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Assessment on the Success Criteria and the Human Error Probability of the Power Uprated Plant

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1. Introduction

Numerous power uprate applications for nuclear power plants (NPP) were approved (109 applications) in the United States since 1970, while the first NPP power uprate is planned for Kori 3&4 / Yonggwang 1&2 in Korea.

There are three categories of power uprate ; (1) MUR (Measurement Uncertainty Recapture power uprate), which is less than 2 percent and can be achieved by implementing the enhanced techniques for reactor power calculations ; (2) SPU (Strech Power Uprate), which is typically up to 7 percent and does not involve major plant modifications ; (3) EPU (Extended Power Uprate), which is usually as high as 20 percent and requires significant modifications to the major BOP equipment.

USNRC requires licensees to evaluate the effect of power uprate on the plant specific PSA results for EPU by issuing the regulatory guidance RS-001[1], but it does not require the PSA evaluation for SPU and MUR plants. There is no established regulatory guidance for the PSA evaluations of power uprated plants in Korea.

Since the power uprates for Kori 3&4 / Yonggwang 1&2 will be SPU, there is no general guidance for their PSA evaluations. But, after reviewing many reference foreign documents related to the PSA evaluations for EPU[2, 3], we discovered that the main changes related to the power uprates were as follows.

(1) The decay heat removal success criteria
(2) The dynamic operator actions
(3) The fission product inventories

This paper discusses the changes of the plant specific level 1 PSA for Kori 3&4 / Yonggwang 1&2 by SPU, and it is mainly focused on the changes of the success criteria and the human error probabilities in the PSA model [4, 5, 6].

2. Assessment on the Success Criteria of the Power-Uprated Plant Level 1 PSA

The success criteria for Kori 3&4 / Yonggwang 1&2 PSA are generally determined by MAAP4 (Modular Accident Analysis Program version 4) analysis results. Since some physical parameters (core thermal power, reactor coolant temperature, etc) are changed by the power uprate, the MAAP4 analysis results and the success criteria used in the PSA model need to be modified. We reviewed the changes of physical parameters of Kori 3&4 / Yonggwang 1&2 by the power uprates[7], and modified MAAP4 parameter file (*.par) like Table 1.

Table 1. MAAP4 Parameter File Variables Changed after Power Uprate

No	Variable Name	Description	Unit	Parameter Value Δ after Power Uprate
1	QCR0	Core Thermal Power	MWt	+ 125
2	TWPSNM , TWPS0	RCS Avg. Temp.	K	- 0.79
3	TFW	MFW Inlet Temp.	K	+3.427
4	PSG0	Main Steam Pressure	Pa	- 2.62E+05
5	TCWHX	CCW Inlet Temp.	K	+1.27
6	FRHB0	Containment Relative Humidity		- 0.5
7	TRWST	RWST Temp.	K	+4.6
8	TAMB	Environment Temp. in Containment	K	+11
9	ACR	Effective Flow Area	m2	-0.014
10	TIRRAD	Average Effective Time of Irradiation for Core	Sec	5.3654E+07
11	EXPO	Average Burnup	MWD/MTU	1.093E+04
12	ENRCH	Enrichment	wt%	+1.1
13	MFPIN	Mass of Fission Product		N/A[1]

Using the modified parameter file, MAAP4 calculations were performed for 29 accident scenarios that were used for the success criteria in Kori 3&4 / Yonggwang 1&2 level 1 PSA. The accident scenarios analyzed by MAAP4 are shown in Table 2.

Table 2. The Accident Scenarios Analyzed by MAAP4

Accident Groups	Analyzed Accident Scenarios
Small LOCA	S1, S2, S3, S4, S5
Medium LOCA	M1,M2, M3, M4
Large LOCA	A1, A2, A3
Loss of Feedwater	T1,T2, T3
Station Black Out	TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8
Loss of Component Cooling	TC1, TC2, TC3, TC4, TC5
Steam Generator Tube Rupture	TR1

Increase of the decay heat level by the power uprate resulted in decrease of accident propagation time. For

[1] *Twenty two fission product variables are included in MAAP4 Parameter file and named as MFPIN(1), MFPIN(2), …, MFPIN(22). The values of these variables are not presented in this paper because of the paper length limitation. These values will be presented in the upcoming report [6].*

example, in the SBO (Station Black Out) scenario shown in table 3, the core damage time after the power uprate was 64.3 minutes less than the core damage time before power uprate.

Table 3. An Example of MAAP4 analysis result (SBO, TP2)

Event Description	Accident Propagation Time Δ (minutes) after Power Uprate
Event Occurred	0.0
Reactor Scram	0.0
TD-AFWP Actuated	0.0
TD-AFWP Stopped	0.0
S/G Dry-out	- 48.5
Core Uncovery	- 59.0
Core Damage	- 64.3

3. Assessment on the Human Error Probability of the Power-Uprated Plant Level 1 PSA

Decrease of the accident propagation time in the success criteria analysis can result in decrease of the available time for the operator to respond to accidents, so the human error probabilities related to the response time can be increased.

In this study, the human error probabilities in the Kori 3&4 / Yonggwang 1&2 level 1 PSA were re-evaluated using the MAAP4 results. Six of all human error probabilities were increased by the power uprate as shown in Table 4, four of them are failure probabilities of the offsite power recovery actions based on EPRI URD data, and two of them are failure probabilities of the post accident human actions based on HCR (Human Cognitive Reliability) and THERP (Technique for Human Error Rate Prediction) data.

Table 4. Changes of the Human Error Probabilities After Power Uprate

Event Name	Available Response Time Δ after Power Uprate	Human Error Probability Δ after Power Uprate
B-101	- 1 hr	+3.00E-03
B-103	- 0.3 hr	+5.00E-03
B-201	- 1 hr	+1.80E-02
B-203	- 0.3 hr	+3.00E-02
HRTCFRPC1-10	- 6 min	+1.22E-03
HRS2FRPC1-10	- 6 min	+1.22E-03

- B-101 : Failure of Offsite Power Recovery within 16 hours
- B-103 : Failure of Offsite Power Recovery within 10.6 hours
- B-201 : Failure of Offsite Power Recovery within 8 hours
- B-203 : Failure of Offsite Power Recovery within 2.6 hours
- HRTCFRPC1-10 : Failure of Core Cooling Recovery in LOCCW
- HRS2FRPC1-10 : Failure of Core Cooling Recovery in Small LOCA

4. Conclusion

The success criteria and the human error probabilities for Kori 3&4 / Yonggwang 1&2 PSA were re-evaluated considering the power uprated condition.

The affected portions on the level 1 PSA after the power uprate were the changes in the available operator action time and resultant recovery failure probabilities or post-accident human error probabilities.

Based on the new physical parameters of Kori 3&4 / Yonggwang 1&2 changed by the power uprate, MAAP4 analyses were performed to determine the success criteria after the power uprate. Increase of the decay heat level by the power uprate caused decrease of the accident propagation time in the MAAP4 analysis results.

The shortened accident propagation time in the success criteria analysis resulted in reduction of the available time for operators to respond to accidents, and finally caused the human error probabilities to increase. Six of the human error probabilities were increased by the power uprates for Kori 3&4 / Yonggwang 1&2.

Since it is expected that these changed human error probabilities would raise a contribution to the CDF (Core Damage Frequency) of the affected accident sequences, the level 1 PSA re-evaluations for Kori 3&4 / Yonggwang 1&2 are necessary. Details of the analysis results will be published in the upcoming report [6].

REFERENCES

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