Experimental Verification of Gas-Cooled T-Tube Divertor Performance

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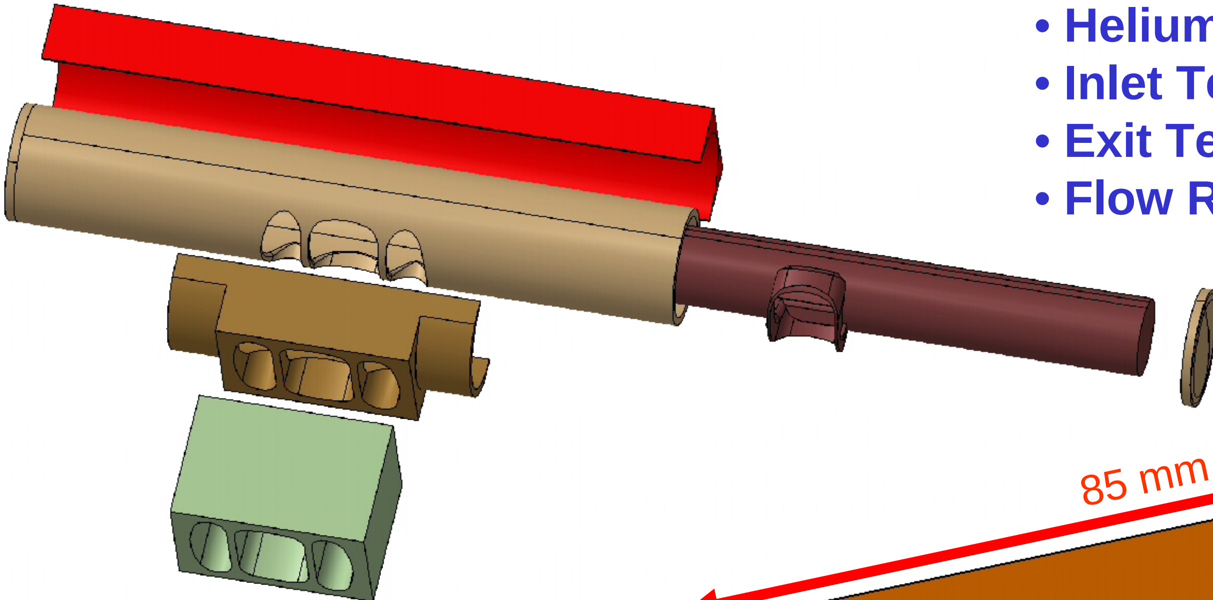
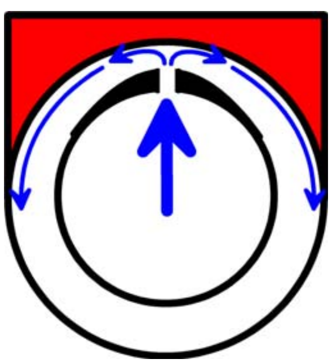
Objectives

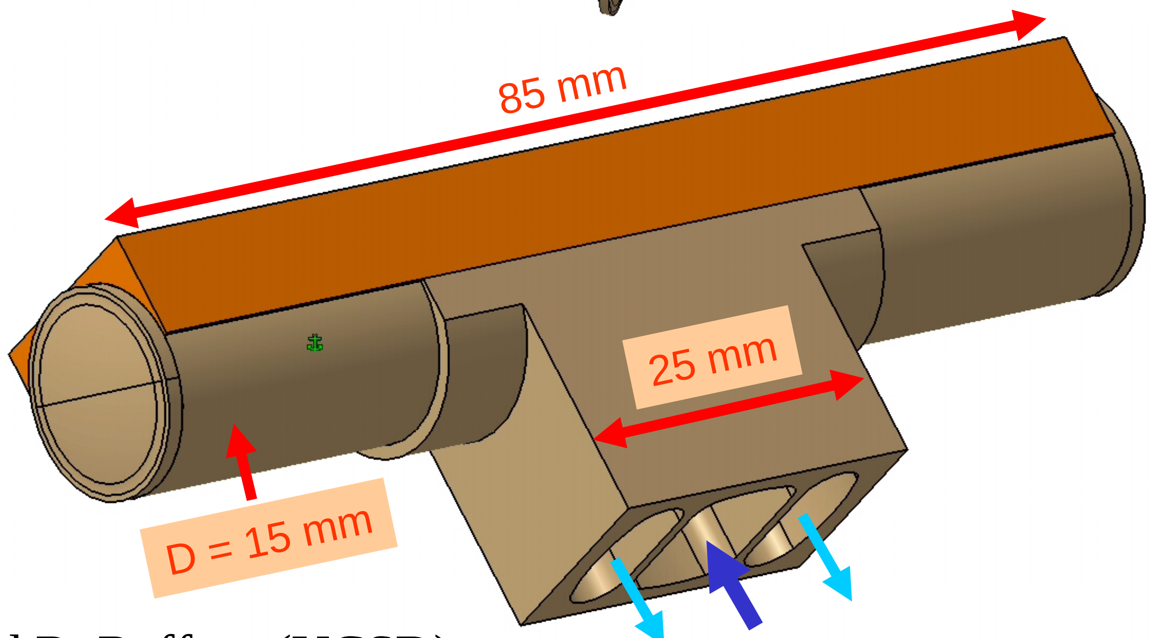
- Design, construct, and instrument a test module which closely simulates the thermal-hydraulic behavior of the proposed helium-cooled T-Tube divertor
- Experimentally measure the axial and azimuthal variations of the local heat transfer coefficient in the test module over a wide range of operating conditions
- Perform *“a priori”* calculations to predict the wall temperature distribution and heat transfer coefficients for the test module using the same methodology used to analyze the actual T-Tube divertor performance
- Compare the measured heat transfer coefficients with predicted values
- Develop an experimentally-validated correlation for the local Nusselt Number for use in future design analyses of similarly-configured gas-cooled components
- Use Experimental Data to guide design modifications to enhance divertor performance

T-Tube Divertor Geometry

- Helium Pressure = 10 MPa
- Inlet Temperature = 873 K
- Exit Temperature = 950 K
- Flow Rate/length = 0.2 kg/s.m



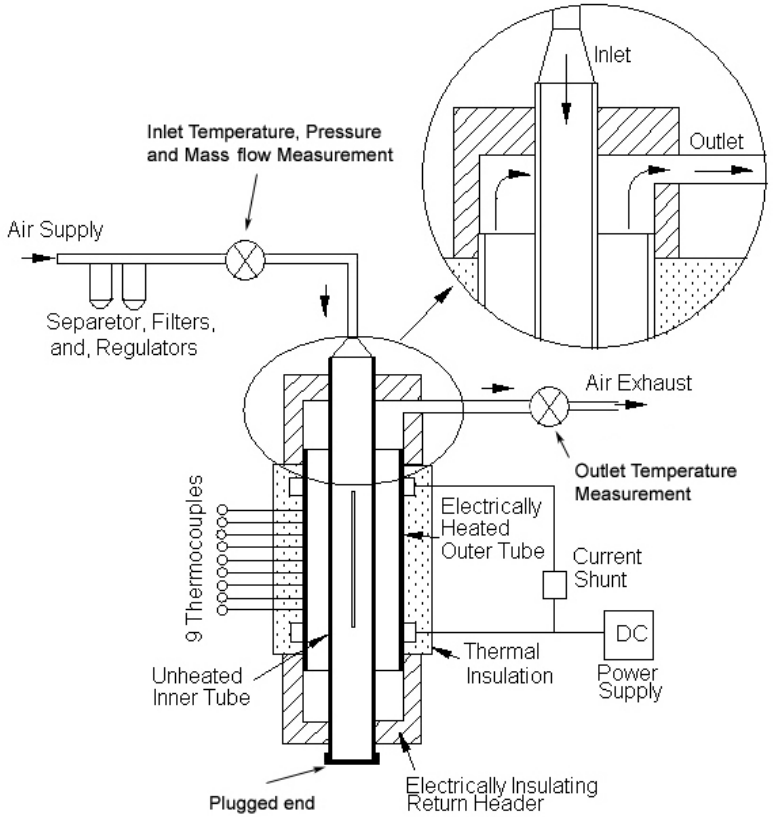




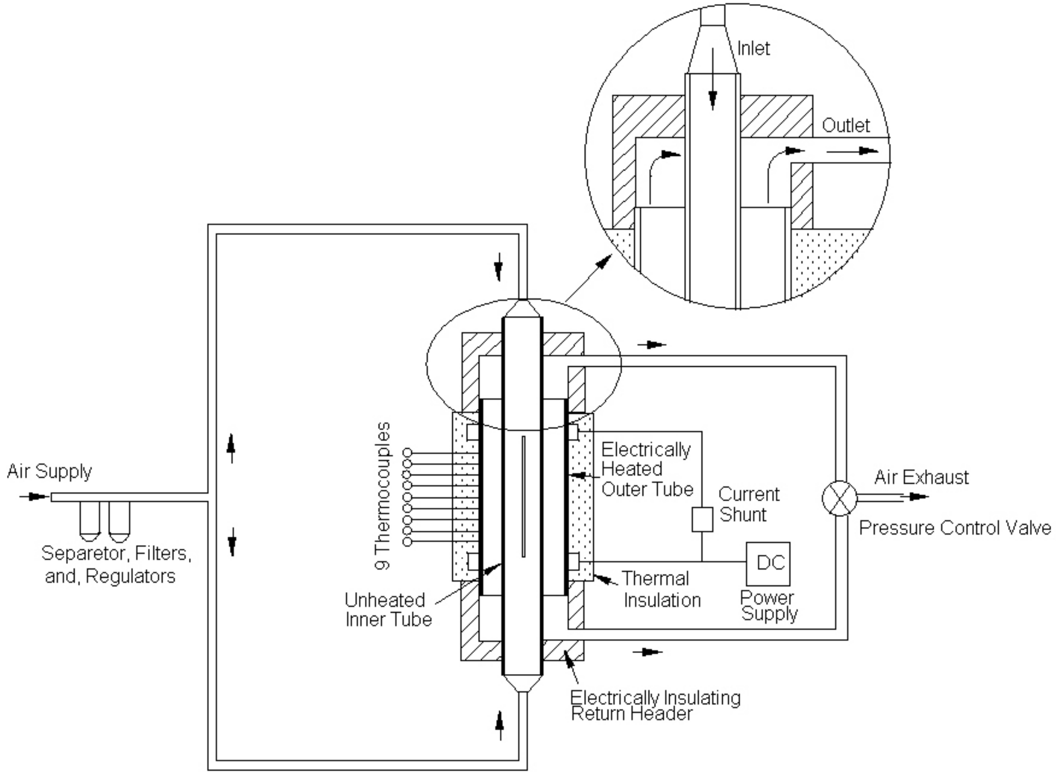
* From T. Ihle (FZK) and R. Raffray (UCSD)

Experimental Flow Loop

- **Single Inlet – Counter (or Parallel) Flow**

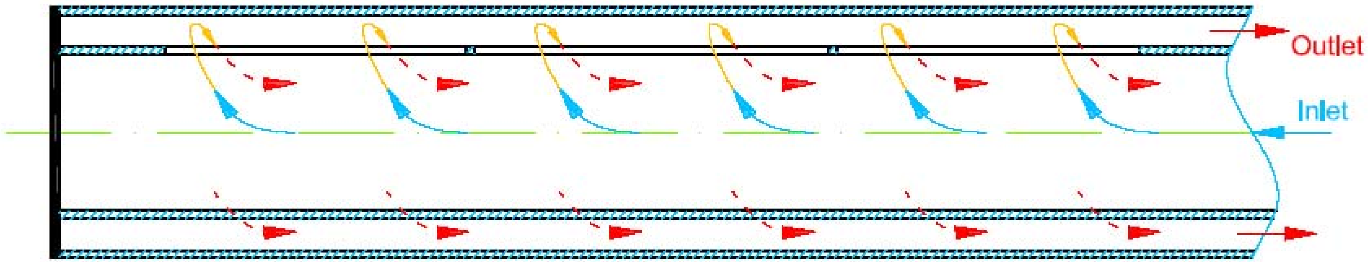


- **Double Inlet**

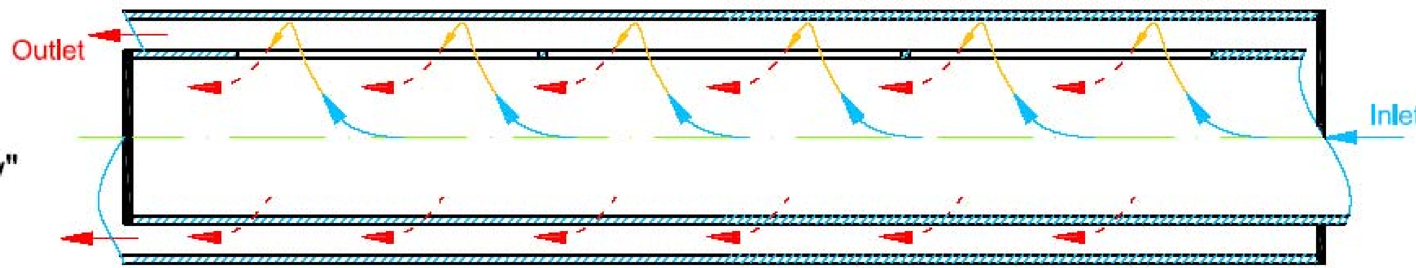


Flow Configurations

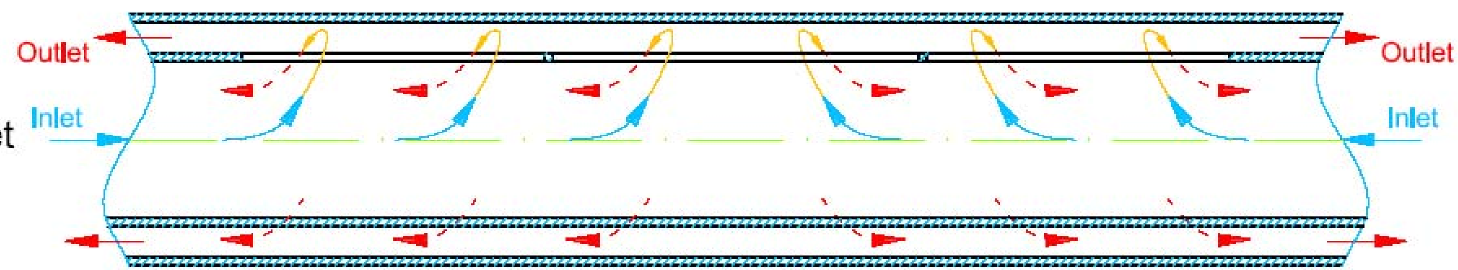
Single inlet:
"counter flow"



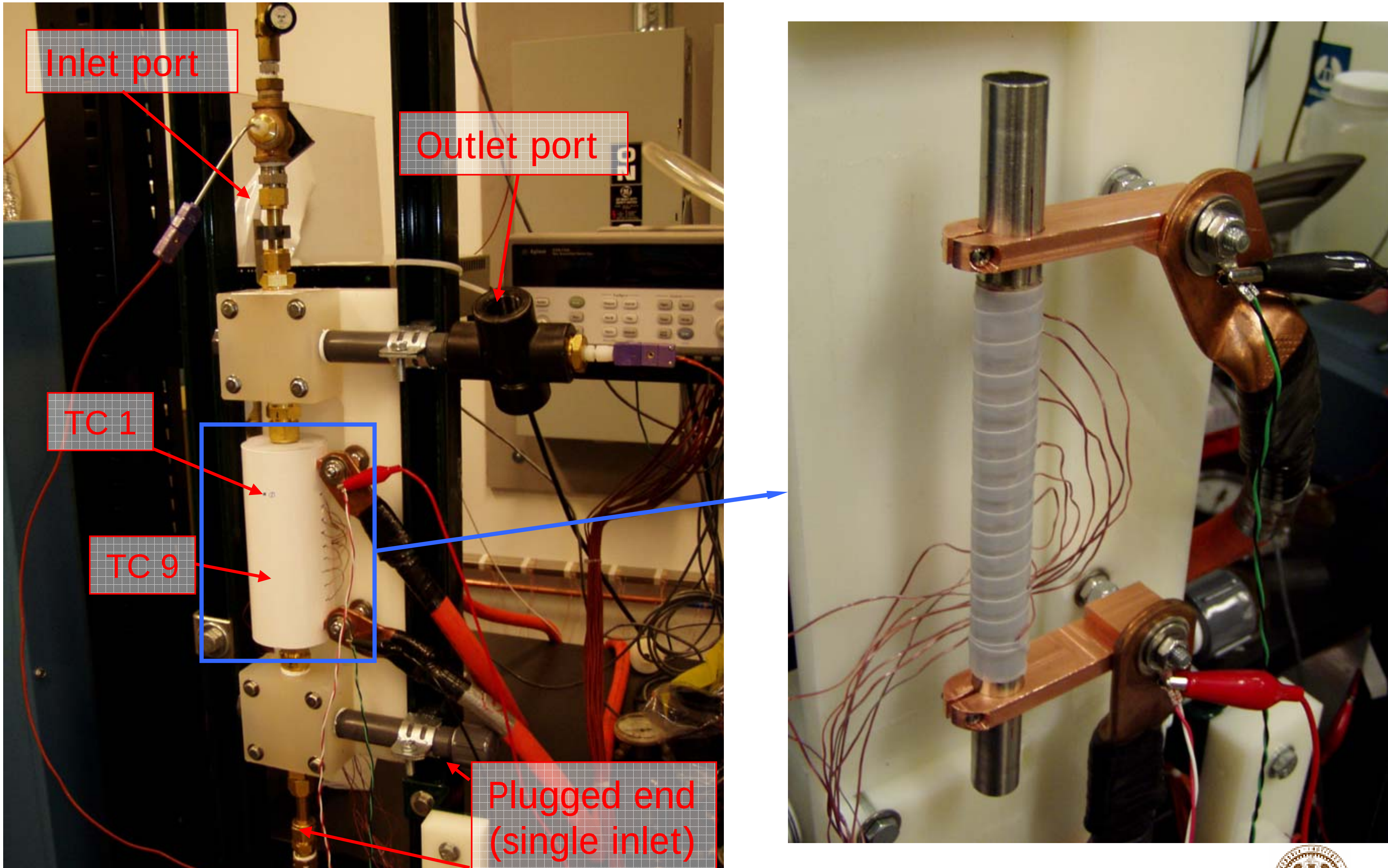
Single inlet:
"parallel flow"



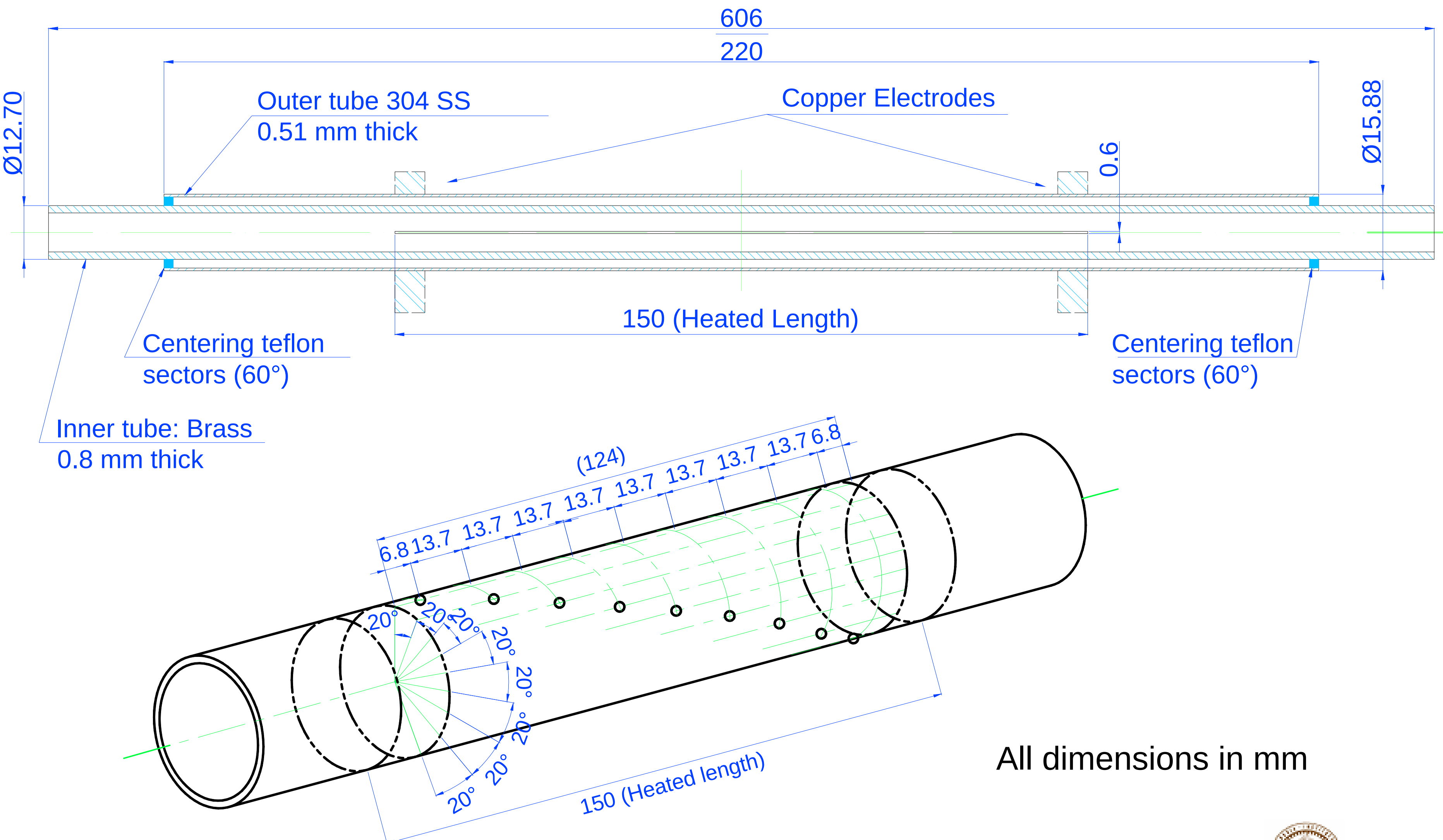
Double inlet



Experimental Flow Loop

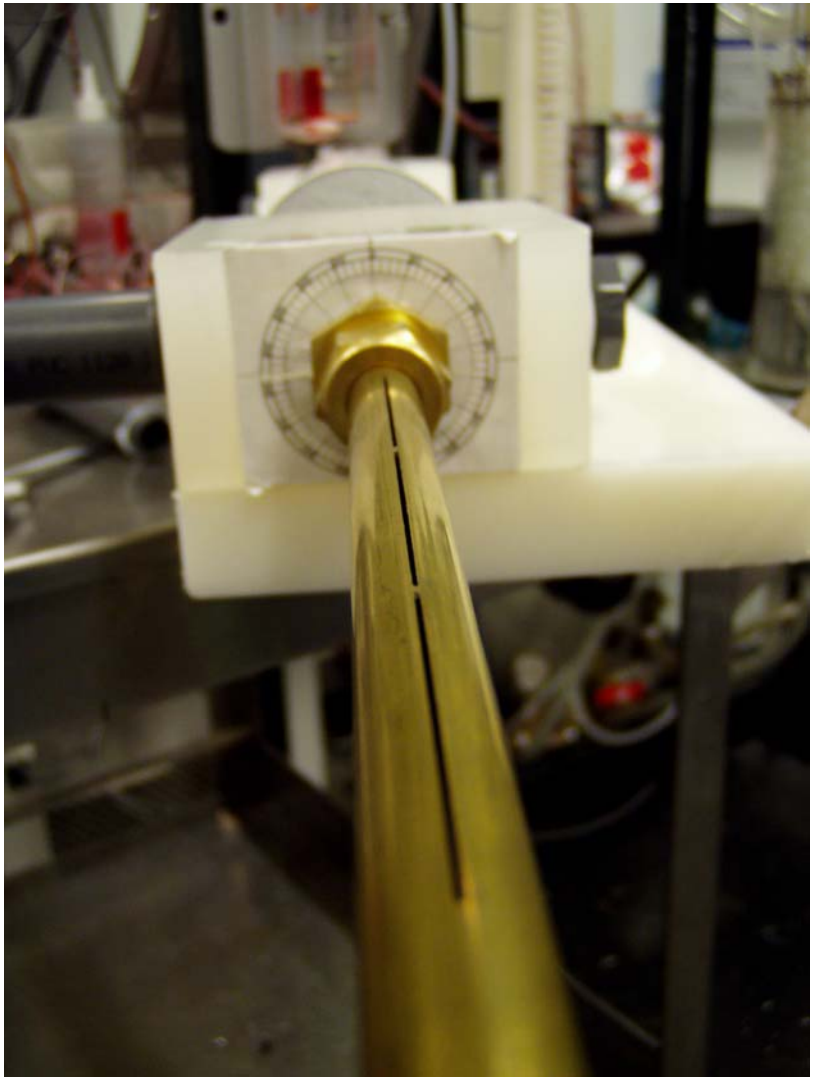


Experimental Test Section

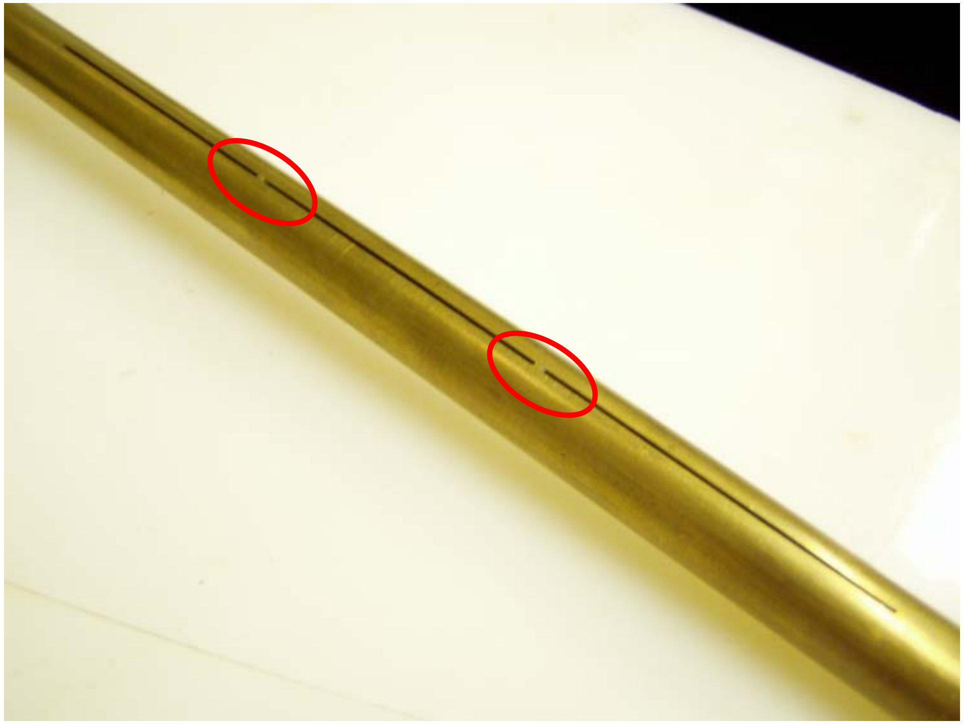


All dimensions in mm

Slit Close-up

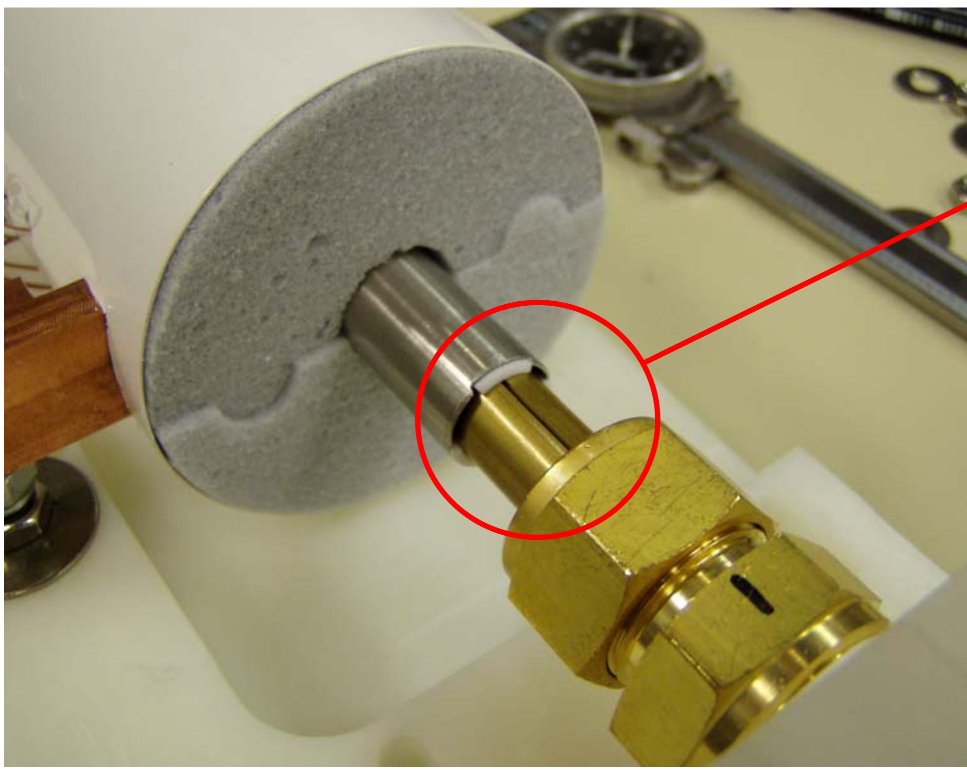


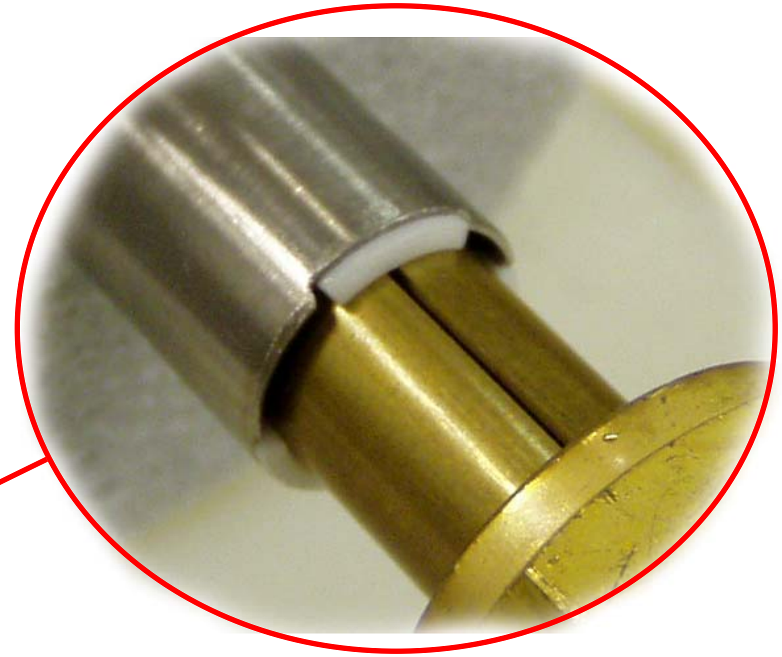
- **Addition of two 1.2 mm wide "bridges" to preserve slit width uniformity after machining**



Centering the tubes

- **Addition of three 60° Teflon ring sectors to each end of outer tube to maintain concentricity with inner tube and allow the flow to discharge**





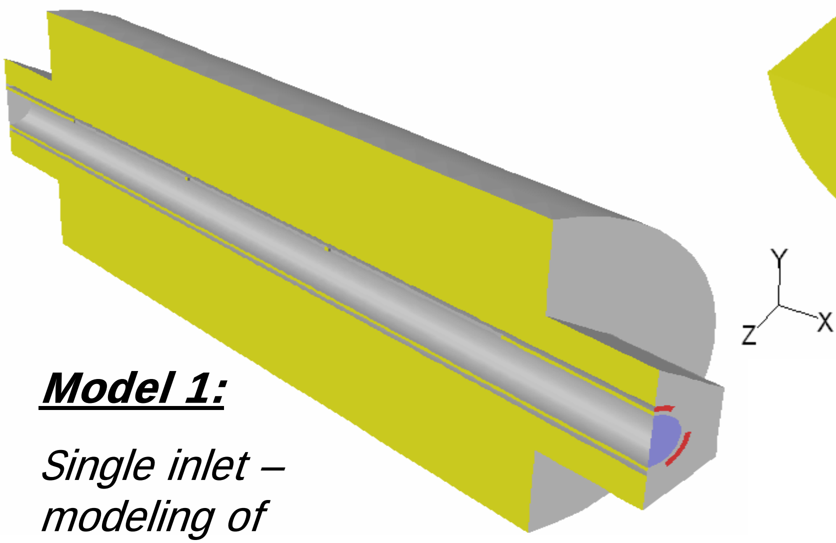
Thermal-Hydraulic Parameters

- **Experimental parameter ranges selected to match the non-dimensional parameters for the proposed helium-cooled T-Tube divertor (double inlet)**

Parameter	Air (low flow)	Air (high flow)	Helium
Operating Pressure	100 kPa	500 kPa	10 MPa
Pressure Drop	3.7 kPa	20 kPa	0.1 MPa
Mass Flow Rate (per unit slit length)	27 g/s.m	94 g/s.m	200 g/s.m
Inlet Temp.	20° C	20° C	600° C
Average Re	1450	5000	4800
Pr	0.71	0.71	0.66

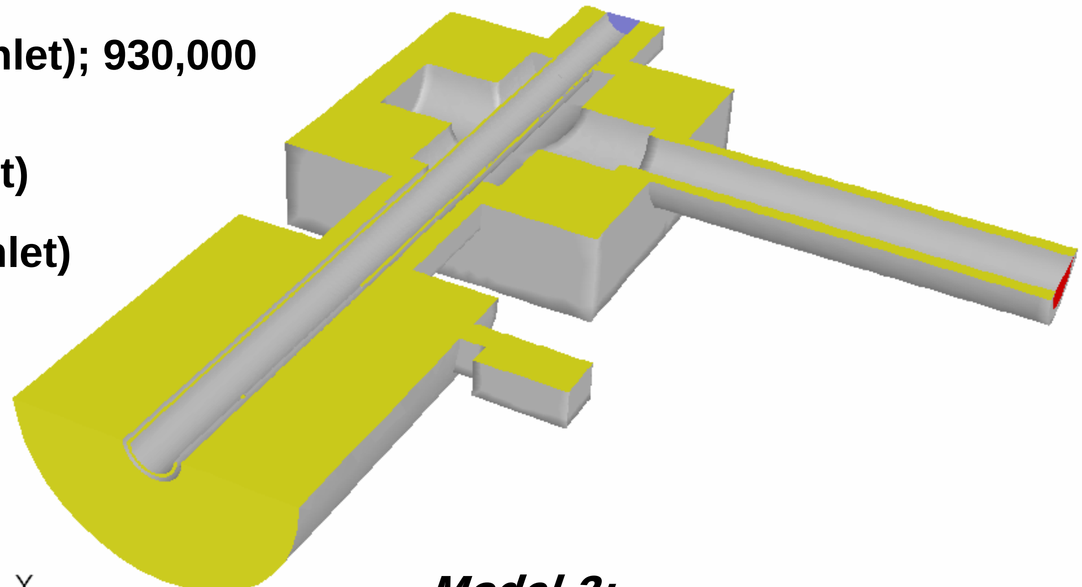
Predicted Performance - 3D Simulation

- **FLUENT 6.2, Steady, turbulent (RNG k-ε) model with standard wall functions**
- **Grid size: 810,000 cells (single inlet); 930,000 cells (double inlet)**
- **One symmetry plane (single inlet)**
- **Two symmetry planes (double inlet)**



Model 1:

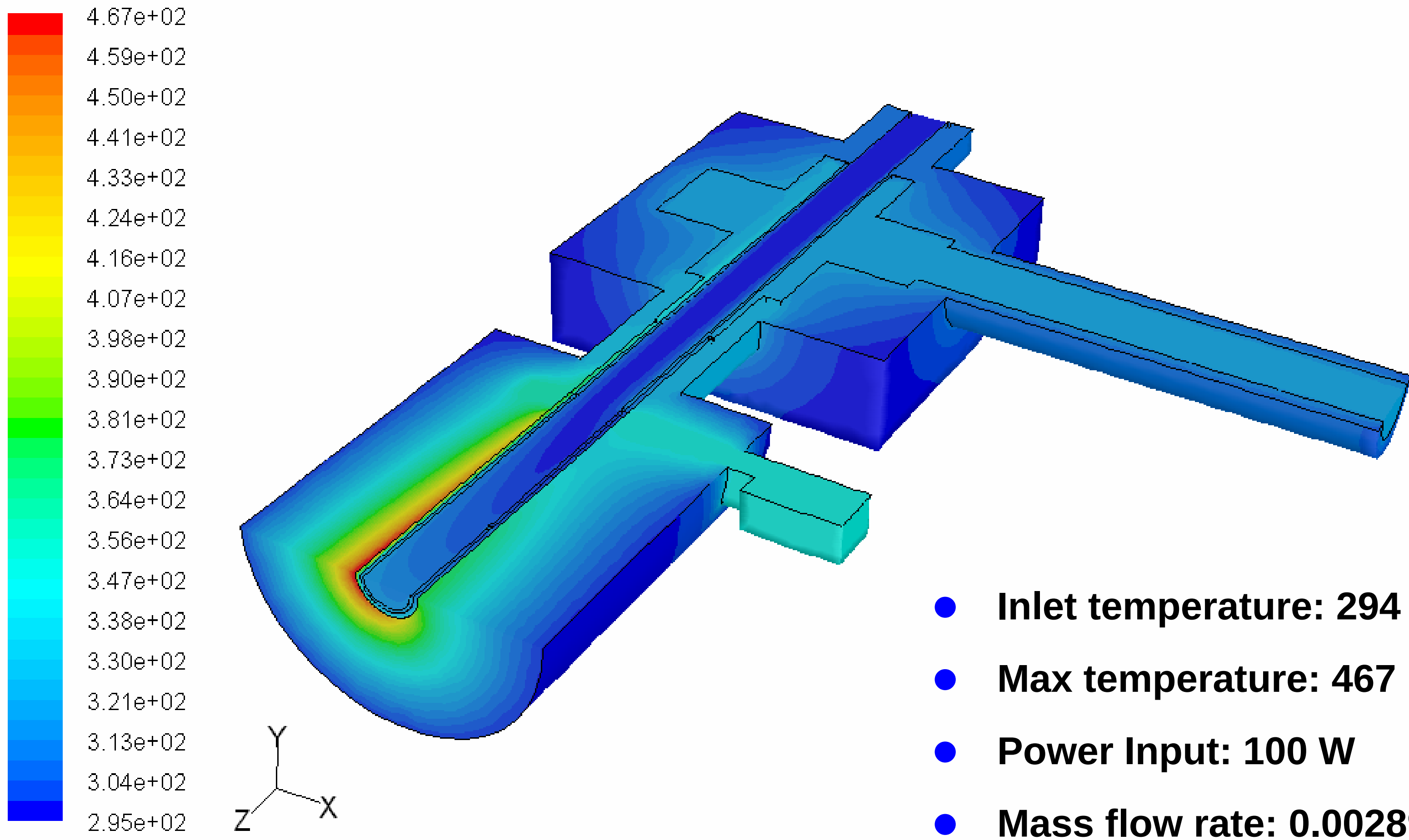
Single inlet – modeling of insulation



Model 2:

Double inlet – modeling of complete test section

Predicted Performance – Temperature (Double Inlet)

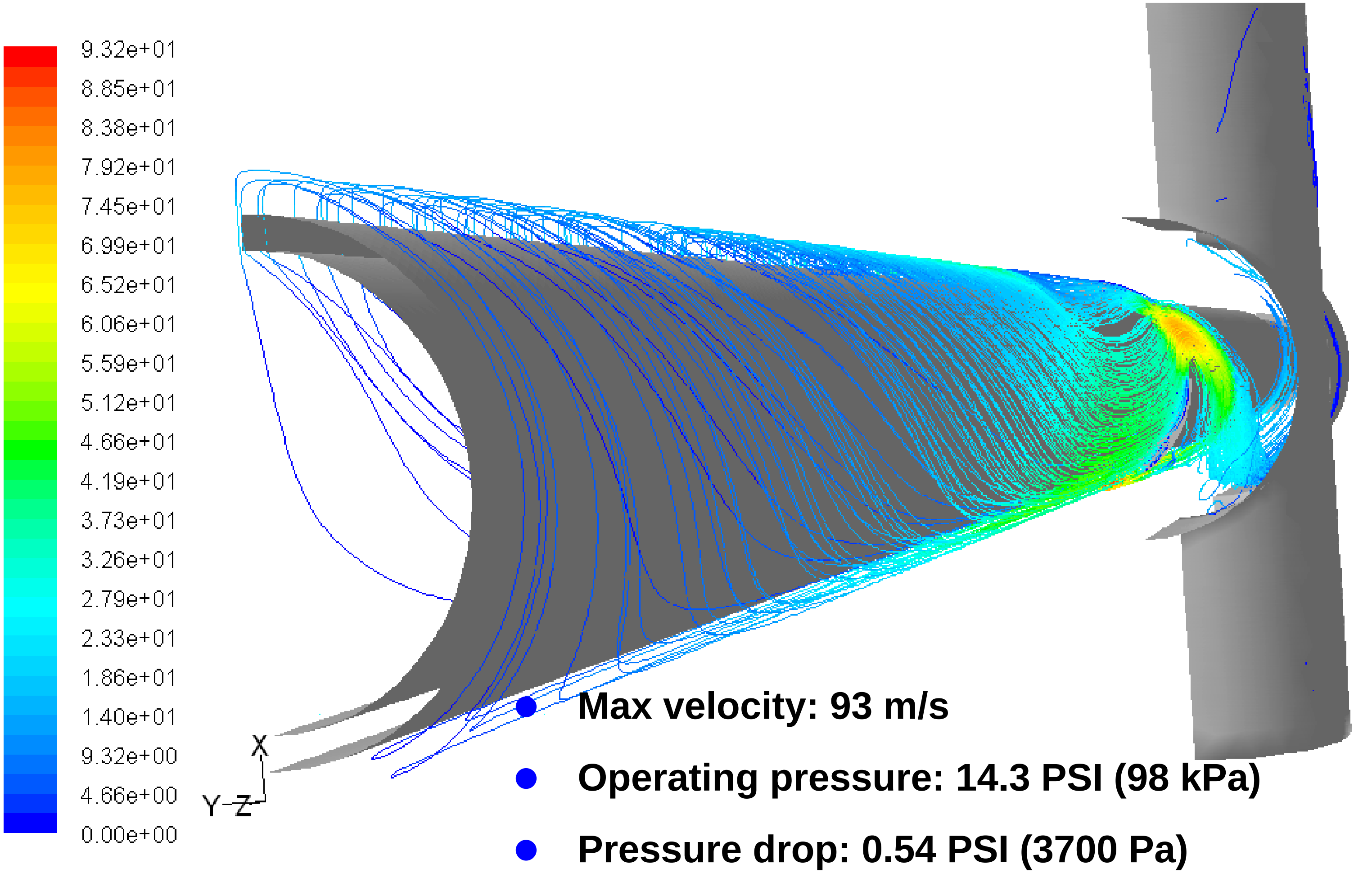


- **Inlet temperature: 294 k**
- **Max temperature: 467 k**
- **Power Input: 100 W**
- **Mass flow rate: 0.00289 Kg/s**

Contours of Static Temperature (k)

Jun 05, 2006
FLUENT 6.2 (3d, segregated, rngke)

Predicted Performance – Flow Field
(Double Inlet)

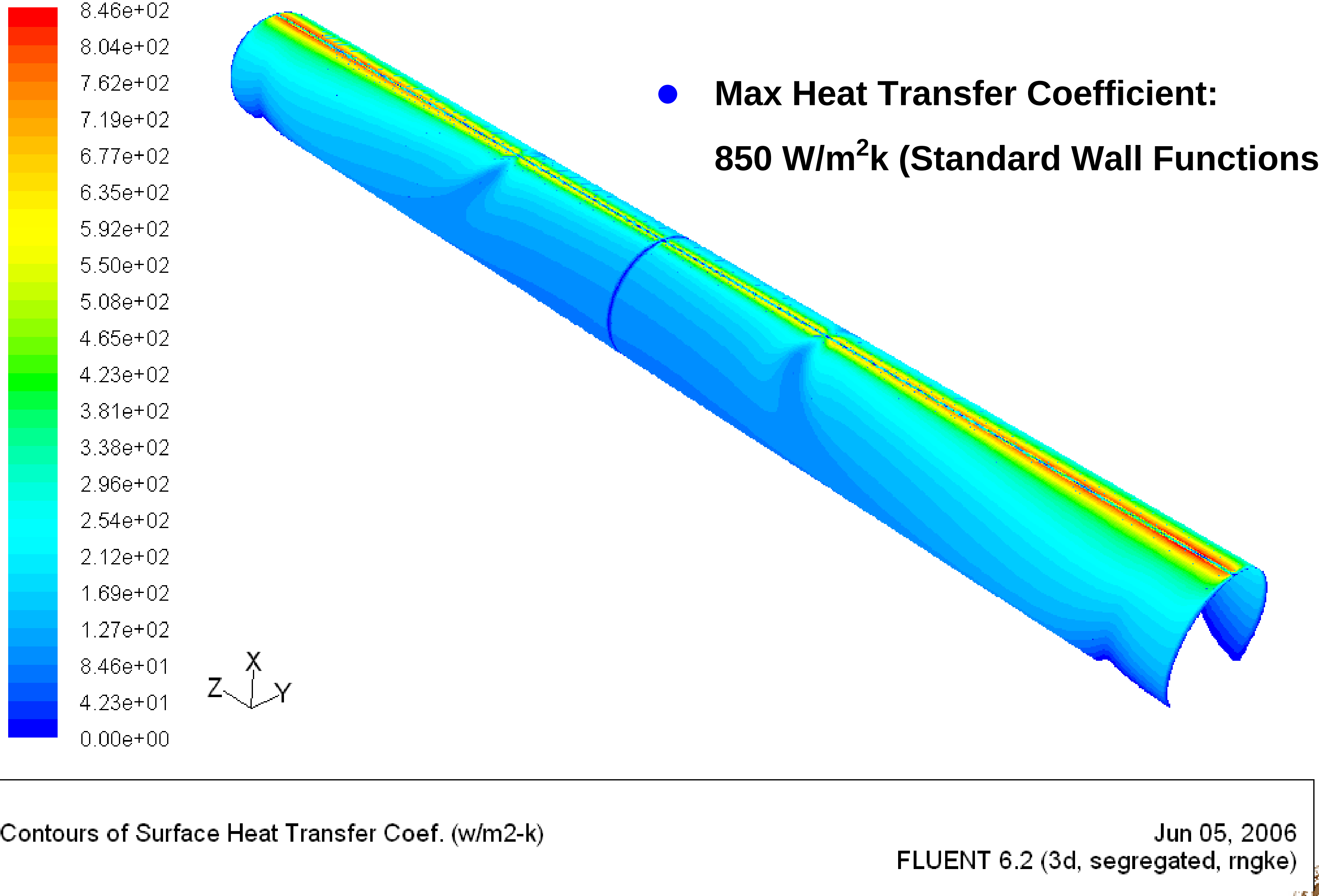


- **Max velocity: 93 m/s**
- **Operating pressure: 14.3 PSI (98 kPa)**
- **Pressure drop: 0.54 PSI (3700 Pa)**

Path Lines Colored by Velocity Magnitude (m/s)

Jun 05, 2006
FLUENT 6.2 (3d, segregated, rngke)

Predicted Performance – Heat Transfer Coefficient (Double Inlet)

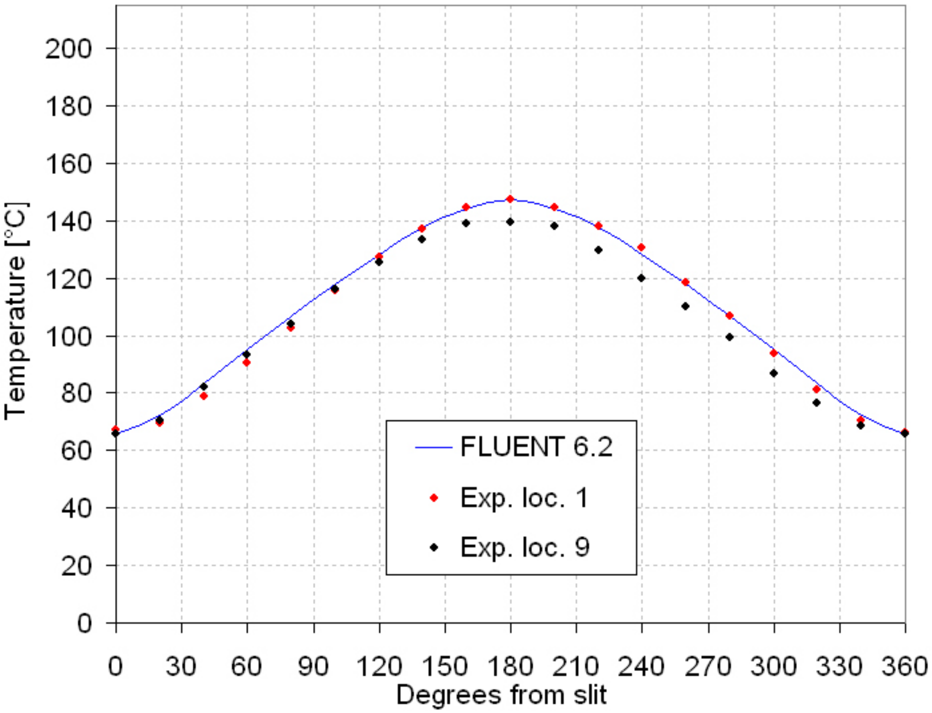


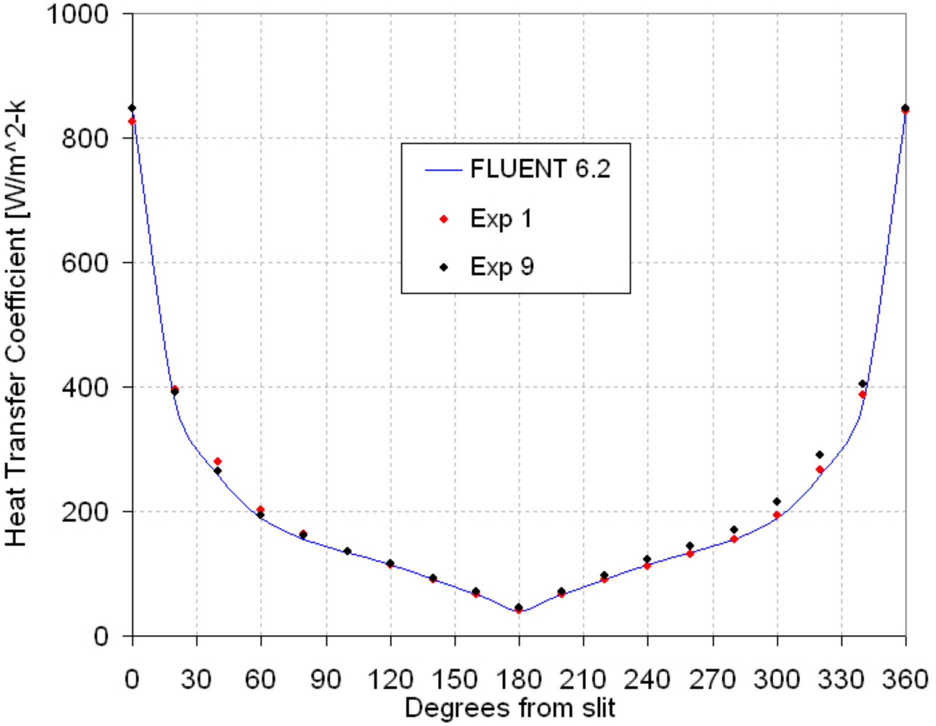
- **Max Heat Transfer Coefficient:**

  850 W/m^{2}k (Standard Wall Functions)

Experimental Results (two inlets) Temperature & Heat Transfer Coefficient

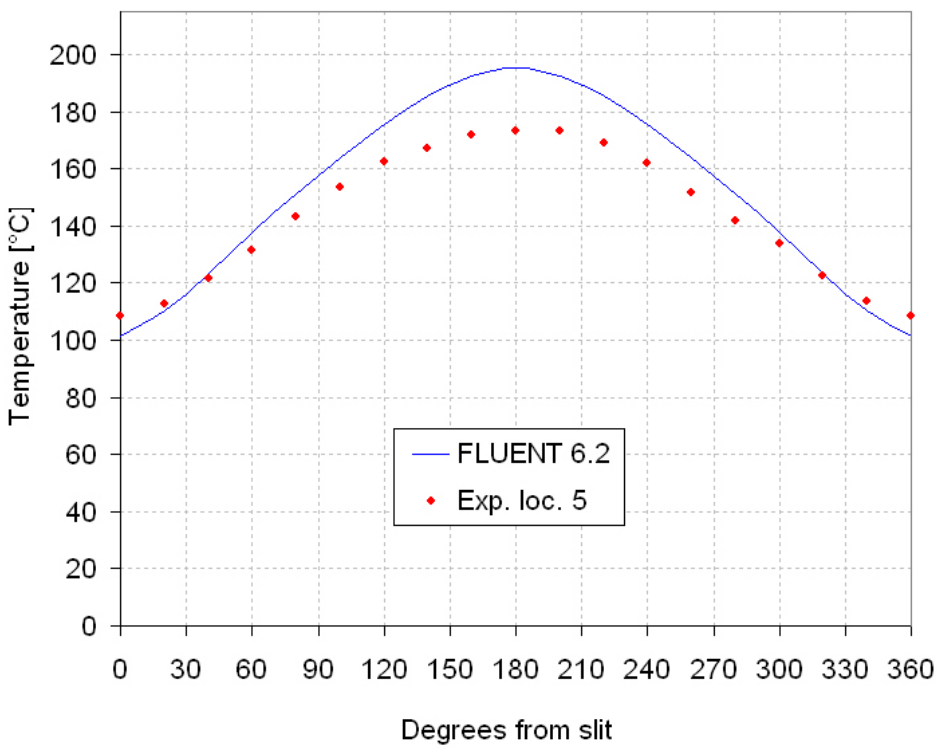
Location 1&9

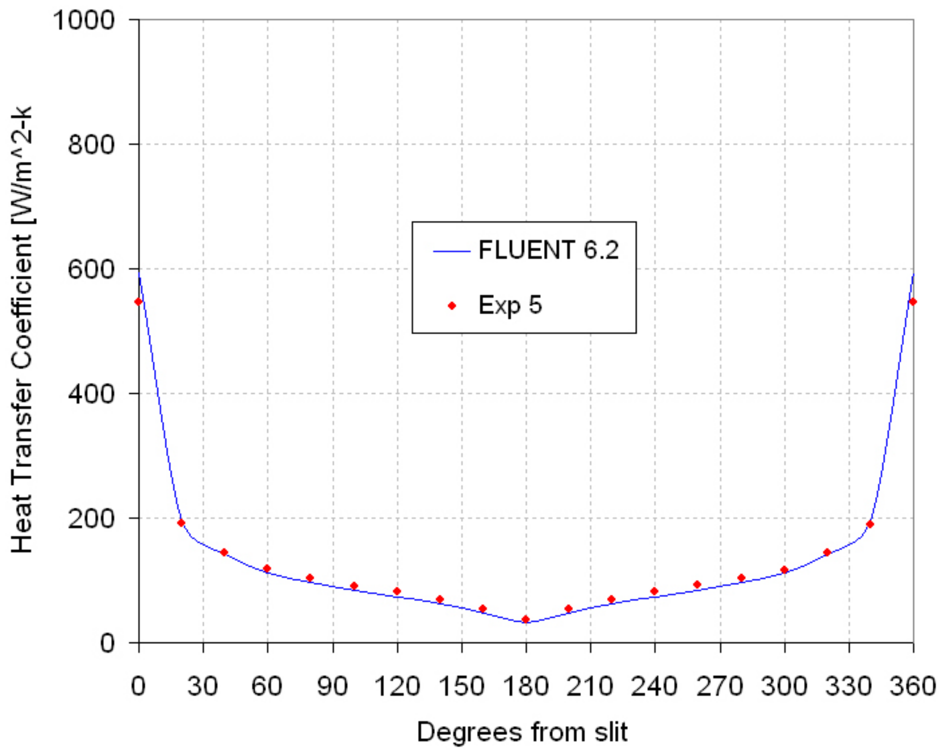




Experimental Results (two inlets) Temperature & Heat Transfer Coefficient

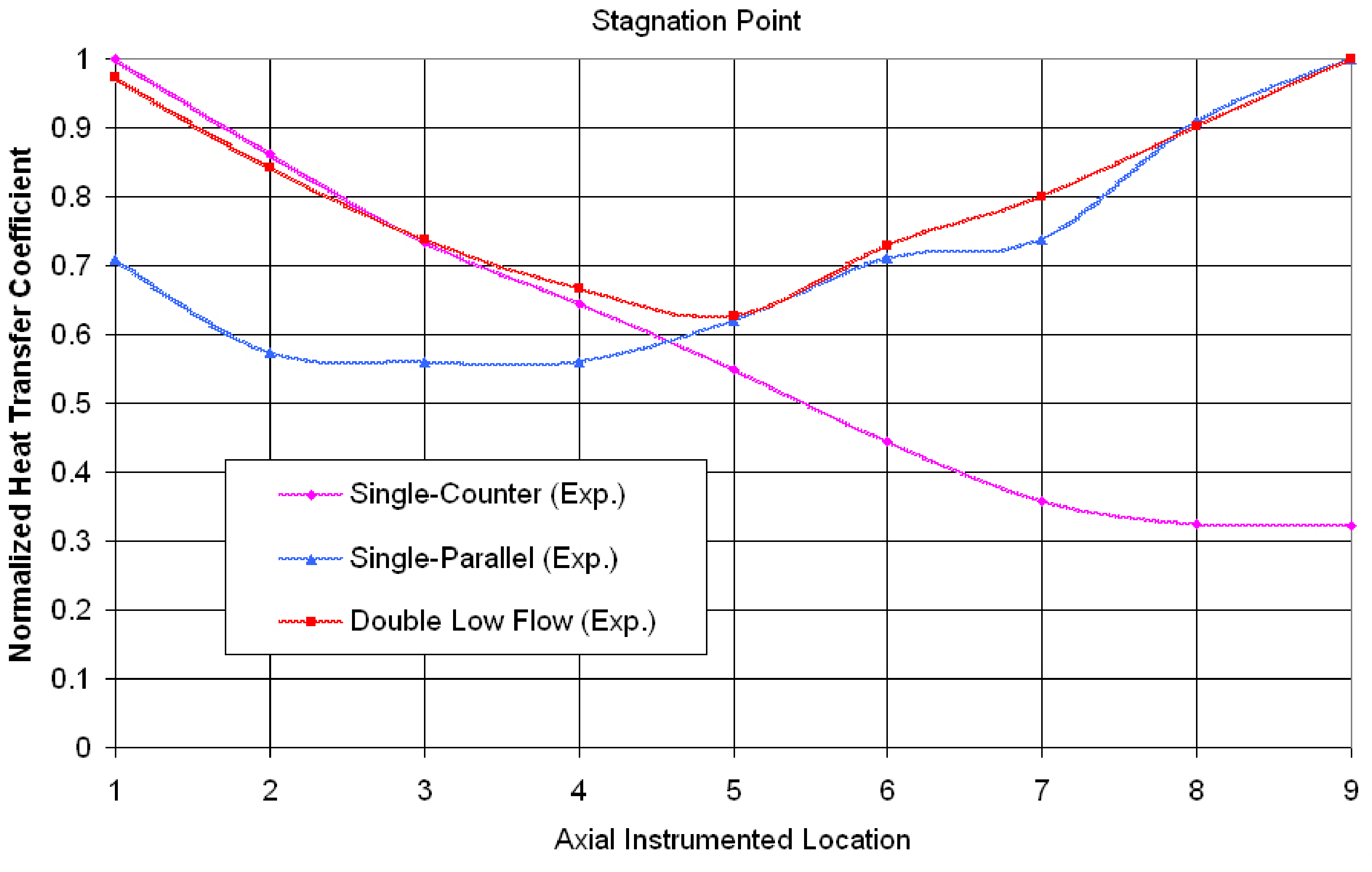
Location 5





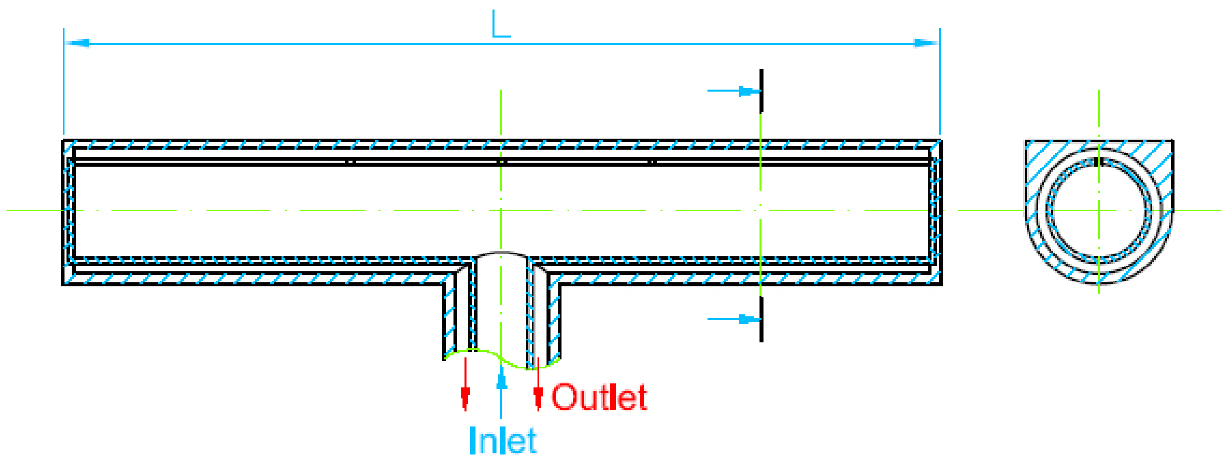
Experimental Results – Axial variation: Effect of Flow Arrangement on Heat Transfer Coefficient

- Flow configuration has a significant effect on axial variation of heat transfer coefficient. Parallel flow arrangement is preferred

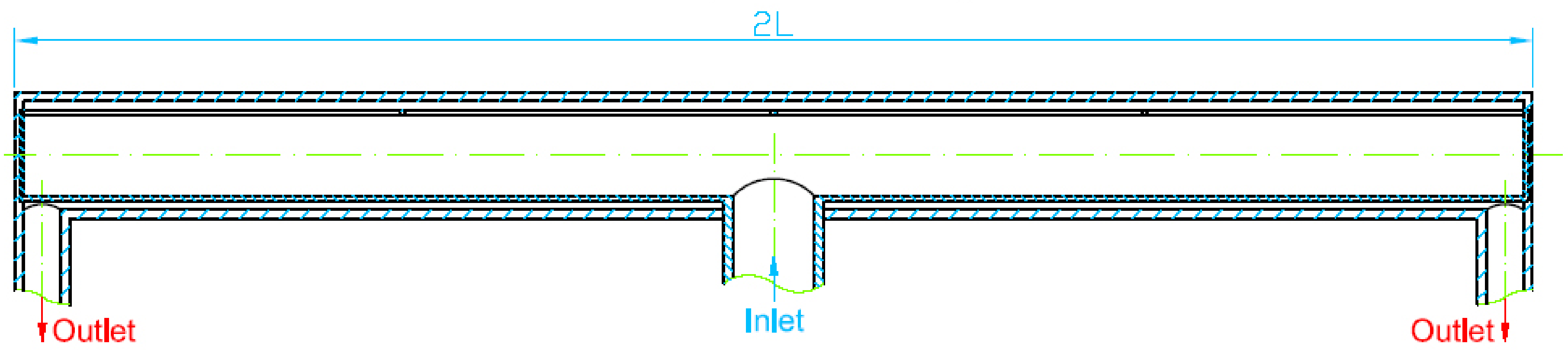


Proposed Design Modification

Current "counter flow" design



Preferred "parallel flow" design



Summary - *Path Forward*

- **Initial results for temperature distribution and local heat transfer coefficient show reasonably good agreement between experimental data and model predictions. Predicted temperatures are conservative.**

- **Flow configuration has a significant impact on axial variations of heat transfer coefficient. Temperature gradients and stress levels in the gas-cooled diveror can be controlled by proper selection of flow configuration. Parallel flow is preferred.**

- **Experiments will be conducted for different gas flow rates, exit pressures, power input levels, and flow configurations.**
  - **Test conditions will be selected to span the expected non-dimensional parameter ranges for the proposed helium-cooled T-Tube divertor**
  - **Data for axial and azimuthal variations of the heat transfer coefficient will be obtained for single and double inlet conditions**