A Study on the Effect of Core Safety due to Power Uprate

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1. Introduction

In general, nuclear power generation is regarded as economical. However, its huge initial investment and social costs involved in site selection make it not-an-ideal solution to meet rising power demand with construction of a new plant. Under the circumstances, other ways to enhance economicality of nuclear power generation such as low low leakage loading pattern, long term fuel cycle and continuous operation are being explored, instead of building additional units that have limited return of investment or developing new system equipment. Power uprate is also another solution that was created in order to increase power output at lower cost.

Unit 3&4 of Kori Nuclear Power Plant acquired permit for operational change of power uprate and is currently in operation with heat output of 2900MWt whereas in Yonggwang site unit 1 and 2 of the same furnace time, power uprate has not been applied.

This study evaluates power uprate of Unit 3&4 of Kori NPP to analyze core safety in case of power uprate of Unit 1&2 of Yonggwang NPP and examines different ways to maximize economic gains of power uprate.

2. Power uprate

2.1 Methods for power uprate

Power uprate means increasing thermal power of the reactor core and has three methods of minute power uprate by decrease in measurement inaccuracy, small-scale power uprate by changing the set point, and large-scale power uprate by change of BOP equipment. In minute power uprate, feed water flow measurement method is changed to increase nominal thermal power by 2% whereas in small-scale power uprate, nominal thermal power is enhanced by about 7% by optimizing design margin of the system. In large-scale power uprate, major BOP equipment such as high pressure turbine, condensate pump and main generator is modified to improve normal thermal power by up to 20%. .

2.2 Cases of power uprate

In the US, unit 1 of Calvert Cliffs Nuclear Power Plant was the first one to enhance thermal power by 5.5% with adjustment of equipment set point in 1977. As of October 2009, a total of 5,726MWe in installed capacity was increased from 129 times of power uprate and other 29 sites are in the process of or planning power uprate.

2.3 Power uprate in Korea

There are 20 nuclear power generation units in Korea and they produce a combined 50,773 MWt in thermal output. Only a 5% of power uprate could have the similar effect of constructing an additional unit. Required cost for power generation is considerably lower at 400$/kWe compared to 1800$/kWe required for constructing a new power plant. The economic effect is deemed even greater in Korea since it is very difficult to secure sites for new power plants.

3. Core safety evaluation after power uprate

In this chapter, a 4.5% of power uprate is applied to unit 3&4 of Kori NPP to evaluate core margin of safety of unit 1&2 of Yonggwang plant.

3.1 Thermal hydraulic design of the core

The purpose of thermal hydraulic design of the core is to create a favorable condition where the thermal source produced in the core could be cooled down through the reactor coolant system (RCS) or emergency core cooling system (ECCS) to ensure fuel integrity and core safety. DNBR limit which is used to prevent departure from nucleate boiling (DNB) by thermal or hydraulic factors in usual/unusual service conditions was analyzed using Revised Thermal Design Procedure (RTDP). It was found that DNBR design margin was decreased compared to what was before power uprate but thermal/hydraulic design basis was satisfied.

Table I : DNBR design limit of power uprate of Kori 3&4

Thermal/hydraulic design factor	Non power uprate (ITDP)	Power uprate (RTDP)
Min. DNBR under normal condition (Typical/Thimble)	2.66 / 2.64	2.53 / 2.51
DNBR design limit (Typical/Thimble)	1.35 / 1.33	1.25 / 1.25
DNBR limit of Safety analysis (Typical/Thimble)	1.71 / 1.68	1.45 / 1.45
DNBR margin	21%	13.8%

3.2 Nuclear design of the core

In relation to power uprate, the purpose of nuclear design is to evaluate whether nuclear design factors used in previous safety analysis is still effective in power-uprated conditions and to provide new safety analysis input values when necessary.

Reload design method of Westinghouse, a bounding value approach, was employed to analyze the core after power uprate and it was found that most of nuclear design factors including core power distribution, reactivity coefficient and kinetics move within the variance range of core cycle and therefore the input values used for analyzing previous Final Safety Analysis Report (FSAR) were found to be still effective. As for some items shown in Table 2, the input values were adjusted for safety analysis and corresponding sections of the Technical Manual were revised to ensure safety.

Table Ⅱ : Nuclear safety factors before/after power uprate

Safety factor		Before	After
Thermal power, MWt		2,775	2,900
RCS Tavg, ˚F		588.5	580.0 ~ 587.0
Avg. linear power density, kW/ft		5.45	5.69
Max. MDC, Δ p/g/cc		0.50	0.54
RAOC Δ I range, %	Full power	-16 ~ 8	-14 ~ 8
	50% power	-42 ~ 26	-24 ~ 22

3.3 Fuel rod and assembly design

Rod inner pressure, clad corrosion, stress, distortion, fatigue, fuel centerline temperature, irradiation growth, and structural integrity of the core were evaluated after power uprate, and all the design criteria were satisfied in power uprate.

4. Optimization of power uprate

Power uprate applied to unit 3 and 4 of Kori NPP (WH type) does not increase fuel concentration or new fuel loading amount, and as a result cycle period of 22EFPD(Effective Full Power Day) is reduced on a 4.5 w/o enrichment, 64 bundles of new fuel and equilibrium core basis. Reduced cycle period drives up power generation unit cost and therefore undermines a portion of economic gains acquired from power uprate. So, in order to maximize economicality of power uprate and to ensure optimal cycle period of 18 months, enrichment or new fuel loading amount should be increased.

Increase in enrichment results in enrichment cost increase but discharge burnup is increased to offset rise in enrichment cost, and power generation unit cost is also reduced. However in case of bundle increase of new fuel, loss in fuel cycle cost occurs to increase power generation unit cost.

Table Ⅲ : Comparison of unit cost by loading pattern (power uprate)

Loading pattern	Fuel cycle cost, ₩/kWhe	Fixed cost, ₩/kWhe	Generation cost, ₩/kWhe	Cost saving, 100Mil ₩ /cycle
4.5 w/o 64 feeds	8.524	28.297	36.821	-
*4.5 w/o 64 feeds	8.583	28.223	36.806	1.8
4.85 w/o 64 feeds	8.524	28.179	36.703	14.5
4.68 w/o 68 feeds	8.730	28.180	36.910	-11.0

* non power-uprated core

5. Conclusions

Power uprate can be applied in cases where site selection is difficult as in Korea or social acceptance of nuclear power generation is not secured. It is an economical and effective way of power generation and capacity increase compared to construction of new units. Therefore a variety of power uprate methods are being tried in USA and Europe and in Korea as well, in unit 3&4 of Kori NPP, 4.5% of small-scale power uprate was applied by optimizing system design margin.

In order to evaluate core safety of Unit 1&2 of Yonggwang NPP, power uprated core of Kori Unit 3&4 with similar furnace type was analyzed and the result was that the design criteria were satisfied in all items. Some items with decrease in safety margin also met the limits and loading of ACE7 fuel with higher thermal performance than RFA fuel could ensure core safety margin.

However, power uprate method that is currently applied has disadvantages of shorter cycle period and higher unit cost. Therefore, in order to take advantages of power uprate and to maximize economicality of power generation, cycle period should be optimized through increase in fuel enrichment.

REFERENCES

[1] Study on the Development of Regulatory System for Power Uprate on Operating Nuclear Power Plants, Ministry of Science and Technology
[2] Evaluation of Optimal Core Cycle Period of Light Water Reactor, Korea Hydro & Nuclear Power, 2008
[3] Safety Analysis Report on Power Uprate of Kori Unit 3&4 and Yonggwang Unit 1&2, Korea Hydro & Nuclear Power 2007
[4] Background on Power Uprates, NRC, 2009