Quantifying the Advantages of Counter Flow Helium First Wall Cooling

A Thermal-Hydraulic Comparison of ITER TBM First Wall Cooling Designs

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Analysis Summary

Objective: Quantify the thermo-hydraulic advantages of a counter flowing helium first wall cooling design to determine whether the additional design complexity is justified.

Method: Computational Fluid Dynamic (CFD) analysis using the commercial software FLUENT.

Results: The complex counter flow design is justified since it utilizes **50% less power** than a more simple "unidirectional" flow design, to achieve an equivalent level of cooling

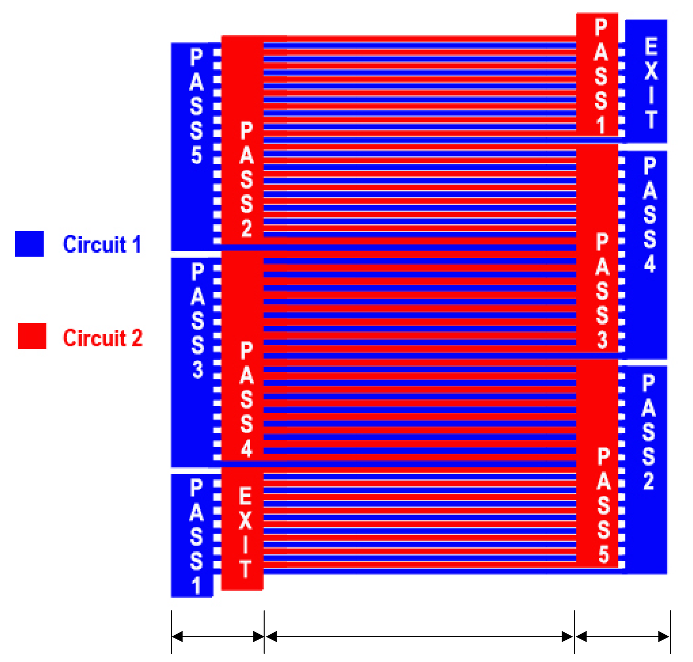
Results					
System	Max. FW Temp. (C)	Mass Flow (kg/s)	He Inlet Temp. (C)	He Outlet Temp. (C)	Power Increase (%)
Counter Flow	523	7.5	360	432	NA
Unidirectional Case I (equivalent mass flow)	538	7.5	360	432	0
Unidirectional Case II (equivalent cooling)	522	7.5	360	423	50

Counter Flowing Helium Analysis

Advantage - Improves Cooling of the First Wall

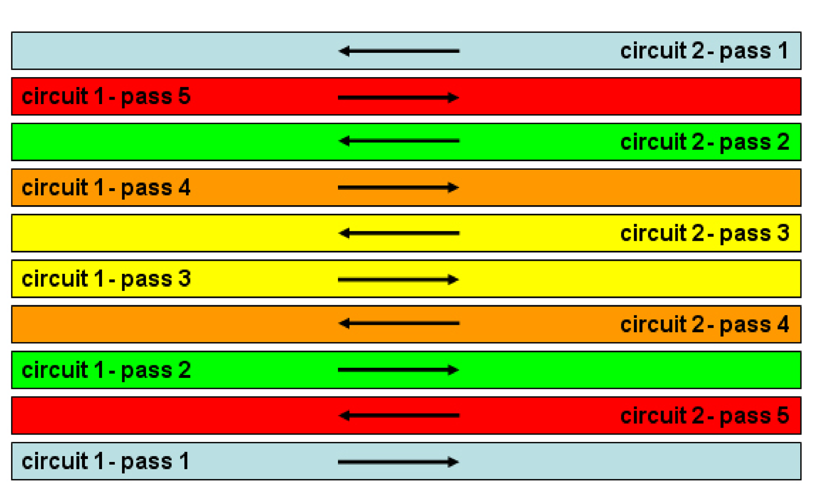
Disadvantage - Complex design requires more space and is more difficult to fabricate and assemble

Counter Flow Design Schematic



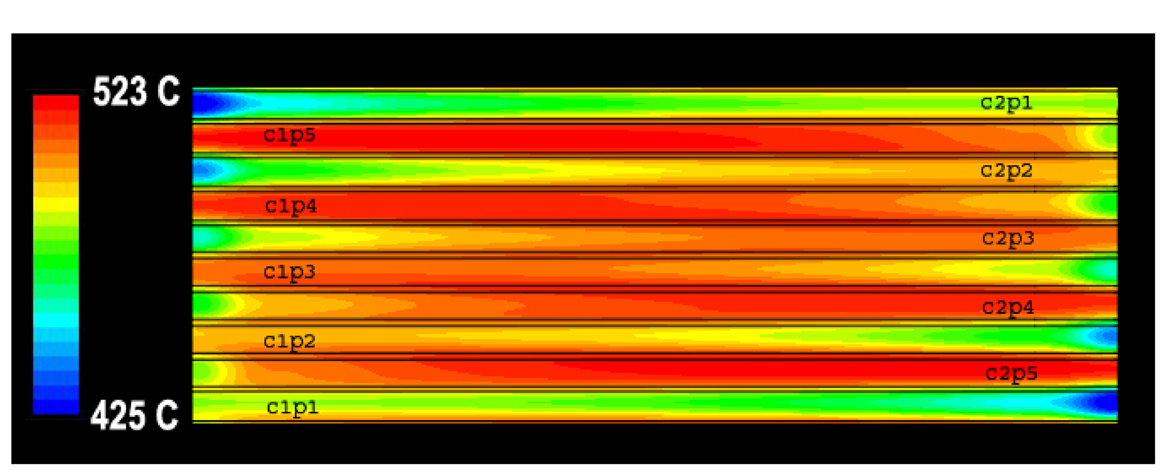
- Two Circuits – Five Passes Each - Counter Channel Flow
- Parallel manifolding requires twice the space

Counter Flow CFD Model Schematic



- Two Circuits – Five Passes Each – One channel per pass

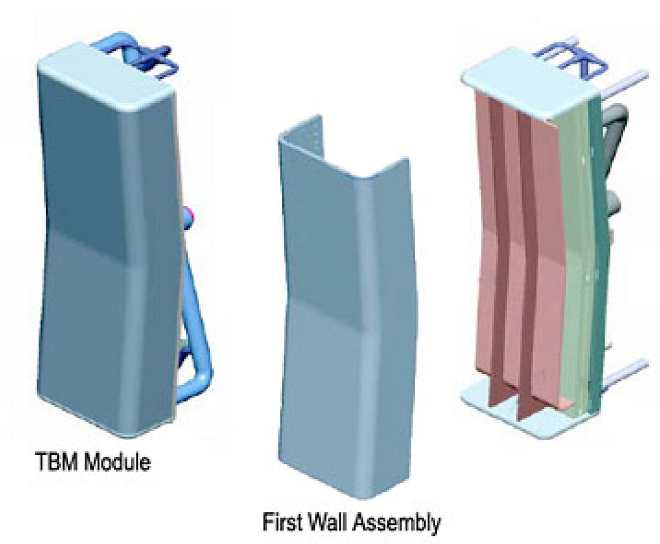
Counter Flow CFD Results



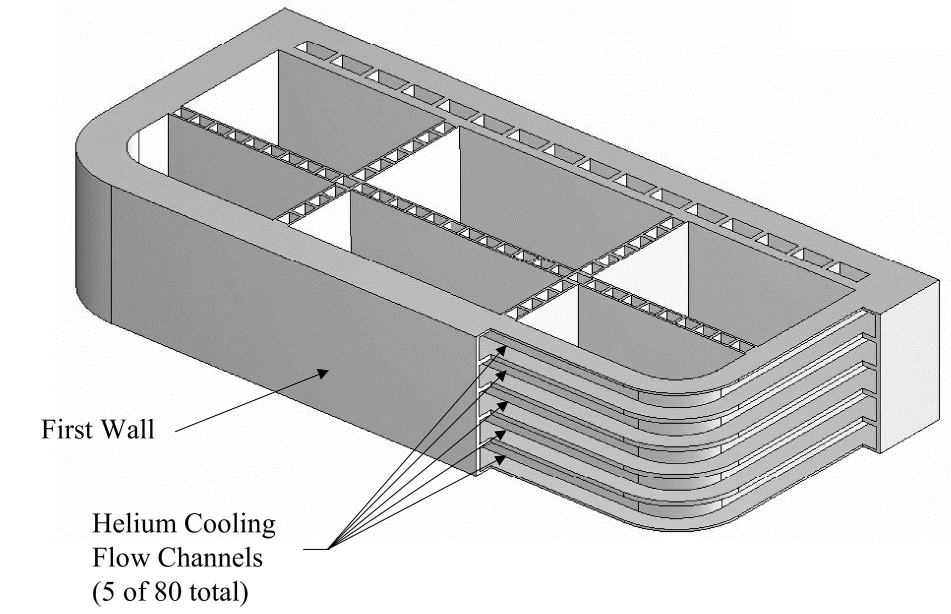
523 C max. FW temperature at 42.6 m/s helium flow velocity

US ITER DCLL Test Blanket Module Design

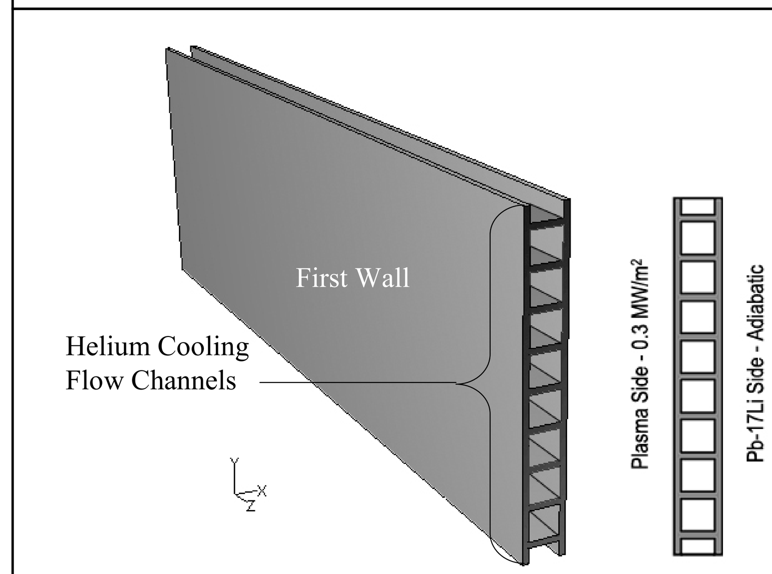
US DCLL Test Blanket Module



TBM Cut-Away Showing FW Cooling Channels



CFD Model



Ten Channel CFD Solution Domain

Material Properties				
Material	Density (kg/m^3)	Cp (J/kg-K)	Thermal Conductivity (W/m-K)	Viscosity (kg/m-s)
He	5.72	5200	0.253	3.5E-05
Fe-(8-9)%Cr	7700	520 to 810[a]	33	NA

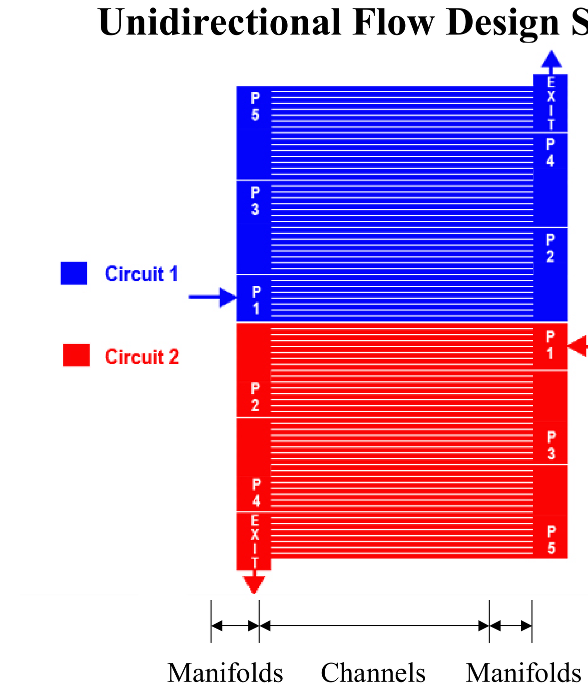
[a] (Cp is defined as a piece-wise linear function of temperature)

"Unidirectional" Flowing Helium Analysis

Advantage – Simple design requiring less space

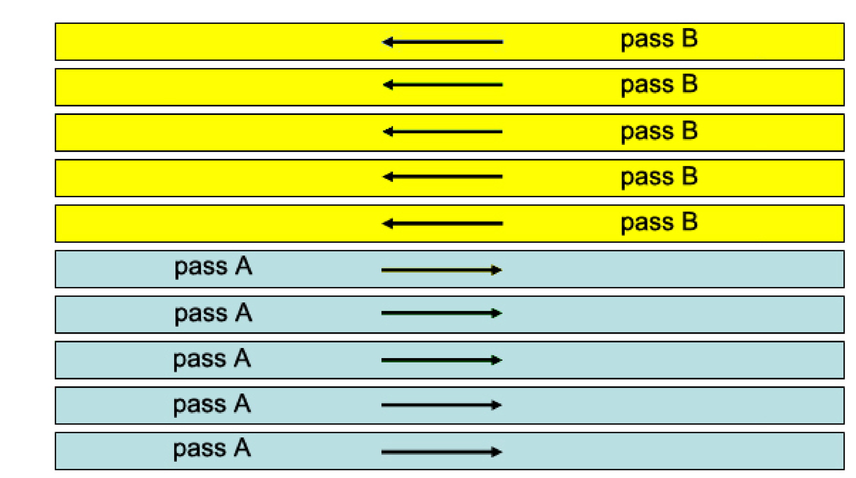
Disadvantage – Requires more helium flow to cool First Wall

Unidirectional Flow Design Schematic



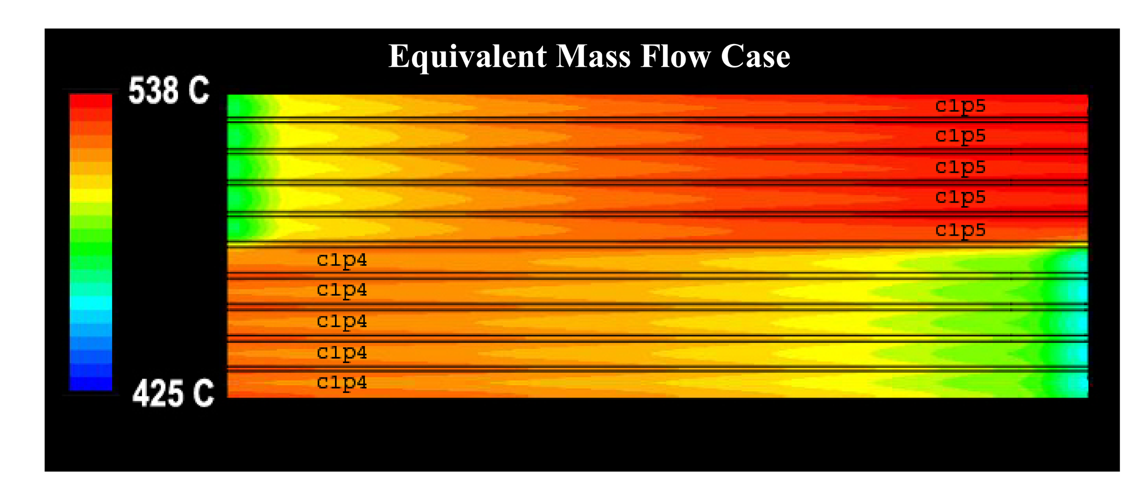
- Two Circuits – Five Passes Each - Unidirectional Channel Flow
- Series manifolding requires half the space of the counter flow design

Unidirectional Flow CFD Model Schematic

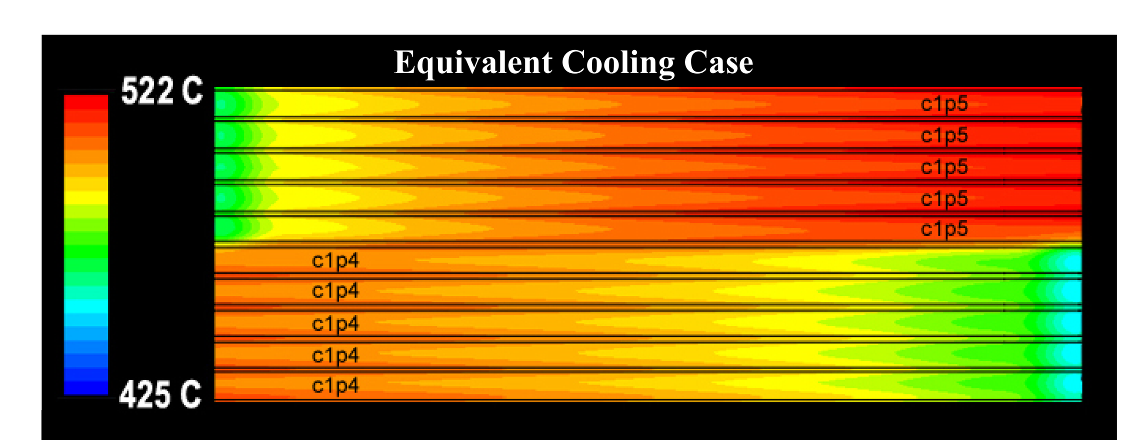


- Two Circuits – Five Passes Each – Five channels per pass
- Successive models solved to reach fifth pass (i.e., models for pass 1 & 2, pass 2 & 3, pass 3& 4, pass 4 & 5

Unidirectional Flow CFD Results



Case I - 538 C max. FW temperature at 42.6 m/s helium flow velocity



Case II - 522 C max. FW temperature at 48.75 m/s helium flow velocity