ATTACHMENT III TO IPN-97-059

APPLICABILITY OF THE WRB-1 CORRELATION FOR 15 X 15 LPD/IFM

NON-PROPRIETARY VERSION

NEW YORK POWER AUTHORITY
INDIAN POINT 3 NUCLEAR POWER PLANT
DOCKET NO. 50-286
DPR-64

9705190068 970512
PDR ADOCK 05000286
P PDR

Applicability of the WRB-1 Correlation for 15x15 LPD/IFM (Vantage +)

The Westinghouse Rod Bundle critical heat flux (CHF) correlation, WRB-1, predicts critical heat flux in rod bundles based on subchannel local fluid conditions. The WRB-1 correlation, described in detail by WCAP 8762-P-A (Ref.1) has proven to be a very robust correlation, as it has successfully predicted CHF over virtually all Westinghouse product lines.

The evolution of Westinghouse fuel designs is depicted by Figure 1 and the paragraphs which follow:

The original WRB-1 database was developed in the 1970's from CHF data collected for 15x15 and 17x17 standard fuel designs (Ref. 1). This database is listed in Table 1. Subsequently, Westinghouse sought to extend WRB-1 to other bundle geometries and grid types. Therefore, Westinghouse developed techniques to scale grid and bundle features. The scaling techniques, which involved careful consideration of [ ]$^{(a,c)}$, were first applied to the 17x17 OFA, made of Zircaloy. To check the scaling methodology, CHF tests were conducted at Columbia University of 5x5 grids representative of 17x17 OFA. The statistical results using the WRB-1 correlation are given in Table 2. The results showed that WRB-1 accurately predicted CHF for the 17x17 OFA. WCAP 9401-P-A (Ref. 2) discusses in more detail the acceptability of both the CHF data and scaling techniques for 17x17 OFA.

Next, the scaling techniques were applied to the development of the 14x14 OFA design. Again, CHF testing was performed. Statistical results using WRB-1 are shown in Table 3. Again, the CHF tests results validated the geometric scaling techniques and showed that the change in material (Inconel to Zircaloy) and bundle geometry was appropriately accounted for. Further details may be found in Reference 1.

With the proven success of the scaling methodology, scaling was next applied to develop the 15x15 OFA design in the 1980's without CHF testing. The 15x15 OFA employed a change from Inconel to Zircaloy grid strap, yet preserved the scaled [ ]$^{(a,c)}$ characteristics of its tested 15x15 counterpart in order to preserve CHF performance. Reference 1 provides the licensing basis for the 15x15 OFA with the WRB-1 correlation and limit DNBR of 1.17.

Also in the early 1980's, Intermediate Flow Mixer grids (IFMs) were added to the 17x17 OFA design. Short span grid spacing equaled 10 inches. The combination (17x17 OFA/IFM) became better known as the 17x17 Vantage 5 design (Ref. 3). Initial evaluation of CHF data representative of the 17x17 Vantage 5 was performed using WRB-1. Results (Table 4), revealed that the WRB-1 correlation underpredicted the IFM benefit by a significant amount. Accordingly, the WRB-2 correlation was developed to capture the additional margin. Therefore, the WRB-1 correlation was found to be a very conservative predictor of CHF for this short span fuel.

In the late 1980's, the scaling techniques were again used to develop the 17x17 V5H fuel grid design relative to the 17x17 Inconel grid design. The 17x17 V5H design is described in Reference 4. The 17x17 V5H employed a change in grid material from Inconel to Zircaloy. It also featured a more [ ]$^{(a,c)}$ while preserving the previous [ ]$^{(a,c)}$ characteristics through scaling.

As part of a separate program in the early 1990's, CHF testing of the 17x17 V5H design was performed to verify the WRB-1 performance. The testing included two configurations: grids aligned with each other, and every other grid rotated 90 degrees. Data is reported in Reference 5. If one applies the WRB-1 correlation, results indicate (Table 5) that WRB-1 is conservative, again attesting to the robustness of WRB-1.

The 17x17 V5H testing program also evaluated the CHF performance of 17x17 V5H / IFM, with short span grid spacing of 10 inches. [ ]$^{(a,c)}$. Data is reported in Reference 5. Evaluation of results with the *WRB-2* correlation [ ]$^{(a,c)}$ as shown in Table 6. Although evaluation with WRB-1 (with no grid spacing term enhancement) is an extrapolation beyond the 13 inch correlation limit, the results (Table 6) are conservative. This further attests to the robustness of the WRB-1 correlation.

The 15x15 LPD/IFM has virtually identical grid strap features as the 17x17 V5H/IFM: [ ]$^{(a,c)}$ The 15x15 LPD/IFM is also similar to both the 15x15 OFA and the 15x15 tested Inconel designs, in that rod size, equivalent diameter, rod pitch, heated length, and long span grid spacing are unchanged. [ ]$^{(a,c)}$. In addition, for all 15x15 designs the [a,c] is identical and [ ]$^{(a,c)}$ are consistent with the scaling techniques employed by Westinghouse. The comparison between the 15x15 LPD/IFM and the tested 15x15 Inconel design [ ]$^{(a,c)}$ to the comparison between the tested 17x17 V5H/IFM and the tested 17x17 Inconel design.

The WRB-1 correlation has been approved by the NRC to cover the range of fuel geometric parameters (Ref. 1) listed below. The 15x15 LPD/IFM design is within this fuel geometry and parameter range.:

grid spacing:	13 to 32 inch
rod diameter:	0.360 to 0.422 inch
rod pitch:	0.496 to 0.563 inch
axial heat flux:	uniform and non-uniform
heated length:	8 to 14 feet

Thus, the grid adjustments used to develop the 15x15 LPD/IFM fuel assembly are [ ]$^{(a,c)}$ prior significant grid modifications included in the WRB-1 database. The grid design features are based upon scaling techniques proven valid by the robust WRB-1 correlation. In addition, the grid and bundle geometry features are [ ]$^{(a,c)}$ the parameters upon which the correlation has been NRC- approved, including a CHF dataset with the same (13-inch) grid spacing. Therefore, the WRB-1 correlation can be used to predict the CHF performance of the 15x15 LPD/IFM fuel assembly.

References:

1. WCAP 8762-P-A, "New Westinghouse Correlation WRB-1 for Predicting Critical Heat Flux in Rod Bundles with Mixing Vane Grids," July 1984.

2. WCAP 9401-P-A, "Verification Testing and Analyses of the 17x17 Optimized Fuel Assembly," August 1981.

3. WCAP 10444-P-A, "Reference Core Report, Vantage 5 Fuel Assembly," September 1985.

4. WCAP 10444-P-A, Addendum 2, "Vantage 5H Fuel Assembly," April 1988.

5. RXS-T2R-003, "Quick Look Report for AP600 Critical Heat Flux (CHF) Test Data," July 30, 1994.

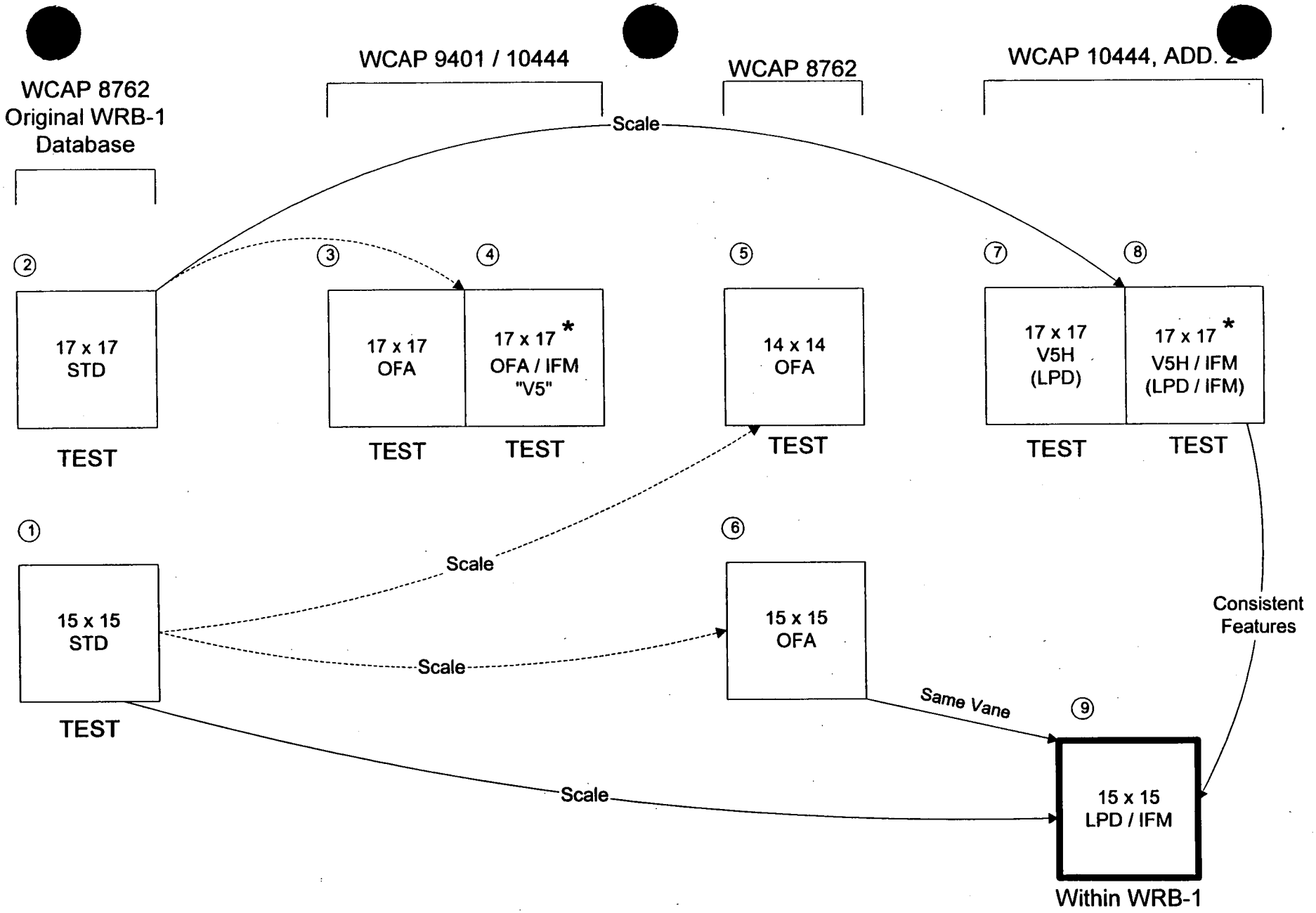

Figure 1

* WRB-1 Conservative

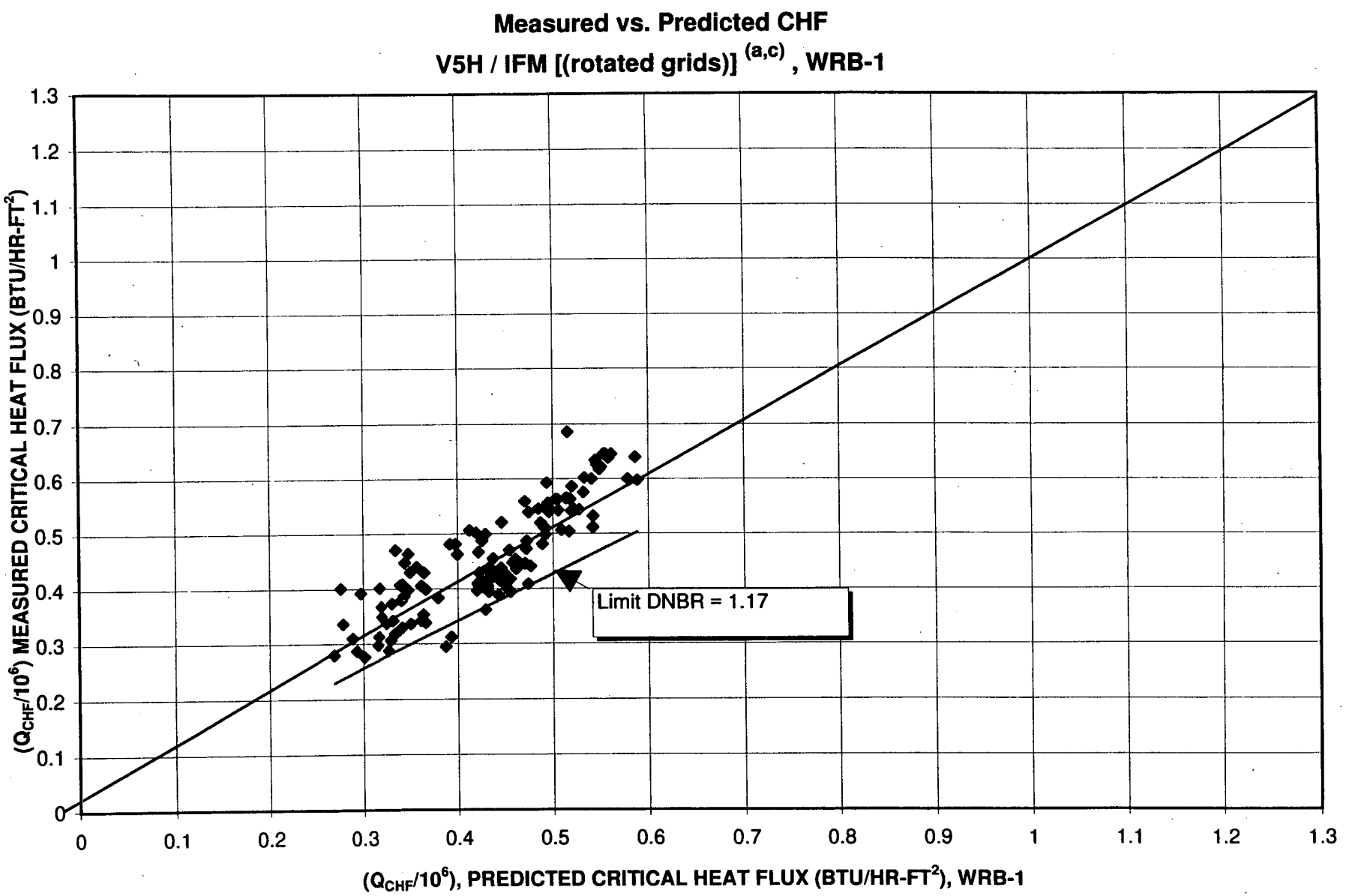
Measured vs. Predicted CHF
V5H / IFM [(rotated grids)] (a,c) , WRB-1
(QCHF/10^6) MEASURED CRITICAL HEAT FLUX (BTU/HR-FT^2)
(QCHF/10^6), PREDICTED CRITICAL HEAT FLUX (BTU/HR-FT^2), WRB-1
Limit DNBR = 1.17
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3

FIGURE 2

M/P versus Local Quality

V5H/IFM [ ] (a,c) , WRB-1

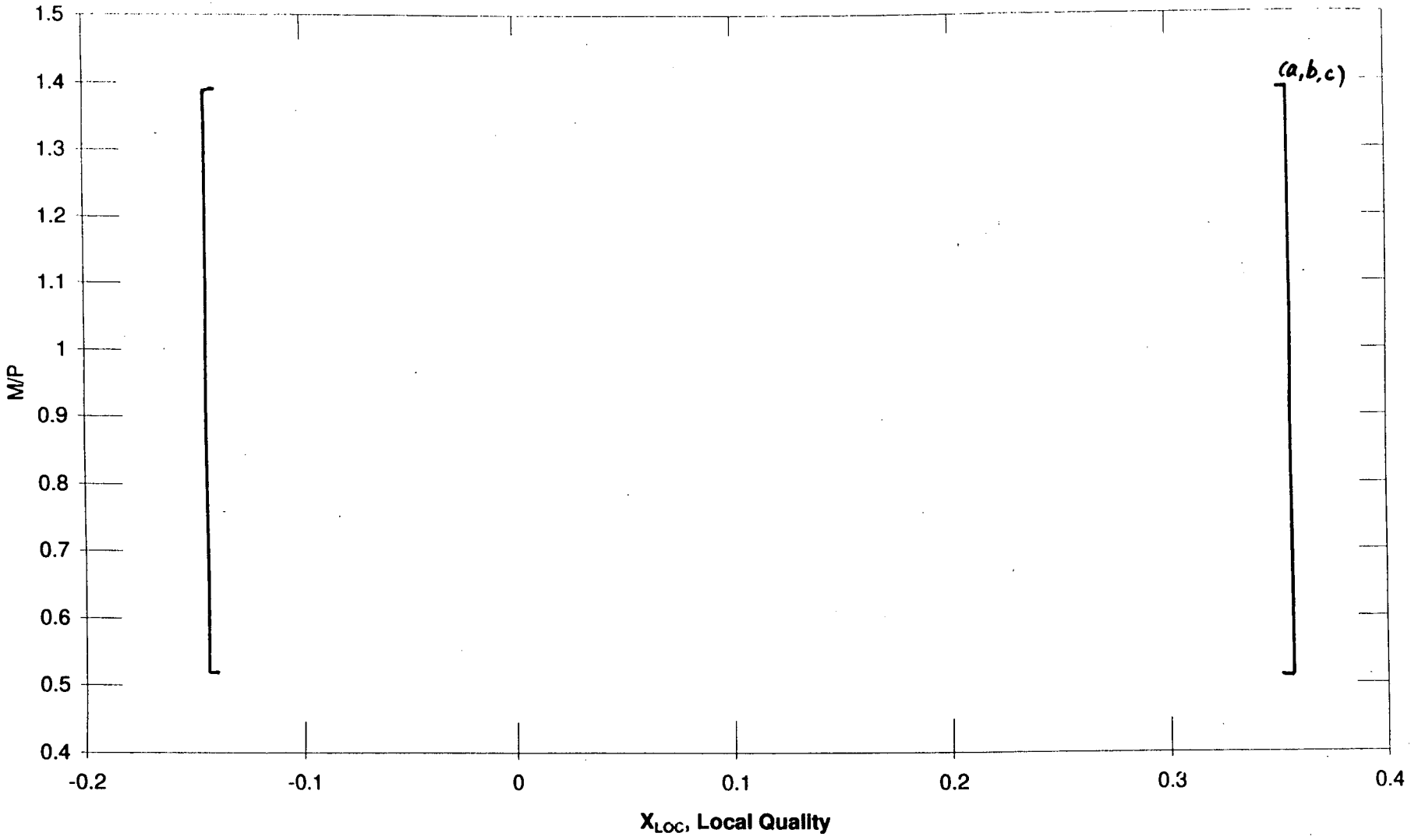

FIGURE 3

M/P versus Local Mass Velocity

V5H / IFM [ ] (a,c), WRB-1

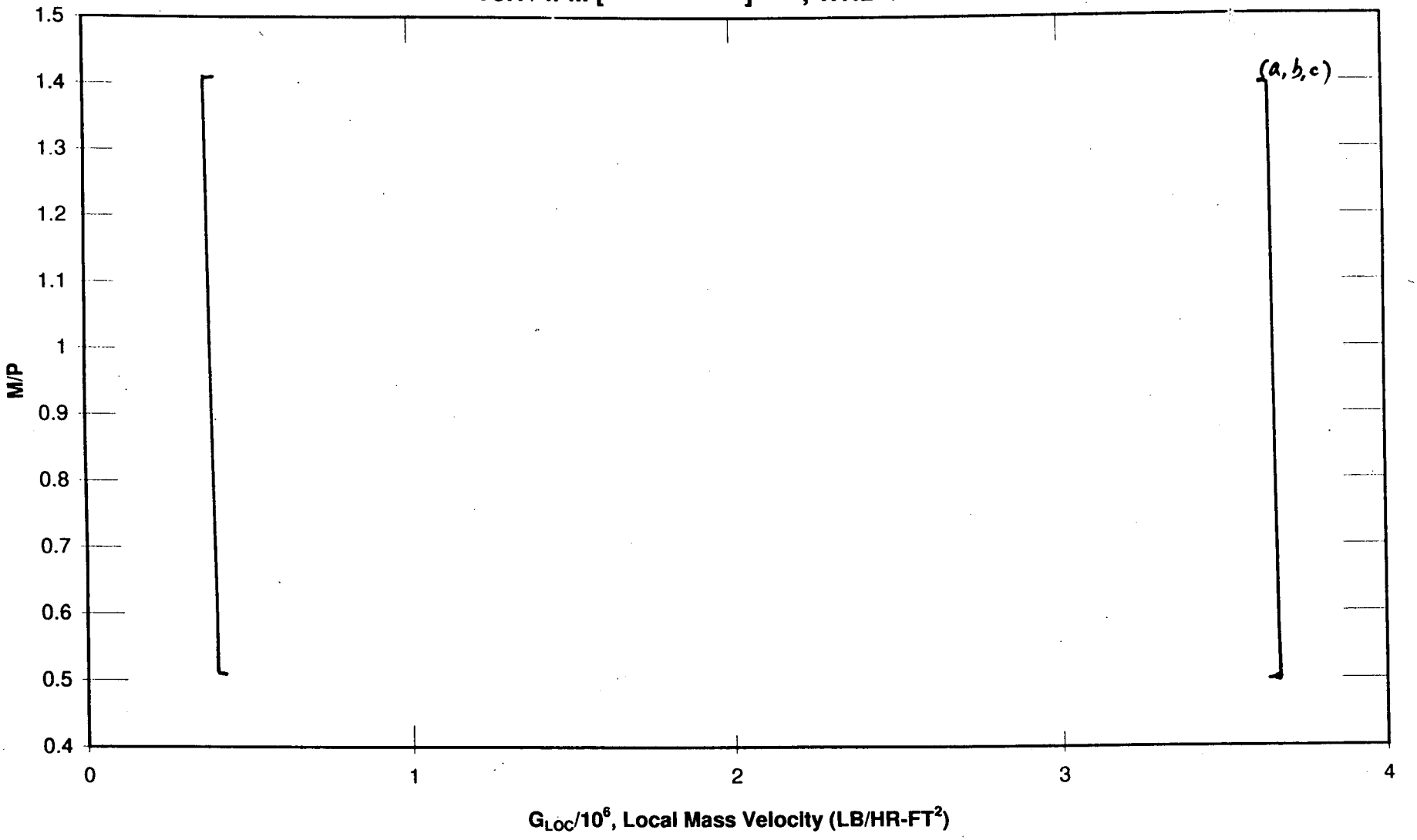

FIGURE 4

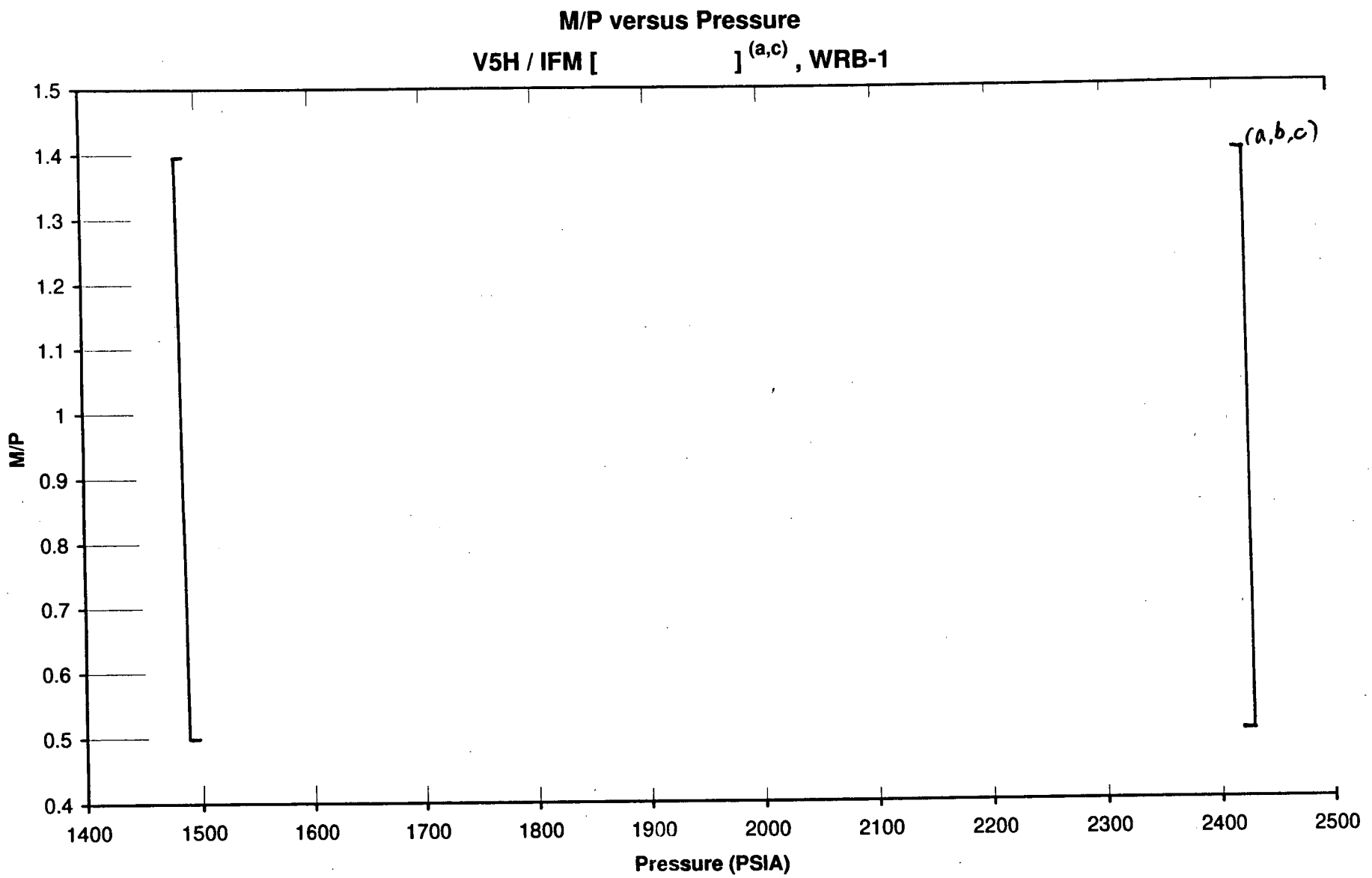
M/P versus Pressure
V5H / IFM [ ] (a,c) , WRB-1
(a,b,c)
M/P
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
Pressure (PSIA)

FIGURE 5

Table 1
Original 17x17 and 15x15 Data Sets for WRB-1 CHF Correlation:
CHF Results for Standard Designs
(from Table 3, WCAP 8762-P-A)

Rod OD (in.)	Pitch (in.)	L_H (ft.)	g_{sp} (in.)	Heat Flux Profile	Config.	N	$(M/P)_{avg}$	Stnd. Dev,S
0.374	0.496	14	22	UNIF	Typical - 5x5	71	0.9964	0.0655
0.374	0.496	14	26	UNIF	Typical - 5x5	73	1.0041	0.0805
0.374	0.496	8	22	UNIF	Typical - 5x5	67	1.0502	0.1020
0.374	0.496	8	26	UNIF	Typical - 5x5	78	1.0136	0.0848
0.374	0.496	14	22	COSINE	Typical - 4x4	74	1.0022	0.0852
0.422	0.555	8	20	COSINE	Typical - 4x4	33	1.0042	0.0528
0.422	0.555	8	20	μSINμ	Typical - 4x4	33	0.9937	0.0649
0.422	0.555	8	26	μSINμ	Typical - 4x4	36	0.9846	0.0922
0.422	0.555	14	26	μSINμ	Typical - 4x4	35	1.0584	0.0816
0.422	0.555	14	20	μSINμ	Typical - 4x4	36	1.0100	0.0915
0.422	0.555	14	13	μSINμ	Typical - 4x4	38	0.9737	0.0781
0.422	0.555	14	32	μSINμ	Typical - 4x4	38	1.0238	0.0752
0.422	0.555	8	32	μSINμ	Typical - 4x4	31	0.9913	0.0724
0.422	0.555	14	26	μSINμ	Typical - 4x4	71	1.0466	0.0829
0.422	0.555	14	26	UNIF	Typical - 4x4	42	0.9321	0.0595
0.422	0.555	14	26	μSINμ	Thimble - 4x4	39	1.0141	0.0579
0.422	0.555	14	32	μSINμ	Thimble - 4x4	37	0.9738	0.0887
0.374	0.496	14	22	COSINE	Thimble - 5x5	70	1.0002	0.0796
0.374	0.496	8	26	UNIF	Thimble - 5x5	68	1.0303	0.1048
				ABOVE DATA		*970*	*1.008*	*0.0858*

Table 2

17x17 OFA
CHF Data Sets Added to WRB-1 Database
(from Table 3, WCAP 8762-P-A)

Rod OD (in.)	Pitch (in.)	L_H (ft.)	g_{sp} (in.)	Heat Flux Profile	Config.	N	$(M/P)_{avg}$	Stnd. Dev,S
[]$^{(a,b,c)}$	[]$^{(a,b,c)}$	14	20	COSINE	Typical - 5x5	63	0.9918	0.0970
[]$^{(a,b,c)}$	[]$^{(a,b,c)}$	14	20	COSINE	Thimble - 5x5	38	0.9755	0.0504

Table 3

14x14 OFA
CHF Data Set Added to WRB-1 Database
(from Table 3, WCAP 8762-P-A)

Rod OD (in.)	Pitch (in.)	L_H (ft.)	g_{sp} (in.)	Heat Flux Profile	Config.	N	$(M/P)_{avg}$	Stnd. Dev,S
[]$^{(a,b,c)}$	[]$^{(a,b,c)}$	14	26	COSINE	Typical - 4x4	37	1.0571	0.0771

Table 4

17x17 Vantage 5 (i.e, OFA / IFM)
CHF Results with WRB-1

Rod OD (in.)	**Pitch (in.)**	**L_H (ft.)**	**g_{sp} (in.)**	**Heat Flux Profile**	**Config.**	**N**	**$(M/P)_{avg}$**	**Stnd. Dev,S**
[]$^{(a,b,c)}$	[]$^{(a,b,c)}$	14	10	COSINE	Typical - 5x5	82	[]$^{(a,b,c)}$	[]$^{(a,b,c)}$
[]$^{(a,b,c)}$	[]$^{(a,b,c)}$	14	10	COSINE	Waterhole - 5x5	23	[]$^{(a,b,c)}$	[]$^{(a,b,c)}$

Table 5

17x17 V5H
CHF Data Set
[ ] (a,c) Grids

Rod OD (in.)	Pitch (in.)	L_H (ft.)	g_{sp} (in.)	Heat Flux Profile	Config.	N	$(M/P)_{avg}$	Stnd. Dev,S
[](a,b,c)	[](a,b,c)	14	20	COSINE	Typical - 5x5	76	[](a,b,c)	[](a,b,c)
[](a,b,c)	[](a,b,c)	14	20	COSINE	Typical - 5x5	60	[](a,b,c)	[](a,b,c)

Table 6

17x17 V5H/IFM *([ ]$^{(a,c)}$Grids)*
CHF Data Set
WRB-1 vs. WRB-2

Rod OD (in.)	**Pitch (in.)**	**L_H (ft.)**	**g_{sp} (in.)**	**Heat Flux Profile**	**Config.**	**N**	**$(M/P)_{avg}$**	**Stnd. Dev,S**
[]$^{(a,b,c)}$	[]$^{(a,b,c)}$	14	10	COSINE	Combined typical & thimble 5x5	128	[]$^{(a,b,c)}$ **WRB-2**	[]$^{(a,b,c)}$
[]$^{(a,b,c)}$	[]$^{(a,b,c)}$	14	10	COSINE	Combined typical & thimble 5x5	124	[]$^{(a,b,c)}$ **WRB-1**	[]$^{(a,b,c)}$

NOTE:

Although the 10-inch grid spacing is below the WRB-1 correlation limit of 13 inches, it's prediction is conservative; [ ]$^{(a,c)}$.

Table 7

CHF Test Results for 17x17 V5H / IFM
WRB-1 Correlation

Run Id.	Inlet Pressure (Psia)	Inlet Temp (F)	Inlet Mass Velocity (Lbm/Hr-SqFt) x10E6	Local Quality (%)	Local Heat Flux (Btu/Hr-SqFt) x10E6 Meas.	Pred.	(Meas / Pred)	Elevation from Inlet (Inches) Pred.	Meas.
Article 1A-1(typical cell)							(a,b,c)		(a,b,c)
6014							1.0410		
6015							0.9117		
6016							0.9439		
6017							1.0917		
6018							0.9478		
6019							1.1260		
6020							1.2671		
6021							0.9537		
6022							0.9749		
6024							1.0125		
6025							1.0417		
6026							1.1051		
6027							1.0158		
6028							1.0867		
6029							1.2330		
6030							0.7602		
6032							0.8432		
6033							0.8788		
6036							0.9313		
6037							0.8665		
6038							0.9883		
6040							0.9179		
6041							0.8624		
6042							0.8856		
Article 1A-2 (typical cell)									
7016							0.9319		
7017							0.9461		
7018							0.9768		
7019							0.9823		
7020							0.9951		
7027							0.9731		
7028							1.0109		

Table 7

CHF Test Results for 17x17 V5H / IFM
WRB-1 Correlation

Run Id.	Inlet Pressure (Psia)	Inlet Temp (F)	Inlet Mass Velocity (Lbm/Hr-SqFt) x10E6	Local Quality (%)	Local Heat Flux (Btu/Hr-SqFt) x10E6 Meas.	Local Heat Flux (Btu/Hr-SqFt) x10E6 Pred.	(Meas / Pred)	Elevation from Inlet (Inches) Pred.	Elevation from Inlet (Inches) Meas.
						(a,b,c)			(a,b,c)
7029							1.0750		
7030							1.0354		
7031							1.0346		
7032							1.1519		
Article 1A-3 (typical cell)									
8014							0.9375		
8015							0.9483		
8025							0.9676		
8043							1.0857		
8044							1.1093		
8045							1.1659		
8046							1.1577		
8047							1.1252		
8048							1.3318		
8049							1.1457		
8050							1.0052		
8051							1.0300		
8052							1.0150		
8053							0.9729		
8054							0.9648		
8055							1.1055		
8056							1.1188		
8057							1.2270		
8058							1.0413		
8059							1.1643		
8060							1.1100		
8061							1.3304		
8062							1.3214		
8063							1.1273		
8064							1.2099		
8065							1.1305		
8066							1.1434		
8067							1.1948		

Table 7

CHF Test Results for 17x17 V5H / IFM
WRB-1 Correlation

Run Id.	Inlet Pressure (Psia)	Inlet Temp (F)	Inlet Mass Velocity (Lbm/Hr-SqFt) x10E6	Local Quality (%)	Local Heat Flux (Btu/Hr-SqFt) x10E6 Meas.	Pred.	(Meas / Pred)	Elevation from Inlet (Inches) Pred.	Meas.
						(a,b,c)			(a,b,c)
8068							1.1955		
8069							0.9429		
8070							0.9592		
Article 2 (thimble cell)									
2014							0.9793		
2015							0.9289		
2016							0.9655		
2017							1.0014		
2018							0.9854		
2019							1.0118		
2020							1.1458		
2021							0.9841		
2022							0.7944		
2023							0.9181		
2024							0.9413		
2026							0.8784		
2027							0.9290		
2028							0.9521		
2030							0.9455		
2031							0.9599		
2032							0.9237		
2034							0.9253		
2035							0.9710		
2058							0.9579		
2084							1.0405		
2085							1.2102		
2087							1.1969		
2088							1.1116		
2089							1.0807		
2090							1.1615		
2091							1.1225		
2092							1.2989		
2093							1.2264		

Table 7

CHF Test Results for 17x17 V5H / IFM
WRB-1 Correlation

Run Id.	Inlet Pressure (Psia)	Inlet Temp (F)	Inlet Mass Velocity (Lbm/Hr-SqFt) x10E6	Local Quality (%)	Local Heat Flux (Btu/Hr-SqFt) x10E6 Meas.	Pred.	(Meas / Pred)	Elevation from Inlet (Inches) Pred.	Meas.
						(a,b,c)			(a,b,c)
2094							1.1439		
2095							1.1507		
2096							1.0726		
2097							1.0966		
2098							1.0673		
2099							1.0435		
2100							1.0297		
2101							1.1294		
2102							1.0956		
2103							1.0305		
2104							1.1278		
2105							1.1242		
2106							0.9801		
2107							1.1224		
2108							1.0887		
2109							1.4566		
2110							1.0368		
2111							1.0995		
2112							1.1777		
2113							1.4036		
2114							1.2292		
2115							1.1347		
2116							1.1135		
2117							1.2011		
2118							0.9857		
2119							1.1870		
2120							1.1629		
2121							1.1670		
2122							1.0914		

M/P avera	**1.0595**
sigma	**0.1235**
N	**124**

5