The Promises and Challenges of Future Reactor System Developments

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ABSTRACT

During the past three decades, nuclear power has provided Korea with a most economically and environmentally-friendly way of generating electric energy, and has contributed a lot to its national economy growth. It will continue to do so in the future. For a stable and economical electricity supply, nationwide efforts toward achieving self-reliance in nuclear power technology have been made. Through a comprehensive nuclear R&D programs, an enhancement of its indigenous nuclear technology capability has been pursued. The effort has focused on improving its indigenous nuclear power technology such as improvements in safety and economy of the KSNP (KSNP+), a 600 MWe class KSNP, and advanced fuels. Advanced Power Reactor (APR 1400) and a System-integrated Modular Advanced ReacTor (SMART) are currently under development. In this paper, nuclear reactor development program in Korean is described together with lessons learned from self-reliance in nuclear reactor technology. In addition, this paper presents the status of the future reactor system development program.

1. Nuclear Power Programs in Korea

Nuclear power is an inevitable option in Korea to overcome scarce national resources and to reduce overseas energy dependence. Nuclear power generation has thus played a major role in electricity supply since 1978 when the Kori unit 1, Korea's first nuclear power plant, went into commercial operation. Furthermore, under circumstances of dramatic economic and industrial growth and two worldwide oil shock experiences in the 1970s, the need for maintaining and expanding the construction of nuclear power plants was widely recognized.

Chronologically, this self-reliance program in nuclear power technology from the 1970s to the present can be divided into three phases. The first phase was characterized as a turn-key base contract by foreign suppliers on the first three units, because domestic industries lacked experience and technology at that time. During this period, all the work, including the design, manufacture and construction, was largely performed by foreign suppliers. Therefore, nuclear power technology could not be accumulated and localized. The second phase was based on a so-called component approach. In this phase, utility was in charge of project management, and the plant design and manufacture of the primary system was performed under contract by foreign suppliers. Expanding the participation of domestic organizations was our aim to expedite our capabilities and progress to a self-supporting position in nuclear technology. This phase covered six 950 Mwe PWR projects.

The third phase, adapting the self-reliance strategy, has been applied to the implementation of Yonggwang units 3&4. The most important objective in this phase is to accomplish complete self-reliance in nuclear power plant construction including plant system design, equipment component design, architectural engineering, manufacturing, and nuclear fuel. For this ambitious goal, domestic industries participated as the main contractors and foreign companies served as the subcontractors supporting the domestic industries. Nationwide efforts toward achieving self-reliance in nuclear power technology have been pursued. A series of nuclear technology self-reliance programs such as CANDU fuel technology, PWR fuel technology, and nuclear reactor (KSNPP) technology have been successfully completed [1].

As a result of intensive nuclear power development programs based on the steady execution of an energy source diversification plan, Korea now has 20 nuclear power plants in operation and 6 units under construction. Nuclear power is currently proving Korea with a most economically and environmentally-friendly way of generating electric energy, and has contributed a lot to its national economy growth.

2. Development of Next Generation Reactors

Through participation in the joint design and R&D efforts in parallel with technical self-reliance, Korea developed the Korean Standard Nuclear Power plant (KSNP) concept. KSNP is an advanced power plant modified by our own operating experience and domestic technology and designed by adapting several effective technologies suitable for our national situation. In the Ulchin units 3&4 projects, 1,000Mwe level PWR reactor plants, the first standard design concept was established in which the primary system and the main components were adapted from those of Yonggwang units 3&4.

An enhancement of its indigenous nuclear technology capability has been pursued through a comprehensive nuclear R&D programs. The effort has focused on improving its indigenous nuclear power technology such as improvements in safety and economy of the KSNP (KSNP+), a 600 MWe class KSNP, advanced fuels, and the establishment of industrial codes & standards. In addition, a Korean Advanced Power Reactor (APR 1400) and a System-integrated Modular Advanced ReacTor (SMART) are currently under development. A strategic program for nuclear reactor development in Korea is shown in Figure 1.

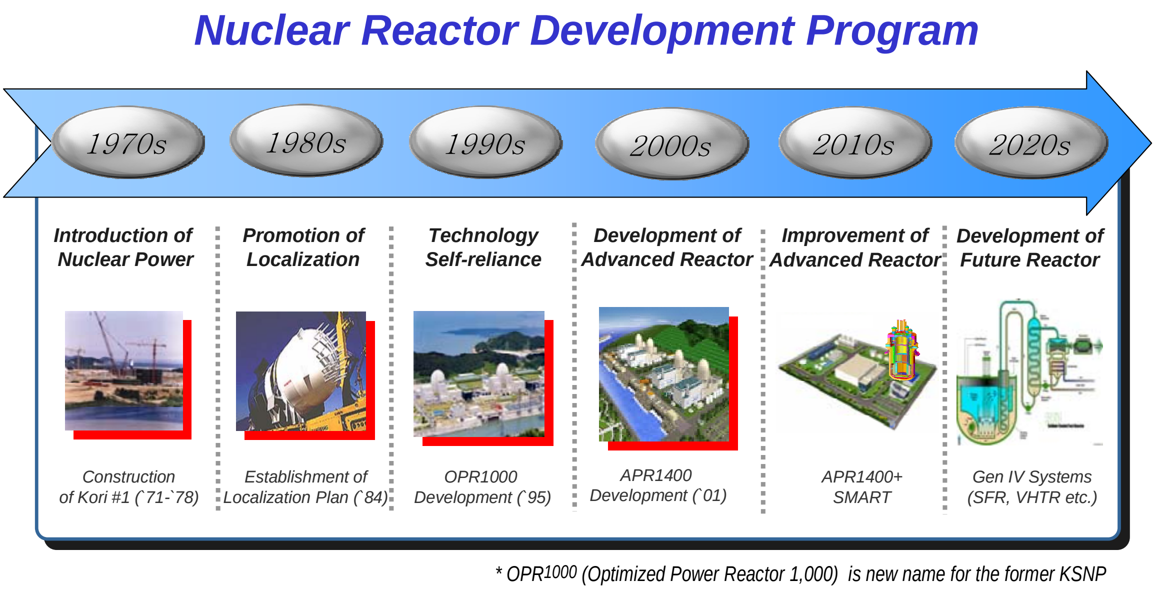

Figure 1. Nuclear reactor development program

Korea developed the Korean Next Generation Reactor (APR 1400) as an advanced PWR into which advanced safety features are incorporated. The APR 1400 with a capacity of 1,400 MWe is characterized by its drastically enhanced safety, reliability, and operability as well as its improved economy when compared to the existing plants. The development program for APR 1400 has been continued since 1991 and it is expected that its first commercial operation will be in 2012.

An integrated nuclear desalination plant coupled with the advanced integral reactor SMART is purposed for dual applications such as for seawater desalination and electricity generation [2]. SMART has been developed at KAERI to produce forty thousand (40,000) m3/day of water and to generate ninety (90) MW of electricity to an area with approximately a ten thousand (100,000) population. The enhancement of safety is realized by incorporating inherent safety improving features and reliable passive safety systems. The improvement in the economics is achieved through a system simplification, component modularization, construction time reduction, and increased plant availability. The new advanced design technologies implemented into the SMART were proven by testing and/or analyses. For the verification of the new technologies adopted in SMART design, comprehensive fundamental thermal-hydraulic experiments were carried out during the design concept development stage.

Upon the completion of the basic design, various thermal-hydraulic and mechanical tests were conducted.

3. Development of Future Reactors

3.1 KALIMER Development

The fast reactor system is one of the most promising nuclear options for an electricity generation with an efficient utilization of uranium resources and a reduction of the radioactive wastes. The development of liquid metal reactor technologies for an efficient utilization of uranium resources put emphasis on basic key technologies development. Efforts are currently being directed towards the development of the advanced fast reactor concept called KALIMER-600 (600MWe), and its key design parameters are shown in Table 1 [3].

Table 1. KALIMER-600 Key Design Parameters

OVERALL		**PHTS**	
Net Plant Power, MWe	600.0	Reactor Core I/O Temp., ^{o}C	390.0/545.0
Core Power, MWt	1523.4	Total PHTS Flow Rate, kg/s	7731.3
Gross Plant Efficiency, %	41.9	Primary Pump Type	Centrifugal
Net Plant Efficiency, %	39.4	Number of Primary Pumps	2
Reactor	Pool Type		
Number of IHTS Loops	2		
Safety Decay Heat Removal	PDRC	**IHTS**	
Seismic Design	Seismic Isolation Bearing	IHX I/O Temp., ^{o}C	320.7/526.0
		IHTS Total Flow Rate, kg/s	5800.7
CORE		IHTS Pump Type	Electromagnetic
Core Configuration	Radially Homogeneous	Total Number of IHXs	4
Core Height, mm	1,000		
Axial Blanket Thickness, mm	No		
Maximum Core Diameter, mm	4867	**SGS**	
Fuel Form	U-TRU-10% Zr Alloy	Steam Flow Rate, kg/s	663.25
Feed Driver Fuel TRU Enrichment for		Steam Temperature, ^{o}C	503.1
Equilibrium Core, %	15.2	Steam Pressure, MPa	16.5
Assembly Pitch, mm	17.48	Number of SGs	2
Fuel Pins per Assembly (IC/MC/OC)	237/256/271		
ZrH_2 Pins per Assembly (IC/MC/OC)	4/0/0		
Duct Pins per Assembly (IC/MC/OC)	18/15/0		
Cladding Material	HT9		
Refueling Interval, months	18		

KAERI has been participating in the Joint Study on “Assessment of Innovative Nuclear Energy Systems based on a Closed Nuclear Fuel Cycle with Fast Reactors” since March 2005. The Joint Study is being implemented within the framework of IAEA INPRO Phase 1B (second part). The innovative nuclear energy system (INS) assessment using the INPRO methodology will dedicate to the improvement of the INPRO methodology. Korea also actively participates in the GEN IV collaboration (GIF : GEN IV International Forum) for a SFR technology development. Through close collaboration with GIF, a proliferation-resistant SFR technology will be developed based on KALIMAER for an effective uranium utilization and waste minimization.

3.2 Development of Hydrogen Production Reactor

The future will require more convenient and clean environment, that is, more demand in resource-free and environmentally friendly energy. Hydrogen has been highlighted as one of the promising future energy resolutions due to its high-energy, clean, abundant and storable nature. One of the big challenges to the hydrogen economy is how to produce massive hydrogen in a clean, safe and economic way. Among various hydrogen production methods, the nuclear hydrogen by water split using high temperature heat of a very high temperature reactor (VHTR) can provide a success path by its clean, safe, efficient and massive hydrogen production. Korea launched a Nuclear Hydrogen Development and Demonstration (NHDD) project in 2004 [4]. Its objective is to design, construct the nuclear hydrogen system and to demonstrate the safe and economic production of massive hydrogen having competitiveness with the steam reforming in early 2020s.

There are several key technical challenges that need to be resolved in order to realize the NHDD system. They include 1) the analysis tools and methodologies to meet the strengthened design and regulatory requirements, 2) the reactor performance at an elevated temperature that includes the core and vessel temperatures during steady and accident conditions, 3) the qualification and codification of high temperature materials for metals, graphite and ceramics, 4) the design and manufacturing of components such as the intermediate heat exchanger, the circulator and the process heat exchanger that interfaces the intermediate loop and the SO3 decomposer, 5) the fabrication and qualification of the coated particle fuel, and 6) the development and demonstration of efficient production of hydrogen using an IS thermo-chemical process. The key technologies development project thus focuses on the resolution of the above technical challenges. It consists of four major sub-projects for the development of: 1) key design technologies, 2) materials and components, 3) TRSIO fabrication technology, and 4) SI process. In parallel, international and domestic collaborations are being carried out.

4. Conclusions

During the past three decades, Korea has accomplished outstanding achievements in facilitating a nuclear power technology development. For a stable and economical supply of electricity, nationwide efforts toward achieving self-reliance in nuclear power technology have been pursued. As a result, nuclear power has provided Korea with a most economically and environmentally-friendly way of generating electric energy, and has contributed a lot to its national economy growth. To date, a series of nuclear technology self-reliance programs such as CANDU fuel technology, PWR fuel technology, and nuclear reactor (KSNPP) technology have been successfully completed. KSNP is a technologically advanced power plant modified based on own operating experience and domestic technology and designed by adapting several advanced technologies suitable for its national situation.

Through a comprehensive nuclear R&D programs, an enhancement of its indigenous nuclear technology capability is continuously being pursued. The effort has focused on improving its indigenous nuclear power technology such as improvements in safety and economy of the KSNP (KSNP+), a 600 MWe class KSNP, advanced fuels, and the establishment of industrial codes & standards. In addition, a Korean Advanced Power Reactor (APR 1400) and a System-integrated Modular Advanced ReacTor (SMART) are under development. The nationwide efforts for developing the future reactor system technologies are also introduced

Korea is really looking ahead by developing new generation of advanced nuclear reactor systems for a sustainable development, economical benefits, a clean environment and public confidence. We are actively participating in the GEN IV collaboration (GIF : GEN IV International Forum) for a VHTR and a SFR technology development and also IAEA INPRO Program. Through close collaboration with GIF, a proliferation-resistant advanced SFR technology will be developed based on KALIMAER for an effective uranium utilization and waste minimization. Also a high temperature reactor under development is expected to demonstrate a nuclear based hydrogen production technology.

5. References

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