Behavior of the S/C pressure gauge of Unit 2 after 21:00 on March 14

■ Introduction

The D/W pressure in Unit 2 gradually increased during the RCIC operation period and started to decrease around 13:00 on March 14 after the RCIC was shut down. Subsequently, an increase in D/W pressure was observed at around 21:20 and 22:40, which was thought to be caused by hydrogen produced in the pressure vessel migrating to the containment side due to the SRV opening operation and it rose to around 0.75 MPa[abs].

On the other hand, measurement of the S/C pressure was started by the S/C pressure gauge for accident management (AM) at 03:00 on the 13th, but the indicated value was below the lower limit of measurement and measurement was in a state of downscaling (DS). From 04:30 to 12:30 on the 14th, measurements were taken by the main S/C pressure gauge, which indicated a similar value to the D/W pressure during this period, and then the measurements were interrupted due to a faulty indication. At 22:10 on the 14th, the indicated value of the S/C pressure gauge for AM was restored, but it had a value much lower than the D/W pressure. It then showed 0 MPa[abs] at 06:00 on the 15th, and finally indicated DS again. The S/C pressure gauge for AM measures the pressure of the reference water column leading to the condensation tank, which is installed on the branch piping from the S/C vent line.

Since the containment structure is such that D/W pressure and S/C pressure inherently behave in tandem due to the action of the vacuum break valve, such a discrepancy between D/W pressure and S/C pressure cannot occur. It is extremely likely that the S/C pressure gauge for AM was not the one that indicated the real pressure, since there were periods when it indicated DS or 0 MPa[abs]. This issue is set as Unit-2/Issue-3 in this report.

Since containment pressure is a very important parameter in accident response, in this attachment, the factors are examined that caused the S/C pressure gauge for AM to show abnormal indicated values.

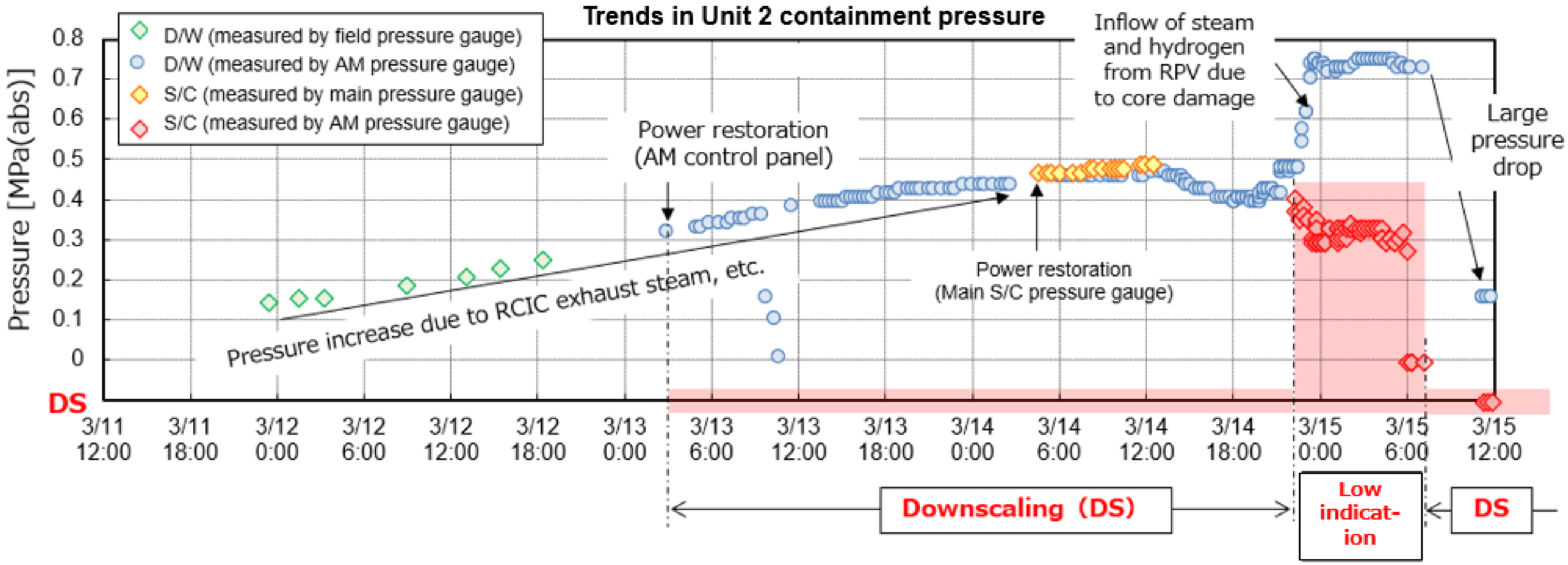


Figure 1.1 Trends in Unit 2 containment pressure

■ 2. Outline of the S/C pressure gauge for AM

Figure 2.1 shows the location of the S/C pressure gauge for AM focused on here; it is located in the southeast triangular corner of the basement floor of the Unit 2 R/B, at a height of 60 cm from the floor (T.P. -3496). The pressure is detected from the condensation tank of the S/C water level gauge for AM (installed height: T.P. 7119), which is connected to the S/C gas-phase section, and the pressure change in the condensation tank piping is measured in accordance with the pressure change in the S/C gas-phase section.

The measurement principle of the S/C pressure gauge for AM is shown in Figure 2.2. A diaphragm type gauge is used. In the detection section, the pressure change at the source of detection is detected by the diaphragm, converted into an electrical resistance change by the semiconductor pressure sensor, and converted into a voltage proportional to the pressure by the bridge circuit. The converted voltage is output as current in the amplifier section, and is indicated as absolute pressure by the S/C pressure indicator for AM installed in the main control room (control panel for AM).

Figure 2.3 shows an external view of the S/C pressure gauge for AM. The dust resistance and water resistance of this pressure gauge are equivalent to IP (Ingress Protection) 67 in the protection class for electrical machinery and apparatus against intrusion of foreign solid objects and water [1] specified by the Japanese Industrial Standards. This grade is defined as "no ingress of dust shall be allowed" for dust resistance and water resistance is defined as "no ingress of water shall be allowed as to cause harmful effects when the gauge enclosure is temporarily submerged at 15 cm to 1 m below the water surface for 30 minutes. Therefore, S/C pressure gauges for AM are designed having a structure that does not allow penetration inside of dust or of water when temporarily submerged in water.

The locations of the containment pressure gauges used during the accident are shown in Table 2.1. The S/C pressure gauge for AM is located at positions lower than the other pressure gauges.

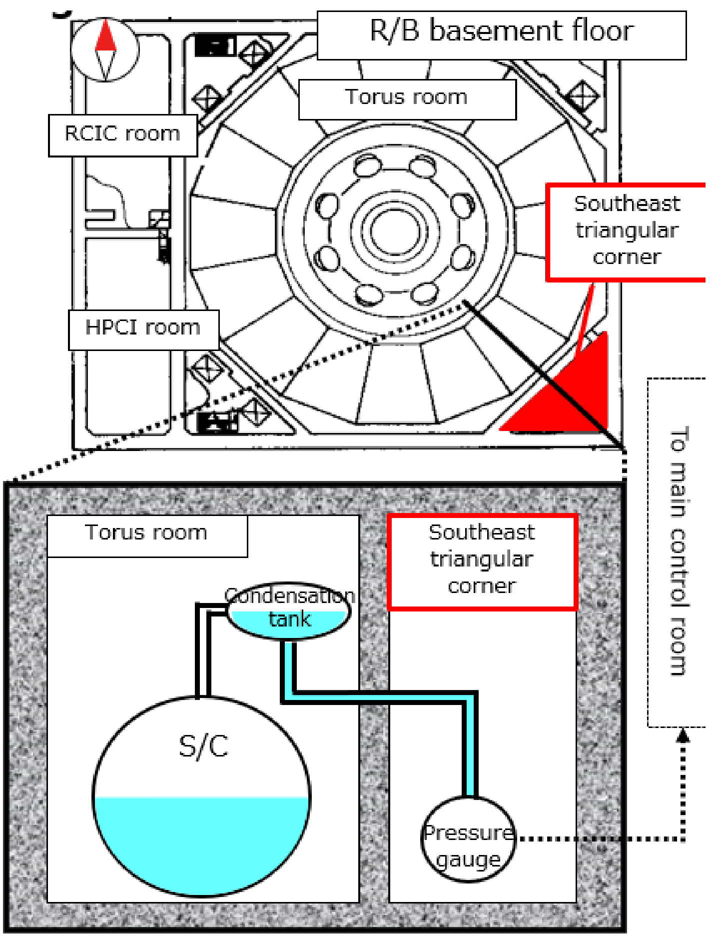


Figure 2.1 Location of S/C pressure gauge for AM

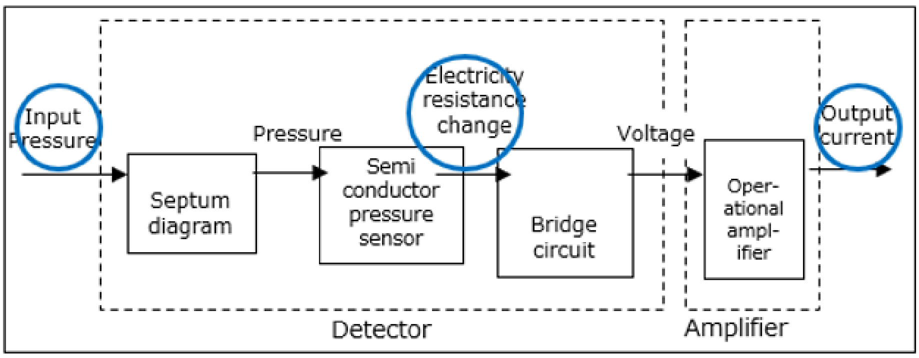


Figure 2.2 Measurement principle of S/C pressure gauge for AM

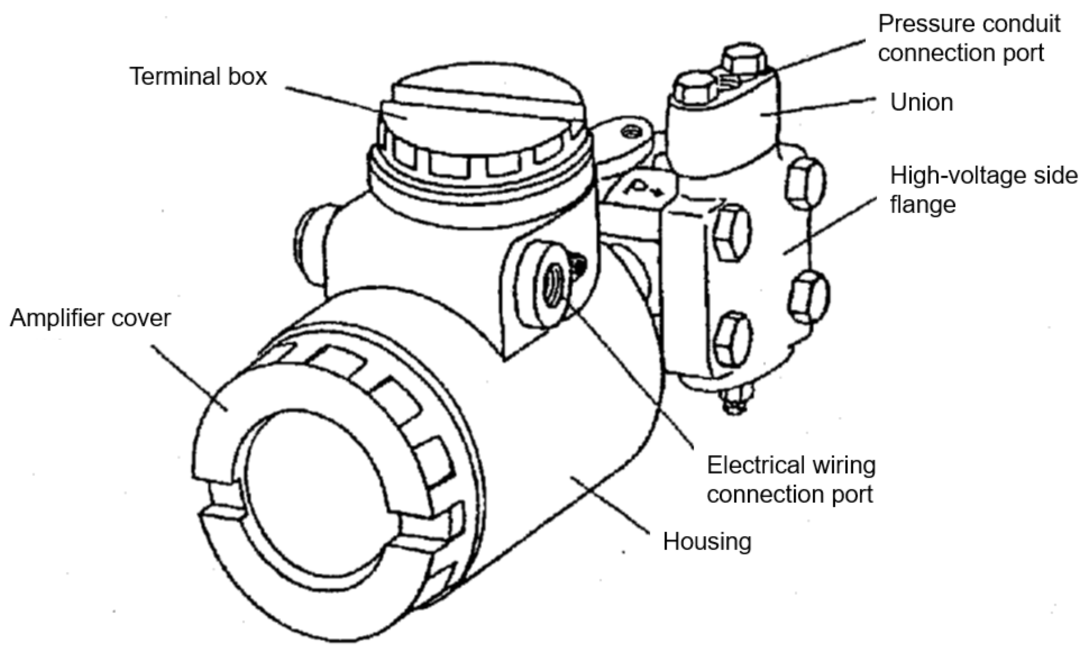


Figure 2.3　External view of S/C pressure gauge for AM

Table 2.1　Locations of containment pressure gauges used during the accident

Gauge	D/W (At site)	D/W (For AM)	S/C (Main)	S/C (For AM)
Location	R/B 2nd floor Northwest area (Floor: T.P. 17264)	R/B 3rd floor Northeast Area (Floor: T.P. 25464)	R/B middle basement floor; Northeast triangular corner (Floor: T.P. 2564) ＊For Unit 4	R/B basement floor; Southeast triangular corner 60 cm from the floor (Floor: T.P. -3496)

■ 3. Extraction and classification of factors causing abnormal indicated values

Since there are multiple possible causes of abnormal indicated values from S/C pressure gauges for AM, a strategy is adopted here of extracting as many possible causes as possible and narrowing down the possibilities using a process of elimination approach.

① Mechanical factors

One of the factors that may cause pressure gauges to show abnormal indicated values is that the pressure gauge itself might have been damaged by a mechanical shock and shown DS when it became impossible to detect the pressure. The possibility that the pressure gauges were subjected to mechanical shocks at the time of the accident can be attributed to the earthquake, the explosions in other units, and the impact of the tsunami. These factors are discussed as "mechanical factors.”

② Factors related to the measurement principle

One of the factors that may cause a pressure gauge to show an abnormal indicated value is the decrease or loss of the water level in the condensation tank piping, which is supposed to be constant, causing the indicated values to decrease. Possible causes of the decrease or loss of water in the condensation tank piping during an accident include a break in the condensation tank piping, evaporation of the water in the piping, and separation of the water in the piping due to bubbles formed in some way. These factors are discussed as "factors related to the measurement principle.”

③ Electrical factors

One of the factors that may cause pressure gauges to show abnormal indicated values is an abnormality in the electrical system transmitting from the pressure gauge to the pressure indicator installed in the main control room, which may cause a drop in the indicated value or DS. Factors that may cause an abnormality in the electrical system of the pressure gauge during an accident include "insufficient battery voltage" or "battery depletion" of the battery connected to the pressure gauge at the time of the accident, and "water intrusion into the pressure gauge body or cable.” These factors are discussed as "electrical factors.”

■ 4. Examination of factors causing abnormal behavior of S/C pressure gauges for AM

In the following the possibilities that the S/C pressure gauge for AM may show abnormal indicated values due to factors classified in Section 3 as "mechanical factors," "factors related to the measurement principle," and "electrical factors" are examined.

■ 4.1 Mechanical factors

One of the "mechanical factors" that may cause abnormal indicated values of S/C pressure gauges for AM is the possibility that the pressure gauge itself may be damaged by the earthquakes, the explosions in other units, or the impact of the tsunami. Here the possibility that the S/C pressure gauge for AM showed DS due to these "mechanical factors" is examined.

(1) Possible damage due to earthquakes and explosion shocks

Table 4.1.1 shows the occurrence times of the main earthquake and aftershocks (intensity 3 or higher) of the Off the Pacific Coast of Tohoku Earthquake observed in the area around the 1F from 14:46 on March 11, 2011 to 12:00 on March 15, 2011. Table 4.1.2 also shows the occurrence times of hydrogen explosions in other units. Figure 4.1.1 superimposes these occurrence times on the containment pressure trend of Unit 2.

It can be seen that multiple earthquakes and the hydrogen explosion in Unit 1 occurred before the S/C pressure gauge for AM was restored, but it is unlikely that the pressure gauge was damaged by these factors before March 15, because if the pressure gauge itself was damaged or the cable was broken by these factors, it is unlikely that the indicated value would return from DS.

The pressure gauge indicated value dropped sharply to 0 MPa[abs] at 06:02 on March 15, but no earthquake occurred immediately before or after that time. The hydrogen explosion in Unit 4 occurred very close by, but the time it occurred is considered to be 06:12. Therefore, the hydrogen explosion in Unit 4 is not considered to be the direct cause of the drop in the indicated value.

Table 4.1.1 Times of earthquake and aftershocks and their seismic intensity in the 1F location area [2][3]

Date	Time	Seismic intensity of the 1F location area (Okuma-machi) (∗ Futaba-machi)
3/11	14:46	6 higher
3/11	14:51	4
3/11	14:54	4
3/11	14:58	4
3/11	15:06	3
3/11	15:08	3
3/11	15:12	4
3/11	15:15	4
3/11	15:25	3
3/11	16:14	3
3/11	16:28	5 lower
3/11	16:30	5 lower
3/11	17:12	3
3/11	17:19	3
3/11	17:40	4
3/11	20:36	3
3/12	10:47	3
3/12	22:15	5 lower
3/13	08:24	4∗
3/14	10:02	3∗
3/14	15:12	3∗

(Among the earthquakes of magnitude 6.5 or greater or seismic intensity 5 or greater that occurred within the aftershock activity area of the Off the Pacific Coast of Tohoku Earthquake, those with seismic intensity 3 or greater in the 1F location area are summarized.

Table 4.1.2 Time of hydrogen explosions

Unit	Occurrence date and time
1	March 12 at 15:36
3	March 14 at 11:01
4	March 15 at 06:12

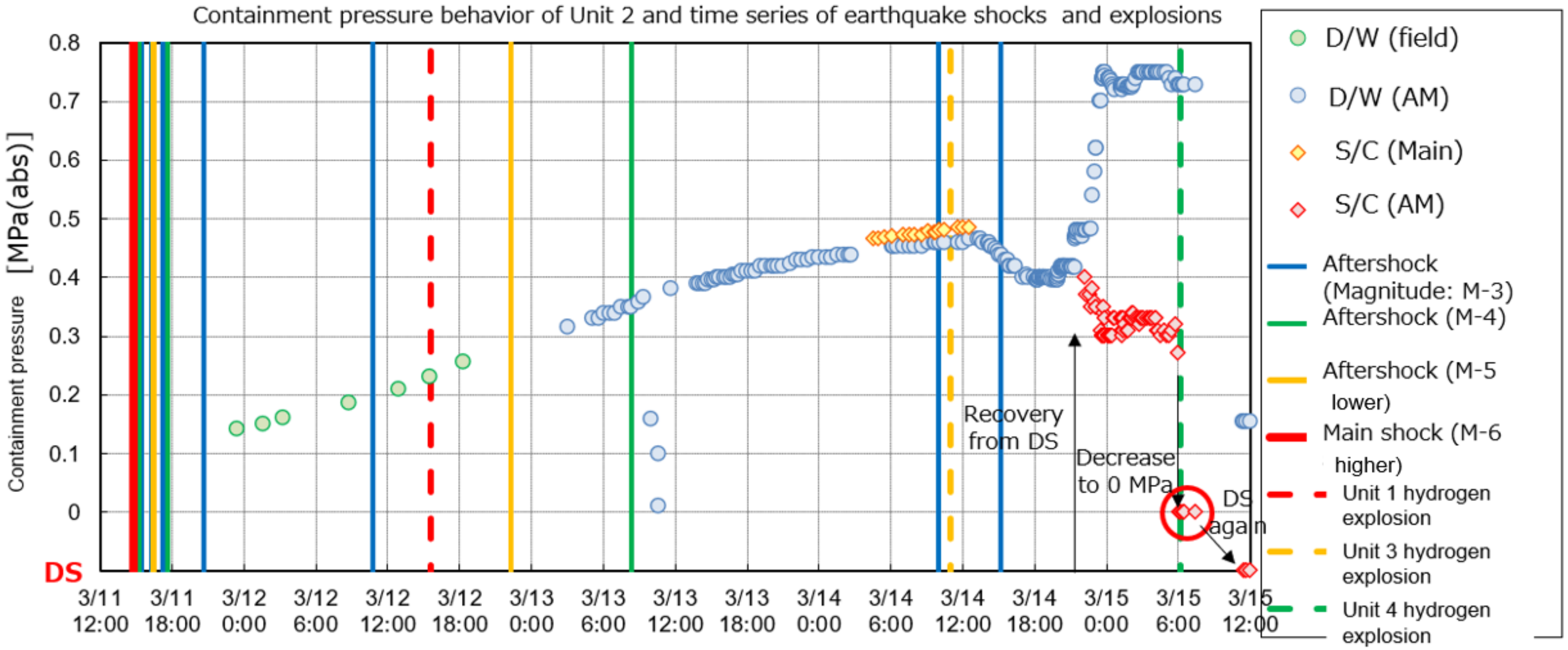


Figure 4.1.1 Trends in Unit 2 containment pressure and time series of earthquakes and explosions

(2) Possibility of damage due to tsunami impact

Table 4.1.3 and Figure 4.1.2 show the results of the categorized tsunami ingress paths (directly, from the side, from above, and from below) into the southeast triangular corner of the R/B basement floor, where the S/C pressure gauge for AM was installed.

Regarding the possibility of direct ingress from outdoors, the southeast triangular corner is located on the basement level, and there are no openings that lead outdoors, so there is no possibility of direct tsunami ingress.

Regarding the possibility of ingress from the side, the triangular corner is adjacent to the torus room and T/B, and there are piping penetrations on the wall surface that abuts each, so it is possible that ingress occurred from the side through the wall penetrations.

Regarding the possibility of ingress from above, the southeast triangular corner has a hatch and stairwells that connect to the upper floors, so it is possible that the tsunami entered via the first floor or the middle basement floor.

Regarding the possibility of ingress from below, there are funnels at the southeast triangular corner, which are connected to other rooms on the first floor and basement floors via the sump, and it is possible that the tsunami entered the building via the funnels. There is a floor drain sump at the southeast corner, and the sump pumps are connected to the waste treatment piping, but there is a check valve on the discharge side of the pump, so it is unlikely that the tsunami flowed backward through the waste treatment system and entered the building.

Based on the above, there are multiple paths of tsunami ingress into the southeast triangular corner, but none of them is a direct ingress path. Therefore, it is difficult for the tsunami to reach there while maintaining wave force, and it is unlikely that the pressure gauge was damaged by the tsunami impact.

Table 4.1.3: Tsunami ingress paths to the southeast triangular corner

Tsunami ingress routes	Possibility of ingress	
Openings to the outdoors (direct)	×	No openings directly connected to the outdoors
Wall penetration (from side)	○	Ingress through the torus room and T/B connection
Ground floor and middle lower ground floor (from above)	○	Ingress through hatch above CS pump or stairwell
Funnel (from below)	○	Reverse flow via sump from ground floor and southwest triangular corner of basement floor
Floor drain sump (from below)	×	Tsunami flowed backward through the piping of the waste treatment system and entered (unlikely due to check valve on discharge side of sump pump)

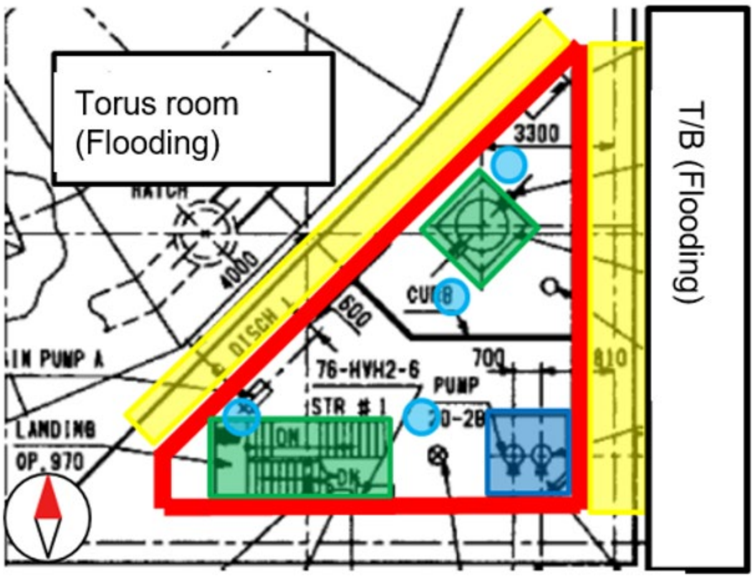


Figure 4.1.2　Tsunami ingress paths to the southeast triangular corner (colors in the figure correspond to Table 4.1.3)

(3) Summary of the results

The possibility that the main body of the S/C pressure gauge for AM was damaged by the earthquakes, the explosions in other units, and the impact of the tsunami and that it showed DS was examined. As a result, the timing of the change in S/C pressure behavior did not coincide with the timing of the earthquakes and the explosions in other units, and the wave force was considered to have decreased by the time the tsunami entered the triangular corner. It is concluded the S/C pressure gauge for the AM are unlikely to have indicated DS due to these “mechanical factors.”

■ 4.2 Factors related to the measurement principle

"Factors related to the measurement principle" that cause the S/C pressure gauge for AM to give a low indicated value may be a decrease or loss of water in the condensation tank piping. This section discusses the possibility that the S/C pressure gauge for AM indicated the low value due to these "factors related to the measurement principle."

(1) Influence of factors related to the measurement principle

In examining the "factors related to the measurement principle," the extent to which the indicated values are affected by these factors is discussed.

Assuming that all the water in the condensation tank piping is lost, the height difference between the condensation tank and the pressure gauge is about 10 m, which means that there is about 0.1 MPa decrease in water pressure, corresponding to this height. On the other hand, the actual measured values shown in Figure 4.2.1 indicate that the difference between the D/W pressure and the S/C pressure during the decrease in the indicated values was maintained at about 0.4 MPa, and it is difficult to explain the decrease in the indicated values even if all the water in the condensation tank piping is lost. Therefore, the following discussion examines the possibility that "factors related to the measurement principle" may have partially contributed to the decrease in the indicated values.

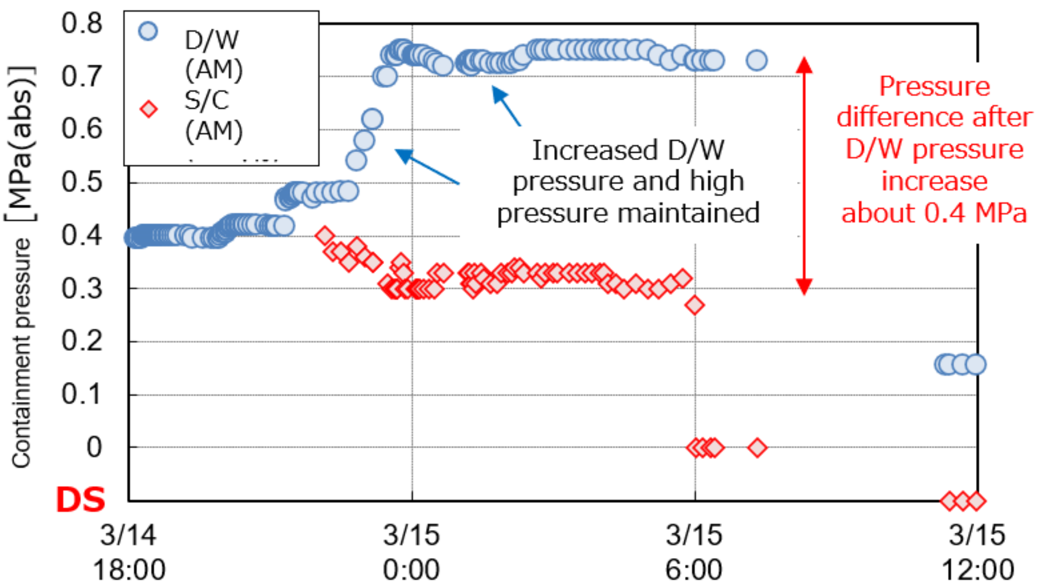


Figure 4.2.1 Containment vessel pressure in Unit 2 after 18:00 on March 14

(2) Examination of the possibility of decrease or loss of water in the piping

Possible phenomena that cause a decrease or loss of water in the condenser piping include "evaporation of water in the piping," "leakage of water in the piping due to a break in the piping," and "separation of water in the piping due to bubble formation." The possibility of these phenomena occurring is discussed (Figure 4.2.2).

① Evaporation of water in the pipings

The cause of evaporation of water in the pipings could be a rise in the temperature of the water in them or a decrease in the saturation temperature of the water in them due to a drop in containment pressure, resulting in depressurization and boiling of the water in the pipings.

Regarding the temperature rise of the water in the pipings, it was confirmed that in the torus room where the condensation tank was installed, when the entrance door was opened after March 12, steam came out and the room was too hot to enter [4]. Since the torus room was at atmospheric pressure and the temperature of the S/C measured on March 14 was about 134 °C, the confirmed steam was thought to have been produced by seawater entering the torus room and coming into contact with the hot S/C. However, since the torus room was at atmospheric pressure, the temperature in the gas phase of the torus room is thought to be below 100 °C. Therefore, it is unlikely that the water in the pipings evaporated as a result of the temperature rise caused by the water in the pipings being heated by the torus room.

With regard to depressurization boiling caused by a decrease in the saturation temperature of the water in the piping, since D/W pressure and S/C pressure are interlocked due to the structure of the containment vessel, the actual S/C pressure during the time when the AM S/C pressure gauge showed a low indicated value is considered to have maintained about the same high pressure as the D/W pressure (Figure 4.2.1). Therefore, it is unlikely that the saturation temperature of the water in the pipings decreased and depressurized boiling occurred, since the high pressure was also maintained in the pipings.

Based on the above, the possibility of evaporation of the water in the piping is considered to be low.

② Leakage of water in the piping due to a break in the piping

If a condensation tank piping breaks (or is partially damaged) due to an earthquake or other impact and water leaks from the piping, gases in the S/C are simultaneously released from the leakage point, and since the time of interest is after the core damage, it is possible that the ambient air dose may increase. However, based on the post-accident measurements in the torus room and the southeast triangular corner of the middle basement floor, the dose rates on the southeast side, where the condensation tank piping is located, do not differ significantly from that at other locations (Figure 4.2.3).

Based on the above, it is considered unlikely that there was a break in the piping and a leakage of water.

③ Separation of water in the piping due to bubble formation

Gases dissolved in water in the piping exist as bubbles and as the temperature rises, there is a possibility that the water in the piping is separated by the bubbles collecting and coalescing at a single location. The behavior of the pressure gauge due to the separation of the water in the piping cannot be ruled out as a possible contributing factor to the decrease in the indicated values, since there is a large degree of uncertainty in conditions such as the position, size, and shape of the bubbles, and it is difficult to estimate how the indicated values would change. However, it is unlikely that the change would exceed the 0.1 MPa drop in the indicated values when all the water in the piping evaporated. Therefore, even if this event were to occur, its effect on the indicated values is not considered dominant.

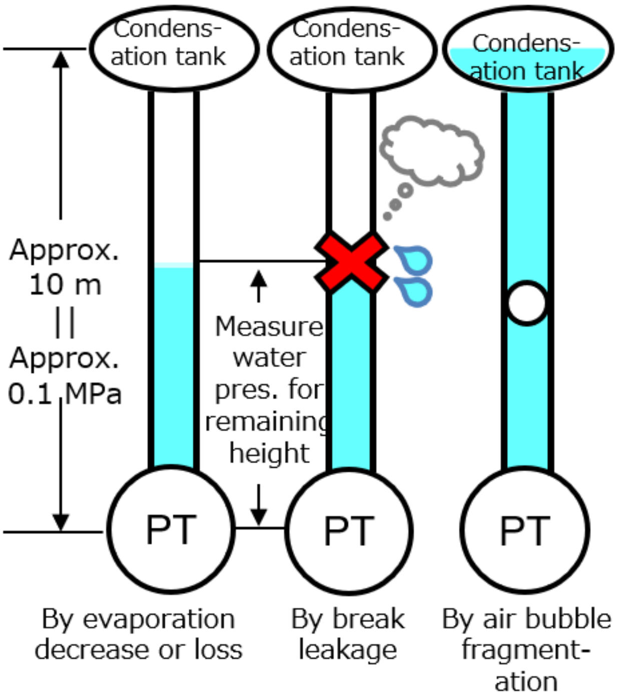


Figure 4.2.2 Image of decrease and loss of water in condensation tank piping

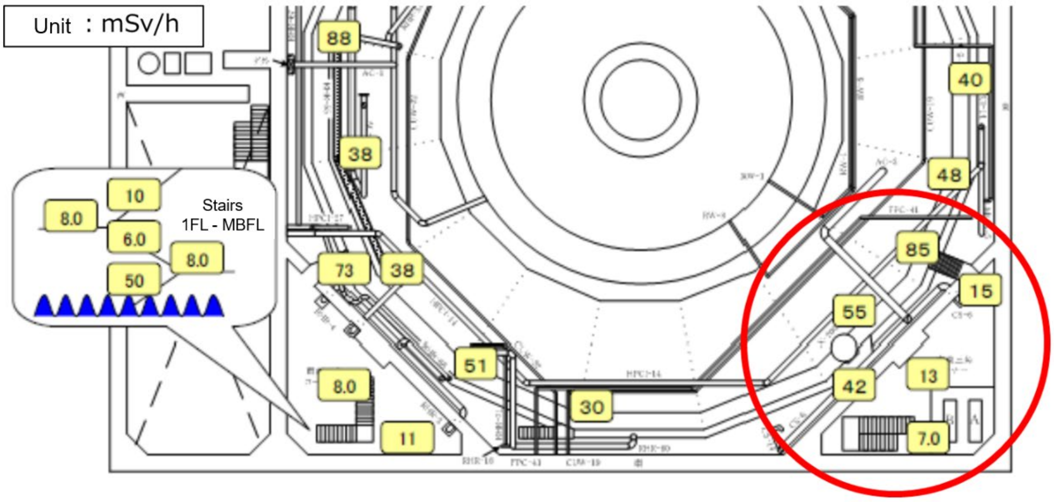


Figure 4.2.3 Measured air dose rates after the accident (April 2011 - February 2014) [5]
(Torus room catwalk, southeast triangular corner of middle basement floor)

(3) Summary of the results

Based on the above discussion, the possibility cannot be denied that the formation of bubbles may have caused the separation of water in the piping among the factors related to the measurement principle. However, the contribution by this factor to the decrease in the indicated values is small and it is not a major factor.

■ 4.3. Electrical factors

Possible electrical factors that cause the S/C pressure gauge for AM to indicate DS are "battery depletion" and "electrical system abnormality in the pressure gauge body or cable due to tsunami inundation." In addition, low indicated values can be caused by "insufficient supply voltage" and "electrical system abnormalities in the pressure gauge body or cable due to tsunami inundation."

In this section, the possibilities for these electrical factors to have caused the S/C pressure gauge for AM to show DS or low indicated values are examined.

(1) Possibility of battery depletion or insufficient supply voltage

At the time of the accident, the power supply for the S/C pressure gauge for AM was restored at around 03:00 on March 13 when the battery was connected to the control panel for AM (panel 9-99) installed in the main control room of Units 1 and 2. The battery was connected in parallel with the D/W pressure gauge for AM and the S/C pressure gauge for AM, and the two pressure gauges shared the power supply (Figure 4.3.1). After the battery was connected, the S/C pressure gauge for AM was in a state of DS, but the D/W pressure gauge for AM returned to the indicated value and continued measurement thereafter (see Figure 1.1). In addition, the battery was replaced as needed and power was continuously supplied. Therefore, it is not likely that only the S/C pressure gauge for AM had a depleted battery.

Before connecting the battery to the control panel for AM, it was confirmed that the S/C pressure gauge for AM and D/W pressure gauges for AM had the necessary voltage (24 V) to operate. In addition, the D/W pressure gauge for AM, whose indicated values were restored, was generally considered to show the correct value for the following reasons.

- This pressure gauge was installed in the torus room, and there was a period of time when it showed values close to those of the main S/C pressure gauge, which is a diaphragm type and measures the S/C gas phase pressure (see Fig. 1.1).
- The measured values of the D/W pressure are not considered to show any particular behavior that would raise doubts about the reliability of the instrument when compared to the changes in the reactor pressure, based on the estimation of the accident progress and the information on SRV opening and closing (see Attachment 2-9 and Figure 4.3.2).

Therefore, it is unlikely that the supply voltage from the battery was insufficient.

Based on the above, it is unlikely that the S/C pressure gauge for AM showed DS or low indicated values due to battery depletion or insufficient voltage supply.

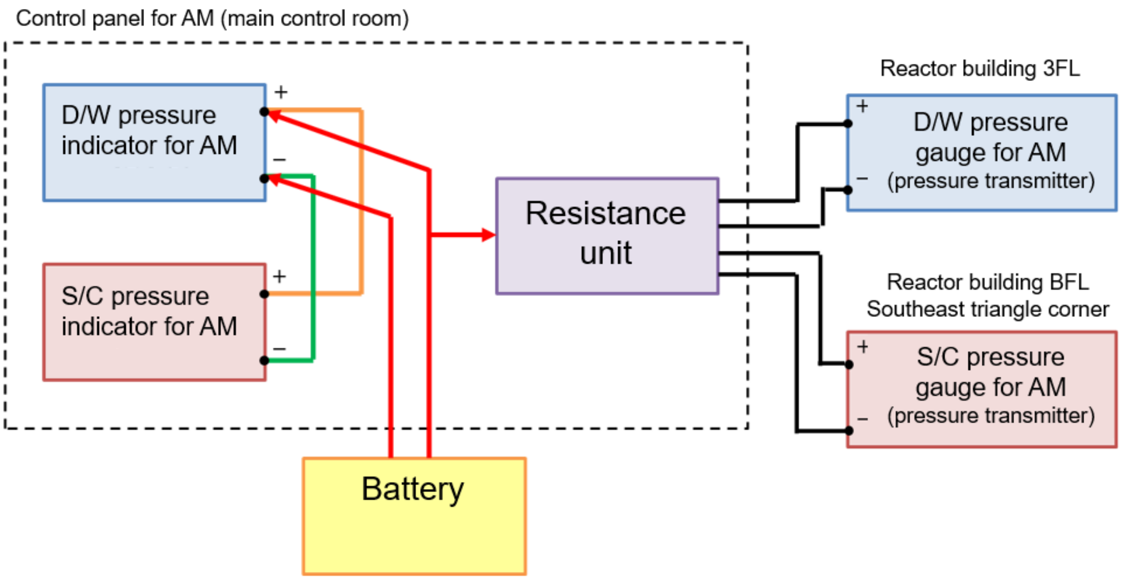


Figure 4.3.1 Connection of battery to control panel for AM (outline)

(Regarding Figure 4.3.1: As shown by the red line, the battery is connected to the D/W pressure indicator for AM, but the + terminal, as shown by the yellow line, and the - terminal, as shown by the green line, are connected to the D/W pressure indicator for AM and the S/C pressure indicator for AM, so the two pressure indicators shared the battery. The D/W pressure indicator for AM (pressure transmitter) and the S/C pressure indicator for AM (pressure transmitter) were connected to the resistance unit shown in purple, and the two pressure indicators (pressure transmitters) also shared a battery because their battery was also connected to this resistance unit as shown by the red line).

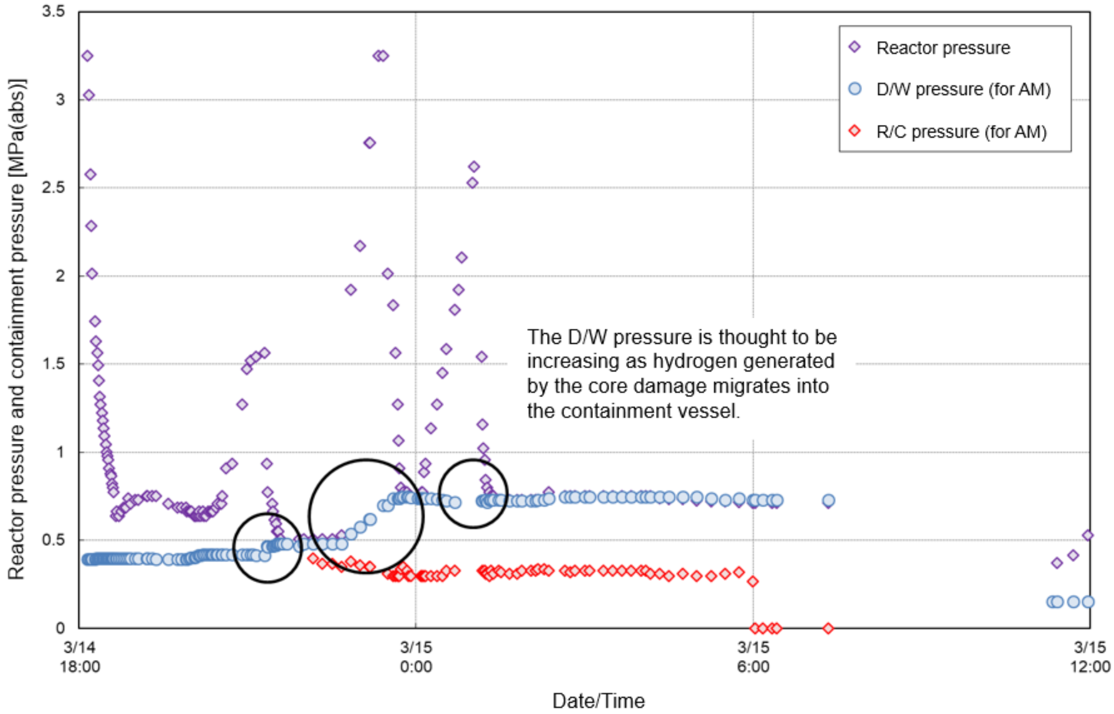


Figure 4.3.2 Reactor pressure and containment pressure in Unit 2 after 18:00 on March 14

(2) Possibility of electrical abnormality in cables

As described in "2. Overview of S/C pressure gauge for AM," the S/C pressure gauge for AM installed in the southeast triangular corner of the first basement floor of R/B and the S/C pressure indicator for AM installed in the main control room of Units 1 and 2 are connected by a single cable, and there is no relay terminal on the way. Although there is a possibility that the cable sheath will deteriorate due to submergence, resulting in insulation degradation, it is unlikely that the sheath will rapidly deteriorate within 2 to 3 days of contact with seawater. Therefore, it is unlikely that electrical abnormality occurred due to the submergence of the cable from the southeast corner to the main control room.

(3) Possibility of electrical abnormality in the main body of the S/C pressure gauge for AM

①Possibility of flooding into the inside of the pressure gauge due to submergence of the S/C pressure gauge for AM

As discussed in "4.1.(2) Possibility of damage due to tsunami impact," it was found that the southeast triangular corner of the first basement floor of the R/B where the S/C pressure gauge for AM was installed was most likely inundated by the tsunami. In this section, the possibility is considered that the pressure gauge was submerged by the tsunami as a preliminary step to the occurrence of electrical anomalies, and that the inside of the pressure gauge was also flooded.

First, the flooding condition of the basement floor is estimated based on the information at the site. Regarding the funnels and wall penetrations, which are likely to have been the tsunami ingress paths into the southeast triangular corner, the funnels are connected to each room of the basement floor through the sump, and there are penetrations in the range of 5 cm to 500 cm above the floor on the wall between the triangular corner and the torus room. Furthermore, since the water level of the water in the basement floor changed in tandem over a long period of time after the accident, it is highly likely that the water level in each room of the basement floor changed in tandem from the beginning of the accident (Figure 4.3.3). As for the flooding of the basement floor being confirmed at the time of the accident, it was confirmed that the water level at the northwest triangle corner (in front of the RCIC room door) at around 01:00 a.m. on March 12 was just enough to top work boots, and when the RCIC room door was opened, the water flowed out from the RCIC room. At this point, the water level in the basement floor may have been about 30 cm above the floor. Subsequently, at 02:12 on March 12, it was confirmed that the water level in front of the RCIC room had risen, and that water was slowly flowing out when the door was opened. This suggests that the water level in the basement floor might have risen gradually from the level of about 30 cm above the floor at 01:00 on March 12.

Next, the flooding condition in the basement floor is estimated based on the plant parameters: Unit 2 continued to operate the RCIC after the arrival of the tsunami until around 09:00 on March 14, but the increase in D/W pressure during that period was slower than the increase expected from the decay heat. This is presumed to be due to the torus room being flooded and the S/C being cooled from the outside (see Attachment 2-2). Subsequently, the D/W pressure dropped significantly in the morning of March 15. This is presumed to be due to the containment leakage and the fact that the torus room water level exceeded the S/C water level, cooling the S/C vapor phase section, which may have accelerated condensation of water vapor in the S/C and contributed to depressurization (see Attachment 2-16). Based on these estimates, it is possible that the torus room water level was continuously rising.

Based on the above, the water level at the southeast triangular corner rose continuously from about 30 cm above the floor during the March 12-15 period of interest, and it is highly likely that the S/C pressure gauge for AM installed at a height of 60 cm above the floor was submerged (Figure 4.3.4).

Therefore, it is possible that the S/C pressure gauge for AM was submerged for a long period, causing seawater to enter through the electrical wiring connection port and flood the terminals of the pressure gauge (Figure 4.3.5). In addition, submerged tests of the same type of pressure gauges conducted by the manufacturer also showed that water entered the inside through the electrical wiring connection port and flooded the terminals, and that water droplets entered the base of the pressure transmitter when the submerged height was raised (Figures 4.3.6, 4.3.7, and 4.3.8.) Therefore, it is highly likely that the S/C pressure gauge for AM was submerged at the time of the accident as well, allowing seawater to enter the interior and flood the terminals and base.

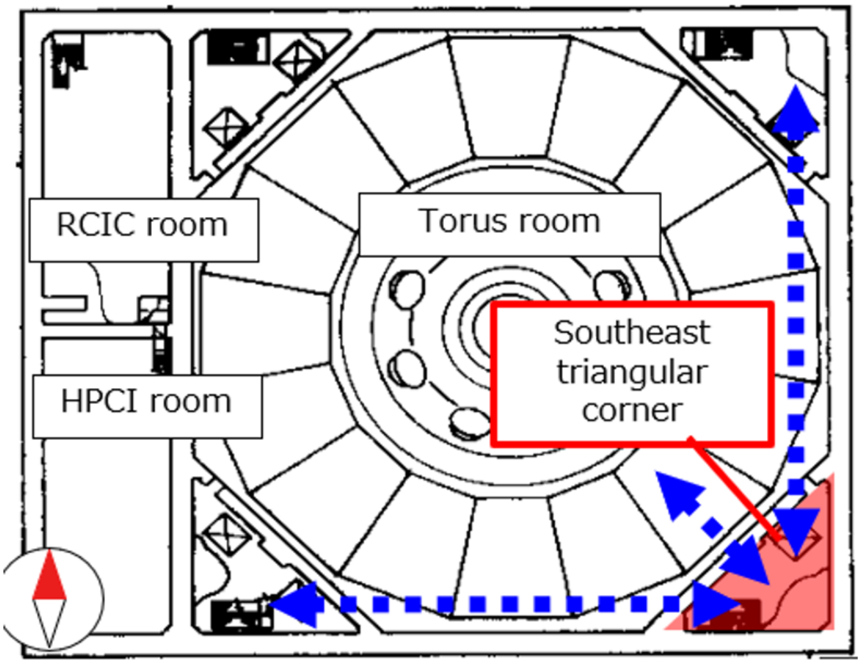


Figure 4.3.3 Water connection to each room through funnel/piping penetrations at the southeast triangular corner (image)

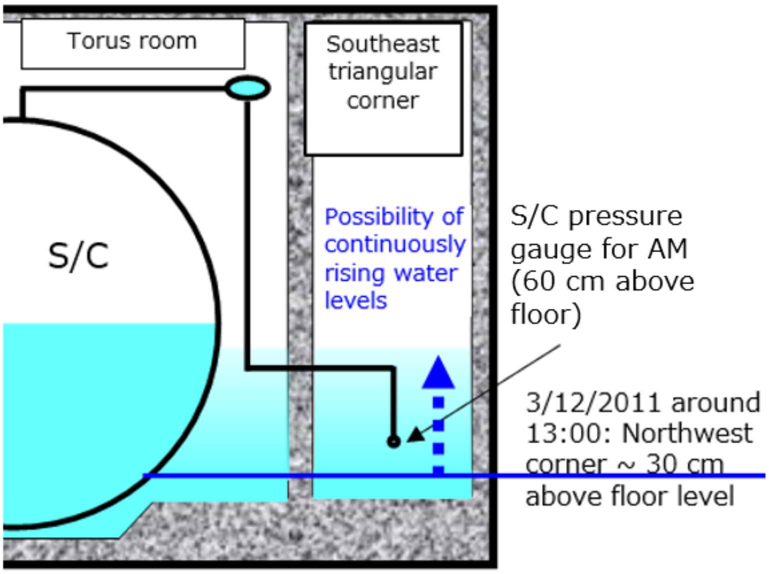


Figure 4.3.4 Water level change in the basement floor of Unit 2 R/B (image)

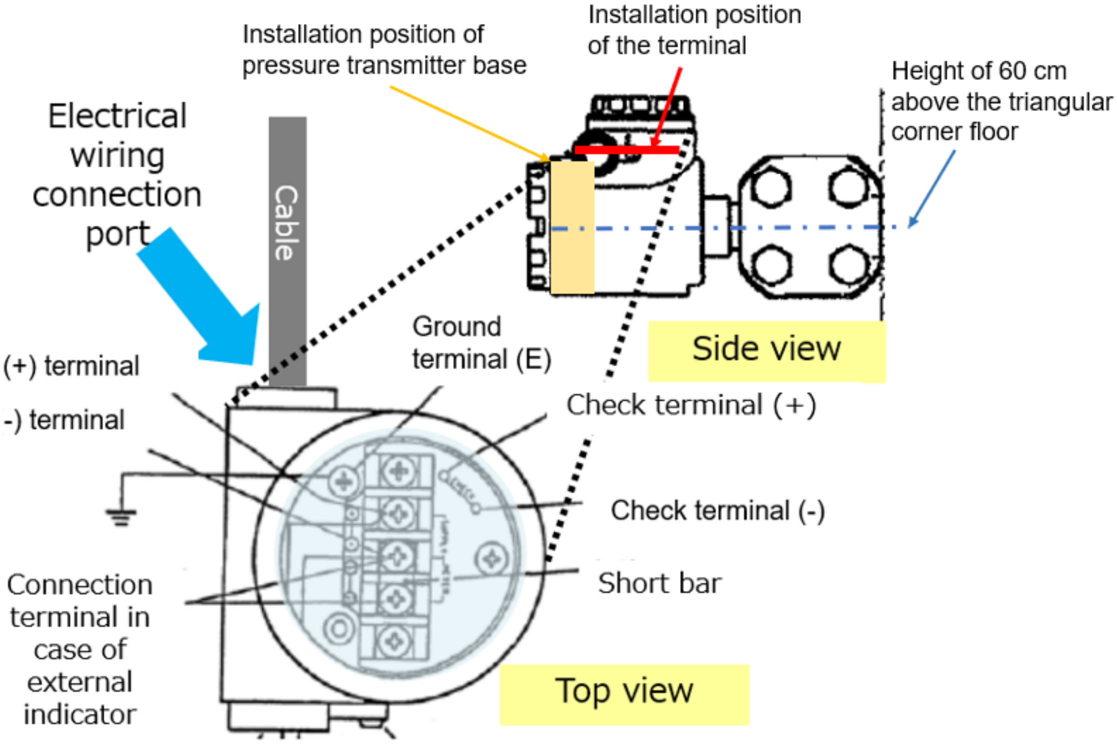
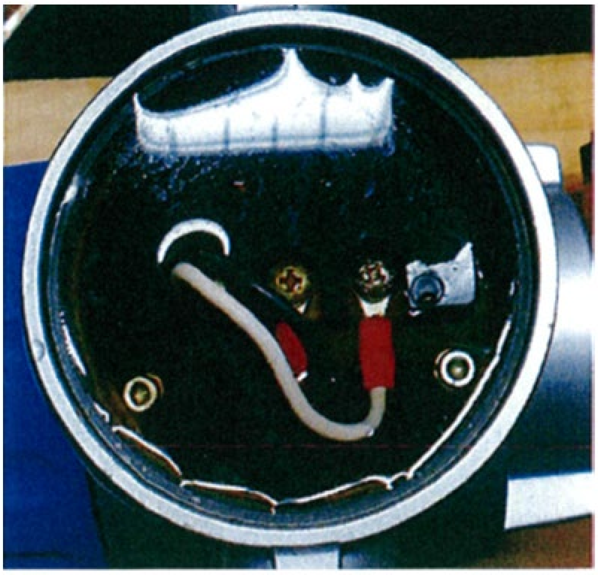
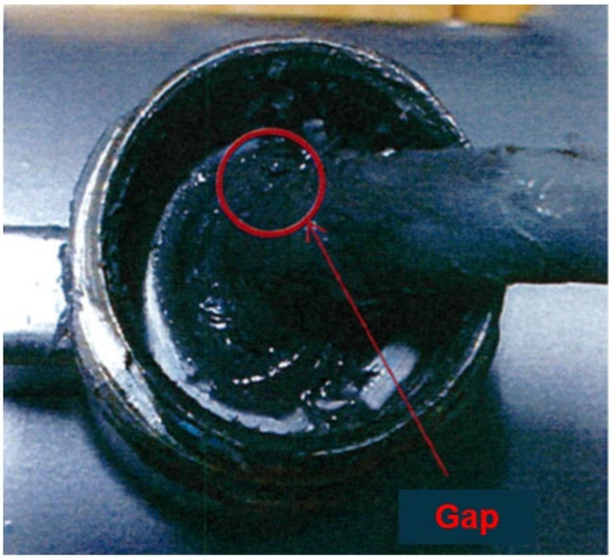


Figure 4.3.5 Outline of S/C pressure gauge for AM



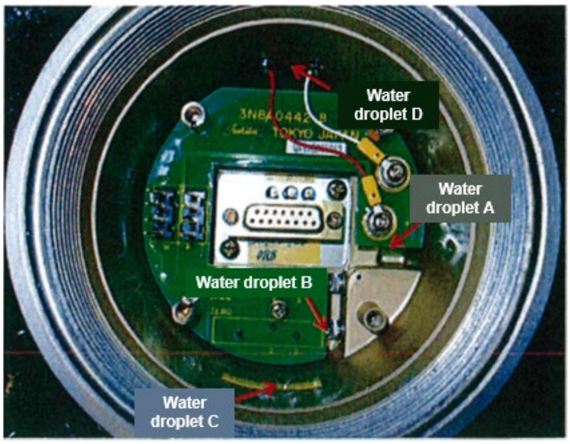
Water leaking of terminals after testing

Figure 4.3.6 Photograph of the terminals after submersion test of a pressure gauge
(Assuming 4 hours of submersion to a flood height of 1.3 m)



Gap of toss seal of electrical wiring connection port

Figure 4.3.7 Photograph of electrical wiring connection port after submersion test of a pressure gauge
(Assuming 4 hours of submersion to a flood height of 1.3 m)



Water droplet penetration at base after test

Figure 4.3.8 Photograph of the base of a pressure transmitter after submersion test of a pressure gauge
(Assuming 4 hours of submersion to a flood height of 18 m)

② Possibility of electrical abnormality due to submerged pressure gauge

Electrical abnormality such as "short circuit," "ground fault," and "insulation degradation" are considered to occur due to flooding of the terminals and base of the pressure gauge as a result of submergence. The following are examples of the occurrence process of electrical abnormality at the terminals. It is quite possible that electrical abnormality may also occur in the base section by the same process.

A) Short circuit: Contact with seawater causes an electrical connection between the (+) and (-) terminals, resulting in a short circuit current. The short circuit works in the direction of increasing the current reaching the S/C pressure indicator for AM in the main control room.

B) Ground fault: Due to contact with seawater, the (+) and (-) terminals are electrically connected to the ground terminal or the case of the pressure gauge (the main material is aluminum alloy), causing current to leak to the ground. A ground fault works in the direction of decreasing the current reaching the S/C pressure indicator for AM.

C) Insulation degradation: Seawater entering the inside of the sheath from the end of the cable sheath connecting to the (+) or (-) terminal is considered to cause current to flow through the seawater to the outside of the cable, resulting in a condition like that of insulation degradation. The insulation degradation works in the direction of reducing the current reaching the S/C pressure indicator for AM.

The distance between the (+) terminal, (-) terminal, ground fault terminal, and the inside of the pressure gauge case, all of which are considered to be involved in the process of generating electrical abnormality, are as small as 10 to 20 mm (Figure 4.3.9). Therefore, when the terminals are flooded, the degree of contact of these terminals, etc. with seawater is about the same, so it is unlikely that a short circuit, ground fault, or insulation degradation occurred alone, and it is highly likely that the electrical anomalies occurred in a combined manner. As described in "2. Outline of the S/C pressure gauge for AM," the S/C pressure gauge for AM converts the S/C gas-phase pressure received by the diaphragm into resistance at the base and measures the S/C pressure from the change in current flowing in the circuit. If these electrical anomalies occur in combination, they may work to reduce the current reaching the S/C pressure gauge for AM, and it may well be possible to show DS or low indicated values that deviates from the D/W pressure by about 0.4 MPa.

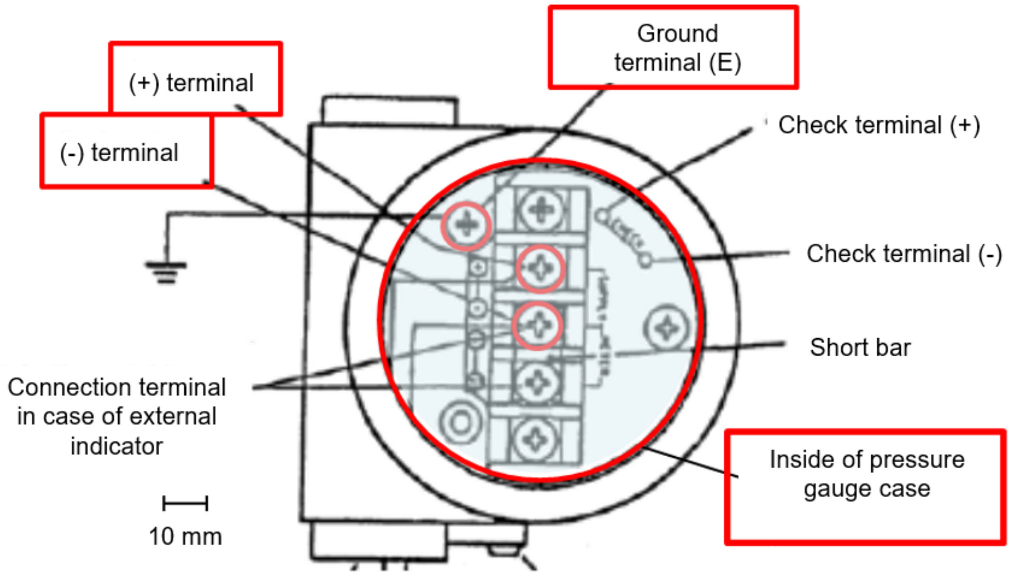


Figure 4.3.9 Enlarged view of terminals of S/C pressure gauge for AM

(4) Summary of the results

Based on the above discussion, there is a possibility that electrical factors caused by the submergence of the S/C pressure gauge for AM may have caused DS or the indicated values to deviate from the D/W pressure.

In this way, it is considered the main reason why the indicated values were restored from the DS at 22:10 on March 14, and the DS was indicated again at 11:25 on March 15 is “electrical factors.” However, there is a great deal of uncertainty regarding the state of water intrusion into the pressure gauge at the time of the accident and the occurrence of electrical abnormality due to this water intrusion. Therefore, it is difficult to estimate the details of what happened.

In addition, since the electrical factors examined this time occur regardless of the accident progression (state changes in the reactor pressure vessel and the containment vessel), the indicated values other than the DS indicated by the S/C pressure gauge for AM is unlikely to reflect the accident progression in any way.

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

From this examination, it was clarified that the decrease in indicated values and DS observed in the S/C pressure gauge for AM were most likely caused by electrical abnormality due to submergence of the pressure gauge by seawater from the tsunami that entered the triangular corner southeast of the basement floor of R/B where the gauge was installed. Therefore, in order to correctly determine plant parameters in the event of an accident, countermeasures against external and internal overflows are necessary for critical measurement equipment. At the Kashiwazaki-Kariwa NPS, these countermeasures are implemented as follows.

(1) Tsunami (external overflow) countermeasures

- External protection
  - Prevention of tsunami run-up by the site elevation
  - Prevention of tsunami inflow into the building by installation of a water intake tank closing plates
- Inner protection
  - Prevention of tsunami inflow into the areas of focus for flooding protection in the event of seawater piping breakage by installing watertight doors, watertight penetrations, etc.
  - Prevention of flooding in the event of damage to outdoor tanks by making R/B perimeter doors watertight, etc.
- Ensuring water intake
  - Ensuring water intake by seawater pumps in the event of receding waves by installing seawater storage weirs.

(2) Internal overflow countermeasures

- Prevention of occurrence
  - Isolation and draining of overflow sources, relocation of overflow sources, ensuring earthquake resistance of overflow sources, etc.
- Prevention of expansion
  - Waterproofing of doors, penetrations, hatches, etc.

- Construction of drainage guidance routes

- Prevention of impact
  - Improvement of drip-proof specifications by sealing, etc. (Figure 5.1), relocation of facilities (e.g., raising the installation height), etc.

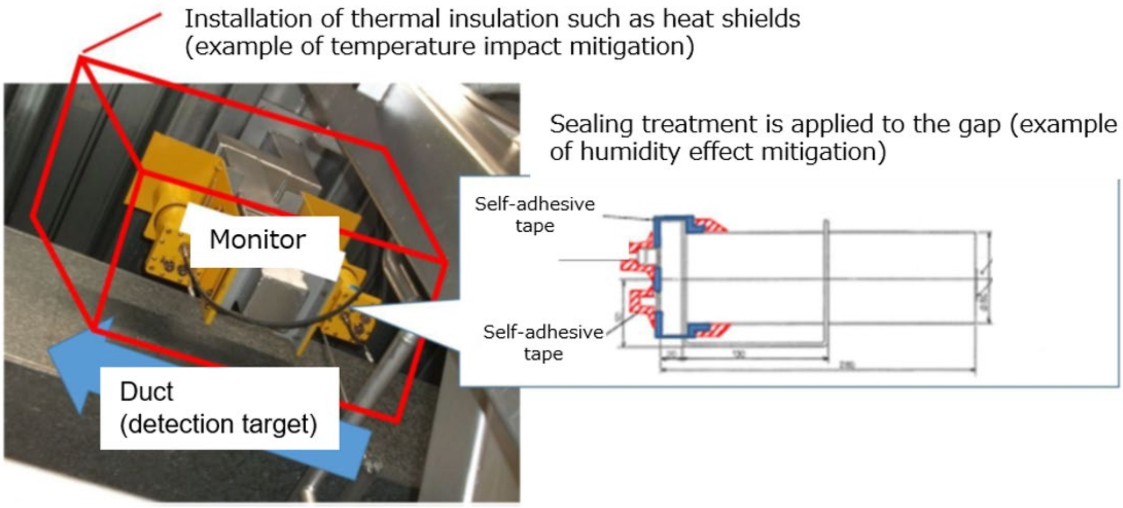


Fig. 5.1 Countermeasure against internal overflow of water into the exhaust monitor in an area of the gas waste treatment system facilities

(3) Response to loss of instrument function

As a response to the loss of function of measuring instruments, a means (alternative parameters) is provided to estimate the parameters that need to be monitored to deal with a major accident (main parameters) when it becomes difficult to measure the parameters. Here, it is confirmed through evaluation that the main parameters and the alternative parameters are not simultaneously unmonitored due to internal overflows.

Example: Alternative parameters for S/C pressure

① D/W pressure (using D/W and S/C vent piping or vacuum break valve to equalize pressure)

② S/C gas temperature (estimated from the relationship between saturation temperature and pressure)

③ Regularly used monitoring instrument for S/C pressure

(4) Education and training of emergency response personnel and operators

In order to provide emergency response personnel (including operators) with a broad knowledge of the phenomena of a major accident, education is provided on the overview of accident management according to their roles, as well as on physical and parameter behavior during a major accident. For operators, simulators that simulate the main control room are used to simulate failures of monitoring instruments used to make judgments in operations, and training is conducted to improve the ability to judge events based on relevant parameters and to improve response skills.

6. Summary

In this attachment, extraction was made of the factors that caused the abnormal indicated values (DS and decreased indicated values) of the S/C pressure gauge for AM at Unit 2 after 21:00 on March 14, and the possibilities of each factor were examined. Based on the results of the examination, it was concluded that the main cause of the DS and low indicated values of the S/C pressure gauge for AM was “electrical factors” caused by electrical abnormality at the terminals due to seawater intrusion inside the S/C pressure gauge for AM caused by submerging the gauge. Table 6.1 summarizes the results.

Regarding the possibility that other factors in addition to “electrical factors” occurred in combination, as for the DS, as was examined among “mechanical factors,” since the indicated values was restored from the DS on March 15, and the timing at which the DS was shown again does not match the time of the earthquake or any explosion, it was considered unlikely that a combination of “mechanical factors” occurred. In addition, as discussed in “factors related to the measurement principle,” the possibility that the water in the condensation tank pipings was separated due to the formation of air bubbles cannot be denied, but the contribution to the decrease in the indicated values is considered to be small.

Table 6.1: Summary of examination results

Factor classification	Result	Details of examination results	
Mechanical factors	×	×	Pressure gauge damage due to earthquake impact
		×	Pressure gauge damage due to impact of explosions of other units
		×	Pressure gauge damage due to tsunami impact
Factors related to the measurement principle	×	×	Decrease due to evaporation of water in condensation tank piping
		×	Water leakage in condensate piping due to piping rupture
		×	Splitting of water in condensation tank piping due to bubble formation
Electrical factors	○	×	Battery depletion or insufficient supply voltage
		○	Electrical abnormality due to seawater intrusion (short-circuit, ground fault, insulation loss)

References
[1] Japan Industrial Standards Committee JISC0920 Protection class by outline of electrical machinery and apparatus (IP code)
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