Startup Test on Unit 3 at Onagawa Nuclear Power Station

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Startup tests on Onagawa Unit 3 continued for 304 days, starting from fuel loading on April 2, 2001 to the
final regulatory inspection on January 30, 2002.

In order to ensure that the plant will operate safely and stably as well as that the plant will shut down safely
in an emergency, the startup test was conducted in the following stages: (1) an open vessel stage, (2) a nuclear
heatup stage, (3) a power stage.

The results of all startup tests confirmed that the plant met the specified function and performance
requirements and thus had a sufficient safety margin.

KEYWORDS: Onagawa Nuclear Power Station Unit 3, Startup Test, BWR

I. Introduction

Construction started on the Onagawa Nuclear Power Station Unit 3 in September 1996, and fuel assemblies were
loaded in April 2001. This was followed by startup tests and a final regulatory inspection on January 30, 2002.
Subsequently the unit commenced commercial operation as Japan’s 53rd commercial reactor.

The completion of Unit 3 was the final development phase of the Onagawa Nuclear Power Station; Unit 1 (524
MWe) started operating commercially in June 1984, and Unit 2 (825 MWe) followed in July 1995.

Here we will briefly describe the startup tests conducted on Onagawa Unit 3.

II. Outline of the Facility

The Onagawa Nuclear Power Station is located on the boundary of the towns of Onagawa and Oshika, about 57 km
east-northeast of Sendai in Miyagi Prefecture. The site is surrounded by mountains on three sides, and faces the
Onagawa Bay on the northeast side. The total area of the site is 1,730,000 m² (see Fig.1).

The combined electric power of Units 1 to 3 is 2,174 MW. The electric power generated is transmitted to the Tohoku
EPCO.’s grid using the two 275 kV Oshika lines and two newly-constructed Matsushima lines.

Unit 3 as well as Units 1 and 2 are boiling water reactors (BWRs). In order to improve reliability and safety, we
incorporated various improvements from the operating experience gained with operating BWRs in Japan and
overseas, as well as the results of the Japanese Light Water Reactor Improvement and Standardization Program.

Table 1 shows an outline of the facility and Fig.2 shows Unit 3 system diagram. Unit 3 has the following features:

1. Moisture Separation and Re-heating System

In order to improve turbine thermal efficiency, Unit 3, as with Unit 2, employs steam re-heating system that removes
moisture from the steam with a moisture separator and sends the steam to low-pressure turbines after re-heating it with
the high-temperature steam.

2. Enlarged Mark-I Primary Containment Vessel

As with Unit 2, Unit 3 has a containment vessel capacity larger than the original Mark-I type, aiming to reduce
occupational exposure and improve work efficiency.

3. Seawater Heat Exchanger Building

Seawater heat exchangers and pumps for cooling auxiliary equipment are concentrated in one separate
building to reduce the length of seawater pipes and to improve the maintainability of the auxiliary equipment
cooling system.

4. Condensation Storage Pool

A condensation storage pool is employed to make effective use of the space in the reactor building created by the re-location of the seawater heat-exchanger systems (see 3.).

5. Advanced Main Control Panels

Since Unit 3 has a separate main control room, whereas Unit 1 and 2 share a common main control room, advanced
main control panels are used that have separate main and sub consoles, and ease-of-operation and ease-of-monitoring
for operators has been improved ergonomically.
### Table 1: Onagawa Unit 3

<table>
<thead>
<tr>
<th>Reactor (manufactured by Toshiba Co.)</th>
<th>Turbine (manufactured by Hitachi Co.)</th>
<th>Generator (manufactured by Hitachi Co.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>BWR-5</td>
<td>Tandem compound</td>
</tr>
<tr>
<td><strong>Thermal Output</strong></td>
<td>2,436 MW</td>
<td>825 MW</td>
</tr>
<tr>
<td><strong>Pressure / Temperature</strong></td>
<td>6.93 MPa / 286°C</td>
<td>3-casing 4-flow exhaust type (with re-heating)</td>
</tr>
<tr>
<td><strong>Uranium Loaded</strong></td>
<td>96 tons</td>
<td></td>
</tr>
<tr>
<td><strong>Enrichment (initial core)</strong></td>
<td>2.5 wt%(average)</td>
<td></td>
</tr>
<tr>
<td><strong>Number of Fuel Assemblies</strong></td>
<td>560</td>
<td></td>
</tr>
<tr>
<td><strong>Primary Containment Vessel</strong></td>
<td>Enlarged Mark- I</td>
<td></td>
</tr>
<tr>
<td><strong>Output</strong></td>
<td>920,000 kVA</td>
<td>920,000 kVA</td>
</tr>
<tr>
<td><strong>Voltage</strong></td>
<td>20,000 V</td>
<td></td>
</tr>
</tbody>
</table>

### III. Startup Test Phase

#### 1. Construction Phase

Milestones in the construction of Unit 3 are listed below. It took 52 months from the bedrock inspection to the start of commercial operation.

- **May 1994**: Application for Nuclear Reactor Installation Permit.
- **November 1994**: Preparatory construction began.
- **April 1996**: Nuclear Reactor Installation Permit.
- **September 1996**: Construction began.
- **October 1996**: Excavation started on the foundation for the main building.
- **October 1997**: Bedrock Inspection
- **July 1998**: Assembly of the reactor containment vessel began (completed in December 1998).

- **December 1999**: Reactor Pressure Vessel Installation.
- **April 2000**: Electricity supply to the station was completed.
- **April 2001**: Fuel Loading
- **January 2002**: Commercial Operation

#### 2. Startup Test Phase

In the startup tests, we confirmed that the plant would operate safely and stably by performing the tests in stages: an open vessel stage, a nuclear heatup stage, and a power stage. We also tested that the plant would shut down safely in an emergency.

The startup test stage is described below (see Fig.3).

(1) **Open Vessel Stage**

The open vessel test started with fuel loading on April 2, 2001. During fuel loading, the reactor physics tests including a shutdown margin test and an initial criticality test, and a control rod drive system test were conducted.

(2) **Nuclear Heatup Stage** (initial criticality, rated reactor pressure – initial turbine operation)

In the nuclear heatup test, the control rods are withdrawn sequentially to increase the reactor pressure and temperature to the rated condition by nuclear heating. A coolant temperature coefficient measurement test and a thermal expansion test on the primary coolant pipes in the containment vessel were conducted.

To test the operation of the turbine and generator systems, after the initial turbine operation, the vibration of the main turbine shaft was evaluated and a control test was performed on the generator system.

(3) **Power Stage** (first grid connection to warranty test)

The first connection to the grid was achieved on May 30, and then the plant entered the power stage tests. In order to ensure stable electricity supply in the summer of 2001, no tests involving power fluctuations were planned from the end of July 2001 to the beginning of September (75% power stage). Static tests were conducted at 20%, 50%, 75%, and 100% electric power to evaluate the operating conditions of the plant. The power stage test conditions were labeled as TC-1 to 6 (see Fig.4), based on the combination of the reactor thermal power and the core flow rate. Control system parameter surveys were then performed to confirm that
control of the plant was stable. Subsequently, transient tests were performed to confirm that the plant would shut down safely in the event of a significant disturbance.

In addition, the plant was subjected to a scheduled outage in between power stages to inspect that the equipment was normal.

All the tests described above confirmed that the plant had the specified performance and functions. A final regulatory inspection was performed from January 28 to January 30, 2002. The plant passed the inspection and began commercial operation on January 30.

3. **Startup Test Data Analysis**

(1) **Plant Diagnosis**

Plant Evaluation Meeting is held on Units 1 and 2 to evaluate and confirm the integrity of the plant at startup after each outage to ensure stable and safe operation. On Unit 3 as well, a similar Plant Evaluation Meeting was held during the start up to the rated power. In the evaluation, major system parameters were compared with data from the previous startups and design data.

(2) **Startup Test Support System**

The startup test support system collects data on each monitoring parameter through LAN. This capability enhanced the level and efficiency of evaluation. The system also records most of the annunciators that were set off or cancelled during trip tests, on the operation consoles in the main control room.

IV. **Outline of Startup Test Results**

1. **Fuel Loading**

560 fuel assemblies were loaded one at a time into their specified positions in the reactor core using a fully automatic refueling machine. Fuel loading started on April 2, 2001, and all the fuel assemblies were loaded into the core by April 8.

2. **Initial Criticality**

Following the completion of fuel loading, the control rods were withdrawn sequentially at low temperature and with no xenon accumulation, and the initial criticality was achieved when the 37th control rod was withdrawn to its middle position (on April 23, 2001).

An effective multiplication factor ($k_{\text{eff}}$) was calculated using the measured period and adjusted by the coolant temperature; the accuracy of the predicted value was evaluated.

3. **Control Systems**

The control system tests include a reactor feedwater controller system test, a turbine inlet pressure controller test, a reactor recirculation flow controller test, a neutron flux response test, and a turbine local controller test. In each test, controller characteristics were evaluated, and a step response test was performed to set the control system constants properly. The results of the turbine inlet pressure controller test are summarized below.

The turbine inlet pressure controller keeps the turbine inlet pressure constant. It controls the opening of the main steam control valves and the turbine bypass valves, and thereby controls the turbine inlet pressure.

A pressure set-point change test was performed at the nuclear heatup stage and each power stage. Based on the test results, the response characteristics for each controller constant were evaluated, including the decay ratios of parameters of interest, the turbine inlet pressure peak response time, and APRM overshoot, and the controller constants were set to give a good response. The results at 100% power output met the criterion (Decay Ratio < 0.25) shown in **Fig.5**.
non-emergency and emergency buses was lost concurrently when the main generator was tripped. After the loss of off-site power, three emergency diesel generators automatically started to supply power to the emergency buses. The test confirmed that the plant would shut down safely in the event of loss of offsite power (see Table 2).

### Table 2 Trip Tests Summary

<table>
<thead>
<tr>
<th>Loss of Off-Site Power Source</th>
<th>Trip</th>
<th>Generator Load Rejection</th>
<th>Main Steam Isolation Valves Closure</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>@20%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@50%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@100%</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Maximum Reactor Pressure</td>
<td>3.37 MPa</td>
<td>2.67 MPa</td>
<td>7.26 MPa</td>
<td>7.29 MPa</td>
</tr>
<tr>
<td>Fuel Integrity</td>
<td>3.32</td>
<td>3.09</td>
<td>3.09</td>
<td>3.09</td>
</tr>
<tr>
<td>Plant interlock</td>
<td>- Automatic startup of standby DGs</td>
<td>- Turbine trip</td>
<td>- Maximum turbine speed: 1596 rpm (5.169kW/m)</td>
<td>- Main steam isolation (reference: 3 – 5 sec)</td>
</tr>
</tbody>
</table>

(2) Turbine Trip Test

When the plant was in operation at 50% electric power, the turbine was tripped and plant transient measurements were made. The test results confirmed that plant interlocks would function normally and the plant would shut down safely in the event of a turbine trip (see Table 2).

(3) Generator Load Rejection Test

The test confirmed that the reactor could continue to operate stably at 20% electric power output and that the plant would shut down safely at other higher power output if the generator load was rejected (see Table 2 and Fig.6). The test confirmed the criteria were met and that the plant would shut down safely.

### Fig.6 Generator Load Rejection Test @ 100%

(4) Main Steam Isolation Valves Closure Test

When the plant was in operation at the rated power, all of the main steam isolation valves (MSIVs) were closed simultaneously, and reactor transients, MSIV closing time were measured. The test confirmed that the plant interlocks would function normally (see Table 2).

### Fig.7 Thermal Efficiency Measurement

5. Warranty Run

(1) 100-Hour Demonstration

The standard deviation and fluctuation of each process parameter was monitored continuously for 100 hours from January 17 to January 21, 2002 under rated power conditions. The test confirmed that the plant would operate safely and stably.

(2) Four-Hour Detailed Measurement

Data necessary to confirm the contract-guaranteed values was gathered continuously for four hours from 13:00 to 17:00 on January 16, 2002. The test confirmed that the plant met the technical specification.

(3) Thermal Efficiency Measurement

The heat balance of the plant was measured at 20%, 50%, 75%, and 100% of the rated electric power. The test confirmed that the plant had a thermal efficiency exceeding the design value at each power stage (see Fig.7).

V. Conclusions

Startup tests on Onagawa Unit 3 continued for 304 days, starting from fuel loading on April 2, 2001 to the final regulatory inspection on January 30, 2002.

The results of each test confirmed the following and demonstrated that the plant has a sufficient safety margin.

1. All systems have the specified functions and performance at high temperature and high pressure.
2. All control systems have the specified functions and performance in the event of a disturbance.
3. The plant is capable of continuous safe operation.

We would like to use the experience obtained in these startup tests for the stable and safe operation of Unit 3, as well as for startup tests on Higashidori Unit 1 (BWR, 1,100MWe), our next power plant.

In closing, we would like to thank the people of the towns of Onagawa and Oshika for their understanding as well as all those who participated in the construction of Onagawa Unit 3.