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17 NGF Grid Concepts and Scoping Analysis
(T/H related)

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Abstract

There are 3 canditates, as C-01, C-02 and C-03, to achieve design goal with the scoping analysis based on proven design. The scoping analyses include Water DNB/Heat Transfer, PIV/ Local Heat Transfer/CFD, Pressure Drop and Mass Evaporation. Mixing, heat transfer, and DNB testing with uniform axial power shape for all three vane designs give the results ; inter-channel mixing was found to be highest for the C-02, followed by the C-01 and the C-03, critical bundle power was similar for the C-01 and C-02, followed by the C-03. However, the DNB performance of the vanes is similar based on the subchannel analysis using the measured mixing factor. The heat transfer coefficient for all candidates may be equivalent at a short span of the grid. The results of the PIV tests and CFD studies showed that all the vane concepts produced similar hotspots. These hotspots were regions of locally low heat transfer, created when the impinging vortex flow separates from the cladding surface. The CFD results, however, were in conflict primarily because of their inability to correctly predict the magnitude of swirl at significant distances downstream of the grid. While the absolute value of predicted heat transfer for large distances could not be trusted, the CFD analysis was still considered acceptable for comparisons of heat transfer within 4-5 inches of the grid. The scoping analyses have provided good validation of methods to estimate the pressure drops of the grids based on specific features. Although a negative aspect of both the I-spring and the additional IFMs, the maximum increase in pressure drop is within a 10 percent relative to baseline. Peak mass is generally considered to be the best indicator of CIPS risk, although there are many other factors that come into play. An assessment was performed of the impact of additional IFMs and the C-02 vane on the mass evaporation for both nominal and extended uprated conditions. The mass evaporation was reduced 15% due to the additional IFMs, and an additional 15% due to increased heat transfer coefficient. These values are reduced to a combined 15% for extended power uprated conditions.

1. Background: Grid Design Goals

The key design goals for the NGF(Next Generation Fuel) grid were:

a) maintaining assembly pressure drop increase below 5% relative to baseline(RFA series),
b) improve forced convection heat transfer and reduce "hot spots", which have been tied to areas of high mass evaporation and excessive crud deposition, while maintaining DNB performance,
c) reduce the manufacturing costs,
d) a goal to achieve sufficient thermal margin to support an uprating of 10% beyond current reactor stretch ratings.

2. Grid Concepts

2.1 Grid Inner Strap Springs and Dimples

The I-spring design consisting of a vertical spring and tall dimples as shown in Figure 1, was chosen as the leading design concept, based on similarity to other vertical spring designs performing well in the field. A key feature of the I-spring is the ability to introduce cold work into the arches supporting the spring, making the I-spring deflect inward during irradiation due to differential growth, reducing the gap between the fuel rod and the grid support. However, a relatively large window is required around the I-spring to allow forming tools to pull the arches back for cold work. This open window may allow cross flow between sub-channels, caused by redistribution of flow around the spring, and resistance to flow by the mixing vanes. This may starve some sub-channels of flow, reducing thermal and possibly fretting margins. This concern was raised because the RFA (and RFA-2) grids, with high DNB margins, have closed windows, while the V5H, with lower DNB margin and high frequency vibration, has an open window.

The NGF IFM grid strap is similar to the current RFA design.

2.2 Mixing Vanes

Three concepts were selected based on proven baseline technology with some modifications :

1. C-01 is a relatively minor modification to the current RFA split vane. The vane tip was modified to allow some clearance for the larger support features.
2. C-02 eliminates the central cut out in C-01, for a solid split vane design. This design requires an internal weld. This design was intended to produce a stronger central swirl compared with C-01, but still producing inter-channel flow.
3. C-03 is a scaled version of the 14TURBO side supported vane. This design also requires an internal weld. This design is intended to produce primarily a strong central swirl in the sub channel.

2.3 Short Span with Additional IFMs

To achieve the goal of both the b) and the d) with conserving the goal of a), the concept of short span is applied at the location of susceptible on CIPS(Crud Induced Power Suppression) or thermal performance. There are spans with more than 2 IFMs at the upper half of the active fuel. They are expected to give less pressure drop and more swirl, and result in increasing of thermal performance without significant challenges.

3. Summary of Analysis and Testing Results

3.1 Water DNB and Heat Transfer

Mixing, heat transfer, and DNB testing with uniform axial power shape were completed at the HTRF in Columbia University for all three vane designs. The inter-channel mixing was found to be highest for the C-02, followed by the C-01 and the C-03. The critical bundle power data are shown in Figure 2. The lower critical power for the C-03 is due in large part to the lower inter-channel mixing of this vane. When sub channel analysis is performed to obtain local fluid conditions using the measured mixing factor, the DNB performance of the vanes becomes similar as shown in Figure 3. For in-reactor situations, there is some additional benefit to be obtained for higher mixing factor vanes as shown in Figure 4.

The key target for improvement for the NGF vane was forced convection heat transfer. Forced convection heat transfer data were also obtained from the HTRF tests, at a distance of 9 inches downstream of the last grid. The C-02 and C-03 vanes produced a higher heat transfer coefficient than the C-01 design as seen in Figure 5. The results were checked at both the end of heated length (EOHL) and a position 10.28” (one grid span) below the EOHL.

3.2 PIV, Local Heat Transfer, and CFD

Particle Image Velocimetry (PIV) tests and heat transfer tests at Clemson of all three vane concepts were completed. Computational Fluid Dynamics (CFD) models of the three vane concepts (with the same spring design) were completed and compared to these data. The results of the tests and CFD studies showed that all the vane concepts produced similar hotspots. These hotspots were regions of locally low heat transfer as shown in Figure 6. The hotspot is created when the impinging vortex flow separates from the cladding surface. It was evident based on these studies that a more substantial change was needed in the vane to produce a significantly different flow pattern and reduced hot spot.

In addition, the CFD calculations produced results in conflict with the Columbia University results. The heat transfer coefficient of the C-01 vane was predicted to be similar to C-02 and higher than C-03. After much analysis and discussion, it was concluded that the CFD results were in conflict primarily because of their inability to correctly predict the magnitude of swirl at significant distances downstream of the grid. Figure 7 shows actual swirl patterns measured by PIV 1.8 and 5.9 inches downstream of the grid. It can be seen that the central uniform swirl is preserved for a longer distance for both the C-02 and the C-03 vane. In contrast, the CFD analysis predicted that the vortex produced by the C-02 vane decayed more rapidly than the other two, as shown in Figure 8. Based on the PIV tests, it was concluded that the increased measured heat transfer is because the C-02 and C-03 vanes were able to preserve the swirl for a larger distance downstream. An additional effect that cannot be ignored is that of the bounding walls in both the HTRF and PIV tests; at large distances, the walls would be expected to affect the central region of the grid, particularly for high mixing grids such as C-01 and C-02.

While the absolute value of predicted heat transfer for longer distances could not be trusted, the CFD analysis was still considered acceptable for comparisons of heat transfer within 4-5 inches of the grid. An extensive effort was initiated to find a new vane design that would improve heat transfer while reducing hotspots. Unfortunately, all of the swirl producing vanes also produced hotspots.

3.3 Pressure drop

The scoping tests have provided good validation of methods to estimate the pressure drops of the grids based on specific features. A negative aspect of the I-spring, the additional IFMs and the C-02 vane is their larger pressure drops relative to RFA-2. For the original design with three IFMs, this issue was successfully addressed by reducing the pressure drop of the bottom nozzle, as shown in Table 1. The NGF assembly with 3 IFMs and C-01 vanes will have the same loss coefficient as the RFA assembly. Although the pressure drop distribution is different, requiring some transition core analysis, several other analyses affected by overall assembly pressure drop (such as spring hold-down force) may not be required. A design with 5 IFMs and C-01 vanes would result in a 8 percent higher loss coefficient. If C-02 vanes are included on all grids, a maximum10 percent increase in pressure drop results. Studies are continuing to determine the impact of a 10 percent higher pressure drop on transition cores and reactor internals.

3.4 Mass Evaporation

Peak mass evaporation (boiling heat flux divided by H_{fg}) is generally considered to be the best indicator of CIPS risk, although there are many other factors that come into play. An assessment was performed of the impact of additional IFMs and the C-02 vane on the mass evaporation for both nominal and extended uprated conditions. The corresponding mass evaporation is shown in Figures 9 and 10. The mass evaporation was reduced 15% due to the additional IFMs, and an additional 15% due to increased heat transfer coefficient. These values are reduced to a combined 15% for extended power uprated conditions. Note also that boiling under the grid is predicted. This is a potential new phenomenon that will have to be carefully tested if extended power uprates are considered, to confirm that fuel rod integrity is not compromised.

Studies are continuing to assess the impact of the additional IFMs and higher heat transfer mixing vane on the prediction of CIPS using the latest tools. Full verification, however, will have to await future heat transfer and crud deposition tests and LTA performance.

4. Summary

The results of scoping tests for 3 canditate models are discussed in this work. The results related to thermal performance, such as DNB/Heat Transfer/Mixing, shows equal or better than that of baseline and maximum increase in pressure drop is within 10% relative to baseline. The results of hot spot, PIV, and CFD analysis give good measures the improvement of the 17 NGF grid concepts as the thermal performance tests do. The mass evaporation rate, indicator of CIPS susceptibility, is significantly reduced even at the uprated conditions.

Acknowledgments

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Reference

[1] FLUENT User’s Manual, Fluent Inc., 2001
[2] 김홍주 외, “ 차세대 핵연료 유동혼합날개 개발을 위한 수치해석, ” 2002 추계학술발표회 논문집, 한국원자력학회 (게재예정)

Table 1. Comparison of Pressure Drop Changes

Canditates	C-01 or C-03		C-02	
IFM Config.			MIFM	RFA IFM
	3 MIFM	5MIFM	5IFM	5IFM
Upper Core Plate	0	←	←	←
Top Nozzle (RTN)	0	←	←	←
Top Grid (8)	0	←	←	←
MV Grid (2-7)	**0.16**	←	**0.21**	←
IFM	**0.08**	←	←	**0**
Rod Friction	-0.08	-0.12	←	←
Bottom Grid/Pgrid	0	←	←	←
Bottom Nozzle	**-1.12**	←	←	←
Lower Core Plate	0	←	←	←
Assembly (%)	0	7.79	9.24	7.29
Core (%)	0	6.85	8.14	6.41

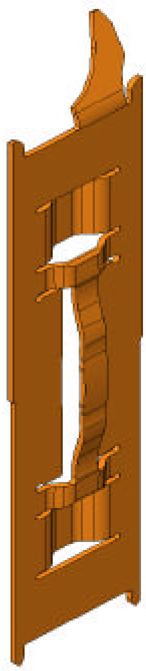


Figure 1. I-spring Strap Design

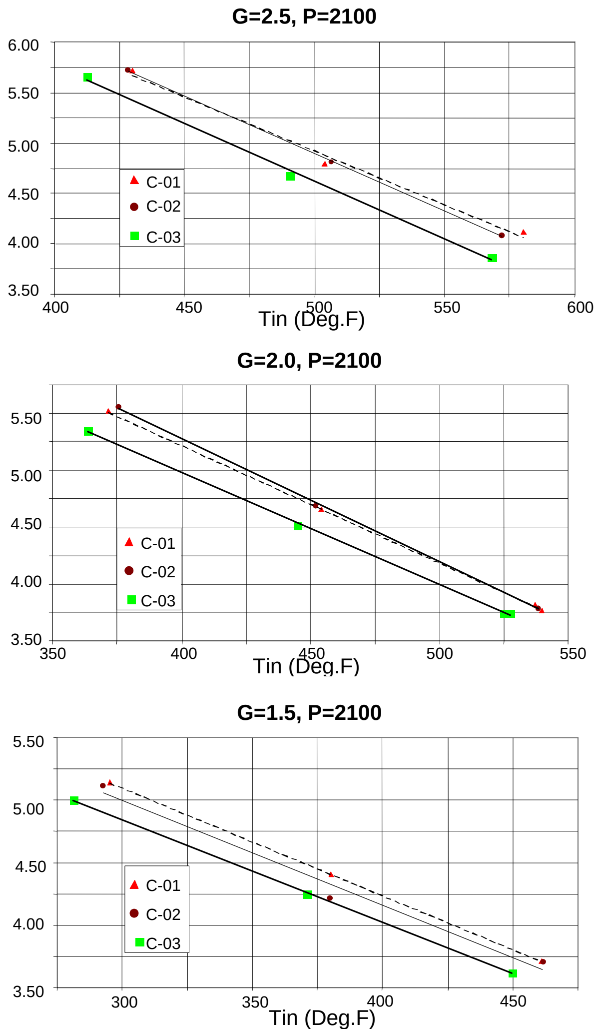


Figure 2. Critical Bundle Power Data

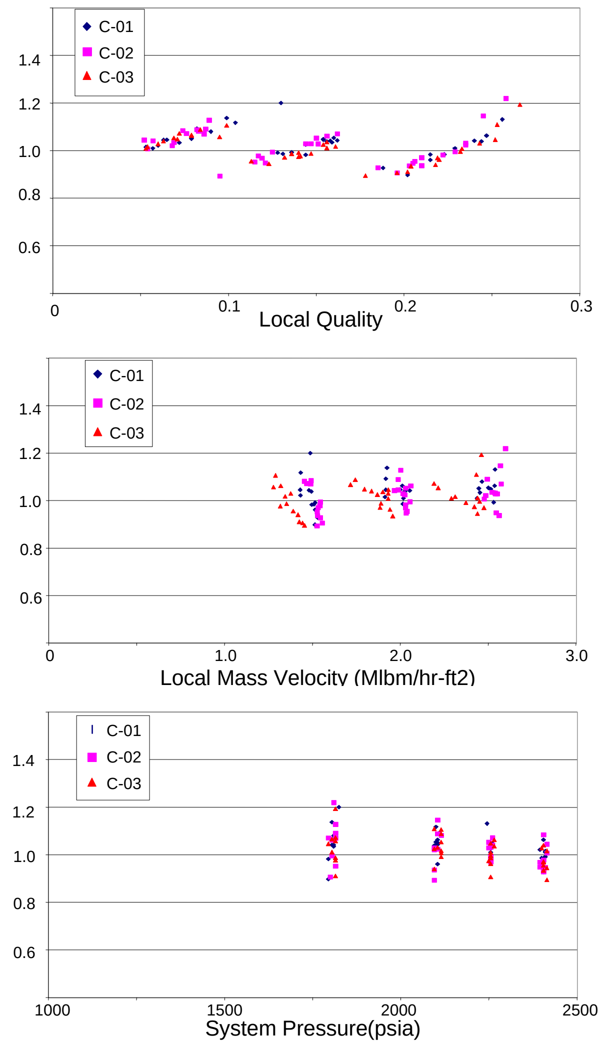


Figure 3. DNB Performance (relative to WRB2M) using Local Coolant Conditions.

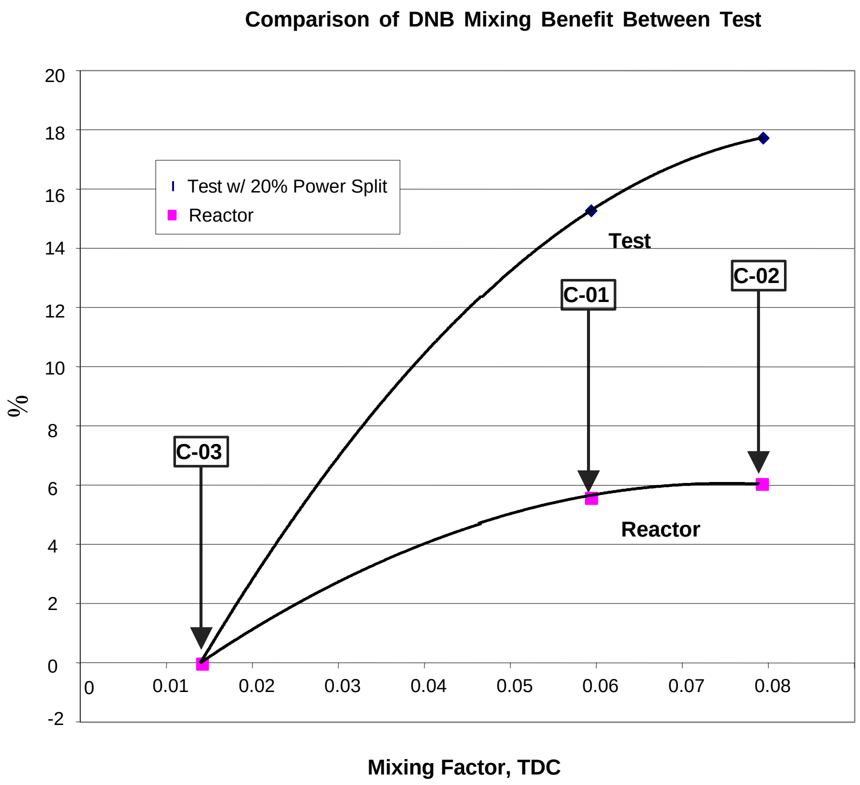


Figure 4. Additional DNB Benefit to be Obtained from High Mixing Design

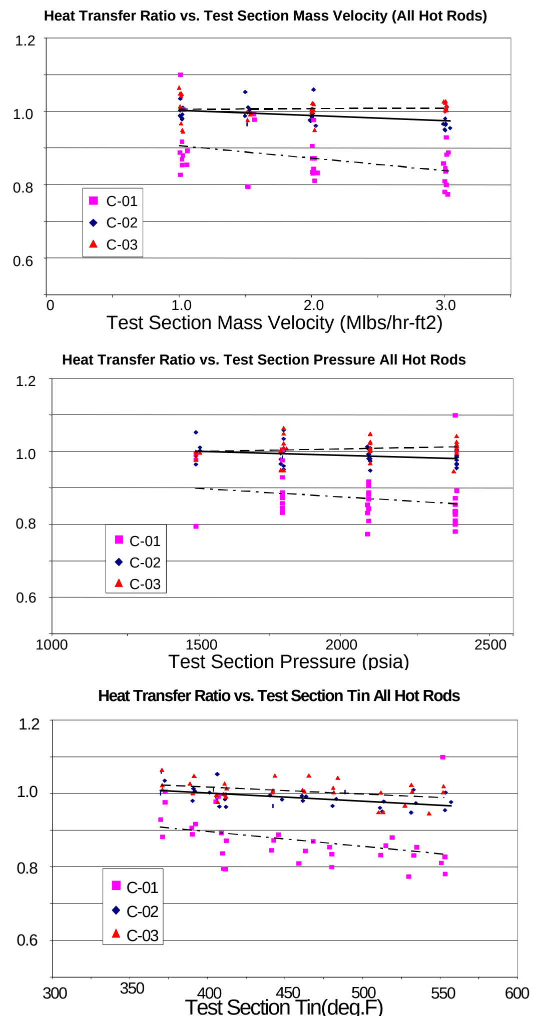


Figure 5. Heat Transfer Test Results, relative to Dittus Boelter

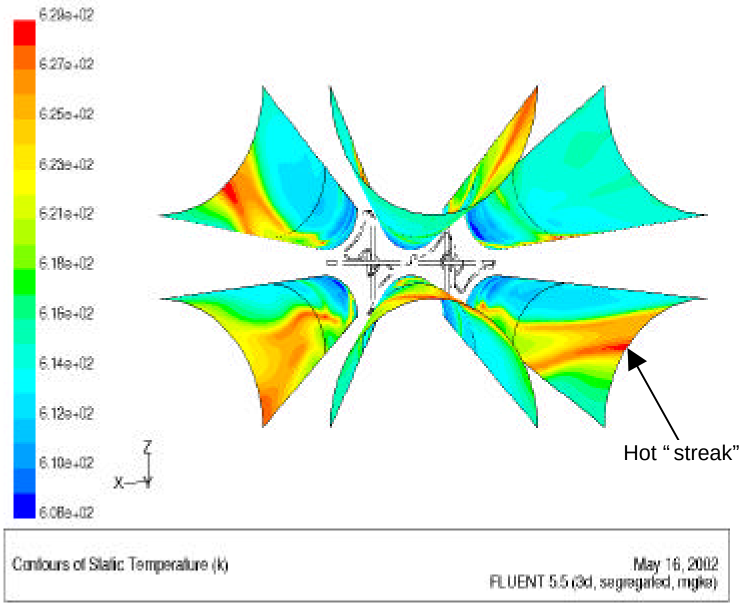


Figure 6. Hot Spot Distribution Pattern in the Channel for C-01 Vane

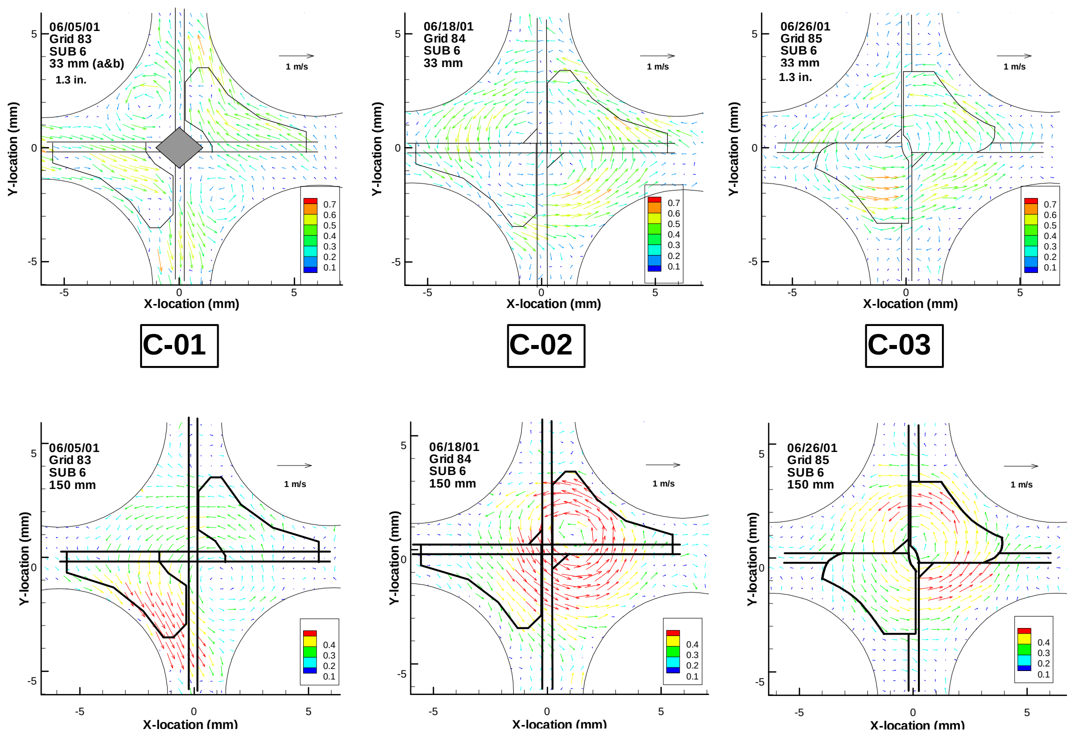
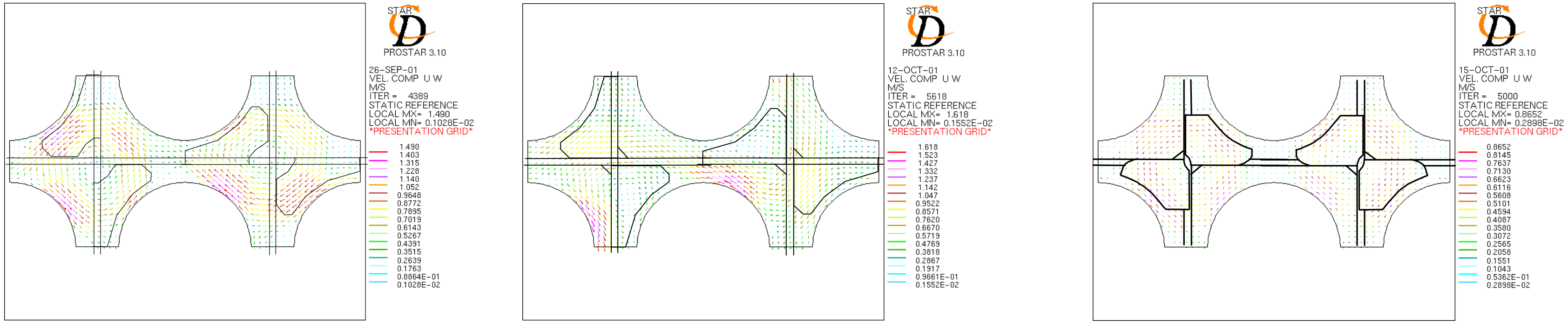


Figure 7. Vane Concepts and Lateral Flow Patterns produced by the Vanes 1.8/5.9 inches Downstream of the Grid



C-01 **C-02** **C-03**

Figure 8. CFD Predicted Flow Patterns 5.9 inches Downstream of the Grid

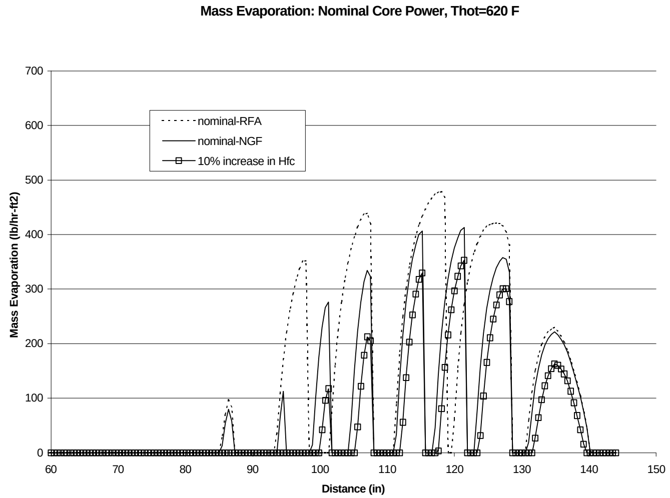


Figure 9. Mass Evaporation at Nominal Power Condition

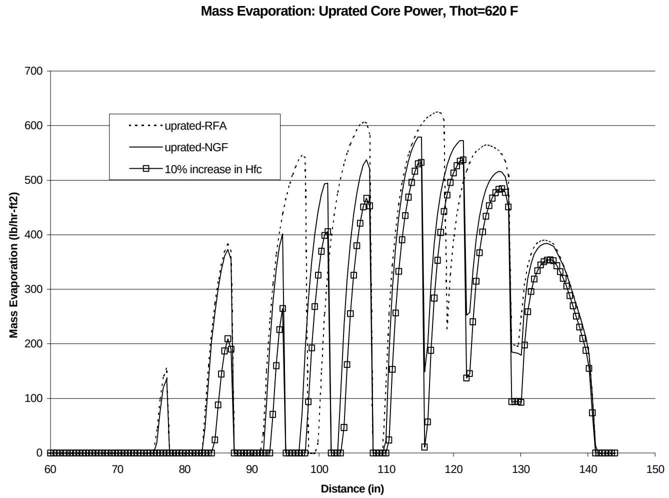


Figure 10. Mass Evaporation at Uprated Power Conditions