ASSESSMENT OF THE CORE FLOW PATTERN AND PRESSURE TUBE CREEP AT CERNAVODA UNIT#1

NASTASE MAZALU

CNE-PROD Cernavoda, Safety Analysis Group

ABSTRACT

In time, the Cernavoda NPP Unit#1 has experienced a core flow redistribution: central core channels increased flows and outer core channels decreased flows. NUCIRC simulations have been performed to investigate the possible causes of the core flow redistribution. Both, commissioning and in-service data sets have been used for this investigation. This lecture will present the results obtained based on these simulations. Also the lecture intend to point out the correlation between core flow redistribution and possible occurrence of pressure tube strain due to creep, mainly in the high power channels.

1. INTRODUCTION

On September 1998 on the occasion of a periodical channel flow verification OM test it has been found a flow reduction in the instrumented channels of about 2% on average (at 100% FP) versus the commissioning flows. Figure 1 shows the history of differences between commissioning average instrumented channel flow and the average instrumented channel flow found at different moments of time. This figure shows a continuous depreciation of instrumented channel flows since commissioning. Also, it can be observed an important decrease after the April, 1998 outage. The reason for this is the increased channel powers (boiling occurrence) on the outer core channels. This was confirmed by the increase in instrumented channel flows (reduction in the percent difference) at four months after outage (channels exiting from boiling due to fuel burn-up).

In order to evaluate if instrumented channel flow reduction has a pass specific pattern or core location specific pattern, it has been drawn the trends of instrumented channel flows of the same pass and the same trip channel (see Reference 1). Based on these trends it has been observed that there is no pass or core location specific pattern. Also it can be observed that the decrease in flow has a common component (all instrumented channel flows have depreciated), and a channel specific component (which gives a random channel by channel behavior).

The reasons for the common component, at the moment of the test, were assumed to be:

- increased resistance of the internal circuit
- increased RIH temperature by about 1° C.

The reasons for the specific channel component, were assumed to be:

- the fuel bundles misalignment
- radial power distribution change,

since all the instrumented channels have been refueled at least once since commissioning by that time.

In order to check if these phenomena are specific to all core channels and not only to the instrumented channels and also in order to check if the total core flow had been decreased by the same amount shown by instrumented channels, there were performed two comparisons of the total core flows determined from the inverse heat balance at two different moments in time. The following data were considered:

- commissioning versus September 1998 flows and,
- January versus September 1998 flows .

The comparisons were made for the data collected at 85% FP in order to avoid the boiling occurrence. These comparisons are presented in Figure 2 and 3, respectively.

Based on Figure 2 it has been observed that there is a decrease of total core flow of about 1.26 %. As expected this reduction is not in agreement with the information provided by the instrumented channels which showed a flow reduction of about 2% (1.8% at 85% FP). Also it has been observed an average flow decrease of about 2.62% for the orificed channels and a flow increase of about 0.26% for the non-orificed channels.

Based on Figure 3 it has been observed that there is a decrease of total core flow of about 0.35%. Again this decrease is not in agreement with the information provided by the instrumented channels which shows a decrease of about 1.23% (1% at 85% FP). Also it has been observed that there is a flow decrease of about 0.79 % for the orificed channels and a flow increase of about 0.14% for the non-orificed channels.

Based on these considerations it has been concluded that there is a real flow redistribution. This redistribution is shown by the increase in the non-orificed channel flows and by the reduction of the orificed channel flows.

The expected causes of this core flow redistribution which have been checked through the NUCIRC simulations were:

- the increase in internal circuit resistance due to depositions of the magnetite displaced by flow assisted corrosion from outlet feeders, on to the inlet feeders and inlet end fittings
- header pressure distribution change
- creep occurrence mainly in the center core channels.

Each of these causes has been investigated by NUCIRC Itype2 runs. The simulations are described in detail in the following sections.

2. NUCIRC SIMULATIONS METHODOLOGY

The instrumented channel flows reduction was assumed to be produced by the increase of the internal circuit resistance. The process was simulated by increasing the feeder pipes roughness in Itype2 NUCIRC runs only for the instrumented channels. The input power used into these simulations was the axial distribution given by the RFSP instantaneous power distribution scaled to that derived by using the measured instrumented channel flow, inlet header temperature and outlet feeder temperature (bias corrected), in order to reduce the power uncertainties.

By using this power as input, a sensitivity analysis on the roughness of feeder pipes was performed, for both January and September 1998 PHTS boundary conditions at 85% FP. The roughness values considered were the ones which minimized the difference between average measured and predicted instrumented channel flow. Table 2 summarizes the differences found.

With the roughness values determined as above, total core flow simulations for different creep values were performed for both January and September 1998 PHTS boundary conditions. The creep value was increased until the total core flow predicted was approximately equal to that determined from inverse heat balance. The creep model was that presented by References 2 and 3 determined based on data from Point Lepreau and Gentilly-2. The pressure tube creep profile has been taken from Reference 2, and the maximum channel power (N17) from Reference 3. The results were compared and they are presented in Table 3.

In order to study the influence of the headers pressure gradient on the core flow distribution, the September 1998 NUCIRC predictions with and without header manifold were compared. The comparison is presented in Table 4.

3. RESULTS

3.1 Feeder Pipe Roughness Influence.

Feeder pipe roughness influence on the core flow redistribution, based on NUCIRC simulations is presented in Table 2. Table 2 data suggests that the instrumented channel flows reduction was generated by the increase in feeder pipe roughness up to 0.0064 mm by January '98 and up to 0.0112 mm by September '98. This shows a much higher increase of circuit resistance on the period January '98 to September '98 compared with commissioning to January '98. We couldn't find the reason for this non-linear increase in circuit resistance.

3.2 Headers Pressure Gradient Influence.

Headers pressure gradient influence on the core flow redistribution, based on NUCIRC simulations is presented in Table 4. The comparison presented in Table 4 suggests that the headers pressure gradient tends to increase the flows on the orificed channels, while the non-orificed channel flows remain almost the same. Even if this effect can partially explain the flow redistribution its magnitude is not significant.

3.3 Pressure Tube Creep Influence.

The sensitivity analysis performed on the pressure tube creep is presented in Table 3. Based on the data presented in this table the estimated creep value in January 1998 was about 0.18%, being in accordance with the values presented in Reference 2. Also, there is a good agreement between total core flow differences (0.42 compared with 0.35), orificed channel flows (0.82 compared with 0.79) and non-orificed channel flows (-0.03 compared with –0.14). On the other hand, the September 1998 estimated creep value (0.72%), is not concordant with the data presented in Reference 2, the value in Refernce 2 being half of the one that was actually obtained. Also there are disagreements between the orificed channel flows (1.91 compared with 2.62) and non-orificed channel flows (0.67 compared with –0.26).

4. CONCLUSIONS

The core flow redistribution exists. This flow redistribution caused an increase in the flow of central core channels of about 0.24% and a decrease in external core channels of about 2.6% compared with commissioning values.

The core flow redistribution was not generated by the change in header pressure distribution, because, as shown by Table 4, this tends to increase the flows in the external core channels. However this effect is not significant.

We can strongly correlate the core flow redistribution, with the occurrence of pressure tube strain due to creep, which is affecting mostly the central core channels. Also we can say that is possible to have different circuit resistances for different types of channels, namely higher resistances on the external core channels and lower resistances on the central core channels. This can be caused by velocity dependent depositions (possible in the inlet end fittings) of the magnetite displaced by flow assisted corrosion from outlet feeders, which is favored on the channels with low velocities of coolant (see Reference 4).

Related to the actual value of pressure tube strain we can state that this is above 0.18 and up to 0.72%. The real value will be determined during September '99 outage by occasion of the first fuel channel inspection.

5. REFFERENCES

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4. BURILL K.A. & others, “Assessment and Mitigation on Outlet Feeder Pipe Wall Thinning in CANDU”, paper presented to “COG/IAEA 5th Technical Committee Meeting on Operating Safety Experience of PHWR’s” - Mangalia, Romania, September 7-11(1998).

TABLE 1. AVERAGE PERCENT DIFFERENCES BETWEEN JANUARY AND SEPTEMBER '98, AND COMMISSIONNING AND SEPTEMBER '98, INSTRUMENTED CHANNEL FLOWS

	January – September (%)	Commissioning-September (%)
Comparison made between measured values at 100% FP	1.22	1.98
Comparison made between measured values at 85% FP	0.99	1.79

TABLE 2. AVERAGE PERCENT DIFFERENCE BETWEEN MEASURED AND NUCIRC PREDICTED INSTRUMENTED CHANNEL FLOWS AT 85% FP

	January '98 (%)	September '98 (%)
NUCIRC Predicted (Roughness = 0.0032)	-0.99	-1.9
NUCIRC Predicted (Roughness = 0.0064)	-0.01	-1.09
NUCIRC Predicted (Roughness = 0.0096)	N/A	-0.4
NUCIRC Predicted (Roughness = 0.0112)	N/A	-0.06

Note: Commissioning NUCIRC predicted instrumented channel flows determined for a roughness of 0.0032 has shown a zero percent difference compared with commissioning measured values at 85% FP

TABLE 3. PRESSURE TUBE CREEP SENSITIVITY

Channel Type	Percent differences between Nucirc Commissioning predicted flows and 0.36% creep September '98 predicted flows	Percent differences between Nucirc Commissioning predicted flows and 0.54% creep September '98 predicted flows	Percent differences between Nucirc commissioning predicted flows and 0.72% creep September '98 predicted flows	Percent differences between Nucirc January '98 0.18% creep predicted flows and 0.72% creep September '98 predicted flows	Percent differences From inverse heat balance-Commissioning -September '98	Percent differences From inverse heat balance January-September '98
All Channels	1.91	1.61	***1.32***	**0.42**	***1.26***	**0.35**
Instrumented Channels	1.45	1.29	***1.14***	**0.49**	***2.54***	**0.46**
Riser Channels	2.11	1.94	***1.78***	**0.78**	***2.37***	**1.63**
1.5" Orificed Channels	3.41	3.34	***3.28***	**1.57**	***3.12***	**1.03**
2" Orificed Channels	1.69	1.46	***1.23***	**0.45**	***2.37***	**0.67**
All Orificed Channels	2.26	2.08	***1.91***	**0.82**	***2.62***	**0.79**
Non Orificed Channels	1.53	1.1	***0.67***	**-0.03**	***-0.26***	**-0.14**

Note: No creep was assumed for the NUCIRC predicted commissioning flows

TABLE 4 COMPARISON BETWEEN NUCIRC PREDICTED FLOWS CONSIDERING AND NOT CONSIDERING THE PRESSURE GRADIENT FROM HEADERS

Channel Type	Difference (%)
All Channels	0.08
Instrumented Channels	0.17
Riser Channels	0.76
1.5" Orificed Channels	0.26
2" Orificed Channels	0.12
All Orificed Channels	0.17
Non Orificed Channels	-0.03

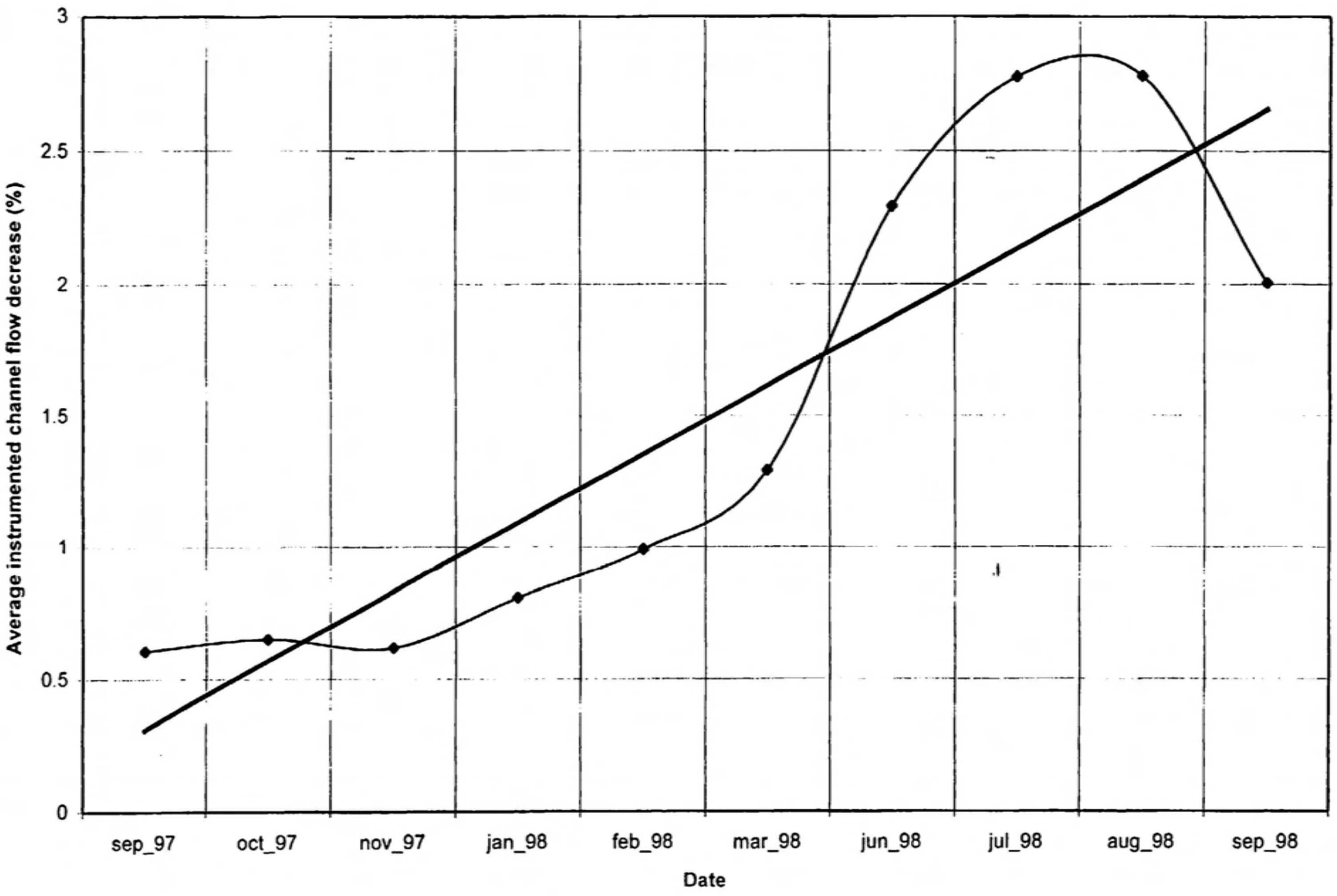

FIGURE 1. PERCENT DECREASE OF THE AVEREGE INSTRUMENTED CHANNEL FLOW VERSUS COMMISSIONNING DATA

ZONE 1 | ZONE 3 | ZONE 6

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A									1.3	3.4	2.2	2.1	3.0	-1.1								
B						3.2	5.8	0.9	2.2	2.4	1.8	1.6	0.5	3.0	4.5	4.8	2.1					
C					1.8	2.8	2.2	3.3	1.1	2.0	5.5	0.3	3.3	3.2	4.7	2.7	3.8	3.4				
D				4.2	3.3	2.5	3.4	3.2	2.6	1.4	3.3	3.2	3.0	0.5	2.0	1.3	1.7	2.1	2.5			
E			5.3	6.1	4.9	4.6	0.3	2.2	0.4	1.1	1.6	2.6	1.9	-0.3	1.8	1.2	2.0	1.6	1.7	2.1		
F			3.8	5.4	5.8	1.5	3.6	13.5	2.1	0.6	0.6	2.2	3.9	0.0	16.7	1.3	1.0	1.6	2.8	2.4		
G		5.6	2.6	3.9	5.5	2.6	0.4	1.4	0.0	0.5	0.1	-2.0	-2.3	-1.2	0.2	-0.1	0.6	2.4	0.5	3.7	3.0	
H		3.2	5.7	4.7	5.4	1.1	2.2	-0.9	-0.1	-2.9	-1.3	-0.1	-1.7	-3.6	-4.5	0.6	1.7	0.4	1.5	2.5	-0.1	
J	4.4	7.4	5.5	3.5	4.8	3.1	0.7	-1.0	-2.5	1.0	-3.5	-4.6	-2.2	-3.9	-0.2	-0.4	1.7	2.2	3.5	2.4	0.8	-0.6
K	6.0	4.8	5.5	1.4	7.9	2.3	0.4	-0.5	-0.6	-4.2	-1.8	-3.7	-4.4	-2.6	-2.2	0.0	1.1	3.1	-0.3	1.7	1.2	3.1
L	6.9	6.5	4.8	4.7	1.2	-0.6	0.4	-2.8	-2.1	0.3	-1.7	-4.4	-3.4	-3.7	-2.5	-1.8	-0.9	-1.8	2.3	2.1	3.0	3.6
M	6.2	4.3	8.1	2.7	3.4	2.4	0.2	-2.8	-0.9	-3.2	-2.9	-4.4	-5.8	-4.1	-3.4	-5.3	-3.3	-2.4	-1.4	-0.1	1.0	2.8
N	3.3	4.4	5.0	5.3	2.0	2.7	1.6	-2.1	-5.7	-2.3	-2.6	-1.7	-3.8	-4.4	-5.1	-1.3	1.2	-0.9	-0.9	-0.4	2.4	1.8
O	5.3	4.8	4.1	1.1	5.3	3.0	2.5	-1.2	-2.5	-1.3	-0.9	0.6	-5.9	-3.4	-1.2	-1.4	1.4	-2.1	1.0	3.3	1.8	0.9
P		4.4	1.4	3.1	1.7	1.5	-1.1	0.4	-3.3	-2.3	-2.4	-2.6	-3.3	-3.4	-1.6	-2.3	-0.2	2.5	3.1	3.0	0.0	
Q		1.7	1.4	2.1	1.9	2.0	-0.5	-0.9	-2.2	-2.5	-0.7	-3.4	-2.4	-1.4	-0.9	-0.3	1.6	1.0	1.6	2.5	0.1	
R			3.3	1.9	-0.2	0.4	0.1	0.1	0.6	-2.6	-2.4	-0.7	-0.8	0.8	-1.2	0.3	-1.6	2.4	2.8	0.3		
S			1.8	-3.8	1.0	-1.5	1.1	1.1	0.5	1.7	4.8	2.9	0.5	-0.6	2.3	2.5	1.1	0.8	-1.7	-0.5		
T				-0.2	2.3	1.1	-1.4	-0.2	1.9	1.7	1.8	2.7	9.1	2.0	3.4	1.8	0.3	1.0	2.0			
U					0.5	1.2	1.6	0.2	1.9	2.2	4.4	4.0	1.2	2.7	2.3	2.2	4.3	1.8				
V						2.8	1.9	6.1	1.4	3.0	1.8	3.5	1.4	3.3	6.6	5.2	2.2					
W									3.4	3.4	8.8	7.5	6.4	2.8								

ZONE 2 | ZONE 5 | ZONE 7

Statistics for all channels

	Average	St.Dev	Minimum		Maximum	
	Value	Value	Value	Channel	Value	Channel
ALL	1.26	2.90	-5.89	O13	16.71	F15
IC	2.54	1.61	0.49	B13	6.48	L 2
RC	2.37	1.50	-0.24	R 5	5.84	B 7
1.5"OC	3.12	2.09	-1.08	A14	8.75	W11
2.0"OC	2.37	1.87	-3.75	S 4	8.10	M 3
OC	2.62	1.97	-3.75	S 4	8.75	W11
NOC	-0.26	3.02	-5.89	O13	16.71	F15

Statistics for power zones channels

	Average	St.Dev	Minimum		Maximum	
	Value	Value	Value	Channel	Value	Channel
Zone 1	3.74	2.05	-0.63	L 6	7.93	K 5
Zone 2	2.13	2.14	-3.75	S 4	8.10	M 3
Zone 3	1.66	3.18	-4.45	H15	16.71	F15
Zone 4	-2.67	1.65	-5.89	O13	0.95	J10
Zone 5	1.21	3.01	-3.44	Q12	9.09	T13
Zone 6	1.63	1.42	-1.77	L18	4.81	B16
Zone 7	0.72	1.99	-5.28	M16	5.18	V16

Notes: IC -Instrumented Channels RC-Riser Channels NOC-Non Orificed Channels

ALL-All Channels IC -Instrumented Channels RC-Riser Channels 1.5"OC-1.5" Orificed Channels 2.0"OC-2.0" Orificed Channels OC-All Orificed Channels NOC-Non Orificed Channels

FIGURE 2. COMPARISON BETWEEN COMMISSIONNING AND SEPTEMBER 1998 FLOWS DERIVED FROM INVERSE HEAT BALANCE AT 85% FP

ZONE 1 · ZONE 3 · ZONE 6 · ZONE 2 · ZONE 5 · ZONE 7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A									-3.4	-3.5	-1.0	-1.4	-2.8	-3.9								
B						-1.8	0.5	-1.1	-2.1	-1.7	-2.1	-2.7	-2.0	-1.8	-0.8	-0.1	-3.3					
C					0.1	-0.1	0.5	-2.2	-2.2	-0.2	1.8	-1.5	-0.6	0.9	0.0	-1.9	-2.7	-1.8				
D				-0.6	0.5	-0.9	0.2	-1.4	1.5	-0.7	0.3	-0.2	1.7	-1.5	-1.4	-2.5	-2.2	-1.1	1.0			
E			0.1	1.1	1.6	0.3	0.3	-1.8	1.9	2.6	-2.5	0.5	-0.6	-2.8	-1.2	-1.4	-0.5	-1.0	-1.3	-1.1		
F			0.9	-0.5	1.2	1.8	1.7	1.5	1.7	1.1	0.6	-0.3	-1.7	-1.2	-5.8	-1.9	-2.5	-1.9	-1.2	-0.4		
G		2.3	-0.6	0.4	0.1	0.7	-1.2	0.4	1.1	2.7	0.7	-1.7	-2.0	-2.8	-1.1	-1.9	-0.7	-0.3	-1.7	-0.7	1.0	
H		0.9	0.6	1.3	1.7	-1.2	2.3	0.4	0.3	0.0	1.2	0.3	-1.2	-0.6	-3.0	-1.1	-1.5	0.5	-2.3	0.0	1.1	
J	3.1	0.9	0.3	1.4	0.8	-1.4	0.3	-0.8	1.7	-1.0	-1.2	-2.1	-1.3	-2.9	-2.6	-2.7	0.4	-1.2	2.4	1.0	-0.2	-8.5
K	3.8	-0.1	1.6	0.6	3.3	-1.2	-1.2	2.1	-0.1	-1.4	-1.0	-0.7	1.2	-2.6	-1.2	-4.4	-2.9	-1.0	2.2	0.4	-1.5	-1.3
L	3.3	1.6	-0.7	2.1	-1.7	-1.1	-1.4	-0.9	-1.9	-1.1	-0.5	-3.5	-0.2	-0.8	-0.6	-1.7	-0.8	-2.4	1.3	0.7	0.1	1.6
M	4.4	0.2	3.0	1.0	0.6	-1.5	-0.1	-1.8	-0.9	-1.8	-1.7	-1.8	-2.0	-2.4	-0.2	-3.2	-1.7	-2.4	0.1	-0.2	0.2	3.1
N	3.9	1.7	1.7	2.9	0.5	-0.1	0.2	-3.7	-0.4	-1.1	-1.3	0.0	-0.9	-1.2	0.8	-0.9	0.7	-0.4	1.1	-0.2	-0.3	2.9
O	4.2	1.6	2.1	1.6	1.5	1.1	1.1	-1.7	-0.3	-1.6	-1.9	-1.9	0.7	-0.4	0.0	0.5	0.6	-0.8	2.8	1.2	0.6	1.9
P		2.6	2.4	2.4	0.1	2.9	2.4	-1.5	-0.2	-2.8	-0.9	-1.8	-1.1	-1.5	-1.6	1.4	2.6	5.3	3.9	3.8	1.1	
Q		4.8	2.8	2.1	3.3	2.7	2.7	1.0	2.1	-0.3	1.3	-3.3	-2.2	1.2	1.2	4.5	6.3	3.6	2.4	3.7	5.4	
R			5.8	5.7	3.6	4.1	0.2	0.2	1.5	0.4	-0.9	-0.5	0.5	0.1	1.5	1.6	3.6	3.6	1.1	4.3		
S			4.4	1.0	3.1	2.3	2.2	2.2	2.7	0.7	0.2	1.8	-1.8	1.2	1.9	3.1	1.9	2.9	0.8	0.3		
T				3.8	3.9	2.0	0.7	1.2	0.6	0.6	2.1	1.6	7.7	2.4	1.8	1.8	2.0	2.6	1.0			
U					3.2	4.2	1.7	0.7	1.0	-0.1	3.0	2.6	1.5	2.6	1.6	0.9	3.2	-0.1				
V						1.7	1.4	3.1	0.2	0.1	0.7	0.7	0.5	0.8	3.1	2.2	1.0					
W									0.7	2.3	3.0	1.8	2.2	1.1								

Statistics for all channels

	Average	St.Dev	Minimum		Maximum	
	Value	Value	Value	Channel	Value	Channel
ALL	0.35	2.04	-8.54	J22	7.65	T13
IC	0.46	2.05	-2.08	B 9	3.65	Q20
RC	1.63	2.61	-2.46	D16	5.84	R 3
1.5"OC	1.03	2.66	-8.54	J22	5.84	R 3
2.0"OC	0.67	1.71	-2.72	B12	5.73	R 4
OC	0.79	2.07	-8.54	J22	5.84	R 3
NOC	-0.14	1.90	-5.80	F15	7.65	T13

Statistics for power zones channels

	Average	St.Dev	Minimum		Maximum	
	Value	Value	Value	Channel	Value	Channel
Zone 1	0.56	1.34	-1.75	B 6	3.79	K 1
Zone 2	2.27	1.57	-1.51	M 6	5.84	R 3
Zone 3	-0.80	1.71	-5.80	F15	2.73	G10
Zone 4	-1.06	1.18	-3.66	N 8	2.08	K 8
Zone 5	0.84	1.73	-3.31	Q12	7.65	T13
Zone 6	-1.03	1.78	-8.54	J22	2.40	J19
Zone 7	1.68	1.98	-3.24	M16	6.34	Q17

Notes: IC -Instrumented Channels RC-Riser Channels NOC-Non Orificed Channels

ALL-All Channels IC -Instrumented Channels RC-Riser Channels 1.5"OC-1.5" Orificed Channels 2.0"OC-2.0" Orificed Channels OC-All Orificed Channels NOC-Non Orificed Channels

FIGURE 3. COMPARISON BETWEEN JANUARY AND SEPTEMBER 1998 FLOWS DERIVED FROM INVERSE HEAT BALANCE AT 85% FP