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Assessment of the Plant Availability in EU-APR

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1. Introduction

A Performance Assessment Methodology (PAM) consists of various performance assessment methodologies, especially the availability assessment methodology and the planning of reliability activities. The main task of PAM is to give input information for planning maintenance activities through analyzing availability based on the probabilistic analysis and operation experiences and ensuring that the plant's availability requirements are met.

In European Utility Requirements (EUR) [1], the availability assessment methodology is mainly suggested in PAM. And EUR requires that the plant has an annual average capability factor greater than 90% over its lifetime. In order to meet EUR requirements, the assessment of the plant availability in EU-APR is performed simply because EU-APR is on the basic design stage.

2. Evaluation of the availability factor

Plant availability is scheduled to be assessed based on probabilistic method by modeling systems impacting unplanned outage during the detailed design phase of EU-APR and currently is in the early stage of analysis engaging such as detail methodology review and data collecting. Because it is difficult to assess plant availability according to the probabilistic method, EU-APR plant availability is assessed according to the deterministic method based on the reference plant data, Korea Standard NPPs outage experiences and the other operation/maintenance data, etc.

2.1. Estimated Outage Duration of EU-APR [2]

Table 1 shows details of outage durations and critical path in the colored box. The whole duration varies depending on items for additional process. Refueling and regular maintenance outage is comprised of basic processes and Main turbine-generator outage includes dismantling inspection of main generator and high pressure turbine as a critical path in addition to basic processes. In-Service Inspection Outage includes Automatic ultrasonic inspection on the upper side/lower side of a nuclear reactor as a critical path in addition to basic processes. The milestone of planned outage is described in Figure 1.

Table 1: Outage Duration and Critical Path in EU-APR

Main Procedure	Detailed Procedure	Duration (hrs)
RCS Cool down/Drain	Decoupling/Turbine manual stop	1
	Boron Boration	6.84
	Cooldown	10.9
	Drain/Reactor Sub-structure Disassemble	20
Reactor Disassemble		39
Fuel Unloading/Inspection		48.2
RCS Drain Valve Maintenance		65
Reactor Stud Hole Check		[31]
Fuel Loading/Core Mapping	Loading	48.2
	Core Mapping/IAEA Inspection	2
Reactor Assemble	Head Assemble	35
	Sub-structure Assemble	40
RCS Fill-up		[30]
RCS Heat-up		22.9
Pre-Criticality Test	Pre-Criticality Test	10
	Boron Dilution	7
Criticality/Core Physics Test	Criticality	6
	0% Core Physics Test	10
	Test prior to power increase	3
T/G Start-up/Synchronization	Reactor power increase(~8%)	0.8
	Turbine starting	1
	Reactor power increase(~12%)	0.4
HP TBN/Generator Maintenance		530
Reacter Upper Side UT		150
Reacter Lower Side UT		150

[ ] : Parallel Process

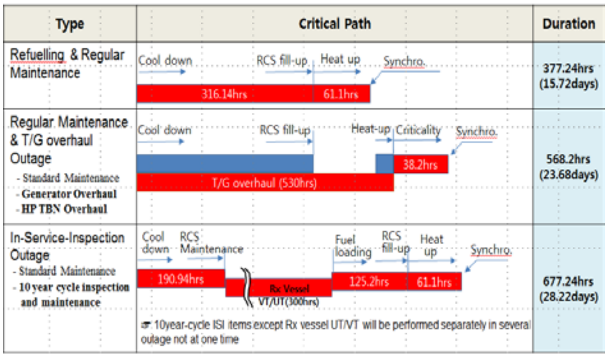

Fig 1: Milestone of each Planned Outage

2.2. Frequencies of Unplanned Trip

Table 2 shows times of unplanned shutdown in Hanul Units 3,4,5,6 and Hanbit Units 5, 6 over the ten-year period from 2004 to 2014. As you can see, occurrence of unplanned shutdown in the Korea NPPs has been decreased gradually within five years and it is expected to keep the trend continuously in the future.

Table 2: Unplanned Reactor Shutdown Data of Korea NPPs

Plant	Number of Occurrence	
	2004~2014 year	2009~2014year
Hanul #3	8	0
Hanul #4	7	0
Hanul #5	6	2
Hanul #6	3	1
Hanbit#5	6	3
Hanbit#6	5	2
Average (Per unit)	5.83	1.33
Average (per unit and year)	**0.58**	**0.27**

Thus, annual average unplanned shutdown of EU-APR is evaluated based on the records of the Korea NPPs. Table 2 shows that average unplanned shutdown per unit and year is 0.58 times in ten years and average unplanned shutdown of EU-APR can be set to annual average of 0.58 times according to the Korea NPPs data.

2.3. Extra Long Unplanned Outage

In spite of 60-year life time of EU-APR, replacement of main equipment including steam generator is assumed to take 1 time during life cycle. For example, such outage occurred only one time at Kori Unit #1 in 1998, which has been operated commercially since 1978. The planned outage duration was estimated as 86 days (6.19~9.12) and the actual working period to replace steam generator was 68 days (6.20~8.26).

During the planned outage, additional outage duration for steam generator replacement was calculated as 38.4 days; about 47.6 days of general planned outage at that time were subtracted from the entire planned outage duration as general process of planned outage was performed.

· Additional outage duration for steam generator replacement in Kori Unit #1

: 86 days –47.6 days = 38.4 days

For EU-APR, additional outage duration requires 62 days for outage considering 24 days, the target planned outage duration for main turbine-generator overhaul according to EUR requirement [2].

· Additional period for steam generator replacement in EU-APR

: 86 days –24 days = 62 days

The calculation above seems very conservative as the entire planned outage duration is regarded, so, it is right to calculate based on the actual working period. As replacement of steam generator during EU-APR plant life cycle is expected only once, additional working period is set by subtracting 24 days of EU-APR planned outage target from 68days of the actual working period of Kori Unit 1.

· Additional actual period for steam generator replacement in EU-APR

: 68 days – 24 days = 36 days (Including installation of temporary lifting device)

2.4. Analysis of Power Increase from Synchronization to 100% Rated Power

After synchronization of the nuclear plant, the core physics tests are performed at 30 % and 80 % of the reactor power. The process of core physic tests are standardized based on the Korea NPPs test experiences, optimized test procedures, the test requirements from each plants, and the equipment improvement, etc. Thus, the process of core physics tests in EU-APR is assessed based on the standardized process of the core physics tests in KHNP. The duration of core physics tests in EU-APR is described in Table 3 and 4, the same as the duration of core physics tests in Korea NPPs.

Table 3: Duration of Core Physics Tests at 30%

No.	Test Description	Duration (hrs)	Note
1	Power Calibration	2.5	
2	Power Stabilization Time	9.5	
3	Symmetry Verification of Neutron Flux	(2)	Parallel Process during Power Stabilization Time
4	COLSS Constant Set (Data Acquisition)	(1)	Parallel Process during Power Stabilization Time
5	Ex-core Instruments Adjustment	8	Performing Test after 12 hrs at 30% Reactor Power
6	Power Calibration	2	
7	VOPT Set Point Change	1	
Total		**23**	

Table 4: Duration of Core Physics Tests at 80%

No.	Test Description	Duration (hrs)	Note
1	Power Calibration	(2.5)	Parallel Process with No. 3 Test
2	COLSS Constant Set (Data Acquisition)	(1)	Parallel Process with No. 3 Test
3	SAM/BPPCC Analysis and Installation	6	
4	Secondary Thermal Power Verification	1	
5	RCS Flow Rate Measurement	3	
6	RCOPS DNBR/LPD Verification	3	
7	Power Distribution Measurement	2	Performing Test after 6 hrs at 80% Reactor Power
8	Fxy Measurement	(1)	Parallel Process with No. 7 Test
9	Power Calibration	2	
10	VOPT Set Point Change	1	
Total		**18**	

Power increase is limited by FPG. The purpose of the FPG is to eliminate the fuel failure by the process of the Pellet Clad Interaction (PCI). The maximum rates of power increase applied FPG are described in Table 5.

Table 5: Maximum rates of power increase

Power escalation from starting after reactor shutdown			
Category	Power Level (%)	Category Definition	Maximum Rate of Change in Reactor Power
1	0~40		No limit
2	40~100	Increase in core power to a level which has been previously sustained for more than 72 cumulative hours to be operated during the past 7 days	No limit
3		Increase in core power to a level which has been previously sustained for more than 72 cumulative hours not to be operated during the past 7 days[1)]	Average 3%/hr[2)]
Note : 1) It can be applied to the initial start-up after fuel handling operation (fuel inspection, refuelling etc.) 2) Maximum allowable ramp rate : 4%/1hr, 7%/2hrs, 10%/3hrs			

For the loading time from synchronization to full power after refueling outage, Category 1, 3 in Table 5 are applied for the maximum rate of the power increase. From 12% to 40% of the reactor power, the operating rate of power increase is 10%/hr with consideration of safety and integrity of the plant. And from 40% to 100% of the reactor power, the rate of power increase is 3%/hr. The core physics tests are performed at 30 % and 80 % of the reactor power in order to adjust the ex-core instruments, to measure the core power distribution in the xenon equilibrium or transient state and etc. According to the reference plant operating experience, the duration of the tests at 30 % and 80 % of the reactor power is around 23 hours and 18 hours, respectively. The total duration from the synchronization to the full power is 63.8 hours and the detailed procedures are described in Figure 2.

Power Level	Test and Increase Rate	Required Time
Increase Rx Power	From 12% to 30% Rx Power - increase rate : 10%/hr	1.8hr
At 30% Rx Power	Core physics tests - ex-core instrument adjustment - measure core power distribution - Etc.	23hrs
Increase Rx Power	From 30% to 40% Rx Power - increase rate : 10%/hr	1hr
Increase Rx Power	From 40% to 80% Rx Power - increase rate : 3%/hr	13hrs
At 80% Rx Power	Core physics tests - ex-core instrument adjustment - measure core power distribution - Etc.	18hrs
Increase Rx Power	From 80% to 100% Rx Power - increase rate : 3%/hr	7hrs
Total Time		63.8hrs

Fig 2: Procedures of power increase

3. Assessment of the plant availability of EU-APR

Basically, EU-APR is operated on an 18-month fuel cycle similar to the reference plant. As a preliminary, a 12 months fuel cycle is chosen with conservatism. The availability factor for 20 years is defined by the following formula which is described in EUR [3];

$A\ (\%) = \{365- [k_1I_1+ k_2I_2+ k_3I_3+I_5+(k_1+k_2+k_3)\ I_6]/ 20+I_4\}/ 365\times100$

where,

I_1: *Reference Outage Duration of a refuelling and maintenance outage in days*

k_1: *Number of refuelling and maintenance outage in a 20-year operating period*

I_2: *Reference Outage Duration of the main turbine-generator overhaul in days*

k_2: *Number of main turbine-generator overhauls in a 20-year operating period*

I_3: *Reference Outage Duration of an In-Service-Inspection Outage in days*

k_3: *Number of In-Service-Inspection Outage* in a 20-year operating period*

I_4: *Annual Forced Outage neglecting loading time in days*

I_5: *Provision in days, for special works over a 20-year period.*

I_6: *Unavailability for loading from breaker to 100% Rated Power in days*

As shown in Section 2.1, I_1 is 15.72 days (377.24 hrs). And I_2 is given as 23.68 days (568.2 hrs). I_3 is given as 28.22 days (677.24 hrs). Since at least 1 set of turbine is overhauled in every planned outage, k_1 and k_2 are 0, 18 respectively with conservatism in a 20-year operating period. And k_3 is 2 considering that the periodicity for the In-Service Inspection is 10 years.

The unplanned reactor shutdown frequency is set to 0.58 times/year according to Section 2.2. And the average maintenance/start-up duration during unplanned reactor shutdown is suggested from the reference plant data which is the duration of shutdown (3 days/occurrence) and loading time from 0% power to 100% power (0.7 day/occurrence). Thus the annual Forced Unavailability Factor i.e. I_4 is calculated to be 2.2 days/year (0.58 times/year×3.7 days/occurrence).

And it is assumed that there will be 1 set of major component replacement (for example SGs) during 20 years with conservatism. Therefore, I_5 is assumed to be 86 days conservatively in accordance to Section 2.3.

The total duration from the synchronization to the full power is 63.8 hours and the detailed procedures are described in accordance to Section 2.4. Thus, I_6 is calculated 2.66 days (63.8 hrs).

As a result, the annual availability factor is calculated as below;

$A(\%)=\{1(0\times15.72+18\times23.68+2\times28.22+86+(0+18+2)\ \times2.66)/20+2.2]/365\}\times100 = 90.9$

In case of 18 months of fuel cycle, the availability is calculated as 93.4%. When converted into a 24 months fuel cycle, availability will be increased further.

4. Conclusions

The plant availability of EU-APR is assessed by the deterministic method as to the above results. And it is analyzed by PAM and complied with EUR requirement. In addition, the outage duration, forced outage, extra-long unplanned outage, and power increase duration will be analyzed later according to the probabilistic methodology including Failure Modes and Effects Analysis (FMEA), safety-based Component Importance Classification, and analysis on the components which have an effect on power (Single Point Vulnerability, SPV), etc.

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