

Behavior of primary containment vessel pressure
starting about 12 o'clock on March 14th in Unit 2

1. Outline of phenomena and subjects of investigation

In Unit 2, it is thought that the reactor core isolation cooling system (RCIC) was continuing water injection during about 3 days, even after losing the control power supply due to damage caused by the tsunami. At about noon on March 14th, the reactor water level showed a falling tendency, and the Emergency Response Center (ERC) at the power stations judged that the RCIC function was lost at 13:25. Both during operation of the RCIC and after its stopping, the phenomena, in which decay heat generated in the reactor pressure vessel (RPV) is carried to the suppression chamber (S/C) by steam, were the same, and it is expected that the pressure of primary containment vessel (PCV) monotonically increased.

However, the measured value of PCV pressure dropped after about 12:00 on the 14th. In this Attachment, the cause of this pressure behavior is examined. In the Government Accident Investigation Report, it was assumed that the pressure drop was basically caused by leakage, and that this pressure drop of the PCV was also caused by leakage.

2. The behavior of the PCV pressure

In Unit 2, as investigated in Attachment 2-2, it is shown that there was a possibility that tsunami inundated torus room and S/C in the room was cooled from the outside by the accumulated seawater. Since the function of the seawater cooling system was lost because the AC and DC power supplies were lost when the equipment was damaged by the tsunami, Unit 2 entered the stage of so called loss of ultimate heat sink (LUHS) after the tsunami hit. Therefore, some of the energy generated by decay heat was in the RPV and in the PCV, and some part was also exhausted to outside the PCV by the increasing seawater temperature in the torus room.

When energy is accumulated in the PCV, this energy is distributed to the water phase and the gaseous phase of the S/C. In the case of the Mark-I type PCV, most of the energy generated in the reactor is accumulated in the water in the S/C since the design is made to suppress the pressure increase of the PCV by condensing steam in the S/C. As a result, the PCV pressure becomes in equilibrium with the water temperature (particularly the surface temperature) of the S/C.

In the period until the RCIC stopped, which is just before the period being focused on here, as investigated in other documents, two-phase flow flows into the RCIC turbine and the situation occurs where the energy of the decay heat from the RPV is transferred to the S/C only by the turbine system of the RCIC. Since the energy of decay heat does not transfer from the RPV to S/C after the RCIC stops, the effect appears in the form of reactor pressure increase. Once the reactor pressure significantly increases, the energy transfer from the RPV which went via the safety relief valve (SRV) to the S/C resumes when the pressure reaches the operation pressure of the SRV.

Therefore, the PCV pressure is determined by the energy accumulated in the PCV, and the accumulated energy changes with the energy transfer from the RPV and the energy release to the seawater.

From these observations, it is expected that the behavior of the PCV pressure changes by the following 3 effects:

- ① The S/C is continuously cooled by seawater.
- ② Energy transfer to the S/C stops when the RCIC stops.
- ③ Operation of the SRV occurs and energy transfer to the S/C resumes.

Therefore, the following qualitative scenario can be made. During RCIC operation, if it is assumed that the effect of ① is smaller than the effect of ②, PCV pressure monotonously increases until the RCIC stops. When the RCIC stops, the PCV pressure decreases because the accumulated energy of the PCV decreases. If the reactor pressure increases to the point at which the SRV operates, the pressure decrease of the PCV stops, since energy transfer to the S/C resumes depending on the magnitude correlation between ① and ③. In addition, the actual pressure behavior of the PCV, described in Fig. 1, shows first a monotonous increase, then a decrease and finally a stop of the pressure decrease.

However, if time change of the PCV pressure is observed, water injection into the reactor by the RCIC stops at about 9:00 on the 14th, which is estimated from the increase of the reactor pressure, and start of pressure reduction of the PCV is at about 13:00 when SRV operation resumes. This behavior is different from the above qualitative explanation. In addition, after some time, when reactor pressure decreases to below 1 MPa at about 18:00 by manually opening the SRV by remote operation from the main control room using a temporary battery power supply, no change in PCV pressure is observed although a lot of steam (and energy) flows into the S/C. Thus, the following chapters describe the detailed investigation of the pressure behavior of the PCV.

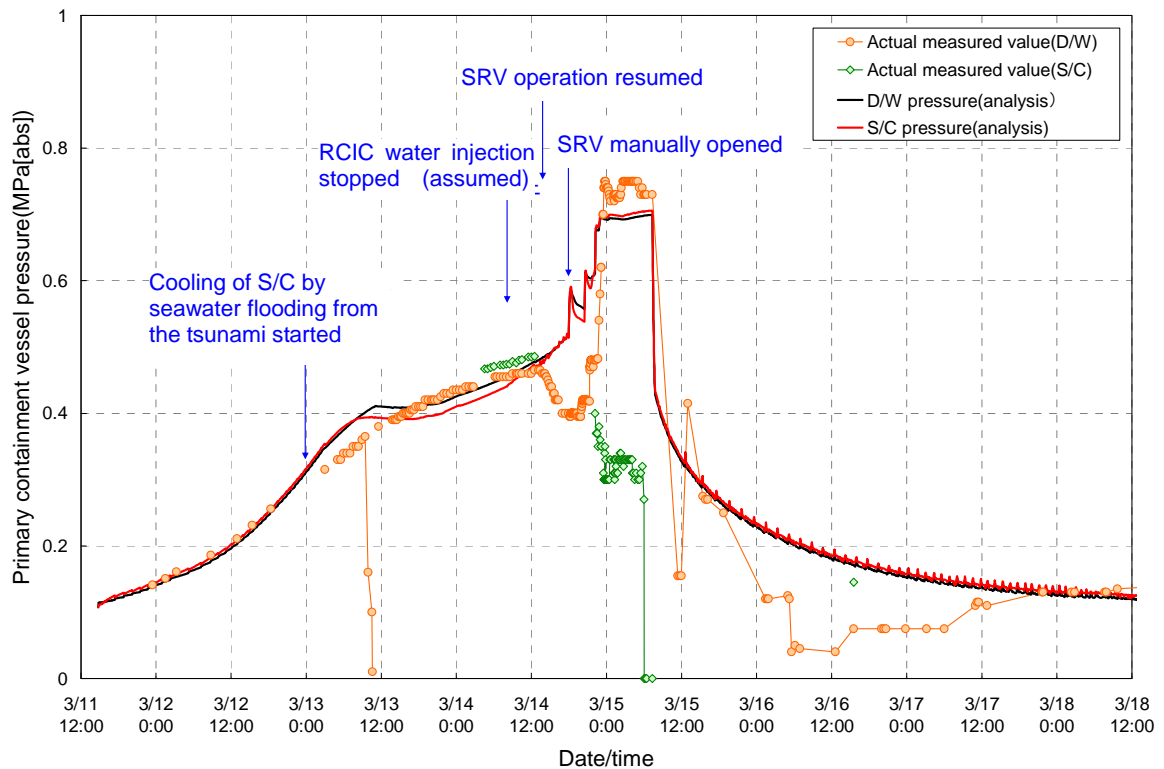


Fig.1 Change of PCV pressure

3. Operation status of the RCIC

Regarding RCIC operation, loss of function is officially reported after observation of water level decreases. The TEPCO Fukushima Nuclear Accident Investigation Report in Attachment 2 describes what happened as follows.

At 13:25 the reactor water level was dropping, indicating the loss of the RCIC function. TEPCO judged that the specific event (loss of reactor cooling function) specified in Paragraph 1, Article 15 of the Act on Special Measures Concerning Nuclear Emergency Preparedness had occurred and reported it at 13:38 to the relevant authorities.

The behavior of measured values of the water level gauge showed later that the water level measured at that time was over the measurement upper limit, thus lowering of the water level started before it appeared in the measurement data. Therefore, water injection to the reactor by the RCIC had a high possibility of having stopped before it.

The reactor pressure can be considered as the parameter in which change of the reactor water injection by the RCIC is reflected, in addition to the measured value of the water level

gauge. If the reactor water injection stops, the reactor pressure starts to increase, since the supply of relatively low temperature water from the S/C stops. According to Fig.2 which shows the time change of reactor pressure, it can be observed that reactor pressure increase started at about 9:00. Therefore, the stop of reactor water injection by RCIC is evaluated as taking place at about 9:00.

Fig. 3 shows close-up of time changes of reactor pressure. While the reactor pressure increase started at about 9:00, the rapid pressure increase is observed after the increase of reactor pressure stops once at about 12:00. The following hypotheses can be considered about this.

- Steam supply is continued although the water injection to reactor stopped at about 9:00. (Energy transfer to S/C is also continued.)
- At about 11:30, reactor water injection is resumed for some reason.
- At about 12:00, the RCIC turbine tripped for some reason and the steam supply to the turbine is also stopped. (The only trip interlock mechanism which can occur during the event of no DC power supply is the mechanical trip due to excess speed of the turbine.)
- The reactor pressure rapidly increases under the conditions of no water injection and no steam supply to the turbine.

Fig. 3 also shows the analysis result obtained using the MAAP code under these conditions (except for resumption of water injection). Fig. 3 reproduces well the slow reactor pressure increase by the continuing steam supply to the RCIC turbine and also the rapid reactor pressure increase by the RCIC turbine trip.

However these hypotheses, in which energy transfer from the RPV to the S/C stops at about 12:00, cannot explain the status reasonably, because the actual start of the pressure decrease in the PCV is after 13:00.

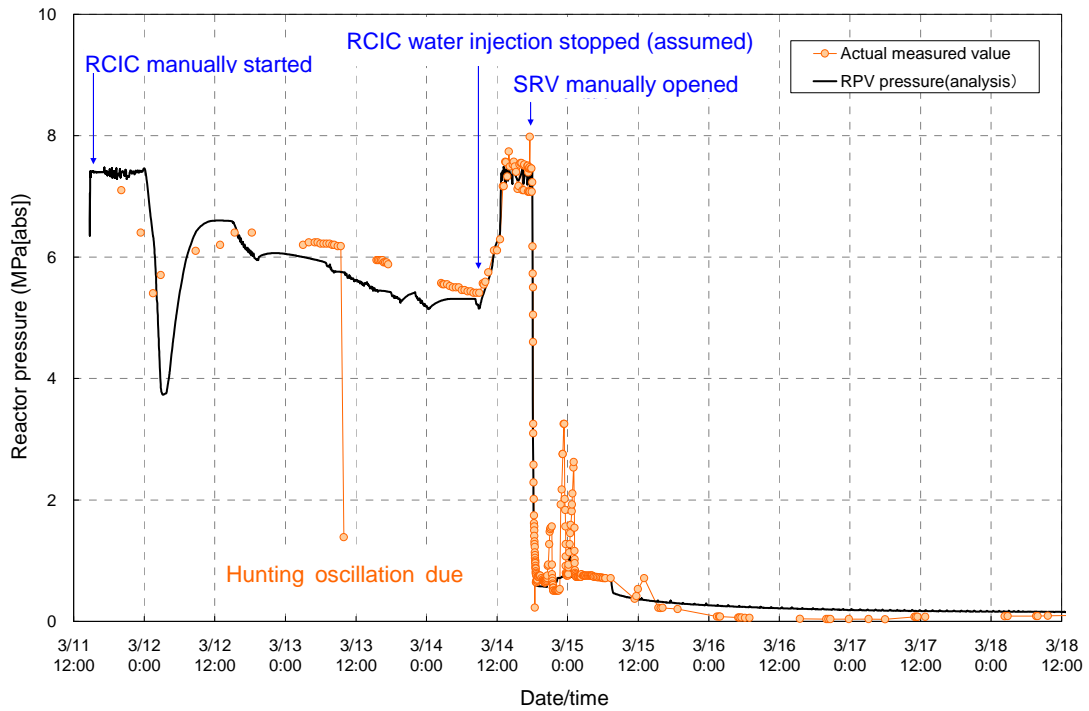


Fig.2 Change of reactor pressure

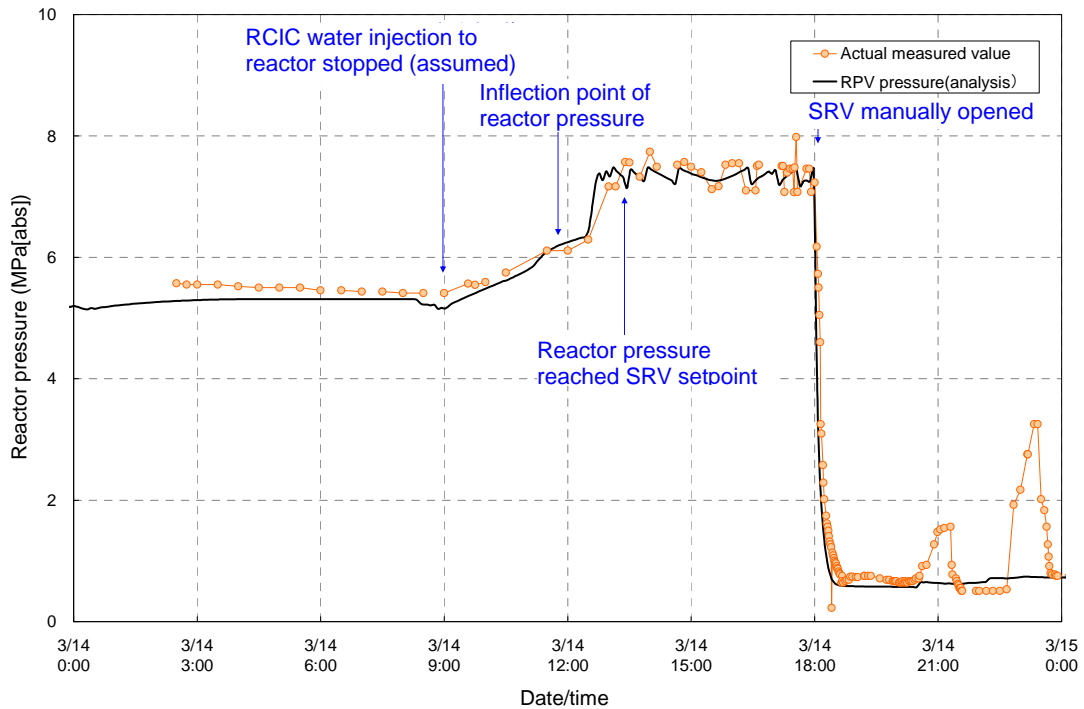


Fig.3 Change of reactor pressure (expanded scale)

4. Operation status of SRV

The SRV of Unit 2 opened a few times before the tsunami hit and its discharge behavior was recorded in the chart of the S/C temperature shown in Fig. 4. The thermometer was installed at O.P.350mm as shown in Fig. 5 and it measured temperature at a point a short distance below the S/C center and at 8 positions which were at intervals of 45° in the radial direction. Regarding the water temperature changes in the charts, it is confirmed that water temperature changed greatly in some locations, and this captured the localized temperature change of the S/C by operation of the SRV. The steam from the SRV was discharged from the T quencher located at the bottom of the S/C. The temperature increased as the thermometer was closer to the T quencher, and it is thought that temperature scattering occurred because of the turbulence at discharge. Moreover it is observed that the thermometer far from the T quencher increased continuously and moderately towards the equilibrium temperature. This is considered to reflect the situation that the location around the thermometer was relatively calm and the temperature of the liquid phase increased gradually.

Then RCIC which lost the control power supply due to the tsunami was driven by two phase flow and, after the decay heat generated in the reactor was completely transferred to the S/C through the RCIC turbine, the RCIC did not operate until the pressure increased after the RCIC stopped.

In the chart shown in Fig. 4, temperature data are recorded after resumption of water level indicator at about 7:00 on March 14th. The water temperature of the S/C is about 146 °C at about 7:00 and about 148 °C at about 12:00. The pressure of the S/C at about 12:00 is 0.46MPa, and the saturation temperature corresponding to this pressure is 148.7 °C. Therefore, at least up to the depth where the S/C water thermometer was installed, the temperature is considered to be almost constant. On the other hand, although accurate estimation of the time is difficult, temperature decrease is observed from about 13:00 when operation of the SRV resumed.

This temperature decreasing behavior agrees in timing with the pressure decreasing behavior of the PCV. The saturation temperature at 15:30, when the PCV pressure decreased to 0.43 MPa, is 146.2 °C. The temperature at the water thermometer position at this time is about 132 – 134 °C, which is lower than saturated temperature. This means that the S/C water temperature does not decrease due to the pressure decrease of the PCV. Therefore, it is estimated that pressure decrease of the PCV is caused by water temperature decrease of the S/C.

The meaning of resumption of the SRV operation is resumption of the energy inflow to the S/C from the viewpoint of energy balance, thus it is difficult to explain the behaviors of

decrease of temperature and pressure while energy inflows. Fig. 7 shows behavior of the water thermometer of the S/C after the RCIC stopped. In the water temperature behavior, existence or non-existence of temperature scattering is observed similar to the behavior during SRV operation before the tsunami hit. However, the difference from behavior before the tsunami is that occurrence of temperature scattering differs by time zone not by position. Although it cannot be declared what meaning this has, it is also possible to assume that the early stage of the temperature decrease is the temperature decrease by the liquid phase and after that the temperature decrease is accompanied by the influence of steam.

Fig. 8 shows close-up in the early stage of the temperature decrease. It is observed that two thermometers at 31° position and 76° position of Fig. 9 show different behavior in temperature decrease. That is, it is observed that there is locality in the decreasing behavior of the temperature decrease. This temperature decreasing behavior is considered to be the proof of the operation of the SRV. The battery was connected to SRV (A) in Unit 2. Table 1 shows the preset pressure. From the value of the measured reactor pressure (slightly below about 7.5 MPa), it is probable that SRV (A) was operated by the relief valve mode and it was assumed that the pressure is relieved from the T quencher near the 76° thermometer, as you can see in Fig.10.. There is high possibility that Main Steam Line A was fulfilled with water, because the RCIC turbine steam was extracted from Main Steam Line B.

In order to explain the pressure decrease of the PCV based on these temperature behaviors, the following hypotheses are made.

- Existence of water with relatively low temperature at the low position of the S/C.
- Discharge of water to the S/C at the early stage of SRV operation, since it is thought that water had accumulated in the main steam (MS) pipes.
- Water discharged from the T quencher moved to the upper part accompanied by lower temperature water.
- The PCV pressure decreased, as a result of the surface temperature of S/C water decrease.
- Steam is discharged to the S/C after discharging water in the MS pipes.
- Since steam condenses mostly by low temperature water at the bottom, the contribution to the water temperature decrease becomes small and temperature decrease finally stops.

If the above hypotheses are correct, the pressure decrease behavior of the PCV starting about 13:00 on the 14th can be explained. If there was low temperature water in the lower part of the S/C, the fact that PCV pressure did not increase when reactor was depressurized by manual opening of SRV can be explained at the same time.

Table 1 Preset pressure of SRV in Unit 2

	pressure setpoint (relief valve mode)	pressure setpoint (safety valve mode)	MS number
SRV-A	7.51[MPa(gage)]	7.72[MPa(gage)]	MS-1
SRV-B	7.58[MPa(gage)]	7.79[MPa(gage)]	MS-1
SRV-C	7.58[MPa(gage)]	7.79[MPa(gage)]	MS-2
SRV-D	7.51[MPa(gage)]	7.72[MPa(gage)]	MS-2
SRV-E	7.51[MPa(gage)]	7.65[MPa(gage)]	MS-3
SRV-F	7.44[MPa(gage)]	7.65[MPa(gage)]	MS-3
SRV-G	7.58[MPa(gage)]	7.72[MPa(gage)]	MS-4
SRV-H	7.58[MPa(gage)]	7.79[MPa(gage)]	MS-4

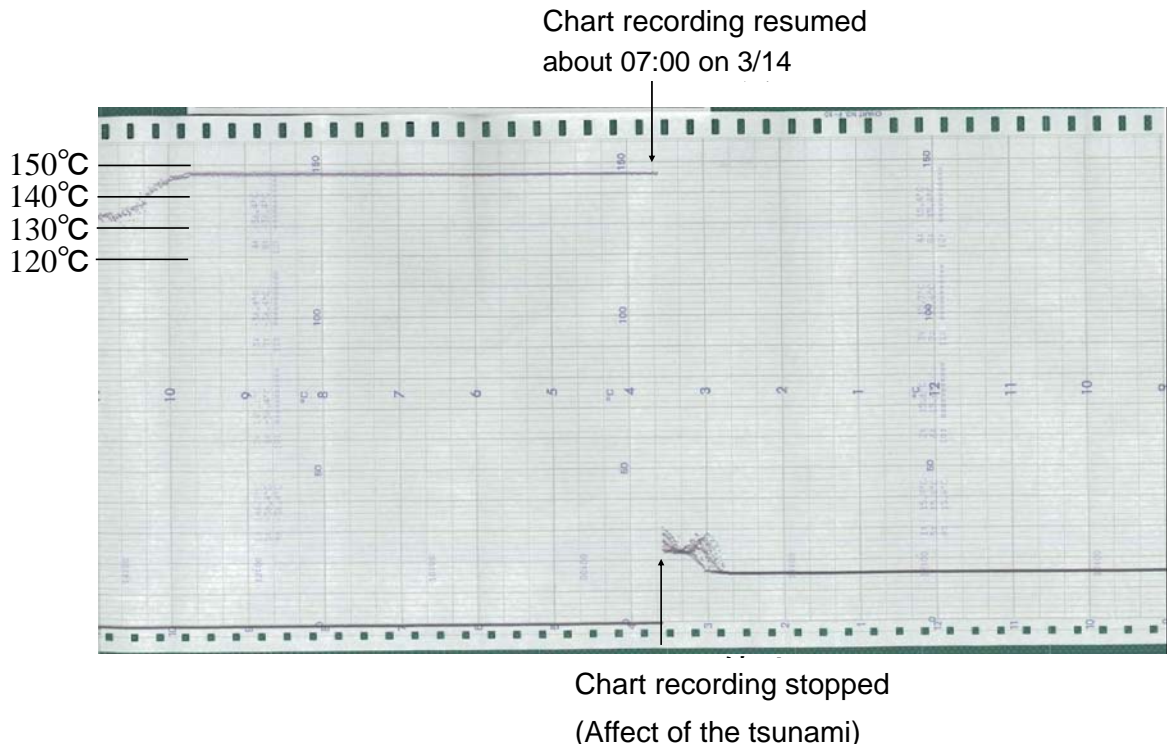
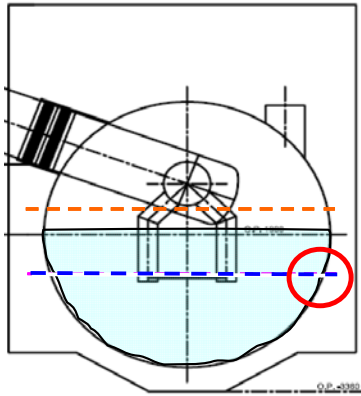


Fig.4 Record chart of water temperature of S/C



Thermometer
 (gas: O.P.2885)
 (water: O.P.350)

Fig.5 Installation position of S/C thermometer

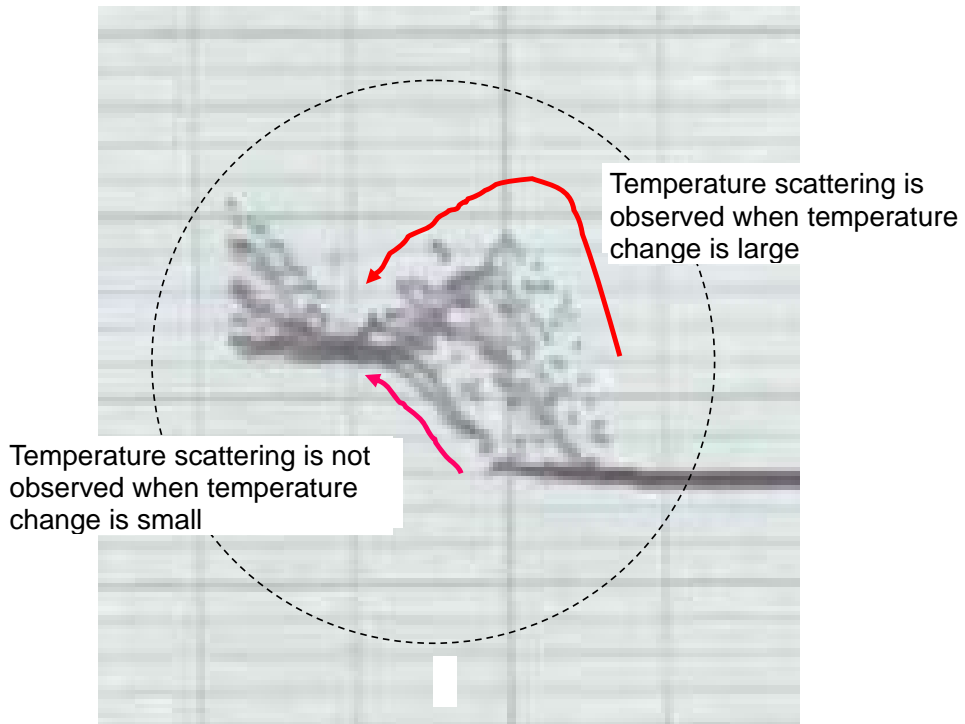


Fig.6 Temperature change of 8 thermometers during SRV operation before the tsunami

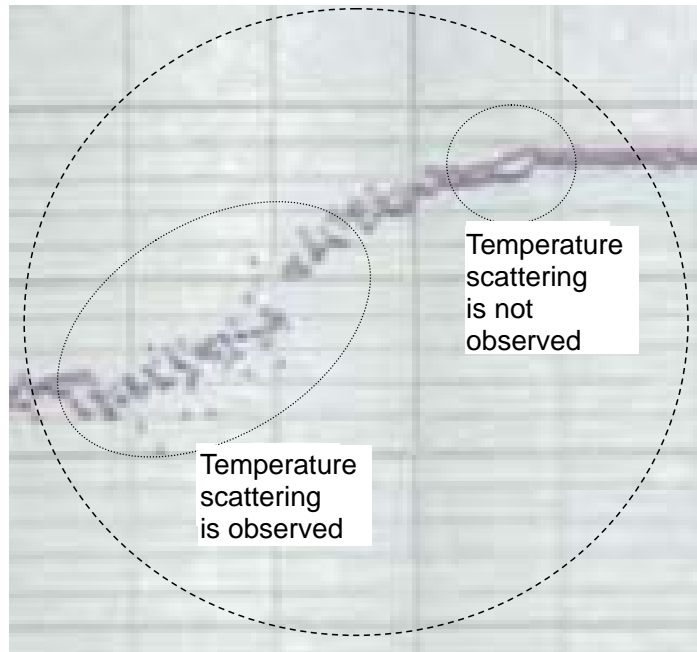


Fig.7 Temperature change of 2 thermometers during SRV operation after RCIC stops

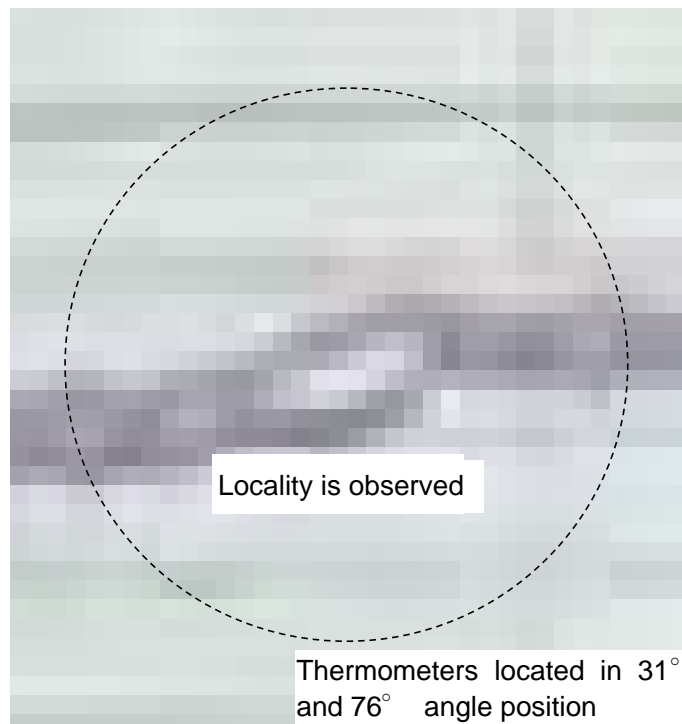


Fig.7 Temperature change of 2 thermometers during SRV operation after RCIC stops
(close-up)

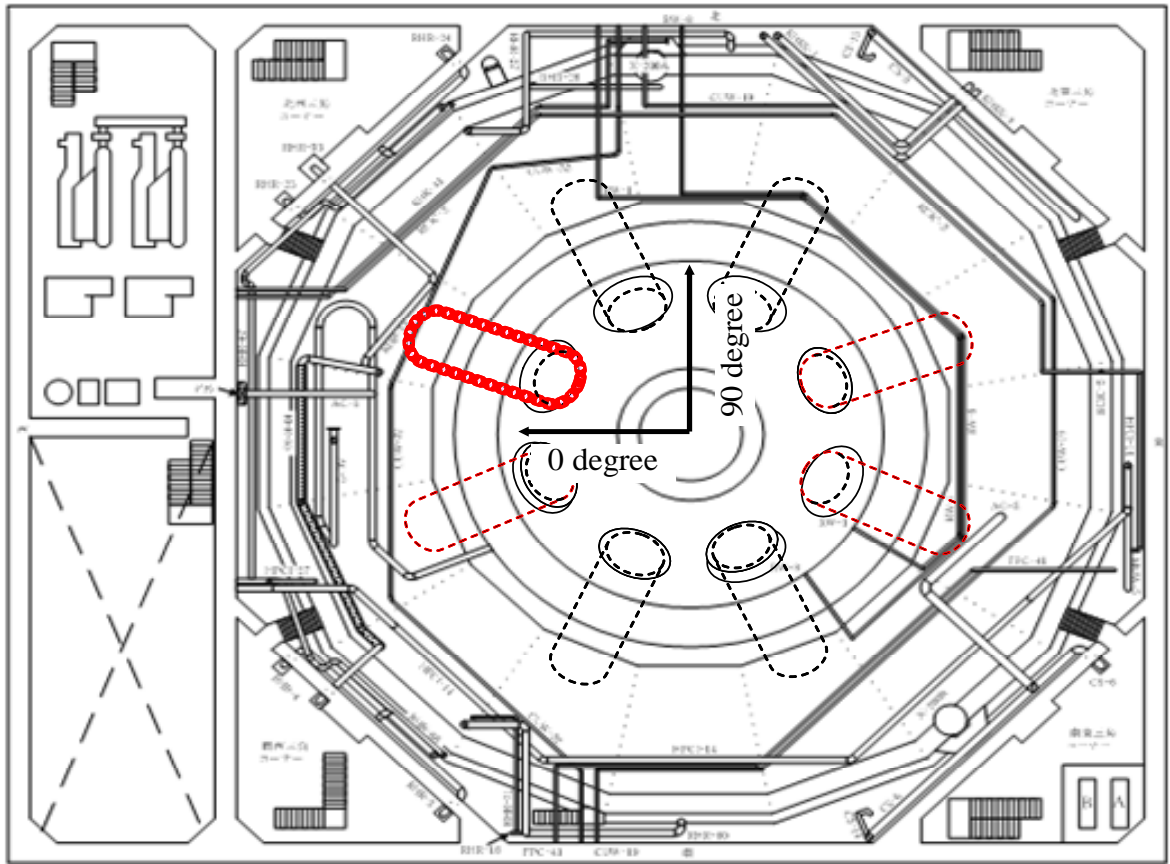


Fig. 9 Relationships between layout of S/C and vent pipes.
 The red dotted line indicates vent pipes with quencher piping.
 Highest dose is observed around the vent pipe indicated by the bold red line.

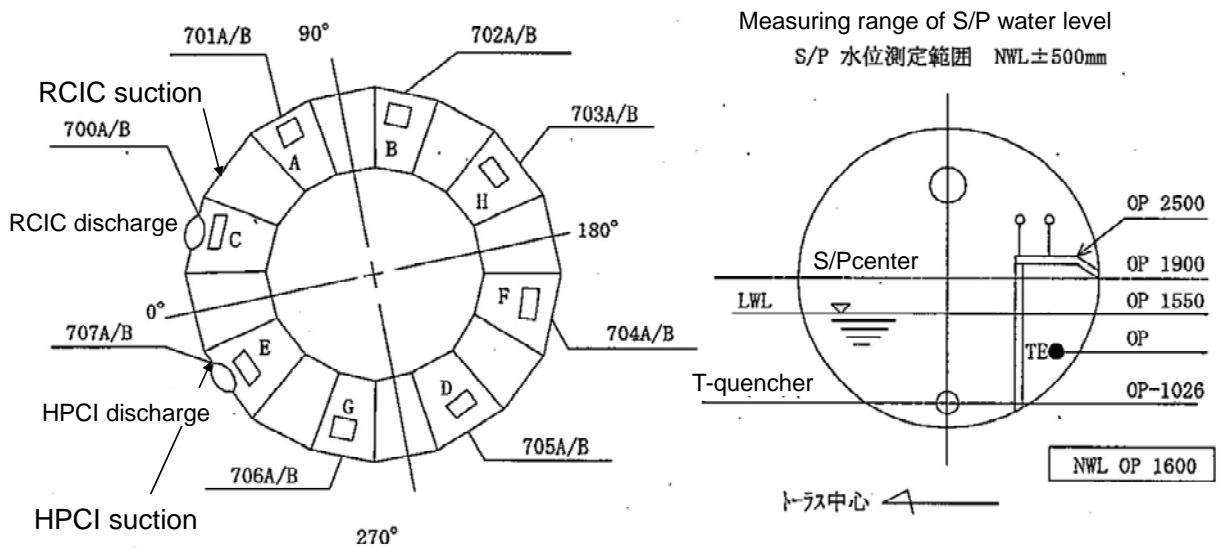


Fig. 10 T-quencher location inside the S/C

5. Summary on cause of pressure decrease of the PCV

The items which were investigated as the causes of the pressure decrease of the PCV which occurred at about 13:00 on the 14th are summarized as follows.

- The possibility that pressure decreased by leakage from the PCV or its neighboring part is low, which was proposed by accident investigation report of the government.
- It is possible that the RCIC stopped injecting water into the reactor at about 9:00 on the 14th, which was related to the start of RPV pressure increase. Then the steam was continued to be supplied to the RCIC turbine before its complete trip at about 12:00, which was related to the start of the rapid RPV pressure increase.
- The existence of water under the saturation temperature is confirmed by water temperature measurement results in the S/C. This strongly suggests that S/C was cooled from outside, which is thought to be caused by seawater flooding the torus room.
- At the SRV operation after the RCIC stopped, water in the MS pipes was discharged into the S/C resulting in a temperature decrease of the surface water of the S/C since the discharged water moved to the upper part accompanied by lower temperature water at the low position of the S/C. This may result in the decrease of PCV pressure.

6. Relationships between issues identified and measures.

The purpose is to investigate the mechanism of pressure decrease of the PCV based on the issues identified above. There is no relationship with the countermeasures.