PHYSOR 2002, Seoul, Korea, October 7-10, 2002

THE INCORE QUADRANT POWER TILT MITIGATION EXPERIENCES FOR KORI NUCLEAR POWER PLANT UNIT 1

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ABSTRACT

During the operation period of Kori Unit 1 Cycle 17, there had been an increase in the Incore Quadrant Power Tilts (IQPT) compared to those of the preceding cycles. Even though such tilts were not large, the trend of increasing magnitude became a concern because of the potential impact that could erode the fuel cost benefits of the core design. Thus, tilt analysis was performed to identify the causes of incore quadrant power tilt, considering the measured plant parameter, assembly geometry, incore flux mapping results and measured assemblywise burnup distribution of each cycle. It was found that there exists a flow forcing function that aggravates IQPT, while the root cause of flow forcing function has not been identified. In addition, to prevent the aggravation of IQPT, fuel shuffle guidelines were implemented for Cycles 18 and 19 reload core designs. As a result, the incore flux maps taken at the beginning of Cycles 18 and 19 showed considerable decrease in incore quadrant power tilts at 75% and 100% of rated thermal power.

1. INTRODUCTION

IQPT indicates the ratio of the maximum to average core quadrant power measured during the incore flux mapping procedure, which is required to verify the peaking factor compliance to the limit specified in the technical specifications.

The plant technical specifications require that the quadrant power tilt ratio measured by ex-core detector be less than 1.02 for power levels above 50% of rated thermal power to limit gross changes in quadrant to quadrant power distribution between monthly incore flux maps.

However, the quadrant power tilt measured by in-core flux mapping system has not been addressed directly in technical specifications. This is because the existing technical specification constraints on core power peaking provide adequate assurance of core protection. The technical specification limit on allowable $F_{\Delta H}^{N}$ typically provides an effective bound on power peaking in all core locations and this requirement provides, in effect, a limit on the magnitude of incore tilt which the technical specifications can accommodate.

During the operation period of Kori Unit 1 Cycle 17, there had been an increase in the incore tilts compared to those of the preceding cycles. Even though such tilts were not large, the trend of increasing magnitude became a concern because of the potential operating impact that could erode the fuel cost benefits of the core design.

Thus, reviews on the measured data, such as temperature, flow and assemblywise burnup distributions of each cycle as well as the as-built manufacturing data and fuel assembly design were performed to find the existence of the forcing function for IQPT. Also, the loading pattern shuffle guidelines to prevent the aggravation of IQPT following the Cycle 17 experiencing the IQPT were implemented for the Cycles 18 and 19 reload core designs.

2. TILT ANALYSIS

To diagnose whether a tilt is being produced, a burnup gradient analysis was performed on the measured data of a particular cycle to determine if a forcing function might exist. Figure 1 and 2 describe the degree of burnup gradient performed on Cycles 16 and 17, respectively. The Cycle 16 did not experience a quadrant power tilt, but Cycle 17 experienced an IQPT closing in upon 2% and was suspected to be under the influence of flow and/or temperature forcing functions as shown in Figure 2.

In order to find out the cause of a sudden IQPT increase for Kori Unit 1 Cycle 17, the following parameters were evaluated as a tilt inducing parameter.

1) Even lattice (14x14) fuel assembly design
2) Center assembly burnup gradient
3) As-built manufacturing data
4) Flow and/or temperature distribution
5) Fuel shuffle strategy

In 14x14 even lattice OFA (Optimized Fuel Assembly) design of Kori Unit 1 assembly, the instrument tube is asymmetrically located within an assembly. Thus, as fuels are depleted, the location of peak power varies and the value of peak pin power within assembly makes a relatively large difference among the symmetrical core locations compared with the odd lattice assembly. However, assembly powers in symmetrical location are not so different. Thus this factor is considered to have little effect on the IQPT.

In general reload core design, the core power distributions and other parameters are generated on a quarter core basis, and the quadrant power distribution is assumed to match one another in symmetrical location. Also, the center assembly is represented as an average of four nodes. Thus it is necessary to deplete the core on a full core basis to find out the effect of the burnup gradient of center assembly. The degrees of the center assembly burnup gradient of Cycles 16 and 17 were about 2%, which is usual. Especially, in the case of Cycle 17, the burnup of southeastern node was higher than others. After the full core depletion of Cycles 16 and 17, the burnup difference caused by the burnup gradient of center assembly was the maximum of 0.02% in a few assemblies near center location. Thus the center assembly burnup gradient was considered to have little impact on the IQPT.

According to the general reload design methodology, the feed fuel assemblies are distributed randomly to reduce the chance of small reactivity variations producing the radial power tilts. The engineering tolerances applied to enrichment, theoretical density, and B^{10} abundance in burnable absorber rods are adequate to control radial power tilts to an insignificant level. Thus as-built manufacturing data are considered to be of minor importance to the IQPT increase.

Uneven distributions of flow and temperature existing at the core produce burnup gradient that aggravate the core tilts. The parameters which cause these uneven distribution of flow and temperatures are called forcing functions of core tilts. The flow factors consist of flow related parameters like loopwise steam generator tube plugging ratio difference or loopwise pump impeller force differences and the temperature factors are related to loopwise heat dissipation rate and heat transfer rate differences. Since Cycle 17 was the first cycle after the replacement of steam generators, there might be a chance of uneven variations in flow and/or temperature characteristics of reactor coolant systems causing core tilts. From this standpoint, the measured temperature and flow data at the beginning of each cycle were reviewed in Table 1, but no dominant function could be pointed out as an IQPT forcing function from these data. Nonetheless, incore flux mapping results of the Cycle 17 as shown in Table 2 show that the axial offsets of the assemblies that were in southeast quadrant were top-shifted and the assembly powers were higher compared to the assemblies in symmetric location, which suggested that the flow forcing function exists. Since the faster flowing regions will have a lower temperature and as a result will have a larger MTC, thus more reactivity feedback will result in more power produced than in symmetrically located regions of slower flow.

Besides, typical fuel loading pattern for Kori Unit 1 is a ring feed pattern where around 80% of feed fuels are located in the periphery or right next to the periphery position as shown in Figure 3, therefore there should be a burnup gradient in each assembly at the end of cycle life. In this type of loading pattern, it is convenient to perform 180-degree rotations on the once-burned fuel as a result of inter-assembly burnup gradient lowering the local peaking. This 180-degree rotation would place the more reactive assemblies into the same quadrant where the forcing function is aligned and thus would exacerbate incore tilts for the upcoming cycle when the current cycle is experiencing the large tilts.

Thus, it is suggested to reduce or remove 180-degree shuffle for the following cycle, especially for once burned fuels that have high reactivity [1].

3. THE IMPLEMENTATION OF FUEL SHUFFLE GUIDELINES

Burnup gradient and incore flux map analysis show that there exist IQPT forcing functions connected with flow in Cycle 17, thus there is a possibility of aggravating IQPT at the next cycle. As in Table 3, when the usual shuffling scheme is applied, the shuffle category is usually divided into four types by the rotation angle reference to the core center. In order to mitigate the core tilts, it is recommended to encourage Category 1 shuffle and exclude Category 3 shuffle as much as possible. Therefore 0-degree rotations (translations) for once-burned fuel assemblies that play dominant roles in IQPT, were encouraged for Cycles 18 and 19 loading patterns. Since once-burned fuels at the southeast quadrant of Cycle 17 had depleted with higher power, the burnup of these fuels were higher than the other quadrants at the end of cycle, and thus had lower reactivity. Therefore, once-burned fuels located at the southeast quadrant were shuffled to the same quadrant at Cycle18 and those at the northwest quadrant at Cycle 17 were shuffled to the northwest quadrant at Cycle 18.

However, complete translations of once-burned fuels were not possible due to the peaking factor constraints for Kori Unit 1. Table 3 shows the percentage of each shuffle category. The percentage of Category 3 shuffle was not completely eliminated or reduced, but that of Category 1 shuffle was increased after applying the above-mentioned fuel shuffle guidelines for Cycles 18 and 19. That is, the ratios of Category 1 shuffle to Category 3 shuffle rotation were increased. Figure 4 and 5 depict that fuel shuffle strategies are well implemented for Cycles 18 and 19 loading patterns.

CONCLUSIONS

Based on the measured burnup distribution and the incore flux map analysis of Kori Unit 1 Cycle 17, it was found there exists a flow forcing function that aggravates IQPT, while the root cause of flow forcing function has not been identified.

As shown in Table 4, the incore flux mapping results at 5% of rated thermal power of Cycle 18 showed that the northwest quadrant power was considerably increased after applying fuel shuffle guidelines, which was opposite to the result of Cycle 17. This was the result of applying the fuel shuffle guidelines. Also, at this low rated thermal power, the effects of IQPT forcing functions did not kick in. In other words, small temperature difference between inlet and outlet and small enthalpy-rise have little impact on the power distribution. Thus there remains only the reactivity effect of the shuffled fuels themselves. However, as reactor thermal power increases, the effects of IQPT forcing functions kick in. That is, as the deviations of temperature and flow distributions increase among quadrants, a phenomenon similar to Cycle 17 begins to appear. Therefore, the quadrant power tilts of Cycle 18 were significantly decreased compared with those of Cycle 17 by the combination of the IQPT forcing functions and the assembly reactivity distribution. Also, the IQPTs of Cycle 19 were decreased to less than 1% at all power levels.

The IQPT forcing function can vary from temporary one time isolated incident of debris blockage of flow path to permanent systematic flow anomaly. However, in this study, only qualitative description for the existence of the flow forcing function was made for Kori Unit 1. Thus a thorough study of plant flow and temperature parameters would be required for the explicit cause of IQPT.

REFERENCES

1. Brian R. Beebe, Chris R. Savage, "Investigations of Core Radial Power Tilts," *Transactions of the American Nuclear Society*, **74**, pp. 307-308 (1996).

2. K. B. Seong, et. al., "Forcing Function Modeling for In-core Quadrant Power Tilt Simulation," *Proceedings of the Korean Nuclear Society Autumn Meeting*, Seoul Korea, October 25-26, 2001, Vol. 1, pp. 73.

Table 1. Measured flows and temperatures

Cycle	Loop	Flow [gpm]	Tin [℃]	Tout [℃]
16	A	91,062	279.2	323.0
	B	90,892	279.9	322.3
17	A	94,428	283.8	318.0
	B	94,148	283.4	318.2
18	A	93,562	283.6	318.0
	B	93,501	283.4	318.3

Table 2. In-core flux mapping results of Cycle 17

	NE		NW		SW		SE	
Cycle Life	Axial Offset [%]	Assembly Power	Axial Offset [%]	Assembly Power	Axial Offset [%]	Assembly Power	Axial Offset [%]	Assembly Power
BOL	4.1	1.137	2.5	1.127	3.4	1.130	4.2	1.151
MOL	-3.0	1.132	-3.7	1.123	-2.5	1.128	-2.1	1.145
EOL	-3.0	1.116	-3.9	1.128	-3.3	1.119	-2.8	1.134

Note) NE : North East Quadrant, NW : North West Quadrant, SW : South West Quadrant,
SE : South East Quadrant

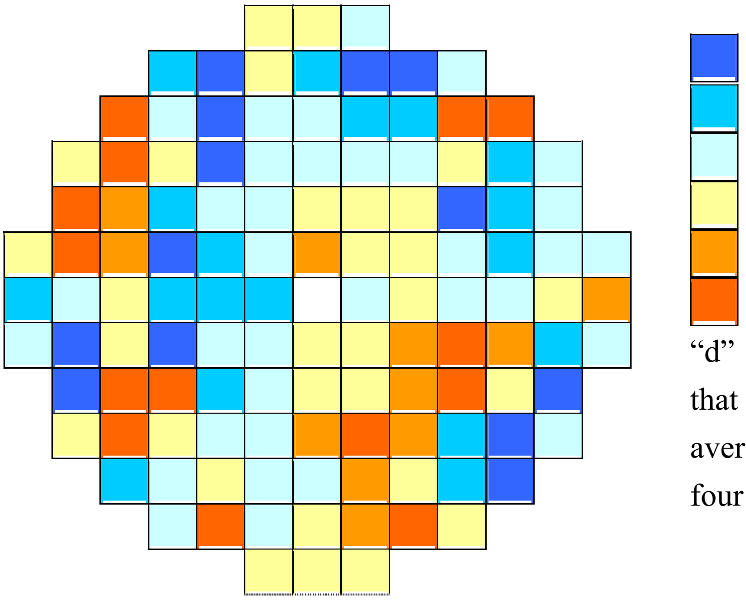
Table 3. Percentage of each shuffle category

Cycle / Category	Cycle 16		Cycle 17		Cycle 18		Cycle 19	
	Once-Burned	Twice-Burned	Once-Burned	Twice-Burned	Once-Burned	Twice-Burned	Once-Burned	Twice-Burned
1	40	20	30	30	56	27	46	45
2	20	20	20	20	11	27	18	22
3	30	20	20	20	22	19	18	22
4	10	40	30	30	11	27	18	11

Note) Category 1 : Shuffle angle greater than or equal to -45° and less than 45°.
Category 2 : Shuffle angle greater than or equal to 45° and less than 135°.
Category 3 : Shuffle angle greater than or equal to 135° and less than 225°.
Category 4 : Shuffle angle greater than or equal to 225° and less than 315°.

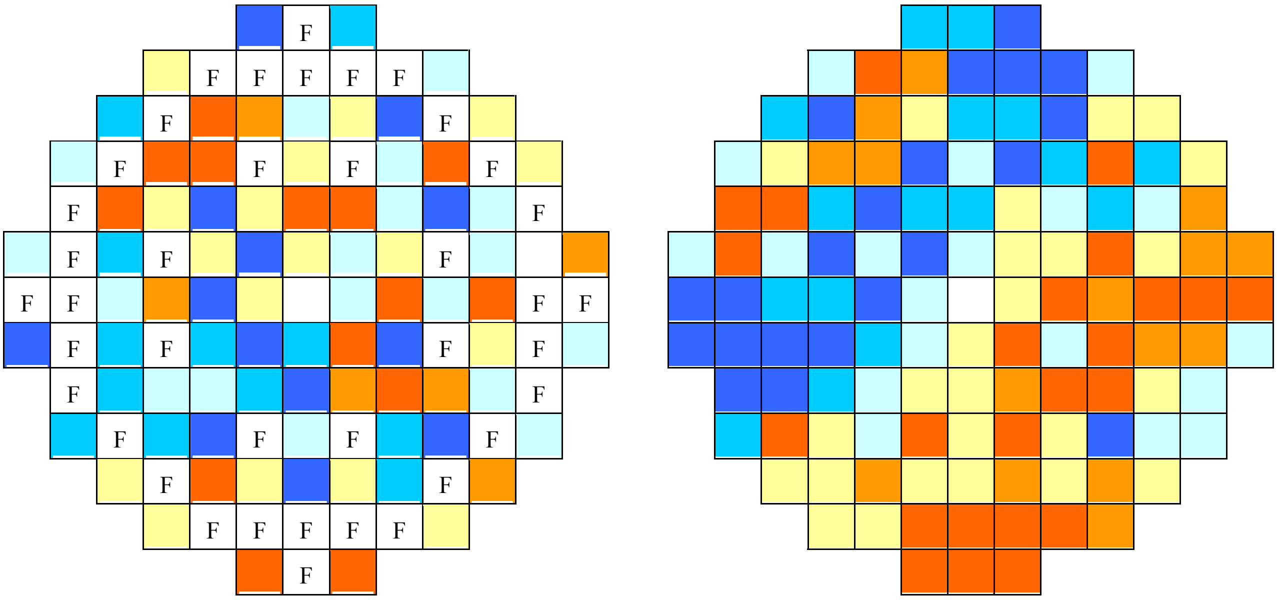
Table 4. IQPT measured during the flux mapping procedures

Cycle / %RTP	Cycle 16		Cycle 17		Cycle 18		Cycle 19	
	Meas. IQPT [%]	Quadrant	Meas. IQPT [%]	Quadrant	Meas. IQPT [%]	Quadrant	Meas. IQPT [%]	Quadrant
5%	1.25	SW	1.02	SE	3.09	NW	0.92	SW
75%	0.49	NW	1.44	SE	0.58	NE	0.78	SW
100%	0.15	NE	1.37	SE	0.50	NE	0.76	SW



"d" is the % difference in delta burnup that the indicated assembly is from the average burnup of the assemblies in the four symmetric core locations

Figure 1. Assembly burnup gradient of Cycle 16 at EOL



BOL EOL

Note) The character “F” means feed fuel.

Figure 2. Assembly burnup gradient of Cycle 17

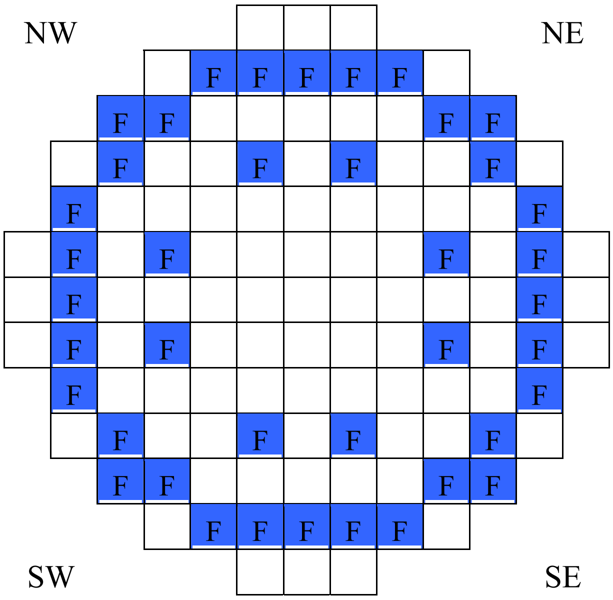
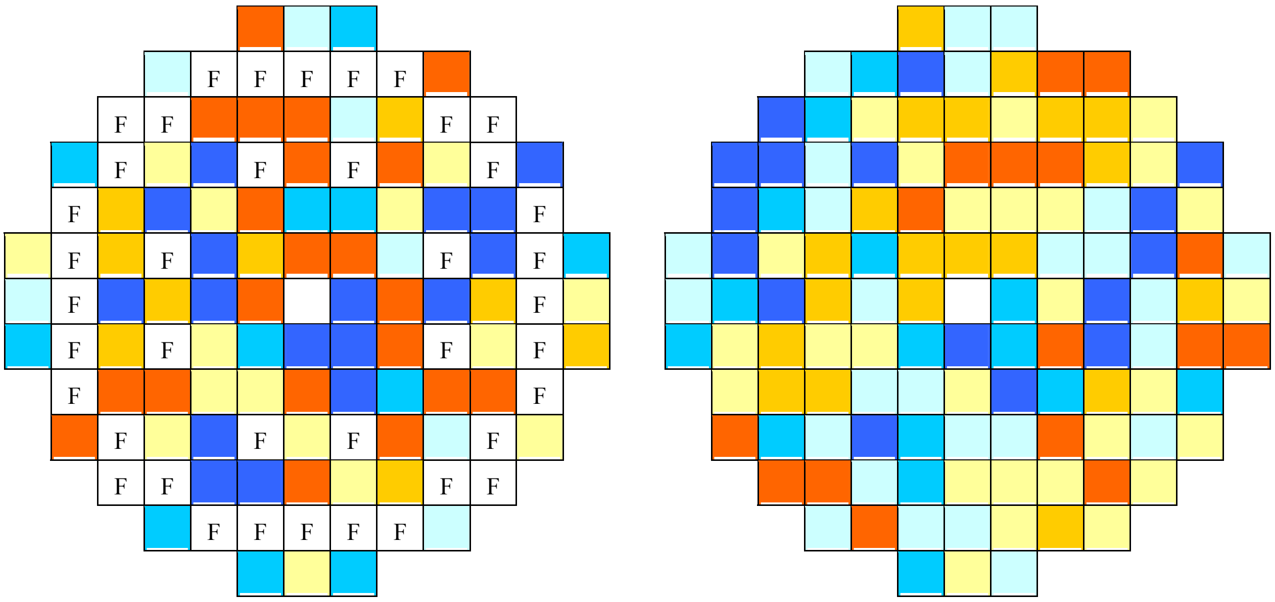
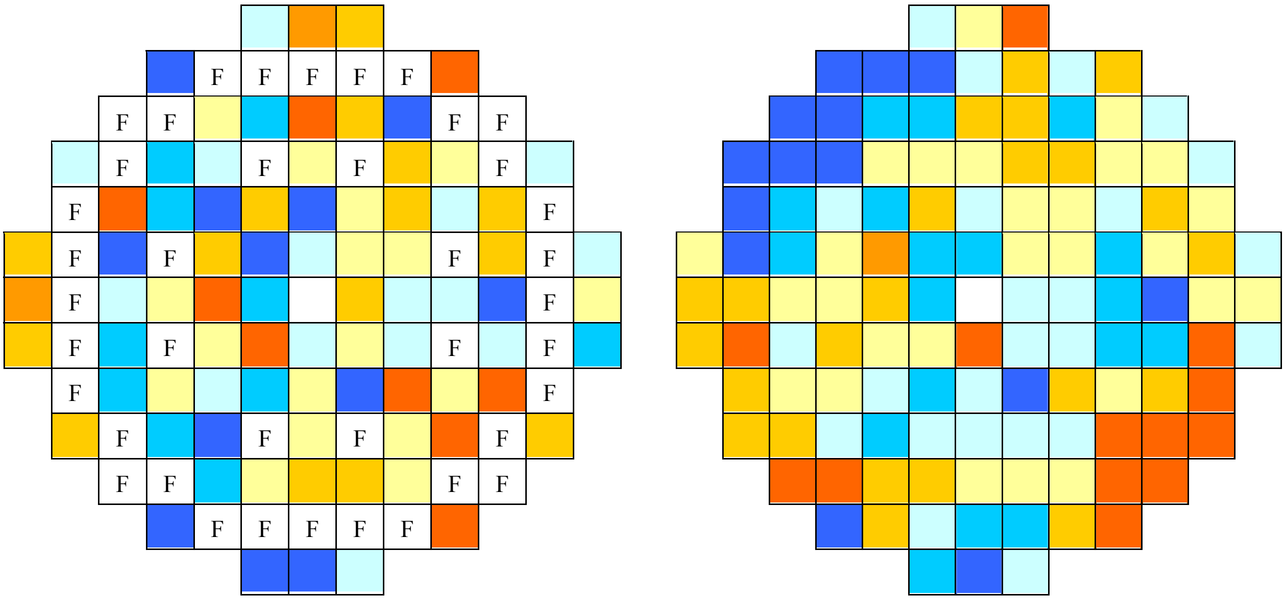


Figure 3. Typical ring feed pattern of Kori Unit 1



BOL EOL

Figure 4. Assembly burnup gradient of Cycle 18



BOL EOL

Figure 5. Assembly burnup gradient of Cycle 19