# Additional examination of station black-out due to tsunami

## 1. Introduction

Relationships between the tsunami arrival time and loss of power sources have been examined and reported in Attachment Earthquake-tsunami-1. In the report, the loss of power was estimated to be attributable to tsunami from the following reasons. The emergency AC power equipment of each unit continued working as intended even after the main shock and all these power sources were lost later in a limited time interval. This fact hints at a likelihood that the power sources were lost due to a certain common cause. The common cause over a wide area of the power station could be the earthquake and tsunami. Earthquakes would be excluded from the common cause, because no aftershocks were recorded at the time of power losses. On the other hand, a consistency was noted between the timings of tsunami arrival at the plant site and the timings of loss of functions of power supply systems, from the analyses of wave height meter records, continuous photographic information of tsunami arrival to the site and the plant data. From these reasons, the tsunami is believed to have caused the loss of functions of emergency power sources.

Most experts involved in the accident analyses share the view that the tsunami is the root cause of emergency AC power equipment losses (station black-out). On the other hand, however, other experts still argue that the earthquake could have been the root cause of the emergency AC power equipment losses. That opinion is based on the grounds that a relationship was not yet clarified between the tsunami inundation process and the emergency power losses. The Technical Committee on Safety Management at the Nuclear Power Plants in Niigata Prefecture also had a view that investigation was still insufficient and should be continued on the ground “the power might have been lost upon inundation, but the inundation process of emergency AC power equipment has not been well clarified” [1]. Thus, this study has been conducted on the correlation between the tsunami inundation process and emergency AC power equipment losses for strengthening the theory of the tsunami being the root cause of emergency AC power equipment losses (Common/Issue 14).

| Refer to Chapter 9 of the Main Body of Progress Report for the expression of O.P. |
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## 2. Method of examination, locations of equipment and the timings of the emergency AC power supply losses

### 2.1. Method of examination

Three possibilities can be considered as the cause for the emergency AC power losses due to tsunami inundation: ① Electrical accident on bus bar; ② Lockout relay activation of emergency diesel generators (D/Gs); and ③ Problems of D/G control system.

[Possible Cause ①: Electrical accident on bus bar]

In electrical systems, powers are distributed to individual loads (systems) from power sources via power distribution panels. Bus bars are the electrical circuit lines which distribute power to power distribution panels or loads in the downstream. Circuit breakers, a kind of switch, are installed between the power source, power distribution panels and individual loads. These circuit breakers are used to alter electrical circuit configurations, connect or disconnect loads, or isolate a circuit when needed, for instance in an unusual event. If an electrical anomaly occurs in an electrical circuit, the upstream circuit breaker closest to the anomalous point is opened and isolates the point from the circuit in order to prevent impact propagation. If an anomaly occurs in the emergency AC power bus bars, the D/G circuit breaker opens between the D/G and the emergency high-voltage power distribution panel (metal-clad gear, hereafter simply M/C) and the power supply to the bus bar stops.

[Possible Cause ②: Lockout relay activation]

A D/G lockout relay is a tripping circuit to shut down a D/G when an anomaly occurs concerning D/G engine operation or an electrical anomaly occurs on the generator. When the lockout relay is activated, the D/G circuit breaker opens, the D/G stops its operation, and the power supply to the bus bar stops. This group also contains a case that the tripping circuit is formed, and the D/G circuit breaker is opened or the D/G operation stops when the relay contacts in the M/C panel or D/G control panel are unintendedly energized by inundation.

[Possible Cause ③: Problems of D/G control system]

If problems in the D/G control system prevent normal D/G operations and power cannot be supplied, the power supply to the bus bar stops even when the D/G circuit breaker does not open.

Consequently, if the power equipment is inundated, these incidents due to causes ① to ③ can occur by ground shorts, circuit shorts, energization of contacts or other electrical problems.

It is certainly not easy to specify the detailed timings of inundation of respective power equipment. But theoretically, the power equipment in the upper stream side of the tsunami path should be inundated before the power equipment in the downstream side. In other words, the inundation timings of each piece of power equipment should have correlations with the length of the tsunami path to that power equipment. If correlations are noted between the tsunami path lengths to each power equipment location and the timing of power loss of that power equipment, the likelihood of tsunami causing power losses would be strengthened. With this background, relationships were analyzed between the tsunami inundation path lengths to the power equipment locations and the power loss timings, with three possible causes ① to ③ above being taken into account.

## 2.2. Locations of emergency AC power equipment and estimation of tsunami inundation path lengths

### 2.2.1. Locations of emergency AC power equipment

Figure 1 shows building locations of each unit, seawater pump locations and tsunami run-up height assumed, while Figure 2 shows locations of power equipment of each unit and main tsunami penetration paths assumed. The emergency AC power equipment, D/G and M/C, were housed in turbine buildings (T/Bs) of each unit. The D/Gs (Line A: D/G1A, 2A, 3A and 5A, and Line B: D/G1B, 3B and 5B) were housed in the T/B Floor B1. The M/Cs of Unit-1 (Line A: M/C1C and Line B: M/C1D) were located near the large component receiving dock entrance on Unit-1 T/B Floor 1, and other M/Cs (Line A: M/C2C, 3C and 5C, and Line B: M/C2D, 3D and 5D) were located on T/B Floor B1. Exceptionally, D/G2B and M/C2E of Unit-2 Line B were located on Floor 1 and B1 of the Common Pool Building (CP/B), respectively. The ground elevations were O.P.+10m for Unit-1 to -4 buildings and CP/B, and O.P.+13m for Unit-5 and -6 buildings.

The seawater pumps including those of the emergency diesel generator seawater systems (hereafter DGSW) for cooling D/Gs were located in the “Seawater Pump Area” so marked in Figure 1 for each unit. Their elevation was O.P.+4m. No operation records of DGSW pumps are available, but circuit breaker signals are left for Unit-1 PCV cooling seawater system (CCSW) pumps, Unit-2 residual heat removal system seawater system (RHSW) pumps and Unit-5 residual heat removal system seawater system (RHRS) pumps. Assuming these pumps tripped upon inundation by tsunami, other seawater system pumps would have tripped at similar timings upon inundation.

### 2.2.2. Estimation of tsunami inundation path lengths

The largest tsunami waves, which are the possible cause of loss of power sources, are considered to have arrived at the plant site almost from the right front, based on the investigations to date (Attachment Earthquake-tsunami-1 and Reference 3). Therefore, it was assumed that the tsunami waves had reached the whole plant site without big time differences. Further, buildings of each unit stood at different locations and elevations when viewed from the sea. The seaside road (Elevation O.P.+10m) in parallel with the seacoast in front of Units-1 to -4 was chosen as the reference position and elevation 0m.

In Figure 2, the triangle marks pinpoint the location of tsunami entrances to the buildings being interpreted from the building investigations to date, while arrows indicate main tsunami inundation paths assumed. The figure illustrates the paths considered as shortest. The tsunami inundation path length to a power equipment item was estimated by adding the distance from the reference point to the tsunami entrance point assumed, and the shortest distance from the entrance point to the power equipment (the floor elevation difference being considered) along the arrow-marked paths, the distances being measured on the drawings. In the path length calculation, the distances from the reference position to the mountain side were treated as plus and to the seaside as minus, while elevation differences on the ground or in the building were treated as plus or minus distance differences as appropriate.

## 2.3. Timings of emergency AC power equipment

The timings of emergency AC power equipment losses were derived from alarm records and other information, while the timings of circuit breaker activation and values of emergency AC power equipment voltage and currents were derived from the records of transient recorders and process computers. Unit-4 was excluded from the evaluation in detail, because no records were available such as those of alarm records, since the process computer and transient recorder were out of service for replacement during the unit outage for periodic maintenance at the time of the earthquake. Only alarm records of Unit-2 and -5 were calibrated against time signals, but the timings of reactor scram due to the earthquake were recorded at all units. Thus, corrections of time of alarm records were conducted as follows: the scram signal timing recorded of Unit-2 Line B reactor scram was considered as the reference scram timing because it was earliest in scram signals of Unit-2 and -5; time of other alarm records was calibrated comparing the preceding scram signal of alarm records of other units to this reference scram timing [2].

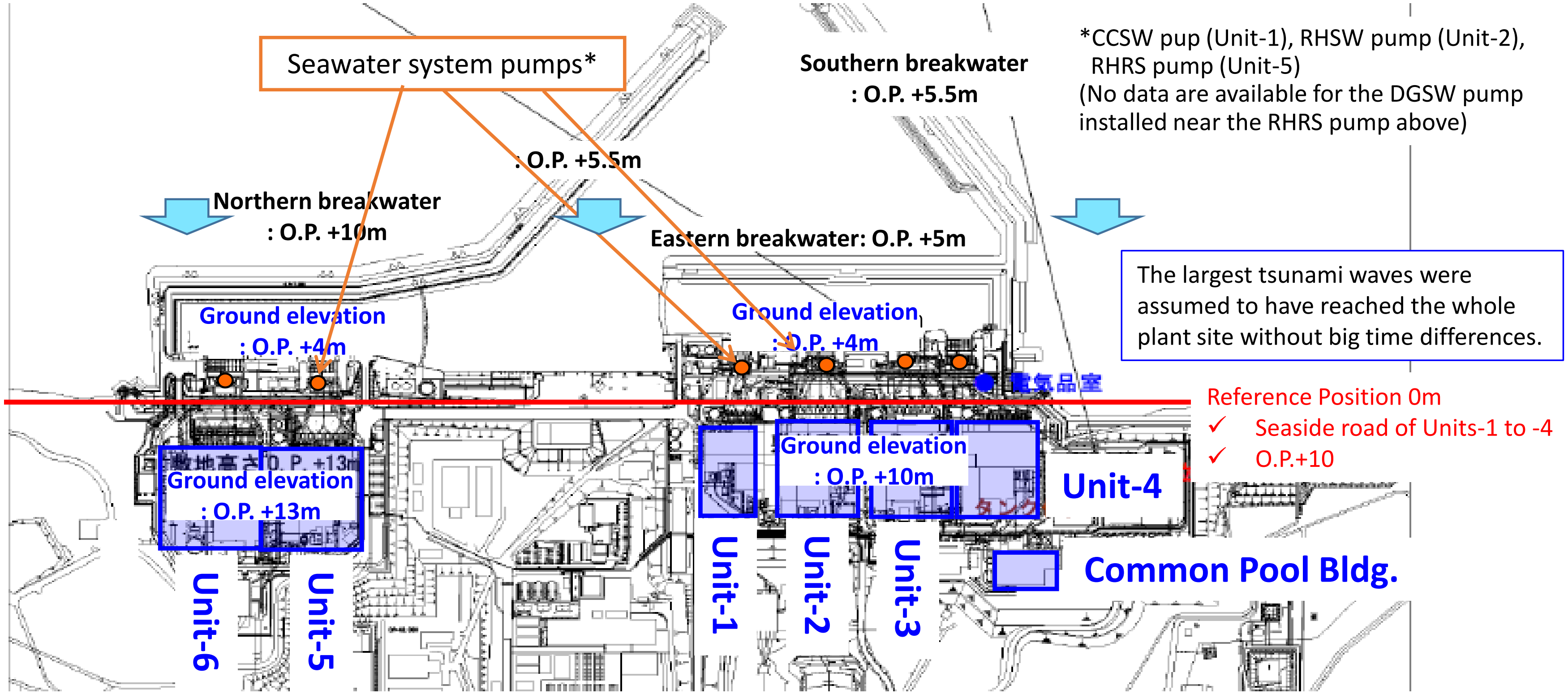


Figure 1 Locations of unit buildings and seawater pumps, and tsunami run-up heights assumed

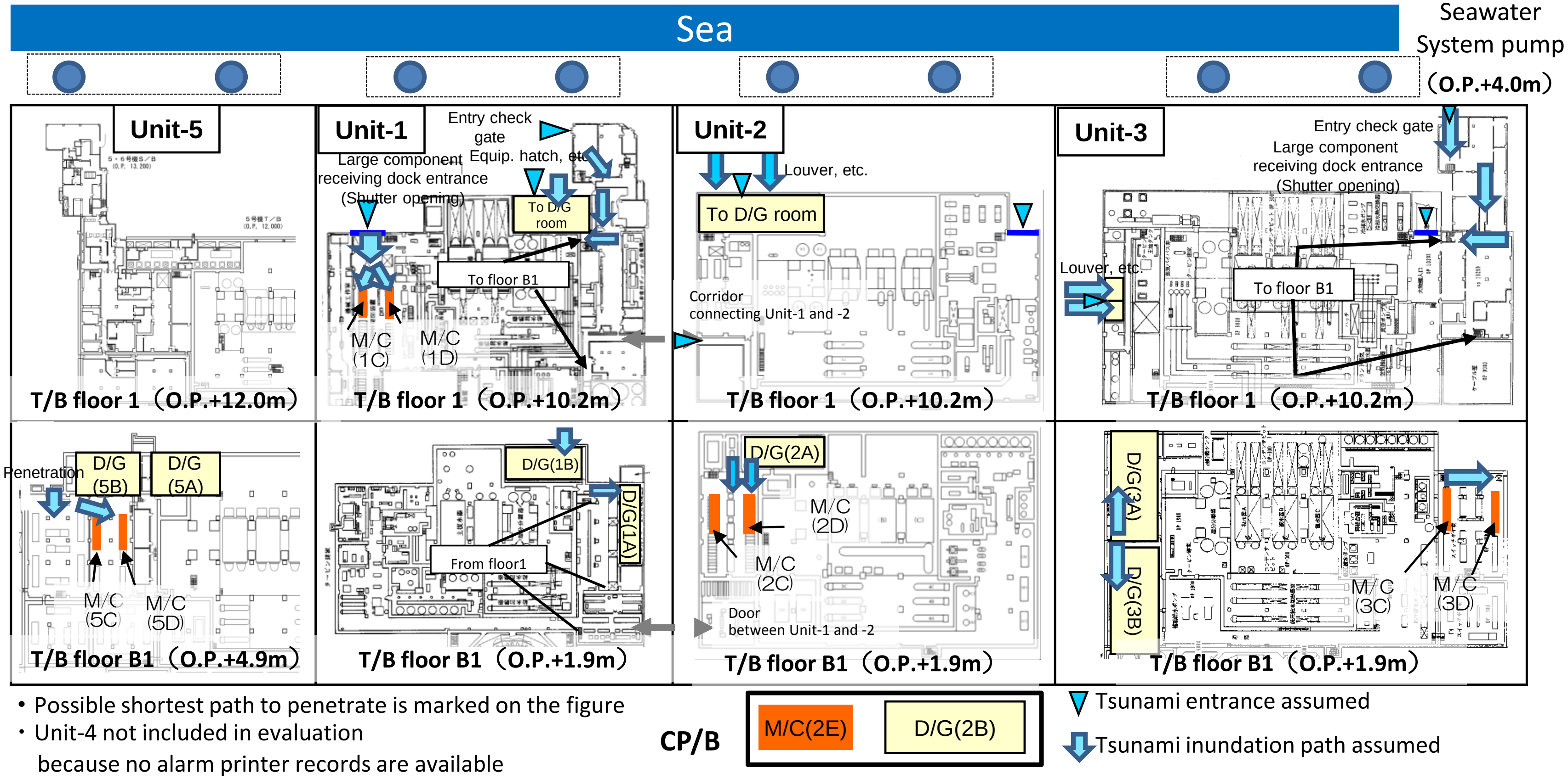


Figure 2 Locations of power equipment of each unit and main paths assumed of tsunami inundation

## 3. Examination results and analyses

### 3.1. Relationship between the inundation path lengths and function loss timings

Figure 3 illustrates correlations between the tsunami inundation path lengths to power equipment and function loss timings of power supply systems. Function loss timings at Unit-1 were derived from the transient recorder records. Since all the records at the time were one-minute cycle data, power supply functions are considered to have been lost during the time width of marks in the figure. The D/G1A, 1B and M/C1D are not marked in the figure, because their function loss timings could not be specified: their voltages were kept at the value at 15:36:59, just before the transient recorder stopped recording and no more data are available after that. But the transient recorder records indicate that the emergency power equipment of Line A was lost first due to trouble in the M/C (the loss of emergency AC power equipment at Unit-1 is analyzed in detail in the NRA report "Interim Report on the Analyses of Nuclear Accidents at the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company" (hereafter the "Interim Report on Accident Analysis") [3]). The function loss timing could not be specified for the Unit-2 M/C2E housed in the CP/B, either, since no alarm records are available. Although function loss timings were partly not specifiable, as mentioned above in this paragraph, correlations were analyzed between the tsunami inundation path lengths and function loss timings, because the overall trend between them could have been grasped based on the function loss timings mostly specified.

Figure 3 shows that seawater pumps lost their functions first followed by power equipment of D/G and M/C. The overall trend in the figure of "upper right to lower left" indicates the trend "the longer the inundation path lengths, the later the function loss timings." From these observations, function losses of power equipment are estimated to have been caused by the tsunami run-ups and inundation one after another.

Meanwhile, when the figure is read in more detail, power supply functions of Unit-1 were generally lost fairly early and the function loss timings of Unit-2 seem somewhat inconsistent with the overall trend. Thus, the behaviors of each unit were analyzed in more detail mainly for the discussion of these causes.

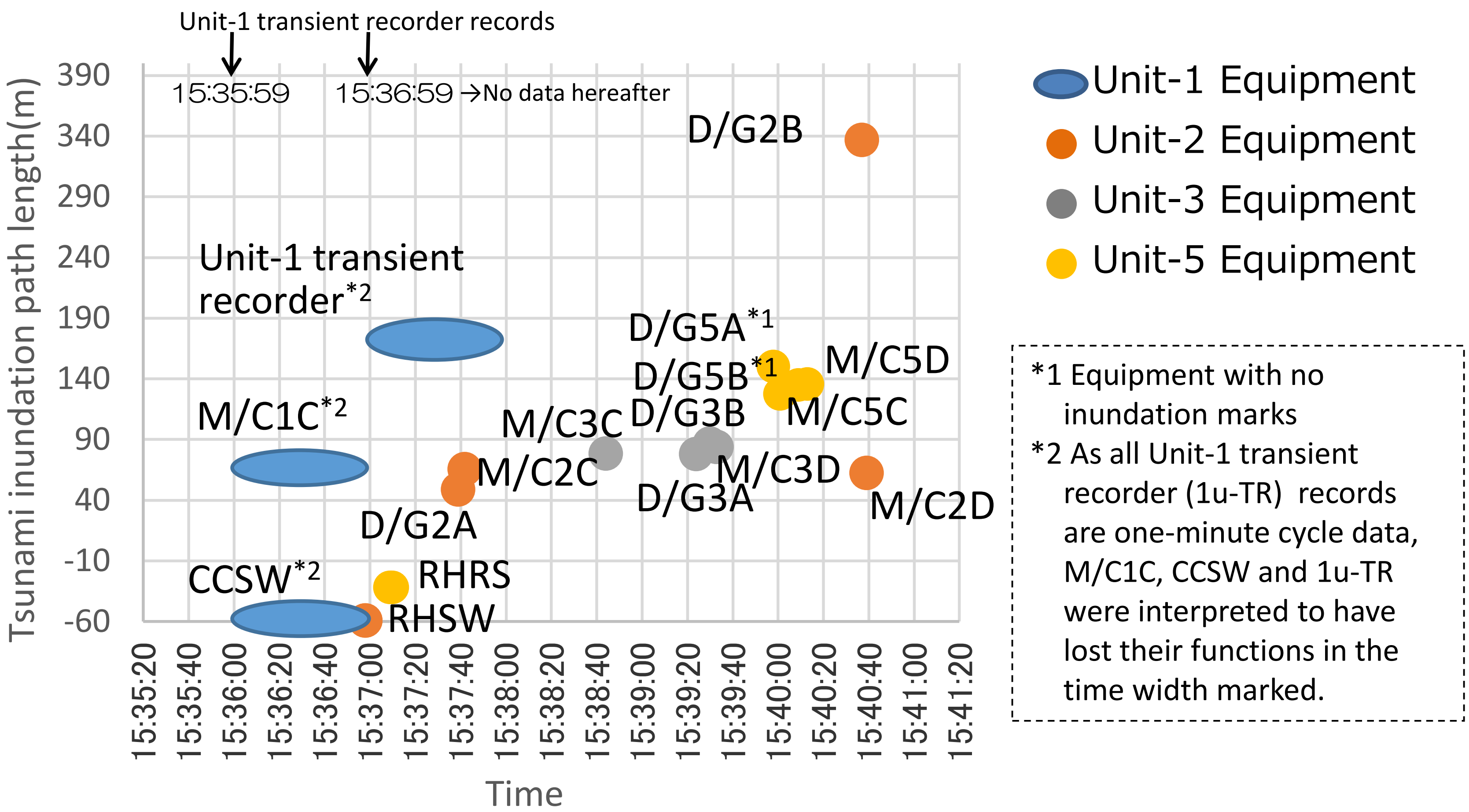


Figure 3 Relations between tsunami inundation path lengths to power equipment and timings of loss of functions

3.2. Analysis of function loss timing at Unit-1

Figure 4 illustrates a tsunami inundation image for Unit-1 T/B. The drawing depicts the tsunami inflow from the reference position to the power equipment along the inundation path assumed.

The upper part of the figure shows that the large component receiving dock entrance stands just before the M/C. The entrance had a protection door and shutter. Usually, they both would be closed, but the door of Unit-1 was open at the time of the tsunami arrival [2]. On that day, the protection door had been opened for scheduled work. The door was left open, upon evacuation of the workers immediately after the earthquake, until the time of the tsunami arrival. If the protection door had been closed, the tsunami flooding might have been controlled to a certain degree, but with the door being left open, the shutter was deformed and broken by the tsunami and drifting wreckage, and inflow of a large amount of seawater was allowed. Consequently, the M/C located near the large component receiving dock is considered to have been inundated at an earlier timing in the overall trend between the tsunami inundation path lengths and function loss timings.

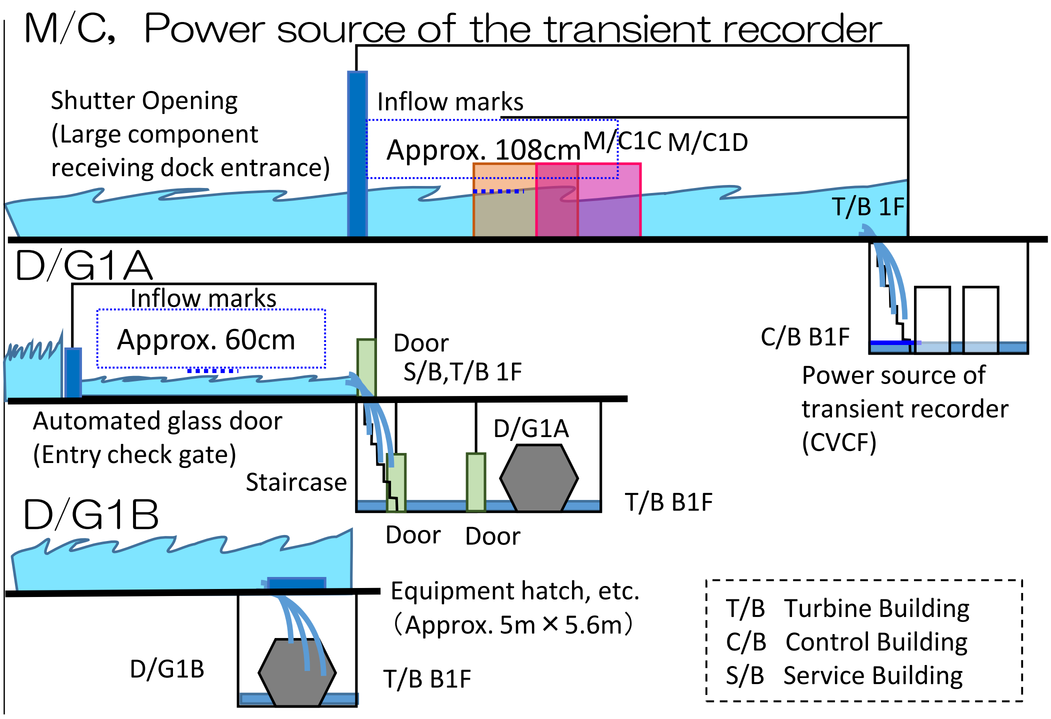


Figure 4 An image of tsunami inflow into Unit-1 turbine building

Figure 5 gives the transient recorder data of Unit-1 power supply systems. No problems would have occurred to the D/G control system, because the D/G1A and 1B kept their voltages at the value at 15:36:59, just before the time when the transient recorder stopped recording (Possible Cause ③ excluded). Further, no electrical accident would have occurred to the bus bars, because the bus bars of M/C1C and 1D were not flooded (Possible Cause ① excluded). On the other hand, concerning the M/C1C an auxiliary relay contact located below the inundation mark might have been flooded and energized, thus the D/G circuit breaker is considered to have been activated (Possible Cause ② cannot be excluded). The M/C1C is considered to have lost its functions at an earlier timing.

The transient recorder received its power from a constant voltage constant frequency (CVCF) unit housed in the Control Building B1 floor. It is estimated that this CVCF unit was flooded, lost its functions and caused the function loss of the transient recorder. The transient recorder is considered to have lost its functions at an earlier timing in the overall trend, since no barriers had existed to prevent a large amount of tsunami inflow on the path from the large component receiving dock entrance to the cell housing the UPS unit.

As seen above, the reason that the power equipment of Unit-1 lost their functions at an earlier timing in the overall trend can be considered that, because the protection door had been kept open at the large component receiving dock, the shutter had been greatly deformed and broken by the tsunami and drifting wreckage, allowing a large amount of tsunami inflow.

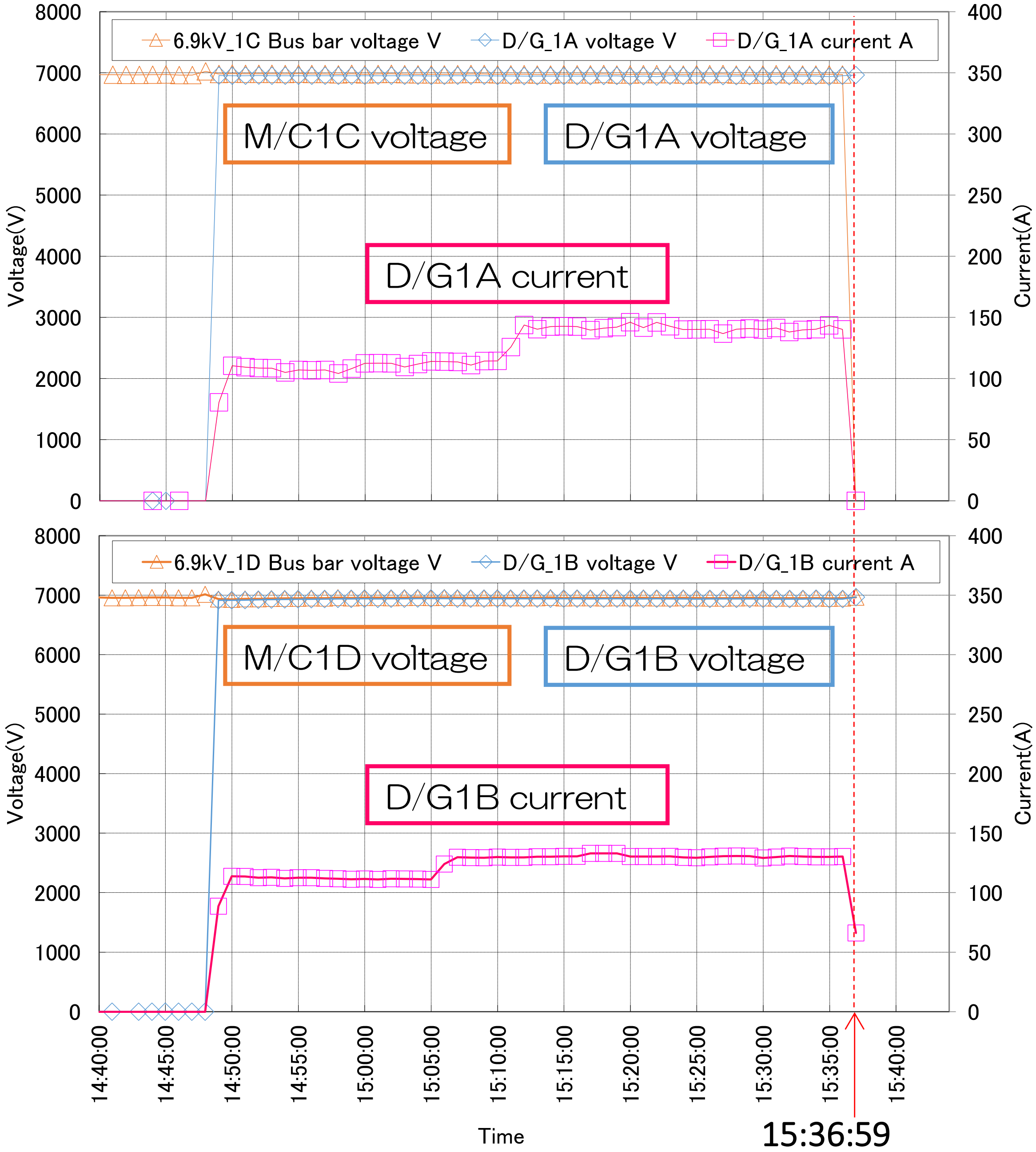


Figure 5 Transient recorder records of Unit-1 power supply systems (Top: Line A, Bottom: Line B)

3.3. Analysis of function loss timing at Unit-2

As was seen in Figure 3, the Unit-2 Line A systems (D/G2A and M/C2C) lost their functions relatively early, while the Line B systems (D/G2B and M/C2D) gave relatively inconsistent correlations between the path lengths and function loss timings in the overall trend. To reveal the cause, the process computer data were analyzed in detail. Figure 6 presents a schematic diagram of emergency AC power equipment of Unit-2 Line A and Line B. In Line A, both D/G2A and M/C2C were housed in the T/B and connected to each other via the circuit breaker D/G2A (this configuration is the same as D/G1A, 1B, 3A, 3B, 5A and 5 B of other units). The M/C is connected directly to its loads or to the low voltage power distribution panel power center (P/C in the figure) after voltage reduction. In Line B, on the other hand, the D/B2B and M/C2E are housed in the CP/B and connected via the D/G2B circuit breaker. The M/C2E is further connected to the M/C2D in the T/B via a circuit breaker.

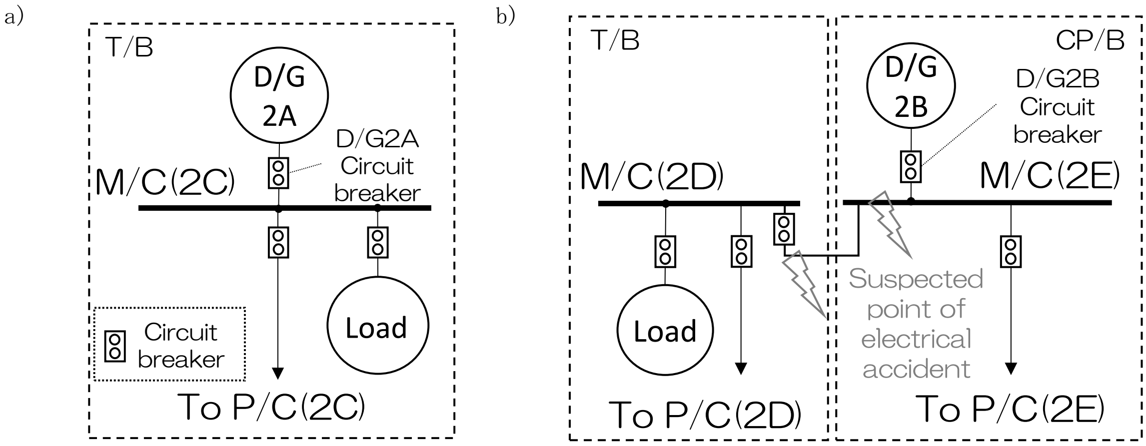


Figure 6 Schematic diagram of Unit-2 emergency AC Power equipment
(a: Line A, b: Line B)

(1) Scenario of Unit-2 Line A Function Loss

Figure 7 gives the process computer data of Unit-2 systems. On Line A, the RHSW circuit breaker opened at about 15:37:00 and the current of D/G2A dropped sharply. The D/G2A circuit breaker opened at about 15:37:40 and the D/G2A current and D/G2A and M/C2C voltages dropped sharply down to zero (Possible Cause ③ excluded). If the D/G supplied an electrical accident-caused current, it should be a spike-shape current, but no such spike-shape currents are noticeable. Therefore, no electrical accident occurred to the D/G or M/C (Possible Cause ① excluded). On the other hand, the D/G2A showed a rise in its current from about 15:36:20 to about 15:37:00, and the RHSW circuit breaker opened at about 15:37:00. This is presumed to indicate that the RHSW pump was overloaded by the tsunami inflow and tripped. Consequently, it is highly possible the DGSW pump, which had been installed at the same seawater pump area, tripped at a similar timing. When the DGSW pump trips, the D/G lockout relay is activated 60 seconds later by the pump discharge pressure “low” signal and the D/G circuit breaker opens (the air-cooled D/G2B has no such trip logic). The D/G2A circuit breaker opened at about 15:37:40. If the DGSW pump is assumed to have tripped sometime between about 15:36:20 and about 15:37:00 when a rise is observed in the D/G2A current, the sequence is roughly consistent with the trip logic. This means, it is highly probable that the DGSW pump trip led to the D/G trip, thus losing the Line A power source (Possible Cause ② cannot be excluded). In this situation, the timing of function loss becomes earlier than the timing derived from the inundation path length. A different scenario of Possible Cause ② may hold, in which terminals in the D/G control panel are energized upon flooding, activating the lockout relay (Possible Cause ② cannot be excluded). In this situation, the function loss timing should have coincided with the timing derived from the inundation path length. It is not possible to specify which scenario actually took place because no direct records are available to identify the D/G trip cause. But it seems probable that the DGSW pump trip caused the D/G trip, losing the Line A power source, because the RHSW pump actually tripped and the timing of function loss was early.

(2) Scenario of Unit-2 Line B function loss

On Line B, the D/G2B circuit breaker opened at about 15:40:40, and the D/G2B current and the M/C2D voltage dropped sharply down to zero. The D/G2B voltage kept its normal value for some time after the quick recovery from a short drop at the time of the D/G2B circuit breaker being opened. This shows that the D/G2B itself kept its functions for some time even after its circuit breaker had opened (Possible Causes ② and ③ excluded). At about 15:40:40, the D/G2B recorded a spike-shape current, showing that the D/G supplied an electrical accident-caused current at that timing. It was presumed therefore that the function loss of Line B was attributable to M/C trouble, in particular to an electrical accident at the suspected accident point in Figure 5 on the side of the M/C2E or M/C2D, which had opened the D/G circuit breaker (Possible Cause ① holds). It should be noted that the M/C2D housed in the T/B is likely to have been flooded, from the viewpoint of the tsunami inundation path length in the current study. As is shown in Figure 8, an image of tsunami inflow into Unit-2 T/B, there is a zone-isolation door that must be passed through by the tsunami inflow entering the building from the D/G louvers and other openings to reach the M/C2D cell. The function loss timing due to this tsunami inflow path will be delayed more than the timing assumed from the inundation path lengths.

From the consideration above, it can be concluded that there is a scenario which explains why the Unit-2 power supply systems showed some inconsistency in the overall trend of correlations between the function loss timings and tsunami inundation path lengths.

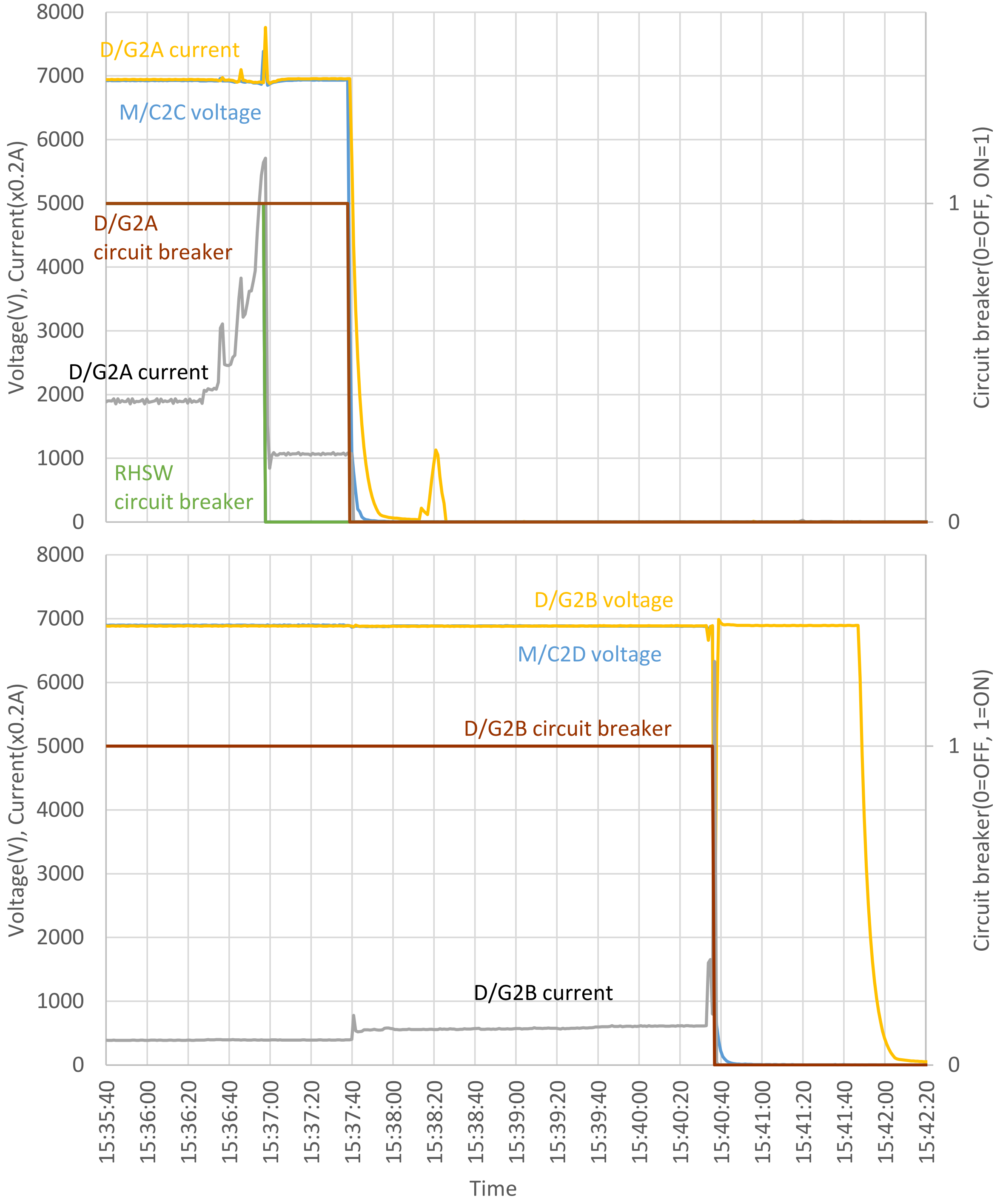


Figure 7 Unit-2 Process computer records (Top: Line A, Bottom: Line B)

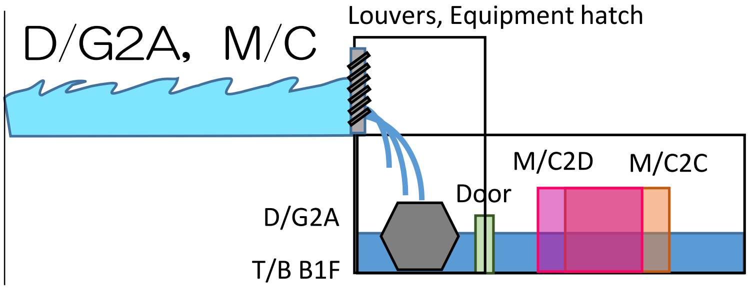


Figure 8 An image of tsunami inflow into Unit-2 turbine building

3.4. Analysis of function loss timings at Unit-3

As shown in Figure 2 and Figure 3, the tsunami inundation path lengths to D/G3A, 3B, M/C3C and 3D are not very different, although they are installed at different locations and their assumed tsunami inundation paths are different. Nevertheless, Line A lost its power supply several tens of seconds earlier than Line B. Possible scenarios behind this difference were examined. Figure 9 provides the transient recorder records of Unit-3 power supply systems. The time was so calibrated that the timing of “D/G Circuit Breaker OFF” recorded by the transient recorder coincided with the timing of “Diesel Generator OFF” recorded in the Unit-3 alarm records, which had been calibrated against the Unit-2 process computer.

On Unit-3 Line B, the D/G3B circuit breaker opened at about 15:39:30 and the D/G3B current and voltage dropped sharply to zero (Possible Cause ③ excluded). No electrical accidents occurred to the D/G and M/C, since no spike-shape currents are recorded (Possible Cause ① excluded). It is presumed, therefore, that the terminals in the D/G control panel had been energized by the DGSW pump trip or inundation, as having occurred to Unit-2 Line A, and the D/G lockout relay had been activated.

On Unit-3 Line A, on the other hand, the D/G3A current and voltage dropped first sharply to zero at about 15:38:40 and then the D/G circuit breaker opened at 15:39:24, that is, the D/G stopped before its circuit breaker opened. It is unlikely that the lockout relay caused the loss of functions (Possible Cause ② excluded). No electrical accidents occurred to the D/G and M/C, since no spike-shape currents are recorded (Possible Cause ① excluded). Consequently, some unknown anomaly occurred to the D/G control system, terminating power supply to the bus bars (Possible Cause ③ cannot be excluded).

A possible scenario of the D/G3A having stopped is that seawater flowed into the D/G cylinder through the intake silencer. Figure 10 shows the installation location of the silencer, and Figure 11 illustrates the operation of a 4-cycle diesel engine. The D/G3A silencer was installed on the seaside at a lower elevation, as can be seen in Figure 10. It is possible seawater flowed to the inside of the D/G engine through the silencer. If this seawater reached the cylinder via the intake pipe, as shown in Figure 11, it would have caused insufficient combustion in the diesel engine. Furthermore, if the seawater reached other cylinders, the D/G rotating speed would have gradually dropped, the voltage would have dropped and eventually the D/G would have stopped. It should be noted that silencers of Unit-1 D/G1A and 1B, and Unit-2 D/G2A were also installed on the seaside at lower elevations, like Unit-3 D/G3A. The inundation path lengths to all these silencers are not very different. Therefore, the tsunami could have eventually flowed into the D/G cylinders of Units-1 and -2 as well. But it is unlikely that seawater, having flowed into the cylinders, stopped Unit-1 D/Gs and Unit-2 D/Gs, because their power supply was stopped earlier than Unit-3 Line A, and their voltage and current drop behavior is different from the unique behavior of Unit-3 Line A. It should also be noted that no seawater would have flowed into the silencers of Unit-3 D/G3B, Unit-5 D/G5A and 5B, because the silencer of Unit-3 D/G3B was installed at an elevated position, and those of Unit-5 D/G5A and 5B were enclosed by side-walls.

In summary, both Line A and Line B would have lost their power sources due to tsunami, but from different causes. This would explain the time difference of several tens of seconds in losing the power sources.

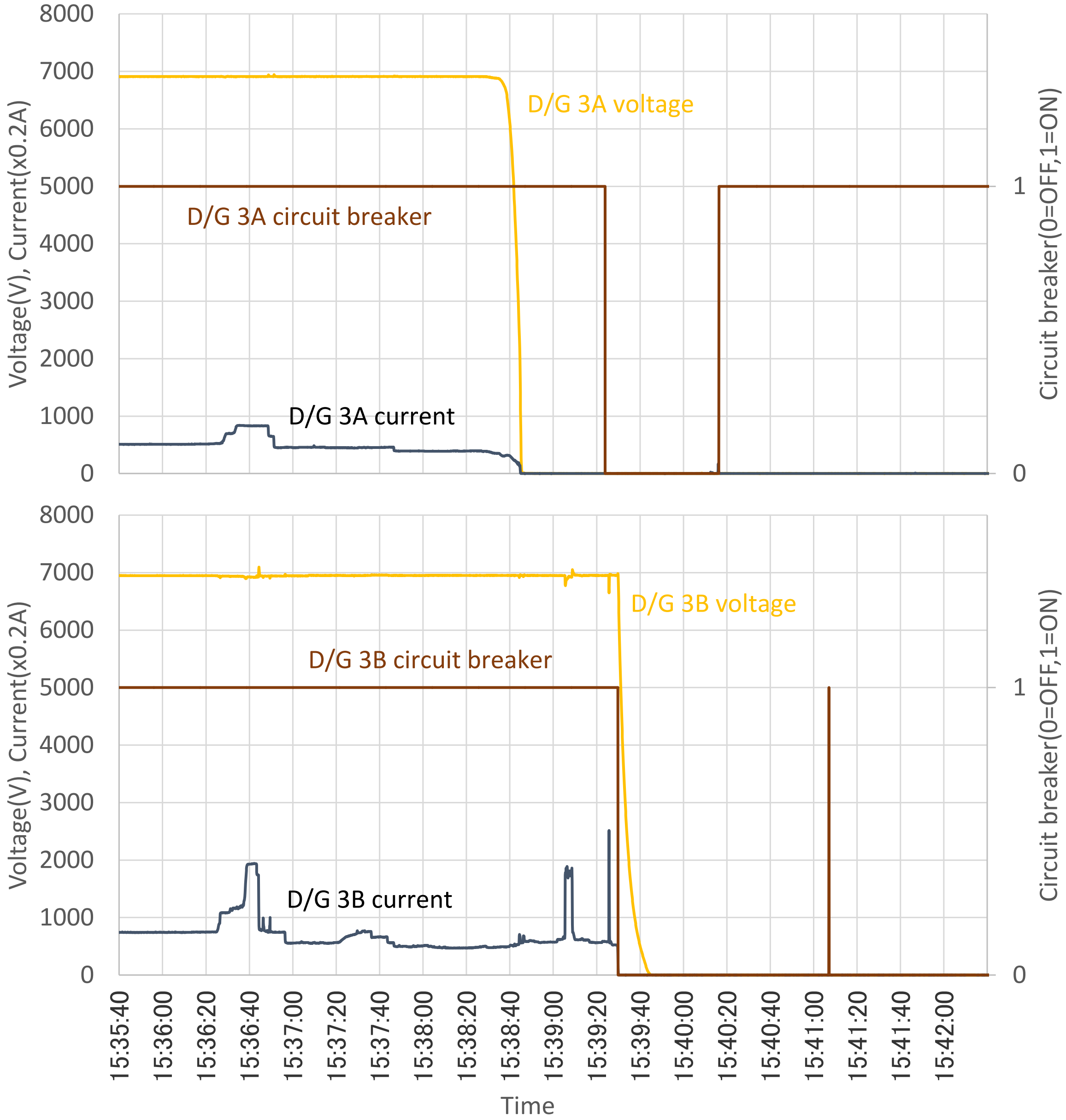


Figure 9 Unit-3 Process computer records (Top: Line A, Bottom: Line B)[1]

[1] D/G circuit breaker signals show changes after 15:40. It is understood that these changes do not represent the actual working conditions of the system, because the signals of the circuit breaker of the RHSWs also changed in the same time span, albeit they were not in service.

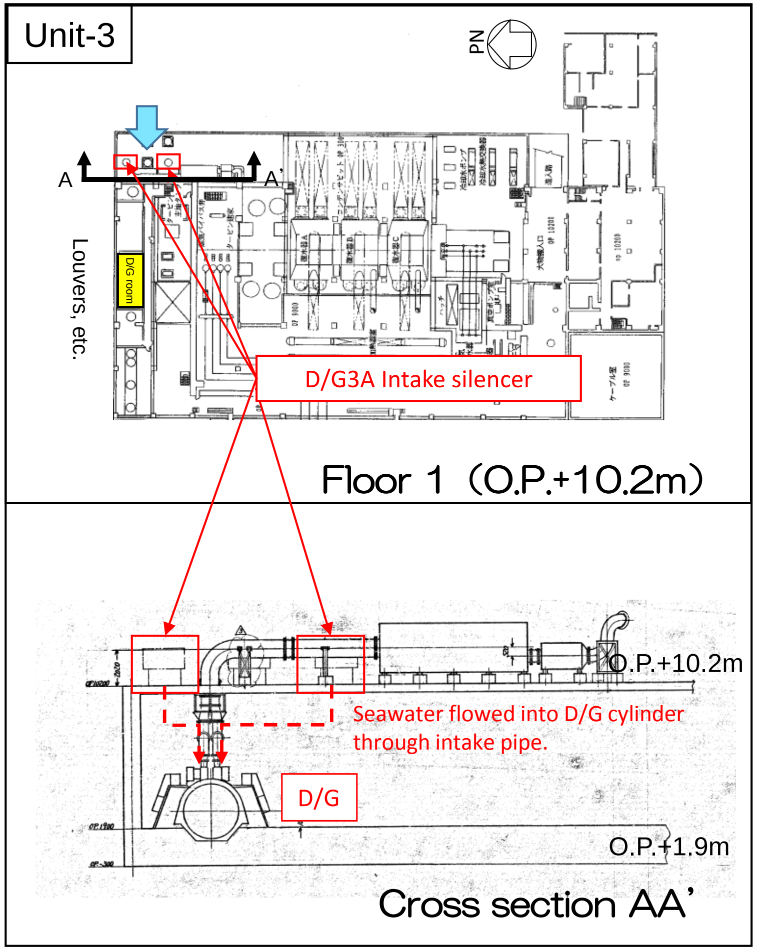


Figure 10　D/G3A Silencer position

(Top: T/B Plan view, Bottom: AA Cross-sectional view)

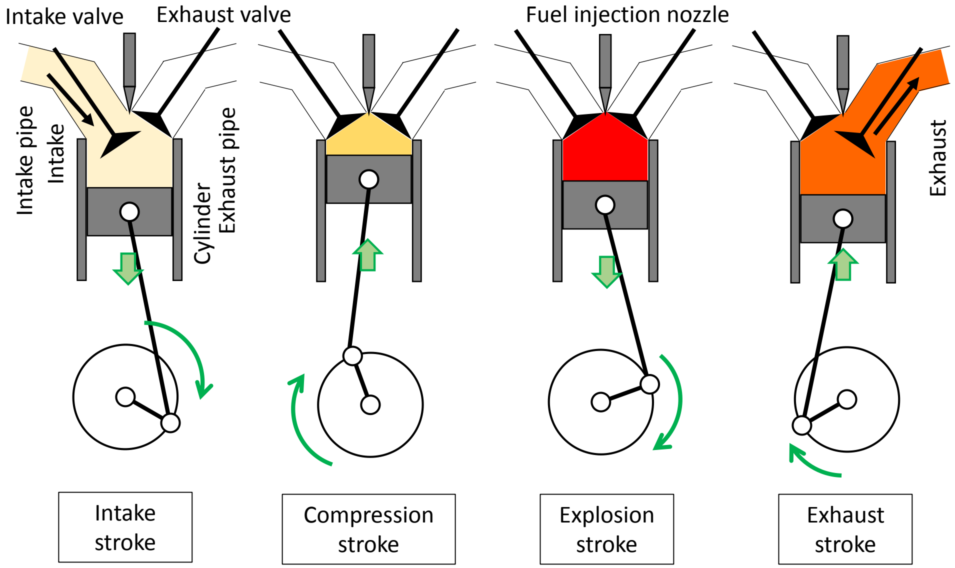


Figure 11　Operation of a 4-cycle diesel engine

3.5. Analysis of function loss timings at Unit-5

Figure 12 is an image of tsunami inflow into the Unit-5 T/B. The M/C5C and 5D were installed in the electrical equipment room of Floor B1, while the D/G5A and 5B were in the D/G cell on a slightly higher floor level than that of the electrical equipment room. D/G control panels were partly in the electrical equipment room. As shown in Figure 3, there is not much difference in tsunami inundation path lengths to the above power supply systems. It is unlikely that the power was lost by the flooded D/Gs, because no tsunami marks were left in the D/G cell. To reach the electrical equipment room, the tsunami is estimated to have flowed from cable penetrations via underground cable ducts, since tsunami marks could be recognized on the cable penetrations in the electrical equipment room. Even if the M/C main circuits were not flooded and did not lose bus bar voltages, the D/Gs could have lost their functions due to energized terminals in the D/G control panel when flooded.

Figure 13 gives the process computer data of Unit-5 power supply systems. Both on Line A and Line B, the D/G circuit breakers opened at about 15:40:00, and D/G currents, D/G and M/C voltages sharply dropped to zero (Possible Cause ③ excluded). No electrical accidents occurred to the D/G and M/C, since no spike-shape currents are recorded (Possible Cause ① excluded). Consequently, it is likely that the power was lost due to the activated lockout relay when the DGSW pump tripped or the terminals in the D/G control panel were energized upon flooding, as was the case in Unit-2 Line A and Unit-3 Line B (Possible Cause ② holds).

Thus, both Line A and Line B lost power due to the tsunami.

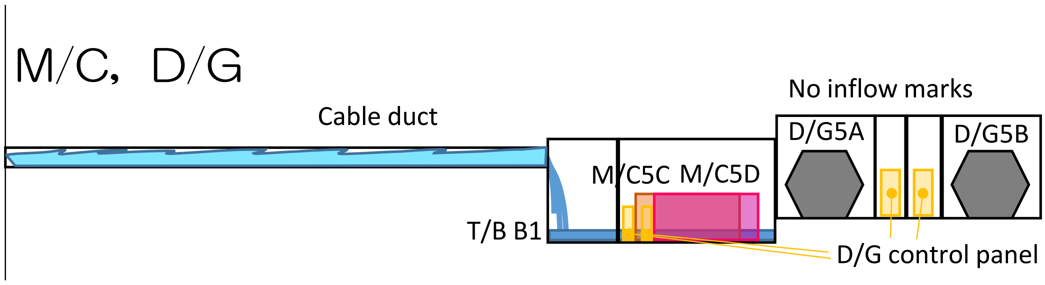


Figure 12 An image of tsunami inflow into Unit-5 turbine building

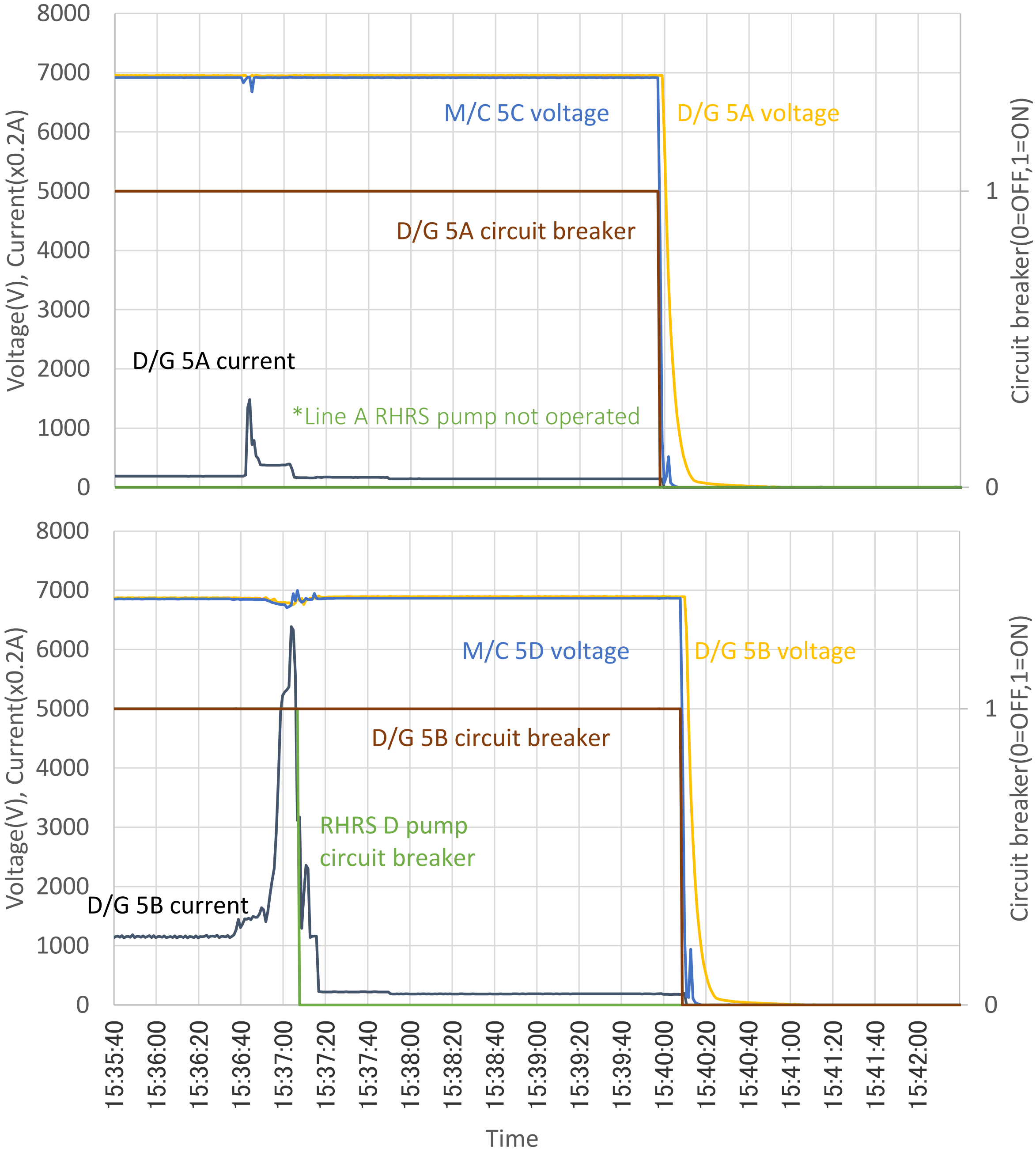


Figure 13 Unit-5 process computer records (Top: Line A, Bottom: Line B)

### 3.6. D/G lockout relay activation due to DGSW pump trips

A possibility has been mentioned that the D/G lockout relay activated by the DGSW pump trip might have caused power losses of Unit-2 Line A, Unit-3 Line B, and Unit-5 Line A and Line B. The D/G currents of all of them increased from about 15:36:20, and the Unit-2 RHSW circuit breaker and Unit-5 RHRS circuit breaker opened at about 15:37:00, both of which had been in operation and that fact was recorded. This indicates that the tsunami arrived at the coastline and the DGSW pump was overloaded after being flooded. In the case that the DGSW pump trips by overloads and the pump discharge pressure “low” is signaled, the D/G lockout relays have been set to be activated 10 seconds later at Unit-3, and 60 seconds later at Unit-2 and Unit-5. However, if the pump discharge pressure “low” were signaled at about 15:37:00, the D/Gs of Unit-3 and Unit-5 should have tripped earlier than the actual trip timings, i.e., the D/Gs tripped fairly later than the timings anticipated from the lockout relay setting. The reason therefore could be that the DGSW pump had tripped later, or the system pressure had been kept at a certain level, even after the DGSW pump trip, due to the tsunami water head or other reasons. The reason has not been identified. The lockout relays could be a cause of power losses as is mentioned in the current study, but it cannot be settled yet whether the pump discharge pressure “low” signal due to the DGSW pump trip triggered the lockout relay activation or the terminals in the D/G control panel being energized due to flooding triggered the lockout relay activation.

## 4. Conclusions

Correlations were analyzed between the tsunami inundation path lengths to respective power equipment and the timings of power losses, in order to supplement the theory that emergency AC power equipment had been lost due to tsunami. The study could confirm the theory to date that power equipment had been lost by the tsunami run-up and flooding of the equipment one after another, by confirming that the power equipment in the location with longer path lengths in the tsunami inundation path had lost their functions generally at a later timing. Concerning the power equipment, for which the correlation between the tsunami inundation path lengths to that power equipment and the timings of the power losses is somewhat inconsistent with the overall trend, the reasonable scenario could explain the inconsistency.

## 5. Implications of the lessons on safety measures

The experience of loss of emergency AC power equipment due to tsunami at the Fukushima Daiichi Nuclear Power Station highlights the importance of two fundamental matters as safety measures at nuclear power stations: one is to strengthen preparedness against external hazards including tsunami; and the other is to prepare for prevention of core damage even when such protective measures fail, and important systems lose their functions.

The TEPCO's Kashiwazaki-Kariwa Nuclear Power Station is tackling safety measures including the lessons above. For instance, preventive measures undertaken for an accident due to tsunami (Figure 14) include prevention of tsunami inflow to the site and buildings, water protection of the important equipment installation areas, securement measures against seawater in a back-rush, storage of transportable equipment at elevated positions, installation tsunami monitoring cameras and other means; and as measures undertaken to secure power sources (Figure 15) against loss of emergency AC power sources, air-cooled gas-turbine power generator vehicles, power supply systems for power distribution and other panels, and power supply vehicles are being deployed at elevated positions, spare batteries are being stored in reserve, and DC power supply systems are added on the elevated floors of reactor buildings.

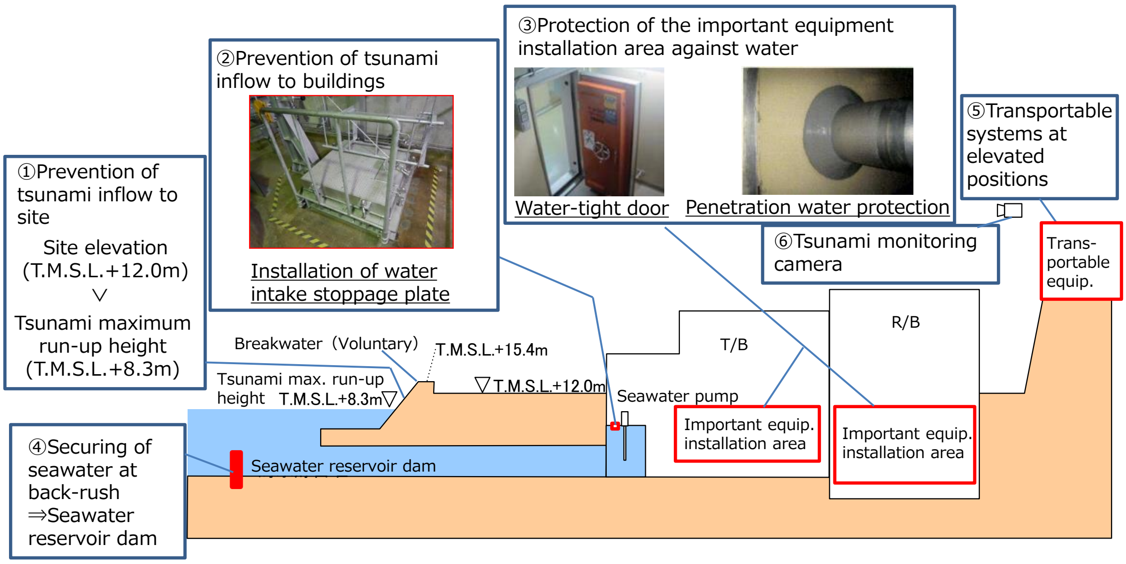


Figure 14 Image of anti-tsunami measures at Units-6 and -7 of the Kashiwazaki-Kariwa Nuclear Power Station

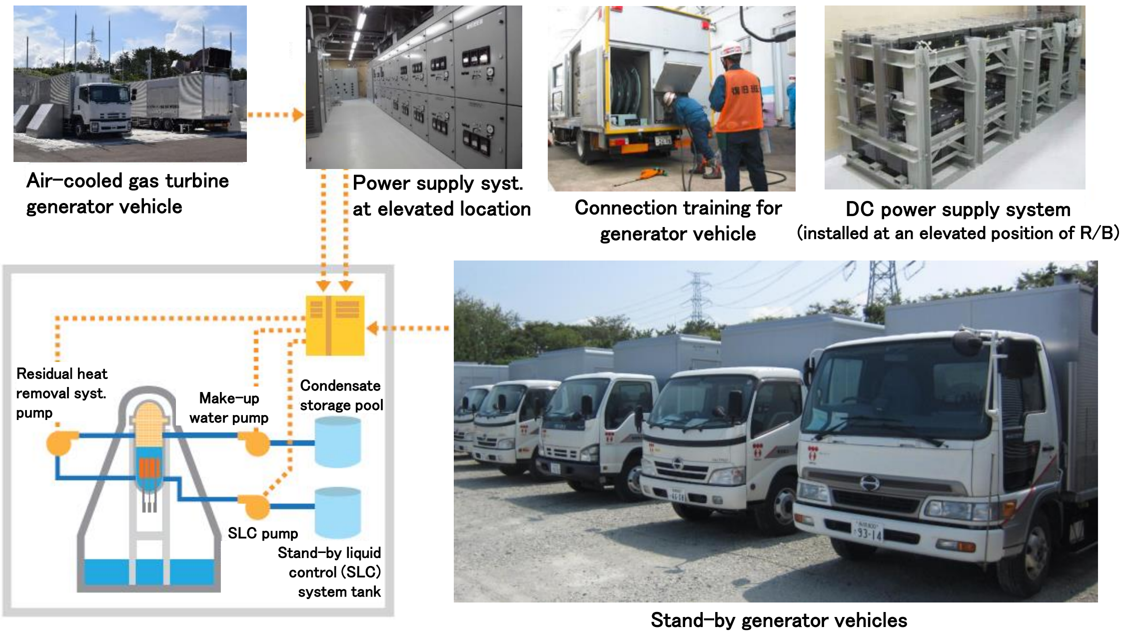


Figure 15 Outline of measures for securing emergency power sources at Kashiwazaki-Kariwa Nuclear Power Station

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Note) The study results are summarized in the November 2017 issue of ATOMS, published by the Atomic Energy Society of Japan.