Safe, Reliable, Economical Advanced Pressurized Water Reactor for European Market

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1. Introduction

The design concept of the European Advanced Pressurized Water Reactor (EU-APWR) is largely based on the US-APWR developed for use in the United States, which in turn comes from the original APWR designed for operation in Japan. It has a large electric output capacity of 1700 MW, an important feature of the US-APWR. It also includes all the economic, safety, and reliability features that result from using four-train safety systems, advanced accumulator tanks, and digital instrumentation and control equipment. Mitsubishi Heavy Industries (MHI) is continuing the development of the EU-APWR for the European market to integrate the European Utility Requirements (EUR), the additional safety requirements of the electric power companies in each European country, the regulations specific to each country, and international electrical standards (IEC), as well tailoring the reactor for 50 Hz applications. **Table 1** compares the main specifications of the APWR and EU-APWR.

Table 1 Comparison of main specifications

		APWR	EU-APWR
Core thermal output (MWt)		4 451	4 451
Electric output (MWe)		1 538	1 700 class
Core		12-ft fuel × 257	14-ft fuel × 257
Safety systems	Electric system	2-train configuration	4-train configuration
	Mechanical system	4-train configuration	4-train configuration
Accumulator tank		Advanced accumulator tank × 4	
Refueling water storage pit		Installed in the containment vessel	
Emergency power supply for safety system		Diesel generator	Gas turbine generator
Final stage blades of the low pressure turbine		54 in	74 in - class

2. Plant overview

The primary component of the EU-APWR is a four-loop pressurized water reactor (PWR) with a thermal output of 4,451 MWt and an electric output on the order of 1,700 MW. The core is loaded with 257 fuel assemblies, each with an effective fuel height of 14 ft. A stainless steel neutron reflector is installed around the fuel assemblies to improve reliability by simplifying the structure and to reduce the fuel cycle cost by using neutrons and the irradiation of the reactor vessel efficiently. **Figure 1** compares the core sizes of the existing PWR, APWR, and EU-APWR. The EU-APWR and APWR have very large thermal outputs compared to the existing PWR. The EU-APWR uses 14-ft fuel assemblies to increase the uranium inventory and reduce the power density without changing the size of the reactor vessel. It also enables a 24-month operation cycle with the present U-235 enrichment limit of 5 wt% and a fuel rod burnup limit of 62 GWd/t to reduce the generation cost and provide a large design margin for improving safety.

The low-pressure turbines of the secondary system use 74-inch class super-long blades to improve efficiency. Both the safety and non-safety instrumentation and control systems are fully digital and provide redundancy, defense in depth, diversity, self-diagnostic ability, and online maintainability. **Figure 2** shows a photo of the main control room.

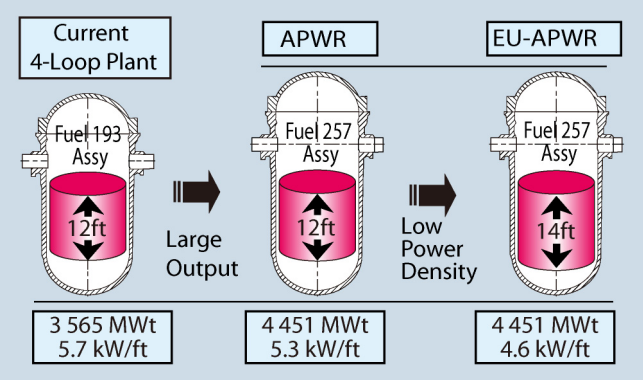

Figure 1 Reactor design improvement
(Increased core thermal output and low power density)

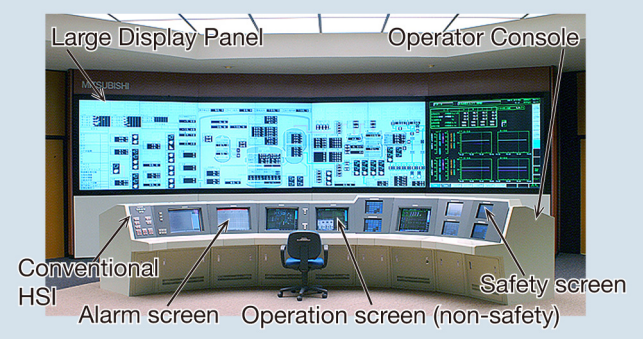

Figure 2 Main control board

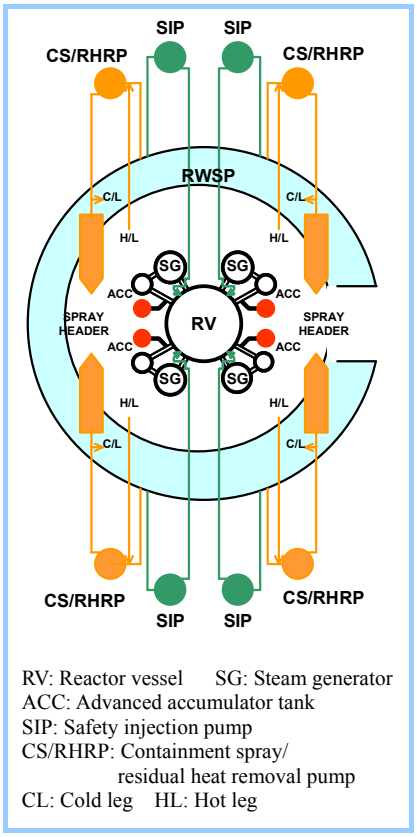

Figure 3 Emergency core coolant system of EU-APWR (4-loop configuration)

3. Safety system features

3.1 Four-train safety injection system

Figure 3 shows the features of the EU-APWR emergency core coolant systems. Whereas the conventional plant uses a two-train configuration where each of the two trains can handle 100% of the capacity, the engineered safety features of the EU-APWR are based on a four-train system wherein each train can handle 50% of the capacity. There is thus no impact on safety in case of an accident even if there is a failure of one train and a second is out of service for maintenance. The reduced size of each train requires smaller equipment.

3.2 Elimination of the low-pressure injection system

The accumulator injection system used for injecting cooling water into the core in case of an accident has the same structure as that in the US-APWR where an advanced accumulator tank (**Figure 4**) is installed in each primary loop. The accumulator injection system has the function of injecting boric acid water when the primary pressure drops. The new accumulator tank developed for use in the APWR injects a large flow of boric acid water in the initial stage of a loss-of -coolant accident (LOCA), initiated by a passive flow damper that requires no outside power for activation. The system also injects a small flow required to continue cooling the core in the subsequent stages. In combination with the high-pressure injection system, this new accumulator injection system has enabled the elimination of the low-pressure injection system installed in the current reactor.

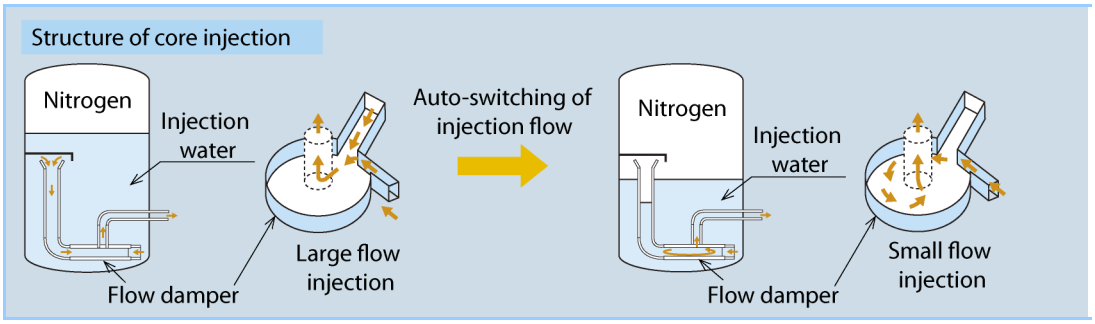

Figure 4 Advanced accumulator tank

3.3 Safety system emergency power supply and gas turbine generator

The safety-related emergency power comes from a 4-train system similar to the safety injection system wherein each train can handle 50% of the load. Online maintenance is possible because only two of the four trains are required for safe shutdown of the plant. The emergency power supply system is based on gas turbine generators. Even though the start-up time of a gas turbine generator is longer than that of a conventional diesel generator, the delay is acceptable because of the time margin for the startup of the high-pressure injection system provided by the advanced accumulator tanks. The simple structure and auxiliary systems of the gas turbine generators mean easy maintenance and reduced cost.

3.4 Refueling water storage pit (RWSP)

Four recirculation sumps are installed at the bottom of the RWSP, which serves as a water source for the emergency core cooling system and is located at the lowest part of the containment. This configuration provides a continuous supply of borated water to the safety injection pumps and the residual heat removal pumps without switching operation to the recirculation sumps, as is required in the conventional design where the RWSP is installed outside the reactor containment vessel. This eliminates the risks from operator error and equipment failure during an accident and provides an even higher level of safety.

4. Building design features

The equipment layout in the EU-APWR buildings is designed to facilitate plant operation and maintenance while minimizing the radiation exposure of personnel. Four-train separation and segregation barriers are included to ensure that the safety-related systems function correctly in the event of possible accidents such as fires, floods, and high-energy pipe failures.

The prestressed concrete containment vessel (PCCV) containing the major equipment of the primary system is designed to provide an efficient leak-proof barrier and radiation protection under all projected conditions including LOCA. The PCCV is also designed to withstand the peak pressure under LOCA conditions. **Figure 5** shows a view of the EU-APWR plant buildings. The EU-APWR safety-related structures, systems, and components are designed to withstand aircraft collisions as well as the effects of natural phenomena such as earthquakes without jeopardizing plant safety.

Furthermore, the safety-critical seismic design is based on the Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE) concepts. The seismic design response spectra (SDRS) for SSE in the seismic design of the EU-APWR standard plant is based on the spectra defined by the modified US RG1.60. As shown in **Figure 6**, the SDRS for the EU-APWR exceeds the EUR Design Basis Earthquake spectra, which are valid for the potential nuclear sites in Europe.

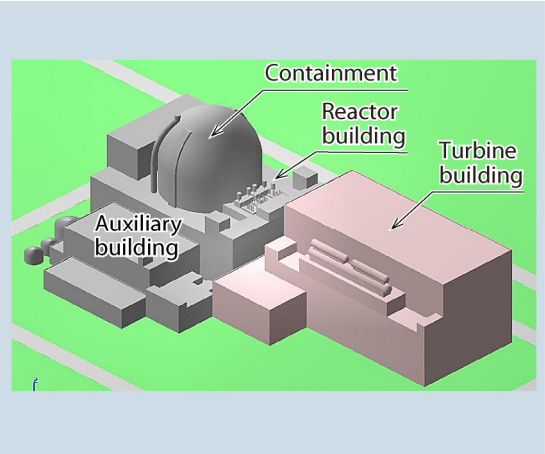

Figure 5 EU-APWR buildings

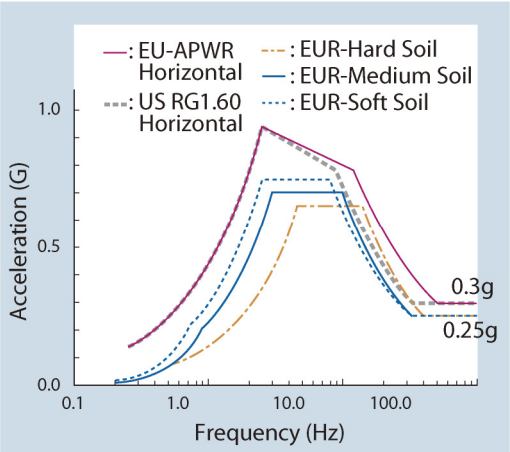

Figure 6 Seismic design response spectra (SDRS)

5. Future directions for the EU-APWR

5.1 Severe accident mitigation

The EU-APWR is designed to prevent any impact on the surrounding area should the reactor vessel be damaged in an accident exceeding the severity of the design scenarios. The severe

accident mitigation posture of the EU-APWR is the same as that of the US-APWR. The fundamental concept is to flood the reactor cavity with coolant water and to keep the molten fuel within the reactor cavity. **Figure 7** shows the basic system of the standard design with the equipment to process low-concentration hydrogen gas, equipment for injection cooling of the damaged core, and equipment to remove decay heat.

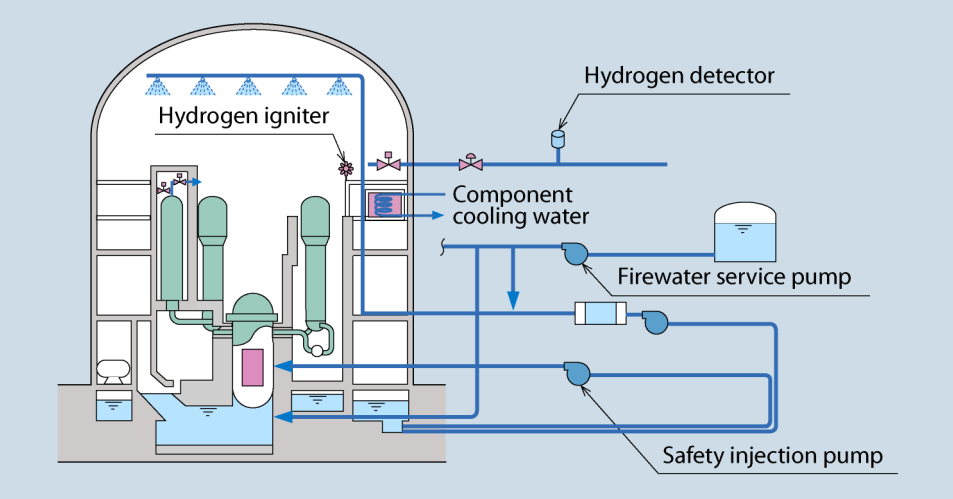

Figure 7 Severe accident mitigation system of the EU-APWR standard design

In addition, because Europe has also directly experienced the impact of the Chernobyl accident, even stricter safety requirements and countermeasures for severe accidents outside the design scenarios are included in the EUR regulations as well as those in each country. Mitigating the results of severe accidents even further requires a cooling water supply system to provide reactor cavity cooling with diversity and independence, allowing the design to meet the more-stringent requirements. The core damage frequency of the EU-APWR based on these design requirements meets the EUR requirement of less than 1×10^{-5} per reactor year).

5.2 Future initiatives

The EU-APWR has been developed to meet the European market requirements. This is in addition to the high level of safety, economy, and reliability inherent in the standard Mitsubishi APWR design. MHI will continue the evolution of the EU-APWR design and may make modifications for specific site or country requirements. This ongoing evaluation and the continuous exchange of technical comments with the electric power companies in each country may lead to more improvements in the standard design. MHI will continue to market the EU-APWR as a plant suitable for the European market.

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