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The Design Characteristics of APR+ NSSS

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1. Introduction

In order to strengthen the competitiveness of nuclear power in the 21st century, the improvements both in safety and economics were found to be necessary in Korea as well. Therefore, a long-term national R&D program, the Advanced Power Reactor Plus(APR+) was launched in 2007, and will continue until 2015. APR+ design is expected to get the standard design approval from the Korean nuclear regulatory body by the end of 2012.

APR+ is an evolutionary ALWR for which the design is based on the current APR1400 design with capacity evolution. In comparison with the APR1400, the plant power of the APR+ is increased about 7% by increasing the fuel assemblies from 241 to 257. It also incorporates a number of design modifications and improvements to meet the utility's needs for enhanced safety goals. This paper describes major APR+ design characteristics: reactor core and fuel, reactor coolant system, safety injection system, passive auxiliary feedwater system and N+2 design.

2. Major Design Characteristics of APR+

2.1 Reactor Core and Fuel

In comparison with APR1400, the plant power of APR+ is increased by 7% by increasing the fuel assemblies from 241 to 257, as shown in Fig. 1.

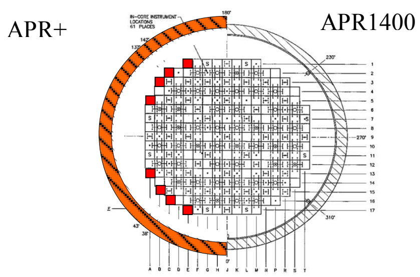

Fig. 1. The composition of APR+ reactor core comparison with APR1400

The APR+ core consists of 257 fuel assemblies, 117 control element assemblies (CEAs), and 65 in-core instrumentation (ICI) assemblies. The refueling cycle of the core is 18 months with a maximum discharge rod burn-up of 60,000 MWD/MTU; the thermal margin of the core is over 10%. The fuel assembly is arranged into 236 fuel rods containing UO_2 pellets or a burnable absorber and five guide tubes in a 16×16 array. The five guide tubes consist of four CEA guide tubes and one ICI guide tube. The CEAs are composed of twelve fingers full strength CEAs, four fingers full strength CEAs, and four fingers part strength CEAs.

The advanced fuel assembly, HIPER, which is enhanced in terms of thermal hydraulics, nuclear performance, and structural integrity compared with a conventional fuel assembly, will be used in the core of APR+.

2.2 Reactor Coolant System

APR+ is a two-loops pressurized water reactor. Its nuclear steam supply system (NSSS) is designed to operate at a rated thermal output of 4,308 MWth. It contains two primary coolant loops, one steam generator(SG) and two reactor coolant pumps(RCPs). The reactor vessel diameter of the APR+ is bigger than that of APR1400 to accommodate the added fuel assemblies, thus the inside diameter is determined to be increased to about 0.3 m (1 ft). The basic design feature of APR+ steam generator (SG) is the same as that of APR1400. The heat transfer area of the SG is increased to accommodate the increased thermal power by increasing the U-tube height. About one(1) feet height is increased as compared to that of the APR1400. Therefore, the upper shell diameter and the head dome radius of the SG would increase 14 inches and 7 inches, respectively, in order to accommodate the increased secondary inventory. The SG vessel material is changed from SA-508 Grade 1A to a high strength alloy steel, SA-508 Grade 3 class 2, to reduce the total weight of the SG by using the optimized thickness of the SG vessel.

One pressurizer(PZR) with heaters is connected to the hot leg of the RCS. The hot leg temperature of APR+ increases to 619˚F from 615˚F (APR1400) to optimize the RCS design. The total RCS flowrate is increased to about 103% of APR1400 which is optimized by the primary component sizing.

2.3 Safety Injection System

The safety injection system consists of 4 safety injection pumps(SIP), 4 safety injection tanks(SIT), the in-containment refueling water storage tank(IRWST), and direct vessel injection(DVI) piping lines.

The DVI+, which is upgraded from DVI methods of APR1400, has been researched in order to increase the safety injection flow during LOCA(Loss Of Coolant Accident). 4 emergency core cooling barrel ducts (ECBDs) are vertically installed on the outer surface of the core support barrel to reduce bypass flowrate of direct vessel injection during LOCA.

The basic concept of the passive flow regulator, the fluidic device(FD) installed in the SIT, is vortex flow resistance, as shown in Fig. 2. The SIT discharges a large amount of water to rapidly fill the lower plenum of the reactor vessel when the water level is above the stand pipe installed in SIT. However, when the water level is below the stand pipe, the SIT injects a relatively small amount of water for a long time to remove residual heat in the reactor core. And the FD installed in the SIT substitutes for the low pressure SIPs.

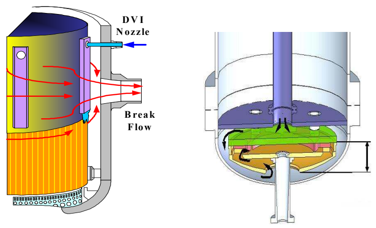

Fig. 2. APR+ advanced design feature of SIS

2.4 Passive Auxiliary Feedwater System

As shown in Fig. 3, the Passive Auxiliary Feedwater System(PAFS) is designed to remove decay heat of the reactor coolant system via the steam generator tubes by natural phenomena during abnormal events such as loss of feed water (LOFW), main steam line break (MSLB), etc. The PAFS loop consists of a PCCT, four U-tube bundles, which is submerged in the PCCT, containment isolation valves(CIVs) on the steam supply line and system actuation valves, check valves, non-condensable gas purge/vent valves, normal and emergency makeup valves, and associated piping and instrumentation.

The steam supply line branched from the main steam line is normally open, and the condensate return line connected to the feed water line is normally closed. When the PAFS actuation signal occurs, an isolation valve on the condensate return line is opened by the DC power and the condensate water flows into the S/G by gravity. The design capacity of heat exchangers and pool water inventory are sized to allow RCS cooldown to a shutdown cooling entry condition within 8 hours assuming a single failure. From this point, the shutdown cooling system (SCS) is used to cool down the RCS temperature to cold shutdown condition.

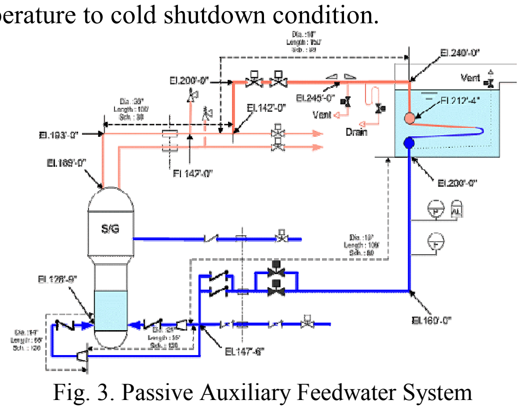

Fig. 3. Passive Auxiliary Feedwater System

2.5 N+2 Design Application

APR+ safety system is designed considering a single failure coincident with simultaneous inoperable conditions due to maintenance. In other words, several safety related systems are designed with 4 channels, the so called N+2 design concept.

The plant essential electricity is supplied by 4 independent emergency diesel generators(EDGs) with sufficient capacity, as shown in Fig. 4. The safety injection(SI) system is composed of not only electrically 4 trains but also mechanically 4 trains. The other safety related systems are also independently designed with electrically and mechanically 4 trains, such as the component cooling water system(CCWS), the essential service water system(ESWS), and so on.

The N+2 design concept contributes to increasing the plant safety, and to making online maintenance possible, and, ultimately it will improve the plant economics.

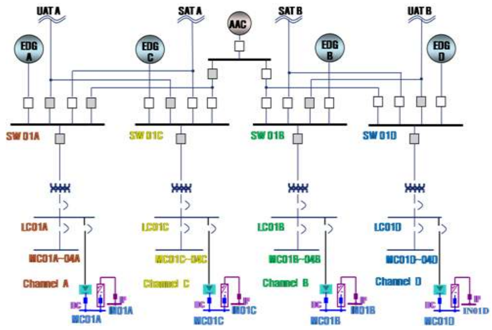

Fig. 4. APR+ independent 4 EDG design concept

3. Conclusions

APR+ will be developed as a two loop, 1,500MWe class evolutionary PWR with a number of advanced design features such as an improved reactor core, reactor coolant system, safety injection system, passive auxiliary feedwater system, and a mechanical and electrical four train safety concept based on N+2 design philosophy to enhanced safety and economics.

According to the long-term power development program in Korea, two units of APR+ are scheduled for operation in June 2022 and June 2023 respectively.

APR+ design will have sufficient competitiveness in terms of economics and safety. We anticipate that APR+ will be the most outstanding reactor among the Gen-III+ reactors in the world.

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