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Evaluation of the Planned Outage Durations in EU-APR

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1. Introduction

EU-APR has been designed to comply with European Utility Requirements (EUR) and nuclear design requirements of the European countries. And it is modified and improved from its original design of APR1400. In EUR [1], there is a requirement of the Planned Outage Durations as follows:

(EUR 2.2.7.2.2 B) The Planned Outages should be completed (breaker-to-breaker) in less than:*

· 16 calendar days for refuelling and regular maintenance outage,

· 24 calendar days for main turbine-generator overhaul,

· 36 calendar days for In-Service-Inspection Outage .*

In order to meet this requirement, the evaluation of the Planned Outage Durations in EU-APR is performed simply using the operation datum, the performance of EU-APR, etc.

2. Outage Duration and Contents of EU-APR

KHNP operates NPPs on an 18-month fuel cycle. Based on its years of experience in running a large number of NPPs and consequently accumulated data on planned outages, KHNP calculated typical outage duration to be applied to its operation. Data on the reference plant (APR1400: Shin-kori Unit 3, 4) were standardized through experiences. The EU-APR outage duration data are based on the reference plant standard outage plan, Korea Standard NPPs outage experiences and the component/system capability.

2.1. Basic Outage Duration of the reference plant

The basic outage duration is calculated on the basis of time needed for fuel exchange, which is applied separately depending on reactor type and capacity. Table 1 describes unit processes and the time required for each unit process comprising the basic outage durations for APR1400.

Table 1 Basic Duration for Planned Outage

Name of Unit Process	Duration (hr)
RCS cooling and drain	32
Dismantling of nuclear reactor supplementary equipment	59
Dismantling of nuclear reactor head	39
Fuel unloading and inspection	80
RCS drain valve maintenance	65
Inspection on nuclear reactor Stud Hole	[31]
Fuel reloading & Core Mapping	73
Nuclear reactor head Assembly	35
Nuclear reactor supplementary equipment Assembly / RCP sealing arrangement Assembly	40
RCS filling / vent	[30]
RCS heat-up	36
Core physics test (or tests on properties of a nuclear reactor).	51
Startup of turbines and generators	12.5
Total	**522.5 (21.8days)**
[ ] : Processes conducted in parallel	

2.2. Additional Outage Duration of the reference plant

Additional outage duration is applied to critical paths in addition to basic outage duration which includes ILRT (Integrated Leak Rate Test), inspections on the inside of a nuclear reactor, nuclear reactor mechanized UT (Ultrasonic Test), etc. Turbine dismantling inspection is performed every cycle in sequence: for example, Low pressure turbine (A) → Low pressure turbine (B) → Low pressure turbine (C) → High pressure turbine/main generator → Low pressure turbine (A). Therefore, HP turbine/main generator dismantling inspection is being as a critical path. Table 2 shows unit processes, the time and frequency required for each unit process comprising additional outage duration for APR1400.

Table 2 Additional Duration for Planned Outage

Name of Unit Process	Duration (hr)	Frequency
ILRT	100	1time/5yr
Automatic ultrasonic inspection on the upper side of a nuclear reactor	150	1time/10yr
Automatic ultrasonic inspection on the lower side of a nuclear reactor	150	1time/10yr
Visual examination on the inside of a nuclear reactor.	28	3times/10yr
Fuel UT	100	-
Control rod ECT	73	-
Replacement of RCP internals	132	1time/10yr
Low pressure turbine 1 set dismantling inspection (A or B or C)	995/3	One of three for every outage
High pressure turbine / main generator dismantling inspection	530	Every 4th outage
Cutting and replacement of rods	154	1time/10yr
Taking out Rx specimen	4	6EFPY, 15EFPY, 32EFPY, EOL

2.3. Methods of Determining EU-APR Outage Duration

Total outage duration is determined by adding basic outage duration to additional outage duration for critical path items as well as inspection and maintenance items to be conducted during the applicable outage. And main process is basically performed for 24 hours in a day of continuous task performance and some sub process to be changed into main process is also performed for 24 hours in a day of continuous task performance.

2.3.1. RCS Cooling/Drain and Dismantling of Reactor Head

After decoupling and Turbine manual stop, CVCS supplies the boric acid water in BAST(4,000 ppm) into RCS to increase RCS boron concentration for refueling (2,150 ppm) using a centrifugal charging pump, which has a rated capacity of 606 L/min (@ 50 ℃). The limiting case in the respect of boration duration following reactor shutdown is that RCS is borated from minimum boron concentration at EOL (10 ppm) to boron concentration for refueling (2,150 ppm) in Technical Specification. The estimated boration duration for the limiting case is 6.84 hours in Table 3:

Table 3 Duration for Boration

Item	Value
Charging Pump Capability	606 L/min(@ 50 °C)[2]
Boration Amount (10ppm → 2,150ppm)	248,775 L (BAST : 4,000ppm)[3]
Duration for Boration	**6.84 hrs**

The duration from Hot Zero Power to the removal of the Reactor Pressure Vessel (RPV) head is 69.9 hours. Actually, the heat removal duration from Hot Zero Power to Cold Shutdown is about 10.9 hours based on the Korea Standard NPP operation experience (Shin-kori Unit 1, 3rd Planned Outage). For worker tolerance during hands-on reactor vessel head operations, RCS temperature reaches to 55°C. The duration for the RPV head removal preparation is 20 hours during RCS Drain. And the duration for removal of RPV head is 39 hours according to the operation procedure of the reference plant (Shin-kori Unit 3, 4). The EU-APR adopts Integrated Head Assembly (IHA) concept for the RPV head similar to the IHA design of the reference plant. The IHA was designed to integrate the followings into one-package component: the head lifting rig; lift columns; missile shield; CEDM forced air cooling system; electrical and instrumentation cable tray; insulation and reactor vessel head. IHA design concept is to lift reactor vessel head and head area equipment at the same time, which can reduce time in critical path required to approach the reactor vessel internals.

2.3.2. Fuel Unloading/Loading

In order to improve performance, function and maintenance of Fuel Handling System Equipment, the advanced Refueling Machine (RM) was developed [4]. The advanced fuel handling system equipment can transfer 6 fuel bundles per hour. However, the capability of fuel handling system is determined as 5 fuels/hour considering operators' ability and safety. Therefore, the duration of Fuel Unloading/Loading in EU-APR is 48.2 hours respectively (241 fuels divided by 5 fuels/hour).

After Fuel Loading, Core Mapping and IAEA Inspection are performed. The duration of Core Mapping and IAEA Inspection is estimated at 2 hours based on the Korea Standard NPP experience.

2.3.3. RCS Heat-up

The minimum duration to heat-up of EU-APR is 22.9 hours based on the plant optimized condition. The maximum heat-up rate for RCS in EU-APR is 55.5°C/h [5]. There is sufficient margin to set the average heat-up rate as 15°C/h with consideration of safety and integrity of the plant. The duration of first heat-up stage from 60°C to 99°C is 2.6 hours. The minimum required duration of first stabilization phase on 99°C is 5.5 hours for PZR heat-up/evaporated and PZR water level control. And the duration of second heat-up stage from 99°C to 135°C is 2.4 hours. The minimum required duration of second stabilization phase on 135°C is 2 hours for SCS Out-of Service and Safety Injection Mode Arrangement. The duration of final heat-up stage from 135°C to 291°C is 10.4 hours.

For example, the RCS Heat-up Graph of the Korea NPP (Shin-kori Unit 1, 3rd Planned Outage) is attached in Figure 1, 2. During the heat-up of RCS, Heat-up, Evaporated and Water Level Control for PZR were performed in the first temperature stabilization phase. And SCS Out-of Service and Safety Injection Mode Arrangement were performed in the second temperature stabilization phase. After the temperature of RCS reached to 286°C, MSSV Set Pressure Test was performed in the third temperature stabilization phase. However, in accordance with the outage schedule, MSSV Set Pressure Test can be performed on the other stage after the temperature of RCS would reach to 296°C. Therefore, the time from 60°C at point (2) to 296°C at point (5) in the RCS Heat-up Graph is within 24 hours except for MSSV Set Pressure Test duration.

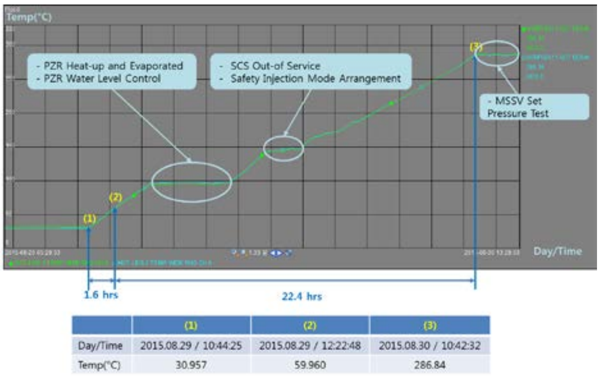

Fig 1 RCS Heat-up Graph of the Shin-kori Unit 1 (1/2)

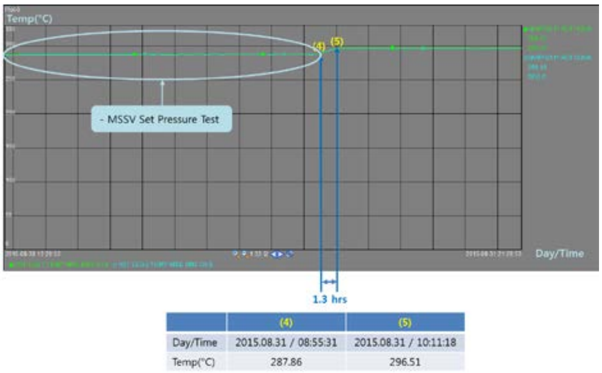

Fig 2 RCS Heat-up Graph of the Shin-kori Unit 1 (2/2)

2.3.4. Core Physics Test and Synchronization

The duration from Hot Shutdown to synchronization is 38.2 hours in Table 4. After the primary circuit reaches to hot shutdown condition, some tests, such as the control rod drop test, are fulfilled before the core becomes critical. In order to make the core critical, RCS boron concentration is controlled through CVCS and the control rods are withdrawn from the core. After the core reached critical, the core physics tests, such as the control rod worth measurement, are conducted at hot zero power. The tests prior to power increase are also conducted, for example, to check if there are differences among the core protection and/or monitoring systems for the core parameters before increasing the reactor power. The duration for the tests including the procedure of core criticality, which mentioned above, is 36 hours. After all necessary tests are finished, the reactor power is increased by controlling the boron concentration or control rods. At 8 % of the reactor power, the turbine set is started. Above 12 %, of reactor power, the synchronization can be performed. According to the start-up procedure, the maximum rate of the power increase is unlimited until the power reaches to 40%. But the operating rate of the power increase is 10%/hr with consideration of safety and integrity of the plant. Therefore, the duration of power increase to synchronization is 2.2 hours.

Table 4 Procedures from Hot Shutdown to Synchronization in EU-APR

Procedure	Detailed Procedure	Duration	Total Duration
Pre-criticality Test	Control rod drop test	3hrs	10hrs
	RSPT[1] channel functional test	4hrs	
	RCOPS[2]/CEAP[3] functional test	3hrs	
Boron Dilution		7hrs	7hrs
Criticality		6hrs	6hrs
0% Core Physics Test	Decision of range for core physics test	2hrs	10hrs
	CBC[4] measurement	1hr	
	ITC[5]/MTC[6] measurement	3hrs	
	Control rod worth measurement	4hrs	
Test prior to power increase	Comparison of RCOPS/COLSS[7] internal input	1hr	3hrs
	COLLS/UTDV[8] initialization	1hr	
	Change of PPS[9] VOPT[10] set point	1hr	
Synchronization	Reactor power increase (~8%)	0.8hr	2.2hrs
	Turbine starting	1hr	
	Reactor power increase (~12%)	0.4hr	

Note:
1) RSPT : Reed Switch Position Transmitter
2) RCOPS : Reactor Core Operating Protection System
3) CEAP : Control Element Assembly Processor
4) CBC : Critical Boron Concentration
5) ITC : Isothermal Temperature Coefficient
6) MTC : Moderator Temperature Coefficient
7) COLSS : Core Operating Limit Supervisory System
8) UTDV : Update Time Dependent Variables
9) PPS : Plant Protection System
10) VOPT : Variable Overpower Trip

2.3.5 In-service Inspection

Items for In-Service Inspection are concentrated on one particular outage and allocated throughout outages within the applicable cycle (10 years). Therefore, it is required to add up inspection items and the time needed to complete inspection for each item in order to calculate In-service outage duration. Automatic ultrasonic inspection on the upper side/lower side of a nuclear reactor is carried out once in ten years as part of additional processes. Typical duration is 150 hours respectively. Being as a critical path, the typical duration is included in the total duration in ten years.

2.4. Estimated Outage Duration for EU-APR

Table 5 shows details of outage durations and critical path in the colored box based on the section 2.1 ~ 2.3. 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. Three types of outage durations in EU-APR are described in Figure 3.

Table 5 Outage Durations and Critical Path of 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

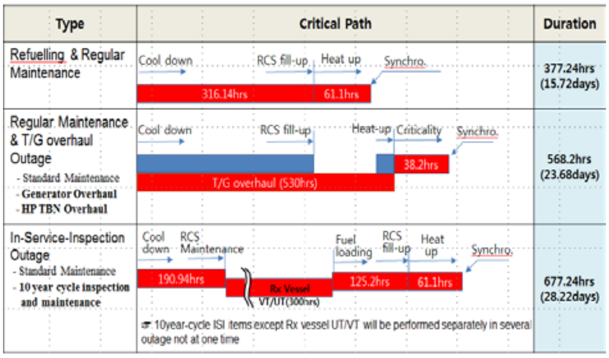

Fig 3 Milestone of each Planned Outage

3. Conclusions

The planned outage durations of EU-APR are optimized according to the above results. And they are complied with EUR Requirement (EUR 2.2.7.2.2 B), respectively. In addition, outage duration can be reduced with improved operating technology and more maintenance friendly environment including betterment of filling, drain and ventilation. If operators' operating techniques are improved, it will make maintenance conditions more operable, leading to reduced outage duration.

Acknowledgement

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