Development of Medium-size ABWR Aiming at Diversification and Amount Control of Plant Investment

Shoichiro Kinoshita
Koji Ando
Shunya Morita
Kazuhito Koyama

OVERVIEW: As a basic power source, nuclear power plants are facing more diversified needs for greater deployment into new areas, improved cost efficiency, and the ability to quickly adapt to emerging market trends. These were the challenges Hitachi, Ltd. faced in developing ABWR (advanced boiling water reactor), a 600-MWe-capacity BWR (boiling water reactor). It is a third-generation light-water reactor that has been significantly improved and optimized by taking full advantage of the innovative technologies and operating experience gained in developing the larger 1,350-MWe class ABWR that is already in commercial operation. Based on accumulated experience from the larger plant, we (1) streamlined and simplified the system, (2) adopted technologies developed for the larger BWR, and (3) achieved a more compact layout design. Because the plant is based largely on proven systems and technologies that do not have to be developed, the necessary construction and operation licensing and approvals can be obtained fairly quickly and the new plant can be put into commercial operation very rapidly.

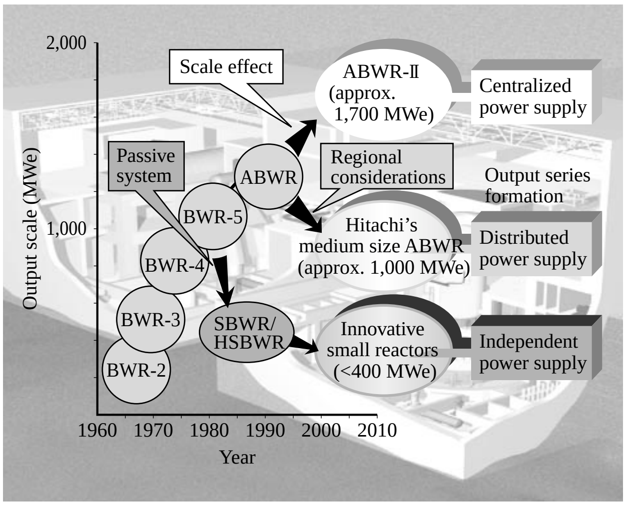
INTRODUCTION

AS the global demand for energy increases, nuclear power is more important than ever before as a basic source of energy, and further deployment and expansion of nuclear capacity in Japan and around the world are critically important. Yet cost reduction is also a major objective in countries and areas where nuclear power has already been introduced against the backdrop of energy market liberalization, and this demands the reduction of commercial risk associated with deploying new plants and equipment by holding down investment costs and accelerating investment recovery.

To promote further deployment and widespread use of nuclear energy, systems and equipment must be developed that support distributed power generation in less developed countries and other areas lacking a power transmission infrastructure. Yet to satisfy the objective of cost reduction, the equipment must also support dispersive plant investment and restrain investment costs in order to satisfy emergent market demand. At the same time, the equipment must also be designed so it can be put on the market very quickly in response to changing market trends.

Hitachi developed an ABWR (advanced boiling water reactor) with medium scale power output of about 650 MWe shown schematically in Fig. 1, as a solution tailored to meet these varying needs of the global market. This paper presents an overview of

Fig. 1—Cutaway View of Hitachi's ABWR.
New ABWR was developed to meet the emergent global demand for electricity generation while supporting diversified capital investment and restraining investment costs.



SBWR: simplified BWR
HSBWR: Hitachi simplified BWR

Fig. 2—Hitachi's View on Future Direction of Nuclear Power Plants.
Tailored to meet the varying needs of the global market, Hitachi first developed a 600-MWe-capacity BWR but plans to implement a series of ABWRs with varying output capacities.

performance and main features of Hitachi's ABWR (see Fig. 2).

BASIC DESIGN GUIDELINES

To tailor a solution satisfying the market requirements outlined above, Hitachi developed new ABWR based on the following guidelines:
(1) Medium-range power output (less than 1,000 MWe), designed as another output scale option in an ABWR series with the 1,350-MWe ABWR that is already in operation, and support a broader range of menu options.
(2) Achieve cost-effectiveness equivalent to the existing ABWR.
(3) Achieve reliability and safety equivalent to the existing ABWR. Optimize operability and maintainability in line with the output scale.
(4) Fully exploit proven construction and operation technologies from the existing ABWR, optimize and streamline the equipment, implement design standardization.
(5) Simplify and reduce the time required to acquire necessary construction and operation licenses and approvals by adopting proven technologies that have already been approved from the existing ABWR.
(6) Build as much freedom into the design as possible so the plant design can be flexibly tailored to different regional conditions, capital resources, and customer needs.

PLANT CONFIGURATION AND MAIN SUBSYSTEMS

Setting Plant Output Scale

The capital costs of a power plant tend to increase on a per-unit output basis as that output scale of the plant decreases. Innovative cost-cutting technologies must be implemented in order to build a medium-size advanced reactor that overcomes this adverse economy of scale predicament. Careful analysis was done to determine the capacity that could be implemented most cost-effectively within a middle-range reactor output and every effort was made to adapt proven systems and equipment that were developed for the larger 1,350-MWe ABWR that is now in operation. Given these parameters, 600 MWe was selected as the output capacity that could achieve the greatest labor savings.

Plant Configuration

Here we will consider some of the key features of the plant configuration based on the design guidelines and power output target mentioned above (see Fig. 3).
(1) System simplification

The equipment was significantly simplified and streamlined (number of equipment units was reduced by close to 50%) while maintaining the same high standard of safety as the ABWR now in operation by adopting standard unit capacities for the ECCS (emergency core cooling system) and other key subsystems used in the existing ABWR.
(2) Extensive use of technologies developed for larger reactors

The design and performance of Hitachi's ABWR was markedly improved by adopting proven technologies that were developed for larger reactors including a large-capacity main steam SRV (safety relief valve) and a low-pressure-loss MSIV (main steam isolation valve). Other key technologies adapted from the existing ABWR for their reliability and performance include a single-casing design for 52-inch last-stage long blade turbine, single-unit implementation of the condenser, and single-train implementation of feedwater heaters.
(3) Rationalized layout design

By streamlining and concentrating plant equipment and rearranging the layout of plant buildings, the building-volume ratio of the newly developed ABWR was substantially reduced by about 50% compared to the existing ABWR.

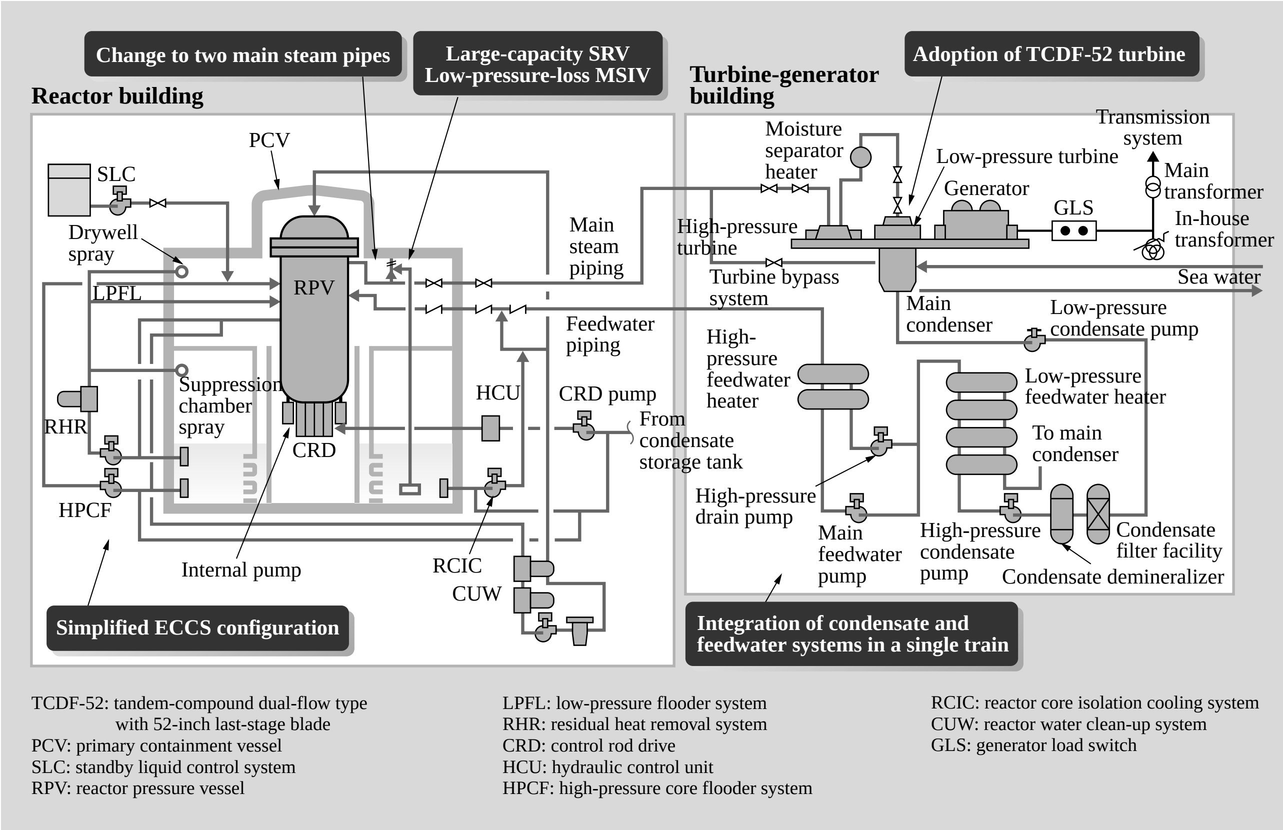


Fig. 3—Newly Developed ABWR Plant Configuration and Features.
By streamlining and optimizing the equipment for medium output scale, a plant configuration is achieved that overcomes any disadvantage resulting from reduced scale.

Characteristics of Key Subsystems

Let us next consider the characteristics of some of the main subsystems and equipment of the newly developed ABWR plant. Table 1 compares some of the auxiliary systems of new ABWR with the 1,356-MWe-capacity ABWR.

Reactor core equipment

(1) Core and reactor specifications

To achieve the target power output of 600 MWe, the arrangement of the core was optimized, the output density was increased into a practical range, and the fuel assemblies were optimized. This enabled a thermal power of 1,862 MWt and an electrical power output of 650 MWe.

(2) Reactor pressure vessel and primary containment vessel

The size of the reactor pressure vessel was optimized to accommodate the number of core fuel bundles, height of the core, the steam dryer and the steam separator. The primary containment vessel was designed based on the reinforced concrete containment vessel of the existing ABWR, but the number of main

TABLE 1. Comparison of equipment specifications for newly developed ABWR and 1,356-MWe ABWR
Performance of the newly developed ABWR equipment is markedly improved substantially beyond the difference in output scale compared to the existing ABWR (1,356 MWe).

	Unit	Newly developed ABWR	Existing ABWR
Electric power output	MWe	650	1,356
RIP	Units	4	10
Main steam piping	—	700 A × 2 lines	700 A × 4 lines
Emergency core cooling system	—	ADS, D/G, HPCF, LPFL (RHR), LPFL (RHR), D/G, D/G	ADS, RCIC, D/G, LPFL (RHR), HPCF, LPFL (RHR), HPCF, LPFL (RHR), D/G, D/G
Turbine	—	TCDF-52 (1 high-pressure casing, 1 low-pressure casing)	TC6F-52 (1 high-pressure casing, 3 low-pressure casings)
Condenser	—	1 unit	3 units
Feedwater heater	—	One 2-stage high-pressure train One 4-stage high-pressure train	Two 2-stage high-pressure trains Three 4-stage high-pressure trains

RIP: reactor internal pump
D/G: diesel generator
ADS: automatic depressurization system
TC6F-52: tandem-compound 6-flow type with 52-inch last-stage blade

steam pipes was reduced to two and the size was optimized based on an analysis of safety factors considering the reduced output scale. Thus, both vessels are about the same height as the existing ABWR, but the inner diameter has been reduced to about 80% of the existing ABWR.

Safety equipment and systems

(1) Equipment configuration

In optimizing the equipment for the reduced output scale, the following safety related subsystems were modified to achieve a standard of safety equivalent to that of the existing ABWR.

(a) The high-pressure ECCS was simplified by reinforcing the ADS (automatic depressurization system) functions and upgrading the all safety relief values with the ADS function.

(b) The single high-pressure system and single low-pressure system from the existing ABWR were simplified by integrating one high-pressure core flooding system, two low-pressure flooding systems, and one reactor core isolation cooling system in the ECCS, and by increasing the per-unit capacity and reinforcing with ADS functionality.

(2) Safety performance assessment

The performance of the ECCS and reactor containment vessel were evaluated based on the same assessment criteria as the existing ABWR but reflecting the changes in specifications and equipment configuration, and it was confirmed that both provided a high level of safety and reliability equivalent to that of the existing ABWR.

Turbine equipment

Considering the tradeoff between thermal efficiency and equipment cost, we adopted a two-stage reheating approach using a moisture separator heater for the turbine heat cycle. Setting the number of feedwater heater stages at six (two high-pressure stages and four low-pressure stages), we significantly streamlined the feedwater and condenser systems by implementing the units as a single train.

Measurement control and electrical systems

In addition, the following measurement control and electrical equipment and systems were also simplified and optimized to match the optimization in the rest of the plant.

(1) Integration of working system control equipment

Floor space required by the core flow control and other main control systems and equipment were substantially reduced by enhancing the functions of the control equipment, adopting high-speed processing, and by enabling some systems to share the same control equipment. Some other working systems and control equipment were eliminated by integrating the control equipment to cover multiple systems.

(2) Elimination of spare transformer

If the main circuit fails due to electrical problems, then the condensate and feedwater systems can no longer continue to operate normally (as in the case of scram event). For this situation and when the main circuit is down for maintenance, a small-capacity transformer has been implemented that eliminates the need for large-capacity spare transformer.

(3) Reduction of emergency diesel generator capacity

By simplifying the ECCS, we were able to reduce the capacity of the emergency diesel generator by about 40% compared to the emergency generator at the existing ABWR.

BUILDING ARRANGEMENT AND PLANT CONSTRUCTION

The earthquake resistant structural design and building structures are largely based on design criteria and proven technologies used in the existing ABWR. At the same time, the building-volume ratio and equipment-volume ratio of the newly developed ABWR has been reduced by close to 50% compared to the existing ABWR by streamlining and deploying the systems more compactly. Moreover, while the first ABWR took 34 months to build (from pouring the concrete for the reactor building to loading the fuel rods), the No. 2 and subsequent units took only 31.5 months to construct, thus significantly shortening the construction schedule.

Regarding the layout and placement of buildings, we studied and implemented the following measures to achieve greater standardization, reduce the equipment-volume ratio, and to shorten the construction schedule.

(1) Compact layout: Along with better integration and streamlining of equipment, the piping, cabling, and duct for the air-conditioning have been shortened, thus permitting the buildings to be implemented more compactly.

(2) Standardization: The layout design was developed to accommodate variable factors due to the unique characteristics of different sites, and to take potential problems that might be caused by standardization into account.

(3) Reduced number of steps: The layout design was developed to minimize the number of floors of buildings, to arrange the equipment comprising the critical path in terms of setup steps as low as possible, and to the extent possible to adopt a modular design approach.

(4) Investment distribution ready arrangement: In order to maintain the scale of the site where a plant is to be constructed, the building configuration and layout is such that two newly developed plants can be built within the area required to build one existing ABWR.

One particular measure to achieve greater standardization was to make a division between a “fixed deployment area” and a “variable deployment area.” This permits the customer to define storage facilities in the reactor and turbine buildings, and enables us to create a layout that is not affected by unique conditions of the construction site and other variable factors.

CONCLUSIONS

This paper presented an overview of the nuclear power plant ABWR developed by Hitachi, Ltd.

A major objective in the development of newly developed ABWR was to achieve a standardized, cost-effective design by adopting mature technologies whose high performance has already been demonstrated by the existing 1,350-MWe-class ABWR. The technical viability and cost-reduction targets have already been verified, so the new ABWR design will be available on the market in the near future. Another major advantage of employing technologies that have already been proven is that all the permissions and approvals relating to the construction and operation of the plant can be obtained fairly easily and quickly. Indeed, government approval for ABWRs has already been obtained in the U.S., and we anticipate that approval from the Japanese government will be soon forthcoming.

Hitachi, Ltd. has also completed work on a somewhat larger 900-MWe-class ABWR that is also highly cost-effectiveness, and plans to develop a whole series of advanced ABWR power plant designs tailored to the varying needs of the global marketplace.

REFERENCE

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ABOUT THE AUTHORS

Shoichiro Kinoshita

Joined Hitachi, Ltd. in 1981, and now works at the Nuclear Power Plant Project Department at the Nuclear Systems Division, the Power Systems. He is currently engaged in project management of domestic nuclear power plants. Mr. Kinoshita can be reached by e-mail at shouichirou_kinoshita@pis.hitachi.co.jp.

Shunya Morita

Joined Hitachi, Ltd. in 1995 and works at the Nuclear Plant Control & Instrumentation Engineering Department at the Nuclear Systems Division, the Power Systems. He is currently engaged in the design of electrical systems for nuclear plants. Mr. Morita can be reached by e-mail at shunya_morita@pis.hitachi.co.jp.

Koji Ando

Joined Hitachi, Ltd. in 1992, and works at the Nuclear Power Plant System Engineering Department at the Nuclear Systems Division, the Power Systems. He is currently engaged in nuclear power plant system design. Mr. Ando can be reached by e-mail at kouji_andou@pis.hitachi.co.jp.

Kazuhito Koyama

Joined Hitachi, Ltd. in 1985 and works at the International Project Management Department at the Nuclear Systems Division, the Power Systems. He is currently engaged in the management of international business development and special projects. Mr. Koyama can be reached by e-mail at kazuhito_koyama@pis.hitachi.co.jp.