Examination of plant conditions during RCIC operation of Unit 3

＊ This document was prepared based on the contents related to the operation of SRVs listed in "Common-1" in the list of issues to be considered in Attachment 2, which was entrusted by TEPCO to TEPCO Systems, Inc. and evaluated using analysis codes.

■ 1. Introduction

In Unit 3, the reactor isolation cooling system (RCIC) was activated twice, once before and once after the arrival of the tsunami, and water was injected into the reactor pressure vessel (RPV). The first RCIC operation was started manually at 15:05 on the 11th before the tsunami arrived and automatically stopped at 15:25 due to the high reactor water level. Since the DC power supply was still available in Unit 3 after the tsunami arrived, the second RCIC operation was started manually at 16:03 on the 11th after the tsunami arrived, and water injection into the RPVs continued until the automatic shutdown at 11:36 on the 12th. In this second RCIC operation, the return line to the condensate storage tank (CST), which is the water source, was utilized to avoid battery consumption due to repeated automatic shutdowns and manual startups caused by high reactor water levels. The reactor water level was secured by continuing the special operation to adjust the amount of water injected into the RPV by utilizing the return line to the CST.

The reactor pressure during the second RCIC operation was measured to show a decreasing trend from the start of water injection into the RPV until about 19:30, and an increasing trend thereafter. During the period of this trend, both small pressure and large pressure drops and rises were repeatedly observed. The large and small pressure drops and increases seen during this period are different from the behavior of pressure changes controlled by the main steam relief safety valve (hereinafter referred to as "SRV"). It is believed that these changes were caused by the opening and closing of the SRVs under the special operating conditions of the RCIC.

In this attachment, the mechanism of the plant behavior at that time was examined, including whether the above-mentioned perception of the pressure behavior was appropriate, through confirmation of the RCIC operation results during this period and analysis to reproduce the reactor pressure behavior. This study is related to issue Common-1 because it is about the SRV operation.

■ 2. Plant parameters during the RCIC operation period

It has been recorded that the RCIC operation of Unit 3 was conducted twice after the earthquake, once before the tsunami arrived and once after the tsunami arrived [1]. In the first RCIC operation before the tsunami, the reactor water level rose due to water injection into the RPV, and the RCIC automatically stopped due to the high reactor water level approximately 20 minutes after startup. In the second RCIC operation after the tsunami, both the return line to the CST and the water injection line to the RPV were used to inject water into the RPV in order to avoid battery consumption due to the start-up and shutdown of the RCIC and to maintain the reactor water level in a stable manner. Reactor pressure and reactor water level during these operation periods were as shown in Figure 1. The reactor pressure shown in the figure is a digitized recording gauge chart.

Here, the changes in the plant parameters before and after the arrival of the tsunami during two RCIC operations are explained separately.

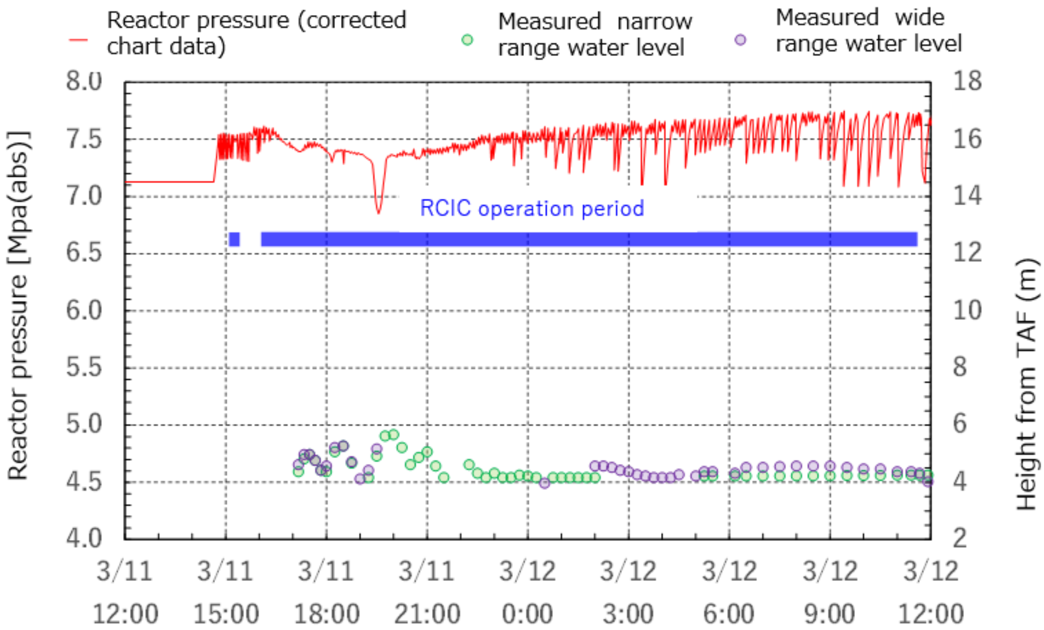

Figure 1 Reactor pressure and reactor water level during RCIC operation

2.1 Plant parameters from earthquake occurrence until tsunami arrival

This section describes the plant parameters during the first RCIC operation period before the tsunami arrival (Figure 1). Although the reactor power decreased due to the automatic scram caused by the earthquake trip, the reactor pressure increased due to the automatic closing of the main steam isolation valve (MSIV). The reactor pressure then reached the set pressure to open the SRV, which caused the SRV to open, leading to the reactor pressure drop, and when the pressure dropped to the set pressure to close the SRV, the SRV closed, leading to the reactor pressure rise again. On the other hand, as it is recorded that the RCIC, which was manually started at 15:05 on the 11th, automatically stopped at 15:25 due to high reactor water level [1], the reactor water level is considered to have increased significantly due to RCIC operation.

■ 2.2 Plant parameters from tsunami arrival to automatic RCIC shutdown

(1) Reactor water level

Although Unit 3 lost all AC power due to the arrival of the tsunami, the DC power supply was still available, so the RCIC was manually started at 16:03. However, since the charging function was lost due to the loss of all AC power, in order to avoid battery consumption during the startup and shutdown of the RCIC, a line configuration was adopted in which both the reactor water injection line and the test line were passed through and a portion of the water injection was returned to the CST in the test line (Figure 2). The amount of water injected into the RPV was then adjusted by operating the valves and flow controllers for switching the above mentioned lines to ensure that the reactor water level did not rise to the level at which the RCIC would automatically shut down. Specifically, the operator monitored the reactor water level, and when the reactor water level approached the upper or lower limit of the adjustment range, the operation to change the aforementioned valve opening and flow rate setting value of the flow rate controller was repeated (Figure 3) [2]. Therefore, although the actual amount of water injected into the RPV was not known, the reactor water level repeatedly rose and fell at a higher level than the TAF, as seen in the narrow range and wide range water level measurements shown in Figure 1.

The changes in the rise and drop of the reactor water level seen during this period represent the mass balance situation between the amount of water injected by the RCIC into the RPV and the amount of steam released from the RPV via the RCIC gas exhaust and SRV into the primary containment vessel (PCV). In other words, when the amount of water injected into the RPV is greater than the amount of steam released, the reactor water level rises, and when the relationship is reversed, the water level drops. For example, when the water level is rising from about 17:00 on the 11th, it indicates that the amount of water injected into the RPV was greater than the amount of steam released, and when the water level turns to decline after reaching about 6m from the TAF at about 17:30, it indicates that the amount of water injected into the RPV decreased.

The reactor water level was observed to rise relatively significantly from about 19:00 to 19:45 on the 11th, suggesting that the amount of water injected from the RCIC to the RPV was high. The reactor pressure, which had shown a declining trend, further dropped significantly at that time, which is considered to be a situation where the amount of steam generated by decay heat decreased due to increased water injection into the RPV. The reactor water level after 21:00 did not show such a large water level change, but the water level continued to rise and fall slowly until 11:36 on the 12th, when the RCIC automatically shut down, probably due to the change in the amount of water injected from the RCIC to RPV.

(2) Reactor pressure

After the tsunami, the reactor pressure rose and fell within the range of the set pressure at which the SRV continued to open or close for a while, and from about 15:56, it rose and fell with a slightly higher pressure (about 7.6MPa[abs]) as the upper limit than for the previous pressure changes. This slightly different behavior was caused by the switching of SRV in the relief valve mode from the C valve to the G valve and then to the A valve, and the status of the switching of the opened and closed valves was recorded by the transient phenomenon recorder [3].

After the manual activation of the RCIC at 16:03 on the 11th, water injection started at 16:16 [4], and the reactor pressure showed a downward trend until about 19:30. This behavior is considered to reflect the decrease in steam formation due to decay heat caused by water injection from the RCIC to RPV. The several pressure rises observed while the reactor pressure was decreasing are considered to reflect the flow rate adjustment of water injection from the RCIC to RPV, as described in the section on changes in the reactor water level.

The drop in reactor pressure accelerated at about 19:20 and dropped to about 6.85MPa[abs] by 19:30. As mentioned above, the reactor water level was rising to its highest about this time during the second RCIC operation, and based on the fact that the amount of water injected from the RCIC to the RPV was quite large, the large drop in reactor pressure at this time is considered to reflect the situation where the steam generation in the RPV decreased further due to this increase in water injection. This behavior is considered to be the result of a further decrease in steam generation in RPV due to the increased water injection.

The reactor pressure then began to rise, reaching about 7.35MPa[abs] at about 19:50. The rise in the reactor water level slowed down about this time and was decreasing after 20:00, which suggests that the amount of water injected from the RCIC to RPV decreased, resulting in a situation where the degree of subcooling at the core inlet decreased. Therefore, the fact that the reactor pressure has begun to rise is considered to be due to the increase in steam generation in RPV due to the decrease in the amount of water injected into the

RPV.

From the time the reactor pressure reached about 7.35MPa[abs] at about 19:50 until RCIC shutdown at 11:36 on the 12th, the pressure behavior was generally in a gradual upward trend, with a series of both small and large rises and drops. Factors that contributed to the reactor pressure behavior observed during this period are discussed in the next section.

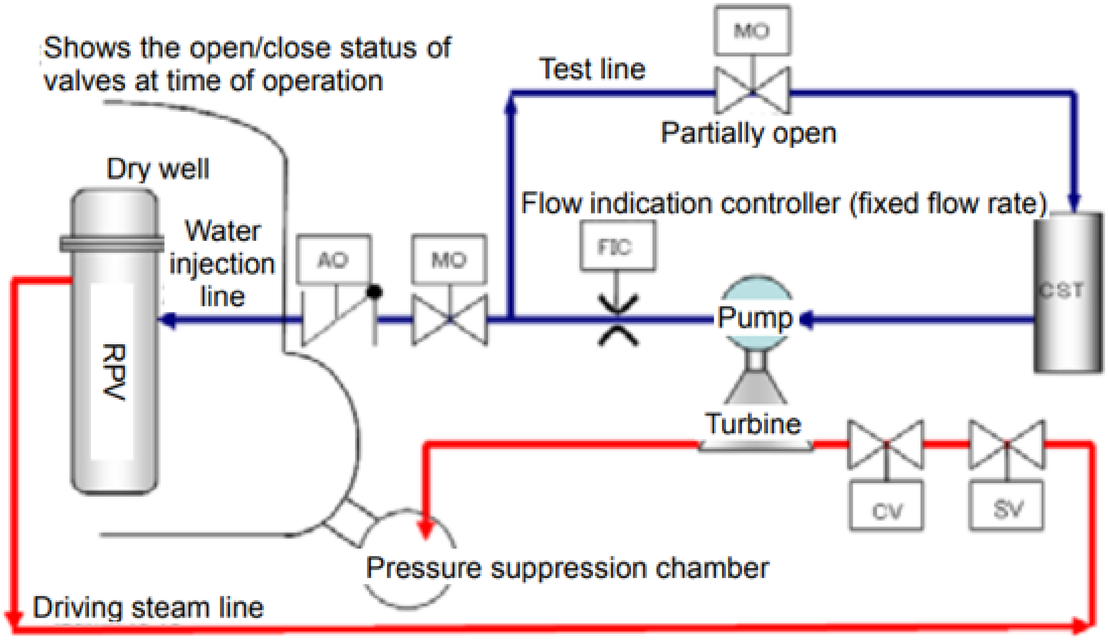

Figure 2　Outline of RCIC and HPCI reactor water injection lines [2]

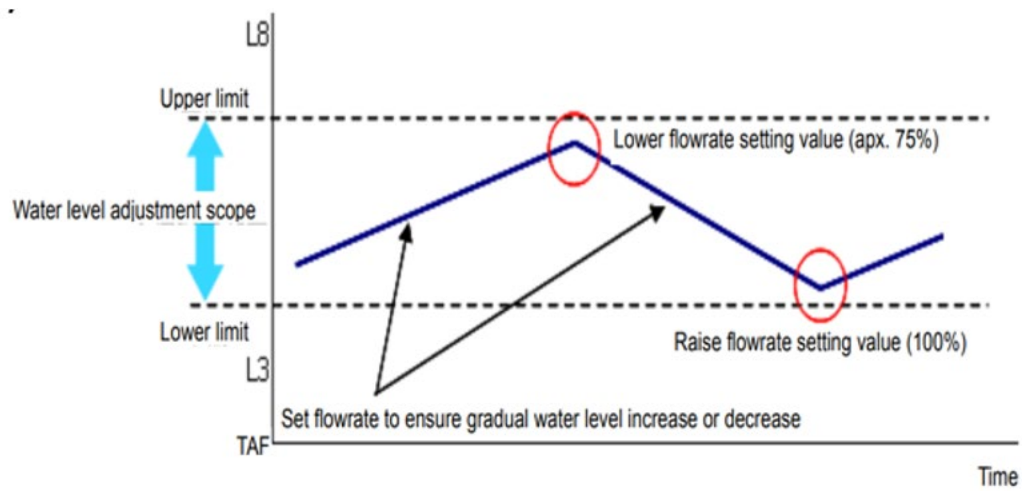

Figure 3　Reactor water level adjustment method (image) [2]

■ 2.3 Reactor pressure behavior during the second RCIC operation

As described in the previous section, the reactor pressure after 19:50 showed an overall upward trend. In addition, the reactor pressure behavior during the second RCIC operation showed a situation in which the small and large pressure drops and rises were repeatedly observed. This section discusses the factors that caused the reactor pressure to exhibit this behavior.

(1) The increasing trend in reactor pressure

The reasons for the overall increasing trend in reactor pressure change is examined. Based on the fact that there was no sudden drop in either the reactor water level or the reactor pressure during this period, it can be assumed that there was no significant leakage in the RPV boundary and that the reactor pressure during this period changed in accordance with the energy balance relationship in the RPV. In other words, the energy balance in the RPV during this period was positive.

The decay heat change in Unit 3 is shown in Figure 4. As seen in the figure, the decay heat at the start of the second RCIC water injection (16:16 on the 11th) was about 27MW, whereas normal RCIC operation can remove about 70MW of decay heat [5]. Therefore, although the reactor pressure is expected to decrease in relation to the energy balance, the reactor pressure at that time showed an increasing trend, and therefore, the RCIC operation could not sufficiently cool the decay heat. In other words, since this was a special operation to avoid battery consumption and, at the same time, to secure the reactor water level, the amount of water injected into the RPV is considered to have been lower than during normal RCIC operation.

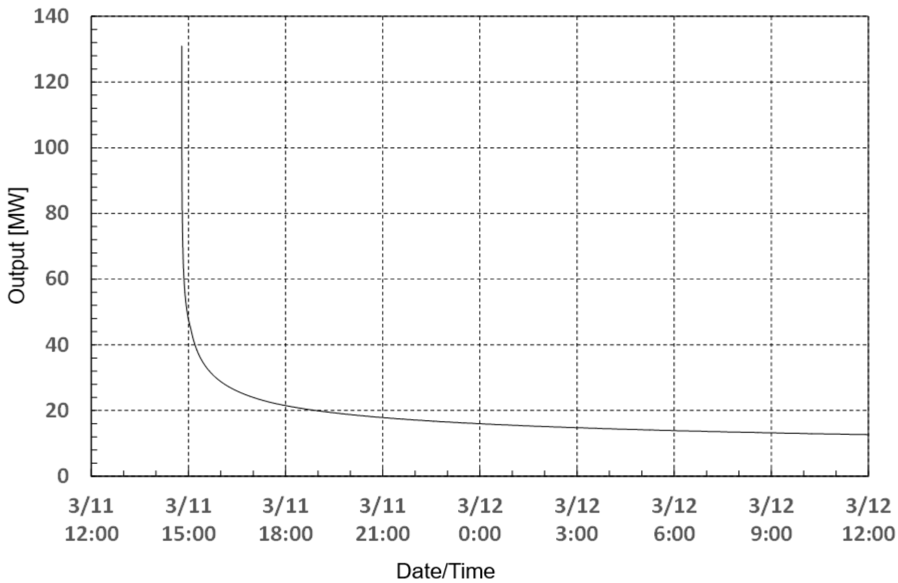

Figure 4 Time change of decay heat [7]

(2) The behavior of repeated small and large pressure rises and drops

This section discusses both the small and the large pressure rises and drops seen in the overall changes in reactor pressure during the second RCIC operation period. In terms of the energy balance with the decay heat, the pressure will not decrease without additional heat removal factors, since the decay heat cannot be removed by water injection to the RPV and extraction to the RCIC turbine alone. Therefore, in addition to steam consumption to operate the RCIC, there might have been steam release from the RPV to PCV via the SRVs during this period.

The expected opening mode of the SRV at this time is considered. As shown in Figure 5, the SRV is designed to open by applying a working force greater than the working force that closes the valve. The mechanism of SRV opening and closing in the normal relief valve mode is described below. When the reactor pressure rises to the outlet pressure of each SRV, the SRV open indicator light is turned on and nitrogen gas is supplied to the cylinder on the left side of the figure, and when the sum of the nitrogen gas working force (P_N in the figure) and the reactor pressure (P_R) is greater than the working force to close the valve (P_P+P_A), the SRV opens. Subsequently, when the reactor pressure drops to the individual SRV blowout stop pressure, the SRV open indicator light is turned off, the nitrogen gas in the cylinder is discharged into the PCV, and SRV closes due to the loss of the nitrogen gas working force (P_N). On the other hand, during the second RCIC operation period, reactor pressure fluctuations that were smaller than the pressure at the SRV blowout and stop were observed, which may have been caused by the SRVs being in an open/closed state that was not fully open or fully closed. The following are possible mechanisms by which the SRV could be in such an open/closed state [5].

- When there is no new nitrogen supply to the accumulators that supply nitrogen to the SRV, the nitrogen in the accumulators is consumed by the SRV opening and closing, and the nitrogen gas working force (P_N) is reduced.
- If the SRV is opened while the P_N has decreased due to several operations, before the reactor pressure drops to the blowout stop pressure (i.e., the SRV open signal is still held), an event can occur in which the SRV closes due to a decrease in the reactor pressure acting force (P_R in the figure).
- Since the SRV open indicator light is on, the nitrogen gas in the cylinder is not discharged and maintains some amount of working force. If the reactor pressure rises in this state, the SRV opens again, but the reactor pressure drops immediately, so the SRV repeats opening and closing with a small pressure change range.

On the other hand, in the safety valve mode, the valve opens when the working force of the reactor pressure (P_R) is greater than the working force to close the valve (P_A), so if the spring load becomes smaller due to factors such as the spring temperature rising and the Young's modulus dropping, the valve might open at a lower pressure than the set value. Although it is difficult to determine which mode caused the steam release via the SRV during this period, given the fact that the amount of steam formation was decreasing during this time period because the decay heat was decreasing as described so far, it is considered possible that even if the SRV opened, the reactor pressure would immediately decrease and the SRV would close.

Another possible factor contributing to the repeated drops and rises in reactor pressure during this period could be the effect of the RCIC adjusting the amount of water injected, as described above. If the amount of water injection by the RCIC increases, the reactor pressure will decrease due to a decrease in steam generation from decay heat, and conversely, if the amount of water injection decreases, the reactor pressure will increase. The large and small pressure rises and drops seen in the reactor pressure during this period might have been related to both opening and closing of the SRV and the increase and decrease in the amount of water injected by the RCIC.

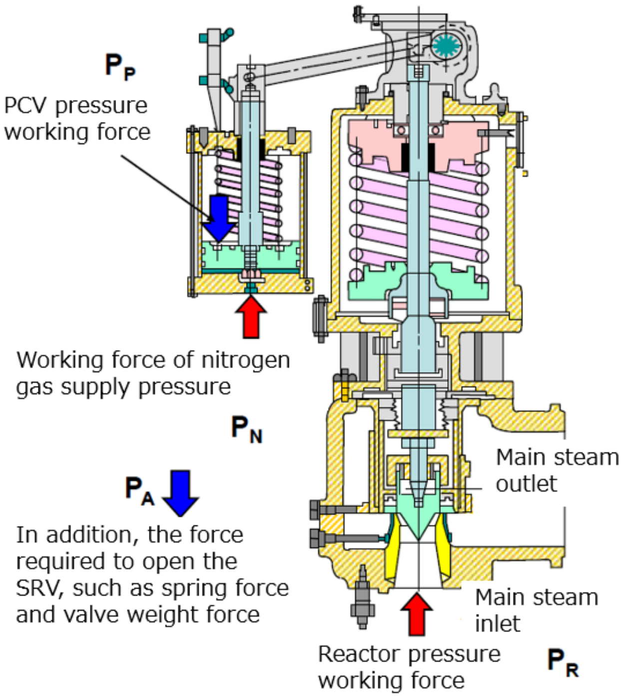

Figure 5 Cross section of SRV [6]

■ 3. Examination by simulation

In this section, the reactor pressure behavior during the RCIC operation period is investigated by simulating the plant parameters of Unit 3 with the analysis conditions of water injection from the RCIC to RPV, SRV opening/closing, and exhaust to the RCIC turbine.

■ 3.1 Analysis system and analysis conditions

The RELAP5 code, a two-fluid model that can more practically evaluate the two-phase flow behavior of a BWR, was used in the reproduction analysis. A node diagram simulating Unit 3 is shown in Figure 6. As seen in the figure, the entire plant was simulated with components simulating the reactor pressure vessel, recirculation loop, feedwater system, and main steam system, etc. In order to reproduce the plant behavior during the period of interest, the following were assumed for steam releases from the reactor under the conditions set in the analysis, the SRV opening and closing according to the design conditions, the RCIC turbine exhaust, and the valve that simulates steam release via the SRV (hereafter referred to as "steam release simulation valve"). Also, a component simulating water injection from the RCIC to the RPV was included. A code-embedded model was used for decay heat after the reactor scram. The main analytical conditions that affect the plant behavior during this period are described below.

(1) SRV opening and closing according to the design conditions

The SRV opening and closing that are normal in the relief valve mode were set until the arrival of the tsunami, and setting for opening according to the opening pressures and the operating sequence are shown in Table 1. The SRV operating sequence was set for convenience, taking into account that the transient record [3] gave switching of the SRV from the C valve to the G valve and then to the A valve. In addition, the number of SRV opening/closing operations was set to eight times after the loss of all AC power due to the arrival of the tsunami, based on the record of the transient phenomenon recorder, in consideration of the drop in accumulator pressure[1].

Table 1 Set pressure for SRV opening and closing and the order of actuation in this analysis (unit: MPa[gage]) [7]

	A	B	C	D	E	F	G	H
Opening pressure	7.51	7.58	7.44	7.58	7.51	7.58	7.51	7.58
Order of actuation	3	5	1	6	4	7	2	8

[1] After the C valve of the SRV stopped showing it was actuated, eight actuations were recorded in the transient recorder for the G valve that was subsequently actuated [3].

(2) Steam release simulation valve (simulating steam release via the SRV)

For the steam release via the SRV during the second RCIC operation period, as described above, the area to reproduce the reactor pressure and reactor water level behavior was set to 10% of one valve fully open, since it is not considered to be normal fully open or fully closed state. For the valve opening and closing conditions, a curve that roughly traces the measured reactor pressure (Figure 7) was used as a set value to control the opening and closing of the valve from time to time, and the valve was set to open and close according to the relationship between this set value and the reactor pressure.

- Valve area: 10% of SRV fully open area
- Open/Close condition: Open: Reactor pressure > set pressure value of Figure 7; Closed: Reactor pressure < set pressure value of Figure 7

(3) Simulation of the first RCIC operation

In the first RCIC operation, which was manually started at 15:05 on the 11th, no flow adjustment operation was performed as in the second RCIC operation until the automatic shutdown at 15:25 due to the high reactor water level. Therefore, the amount of water injected from the RCIC to the RPV during this period was assumed to flow in at a constant value.

- Injection period: Water injection was started at 15:06[2] and stopped at 15:25 when the reactor water level reached L8 in the analysis.
- Injected water volume: 30kg/s (the amount of water injected at the time when the RCIC stopped at water level L8 coincided with the measured value)

(4) Simulation of the second RCIC operation

The second RCIC operation, which was started manually at 16:03 on the 11th and water injection from the RCIC to the RPV which began at 16:16, was carried out while monitoring the reactor water level to avoid an automatic shutdown due to high reactor water level, so the actual status of water injection to the RPV is unknown. However, as mentioned above, the measured reactor water level (Figure 1) can be considered to reflect the status of water injection into the RPV. Therefore, similar to the concept of the opening/closing conditions of the steam release valve, a curve (Figure 7) that roughly traces the measured values of the reactor water level was set, and presence or absence of water injection into the RPV was switched according to the relationship between this set value and the reactor water level.

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[2] The analysis was set up based on the time in the duty officer's handover logbook. It should be noted that reference [1] describes the time recorded according to the Unit 3 alarm type.

This water injection condition was continued until 11:36 on December 12, when the RCIC automatically shut down. The amount of water injected into RPV was set to 80% of the first injection amount to reproduce the reactor pressure and water level.

- Injection period: On the 11th from 16:16 to the 12th at 11:36
- Water volume: 80% of 1st water injection volume
- Water injection condition: Water injection was switched on under the following conditions starting at 17:10 on the 11th when the reactor water level was measured. However, the trip under which the RCIC automatically stops depending on the reactor water level was disabled.
  Start: Water level < set value of water level of Figure 7
  Stop: Water level > set value of water level of Figure 7

(5) Exhaust flow to the RCIC turbine during RCIC operation

To simulate the exhaust of air to the RCIC turbine, the valve area was set to extract an amount equivalent to the steam consumption required to operate the RCIC, and the valve was set open during RCIC operation.

- Valve area: Area equal to steam consumption during RCIC operation
- Exhaust period: Period during which RCIC operation took place (1st and 2nd)

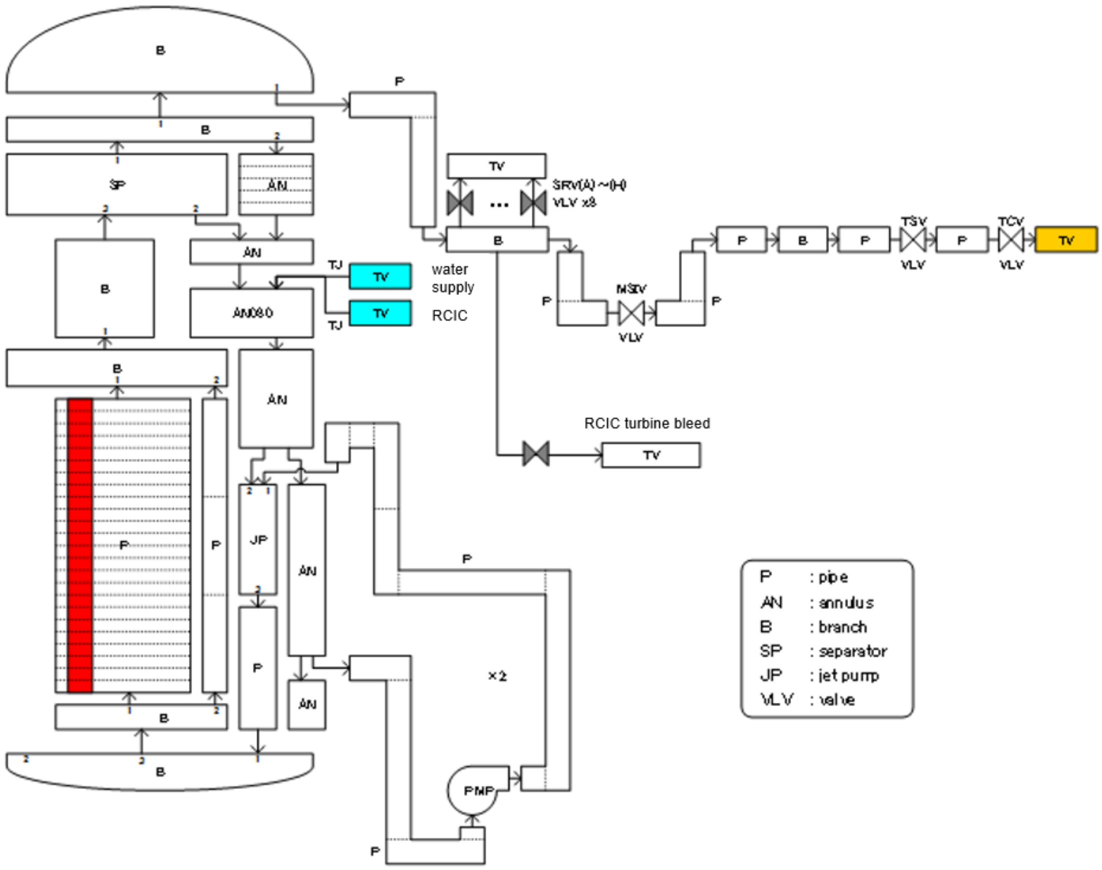

Figure 6 Analysis node diagram

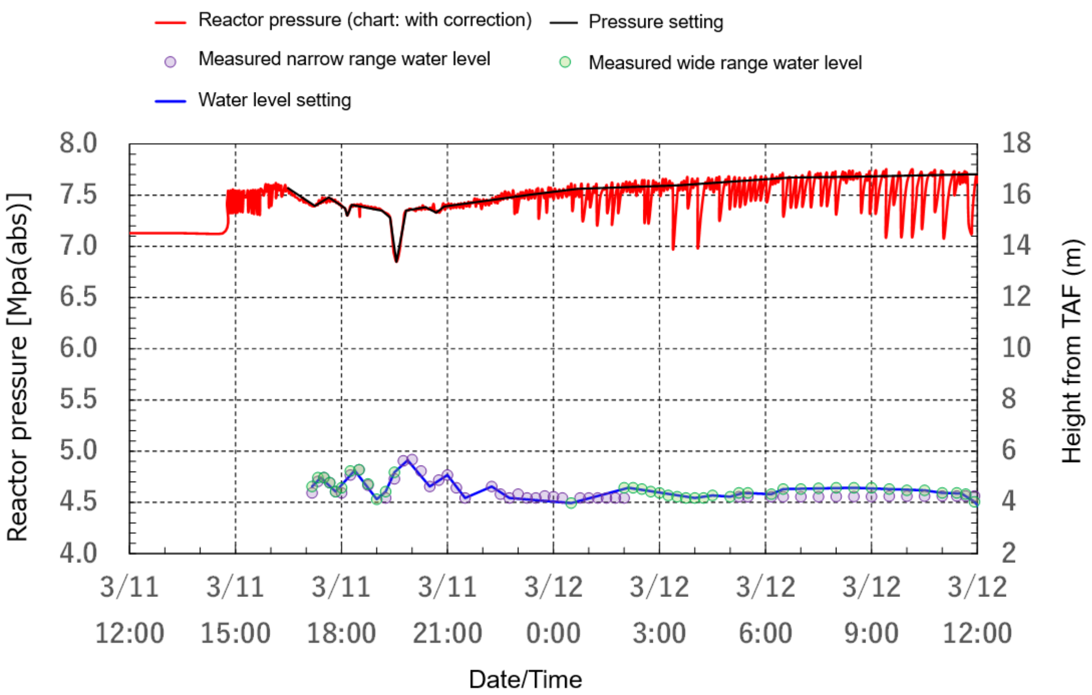

Figure 7 Analysis set values (black, pressure set value; blue, water level set value)

■ 3.2 Analysis results

The analytical results of the reactor water level and pressure are shown in Figure 8 in comparison with the measured values. The plant behavior until the RCIC was manually activated was that the reactor water level and pressure decreased due to the reactor power drop caused by the reactor scram after the earthquake, but these parameters started to rise as the MSIV was closed, and the reactor pressure control by SRV opening and closing continued until the RCIC operation started. The results of the analysis after the start of RCIC operation are described below.

(1) Reactor water level

The reactor water level changed during the period simulating the first RCIC operation as follows. Although the water level drops as steam was released with the SRV opening and closing, the reactor water level began to rise as the RCIC started injecting water at 15:06 on the 11th. The reactor water level continued to rise and reached L8 at 15:25, and the water injection was stopped according to the analysis conditions described above, which resulted in the reactor water level decreasing again. Although there are no measurements of the reactor water level during this period, given that the timing of the automatic shutdown of the RCIC at the high reactor water level was roughly the same as that recorded at the time of the accident [1], it is believed that this reproduced the water injection situation into the RPV during the first RCIC operation.

The results of the analysis for the second RCIC operation after 16:03 on the 11th are described next. The reactor water level rose with the start of water injection into the RPV at 16:16. Although the rise in the reactor water level at this time was similar to the measured value, the simulated water level rose earlier, and the water level was higher than the measured value at the time when the water injection was stopped in the analysis (17:10). This was a result of the fact that the water injection condition for the second RCIC operation was set after 17:10, when the measured value was recorded, as described in the analysis conditions, so that from 16:16 to the same time, the water injection continued at 80% of the rated level, regardless of the reactor water level status. Therefore, it can be said that the simulation results in a larger amount of water being injected into the RPV than in reality. The result of the higher than actual amount of water injected into the RPV might also be a factor in the large drop seen in the reactor pressure, which is discussed later.

Water injection from the RCIC to RPV after 17:10 results in reproducing the measured reactor water level by repeatedly injecting and stopping water from the RCIC to RPV as shown in Figure 9, according to the relationship between the set value traced from the water level measurement and the reactor water level.

(2) Reactor pressure

The reactor pressure until the RCIC started injecting water at 15:06 on the 11th was the result of the reactor pressure being controlled by the SRV opening and closing, although the pressure dropped due to the decrease in reactor power caused by the reactor scram, but then the MSIVs closed, so the reactor pressure started to rise.

Reactor pressure behavior during the first RCIC operation period is described. Water injection into the RPV started at 15:06 and reactor pressure started to decrease about 15:13, but at 15:25 the reactor water level reached the reactor water level high L8 and the RCIC shut down. The reactor pressure then rose and reached the SRV opening pressure again, and the reactor pressure continued to be controlled by SRV opening and closing.

In the second RCIC operation, the reactor pressure began to drop significantly about 16:30, and the analyzed pressure drop at this time was larger than the measured one. The following factors are considered to be responsible for these differences. As explained in the results of the reactor water level, more water was injected into the RPV from 16:16, so the heat produced by the decay heat was cooled down more, therefore the difference in the RCIC water injection into the RPV can be considered as the reason for the RPV pressure analysis results showing the big decrease. It is also possible that the analysis code simulated the entire plant by dividing it into multiple nodes, the temperatures in the nodes are homogenized and the depressurization behavior tends to be overestimated [5].

These large pressure drops were also observed at about 18:08 and 19:15. As shown in Figure 9, the analysis indicated that water injection from the RCIC to RPV started at this time, and since the decay heat then was even lower than at 16:16 (Figure 4), the large pressure drops were caused by the same mechanism as the large pressure drop seen when water injection started for the second RCIC operation.

In the analysis, the reactor pressure began to rise as the water injection to the RPV was stopped about 19:55, and the pressure rose to the set pressure for opening and closing the steam release simulation valve. The subsequent transition reproduced the trend of a gradual increase in reactor pressure with repeated intermittent pressure drops and increases as seen in the measured values due to intermittent water injection from the RCIC to RPV (Figure 9) and the opening and closing of the steam release simulation valve (Figure 10).

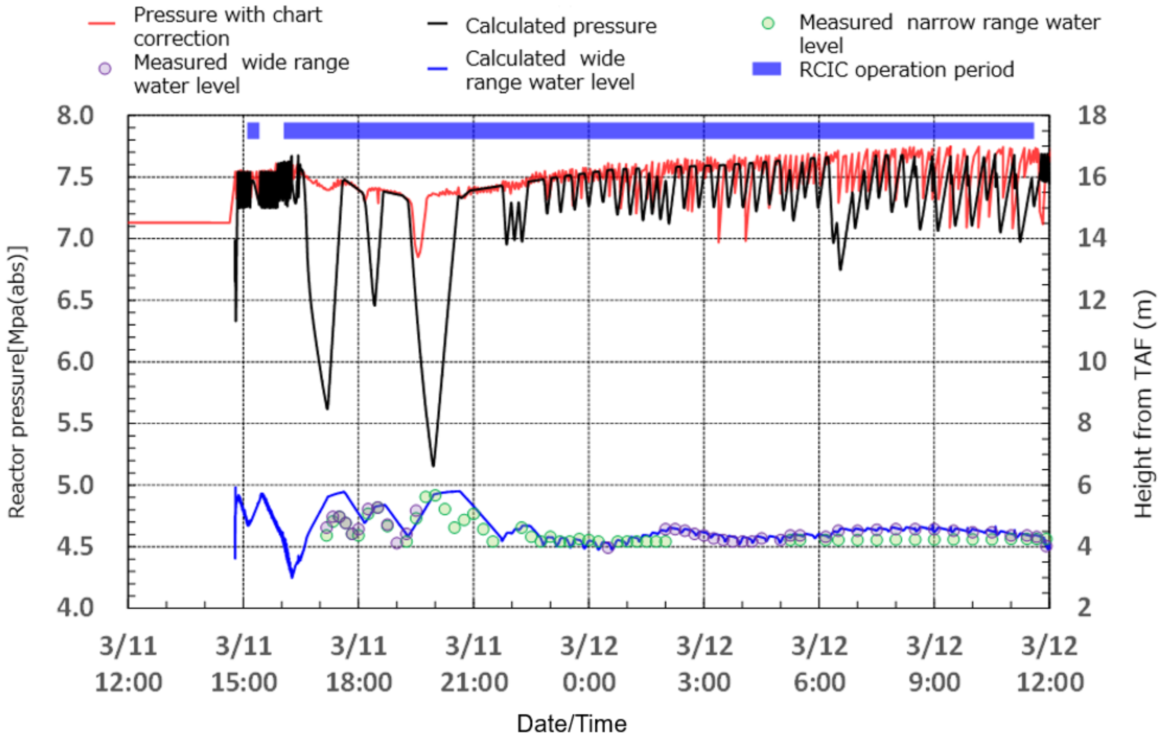

Figure 8 Reactor water level and reactor pressure

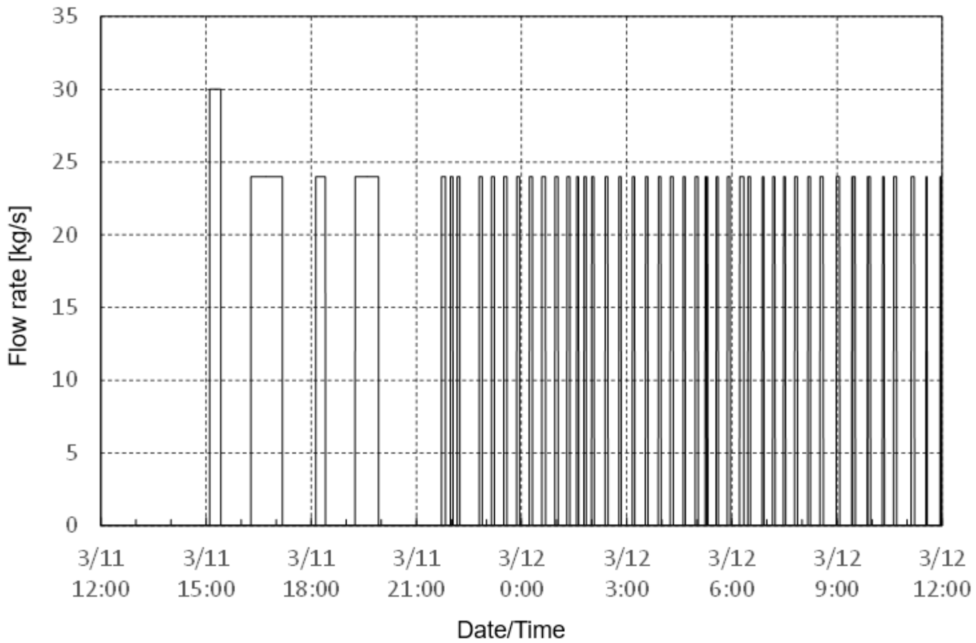

Figure 9 Water injection flow rate from RCIC to RPV

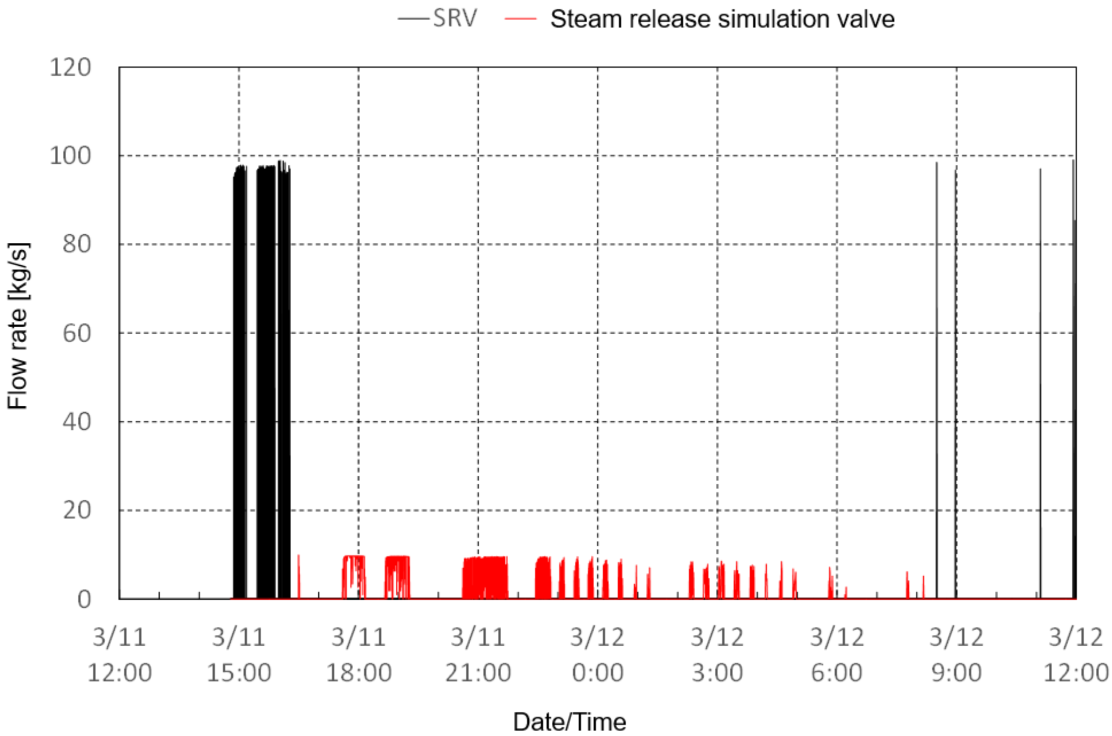

Figure 10　Flow rate of SRV and steam release simulation valve

■　3.3 Reactor pressure behavior during the RCIC operation period

This section describes the actual mechanism of reactor pressure behavior during the RCIC operation period based on the analysis results described above.

The analysis results showed that the RPV was cooled by the first RCIC operation, which started at 15:06 on the 11th, so the repetitive decrease and increase in reactor pressure caused by the SRV opening and closing, which had continued until about this time, temporarily ceased to be observed. Then, at 15:25, the reactor water reached a high level and the RCIC was shut down, so the reactor pressure was again controlled by the SRV, this situation continued until about 16:00. This can be confirmed by the fact that the heat removal associated with the SRV steam release, which was set as the SRV opening and closing condition until the tsunami arrived, was larger than the decay heat, as seen in the comparison of decay heat and heat removal by the SRV, RCIC exhaust, and steam release from the steam release simulation valve shown in Figure 11.

In the second RCIC operation, the reactor pressure from the start of water injection at 16:16 until about 20:00 showed an overall downward trend with repeated decreases and increases, and after 20:00 showed an overall upward trend with smaller pressure decreases and increases than before.

The behavior of the reactor pressure from the start of water injection until about 20:00 is summarized below. As seen in Figure 8, the reactor water level continued to rise due to water injection into RPV that started at 16:16. When the control of water injection to the RPV was started at 17:10[3], the reactor water level was higher than the set value, so the water injection was stopped (Figure 9), and the reactor pressure was increasing. This is due to water injection into RPV decreasing the amount of steam formation in the reactor by decay heat, and when the water injection was stopped, the amount of steam formation increased. Similar behavior also occurred from 18:07 to 18:23 and from 19:15 to 19:55. The overall downward trend of the reactor pressure until about 20:00, as seen in the analysis results, suggests that the cooling effect of water injection from RCIC to RPV during that period was related to the cooling effect exceeding the decay heat.

The reactor pressure began to increase about 20:00, and remained in an overall upward trend until 11:36 on the 12th, when the second RCIC operation was stopped, with smaller pressure drops and increases than before. The small pressure drop observed in the analysis results is consistent with the timing of water injection from RCIC to RPV according to the analysis conditions (Figure 9), and is considered to be due to the cooling effect of water. Injection from the RCIC to RPV and the pressure drop were observed until about 20:00. On the other hand, until the RCIC stopped, there was an overall upward trend, similar to the measured values. This indicated that the steam release from the exhaust to the RCIC turbine alone was not enough to consume the decay heat; a separate steam release was needed. The integrated heat production from decay heat and heat removal by vapor release is compared in Figure 12. To reproduce the upward trend in reactor pressure during the second RCIC operation period, it was necessary to consume the decay heat by steam release from the steam release simulation valve in addition to the steam release from the SRV opening according to design conditions and the exhaust to the RCIC turbine.

Considering that there was no significant leakage in the RPV boundary, it is highly likely that there was a steam release flowing into the suppression chamber via the SRV, as seen in the above analysis results, given that no sudden drop in reactor water level or significant pressure drop in the reactor pressure was observed in the measurements taken while the RCIC was in operation. As can be seen in the above analysis results, there is a high possibility that there was a vapor release through the SRV to the suppression chamber. However, as can be seen from Figure 11, it is considered that the steam release was less than if the SRV condition was fully opened according to the design.

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[3] Water injection control for the second RCIC operation was set from 17:10, when the reactor water level was recorded.

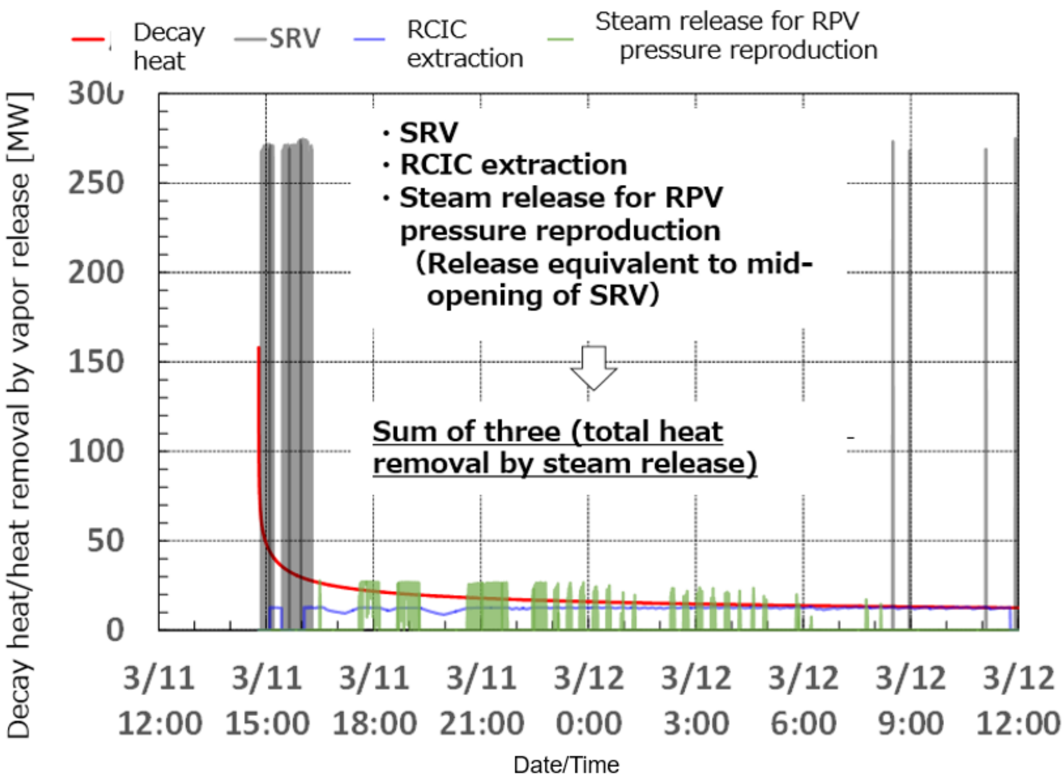

Figure 11　Comparison of heat removal by decay heat and vapor release

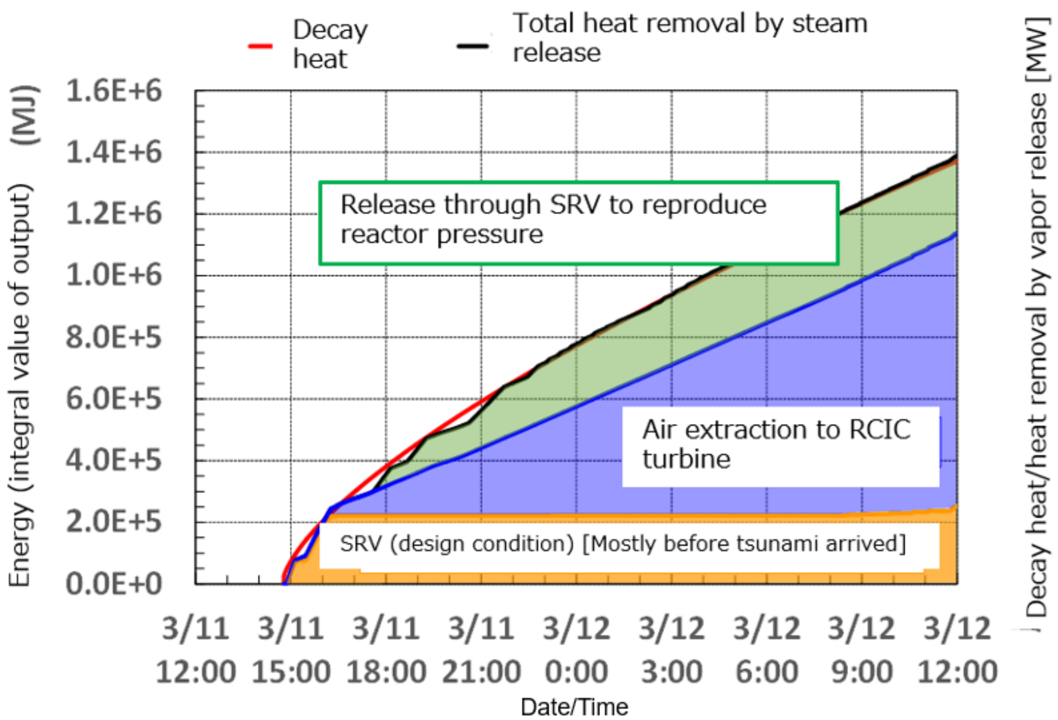

Figure 12　Integrated heat production from decay heat and heat removal by vapor release

■ 4. Summary

In this attachment, the reactor pressure behavior during the Unit 3 RCIC operation was focused on examination of the plant behavior at that time and the following items were confirmed.

- Considering that the RPV boundary was not damaged during this period, the reactor pressure behavior during RCIC operation followed the energy balance relationship in the RPV.
- The large drop in reactor pressure seen during the period from the start of the second RCIC operation until about 19:30 was confirmed to be caused by the cooling effect of the water injection from the RCIC to RPV, although the analysis tended to overestimate the depressurization due to the homogenization of the temperature in the nodes.
- Regarding the reactor pressure behavior during the second RCIC operation period, it is likely that there was a steam release flowing to the suppression chamber via the SRV because the steam release from the SRV opening and exhaust to the RCIC turbine according to the design conditions alone was not sufficient to consume the decay heat. However, the steam release would have been less than if the SRV condition was fully opened according to the design.

Through these examinations, it is believed that the behavior of the reactor pressure during RCIC operation reflects the steam release via the SRV and the depressurization effect associated with water injection from the RCIC to RPV, although the opening and closing modes cannot be identified.

■ 5. Relationship to safety measures at the Kashiwazaki-Kariwa Nuclear Power Station (NPS)

From this examination, it is possible that after the tsunami arrived, while there was no new nitrogen supply to the accumulators that supply nitrogen due to the loss of power, SRV opening and closing continued, which consumed nitrogen in the accumulators, and the SRV condition might have been a state where it was not fully opened or fully closed during the RCIC operation period. On the other hand, the ADS function to depressurize the reactor and promote low-pressure water injection and the manual rapid depressurization function are particularly important from the viewpoint of reactor safety, and it is important to secure a nitrogen supply means and power source to maintain these functions.

At the Kashiwazaki-Kariwa NPS, the following measures ensure the ADS function of the SRV and the manual rapid depressurization function (Figures 13 and 14).

- The nitrogen supply means in case of nitrogen loss in the accumulator is secured by a cylinder in the high-pressure nitrogen gas supply system. In addition, a line independent of the high-pressure nitrogen gas supply system is installed to enable the relief safety valve to operate only by supplying nitrogen from the cylinder.

- The sealing material of the solenoid valve in the nitrogen supply line to the relief valve was changed to EPDM, which has superior high temperature resistance.
- An alternative spray procedure was added to mitigate thermal effects on the relief valve.
- A supply method was added using storage batteries for accident management, portable DC power equipment (power supply vehicles), or portable storage batteries for the relief valve in the case of loss of permanent DC power.

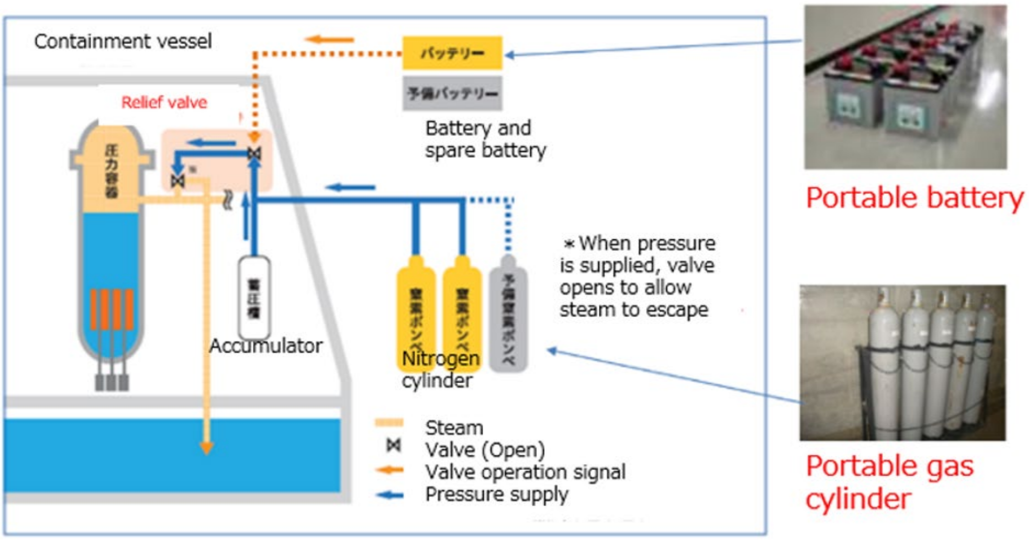

Figure 13　Measures to maintain SRV open (1/2)

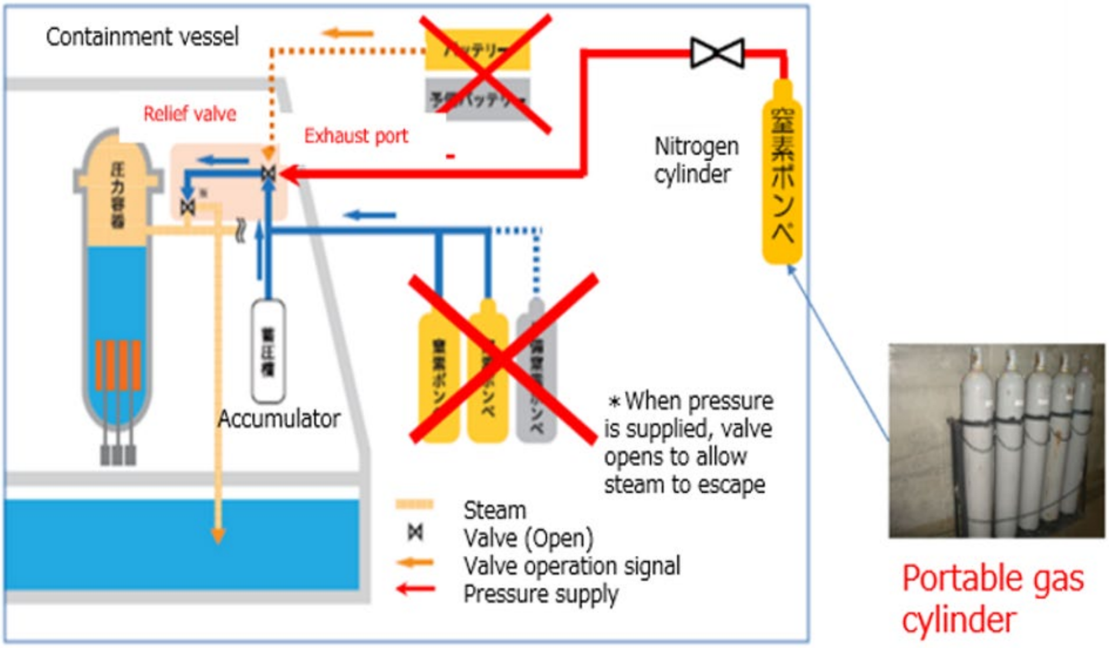

Figure 14　Measures to maintain SRV open (2/2)

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