MAAP Code-based Analysis of the Development of the Events at the Fukushima Daiichi Nuclear Power Station

March 12, 2012

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東京電力

TEPCO

Contents of This Report

1. Introduction

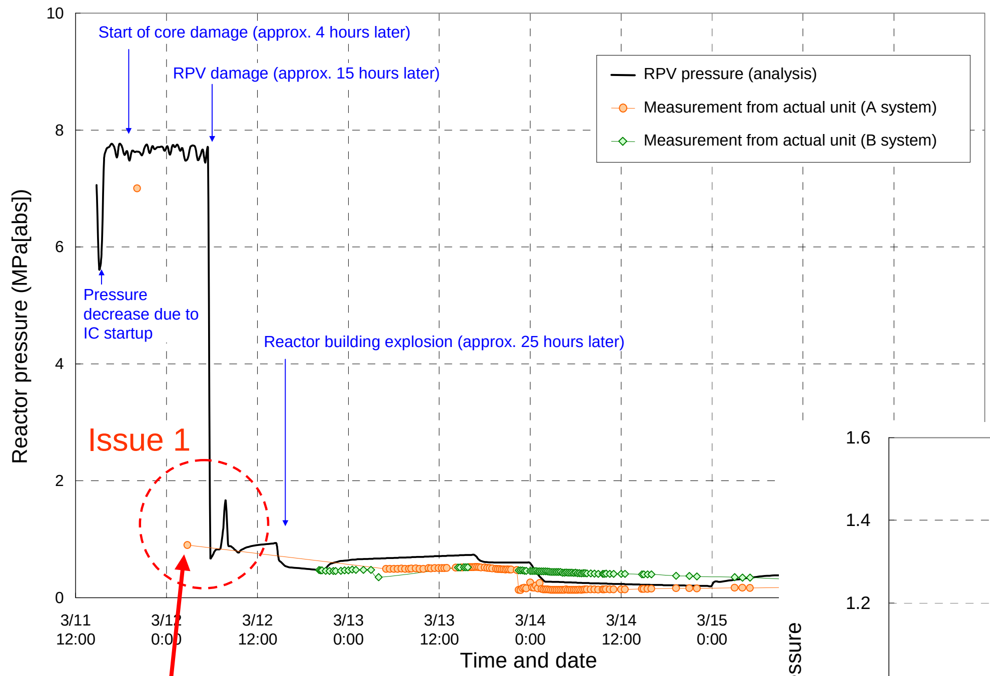
- On May 23, 2011, we conducted a MAAP-code-based plant-state analysis based on information that had been obtained on the state of the plant and how the plant had been operated immediately after the earthquake, and made the analysis results public.

- Because there were inconsistencies at that point between the observation data and the analysis results, we have continued conducting hearings from operators and on-site surveys since the publication in order to obtain more detailed information on the plant.

- In parallel with the hearings and surveys, we have developed, from data taken from the actual units in the plant and the MAAP analysis results, plant-state presumptions that allow the course of the accidents to be rationally accounted for.

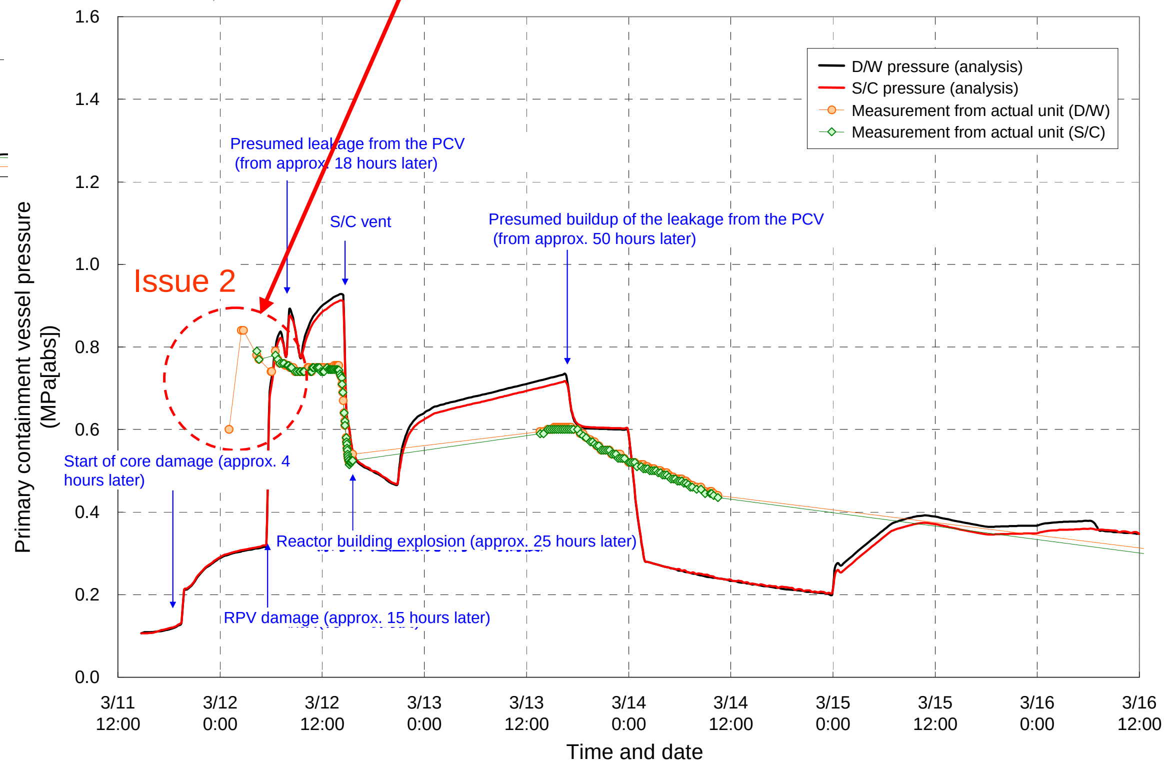
- The present analysis was conducted with the analysis conditions set in such a way that the behavior of the plant immediately after the accidents can be reproduced as accurately as possible based on the information of the plant obtained to date and our plant-state presumptions.

2.1. Issues to be solved regarding the MAAP analysis results of Unit 1 published in May 2011



Primary containment-vessel (PCV) pressure values from the analysis are inconsistent with the measured PCV pressure values.

Reactor-pressure values from the analysis are inconsistent with the measured reactor-pressure values



2.2. Main presumptions made for the analysis of Unit 1

< Main presumptions >

- It was presumed that the emergency condenser (IC) had not operated since the loss of all AC power due to the tsunami.

- It was presumed that a leakage from the gaseous phase section of the reactor pressure vessel (RPV) had occurred when the maximum fuel clad temperature of 727°C (1000 K) had been reached and when the temperature of the gas in the reactor had reached 450°C respectively. Issues 1 and 2

- To reproduce the behavior of the PCV pressure, it was presumed that a gaseous phase leakage from the PCV had occurred approximately 12 hours, 50 hours and 70 hours after the earthquake.

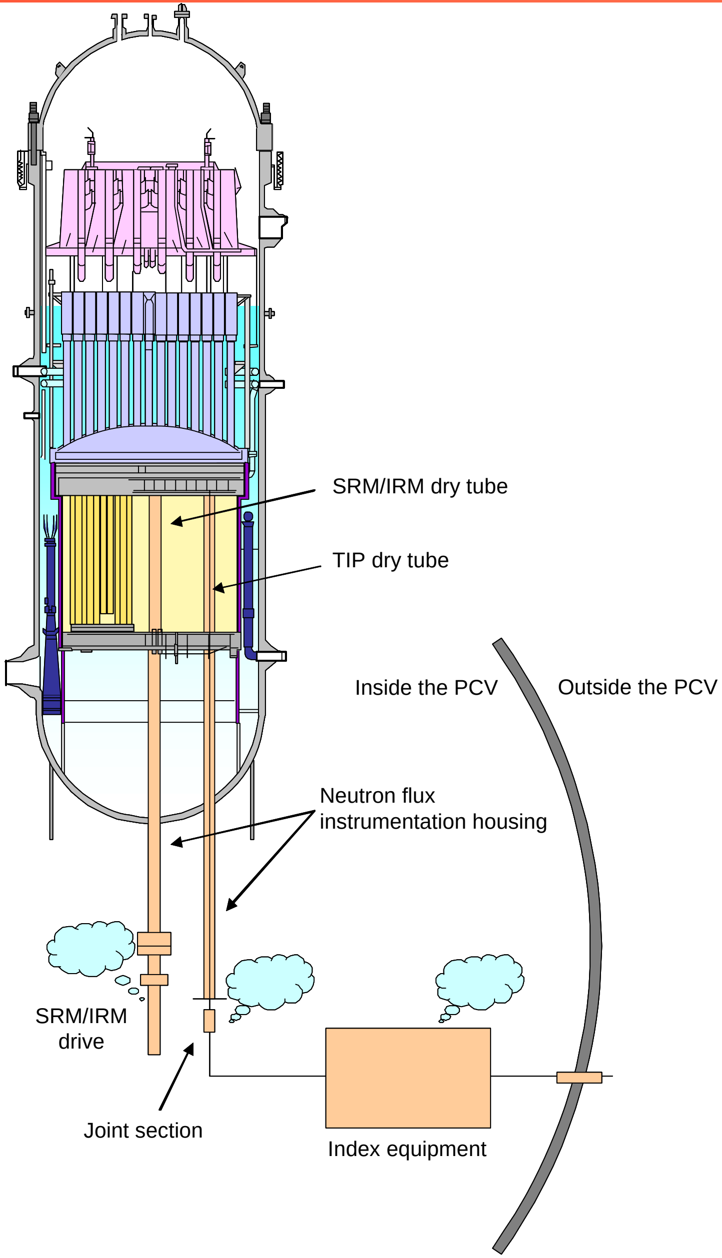
2.2. Gas leakage locations (1)

If the fuel is exposed and the temperature of the core becomes high, the nuclear instrumentation piping in the core may be damaged.

If the dry tubes of the SRM/IRM and TIP, which have a mechanism for extraction to outside the reactor, are damaged, steam in the gaseous section in the reactor may leak to D/W.

In this analysis, it was presumed that a leakage had occurred when the maximum temperature of the fuel clad had reached 727 °C (1000 K).

(Cross section of leakage hole is presumed as 0.00014 m^2)



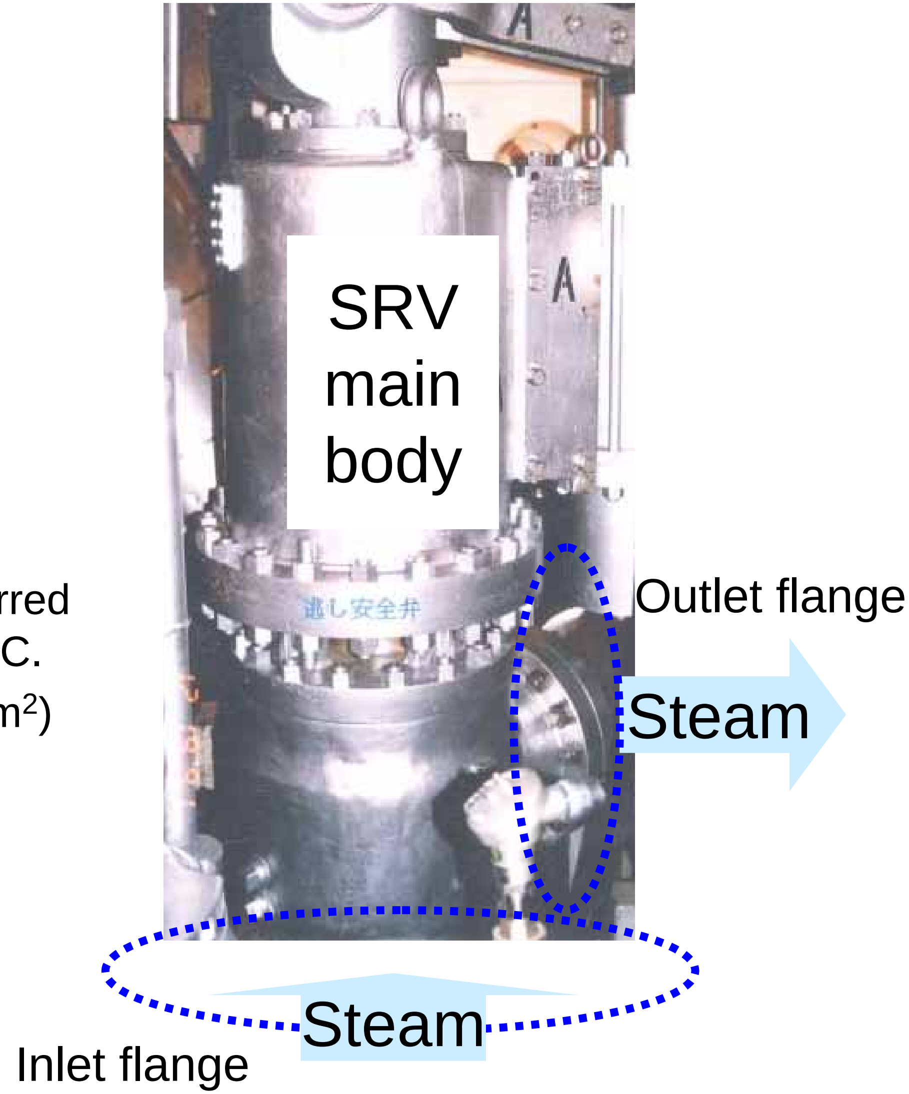
2.2. Gas leakage locations (2)

The gaskets used in the flange sections of such parts as the SRV pipe beds of the main steam piping may lose their sealing capability if the fuel is exposed; the temperature of the core becomes high, and the temperatures of the gases (steam and hydrogen) in the core become high.

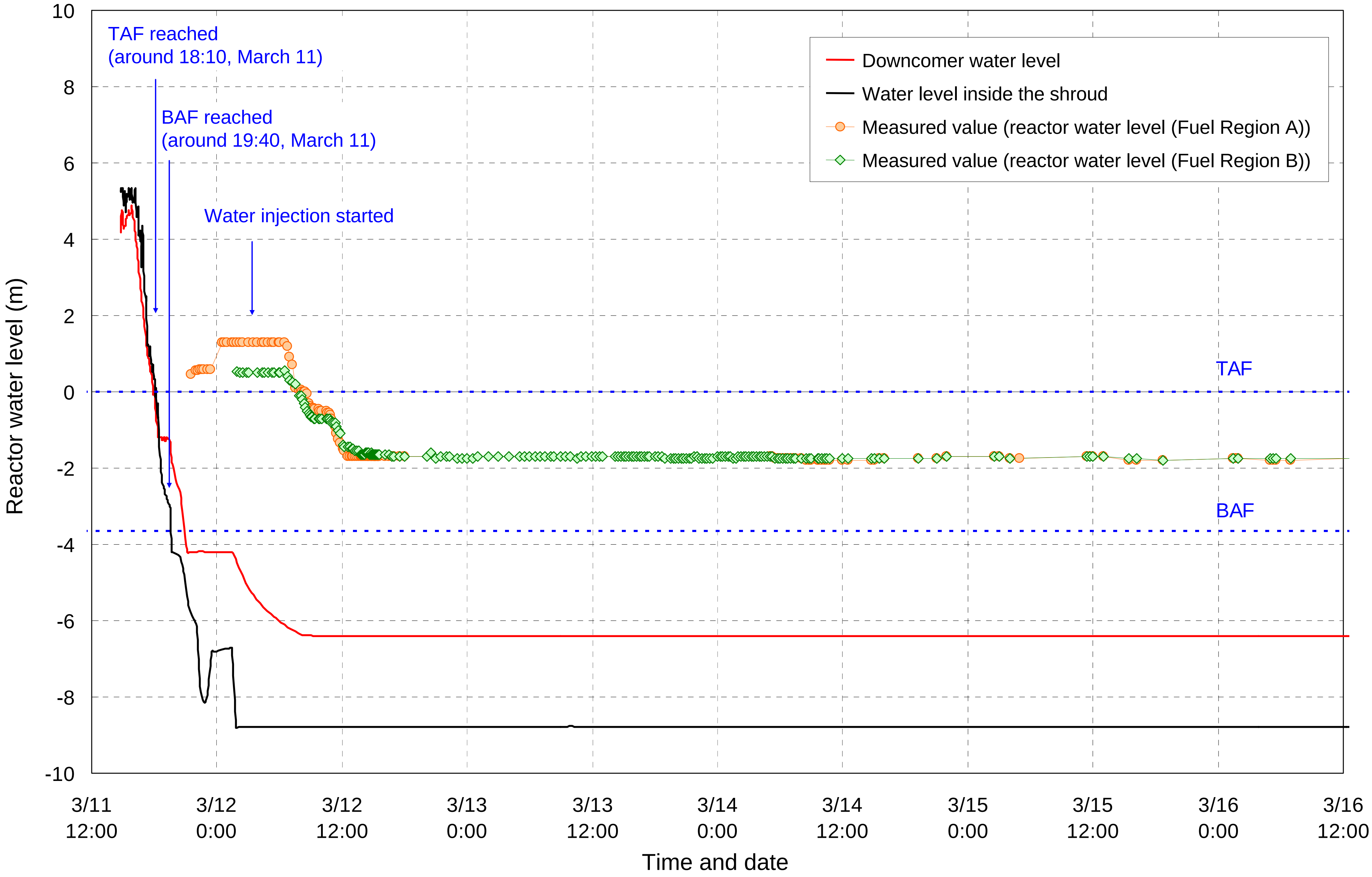
In particular, the temperature the expansion graphite gaskets can withstand is approx. 450 ℃.

In this analysis, it was presumed that a leakage had occurred when the gas temperature in the core had reached 450°C.

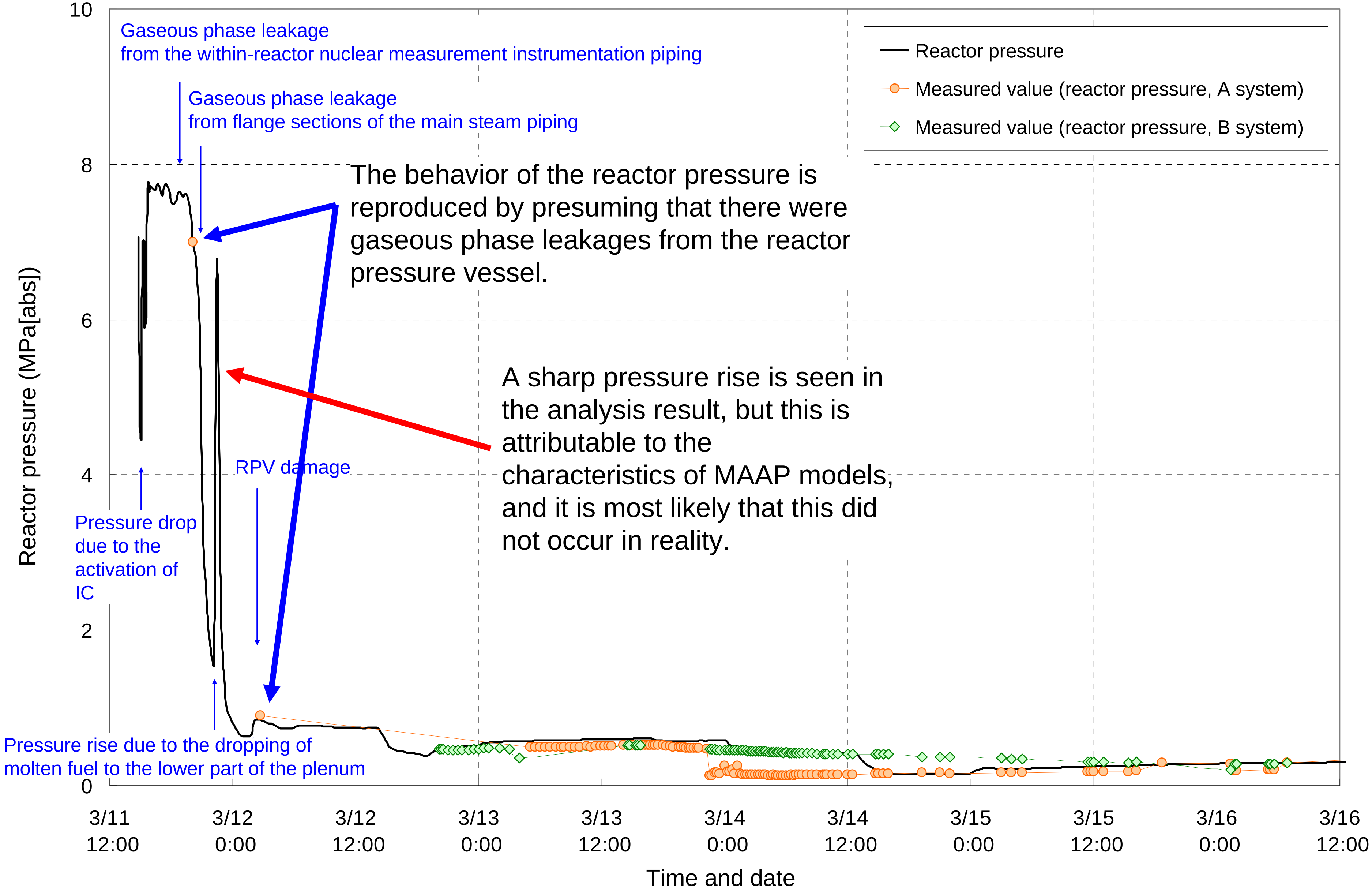
(Cross section of leakage hole is presumed as 0.00136 m^2)



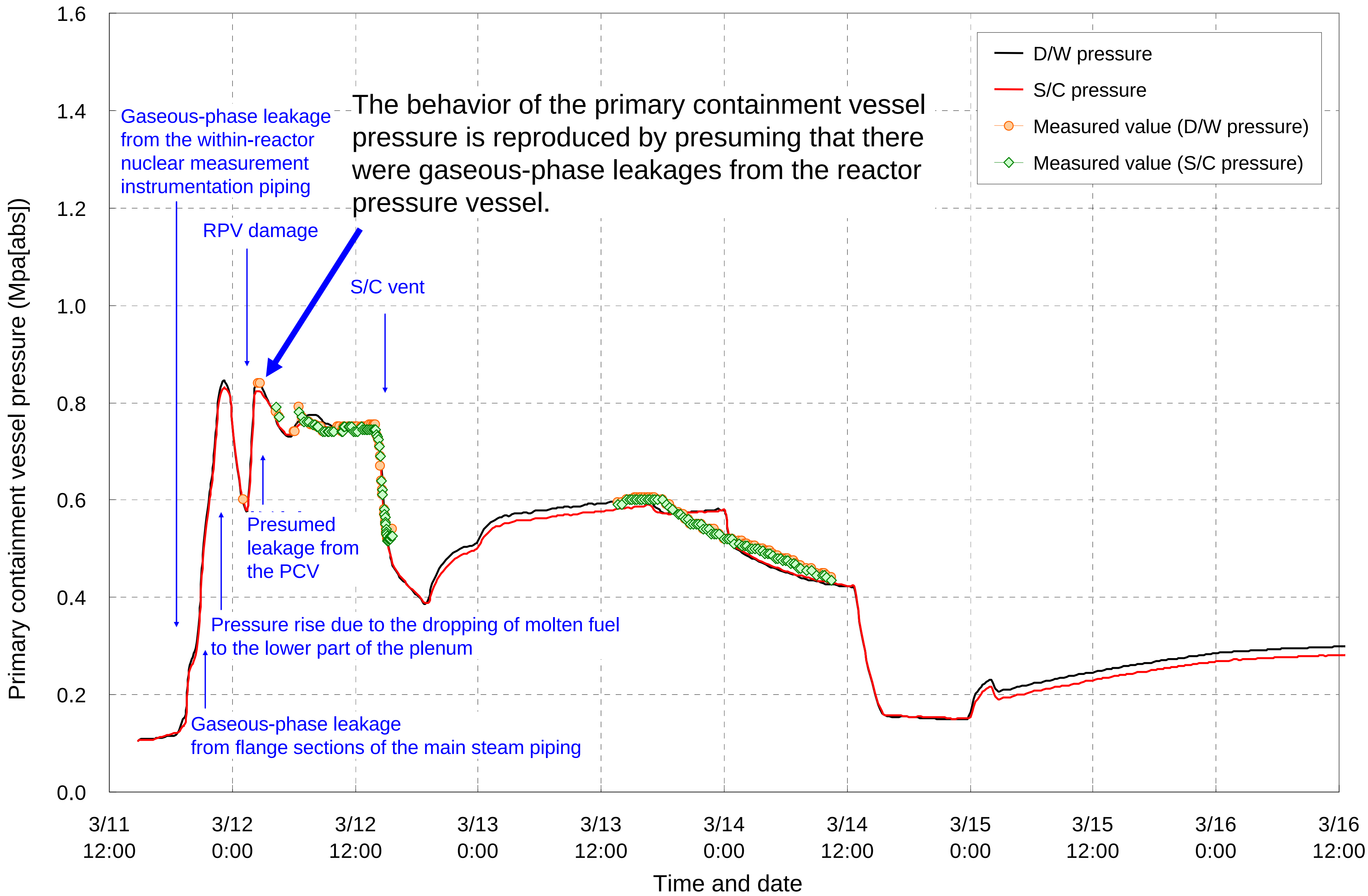
2.3. Overview of the analysis results of Unit 1 (reactor water level)



2.3. Overview of the analysis results of Unit 1 (reactor pressure)



2.3. Overview of the analysis results of Unit 1 (Primary containment vessel pressure)



2.3. Summary of the analysis results of Unit 1

< Summary of the analysis results >

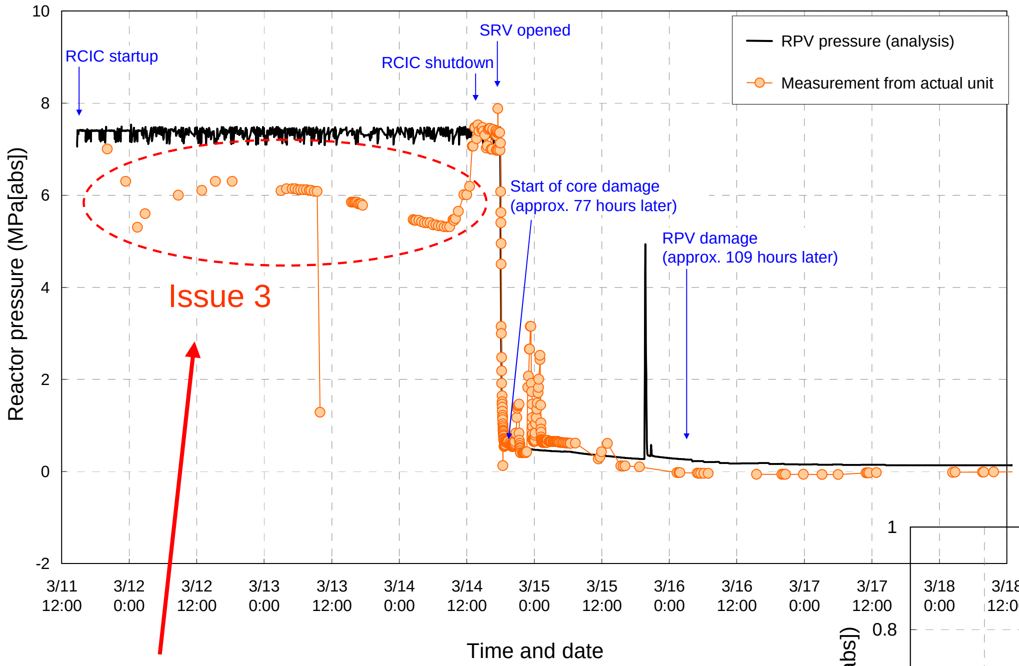
- Time at which the exposure of the core started:
  around 18:10, March 11 (approx. 3 hours after the earthquake)
- Time at which the core started being damaged:
  around 18:50, March 11 (approx. 4 hours after the earthquake)
- Time at which the RPV was damaged:
  around 1:50, March 12 (approx. 11 hours after the earthquake)

- As a result of the adoption of the presumption of gaseous phase leakage, we succeeded in reproducing the reactor-pressure behavior (Issue 1) and PCV pressure behavior (Issue 2) fairly accurately.

- Because of the presumption that the IC had not operated since the loss of all AC power due to the tsunami, the damage of the core and the RPV occurred relatively early in the analysis.

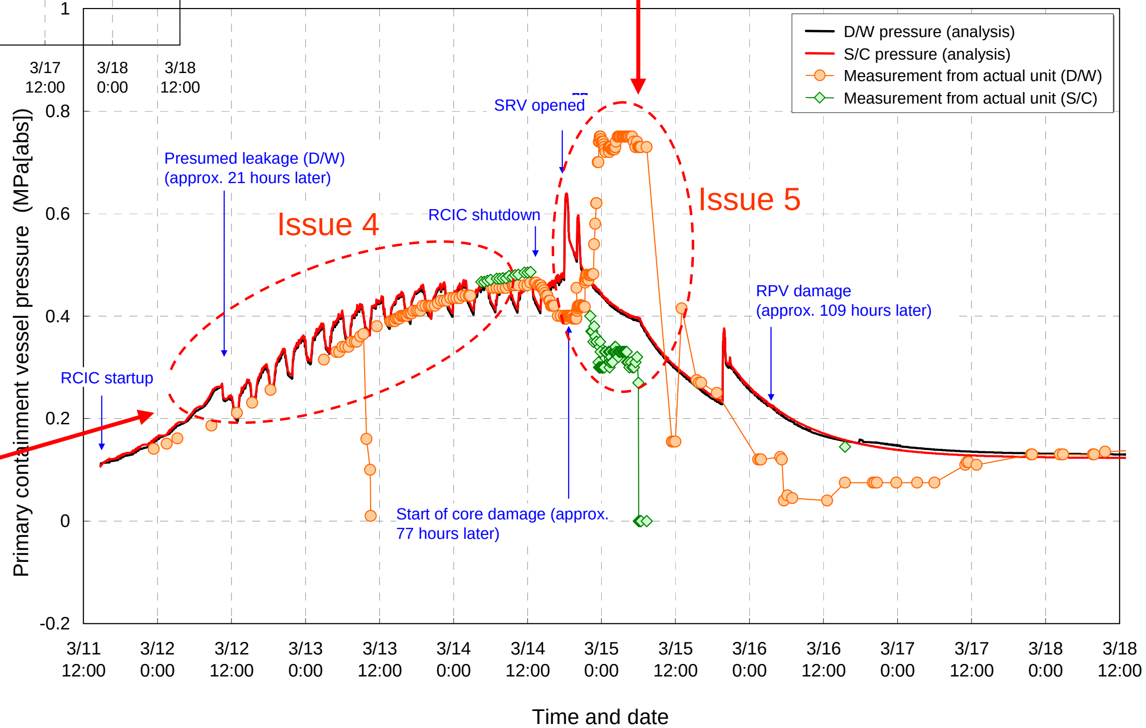
- The time at which the RPV damage occurred is about 4 hours earlier. This is a result of the unrealistic pressure behavior due to the characteristics of the MAAP code, and we think that further enhancement of the analysis code should be made.

3.1. Issues to be solved regarding the MAAP analysis results of Unit 2 published in May 2011



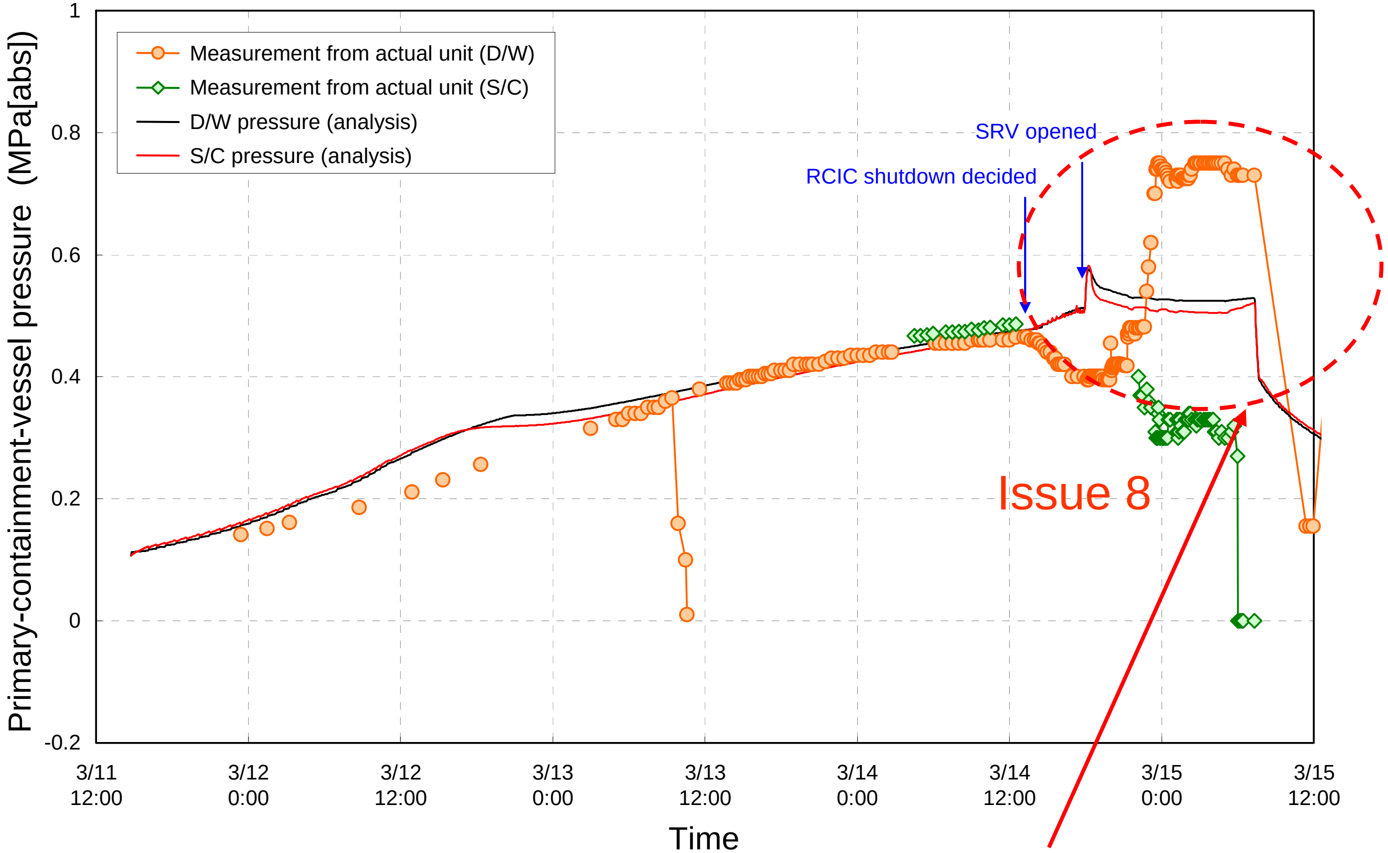
If it is presumed that there were leakages, it will not be possible to reproduce measured values that allow a high primary-containment-vessel pressure level to be maintained.

Reactor pressure values from the analysis are inconsistent with the measured-reactor pressure values



PCV pressure values from the analysis are inconsistent with the measured PCV pressure values unless it is presumed that there were leakages from the primary containment vessel.

3.1. Issues to be solved regarding the MAAP analysis results of Unit 2 published in December 2011



An analysis result was obtained that allowed high PCV pressure level to be maintained, but the analysis values did not quantitatively reproduce the measured values (because of the small volume of the hydrogen generated).

3.2. Main presumptions made for the analysis of Unit 2 and a summary of the analysis results of Unit 2

< Main presumptions made for the analysis of Unit 2 >

- It was presumed that the steam to the reactor core isolation cooling system (RCIC) turbine had been a two-phase flow condition with a level of energy equivalent to the decay heat, so that a pressure behavior can be reproduced, which is characterized by the staying of the pressure at a level below the SRV activation pressure setting.

  Issue 3

- It was presumed that gradual ingress of water into the torus room after the arrival of the tsunami had caused the heat in the PCV to be transferred from the S/C boundary to outside the PCV.

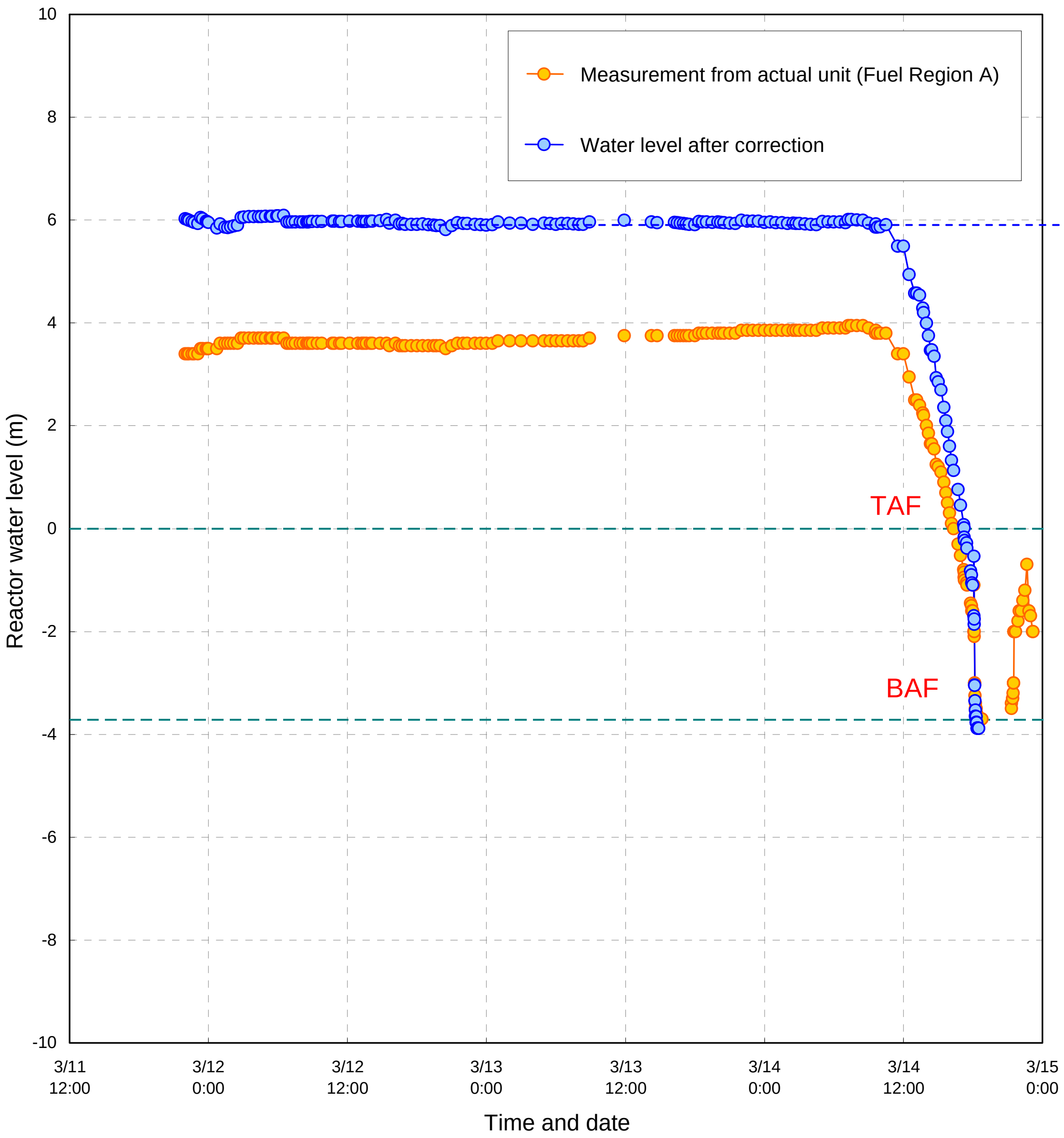
  Issues 4 and 5

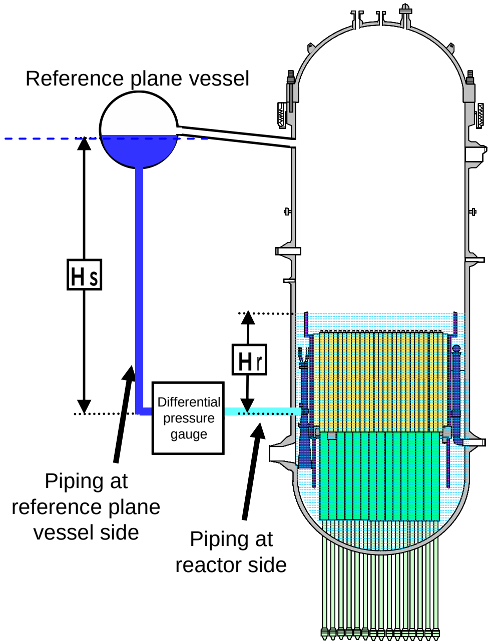
- It was presumed that the amount of water injected into the reactor using fire engines had been an amount that had raised the reactor water level to a level below the fuel region taking into consideration the volume of hydrogen generated.

  Issue 8

- To reproduce the behavior of the PCV pressure, it was presumed that a gaseous-phase leakage from the PCV had occurred approximately 89 h after the earthquake.

3.2. Operation states of the RCIC in Unit 2





The measured water level coincides with the water level of the reference plane vessel (highest value on the water gauge) after corrections.* It is most likely that the actual water level was higher, and it is considered that steam mixed with water was flowing into the RCIC turbine (in the form of a two-phase flow).
(If there is a power source, the injection of water is stopped at a water level that is lower than the power source (L8).)

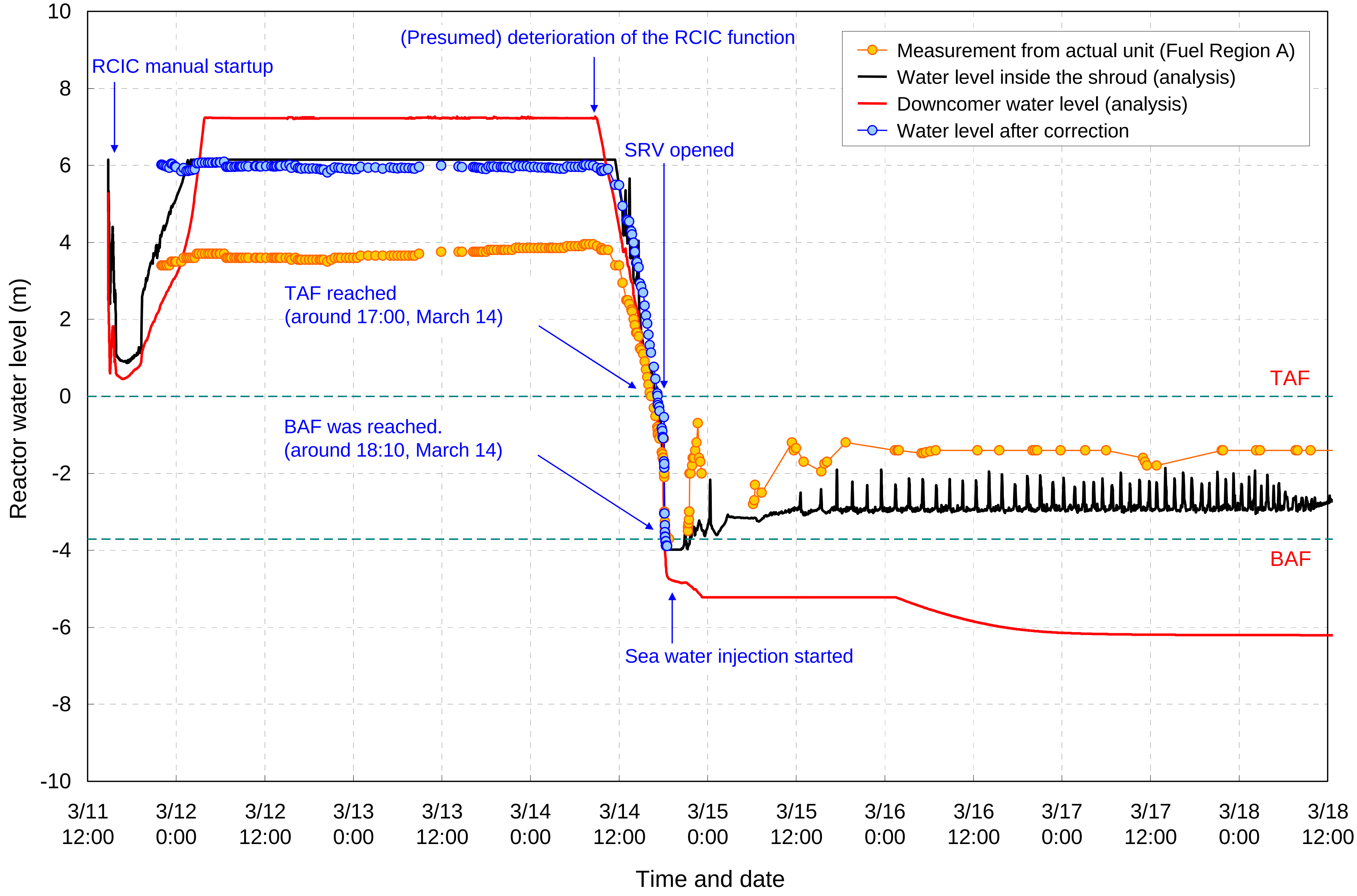
*: Corrections based on the reactor pressure and PCV temperature

3.2. State of the primary containment vessel (S/C) in Unit 2

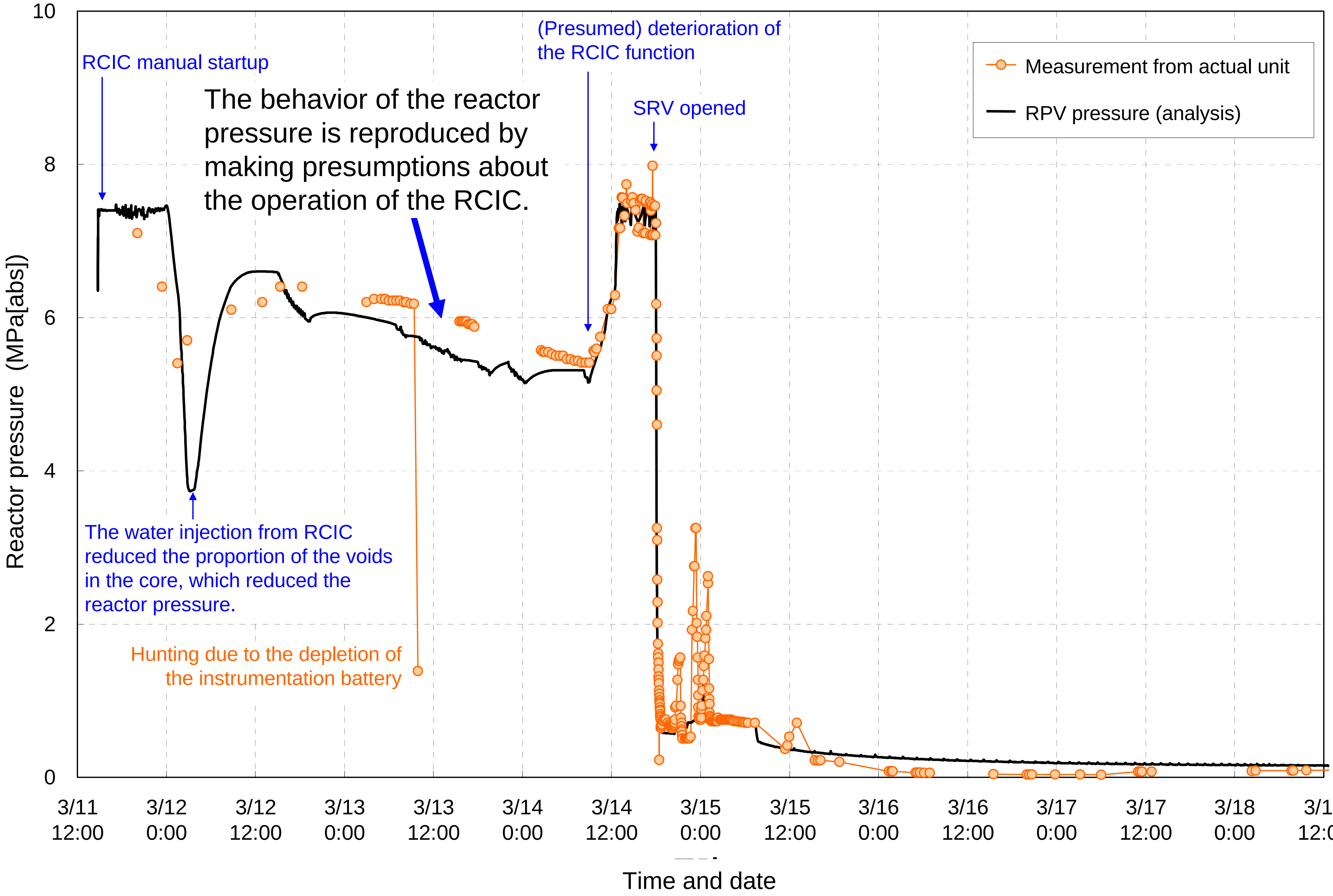
It was presumed that ingress of water into the torus room, in which the S/C is installed, had occurred and that a heat transfer path had been established, which had allowed the heat transferred to the S/C to be transferred to the water in the torus room via the S/C wall.
The state of the torus room for Unit 2 has not been confirmed, but it has been confirmed that the S/C for Unit 4 was submerged.

Photograph of the area directly below the catwalk in the torus room for Unit 4 (taken from the catwalk)

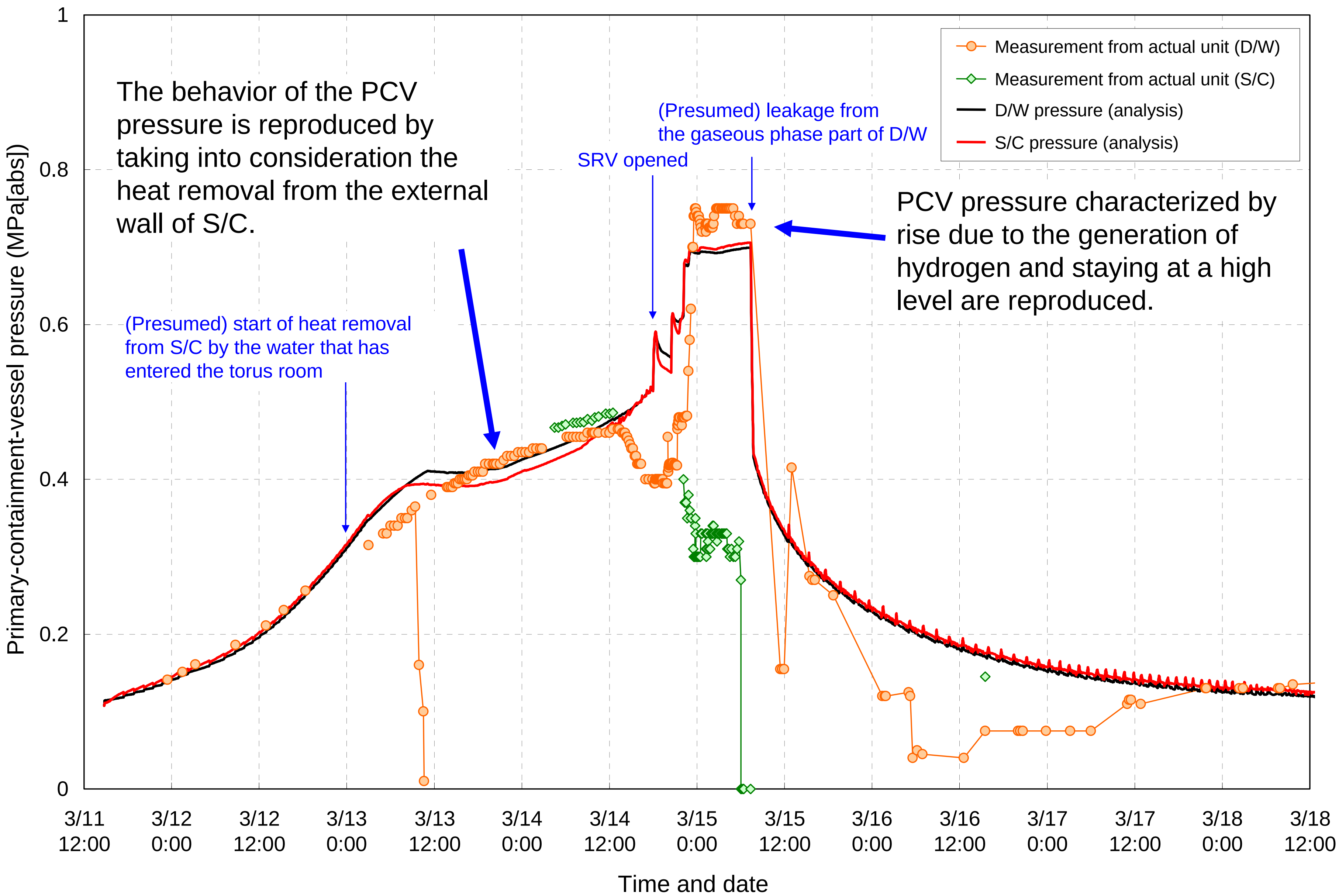
3.3. Overview of the analysis results of Unit 2 (reactor water level)



3.3. Overview of the analysis results of Unit 2 (reactor pressure)



3.3. Overview of the analysis results of Unit 2 (primary containment vessel pressure)



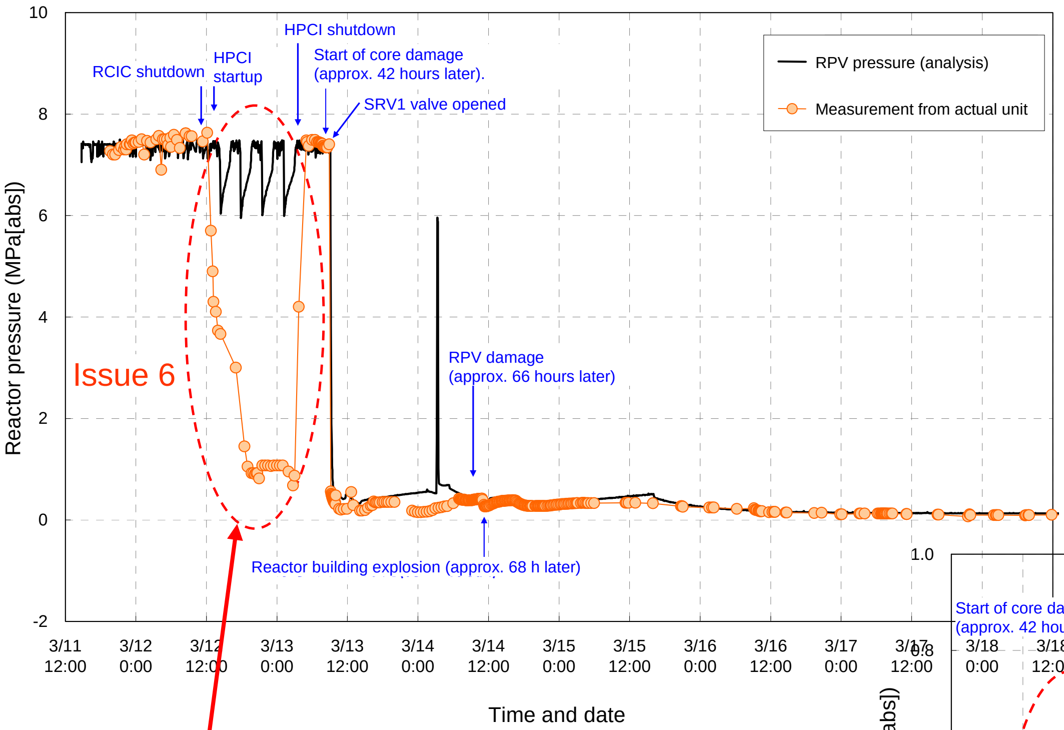
3.3. Summary of the analysis results of Unit 2

< Summary of the analysis results >

- Time at which the exposure of the core started:
  around 17:00, March 14 (approx. 74 hours after the earthquake)
- Time at which the core started being damaged:
  around 19:20, March 14 (approx. 77 hours after the earthquake)

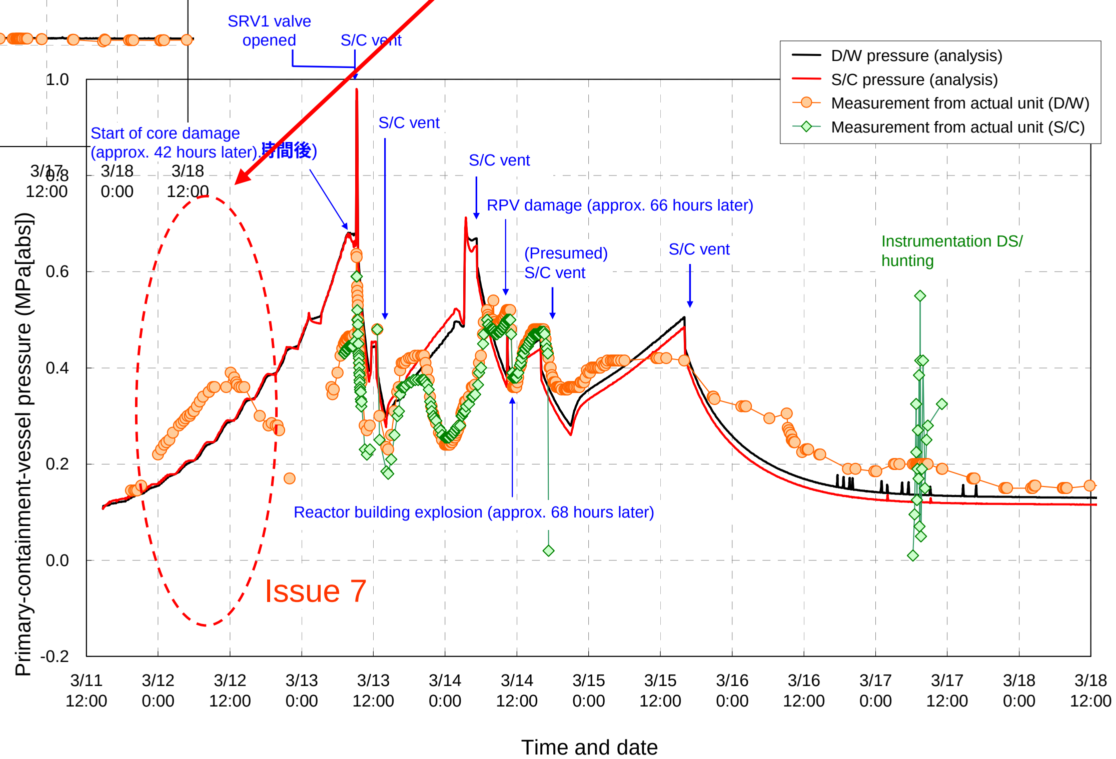
- We succeeded in reproducing the reactor-pressure behavior (Issue 3) fairly accurately by making presumptions about the operating conditions of the RCIC.
- We succeeded in reproducing the PCV pressure behavior (Issue 4) fairly accurately and reproducing the PCV pressure behavior characterized by the staying of the pressure at a high level (Issue 5) by making presumptions about the ingress of water into the torus room.
- We succeeded in quantitatively reproducing the pressure values during the period in which the PCV pressure stays at a high level (Issue 8) by adjusting the water volume injected using fire engines.
- The reactor-water level drop due to the RCIC shutdown led to damaging of the core, but the RPV damage did not occur.
  (According to our total evaluation based on the plant data obtained to date and other information, it is most likely that RPV damage had occurred.)

4.1. Issues to be solved regarding the MAAP analysis results of Unit 3 published in May 2011

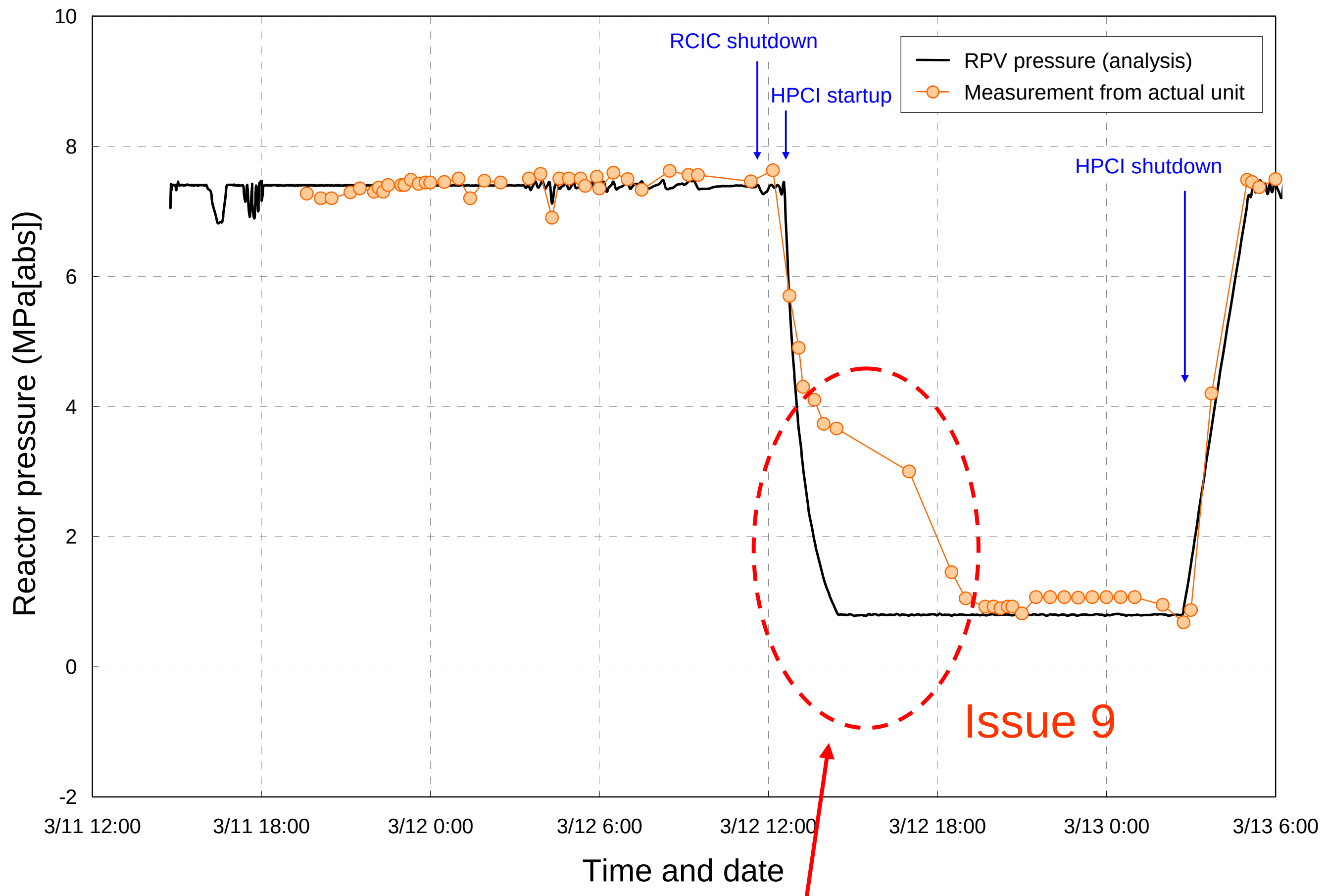


Reactor pressure values from the analysis are inconsistent with the measured reactor pressure values.
(The trend can be reproduced if it is presumed that leakages occurred from the piping of the high-pressure core injection system (HPCI)).

There are periods in which measured PCV pressure values are higher than the corresponding analysis values and periods in which the trend in pressure behavior differs between measured values (falling) and analysis values (rising).



4.1. Issues to be solved regarding the MAAP analysis results of Unit 3 published in December 2011



The reactor pressure decreased monotonically in the analysis, whereas the reactor-pressure measurement shows that the pressure decreased stepwise.

4.2. Main presumptions made for the analysis of Unit 3

< Main presumptions >

- It was presumed that the RCIC and HPCI had been operating continuously with flow rate adjustments made to keep the reactor water level within the appropriate range (in order to prevent repeated starts and stops due to excessive water level rises and falls).

  Issues 6 and 9

- A realistic decay heat value was adopted, which reflected the fuel loading history. Issue 7

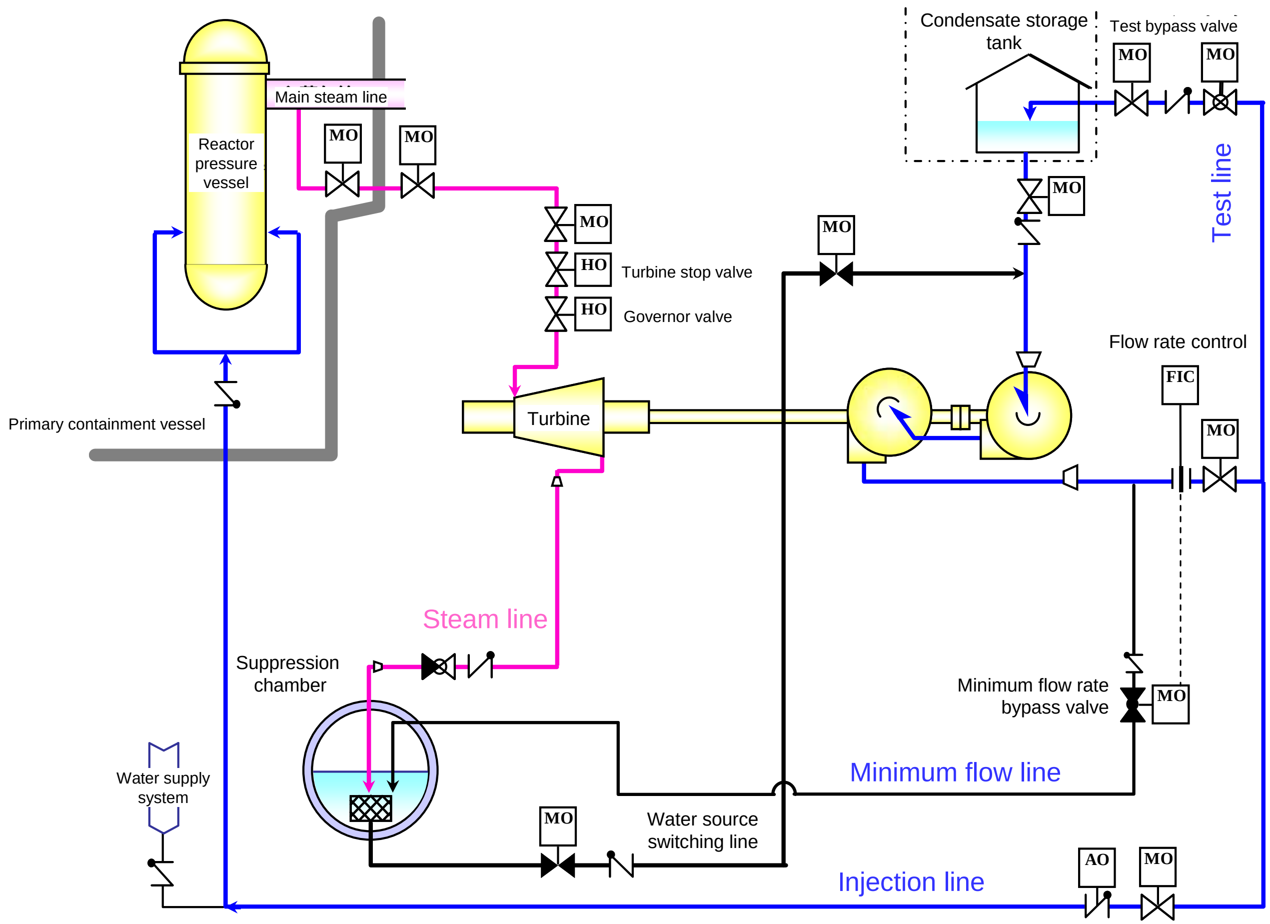
- It was presumed that operators had been spraying water into S/C using a diesel-engine-driven firefighting pump. Issue 7

- It was presumed that the amount of water injected into the reactor using fire engines had been an amount that had keeps the reactor water level to a level below the fuel region.

4.2. Operations performed by operators during operation of the HPCI in Unit 3

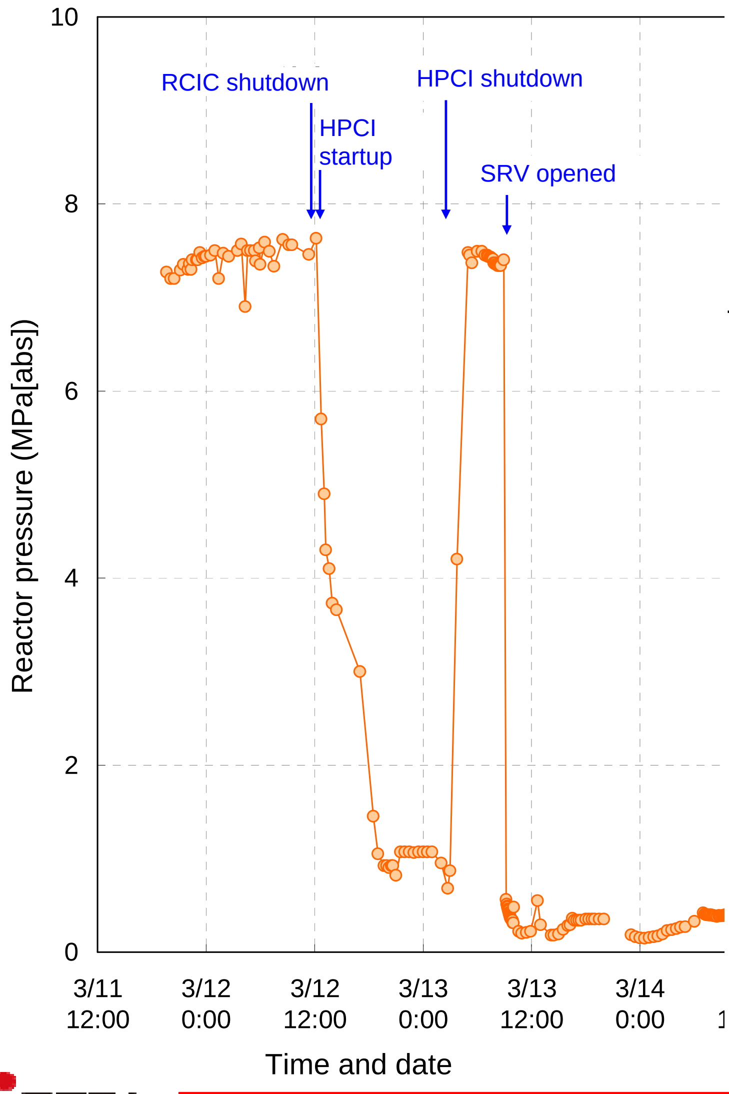
From operators' testimonies, it is known that they were adjusting the HPCI flow rate using the test line while confirming the reactor water level. They fully closed the minimum flow line to prevent the S/C water level from rising.

It is also known that they were spraying water into S/C at that time using a diesel-engine-driven firefighting pump.

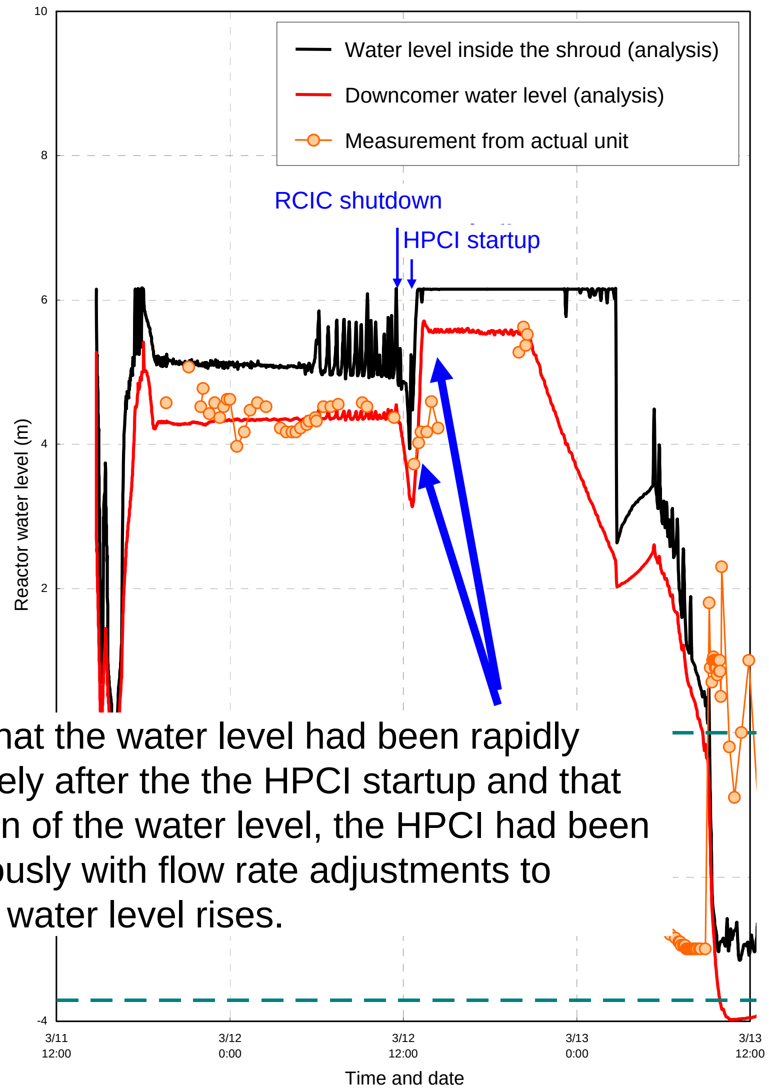


4.2. Operation status of the HPCI in Unit 3

The reactor pressure dropped after the HPCI startup, but it did not drop monotonically. There is a period during which the pressure drop rate is lower.

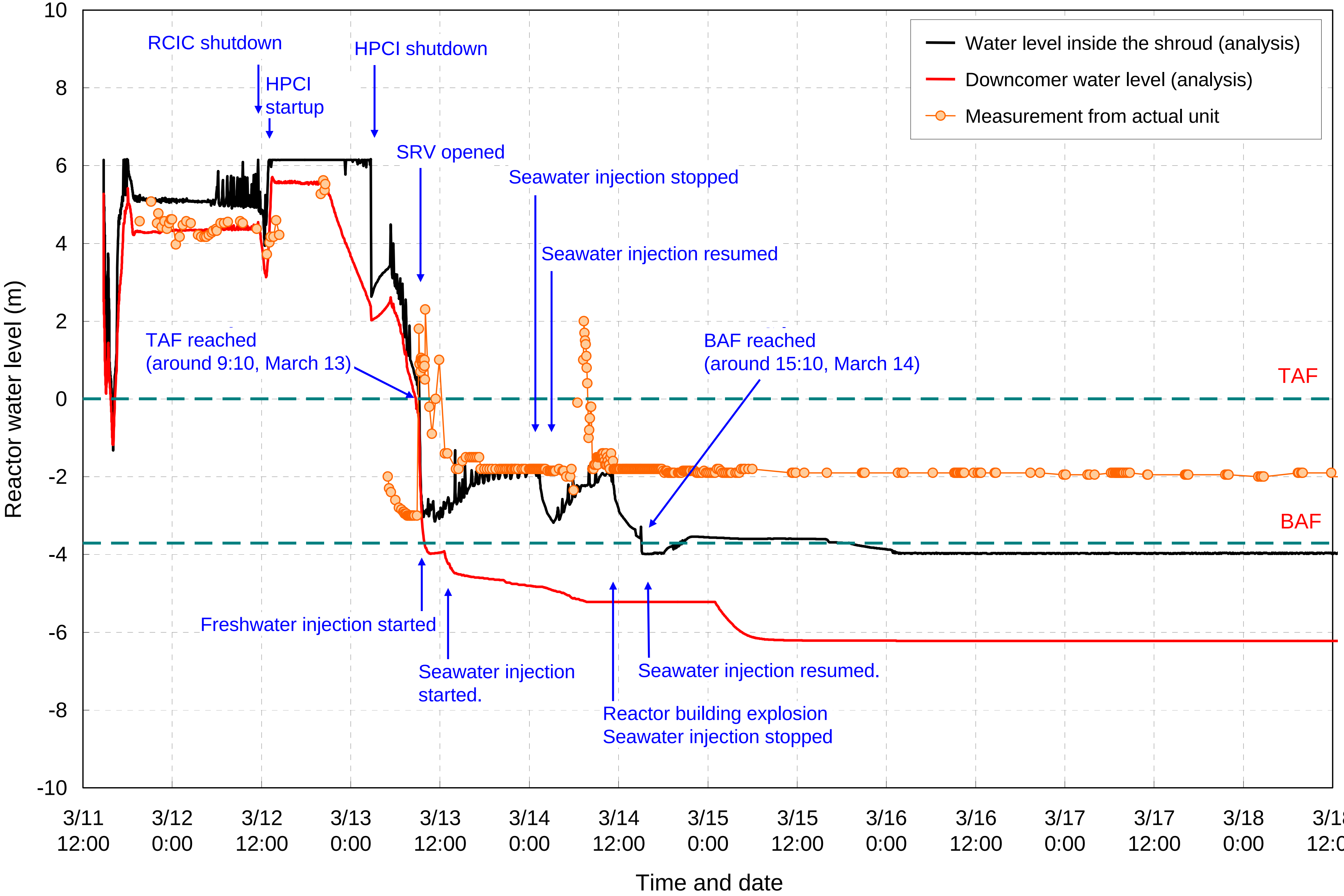


May be attributable to the change in the operation status of the HPCI.

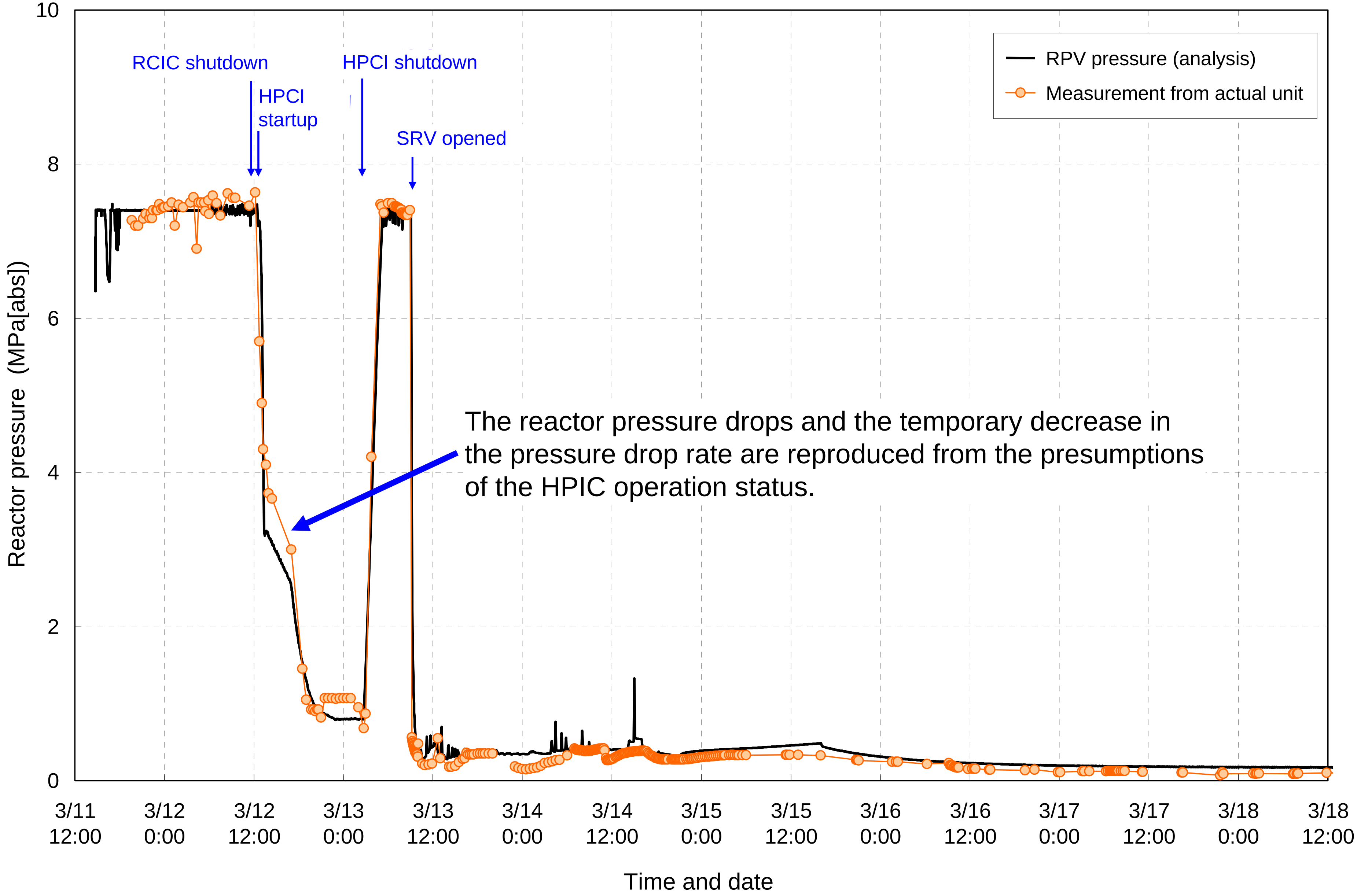


It was presumed that the water level had been rapidly restored immediately after the the HPCI startup and that after the restoration of the water level, the HPCI had been operating continuously with flow rate adjustments to prevent excessive water level rises.

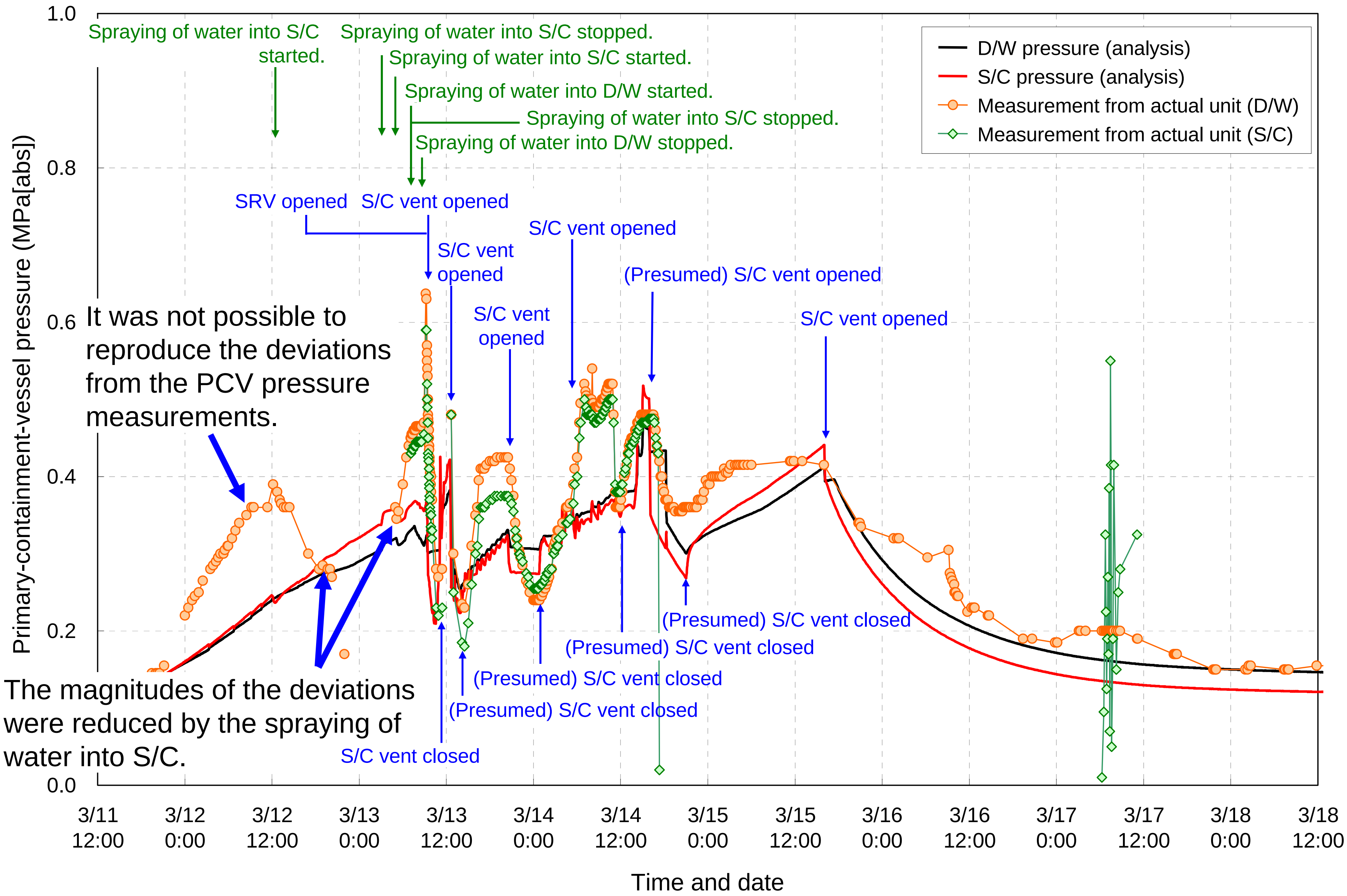
4.3. Overview of the analysis results of Unit 3 (reactor water level)



4.3. Overview of the analysis results of Unit 3 (reactor pressure)



4.3. Overview of the analysis results of Unit 3 (primary-containment-vessel pressure)



4.2. Summary of the analysis results of Unit 3

< Summary of the analysis results >

- Time at which the exposure of the core started:
  around 9:10, March 13 (approx. 42 hours after the earthquake)
- Time at which the core started being damaged:
  around 10:40, March 13 (approx. 44 hours after the earthquake)

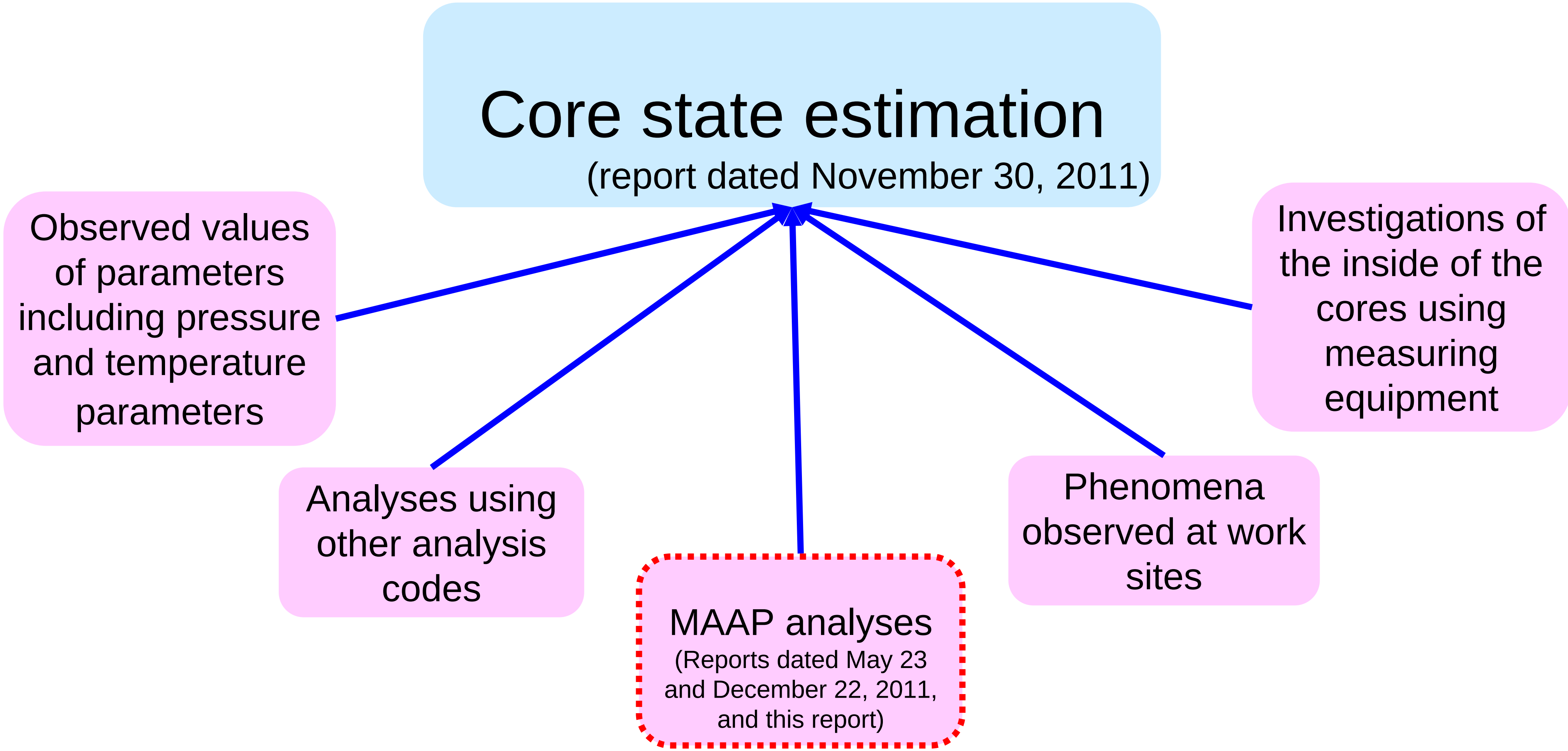
- The trend in the dropping of the reactor pressure (Issues 6 and 9) was reproduced by presuming that the HPCI had been operating continuously with flow rate adjustments made.
- It was not possible to eliminate the deviations of the PCV pressure values obtained from the analysis from the measured PCV pressure values during the periods in which the RCIC had been in operation, but the magnitudes of the deviations were reduced and the analysis values became roughly the same as the measured values after commencement of the spraying of water into the S/C.
  (The deviations may be attributable to the effects of the stratification of the S/C pool water, which cannot be analyzed with MAAP, and we think that further enhancement of the analysis code should be made.)
- The reactor water level drop due to the HPCI shutdown led to the core damage, but RPV damage did not occur.
  (According to our total evaluation based on the plant data obtained to date and other information, it is most likely that the RPV damage occurred.)

5. Conclusions

- We conducted an analysis based on the currently available information including estimations (such as information on the operations performed by operators and estimations from the characteristics of the plant).
- As a result, we succeeded in reproducing the behavior of the plant at the time of the accident fairly accurately for the stages before the core melted.
- On the other hand, the RPV damage of Units 2 and 3 did not occur in this analysis, which is contrary to the observed facts (See the report of the “The Evaluation Status of Reactor Core Damage at Fukushima Daiichi Nuclear Power Station Units 1 to 3 at Technical Work Shop.” (dated November 30, 2011)).
- The points made above shows the analysis capability limits of the current MAAP Code.

- Nuclear Emergency Response Headquarters Government-TEPCO Mid-and-long Term Response Council has set up a sub-working team for investigating and analyzing the states of the inside of the reactors under the Research and Development Promotion Headquarters and started making efforts to further enhance the severe accident analysis codes including the MAAP Code.
- From now onwards, we will strive to further elucidate the development of the events and obtain a clearer picture of the states of the inside of the reactors by achieving higher analysis accuracy levels utilizing the results of the abovementioned activities’ efforts and findings.

(Reference information)
Relationship between core state estimation and MAAP analyses



Core state estimation involves total assessments of various kinds of information.

(The present MAAP analysis did not succeed in reducing the degree of uncertainty of the published core state estimation.)