# SRV operation states after core damage at Unit-2

## 1 Introduction

Unit-1 to Unit-3 lost all water injection functions eventually which had been designed to work in an accident. As an emergency measure, fire engines were used to inject water into the reactor vessels. To this end, the safety-relief valves (SRVs) had to be opened to depressurize the reactor and to be kept open to maintain the reactor pressure at a low enough value so that the water discharged at low discharge pressure from the fire engines could be injected into the reactor.

However, the DC power sources necessary for SRV operation were lost in the course of accident progression and the SRV opening operation needed temporary batteries. Despite strong efforts, the reactor pressures did not always decrease.

For failed opening operation of the SRVs, the cause could be insufficient nitrogen gas pressures for driving against the high pressure containment vessel (PCV) back-pressure (the force acting against the SRV opening operation), or inoperable solenoid valves due to insufficient voltage. But the real cause is unknown. It is necessary to clarify the SRV operating conditions after the core was damaged, in consideration of the reactor pressure behavior. This issue has been identified as "Common/Issue-1."

SRV operation conditions at Unit-1 and Unit-3 are reviewed separately in Attachment 1-3 and Attachment 3-4.

This document presents the results of examination into the SRV conditions at Unit-2.

## 2 SRV operation at Unit 2 before the tsunami arrival

Table 1 gives the specifications of the Unit-2 SRVs, while Figure 1 and Figure 2 present the reactor pressures recorded on the transient recorder before the tsunami arrival and the loss of power supplies, and the operation record of SRV (F), which had the lowest blowout pressure for the pressure relief function.

Table 1 Specifications of Unit-2 SRVs

| Valve # | Safety Function | Relief Function | Availability of Automatic |
|---|---|---|---|
| | Blow-out Pressure | Blow-out Pressure | Depressurization System (ADS) |
| A | 78.7 kg/$cm^2$[g]<br>(≒7.71MPa[g]) | 76.6 kg/$cm^2$[g]<br>(≒7.51 MPa[g]) | Yes |
| B | 79.4 kg/$cm^2$[g]<br>(≒7.78 MPa[g]) | 77.3 kg/$cm^2$[g]<br>(≒7.58 MPa[g]) | Yes |
| C | 79.4 kg/$cm^2$[g]<br>(≒7.78 MPa[g]) | 77.3 kg/$cm^2$[g]<br>(≒7.58 MPa[g]) | Yes |
| D | 78.7 kg/$cm^2$[g]<br>(≒7.71 MPa[g]) | 76.6 kg/$cm^2$[g]<br>(≒7.51 MPa[g]) | No |
| E | 78.0 kg/$cm^2$[g]<br>(≒7.64 MPa[g]) | 76.6 kg/$cm^2$[g]<br>(≒7.51 MPa[g]) | Yes |
| F | 78.0 kg/$cm^2$[g]<br>(≒7.64 MPa[g]) | 75.9 kg/$cm^2$[g]<br>(≒7.44 MPa[g]) | No |
| G | 78.7 kg/$cm^2$[g]<br>(≒7.71 MPa[g]) | 77.3 kg/$cm^2$[g]<br>(≒7.58 MPa[g]) | Yes |
| H | 79.4 kg/$cm^2$[g]<br>(≒7.78 MPa[g]) | 77.3 kg/$cm^2$[g]<br>(≒7.58 MPa[g]) | Yes |

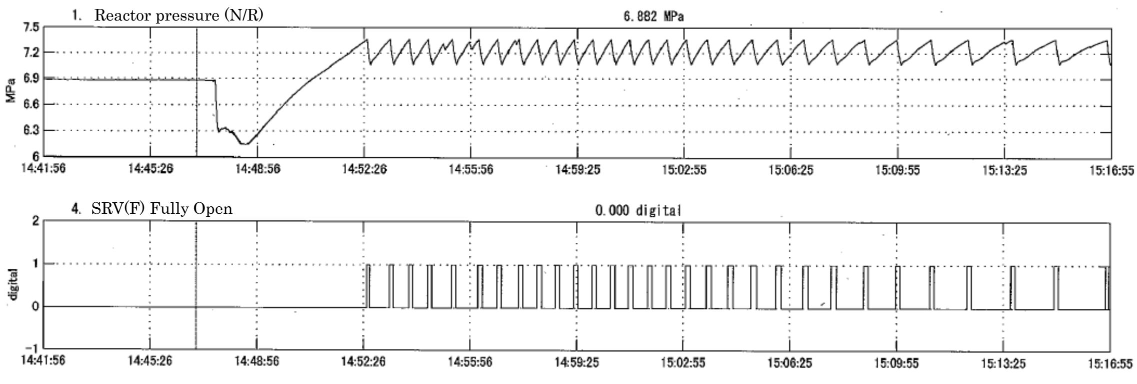


Figure 1 Reactor pressure changes and SRV (F) operation recorded (transient recorder)
(14:41:56 to 15:16:55, March 11th, 2011)

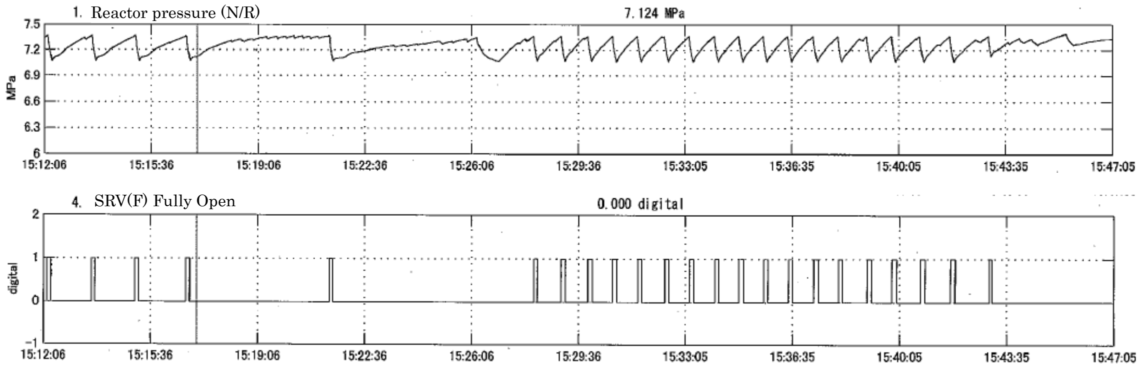


Figure 2 Reactor pressure changes and SRV (F) operation recorded (transient recorder) (15:12:06 to 15:47:05, March 11th, 2011)

Figure 1 and Figure 2 indicate that the relief function of SRV (F) worked as designed and the reactor pressure was under control from the time of the earthquake to the time of the tsunami arrival. From the time of the earthquake to the time of loss of power supply, the SRV (F) was driven by the pressurized instrument air-system (IA).

3 SRV operation at Unit 2 after the tsunami arrival

Table 2 shows the SRV operational records after the tsunami arrival, being compiled from the survey results for the Fukushima Nuclear Accident Analysis Report [1] (TEPCO, June 20, 2012). Reactor pressures at each operation are shown in Figure 3 and Figure 4 (numbers in the graphs of these figures correspond to the operation step numbers in Table 2). It should be noted that some timings of the SRV operation given in Table 2 have been determined based on the reactor pressure changes.

Table 2 SRV operational records after the tsunami arrival

| Operation step no. | Valve ID | Actions taken | Timing | Pressure dropped? |
|---|---|---|---|---|
| 1 | A | Batteries connected to control panel for opening operation, but failed (relief function) | 3/14 16:34 | No |
| 2 | B | Batteries connected instead to control panel for valve B for opening operation, but failed (relief function) | | No |
| 3 | C | Batteries connected instead to control panel for valve C for opening operation, but failed (relief function) | | No |

| | | | | |
|---|---|---|---|---|
| 4 | G | Batteries connected instead to control panel for valve G for opening operation, but failed (relief function) | | No |
| 5 | E | Batteries connected directly to solenoid valve of valve E for activation, depressurization (relief function) started but not sufficient | 3/14 18:02 | Yes |
| 6 | F, D | Direct battery connection switched to the solenoid valves of valve F and valve D for activation, reactor pressure decreased, depressurization (relief function) restarted but after a while the reactor pressure increased again | | Yes |
| 7 | A, B | Depressurization started again, when other solenoid valves (relief function) of valves A or B were activated for depressurization again, but after a while the reactor pressure increased again | 3/14 21:00 - | Yes |
| 8 | Not known | Solenoid valves activated (function unknown) for depressurization again and the reactor pressure decreased | 3/14 23:00 - | Yes |
| 9 | C | Activation of solenoid valve (relief function) attempted, but given up due to sparks | 3/16 dawn | No |
| 10 | G | Solenoid valve activated (relief function), but no reactor depressurization (sparks) | | No |
| 11 | E | Solenoid valve activated (relief function), but no reactor depressurization | | No |
| 12 | A | Solenoid valve activated (ADS), but no reactor depressurization | | No |
| 13 | B | Solenoid valve activated (ADS), but no reactor depressurization | | No |
| 14 | E | Solenoid valve activated (ADS), but no reactor depressurization | | No |
| 15 | G | Solenoid valve activated (ADS), but no reactor depressurization | | No |
| 16 | H | Solenoid valve activated (ADS), but no reactor depressurization | | No |
| 17 | C | Solenoid valve activated (ADS) for depressurization again, but batteries depleted on March 18th, reactivated after battery replacement | | Yes |
| 18 | Not known | Another valve opened upon slight increase of reactor pressure after operating valve C | 3/15 02:22 | Yes |

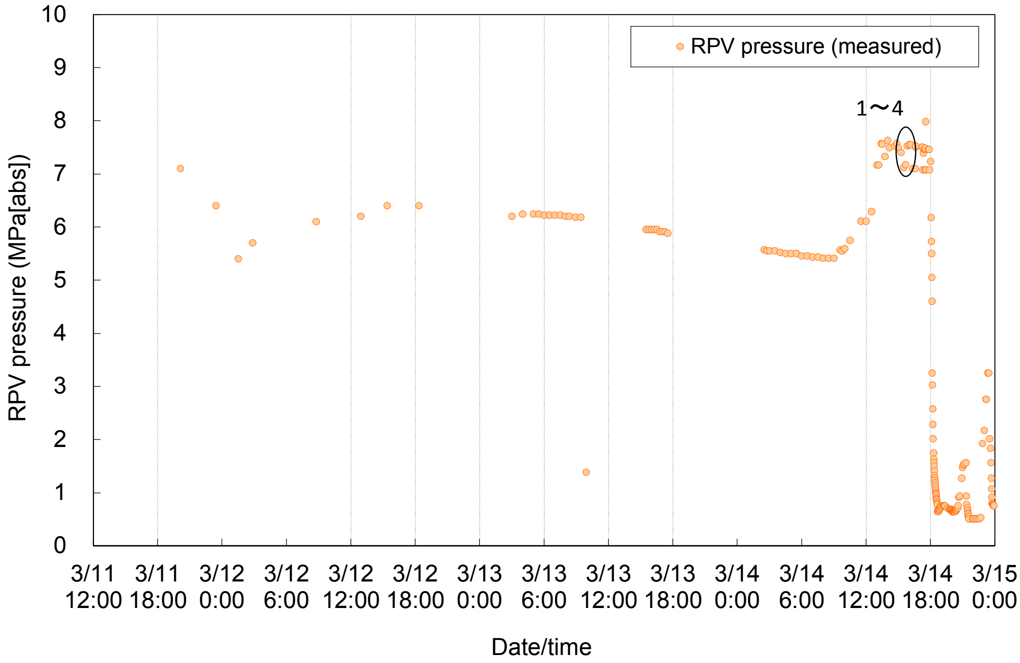


Figure 3 Reactor pressure changes of Unit-2 (12:00 on March 11th –00:00 on March 15th)

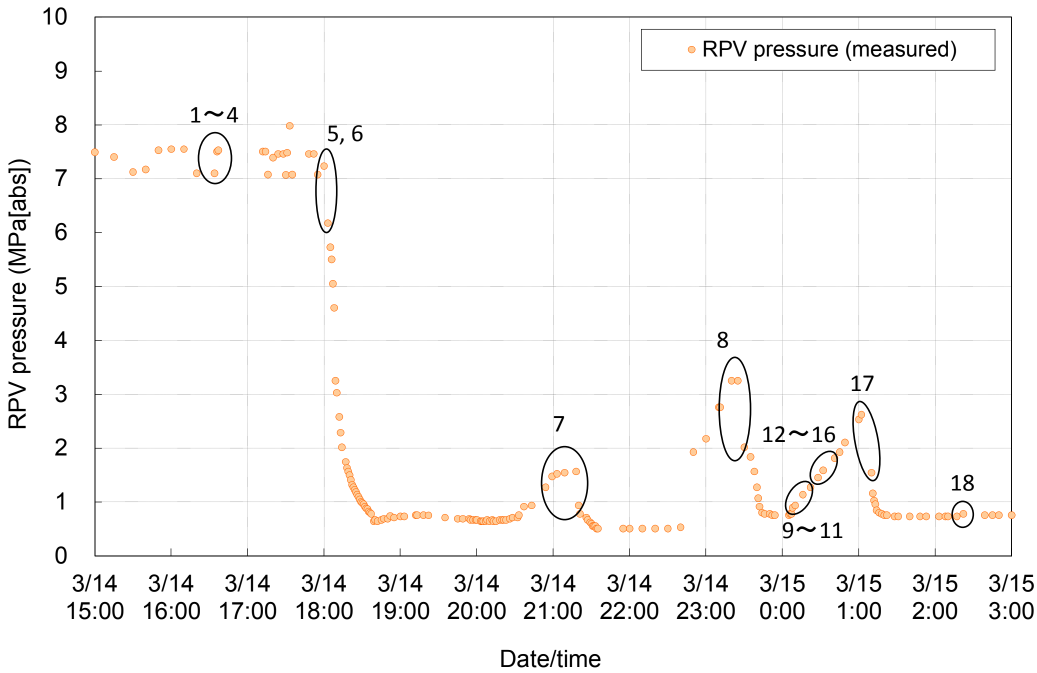


Figure 4 Reactor pressure changes of Unit-2 (12:00 on March 14th –03:00 on March 15th)

As can be seen in Figure 3, the reactor pressure stayed below the SRV working pressure after 20:07 on March 11th, when the reactor pressure measurement had started, although the number of data was limited. This is considered to indicate that the reactor pressure could stably change below the normal operating pressures by the continued operation of the reactor core isolation cooling (RCIC) system, which had started up immediately before the tsunami arrival and the loss of all AC power supply (Attachment 2-1).

This means that the reactor pressure was not on the level to activate SRVs, except for the period immediately after the tsunami arrival, until it increased after about 09:00 on March 14th, when the RCIC performance seems to have dropped.

At 13:10 on March 13th, temporary batteries were connected to the SRV control panel in the main control room and only SRV (A) was in a situation to return to being operable by the operation switch on the panel.

The reactor pressure was stable at about 7.5MPa[abs] between about 13:00 and 18:00 on March 14th. This could be due to either the SRV relief function or the SRV safety function. The pressure of about 7.5MPa[abs] is certainly close to the SRV (F) relief valve activating pressure, as seen in Table 1. It is possible that the SRV (F) relief valve worked. There is another piece of information that the DC power to detect "high reactor pressure" for activating the SRV relief function was not available at Unit-2, which had lost DC power supplies because of the tsunami. If this is the case, the SRV relief function could not be activated. The SRV safety function could have been activated. The lowest activating pressure for the safety function is 7.64MPa[gage], that of SRV (E) and SRV (F). The reactor pressure seems to have changed below this safety function activating pressure. The SRV (F) worked repeatedly before the tsunami arrival and may have suffered some damage, as discussed later in Item 5.4 (such as spring deterioration), lowering the activating pressure.

As can be seen in Table 2 and Figure 4, SRVs (A, B, C and G) were operated to open by turns from 16:34 on March 14th on the control panel connected to the batteries (operation steps 1 to 4), but the reactor pressure did not decrease and the SRVs seem to have remained closed.

All batteries were disconnected once and rewired in series and the power supply for activating SRVs was limited only to solenoid valves, not the whole circuit, and, at 18:02, the SRV (E) opened successfully. But the reactor pressure did not drop enough. Solenoid valves of SRVs (F and D) were directly powered instead (operation steps 5 and 6) and the reactor was successfully depressurized.

The reactor pressure tended to increase again after 20:30. Upon operating SRVs (A, B) to open (operation step 7), the reactor pressure decrease was confirmed at

21:20.

The reactor pressure increased again after about 22:40. Upon operating SRVs (actual valves operated are unknown), the reactor pressure decrease was confirmed at 23:30.

The reactor pressure increased again after about 00:00 on March 15th. The relief function of SRVs (C, G and E by operation steps 9 to 11) and the ADS function of SRVs (A, B, E, G and H by operation steps 12 to 16) were activated, but no reactor pressure decrease was confirmed. Upon activating the ADS function of SRV (C), the reactor pressure decreased at 01:10.

In brief, SRV opening operations were done by connecting battery power supplies directly to their solenoid valves for opening in the SRV control circuits as reviewed in Table 2. In some cases, the reactor pressure decreased, but in other cases it did not. The examination results into the causes for this are presented in Item 4 below and thereafter.

4 Causes of failure of the reactor pressure to drop by the SRV opening operations

There are two possible causes for the failure of reactor pressure to drop despite the SRV opening operations.

(i) The SRVs failed to open for some reasons.

(ii) The SRVs opened, but at the same time some gas-generating incident occurred in the reactor vessel, overwhelming the depressurization by the SRVs.

Concerning possibility (i), the following five factors can be considered as possible reasons for inoperable SRVs. Each of these factors is examined in Item 5 below.

- Deterioration of working environment
- Insufficient $N_2$ gas feed pressure due to repeated operations
- Poor connection or insufficient power of temporary batteries
- Physical damage due to repeated operations
- Dynamic relations between the $N_2$ gas feed pressure, reactor pressure and PCV pressure

Possibility (ii), gas generation in the reactor vessel, is examined in Item 6 below.

5 Examination into possible incidents to cause inoperable SRVs

5.1 SRV working environment

The SRVs could have been unable to work properly due to changes in environmental conditions (temperature, humidity, radiation effects, etc.).

No measured data are available concerning the PCV air temperatures at the time of the accident. The MAAP5.01 analysis shown in Figure 5 gives the temperature as about 170 deg C while the SRVs were being operated (Attachment 3). It should be noted that the MAAP analysis modeled the PCV as a single node. In reality, it is quite possible that the temperatures could have been higher at local locations. The SRV design temperature at emergency operations is 171 deg C. It is possible, therefore, that the temperatures around the SRVs exceeded the design temperature when the SRVs were operated.

Organic materials are generally vulnerable to radiation (for example, the fluorine-based packing used for solenoid seals of $N_2$ gas supply lines and grease used for SRV cylinders and pistons). The containment atmospheric monitoring system (CAMS) data presented in Figure 6 show that the dry-well (D/W) radiation dose increased after about 21:00 on March 14th due to fuel melting. This radiation dose increase could have influenced the SRV operating conditions.

A rapid increase in the reactor pressure was noticed at and after around 22:40 on March 14th, during which time the most violent fuel melting is considered to have been in progress (Attachment 2-9). It is considered that the environment in the PCV especially worsened thereafter.

In addition, the CAMS data indicate a possibility of gaseous leakage from the reactor vessel to the D/W after 23:42 on March 14th. If this is the case, steam would be discharged directly to the D/W and the humidity conditions would have worsened also.

As discussed in the above, the environmental conditions in the PCV are considered to have become severe, as the accident progressed, in terms of temperature, humidity, radiation and other features. The possibility of impacts to the SRV operability due to these conditions cannot be excluded, for example, the seal materials used in the solenoid valves and other equipment deteriorated and caused leaks of $N_2$ gas intended for driving SRVs.

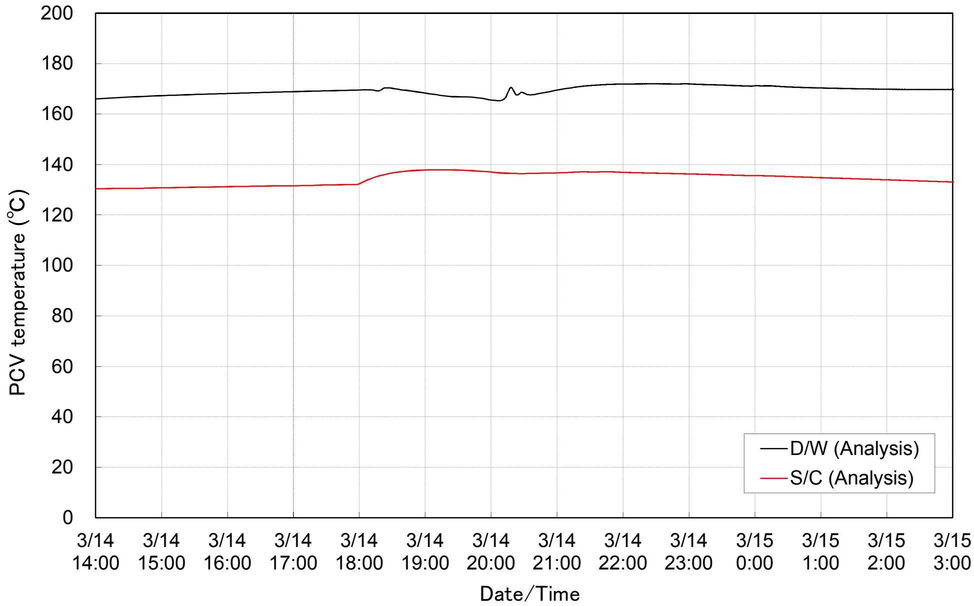


Figure 5 PCV temperature changes of Unit-2 (MAAP5.01)

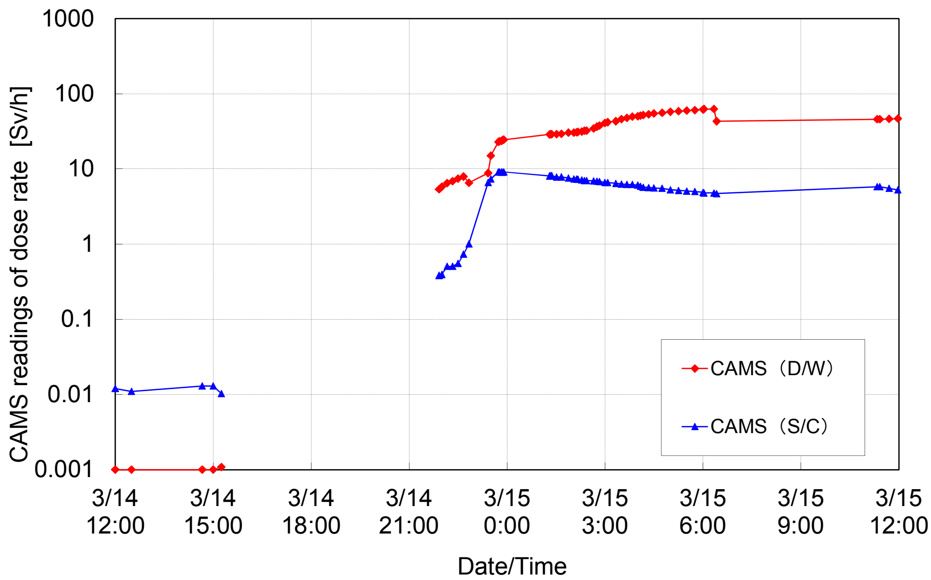


Figure 6 CAMS readings at Unit-2

5.2 Number of operations and the nitrogen gas feed pressures

The accumulator for the ADS has the capacity to operate the SRV at least five times even with no feed from $N_2$ cylinders.

As described in Items 2 and 3 above, the ADS function of the SRVs in Unit-2 is considered not to have been activated until the SRV opening operations shown in Table 2.

Concerning the relief function, only the SRV (F) was activated before the loss of power supply and the SRV (F) was driven by the IA. The possibility remains that the SRV (F) relief function was activated after the tsunami arrival between 13:00 and 18:00 on March 14th, but the possibility for this can be considered as low; at least in the opening operation of SRVs other than SRV (F) mentioned in Table 2, the $N_2$ gas feed pressure was insufficient due to over-consumption of $N_2$ gas in the accumulator prior to the opening operation.

5.3 Temporary batteries

Unit-2 lost its DC power supplies and the SRVs were operated to open by connecting temporary batteries and supplying power to the solenoid valves via the control circuits. The battery voltage was confirmed in advance. Furthermore, the SRV opening operations seem to have succeeded in depressurizing the reactor, as described in Item 6 below, at the opening operations at about 18:02 and 21:20 on March 14th, and at about 01:10 on March 15th. This indicates that the likelihood of insufficient battery capacities was low for ensuring the SRV operation voltage and for giving adverse impacts to the SRV opening operations mentioned in Table 2.

It should be noted, however, that the battery wiring was fully disconnected once after the opening operation at 16:34 on March 14th (operation steps 1 to 4). Ten batteries were rewired in series and the power supply for activating SRVs was limited only to solenoid valves, not the whole circuit. Therefore, it is possible that the SRVs could not be opened by the opening operations at 16:34 on March 14th because of power supply conditions from the batteries to the solenoid valves, which were different from those at the operation steps 5 and 6 for opening.

5.4 Impact of repeated operations

Possible causes of inoperable SRVs due to physical damage by repeated operations are:

(i) increased friction due to wear and sticking of sliding portions;

(ii) damage of colliding portions;

(iii) valve seats roughened by blowing out;

(iv) weakened springs; and

(v) deterioration of grease and seal materials of pistons, etc.

But all SRVs, except SRV (F) and possibly SRV (E), can be considered not to have experienced repeated operations after the earthquake and the impact of such repeated operations on the opening operation is considered unlikely. Exceptionally, SRV (F) worked for the relief function before the power supply loss and possibly for the relief function or safety function at around 13:00 to 18:00 on March 14th (and SRV (E), too, if SRV (F) worked for safety function).

The SRV (E) cannot be considered to have been inoperable due to the repeated operations, because the reactor pressure decreased upon its opening operation at 18:02 on March 14th (operation step 5). But the reactor pressure was not sufficiently decreased by the opening operation of SRV (E). After 18:02, SRV (D) and SRV (F) were both operated to open for successful reactor depressurization. It cannot be concluded, as two SRVs were working, whether SRV (F) had been inoperable due to any of the causes (i) to (v) above.

## 5.5 Dynamic factors caused by the relationship between nitrogen gas feed pressure, reactor pressure and PCV pressure

For opening operation of SRVs, dynamic balance needs to be considered, apart from the integrities of mechanical parts: the $N_2$ gas feed pressure and reactor pressure for opening, and the PCV pressure for closing (back pressure). Figure 7 illustrates forces working on the SRVs.

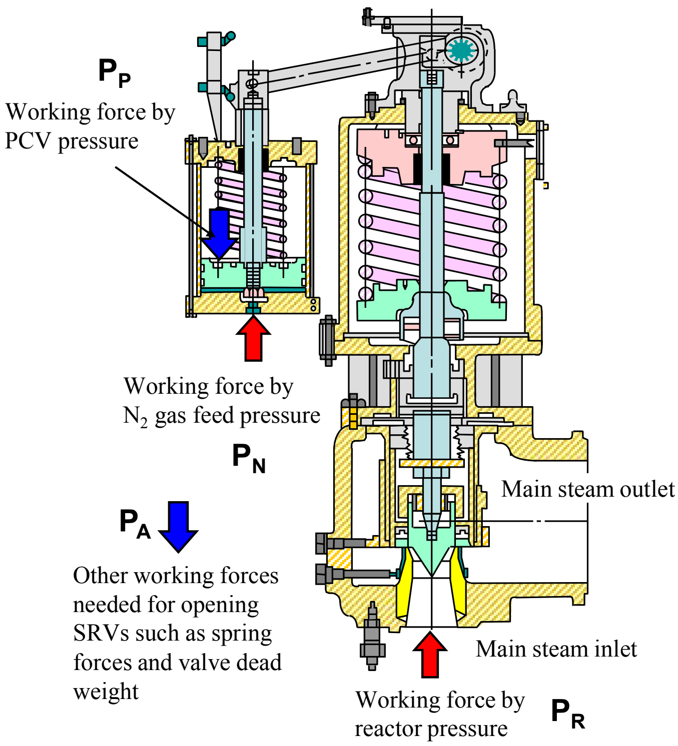


Figure 7 Cross-sectional view of an SRV

For an SRV to open, the relation "$P_R+P_N>P_P+P_A$" needs to be satisfied.

Unit-2 was in the state of all AC power supplies being lost after the accident. Consequently, the $N_2$ gas supply lines from outside the PCV were isolated. The SRVs were driven by $P_N$ of $N_2$ gas in each accumulator. Figure 8 outlines the system to supply $N_2$ gas to an SRV.

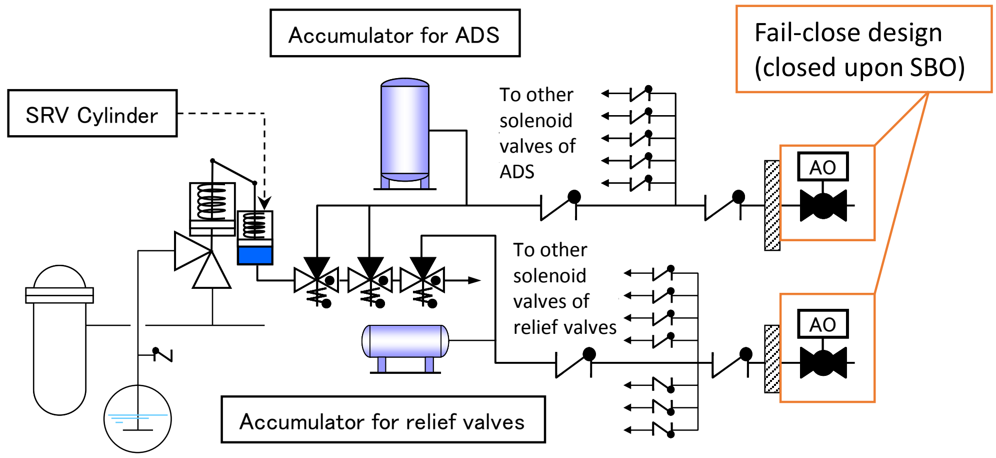


Figure 8 Schematic of the system to supply $N_2$ gas to an SRV

Figure 9 presents the results from evaluation of dynamic factors. The blue line corresponds to $P_P+P_A$ (the force for closing), while orange and red lines correspond to $P_N+P_R$ (the force for opening). The orange line shows the opening force when the accumulator for the ADS is used, and the red line shows the opening force when the accumulator for the relief function is used. It should be noted that the results correspond to the forces needed to fully open the SRV on designed values.

The evaluation results clarify the following.

(i) When the relief valve function worked, the SRVs could not work as designed after about 23:00 on March 14th due to the increased PCV pressures.

(ii) The ADS function could work over the whole time span of interest as designed.

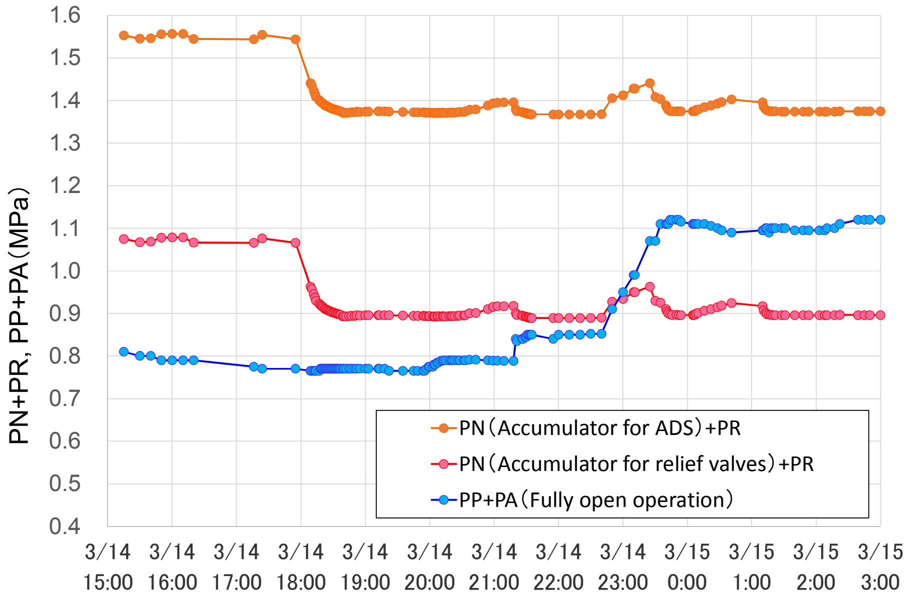


Figure 9 Evaluation results of dynamic factors

In the evaluation above, the following assumptions were made, causing some uncertainties.

(i) SRV apertures: Fully open

(ii) PCV temperature: Constant at 170 deg C over the time span of interest

(iii) $N_2$ gas feed pressure from accumulators: Maximum design value

(iv) Leaks from the $N_2$ gas supply line to SRVs: None

6 Deliberation on the SRV operating conditions based on dynamic factors and the progress of incidents

SRV operating conditions at operation steps 1 to 18 (Table 2) are discussed below, based on possibility (ii) in Item 4 (gas-generating incidents in the reactor vessel, overwhelming the SRV depressurization effect) and the evaluation results of dynamic factors mentioned in Item 5.5 above.

(a) Operation steps 1 to 4 and operation steps 5 and 6

Operation steps 1 to 4 and steps 5 and 6 (before depressurization) were taken when the reactor pressure was under control by the SRV relief valve function or safety valve function. It was after about 17:00 on March 14th when the measured reactor water level was lowered to TAF, and after about 18:00 when the water level was lowered to BAF (Figure 10). On the occasion of reactor pressure decrease at about 18:02, the D/W pressure almost stayed constant. The steam discharged via SRVs can be considered to have condensed in the suppression chamber (S/C) (Figure 11).

Operation steps 1 to 4 attempted to operate the relief valve function of four SRVs (A, B, C and G). No evidence of reactor pressure decrease is visible, but Figure 9 indicates that the SRVs were dynamically in operable conditions. On the other hand, operation steps 5 and 6 attempted to operate the relief valve function of three SRVs (E, F and D). Little decrease of the reactor water level was noticed, but the conditions surrounding the SRVs were almost the same as those for operation steps 1 to 4. Nevertheless, the reactor pressure decreased.

The difference came probably from the rewiring of batteries, as mentioned in Item 5.3. After the opening operation at 16:34, the batteries were completely disconnected once and rewired for supplying power directly to solenoid valves for activation, not to the whole circuit.

As further described in (b) below, the valves opened at operation steps 5 and 6 seem to have closed before the operation step 7 at about 21:00 on March 14th. The following two scenarios are possible for this closure.

(i) Water injection by fire engines started at about 20:00 on March 14th. The reactor pressure increased due to steam and hydrogen gas generated accordingly, while the subject SRVs remained open. The shift operators might have noticed the reactor pressure increase, thought that the SRVs had closed, and rewired temporary batteries to other SRVs, by which the SRVs having been opened at operation steps 5 and 6 might have closed.

(ii) Seal materials used in solenoid valves and other equipment deteriorated as the environment in the PCV worsened (temperature, humidity and radiation). $N_2$ gas for driving SRVs might have leaked and sufficient forces to keep SRVs open might have been lost. This might have closed the SRVs. But, as discussed in (c) below, the SRVs having been opened at operation step 7 at about 21:00 on March 14th seem to have remained open until about 00:00 on March 15th. In other words, the SRVs could have remained open under severer environmental conditions in the PCV. Therefore, the SRVs having been opened at operation steps 5 and 6 seem unlikely to have closed due to $N_2$ gas leaks and the loss of forces to keep them open.

The timing cannot be specified when the SRVs having been opened at operation steps 5 and 6 closed, but they seem to have remained open until about 20:00 on March 14th, when the D/W pressure increased upon initiation of water injection by fire engines (Figure 11).

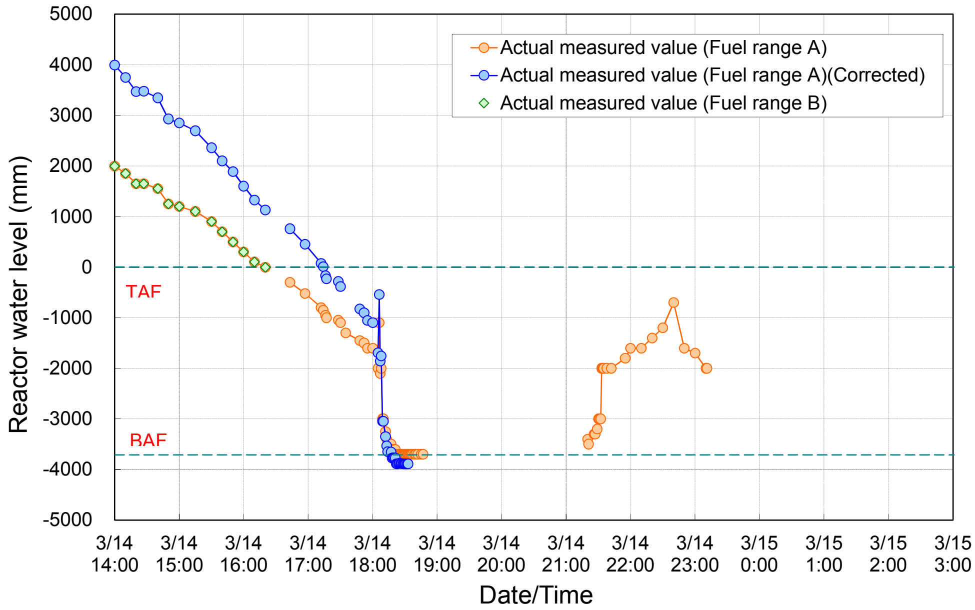


Figure 10 Reactor water level changes

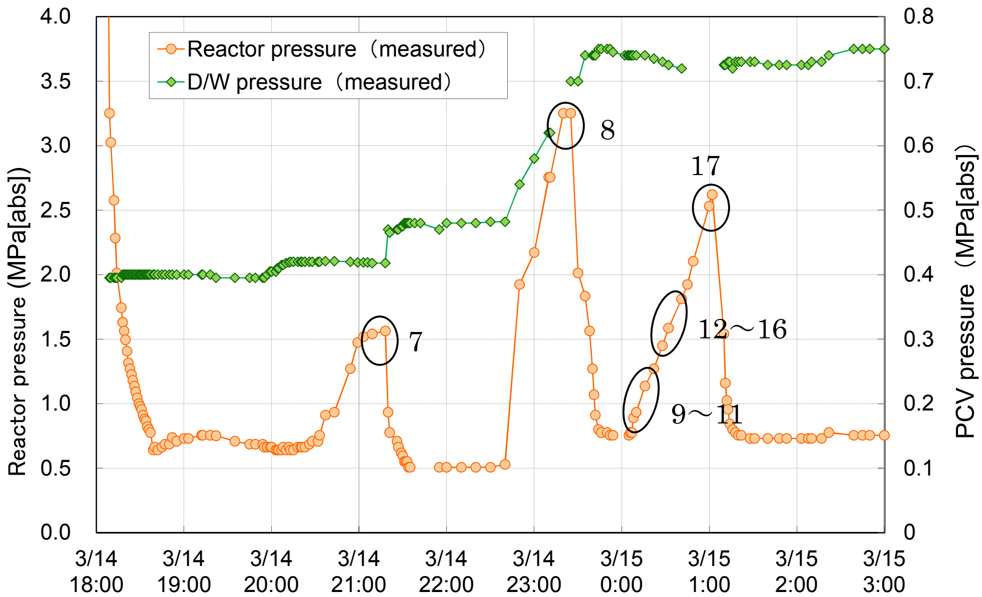


Figure 11 Reactor pressure changes and PCV pressure changes

(b) Operation step 7

Operation details at operation step 7 (relief valve function of SRVs (A, B) are given below.

"The reactor pressure increased at around 21:00 on March 14th. In order to open a second SRV, its solenoid valve was activated but the reactor pressure did not decrease. Upon activating another SRV solenoid valve, the reactor pressure decreased at 21:20 [1].

Figure 9 indicates that dynamically the SRV relief valve function could be activated at around 21:00 on March 14th.

At around 21:20 when the reactor pressure decreased, the D/W pressure increase (about 50kPa) was observed. The D/W pressure increase can be considered to have occurred due to the inflow of steam and hydrogen gas generated in the reactor into the S/C at this timing. In other words, the SRVs having been opened at around 18:02 (SRVs (E, F and D) opened at operation steps 5 and 6) are considered to have closed by this time and to have opened at around 21:20 at operation step 7, because the D/W pressure did not show any increase between 20:15 and 21:20, despite the increasing reactor pressure (Attachment 2-9).

It should be noted that no reactor pressure decrease was confirmed at operation step 7 upon operating SRVs to open at around 21:00. It is interpreted that the SRVs failed to open for unknown reasons.

(c) Operation step 8

It is unknown which SRV was operated at operation step 8. What function was activated is not known, either. But the plant data changes indicate the following.

As seen in Figure 11, the PCV (D/W) pressure increased consistently with the reactor pressure. This indicates that gases and energy were transferred from the reactor vessel to the PCV. Figure 12 gives the changes of CAMS readings and reactor pressures. The CAMS readings were increasing from 21:55 on March 14th both in the D/W and S/C. But from 23:42 on March 14th the CAMS (D/W) readings continued to increase, while the CAMS (S/C) readings remained constant for a while and tended to decrease thereafter. This suggests a possibility of gaseous leaks from the reactor vessel to the D/W from 23:42 on March 14th (Attachment 2-10). Therefore, the scenario could be: the D/W pressure increased consistently with the reactor pressure from 22:40 to this timing (23:42) on March 14th, not due to the gaseous leaks from the reactor vessel to the D/W, but due to the steam and hydrogen gas generated in the reactor vessel and discharged to the S/C via the SRV (A or B), which had opened at operation step 7 and remained open, while the reactor vessel was integral. It should be mentioned that the subject pressure changes could be reproduced in the analysis by assuming the SRV aperture was in the mid-open position (Attachment 2-9). The SRV aperture being in the mid-open position may be explained by the relationship $P_R+P_N>P_P+P_A$ shifting to

$P_R+P_N<P_P+P_A$ during this time period and the SRVs no longer could be kept fully opened.

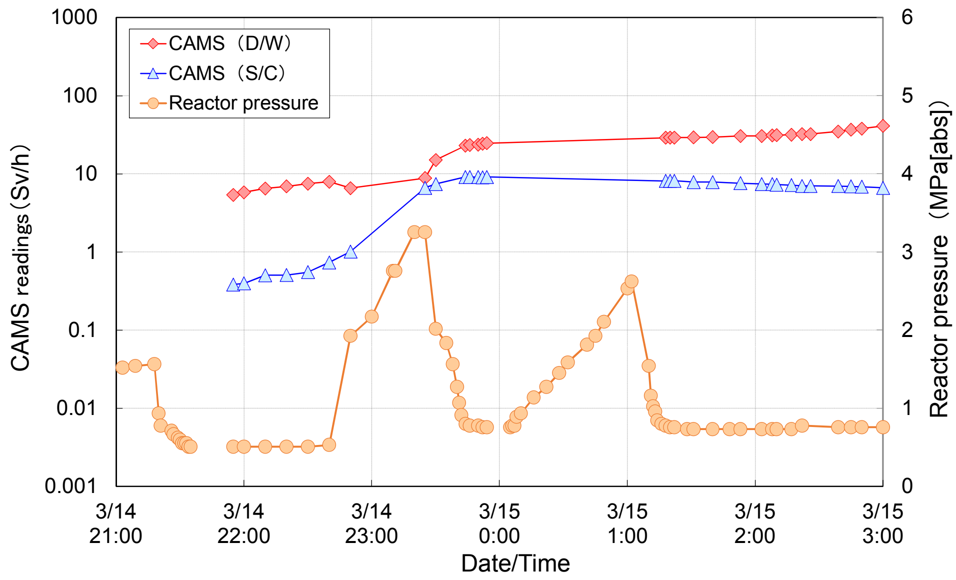


Figure 12 CAMS readings and reactor pressure

(d) Operation steps 9 to 11

Operation steps 9 to 11 attempted to operate the relief valve function of three SRVs (C, G and E).

Operations to open SRV (C) and SRV (G) were halted upon seeing sparks when activation of their solenoid valves was tried. Figure 9 shows that the relief valve function is unable to work as designed during the time for operation steps 9 to 11. Therefore, the SRV (E) may have been inoperable for dynamic reasons.

In the meantime, the SRVs which are considered to have been kept open for their relief valve function since operation step 7 may have been no longer able to remain open for dynamic reasons at the time of operation steps 9 to 11 when the PCV pressure was increasing, as shown in Figure 11.

(e) Operation steps 12 to 16 and operation step 17

Operation steps 12 to 16 attempted to operate the ADS function of SRVs (A, B, E, G and H). Although unable to confirm the reactor pressure decrease during the period, they are considered to have been operable in design, as can be seen in Figure 9. The reactor pressure decrease was confirmed, when SRV (C) was operated for its ADS function at operation step 17. The following two possibilities can be considered for this incident.

(i) SRVs worked at each operational step, but the reactor pressure changed according to the steam and hydrogen gas being generated in the reactor vessel.

(ii) Deteriorated seal materials of solenoid valves and other parts operated at operation steps 12 to 16 (operating the ADS function of SRVs (A, B, E, G and H)) caused $N_2$ gas leaks for SRV driving and failures of SRVs opening.

Possibility (i) can be explained by the following scenario. The SRVs opened but the D/W pressure did not increase. This may occur if almost no hydrogen gas was generated, and steam was almost completely condensed in the S/C, or if the PCV had lost its integrity (Attachment 2-9).

Concerning possibility (ii), deterioration of seal materials of SRV solenoid valves might have developed by this time (about 23:00 on March 14th) due to the worsened environmental conditions in the PCV, because the most violent fuel damage is considered to have occurred at around 23:00 on March 14th (Attachment 2-9) and gaseous leaks might have occurred from the reactor vessel to the D/W (Figure 12). The reactor pressure decreased at operation step 17 (SRV (C)). This might be possible if the seal materials of SRV (C) did not deteriorate enough to cause leaks or if it could have been restored to dynamically operable conditions for some reasons even with leaks, as seen in Figure 11, which shows a slight decrease of D/W pressure while the reactor pressure continued to increase.

There may be a third possibility that the reactor pressure decrease just after 01:00 on March 15th was caused, not by the SRV opening operations, but by enlarged gaseous leaks from the reactor vessel to the PCV. This possibility can be considered unlikely, because no big changes of CAMS (D/W) readings were observed before and after the time period of about 00:00 to just after 01:00 on March 15th, although no measured data are available during this period (Figure 12).

(f) Operation step 18

At around 02:22 on March 15th, the ADS function was activated (the actual SRV operated is unknown), because a slight increase was observed in the reactor pressure. The SRV could have opened, since the reactor pressure decreased after the SRV operation (Figure 13), and the SRV can be considered dynamically operable (Figure 9). But it is also possible, by looking at the balanced pressures of the reactor vessel and PCV from about 01:30 that the reactor pressure, which increased once when gases were generated in the reactor vessel, decreased consistently with gaseous leaks from the reactor vessel to the PCV.

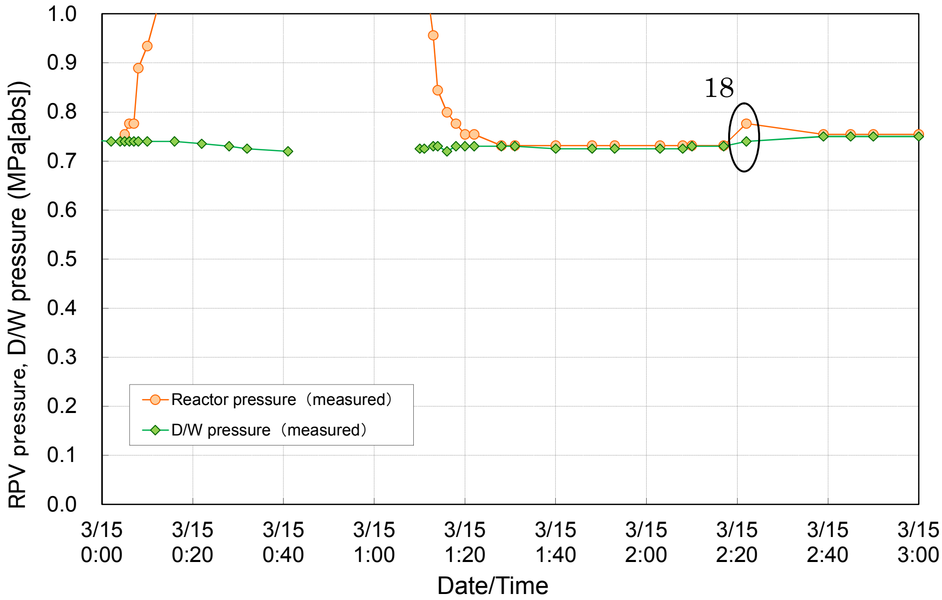


Figure 13 Pressure changes of reactor vessel and D/W (00:00 to 03:00 on March 15th)

7 Relation to safety measures at the Kashiwazaki-Kariwa Nuclear Power Station

The following points have been concluded from the discussions in Item 6 above.

(i) It is highly possible that improper power supply to the solenoid valves affected the SRV operations of opening and closure.

(ii) The increased PCV pressure in the accident progression could have influenced the SRV operations.

(iii) The seal materials of solenoid valves and other equipment could have been deteriorated by effects of temperature, humidity and radiation and this might have caused the SRV failures to open.

Concerning these possibilities, the following safety measures are being taken at the Kashiwazaki-Kariwa Nuclear Power Station (Figure 14).

<Measures for power supply>

(i) Not only power source vehicles but portable batteries will be deployed in order to enable solenoid valves to be activated even when the DC power supply is lost.

(ii) New piping will be installed for feeding nitrogen gas from the solenoid discharge side to the SRV (an alternative driving tool for SRVs)

<Measures for nitrogen gas supply>

(iii) The nitrogen gas supply pressure will be increased so that SRVs can be opened even when the PCV pressure increases to twice the pressure value of its maximum duty pressure.

(iv) Fluorine-based seal materials used for solenoid valves will be replaced with ethylene-propylene rubber materials that have better resistance to harsh environments to lower the chance of nitrogen gas leaks from lines.

(v) Stand-by nitrogen gas cylinders will be reserved as a back-up nitrogen gas source.

<Others>

(vi) The automatic depressurization capability will be strengthened (the ADS will be activated by the signal "Low reactor water level L1 + 10 minutes + RHR pump in operation" (the logic is added to four valves) as a measure for the case in which the high pressure coolant injection system loses its function and the reactor pressure vessel cannot be depressurized.

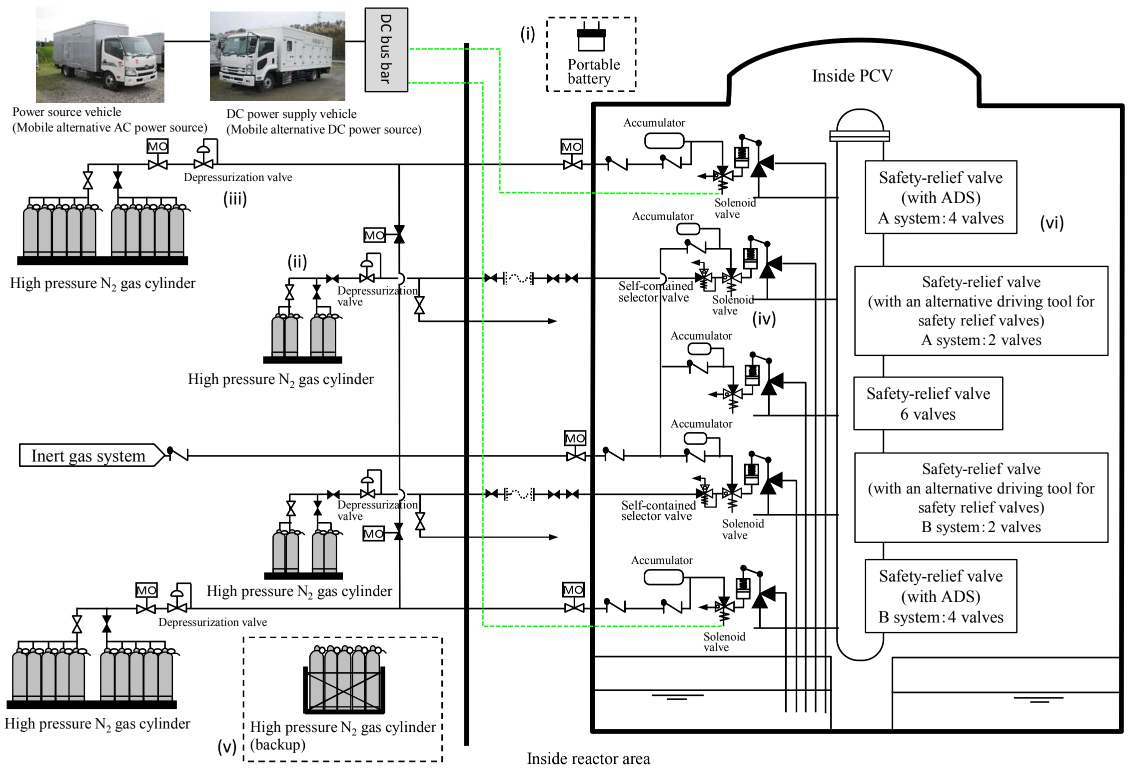


Figure 14 Overview of safety measures being taken at the Kashiwazaki-Kariwa Nuclear Power Station

## 8 Conclusion

The operating conditions of Unit-2 SRVs were examined based on the changes of reactor pressures and PCV pressures as well as dynamics. Consequently, as discussed in Item 7, it was confirmed as important: to secure the power source for solenoid valves; to secure nitrogen gas feed pressures; and to mitigate nitrogen gas leaks from lines. Although some unknown matters remain in the operational conditions of individual SRVs, the currently conceivable causes of inoperable SRVs can be solved by the safety measures being explored. These measures will improve the SRV operating credibility and can be concluded to be appropriate.

## 9 Reference

[1] Fukushima Nuclear Accident Analysis Report Appendix-2, Tokyo Electric Power Company, June 20, 2012