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.
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.
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 steam piping units was reduced.

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).

<table>
<thead>
<tr>
<th>Unit</th>
<th>Newly developed ABWR</th>
<th>Existing ABWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric power output</td>
<td>MWe</td>
<td></td>
</tr>
<tr>
<td>RIP</td>
<td>Units</td>
<td></td>
</tr>
<tr>
<td>Main steam piping</td>
<td>700 A × 2 lines</td>
<td>700 A × 4 lines</td>
</tr>
<tr>
<td>Emergency core cooling system</td>
<td>ADS (1 high-pressure casing, 1 low-pressure casing)</td>
<td>ADS (1 high-pressure casing, 3 low-pressure casings)</td>
</tr>
<tr>
<td>Condenser</td>
<td>1 unit</td>
<td>3 units</td>
</tr>
<tr>
<td>Feedwater heater</td>
<td>One 2-stage high-pressure train</td>
<td>Two 2-stage high-pressure trains</td>
</tr>
<tr>
<td></td>
<td>One 4-stage high-pressure train</td>
<td>Three 4-stage high-pressure trains</td>
</tr>
</tbody>
</table>

RIP: reactor internal pump
DG: diesel generator
ADS: automatic depressurization system
TCDF-52: tandem-compound dual-flow type with 52-inch last-stage blade
PCV: primary containment vessel
SLC: standby liquid control system
RPV: reactor pressure vessel
LPFL: low-pressure flooder system
RHR: residual heat removal system
CRD: control rod drive
HCU: hydraulic control unit
HPCF: high-pressure core flooder system
RCIC: reactor core isolation cooling system
CUW: reactor water clean-up system
GLS: generator load switch
TC6F-52: tandem-compound 6-flow type with 52-inch last-stage blade

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.
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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