Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

Dryout Margin Analysis for Transition Core of CANDU

Ryu Eui-Seung*
Korea Hydro & Nuclear Power Co., Ltd. 1312, Yuseong-daero, Yuseong-Gu, Daejeon, Korea, 305-343
**Corresponding author: esryu2002@khnp.co.kr*

1. Introduction

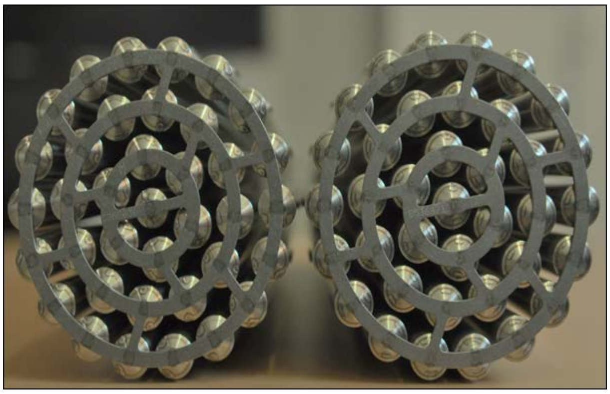
Canadian Utilities (PHWR) have performed the project that developing the new fuel design (modified 37-element bundle) to increase Critical Heat Flux. The modified 37-element (37M) bundle has the same overall geometry as the reference 37-element (37R) bundle that is using in the Wolsong units now but the center element diameter has been reduced. The reduction in center element diameter of the 37M bundle design increase the flow of center areas to improve the cooling and to enhance CHF[1]. Ontario Power Generation (OPG) and Bruce Power (BP) have increased the operational margin with this 37M fuel CHF correlation and have fully refueled the new bundle. KHNP also decided to introduce the 37M fuel and the project is currently underway.

While the design change is relatively minor, channel flow area and reduced flow resistance will affect the Heat Transport Systems (HTS) thermal hydraulic operating conditions. Especially during the transition core condition, there is potential safety margin change. This paper summarizes the thermal hydraulic analysis and impact for safety margin using with margin to dryout(Critical Channels Power) during this transition period.

2. Methodology and Modeling Approach

2.1 Methodology

The difference of geometry of 37M bundle is that the center element diameter has been reduced compared with the 37R bundle. Because of this change, flow area and hydraulic diameter are increased. The 37M fuelled core will have slightly lower header to header differential pressure and slightly higher core flows. During transition core, as more 37M bundles are fuelled into the core, the header to header ΔP gradually decreases while the total core flow increases. Channels with only 37R fuel strings, however, will experience a slight reduction in flows due to the lower header to header ΔP. For the purposes of evaluating potential impacts on the margin to dryout, the most limiting core condition is one where a limiting channel is fuelled with 37R channel, in fuelled with all 37M fuel(379 channels). The 37R fuel in the limiting channel will result in a relatively higher flow resistance and reduced flow. Because of the flow redistribution, the margin to dryout of the only 37R channel is reduced than in the case of full 37R fuelled(380 channels) core. The impact of margin to dryout during transition core could be evaluated with the comparison of the limiting 37R channel between in the full 37R core and in full 37M (379channels) core except one channel [2].



(a) 37M bundle (b) 37R bundle
Figure 1. Geometry of the fuel bundle

2.2 Modeling Approach

This analysis performed with the thermal hydraulic code(NUCIRC), the site measured and predicted data at the Wolsong Unit2(7300EFPD). 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 [3].

The main steps in this analysis are as follows;

a) Full 37R fuelled core model at Wolsong unit2 aged condition for 7300EFPD is made with NUCIRC code and site data.
b) Full 37M fuelled core model is made from the aged NUCIRC model in Step a) with changing the 37M fuel geometry and radial power distribution.
c) Using the header conditions obtained in Step a), CCPs are calculated for 37R channels. CCPs for all 380 channels are calculated.
d) Using the header conditions obtained in Step b), CCPs are calculated for 37R channels. CCP of only 37R channel is calculated in this Step.
e) Comparison of the CCPs generated Steps c) and d) is performed to provide an indication of the maximum reduction in CHF margins that could occur during transition core[4].

3. Analysis Result

3.1 Steady state Header Conditions for 7300EFPD

The typical model of Wolsong unit2 at aged conditions (7300EFPD) for a fully fuelled 37R core was generated and a fully fuelled 37M core is generated by implementing the 37M fuel geometry. Based on the calculated system header conditions presented Table 1, inlet temperature and outlet pressure is the same between the 37M fuelled core and the 37R fuelled core. The reduction in header to header ΔP is approximately 0.7% and the core pass flow is increased approximately 21kg in the 37M core. As the overall fuel design change is small, it is assumed that differences in thermal hydraulic condition is very minor.

Table 1. Header condition for 37R and 37M core

Parameter	37R core	37M core
Inlet header temp (℃)	265.6	265.6
Outlet header Press (MPa)	9.976	9.977
Header to Header DP(kPa)	1207.96	1199.49
Total core pass flow(kg/s)	8683.48	8704.80

3.2 Critical Channel Power for Full core

CCP calculations with conditions corresponding to a fully 37R fuelled core and fully 37M fuelled core in Wolsong unit2 for 7300EFPD are analyzed. As a result, CCP in 37M core is increased average 7.25%, maximum 10.27%(P6) with normal steady state flux shape(Case 001). Full core implementation of 37M fuel provides additional margin with improved 37M fuel CHF correlation. 37M fuel provides a beneficial impact on CCP and dryout margins.

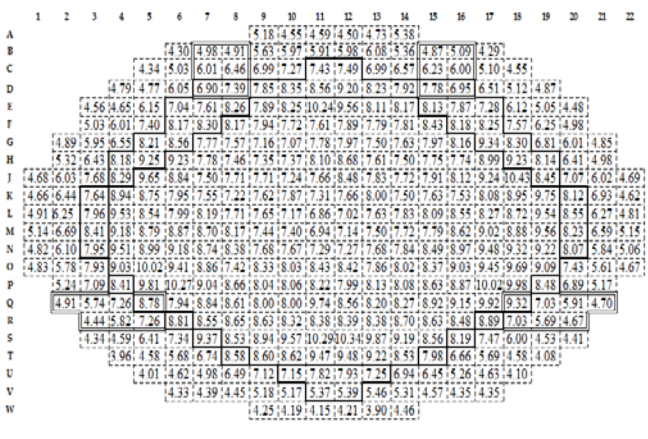


Figure 2.Increased CCP in fully 37M fuelled core(%)

$* \% CCP = [(CCP_{37M}/ CCP_{37R}) - 1] \times 100$

3.3 Critical Channel Power during transition core

The limiting condition from cooling and margin to dayout will be the last remained one 37R fuel channel during the transition core. Based on Table 1, total core flow in fully 37M fuelled core is slightly higher (average 0.4%) than in fully 37R fuelled core because of increased channel flow area and reduced flow. However, channel flow increase in 37M channels makes 37R fuel channel to be reduced due to flow redistribution and lower header to header ΔP. Table 2 shows flow changes in different core conditions.

Table 2. Flow change during transition core

Region	Channel	Power (kw)	Channel flow(kg/s)		
			Full 37R	Only 37R	Full 37M
Low flow	A9	3205	11.78	11.73	11.79
	B10	4431	17.10	17.03	17.11
Mid flow	G5	5791	24.06	23.93	24.14
	L3	5682	23.62	23.39	23.67
High flow	O6	6592	27.00	26.78	27.12
	S10	6355	28.87	28.73	28.95

The presence of 37R fuel in the limiting channel is result in a relatively higher flow resistance in that particular channel. The effect is a potential small reduction in CCP. The impact of this limiting core condition on CCP is maximum 0.32%, average 0.29%. However, the reduction doesn't mean decrease of the ROP(Regional Overpower Protection) Trip setpoint. When ROP Trip setpoint is calculated, there is approximately 1.5% included uncertainty for boundary condition (header condition).

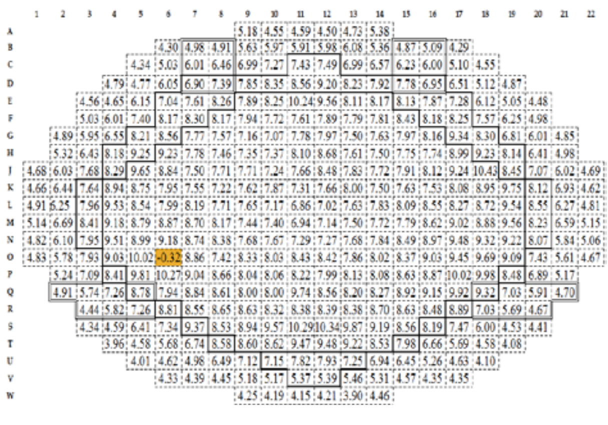


Figure 3.CCP comparison between core in fully 37R fuel channel and core in 278 37M fuel Channel and one 37R fuel channel (O6) (%)

3. Conclusions

The impact of transition core on dryout margins is assessed by comparing CCP predictions based on header conditions for the 37R and a 37M core. The lower flow resistances of the 37M bundle design results in a 0.7% reduction in the average header to header differential pressure. CCP calculations with fully 37M fuelled core is increased average 7.25%, maximum 10.27% with normal steady state flux shape(Case 001). It means the CHF correlation for 37M fuel design has been improved. The average decrease in CCP is about 0.29% in limiting Core condition, one 37R fuel channel in the fully 37M fuelled core, during transition core. However, considering approximately 1.5% included ROP uncertainty for boundary condition (header condition), this decrease will be acceptably small. Besides, the impact of transition core can be accounted for within the existing ROP detector calibration process which considers flow reduction.

REFERENCES

[1] L.Q Yuan and L.K.H Leung "Analysis of Dryout Experiment and Heat –Flux-Values For A Simulated String Of Modified 37-Element Bundle in Uncrept And Crept Channels At Stern Laboratories", COG-10-2030, February 2011.

[2] Zlatko Catovic "Darlington NGS: Assessment of Impacts of Modified 37-element Fuel Bundles on Safety Analyses During the Core Transition, NK38-REP-37400-10019-R0, September 2011.

[3] Freobe, Scott "NUCIRC 2.3 Theory Manual" CE-116190-STM-001, February

[4] P.Peterick "Assessment of Impacts of modified 37 Element Fuel Bundle Design on Design Basis Accidents for Darlington NGS", NK38-REP-37400-10008, February 2011.

[5] KHNP "Safety Analysis Report for Transition Core of Wolsong CANDU Modified -37 Fuel Buldnes.", 2014.05.