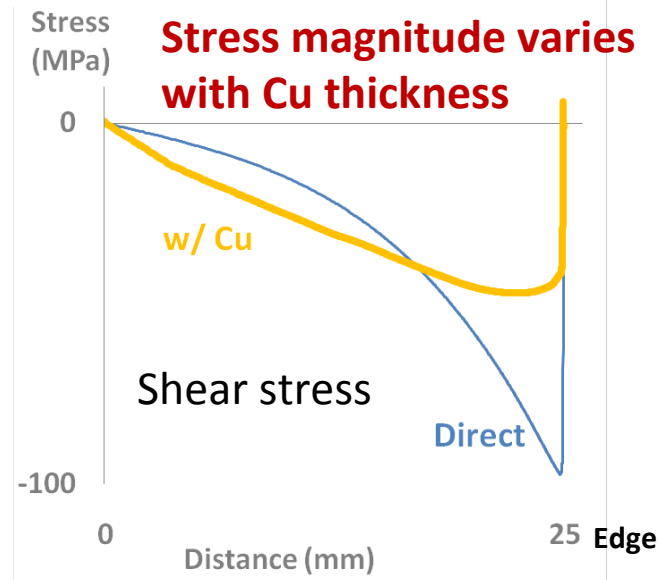
Numerical modeling performed to determine fabrication processes/parameters and interface stress state



ABAQUS model (axisymmetric) with identical dimensions to experimental sample

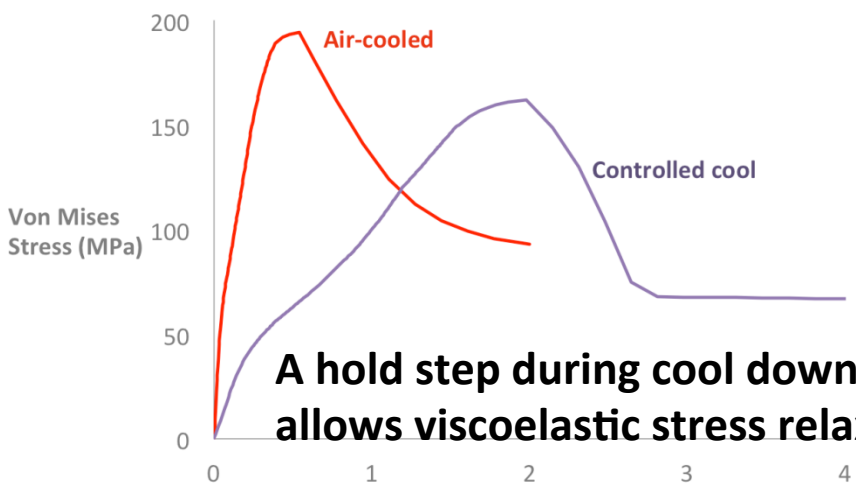
Copper layer reduce residual stress at interface near edge



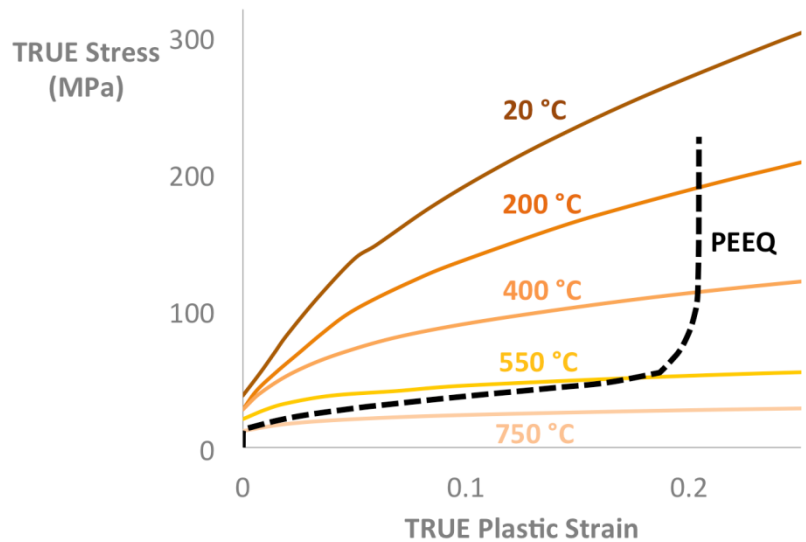


Stress magnitude varies with Cu thickness

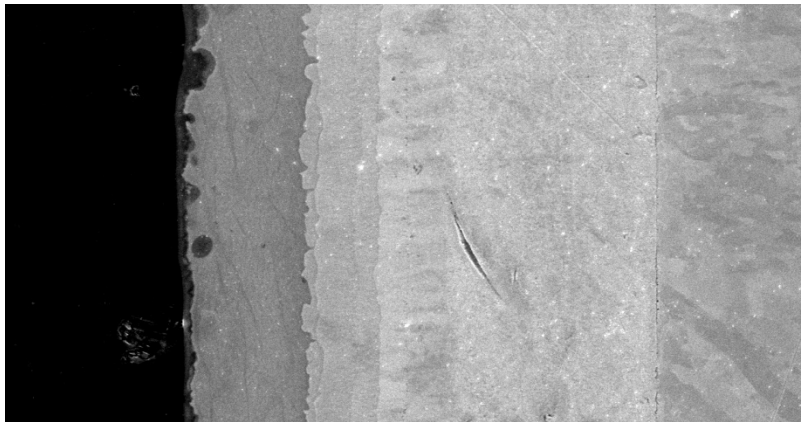
Cu stiffens as it cools. Is less effective at lower temp



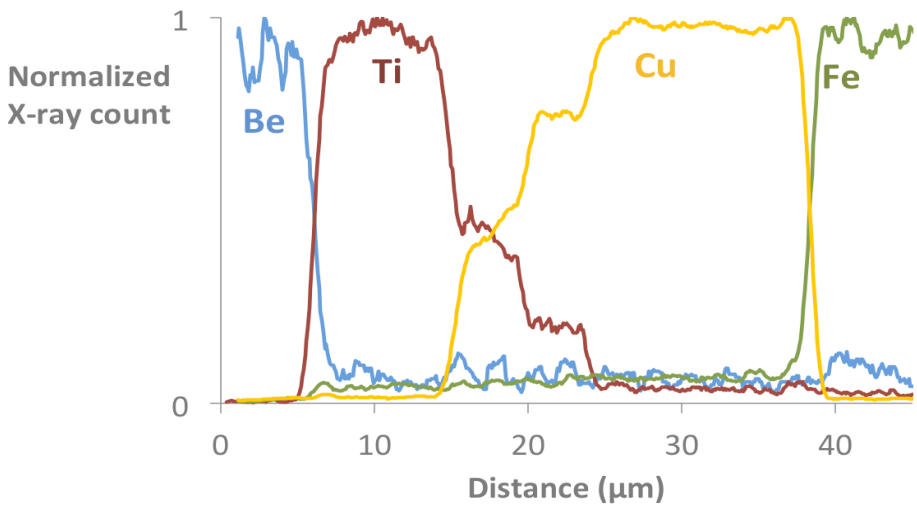
A hold step during cool down allows viscoelastic stress relaxatior



With 10µm Ti and 20µm Cu, joint withstood 150 MPa tensile load



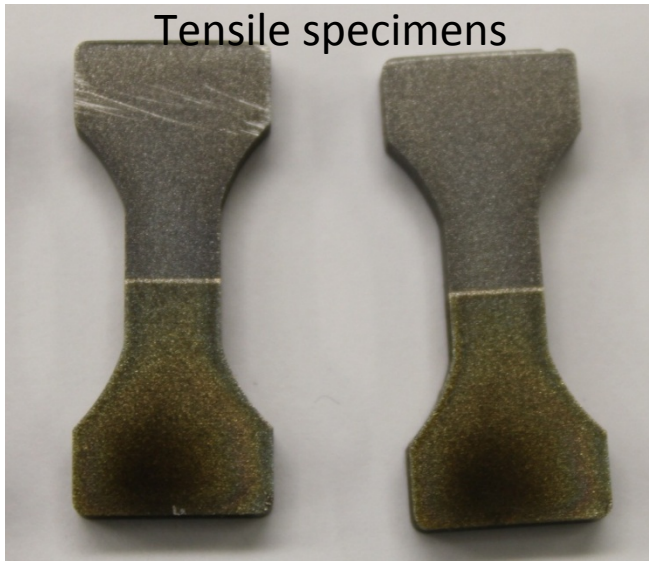
- Beryllium-titanium form thin intermetallic
- Titanium-copper forms *CuTi* and *Cu_4Ti (can be problematic)*
- Copper-F82H are insoluble



EDS and WDS conducted at UCSD

- Ti thickness determined via vacuum annealing experiments

Tensile tests conducted at Livermore



Proposed joining technique:

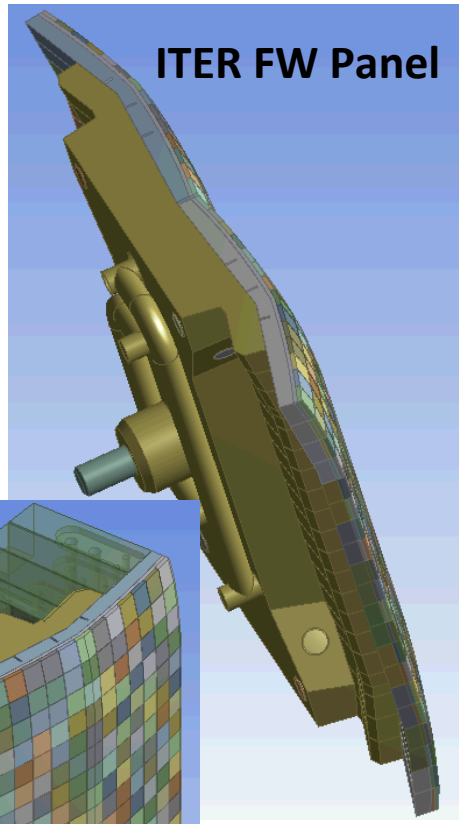
- 20µm Cu ductile interlayer
- 10µm Ti diffusion barrier
- HIP at 700-750 °C for 2 hours @ 103MPa

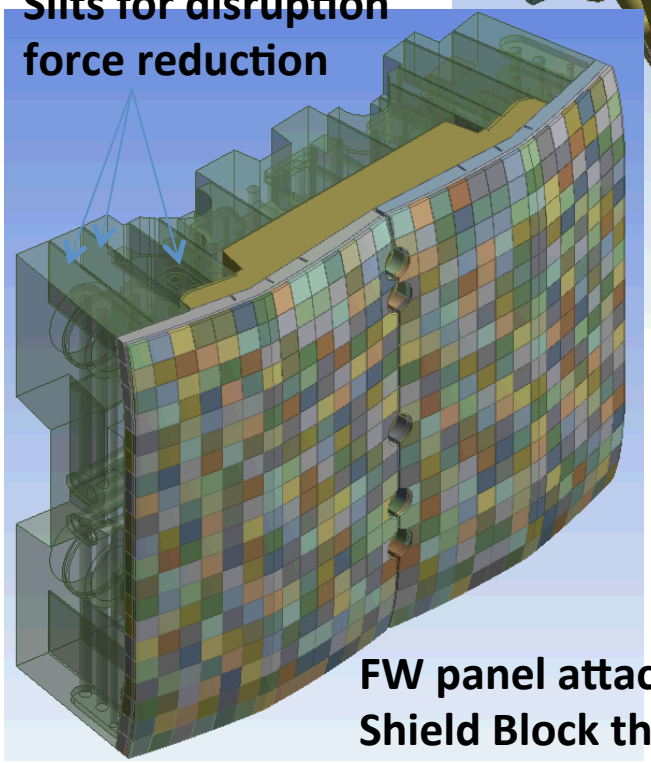
An oral presentation will be given at the ICFRM

Impinging jet concepts for FW high heat load removal (an exploratory study- conducted as a master thesis)

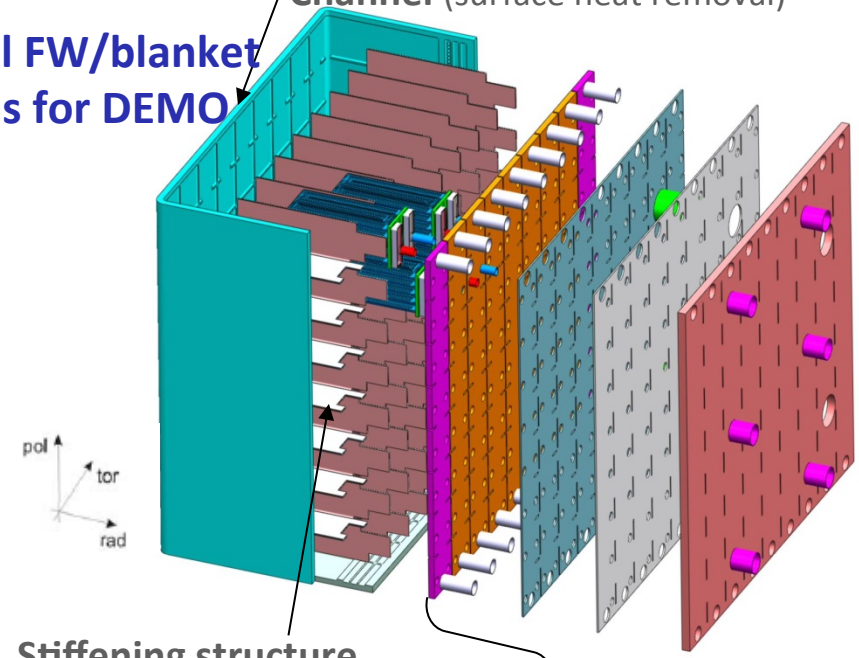
- **The FW is an integrated part of the blanket in order to minimize the structural contents and ensure adequate tritium breeding.**
- **ITER adopts a separate FW concept, which posts a challenge issue concerning the design integration.**
- **It has been recognized that a portion of the ITER FW will be exposed to high surface heat loads (up to 4.7 MW/m^2.) A similar situation seems expected for the FNSF/Demo. (There are also transient events.)**
- **To accommodate this, hypervaportron channels are being incorporated into the enhanced heat flux FW panels. The heat transfer is further augmented by a sub-cooled boiling heat transfer mechanism.**
- **Sub-cooled boiling heat transfer may not be possible for the FNSF/DEMO FW design for power production (even for super-critical water).**
- **The question is can a typical FW design with minimum modifications remove ITER-like high heat loads within its structural temperature limit? If not, what will the maximum allowable surface heat load be for RAFS?**

FW and Blanket





Typical FW/blanket designs for DEMO

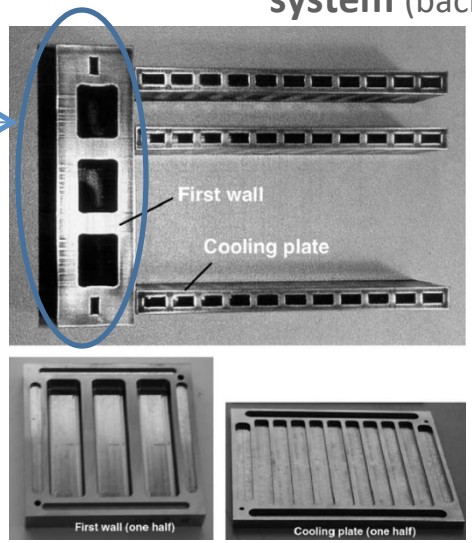


FW Structure with Cooling Channel (surface heat removal)

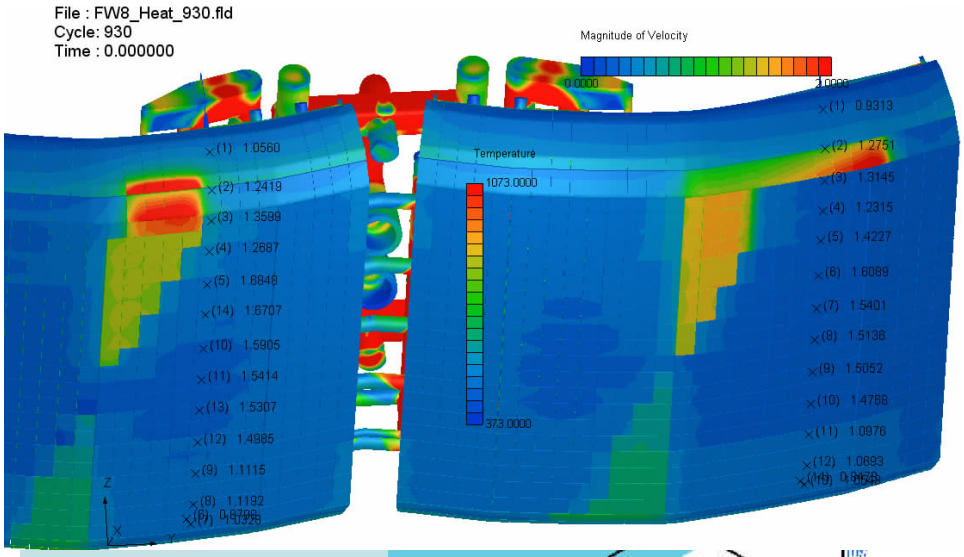
Stiffening structure (resistance to accidental in-box pressurization i.e He leakage)

He collector system (back)

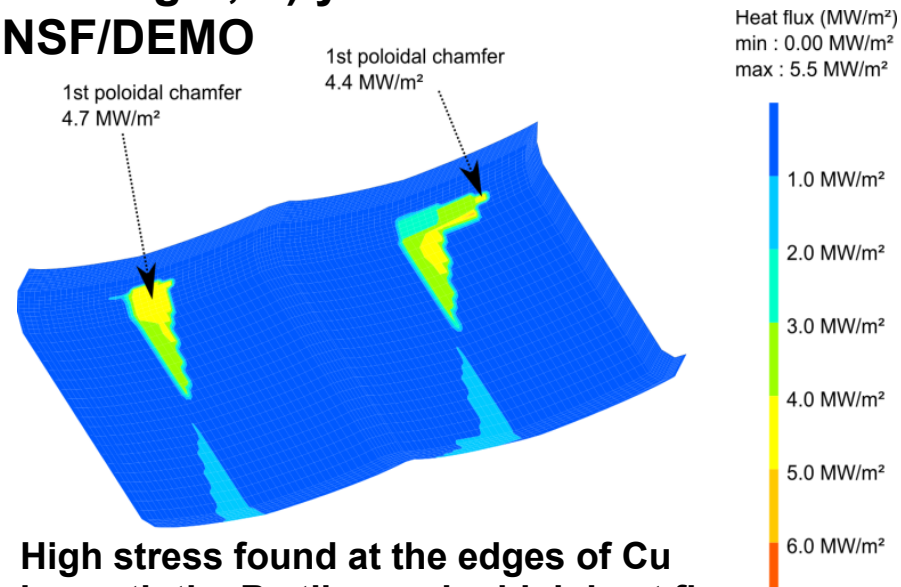
Typical FW: rectangular duct with some surface roughness to enhance heat transfer



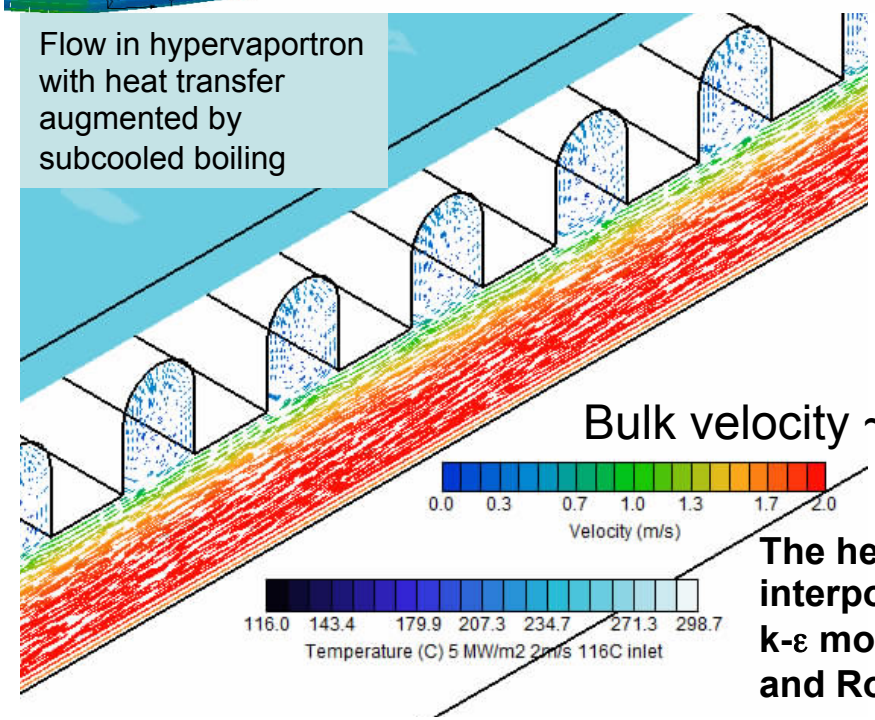
Low temperature water not practical for fusion reactor application



Magnitudes~ f(power, plasma physics, SOL length, --) yet to be determined for FNSF/DEMO

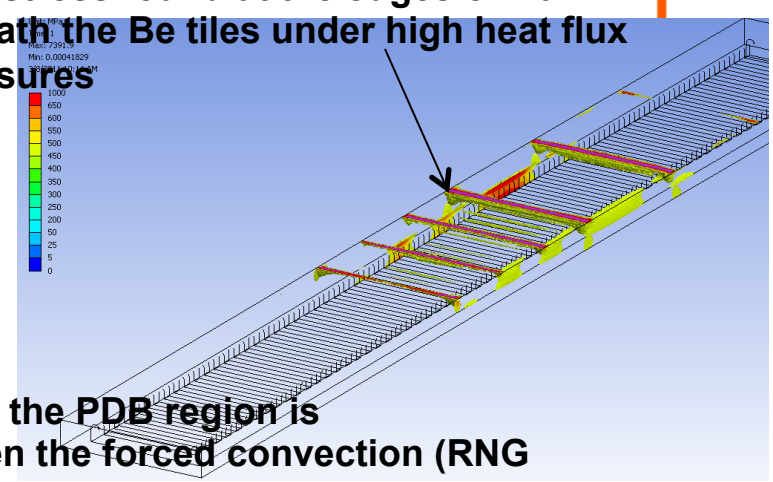


Flow in hypervaportron with heat transfer augmented by subcooled boiling



Bulk velocity ~ 2 m/s

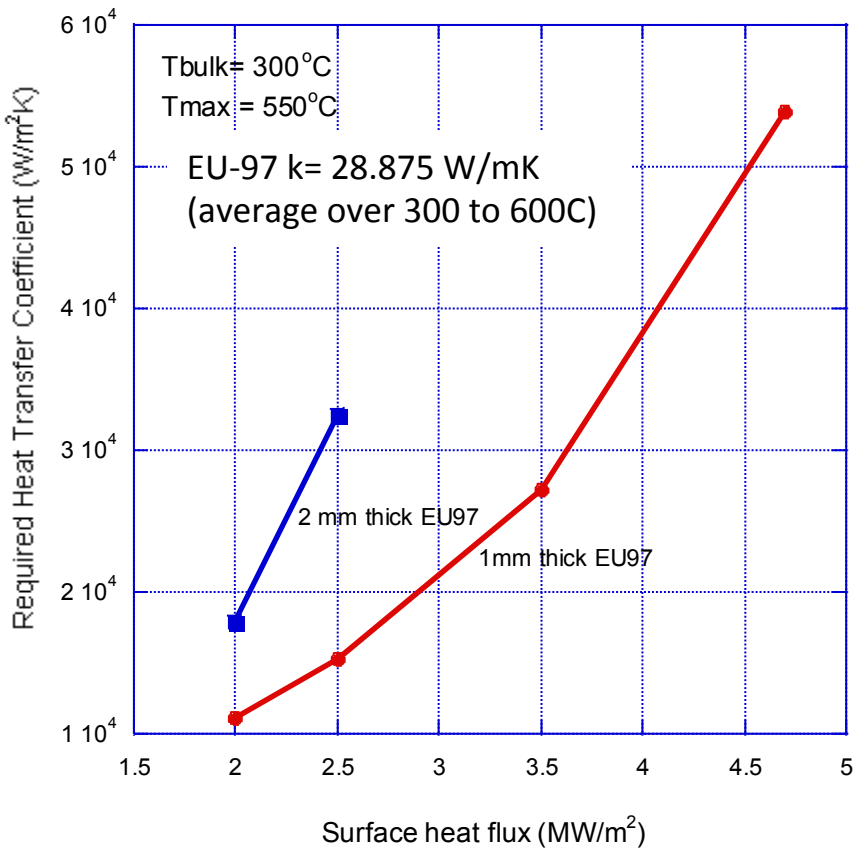
High stress found at the edges of Cu beneath the Be tiles under high heat flux exposures

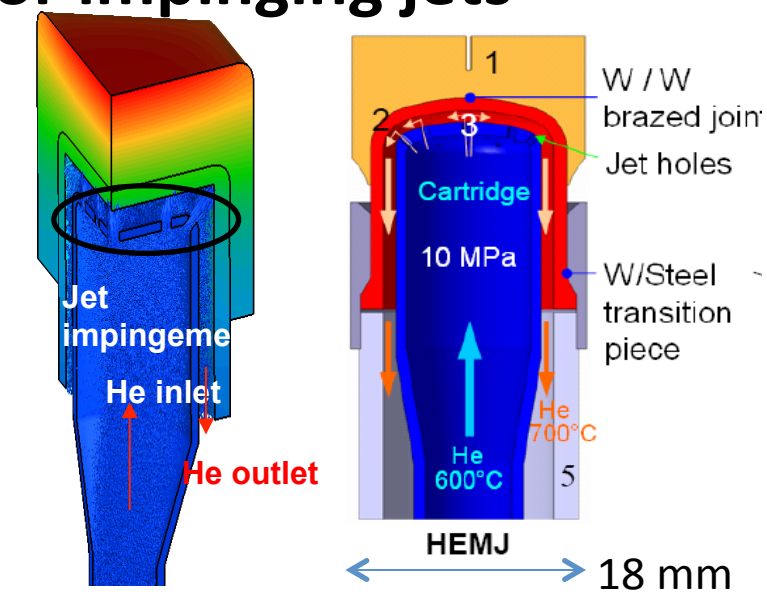


The heat transfer in the PDB region is interpolated between the forced convection (RNG k-ε model) and FDB curves as given by Bergles and Rohsenow.

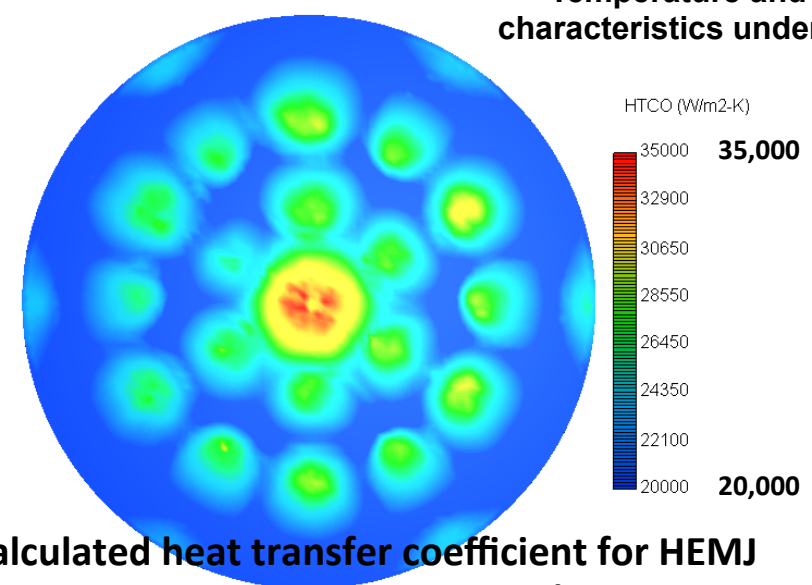
Past thermo-fluid analysis revealed high heat transfer removal capability possible for impinging jets

Required heat transfer coefficient for ITER FW-like surface heat flux removal while maintaining ferristic steel less than 550°C



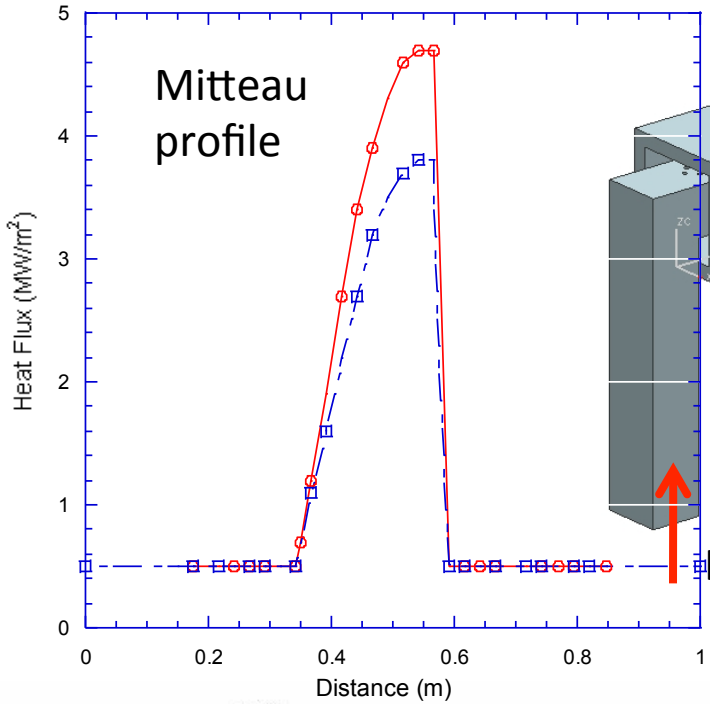


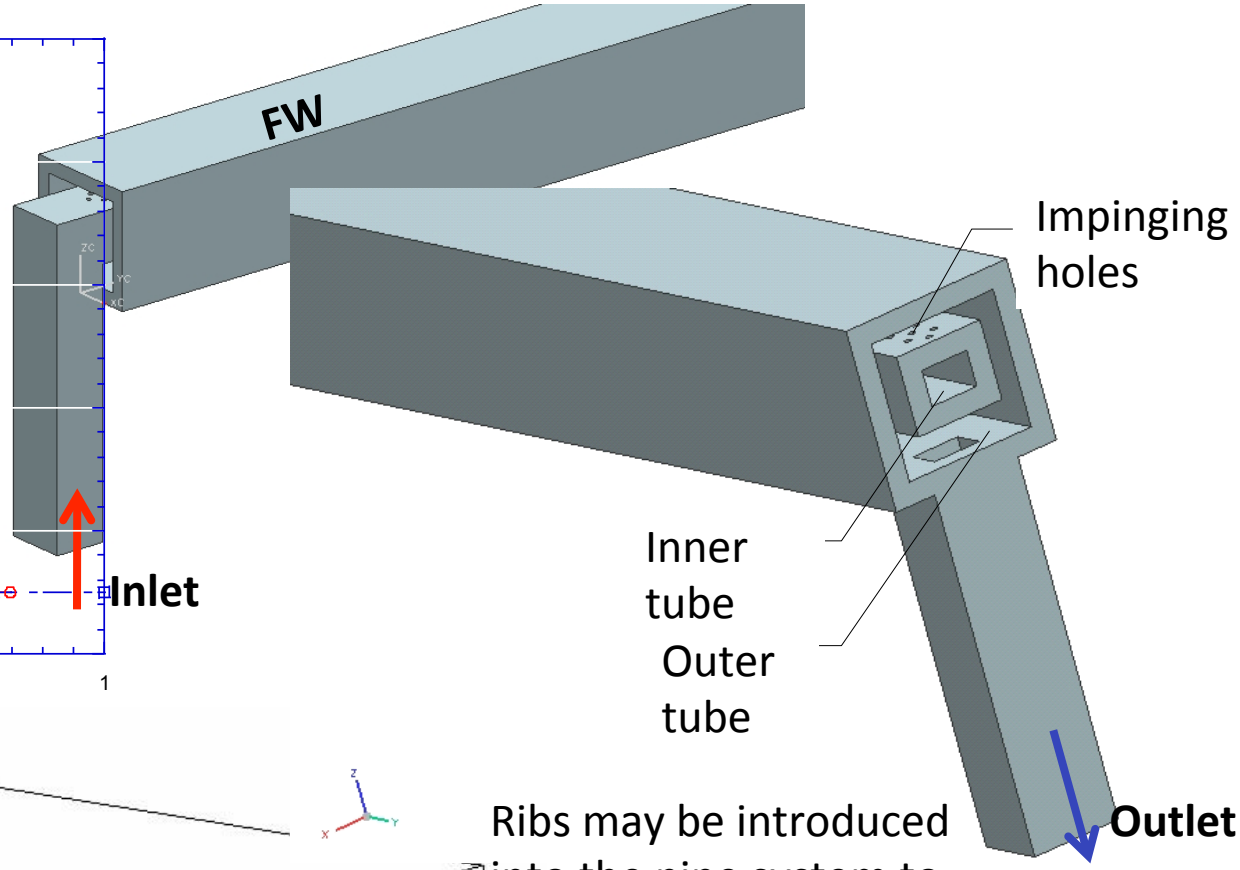
Temperature and He flow characteristics under 10 MW/m²

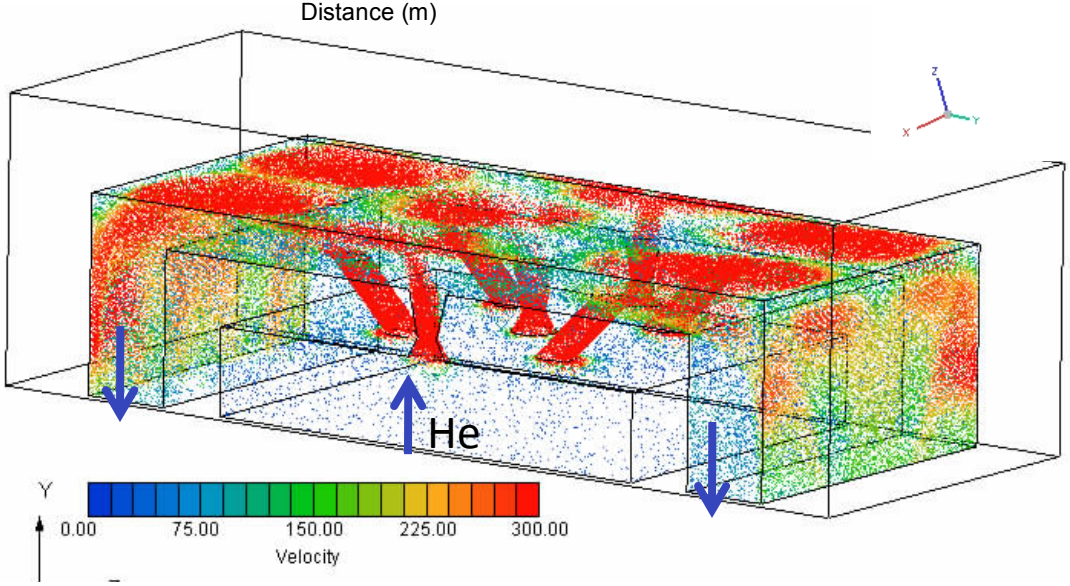


Calculated heat transfer coefficient for HEMJ impinging jet (20000 to 35000 W/m2K shown)

A double tube with impinging holes FW





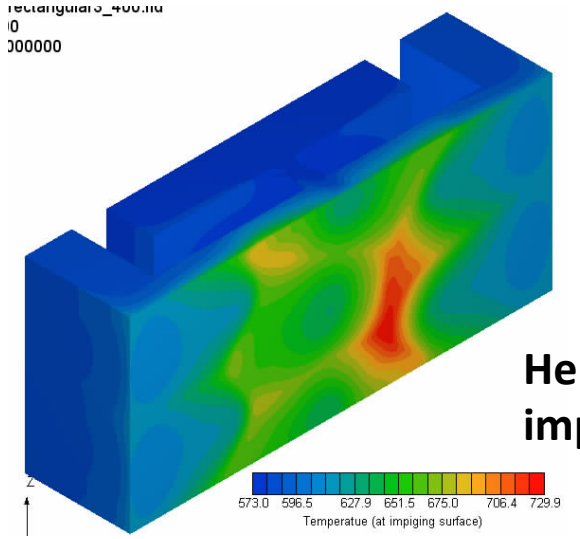


Ribs may be introduced into the pipe system to enhance structural integrity

Jet hole diameter (d) = 0.6 mm
H/d= 2

Velocity through the impinging holes should be limited to < 300 m/s (Marc < 0.3)

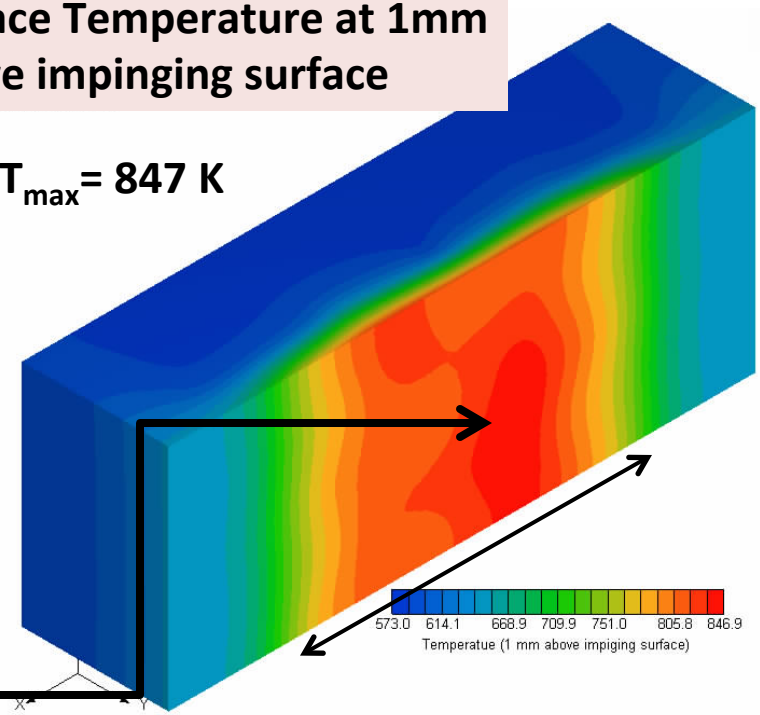
A double tube with impinging holes FW (Cont'd)



He Temperature at the impinging surface

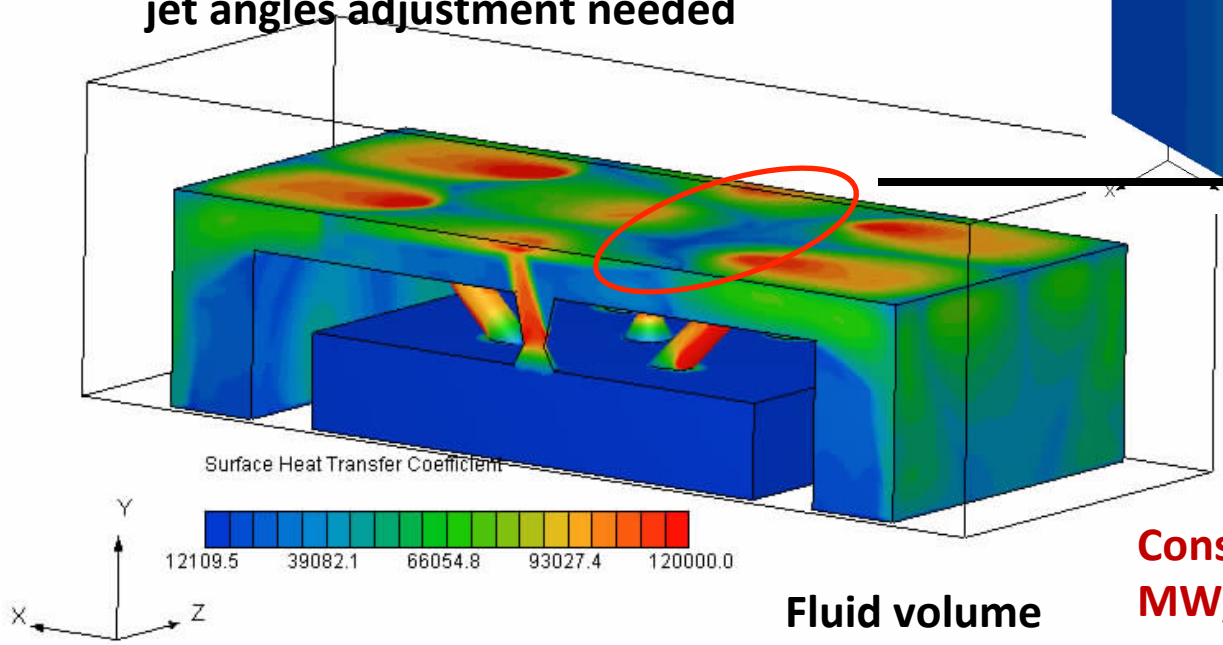
Surface Temperature at 1mm above impinging surface

T_{max}= 847 K



Solid volume

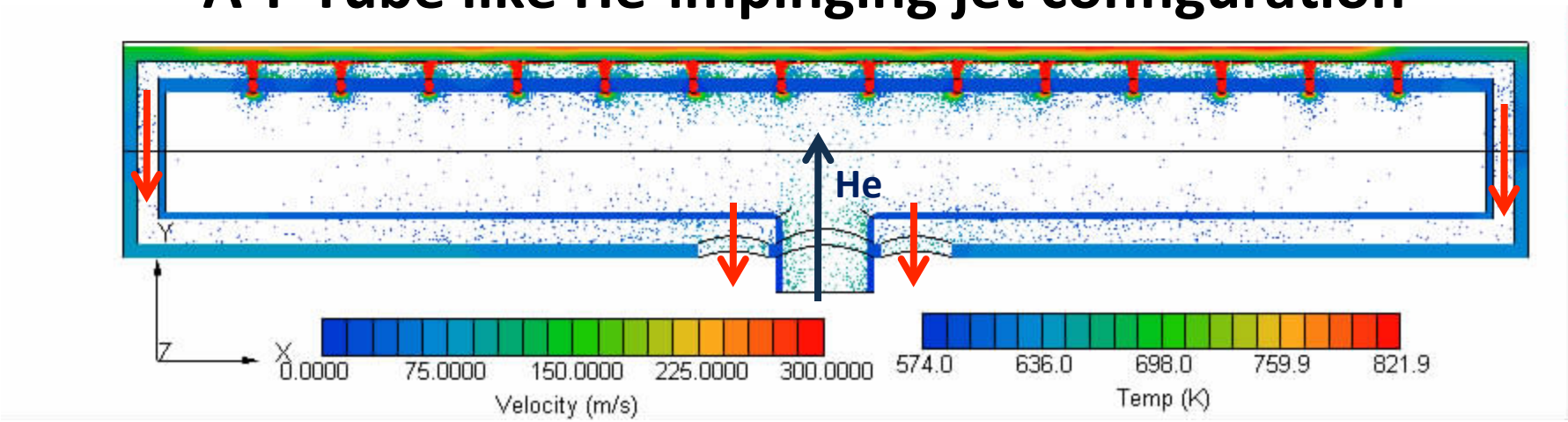
Heat transfer coefficient plot shows jet angles adjustment needed

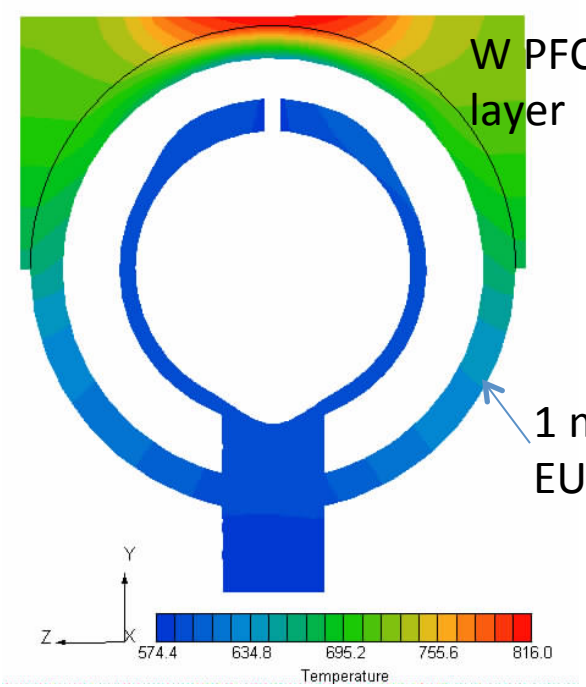


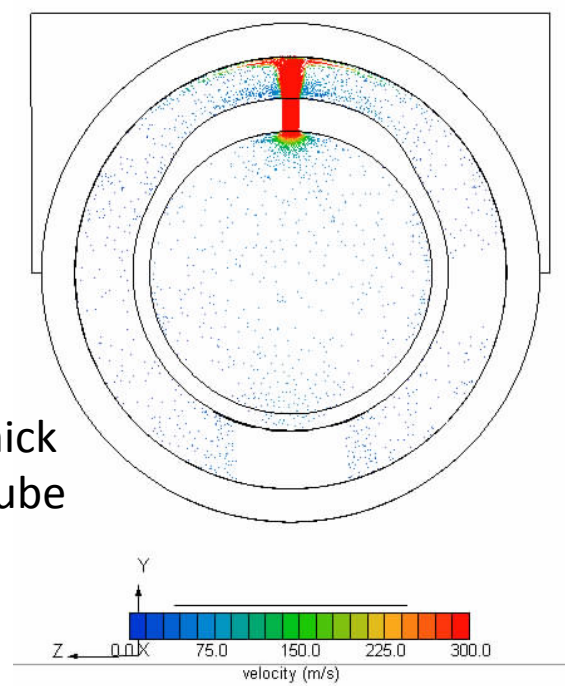
Fluid volume

Constant surface heat flux of 4.7 MW/m^2 applied

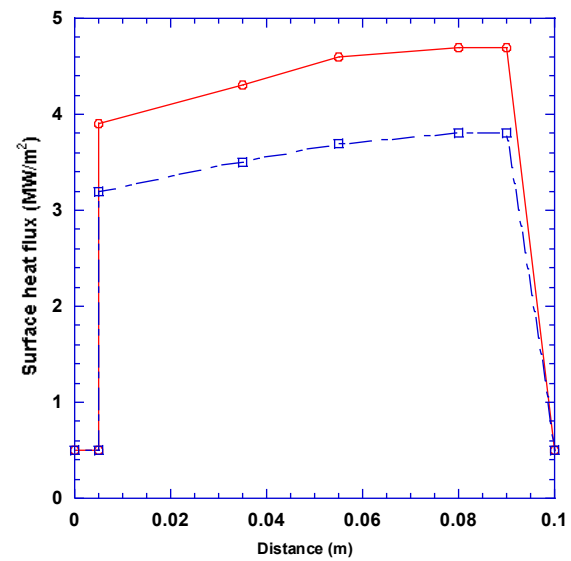
A T-Tube like He-impinging jet configuration



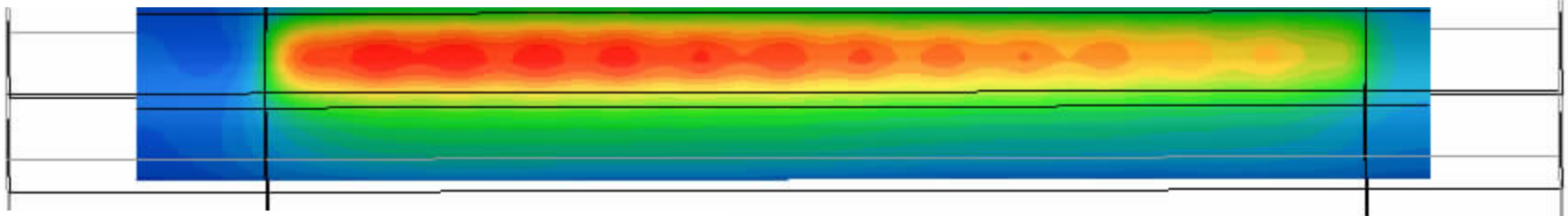




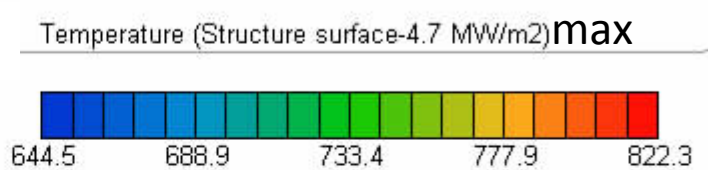
Applied heat flux profile (axial direction)

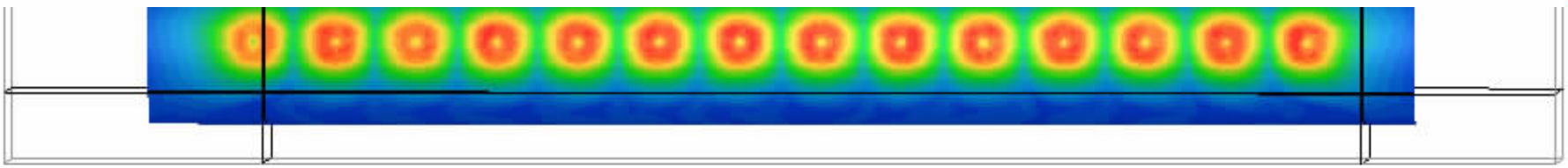


A T-Tube like He-impinging jet configuration (cont'd)

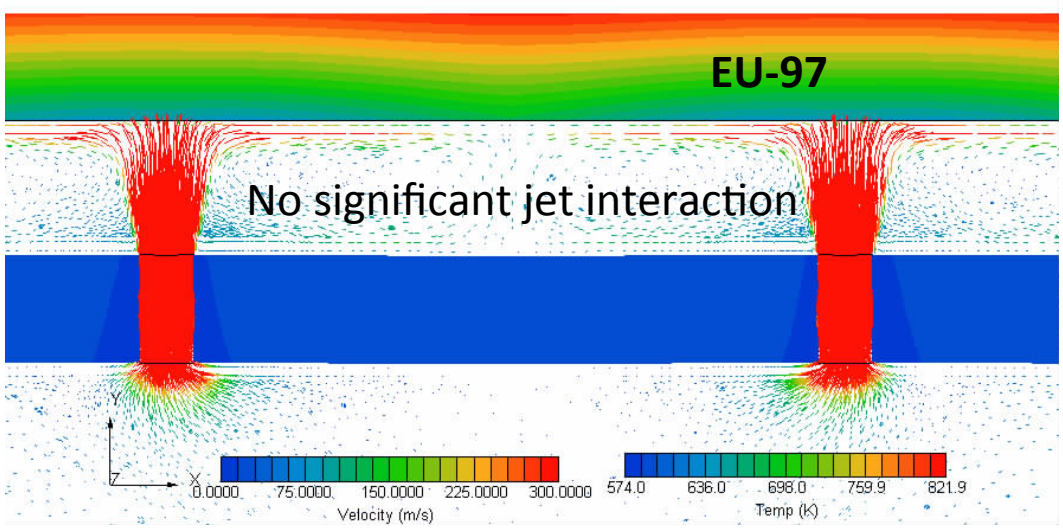


Temperature at EU-97 tube outer surface





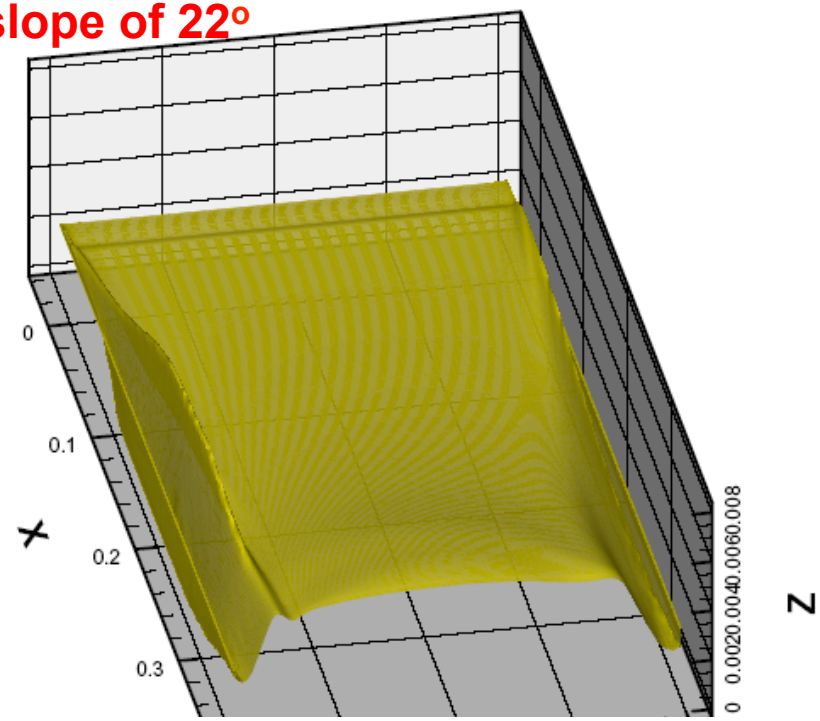
Heat transfer coefficient at the impinging surface



Previous work and current activity in lithium free surface flow study for particle pumping and high surface heat flux removal

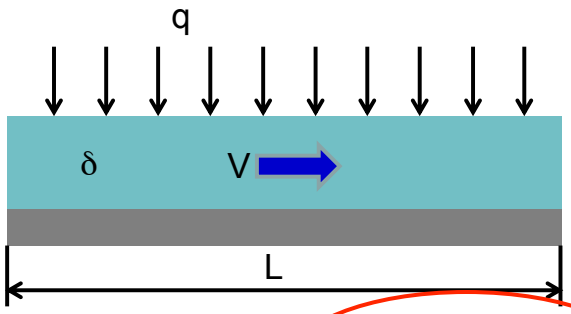
- HIMAG code has been developed, which is capable of simulating both closed channel flow and free surface flow with MHD effect.
- Benchmark numerical simulations of MHD free surface film and jet flows (without heat transfer) have been performed .
- Effort is underway to include a heat transfer model to study surface heat flux effects and temperature distribution in the HIMAG free surface flow code
- Estimation of temperature field in a liquid lithium film flow with high heat flux deposition on surface was carried out at first hand.
- Examination of the MHD effect on low velocity flow (1 cm/s like flow.)

Lithium film height evolution (HIMAG calculation)
Lithium flows from inboard (CHI) to outboard and climbs uphill at a slope of 22°

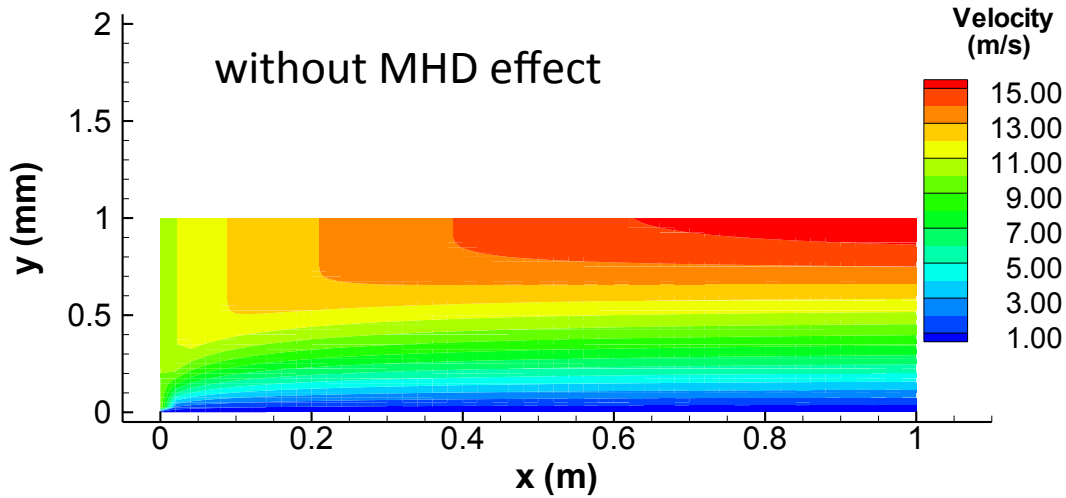


- NSTX like toroidal and normal fields
- Initial velocity = 10 m/s
- Initial film height= 2 mm
- Film height ~ 5 mm at 30 cm downstream

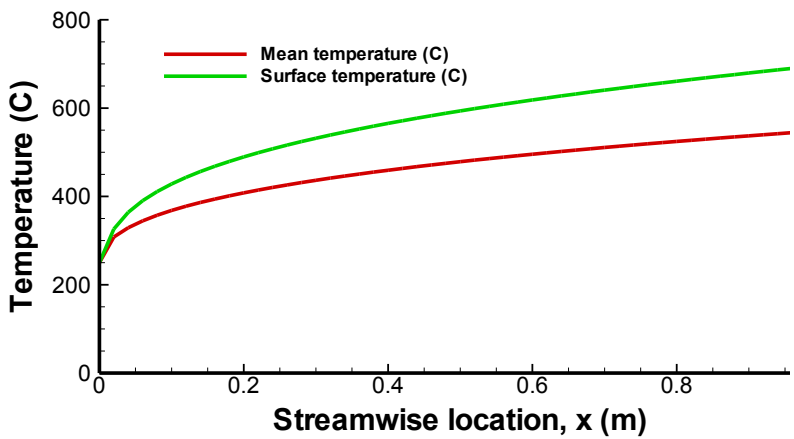
A simple method for estimating surface temperature in liquid metal film flow with high heat flux deposition



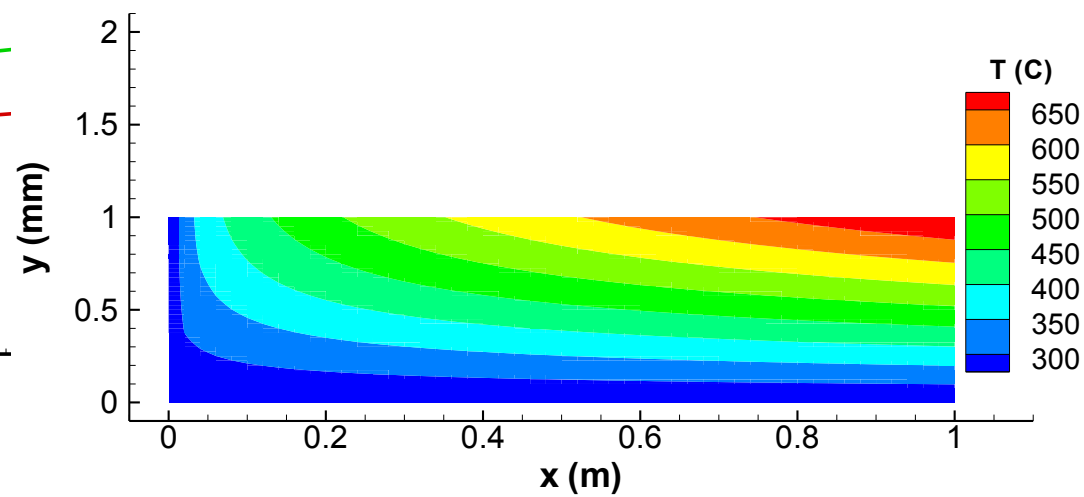
- Heat flux at surface: $q = 7 MW/m^2$
- Film thickness: $\delta = 1$ mm
- Inlet film flow velocity: $V = 10$ m/s



Velocity distribution in a liquid lithium film flow



Local mean & surface temperatures in the streamwise direction



Temperature distribution in a liquid lithium film flow