# Practical Application of NUCIRC Methodology for CANDU 6 PHTS Core Flow Estimation

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## 1. Introduction

PHTS (Primary Heat Transport System) coolant flow is one of the most important thermal-hydraulic parameters governing the safety and operational performance of CANDU 6 (CANadian Deuterium Uranium-6) reactors. Accurate measurement of individual fuel channel flow rates directly affects the operating power and related safety parameters such as CCP (Critical Channel Power) and ROP TSP (Regional Overpower Protection Trip SetPoints) [1,2]. Although NUCIRC (NUclear heat transport CIRcuit thermo hydraulics analysis Code)-based thermal-hydraulic analysis and the lock-on methodology have been widely established for CANDU 6 reactors, direct measurement of the flow rates of all 380 fuel channels is practically infeasible due to physical and structural limitations as depicted in Fig. 1. Therefore, reliable estimation of the uninstrumented channel flow rates remains necessary for full-core flow assessment

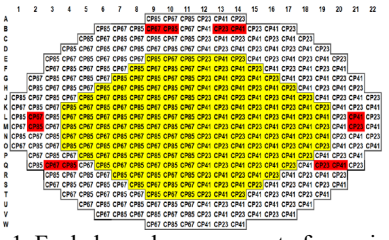



Fig. 1. Fuel channel arrangement of generic CANDU 6 reactor.

This study presents a practical methodology for estimating the full-core coolant flow distribution using the NUCIRC lock-on framework, with an emphasis on the systematic integration of available plant measurement data, design information, reactor physics parameters, and etc. Rather than introducing a new code or modeling concept, this paper focuses on establishing a practical procedure for consistently reflecting plant-specific information in the core flow estimation process. The main contribution of this study is the systematic organization and iterative reconciliation of these inputs to estimate the flow distribution of all fuel channels from limited follow measurement data.

## 2. Methodology and Estimation

NUCIRC, core thermal-hydraulic analysis code for CANDU, version 2.3.5 is used for channel flow prediction [1,2]. Key assumptions and modeling methodology applied in this study are stated.

### *2.1 Assumptions*

Several practical assumptions were introduced to establish a core coolant flow estimation model. First, the RTD (Resistance Temperature Detector) signals associated with the fuel channels were treated with caution and used as tuning references rather than as exact true values. Because the RTD sensing locations are not in direct contact with the coolant flow, the measured temperatures inevitably include instrumentation and installation-related deviations from the true coolant temperature. Second, the steam generator heat balance was assumed to be a comparatively reliable constraint for model tuning. Unlike local temperature measurements that are susceptible to installation effects and local disturbances, the steam generator thermal balance reflects an integrated system response and is therefore less sensitive to local measurement bias. Third, once the model was produced and locked on to the target condition, the aging effect was represented by a power-independent degradation factor. It was considered reasonable because the model is intended for a limited operational period over which abrupt changes in hydraulic characteristics are not expected. Finally, the model was constructed using all available sources of information, including design data, plant measurement data, and reactor physics code-estimated parameters.

### *2.2 Modeling Methodology*

Fig. 2 demonstrates the CANDU 6 PHTS model was established by iteratively coupling the four NUCIRC modules using plant measurement data including boundary conditions, channel temperature and creep, design data such as feeder and orifice geometry, and code-estimated parameter for channel bundle power.

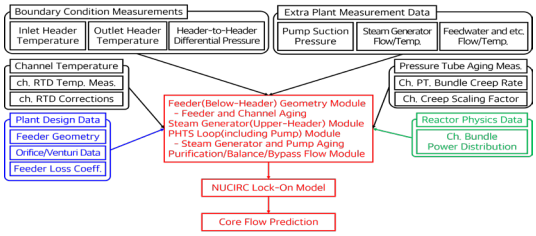



Fig. 2. Input and output data for core flow modeling.

As shown in Fig. 3, the module outputs, including feeder and fuel channel parameters, steam generator conditions, balance and bypass flows, and half-loop PHTS parameters, were exchanged iteratively until the overall model reached a physically consistent state. Thus, the proposed procedure provides an integrated approach for reflecting the interdependence among the major thermal-hydraulic parameters involved in full-core flow estimation as shown in Figure 4.

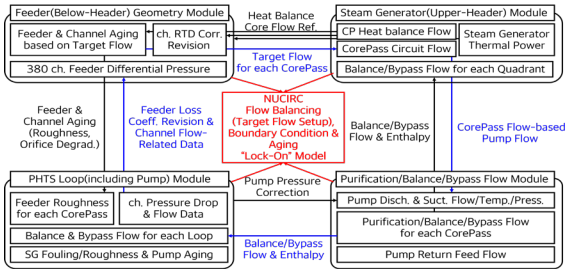


Fig. 3. Parameter interactions in NUCIRC for lock-on model.

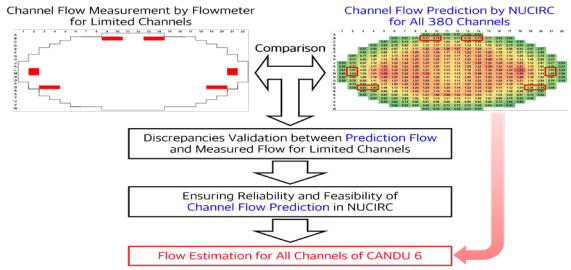
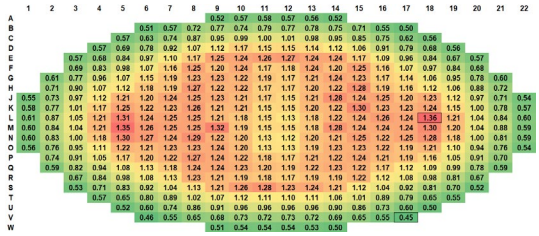


Fig. 4. Verification procedures of predicted core flow compared with flowmeter measurement.

## 3. Result and Analysis

### *3.1 Flow Distribution*

The predicted core coolant flow distribution was normalized with respect to the average channel flow rate to facilitate comparison among individual fuel channels. The analysis indicates that fuel channels located near the central region, yellow region in Figure 1, of the reactor core generally exhibit higher flow rates than those near the peripheral region in Figure 5. This distribution is consistent with the hydraulic design philosophy of the CANDU 6 reactor. Because the central region produces a relatively higher power density, greater coolant flow is intentionally allocated to maintain adequate thermal margin and controlled by feeder characteristics and orifices. The predicted flow distribution reflects properly the radial power shape and demonstrates that the developed model adequately reproduces the hydraulic characteristics of PHTS.


Fig. 5. Normalized core flow distribution of generic CANDU 6.

### *3.2 Comparison with Measurement Data*

In order to assess the applicability of the proposed estimation procedure, the predicted flow rates were compared with available measurements from instrumented fuel channels. The maximum deviation between the predicted and measured channel flow rates was approximately 5%, with an average bias of -3.49% for the channels presented in Table I. Furthermore, the predicted flow rates were generally slightly conservative compared to the measure values. The predicted flow rates were generally slightly lower than the measured values, indicating a conservative tendency in the present estimation results.

Table I: Channel flow comparison

| Channel | Meas. (kg/s) | Pred. (kg/s) | Bias (%) |
|---|---|---|---|
| Meas. #1 | 17.87 | 17.80 | -0.39 |
| Meas. #2 | 20.86 | 20.11 | -3.60 |
| Meas. #3 | 19.84 | 18.84 | -5.04 |
| Meas. #4 | 21.44 | 20.47 | -4.52 |
| Average | 20.00 | 19.31 | -3.49 |

## 4. Conclusions

A practical, generic procedure for estimating the full-core coolant flow distribution of CANDU 6 PHTS using the NUCIRC lock-on framework was presented. The proposed procedure systematically integrates available plant measurement data, design information, reactor physics parameters, and aging parameters and iteratively reconciles the major NUCIRC module parameters to obtain a physically steady PHTS model. Comparison with available instrumented-channel measurements showed deviations of approximately 5% or less, demonstrating the practical applicability of the proposed procedure for full-core channel flow estimation. However, the available measurement data are limited and are concentrated mainly in the peripheral region. Therefore, additional measurement data or independent validation would be desirable to further establish confidence in the estimated flow distribution for uninstrumented channels.

## REFERENCES

[1] Froebe, Scott, "NUCIRC 2.3 User`s Manual", Candu Energy Inc., CE-116190-UM-001, Revision 1, Feb. 2021.
[2] Froebe, Scott, "NUPREP 2.3 User`s Manual", Candu Energy Inc., CE-116190-UM-002, Revision 1, Feb. 2021.