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The Design Concept of PWR-2000 Based on APR1400 (KNGR)

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ABSTRACT

This paper proposes the concept of a 2,000 MWe class advanced pressurized water reactor, PWR-2000, which could be suitable to serve after the APR1400 (KNGR). The PWR-2000 achieves the high power level by adopting most design features of the APR1400 but increasing the number of coolant loops from two to three. Preliminary design parameters have been determined through simple sizing calculation and engineering decision for reactor, reactor coolant system, and safety systems. The performance and safety analysis using detailed computer codes is now underway.

I. INTRODUCTION

Due to the rapid growth of electric demand, the lack of domestic energy sources, and the problems related to other energy sources, Korea has been heavily relying on nuclear energy. Presently nuclear power generation shares more than 40% of Korea's electricity generation and the role of nuclear power in energy supply should be further increased in the future, supplying about 40~50% of electricity.

Korea is now constructing several Korea Standard Nuclear Power Plants (KSNPs, 1,000 MWe) and developing the APR1400, that is the new name of the Korean Next Generation Reactor (KNGR, 1,400 MWe), to start commercial operation after 2010. Considering the speed of technology improvement, we would need another advanced reactor design to serve after the year 2020, following the APR1400. The reactor concepts based on APR1400 design features would be the most appropriate; the Center for Advanced Reactor Research has performed the conceptual design for CP-1300, a 1,300 MWe-class passive PWR based on the reactor coolant system of APR1400. [1]

There are other advanced light water reactor concepts of 1300~1500 MWe at various stages of operation, construction, or development: ABWR by General Electric, Toshiba and Hitachi, System 80+ by ABB-CE, EPR by Framatome and Siemens, APWR by Westinghouse and Japanese companies, as shown in Table 1. To further improve their economic competitiveness, there are some efforts to increase the power rating up to 1,700 MWe [2].

In general, higher power rating provides advantages from the viewpoint of economics and site area, if it is technically feasible and suitable for the electric power grid system. In this regard, we started to develop the concept of an extra-large scale PWR, PWR-2000. The name of PWR-2000 indicates the PWR that is of 2000 MWe rating and suitable for the new millennium. The important concept of the PWR-2000 is its large power rating that abates the construction cost per unit of electric generation capacity. [2]

The motives of this study are (1) to prepare the national energy demand for future, (2) to solve the siting problem, (3) to enhance the safety and economics (4) to subside the construction cost.

This paper presents the design strategy, overall design requirements, overall design concepts with important design parameters, and future developmental directions.

II. DESIGN DIRECTION

II.1. Design Strategy

The design strategy of PWR-2000 is illustrated in Figure 1 and can be summarized as follows:

(a) adopt the APR1400 as the reference design to take the maximal advantage of domestic and established technologies,
(b) assess both 16x16 (ABB-CE design) and 17x17 (Westinghouse design) fuel assemblies in core design,
(c) increase the number of reactor coolant system loops from two (2) to three (3),
(d) modify the safety system to incorporate recent findings and high thermal power requirements, and
(e) re-size the system and components to reflect the increased power level.

The present work is not intended to provide the optimized design details for all important systems. However, the more detailed conceptual design work will follow after verification of feasibility and identification of potential problems.

II.2. Design Requirements and Constraints

The following design requirements and limitations are considered in developing the concept of PWR-2000:

- Electric power: 2000 MWe
- Design life: 60 years
- Refueling interval: ≥ 18 months
- Use the proven technologies
  - Reference reactor: APR1400
  - Fuel Assembly: Westinghouse or CE type
- Technical Limitation
  - Reactor vessel outer diameter: ≤ 6.5m

- Core height: ≤ 14ft (4.267m) (We decided that core height fixed on 14 ft)
- Operating pressure: 2250 psia (15.5 MPa)
- Core inlet/outlet temperatures: 565 K, 600 K

III. SYSTEM CONFIGURATION

III.1. Reactor and Reactor Coolant System

The nuclear steam supply system (NSSS) of the PWR-2000 is designed to operate at thermal output of 5,900 MWt to produce an electric power of 2,000 MWe.

III.1.1. Reactor

Basically the APR1400 design features are maintained except for the increase in the number of fuel assemblies. Two options of the core are being assessed: Westinghouse (WH) and Combustion Engineering (CE) type.

The option A is the WH core assembly type. The core consists of 293 fuel assemblies of 17×17 array, and the linear heat rate is 17.90 kW/m. The core equivalent diameter and reactor vessel outer diameter are 4.16 m and 5.79 m.

The option B is the CE core assembly type. The core consists of 333 fuel assemblies of 16×16 array, and the linear heat rate is 17.60 kW/m. The core equivalent diameter and reactor vessel outer diameter are 4.28 m and 5.96 m. The vessel O.D. for both options are less than the technical limit of 6.5 m. Figure 2 and 3 show the cross-sectional view of the two options.

The core design should allow the refueling cycle of 18 to 24 months.

III.1.2. Reactor Coolant System

The major components of primary circuit are a reactor vessel, three coolant loops, each containing one hot leg, two cold legs, one steam generator (SG), and two reactor coolant pumps (RCPs), and one pressurizer (PZR) connected to one of the hot legs. [3]

We use all components of APR1400. But the pressurizer volume is increased to 3,540 ft^{3}, which is reflected power increase. This is to provide more operational stability by absorbing pressure fluctuation as much as possible. The large pressurizer can eliminate the operation of pressure relief valves during minor transients as well as normal operation, resulting in easier operation and higher safety. [4]

The RCS schematic feature is shown in Figure 4.

III.2. Safety System and Features

The safety systems consist of a 6 train safety injection system (SIS), a safety depressurization system (SDS), an in-containment re-fueling water storage system, a shutdown system, a 6 train emergency feedwater system and a containment spray system.

Therefore, the safety system is like APR1400, except for having two SIS options, direct vessel injection (DVI) or cold leg injection (CLI), shown as Figure 4 and 5. We should choose a better type by considering the structural and analytic aspects.

IV. CONCLUSIONS AND RECOMMENDATION

In order to prepare the national energy demand in the future, this paper suggested a new extra-large scale PWR concept that is based on APR1400. The preliminary design is performed, and this result is summarized in Table 2~4, which is compared with APR1400.

The present study provides the first step for the future development of a large-scale PWR that is the most leading in Korea. And it is expected that the Korean nuclear field advance its basic nuclear technology through the achievement of the PWR-2000 development.

In the future, works should be followed in several areas including a more detailed design and a comprehensive safety analysis.

V. REFERENCES

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Table 1. Large Scale LWR Operation /Development Trend over the World

Reactor Name	Net Electric Power	Developer	Operation/Development Situation
ABWR	1311 MWe	Toshiba/Hitachi/GE	Commercial Operation from 1996
N4	1455 MWe	Framatome	Commercial Operation from 1997
APWR	~1500 MWe	MHI/WH/Utilities	Basic Design Development
System 80+	~1300 MWe	ABB-CE	Basic Design Development
EPR	~1500 MWe	Fram./Siemens	Basic Design Development
APR1400 (KNGR)	~1400 MWe	KEPCO	Basic Design Development

Table 2. Summary of Basic Design Concepts

	PWR-2000	APR1400
Type and Electric Power	PWR, 2000 MWe	PWR, 1400 MWe
Plant Lifetime	60 years	60 years
Refueling Interval	18-24 months	18-24 months
Containment	Double Cylindrical Building	Double Cylindrical Building
Reactor Coolant System	3-loop	2-loop

Table 3. Summary of NSSS Design

	PWR-2000		APR1400
Thermal Power	5900 MWth		4000 MWth
Coolant Pressure	2250 psia (15.5 Mpa)		2250 psia (15.5 Mpa)
Coolant Inlet/Outlet Temp.	292 / 326 ℃		296 / 327 ℃
Total Mass Flow	29,450 kg/s		20,889 kg/s
Presurizer Heat Capacity	3540 kW		2400 kW
Fuel Assembly Type	17×17 (264 rods/ass.)	16×16 (236 rods/ass.)	16×16 (236 rods/ass.)
Fuel Assembly No.	293	333	241
Effective Core Height	4.267 m	4.267 m	3.81 m
Core Equivalent Diameter	4.16 m	4.28 m	3.65 m
Average Linear Heat Rate	17.90 kW/m	17.60 kW/m	18.37 kW/m
Reactor Vessel ID	5.22 m	5.37 m	4.64 m

Table 4. Summary of Safety System Design

	PWR-2000	APR1400
No. of Trains	6	4
Injection Methods	Direct Vessel Injection or Cold Leg Injection	Direct Vessel Injection
No./Type of High Pressure .Injection Pump	3	2
No./Type of Low Pressure.Injection Pump	3	2

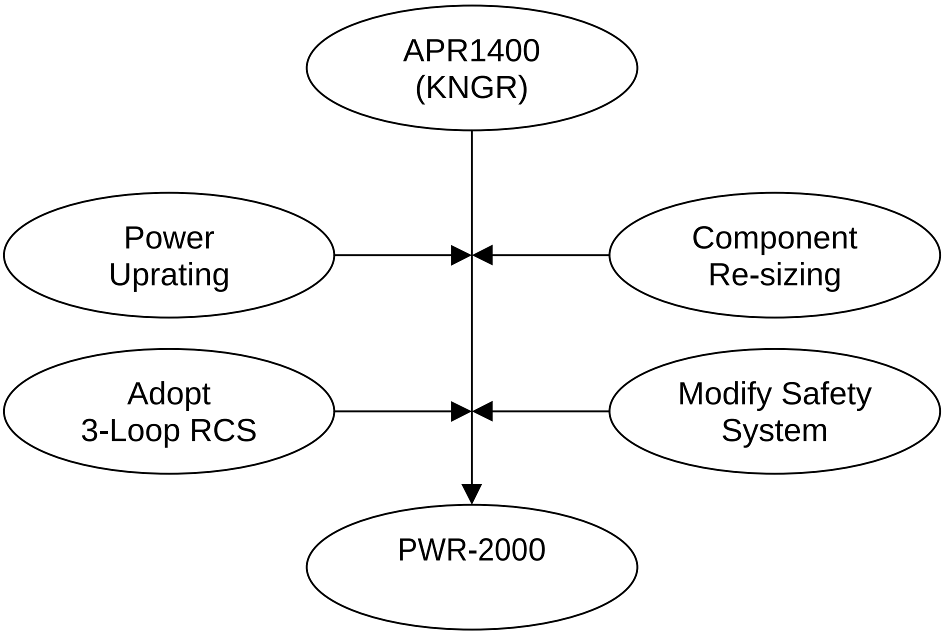

Figure 1. PWR-2000 Development Strategy

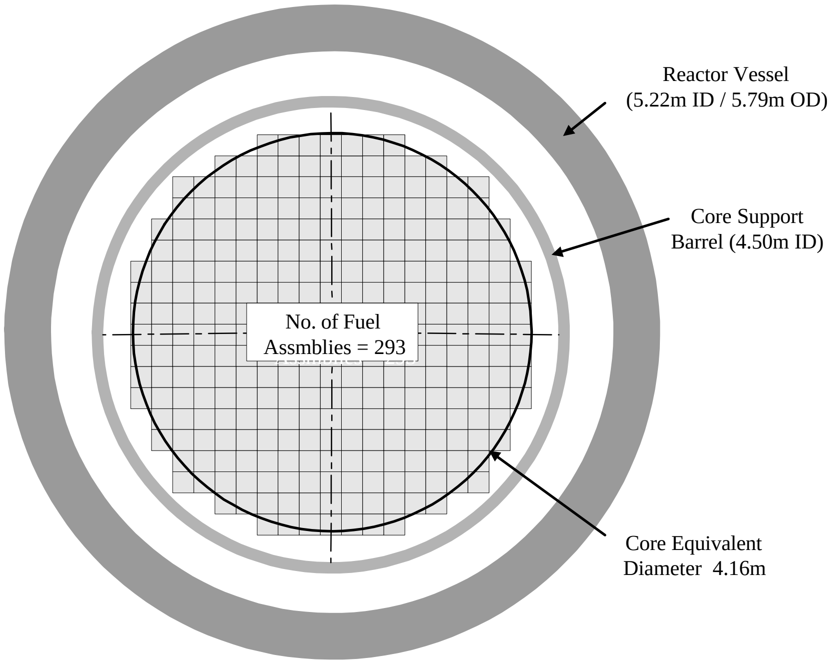

Figure 2. Cross-Sectional View of the Reactor (WH type)

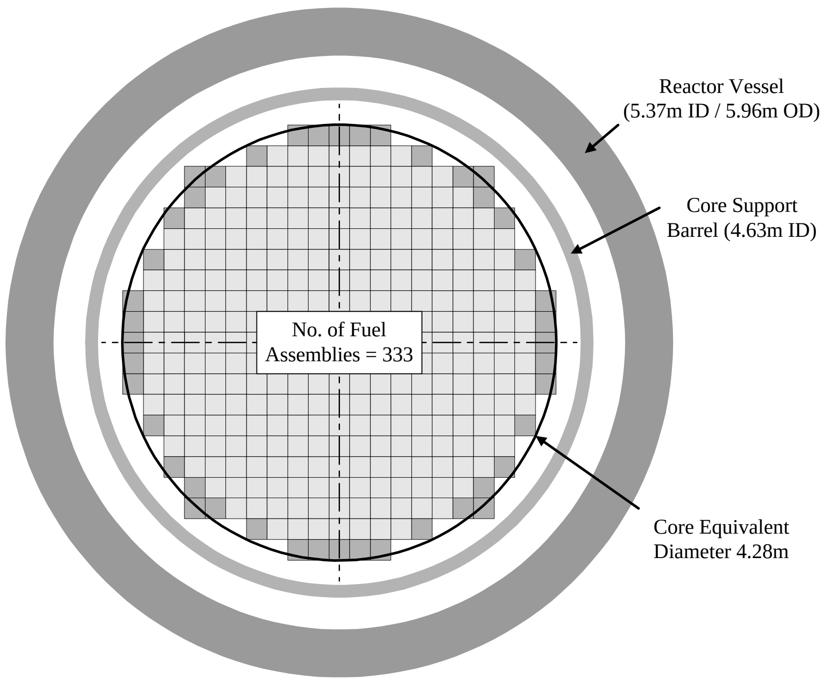

Figure 3. Cross-Sectional View of the Reactor (CE type)

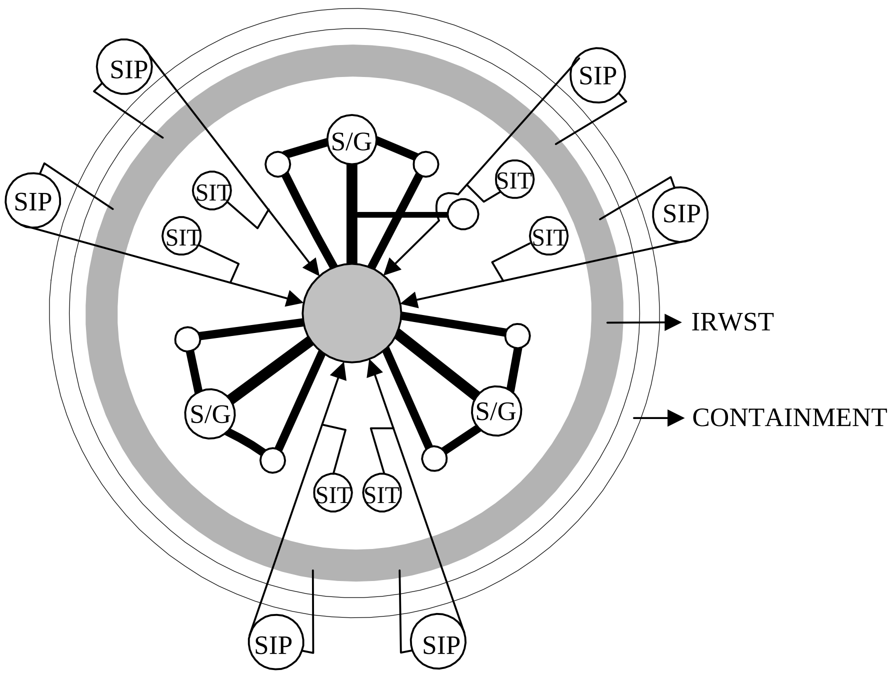

Figure 4. Arrangement of PWR-2000 RCS and DVI

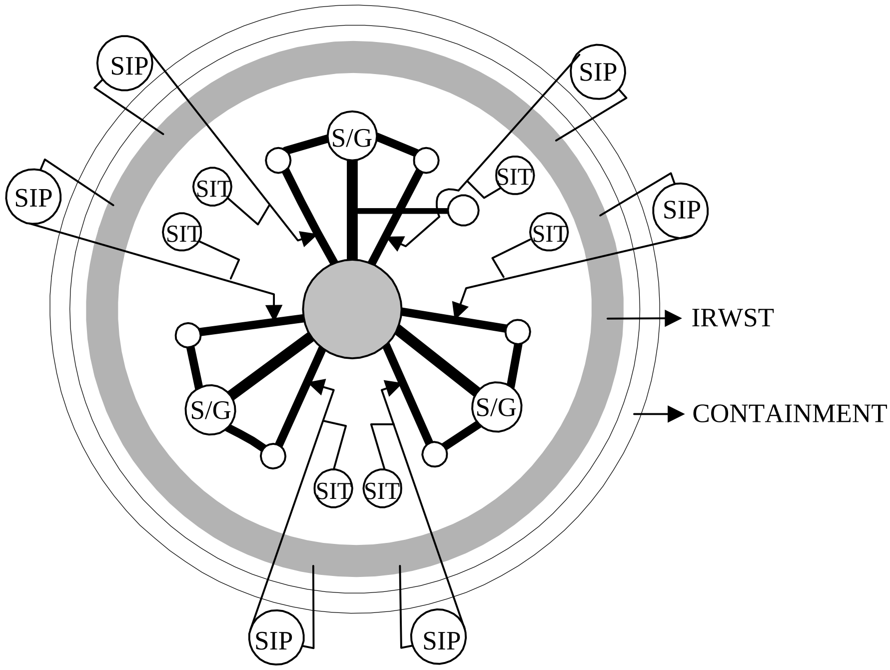

Figure 5. Arrangement of PWR-2000 RCS and CLI