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Comparison of CCP using CHF Correlations under HSP-2 & 3 Conditions

Jae Yong Oh [a*], Euiseung Ryu [a], Donghwan Park [a]
[a]*KHNP Central Research Institute, 70, Yuseong-daero 1312beon-gil, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: jaeyongoh@khnp.co.kr*

1. Introduction

Thermalhydraulic analysis of reactor core in nuclear power plants (NPPs) estimate the heat transfer mechanism in which the primary heat transport system (PHTS) coolant comes into contact with the high-temperature fuel during power operation to analyze whether critical heat flux (CHF) is generated on the fuel rod sheathes. In CANadian Deuterium Uranium (CANDU) reactor, Critical Channel Power (CCP) means the power at which CHF occurs on the surface of fuel channel [1]. This concept is similar to Departure from Nucleate Boiling (DNB) in PWR.

Recently, based on the experimental results by Stern Laboratories for the condition that the pressure tube diametrical creep expands up to 5.1%, CHF and Onset of Significant Void (OSV) correlations applied to the thermalhydraulic safety analysis were revised. It was assessed that a few CANDU reactors, for example, Bruce NPP in Canada, could progress to the creep more than 5.1% in the future due to the aging deterioration by life extension. CCP is used to analyze the thermal margin and assess Regional Overpower Protection (ROP) trip setpoints for the core safety design and licensing, by modeling the operating conditions of CANDU using the NUCIRC code. Thus, when revising the thermalhydraulic correlations and computational codes used for the evaluation, sensitivity analysis on CCP is necessary.

Operating scenarios and modes for CANDU reactor to estimate ROP trip setpoints is usually named to Hand Switch Position (HSP). HSP can be divided into three positions, HSP-1, 2, and 3. HSP-2&3 cases are the operating modes that have some constraints or penalties unlike HSP-1, and therefore must be taken into consideration in safety analysis.

In this research, CCP was compared by using NUCIRC under the HSP-2&3 operating cases.

2. CHF Correlations and CCP Prediction

The thermalhydraulic configuration of the generic CANDU PHTS was modeled using the latest version of the NUCIRC code (NUCIRC 2.3.5) [2,3]. NUCIRC 2.3.5 was developed with the assumption of thermal-hydraulic conditions, such as flow rate, inlet header temperature, and header-to-header pressure drop. NUCIRC applies various correlations and factors, depending on fuel type and PHTS geometry. For ensuring safe operation, this study predict CCP under various HSP conditions with the processes described in Fig.1.

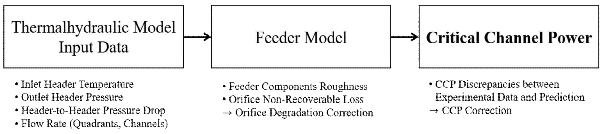

Fig. 1. Conceptual CCP prediction modelling flowchart.

2.1 CHF Correlations

The CHF and its related correlations, for example, OSV and Two-Phase Frictional Multiplier (TPFM) correlations, were developed by Canada Nuclear Laboratories (CNL) and based on the Stern Laboratories experiments under various conditions such as flow rate, temperature, pressure, and creep. The revised correlations have been established covering 6.8% creep data of the modified 37-fuel element (37M) in addition to the data used by the existing correlations. Although the basic structure of correlations is similar, some coefficients and constants within the correlations have minor differences each other. NUCIRC 2.3.5 has included the revised correlations, and so, this prediction used NUCIRC 2.3.5 applying the existing and revised CHF-related correlations for 37M as sensitivity analysis.

2.2 Critical Channel Power

The thermalhydraulic analysis of reactor core is vital in ensuring the safe NPP operation and securing the sufficient thermal safety margin, particularly when using nuclear fuel with a heat flux higher than CHF, which may result in fuel damage.

CCP is deemed instead of CHF in CANDU, so NUCIRC assesses CCP using CHF correlation and other relevant correlations such as OSV and TPFM. CCP was calculated for every fuel channel and bundles.

2.3 Assumption for Operating Condition

This calculation assumed that the modified 37-fuel element (37M) is loaded in the generic CANDU. The main thermalhydraulic parameters such as temperature of reactor inlet header and outlet header, pressure of reactor outlet header and pressure drop between inlet and outlet headers were hypothesized from the aging and operating conditions of the generic CANDU.

2.4 Hand Switch Positions

In CANDU, each HSP category is defined and has its setpoints depending on the different operating conditions as stated below [4].

HSP-1: Normal operations with configuration of reactivity device, adjuster, absorber, and etc.
HSP-2: Abnormal operations not satisfying HSP-1 conditions with abnormal flux-shapes
HSP-3: Operations with symmetric only one HTS pump per PHTS loop

In particular, a key criterion for distinguished between HSP-1 and HSP-2 is whether the axially-averaged zone deviation exceeds a designated value covering uncertainties. CANDU operating cases could be distinguished into three categories as listed above, with HSP-1 consisting of 633 cases, HSP-2 consisting of 180 cases, and HSP-3 consisting of 52 cases.

2.5 CCP Prediction using CHF Correlations

In this prediction, CCPs under HSP-2&3 conditions were computed. The specific case A classified in HSP-3 is one of the specific operating condition with single pump per loop, activating pump 1 & 3, spatially controlled. Fig. 2 & Fig. 3 describe the CCP profile for the case A by using existing and revised CHF-related correlations. In addition, relative error and deviation of CCP derived by the existing and revised correlations for all 37M fuel channels are illustrated in Fig. 4 & 5. The evaluated CCP was calculated to be an average of 5,620 kW for overall 37M channel and a minimum of 3,473 kW for V06 channel using the existing correlations. The results using the revised correlations were an average of 5,591 kW and a minimum of 3,441 kW for V06. The sensitivity analysis on CCP with respect to the revised correlations showed about 0.51% decrease in overall average and approximately 0.90% decrease in the minimum compared with the existing correlations. As a result, it was confirmed that the revised correlations provide slightly conservative CCP value within the deviation range under HSP-2&3 conditions compared to the existing correlations.

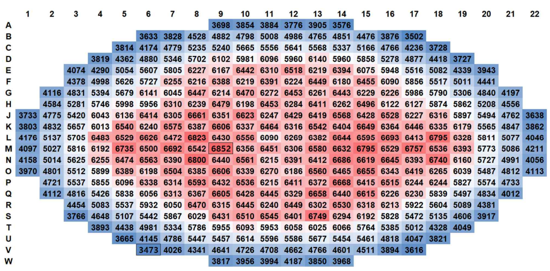

Fig. 2. CCP calculation result applying existing CHF correlation for the specific HSP-3 case A.

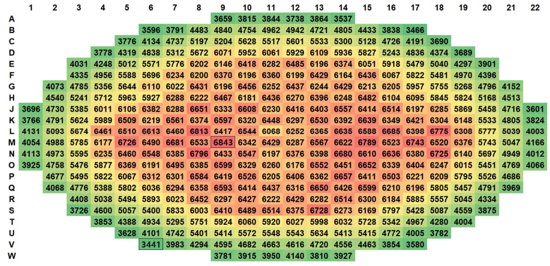

Fig. 3. CCP calculation result applying revised CHF correlation for the specific HSP-3 case A.

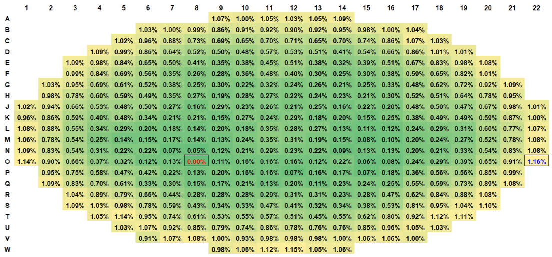

Fig. 4. Relative error of CCP applying between the existing and revised CHF correlations for the specific HSP-3 case A.

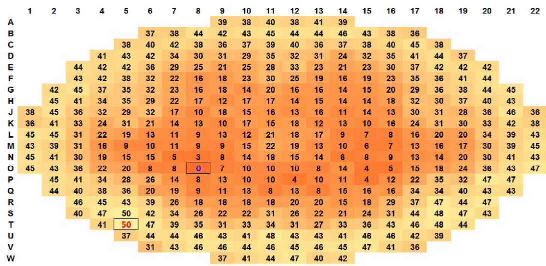

Fig. 5. Relative deviation of CCP applying between the existing and revised CHF correlations for the specific HSP-3 case A.

3. Conclusions

According to this analysis, it is noticed that the estimation results of applying the revised correlations reckoned CCP less and more conservatively than those of applying the existing correlations under HSP-2&3 conditions. Meanwhile, in order to verify and complement the impact of correlation revision on CCP and ROP trip setpoints, further sensitivity analysis is being executed under limiting operating cases for the upcoming thermalhydraulic safety analysis of CANDU fuel element and core management.

REFERENCES

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