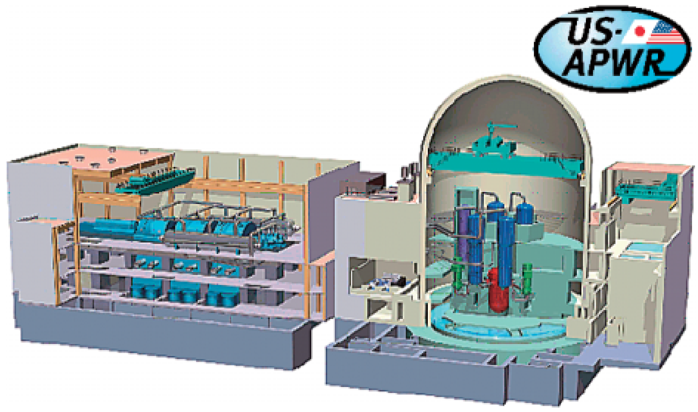

US-APWR for Deployment in the United States

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The US-APWR, developed especially for use in the United States, is an economically efficient, reliable, safe, and well-proven 1,700 MW class plant based on the advanced pressurized water reactor (APWR), which has been already developed in Japan. It utilizes the latest and best technology such as high-performance steam generators and turbines, complies with US regulatory requirements such as enhanced safety power systems, reflects US customer needs such as reduced generation costs for long cycle operation, and applies US site conditions which enable a compact building layout based on moderate seismic conditions. The design certification (DC) application to the U.S. Nuclear Regulatory Commission (NRC) is scheduled for December 2007 and efforts to obtain orders will be strengthened, targeting electric utilities in the US.

1. Introduction

The United States, with the momentum of a nuclear renaissance, has become a promising market, and dozens of new plants are expected to be constructed in the next 20 years. Under these circumstances, Mitsubishi Heavy Industries, Ltd. (MHI) has decided to introduce the US-APWR to the US market. This is based on the already developed APWR which is capable of obtaining an NRC license quickly and can respond to a wide range of electric utilities' needs.

2. Characteristics of plant

Development of the APWR was started in 1982 as a part of the third improvement and standardization program for Japanese nuclear power plants. Its basic design was completed on a whole plant basis using new and advanced technology based on previous experience in operation and maintenance. The new design has been demonstrated and verified by a series of tests. The first APWRs are the Tsuruga Power Station Units 3 and 4 of the Japan Atomic Power Company which are now undergoing licensing.

The US-APWR is based on the APWR, a fully developed design which incorporates MHI's improved technology. It is a highly efficient 1,700 MW class plant, which utilizes the latest development technology to replace existing plant equipment such as high-performance steam generators and turbines. It has been extensively customized for use in the US by responding to US regulatory requirements, customer needs and site conditions, including, for example, enhancing safety power systems, reducing the generation costs for long cycle operation by adopting 14-foot fuel assemblies, and realizing a compact plant layout based on moderate seismic conditions. This plant, while conforming to global safety standards including those of the US, is highly competitive in terms of safety, reliability, operability, maintainability, and economic efficiency. Because of its proven and fully developed basic design, we expect early approval by NRC's DC and Combined License (COL), and assume that it is a candidate reactor with high potential for the six plants eligible for the energy loan guarantee program established by the U.S. Energy Policy Act of 2005.

3. Outline of plant

3.1 Main plant specifications

Table 1 shows the main specifications of the US-APWR.

Table 1 Comparison of main specifications

	Latest 4-loop plant	US-APWR
Electric output	About 1 180 MW	1 700 MW class
Core thermal output	3 411 MW	4 451 MW
Core	12 ft fuel × 193	14 ft fuel × 257
Steam generator heat transfer area	About 4 870m^2	About 8 500m^2 (about 91 500ft^2)
Reactor coolant pump flow	About 20 100m^3/h	About 25 400m^3/h (about 112 000gpm)
Final stage blades of the low pressure turbine	44-inch	70-inch class
Safety system	Electric system: 2-train configuration Mechanical system: 2-train configuration	Electric system: 4-train configuration Mechanical system: 4-train configuration

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The US-APWR is a highly efficient plant 1,700 MW class, with scaled-up steam generators and turbines with improved performance, despite the same core thermal output as the APWR.

Although it employs 257 fuel assemblies which is the same as that of the APWR, the effective fuel height has been extended from 12 feet to 14 feet, realizing long cycle operation at low generation cost.

The lower core internals have been simplified by changing the method of inserting the in-core instrumentation from the bottom insertion of the APWR to top insertion for the US-APWR. Because of this, despite the extended effective fuel height, the size of the reactor vessel (RV) which contains the fuel assemblies remains the same as that of the APWR.

As for the safety systems, in addition to the new designs, including adoption of a 4-train configuration for the mechanical system adopted by the APWR, installation of a refueling water storage pit in the containment vessel, and the use of an advanced accumulator tank, the US-APWR has a 4-train configuration for the electric power source system in consideration of the less reliable offsite power supply in the US and with the aim of facilitating the on-line maintenance (OLM) of the safety system equipments.

3.2 Main component design

(1) Core and fuel

Figure 1 shows the core and the reactor vessel (RV) of the US-APWR.

Although the core of the US-APWR consists of 257 fuel assemblies with the effective fuel height of 14 feet, the core thermal output (4,451 MW) of the US-APWR is the same as that of the APWR. The US-APWR, with a low power density core, not only reduces the number of fuel assembly replacements, which improves fuel economic efficiency, but also enables the long-cycle operation of about 24 months, leading to better availability and reduction of generation costs.

(2) Reactor vessel and reactor internals

Dimensions of the reactor vessel of the US-APWR are the same as those of the APWR (total height 13.6 m, inner diameter 5.2 m). As for the in-core instrumentation system, whereas the conventional design uses a bottom insertion method, the US-APWR uses a top insertion method so as to reduce the number of reactor vessel nozzles, which improves reliability and maintainability. Because of this, the lower core internals have been simplified, the number of lower core plates has been reduced from two to one to increase the core region, and the effective fuel height has been extended from 12 to 14 feet. Nevertheless, we are still able to utilize a reactor vessel of the same size as the APWR.

(3) Steam generator

Figure 2 shows a cut-away view of the steam generator

Although the US-APWR employs steam generator tubes of the same size (3/4 inch) as the APWR, the layout of the tubes has been changed from square pitch to triangular pitch whose high performance has been proven in operations overseas. This change has brought about an increase in the heat transfer area without any drastic change in the barrel diameter, improving thermal efficiency.

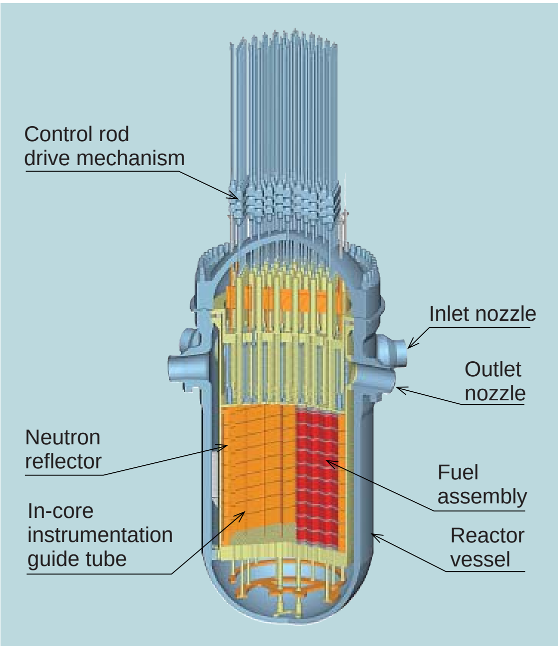

Fig. 1 Core and reactor vessel
The figure above illustrates the construction of the fuel and core instrumentation inside the reactor vessel.

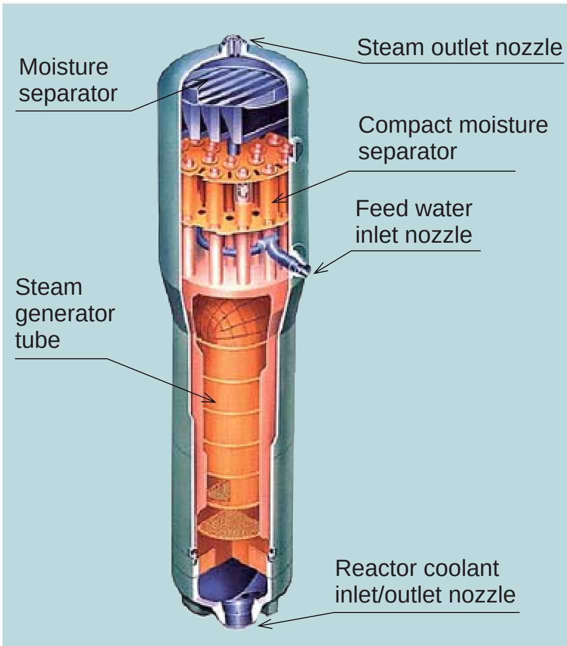

Fig. 2 Steam generator
The figure above illustrates the construction of the tube, and moisture separator inside the steam generator.

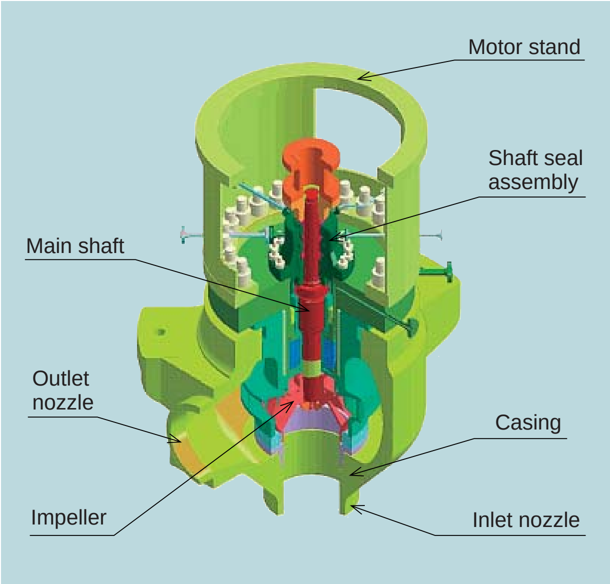

Fig. 3 Reactor coolant pump
The figure above illustrates the construction of the impeller, main shaft and shaft seal.

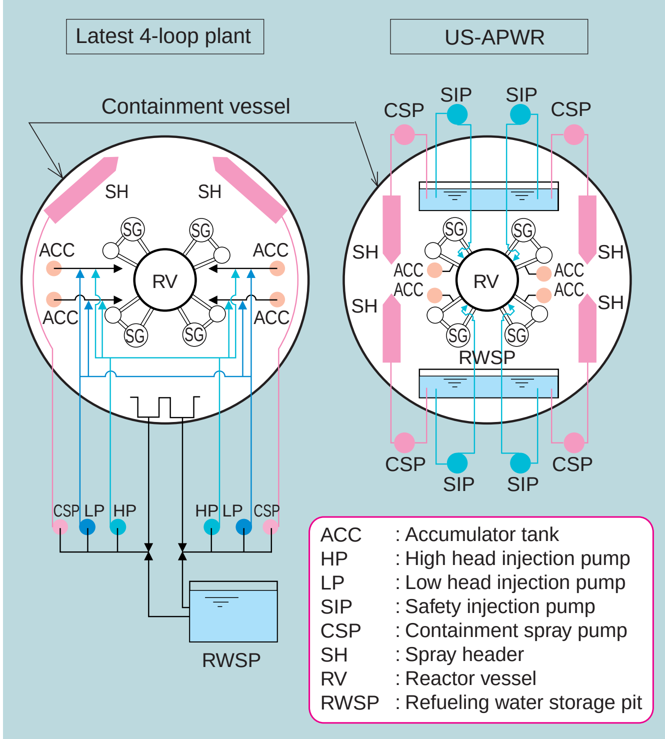

Fig. 4 Comparison of system configuration of emergency core coolant systems
The figure above illustrates the difference between the configurations of the latest 4-loop plant and the US-APWR.

(4) Reactor coolant pump

Figure 3 shows a cut-away view of the reactor coolant pump.

In the US-APWR, the effective fuel height has been extended to 14 feet, bringing about an increase in the flow resistance of the core. However, as the flow passage area has been increased owing to the increased number of steam generator tubes, which has been realized by tightly packing them, the flow resistance of the tubes has become smaller. Thus, as there is no significant difference in the overall flow resistance of the primary system loop, the large capacity pump, whose impeller and diffuser were configured to attain higher pump efficiency, is the same as that of the APWR.

3.3 Safety design

To combat the assumed risk of a primary coolant outflow caused by the failure of the reactor coolant pressure boundary in the PWR, the engineered safety features include an emergency core cooling system to cool the core with boric acid solution injected into the core with multiple trains to provide assured redundancy and independence. Further, it is designed to secure an electricity supply from the emergency generator, ensuring redundancy, so that its functions can be maintained in the event of a station blackout.

To improve the reliability of the emergency core cooling system the APWR was given various improvements such as enhanced redundancy and independence, a simplified system configuration (use of an advanced accumulator tank), an optimized emergency power supply, and elimination of the emergency water source switching operation. The US-APWR also adopts the same design. As for the emergency core cooling system, which consists of three kinds of sub-system in conventional designs, accumulator injection, high head injection, and low head injection systems, the US-APWR, as with the APWR, has integrated the role of the low head injection system into that of the accumulator injection system.

Figure 4 shows a comparison of the system configuration of the emergency core cooling system. The US-APWR, in consideration of the low reliability of the external power supply system in the US, ensures both safety and economic efficiency by improving reliability through use of a 4-train configuration for the emergency power supply and by adopting a gas turbine generator which has a simple structure.

(1) Improvement of redundancy and independence

In a conventional design the high head injection system is configured to have two trains of equipment of the necessary capacity (100% × 2-train configuration) so that the security of the core is assured even in the event of a loss of coolant accident, whereas the high head injection system of the US-APWR has further enhanced its redundancy through the adoption of a 50% × 4-train configuration. The adoption of this 4-train configuration eliminates the connecting piping between trains, thus enhancing system independence. This also facilitates maintenance work during the plant operation of one train and shortens the plant shutdown period for periodic inspections.

Further, while conventional 3- and 4-loop plants employ a loop injection system to inject boric acid solution into the reactor vessel via the primary coolant pipe, the US-APWR adopts a new system, direct injection into the reactor vessel, in which the high head injection system is directly injected into the reactor vessel. This minimizes the ratio of boric acid solution which does not contribute to core cooling by flowing out of a rupture of the primary coolant pipe after loop injection resulting in the more efficient injection of cooling water into the core in the event of a loss of coolant accident. Because of this, the capacity of one train is sufficient at 50%.

(2) Simplification of system configuration

The accumulator tank is an important part of the system for injecting cooling water into the core after an accident. In the US-APWR, this accumulator tank has been improved and enhanced performance by integrating the role of the low head injection system into that of the accumulator injection system and by separating it into two systems, the accumulator injection system, and the high head injection system.

In a conventional design cooling water is injected immediately after an accident by the accumulator tank until the downcomer-refill level is reached and is then injected into the core by the high and low head injection systems after the downcomer-refill level is reached. However, the US-APWR has been designed to use an advanced accumulator tank equipped with a vortex damper, which injects cooling water at a high flow rate right after an accident, as in the case of the conventional accumulator tank, but eventually shifts passively and injects cooling water into the core at a low flow rate.

(3) Optimization of emergency power supply

The high head injection system of the US-APWR has a 4-train configuration. The adoption of this 4-train configuration is not limited to its mechanical system such as the pumps, piping and valves but is also extended to its electric system such as the drive power supply for the pumps and valves, thus enhancing reliability and safety. This measure has been taken based on the consideration of the relatively low reliability of the external power supply in the US. With regard to the emergency power supply, as the duration of injection from the tank is now longer than before due to the use of the advanced accumulator tank, there is sufficient time to start up the high head injection system. Therefore, as there is no need to use a conventional quick start type diesel generator, a gas turbine generator has been adopted for the US-APWR. The gas turbine generator is utility free and is small in size. Further, considering that the US-APWR has introduced an emergency power supply in a 4-train configuration, it is judged to be highly cost-effective.

(4) Elimination of water source switching operation

In a conventional design, the refueling water storage pit, which is the water source for the emergency core coolant system, is placed outside the containment vessel. In the high head injection system and the low head injection system of the emergency core cooling system, boric acid solution from the refueling water storage pit is injected into the core when a loss of coolant accident occurs. However, for long-term core cooling, the pump water source needs to be switched from the refueling water storage pit placed outside the containment vessel to the recirculation sump mounted in the lower section inside the containment vessel, this is recirculation switching.

For the US-APWR, with the intention of eliminating possible erroneous operation or equipment failure caused by recirculation switching, the refueling water storage pit is mounted in the lower section inside the containment vessel, thus eliminating the water source switching operation after the occurrence of an accident. **Figure 5** is a schematic diagram of the refueling water storage pit.

3.4 Layout design

(1) Reduction of the plant building volume

Figure 6 is a plan view of the US-APWR plant.

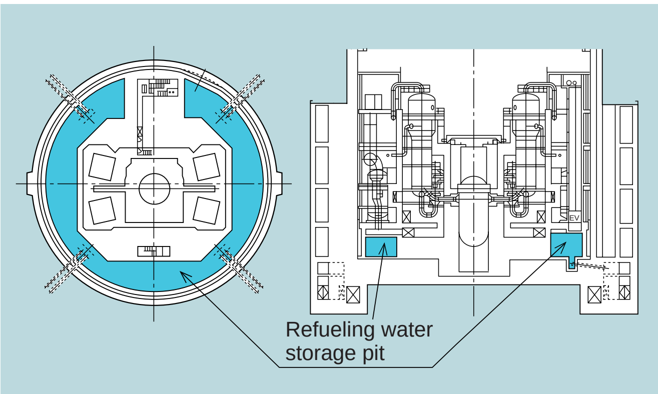

Fig. 5 Schematic diagram of refueling water storage pit

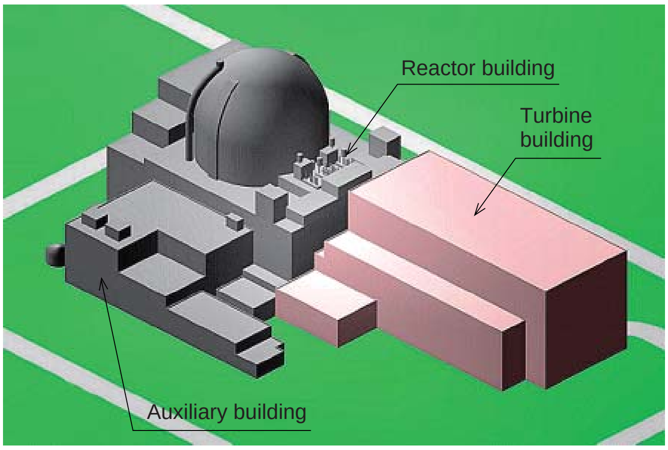

Fig. 6 Plan view of plant buildings
The figure above illustrates the configuration and layout of the buildings.

Regarding the primary building of PWR plants in Japan, the building width must be based on the ground contact ratio of the building during an earthquake in accordance with severe seismic conditions (design acceleration about 0.4 - 0.6 g). Unlike Japan, as lower seismic conditions (design acceleration about 0.3 g) apply to the US, it is possible to use smaller building widths and to reduce the primary plant building volume by adopting a layout using small-scale distributed buildings instead of a large-scale building.

Constructing a large building brings about an increase in bulk materials such as piping, cables, and air-conditioning ducts connecting the devices, resulting in an increase in plant cost. Therefore, it is desirable to design buildings with the minimum volume. The US-APWR, in accordance with the moderate seismic conditions, has been designed with the intention of reducing the building volume by making best use of the efficient layout of equipment, the optimization of maintenance space and the rationalization of the system equipment.

(2) Securement of separation and independence

In designing engineered safety features redundancy and independence have to be enhanced to increase tolerances against failures. The sections where such features are placed must be separate and independent so that a failure in one train does not affect the other trains. For the US-APWR, each of the four trains is located in each of the four corners of the rectangular reactor building, realizing a rational layout which minimizes building size and simultaneously assures separation and independence.

3.5 Turbine plant

The APWR steam turbine consists of one high-pressure turbine and three low-pressure turbines. In order to provide increased output and increased capacity to improve performance, the low-pressure turbines use 54-inch long blades to reduce exhaust loss and also adopt full three-dimensional blades that reduce blade loss by a complete three dimensional flow design. For the US-APWR, aiming at further improvement in turbine efficiency, we plan to adopt super long blades of the 70-inch class.

3.6 Instrument and Control System

With regard to the instrumentation and control system, from the viewpoints of operability and economic efficiency, an advanced main control board using total digital technology has been adopted. This decreases the load on operators by means of soft operation using CRTs and reduces the cable volume through using multiplex transmissions. In the development of the advanced main control board, the preliminary verification of operability was conducted using mock-up testing equipment along with V&V (verification and validation) to verify the software of the safety system equipment and was found to sufficient. This total digital I&C system has been developed to comply with applicable US standards, and verification of the advanced main control board by US operators is scheduled.

Figure 7 shows the external appearance of the advanced main control board prototype.

3.7 Construction method and construction period

To reduce the total plant construction costs, it is essential to shorten the construction period by improving the construction method.

As the construction period of a PWR plant largely depends on the construction period of the containment vessel, starting constructing the containment vessel at the earliest possible time is most desirable. Various large pieces of equipment such as the reactor vessel, steam generator, and reactor coolant pump are installed inside the containment vessel. Therefore, by directly installing such equipment with a large crane while the cylindrical part of the containment vessel is being assembled, and by concurrently conducting the equipment installation work and the containment vessel construction work, we can shorten the construction period.

Fig. 7 External appearance of the advanced main control board prototype
The picture above shows the compactness of the profile of the advanced main control board.

Further, the conventional type module, which mainly consists of piping and frames, can be enlarged to include equipments, conduit tubes, and instrument piping. In addition the fabrication of these modules can be carried out in a different place and on-site work consists of only bringing in the modules, lifting them with large cranes and installing them, resulting in a shorter construction period.

Conventional reinforced concrete construction methods require procedures such as the assembly of reinforcing rods, installation of formworks, pouring of concrete, and removal of formworks. However, we can further shorten the construction period by adopting the steel concrete construction method. In this construction method, the walls are formed of steel plates instead of the conventional formworks, into which concrete is poured. Therefore, the work normally required for the installation and removal of formworks is eliminated.

4. Efforts in overseas deployment

MHI has so far exported equipment such as reactor vessels, reactor coolant pumps, and steam turbines to new plants in Asian, North American, and European countries. It has also exported numbers of replacement upper reactor vessels and steam generators. At present, MHI is actively working on the preparation of a DC application to establish a nuclear power plant export business by making good use of its accumulated experience in manufacturing unit devices in accordance with the applicable US regulations and standards.

Also, more effort will be directed toward the electric utilities in the US who are now in their plant selection process with the aim of entering the energy loan guarantee program.

On July 1, 2006, MHI Nuclear Energy Systems Inc. (MNES) was established in Washington D.C., which is a local corporation owned 100% by MHI. MNES deals with not only with local procedural work toward DC acquisition but also strives to obtain orders for new plants and large components as replacement parts. It has already launched sales activities as the primary center in the US for MHI's nuclear business.

5. Conclusion

The US-APWR has been developed based on the APWR already developed in Japan and is an outstanding plant that provides economic efficiency by increasing output, and ensures safety and reliability using proven technology.

At present we are in the process of a pre-application review which started in July 2006 in which an outline of the application is presented to the NRC for a DC application in December 2007, and are making our best efforts to acquire a DC at the earliest possible time.

Also, we will redouble our efforts toward the electric utilities in the US, in the hope that the US-APWR will be widely adopted.


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