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EU-APR Safety Features Reflecting Recent European Requirements

Ji Hwan Kim* and Keun Seong Lee
KHNP Central Research Institute, 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, Republic of Korea
**Corresponding author: jihwan.kim@khnp.co.kr*

1. Introduction

As a long-term governmental R&D project, Korea Hydro & Nuclear Power Co. Ltd. (KHNP) launched a new project to penetrate the European market in June 2009. The EU-APR is an evolutionary Pressurized Water Reactor (PWR) based on the reference plant, which is the APR1400, reflecting the recent European requirements. The redundancy design of safety systems, the diversity design of safety functions, and the dedicated mitigation systems for severe accidents were taken into account to resolve the differences between licensing approaches in Korea and the Europe. Also, new safety issues on the extreme external hazards were implemented in the plant design. Finally, the EU-APR achieved a high level of compliance with the EUR and certified by the EUR organization in November 2017. In this paper, its design modifications from the APR1400 are presented with emphasis on the safety features.

2. EU-APR Development

2.1 Overview of the reference plant

The APR1400 is a two-loop, 1400 MWe class advanced PWR with 60 years design life time. It was evolved from the 12 units of the OPR1000 in operation. The APR1400 received design approval from Korean nuclear regulatory authority in May 2002. As the first of its kind, Shin-Kori unit 3 has been in commercial operation from December 2016.

To provide more benefits than the conventional plants, advanced design features and design improvements were implemented such as hot-leg temperature reduction, larger pressurizer, adoption of Pilot-Operated Safety Relief Valves (POSRVs), steam generator improvement, mechanical four-train Safety Injection System (SIS) with Direct Vessel Injection (DVI) nozzle, Safety Injection Tank (SIT) with Fluidic Device (FD), In-containment Refueling Water Storage Tank (IRWST), Cavity Flooding System (CFS), Emergency Containment Spray Backup System (ECSBS), and Integrated Head Assembly (IHA).

2.2 Key requirements for the EU-APR

To reflect the key requirements by European regulators and utilities, we reviewed the IAEA SSR-2/1 [1], the European Utility Requirements (EUR) revision D [2], Finnish regulatory guides on nuclear safety and security (YVL) [3], and Western European Nuclear Regulators' Association (WENRA) requirements [4]. As a result, we derived the main items for safety features to comply with the key European requirements, as summarized in Table 1.

Table 1 Main Items for Safety Features

	European Requirements
Redundancy of Safety system	For important safety systems, single failure criterion and 1 train out of operation due to maintenance shall be assumed to achieve their functions during postulated accidents.
Diversity of Safety Function	In ensuring the most important safety functions, systems based on diverse principles of operation shall be used to the extent possible.
SAs mitigation system	To ensure containment integrity in severe accidents, SSCs shall be designed independent of systems designed for plant operational conditions and postulated accidents.
Protection against extreme external hazards	The protection design against a large commercial aircraft crash shall be incorporated as a man-made hazard. Loss of the primary ultimate heat sink or access to it should be considered in the design.

3. Major Characteristics of the EU-APR

3.1 Defence-in-Depth approach

Following the defence-in-depth (DiD) approach in the WENRA [4], the EU-APR adopted the successive five levels of DiD as shown in Figure 1. Design Extension Conditions (DEC) is newly introduced as Level 3b instead of Level 4 in the previous DiD concept.

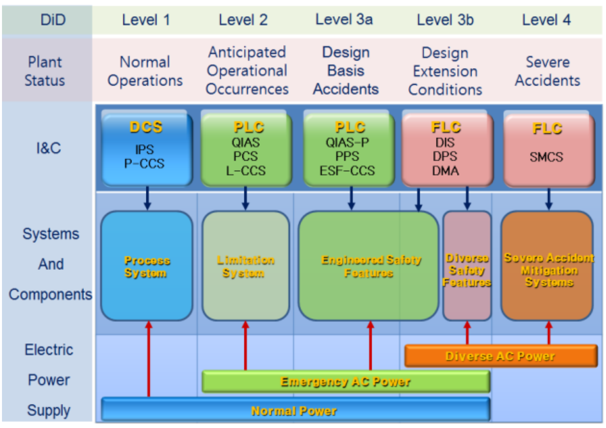

Figure 1 EU-APR Safety Architecture

Each Structure, System and Component (SSC) performing a safety function in each DiD level is assigned to one specific safety function or family of safety function. The safety features performing the required safety functions for Anticipated Operational Occurrences (AOO), Design Basis Accidents (DBA), Design Extension Conditions (DEC), and Severe Accidents (SA) are dedicated to each DiD level, respectively. The mechanical, electrical and I&C systems providing safety and non-safety functions are designed based on the different design principles for each DiD level.

3.2 Failure criteria

All the safety systems adopt basically the N+1 concept. However, the failure criteria of the YVL [3] are more stringent than those of the other requirements, so that N+2 concept are incorporated in Engineered Safety Features (ESF) for DBA, such as SIS, Shutdown Cooling/Containment Spray System (SC/CSS), Auxiliary Feedwater System (AFWS), their associated cooling chains and Emergency Diesel Generators (EDG).

- N+1: it must be possible to perform a safety function despite the potential failure of any single component design to secure the function.
- N+2: it must be possible to perform a safety function even if any single component designed to secure the function fails and any other component or part of a parallel or redundant system – or a component of an auxiliary system necessary for its operation – is simultaneously out of operation due to repair or maintenance

Table 2 Failure criteria for safety features

Level of DiD	Plant Status	Essential Means	Failure Criteria
2	AOO	Limitation Systems	N+1
3a	DBA	Engineered Safety Features	N+2
3b	DEC	Diverse Safety Features	N+1
4	SA	Severe Accident Mitigation Features	N+1

3.3 Protection against Common Cause Failure

To meet IAEA SSR-2/1 [1] and the YVL [3], the diversity principle is incorporated to cope with the postulated Common Cause Failures (CCF) combined with AOO or DBA of event frequency higher than 10^{-3}/yr and the multiple failures. For Anticipated Transient Without Scram (ATWS), Station Blackout (SBO), Loss of Ultimate Heat Sink (LOUHS), and loss of spent fuel pool cooling, the Diverse Safety Features (DSF) provides accident mitigation functions in case that the front system fails to conduct its assigned safety function.

Table 3 Diverse Design against CCF

Safety Function	Front System	Alternative Measures
Core Cooling	SIS	Primary depressurization using secondary ADVs + SIT Injection + IRWST water Injection by SCS
	AFWS	Primary feed and bleed operation using POSRVS and safety injection
Spent Fuel Pool Cooling	SFP Cooling System	SFP Makeup System
Reactor Shutdown	Control Rods	Emergency Boration System
Emergency AC Power	EDGs	AACDGs

3.4 Severe Accident Mitigation

In accordance with the YVL [3] and the WENRA [4], the SA mitigation systems are dedicated to providing an independent defence line from that of the ESF and the DSF. The EU-APR aims to practically eliminate certain conditions which would lead to early or large releases and to limit the off-site releases after the core melt accidents. The systems consist of an Emergency Reactor Depressurization System (ERDS) on the pressurizer, a Passive Ex-vessel corium retaining and Cooling System (PECS) under the reactor vessel, a SA Containment Spray System (SACSS) and a Hydrogen Mitigation System (HMS) inside the primary containment. In addition, the plant is equipped with a Containment Filtered Vent System (CFVS) as a final measure to prevent the containment failure. SA dedicated I&C system is provided with electric power by AACDGs.

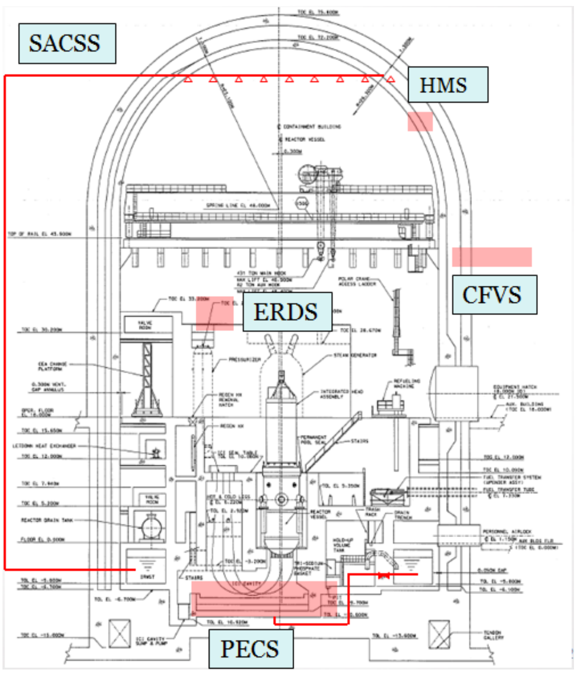

Figure 2 SA Dedicated Mitigation Systems

3.5 Consideration of Extreme External Hazards

The EUR [2] requires that the plant design needs protection against the intentional crash of a commercial airplane as a result of a human malevolent action. Therefore, the safety buildings of the EU-APR is designed to maintain the leak-tightness of primary containment and to protect safety-related SSCs, fuel handling area and main control room to protect the required trains of safety systems for safe shutdown and their cooling chain remain intact to avoid the core melt. As shown in Figure 3, the EU-APR adopts secondary containment and the auxiliary building is structurally reinforced. In addition, the Essential Service Water/Component Cooling Water (ESW/CCW) buildings and EDG/AACDG buildings are physically separated between each division against the intentional aircraft crash.

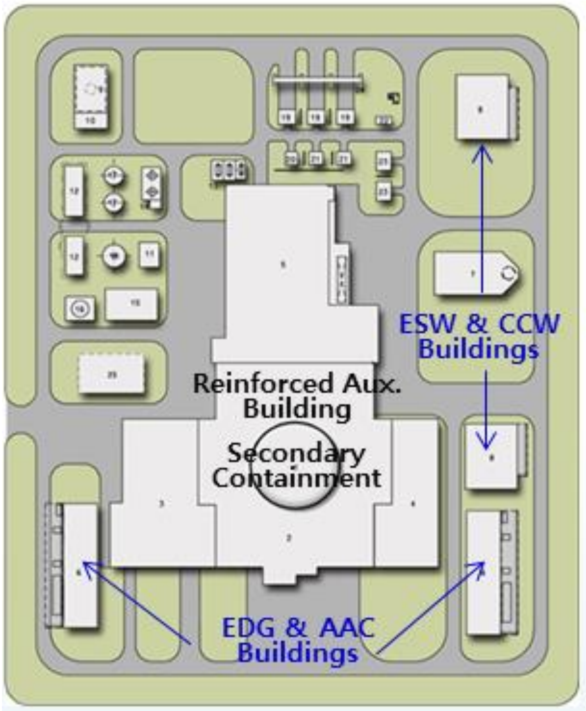

Figure 3 Safety Building Design against aircraft crash

Also, the lessons-learned after the Fukushima accident in the WENRA [4] are reflected into the EU-APR design as an additional countermeasures to maintain or restore core cooling, containment function, and SFP cooling capabilities following the event as follows;

- enhanced provision is considered to ensure possibilities to use mobile power supply units after 72 hours such as mobile generator at the site, and
- design enhancements such as primary side pump(s) and connection, secondary side pump(s) and connection, SFP makeup lines, external connection for containment spray lines are implemented to utilize external water source after 72 hours.

4. Conclusions

The EU-APR is a 1400 MWe Gen III+ reactor intended for European market. We derived the refined DiD approach, reinforced failure criteria for safety features, protection against CCF, SA dedicated mitigation systems, the aircraft crash protection, and countermeasures against Fukushima accident to cope with the safety issues with European approach so that the EU-APR will be licensed in any of the European countries with minimum changes.

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