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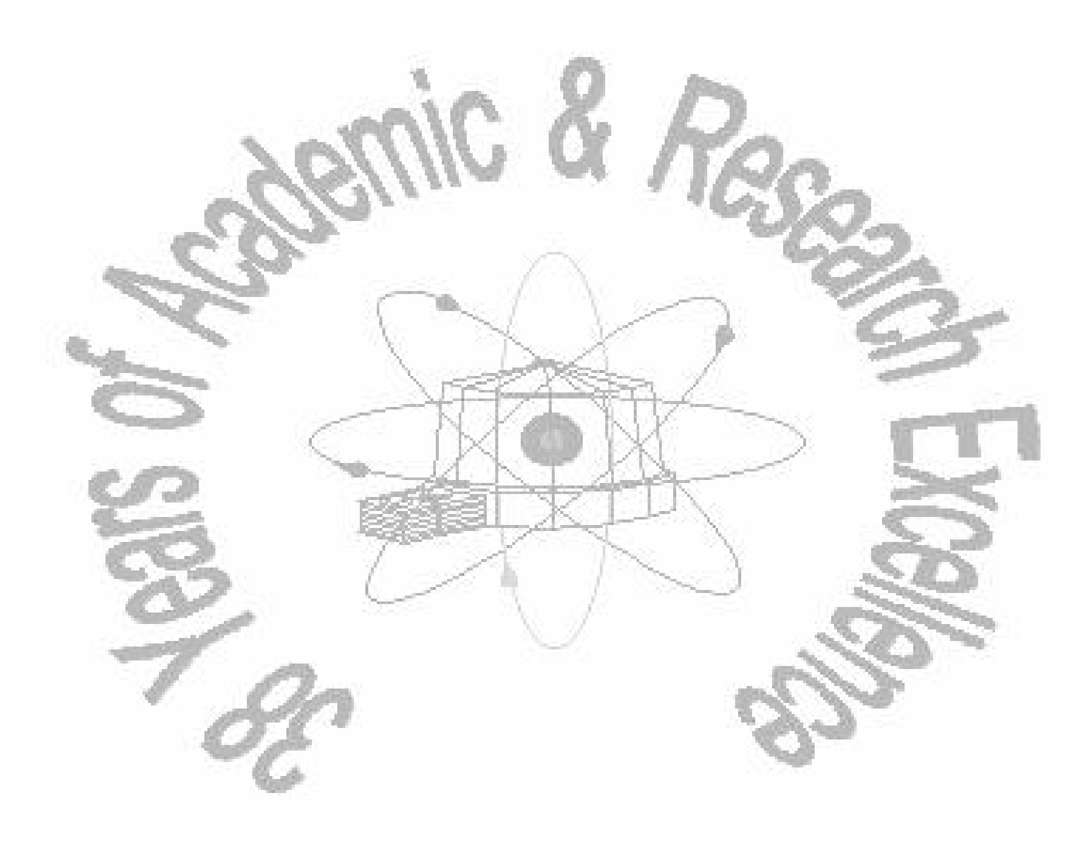
Technical Report 97-06

CATHENA Simulation of the MNR CORE with more than 8 PTR Fuel Assemblies



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1. Introduction

The current MNR license permits the use of up to eight 10 plate PTR type fuel assemblies. In the event that the proposed LEU type fuel is not available before the current fuel supply is depleted, it is proposed that additional available PTR assemblies be used. To support such a proposal, this report addresses the thermalhydraulics ramifications of the use of more than 8 PTR assemblies.

2. Model Setup

The current core (48c) is modelled as a base case. The core layout and associated flow assignments are depicted in figure 1. The modelling details are described in [TR97-04]. Table 1 summarizes the flows and temperatures of the various core regions. The hottest fuel plates for this base case are the outer plates of the high power 10 plate PTR fuel assembly (65°C), compared to a maximum of 60°C for the high power 18 plate assembly. A core inlet temperature of 30° is assumed throughout this report. The coolant velocity in the PTR assembly is calculated to be 1.0 m/s, compared to a velocity of 0.72 m/s in the 18 plate assembly. The higher power per plate accounts for the higher temperatures in the PTR fuel in spite of the higher coolant velocities.

Figure 2 shows the core layout with 15 PTR assemblies. To be conservative, the PTR assemblies have been placed preferentially in the central, higher power region of the core and next to the shim control assemblies (i.e., face to face outer fuel plates giving the highest heat load to the bypass flows). Figure 3 shows the case in which the core is composed of almost all (28) PTR assemblies. In all cases, the shim control assemblies remain as in the current design and configuration. Table 2 gives the flows and temperatures for the 15 PTR case and table 3 gives the flows and temperatures for the 28 PTR case.

3. Simulation Results

The PTR assemblies have a lower flow resistance than the 18 plate assemblies, hence, the use of more PTR assemblies will tend to "steal" coolant from the 18 plate assemblies. Given that the PTR assembly represents the limiting case, this is desirable. As more and more PTR assemblies are added, however, they will increasingly "steal" from each other, i.e., the core flow will redistribute such that the benefit of the lower hydraulic resistance of the PTR assemblies is reduced. This effect is seen in the results. For the 15 PTR case the maximum fuel temperature has risen 4°C over the base case to 69°C and the velocity has dropped to 0.91 m/s. In the extreme case of 28 PTR assemblies, the maximum temperature is 74°C and the velocity is 0.77 m/s. These temperatures are insignificantly different than the base case compared to the saturation temperature of the coolant (116°C).

To assess the margin to sheath dryout and centreline melting, a high power (10 MW) case was run for the base core and for the core with 15 PTR fuel assemblies. As shown in tables 4 and 5, the hot PTR assembly represents the limiting case. At 10 MW, the assembly is on the verge of boiling at the sheath surface. The predicted ratio of critical heat flux to actual heat flux (termed the critical power ratio, CPR) is 19.2 for the base core and 16.3 for the core with 15 PTR assemblies. This confirms that the margin is large for the base core and insignificantly different for the core with 15 PTR assemblies.

4. Verification

Verification includes:

- Independent thermalhydraulic experiments and analysis [RUM88]of a fuel assembly mockup at McMaster.
- CATHENA model verification as part of the ongoing model development under the guidance of AECL.

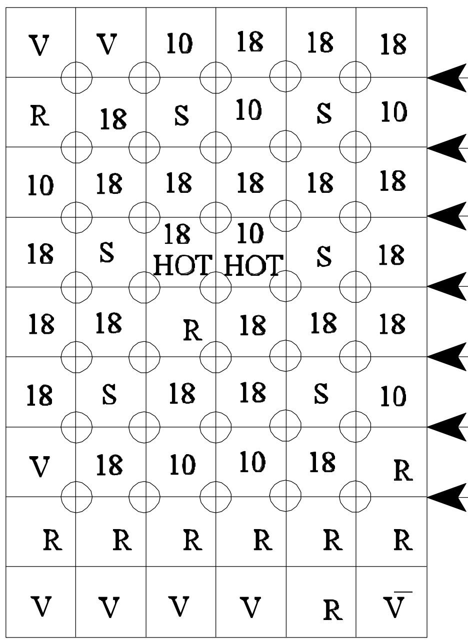
5. Conclusion

Both the 18 plate temperatures and the PTR assembly temperatures are insignificantly different than the base case. From the thermalhydraulic perspective, there appears to be no reason to restrict the use of the PTR assemblies for 2 MW operation.

6. References

RUM88 Helena E.C. Rummens, "Thermalhydraulic Studies of the McMaster Nuclear Reactor Core", M.Eng. Thesis, Department of Engineering Physics, McMaster University, April 1988.

TR97-04 Wm. J. Garland, "Thermalhydraulic Modelling of MNR", McMaster University Nuclear Reactor, Technical Report MNR-TR 97-04, April 28, 1997.

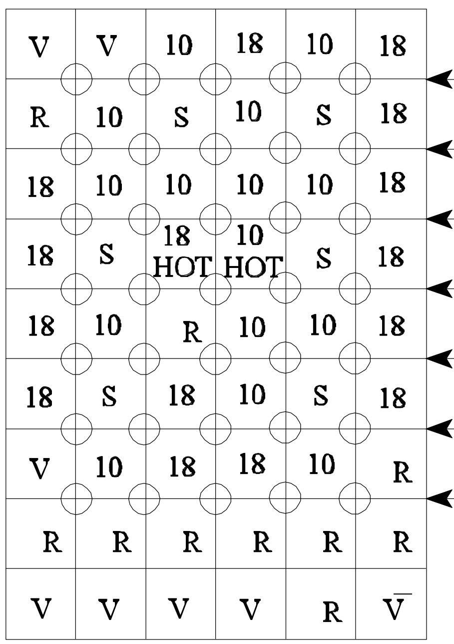


APTRBYP	HPTRBYP	SHIMBYP	COREBYP	Total
1.5		2	1.5	5
2		2	1	5
0.5		2	1.5	5
	1	2	2	5
0.5	1	2	2.5	5
0.5		2	2.5	5
2			3	5
7	**2**	**12**	**14**	**35**

Figure 1 Bypass flow assignment for the base case (core 48c)

Table 1 Flow and temperature results for the base case

ASSEMBLY GROUP (# of assemblies in the group)	COOLANT VELOCITY (m/s)	TOTAL FLOW (kg/s)	COOLANT OUTLET TEMP (°C)	MAXIMUM SHEATH SURFACE TEMP (°C)	MAXIMUM FUEL TEMP (°C)
MNR18 (21)	0.72	49.20	36	43	44
MNR18HOT (1)	0.73	2.35	43	59	60
APTR (7)	1.00	27.28	34	45	46
APTRBYP	0.72	2.21	36	47	48
HPTR (1)	1.00	3.03	37	59	62
HPTROUT	1.00	0.87	34	59	62
HPTRBYP	0.72	0.63	34	63	65
SHIM (6)	0.72	7.43	34	45	46
SHIMBYP	0.73	3.80	36	46	47
COREBYP	0.72	4.43			
SAMPLES	0.03	0.29			
SHIMABS	0.06	0.29			

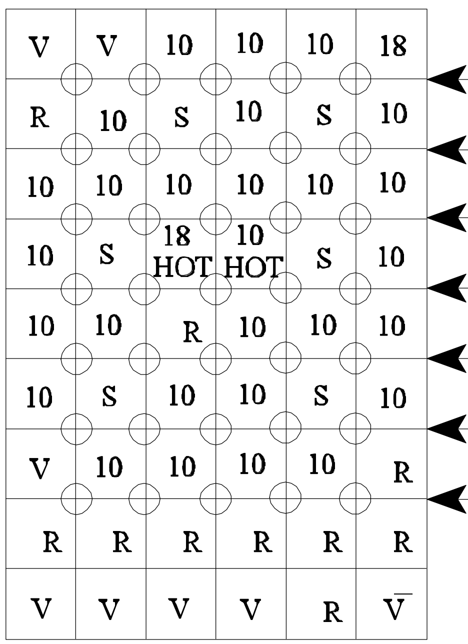


APTRBYP	HPTRBYP	SHIMBYP	COREBYP	Total
3.0		1	1.0	5
3.0		1	1.0	5
2.0	0.5	1	1.5	5
1.5	0.5	1	2.0	5
2.0		1	2.0	5
1.5		1	2.5	5
1.0			4.0	5
14	1	6	14	35

Figure 2 Bypass flow assignment for the 15 PTR case

Table 2 Flow and temperature results for the 15 PTR case

ASSEMBLY GROUP (# of assemblies in group)	COOLANT VELOCITY (m/s)	TOTAL FLOW (kg/s)	COOLANT OUTLET TEMP (°C)	MAXIMUM SHEATH SURFACE TEMP (°C)	MAXIMUM FUEL TEMP (°C)
MNR18 (14)	0.65	29.62	36	45	45
MNR18HOT (1)	0.65	2.12	44	61	63
APTR (14)	0.9	49.5	33	46	47
APTRBYP	0.65	4	34	48	49
HPTR (1)	0.91	2.75	37	62	65
HPTROUT	0.91	0.79	37	62	65
HPTRBYP	0.66	0.79	39	66	69
SHIM (6)	0.65	6.71	34	47	47
SHIMBYP	0.66	1.72	41	49	50
COREBYP	0.65	4			
SAMPLES	0.03	0.27			
SHIMABS	0.05	0.26			



APTRBYP	HPTRBYP	SHIMBYP	COREBYP	Total
3.5		1	0.5	5
4.0		1		5
3.5	0.5	1		5
2.5	0.5	1	1	5
4.0		1		5
4.0		1		5
4.0			1	5
25.5	**1**	**6**	**2.5**	**35**

round to 25   round to 3

Figure 3 Bypass flow assignment for the 28 PTR case

Table 3 Flow and temperature results for the 28 PTR case

ASSEMBLY GROUP (# of assemblies in the group)	**COOLANT VELOCITY (m/s)**	**TOTAL FLOW (kg/s)**	**COOLANT OUTLET TEMP (°C)**	**MAXIMUM SHEATH SURFACE TEMP (°C)**	**MAXIMUM FUEL TEMP (°C)**
MNR18 (1)	0.55	1.78	38	47	48
MNR18HOT (1)	0.55	1.79	47	66	67
APTR (27)	0.77	81.16	34	48	50
APTRBYP	0.55	6.02	35	51	52
HPTR (1)	0.77	2.34	38	66	69
HPTROUT	0.77	0.67	39	65	69
HPTRBYP	0.55	0.24	40	70	74
SHIM (6)	0.55	5.66	35	49	50
SHIMBYP	0.55	1.45	43	52	53
COREBYP	0.55	0.72			
SAMPLES	0.02	0.23			
SHIMABS	0.04	0.22			

Table 4 Margin to dryout for the base case

Assembly	Actual heat flux (kW/ m^2/s)	Critical heat flux (kW/ m^2/s)	Critical Power Ratio at 10 MW	Critical Power Ratio at 2 MW
18 plate hot	666.9	3122.9	4.68	23.4
PTR hot (central plates)	1011.6	3614.2	3.57	17.8
PTR hot (edge plates)	976.4	3643.5	3.85	19.3

Table 5 Margin to dryout for the15 PTR assembly case

Assembly	Actual heat flux (kW/ m^2/s)	Critical heat flux (kW/ m^2/s)	Critical Power Ratio at 10 MW	Critical Power Ratio at 2 MW (inferred)
18 plate hot	666.8	3009.3	4.51	22.6
PTR hot (central plates)	1011.4	3539.2	3.5	17.5
PTR hot (edge plates)	1015	3539	3.26	16.3

APPENDIX 1 CATHENA Input and Output files

Table of Contents:

grid6e.inp	Steady state input file for the base case
grid6-core.out	Output file (selected core parameters vs. time)
grid6e.lis	Full output listing
grid7a.inp	Steady state input file for the 28 PTR case
grid7-core.out	Output file (selected core parameters vs. time)
grid7a.lis	Full output listing
grid8a.inp	Steady state input file for the 15PTR case
grid8-core.out	Output file (selected core parameters vs. time)
grid8a.lis	Full output listing

Archive directory (AECL-SP): herzberg:u94/garlandw/cathena/development/mod5-grid.