A Correlation between the Core Thermal Power Distribution and Hot Leg RTD Temperature

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1. Introduction

Hot leg average temperature is one of the major input parameters to RCS(Reactor Coolant System) flow measurement based on secondary calorimetric heat balance method (hereafter called as heat balance method). Heat balance method is currently used as an official RCS flow measurement method in OPR(Optimized Power Reactor) 1000s. In the heat balance method, if the measured average hot leg RTD(Resistance Thermo Couple) temperature is higher than the actual average hot leg temperature, then the calculated RCS flow rate will be smaller than the actual RCS flow rate as can be seen in the following equation, and vice versa.

$$m = \frac{Q}{C_P(T_H - T_C)}$$

where, m : RCS mass flow rate, Q : core thermal power, C_P : coolant specific heat, T_H : measured average hot leg RTD temperature, T_C : measured average cold leg RTD temperature.

The RCS flow rates measured by heat balance method for OPR 1000s in the past have shown a considerable change depending on the operation cycle or even within the same operation cycle. Specifically, in recent years, the measurement for YGN 3&4 and UCN 3&4 by heat balance method showed unexpectedly a very small RCS flow rate. The measured flows from beginning of operation up to recent time are plotted in Fig.1 for UCN 3 as an example. However, the flow rates measured by pump DP(Differential Pressure) method which well observes the trend of flow rate change showed that a relatively constant RCS flow rate was maintained between operation cycles and within the same cycle. This means that there was actually no RCS flow rate change. If measured RCS flow rate goes smaller, then the operation margin and safety margin will also be reduced.

To investigate the reason of changing flow rate measured by heat balance method, various operation parameters, such as core thermal power, hot/cold leg temperatures, core exit temperatures, turbine power, etc., were observed. One thing noticed is that there is a strong relationship between core exit temperature or power distribution and the hot leg RTD temperature measurements. This suggests that if the local core exit temperature pattern is different, there may exist a different thermal stratification pattern in hot leg though the average core exit temperature is the same. So, hot leg RTD temperature measurement changes and thus the average temperature of hot leg RTDs changes. One notable observation is that the core exit temperature at core center region goes higher then the average temperature of hot leg RTDs goes higher. In recent years, low leakage core loading pattern is prevailing to improve the availability of neutron economy. Then the core power distribution is more concentrated in the core center region, and in turn the temperature of core center region may go even higher. This causes the smaller RCS flow rate measurement than the actual.

2. Observed Relationship

The observed relationship between local core exit temperatures (CET) and average temperature of hot leg RTDs is as follows. Fig.2 represents the core exit plane divided into 3 regions depending on the CET location. The grouped regions are core center region, core middle region, and core peripheral region. Generally, the local temperature at core exit plane is higher when it goes closer to the center. Fig.3 shows the hot leg RTD circumferential locations. Fig.4 shows the schematic diagram for coolant flow path from core exit plane to hot leg RTD location. As shown in Fig.4, the coolant exiting core center region mainly passes through the upper part of hot leg, while the coolant from core peripheral region mainly passes through the lower part of hot leg. Fig.5 represents the measured temperature difference between the average CET temperature of center region and the average CET temperature of peripheral region classified in Fig.2 (hereafter called as core exit DT(Differential Temperature)) for UCN 3. Also shown in Fig 5 is the measured average temperature of hot leg RTDs (hereafter called as hot leg average T) for UCN 3. Fig.6 represents the measured temperature difference between the average temperature of hot leg and cold leg (hereafter called as hot leg and cold leg DT) for UCN 3.

The trend of changing shapes shown in Figs. 5 and 6 suggests that there are strong correlations between core exit DT, hot leg average T, and hot leg and cold leg DT. The similar trend can also be observed for YGN 3&4 and UCN 4.

This phenomenon means that though the total core power is maintained constant, the hot leg RTD temperature measurement can change due to the thermal stratification if the local core exit power distribution changes. And apparent change in hot leg average temperature distorts the calculation of RCS flow rate by heat balance method. Especially, under current RTDs location of OPR 1000s, the average RTD temperature goes higher if the core power concentrates in center region. Thus, the calculated RCS flow rate goes smaller than actual flow rate.

3. Conclusion

To improve the accuracy of heat balance method, there is a need for correcting the hot leg RTD temperature measurements using the local core exit temperature distribution. In a preliminary evaluation, the core exit plane was divided into 3 regions to observe the relationship mentioned above. A further research is required to establish the quantitative correlation between local core exit temperature distribution and hot leg RTD temperature.

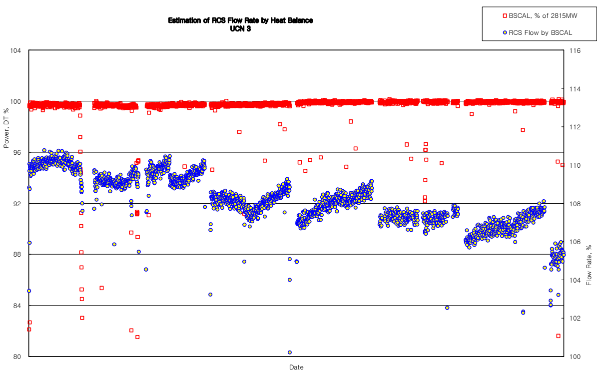

Figure 1. BSCAL and Measured RCS Flow Rate by Heat Balance Method (UCN 3)

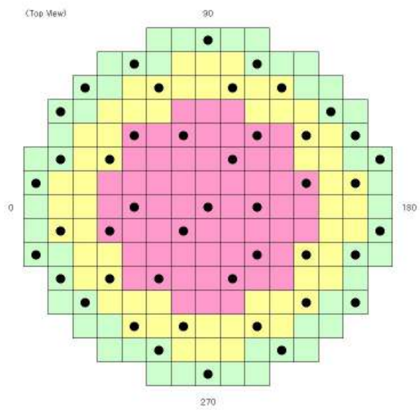

Figure 2. Core Exit Regions Divided by CET Location

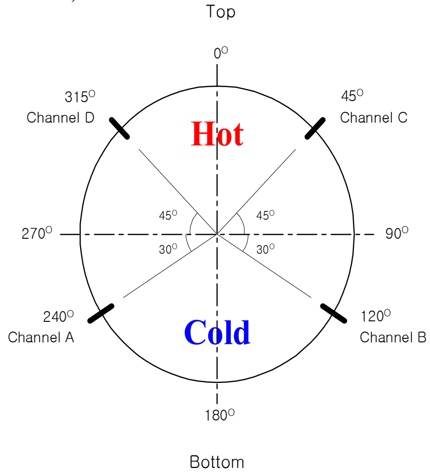

Figure 3. Hot Leg RTD circumferential Locations

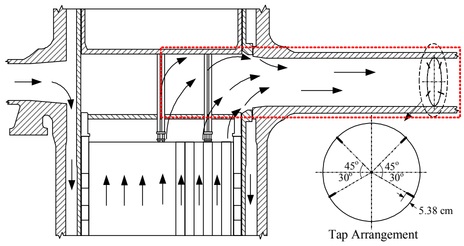

Figure 4. Coolant Flow Path from Core Exit Plane to Hot Leg RTD Location

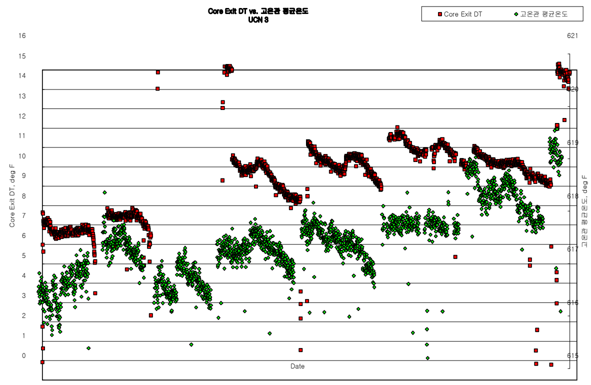

Figure 5. Core Exit DT and Hot Leg Average Temperature for Several Operation Cycles (UCN 3)

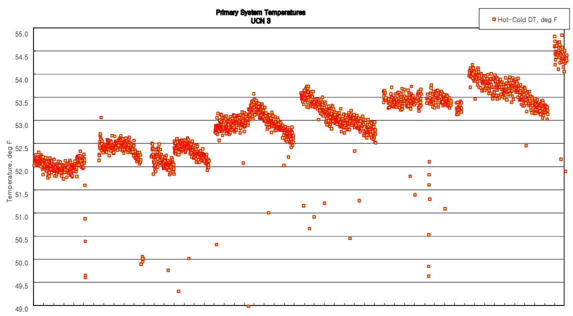

Figure 6. Temperature Difference between Average Temperature of Hot and Cold Leg (UCN 3)