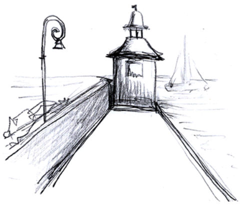

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# Design features of EU-APWR

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## ABSTRACT

Mitsubishi heavy industries designed 1,700 MWe class Advanced Pressurized Water Reactor for European utilities. The plant is a member of the APWR family, is called EU-APWR, which has been developed based on the APWR technology in Japan. The basic plant configuration of the EU-APWR is similar to conventional well known PWRs, but various advanced technologies are adopted to achieve enhanced safety, reliability, and economy.

## 1 INTRODUCTION

EU-APWR is designed as a larger-scale version of the Japanese APWR, aiming at higher electrical outputs and improved economy with satisfaction of European utilities requirements.

Basic design concept is similar to the US-APWR whose design control document (DCD) [1] was submitted to the US nuclear regulatory committee on December 31, 2007 and docketed on February 29, 2008.

TABLE 1 summarizes the features of the Japanese APWR and the EU-APWR.

Table 1 : EU-APWR Feature Comparison with the Japanese APWR

| Design parameter | Japanese APWR | EU-APWR |
|---|---|---|
| Thermal output | 4,451 MWt | 4,451 MWt |
| Electric output | 1,538 MWe | 1,700 MWe class |
| Core | 257Asseys<br>12 ft Fuel | 257Asseys<br>14 ft Fue |
| SG heat transfer area | 6,500 $m^2$ | 8,500 $m^2$ |

## 2 OPERATIONAL TECHNOLOGY

The EU-APWR is a four-loop pressurized water reactor with a power rating of 4,451 megawatt thermal (MWt) and a nominal gross electrical output of 1700 megawatt-class electric (MWe). Its core consists of 257 fuel assemblies and has an active fuel length of 14 ft.

The fuel assemblies are surrounded by a stainless steel radial reflector designed to improve neutron utilization, which reduces fuel cycle cost and reactor vessel irradiation.

Figure 1 shows a comparison of the core size between three reactor designs. Both the EU-APWR and the Japanese APWR have much larger thermal outputs than the conventional PWRs. The introduction of 14-foot fuels to the EU-APWR achieved, without changing the reactor vessel size, with low linear power density, 4.6 kW/ft which allows 24-month operation with 2-batch fuel management as an equilibrium cycle under constraints of 5 wt% U-235 enrichment at the maximum and also at the well- proven maximum fuel rod burnup of 62 GWd/t.

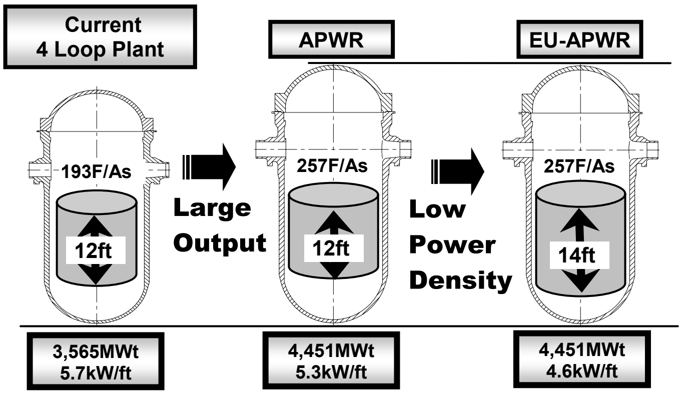


Figure 1 : Reactor Designs

The basic configuration of reactor coolant system, shown in Figure 2, is the same as a currently operating 4-loop plant that has been proven through long term operating experience and enhanced reliability. The main components of the reactor coolant system are enlarged in size corresponding to the large thermal output and improved plant efficiency. The steam generator tubes are 3/4-inch in diameter, smaller than the 7/8-inch tubes used in the existing plants. Tube material is thermally treated alloy 690. Anti-vibration bars in the U-bend area have a shorter supporting span design. Moisture carry over is less than 0.1% with the high-performance moisture separators.

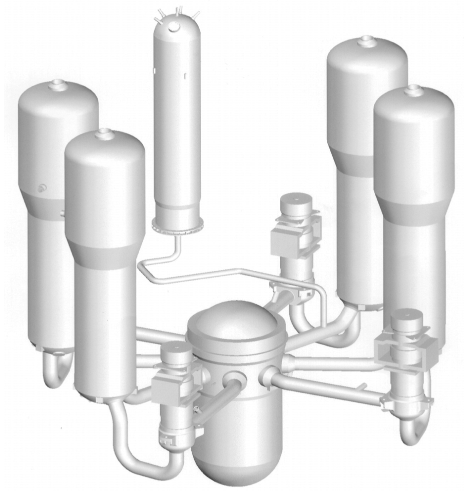

Figure 2 : Reactor Coolant System

One HP turbine and three LP turbines are provided in the EU-APWR secondary system. Longer blades with 70 inches class for the LP turbines contribute to improvement in higher turbine efficiency.

The moisture separator and reheater is adopted to remove the moisture and to reheat the steam between the HP turbine and the LP turbines.

The full digital system is applied to the instrumentation and control (I&C) system for both safety and non-safety systems. I&C system includes redundancy, defense-in-depth and diversity, self-diagnosis and on-line maintenance. Figure 3 shows the main control room.

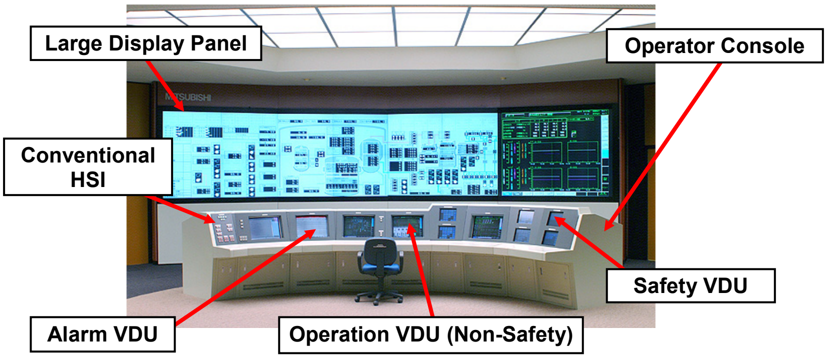


Figure 3 : Main Control Room

The reactor coolant pumps has achieved a larger capacity and higher efficiency (over 85 %) by improving the impeller and diffuser configuration. Reactor coolant leakage to the containment is essentially reduced to zero.

## 3 SAFETY FEATURES

Figure 4 shows the EU-APWR safety system features explained below.

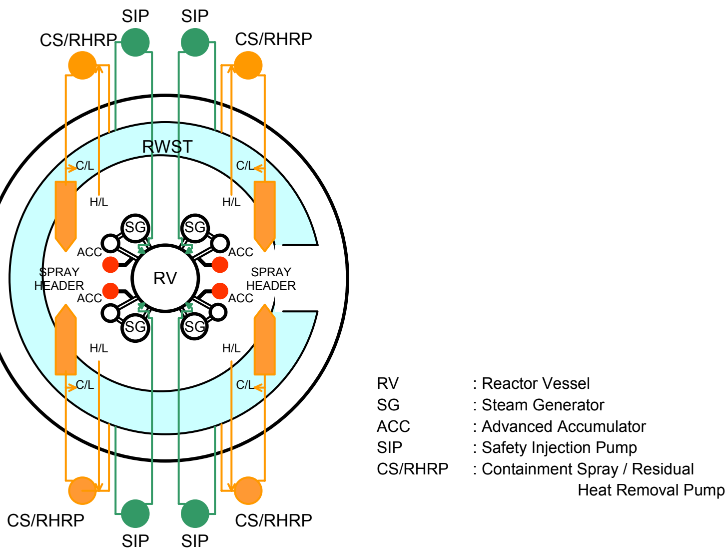


Figure 4 : Safety System

*1) Four-Train Safety Injection System*

The engineered safety features of the EU-APWR is four-train system to perform required safety functions following an accident assuming a single failure in one train with a second train out of service for maintenance. The four-train direct vessel injection (DVI) system brings about a simple and compact safety system and reduces the capacity of each train from 100% to 50%.

*2) Accumulator System and Elimination of Low Head Safety Injection System*

The accumulator system consists of four advanced accumulators and the associated valves and pipings, one for each RCS loop. Figure 5 illustrates the Advanced Accumulator. The system is connected to the cold legs of the reactor coolant piping and injects borated water when the RCS pressure falls below the accumulator operating pressure. The system is passive. The advanced accumulator incorporates an internal passive flow damper which function to injects a large flow to refill the reactor vessel in the first stage of injection, and then reduce the flow as the water level in the accumulator drops. When the water level is above the top of the standpipe, water enters the flow damper through both the top of the standpipe and the side of the flow damper and thus water is injected at a high flow rate. When the water level drops below the top of the stand pipe, water enters the damper only through the side inlet and water is injected at a relatively low flow rate. The advanced accumulators perform large flow injection to refill the reactor vessel and a succeeding small flow injection during core reflooding in association with the safety injection pumps. The combined performance of the accumulator system and the high head injection system eliminates the need for a conventional low head injection system.

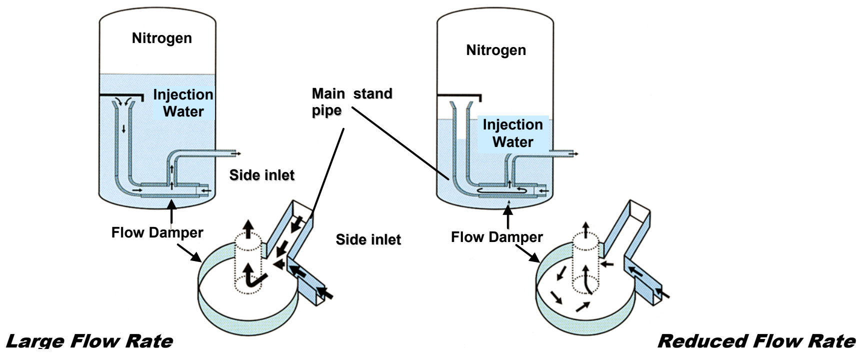


Figure 5 : Advanced Accumulator

3) Containment Spray System

The containment spray system consists of four independent trains, each containing a containment spray/residual heat removal (CS/RHR) heat exchanger, a CS/RHR pump, spray nozzle and valves. Advanced Accumulator eliminates the low head injection pumps, and the CS/RHR heat exchangers and the CS/RHR pumps are used for both CSS and RHRS functions.

4) Electrical Safety System and Gas Turbine Generator

Safety related electrical systems consist of four 50% systems. Two (2) of fur trains are required for safely shutdown the plant. This configuration allows on-line maintenance. Gas Turbine Generators are adopted for emergency power supply system. Longer start time of the GTG,100 sec, is allowed by the advanced accumulators. GTG contributes easy maintenance, small footprint and fewer auxiliary systems.

*5) RWSP*

The refueling water storage pit of the EU-APWR is located at the lowest part of containment, and 4 recirculation sumps are installed at the bottom of the refueling water storage pit. This configuration provides a continuous suction source for the SI pumps and CS/RHR pumps thus eliminating the conventional realignment from the refueling water storage pit (outside containment) to the containment recirculation sump. See Figure 6

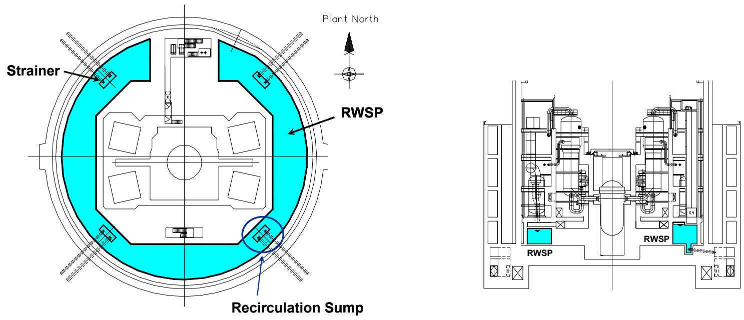


Figure 6 : Refueling Water Storage Pit (RWSP)

*6) Full Digital I&C*

The EU-APWR utilizes a fully digital I&C system with design features that improve plant reliability and operability.

- 4-train separation is completely applied to the safety and safety related systems.
- Both safety and non-safety visual display units (VDUs) can be used for control of safety systems and components (multi-channel operator station).
- Defense-in-depth and diversity features include systems which provide the countermeasures for common mode failures (CMF) of the digital safety systems.

*7) Main Control Room Emergency Habitability System*

The main control room (MCR) HVAC system that includes MCR emergency filtration system allows operators to stay safe inside the control room envelope (CRE) both in the normal and accident conditions. In the emergency pressurization mode, this system establishes the CRE pressure higher than that of adjacent areas during a radiological accident.

*8) Fission Product Release*

When an accident which involves a large release of radioactive materials in the containment (ex. LOCA) occurs, some radioactive nuclides in the containment atmosphere are removed by the containment spray system.
Numerous NaTB (sodium tetraborate decahydrate） baskets are placed in the containment to maintain the desired post-accident pH conditions in the recirculation water. This equipment helps to prevent re-suspension of iodine.
Furthermore, if the containment leakage occurs, fission products will be filtered as they are released through the annulus emergency exhaust system as shown in Figure7. Therefore design integrate leak is 0.1%/day

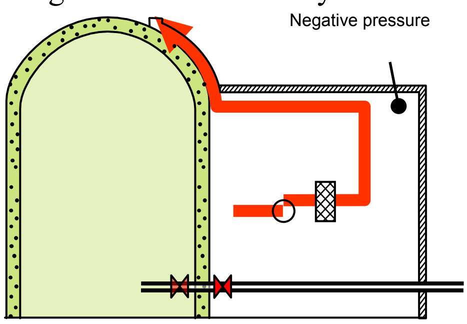


Figure 7 : Annulus Emergency Exhaust System

9) Core Damage Frequency

The result of the calculation for EU-APWR core damage frequency (CDF) meets the EUR goal, $1 \times 10^{-5}$.

## 4 SEVERE ACCIDENT MITIGATION

The EU-APWR is designed to mitigate the consequences of the hypothetical severe accidents such as a reactor vessel failure. The fundamental concept of the EU-APWR for severe accident mitigation is to flood the reactor cavity with coolant water and to keep the molten fuel within the reactor cavity. In order to achieve this, the EU-APWR is provided with the reliable reactor cavity flooding system, which consists of two diverse independent coolant water supply systems as shown in Figure 8. Molten fuel behaviour under postulated reactor vessel failure was analyzed using a computational code. The calculation result shows that the molten fuel spreads out on the flooded reactor cavity floor and the corium layer thickness is adequately thin and evenly distributed. Therefore the core debris coolability is sufficient enough for severe accident mitigation. An analysis was also made on the challenge to the containment integrity due to a postulated ex-vessel steam explosion. It is concluded through this analysis that containment integrity is maintained with safety margin, and the risk associated with the challenge to the containment integrity is negligibly small and acceptable.

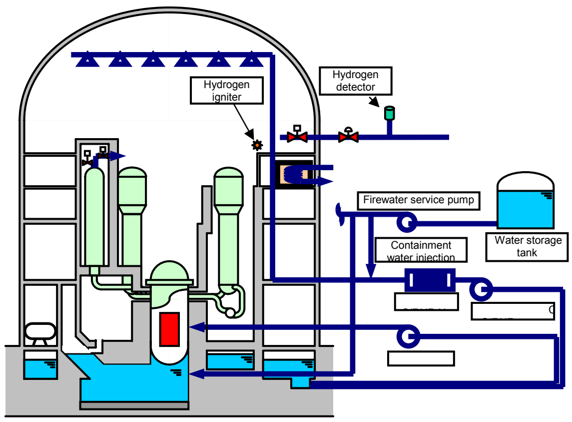


Figure 8 : Severe Accident Mitigation System

## 5 BUILDING CONFIGURATION

The equipment layout within the EU-APWR buildings is determined to facilitate plant operation and maintenance, and minimize personnel radiation exposure. Provisions including redundant train separation and segregation barriers have been made to assure that the functions of the safety-related systems are maintained in the event of postulated incidents such as fires, floods, and high-energy pipe break events. Figure 9 shows the arrangement of the buildings.

The symmetrical arrangement for the safety equipment efficiently reduces the required space in the buildings. These design features provide less building volume and cost reduction compared to conventional PWR plants.

The radioactive equipment and pipings in all of the buildings is arranged and shielded to minimize radiation exposure.

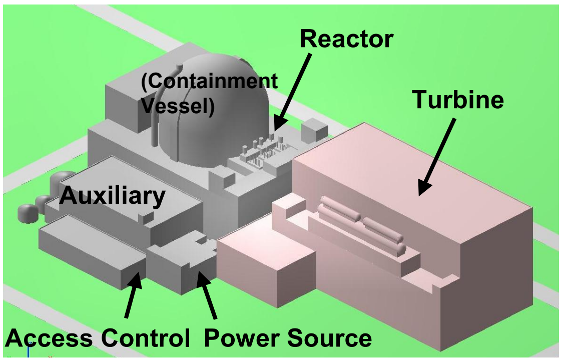

Figure 9 : Arrangement of Buildings

The containment facility is comprised of the pre-stressed concrete containment vessel (PCCV) and the annulus enclosing the containment penetration area, and provides an efficient leak-tight barrier and radiation protection under all postulated conditions including LOCA. The PCCV is designed to withstand the peak pressure under LOCA conditions. Access galleries are provided for a periodic inspection and testing of circumferential and axial pre-stressing tendons. Figure 10 shows a sectional view of the power block buildings.

For easy accesses during operation, maintenance, repair, and refueling, the following means to access the PCCV are also established: two personnel airlocks at different elevations, and one large equipment hatch on the operating floor of the containment. The dimensions of the equipment hatch are determined to allow the future replacement of the steam generators without cutting through the containment. These features significantly improve the maintainability of the equipment and the accessibility to the containment during outages.

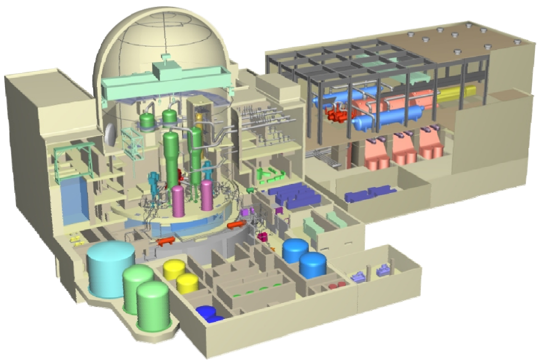

Figure 10 : EU-APWR Plant

The EU-APWR safety-related structures, systems, and components (SSCs) are designed to withstand the effects of natural phenomena, including earthquakes, without jeopardizing the plant safety.

The standard seismic design is based on the safe shutdown earthquake and the operating-basis earthquake. Seismic design response spectra (SDRS) define the site-independent SSE for the seismic design of the EU-APWR standard plant. The Peak Ground Acceleration of the SDRS is 0.3 g for the two horizontal directions and the vertical direction. The PGA of the OBE is set at 1/3 of the SSE (SDRS), and then no design analysis is required to address the OBE loads. SDRS of EU-APWR is modified US RG1.60 spectra[2]. RG 1.60 spectra control points have been modified by shifting the control points at 9 Hz and 33 Hz to 12 Hz and 50 Hz, respectively, for both the horizontal and the vertical spectra as shown in

Figure 11. SDRS of EU-APWR envelope EUR DBE which is valid for the majority of potential nuclear sites in Europe.

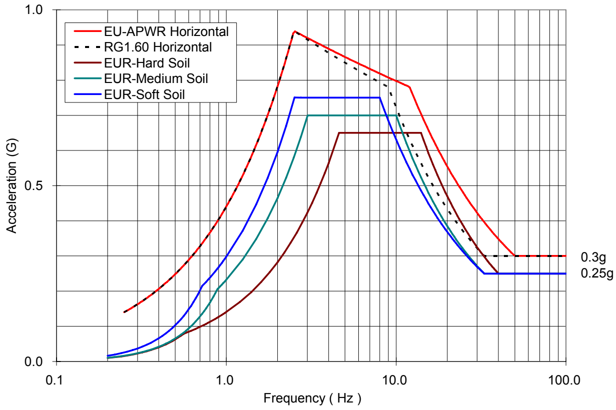


Figure 11 : SDRS (Horizontal. Damping 5%)

## 6 MODULARIZATION AND CONSTRUCTION

MHI constructed 24 PWR nuclear power plants in Japan. Based on those experiences, the construction period(from the First Concrete to the first Fuel Loading) target for EU-APWR is shorter than 41 months.

The main features of the innovative construction methods are as follows:

- Use of Super Heavy Duty Crane (1000 ton Class)
- Application of SC Structure in All Parts of Internal Concrete Structure
- Large PCCV Liner Block (One Piece for Dome Liner and Two Pieces for Cylinder Liner)
- Direct Carry-in of Heavy Components inside CV by Super Heavy Duty Crane

## 7 FUTURE DIRECTION OF THE EU-APWR

The EU-APWR technology, with its emphasis on proven evolutionary improvements in safety, economics and reliability should have broad appeal in the Europe. The future direction currently being pursued involves the completion of the EUR assessment and application of the standard design to as large a fleet of power stations as possible. In the longer term, there may be minor variations driven by specific site conditions. The EUR assessment process and continuing careful evolution may lead to further improvements in the standard design.

## REFERENCES

[1] US-APWR Design Control Document (US-APWR DCD).

[2] Regulatory Guide 1.60, “Design Response Spectra for Seismic Design of Nuclear Power Plants”.