IAEA-SM-353/23

# MAJOR NSSS DESIGN FEATURES OF THE KOREAN NEXT GENERATION REACTOR



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**Abstract**

In order to meet national needs for increasing electric power generation in the Republic of Korea in the 2000s, the Korean nuclear development group (KNDG) is developing a standardized evolutionary advanced light water reactor 9alwr), THE Korean Next Generation Reactor (KNGR). It is an advanced version of the successful Korean Standard Nuclear Power Plant (KSNP) design, which meets utility needs for safety enhancement, performance improvement and ease of operation and maintenance. The KNGR design starts fro the proven design concept of the currently operating KSNPs with uprated power and advanced design features required by the utility. The KNGR design is currently in the final stage of the basic design, and the paper describes the major nuclear steam supply system (NSSS) design features of the KNGR together with introduction of the KNGR development program.

## 1 INTRODUCTION

### 1.1 Background

The KNGR is an evolutionary ALWR being developed by the KNDG. The KNGR development project is a long-term governmental R&D program and is to complete an advanced and upgraded standard nuclear power plant (NPP) design using the KSNP design [1, 2] as a starting point. It is also to solve the Korean specific problems in securing sites for NPPs and to reduce the construction cost per unit electricity output in accordance with the economy of scale.

The KNGR development project consists of four phases. During the first phase ended in 1994, major effort was focused on finding the most suitable reactor type in Korea and to develop utility requirements for the selected type. Revolutionary and evolutionary types of the ALWRs were carefully studied by the KNDG, and as a result the evolutionary type was selected. The second phase that is currently under way and to be ended in February 1999 aims at completing a basic design of the KNGR which meets the utility requirements. Third phase, scheduled to be continued for three years after the second phase, is to focus on further optimization of the KNGR design including technical and economical improvements. Standard safety analysis report (SSAR) of the KNGR will be submitted to the regulatory body during this phase to obtain a design approval of the KNGR standard design in accordance with the one-step licensing procedure which is expected to be legislated in due time. Next phase is the construc-tion phase during which the detailed design will be performed to support the construction. According to the mid- and long-term construction plan of power plants in Korea, the first KNGR unit is scheduled to be put into the grid in 2010.

The KNGR design is being performed by a multi-disciplinary team of Korean professional engineers capable of incorporating features that enhance operability and maintainability to the benefit of the plant owner with their experiences in the design of the KSNP units.

### 1.2 Design Requirements

The KNGR design will incorporate advanced features to enhance safety, to increase margins, to improve operability and maintainability, and to reduce cost. The major design requirements, which are consistent with the top-tier requirements of the Korean Utility Requirements Documents (KURD) [3], are shown in Table 1 along with those of the KSNP for comparison purposes.

Table 1. Comparison of Major Design Requirements for KNGR and KSNP

| Items | KNGR | KSNP |
|---|---|---|
| Capacity | 4000MWt | 2825MWt |
| Plant design lifetime | 60 years | 40 years |
| Seismic design | SSE 0.3g | SSE 0.2g |
| Safety requirements | | |
| - Core damage frequency | $< 10^{-5}$/RY | $< 10^{-4}$/RY |
| - Containment failure frequency | $< 10^{-6}$/RY | $< 10^{-5}$/RY |
| - Occupational radiation exposure | < 1 man·Sv/RY | < 1.2 man·Sv/RY |
| - Operator action time | Min. 30 minutes | Min. 10 minutes |
| - SBO coping time | Min. 8 hours | Min. 4 hours |
| - Thermal margin | 10-15% | 8% |
| - Hot-leg temperature | $< T_{KSNP}$ | 327.3 °C |
| - Emergency core cooling system | 4-train | 2-train |
| | Direct vessel injection | Cold-leg injection |
| | IRWST | Outside RWT |
| Performance requirements | | |
| - Plant availability | 90% | 87% |
| - Unplanned trip | < 0.8/year | < 1/year |
| - Refueling cycle | 18-24 months | 15-18 months |

The thermal power of the KNGR, 4000 MWt, has been increased by approximately 40% from the current 2825 MWt KSNP. With the power increase for the KNGR, preliminary size modification of the primary components has been completed during the basic design phase providing the required thermal margin throughout the 60-year plant design life as recommended in the KURD.

## 1.3 Development Procedure

The KNGR NSSS has evolved from the proven design of the currently operating KSNPs. Figure 1 depicts the KNGR development procedure. With the utility requirements recommended in the KURD, careful

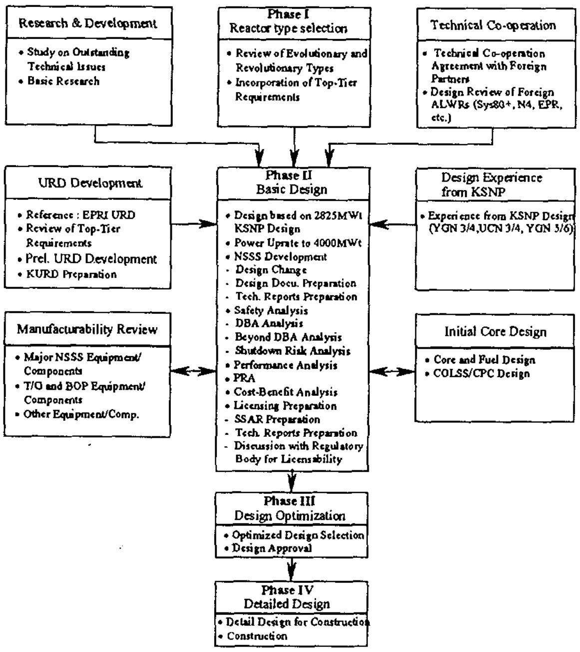


*FIG. 1 KNGR Development Procedure*

consideration has been given to the R&D results performed by universities and research institutes and information on foreign ALWRs including the advanced features. Also, the experiences in fabrication, construction, start-up and operating of the KSNPs have been reflected to the KNGR development. An intimate technical cooperation has been collaborated with the foreign partners from the beginning stage of the development. During the basic design phase, the analyses for design basis accidents (DBAs), beyond DBAs and shutdown risk, etc. have been performed as the design progresses and the results have been fed back to the KNGR design. Manufacturability of the major NSSS components and equipment has also been reviewed to secure the possible hardware provision.

During the design process, each addition or modification from the KSNP design has been assessed for its impact on safety, performance, operability, maintainability, and cost. Safety and performance analyses, probabilistic risk assessment (PRA) and cost-benefit analyses are used to assist in this evaluation process. Design results are to be evaluated to confirm the fulfillment of the requirements and iteration is to be continued either by re-performing the design process or modifying the requirements until the final design fix.

## 2 MAJOR NSSS DESIGN FEATURES

Development of the KNGR NSSS design has focused on reducing the hot-leg temperature to improve the safety margins of the reactor core, increasing the pressurizer volume to accommodate transients and reduce unnecessary challenges to the plant safety systems, and using improved material to reduce stress corrosion cracking of steam generator tubes, etc. The KNGR safeguards system includes safety injection system (SIS) with several advanced features such as four independent trains and direct vessel injection (DVI), in-containment refueling water storage tank (IRWST), and fluidic device in the safety injection tanks (SITs) to improve operability and to increase redundancy over the KSNP. The control room complex utilizes a great number of soft controllers and workstations emphasizing the human factors in designing the man-machine interface systems, thus providing far enhanced operability of the KNGR. The reactor vessel (RV) upper head area has been simplified to improve maintainability. The features that contribute to the improvements are summarized below.

### 2.1 Reactor Coolant System (RCS)

A schematic of the KNGR RCS with its major improvements is shown in Figure 2.

The RCS consists of a RV, two independent coolant loops connected to the reactor, and safety and auxiliary systems. Each loop consists of a 1066.8 mm ID outlet pipe, two 762 mm ID inlet pipes, a steam

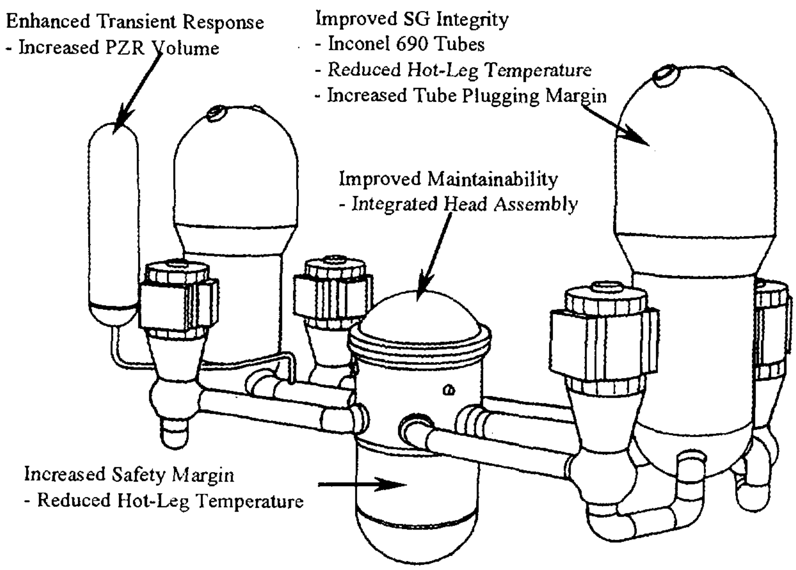


*FIG. 2 Schematic of the KNGR Reactor Coolant System*

generator (SG) and two reactor coolant pumps (RCPs). The RCPs are electric motor-driven single stage centrifugal pumps. The RCS operates at a nominal pressure of 158 $kg/cm^2$; the system pressure is maintained by an electrically heated pressurizer (PZR) that is connected to one of the loops. Core outlet temperature is 323.9 °C, which has been lowered by about 3.5 °C from the current KSNP design to provide additional core thermal margin, which allows more flexibility in operation. It also increases margin against SG primary side corrosion attack. The PZR volume has been increased by 33% to better accommodate transients and reduce unnecessary challenges to the plant safety system. The SG incorporates design enhancements including the use of Inconel 690 tubes which dramatically reduces stress corrosion cracking, and 10% tube plugging margin to assure the capability to produce the design steam flow rate and pressure over entire design life with a significant number of tubes plugged. Implementation of the pilot-operated safety relief valves (POSRVs) provides another advantage to the KNGR. Conventional spring-loaded safety valves connected to the PZR are replaced by the POSRVs, and functions of the RCS overpressure protection and safety depressurization could be performed by the POSRVs.

## 2.2 Safeguards System

Comparing with the KSNP design, the most significant change of the KNGR NSSS is in the safeguards system design. The SIS has been improved to provide a simpler and more reliable system with increased redundancy (Figure 3). Redundancy of the SIS is increased by having four independent mechanical trains. The SIS takes suction from the IRWST and discharges directly into the downcomer of the RV. The injected coolant flows directly into the RV to provide a simpler and more reliable system that avoids the potential of coolant loss in case of a cold-leg break accident inherent in the previous cold-leg injection scheme. The common headers and associated valves are eliminated, and the low-pressure safety injection function and the switchover from the external water supply to the containment sump are also eliminated. This SIS configuration improvement is a major contributor in reducing the core damage frequency by one order of magnitude from the KSNP design, according to the preliminary PRA results.

Safety injection and containment spray pumps take suction from a storage tank, IRWST, located low inside the containment completely surrounding the reactor cavity. The ability to cope with a degraded core accident has been enhanced by providing an in-containment water source to flood the cavity. A flow regulating device, a fluidic device, is being considered to be installed in the SITs. It takes an advantage of utilizing water inventory in the SITs by controlling the injected flow rate, and thus minimizes the possible injected coolant loss in the event of large break loss-of-coolant accident (LOCA). The performance tests are currently being conducted and a decision will be made for its implementation during the design optimization period.

For reconfiguration of the SIS, exclusive studies have been performed. Preliminary safety analysis has been carried out to confirm whether the results with the determined parameters and selected components

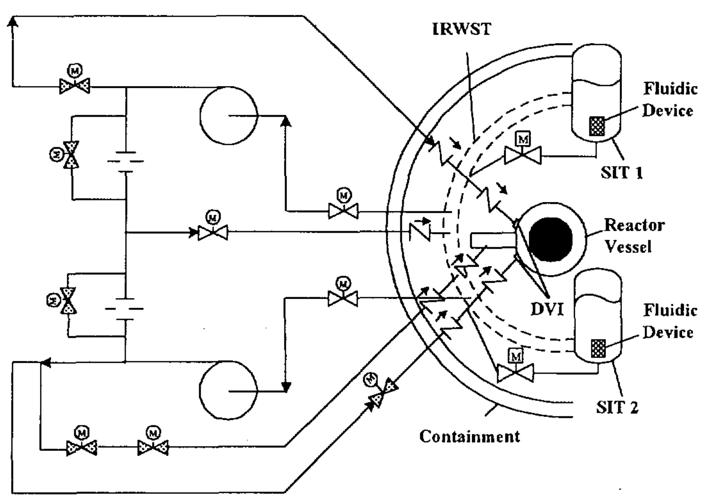


*FIG. 3 KNGR Safeguards System*

sizing to meet the acceptance criteria, and the results have been fed back to the SIS design. For the DVI, several candidate nozzle locations are considered and being reviewed with respect to the PTS concern as well as its manufacturability.

Another design improvement is the interconnection of the shutdown cooling system (SCS) and the containment spray system (CSS), which allows the pumps of each system to serve as a backup for the other. Operation of the SCS is now simplified by eliminating the need to shift alignment from low-pressure safety injection to shutdown cooling.

### 2.3 Auxiliary Systems

The chemical and volume control system (CVCS) of the KNGR has been improved, especially in letdown and charging systems. The letdown flow control devices are located downstream of the letdown heat exchanger, which allows for an increased life and reduced maintenance of the letdown valves and orifices resulting from subcooling of the letdown flow prior to pressure reduction. The letdown heat exchanger is located inside containment, which minimizes high energy piping runs outside containment and is beneficial with respect to the ALARA principle. Three positive displacement pumps of the KSNP have been replaced to two centrifugal charging pumps each with flow capacity equal to the system design flow, which results in significantly less maintenance requirements and better reliability.

The KNGR is designed to reduce the level of pressure challenges to all systems interfacing with the RCS. General design features to address intersystem LOCA challenges consist of an increase of the system design pressure and incorporation of design features which terminate and/or limit the event by means of isolation or pressure relief.

### 2.4 Instrumentation and Control (I&C) Systems

The I&C systems of the KNGR have been designed to meet all the relevant requirements recommended by the KURD, which emphasizes human factor engineering in designing the advanced man-machine interface systems (MMIS). The I&C systems fully support the advanced control room design and, are characterized by state-of-the-art technologies, such as plant wide data communication network (DCN),

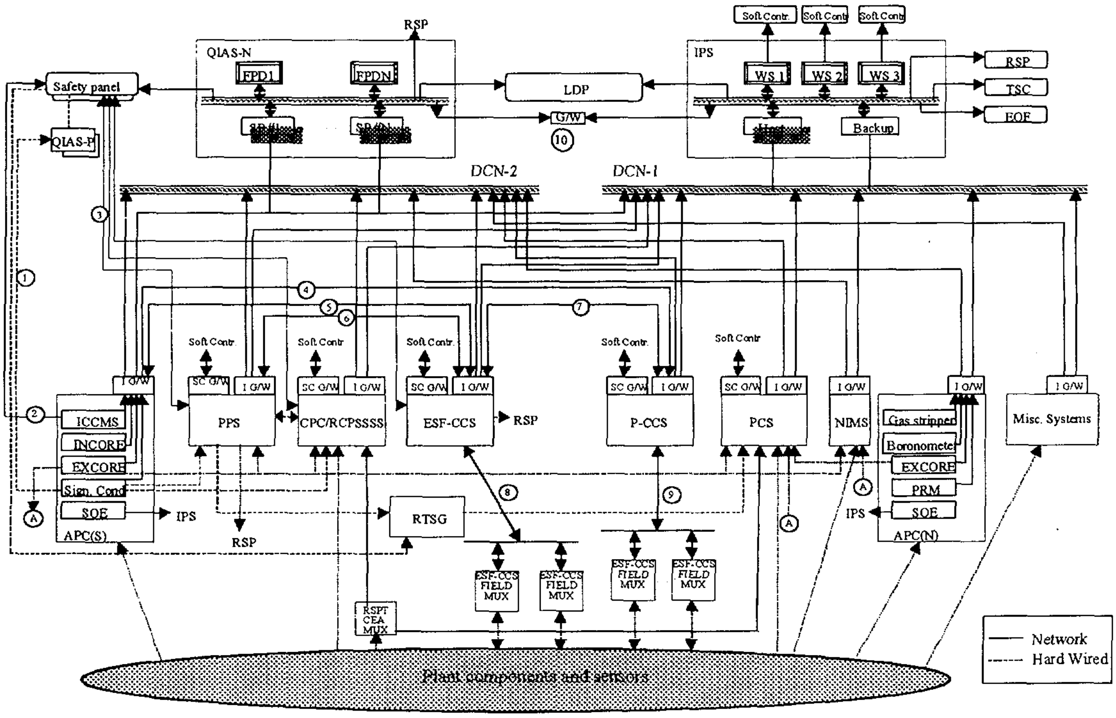


*FIG. 4 I&C Overview Diagram of KNGR*

distributed digital processing, advanced alarm and display processing, enhanced operator aid functions, signal multiplexing and soft control concept, etc. They utilize a top-down design concept in designing to achieve full integration with the various MMIS of the main control room (MCR). The MCR includes compact work stations consisting of two sets of operator's work stations and one additional set of backup work station, a large display panel (LDP), and the qualified indication and alarm system (QIAS). These advanced features replace the conventional display and controls used in the KSNP design and therefore, enhance operability of the KNGR. Figure 4 shows an overview of the KNGR I&C systems.

### 2.5 Integrated Head Assembly

The RV upper head area of the KSNP consists of many components, which are usually disassembled, separately stored and reassembled during every refueling outage. In order to make ease on this undesirable procedure and to simplify the complicated upper head region structure, the concept of an integrated head assembly (IHA) is adopted in the KNGR (Figure 5).

The IHA contains not only the RV upper head, control element driving mechanisms (CEDMs), heat junction thermocouples and head lift rig as in the KSNP, but also the head area cable tray, missile shield, seismic restraints and the CEDM cooling fan and ducts, which now can be handled together as a package. It is designed compact by making the CEDM cooling air flow inside the enclosing shroud and locating the CEDM cooling fans on the missile shield plate. The main columns and the lifting frame are designed to satisfy the NUREG-0612 [4] requirements and each component is designed to be shipped and installed easily. The IHA contributes to the reduction in radiation exposures to the installers, as well as the reduction in refueling outage duration.

## 3 CONCLUSION

The KNGR development is a national long-term R&D program consisting of four phases. The reactor type was selected and utility requirements were developed during the first phase. Basic design of the KNGR is under way in the second phase, and a design optimization process will follow before the finalization of the KNGR design configuration in the third phase. Construction of the first KNGR unit as a final product of the fourth phase through the detailed design work is planned to be completed in 2010.

The KNGR is a standardized evolutionary ALWR upgraded from the proven KSNP design. Compared with the KSNP, which serves as a starting point of this development, the KNGR NSSS incorporates several

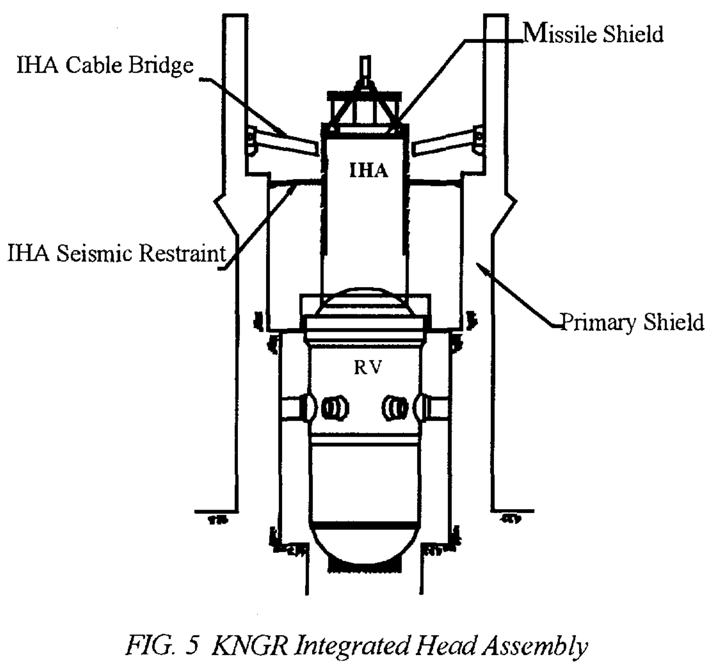


*FIG. 5 KNGR Integrated Head Assembly*

advanced design features, which may lead to safety enhancement and performance improvement as described in this paper.

With the current KNGR design, more safety margin is expected and the results of the PRA show one order of magnitude reduction in core damage frequency compared with those of the KSNP. This low risk of core damage compares favorably with the figure suggested by the IAEA [5] for "Good Plants" in the year of 2000. Such high degree of the KNGR design improvement assures a high degree of certainty in its successful application to the future plants required by Korea and moreover by the world.

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