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Design Features of APWR in Japan

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ABSTRACT

Development of the Advanced Pressurized Water Reactor (APWR) was executed in the Improvement and Standardization Program which was organized by the Ministry of International Trade and Industry, Japanese utilities (Hokkaido, Kansai, Shikoku, Kyushu Electric Power Companies and the Japan Atomic Power Company) and manufacturers (Mitsubishi Heavy Industries and Westinghouse Electric). Improvements in terms of safety, reliability, operability, maintainability and economy have been incorporated based on comprehensive evaluations of both the advanced technologies available today, and the experience associated with construction and operation of current PWR plants.

The main design improvement features applied in APWR include a core design which contributes to effective use of uranium resource, safety enhancement in the engineered safeguard system, and reliability enhancement in the reactor internal structures.

This paper briefly describes the main features of APWR design focusing on the radial reflector which enhances reliability of reactor internal structures as well as neutron economy in the core region.

I. INTRODUCTION

In Japan, twenty-three PWRs are currently in operation. Experience in operating the early PWRs has dictated future plants might be improved, particularly in the areas of plant availability, safety, and occupational radiation exposure. So, since the mid 1970s, the Japanese government and industrial group have worked together towards these objectives and started the Improvement and Standardization Program for Light Water Reactors. The fruits of these efforts can be seen in the APWR which is an advanced standardized plant design with higher reliability and safety characteristics. APWR design was executed by the joint program of the PWR utilities (Hokkaido, Kansai, Shikoku, Kyushu Electric Power Companies and the Japan Atomic Power Company) and manufacturers (Mitsubishi Heavy Industries and Westinghouse Electric). The APWR is now a plant which incorporates outstanding improvement in safety, reliability, operation, maintenance and economy. The first APWR is to be adopted into the Tsuruga power station unit 3 and 4 of The Japan Atomic

Power Company.

II. DESIGN FEATURES

The principal specification of the APWR is shown in Table-1.1 with that of a current 4-loop PWR plant for comparison.

One of the important concepts of the APWR is the large power rating which decreases the construction cost per electric generation capacity. Though the electric output was planned as approximately 1420MWe at the early stage of basic design, it was uprated to approximately 1530MWe as a result of design progress, with efficiency improvement of the steam turbine and reactor coolant pumps, and without any change in the system configuration or main components.

The APWR core consists of 257 fuel assemblies of an advanced 17x17 type and incorporates flexibility to meet future requirements such as operation with mixed oxide fuel (MOX) more than 1/3 core and high burn-up fuel of more than 55GWd/t. The inner diameter of the reactor vessel is approximately 5.2 m in order to accommodate 257 fuel assemblies.

Major components such as reactor internals and steam generators are designed to achieve high reliability taking into account actual operating experience of current PWR plants, including consideration of aging degradation mechanisms. One of the most outstanding features of the APWR is the adoption of the radial reflector, which is made of stainless steel ring blocks and contributes to simplification of the reactor internal structures.

Enhanced safety systems appropriate for an advanced LWR coming into operation early in the 21st century are introduced. The enhanced features of these systems increase redundancy and diversity through the adoption of four mechanical subsystems in the safety injection system and containment spray system. They also require less operator action in case of abnormal events due to the emergency water storage tanks located inside containment. In addition, the APWR adopts the original passive technology in the accumulator design called "advanced accumulator", which contributes to simplification of the ECCS design.

State of the art electronics, including digital protection and control systems and an advanced control board are used to improve man-machine interface (MMI). Additional advanced technologies have been incorporated to facilitate operation and maintenance of the plant and to reduce occupational radiation exposure (ORE), especially during the periodic refueling and maintenance outages.

Severe accident measures for APWR are also planned based on accident management plans for existing PWR plants and the latest R&D information in the world.

Table-1.1 PRINCIPAL SPECIFICATION OF APWR

ITEM	APWR	Current 4-loop PWR
Electrical Output	Approx. 1530 MWe	1180 MWe
Core Thermal Output	Approx.4450MWt	3411MWt
Fuel Type	Advanced 17x17	17 x 17
Fuel Assemblies	257	193
Fuel Assembly Effective length	approx. 3.7 m	approx. 3.7 m
Core Load	Approx. 120 MTU	approx. 89 MTU
Reactor Vessel inner diameter total height	approx. 5.2 m approx.13.6 m	approx. 4.4 m approx.12.9 m
Steam Generator heat transfer surface area	6500 m^2	4870 m^2
Loop Flow Rate	Approx. 2.6 x 10^4 m^3/h/loop	approx. 2.0 x 10^4 m^3/h/loop
Steam Turbine	TC6F54	TC6F44
Reactor Containment	PCCV	PCCV
Engineered Safeguard System	4 trains (Mechanical)	2 trains
Emergency Water Storage	Inside Containment	outside Containment

III. Radial Reflector

One of the advanced features of the APWR is the radial reflector. In current PWR plants in Japan, the reactor internal structures have generally had an excellent operating experiences; however, there remain uncertainties regarding the long-term behavior of the materials used in the baffle because of the severe radiation environment. In case of new plants, a longer design life and a higher assumed capacity factor increase the potential of operational issues surfacing late in life.

For the APWR, therefore, the radial reflector was developed as an alternate concept to the baffle structure. The basic concept of the radial reflector was the structural simplification for reliability and improvement of neutron economy. The radial reflector design feature and supporting evaluations are described in the following.

1. Structure and Configuration

In current PWRs in Japan, the core is supported by the lower internals. The lower internals consist of the core barrel, the core baffle, the neutron shield pads, the lower core plate, support columns, and the core support plate which is welded to the core barrel. The core baffle forms a cavity which contains the fuel assemblies; it consists of vertical plates which are bolted to the horizontal plates called formers. The formers are in turn bolted to the core barrel. The baffle/former structure is shown in Figure-2-1.

The APWR radial reflector is shown in Figure-2-2. The design consists of eight stacked ring blocks. Each block is machined from a single forged 304 stainless steel ring. The interior of each block has the shape of the core cavity. The exterior is circular with four flat regions; the top and bottom blocks also incorporate a circular flange.

The interface gaps between the blocks are located opposite the fuel assembly grids in order to preclude any possible leakage flow impinging on the fuel rods.

Each block has about 1600 flow holes, each with a diameter of 20 mm in order to cool the blocks heated by gamma rays. Flow hole size and arrangement are decided considering the cooling effect and the neutron reflecting effect. The flow holes are orificed in the bottom block only. This arrangement results in the pressure of the core cavity being higher than in the flow holes.

There are four corner pins between each block; these are shrunk into the lower block with clearance in the upper block. The complete radial reflector is aligned to the core barrel with four horizontal pins and customized inserts at the circular flanges of both the bottom and top blocks; this is similar to the design currently used for aligning in the upper internals to the core barrel. The stacked blocks are also fastened to the lower internals with eight tie rods.

Neutron pads which are installed in the current PWR are eliminated in the APWR because the neutron exposure rate is decreased sufficiently by the radial reflector.

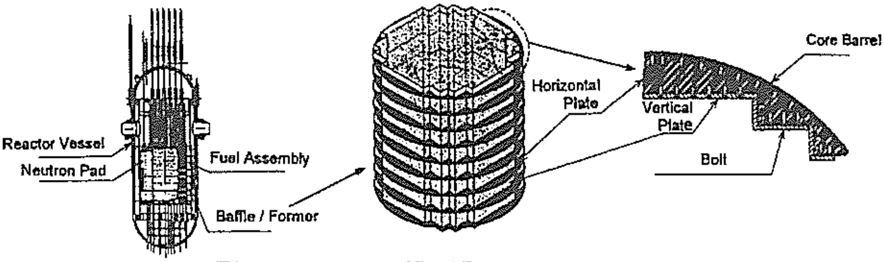

Figure-2-1 Baffle / Former in current PWR

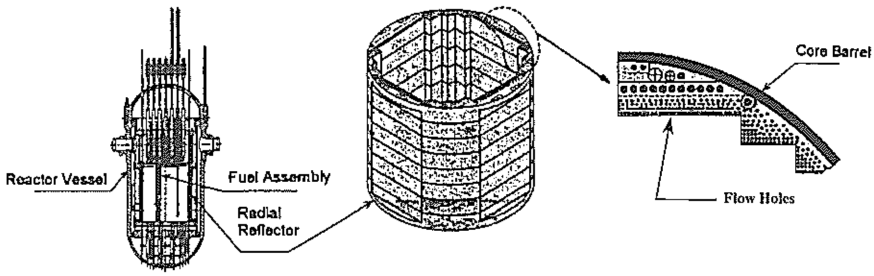

Figure-2-2 Radial Reflector in APWR

2. Radial Reflector Analysis

The R/R is an integral part of the overall reactor system. Supporting analyses have been performed to verify the integrity of the R/R. Key analyses are summarized below.

(1) Coolability Analyses - because of gamma heating, cooling of the R/R is necessary. Analyses were performed to assess both cooling flow and temperature distributions.
- A model of the complete R/R, including inlet holes, cooling holes, block-to-block gaps, annulus between R/R and core barrel, and exit holes, was constructed. Hydraulic analyses confirmed uniform flow distribution between cooling holes.
- Temperature Distribution - Extensive thermal/hydraulic analyses were performed to optimize the cooling hole size and geometry, and the required flow rates. The goals of the optimization were to minimize the peak temperatures in order to prevent bulk boiling, and to obtain an even temperature distribution in order to minimize thermal stress and distortion. Results confirm that the peak fluid and metal temperatures remain well below the saturation temperature of 343℃(650°F) for the expected range of gamma heating distribution; additionally, thermal stresses are shown to be low.

(2) Structural Analyses - The principal structural components which make up the R/R assembly are the blocks, the tie rods, the corner alignment pins, and the alignment pins at the bottom and top flanges. The major loads acting on these components are deadweight, pressure differentials, thermal (from transients and gamma heating), and dynamic (due to seismic and postulated pipe break accidents, including effects of fuel impact and hydrodynamic coupling between the reflector and core barrel). Stresses from these loads were evaluated and shown to be below MITI and ASME Code allowable. The limiting fatigue usage was calculated to be very low.

3. Inspectability and Maintainability

A study was performed to assess operational aspects of the radial reflector; this included a comprehensive assessment of all known degradation mechanisms and their potential effects.

The only fasteners of the radial reflector are the eight tie rods that hold the blocks. The total number of the fasteners which includes the few bolts used at the alignment point with the core barrel, is less than fifty. However, all threaded portions are located out of core region. And there are no welds in the design.

Based on these design features, it assessed that no degradation mechanism which threatens the design life can be expected. Nevertheless, radial reflector is designed to be removable from the core barrel considering the inspectability and the maintainability.

4. Design Verification

In order to verify the radial reflector coolability, a flow test was conducted by using 1/8 sector full scale model as shown in Fig.2-3.

The purpose of this test is to measure inlet flow rate distribution into flow holes. As the test result, it was confirmed that inlet flow distribution is very flat and satisfies design requirement.

Furthermore, the integrity against flow induced vibration was qualified by the 1/5 integrated scale model hydraulic test.

In addition to these tests by utilities, another hydraulic test program was initiated by MITI to obtain data for development of safety analysis code which verify the flow behavior and its influence on core components integrity . A schematic view of the test facility is shown in Fig 2-4

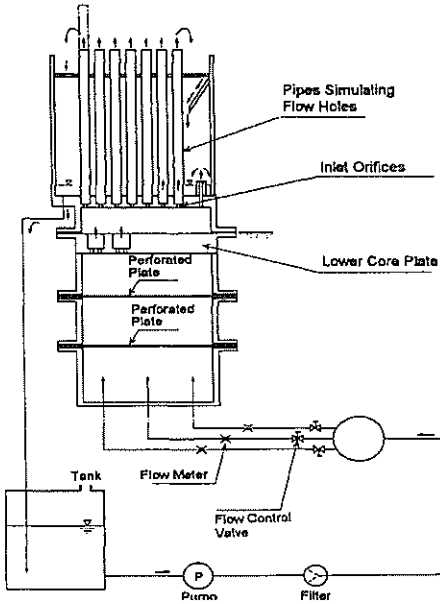

Figure-2.3 Test Loop of Flow Distribution of Radial Reflector Flow Holes

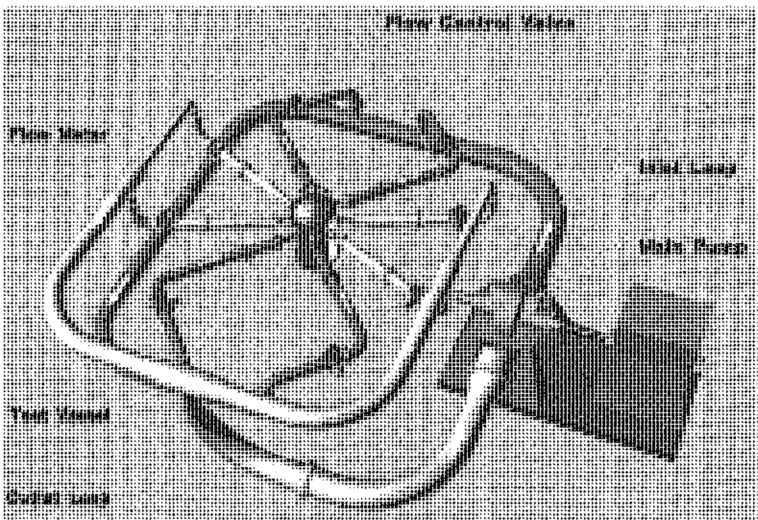

Figure-2-4 Schematic View of Hydraulic Test Facility

5. Design Evaluation

An extensive design, analysis and testing was conducted for APWR radial reflector. The design evaluation are as follows;

a)Threaded portions are less than fifty and are only located out of the core region. There are no welds in the design. As a result, high reliability will be expected even for a longer design life.

b)Neutron irradiation on the inner surface of the reactor vessel can be reduced by approximately one-third of the current 4 loop design without neutron pads.

c)The effect of the fuel cycle cost reduction is approximately 1% compared with the current 4 loop PWR

IV. CONCLUSION

In the APWR design, improvements in terms of safety, reliability and economy have been incorporated based on comprehensive evaluations of both the advanced technologies available today, and the experience associated with construction and operation of current PWR plants.

The radial reflector is a representative feature of the APWR, which contributes to the enhancement of safety and reliability of the plant, and to the improvement of the plant's economics. This newly introduced technology has been verified thorough extensive tests by Japanese industry groups. Therefore, it is concluded that this feature complies with Japanese utilities requirements.