Improved Geometrical Design of the US DCLL ITER Test Blanket Module

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INTRODUCTION & OBJECTIVES

ABSTRACT:

A Test Blanket Module (TBM) design based on the dual coolant lithium lead (DCLL) blanket concept has been developed by the US in support of the ITER Test Blanket Module program. The ferritic steel structure is cooled by flowing helium within the structural panels. A lithium lead (PbLi) breeder is circulated through the TBM in the poloidal direction for tritium breeding and power extraction.

The current design involves a complex flow path for the helium coolant. Sections of the flow are in series while others are in parallel. This causes flow irregularities that are illustrated here. Design improvements are presented for the areas listed below, which will resolve each problem.

The improved design illustrates a new inlet section which alleviates asymmetric flow in the entry region, new header geometry options between the first wall passes, and a completely new grid plate/divider helium flow scenario. These changes can be incorporated into a global redesign of the TBM based on thermal hydraulic analysis results. The global redesign greatly simplifies the helium flow path within the TBM.

PROBLEM AREAS:

This poster presents design improvements or changes that will alleviate the following problems with the current TBM design:

- **PbLi Hot-Spot due to Neutron & Gamma Heating**
- **Helium Flow Asymmetry in the Entry Region**
- **Uneven Flow in the First Wall and Headers**
- **Uneven Flow in Grid Plates & Dividers**

PbLi HOT SPOT ANALYSIS & REDESIGN

THE PROBLEM:

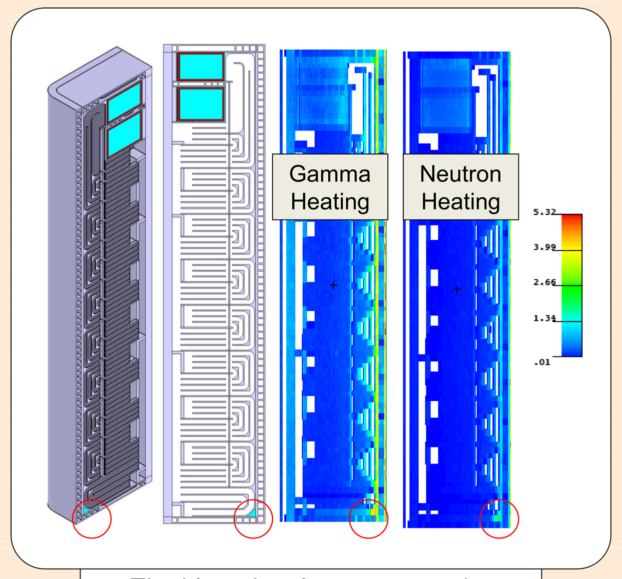
Neutronics analysis of the TBM has shown that a hot spot exists between the poloidal PbLi channels where a geometrical feature has been added to allow for draining of the PbLi from the TBM.

This hot spot could cause undesired thermal expansion and stress in that region.

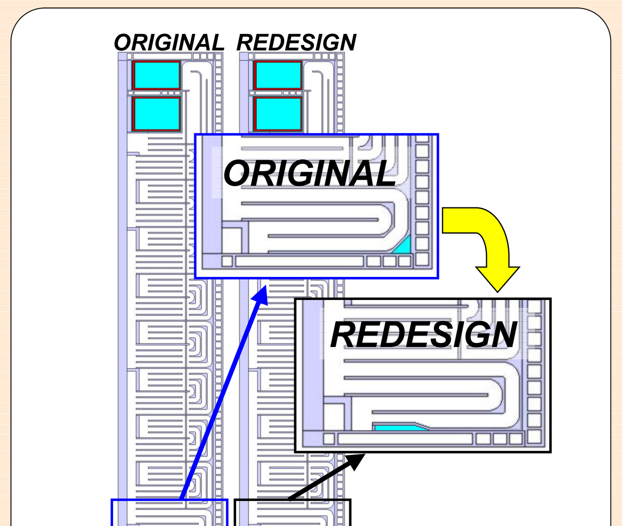
THE SOLUTION:

A local solution can be found by moving the PbLi drain feature from the front of the TBM to the rear of the PbLi region.

This moves the area of stagnant PbLi flow away from the high heating region of the front of the TBM.



The blue triangle represents the location of the PbLi Hot Spot



The PbLi drain moves from the front to the middle into a lower heat zone

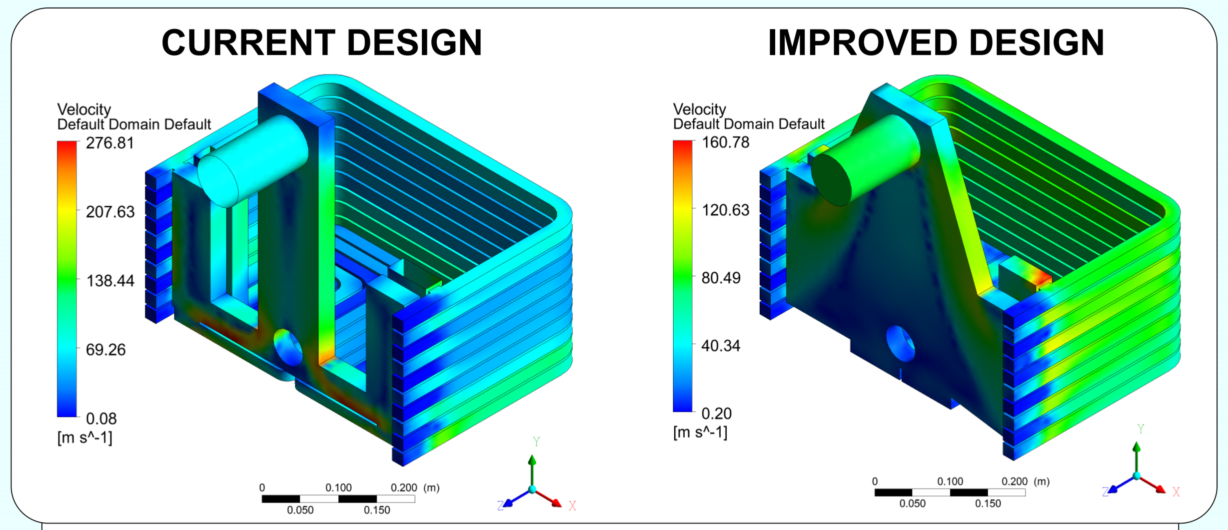
HELIUM INLET ASYMMETRY ANALYSIS & REDESIGN

THE PROBLEM:

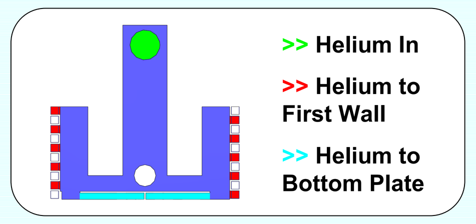
The helium Inlet region induces uneven flow within the initial first wall passes. This is due to helium flow entering the bottom plate and first wall differently for the two helium circuits.

On one side the flow enters the bottom plate and one of the first wall channels at the same 'elevation.' On the other side the flow enters the bottom plate and the first wall channels at different 'elevations.'

This leads to flow asymmetry in the first wall channels and bottom plate.



These images show the velocity throughout the helium entry region. Note that the peak velocity in the current design reaches 276 m/s while the redesign only reaches 160 m/s. Also note (by color) the differences in velocity across the 10 first wall channels in the current design and the similarity of velocity across the channels in the redesign.

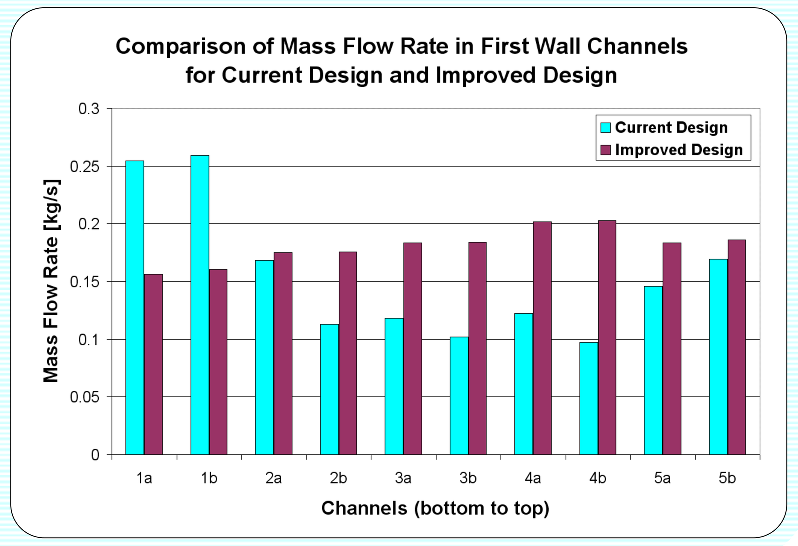


THE SOLUTION:

A global redesign allows for a fully redesigned helium entry region. The redesigned entry region routes helium to the bottom plate through openings in the middle of the TBM. The helium to the first wall channels is much less restricted, which results in more symmetric flow.

KEY RESULTS:

	CURRENT DESIGN	IMPROVED DESIGN
Maximum Channel Mass Flow Rate [kg/s]	0.2594	0.2027
Minimum Channel Mass Flow Rate [kg/s]	0.0971	0.1562
Channel Mass Flow Rate Ratio [max/min]	2.672	1.298
Average Channel Mass Flow [kg/s]	0.1550	0.1809
Ratio of Outlet 1 Mass Flow to Outlet 2 Mass Flow	0.8839	1.0011



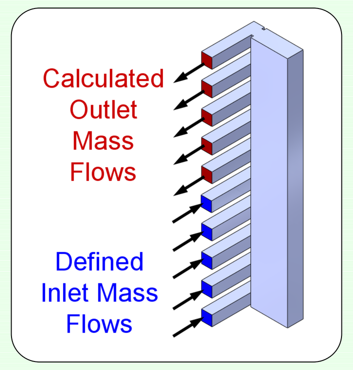
HEADER FLOW DISTRIBUTION ANALYSIS & REDESIGN

THE PROBLEM:

It is believed that hot spots and potential melting could occur on the first wall if helium flow is not uniform through the first wall channels.

A small difference in channel mass flow rate could lead to heat transfer rates that vary by up to 25%.

It is critical that the first wall temperature remains below 550C to prevent melting.



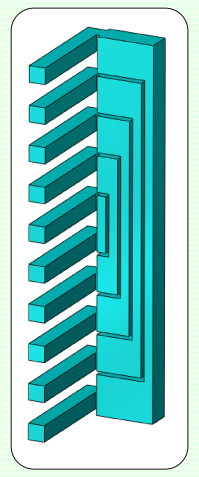
THE ANALYSIS:

Fluid dynamics software was used to analyze the current geometry and the flow steering geometry to determine the flow evenness through the first wall channels.

Three simulations were done for each geometry. The outlet conditions of the first simulation were used as the inlet conditions for the second. This was repeated with the outlet conditions of the second simulation as the inlet conditions of the third simulation.

POSSIBLE SOLUTIONS:

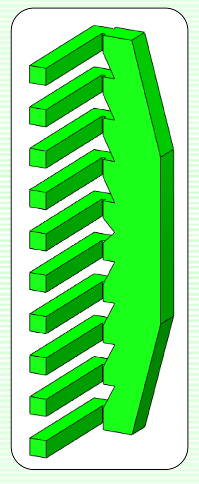
FLOW CONTINUATION



This concept directly routes flow from one channel to the next.

Mass Flow rates would be equal but no mixing would occur.

FLOW STEERING

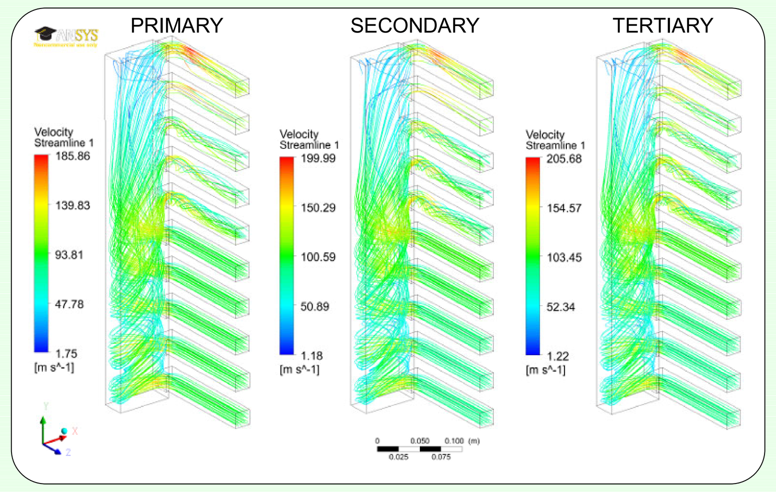


This concept attempts to 'steer' flow into channels more evenly while still mixing within the header.

Mass flow rates would not be equal.

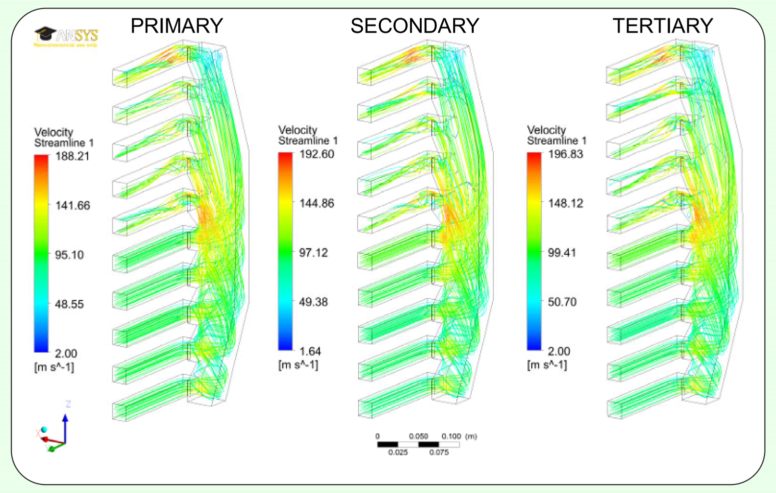
Current Geometry:

	Initial V	Primary Out	Secondary Out	Tertiary Out
In 1	90	84.82	86.00	85.96
In 2	90	83.10	83.18	83.23
In 3	90	87.38	86.66	86.66
In 4	90	93.74	93.07	93.06
In 5	90	101.0	101.1	101.1



Improved Geometry:

	Initial V	Primary Out	Secondary Out	Tertiary Out
In 1	90	85.11	86.51	86.18
In 2	90	87.47	87.60	87.08
In 3	90	85.30	83.57	83.93
In 4	90	91.37	91.21	91.48
In 5	90	100.7	101.1	101.3



THE RESULTS:

The flow steering analysis was expected to produce more even flow than the current geometry. This can be measured by determining the standard deviation of velocities in each simulation of the channels. Doing so illustrates the (minor) improvement of the flow steering geometry.

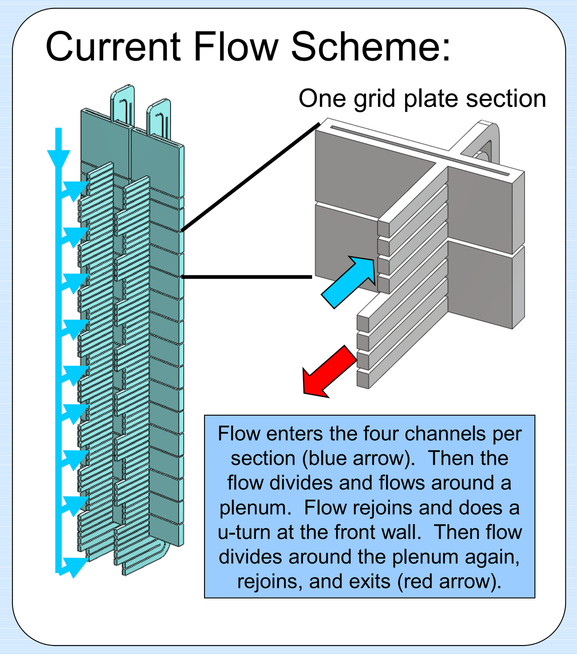
	Current Geometry	Improved Geometry
Primary Out – Secondary In	7.33	6.51
Secondary Out – Tertiary In	7.18	6.79
Tertiary Out	7.18	6.90

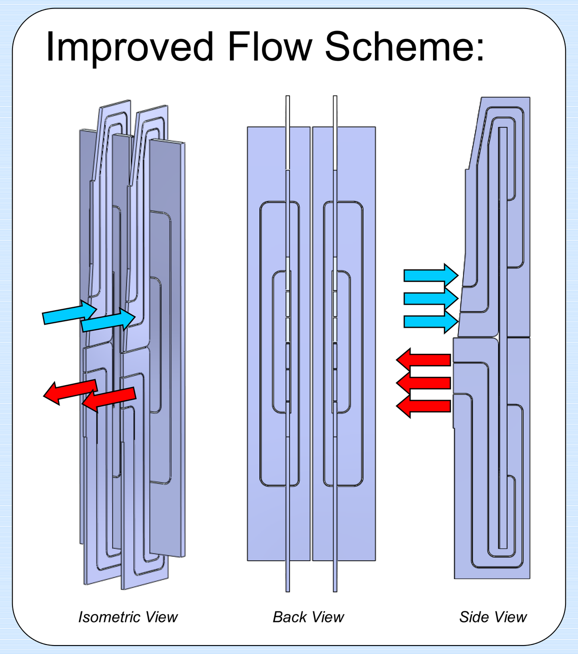
GRID PLATE/DIVIDERS ANALYSIS AND REDESIGN

THE PROBLEM:

At this point in the TBM the helium switches from serial flow to parallel flow. The helium must enter the Grid Plate/Divider assembly in 68 individual channels from the same manifold. Analysis results indicate that the current design will not achieve even flow in those 68 channels.

Even flow is important for achieving appropriate heat transfer with the PbLi. Hot spots within the Grid Plate/Divider assembly could cause warping and/or fracture in the PbLi region, which would be unacceptable.





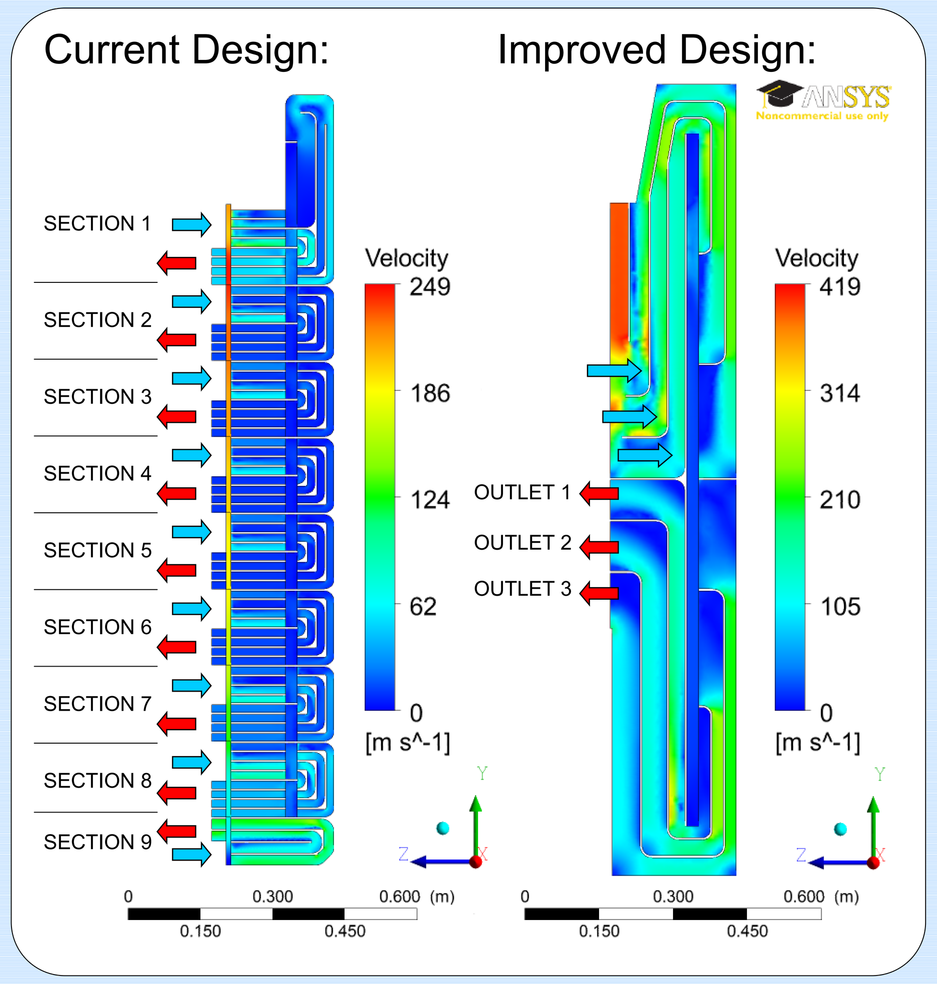
THE SOLUTION:

The proposed solution here eliminates much of the parallel flow, reducing the number of parallel channels from 68 to six. The number of turns within the channels, and therefore the pressure drop, will also be reduced.

Flow enters the grid plates, flows vertically over the top of the dividers and down the front side of the TBM. Flow then enters the divider plates, where it spreads and flows down. It then re-enters the grid plates in the front, flows down and around the dividers at the bottom. Finally flow goes up the grid plate and exits.

THE ANALYSIS:

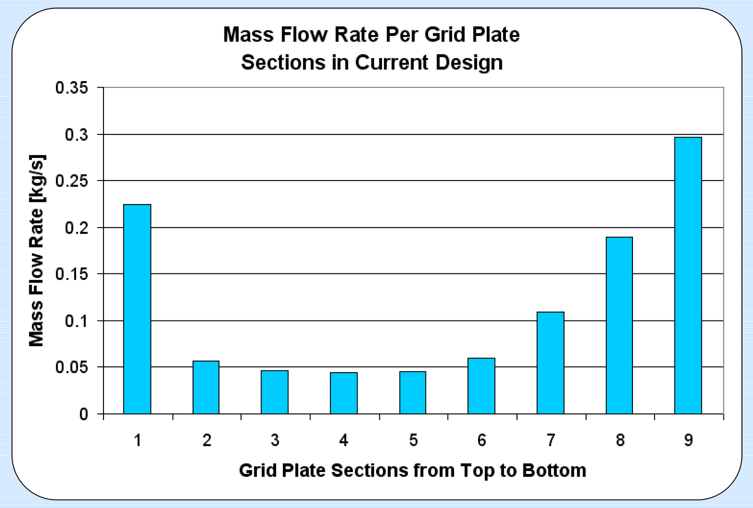
Fluid dynamics software was used to analyze the current flow scheme and the improved flow scheme to determine the evenness of flow and to determine if the improved geometry is advantageous over the current geometry.



THE RESULTS:

The results from the analysis of the current geometry illustrate that there is very uneven flow received by the grid plate sections. The figure below shows this discrepancy. If flow went evenly to each section, then each section should have 0.11 kg/s mass flow rate. The results show several sections with less than 0.05 kg/s while others have over 0.2 kg/s. This is unacceptable for flow uniformity.

The results from the improved geometry show that flow is very even between the three channels. These values are shown in the table below right.



IMPROVED DESIGN RESULTS AND NOTES:

	MASS FLOW RATE [kg/s]
OUTLET 1	0.347
OUTLET 2	0.383
OUTLET 3	0.336

The peak velocity can easily be alleviated with a graduated flow reduction to the three grid plate inlets.

Flow evenness within the three channels can be increased with interior baffles.

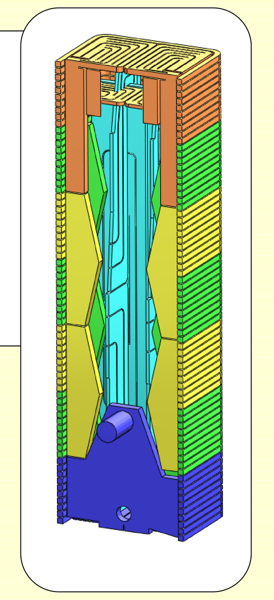
CONCLUSIONS & FUTURE WORK

This poster has presented improved designs for four problematic flow areas in the Test Blanket Module. The results have shown improvements in terms of mass flow evenness and flow uniformity.

These results are not complete or exhaustive, but are meant to illustrate that considerable improvements can, and should, be made to the Test Blanket Module design.

FUTURE WORK:

A full redesign of the helium flow within the TBM can be completed by implementing and optimizing the improvements presented in this poster. Analysis should follow.



What we can take from the results are the following:

1. **The PbLi Hot Spot can easily be adjusted.**
2. **Flow in the current helium entry region does not evenly distribute to the first wall channels, but can be more even with the improved design.**
3. **Modifications can be made to increase the flow uniformity through the first wall header regions.**
4. **Highly uneven flow distribution exists in the Grid Plate/Divider assemblies. Higher uniformity can be achieved with the improved design.**