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The Comparison Analysis of Thermalhydraulic Behavior Between A Reference 37-element Bundle and A Modified 37-element Bundle

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1. Introduction

The Heat Transport Systems (HTS) of CANDU nuclear power plants (PHWR) are aging. One of the effects of aging is the non-uniform change in the dimension of the reactor pressure tubes through the mechanism of diameter creep. As pressure tube diameter creep increase, the coolant flows through some of the interior subchannels of the fuel bundle are reduced and consequently reduces the Critical Heat Flux (CHF). For this reason, Canadian Utilities have performed the project that developing the new fuel design (modified 37-element bundle) to increase critical heat flux. The modified 37-element (37M) bundle has the same overall geometry as the reference 37-element (37R) bundle that is using in the wolsong units now but the center element diameter has been reduced from 13.06mm to 11.5mm. The reduction in center element diameter of the 37M bundle design increase the flow of center areas to improve the cooling and thus to enhance CHF. The CHF experiments with 37M bundle string simulator in un-crept and crept (3.3%, 5.1% peak creep) flow channels were completed at Stern Laboratories in 2008 [1]. A substantially large increase in dryout-power was observed for the 37M bundle compared to the 37R bundle, particularly in the 5.1% crept channel. As a result of the experiments, Ontario Power Generation (OPG) and Bruce Power (BP) have increased the operational margin with this CHF correlation and has fully refueled the 37M fuel on some units or almost done on the other units. KHNP also has performed the project to refuel the 37M bundle which is the same design with OPG and BP recently.

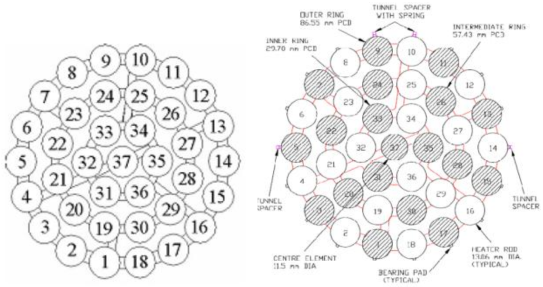
This paper summarizes the comparison assessment of Thermalhydraulic (T/H) behavior for 37M bundle and 37R bundle with their own correlations and geometry parameters. This analysis performed with the thermal hydraulic code (NUCIRC) and the site measured data at the Wolsong Unit2 .

2. Modeling Approach and Assumption

2.1 Modeling Approach

The NUCIRC code is a steady-state one dimensional T/H code used for the design and performance analysis of the HTS and components of a CANDU reactor for variety of operating conditions. It can be used to a) predict pressure, flow, temperature at any location b) determine critical channel power c) establish critical channel flow at dryout d) calculate fuel and fuel sheathe temperatures. etc[2]. For the comparison of two types of bundle design, the bundle geometry and the correlation, like a critical heat flux (CHF), onset of significant void (OSV), two-phase friction multiplier (TPRM), are put into the NUCIRC input deck related to each fuel design. The code calculates the T/H behavior of all 380 channels independently. Then the results show the difference of the mass flow rate, pressure drop and critical channel power. etc. come from the differences of fuel geometry and the correlations. Besides the result using the measured data of the Wolsong unit is acquired a meaning as a verification against Canada's experimental results.

The difference of geometry from 37R bundle to 37M bundle is that the center element diameter has been reduced from 13.06mm to 11.5mm. Because of this change, flow area and hydraulic diameter are increased. The modeling was applied this geometry changes.



(a) 37M bundle [1] (b) 37R bundle [3]

Figure 2-1. Geometry of the fuel bundle

2.2 Assumption

This assessment used the T/H data which was measured at the Wolsong unit 2 (5345EFPD, '13.7). The data for NUCIRC execution, especially inlet header temperature, differential Pressure between headers and outlet header pressure represents the operational condition of specific plants. If the fuel design is different, the T/H data could not be exactly the same. However, it assumes that the same T/H data (measured with 37R bundle) is used during the assessment because the data fueled with 37M bundle cannot be obtained now and predicts the small design change cannot affect the total HTS. Pressure drop is a strong function of geometry and operating conditions. The Pressure drop has two components, friction and form losses. However, because the difference in geometry between the two bundle designs is very small and a perceptible change in the friction and form losses is not expected, these coefficients used the same values between two models.

Table 2-2 NUCIRC code input for T/H parameters

Parameter	Unit	Value
Power Plant	-	Wolsong Unit 2
Effective Full Power Day	EFPD	5345
Reactor Power	%	94.91
Inlet header Temperature (avg)	℃	264.15
Differential Pressure (avg)	kPa	1247.33
Outlet header Pressure (avg)	Mpa(a)	9.98
Pump Suction Pressure (avg)	Mpa(a)	9.50

3. Analysis Result

Most of all analysis results, channel flow rate, pressure drop at the location of subchannel and critical channel power with specific power shape are important results for the comparison of effects due to fuel design changes. This section summarizes these key results of the T/H behaviors for the 37M bundle and 37R bundle.

3.1 Result of Mass Flow Rate

Table 3-1, 3-2 shows the flow rate of 37M fueled core and 36M fueled core. The total flow of 37M fueled core is 8917kg/s and 37R fueled core is 8872kg/s. Figure 3.1 shows different channel flow distribution. All the 37M strings increases the channel flow and center area channels that have more flow and high power have more channel increase relatively. The average flow rate of 37M strings increases about 0.7% than 37R string. This result could be similar to or less than the out-reactor test results in Canada[4] that the difference of flow rate is about 1%. A reduction in the diameter of the center element form 13.06mm to 11.5mm cause a minor reduction in the channel resistance leading to a slight increase in the channel flow. It could be beneficial from a fuel cooling point of view.

Table 3-1 Mass Flow Rate of **37M** Fueled Channels

CORE	TOTL	center core	orifice core	HD4-1 pass1	HD2-3 pass2	HD8-5 pass3	HD6-7 pass4
AVG.:	23.47	28.00	19.38	23.65	23.55	23.33	23.33
SUM:	8917	5040	3877	2246.370	2237.710	2216.330	2216.410
ST.D.:	5.43	0.95	4.47	5.58	5.50	5.40	5.28
MIN.:	11.32	24.70	11.32	11.32	12.61	12.67	11.54
MAX.:	29.98	29.98	27.76	29.96	29.98	29.93	29.59

Table 3-2 Mass Flow Rate of **37R** Fueled Channels

CORE	TOTL (Kg/s)	center core	orifice core	HD4-1 pass1	HD2-3 pass2	HD8-5 pass3	HD6-7 pass4
AVG.:	23.35	27.83	19.32	23.52	23.44	23.21	23.21
SUM:	8872	5009	3863	2234.850	2226.470	2205.370	2205.360
ST.D.:	5.37	0.94	4.43	5.52	5.44	5.34	5.22
MIN.:	11.31	24.58	11.31	11.31	12.59	12.65	11.52
MAX.:	29.77	29.77	27.59	29.75	29.77	29.72	29.38

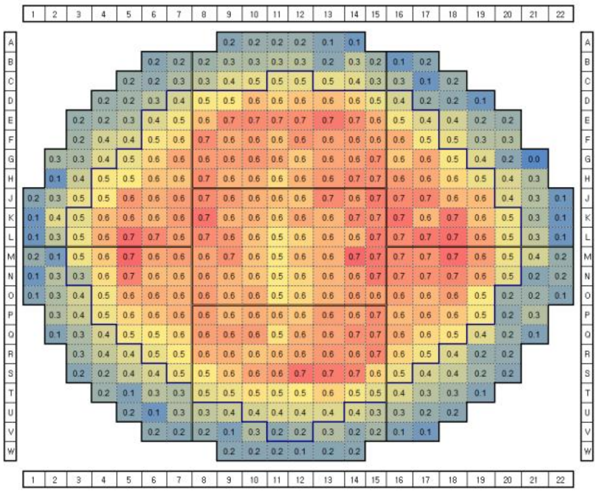


Figure 3-1 Channel Distribution of Flow Difference

3.2 Result of Pressure Drop

Figure 3-2 shows the fuel string pressure drop of 37M fueled core and 37R fueled core. A09 channel pressure drop of 37M string is 165.83kPa and 37R sting is 169.19kPa. Overall the pressure drop for channels of 37M string is lower than channels of 37R string. Based on the calculated reduction of the pressure drop for 37M string is approximately 1.48% than 37R string. A reduction in the diameter of the center element form 13.06mm to 11.5mm result in an increase in the coolant flow area of approximately 0.9% for a non-crept pressure tube and a decrease in total wetted perimeter of 0.3%. It causes a slight decrease pressure drop in the channel due to the slight increase in the hydraulic diameter. However, the differences of pressure drop across the 37M and 37R strings are relatively small.

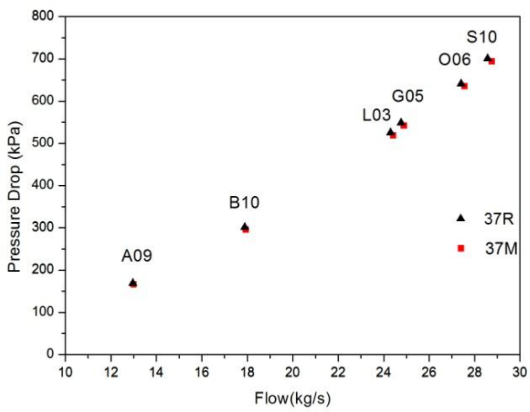


Figure 3-2. Pressure Drop Between 37M and 37R

3.3 Result of Critical Channel Power

According to the results of 37M fuel CHF tests, the average improvement in dryout power for the 37M fuel simulator tests over the correlation developed from the 37R fuel simulator tests, for the range of conditions tested, is 3.3% for the un-crept flow channel, 6.5% for the 3.3% crept flow channel and 16.9% for the 5.1%

crept flow channel[1]. Table 3.3 shows the Critical Channel Power(CCP) for wolsong unit 2(5345EFPD) with steady state power shape. The CCPs of 37M bundle using the new CHF correlation are higher than 37R bundle, the average CCP of 37M bundle increase 446kw than 37R bundle. Figure 3.3 shows the increased ratio of 37M bundle between 380 channels. Average improvement in CCP for 37M string is 5.7% and maximum value is 8.4% in E11 channel. The maximum creep is 3.1% for Wolsong unit2(5345EFPD). This average result(5.7%) could be the same with the CHF tests in Canada shown 6.5% improvement with 3.3% crept flow.

Table 3-3 Critical Channel Power between 37M and 37R

FUEL	CORE	TOTL (kw)	center core	orifice core	HD4-1 pass1	HD2-3 pass2	HD8-5 pass3	HD6-7 pass4
37M	AVG.:	8102.46	9253.34	7066.68	8126.07	8112.89	8050.58	8120.31
37R	AVG.:	7655.95	8693.11	6722.50	7677.75	7664.55	7609.29	7672.20
	Diff	446.52	560.22	344.18	448.32	448.34	441.29	448.10

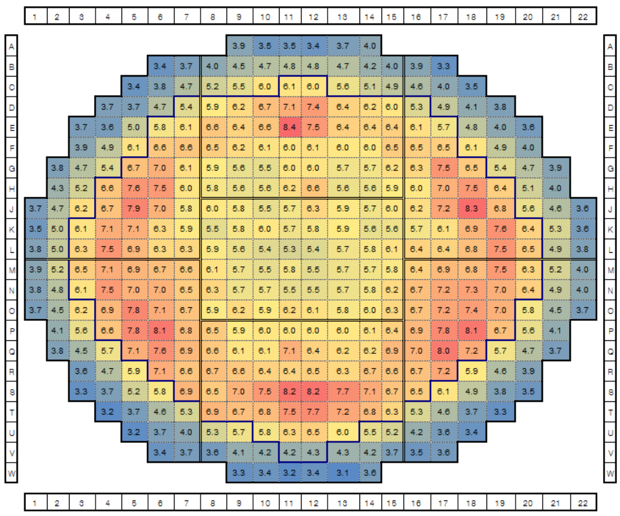


Figure 3-3. Channel Distribution of CCP Improvement

4. Conclusions

Tests to evaluate the CHF performance with the 37M fuel bundle have been conducted in 2008 using the un-crept, 3.3% crept and 5.1% crept flow channels in the CHF Test facility at Stern Laboratories. In addition pressure drop tests have been performed at the same time. The changes of geometry from 37R bundle to 37M bundle reduced the center element diameter little but gave the large CHF improvement, especially 5.1% crept flow. Results of applying the Geometry and correlations of 37M bundle with the data for Wolsong unit2 are very similar with test results performed in Stern. Lab.

The average flow rate of 37M strings increases about 0.7% than 37R string. This result could be similar to or less than the out-reactor test results in Canada. The calculated reduction of the pressure drop for 37M string is approximately 1.48% than 37R string. The improvement of average CCP results of 37M bundle shows 5.7% with 3.1% maximum crept flow, it could be similar to the CHF tests in Canada shown 6.5% improvement with 3.3% crept flow.

These T/H behaviors depend on the operation condition of plant like temperature, pressure, mass flow, void .etc and channel distribution of aging condition like pressure tube creep and magnetite deposit therefore it is difficult to define initial conditions between tests and assessment are the same. However this assessment shows that the trend and quantitative results is very similar.

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