Report on Measures Based on Temperature Rise in the Bottom Section Reactor Pressure Vessel of Reactor #2 at the Fukushima Daiichi Nuclear Power Station

February 15, 2012
Tokyo Electric Power Company

This document reports the contents directed in a report collection order, “Collection of a Report on Measures Based on Temperature Rise in the Bottom Section Reactor Pressure Vessel of Reactor #2 at the Fukushima Daiichi Nuclear Power Station” (Number 20, Nuclear and Industry Safety Agency, February 13, 2012).

1. Overview

As to the temperature in the bottom section of the reactor pressure vessel (hereinafter called RPV) of reactor #2 at the Fukushima Daiichi Nuclear Power Station, one of the thermometers mounted in the upper part of the bottom head (TE-2-3-69H1, RPV 0° direction) has indicated a tendency of slight increase since February 2nd, 2012. Therefore, we have changed the flow rate of reactor coolant injection and monitored the tendency of the temperature.

(Time series of flow rate operation)

- On February 3, we changed the coolant injection flow rate balance (the coolant injection rate of the core spray system reduced by 2 m^3/h and that of the reactor feedwater system increased by 2 m^3/h). [Flow rate of the reactor feedwater system and the core spray system (hereinafter called the total flow rate): Approximately 9 m^3/h].
- On each of February 5 and 6, we increased the flow rate from the reactor feedwater system (FDW) by 1 m^3/h [Total flow rate: Approximately 11 m^3/h]. Further on February 7, we injected boric acid solution, increased the flow rate from the core spray system by 3 m^3/h, and kept monitoring [Total flow rate: Approximately 14 m^3/h].
- As the temperature reading rose again on February 11, we further increased the flow rate from the reactor feedwater system by 1 m^3/h [Total flow rate: Approximately 15 m^3/h].
- Thereafter, we still saw a tendency of rise of the temperature reading and at around 2:15 PM on February 12, the reading of the aforementioned thermometer reached 82 °C. We determined that this condition did not satisfy the operational limits set forth in the reactor safety regulation.
- As a measure to prevent re-criticality, therefore, we injected boric acid solution and at the same time performed operation to increase the flow rate from the core spray system from approximately 6.9 m^3/h to approximately 9.9 m^3/h [Total flow rate: Approximately 18 m^3/h]. In addition, as we observed a change in the flow rate from the reactor feedwater system, we adjusted this flow rate from approximately 7.2 m^3/h to 7.5 m^3/h.

With regard to the temperature readings in the upper part of the bottom head of the RPV of reactor #2, the reading of the aforementioned thermometer rose. However, only this reading rose and the other readings showed a tendency of temperature lowering due to the increased flow rate of the coolant injection (see figure 1). The thermometer readings around the RPV and inside the primary containment vessel (hereinafter called PCV) also showed a tendency of temperature lowering. Thus we supposed that the reactor was entirely kept cooled (see figure 2). Considering the relation between the inlet pressure of the primary loop recirculation system and the flow rate from the reactor feedwater system, we supposed that water existed in the section around the aforementioned part and was cooling (see figures 3 and 4). Therefore, comprehensively, we determined that the reactor was kept cooled.

As to this event, we continuously carried out sampling of gas from the reactor-#2 PCV. As a result, the amount of xenon (Xe), a nuclide having a short half life, was less than the detection limit at every sampling and the amount of Xe-135 did not exceed the re-criticality judgment criterion (1 Bq/cm^3). Thus we determined that the condition did not reach the criticality and the same time determined that the value of cesium (Cs) 134 and 137, which are radioactive materials in particulate form, did not increase (see table 1).

As the reading of the aforementioned thermometer rose, we additionally measured the radioactivity concentration to determine whether the released amount from the blowout panel opening of the reactor-#2 reactor building increased or not (Dates of measurement: February 6 and February 13). At each measurement time, the measured radioactivity concentration was 1.0×10^{-5} Bq/cm^3 or less, i.e., within the range of the concentration values measured in the past (see figure 5).

Because the readings of the other thermometers mounted on the RPV and the PCV and those of the thermometer in the upper part of the RPV support skirt junction showed a tendency of temperature lowering (see figure 1), we supposed that occurrence of a failure of the thermometer was more possible than an actual increase in the RPV temperature and thus we verified the soundness of the aforementioned thermometer, including direct current resistance measurement, on February 13.

As a result, considering the temperature reading of approximately 340 °C after inspection (see figures 6-1 and 6-2) and the result of the direct current resistance measurement, we determined that the aforementioned thermometer reached a disconnection condition (see table 2).

As the reasons why the thermometer reading rose, the following two factors were supposed: The cooling effect of coolant injection to the fuel debris was reduced and the temperature actually rose or just the appearance of the thermometer reading rose due to a failure of the thermometer.

For the former factor, we analyzed the section of the aforementioned thermometer in the reactor by use of a simple system and as a result we concluded that the possibility of occurrence of actual temperature rise was low.

For the latter factor, on the other hand, we reviewed some presumed factors with regard to the series of reading variation indicated by the aforementioned thermometer and performed mock-up tests to verify those factors.

As a result of the mock-up tests, the short-cycle variation of the reading of the aforementioned thermometer observed this time (hunting) and the rise of the thermometer reading were both verified to be likely to occur, though these were indicated in different tests.
In conclusion, we determined that the event of this time was a failure of the aforementioned thermometer. Therefore, we decided to exclude the aforementioned thermometer from the monitored objects for the bottom temperature in the reactor pressure vessel set forth in Article 138 of the safety regulation.

The following chapters describe the details of the assumed cause of the rise of the thermometer reading of this time and the measures to be taken in the future.

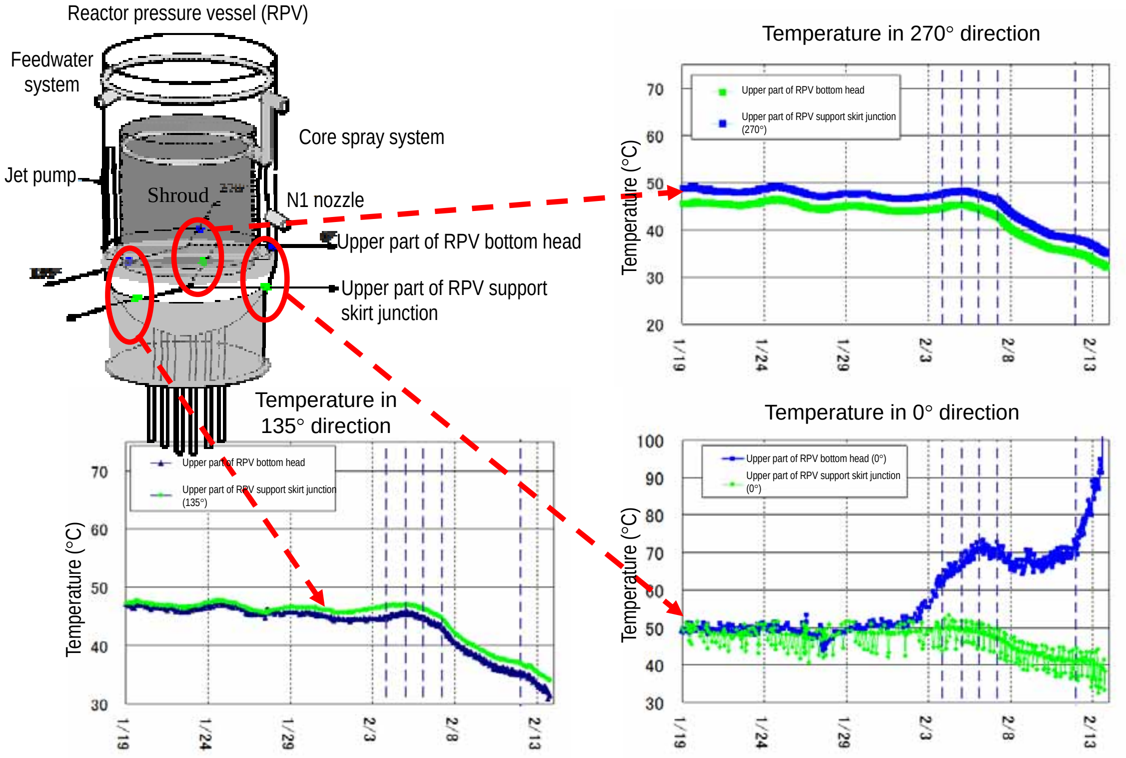


Figure 1 Transition of temperatures around the RPV bottom

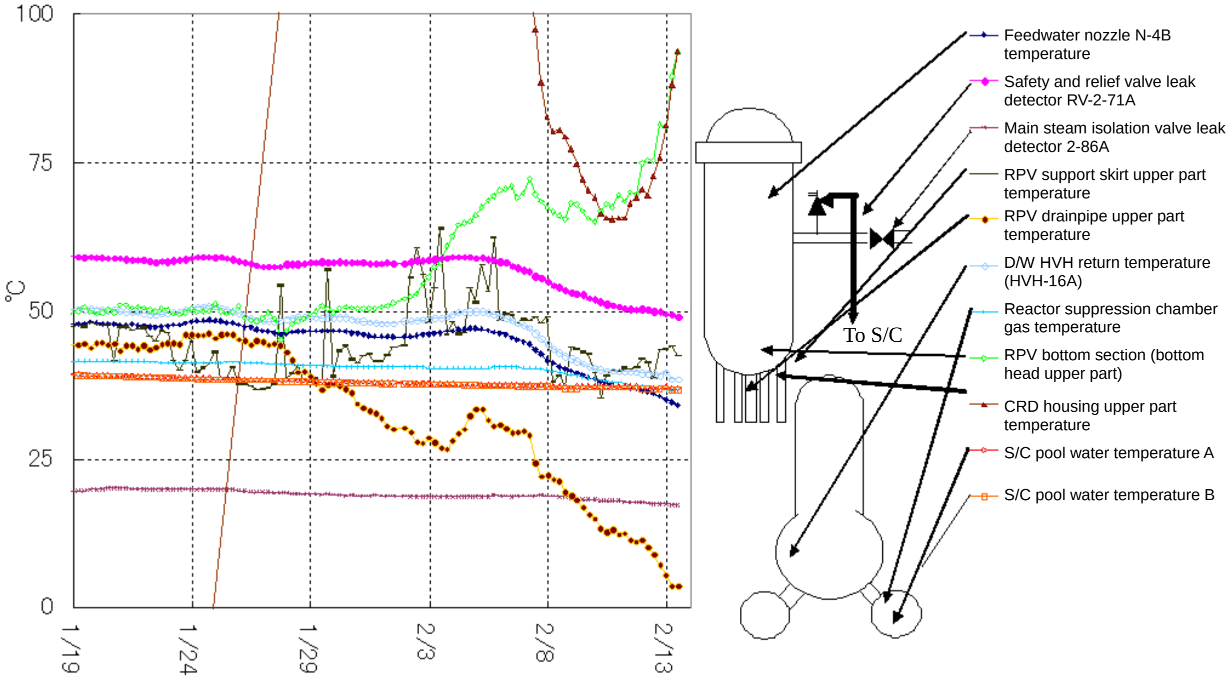


Figure 2 Transition of RPV and PCV temperatures

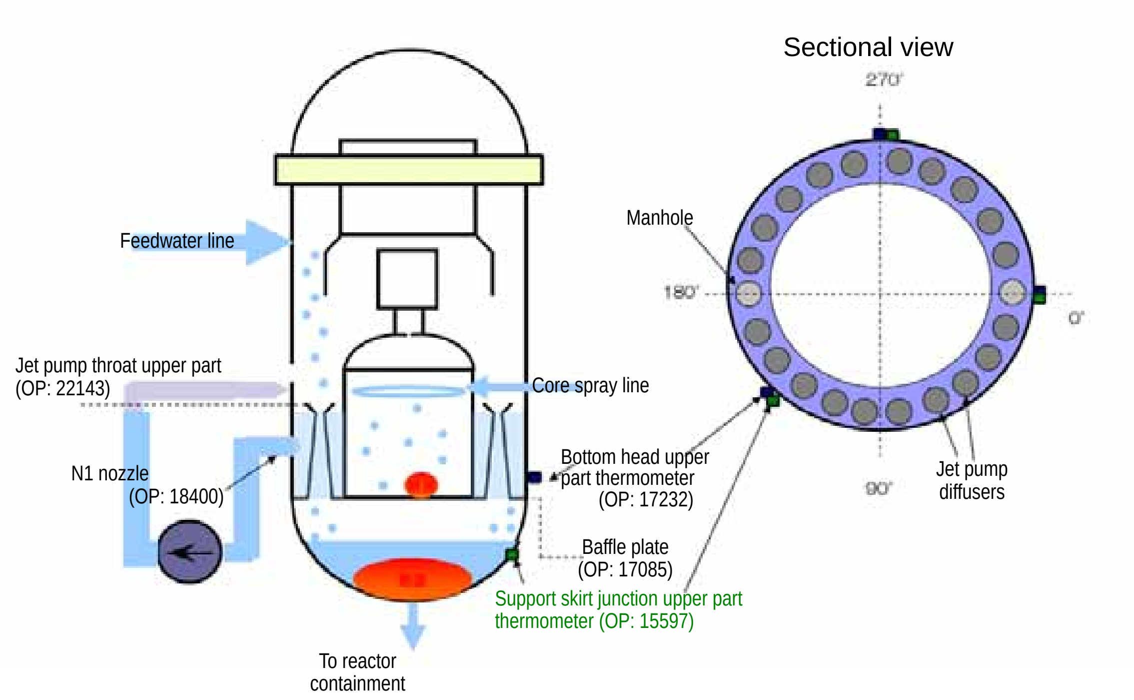


Figure 3 RPV sectional view and coolant injection system

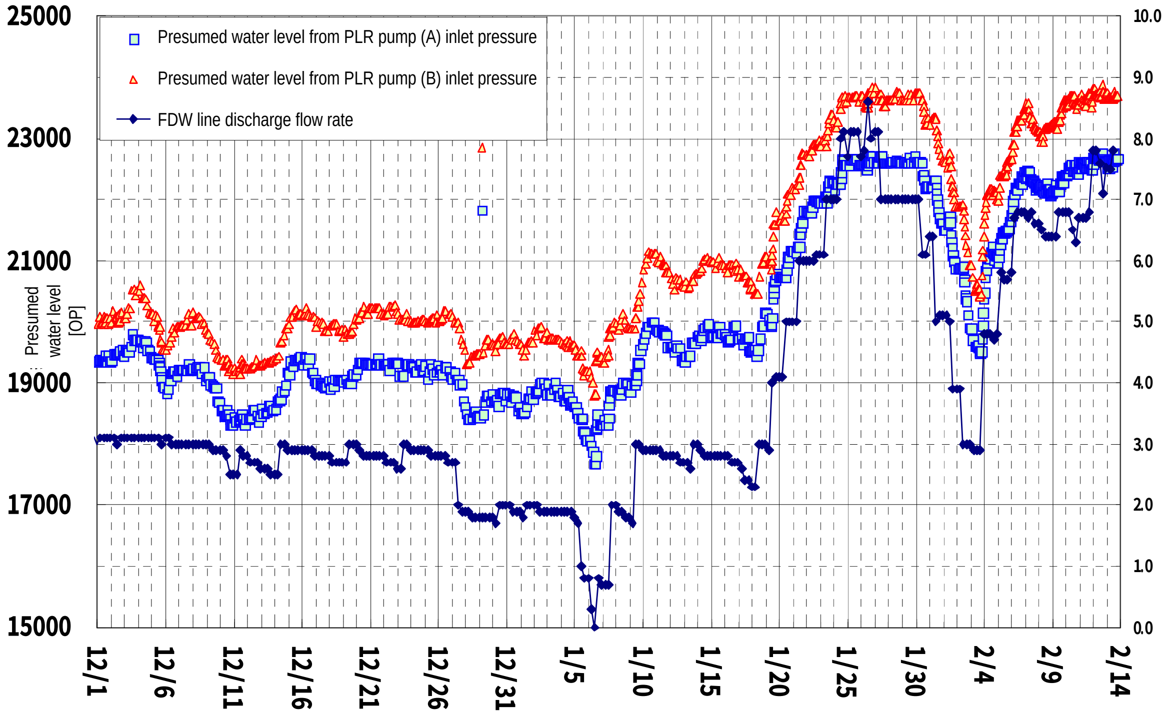


Figure 4 Presumed water level in annulus section* and flow rate of coolant injection to reactor feedwater system

*Annulus section: Area where the bottom head upper part thermometer is mounted

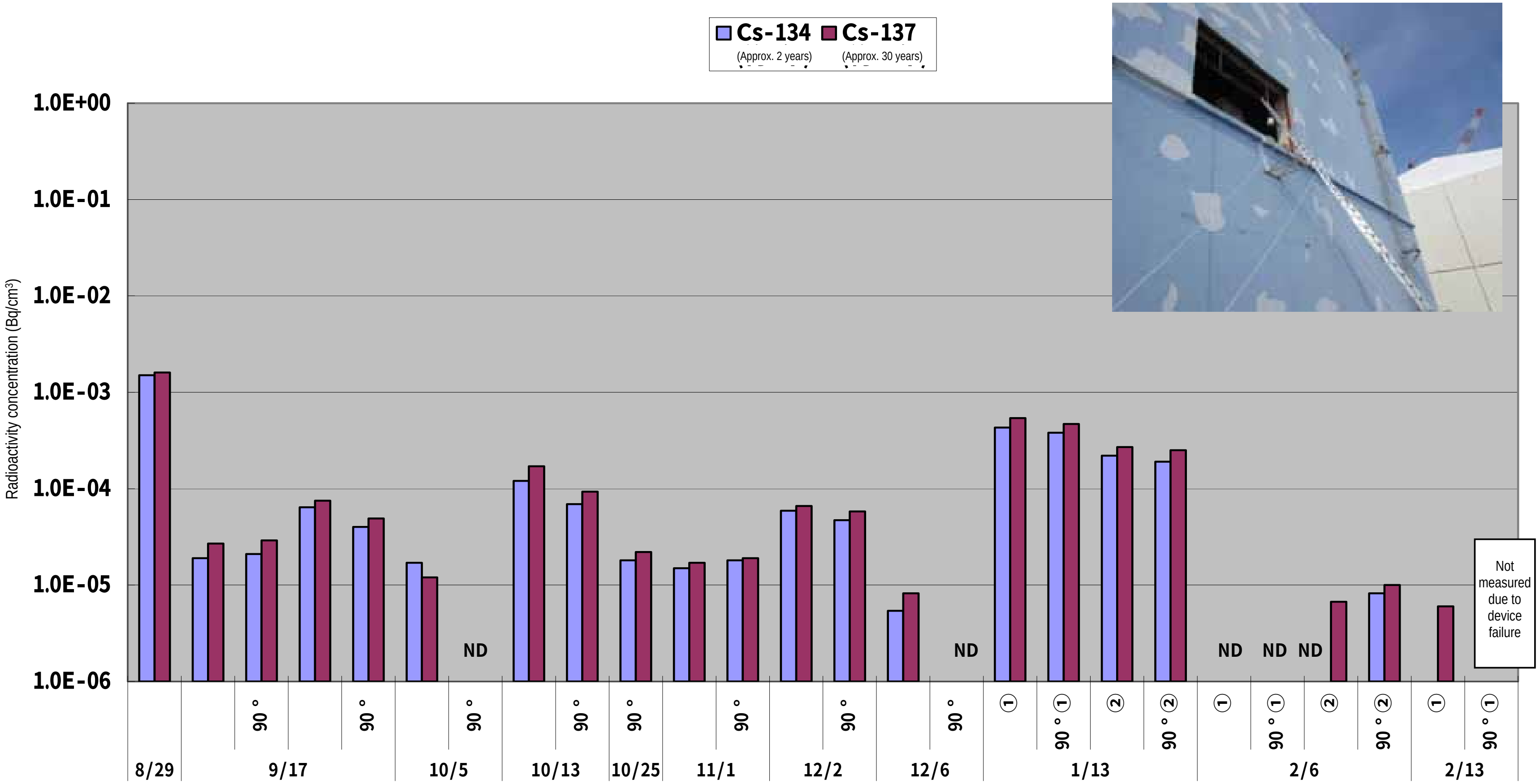


Figure 5 Results of radioactivity concentration measurement at blowout panel opening of reactor-#2 reactor building

* Indicated in range of 60 °C to 95 °C

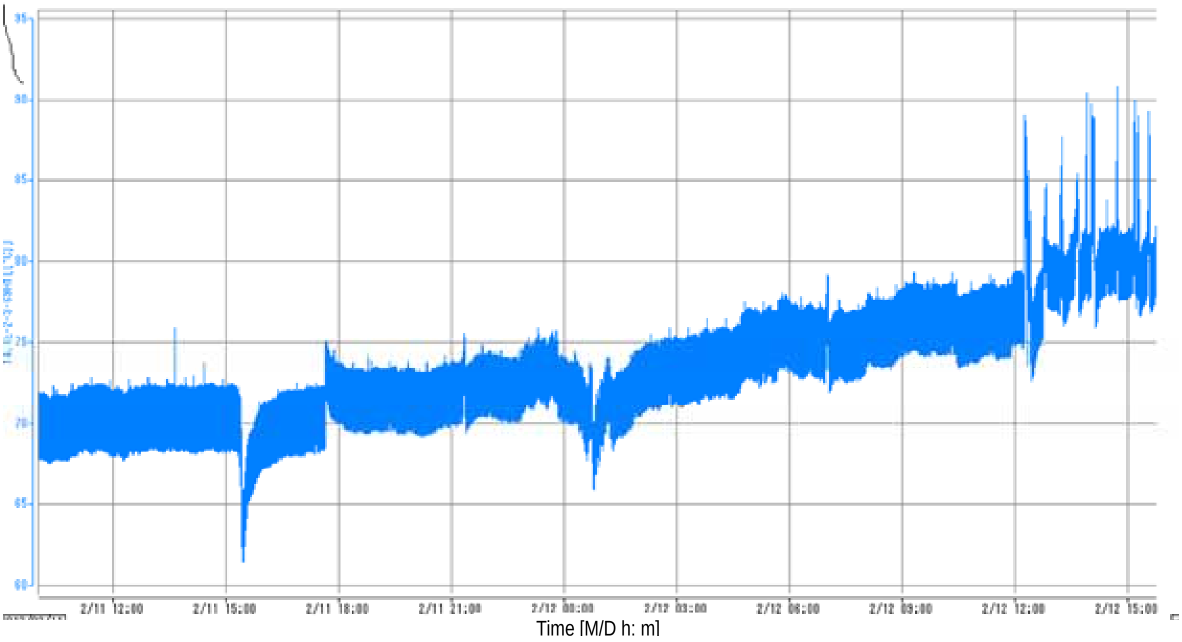


Figure 6-1 Sample of hunting of RPV bottom head upper part thermometer reading (0°)
(1-second sampling)

* Indicated in range of 65 °C to 400 °C

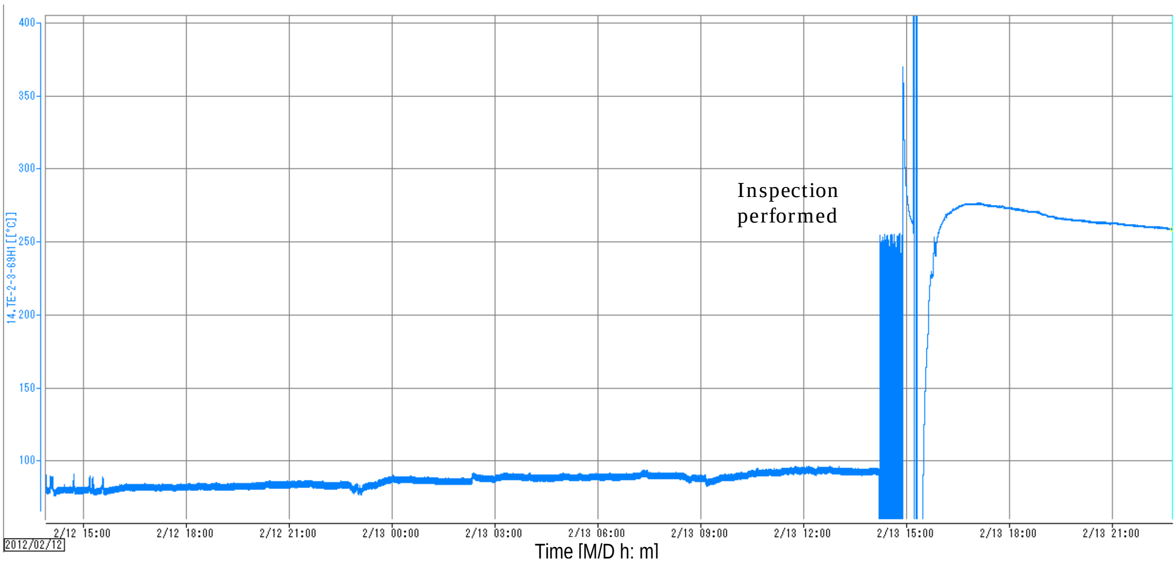


Figure 6-2 Sample of hunting of RPV bottom head upper part thermometer reading (0°)
(1-second sampling)

Table 1 Results of gas sampling in reactor-#2 PCV (vial)

(Bq/cm^3)

Nuclide (half life)	Reactor containment gas control facility (vial (inlet side))					
	Feb. 12, 2012 3:22	Feb. 12, 2012 17:01	Feb. 13, 2012 11:12	Feb. 13, 2012 17:10	Feb. 14, 2012 10:52	Feb. 15, 2012 11:08
I-131 (Approx. 8 days)	ND ($<1.3 \times 10^{-1}$)	ND ($<1.2 \times 10^{-1}$)	ND ($<1.3 \times 10^{-1}$)	ND ($<1.5 \times 10^{-1}$)	ND ($<1.2 \times 10^{-1}$)	ND ($<1.5 \times 10^{-1}$)
Cs-134 (Approx. 2 years)	ND ($<3.1 \times 10^{-1}$)	3.6×10^{-1}	ND ($<3.1 \times 10^{-1}$)	ND ($<3.3 \times 10^{-1}$)	ND ($<3.2 \times 10^{-1}$)	ND ($<3.3 \times 10^{-1}$)
Cs-137 (Approx. 30 years)	ND ($<3.7 \times 10^{-1}$)	6.4×10^{-1}	4.3×10^{-1}	4.7×10^{-1}	5.1×10^{-1}	4.0×10^{-1}
Kr-85 (Approx. 11 years)	ND ($<2.6 \times 10^{1}$)	ND ($<2.7 \times 10^{1}$)	ND ($<2.6 \times 10^{1}$)	ND ($<2.7 \times 10^{1}$)	ND ($<2.7 \times 10^{1}$)	ND ($<2.5 \times 10^{1}$)
Xe-131m (Approx. 12 days)	ND ($<3.0 \times 10^{0}$)	ND ($<3.0 \times 10^{0}$)	ND ($<2.9 \times 10^{0}$)	ND ($<3.4 \times 10^{0}$)	ND ($<3.0 \times 10^{0}$)	ND ($<3.6 \times 10^{0}$)
Xe-133 (Approx. 5 days)	ND ($<2.4 \times 10^{-1}$)	ND ($<2.4 \times 10^{-1}$)	ND ($<2.6 \times 10^{-1}$)	ND ($<2.4 \times 10^{-1}$)	ND ($<2.3 \times 10^{-1}$)	ND ($<2.4 \times 10^{-1}$)
Xe-135 (Approx. 9 h)	ND ($<9.5 \times 10^{-2}$)	ND ($<9.3 \times 10^{-2}$)	ND ($<9.9 \times 10^{-2}$)	ND ($<1.0 \times 10^{-1}$)	ND ($<1.0 \times 10^{-1}$)	ND ($<1.1 \times 10^{-1}$)

Table 2 Measurement results of direct current resistance of RPV bottom head upper part thermometer (TE-2-3-69H1)

Object	Date of measurement	(1) Direct current resistance (Ω)	(1)/(2)	Judgment
RPV bottom head upper part (0°) (TE-2-3-69H1)	Sep. 30, 2011 (at report evaluation)	175.47	0.58	Insulation deteriorated
	Feb. 3, 2012 (after rise of reading)	244.25	0.81	Insulation deteriorated
	Feb. 13, 2012 (this time)	500–535	1.65–1.76	Disconnected
	(2) Average at time of periodical inspection	303.37		
RPV bottom head upper part (135°) (TE-2-3-69H2)	Sep. 29, 2011 (at report evaluation)	151.71	0.50	Insulation deteriorated
	Feb. 13, 2012 (this time)	155.32	0.52	Insulation deteriorated
	(2) Average at time of periodical inspection	300.47		
RPV bottom head upper part (270°) (TE-2-3-69H3)	Sep. 29, 2011 (at report evaluation)	148.64	0.51	Insulation deteriorated
	Feb. 13, 2012 (this time)	144.65	0.49	Insulation deteriorated
	(2) Average at time of periodical inspection	292.30		

2. Presumed causes and evaluation

(1) Evaluation of condition inside reactor based on analyses, etc.

1) Introduction

Considering the temperature rise event of this time as an actual event, we performed evaluation assuming that the cooling effect of the coolant injection to the debris near the aforementioned thermometer was reduced by a certain reason at the time of flow rate change, etc., causing the reading of the aforementioned thermometer to rise. Here, performing evaluation by use of a simple system that simulates the aforementioned section of the reactor, we verified the likeliness of a temperature rise event. In the concrete, we evaluated the following two cases:

Case (1): Heat from the debris inside the shroud caused the temperature of coolant water of the reactor feedwater system (FDW) coolant in the annulus section to rise, resulting in rise of the temperature indicated by the aforementioned thermometer (figure 1)

Case (2): Heat from the debris inside the shroud heated the baffle plate by the effect of heat transfer, resulting in rise of the temperature indicated by the aforementioned thermometer (figure 2)

In the above two cases, we evaluated that there was water in the annulus section near the aforementioned thermometer. Figure 3 shows the presumed water levels in the annulus section (difference between the recirculation system (PLR) pump inlet pressure and the dry well pressure) and the FDW flow rate. The presumed water levels were corresponding to the changes in the FDW flow rate and thus it was assumed that there was a water level in the annulus section. As there was a water level in the annulus section, we evaluated that the debris stayed within the shroud (including the shroud support) and existed near the aforementioned thermometer inside the shroud.

2) Case (1) (Rise of water temperature of FDW in annulus section)

The methods and preconditions used for evaluation are as follows:

(a) Assuming that heat generated from the debris near the aforementioned thermometer inside the shroud caused the rise of the feedwater temperature at the annulus section, we calculated the calorific value necessary for the rise of the feedwater temperature.

(b) Because it might be considered that the injected feedwater flowed from the annulus section to such sections as the RPV bottom head via the recirculation system water outlet nozzles in the directions of 0° and 180° and the baffle plate manholes, we considered 50% of the feedwater flow rate (flow rate in the direction of 0°).

(c) We presumed that the water in the annulus section had the same temperature as the water in the upper part of the RPV bottom head (in the direction of 0°).

(d) On each date of evaluation, the water temperature in the upper part of the RPV bottom head (in the direction of 0°) was a value calculated by rounding the average values and in addition, we assumed that the injected feedwater temperature was 10 °C.

(e) The equation used for the evaluation is as follows:

$$Q = \left(h_T - h_{in}\right) \times \rho \times 0.5 \times W_{FDW} \; / 3600 / 1000$$

Q : Calorific value necessary for rise of water temperature (MW)

h_T : Injected feedwater enthalpy (temperature in upper part of RPV bottom head (in direction of 0°)) (kJ/kg)

h_{in} : Injected feedwater enthalpy (temperature of 10 °C) (kJ/kg)

ρ : Water density (kg/m^3)

W_{FDW} : Feedwater flow rate (m^3/h)

The evaluation results are as follows:

Evaluation date	Jan. 17	Feb. 11	Feb. 12	Feb. 13
Feedwater flow rate (m^3/h)	3	6.7	7.6	7.8
Temperature in upper part of RPV bottom head (in direction of 0°) (°C)	50	70	80	90
Calorific value necessary for rise of water temperature (MW) (Rate in decay heat)	0.07 (11%)	0.23 (39%)	0.31 (52%)	0.36 (61%)

As this case had discrepancies as shown below, the likeliness of this case as a presumed case was considered low.

- The calorific value necessary for the rise of the water temperature was evaluated as 60% or more of the decay heat at maximum.
  → Because it was difficult to suppose that more than half of the melted fuel was accumulated inside the shroud near the aforementioned thermometer.
- The calorific value necessary for the rise of the water temperature was increasing everyday.
  → Because it was difficult to suppose that major relocation of debris and/or extreme malfunction of cooling occurred during this period.

3) Case (2) (Heat transfer by baffle plate)

The methods and preconditions used for evaluation are as follows:

(a) Assuming that heat from the debris inside the shroud (including the shroud support) heated the baffle plate by the effect of heat transfer, resulting in the rise of the temperature indicated by the aforementioned thermometer mounted on the RPV wall, we evaluated the temperature of the baffle plate section by means of an equation for heat transfer from the inside of the shroud support to the RPV wall.

(b) Heat transfer from the baffle plate to the liquid phase in the annulus section was considered.

(c) The temperature on the shroud side was assumed to be 100 °C, which was identical to the liquid phase boiling point. The temperature of the liquid phase in the annulus section was assumed to be 40 °C, which was calculated by rounding the average values of the temperatures of the upper part of the RPV bottom head (in the directions of 135° and 270°).

(d) For evaluation, we used the following equation based on the flat-plate, steady-state, one-dimensional heat transfer:

$$\lambda \frac{d^2T}{dx^2} + Q = 0$$

Q : Amount of heat transfer to liquid phase (W/m^3)
T : Temperature (K)
x : Length in the radial direction (m)
λ : Heat conductivity of baffle plate (W/mK)

The following equation was used to obtain the value of Q, or the heat removal to the liquid phase:

$$Q = h \times \Delta T / L$$

h : Coefficient of heat transfer to liquid phase (W/m^{2}K)
ΔT : Difference between the temperatures of baffle plate and liquid phase (K)
L : Baffle plate thickness (m)

The evaluation result is as shown in figure 4. As the coefficient of heat transfer from the baffle plate to the annulus section was great, the heat from the debris was transferred to the liquid phase. Therefore, even if the shroud support was supposed to be at a high temperature, the temperature of the baffle plate at a point about 0.2 m far from the shroud support became the same level of the liquid phase temperature, resulting in no rise of the RPV wall temperature. Therefore, the likeliness of this case as a presumed case was considered low.

4) Conclusion

As shown above, considering the event of temperature rise of this time as an actual event, we presumed two cases and evaluated them by use of a simple system. However, we obtained an evaluation result that the likeliness of both cases was low and thus, as a conclusion, we supposed that it was difficult to consider the event of this time as an actual event.

In an attempt to review the likeliness of the event of this time as an actual event by considering not only the aforementioned thermometer but also the consistency with the readings of the other thermometers, we are planning, in the future, to conduct a detailed evaluation by use of a more realistic, three-dimensional system (figure 5). We believe that the result of this detailed evaluation will help presume the mechanism in case of occurrence of a similar event.

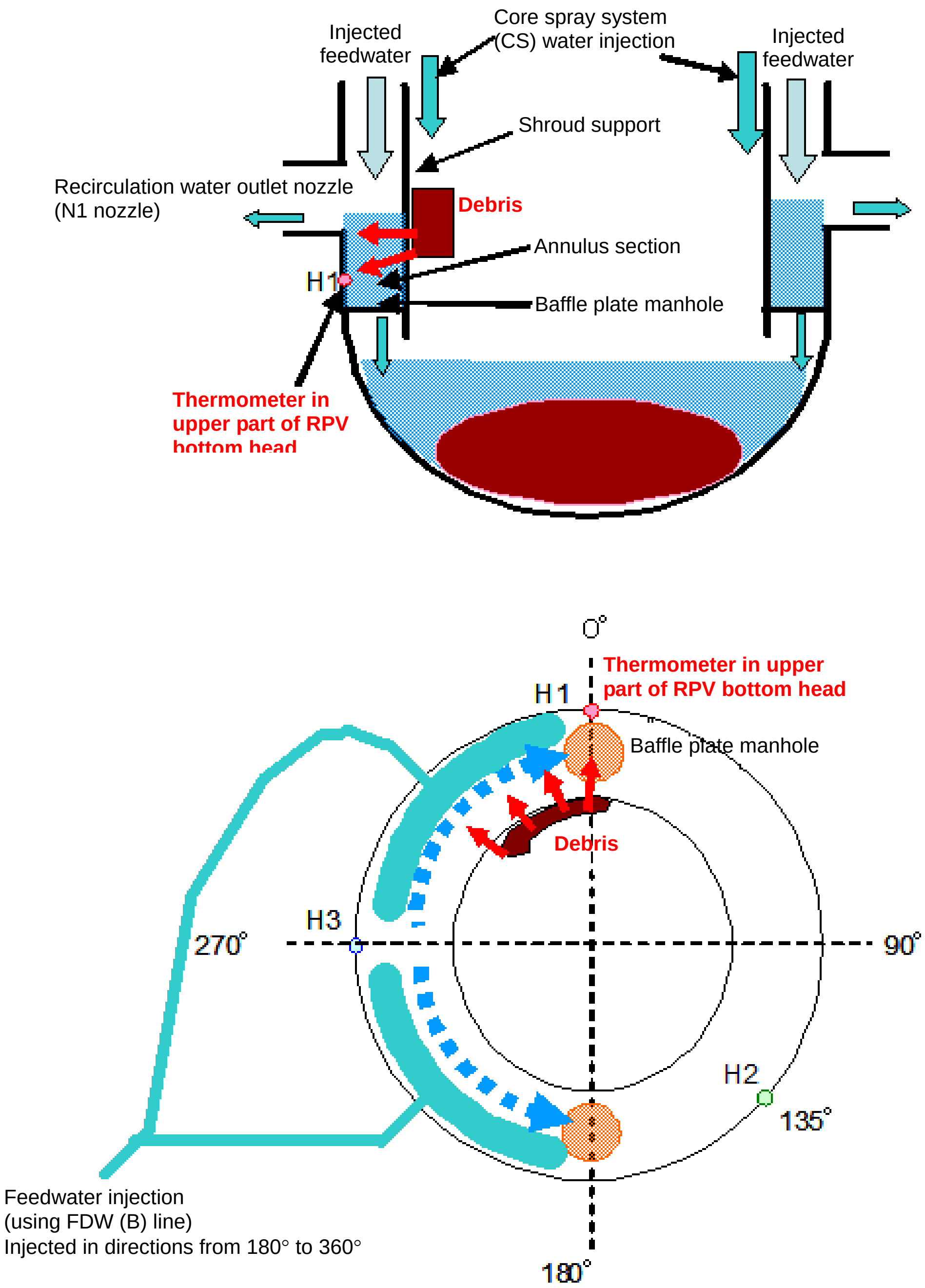


Figure 1 Overview of case (1) evaluation
(Upper illustration: Vertical section; Lower illustration: Horizontal section)

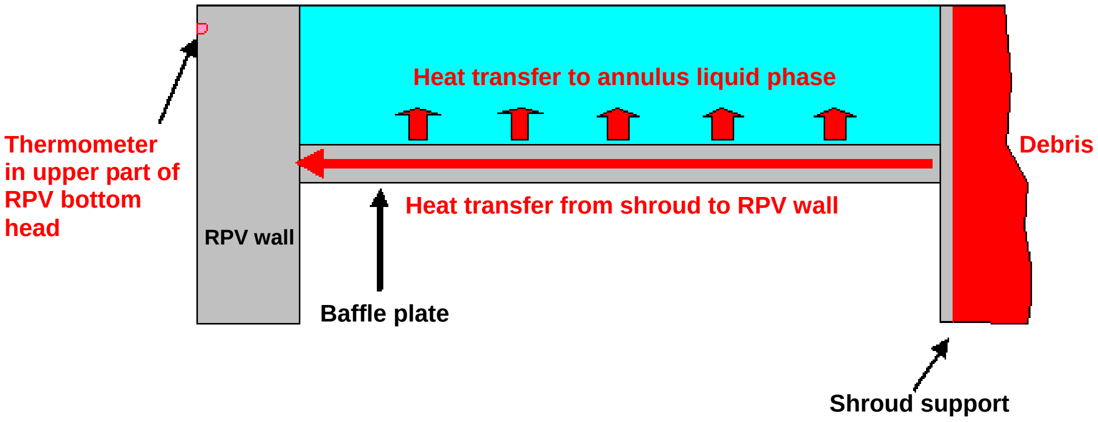


Figure 2 Overview of case (2) evaluation

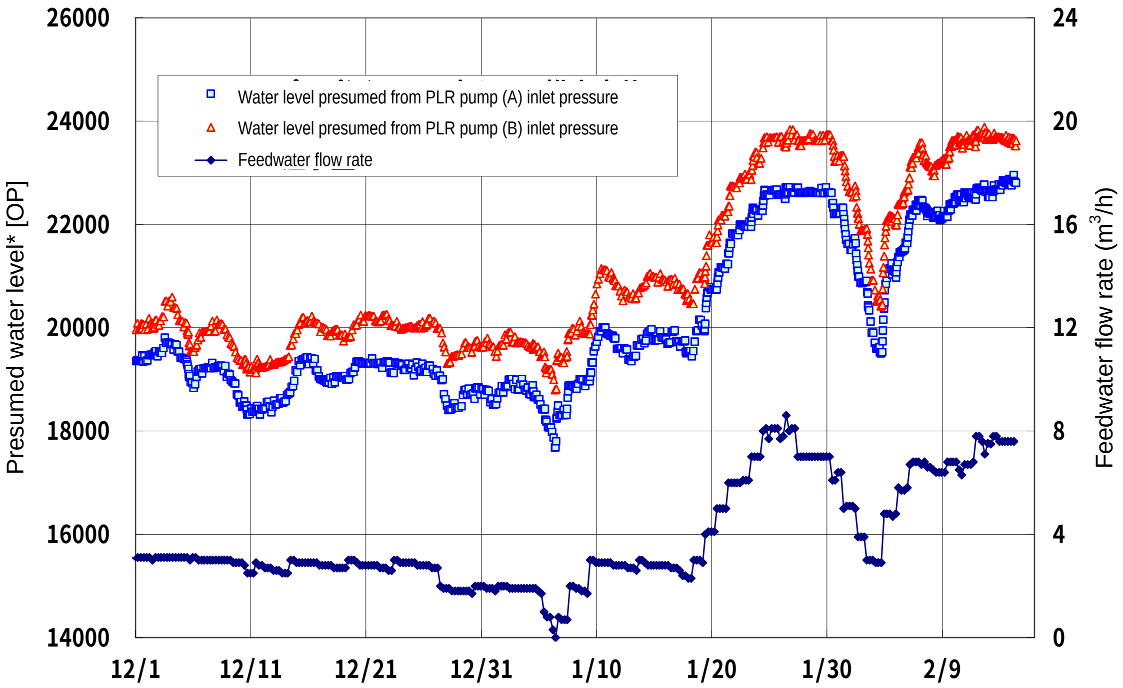


Figure 3 Presumed water levels in annulus section and feedwater flow rate

*: Presumed water level: Water level presumed by considering the difference between the recirculation system (PLR) pump inlet pressure and the dry well pressure as the water head at the PLR pump inlet and converting it to a water level.

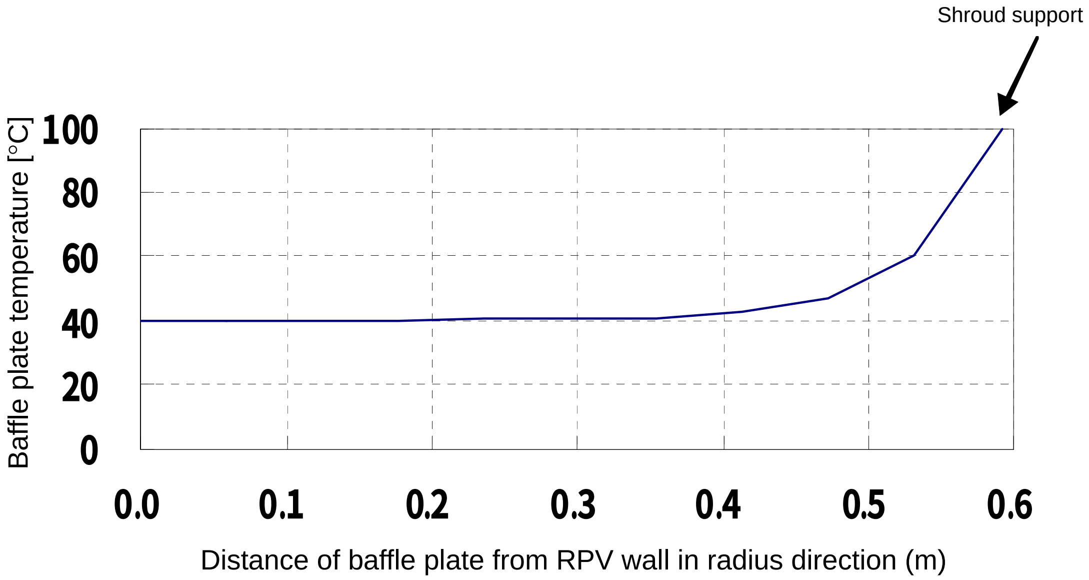


Figure 4 Evaluation result of case (2)

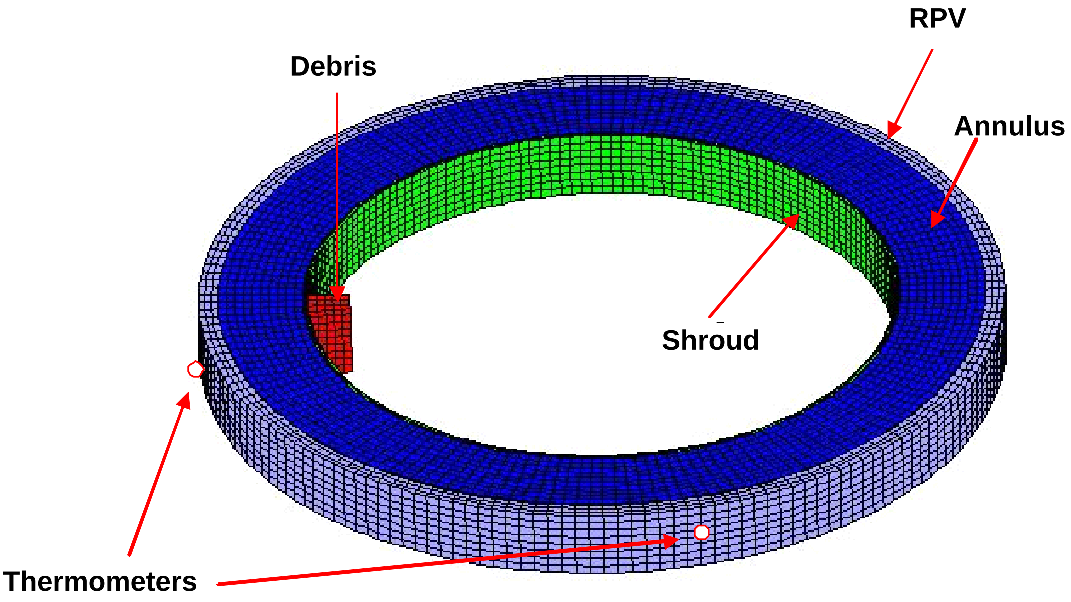


Figure 5 Analysis system proposed for detailed evaluation

2. (2) Presumed factors with regard to the series of reading variation indicated by the aforementioned thermometer

a. Introduction

One of the thermometers mounted in the upper part of the bottom head (TE-2-3-69H1) (hereinafter called “aforementioned thermometer”) in the reactor pressure vessel of reactor #2 at the Fukushima Daiichi Nuclear Power Station kept a tendency of rise of the reading while indicating a short-cycle variation (hunting) since February 2, 2012 (rise from approximately 50 °C). Thereafter, as the reading exceeded 80 °C on February 12, we declared deviation from the operational limits set forth in the safety regulation. Therefore we measured the direct current resistance of the aforementioned thermometer for inspection on February 13. We found a tendency of disconnection (*) (tendency of increase in the direct current resistance) and thus determined a failure of the aforementioned thermometer.

(Attachment-1)

Here, we reviewed some presumed factors with regard to the series of reading variation indicated by the aforementioned thermometer and performed mock-up tests to verify those factors.

(*) Tendency of disconnection: Indicated by a value exceeding 1.1 times of the direct current resistance measured during regular inspection.

[Table 1] Inspection results: Reactor #2 reactor pressure vessel bottom thermometer (TE-2-3-69H1)

Date of measurement	(1) Direct current resistance (Ω)	(2) Direct current resistance (Ω) at time of regular inspection	(1)/(2)
Sep. 30, 2011	175.47	303.37	0.58
Feb. 3, 2012	244.25		0.81
Feb. 13, 2012	500 to 535		1.65 to 1.76

b. Review of presumed factors

As the aforementioned thermometer was mounted within the primary containment vessel (PCV), we now could not directly inspect it. As an option, we might disassemble the cable at the local terminal block to locate the failure. However, the local terminal block, where the cable would be disassembled, was located near the penetration section of the primary containment vessel (PCV) above the TIP room on the first floor in the reactor building and was inaccessible due to very high dose. Therefore we could not even identify the range.

Under the circumstances, we verified the currently presumed factors in the possible scope, at the same time performed mock-up tests, simulating the presumed environment around, and the tendency of deterioration of, the aforementioned thermometer.

(1) Review of presumed factors

a. Failure of digital recorder characteristics

1) Erroneous connection or short circuit between terminals at terminal block
Remote inspection in the main control room found no abnormality.

2) Failure of digital recorder input circuit
   We removed the digital recorder and compared the readings with another thermometer (electromotive force converted to temperature). We found no difference between the readings and thus no abnormality with the digital recorder input circuit.

b. Failure of temperature sensor characteristics

1) Failure of reading caused by changes in material characteristic due to thermal degradation
   In "Report with regard to the facility operation plan based on 'Policy on the mid and long term security' for reactors #1 to #4 at Fukushima Daiichi Nuclear Power Station (Vol. 1)," we ensured that the temperature sensor characteristics showed no problem in a heat test up to 600 °C.
2) Electromotive force affected by insulation deterioration caused by dissimilar metals
   According to the theory of thermocouple, the thermoelectromotive force does not increase nor decrease even in cases where the temperature sensor touches any other metals than copper and constantan, which are the metal materials of the aforementioned thermometer (type T) (law of intermediate metals).
3) Rise of reading due to tendency of disconnection (tendency of increase in direct current resistance) of sensor
   As a result of direct current resistance measurement, we determined a tendency of disconnection (tendency of increase in direct current resistance). However, we could not locate the disconnected point from the result of TDR (time-domain reflectometry) measurement.
   Nonetheless, we could not deny the possibility that the reading might be affected by increase in the resistance of the thermometer circuit due to cable deterioration.
4) Rise of reading due to deterioration caused by experience of severe environmental conditions
   We could not deny the possibility of rise of the reading due to deterioration of the aforementioned thermometer caused by experience of severe environmental conditions.

c. Effect of disturbance (noise)

1) Noise intruding into digital recorder power source
   If noise intruded into the power source of the digital recorder, it would be supposed that the readings of the other thermometers were also changed. However, as the other temperature data of the same digital recorder did not indicate the same rise as the aforementioned thermometer, there was no possibility of noise intruding into the power source of the digital recorder.
2) Noise intruding from main recorder
   We switched off the power of all the temperature recorders within the same board as the recorder to which the aforementioned thermometer was connected but found no variation in the readings. Therefore, there was no possibility of noise intruding from the main recorder.
3) Noise intruding into signal cables
   For this inspection, we needed to disassemble the cables at the local terminal block but it was located near the penetration section of the primary containment vessel (PCV) above the TIP room on the first floor in the reactor building and was inaccessible due to very high dose. So we could not conduct this inspection.

(Attachment-2)

As shown above, the presumed factors included rise of the reading due to a tendency of disconnection of the detection circuit (tendency of increase in direct current resistance) and rise of the reading due to deterioration of the aforementioned thermometer caused by experience of severe environmental conditions.

(2) Mock-up tests simulating presumed environment around, and failure of, aforementioned thermometer

As the aforementioned thermometer was mounted inside the primary containment vessel (PCV) and was supposed to experience severe environmental conditions after the accident, we performed mock-up tests, simulating the environment around, and the tendency of deterioration of, the aforementioned thermometer.

a. Verification of short-cycle variation of reading (hunting)

1) Test conditions

We verified the reading after inserting a variable resister in the thermometer circuit.

2) Test results

As a result of simulation of disconnection tendency by a variable resister inserted in the line (to increase the direct current resistance), we verified a short-cycle variation of thermometer reading (hunting).

(Attachment-3)

b. Verification of rise of temperature reading

1) Test conditions

Presuming the environment around, and the deterioration condition of, the aforementioned thermometer, we performed mock-up tests under the following conditions:

○ Used a type-T thermometer, which was the same type of the aforementioned thermometer.

○ Simulated a resistance increase according to the direct current measurement results.

○ Simulated cable deterioration by damaging the cable covering and leaving one copper wire.

○ As seawater was injected in the early phase of the accident, we presumed that the sensor section had been exposed to water containing salt.

○ Simulated a highly humid condition as we presumed that the sensor section was in a highly humid condition.

2) Test results

We checked the transition of the temperature reading by use of the digital recorder under the test conditions. When the highly humid condition was simulated (exposed to steam), though the reference temperature at the sensing section was around 80 °C, the temperature reading moved between 50 and 180 °C immediately after simulation. Then it stably became around 170 °C and thereafter gradually rose. Three and a half minutes later, it reached approximately 230 °C and became almost stable (tendency of slight rise) in that condition.

This test was conducted three times, in each of which we verified a tendency of temperature rise.

(Attachment-4)

c. Conclusion

We reviewed some presumed factors with regard to the series of reading variation indicated by the thermometer mounted in the bottom section of the reactor pressure vessel (TE-2-3-69H1) and performed mock-up tests to verify those factors.

As a result of the mock-up tests, the short-cycle variation of the reading of the aforementioned thermometer observed this time (hunting) and the rise of the thermometer reading were both verified to be likely to occur, though these were indicated in different tests.

As to the event of this time, therefore we could verify as follows:

- ○ The temperatures indicated by the thermometers mounted in upper and lower parts and near the circumferential direction did not rise.
- ○ Through mock-up tests, variation of the reading (hunting) and rise of temperature reading were verified to be likely to occur.

Therefore, we determined that the thermometer mounted in the bottom section of the reactor pressure vessel (TE-2-3-69H1) had been malfunctioning since February 2, 2012.

On determining malfunction of the thermometer mounted in the bottom section of the reactor pressure vessel (TE-2-3-69H1), we excluded it from the monitored objects for the bottom temperature in the reactor pressure vessel set forth in Article 138 of the safety regulation.

d. Future schedule

As a result of the mock-up tests, we could verify that a behavior similar to that of this time was likely to occur. In the future, based on the mock-up test results, we will review the consistency with the event that occurred in the practical reactor and make efforts to clarify the mechanism of occurrence.

(Attachments)

Attachment-1:	Time series with regard to reactor pressure vessel bottom thermometer (TE-2-3-69H1)
Attachment-2:	Configuration of reactor pressure vessel bottom thermometer
Attachment-3:	Mock-up test results with regard to short-cycle variation of thermometer reading (hunting)
Attachment-4:	Mock-up test results with regard to rise of temperature reading

Attachment-1

Time series with regard to reactor pressure vessel bottom thermometer (TE-2-3-69H1)

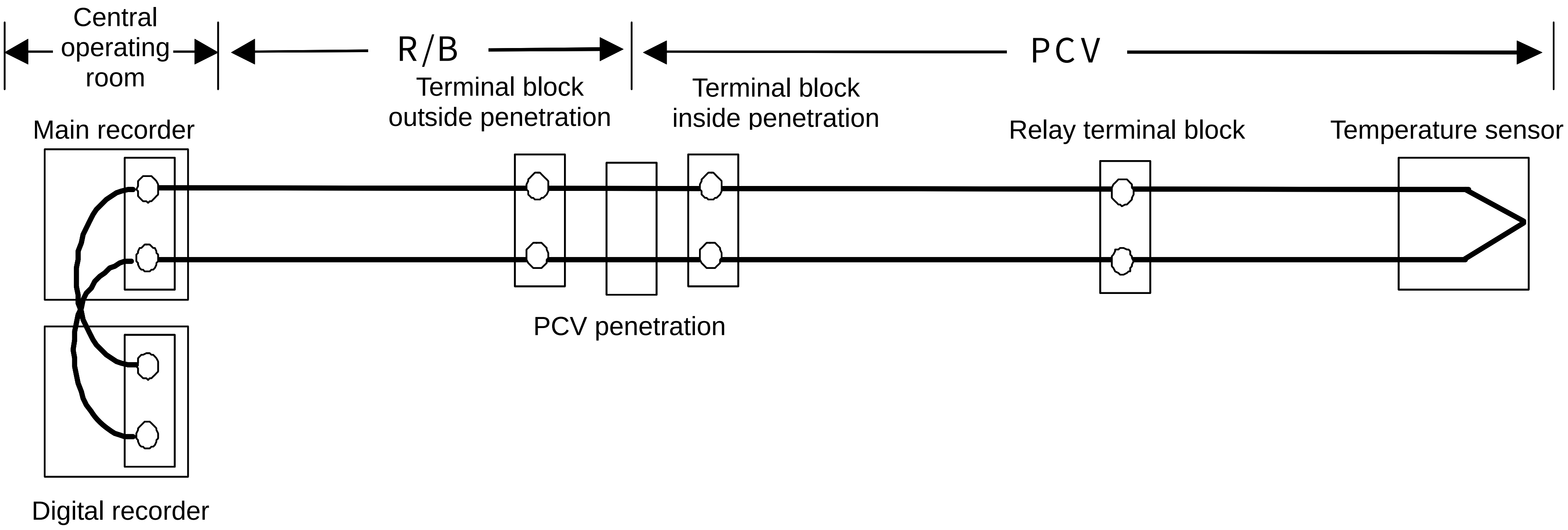
2011

- Mar. 20: Started sampling of thermometer readings by means of electromotive force measurement in central operating room (approximately 5 h per one time)
- Mar. 26: Recovered the thermometer power source and checked the reading. Since then, we took reading data for approximately 5 h per one time, using the central operating room recorder.
- May 29: Connected a digital recorder. Using it, we monitored the data in the main anti-earthquake building. Took record for 1 h per one time.
- Sep. 30: Electrical characteristic testing: Determined tendency of insulation deterioration.
- Dec. 1: Electrical characteristic testing
- Dec. 6: Evaluated the impact of the above-mentioned insulation deterioration and submitted a report, “Report with regard to the facility operation plan based on ‘Policy on the mid and long term security’ for reactors #1 to #4 at Fukushima Daiichi Nuclear Power Station (Vol. 1) (Amendment 2) (December 2011), Reactor pressure vessel and primary containment vessel (PCV) coolant injection facility, Attachment-1, Reliability of thermometers to monitor the reactor cooling condition,” based on a report collection order, “Collection of a report with regard to the facility operation plan based on ‘Policy on the mid and long term security’ for reactors #1 to #4 at Fukushima Daiichi Nuclear Power Station (dated October 3, 2011: Heisei 23・09・30 Gen No. 12).”
- Dec. 7: Electrical characteristic testing
- Dec. 12: Electrical characteristic testing

2012

- Jan. 27: Electrical characteristic testing
- Feb. 3: Electrical characteristic testing
- Feb. 13: Electrical characteristic testing. Determined a failure of the reading due to rise of direct current resistance and tendency of disconnection.

Configuration of reactor pressure vessel bottom thermometer



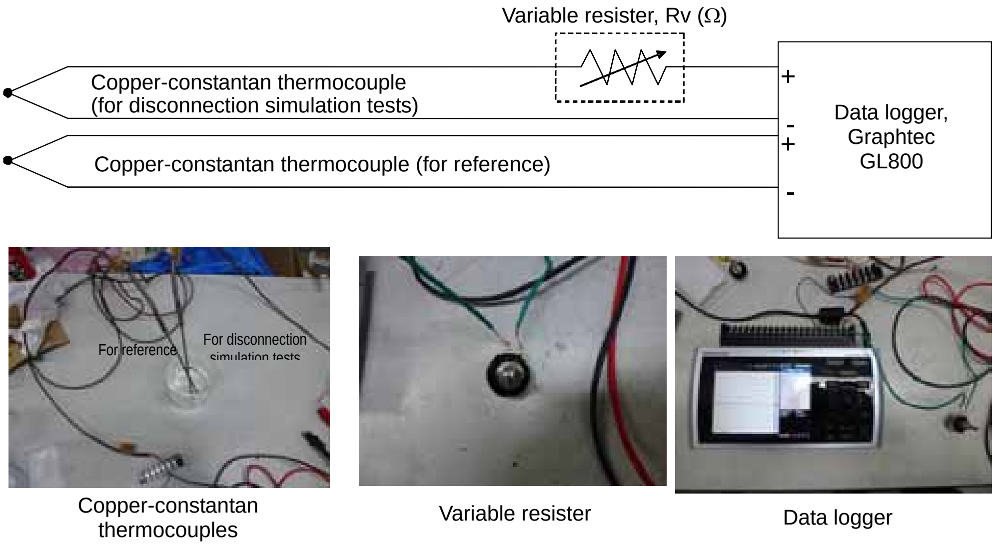
Attachment-3

Mock-up test results with regard to short-cycle variation of thermometer reading (hunting)

As to the event of temperature rise along with increase in the direct current resistance with regard to the reactor pressure vessel bottom thermometer (TE-2-3-69H1) in reactor #2, we checked the behavior in cases where the line resistance was increased:

1. Test circuit configuration

Figure 1 shows the test circuit configuration:



Copper-constantan thermocouples

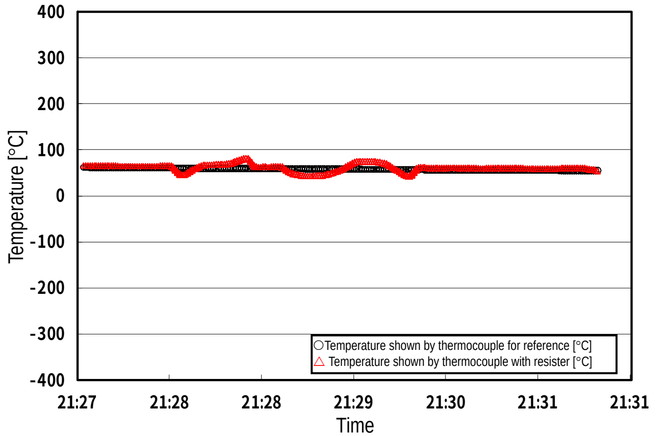
Variable resister

Data logger

Figure 1. Test configuration

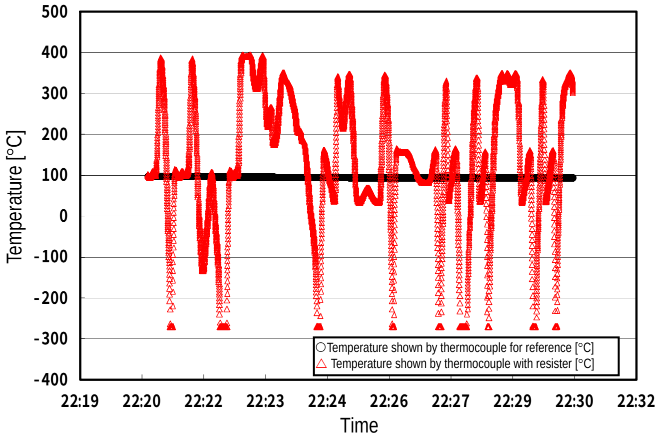
2. Test results

Figures 2 and 3 show the test results:



Temperature average shown by thermocouple for reference 59 [°C]
Temperature average shown by thermocouple with resister 57 [°C]

Figure 2. Behavior with variable resister set to 1.2 kΩ



Temperature average shown by thermocouple for reference 95 [°C]
Temperature average shown by thermocouple with resister 123 [°C]

Figure 3. Behavior with variable resister set to 8 kΩ

3. Conclusion

As a result of simulation of tendency of disconnection (increase in direct current resistance) by means of a variable resister inserted in the line, we verified short-cycle variation of temperature reading (hunting).

End of document

Mock-up test results with regard to rise of temperature reading

As to the event of temperature rise along with increase in the direct current resistance with regard to the reactor pressure vessel bottom thermometer (TE-2-3-69H1) in reactor #2, we conducted mock-up tests as follows:

1. Test direction

As the components of the aforementioned thermometer (including compensation lead wire and terminal block) were likely to be exposed to high temperatures, pressures, and humidity and the temperature detection circuit encountered decrease in insulation and tendency of disconnection, we tried to simulate these conditions as much as possible. In addition, as seawater was injected in the early phase of the accident, we presumed that the sensor section had been exposed to water containing salt.

2. Test method

Figure 1 shows an outline of the test circuit.

We used a type-T (copper-constantan) compensation lead wire, which was the same type as the aforementioned thermometer, as the tested sample. To more closely simulate the conditions shown in the above-mentioned test direction, we removed the covering on both sides (both copper and constantan sides) of the type-T compensation lead wire to expose the bare leads (*1). Soaking the bare leads in seawater (*2) and then exposing them to steam, we measured the temperature.

(*1) All copper leads but one cut. No constantan leads cut.

(*2) Salt water of a salt concentration of 3.5% used as seawater.

While inserting a 40-kΩ resister on the copper side of the compensation lead wire to simulate the disconnection condition, we measured the temperature trend by use of a digital recorder (1-second sampling) (putting the temperature sensing element in the liquid phase section within the electric pot). In addition, we measured the direct current resistance between the copper and constantan with the variable resister set to 40 kΩ (measurement omitted when no change in temperature appeared).

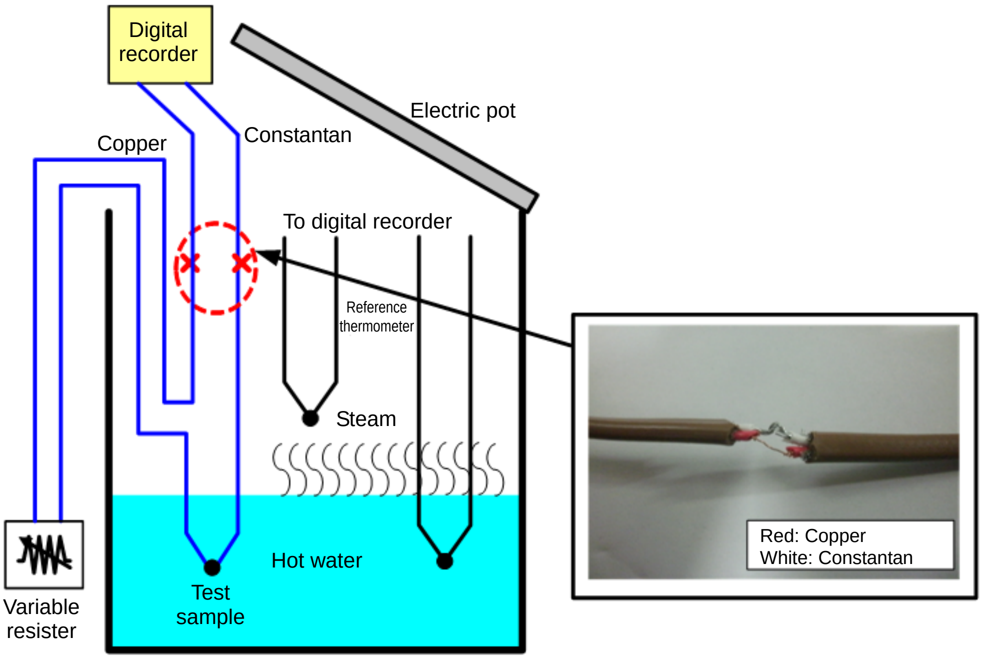


Figure 1. Outline of mock-up tests

3. Test results

a) Direct current resistance measurement results (measured on February 15, 2012)

Table 1. Direct current resistance measurement results

Value of inserted resister	Direct current resistance			
	Before test	When soaked in seawater	When raised out of seawater	When exposed to steam
40 kΩ	40.3 kΩ	11.2 kΩ	40.3 kΩ	16.5 kΩ

b) Temperature trend (measured on February 15, 2012)

When the temperature sensing section was exposed to steam, though the reference temperature at the temperature sensing section was around 80 °C the temperature reading moved between 50 and 180 °C immediately after exposure. Then it stably became around 170 °C and thereafter gradually rose. Three and a half minutes after exposure, it reached approximately 230 °C and became almost stable (tendency of slight rise).

This test was repeated three more times under the same conditions, in each of which we verified a similar tendency of temperature rise.

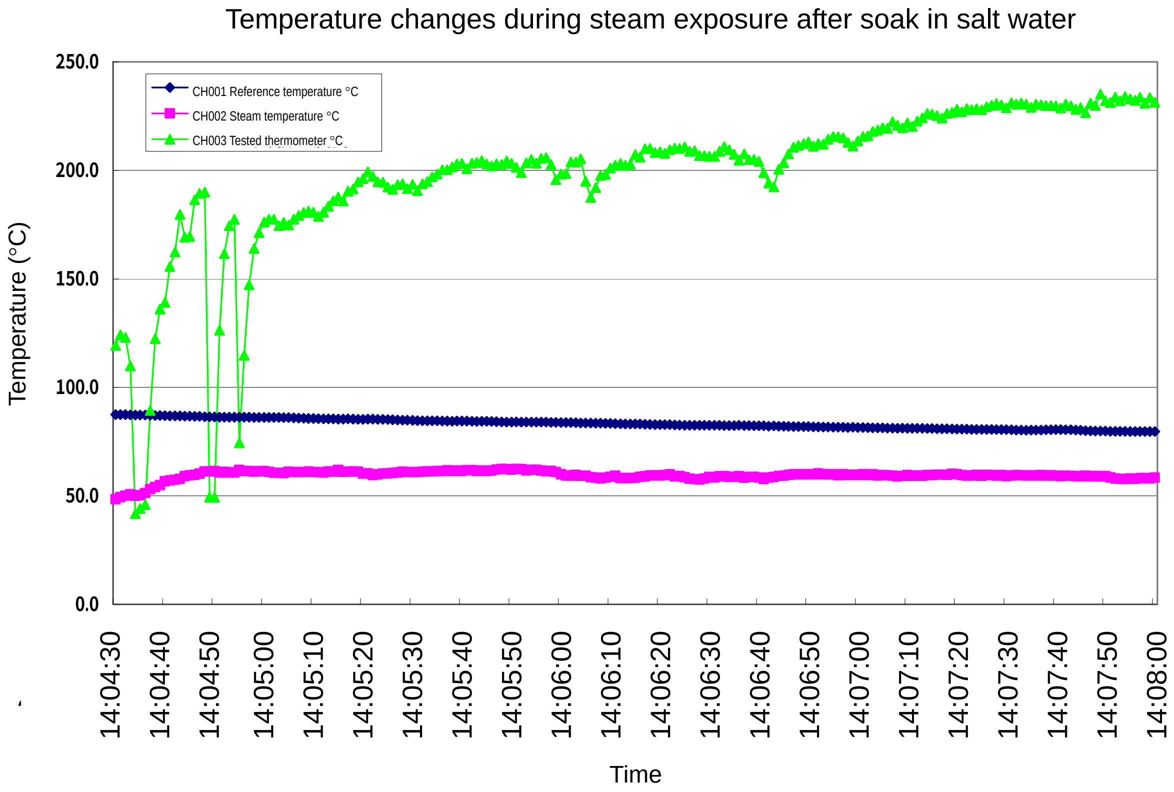

Temperature changes during steam exposure after soak in salt water

Figure 2. Temperature trend

4. Considerations

By conducting the mock-up tests this time, in which we removed the covering on both sides (both copper and constantan sides) of the type-T compensation lead wire to expose the bare leads, soaked them in seawater, and then exposed them to steam at a temperature of about 60℃, we obtained a result of gradual rise of temperature three times.

From the mock-up test results, the following conditions are likely:

(1) As the thermometer components (including compensation lead wire and terminal block) were exposed to high temperatures, pressures, and humidity after the accident, the use condition was exceeded, causing insulation deterioration and tendency of disconnection to occur in the temperature sensing circuit. Thereafter, injection of seawater and other measures caused attachment of materials such as seawater (electrolyte solutions), which generated corrosion potential where insulation was deteriorated, and therefore a potential difference occurred due to corrosion caused by the effects of electrolyte solutions and humidity, affecting the thermometer circuit as a faint potential.

(2) At the same time, the points having tendency of disconnection on the thermometer configuring circuit were deteriorated by such factors as the humid environment and the tendency of disconnection proceeded, causing increase in resistance.

(3) By the effect of (1) and (2), the reading of the thermometer gradually indicated values higher than the actual temperatures.

End of document

3. Measures to be taken in the future

(1) Ideas with regard to indices for verification of maintenance of the cold shutdown state and its application

In December 2011, reactors #1 to #3 were determined to be in the cold shutdown state based on the facts (1) that the temperatures at the bottom part of the pressure vessel and inside the primary containment vessel (PCV) were approximately 100 °C or less, (2) that release of radioactive materials from the primary containment vessel (PCV) was controlled and the public exposure dose was greatly restricted (0.1 mSv/year at premises boundary. Target: 1 mSv/year or less), and (3) that the middle-term safety of the circulating injection cooling system was ensured.

When monitoring the temperature of the reactor pressure vessel, we not only focus on the behavior of each thermometer but also check the correlations between those thermometers set at the same elevation and at different angles and between those set at different elevations and at the same angle, so as to make comprehensive judgment. If we suppose that the temperature is actually rising, we check the pressure in the primary containment vessel (PCV) because steam is likely to be generated. At this point, because re-criticality is possible as a factor of the temperature rise, we check the concentrations of noble gases. In addition, in parallel, we check whether radioactive materials are released to the environment due to generation of steam.

For temperature measurement in reactor #2, we have so far used five thermometers in the bottom section of the reactor pressure vessel and nine thermometers for the ambient temperature in the primary containment vessel (PCV) as the temperature monitoring points according to the safety regulation. The thermometer in which disconnection was found this time is one of the five mounted in the bottom section of the reactor pressure vessel.

To judge maintainability of the cold shutdown state and stability of the plant in the future, we will keep monitoring the following plant parameters of each reactor aiming at grasping insufficient heat removal conditions at local points and identifying abnormal amount of entire release as well:

(1) Reactor pressure vessel bottom temperature (within the scope of the safety regulation)
(2) Primary containment vessel (PCV) ambient temperature (within the scope of the safety regulation)
(3) Drywell pressure
(4) Gas control facility exhaust temperature
(5) Radiation dose on gas control facility filter unit surface and concentrations of radioactive materials at exhaust filter inlet/outlet
(6) Concentrations of noble gases in gas control facility exhaust
(7) Amount of radioactive material release from reactor building to atmosphere

If any reading of the thermometers indicates abnormal behavior in the future, we will analyze the behaviors of the above parameters in an attempt to grasp the condition inside the reactor. ([Reference 1])

Note that, in addition to the above, as a complement to confirmation of the cold shutdown state, we will consider monitoring of other parameters while taking into consideration exposure caused by measurement, accessibility, and instrument conditions.

○ Examples of supplementary parameters

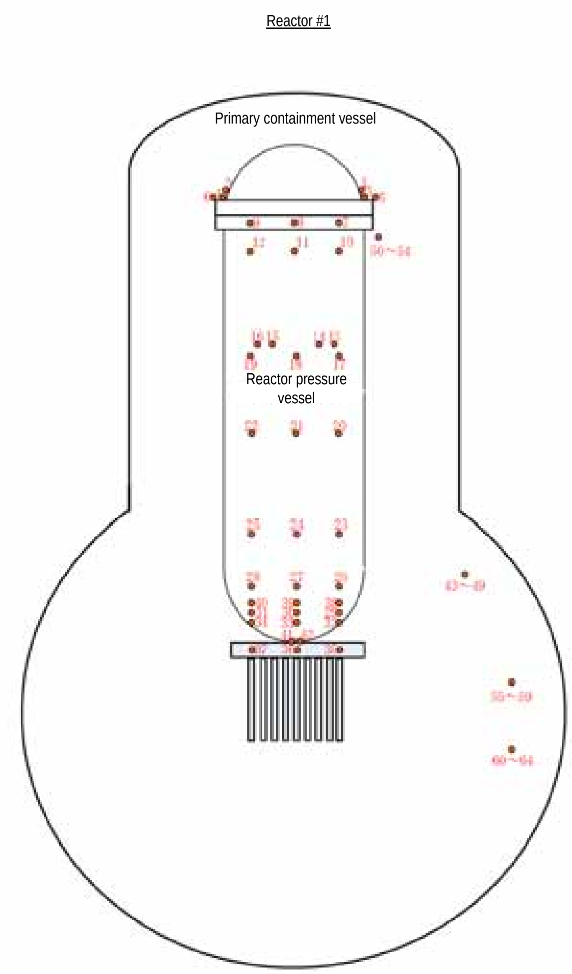
- Water level inside the reactor (monitoring of cooling of the heat source inside the reactor pressure vessel to grasp foreshadowing of insufficient cooling)
- Water level inside the primary containment vessel (PCV) (to monitor cooling of the heat source inside the primary containment vessel (PCV))
- Temperature at each section of the reactor pressure vessel（As it is likely to grasp significant changes with regard to steam generation within the reactor.）[Reference 2]
- S/C pool water temperature (As it is likely to detect abnormality of heat exchange amount of the heat sources inside the reactor and the primary containment vessel (PCV).)
- Temperature at each section near 0° (To complement the exclusion of the thermometer in the upper part of the RPV bottom head.　Reactor #2 only.)

[Reference 1] Relativity of each plant parameter with cold shutdown state

Plant parameter	Relativity with cold shutdown state	Remarks
(1) Reactor pressure vessel bottom temperature	This is a section that is presumed to have many heat sources. If we ensure a cooling condition there, then we can determine a cold shutdown state.	Within the scope of the safety regulation
(2) Primary containment vessel (PCV) ambient temperature	We presume that the fuel has fallen out of the reactor and the heat sources exist at the bottom of the primary containment vessel (PCV). If these heat sources are insufficiently cooled, the ambient temperature in the primary containment vessel (PCV) will rise. If we ensure a cooling condition of the ambience of the primary containment vessel (PCV), then we can determine a cold shutdown state.	Within the scope of the safety regulation
(3) Drywell pressure	If the heat source within either reactor pressure vessel or primary containment vessel (PCV) is insufficiently cooled, the steam temperature will rise and the generated steam will pressurize the inside of the primary containment vessel (PCV), possibly causing the drywell pressure to rise. Unless the drywell pressure indicates a significant rise, we can determine that the generation of steam is not remarkable. (This is applicable in case where the leak hole is not remarkably large.)	As we have ensured that the drywell pressure is changed by the following parameters, etc. in addition to steam generation, it is required to consider these parameters for monitoring: - Amount of injected nitrogen - Exhaust flow rate of gas control facility - Outside pressure - PCV water level
(4) Primary containment vessel (PCV) gas control facility exhaust temperature	If the heat source within either reactor pressure vessel or primary containment vessel (PCV) is insufficiently cooled, the steam temperature will rise and the generated steam will heat the inside of the primary containment vessel (PCV), causing the primary containment vessel (PCV) ambient temperature to rise. Unless the exhaust temperature of the gas control facility for the primary containment vessel (PCV) indicates a significant rise, we can determine that the generation of steam is not remarkable.	As we have ensured that the exhaust temperature of the gas control facility for the primary containment vessel (PCV) is changed by the following parameters, etc. in addition to steam generation, it is required to consider these parameters for monitoring: - Amount and temperature of injected nitrogen - Exhaust flow rate of gas control facility - Outside pressure (See [Reference 3] for schematic drawings of primary containment vessel (PCV) gas control facility system.)
(5) Radiation dose on gas control facility filter unit surface and concentrations of radioactive materials at exhaust filter inlet/outlet	If the heat source within either reactor pressure vessel or primary containment vessel (PCV) is insufficiently cooled, the steam temperature will rise and such radioactive materials as cesium accompanying the steam will be absorbed by the gas control facility of the primary	As we have ensured that the dust concentration of the gas control facility exhaust is changed depending on the following parameters, etc. in addition to steam generation, it is required to consider these

	containment vessel (PCV). If the radioactive material amount is larger, it is likely that the radioactive material concentration may rise at the filter outlet. Unless the radioactive dose on the surface of the exhaust filter unit of the gas control facility of the primary containment vessel (PCV) and the dust concentration at the exhaust filter outlet (multichannel analyzer waveform) significantly rise (change), then we can determine that the release of radioactive materials from inside of the primary containment vessel (PCV) is not significantly increased.	parameters for monitoring: - Amount of injected nitrogen - Exhaust flow rate of gas control facility Note that sampling of the exhaust filter inlet should be performed if the other parameters significantly change, taking into consideration the work exposure dose of the workers due to sampling work.
(6) Concentrations of noble gases in gas control facility exhaust of primary containment vessel (PCV)	If re-criticality occurs inside the reactor pressure vessel or the primary containment vessel (PCV), the concentrations of noble gases will rise. Unless the concentrations of noble gases significantly rise, then we can determine that re-criticality does not occur.	Reactor #1 can continuously be monitored. Reactors #2 and #3 will be able to be continuously monitored after introduction of noble gas monitors.
(7) Amount of radioactive material release from reactor building to atmosphere	If the heat source within either reactor pressure vessel or primary containment vessel (PCV) is insufficiently cooled, the steam temperature will rise and such radioactive materials as cesium accompanying the steam will leak out of the primary containment vessel (PCV). Unless the dust concentration in the upper part inside the reactor building significantly rises, we can determine that no radioactive material is released to the environment.	See [Reference 4] for conditions of the individual reactors.

[Reference 2] Thermometer locations in individual reactors
(Gray backgrounds indicate unused or unusable instruments.)



No.	Tag No.	Service name	Measurement device condition	Digital recorder input
1	TE-263-66A1	VESSEL HEAD ADJAC. TO FLANGE	○	Input
2	TE-263-66A2	VESSEL HEAD ADJAC. TO FLANGE	A1	No input
3	TE-263-66B1	VESSEL HEAD FLANGE	○	Input
4	TE-263-66B2	VESSEL HEAD FLANGE	A1	No input
5	TE-263-67A1	VESSEL STUD	○	Input
6	TE-263-67A2	VESSEL STUD	A1	No input
7	TE-263-69A1	Reactor flange	○	Input
8	TE-263-69A2	Reactor flange	A1	No input
9	TE-263-69A3	Reactor flange	○	Input
10	TE-263-69B1	Reactor steam	○	Input
11	TE-263-69B2	Reactor steam	○	Input
12	TE-263-69B3	Reactor steam	A2	Input
13	TE-263-69D1	N-4B nozzle END	○	Input
14	TE-263-69D2	N-4B nozzle END IN BOARD	○	Input
15	TE-263-69E1	N-4C nozzle END	○	Input
16	TE-263-69E2	N-4C nozzle END IN BOARD	○	Input
17	TE-263-69C1	VESSEL BELOW WATER LEVEL	○	Input
18	TE-263-69C2	VESSEL BELOW WATER LEVEL	A1	No input
19	TE-263-69C3	VESSEL BELOW WATER LEVEL	A2	Input
20	TE-263-69F1	VESSEL CORE	○	Input
21	TE-263-69F2	VESSEL CORE	A1	No input
22	TE-263-69F3	VESSEL CORE	○	Input
23	TE-263-69G1	VESSEL DOWNCOMER	○	Input
24	TE-263-69G2	VESSEL DOWNCOMER	○	Input
25	TE-263-69G3	VESSEL DOWNCOMER	○	Input
26	TE-263-69H1	Reactor SKIRT JOINT upper part	○	Input
27	TE-263-69H2	Reactor SKIRT JOINT upper part	A1	No input
28	TE-263-69H3	Reactor SKIRT JOINT upper part	○	Input
29	TE-263-69K1	VESSEL SKIRT NEAR JOINT	○	Input
30	TE-263-69K2	VESSEL SKIRT NEAR JOINT	A1	No input
31	TE-263-69K3	VESSEL SKIRT NEAR JOINT	A1	No input
32	TE-263-69L1	VESSEL BOTTOM HEAD	○	Input
33	TE-263-69L2	VESSEL BOTTOM HEAD	○	Input
34	TE-263-69L3	VESSEL BOTTOM HEAD	A1	No input
35	TE-263-69M1	SUPPORT SKIRT AT MTG. FLANGE	○	Input
36	TE-263-69M2	SUPPORT SKIRT AT MTG. FLANGE	A1	No input
37	TE-263-69M3	SUPPORT SKIRT AT MTG. FLANGE	A1	No input
38	TE-263-69N1	CRD housing upper part	○	Input
39	TE-263-69N2	CRD housing upper part	A1	No input
40	TE-263-69N3	CRD housing upper part	○	Input

No.	Tag No.	Service name	Measurement device condition	Digital recorder input
41	TE-263-69P1	N-12 VESSEL BOTTOM	○	Input
42	TE-263-69P2	N-12 VESSEL BOTTOM	○	No input
43	TE-261-13A	Safety valve 4A	○	Input
44	TE-261-13B	Safety valve 4B	○	Input
45	TE-261-13C	Safety valve 4C	○	Input
46	TE-261-14A	RV-203-3A (blowdown valve)	○	Input
47	TE-261-14B	RV-203-3B (blowdown valve)	○	Input
48	TE-261-14C	RV-203-3C (blowdown valve)	○	Input
49	TE-261-14D	RV-203-3D (blowdown valve)	○	Input
50	TE-1625L	EQ AROUND CIRCUM RPV BELLOWS SEAL AREA	○	Input
51	TE-1625M	EQ AROUND CIRCUM RPV BELLOWS SEAL AREA	○	Input
52	TE-1625N	EQ AROUND CIRCUM RPV BELLOWS SEAL AREA	○	Input
53	TE-1625P	EQ AROUND CIRCUM RPV BELLOWS SEAL AREA	○	Input
54	TE-1625R	EQ AROUND CIRCUM RPV BELLOWS SEAL AREA	○	Input
55	TE-1625F	HVH-12A SUPPLY AIR	○	Input
56	TE-1625G	HVH-12B SUPPLY AIR	○	Input
57	TE-1625H	HVH-12C SUPPLY AIR	○	Input
58	TE-1625J	HVH-12D SUPPLY AIR	○	Input
59	TE-1625K	HVH-12E SUPPLY AIR	○	Input
60	TE-1625A	HVH-12A RETURN AIR	○	Input
61	TE-1625B	HVH-12B RETURN AIR	○	Input
62	TE-1625C	HVH-12C RETURN AIR	○	Input
63	TE-1625D	HVH-12D RETURN AIR	○	Input
64	TE-1625E	HVH-12E RETURN AIR	○	Input

○: Hygrometer with which failure has not been judged

A1: Hygrometer the cable of which does not reach the central operating room
(Spare detector. Floor 1 of reactor building is inaccessible due to a high dose area.)

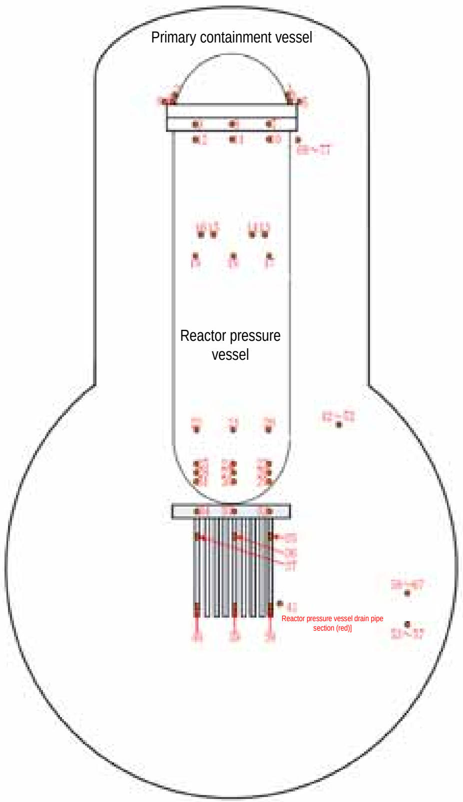
A2: Hygrometer with which failure has been found during periodical inspection

B1: Hygrometer with which disconnection has been judged in report of middle-term safety assurance

B2: Hygrometer with which failure (disconnection) has been judged after evaluation in report of middle-term safety assurance

Gray background indicates A1, A2, and no input to digital recorder.

Reactor #2

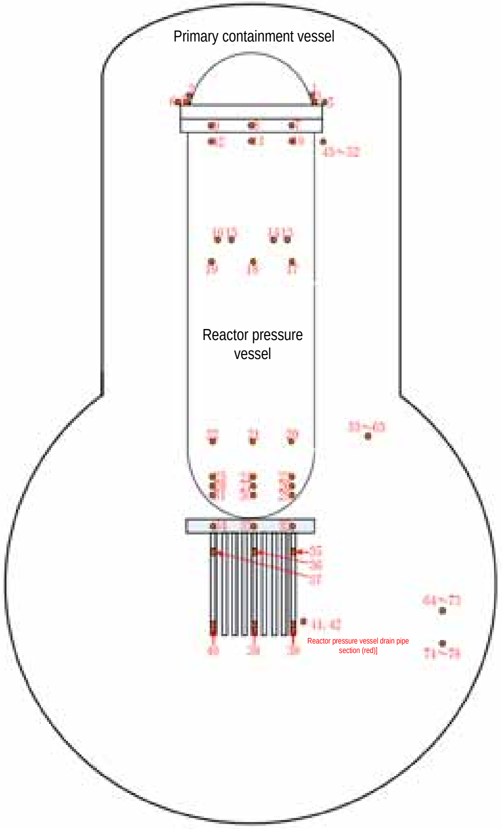


No.	Tag No.	Service name	Measurement device condition	Digital recorder input
1	TE-2-3-66A1	VESSEL HEAD ADJAC. TO FLANGE	A2	Input
2	TE-2-3-66A2	VESSEL HEAD ADJAC. TO FLANGE	○	Input
3	TE-2-3-66B1	VESSEL HEAD FLANGE	B2	Input
4	TE-2-3-66B2	VESSEL HEAD FLANGE	○	Input
5	TE-2-3-67A1	VESSEL STUD	○	Input
6	TE-2-3-67A2	VESSEL STUD	○	Input
7	TE-2-3-68A1	VESSEL FLANGE	○	No input
8	TE-2-3-68A2	VESSEL FLANGE	○	No input
9	TE-2-3-68A3	VESSEL FLANGE	○	Input
10	TE-2-3-69B1	VESSEL WALL ADJ TO FLANGE	○	No input
11	TE-2-3-69B2	VESSEL WALL ADJ TO FLANGE	○	Input
12	TE-2-3-69B3	VESSEL WALL ADJ TO FLANGE	○	Input
13	TE-2-3-69D1	FEEDWATER NOZZLE N4B END	○	No input
14	TE-2-3-69D2	FEEDWATER NOZZLE N4B INBOARD	○	Input
15	TE-2-3-69E1	FEEDWATER NOZZLE N4D END	○	Input
16	TE-2-3-69E2	FEEDWATER NOZZLE N4D INBOARD	○	Input
17	TE-2-3-69J1	VESSEL WALL BELOW FW NOZZLE	○	Input
18	TE-2-3-69J2	VESSEL WALL BELOW FW NOZZLE	○	Input
19	TE-2-3-69J3	VESSEL WALL BELOW FW NOZZLE	○	Input
20	TE-2-3-69H1	VESSEL WALL ABOVE BOTTOM HEAD	B2	Input
21	TE-2-3-69H2	VESSEL WALL ABOVE BOTTOM HEAD	○	Input
22	TE-2-3-69H3	VESSEL WALL ABOVE BOTTOM HEAD	○	Input
23	TE-2-3-69F1	VESSEL BOTTOM ABOVE SKIRT JOT	○	Input
24	TE-2-3-69F2	VESSEL BOTTOM ABOVE SKIRT JOT	○	Input
25	TE-2-3-69F3	VESSEL BOTTOM ABOVE SKIRT JOT	○	Input
26	TE-2-3-69K1	SUPPORT SKIRT TOP	○	Input
27	TE-2-3-69K2	SUPPORT SKIRT TOP	○	Input
28	TE-2-3-69K3	SUPPORT SKIRT TOP	○	Input
29	TE-2-3-69L1	VESSEL BOTTOM HEAD	B1	Input
30	TE-2-3-69L2	VESSEL BOTTOM HEAD	○	Input
31	TE-2-3-69L3	VESSEL BOTTOM HEAD	A2	Input
32	TE-2-3-69M1	SUPPORT SKIRT AT MTG.FLANGE	B2	Input
33	TE-2-3-69M2	SUPPORT SKIRT AT MTG.FLANGE	B2	Input
34	TE-2-3-69M3	SUPPORT SKIRT AT MTG.FLANGE	○	Input
35	TE-2-3-69N1	TOP CONTROL ROD DRIVE HOUSING	B2	Input
36	TE-2-3-69N2	TOP CONTROL ROD DRIVE HOUSING	B1	Input
37	TE-2-3-69N3	TOP CONTROL ROD DRIVE HOUSING	A1	Input
38	TE-2-3-69P1	BOTTOM CONTROL ROD DRIVE HOUSING	○	No input
39	TE-2-3-69P2	BOTTOM CONTROL ROD DRIVE HOUSING	A1	Input
40	TE-2-3-69P3	BOTTOM CONTROL ROD DRIVE HOUSING	B2	Input

No.	Tag No.	Service name	Measurement device condition	Digital recorder input
41	TE-2-106	VESSEL BOTTOM DRAIN	○	Input
42	TE-2-112A	SAFETY VALVES RV 2-70A	B2	Input
43	TE-2-112B	SAFETY VALVES RV 2-70B	B2	Input
44	TE-2-112C	SAFETY VALVES RV 2-70C	○	Input
45	TE-2-113A	Blowdown Valves A	○	Input
46	TE-2-113B	Blowdown Valves B	○	Input
47	TE-2-113C	Blowdown Valves C	○	Input
48	TE-2-113D	Blowdown Valves D	○	Input
49	TE-2-113E	Blowdown Valves E	○	Input
50	TE-2-113F	Blowdown Valves F	○	Input
51	TE-2-113G	Blowdown Valves G	○	Input
52	TE-2-113H	Blowdown Valves H	○	Input
53	TE-16-114A	RETURN AIR DRYWELL COOLER	○	Input
54	TE-16-114B	RETURN AIR DRYWELL COOLER	○	Input
55	TE-16-114C	RETURN AIR DRYWELL COOLER	○	Input
56	TE-16-114D	RETURN AIR DRYWELL COOLER	○	Input
57	TE-16-114E	RETURN AIR DRYWELL COOLER	○	Input
58	TE-16-114F#1	SUPPLY AIR D/W COOLER HVH 2-16A	○	Input
59	TE-16-114F#2	SUPPLY AIR D/W COOLER HVH 2-16A	○	No input
60	TE-16-114G#1	SUPPLY AIR D/W COOLER HVH 2-16B	○	Input
61	TE-16-114G#2	SUPPLY AIR D/W COOLER HVH 2-16B	○	No input
62	TE-16-114H#1	SUPPLY AIR D/W COOLER HVH 2-16C	○	Input
63	TE-16-114H#2	SUPPLY AIR D/W COOLER HVH 2-16C	○	No input
64	TE-16-114J#1	SUPPLY AIR D/W COOLER HVH 2-16D	○	Input
65	TE-16-114J#2	SUPPLY AIR D/W COOLER HVH 2-16D	○	No input
66	TE-16-114K#1	SUPPLY AIR D/W COOLER HVH 2-16E	○	Input
67	TE-16-114K#2	SUPPLY AIR D/W COOLER HVH 2-16E	○	No input
68	TE-16-114L#1	RPV BELLOWS SEAL AREA	○	Input
69	TE-16-114L#2	RPV BELLOWS SEAL AREA	○	No input
70	TE-16-114M#1	RPV BELLOWS SEAL AREA	○	Input
71	TE-16-114M#2	RPV BELLOWS SEAL AREA	○	No input
72	TE-16-114N#1	RPV BELLOWS SEAL AREA	○	Input
73	TE-16-114N#2	RPV BELLOWS SEAL AREA	○	No input
74	TE-16-114P#1	RPV BELLOWS SEAL AREA	B1	Input
75	TE-16-114P#2	RPV BELLOWS SEAL AREA	B2	Input
76	TE-16-114R#1	RPV BELLOWS SEAL AREA	B2	Input
77	TE-16-114R#2	RPV BELLOWS SEAL AREA	○	Input

○: Hygrometer with which failure has not been judged
A1: Hygrometer the cable of which does not reach the central operating room (Spare detector. Floor 1 of reactor building is inaccessible due to a high dose area.)
A2: Hygrometer with which failure has been found during periodical inspection
B1: Hygrometer with which disconnection has been judged in report of middle-term safety assurance
B2: Hygrometer with which failure (disconnection) has been judged after evaluation in report of middle-term safety assurance
Gray background indicates A1, A2, and no input to digital recorder.

Reactor #3



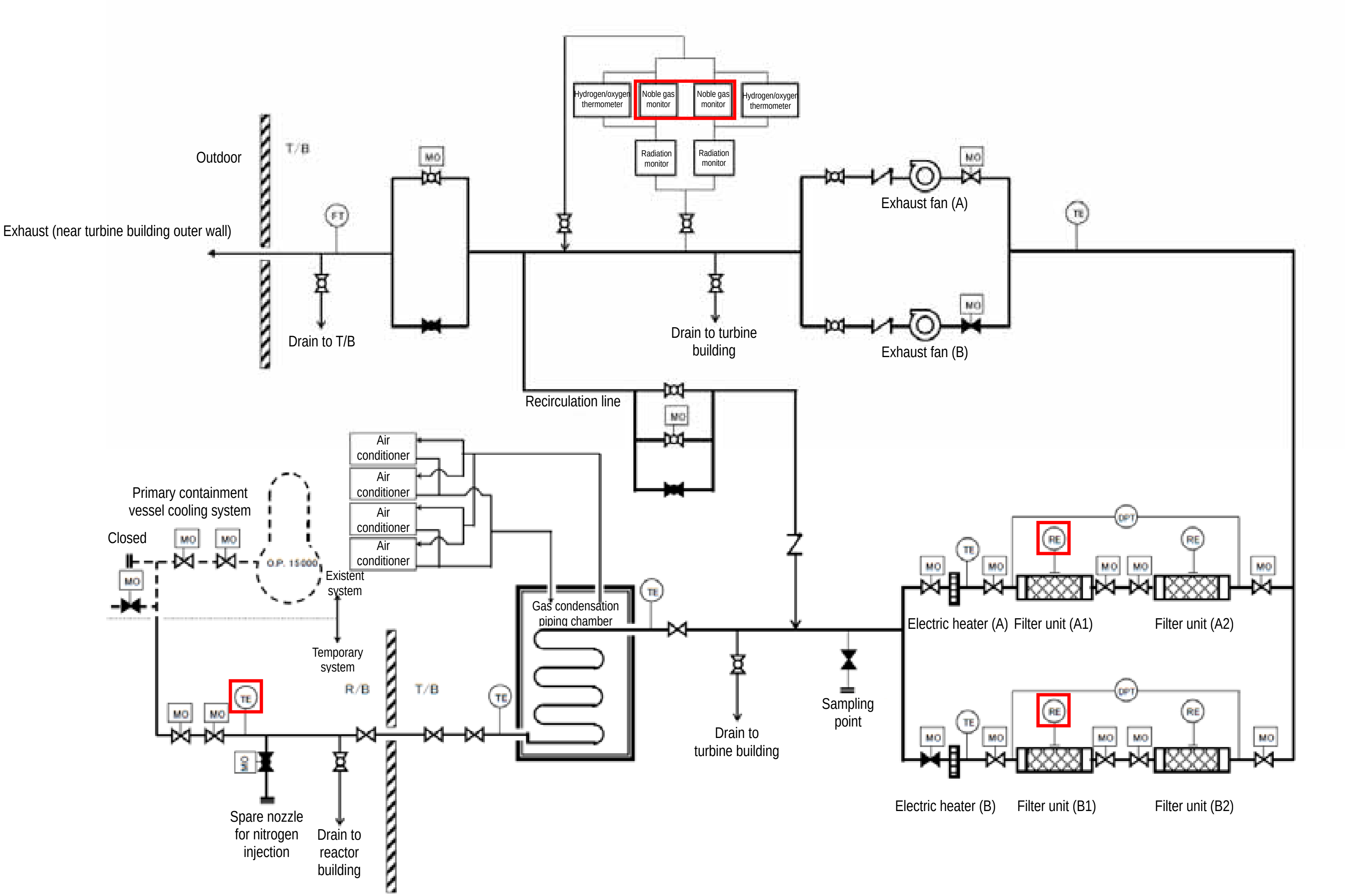
No.	Tag No.	Service name	Measurement device condition	Digital recorder input
1	[illegible]	Temperature around RPV upper cover flange	○	Input
2	[illegible]	Temperature around RPV upper cover flange	○	Input
3	[illegible]	RPV upper cover flange temperature	○	Input
4	[illegible]	RPV upper cover flange temperature	○	Input
5	[illegible]	RPV stud bolt temperature	○	Input
6	[illegible]	RPV stud bolt temperature	○	Input
7	[illegible]	RPV flange temperature	○	Input
8	[illegible]	RPV flange temperature	○	Input
9	[illegible]	RPV flange temperature	○	Input
10	[illegible]	Temperature around RPV flange	○	Input
11	[illegible]	Temperature around RPV flange	○	Input
12	[illegible]	Temperature around RPV flange	○	Input
13	[illegible]	RPV feedwater nozzle N4B temperature	○	Input
14	[illegible]	RPV feedwater nozzle N4B temperature	○	Input
15	[illegible]	RPV feedwater nozzle N4D temperature	○	Input
16	[illegible]	RPV feedwater nozzle N4D temperature	○	Input
17	[illegible]	RPV feedwater nozzle lower part temperature	○	Input
18	[illegible]	RPV feedwater nozzle lower part temperature	○	Input
19	[illegible]	RPV feedwater nozzle lower part temperature	○	Input
20	[illegible]	RPV bottom head upper part temperature	○	Input
21	[illegible]	RPV bottom head upper part temperature	○	Input
22	[illegible]	RPV bottom head upper part temperature	○	Input
23	[illegible]	Skirt junction upper part temperature	○	Input
24	[illegible]	Skirt junction upper part temperature	○	Input
25	[illegible]	Skirt junction upper part temperature	○	Input
26	[illegible]	RPV skirt upper part temperature	○	Input
27	[illegible]	RPV skirt upper part temperature	○	Input
28	[illegible]	RPV skirt upper part temperature	○	Input
29	[illegible]	RPV lower head temperature	○	Input
30	[illegible]	RPV lower head temperature	○	Input
31	[illegible]	RPV lower head temperature	○	Input
32	[illegible]	RPV support skirt flange temperature	○	Input
33	[illegible]	RPV support skirt flange temperature	○	Input
34	[illegible]	RPV support skirt flange temperature	○	Input
35	[illegible]	CRD housing top temperature	○	Input
36	[illegible]	CRD housing top temperature	○	Input
37	[illegible]	CRD housing top temperature	○	Input
38	[illegible]	CRD housing bottom temperature	○	Input
39	[illegible]	CRD housing bottom temperature	○	Input
40	[illegible]	CRD housing bottom temperature	○	Input

No.	Tag No.	Service name	Measurement device condition	Digital recorder input
41	[illegible]	RPV drain temperature	○	Input
42	[illegible]	RPV drain temperature	○	No input
43	[illegible]	Safety valve leak detection	○	Input
44	[illegible]	Safety valve leak detection	○	Input
45	[illegible]	Safety valve leak detection	○	Input
46	[illegible]	Safety relief valve A outlet temperature	○	Input
47	[illegible]	Safety relief valve B outlet temperature	○	Input
48	[illegible]	Safety relief valve C outlet temperature	○	Input
49	[illegible]	Safety relief valve D outlet temperature	○	Input
50	[illegible]	Safety relief valve E outlet temperature	○	Input
51	[illegible]	Safety relief valve F outlet temperature	○	Input
52	[illegible]	Safety relief valve G outlet temperature	○	Input
53	[illegible]	Safety relief valve H outlet temperature	○	Input
54	[illegible]	Reactor bellows seal part temperature	○	Input
55	[illegible]	Reactor bellows seal part temperature	○	Input
56	[illegible]	Reactor bellows seal part temperature	○	Input
57	[illegible]	Reactor bellows seal part temperature	○	Input
58	[illegible]	Reactor bellows seal part temperature	○	Input
59	[illegible]	Reactor bellows seal part temperature	○	Input
60	[illegible]	Reactor bellows seal part temperature	○	Input
61	[illegible]	Reactor bellows seal part temperature	○	Input
62	[illegible]	Reactor bellows seal part temperature	○	Input
63	[illegible]	Reactor bellows seal part temperature	B1	No input
64	[illegible]	Temperature of air fed to primary containment vessel air conditioner	○	Input
65	[illegible]	Temperature of air fed to primary containment vessel air conditioner	○	No input
66	[illegible]	Temperature of air fed to primary containment vessel air conditioner	○	Input
67	[illegible]	Temperature of air fed to primary containment vessel air conditioner	○	No input
68	[illegible]	Temperature of air fed to primary containment vessel air conditioner	○	Input
69	[illegible]	Temperature of air fed to primary containment vessel air conditioner	○	No input
70	[illegible]	Temperature of air fed to primary containment vessel air conditioner	B1	Input
71	[illegible]	Temperature of air fed to primary containment vessel air conditioner	○	Input
72	[illegible]	Temperature of air fed to primary containment vessel air conditioner	○	Input
73	[illegible]	Temperature of air fed to primary containment vessel air conditioner	○	No input
74	[illegible]	Temperature of air returned from primary containment vessel air conditioner	○	Input
75	[illegible]	Temperature of air returned from primary containment vessel air conditioner	○	Input
76	[illegible]	Temperature of air returned from primary containment vessel air conditioner	○	Input
77	[illegible]	Temperature of air returned from primary containment vessel air conditioner	○	Input
78	[illegible]	Temperature of air returned from primary containment vessel air conditioner	○	Input

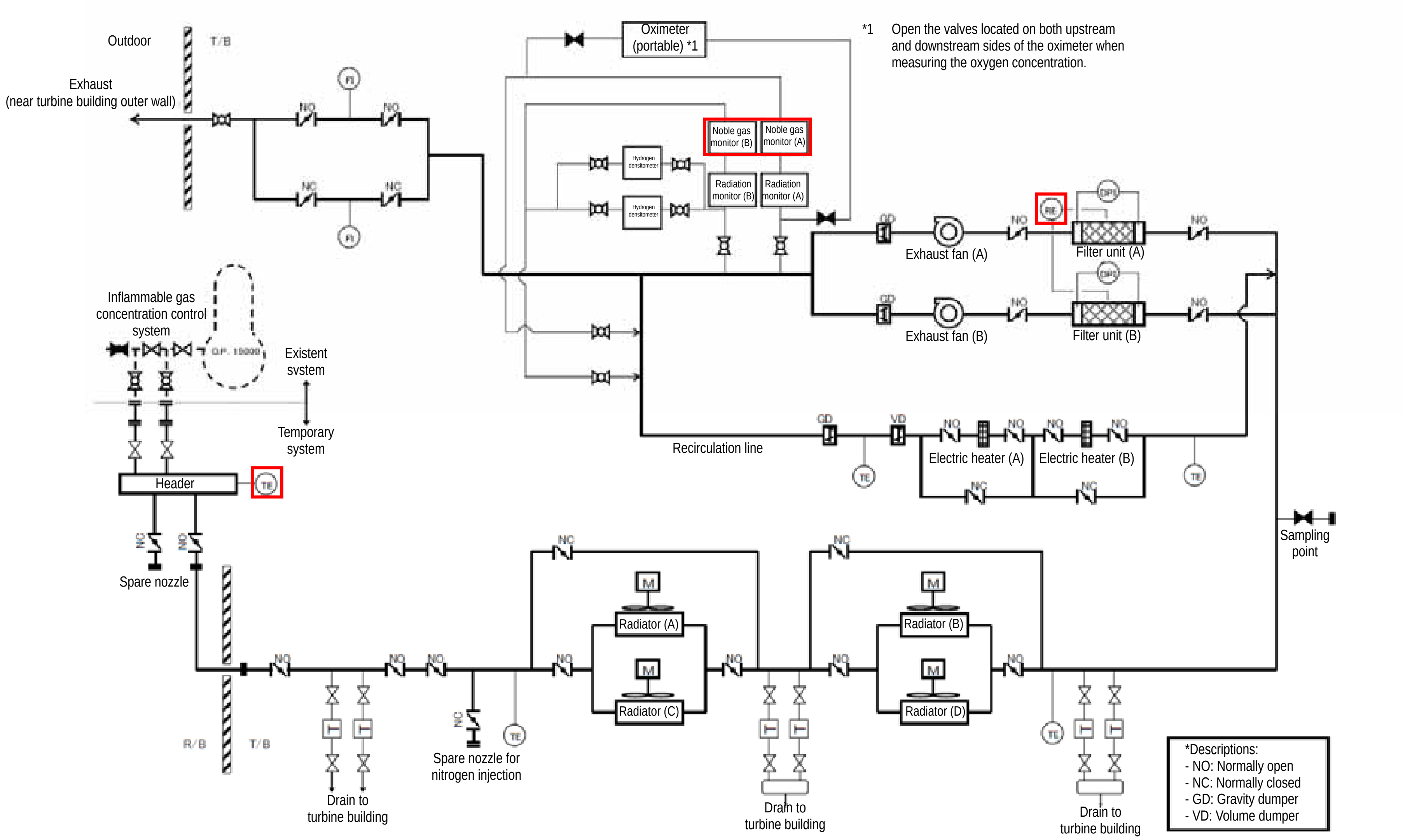
○: Hygrometer with which failure has not been judged
A1: Hygrometer the cable of which does not reach the central operating room
(Spare detector. Floor 1 of reactor building is inaccessible due to a high dose area.)
A2: Hygrometer with which failure has been found during periodical inspection
B1: Hygrometer with which disconnection has been judged in report of middle-term safety assurance
B2: Hygrometer with which failure (disconnection) has been judged after evaluation in report of middle-term safety assurance
Gray background indicates A1, A2, and no input to digital recorder.

[Reference 3] Schematic drawings of primary containment vessel (PCV) gas control facility systems

(objects to be monitored described in red boxes)



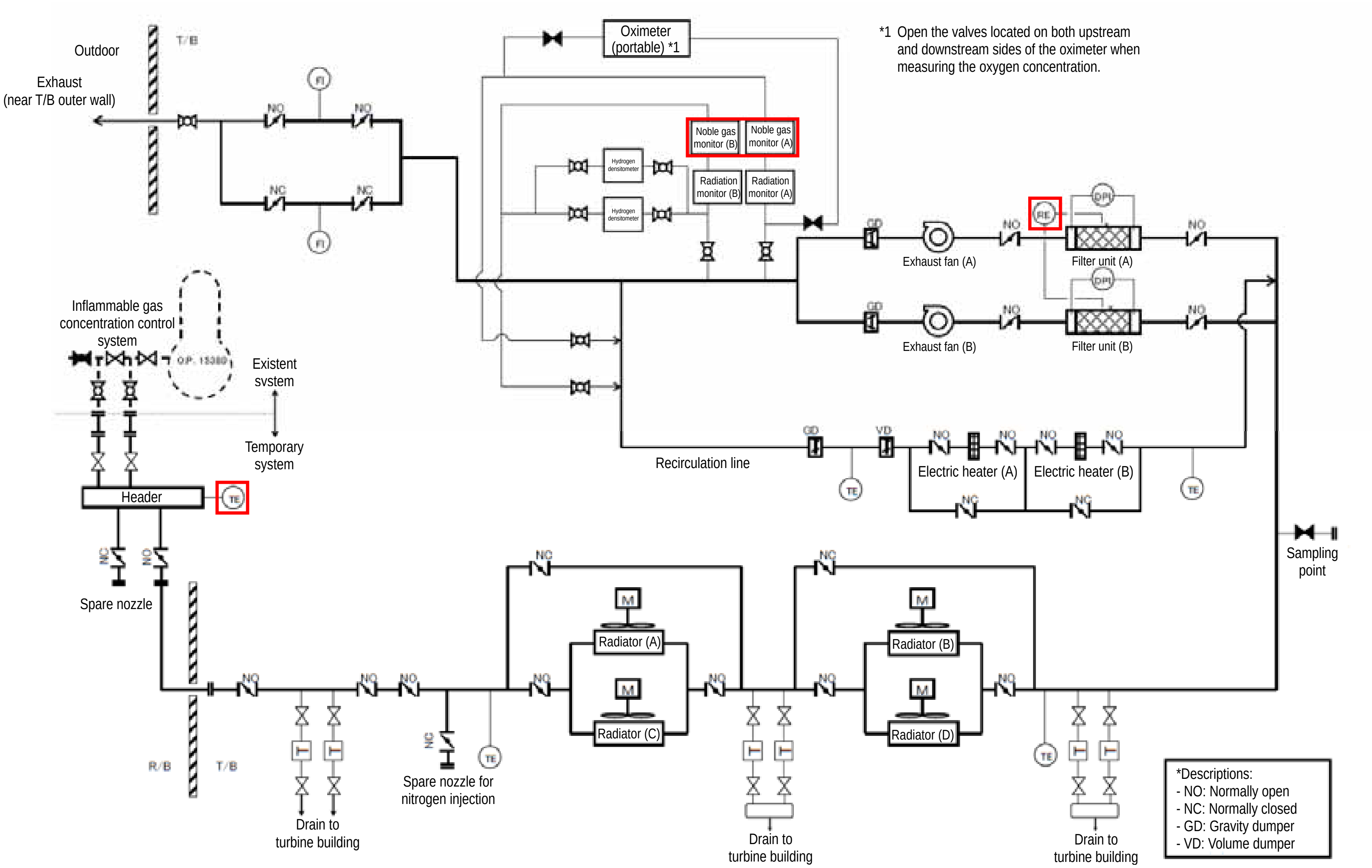
(Reactor #1)



*1 Open the valves located on both upstream and downstream sides of the oximeter when measuring the oxygen concentration.

*Descriptions:
- NO: Normally open
- NC: Normally closed
- GD: Gravity dumper
- VD: Volume dumper

(Reactor #2)



*1 Open the valves located on both upstream and downstream sides of the oximeter when measuring the oxygen concentration.

*Descriptions:
- NO: Normally open
- NC: Normally closed
- GD: Gravity dumper
- VD: Volume dumper

(Reactor #3)

[Reference 4] Monitoring and evaluation of radioactive materials released outside

In addition to monitoring of the radioactive materials in the atmosphere (concentrations of noble gases and radioactive materials) extracted from the primary containment vessel (PCV) by the primary containment vessel (PCV) gas control facility, we have performed measurement of the radioactive materials in the atmosphere (dust concentration) at major openings in the upper part of each reactor building since September 2011 to verify the quantity of the radioactive materials released to the atmosphere from the reactor building of each reactor. We will increase the frequencies of these measurements step by step as shown below:

Reactor #1

We set a reactor building cover in October 2011. Since then, we have continuously sampled and monitored the dust in the upper part of the reactor building inside the cover and at the exhaust facility filter outlet by use of dust radiation monitors.

Reactor #2

To calculate the quantity of release, we currently measure the dust concentration and the wind velocity once a month by lifting sampling equipment from beneath the blowout panel opening, which is one of the major openings in the upper part of the reactor building. For the time being, we are planning to perform additional dust concentration measurement if increase in the quantity of release is presumed from the result of comprehensive review of the individual monitoring parameters used to determine whether the cold shutdown state is maintained. To decide the sampling frequency, we will consider the dose exposed during sampling work. We will mount a sampling line from the blowout panel opening and sampling equipment for it (Targeted time: End of April) and increase the frequency of the periodical measurement to realize sampling work in an area of a low air dose rate. As before, we will make efforts to install dust radiation monitors so that we can perform continuous monitoring and perform monitoring in the main anti-earthquake building (Targeted time: September or later).

Reactor #3

To calculate the quantity of release, we currently measure the dust concentration and the wind velocity once a month by suspending sampling equipment by a large crane in the upper part of the reactor building (above the reactor and inside the equipment hatch opening). For the time being, we are planning to perform additional dust concentration measurement if increase in the quantity of release is presumed from the result of comprehensive review of the individual monitoring parameters used to determine whether the cold shutdown state is maintained. To decide the sampling frequency, we will consider the dose exposed during sampling work. We are planning to perform continuous monitoring with dust radiation monitors in the future by sampling the dust on the working platform to be mounted in the upper part of the reactor building for removal of the rubble (Targeted time: October or later, after mounting the working platform).

3. Measures to be taken in the future

(2) Review of a means of temperature monitoring inside reactor other than existent thermometers

1) Introduction

As to alternative means to monitor the temperature inside the reactor other than the existent thermometers, we reviewed, and performed evaluation in the rough of, extraction of concrete methods and their feasibilities. For this review, we used the following preconditions:

1. As representative methods, we should review methods to measure the reactor pressure vessel bottom part temperature, which is a condition for determination of the cold shutdown state and required to be 80 °C or lower as the operational limit set forth by the safety regulation.
2. As the alternative means of temperature monitoring, we should review not only setting of thermometers but also other means multidirectionally.
3. For extraction of the temperature monitoring methods, we should use a precondition that even those methods that do not seem feasible will be feasible due to technological development.
4. We should review all the means that we can consider at present. We should extract technical problems to be solved for realization of each means and review the feasibility taking into consideration the presumed difficulties for its realization.

2) Result of alternative method extraction and result of rough evaluation

As the alternative means to monitor the reactor pressure vessel bottom temperature, we can consider the following four major means: (1) Insertion of a thermometer in the piping connected to the reactor pressure vessel (hereinafter called RPV), (2) inserting a thermometer by accessing the inside of the primary containment vessel (hereinafter called PCV), (3) a method to presume the RPV temperature other than use of RPV surface thermometer (or equivalent), and (4) restoring the existent thermometers.

Figure 1 shows concrete approaches of these alternative methods, rough evaluation of each approach, preconditions, and technical challenges for realization and results of rough evaluation.

The result of rough evaluation is listed as follows:

(1): The method of using the process piping or the instrumentation piping was evaluated as △ (fair possibility) because we found a system that could be said to have feasibility by extraction from the systems connected to the RPV nozzles (See Attachment-1).

Note that, in addition to the above, we can consider a means of blowing the water inside the instrumentation piping connected to the RPV bottom part to the outside of the PCV and measuring the water temperature. Therefore this method is included in the candidates of the alternative method to monitor the temperature inside the reactor (See Attachment-4).

(2): The approach through the PCV penetration section and the approach from the reactor upper section were both evaluated as × (little possibility) due to many technical challenges (See Attachment-2).

(3): Presumption by measuring the temperature of water leaking from the RPV to the pedestal was evaluated as △ (fair possibility).

(4): Use of the PIP (control rod position detector) thermometer was evaluated as × (little possibility) because it was highly likely that the connector had been damaged.

As to the approaches evaluated as △ (fair possibility) in the rough evaluation, we need to study and review further details on their preconditions and technical challenges for realization, aiming at evaluation in higher accuracy of their applicability to the actual reactor.

We evaluated the methods to measure the RPV bottom part temperature as the representative methods. Note, however, that we will review the methods to measure the temperatures of the other parts inside the reactor (including the core and the reactor upper part) for their applicability to the actual reactor.

3) Review of installation of facility to measure the PCV internal temperature

In addition to monitoring of the reactor internal temperature, in an attempt to grasp the condition of cooling of debris that is presumed to fall out of the RPV to the pedestal, we will review new installation of a facility used to measure the temperature of the water stagnating inside the PCV by using the penetration section (X-53 penetration) that was used for PCV inside condition check with an industrial endoscope (conducted in reactor #2 on January 19).

○: Great possibility
△: Fair possibility
×: Little possibility

Matter to be reviewed	Alternative methods	Concrete approaches	Outline of review	Preconditions and technical challenges for realization	Rough evaluat	Attachment
Review of methods to monitor the temperature of the reactor pressure vessel bottom part	(1) Insertion of thermometer in piping connected to RPV	Use of process piping	Though we need to evaluate the obstacles against insertion of thermometers (valves, orifices, and bends), this approach has possibility.	・Method to confirm the thermometer location ・Is it allowed that the sensing section does not touch the metal? ・Is measurement near the nozzle allowed?	△	Attachment-1
		Use of instrumentation piping	If we can disconnect the upstream side of the EFCV (excessive flow prevention check valve), this approach has possibility though we need to evaluate the obstacles against insertion of thermometers (valves, orifices, and bends).	・Method to confirm the thermometer location ・Is it allowed that the sensing section does not touch the metal? ・Is measurement near the nozzle allowed?	△	Attachment-1
		Use of CRD (control rod drive hydraulic system) piping	There is presumption that the damaged fuel has fallen to the core bottom part and thus there is a possibility that the CRD drive system piping has been damaged. (Note) Nozzles are likely to be damaged or choked.	–	×	–
		Use of TIP (portable core internal instrumentation) guide piping	If we can disconnect the TIP guide piping at a position between the TIP chamber valve assembly and the PCV, then insertion of a thermometer is possible.	・TIP guide piping in the core bottom part must be normal. ・Method to confirm the thermometer location ・Is it allowed that the sensing section does not touch the metal?	△	–
	(2) Inserting thermometer by accessing inside of PCV	Approach through PCV penetration (X-6)	To reach the outer wall surface, we open X-6, access inside of PCV, access the appropriate RPV level by using air conditioner duct holes or other holes in the biological shield, and then remove the RPV metal lagging material. We need to remove obstacles by remote control.	・Development of a remote control device for obtaining access route ・Method to remotely set a thermometer ・Environmental improvement for access by workers to some	×	Attachment-2
		Approach from reactor upper part	To reach the outer wall surface, we remove the well cover or open the PCV head manhole, pass through the bulkhead cover, metal lagging material, etc., access the lower level through the space between the biological shield and the RPV, and then remove the RPV metal lagging material. We need to remove obstacles by remote control.	・Access to the operating floor and restoration of ceiling crane ・Development of a remote control device for obtaining access route ・Method to remotely set a thermometer ・Environmental improvement for access by workers to some degree	×	Attachment-2
	(3) Method to presume RPV temperature other than use of RPV surface thermometer (or equivalent)	Presuming by use of infrared camera (thermography, radiation thermometer, etc.)	We can consider a presumption method by use of an infrared camera (thermography, radiation thermometer, etc.) from outside of the biological shield.	・Review of applicability to the site environment ・Review of possibility of presumption from outside of the biological shield	×	Attachment-3
		Presuming by use of temperature of water leaking from RPV to pedestal	It is presumed that the core water has leaked from the lower side of the RPV to the pedestal. We can consider a method to determine the cooling condition inside the core by measuring the temperature of the water leaking from the upper part.	・It is required to review the possibility to identify the core water leak because it is possible that we may detect the temperature of water that does not affect the debris cooling. ・Review of method to access the pedestal	△	–
	(4) Restoring existent thermometers	Using PIP (control rod position detector) thermometer	・By using the temperature recorder existing at site or temporarily installing a digital recorder, we make it possible to output the temperature data to the central operating room or the anti-earthquake building. ・Connectors are highly likely to have been damaged.	–	×	–

Figure 1 Review of alternative means of monitoring of reactor pressure vessel bottom part temperature, reactor #2

4) Future schedule

The construction plan (proposal) is as shown in figure 2.

With regard to the approaches evaluated as △ (fair possibility) in the rough evaluation, we will study and review further details on their preconditions and technical challenges for realization, aiming at evaluation of their applicability to the actual reactor (further selection of approaches and extraction of technical development items and challenges for application to the actual reactor). In addition, we will review installation of a facility used to measure the temperature of the water stagnating inside the PCV.

Item		FY 2011		FY 2012			FY 2013	FY 2014 onward
		Feb.	Mar.	Apr.	May	June to March 2013		
Review of alternative means to monitor reactor internal temperature	1. Evaluation of applicability to actual reactor: - Further selection of approaches - Extraction of technical development items - Extraction of challenges for application to actual reactor	■	■	■	■			
	2. Site survey* - Site survey - Mock-up *If necessary			□	□	■		
	3. Technical development			□	□	■	■	
	4. Construction* *Time to install to be determined based on the results of 1 to 3 above.							■
Review of installation of facility to measure PCV internal temperature	- Reactor #1				□	■	■	
	- Rector #2			■	■	■		
	- Reactor #3* *Due to high dose at site, the time of installation should be determined according to the progress of improvement of the working environment.					□	■	■

Figure 2 Construction plan (proposal)

End of document

Attachment-1

1F-2 Review of reactor pressure vessel bottom part temperature measurement considering systems connected to RPV nozzles

Systems connected to RPV nozzles						RPV nozzle height data			Primary judgment according to review of reachableness of such hose-shape devices as thermocouples to RPV by device/system configuration (configuration drawing/P&ID) (○: Possible to review; △: Not applicable; ×: Unusable)		Secondary judgment including consideration of such structures as system piping, valves, etc. (Note 3) (○: Great possibility; △: Little possibility; ×: No possibility)	
No.	System name			RPV nozzle name		RPV/core inside relative position (vertical direction)	Height from VESSEL 0 (mm)	OP conversion (Vessel 0 = op 14320) (mm)	Primary judgment result	Judgment descriptions	Secondary judgment	Remarks
(1)	Reactor residual heat removal system			Upper cover cooling spray nozzle	N6A	RPV cover top	21515	OP 35835	×	Unusable due to closed motor-operated valve inside PCV	-	-
(2)	–			Upper cover instrumentation nozzle	N6B	RPV cover top			×	Nozzle is closed (This is for drawing fluid vibration test sensor cables so not used while used for this purpose.)	-	-
(3)	Main steam line			Vent nozzle (Note 1)	N7	RPV cover top	RPV nozzle and piping flange section	Same as left	△	Currently used for nitrogen injection to RPV. (If used for this purpose, it is required to pass through EFCV (in reverse direction) or review methods of insertion from the RPV side of the EFCV while keeping the boundary.)	△	Essential to pass through components of reactor external systems (EFCVs, manual valves, orifices, elbows). Temperature measurement in the vicinity of reactor bottom part is to be possible by passing the device through the RPV upper cover and the shroud annulus section while bypassing the reactor internal devices (dryers and separators) to the shroud support baffle plate.
(4)	Main steam line	Main steam line system A		Steam outlet nozzle	N3A	RPV body upper part (below main flange)	16256	OP 30576	×	Unusable due to fully closed MSIV	-	-
		Main steam line system B			N3B							
		Main steam line system C			N3C							
		Main steam line system D			N3D							
(5)	Water level instrumentation	Water level instrumentation (gaseous phase)		Instrumentation nozzle (Upper level: Gaseous phase)	N12A	Above NWL	14891	OP 29211	△	Currently used as water level measurement system. (If used for this purpose, it is required to pass through EFCV (in reverse direction) or review methods of insertion from the RPV side of the EFCV while keeping the boundary.)	△	Essential to pass through components of reactor external systems (EFCVs, manual valves, orifices, elbows). Temperature measurement in the vicinity of reactor bottom part is to be possible by passing the device through the RPV upper body where the nozzle is located and the shroud annulus section while bypassing the reactor internal devices (dryers and separators) to the shroud support baffle plate.
		Water level instrumentation (gaseous phase)			N12B							
(6)	Water level instrumentation	Water level instrumentation (gaseous phase)		Instrumentation nozzle (Middle level: Liquid phase)	N11A	Below NWL	12929	OP 27249				
		Water level instrumentation (gaseous phase)			N11B							
(7)	Reactor feedwater system	Feedwater system A		Feedwater nozzle	N4A	Lower end of steam-water separator Above stand pipe	12281	OP 26601	○	Usable if the device can pass through check valves inside and outside PCV (in forward direction).	△	Essential to pass through check valves inside and outside PCV (in forward direction). After reaching the RPV nozzle, the thermocouple must pass through the reactor internal device (feedwater sparger) for temperature measurement in the reactor bottom part. Note that, in order to make the thermocouple reach inside the reactor after reaching the sparger, we need to insert it along the header pipe that branches in the reactor internal circumference at the sparger tee and further guide it into a small-diameter nozzle mounted on the upper part of the header pipe.
					N4B							
		Feedwater System B (Note 2)		Feedwater nozzle	N4C				△	Currently used as water inject system from feedwater system. Usable if the device can pass through check valves inside and outside PCV (in forward direction).		
					N4D							
(8)	Core spray system	Core spray system A		Core spray nozzle	N5A	Above stand pipe	11811	OP 26131	○	(1) Usable if the device can pass from the process piping through isolation valves outside PCV and check valves inside PCV (in forward direction). (2) Usable if the device can pass from the differential pressure detection line through EFCV (in reverse direction). Otherwise, we need to review a method to insert the device from the RPV side of EFCV while keeping the boundary.	△	(1) In case of process piping Essential to pass through isolation valves outside PCV and check valves inside PCV (in forward direction). If the device can reach the RPV nozzle and pass through the reactor internal devices (reactor internal piping and sparger), then it can reach inside the shroud. (2) In case of differential pressure detection line Essential to pass through the reactor external system components (EFCVs, manual valves, orifices, and elbows). If the device can reach the RPV nozzle and pass through the reactor internal devices (reactor internal piping and sparger), then it can reach inside the shroud.
		Core spray System B (Note 2)		Core spray nozzle	N5B	Above stand pipe			△	Currently used as water injection system from CS systems. (1) Usable if the device can pass from the process piping through isolation valves outside PCV and check valves inside PCV (in forward direction). (2) Usable if the device can pass from the differential pressure detection line through EFCV (in reverse direction). Otherwise, we need to review a method to insert the device from the RPV side of EFCV while keeping the boundary.		
(9)	Control rod drive water pressure system			Control rod drive water return nozzle	N9	Near nozzle N5	11481	OP 25801	×	Unusable as manual valves inside PCV are fully closed and there is a blanking cover outside PCV.	-	-
(10)	Water level instrumentation	Water level instrumentation (Liquid phase)		Instrumentation nozzle (Lower level: Liquid phase)	N16A	Near above TAF	9093	OP 23413	△	Currently used as water level measurement system. (To use the device, we need to pass it through EFCV (in reverse direction). Otherwise we need to review a method to insert the device from the RPV side of EFCV while keeping the boundary.)	△	Essential to pass through the reactor external system components (EFCVs, manual valves, orifices, and elbows). Temperature measurement in the vicinity of reactor bottom part is to be possible by passing the device through the RPV upper body where the nozzle is located and the shroud annulus section to the shroud support baffle plate.
		Water level instrumentation (Liquid phase)			N16B							
(11)	Recirculation system	Recirculation system A		Recirculation water outlet nozzle	N1A	Below BAF Lower end of RPV body plate Shroud support Baffle plate	4120	OP 18440	○	(1) Usable if the device can pass from the instrumentation line that is connected to the PLR suction piping through EFCV (in reverse direction). Otherwise we need to review a method to insert the device from the RPV side of EFCV while keeping the boundary. (2) RHR suction line is unusable as the isolation valve inside PCV is closed. (3) CUW suction line is unusable as the isolation valve inside PCV is closed.	×	(1) In case of PLR suction piping instrumentation line Difficult to access because the PLR suction line instrumentation is located in the basement.
				Recirculation water inlet nozzle	N2F	Below BAF Lower end of RPV body plate Shroud support Baffle plate	4535	OP 18855		(1) Usable if the device can pass from the instrumentation line through EFCV (in reverse direction). Otherwise we need to review a method to insert the device from the RPV side of EFCV while keeping the boundary. (2) Usable if the device can pass from the RHR system process piping through isolation valves outside PCV and check valves inside PCV (in forward direction). (3) Sampling line is unusable as the pneumatic valve inside PCV is closed.	△	(1) In case of instrumentation line Essential to pass through the reactor external system components (EFCVs, manual valves, orifices, and elbows). Essential to insert the thermometer and raise it vertically at the T junction with the PLR system. (2) In case of RHR system process piping Essential to pass through the reactor external system components (isolation valves outside PCV, check valves inside PCV, PLR cross piping, etc.)
					N2G							
					N2H							
					N2J							
					N2K							
		Recirculation system B		Recirculation water outlet nozzle	N1B	Below BAF Lower end of RPV body plate Shroud support Baffle plate	4120	OP 18440	○	Usable if the device can pass from the instrumentation line that is connected to the PLR suction piping through EFCV (in reverse direction). Otherwise we need to review a method to insert the device from the RPV side of EFCV while keeping the boundary.	×	Difficult to access because the PLR suction line instrumentation is located in the basement.
				Recirculation water inlet nozzle	N2A	Below BAF Lower end of RPV body plate Shroud support Baffle plate	4535	OP 18855		(1) Usable if the device can pass from the instrumentation line through EFCV (in reverse direction). Otherwise we need to review a method to insert the device from the RPV side of EFCV while keeping the boundary. (2) Usable if the device can pass from the RHR system process piping through isolation valves outside PCV and check valves inside PCV (in forward direction).	△	(1) In case of instrumentation line Essential to pass through the reactor external system components (EFCVs, manual valves, orifices, and elbows). Essential to insert the thermometer and raise it vertically at the T junction with the PLR system. (2) In case of RHR system process piping Essential to pass through the reactor external system components (isolation valves outside PCV, check valves inside PCV, PLR cross piping, etc.)
					N2B							
					N2C							
					N2D							
					N2E							
(12)	JP instrumentation	JP instrumentation system A	Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor	Jet pump instrumentation nozzle	N8A	Below BAF Lower end of RPV body plate Shroud support Baffle plate	3353	OP 17673	○	Usable if the device can pass through EFCV (in reverse direction). Otherwise we need to review a method to insert the device from the RPV side of EFCV while keeping the boundary.	△	Essential to pass through the reactor external system components (EFCVs, manual valves, orifices, and elbows).
		JP instrumentation system B	Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor Instrumentation piping outside reactor	Jet pump instrumentation nozzle	N8B	Below BAF Lower end of RPV body plate Shroud baffle plate	3353	OP 17673	○	Usable if the device can pass through EFCV (in reverse direction). Otherwise we need to review a method to insert the device from the RPV side of EFCV while keeping the boundary.	△	Essential to pass through the reactor external system components (EFCVs, manual valves, orifices, and elbows).
[Reference] Temperature measurement position in RPV bottom head upper part				RPV surface		(0°, 135°, 270°) 69H1 to H3		OP 17232	-	-	-	-
(13)	Boric acid water injection system Differential pressure detection system			Core differential pressure gauge nozzle	N10	Below baffle plate Lower mirror	2111	OP 16431	○	(1) Usable if the device can pass from the SLC process piping through check valves inside and outside PCV (in forward direction). (2) Usable if the device can pass from the differential pressure detection line through EFCV (in reverse direction). Otherwise we need to review a method to insert the device from the RPV side of EFCV while keeping the boundary. (Note) It is possible that the nozzle is damaged or choked.	△	(1) Essential to pass through obstacles outside reactor (check valves and elbows). It is possible that the nozzle is damaged or choked. (2) Essential to pass through obstacles outside reactor (EFCVs, manual valves, orifices, and elbows). It is possible that the nozzle is damaged or choked.
							Roughly calculated from inner radius of the mirror under RPV and angle of nozzle installation position.	Same as left				
[Reference] Temperature measurement position in RPV support skirt junction upper part				RPV surface		(0°, 135°, 270°) 69F1 to F3		OP 17232	-	-	-	-
(14)	Reactor coolant cleanup system			Drain nozzle	N15	Lower end of lower mirror Open to reactor bottom part	0	OP 14320	×	Unusable as motor-operated valves inside PCV are closed.	-	-
(15)	Control rod drive system			CRD housing to control rod guide pipes	CRD	Lower end of CRD housing	-3346	OP 10974	×	Because it can be presumed that the damaged fuel has fallen to the reactor bottom part, it is possible that the CRD drive system piping (macaroni piping) has been damaged. (Note) It is possible that the nozzle is damaged or choked.	-	-

Note 1: Nitrogen injection system inside RPV

Note 2: Injection system inside RPV

Note 3: Review of feasibility of construction, etc. is not included.

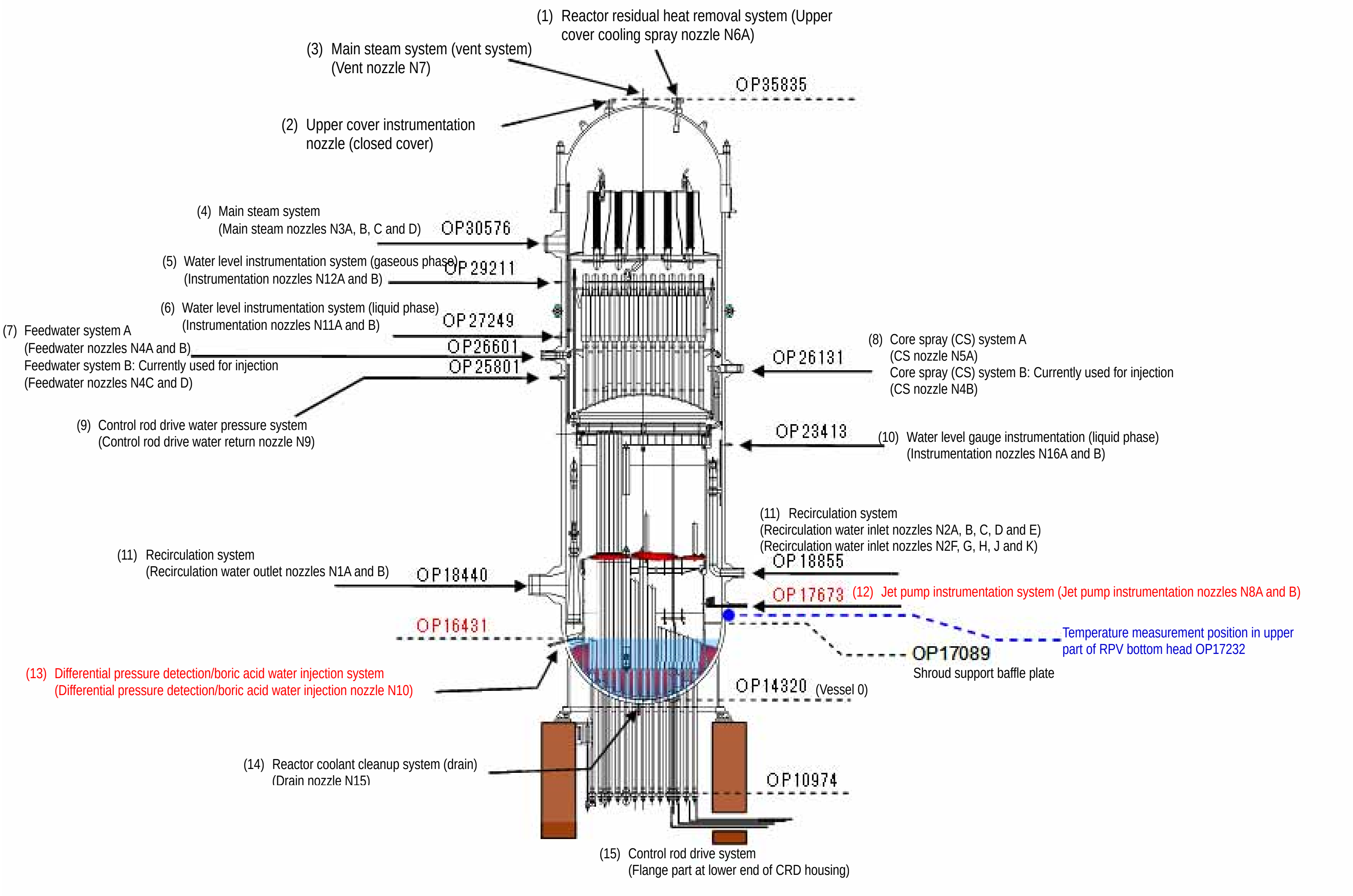


Figure 1 Systems connected to RPV and locations of nozzles

Attachment-1

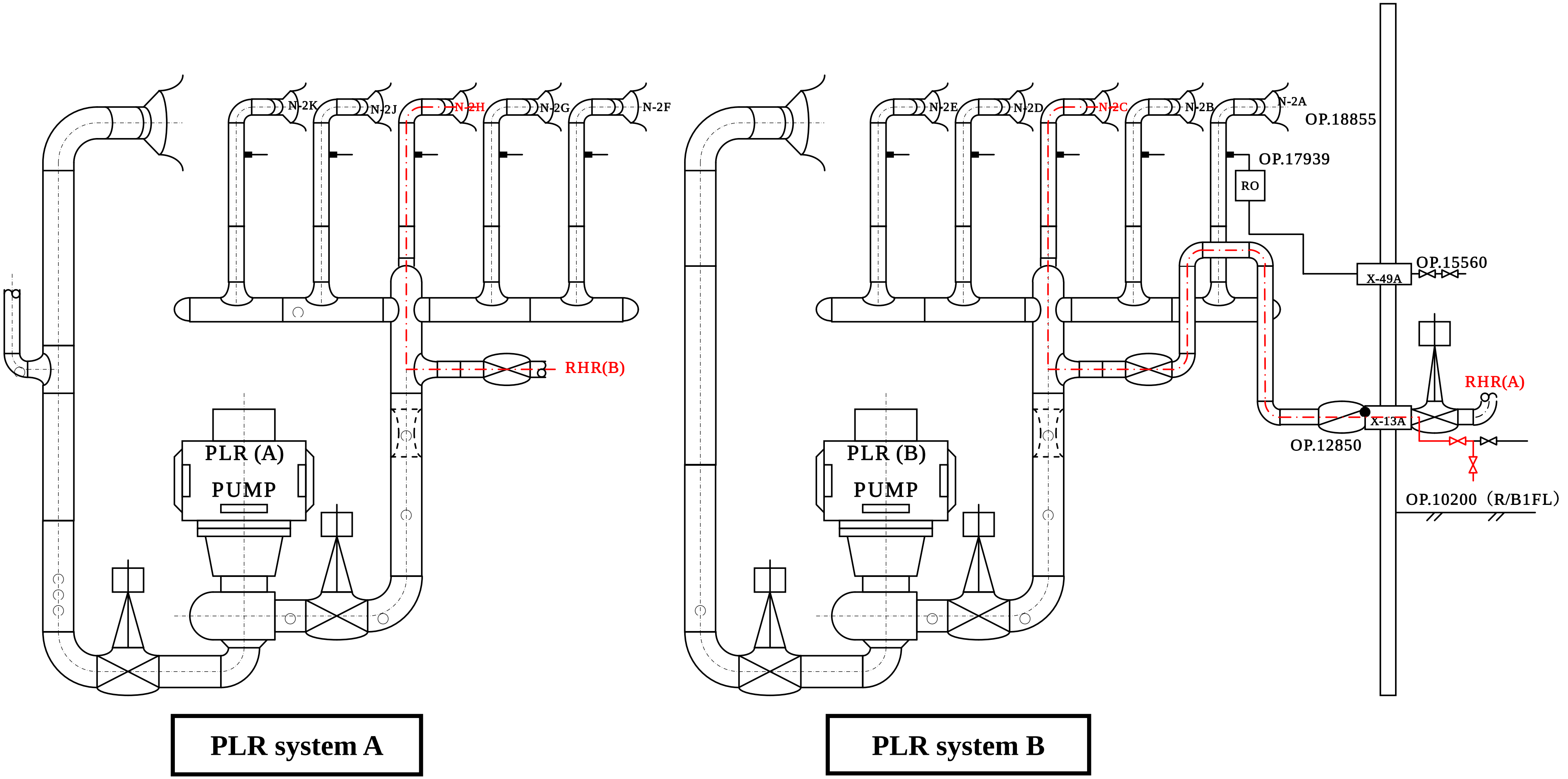


Figure 2 (11)Schematic drawing of recirculation system piping (RHR to nozzle N-2)

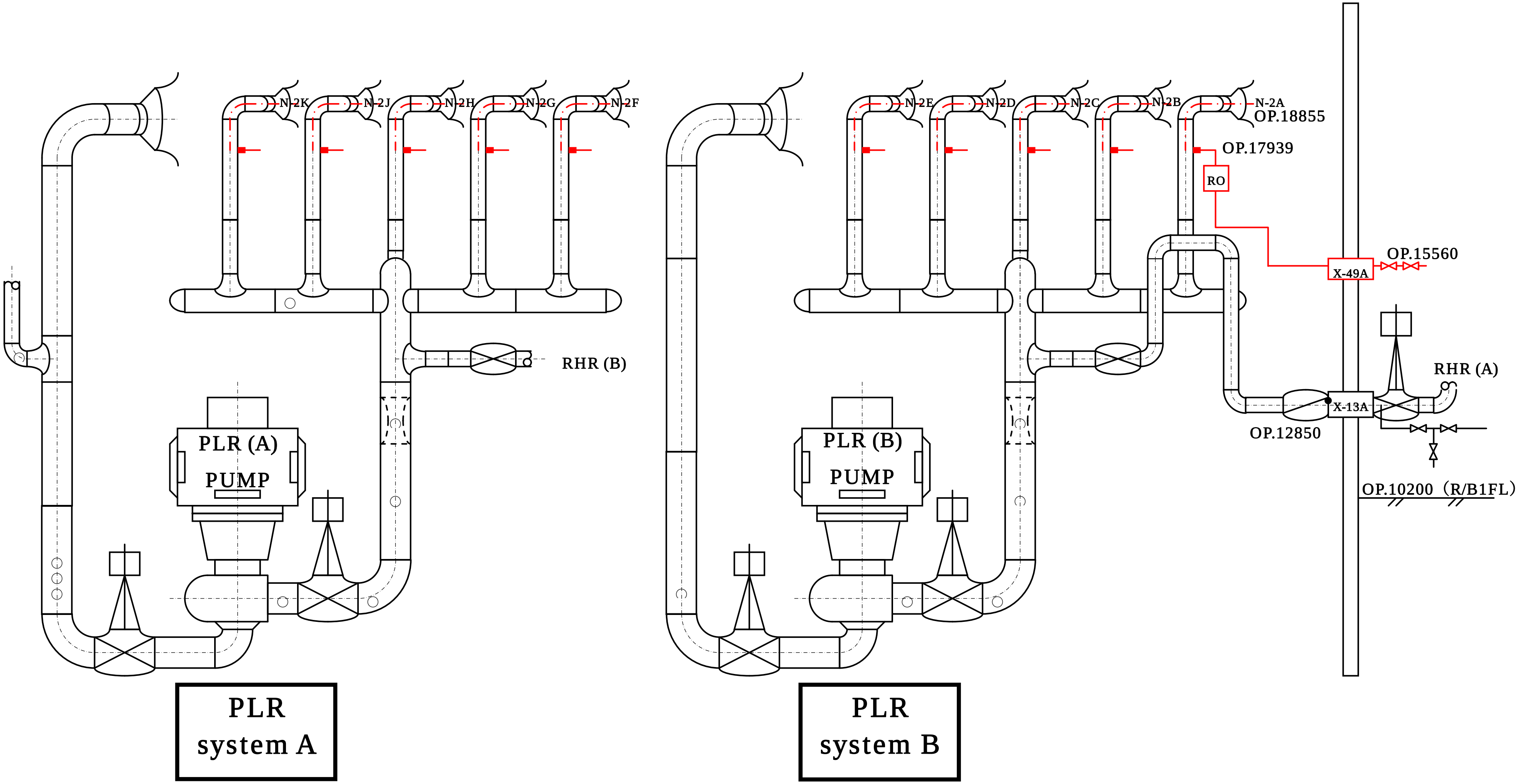


Figure 3 (11) Schematic drawing of recirculation system piping (riser instrumentation to nozzle N-2)

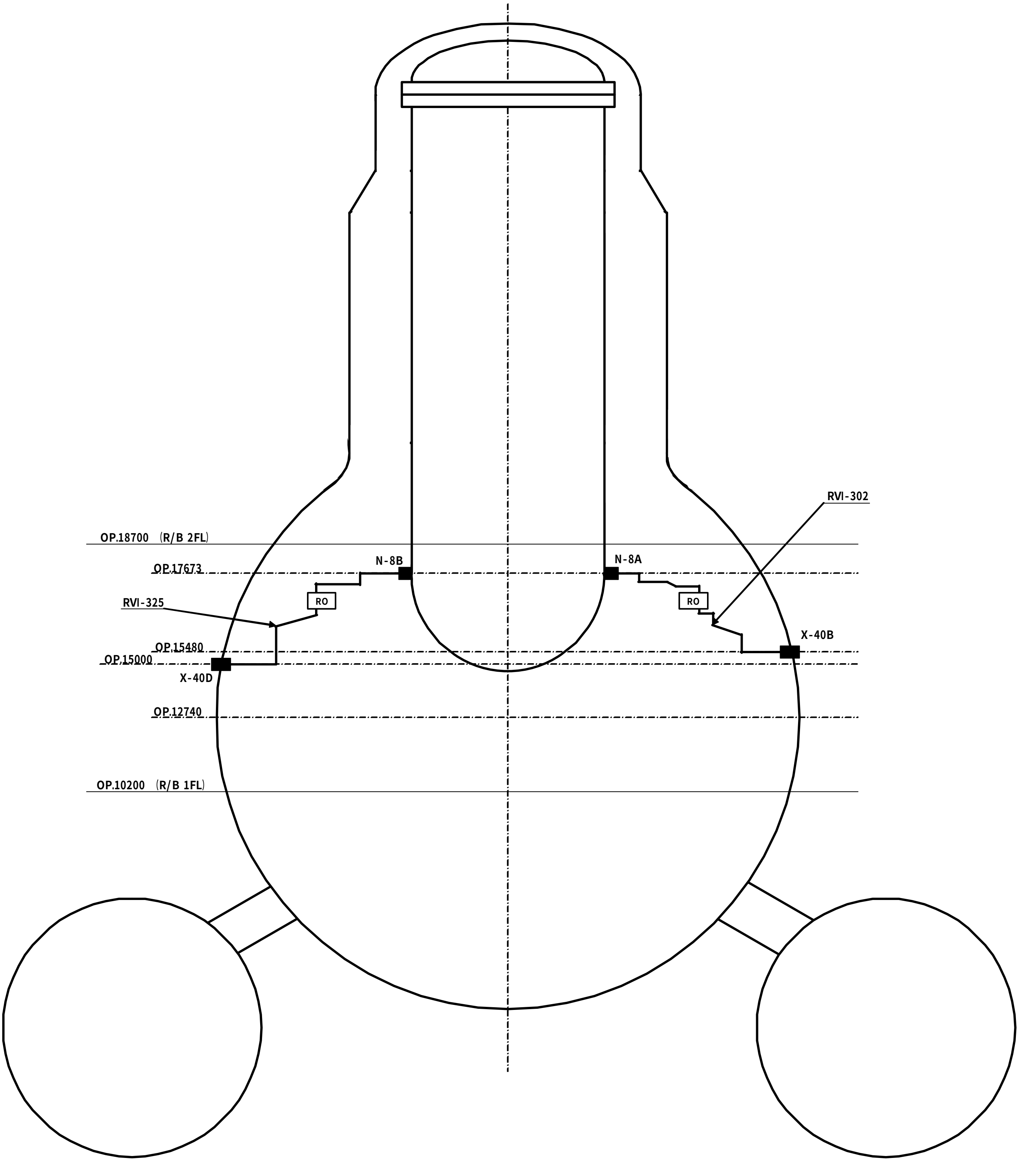


Figure 4 (12) Schematic drawing of jet pump instrumentation piping (nozzles N-8)

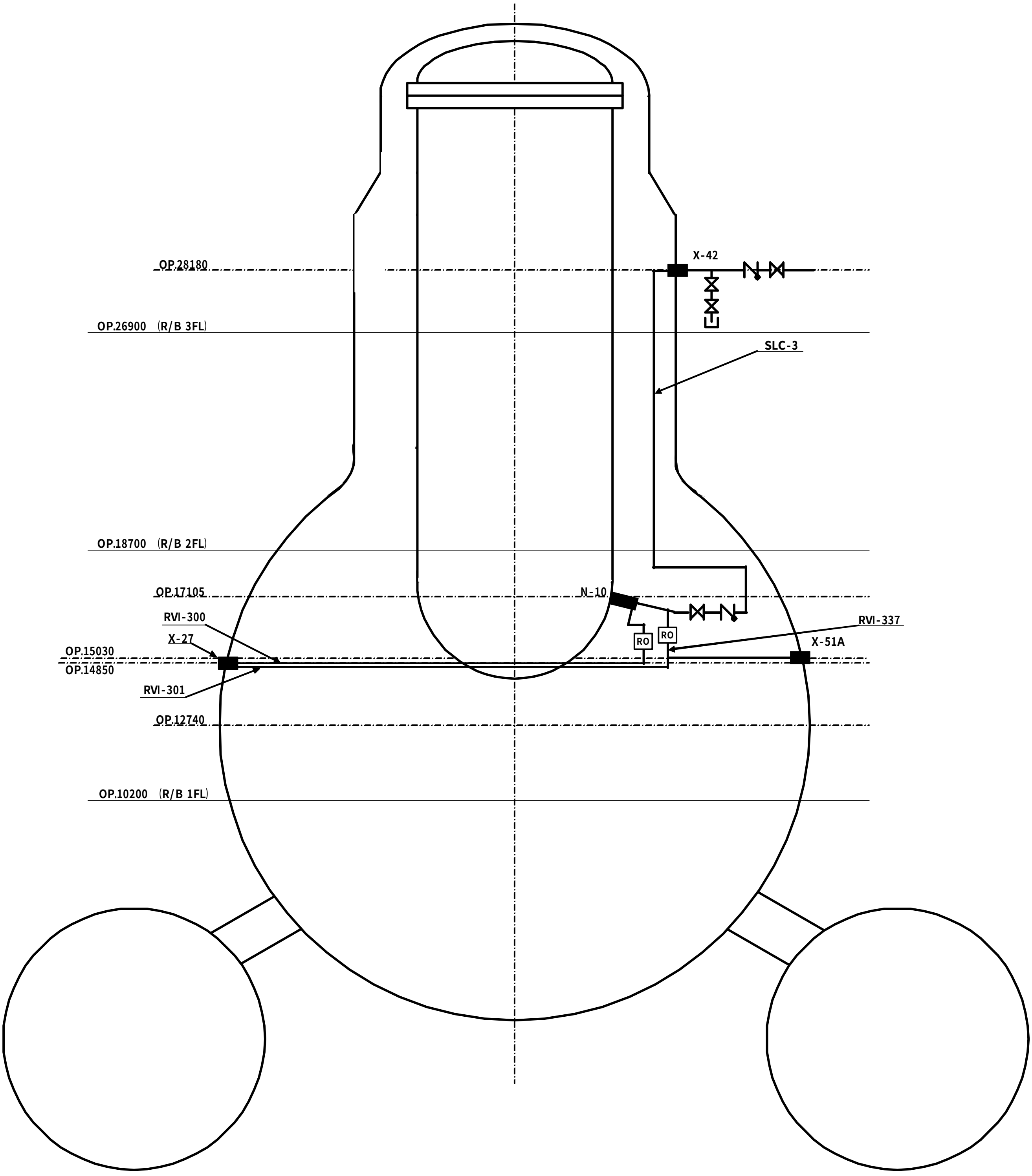


Figure 5 (13) Schematic drawing of boric acid water injection/differential pressure detection system piping (nozzle N-10)

Approach from upper part of reactor

(1)Remove the well cover (ceiling crane needed).
(2)Open or drill a hole in the PCV head manhole by remote control.
(3)Access the upper part of biological shielding by breaking the air conditioner duct from the bulkhead manhole by remote control.
(4)Remove metal shielding material (in the vicinity of feedwater nozzle upper part)
(5)Access the lower part of RPV through the space between the biological shielding and the RPV main body.
(6)Remove lagging material by remote control.

Approach from X-6 (CRD hatch)

(1)Remove the X-6 concrete shielding.
(2)Open or drill a hole in the CRD hatch by remote control.
(3)Access the outer wall of biological shielding from the CRD rail
(4)Access the lower part of RPV by breaking the air conditioner duct outlet in the vicinity of the foundation bolts by remote control.
(5)Remove lagging material by remote control.

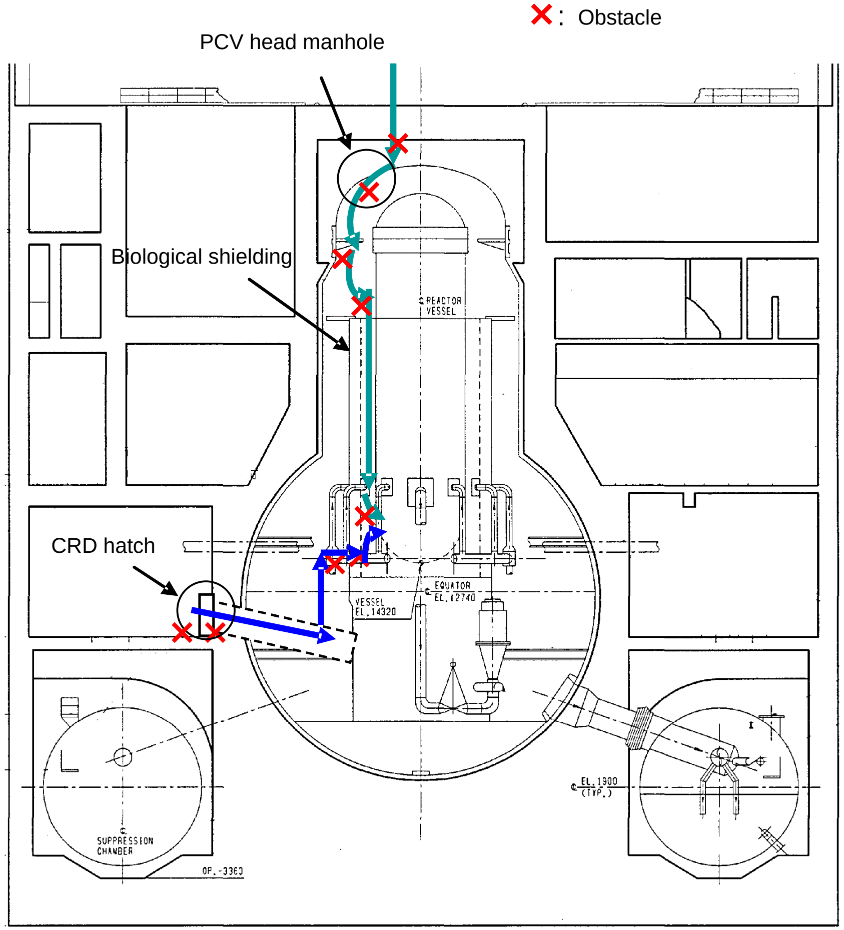


Figure 1 Access routes to RPV body outer wall from outside of PCV

Evaluation of RPV inner surface temperature by RPV external temperature

According to the heat conduction in a one-dimensional system, we evaluated the temperatures outside of the shielding wall in two cases of RPV inner surface temperatures of 100 °C and 60 °C (Primary containment vessel (PCV) D/W temperature was 40 °C) (Evaluation conditions were as follows).

- Steady-state heat conduction in a one-dimensional system
- Thermal conductivity of inner lining of RPV wall: 43 W/mK (@carbon steel (300 K))
- A natural convection heat transfer was applied to the two spaces. Natural convection heat transfer: 5 W/m^{2}K
- Thermal conductivity of lagging material: 0.64 W/m^{2}K (including one space)
- Thermal conductivity of shielding wall: 1.2 W/mK (presumed to be of concrete)

Table 1 shows the evaluation results. As a result of evaluations at temperatures of 100 °C and 60 °C, the temperatures of the outside of the shielding wall were approximately 44 °C and approximately 41 °C, respectively, and thus did not show a large difference. Note that, if the outside of the shielding wall was soaked in water, it is supposed that the temperature difference would be still less.

As shown above, it is supposed that measurement of the temperature distribution on the outside of the shielding wall by use of such a device as a thermograph will not show a clear temperature distribution and as a result, it will be difficult to use this method to presume the temperature of the inner surface of the RPV.

Table 1 Evaluation results

	Evaluation condition		Evaluation result
	Temperature of RPV inner surface (°C)	Primary containment vessel (PCV) D/W temperature (°C)	Temperature of outside of shielding wall (°C)
Case 1	100	40	44
Case 2	60	40	41

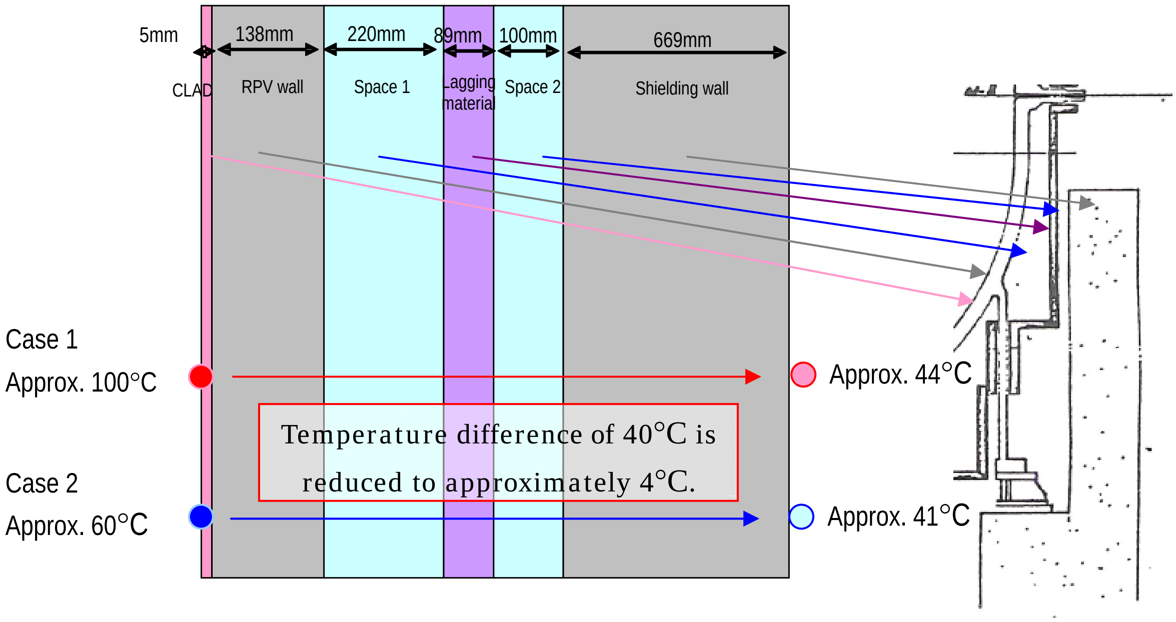


Figure 1 Outline of evaluation model

Temperature measurement by blow from instrumentation piping

As an alternative method to replace the RPV lower part thermometer, we can consider a method of blowing the internal water out of the primary containment vessel (PCV) from an instrumentation piping system that is connected to the RPV power part and measuring the water temperature. We have two instrumentation piping systems that are connected to the RPV power part: The jet pump instrumentation piping (JPSL) and the core plate pressure detection piping. To blow the internal water, the water level inside the RPV is required to reach a level higher than the respective pressure outlets. As the water level inside the RPV is unknown, however, we need to perform a trial blow to determine the feasibility of this method.

We are planning to study, in the future, such items as the dose around the instrumentation rack, which is expected as the position of blow, and its accessibility.

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