Operation and Refueling Outage Experience of the First Advanced BWRs

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OVERVIEW: Constructed for enhanced safety, reliability and cost-effectiveness, Tokyo Electric Power Company's Kashiwazaki-Kariwa units 6 and 7, the world's first advanced boiling water reactors (ABWRs), have continued to operate stably since they first entered commercial operation. Now at the end of November 2000 with unit 6 in its 4th in-service cycle and unit 7 in its 3rd cycle, both plants have demonstrated high levels of operational performance. The new systems and equipment developed for the ABWR units (reactor internal pumps, and fine motion control rod drive mechanism) have also exhibited excellent dependability. Unit 6 which entered service in November 1996 has now been subjected to 3 annual inspections, while unit 7 which entered service eight months later in July 1997 has had 2 inspections. The first periodic inspection took 55 days, but subsequent inspection outages were reduced to 44 days for unit 6 and 45 days for unit 7, thus contributing to the high performance of the two reactors. It should be possible to reduce the inspection outage length to 30-35 days in the future, which will boost the cost-effectiveness of the plants even further. At the same time, the occupational radiation exposure during annual inspection has been held to a very low level; during the first inspection of unit 7, for example, an excellent exposure figure of about 150 man • mSv was obtained. The periodic inspection results confirm that the operational performance of the ABWR units have met and exceeded the performance targets that were set when the reactors were designed and deployed.

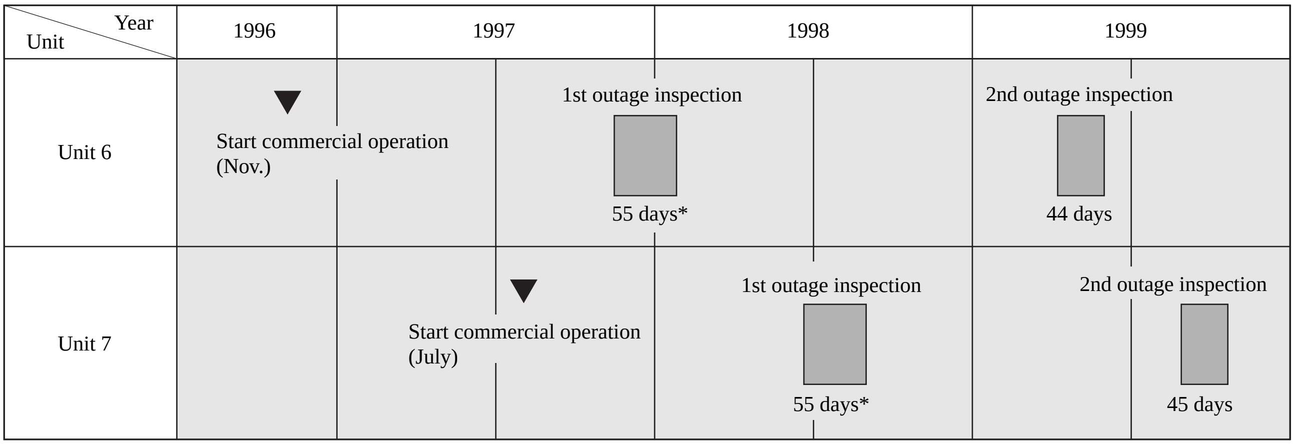
INTRODUCTION

THE world's first advanced boiling water reactors (ABWRs), units 6 and 7 (see Fig. 1) of Tokyo Electric Power Company's (TEPCO) Kashiwazaki-Kariwa nuclear power plant, have continued to operate stably since they were put into commercial service. Based on their operational performance and periodic inspection results, this article will assess how well the two ABWR plants have met their initial performance targets in terms of (1) improved reliability, (2) enhanced operation and operability, (3) reduced occupational radiation exposure and handling of radioactive waste, and (4) improved cost-effectiveness.

Fig. 1— Status of Annual Inspection at TEPCO's Unit 7 of Kashiwazaki-Kariwa Nuclear Power Plant (Fuel Handling Machine).
The fuel handling machine is directly controlled by computer and three modes of operation are available: (1) automatic, (2) semi-automatic, and (3) manual. The fuel handling work is mostly conducted under automatic operating mode, and about 150 fuel rods can be replaced in a day.

OPERATIONAL PERFORMANCE

Since ABWR unit 6 entered commercial service in November 1996 and unit 7 went on line eight months later in July 1997, they have been subjected to annual inspections. As of the end of November 2000, unit 6



*Six days of holiday over New Year's excluded

Fig. 2— Operational Performance of the ABWR Plants.
Operational performance and outages for units 6 and 7 from launch of commercial operations until the end of 1999.

was in its 4th cycle, and unit 7 was in its 3rd operational cycle. Fig. 2 shows the start-up dates and scheduled outages for the two units during their first few years of operation. The operational performance of each plant, from start up through the end of 1999, was 90.3% for unit 6 and 85.8% for unit 7, substantially higher than Japan's nationwide average for nuclear power plants of 80.1%. The two reactors have continued to operate stably up to the present.

OUTAGE INSPECTION RESULTS

The target annual inspection length for the ABWRs was initially set at 55 days that would subsequently be reduced to 45 days. An emphasis was placed in the inspections on the systems and equipment that are unique to ABWR plants, and TEPCO was closely involved in specifying the tests and inspections that would be performed in the first annual inspection. Hitachi had primary responsibility for inspecting the turbine equipment of unit 6 and the reactor equipment of unit 7.

Overview of the Inspections

As in the periodic inspections for conventional boiling water reactors (BWR), the specific items to be examined in each inspection are determined in accordance with a long-term inspection schedule that is based on the inspection period of each piece of equipment. Aside from the new equipment for the ABWR plants, the rest of the systems and equipment to be examined were the same as in BWR inspections, and the amount of work involved in the inspections was also unchanged. In some cases, rotation equipment has been provided in an effort to reduce the amount of work and the length of the inspection outages. Table 1 shows an overview of the main systems and equipment that were inspected, as well as the number of spare equipment that are deployed where applicable.

Inspection Schedule

The first inspection of both units 6 and 7 took 55 days, while the second inspection of unit 6 took 44 days and the second inspection of unit 7 took 45 days. This is about a month shorter than the 70 days that are typically needed to inspect a 1,100-MWe class BWR plant, a time saving that contributes significantly to the improved performance of the ABWR units. During the first inspection, the turbine was disassembled and examined and the generator was also inspected. A good portion of the work and outage days of the first inspection were taken up with this work. Fig. 3 shows how the 45 days of the second inspection of unit 7 were allocated.

Reactor equipment schedule

The critical procedures are largely the same as in the case of a conventional BWR plant. The major difference is that the disassembly and inspection of the reactor internal pump (RIP) impeller, a new feature of the ABWR units, has been added to the critical procedures. Note too that in the inspection of the FMCRD (fine motion control rod drive mechanism), only the examination of the main unit is included in the critical item. The inspection of the spool pieces and motors are done in parallel with the fuel loading and shuffling work.

Table 1. Overview of Inspection Tasks
Overview of 1st and 2nd ABWR plant inspections: subsystems, features inspected, number of units inspected, and number of stand-by units.

Inspected, maintained		No. of units inspected: 1st inspection	No. of units inspected: 2nd inspection	Rotation equipment
Fine motion control rod drive mechanism	Main body	11	3	3
	Spool piece	21	21	21
	Motor	21	21	21
Reactor internal pump	Entire unit	2	2	2
Main steam isolation valve	Entire unit	4	3	2
Hydraulic control unit	Pilot valve exchange	21	21	21
	Accumulator	15	15	—
RCW pump	Entire unit	6	6	2
Main turbine	Entire unit	4	2	—
Generator	Entire unit	1	—	—
EHC	EHC servo valve	11	11	11
	EHC pump	1	1	1
Turbine main valve	Main stop valve	4	4	—
	Control valve	4	4	—
	Combined intercept valve	6	2	—
	Bypass valve	3	3	—
Auxiliary equipment	Moisture separator/reheater (separator)	2	2	—
	Moisture separator/reheater (heater)	1	1	—

RCW: reactor cooling water system
EHC: electro-hydraulic control system

Reactor equipment (critical processes)

RPV open	Fuel transfer	RIP removal	NS removal	Control rods replace / FMCRD inspection	LPRM SRNM replace	Fuel loading / FMCRD spool piece, motor unit inspection	RIP installation	Core verification	RPV closure	RPV hydraulic test	RCCV closure	Pre-start up test	RCCV leak test	System configuration	Plant start up
4.5 days	1.5 days	2 days	1.5 days	5 days	2 days	7 days	2 days	1.5 days	6 days	1 day	3 days	2 days	3 days	1 day	3 days

Turbine equipment (inspect two turbines)

Turbine disassembly and inspection (use 3 shifts just for honing)	MITI inspection	Turbine assembly	Oil flushing	EHC function test, in leak test	System configuration, plant start up
19 days	1 day	13 days	3 days	5 days	4 days

RIP: reactor internal pump
LPRM: local pressure region monitor
FMCRD: fine motion control rod drive mechanism
RCCV: reinforced concrete containment vessel
NS: neutron source
SRNM: start-up region neutron monitor
RPV: reactor pressure vessel

Fig. 3— Number of Days for Each Inspection Task.
This shows the number of days required for each inspection task during the 45-day inspection outage of ABWR unit 7. The reactor equipment involves critical processes, while the turbine equipment involves inspection of two turbine assemblies.

Turbine equipment schedule

Normally it takes 45 days to disassemble and inspect two turbine cases. We succeeded in reducing the inspection time by doing some of the work in two shifts and by introducing a new oil flushing machine that reduced the time required for oil flushing.

Prospects for reducing annual inspection lengths

The recent liberalization of the power industry and other external factors have exerted pressure to reduce the length of annual inspection. A thorough-going analysis revealed that it should be possible to reduce the inspection outage length for ABWR plants to 30-35 days by implementing the following measures:

- increase use of rotation equipment,
- reassess equipment inspection periods, and prolong inspection cycles where appropriate,
- strengthen work routines and systems, and
- implement fine-tuned schedule management on an hourly basis.

A study is now in progress to determine whether the inspection period for the RIP and the FMCRD can safely be extended. More specifically, we are evaluating the lifetimes of the consumable parts (i.e., parts that wear out) of each piece of equipment that is examined in each inspection. By continuing these assessments, we will determine if and to what extent the inspection period can be extended for each system and piece of equipment that is subject to inspection.

ABWR-Specific Equipment Inspections

RIP inspections

Inspection of the RIPs is on a five-year cycle and mainly consists of changing worn-out parts and examining each constituent part. Two RIPs are examined during each inspection, and four out of ten units have been inspected so far. The specific examination involves removing and visually examining the impeller shaft and inspecting the motor. No abnormalities have been detected in the inspections that have been conducted so far. Beginning with the 2nd inspection, we started using a device that removes the surface cladding of the impeller shaft, thus improving the accuracy and reliability of the visual inspection.

It takes approximately 30 hours to remove and reassemble a RIP, which is somewhat less time than originally specified in the design. Out of this, 14 hours to remove and reinstall the impeller shaft for a single unit is included in critical tasks, so it takes four days of critical task time to inspect two RIPs.

FMCRD inspections

The FMCRD consists of three main parts: the main body, the spool piece, and the motor, and the inspection cycle varies for each component part. The main body was designed to be maintenance-free, but since this is the first time that this system has been deployed in Japan, the one-forth of the core (consisting of 50 rods) is inspected every ten years. As of the 2nd inspection, 14 rods had been examined. The spool pieces and motors are also inspected on a ten-year cycle, and 21 of each are examined during each annual inspection. All inspection results have been normal so far.

One strategy for reducing the time and work of inspecting the FMCRD is to deploy stand-by equipment; there are three live systems that are actually being used, and 21 stand-by spool pieces and motors. Just the removal and reinstall work thus has a critical impact on the inspections. It takes about 5 hours to change 1 unit.

New central control panel

A new type of main control console was installed in the ABWR plants featuring a large display panel and several flat-screen displays operated by touch-screen control. In addition, the control system (including safety systems) has been completely digitized, and we had not previous experience in conducting inspections in this kind of an environment. The annual inspections thus evaluate (1) isolation capability using touch-screen controls, (2) software logic isolation, and (3) monitoring capability when process computers are completely shut down.

There have been no problems with the touch-screen control, nor with the software isolation (simulated conditions are input for each unit of equipment tested) even though the tests are performed about 100 items during each inspection. The large display panel and flat-screen displays remained fully responsive and continued to accurately monitor plant conditions even after the process computers had been completely shut down for four days. Although the man-machine interface of the new ABWR plants is different from the previous generation BWR plants, the differences were found to have little impact on the overall annual inspection processes.

Occupational Radiation Exposure during Inspections

The ABWR units were designed to reduce radiation exposure in the reinforced concrete containment vessel by applying RIPs and reduce occupational radiation exposure during inspections by installing radiation shields on the reactor water clean-up system inside the reinforced concrete containment vessel.

These measures succeeded in their purpose, for the occupational radiation exposure during the first inspection of unit 7 was held down to about 150 man•mSv. The improved radiation protection compared to conventional BWR plants is especially apparent in the large reduction in exposure when

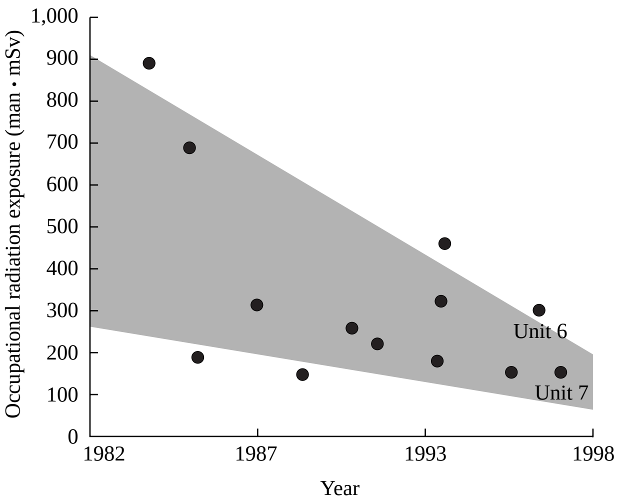


Fig. 4— Occupational Radiation Exposure of ABWR Units 6 and 7 Compared to Previous Generation BWR Plants.
This shows the trend in occupational radiation exposure at nuclear power plants in recent years including the figures for the first inspection of ABWR units 6 and 7. One can see that the results for units 6 and 7 are relatively low. In fact, the occupational radiation exposure for the first inspection of unit 7 is the lowest 150 man • mSv figure that has been measured.

inspecting the reactor pressure vessel (RPV) recirculation system.

Fig. 4 compares the occupational radiation exposures obtained during the first inspections of units 6 and 7 with exposure figures for other nuclear power plants in Japan. One can see that the exposure levels during inspections are quite low, and well within the performance targets set in the initial design stage.

The new ABWR-specific systems and equipment have now been subjected to a number of inspections without incident, thus indicating that they will continue to support stable operation of the ABWR plants in the years ahead. The level reached of about 150 man • mSv during the inspection of unit 7 is the lowest level occupational radiation exposure during an inspection outage that has been achieved to date. This amount of exposure is extremely small, and is equivalent to the individual dose limit for three radiation workers (50 mSv) for a year.

It will be clear from this summary of operational performance and inspection results for units 6 and 7 that all performance targets for the ABWR plants have been fully satisfied. In future annual inspections we will continue to look for ways to further safely reduce inspection outage lengths and thereby further boost the performance of ABWR plants.

CONCLUSIONS

This article provided a summary overview of the operational performance and annual inspection results of units 6 and 7 of the Kashiwazaki-Kariwa nuclear power plant, the first advanced boiling water reactors to be put into commercial operation. The inspection results reveal that the ABWR units already deliver excellent performance and are likely to show further improvement as inspection outages are reduced.

The continued safe and stable operation of Japan’s first ABWR plants can be attributed to the dedication and professionalism of our many colleagues, including first and foremost, the employees of Tokyo Electric Power Company.

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