Relationship between Lifetime Average Neutron Flux and Pressure Tube Diametral Creep for Wolsong NPP

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1. Introduction

Pressure tube diametral creep (PTDC) is the major aging mechanism governing the heat transfer from fuel to the primary heat transport system in CANDU nuclear reactors. PTDC affects the critical heat flux (CHF) which is the key factor to determine critical channel power (CCP). Pressure tubes in CANDU reactors increase in diameter during their normal operation due to the effects of irradiation, stress and operating temperatures. Deformation equations have been developed and incorporated into the RC-1980 code to provide predictions of pressure tube diametral strain at any time in the plant life [1][2]. These predictions are necessary input required by NUCIRC to assess the impact of pressure tube diametral strain on reactor operating. This study is to confirm the relationship between lifetime average neutron flux and PTDC used by NUCIRC in point of ROP trip setpoint evaluation.

2. Data, Models, and Results

In this section, operational data to review and pressure tube creep estimation tool are introduced.

2.1 Lifetime Average Flux Data

2.1.1 Assumptions

CANDU reactor physics code has been used by PPV/RFSP before changing to WIMS/RFSP[3][4]. Most of physics results were obtained by PPV/RFSP. To use all data without reproducing, assumptions are as bellows;

- Ratio of reference channel power distribution between PPV/RFSP and WIMS/RFSP for each channel is equal to ratio of reference flux distribution between those for each channel.

$$\frac{CP_0^{PPV}}{CP_0^{WIMS}} = \frac{\Phi_0^{PPV}}{\Phi_0^{WIMS}}$$

- Channel power distribution is equal between PPV/RFSP and WIMS/RFSP for each channel.

$$CP_k^{PPV} = CP_k^{WIMS} \text{ (k = 1, … all ripples)}$$

- No channel power variation between ripples. Because the variation will be linear, it will be offset.

2.1.2 Operation Data for Wolsong 2, 3 & 4

Fig. 1 shows variation of channel power ratios (CP/CP_0) at channel L12 in Wolsong 3. It explains that refueling has been done three times per year, because L12 channel is located at inner core. Hence refueling has been done twice per year shown in Fig. 2, because O01 channel is located at outer core. If those are averaged, it would be very similar as time-average (design) value. However, channel power variation for each channel should be quantified and confirmed to affect to pressure tube creep. Collected Operation Data for Wolsong 2, 3 & 4 are summarized in Table I.

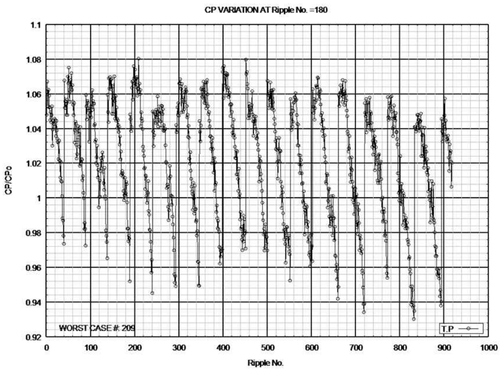

Fig. 1. Channel Power Variation (Ch. ID : L12)

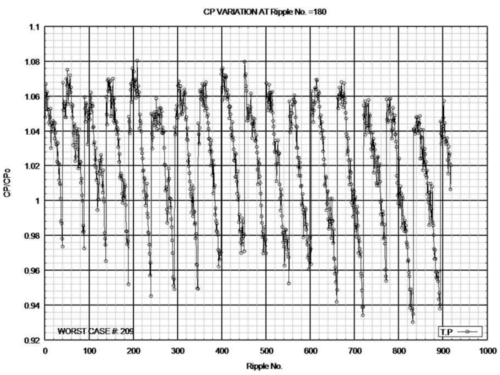

Fig. 2. Channel Power Variation (Ch. ID : O01)

Table I. Collected Operation Data for Wolsong 2, 3 & 4

	Collected Data History (No. of Ripples)
Wolsong 2	1999.01 ~ 2019.10 (1982)
Wolsong 3	2009.01 ~ 2019.09 (936)
Wolsong 4	2009.01 ~ 2019.12 (999)

2.2 RC-1980(Creep Rate Estimation Tool)

RC-1980 can estimate generic pressure tube creep rate based on CANDU6 design data as shown in Fig. 3[5].

However the PTDC is very dependent on operating condition (power distribution, PHTS conditions) of each NPP as shown in Fig. 4 ~ Fig. 6 for Wolsong Unit 2, 3 & 4, respectively.

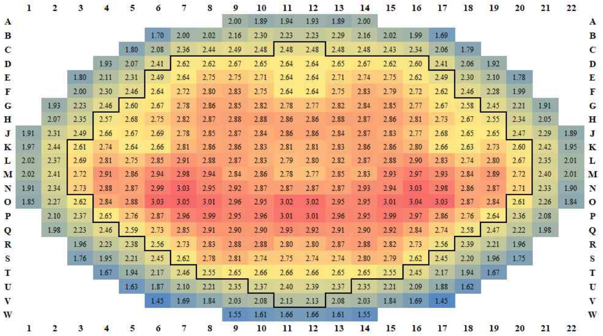

Fig. 3. Estimated (6000EFPD) Pressure Tube Diametral Creep Rate by RC-1980 based on Design Condition

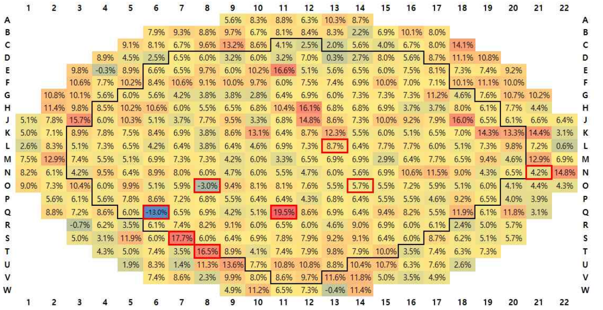

Fig. 4 PTDC Ratio of Site-specific Estimation vs. to RC-1980 Estimation for Wolsong Unit 2(6000EFPD)

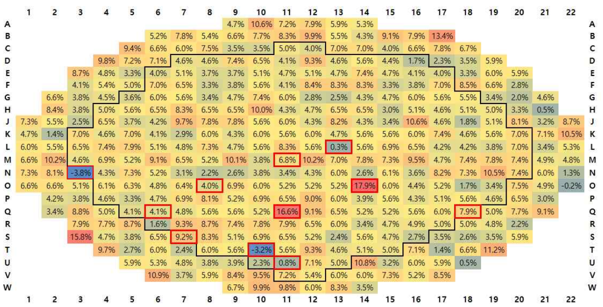

Fig. 5 PTDC Ratio of Site-specific Estimation vs. to RC-1980 Estimation for Wolsong Unit 3(6000EFPD)

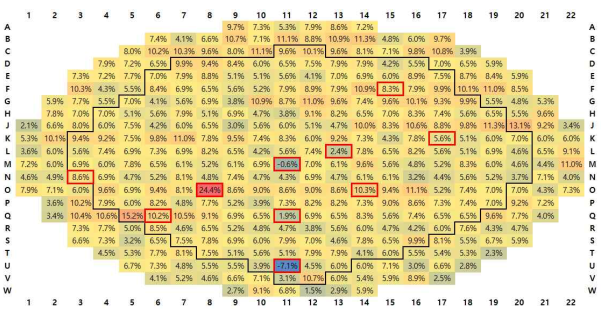

Fig. 6 PTDC Ratio of Site-specific Estimation vs. to RC-1980 Estimation for Wolsong Unit 4(6000EFPD)

Pressure tube diametral creep is commonly the highest in the central core, where the fast neutron flux is the highest as shown in Fig. 7[2]. However, PTDC Ratio of Wolsong 2, 3 & 4 have different trend, because site-specific pressure tube diametral creep is reflecting operating history of each unit. The highest crept channel is very similar to the highest fast flux channel as shown in Fig. 8 ~ Fig. 10. Site-specific PTDC is based on decades of PT measurement channel, and bias was reflected to unmeasured channel as the methodology of ROP trip setpoint evaluation. It confirmed the site-specific PTDC has reflected operating condition specially physics operating history very well.

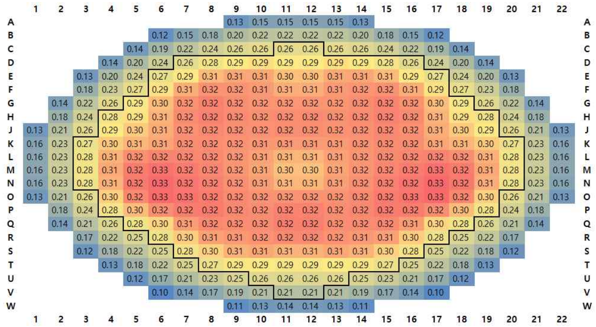

Fig. 7. Time-Average Fast Flux (> 1MeV, 10^{14})

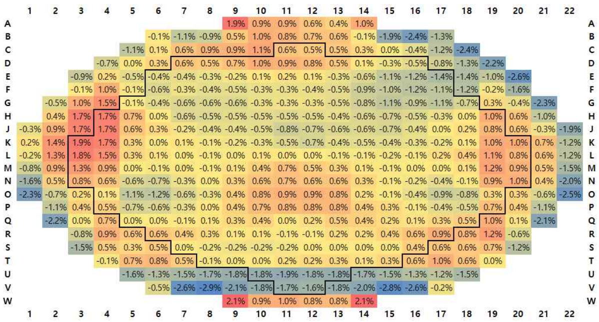

Fig. 8. Ratio of Lifetime Average Fast Flux (> 1MeV) against Time-Average Model for Wolsong 2

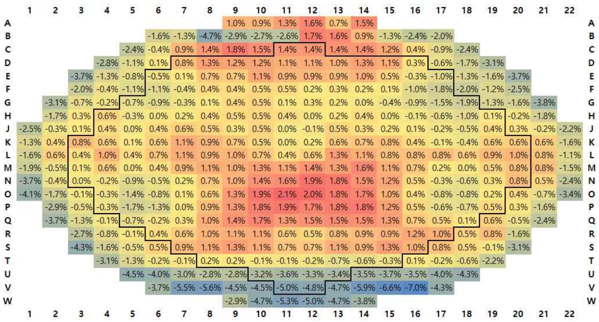

Fig. 9. Ratio of Lifetime Average Fast Flux (> 1MeV) against Time-Average Model for Wolsong 3

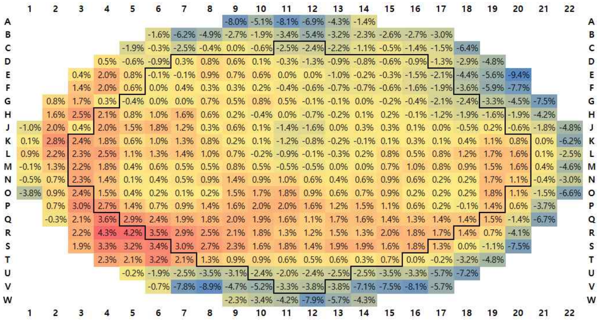

Fig. 10. Ratio of Lifetime Average Fast Flux (> 1MeV) against Time-Average Model for Wolsong 4

3. Conclusions

Pressure tube diametral creep (PTDC) is the major aging mechanism governing the heat transfer from fuel to the primary heat transport system in CANDU nuclear reactors. The relationship between lifetime average neutron flux and PTDC used by NUCIRC in point of ROP trip setpoint evaluation was reviewed. The highest crept channel is very similar to the highest fast flux. It confirmed the site-specific PTDC has reflected operating condition specially physics operating history very well.

REFERENCES

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