STATUS OF THE ADVANCED POWER REACTOR 1400

Jhun S.J. and Lee S.J.
Korea Hydro & Nuclear Power Co., Ltd., Seoul, Korea

1. Introduction

The Korean Nuclear Power Plant was launched from Kori Unit 1 of 600MWe class in 1978. Twenty units have been constructed in the past three decades. As a result, six units of 600-700MWe class and fourteen units of 950-1000MWe class are now in operation. The construction of four additional units, which are 1000MWe, was recently initiated.

As of the end of 2005, the installed nuclear power capacity in Korea was 17,716MW representing 28.5% of the country's total installed capacity. Also, the nuclear power generation in 2005 accounts for 40.3% of total nationwide generation. The scale of Korean nuclear power ranked us 6th largest in the world.

The Korean nuclear industry achieved technology self-reliance through this excellent performance and the Optimized Power Reactor 1000 (OPR1000), which was formerly Korean Standard Nuclear Power Plant (KSNP), has been constructed.

To improve public acceptance and enhance economics, Korea has been continuously developing a new reactor model for a long time along with the improvement of OPR1000. As a result of such an effort, Korea developed the Advanced Power Reactor 1400 (APR1400) as a Korean national R&D project spanning ten years and the standard design certification was issued in May of 2002. The APR1400 is an evolutionary pressurized water reactor with a thermal output of 4000MWt.

This paper will cover the purposes of the APR1400’s development, its characteristics in terms of safety, economics and technology and explain the construction projects implementing the APR1400 design. The future vision of the APR1400 will also be discussed.

2. APR1400 Development Project

2.1 Overview of the Development Project

TMI-2 and Chernobyl accidents raised a lot of concerns about the safety of nuclear power. To improve public acceptance after these two events, more stringent safety standards, including severe accident mitigation, were needed and proposed. Internationally, a large capacity evolutionary Advanced Light Water Reactor (ALWR) had been developed as a vital step for preserving the global environment and ensuring public safety not to be threatened again by accidents such as those occurred at TMI-2 and Chernobyl. The focus of the ALWR design was to improve safety and economics. Furthermore, improvement in the generation cost was principal to meet the challenge presented by other sources of power generation, such as coal and gas-fired power plants.

The APR1400 Program was one of the Korean answers to international and domestic demands of electric power generation with enhanced assurance of public safety, improved economic competitiveness, and lowered impact on the environment than any other electric power sources. This reactor concept has been promoted to secure a stable energy supply means for industrial development and national energy security, and to elevate nuclear power technology.

On these domestic and international backgrounds, the Korean Government launched a national R&D project named the “Korean Next Generation Reactor (KNGR)” program in 1992.

The project was promoted as a national project with the joint participation of most of the nuclear-related organizations in Korea under the leadership of KHNP (Korea Hydro & Nuclear Power Co., Ltd.) and under
the direction of MOCIE (Ministry of Commerce Industry & Energy).

Each entity was given responsibility for different tasks: KOPEC (Korea Power Engineering Company) was responsible for NSSS design and architectural engineering; KNFC (Korea Nuclear Fuel Company) for the initial core and fuel assembly design; Doosan, the equipment manufacturer, was responsible for the manufacturability review and component design; the research institutes KAERI (Korea Atomic Energy Research Institute) and CARR (Center for Advanced Reactor Research) performed the specific R&D issues necessary for design and test programs; and KINS (Korea Institute of Nuclear Safety) developed the licensing requirements and conducted the licensing review.

The KNGR project consisted of three phases. The first phase, the conceptual design stage, was completed in Dec. 1994. The second phase, the basic design stage, was finished in Feb. 1999. The third phase, design optimization, took place between Mar. 1999 and Dec. 2001.

In Phase I, the conceptual design was performed. The evolutionary PWR was selected through a comparative study of the candidate reactor types. The reasons for this choice were twofold: higher power and the use of proven technology. Improved power generation economics could be counted upon with higher power output. The use of proven technology ensures that the design would be more practical from a commercialization standpoint. Once the reactor type was selected, the top-tier utility requirements were developed; for instance, power level, safety and economic goals, etc. A comparative study on major systems and components was also conducted.

During Phase II, detailed design requirements and design specifications were developed for NSSS major components, such as the reactor vessel, steam generator, pressurizer, and RCS piping. In parallel with the basic design development, the SSAR (Standard Safety Analysis Report) was prepared for the future design certification.

During Phase III, design optimization was performed to reinforce the economic competitiveness, operability and maintainability while maintaining the overall safety goals. Major categories in design optimization were power up-rating, NSSS & BOP system optimization, and GA (General Arrangement) & building structure optimization and wide experience of utility in operation and maintenance was also considered. Detailed design of the long-lead items such as the main control room with digital I&C was performed during this period. Design certification was issued in May 2002 as a result of an extensive licensing review.

Overall development schedule and major activities are shown in Figure 1.

![Figure 1 Development schedule and major activities of APR1400](image)

### 2.2 Major Design Requirements and Features

The APR1400 incorporates a lot of design modifications and improvements to satisfy the utility’s needs for enhanced safety and economic goals and to address new licensing issues such as mitigation of severe accidents.
The major concepts and requirements of APR1400 were established during the two years of research during Phase I. During this period, Major design concepts and requirements were set up to meet utility’s needs and reflect the construction/operation experiences and capabilities. And the design requirements of ALWRs being developed worldwide, i.e., EPRI URD (Utility Requirements Documents) and EUR (European Utility Requirements) were also reviewed and compared to establish the safety and economic goals. As a result, the 42 top-tier design requirements were established covering every aspect from design to operation. Major requirements are as follows.

- **Type and Capacity:** PWR, 4000 MWt
- **Plant design lifetime:** 60 years
- **Safety Requirement**
  - Seismic design: SSE 0.3g
  - Core damage frequency: \(<10^{-5}/\text{RY}\)
  - Containment failure frequency: \(<10^{-6}/\text{RY}\)
  - Operator action time: Min. 30 minutes
- **Performance Requirements**
  - Plant availability: \(>90\%\)
  - Refueling cycle: 18 months
  - Occupational radiation exposure: \(<1 \text{ manSv/year}\)
  - Economic goal: generation cost to be equal or less than coal-fired power plants

APR1400 incorporates many advanced design features to enhance its performance and safety. These features in APR1400 include four trains of the SIS with Direct Vessel Injection (DVI) mode, passively operating Safety Injection Tank (SIT) with Fluidic Device (FD), the In-containment Refueling Water Storage Tank (IRWST), and man-machine interface system (MMIS).

Since these new design features are required to evaluate and verify their performance for ensuring their contribution to the enhancement of APR1400 performance and safety, it has been decided to implement relevant experimental activities for evaluation or verification about some selected items into the national nuclear mid- and long-term R&D projects and it was started in early 1999 during Phase I. They include the large break LOCA DVI ECCS performance evaluation test, the FD performance verification test, and the sparger performance evaluation test.

The DVI performance test was to evaluate major thermo-hydraulic phenomena in downcomer during LBLOCA. The Full-scale fluidic device test was to obtain basic data for designing and manufacturing fluidic devices. The Sparger test was to quantify the hydro-dynamic force created due to condensation and/or dynamic oscillation when air and/or steam is discharged into IRWST.

### 2.3 Constructability and Economics of APR1400

To enhance the constructability and economic viability of APR1400, it was designed to increase electrical output, to optimize building volumes and construction materials and to facilitate application of new construction methods.

Several new construction methods and techniques such as over-the-top method for major NSSS components, automatic welding of RCS piping and modularization were reviewed and applied to APR1400 design. Constructability analysis was performed in the early design phase, which made it possible for APR1400 to accomplish better constructability by periodically assessing and feeding result back to the design team during the whole design period.

APR1400 construction schedules were developed in three steps to improve constructability during the APR1400 design process. A 56-month basic schedule, a 47-month reducible schedule and a less than 42-month target schedule from the first concrete pouring to the fuel loading were developed in turn. The 56-
month basic schedule was developed based on the experience of OPR1000 and the design characteristics of APR1400. Some items such as new construction methods to improve constructability of APR1400 were reflected in the 47-month reducible schedule. And finally, the less than 42-month target schedule was developed by incorporating the enlarged scope of the modularization and the learning effects from the 47-month reducible schedule.

The economic competitiveness goal of APR1400 is to achieve the cost of electricity equal or less than coal-fired power plants. To achieve this goal, simplification, standardization, improvement of availability and capacity upgrade are adopted as basic design principles. Design optimizations, which do not compromise the reliability and safety goals of APR1400, were also carried out to improve the economics of APR1400 during the third phase. Through the design optimizations, various design improvements have been achieved and they practically raised the economics of APR1400.

As shown in Table 1, the cost estimate was performed based on the actual nuclear market conditions. The generation cost of APR1400 Units #1&2 (N<sup>th</sup> units) is estimated to be US3.54cent/kWh (US3.17cent/kWh) respectively.

From the analysis, the generation cost of APR1400 N<sup>th</sup> units was determined to be 15.5% lower than that of 800MW coal-fired plant. (Cost Basis: Jan.1, 2006, Discount Rate: 7%, Exchange Rate: 1,000 KRW/US$, Economic Lifetime: 40years, Capacity Factor: 90%)

<table>
<thead>
<tr>
<th>Units</th>
<th>APR #1,2 (1400MW×2)</th>
<th>APR Nth (1400MW×2)</th>
<th>Coal 800MWe (800MW×2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation Cost</td>
<td>cent/kWh</td>
<td>3.54</td>
<td>3.17</td>
</tr>
<tr>
<td>Competitiveness</td>
<td>%</td>
<td>5.6</td>
<td>15.5</td>
</tr>
</tbody>
</table>

*Table 1 Cost Estimate of APR1400*

3. **APR1400 Construction Project**

3.1 **Shin-Kori Units 3&4 Project**

Shin-Kori Units 3&4 represent the first APR1400 project to be built. The plants will be located adjacent to the Kori NPP site, where four units are currently in operation and two units, Shin-Kori Units 1&2, are under construction. Shin-Kori Units 3&4 will be constructed based on the APR1400 standard design, incorporating unique site characteristics.

The basic construction plan for Shin-Kori Units 3&4 was set in Feb. 2001, and the follow-up activities for the project have been made accordingly. The final price negotiations for the main contract packages are now underway. Tentative commercial operation dates for Shin-Kori Units 3&4 are September 2013 & September 2014, respectively. Originally it was planned to be operational in Sept. 2010 and Sept. 2011, respectively. The reasons for the postponement are the delay in contract negotiation and the opposition from anti-nuclear groups related with the site selection of radioactive waste repository.

Construction of Shin-Kori Units 3&4 is scheduled to be completed within 58 months, excepting an additional six-month reliability test period considering the uncertainty of the first project. Thus, the total construction period of Shin-Kori Units 3&4 is 64 months, from first concrete to commercial operation.

The organizations involved in Shin-Kori Units 3&4 project are those companies which participated in the APR1400 development. KHNP directly oversees the overall project management as well as executing BOP procurement, construction management, and start-up. KOPEC will perform system design and architectural engineering. Doosan will supply the NSSS and turbine/generator facilities, with WEC & GE as subcontractors. KNFC will fulfill initial core design and supply the fuel.
In particular, Shin-Kori Units 3&4 will adopt CIE (Computer Integrated Engineering) using the 3D CAD (Three-dimensional Computer Aided Design) technology to improve design quality and maximize engineering work efficiency during the whole design cycle. It can give various useful functions such as engineering a data link between drawings and EDB (Engineering Database), interference check, verifications of design, operability, maintainability & accessibility, etc. The design information and history will be systematically managed & used by CIE throughout the plant life cycle.

Shin-Kori Units 3&4 will use the submerged intake and discharge system instead of the surface intake and discharge system to protect existing coastline and avoid the possibility of coastline deterioration caused by uneven erosion and build-up. It embraces an advanced environmentally friendly technology for cooling water system. It suppresses entrainment of jelly fish or shrimp as well as floating pollutants, and significantly lowers the temperature of thermal discharge compared with surface intake system. The submerged discharge system minimizes the high temperature diffusion region at surface. Consequently it reduces environmental problems which can be created when discharge temperatures exceed 37 ºC, such as reducing the population of phytoplankton and zooplankton.

To improve public acceptance of Shin-Kori Units 3&4, various efforts such as local community cooperation & support program, proactive approach to civil affairs and publicity activities are in progress.

3.2 Shin-Ulchin Units 1&2 and the Following Project

Shin-Ulchin Units 1&2 represent the second APR1400 project to be built. The two unit plants will be located near the Ulchin NPP site, where six units are currently in operation. The basic construction plan for Shin-Ulchin Units 1&2 was set in June 2005, and thereafter a detailed plan was established according to the basic plan. Tentative commercial operation dates for Shin-Ulchin Units 1&2 are December 2015 & December 2016.

And the plan of the following APR1400 project will be reflected in the Korean government’s “Long-term Electricity Plan,” of 2006 and tentative commercial operation dates for them are the year of 2018 & 2019.

4. Future Vision of APR1400

The APR1400 has been developed by cooperative efforts of nuclear-related organizations in Korea and is a unique trademark of KHNP. As a leader and owner of APR1400, KHNP recognized the necessity of solving the potential technology issues during the construction & operation of APR1400 and maintaining & improving the core technology of APR1400.

Hence, an initiative named “APR1400 Road Map” has been established and selected as one of the main subjects of KHNP’s “VISION 2015”. The objectives of this bold initiative are to enhance the relevant technologies for the successful construction & reliable operation of the first APR1400 plants.

It will be performed strategically to obtain all the necessary superior technologies of APR1400 through the Shin-Kori Units 3&4 project experience together with various R&D programs. The technology management system will be thoroughly built and skillful experts for the detailed technologies will be brought up.

The APR1400 Road Map consists of three phases until the year 2015. The first phase from 2006 to 2008 will be carried out to enhance the technologies such as design verification & evaluation technologies for the advanced design features and those technologies related with licensing issues during the Shin-Kori Units 3&4 design and construction stage, the second phase from 2009 to 2011 for the operation & maintenance technologies such as digital I&C, simulator upgrade, and etc. during the Shin-Kori Units 3&4 start-up stage,
and the third phase from 2012 to 2015 for the improvement technologies for the major components, extended application of passive safety facilities, and etc. during the Shin-Kori Units 3&4 operation stage.

The APR1400 will be continuously improved by incorporating valuable experiences of respective projects and state-of-the-art technologies for better safety and economic competitiveness. It will be a main reactor model until the next generation reactor is deployed and will be promoted as such to the overseas countries based on the acquired experiences and technologies.

5. Conclusion

Though nuclear energy faces challenges regarding safety and economics, it has been re-evaluated as a reasonable energy source against the increase of the price of oil and gas, as well as the effect on the environment of greenhouse gas emissions. It is thus considered one of any energy mix for the future energy demand and the use of nuclear energy is necessary and inevitable for sustainable development.

The APR1400 is the result of all Korean nuclear power technology and experience. It stands as a promising reactor model at this time when nuclear power is recognized as a realistic solution against energy uncertainty and global warming. It will also play a key role to supply energy in Korea through the successful completion of ongoing construction projects and become a main reactor type to be exported to overseas markets.

I hope to have an official channel by shaping a cooperative committee for technical exchange with ALWR utilities or suppliers for our mutual benefit and partnership. KHNP has already proposed the formation of a cooperative committee among ALWR utilities such as JAPC & TVO and plans to have detailed discussions after the main contracts of the Shin-Kori Units 3&4 project. Additional participation of more ALWR utilities or suppliers interested in this cooperative effort would be cordially welcomed.

6. References


