Estimation of Radioactive Material Released to the Atmosphere during the Fukushima Daiichi NPS Accident

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Contents

1 Introduction

The Tohoku-Chihou-Taiheiyou-Oki Earthquake, which had its hypocenter off the coast of Sanriku striking at 14:46 on March 11, 2011, and the accompanying tsunami led to the accident at Units 1~3 of the Fukushima Daiichi Nuclear Power Station where a situation continued in which all AC and DC power sources as well as the ultimate heat sink were lost, fuel was damaged and melted, and damage occurred to the primary containment vessel, resulting in radioactive material being released to the atmosphere.

In connection with the investigation into this accident, the purpose of this document is to estimate the amount of each principal nuclide released to the atmosphere from the power station accompanying the accident, and to clarify the time sequence of releases, the effectiveness of primary containment vessel venting, and factors pertaining to deposition in a northwesterly direction.

Because of uncertainties in computational conditions and the limits on systems used in the estimation, the content of this document may be revised as the investigation into the accident develops in the future.

2 Release of Radioactive Material

After the accident, radioactive material was released from Units 1~3. In addition to releases accompanying venting and building explosions, there were continuing releases of radioactive material to the atmosphere from buildings after the building explosions.

The established monitoring posts and stack monitors should have been able to ascertain releases of radioactive material to the atmosphere, but the power source for monitoring posts was lost due to the earthquake and the power source for stack monitors was lost in the wake of the tsunami, so function of stack monitors and other such equipment was lost. Therefore, monitoring cars were posted around the power station to measure the air dose rate, meteorological data (wind direction and velocity) and other data in an effort to ascertain the status of radioactive material release.

Of the radioactive materials released to the atmosphere as shown in Figure 1, noble gases, which are not affected by gravity or rainfall, are carried off on the wind and dispersed. On the other hand, iodine, cesium and other such nuclides are affected by gravity and rainfall, and fall to the ground surface or sea surface while they are dispersed by the wind. Moreover, even after depositing on the ground surface, they exhibit complex behavior, such as being carried by rainwater to rivers and migrating thereafter to the ocean.

In addition, of the radioactive material released from the primary containment vessel which does not migrate to the atmosphere as shown in Figure 2, that associated with water injected into the reactor from outside the primary containment vessel leaks from the primary containment vessel, traverses through the interior of the reactor building, and accumulates in the turbine building (In this report, the amount of such radioactive material is not subject to the assessment.).

3 Method of Assessing Amounts Released

Based on air dose rates and other data measured by monitoring cars and other equipment as well as rainfall and other meteorological data measured at the Meteorological Agency's meteorological stations, the amount of radioactive material released to the atmosphere from the power station was assessed.

3.1 Assessment Sequence

The sequence through which amounts released are assessed is as follows. This sequence is shown in Figure 3. In addition, specifics are listed in the following paragraphs indicated by numerals ①~⑤.

Step 1: Observed data (air dose rates, meteorological data (wind direction, wind velocity, rainfall amounts, sunshine duration)) are input into TEPCO’s system for assessing the atmospheric dispersion of radioactive material (see section 3.2 DIANA) to estimate the amounts released to the atmosphere.

Step 2: Based on time variations in the air dose rate, the percentages of noble gases, iodine and cesium released are assessed for the amounts releases as obtained in Step 1.

Step 3: From amount of cesium-137 released as obtained in Step 2 and meteorological data, the amount deposited on the ground surface is assessed.

3.2 DIANA (Figure 3-①)

The Dose Information Analysis for Nuclear Accident (DIANA) is a system which assumes an event in which radioactive noble gases, iodine, and particulate matter have been released to the atmosphere. The system is capable of simulating three-dimensional advection dispersion phenomenon in the area surrounding a nuclear power station for each 10-minute period as well as assessing the air dose rate at arbitrary points. The system's detailed specifications are given below.

Calculation method: Based on measured meteorological data (wind direction and velocity at the power station), a three-dimensional windy spot within the area assessed (range extending 50km east-west × 50km north-south × height of 2000m which includes the power station; calculation mesh: 1km×1km×100m) is prepared with consideration given to geographical influences, and particle-based advection-dispersion is calculated.

Dispersed particles: 0.5MeV-equivalent particles are assumed

Assessment of windy spots: Assessment of windy spots satisfying the law of conservation of mass

Advection-dispersion: Lagrangian virtual particle dispersion model

Release location: A points assuming release at the same time is one point

Calculation steps: Every 10 minutes (10-minute period is assumed to be the uniform release rate)

Deposition rate: The deposition rate expresses the susceptibility of radioactive material to deposition, and the numerical values in the tables below have been used to assess the concentration of deposition on ground surface. These numerical values have been noted in the following papers and are common numerical values in calculations of atmospheric dispersion.

- Engelmann, R.J. (1968) The Calculation of Precipitation Scavenging in Meteorology and Atomic Energy – 1968, D.H.Slade, Ed., US AEC, TID-24190
- Crandall, W.K. et. al, An Investigation Of Scavenging Of Radioactivity From Nuclear Debris Clouds: Research In Progress, Larwence Livermore Laboratory, 1973. UCRL-51328, TID-4500
- Sehmel, G.A., Particle And Gas Dry Deposition: A Review, Atmospheric Environment, 14, pp.983-1011, 1980

(Dry deposition)

Atmospheric stability	Iodine (cm/s)	Cesium (cm/s)
A~F	0.3	0.3

(Wet deposition)

Atmospheric stability	Iodine (1/s)/(mm/hr)	Cesium (1/s)/(mm/hr)
A~D	1.0E-03	2.0E-04
E, F	1.0E-04	

Rainfall conditions: It is assumed that there is uniform rainfall within an area in the range assessed at the same time.

Range assessed for deposition:

25km to the north of the power station

25km to the south of the power station

20km to the east (sea side) of the power station

30km to the west (land side) of the power station

Due to limitations imposed by the aforementioned specifications, there is uncertainty in the assessment.

3.3 Meteorological Data Used in Assessment (Figure 3-②)

The meteorological data input into DIANA comprises wind direction, wind velocity, atmospheric stability and rainfall, but, due to the loss of power following the earthquake and other such influences, the data is not limited to meteorological data from the Meteorological Observation System installed on site.

Wind direction and velocity were measured using monitoring cars (2m aboveground), which were arranged on the premises of the Fukushima Daiichi Nuclear Power Station at the time of the accident.

Atmospheric stability was determined using the values for sunshine duration obtained at the Japan Meteorological Agency's Funehiki AMEDAS observation station, which was not missing any observations due to power failure and is located comparatively close to the Fukushima Daiichi Nuclear Power Station.

The wind velocity at 10m aboveground, which was used in the assessment, was determined in accordance with the "Manual of Methodology for Environmental Impact Forecasting in Areas Surrounding the Source of Hazardous Air Contaminants (Ministry of Economy Trade and Industry, February 2008)" by using the atmospheric stability and wind velocity at 2m aboveground as measured by the monitoring cars.

With regard to wind direction, 16 directions measured by the monitoring cars were used. DIANA takes into account geographical influences, and assesses changes in wind direction due to geographical influences at the time of dispersion.

With regard to rainfall, basically, those observation stations around the power station that were downwind at the time of the release of radioactive material were selected. It was confirmed whether or not the deposition amount actually measured by the Ministry of Education, Culture, Sports, Science and Technology was reproduced, and the rainfall amounts at the optimum observations stations (see Table 1 and Figure 4) were used.

Table 1. AMEDAS Observation Points Used

Time period	Hourly rainfall (mm/h)	AMEDAS observation point used
March 15 11:10~21:20	0~3	Iitate
March 15 21:30~24:00	0~3	Haramachi
March 16	0~3	Kawamae
March 21 AM	0~3	Hirono
March 21 PM	0~3	Kawamae
March 22~23 AM	0~3	Hirono[Note 1]
March 23 PM	0~3	Kawamae
March 25 0:00~18:00	0~3	Tsushima
March 25 18:10~21:00	0~3	Funehiki
March 25 21:10~March 26	0~3	Hirono
March 30~31	0~3	Namie[Note 2]

Note 1: The measurement for 24:00 on March 22 is missing. Although there is no rainfall

in the 10-minute periods before and after, rainfall has been set at 3mm/h after taking into consideration the circumstances of other points and radar AMEDAS.

Note 2: The measurement for 8:00 on March 31 is missing. At the same point, there was no rainfall at 7:50, and there was rainfall (3mm/h) at 8:10. Rainfall has been set at 3mm/h after taking into consideration the circumstances of other points and radar AMEDAS.

3.4 Air Does Rates Used in Assessment (Figure 3-③)

Monitoring posts (Figure 5) are set up around the power station for ordinarily monitoring the release of radioactive material to monitor air dose rates. During the accident at Fukushima Daiichi Nuclear Power Station, the function of monitoring posts was lost following the loss of power sources, so monitoring cars were arranged within the power station premises to measure air dose rates and other indices during the accident. The monitoring data, which provides a record of the measurement results and events, is shown in Figures 6~25.

In addition to the times when events occurred such as venting of the primary containment vessel and building explosions, the release of radioactive material during the accident at the Fukushima Daiichi Nuclear Power Station is regarded to have been radioactive material released to the atmosphere from damaged primary containment vessels.

In cases where the air dose rate fluctuates significantly, the air dose rate data varies due to a plume passing directly over the area around an observation station, as shown in the reference materials. Also, even when a plume does not pass directly over the observation station, the air dose rate data fluctuates due to the impact of direct radiation from the plume. From the aforementioned, in time periods when the air dose rate data fluctuates, it is possible to assess the release at that point in time as a time-course release rate by performing a dispersion calculation in detail based on the range in the rise of the air dose rate data.

In addition, when the air dose rate data do not vary, there are cases where there was a release event but no fluctuation in the air dose rate data and cases where there was no release per se. For periods where the air dose rate data do not vary, it is believed that there was no release large enough such as to cause a peak in the amount released. However, it has not been assumed that there was no release, but the assessment has been conducted in which it is postulated that there was a continuing release of radioactive material equivalent to 1 percent of the air dose rate data. Also, when fluctuations in actual measured data for the air dose rate are calculated, because of the fact that such were less than roughly 1% of the air dose rate (Table 2 and Figure 26), it can be said to be conservative in making the assessment to assume a release rate of 1% which is larger than even the fluctuation in the measured value for periods where the air dose rate data do not vary.

Table 2. Standard Deviation of Air Dose Rates in Time Periods where Peaks not Observed

Time period	Location	Air dose rate (μSv/h)	Standard deviation (%)
March 12 22:00~22:30	MP-4 vicinity	~50	0.07%
March 14 0:00~2:00	MP-2 vicinity	~400	0.00%
March 15 15:30~16:30	Main gate vicinity	~500	0.89%
March 19 18:00~21:00	Administrative building - North	~3000	0.10%

3.5 Release Circumstances at Each Time (Figure 3-④)

In cases where the unit releasing due to explosion, venting or other event has been identified, the assessment is performed as a release of the unit in question. However, from March 13 on, core damage and the release of radioactive material accompanying such damage occurred at multiple units, and radioactive material is thought to have been released from multiple locations (units) at the same time. However, the DIANA system specifications limit the releasing locations to one location, so the unit emitting the major release was estimated based on in-core conditions, various operating conditions, Fukuichi live camera video and other data, and the assessments were conducted using an event tree for the unit. Release from stack height has been assumed in the case of venting, and release from the height of a building in the case of releases from an explosion or building.

3.6 Sorting According to Nuclide (Figure 3-⑤)

As stated above, DIANA, which treats radioactive material as the object of a dispersion calculation of 0.5MeV-equivalent virtual particles, was used to assess the amount of 0.5MeV-equivalent virtual particle released.

Then, energy conversion factors and other quotients pertaining to each nuclide are used to sort the amount of 0.5MeV-equivalent virtual particle released into the amount of radioactivity of the nuclides targeted for assessment, and to determine the amounts released.

Using the method described in section 3.4, where the release rate of 0.5MeV-equivalent virtual particles is assessed using DIANA at time t (R(t)), the approach to sorting by nuclide is given in the following equation.

$$R(t)=Q'(t)\,(100X(t)*C1+10Y(t)*C2+Z(t)*C3)$$

R(t): 0.5MeV-equivalent virtual particle release rate (Bq/s) calculated backwards using DIANA from the air dose rate

X(t): Noble gas inventory (Bq) at time t

Y(t): Iodine inventory (Bq) at time t

Z(t): Cesium inventory (Bq) at time t

C1: Coefficient converting the noble gas inventory to 0.5MeV-equivalent value

C2: Coefficient converting the iodine inventory to 0.5MeV-equivalent value

C3: Coefficient converting the cesium inventory to 0.5MeV-equivalent value

Q'(t): Coefficient (1/s) for converting a certain released amount (0.5MeV-equivalent value) to a release rate determined from the air dose rate

Because the numerical values other than for Q'(t) are determined for each time t, Q'(t) is determined. From the above equation, the release rate for each nuclide at time t is as given below.

- Noble gas[Note 1]: Q'(t)* 100C1* X(t)Bq/s
- Iodine: Q'(t)*10C2* Y(t) Bq/s
- Cesium: Q'(t)*C3* Z(t) Bq/s

Based on the above approach, the release rate has been assessed. The ORIGEN code has been used for in-core inventories, and, assuming a five-batch fuel conversion, it is assessed as the average composition. The ORIGEN code uses the characteristics of atomic nuclei (fission cross section, fission yield, decay constant, etc.), which are known as the nuclear data library, to find the amount of radioactivity resulting from disintegration and formation of fission products inside a reactor.

The results of an examination of ratio of the susceptibility of radioactive nuclides to release, such as reproducing the shape of a peak in the air dose rate, showed that the ratio of noble gases, iodine and cesium was 100:10:1. (See Chapter 2 of the Reference Material) Noble gases are treated as not having been released from the time at which the entire amount is assessed to have been released and thereafter. With regard to cesium, a ratio of susceptibility to release which is the same respectively for both Cs-134 and Cs-137 was used.

Note 1: The nuclides assessed are as follows:
Kr-79.80.81.81m.82.83.83m.84.85.85m.86.87.88.89.90.91.92.93.94.95.96.97.98
Xe-126.127.128.129.129m.130.131.131m.132.133.133m.134.134m.135.135m.136.
137.138.139.140.141.142.143.144.145.146.147

4 Assessment Results

4.1 Assessment Results of Amounts Released

The amounts released to the atmosphere during March 2011 as assessed using the method described in the previous chapter (sum total of amount of radioactivity (Bq) at the time of release) are given in Table 3. The assessment period is from March 12, 2011 until March 31, and assessments for April and later account for less than 1% of the total amount for March as shown in Attachment 1.

Table 3. Assessment Results (Unit: PBq=10^{15}Bq)

Noble gases (0.5MeV-equivalent value)	I-131	Cs-134	Cs-137	INES assessment Note 1
Approx. 500	Approx. 500	Approx. 10	Approx. 10	Approx. 900

Note 1: The International Nuclear Event Scale (INES) assessment is an iodine-converted value of the amount of radioactivity. Here, because only limited nuclides are able to be assessed, I-131 and Cs-137 were used to assess the scale of the accident. It has been added to the assessment of only Cs-137.
(Ex.: Approx. 500PBq＋approx. 10PBq×40 (conversion factor) = approx. 900PBq)

4.2 Time Variation of Amount Released

The time variation of the amount released as described in section 4.1 is shown in Figure 27, and the time variation of the release rate is shown in Figure 28.

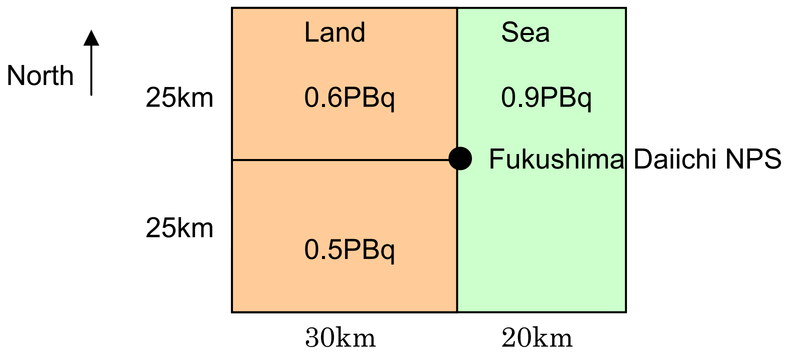
4.3 Results of Assessment of Amount of Radioactive Material Deposited

When the Cs-137 deposition amounts were assessed within the DIANA assessment range based on the amount released as assessed by DIANA, it was assessed that there was deposition of 0.6PBq on the land to the north (range of 30km west × 25km north) and deposition of 0.5PBq on the land to the south ((range of 30km west × 25km south) of the Fukushima Daiichi Nuclear Power Station, as shown in Table 4 (simplified illustration is below the table). The deposition was 0.9PBq over a range extending 20km east (sea side) × 50km north-south.

Table 4. Amount of Cs-137 Deposited in Area
Surrounding Fukushima Daiichi Nuclear Power Station (as of April 1 at 0:00)

	Deposition amount according to DIANA
North side (25km)	0.6PBq
South side (25km)	0.5PBq
Total amount	1PBq

(Illustration of range assessed for deposition amounts)



5 Discussion

5.1 Comparison of Amounts Released Against Assessment Results of Other Institutions

The results of assessments conducted by other institutions of the amounts released are shown in Table 5. From these results, the amount of Cs-137 released is almost on par with that announced by other institutions. Also, with regard to I-131, the results ended up being approximately three times more than the assessment results of other institutions. Because this assessment used a fixed ratio for the rate of the susceptibility to release from the in-core inventory at Units 1~3 across the entire assessment period (However, the in-core inventory for each time uses a calculated value which takes into consideration decay. See Chapter 2 of the Reference Materials for specific details.), there is the possibility that the amount of I-131 released is greater. For instance, in the estimation of the amount of atmospheric discharge by the Japan Atomic Energy Agency[Note 1], the results were that I-131 measured in the environment and the release rate of Cs-137 fluctuated depending on the time of release (form equivalent to approx. 100 times greater), and the ratio of susceptibility to release needs to continue to be examined.

Note 1: Open workshop held on March 6, 2012
"Reconstructing the Dispersion Process and Environmental Release Resulting from the Accident at Fukushima Daiichi Nuclear Power Station" (Sponsor: Japan Atomic Energy Agency)

Table 5. Assessment Results of Other Institutions

Institution	Announcement date	Period Assessed	Amount Released (PBq)				
			Noble gases	I-131	Cs-134	Cs-137	INES assessment
Japan Atomic Energy Agency and Nuclear Safety Commission of Japan	April 12, 2011 May 12, 2011	March 11 ~ April 5, 2011	—	150	—	13	670
Japan Atomic Energy Agency and Nuclear Safety Commission of Japan	August 22, 2011	March 12 ~ April 5, 2011		130		11	570
Japan Atomic Energy Agency	March 6, 2012	March 11 ~ April 10, 2011		120		9	480
Nuclear and Industrial Safety Agency	April 12, 2011	-	—	130	—	6.1	370
Nuclear and Industrial Safety Agency	June 6, 2011	-	—	160	18	15	770
Nuclear and Industrial Safety Agency	February 16, 2012	-	—	150	—	8.2	480
French Institute de radioprotection et de sûreté nucléaire (IRSN[Note 2])	March 22, 2011	March 12 ~ March 22, 2011	2000	200	30		

Note 2: IRSN assessed noble gases, iodine and cesium. The data were not arranged according to each nuclide, so a simple comparison cannot be made against this assessment.

5.2 Comparison Against Actually Measured Deposition Amounts

Surveys have been conducted of deposition amounts of radioactive materials by the Panel on Creation of Maps of Distributions of Radiation Doses, etc. of the Ministry of Education, Culture, Sports, Science and Technology. The surveys were conducted over the period from June until July 2011, and the revised results (amount of radioactivity) were released for deposition amounts as of June 14, 2011. (See Figure 29) Based on those survey results, the deposition amounts for Cs-137, Cs-134 and I-131 were computed for a land range extending 50km north-south and 30km east-west, which includes the Fukushima Daiichi Nuclear Power Station. The results are as follows. With DIANA, it was decided to make a comparison of the deposition amounts as of March 31, and, because the half-life of Cs-137 is longer than Cs-134 or I-131, the comparison was against the deposition amount of Cs-137 as of June 14.

Table 6. Calculated from Results (Deposition Amounts) of Surveys Conducted by Ministry of Education, Culture, Sports, Science and Technology

Cs-137	(Reference) Cs-134	(Reference) I-131
(North side) 0.8PBq	(North side) 0.7PBq	(North side) 1E-3 PBq
(South side) 0.3PBq	(South side) 0.3PBq	(South side) 8E-4 PBq
(Total) 1 PBq	(Total) 1 PBq	(Total) 2E-3 PBq

From a comparison of the DIANA assessment results and the survey results of the Ministry of Education, Culture, Sports, Science and Technology regarding Cs-137, the following were found.

① The total deposition amounts largely coincided.

② According to the survey results of the Ministry of Education, Culture, Sports, Science and Technology, the deposition amounts for Cs-134 and Cs-137 were almost the same, so the amount of Cs-134 and Cs-137 released from the power station is regarded as having been the same, and the amounts were consistent also with the results of this assessment.

③ According to the survey results of the Ministry of Education, Culture, Sports, Science and Technology, the deposition amount on the north side was larger than that on the south side, but the south and north had equal values in the results of our estimation. When making this assessment of the deposition amount, wind directions were reproduced for 16 directions using a monitoring car within the site, so it is conceivable that an error of measurement occurred for the south-north direction.

A comparison of the results of airborne monitoring by the Ministry of Education, Culture, Sports, Science and Technology (Figure 30) and the deposition assessment results by DIANA is shown in Figure 31. According to this comparison, although there are some differences regarding the direction of high contamination in assessment of the northwest direction, DIANA also reproduced a trend in which there was large deposition in the northwest direction. This is considered to have been able to largely recreate the release trend by employing rainfall data from observation stations downwind at times of rainfall when the deposition amount increases.

5.3 Assessed Values for Periods Where Air Dose Rate Data Fluctuate

Of the assessments of release amounts as stated above, the assessed values for periods where the air dose rate fluctuated are shown in Table 7, and a more detailed breakdown is given in Table 8. The assessed values for the amounts released during the period where the air dose rate fluctuated account for a large proportion of the total amount of the period from March 12 thru 31, 2011.

Table 7. Sum Total of Assessed Values for Period Where Air Dose Rate Fluctuated (Unit: PBq)

Noble gases	I-131	Cs-134	Cs-137
Approx. 500	Approx. 400	Approx. 10	Approx. 8

Table 8. Assessed Values for Periods Where Air Dose Rates Fluctuated

No	Date	Time		Putative releasing unit	Release height (m)	Noble gases (PBq)	I-131 (PBq)	Cs-134 (PBq)	Cs-137 (PBq)	Basis for unit selection (due to limitations in terms of DIANA specifications, the unit with the largest release has been selected)
1	March 12	04:00	10:10	1	~30	20	3	0.06	0.04	Only Unit 1 had core damage and venting operations were not executed, so this is regarded as a building release.
2		10:10	10:50	1	~120	3	0.5	0.01	0.008	Because S/C vent valve operation was implemented at Unit 1, this is regarded as a stack release. (Actually, it is unclear whether or not venting was able to be performed.)
3		10:50	14:00	1	~30	0.2	0.03	0.0006	0.0004	Same as No. 1.
4		14:00	15:10	1	~120	4	0.7	0.01	0.01	Same as No. 2.
5		15:30	15:40	1	~30	10	3	0.05	0.04	Because a building explosion occurred at Unit 1, this is regarded as a building release.
6		18:00	24:00	1	~30	3	0.5	0.01	0.008	Same as No1.
7	March 13	08:00	09:00	1	~30	3	0.7	0.02	0.01	The timing was prior to Unit 3 sustaining core damage, and the Unit 1 building where the refueling floor was blown off is regarded as the release location.
8		09:00	09:10	3	~120	1	0.3	0.005	0.003	Based on the venting results, this is regarded as a stack release.
9		13:30	17:00	3	~30	20	4	0.07	0.05	Because no major fluctuations were seen in D/W pressure at Units 1 and 2 and a vent valve operation was not executed for Unit 3, this is regarded as a building release.
10	March 14	02:00	04:00	3	~30	10	7	0.1	0.09	Because the reproducibility of changes in dose rate was good compared to cases where other release locations are hypothesized, the Unit 3 building is regarded as the release location.
11		07:20	09:20	3	~30	2	1	0.02	0.02	Same as No. 9.
12		11:00	11:10	3	~30	1	0.7	0.01	0.009	Because a building explosion occurred at Unit 3, this is regarded as a building release.
13		21:20	22:20	2	~120	60	40	0.9	0.6	Although it is unclear where the release location is, the assessment was made assuming that the release came from the Unit 1 and 2 stack. (See Attachment 3 Chapter 3.2)
14	March 15	06:10	07:20	1	~30	5	4	0.1	0.07	Because there was no change in the D/W internal pressure at Units 2 and 3, this is regarded as a Unit 1 building release.
15		07:20	10:20	2	~30	80	60	1	0.9	See Chapter 5.5.
16		21:30	24:00	2	~30	50	40	0.8	0.6	Same as above.
17	March 16	10:00	13:00	3	~30	100	100	2	2	Because a large volume of white smoke was confirmed to have been emitted from the reactor building at 8:30 and the Unit 3 D/W pressure decreased, this is regarded as a building release.
18	March 18	15:20	17:30	1	~30	20	20	0.7	0.5	Because there was no change in the D/W pressure at Units 2 and 3, this is regarded as a Unit 1 building release.
19	March 19	07:50	08:00	3	~30	30	30	0.9	0.6	Because the Unit 3 D/W pressure changed, this is regarded as a building release.
20		08:30	08:40	3	~30	7	6	0.2	0.1	
21		09:30	09:40	3	~30	2	1	0.04	0.03	
22	March 20	03:40	03:50	2	~30	0	1	0.03	0.02	Because the reproducibility of changes in dose rate was good compared to cases where other release locations are hypothesized, the Unit 2 building is regarded as the release location.
23		09:30	09:50	2	~30	0	0.2	0.008	0.006	
24		13:50	16:40	2	~30	0	20	0.5	0.4	
25		19:50	20:10	2	~30	0	4	0.1	0.09	
26	March 21	16:20	16:30	2	~30	0	2	0.07	0.05	Because it was confirmed that steam was rising from Unit 2 at 18:20, the Unit 2 building is regarded as the release location.
27		17:00	18:00	2	~30	0	5	0.2	0.1	
28	March 22	15:10	16:30	3	~30	0.2	0.3	0.01	0.007	Because it was confirmed that smoke was rising from Unit 3 at 7:11, the Unit 3 building is regarded as the release location.
29	March 23	13:40	16:00	3	~30	2	6	0.2	0.2	Because it was confirmed that black smoke was rising from Unit 3 reactor building at 16:20, the Unit 3 building is regarded as the release location.
30	March 25	10:10	10:30	1	~30	8	10	0.6	0.4	Because the Unit 1 D/W pressure changed, the Unit 1 building is regarded as the release location.
31		18:30	21:00	1	~30	0.6	0.8	0.05	0.04	
32	March 28	08:40	08:50	2	~30	0	0.6	0.04	0.03	Because the Unit 2 D/W pressure changed, the Unit 2 building is regarded as the release location.
33		09:40	17:00	2	~30	0	20	1	0.9	
34	March 29	04:20	05:50	1	~30	1	2	0.2	0.1	Because the Unit 1 D/W pressure changed, the Unit 1 building is regarded as the release location.
35		06:50	11:50	1	~30	4	6	0.5	0.4	
36		14:50	16:20	1	~30	0.7	1	0.1	0.07	
37		16:50	18:20	1	~30	0.1	0.2	0.02	0.01	
Total						500	400	10	8	

Guide: S/C: Suppression chamber; D/W: Dry well; MAAP: Modular Accident Analysis Program

5.4 Assessed Values for Periods Where Air Dose Rate Data Do Not Fluctuate

The assessed values for the amount released during periods where air dose rate data do not fluctuate are shown in Table 9.

Table 9. Amounts Released in Periods Where Air Dose Rate Data Do Not Fluctuate

No	Date	Time		Release height (m)	Noble gases (PBq)	I-131(PBq)	Cs-134(PBq)	Cs-137(PBq)
1	March 12	03:00	04:00	~30	0.000002	0.0000002	0.000000004	0.000000003
2		15:10	15:30	~30	0.00008	0.00002	0.0000004	0.0000003
3		15:40	18:00	~30	0.003	0.0006	0.00001	0.00001
4	March 13	00:00	08:00	~30	0.001	0.0003	0.000006	0.000004
5		09:10	11:00	~120	0.001	0.0003	0.000005	0.000003
6		11:00	12:30	~30	0.002	0.0004	0.000007	0.000005
7		12:30	13:30	~120	0.04	0.009	0.0002	0.0001
8		17:00	20:40	~30	0.003	0.001	0.00003	0.00002
9		20:40	24:00	~120	0.003	0.001	0.00002	0.00002
10	March 14	00:00	02:00	~30	0.01	0.007	0.0001	0.00009
11		04:00	05:20	~30	0.01	0.005	0.00009	0.00006
12		05:20	07:20	~30	0.07	0.04	0.0007	0.0005
13		09:20	11:00	~30	0.004	0.002	0.00004	0.00003
14		11:10	21:20	~30	0.002	0.001	0.00002	0.00002
15		22:20	23:40	~120	0.00003	0.00002	0.0000005	0.0000003
16		23:40	24:00	~30	0.008	0.005	0.0001	0.00008
17	March 15	00:00	06:10	~30	0.02	0.02	0.0003	0.0002
18		10:20	16:10	~30	7	5	0.1	0.08
19		16:10	20:50	~30	0.5	0.4	0.009	0.006
20		20:50	21:30	~30	1	0.9	0.02	0.01
21	March 16	00:00	02:20	~30	0.3	0.3	0.006	0.004
22		02:20	06:20	~30	6	4	0.1	0.07
23		06:20	08:30	~30	1	0.8	0.02	0.01
24		08:30	10:00	~30	0.7	0.6	0.01	0.009
25		13:00	24:00	~30	1	1	0.02	0.02
26	March 17	00:00	21:30	~30	0.03	0.03	0.0007	0.0005
27		21:30	21:40	~30	30	40	1	0.8
28		21:40	24:00	~30	0.004	0.003	0.00009	0.00006
29	March 18	00:00	05:30	~30	0.09	0.08	0.003	0.002
30		05:30	07:20	~30	0	2	0.07	0.05
31		07:20	15:20	~30	0.1	0.1	0.004	0.003
32		17:30	24:00	~30	0.1	0.1	0.004	0.003
33	March 19	00:00	07:50	~30	0.06	0.06	0.002	0.001
34		08:00	08:30	~30	0.004	0.004	0.0001	0.00008
35		08:40	09:30	~30	0.007	0.006	0.0002	0.0001
36		09:40	24:00	~30	0.1	0.1	0.004	0.003
37	March 20	00:00	03:40	~30	0	0.9	0.03	0.02
38		03:50	09:30	~30	0	0.5	0.01	0.01
39		09:50	11:20	~30	0	0.2	0.006	0.004
40		11:20	12:50	~30	0	0.2	0.006	0.004
41		12:50	13:50	~30	0	0.1	0.004	0.003
42		16:40	19:50	~30	0	0.7	0.02	0.02
43		20:10	24:00	~30	0	7	0.2	0.2
44	March 21	00:00	16:20	~30	0	1	0.04	0.02
45		16:30	17:00	~30	0	0.03	0.001	0.0007
46		18:00	24:00	~30	0	0.2	0.008	0.006
47	March 22	00:00	15:10	~30	0.3	0.3	0.01	0.007
48		16:30	24:00	~30	0.1	0.1	0.005	0.003
49	March 23	00:00	13:40	~30	0.3	0.3	0.01	0.008
50		16:00	24:00	~30	0	0.2	0.008	0.005
51	March 24	00:00	24:00	~30	0	3	0.1	0.1
52	March 25	00:00	10:10	~30	0.04	0.04	0.003	0.002
53		10:30	18:30	~30	0.03	0.03	0.002	0.002
54		21:00	24:00	~30	0.01	0.01	0.0009	0.0006
55	March 26	00:00	24:00	~30	0	0.2	0.01	0.008
56	March 27	00:00	24:00	~30	0	0.2	0.01	0.009
57	March 28	00:00	08:40	~30	0	0.09	0.006	0.004
58		08:50	09:40	~30	0	0.009	0.0006	0.0004
59		17:00	24:00	~30	0	0.08	0.006	0.004
60	March 29	00:00	04:20	~30	0.02	0.03	0.002	0.002
61		05:50	06:50	~30	0.004	0.006	0.0005	0.0004
62		11:50	14:50	~30	0.01	0.02	0.002	0.001
63		16:20	16:50	~30	0.002	0.003	0.0003	0.0002
64		18:20	24:00	~30	0.02	0.04	0.003	0.002
65	March 30	00:00	24:00	~30	0.02	0.04	0.003	0.002
66	March 31	00:00	24:00	~30	0.02	0.04	0.004	0.003
Total					50	70	2	1

5.5 Assessment of Each Event

The results in the previous chapter have been compiled and the assessment results for the release amounts as assessed for each event, including explosions which occurred at Units 1~3, venting and so on, are shown in Table 10.

The sum total released due to these events is approximately 1/10 of the sum total calculated in regard to Cs-137. As stated previously, in addition to calculation of the amounts released being premised on conservative assumptions, it is believed that these results are because of continuing building releases due to leaks from the primary containment vessel as well as these events.

Table 10. Amounts Released by Event

Unit	Date/time	Event	Amount released (PBq)			
			Noble gases	I-131	Cs-134	Cs-137
1	March 12 after 14:00	Primary containment vessel venting	4	0.7	0.01	0.01
	March 12 15:36	Building explosion	10	3	0.05	0.04
3	March 13 after 9:00 Note 1	Primary containment vessel venting	1	0.3	0.005	0.003
	March 13 after 12:00 Notes 1, 2	Primary containment vessel venting	0~0.04	0~0.009	0~0.0002	0~0.0001
	March 13 after 20:00 Notes 1, 2	Primary containment vessel venting	0~0.003	0~0.001	0~0.00002	0~0.00002
	March 14 after 6:00 Note 3	Primary containment vessel venting	0~0.003	0~0.001	0~0.00002	0~0.00002
	March 15 after 16:00 Note 3	Primary containment vessel venting	0~0.003	0~0.001	0~0.00002	0~0.00002
	March 16 around 2:00 Note 3	Primary containment vessel venting	0~0.003	0~0.001	0~0.00002	0~0.00002
	March 17 after 21:00 Note 3	Primary containment vessel venting	0~0.003	0~0.001	0~0.00002	0~0.00002
	March 18 after 5:00 Note 3	Primary containment vessel venting	0~0.003	0~0.001	0~0.00002	0~0.00002
	March 20 after 11:00 Note 3	Primary containment vessel venting	0~0.003	0~0.001	0~0.00002	0~0.00002
	March 14 11:01 Note 2	Building explosion	1	0.7	0.01	0.009
Total			Approx. 20	Approx. 4	Approx. 0.09	Approx. 0.06

Note 1: It is believed that Units 1~3 released radioactive material directly to the atmosphere from the primary containment vessel due to the building explosions and opening of blowout panels. Because it is difficult to separate the releases resulting from venting and releases directly from the primary containment vessel in making an assessment, building explosions occurring after or venting implemented after a building explosion or blowout panel opened are assessed as comprising also radioactive material released directly from the primary containment vessel.

Note 2: Because peaks do not appear in the dose rate, it is assumed in making the assessment that there was a release to the extent that it did not effect any variation in the dose rate.

Note 3: With regard to the venting of Unit 3, it has been found that the amount released at the time of venting decreases with each time a based on the assessment results of venting which was conducted three times on March 13. Fluctuations in the air dose rate have not been confirmed in regard to venting conducted on or after March 14, so it is possible that the release of radioactive material was even less, and this is regarded as being the same as the amount released during venting after 20:00 on March 13.

5.5.1 Amount of Radioactive Material Released at Time of Building Explosion

At Units 1, 3 and 4, the reactor buildings (hereinafter “R/B”) were damaged due to explosions presumed to have been caused by hydrogen gas generated by damaged fuel. The assessment results of the amount of radioactive material released in each building explosion are compiled below.

- Unit 1

At around 15:36 on March 12 at Unit 1, an explosion occurred in the upper part of the R/B, and the roof and exterior walls of the 5th floor were damaged. At the time of the explosion, a southeast wind was blowing, and the air dose rate was measured by monitoring cars near the main gate, monitoring post (MP)-4 and MP-8. Near MP-4, the air dose rate peaked just a short time prior to the explosion. The cause of this may be an error of measurement of several minutes as the times when dose rates were measured were recorded using wristwatches and other time pieces possessed by the observers in monitoring cars, etc. Also, steam released from the building before the explosion may have altered the air dose rate. For this reason, the amount released due to the explosion was assessed based on the peak in the air dose rate observed near MP-4. The assessment results for amounts of radioactive material released at the same building explosion are shown in Table 11.

- Unit 3

At around 11:01 on March 14 at Unit 3, an explosion occurred in the upper part of the R/B, damaging the entire portion above the refueling floor and the exterior walls on the south and north of the floor beneath the refueling floor. At the time of the explosion, the air dose rate was being measured by monitoring cars near MP-3 and MP-4, the wind was blowing northwest, and a significant peak did not appear in the air dose rate. In contrast to the direction the plume was flowing and even with the MPs upwind, a peak would likely appear in the dose rate at an MP if there a large amount of radioactive material were released due to the impact of direct radiation. However, with the Unit 3 building explosion, the wind was blowing northwest and significant peaks did not emerge in the air dose rate, so it is difficult to conceive that there was a release of a large amount of radioactive material. The assessment results for amounts of radioactive material released in the same building explosion are shown in Table 11.

- Unit 4

With regard to Unit 4, an explosion occurred in the R/B at around 6:12 on March 15, and the area of the roof at the 5th floor of the R/B was damaged. At the time of the explosion, a north wind was blowing, and the air dose rate was not measured for a short time after the explosion. When it is taken into consideration that the wind velocity at the time was 2m/s, the plume released accompanying the building explosion is believed to have moved outside the power station premises a short time later when measuring of air dose rates was available. The amount released following the building explosion at Unit 4 was not able to be assessed. With regard to the building explosion at Unit 4, the hydrogen generated in the Unit 3 reactor is thought to have traversed the Unit 3 venting line and flowed backward into the Unit 4 standby gas treatment system and then flowed into the Unit 4 building. When the dose was measured of the filter on the Unit 4 standby gas treatment system on August 25, 2011, it was confirmed that while there was a small amount in the filter, radioactive material had been captured, and it is thought that very little radioactive material flowed into the Unit 4 building, so it is conceivable that the amount of radioactive material released following the Unit 4 building explosion was also small.

Table 11. Assessment Results of Amount of Radioactive Material Released at Time of Building Explosion

Unit	Date/time	Amount released (PBq)			
		Noble gases	I-131	Cs-134	Cs-137
1	March 12 at around 15:36	~10	~3	~0.05	~0.04
3	March 14 at around 11:01	~1	~0.7	~0.01	~0.009
4	March 15 at around 6:12	-	-	-	-
Total		~10	~3	~0.07	~0.05

When compared with the assessment results stated in section 4.1, the release accompanying building explosions at any of the units is considered to be smaller.

5.5.2 Amount of Radioactive Material Released Accompanying Primary Containment Vessel Venting

Operations were attempted to depressurize the primary containment vessel using venting at Units 1~3. At Units 1 and 3, primary containment vessel venting is thought to have succeeded, but it is not known whether or not primary containment vessel venting succeeded at Unit 2.

The assessment results of the amount released due to venting are shown in Table 12. In these venting operations, radioactive material ended up being released to the atmosphere along with steam and hydrogen. In this assessment, the amount of radioactive material released accompanying primary containment vessel venting has also been assessed, but, as shown on Attachment 2, the amount released following primary containment vessel venting is less than 1 percent of the total, and it has not been assessed as having been the controlling release of radioactive material. This is thought to be due to primary containment vessel venting having decreased the release of radioactive material. (See Attachment 2)

Table 12. Comparison of Amount Released Accompanying Primary Containment Vessel Venting and Amounts Released Accompanying the Other Events

Radioactive material / Mode of release	Noble gases (PBq)	I-131 (PBq)	Cs-134 (PBq)	Cs-137 (PBq)
Primary containment vessel venting Note 1	~5	~1	~0.02	~0.01
Building explosion	~10	~3	~0.07	~0.05
Release from building	~500	~500	~10	~10
Total	~500	~500	~10	~10

Note1: Because it is not known whether or not steam was released accompanying venting, the amount released at the time of the first venting valve operation at Units 1 and 2 is not included in the amount released at the time of primary containment vessel venting.

5.5.3 Amounts Released from Reactor Buildings

In this accident, in addition to releases accompanying primary containment vessel venting and building explosions, it is believed that radioactive material was released to the atmosphere from R/Bs. The assessment results for the amount of radioactive material released from R/Bs are shown in Table 12. The amount released from R/Bs was larger than even the releases accompanying primary containment vessel venting and building explosions, but this is inferred to be due to radioactive material leaking without undergoing S/C pool scrubbing.

It is difficult to specify the path of release from the primary containment vessel to the R/B (leak location), but, from the results of field surveys and data on the design of the primary containment vessel, it is thought that the leak might have occurred at the seal of the primary containment vessel top head flange. (See Attachment 3)

5.6 Factors in Contamination of Area Northwest as Viewed from Fukushima Daiichi Nuclear Power Station

With regard to the area northwest from the Fukushima Daiichi Nuclear Power Station, the extent of contamination is larger than other areas due to radioactive material as is clear even in the soil sampling surveys of the Ministry of Education, Culture, Sports, Science and Technology shown in Figure 30. As stated previously, the amount of radioactive material released accompanying building explosions and primary containment vessel ventings is less than the assessment results in section 4.1 and the factors leading to contamination are thought to be due to other release events. This chapter will examine factors involved in the contamination of this area.

○ Change in Deposition Amounts on North Side of Power Station

According to the assessment results for deposition amounts as derived by DIANA (Table 13), the deposition amount on the north side of the power station increased on March 15, and releases on the same day are estimated to have contributed to the contamination in the northwestern area. Below, March 15 is discussed.

Table 13. Changes in Deposition Amounts of Cs-137
(25km north ×30km west of the power station)

	March 15 0:00	March 16 0:00	April 1 0:00
Deposition amounts of Cs-137 (unit: PBq)	0.004	0.3	0.6

○ Air dose rate on March 15

According to Figure 9, near the main gate for a period of several hours beginning after 7:00 on March 15, the dose rate rose rapidly from several hundred μSv/h to 10,000μSv/h, and, although the dose rate lowered to 1,000μSv/h after 12:00 on the same day, a dose rate close to 10,000μSv/h was again measured after 23:00, and it is estimated that radioactive material was released on the same day.

○ Amount Released on March 15

Based on fluctuations in the air dose rate as stated above, the results assessed for noble gases, iodine and cesium released from the power station on March 15 are shown in Table 14. From these results, the amount released on the same day is found to have been larger than the amount released accompanying the building explosions and primary containment vessel venting. This sort of release is significantly different from the behavior at the time of venting of the primary containment vessels at Units 1 and 3, and it is inferred to be due to radioactive material leaking without undergoing S/C pool scrubbing.

Table 14. Amounts Released on March 15

	Noble gases (PBq)	I-131(PBq)	Cs-134(PBq)	Cs-137(PBq)
Unit 2 building release	100	100	2	2

○ Location of Release of Radioactive Material on March 15

As to the location of the release of radioactive material on the same day, because of the fact that it was confirmed white smoke, which had been confirmed in the morning at Unit 2, increased around 9:40 which was also able to be confirmed on video by the Fukuichi live camera (Figure 32), that the dose increased to 10,000μSv/h at the same time period, and that the Unit 2 D/W pressure decreased significantly during the period from 7:00 to 11:00, it is considered highly likely that the Unit 2 building was the location of the release in the morning of that day. The possibility of releases from other units is also conceivable, but because of the fact that the pressure of Unit 3 was able to be controlled using venting of the primary containment vessel and the release of radioactive material is thought to have been able to be controlled until March 20, that the D/W pressure of Unit 1 was stable on March 13 and 14 and it is difficult to conceive that releases increased on the March 15, and that there was no significant change in wind velocity from early in the morning on that day until 7:00 and it is conceivable that an event which occurred after 7:00 on the same day was involved in raising the air dose rate, it is thought that there is little likelihood that a release from Unit 1 or Unit 3 contributed to a rise in the dose rate on March 15. The locations of the release in the afternoon of that day also continued to the morning, and there is a high likelihood that it was the Unit 2 building. The reasons cited are that it is difficult to conceive of the release from the Unit 2 building in the morning suddenly stopping, and that a high dose rate was observed equivalent to that measured in the morning of the same day near the main gate when the wind direction changed from southeast to northeast around 23:00 on the same day and it is thought that the release had continued from the morning of the same day.

○ Relationship Between Path of Plume Released from Unit 2 Building and Contamination in Area to the Northwest

The path of the plume released from the Unit 2 building, which was estimated from wind direction, wind velocity and atmospheric stability, is shown in Figures 33 and 34. As shown in these figures, the plume initially was headed southwest, which included the direction of the main gate. It is estimated that the dose rate near the main gate rose rapidly in the morning of March 15 due to the movement of this plume. After that, the wind direction shifted to the south-southeast beginning around 12:00, and the plume would flow toward the area of high contamination in a northwestern direction as viewed from Fukushima Daiichi Nuclear Power Station. The wind direction continued until around 23:00 on the same day, and it is thought that the plume released from Fukushima Daiichi Nuclear Power Station flowed in a north-northwest direction over a long period of time beginning at around 12:00 and floated through the sky over the area in the same direction. These plumes are presumed to have deposited on the ground surface radioactive material, which had been floating, due to the influence of rainfall observed after 23:00 (Figure 35), bring about the high contamination in the area northwest from Fukushima Daiichi Nuclear Power Station.

6 Summary

Although the assessment methods employed by each institution differ with regard to estimating the amounts released to the atmosphere, our estimation results for Cs-137 were values almost equivalent to those announced by other institutions. Also, the deposition amounts assessed from the results of values measuring Cs-137 soil contamination density, which the Ministry of Education, Culture, Sports, Science and Technology conducted, and the assessed values for deposition amounts by DIANA showed the deposition amounts to be almost equal. From these results also, we believe that the assessment results for the amount of Cs-137 released are on the whole valid. However, our results for I-131 ended up being three times greater than those of other institutions. A factor contributing to this difference is thought to be that the ratio of susceptibility of the radioactive nuclides to release was assumed to be a fixed ratio.

In addition, there are chiefly the following types of uncertainties over the entire assessment.

- From changes in the air dose rate data at one location within the power station premises at each time during the assessment period, DIANA was used to assess the release rate such that the air dose rate data was reproduced. However, in periods when the air dose rate data was taken at two or more locations at the same time, the result is not a release rate that reproduces all of the air dose rate data.
- For wind direction, data was used for 16 directions as measured by monitoring cars.
- In light of DIANA specifications, the location of release at each time during the assessment period is limited to one location.
- Because there is no data for rainfall at the power station, data from nearby AMEDAS observation points was used.

Because of the aforementioned uncertainties, information will be exchanged with outside research institutions and continue to collect more information. When new knowledge is obtained, it will be reflected in the estimation methods and results.

7 Attachments

(1) Assessed Values for April and Later Months
(2) Impact Resulting from Primary Containment Vessel Venting
(3) Discussion of Leakage from Primary Containment Vessel

End

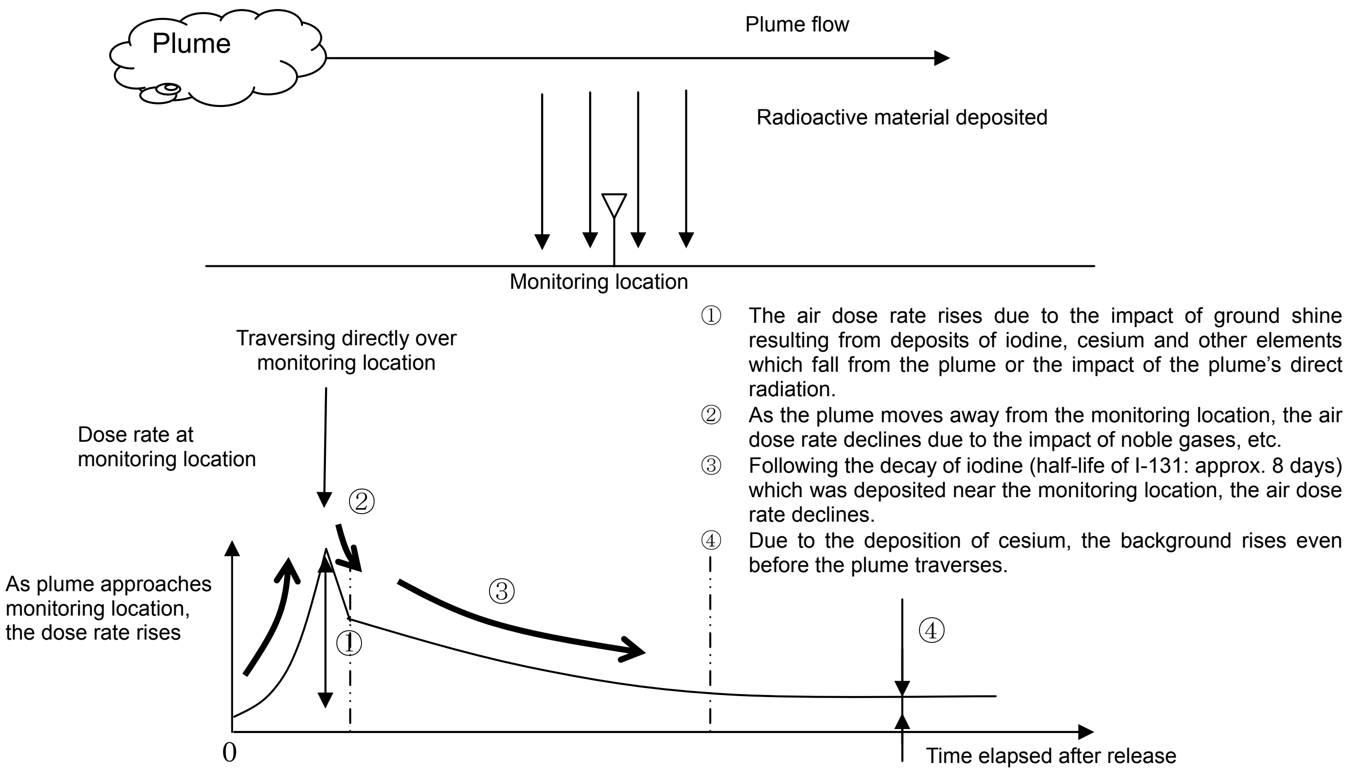
1 Plume Movement and Changes in Air Dose Rates

After the accident, multiple peaks appeared in the air dose rates measured by the monitoring cars. There are the following two types of cases in which peaks appear in the air dose rate.

1.1 Case Where Plume Approaches the Sky above Monitoring Location

A plume (steam comprising radioactive material), which comprises radioactive material released to the atmosphere as a result of venting, explosion, or other event, moves on the wind around the power station as the plume diffuses. When the plume traverses the sky over or near a monitoring location (monitoring car), a peak emerges in the air dose rate. Although differences arise also depending on wind velocity, its distinguishing feature is that the rate at which the air dose rate increases (or decreases) is less than in the case described in section 1.2 hereafter and it changes comparatively moderately. Also, because the plume comprises radioactive material, when the radioactive material is deposited (falls) near the monitoring location in the process of the plume moving, it may create a rise in background of the air dose rate.

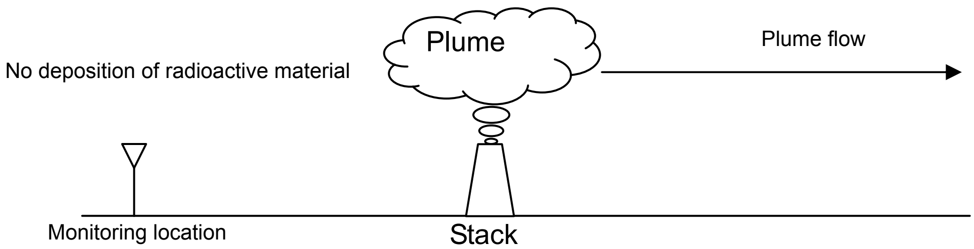
Although influenced by changes in wind direction, when wind is blowing at a velocity of 1m/s, a plume released from a stack will travers the sky over a monitoring location and move outside the site of the power station in about 10~20 minutes. Therefore, a peak appearing in the air dose rate has a high likelihood of being associated with a release event occurring approximately 10~20 prior.

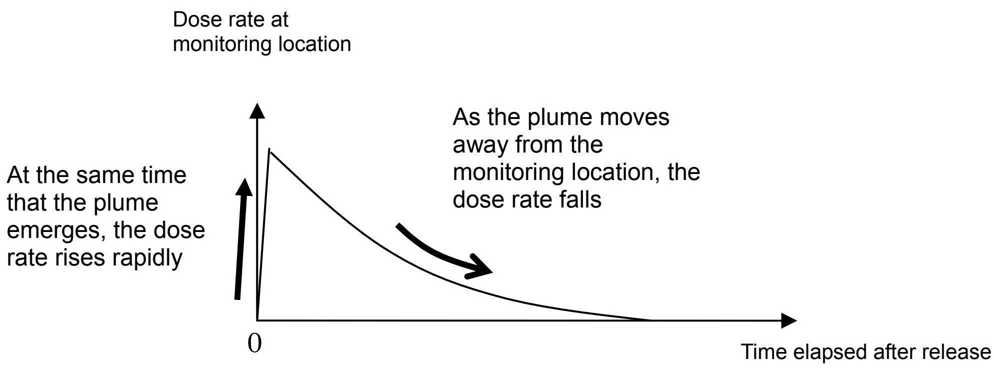


Depending on the direction of the plume and weather conditions, radioactive material may be deposited at the monitoring location, and a rise in the monitoring dose rate data is thought to occur due to the effects of ground shine resulting from the amount of radioactive material deposited and the impact of the plume's direct radiation. (See diagram above) However, the entire extent of any rise in the air dose rate data is conservatively assessed in the amount released as an impact of direct radiation.

1.2 Case Where Plume Does Not Approach the Sky above Monitoring Location

Because a plume containing radioactive material emits direct radiation and skyshine radiation, if the plume does not traverse the sky above or near the monitoring location (monitoring car) but radioactive material is released in a large amount, a peak may appear in the air dose rate. In such a case, the air dose rate rises rapidly at the point in time when the plume is released. Thereafter, when the plume traverses the sky above or near the monitoring location, a change in the air dose rate as described in section 1.1 previously is shown, but when the plume moves away from the monitoring location, the air dose rate will decrease moderately. Also, because a plume containing radioactive material does not traverse near the monitoring location, there is no deposition of radioactive material and no rise in background is brought about.





2 Ratio of Susceptibility of Radioactive Nuclides to Release

Although the ratio of the susceptibility of radioactive nuclides to release is thought to change due to factors such as the releasing unit, release location and so on, the time variation of such numerical values cannot be ascertained. Accordingly, in this assessment, it was decided to estimate the ratio of susceptibility of radioactive nuclides to release from their decay and the amount of radioactive material deposited on the soil, and then use that data in assessing the amounts released.

Specifically, the air dose rate measured in the area surrounding the power station was used to estimate the ratio of susceptibility of radioactive nuclides to release from a decay curve of the background. Because the tendency of background to decay varies depending on the amount of radioactive material (nuclides) deposited, this was utilized. In estimating the ratio of susceptibility to release, time periods when rainfall was not observed and time periods when there was commensurate deposition before and after peaks in the air dose rate as well were selected.

In this assessment, three time periods were selected: ①the peak near MP-4 around 9:00 on March 13, ②the peak after 21:00 on March 14, and ③the peak at Administrative Building-North around 15:00 on March 20. The ratio of susceptibility of iodine and cesium to release was then estimated. The results are shown in Figures 36, 37, and 38.

Although it was difficult to uniquely determine the ratio of susceptibility to release from these results, if it is assumed that the ratio of iodine to cesium is roughly 10:1, it is conceivable that a decay curve can be largely reproduced for any time period. Accordingly, in this assessment, it was decided that throughout the assessment period, the ratio of susceptibility of iodine and cesium to release would be assumed to be 10:1 and the amounts released were then assessed.

On March 21, 2011, the airborne radioactivity concentration was measured on the premises of the power station site (Administrative Building-North), but, when this data was checked, the ratio of the airborne radioactivity concentration of iodine and cesium was 40:1 (see Table 15) and based on the fact that the ratio of the in-core inventory of iodine and cesium at the same time was 4:1, it was considered to be generally appropriate to use 10:1 as the ratio of susceptibility to release.

Table 15. Airborne Radioactivity Concentration at Administrative Building-North (Samples taken from 10:19~10:39 on March 21)

	Radioactivity concentration (Bq/cm^3)	Ratio to Cs-134	Ratio to Cs-137
I-131	1.516E-3	44.8	39.9
Cs-134	3.383E-5	1	—
Cs-137	3.801E-5	—	1

In addition, based on the aforementioned ratio of susceptibility of iodine and cesium to release, the ratio of noble gases to iodine was estimated. That result is shown in Figure 39. By varying the ratio of noble gases to iodine, the background after each peak ends up fluctuating up and down, but because the change in air dose rates can be largely reproduced if the ratio of noble gases to iodine is 100:10, cesium was also included in this assessment, and the calculations were performed using 100:10:1 as the ratio of susceptibility of noble gases, iodine and cesium to release.

Because the extent of a rise in the air dose rate which results from direct radiation of released radioactive material is assessed by DIANA as the amount released, there are cases where the impact of ground shine increases and the air dose rate is not reproduced in an environment which effects a large quantity of deposition as shown in Figure 39.

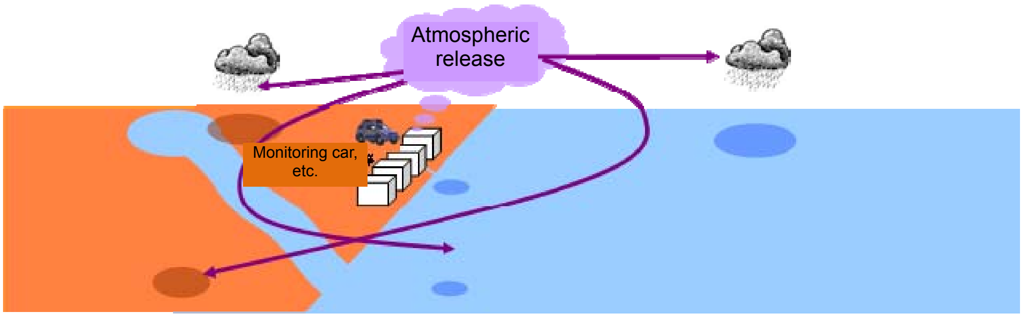


Figure 1. Illustration of Migration of Released Radioactivity

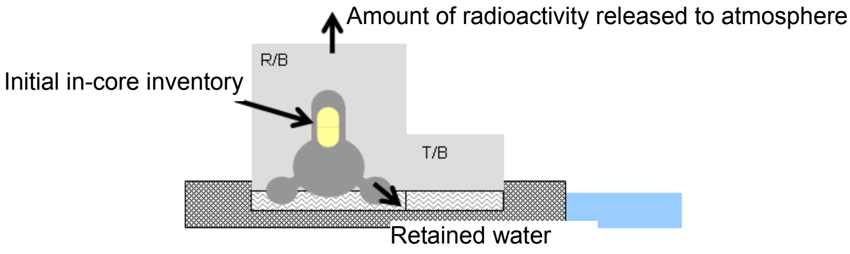


Figure 2. Illustration of Migration of Radioactivity inside a Building

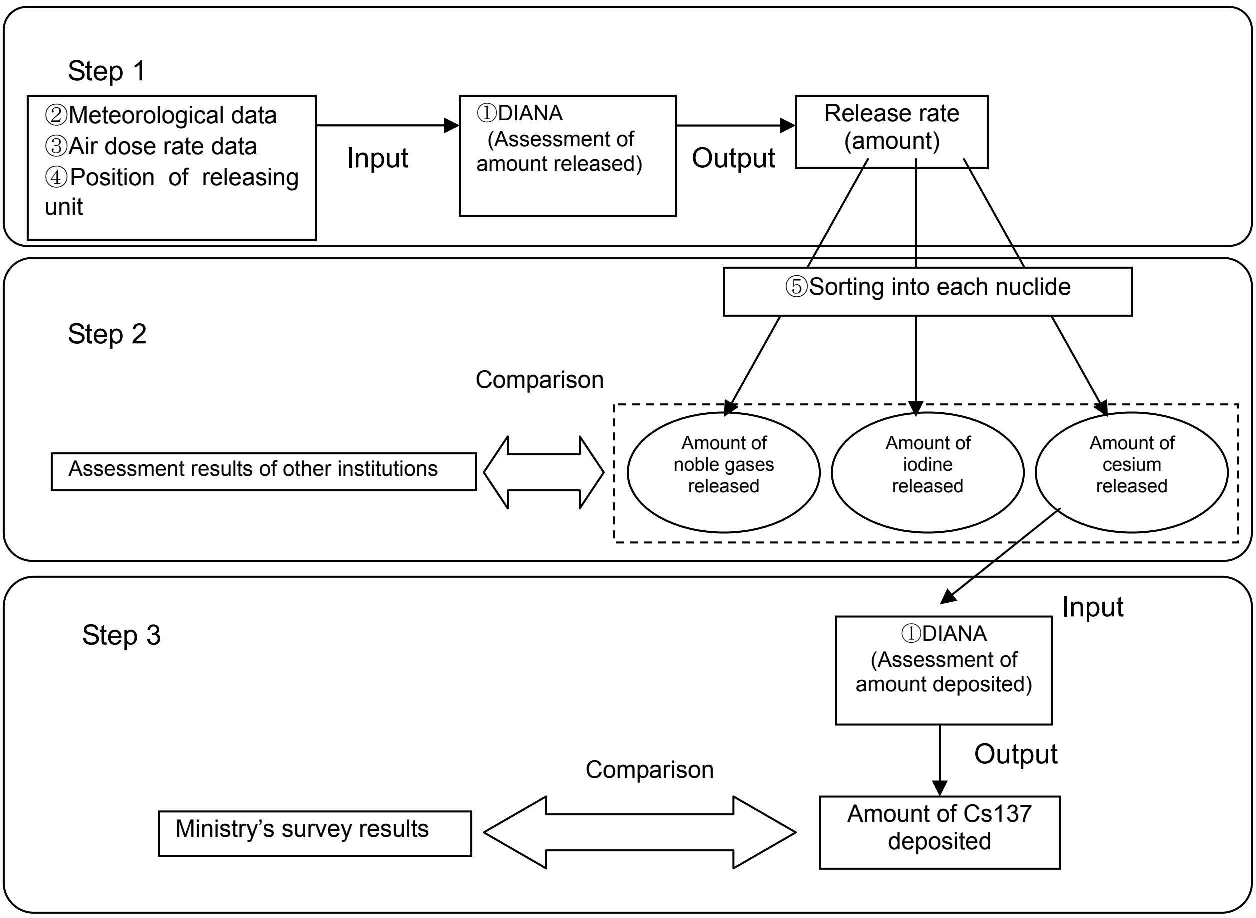


Figure 3. Assessment Sequence

Figure 4. Japan Meteorological Agency's Meteorological Observation Stations

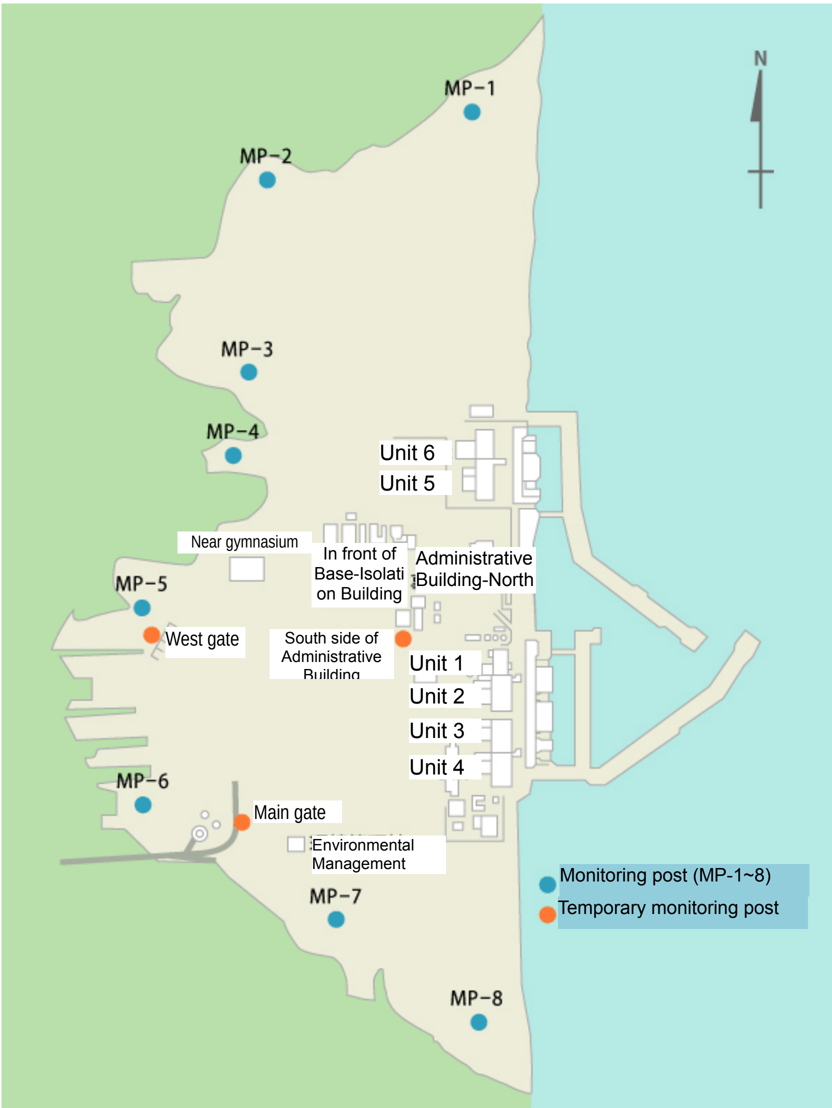


Figure 5. Diagram of Monitoring Post Arrangement

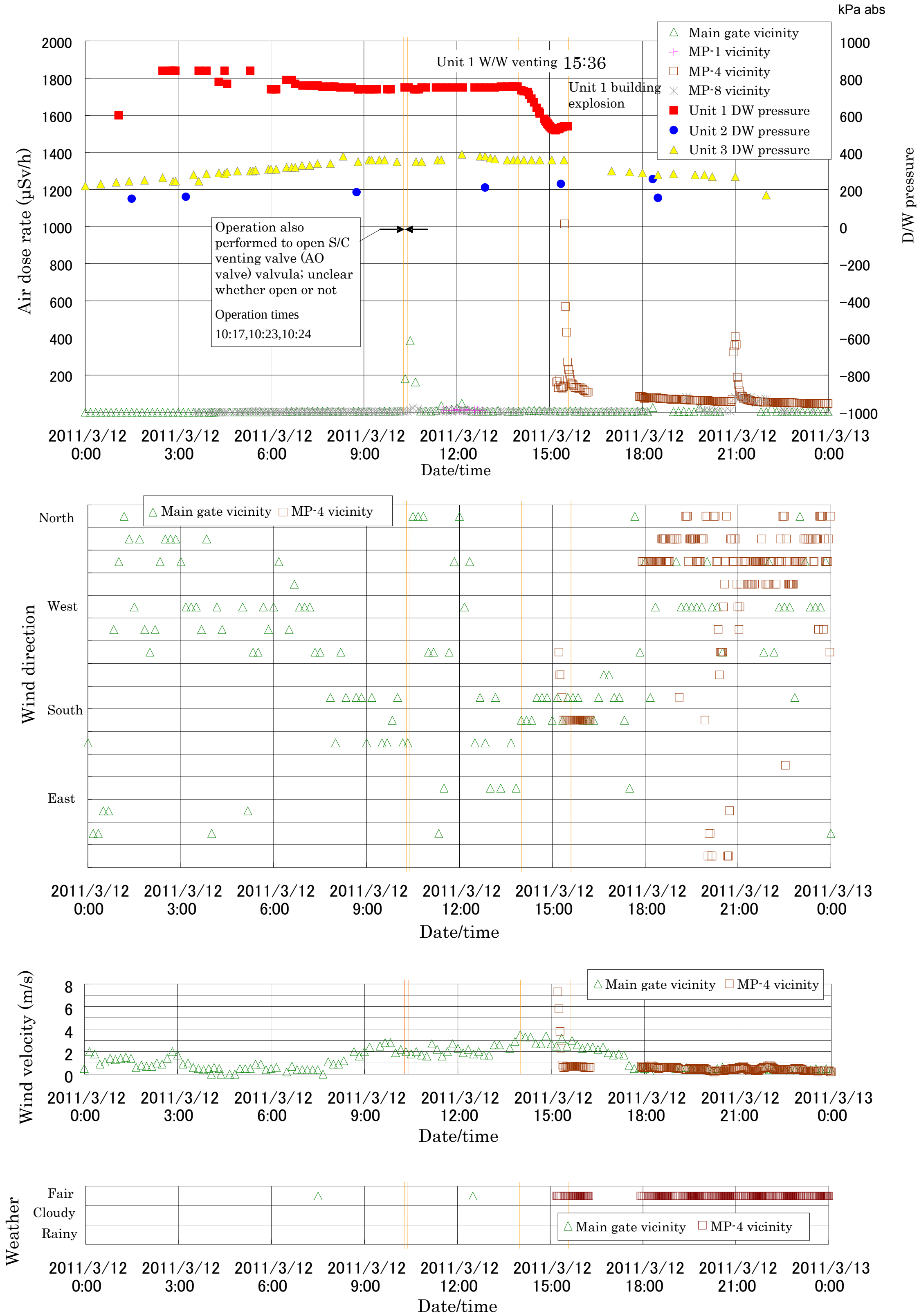


Figure 6. Change in Air Dose Rate (March 12)

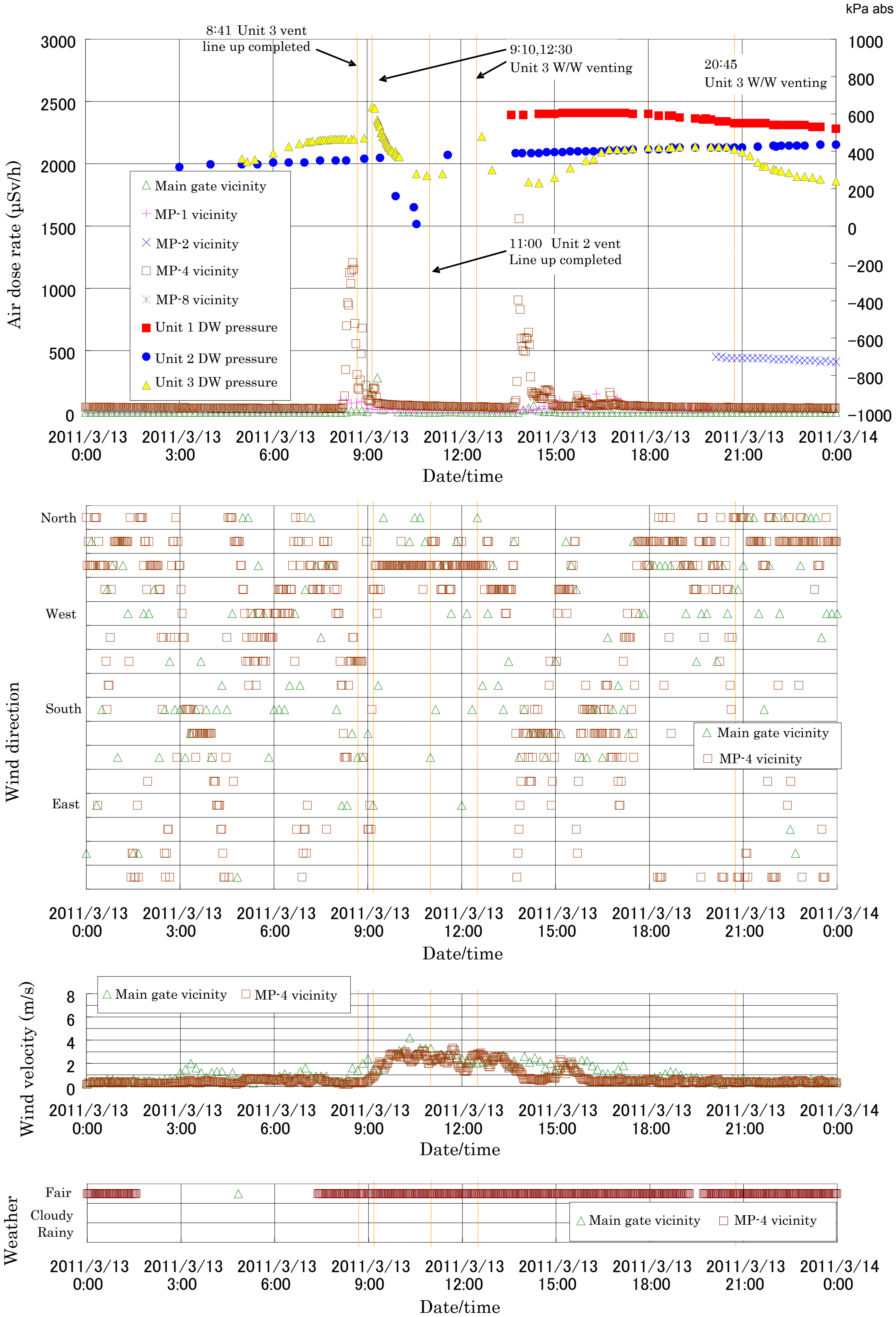


Figure 7. Change in Air Dose Rate (March 13)

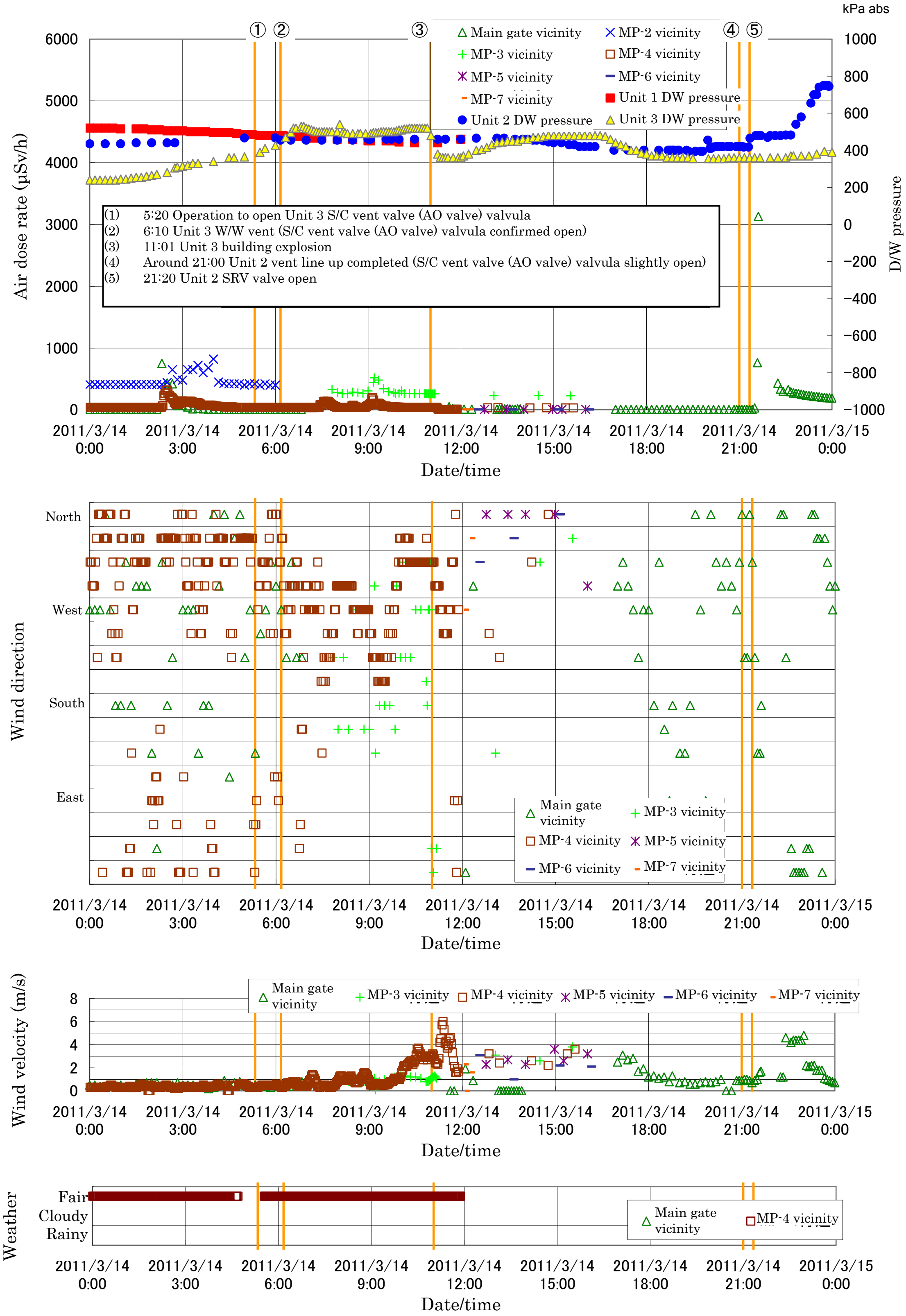


Figure 8. Change in Air Dose Rate (March 14)

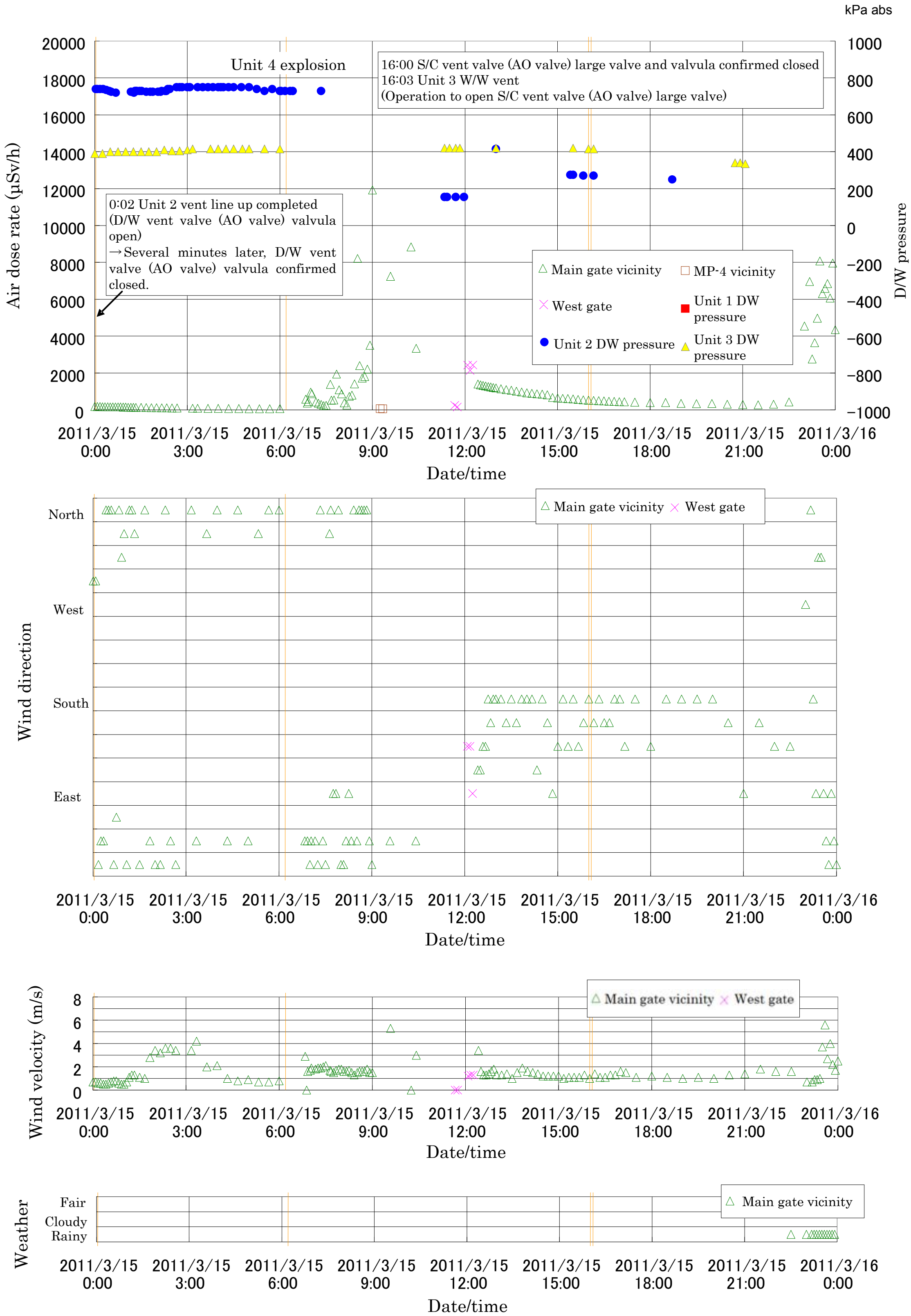


Figure 9. Change in Air Dose Rate (March 15)

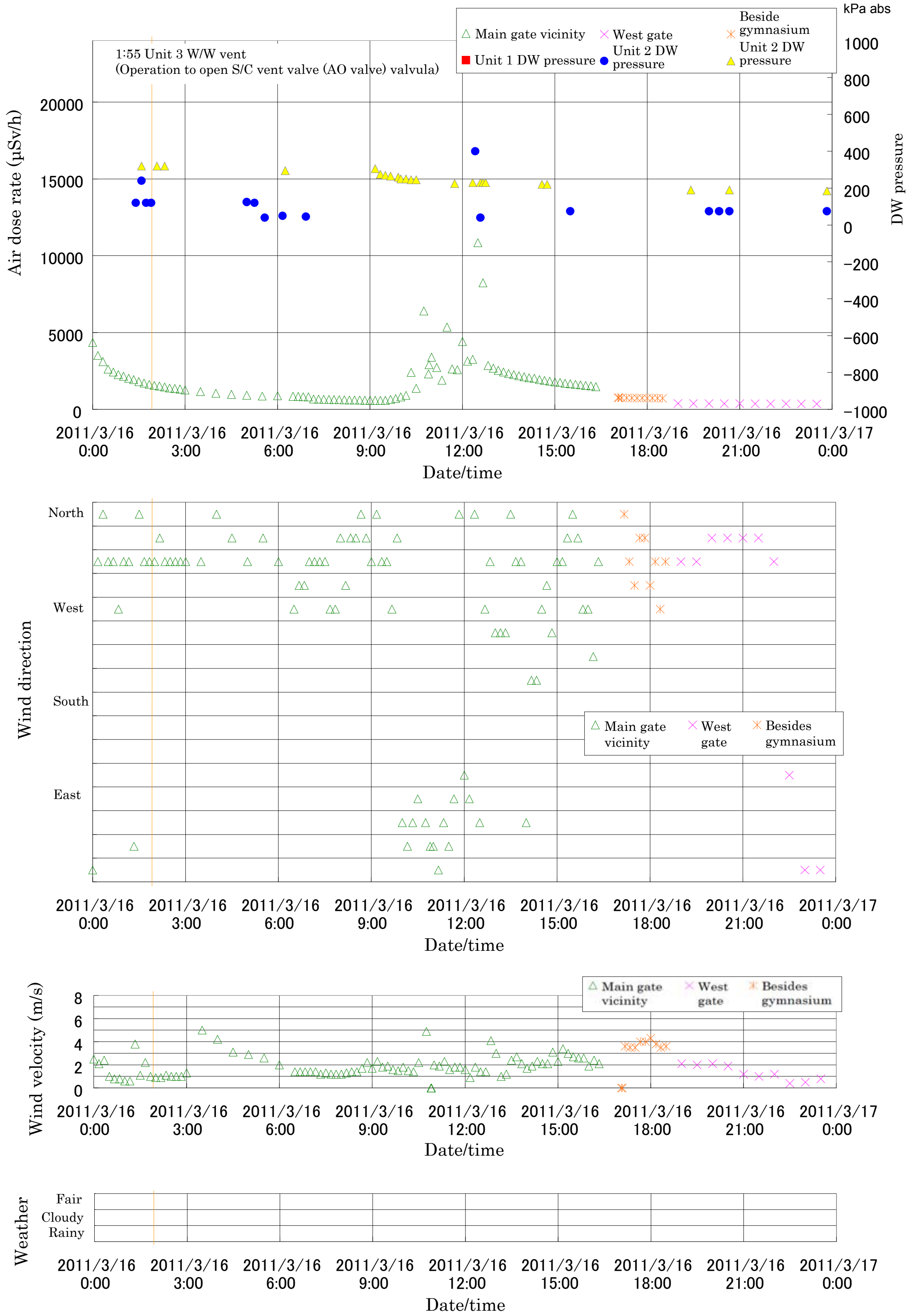


Figure 10. Change in Air Dose Rate (March 16)

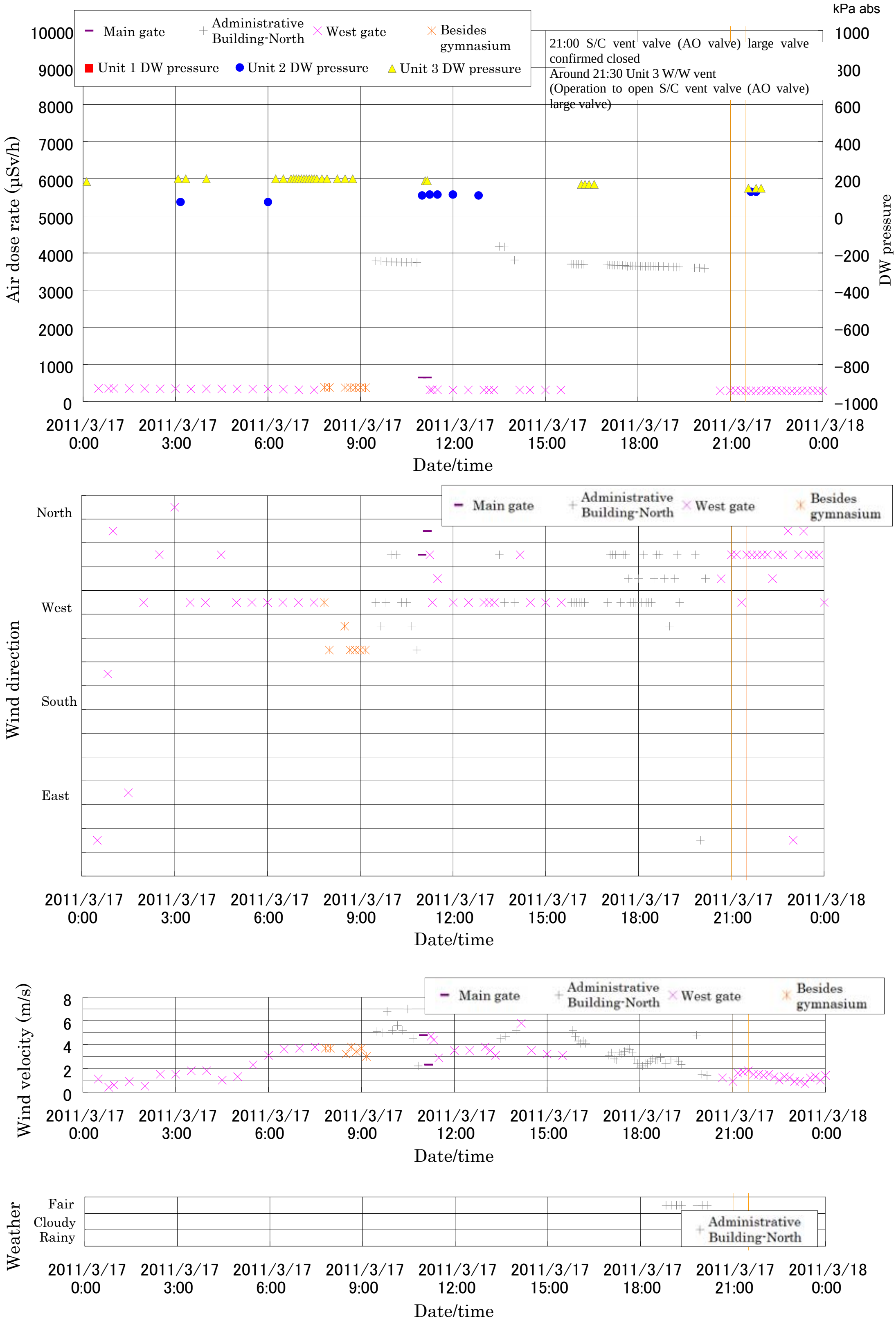


Figure 11. Change in Air Dose Rate (March 17)

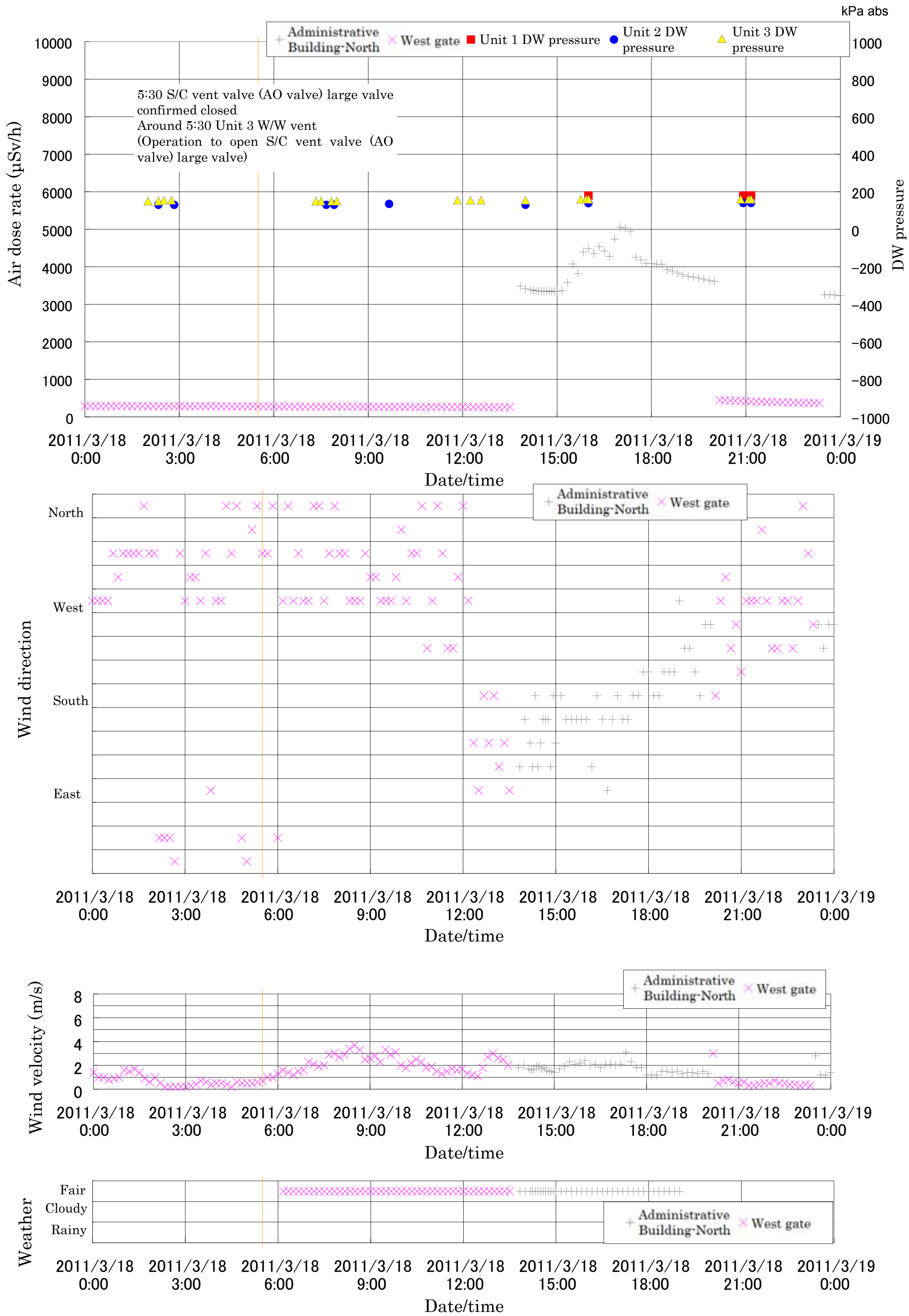


Figure 12. Change in Air Dose Rate (March 18)

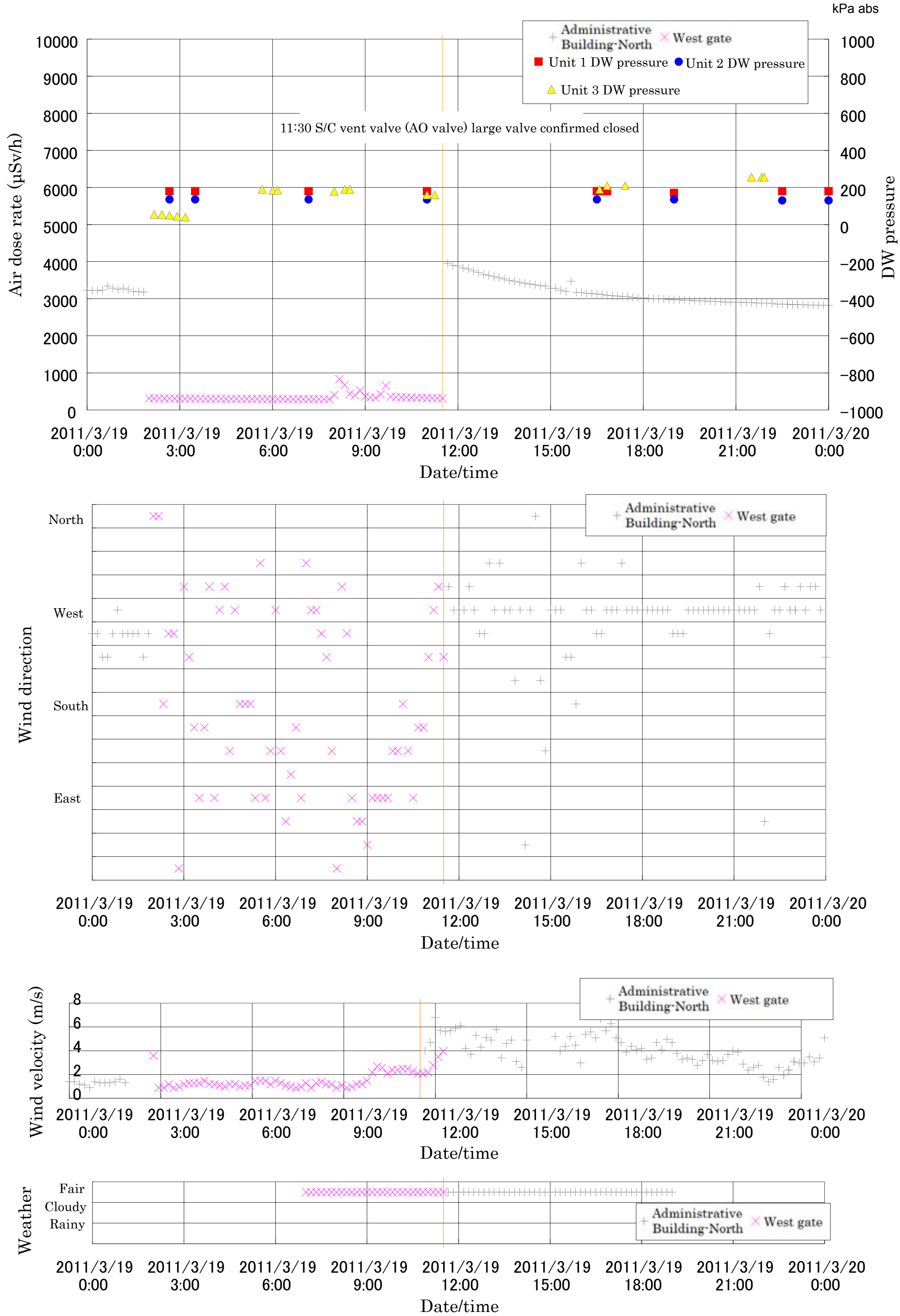


Figure 13. Change in Air Dose Rate (March 19)

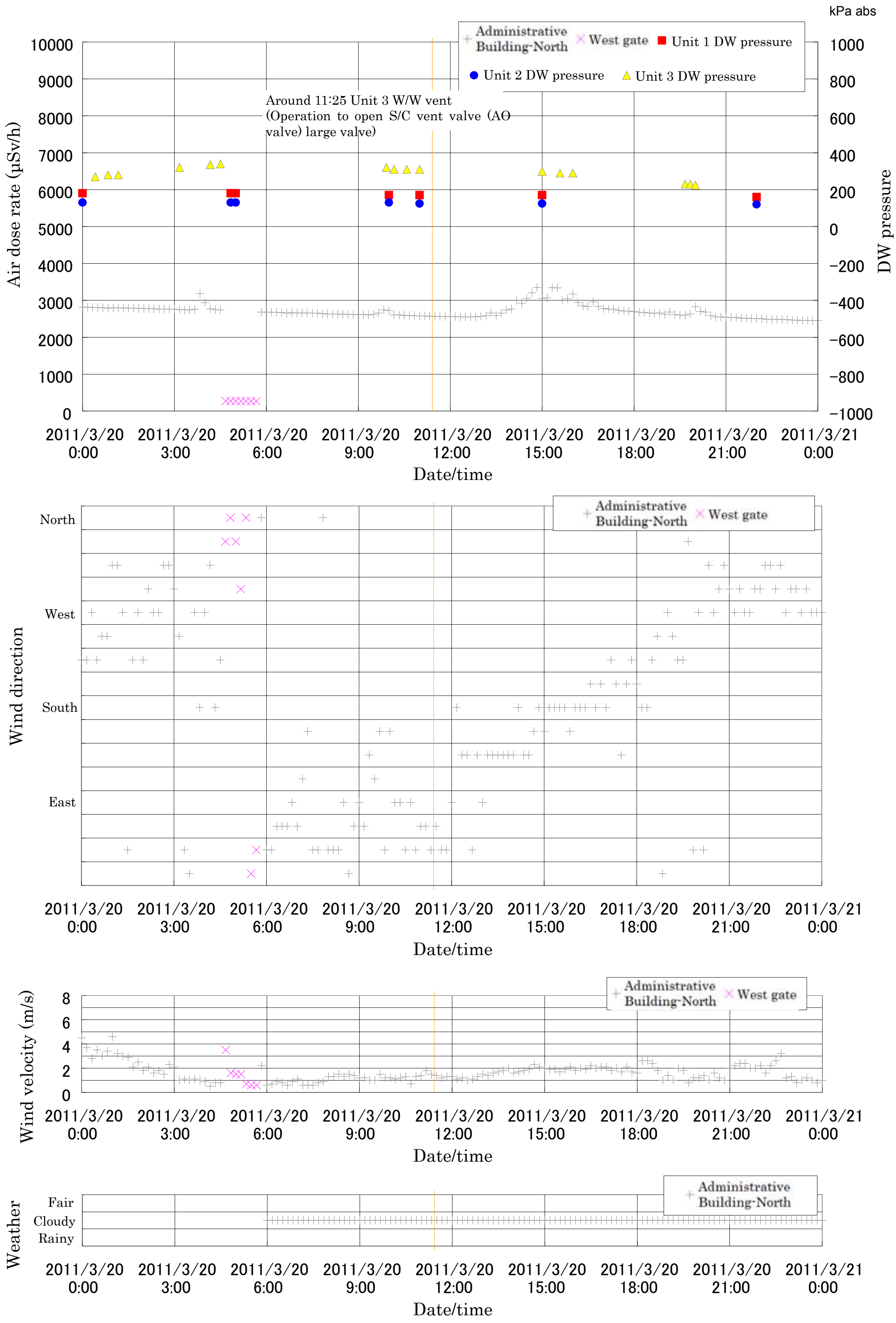


Figure 14. Change in Air Dose Rate (March 20)

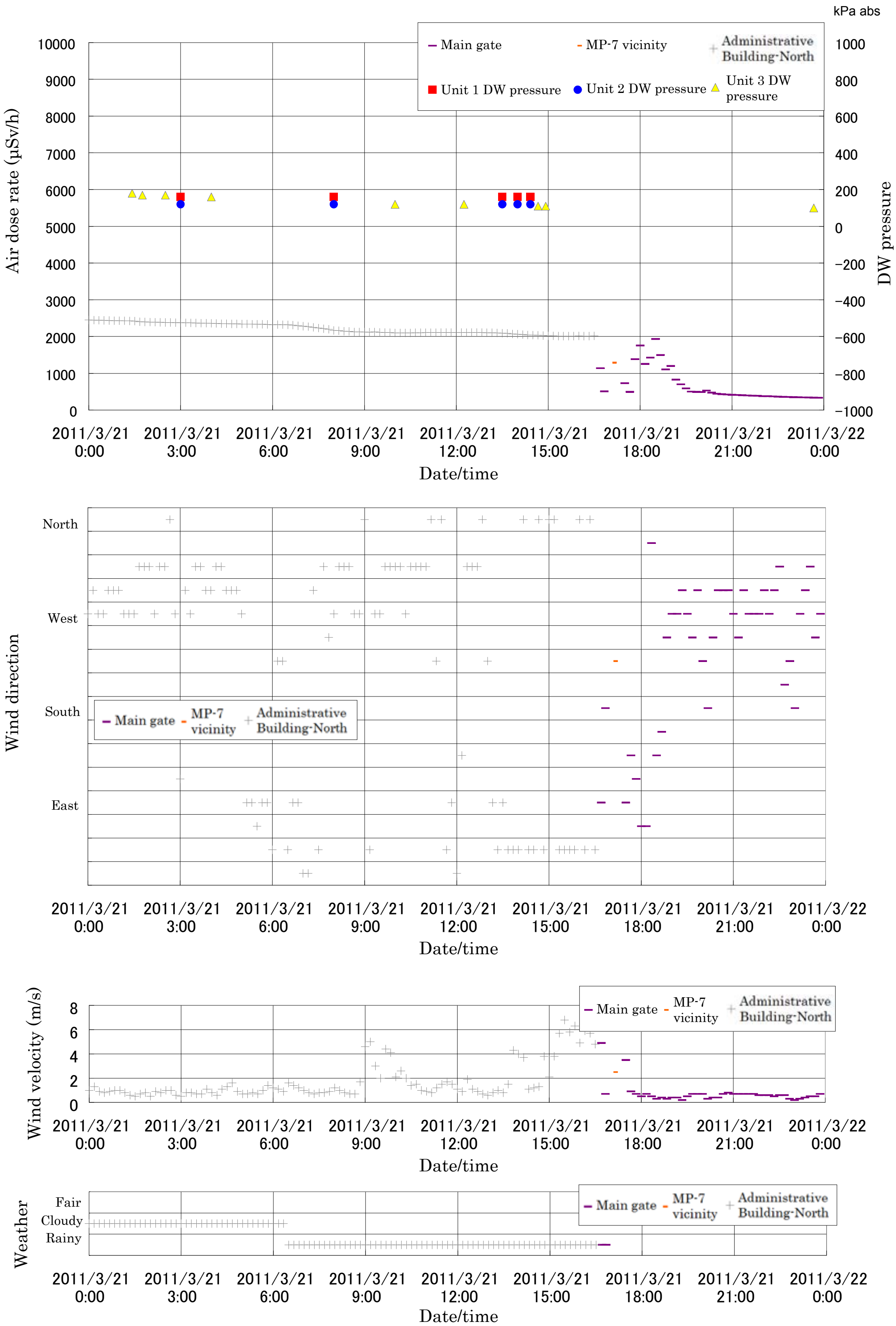


Figure 15. Change in Air Dose Rate (March 21)

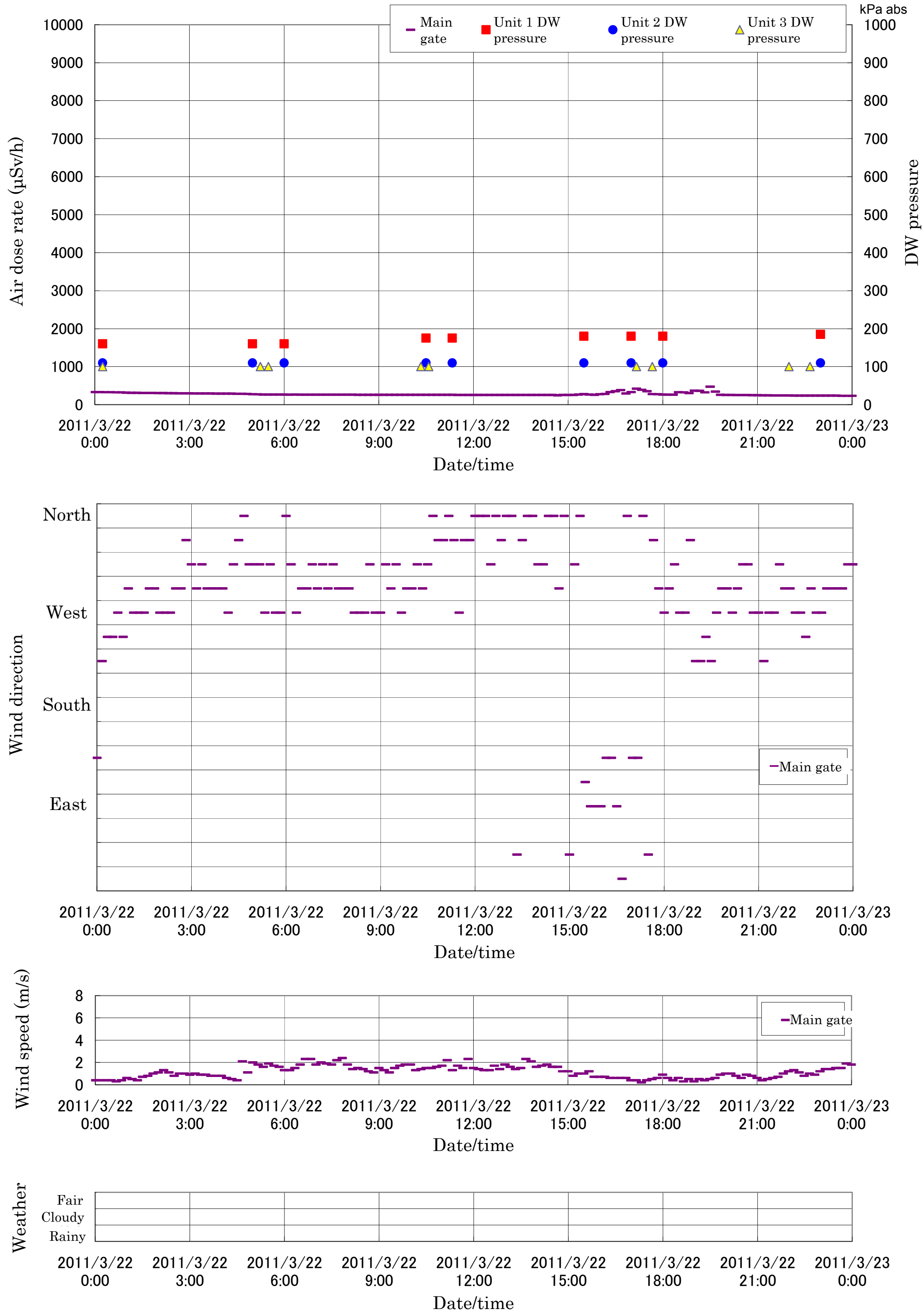


Figure 16. Change in Air Dose Rate (March 22)

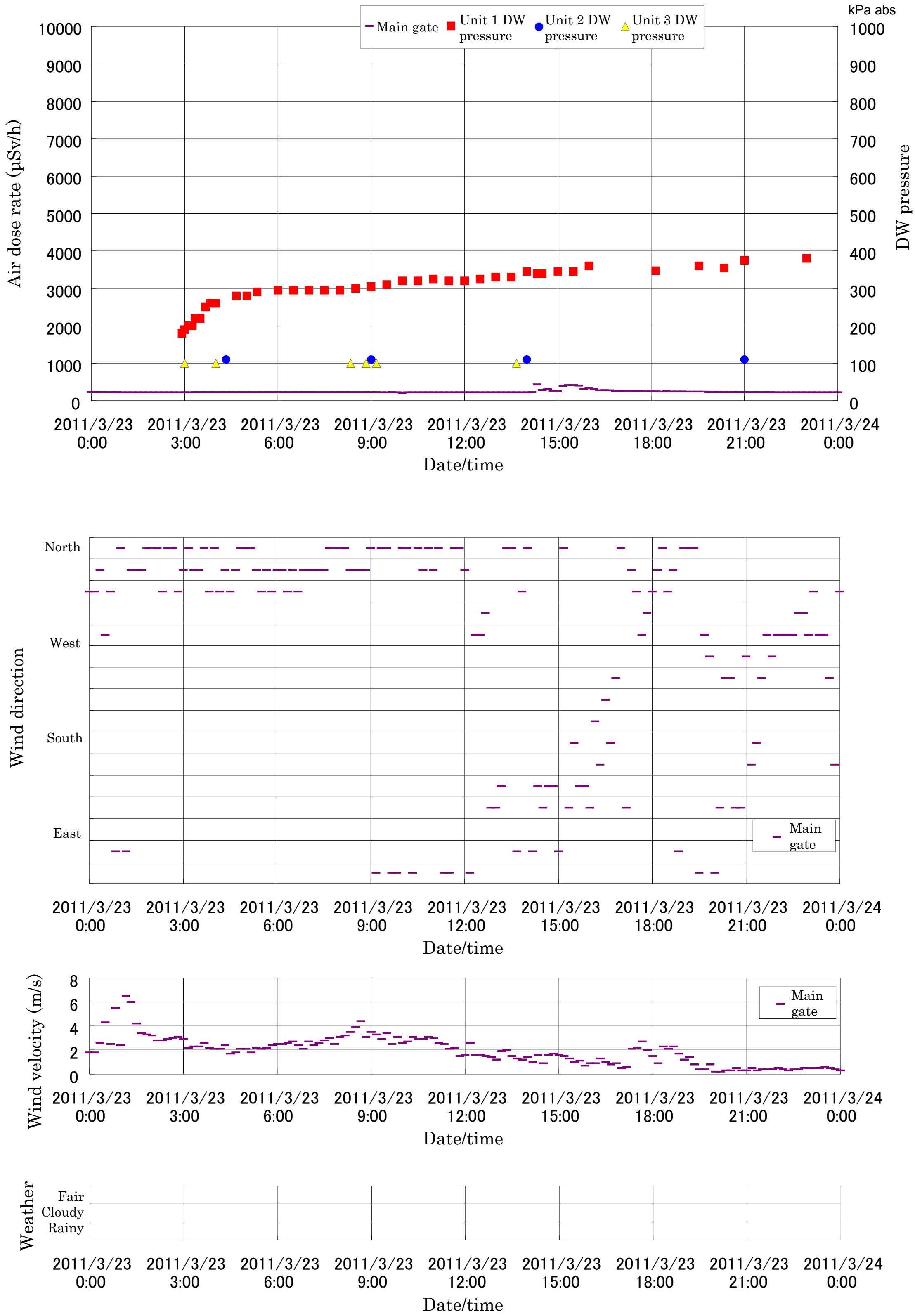


Figure 17. Change in Air Dose Rate (March 23)

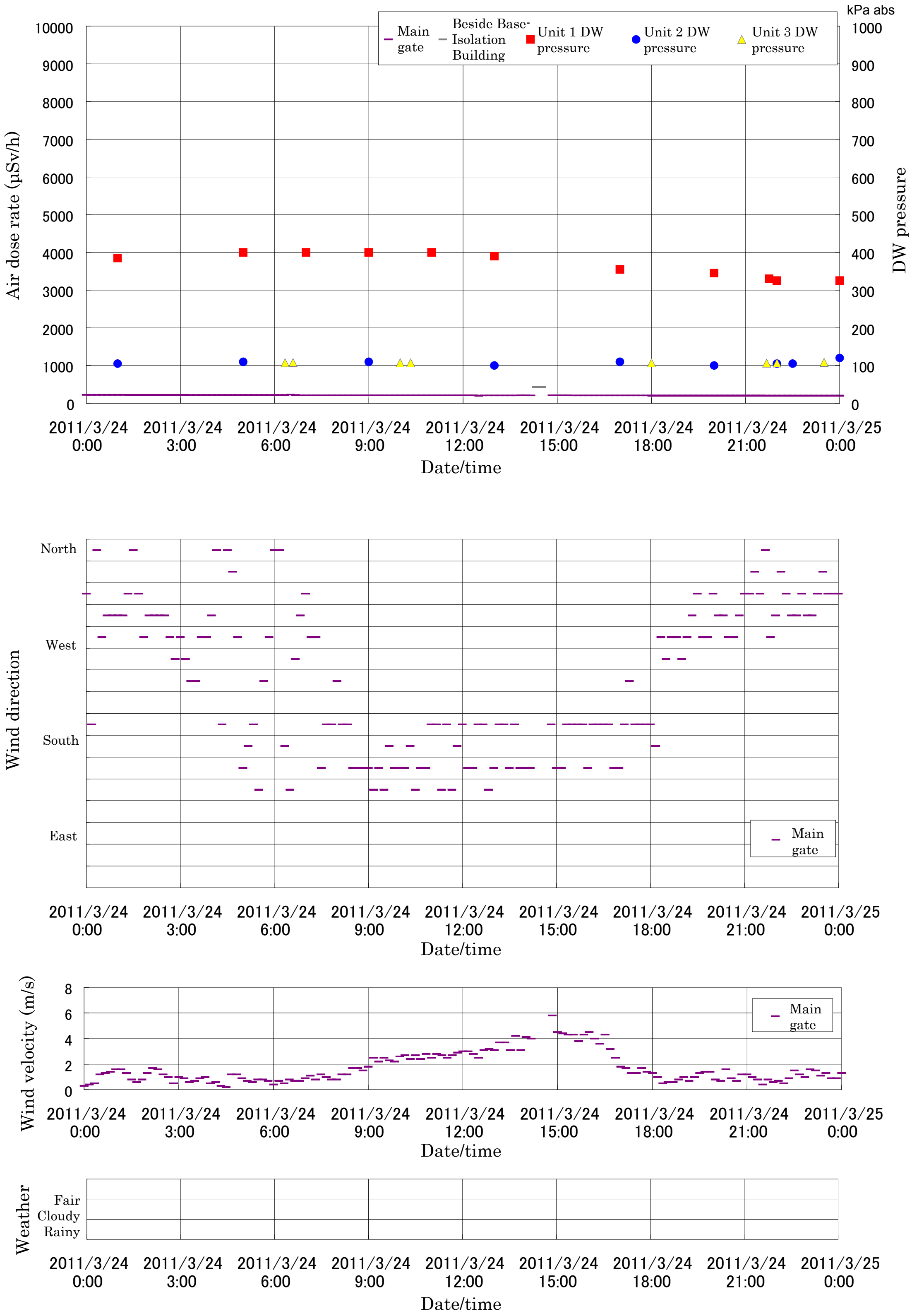


Figure 18. Change in Air Dose Rate (March 24)

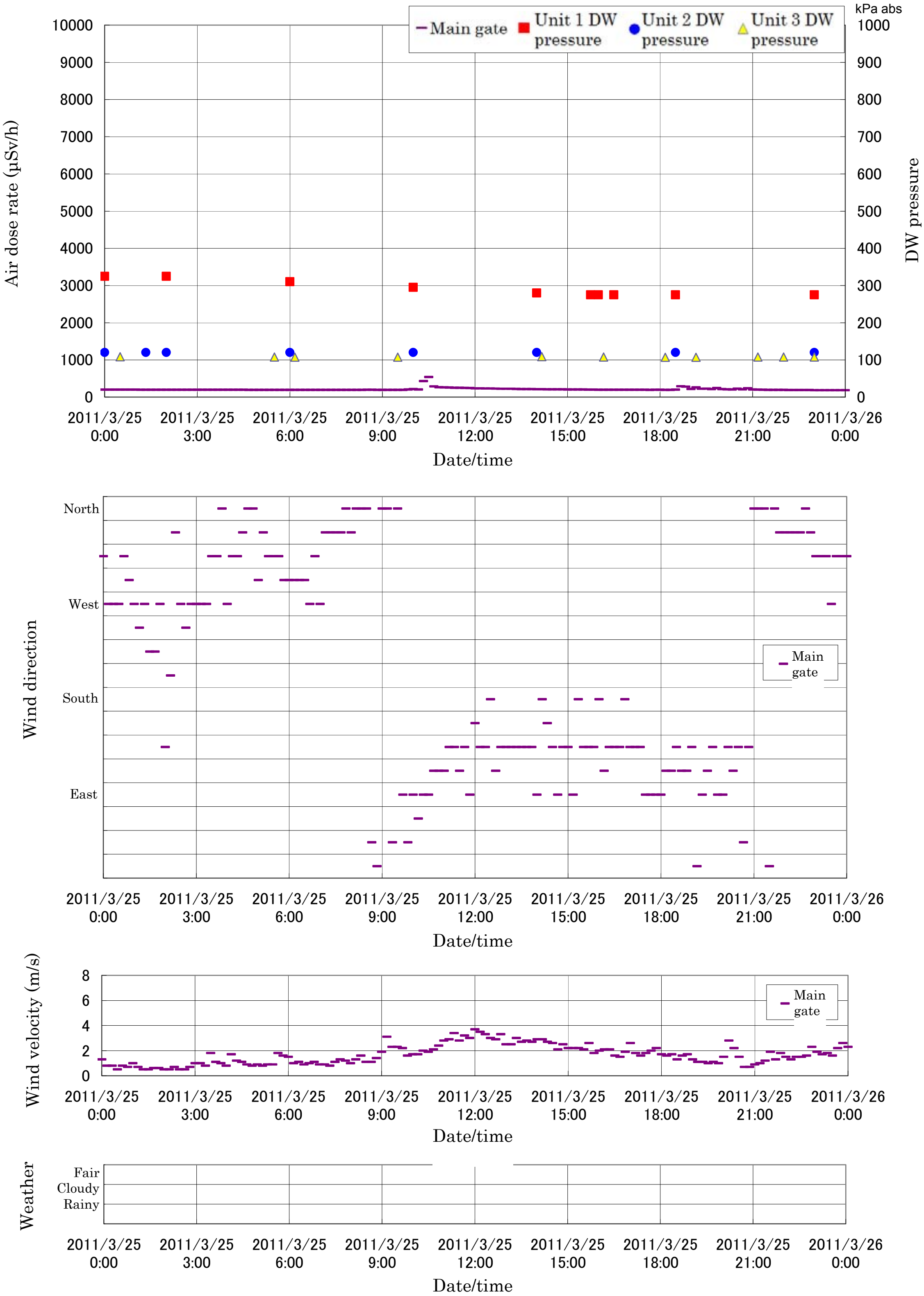


Figure 19. Change in Air Dose Rate (March 25)

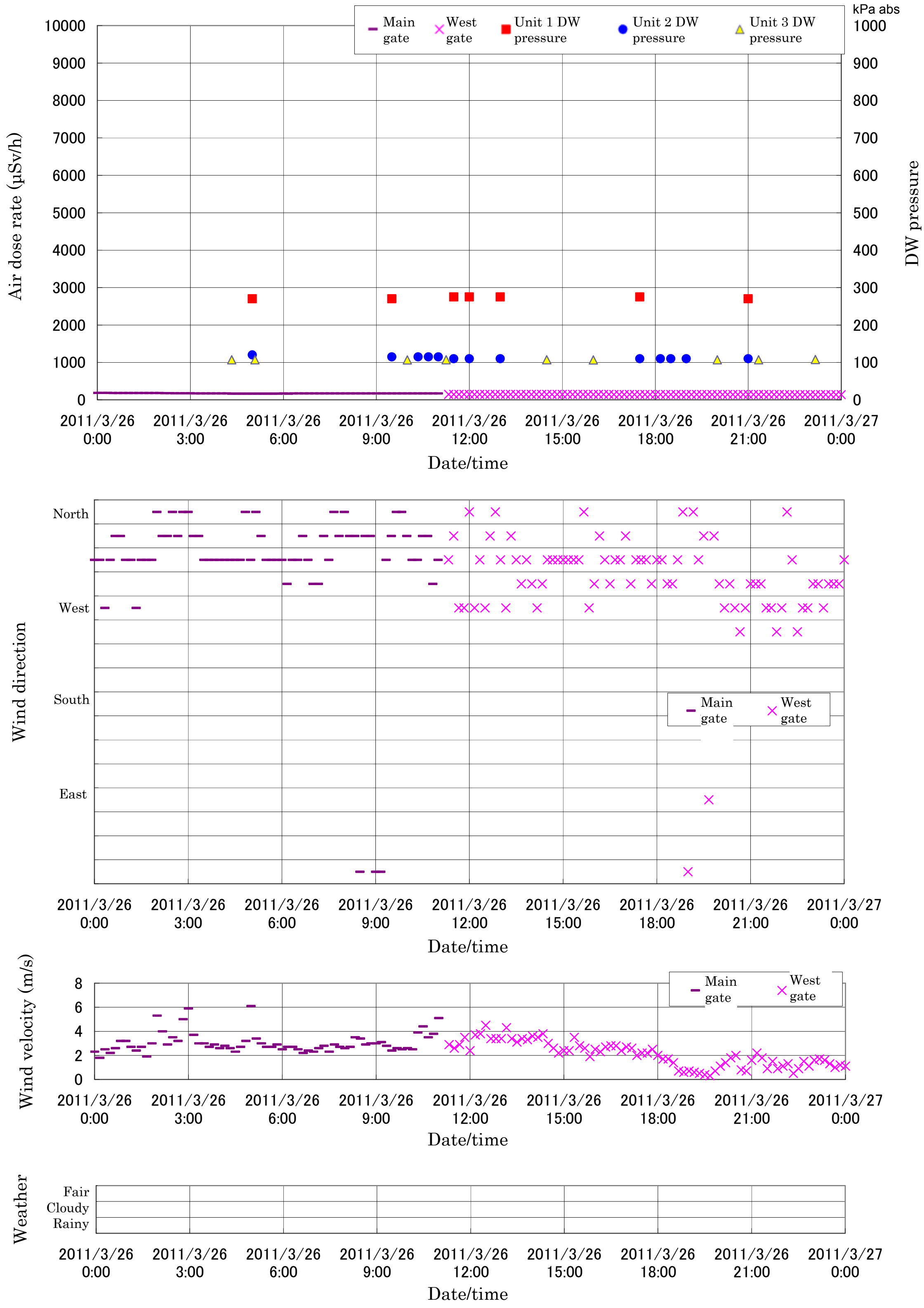


Figure 20. Change in Air Dose Rate (March 26)

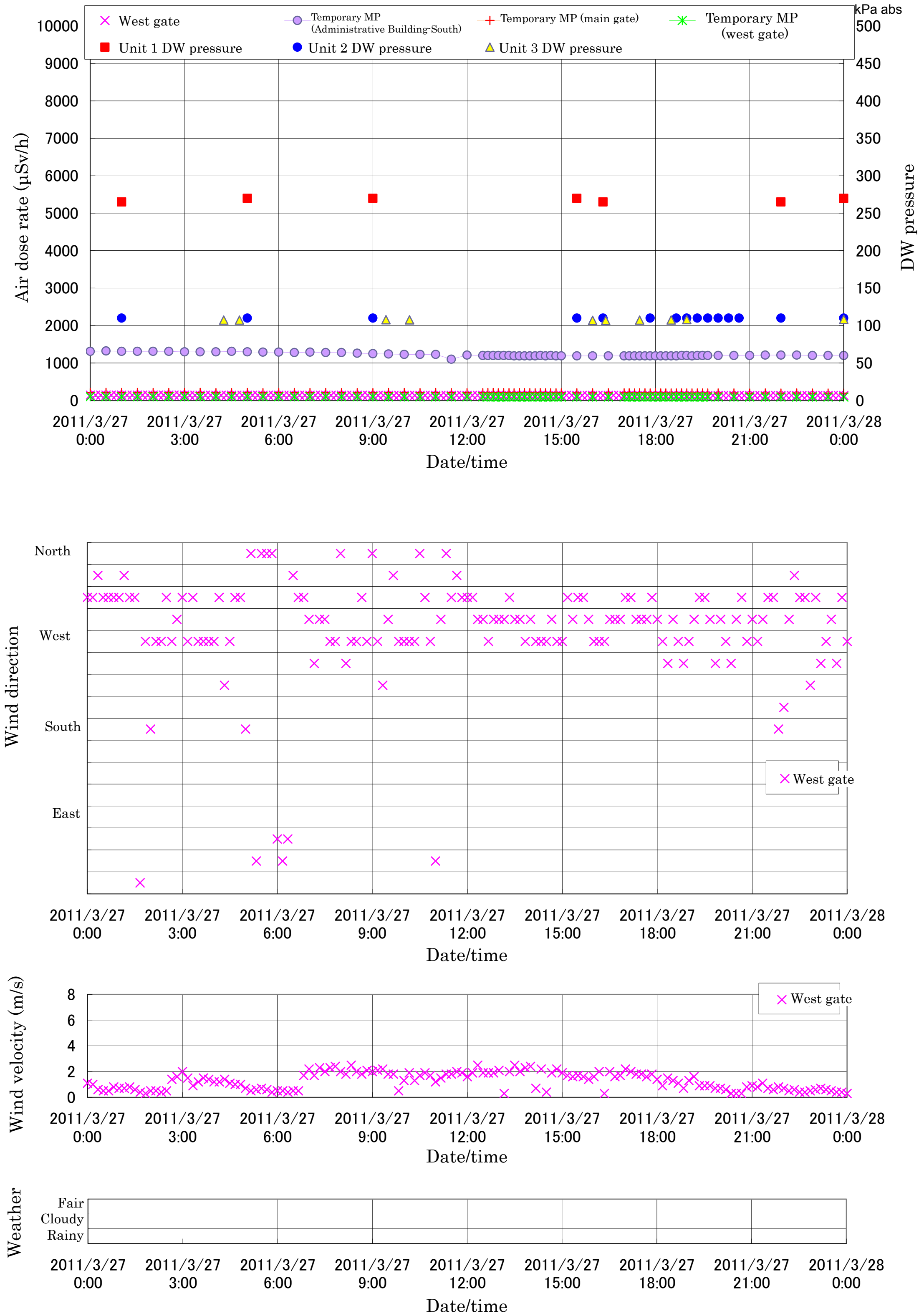


Figure 21. Change in Air Dose Rate (March 27)

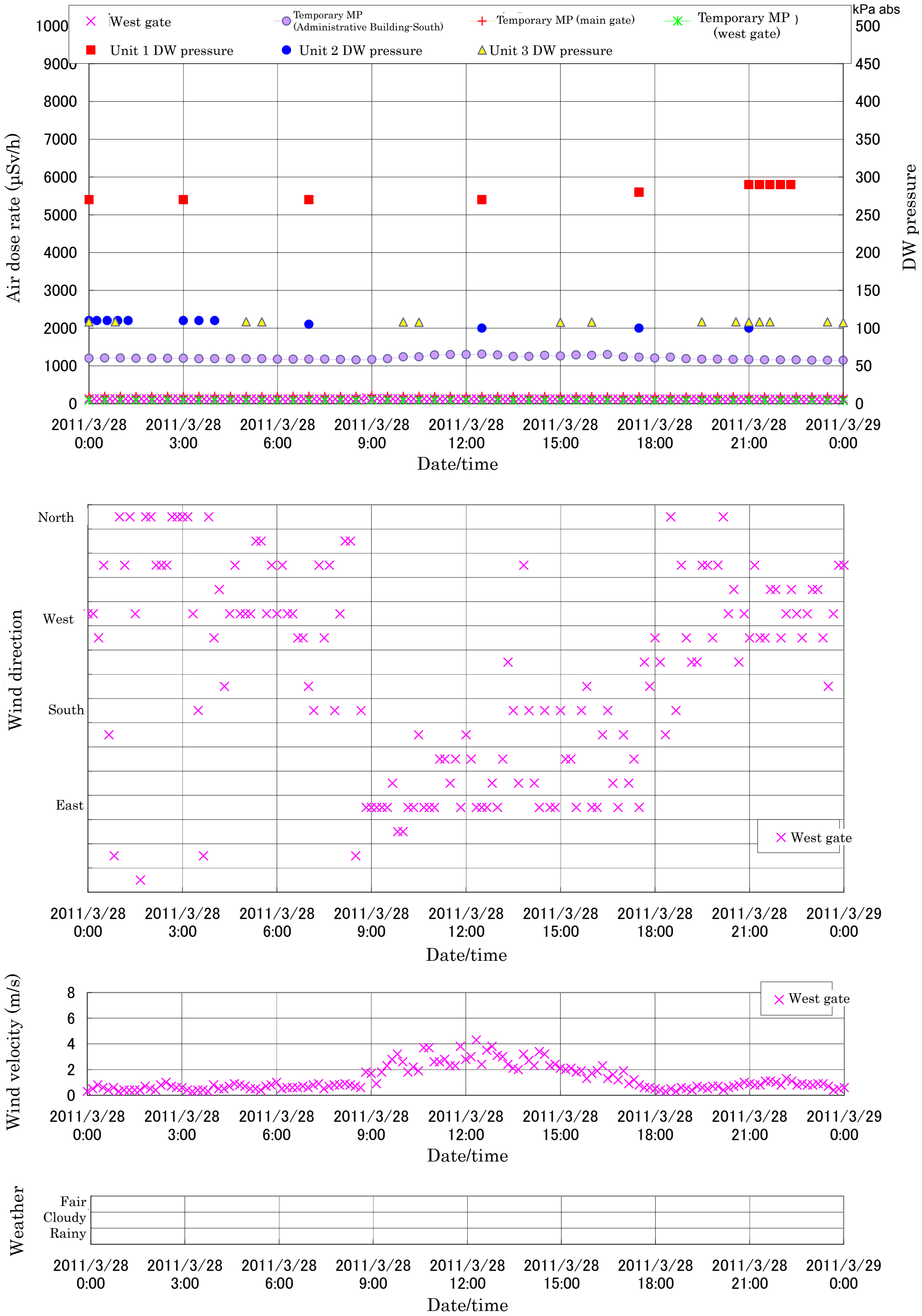


Figure 22. Change in Air Dose Rate (March 28)

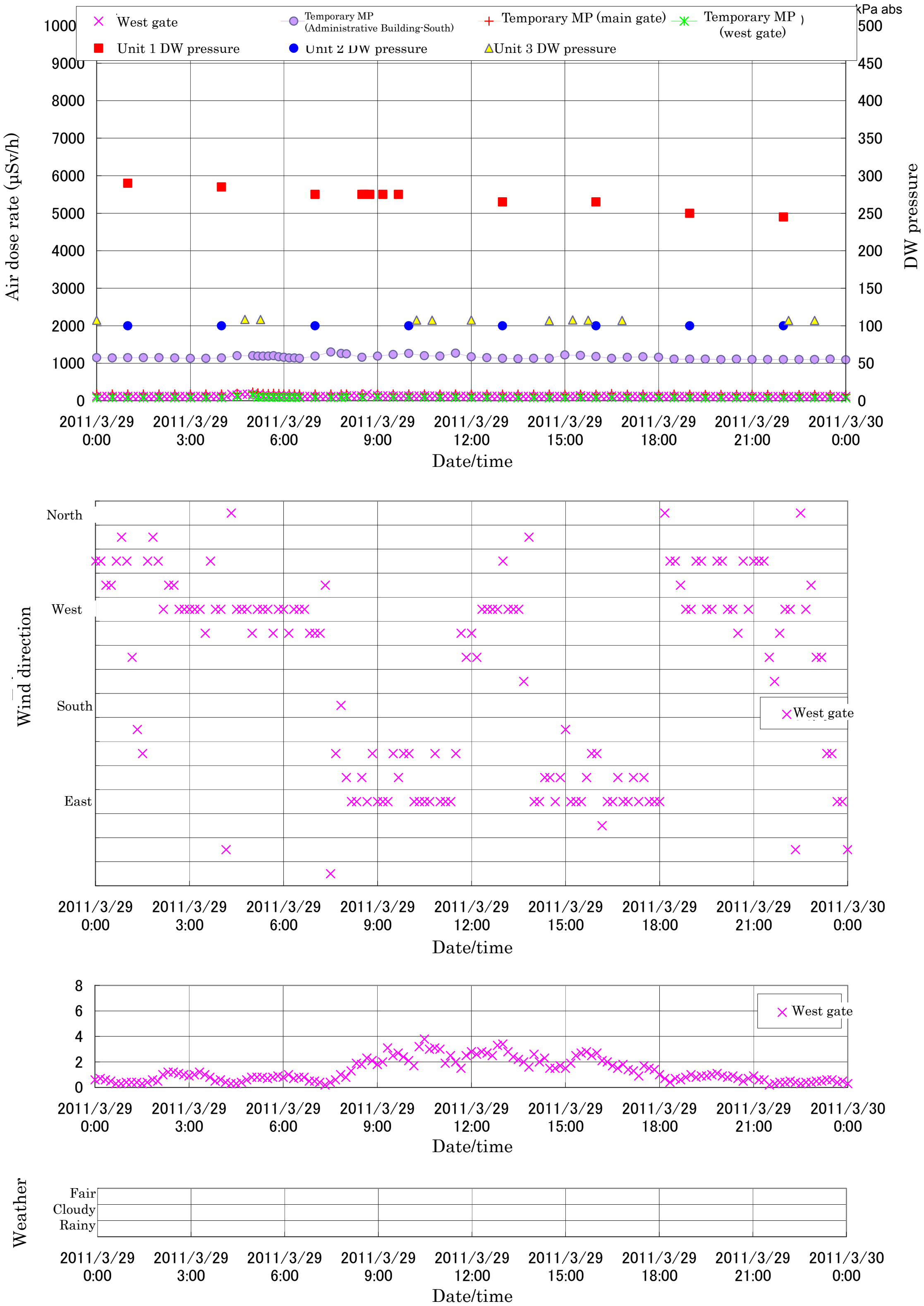


Figure 23. Change in Air Dose Rate (March 29)

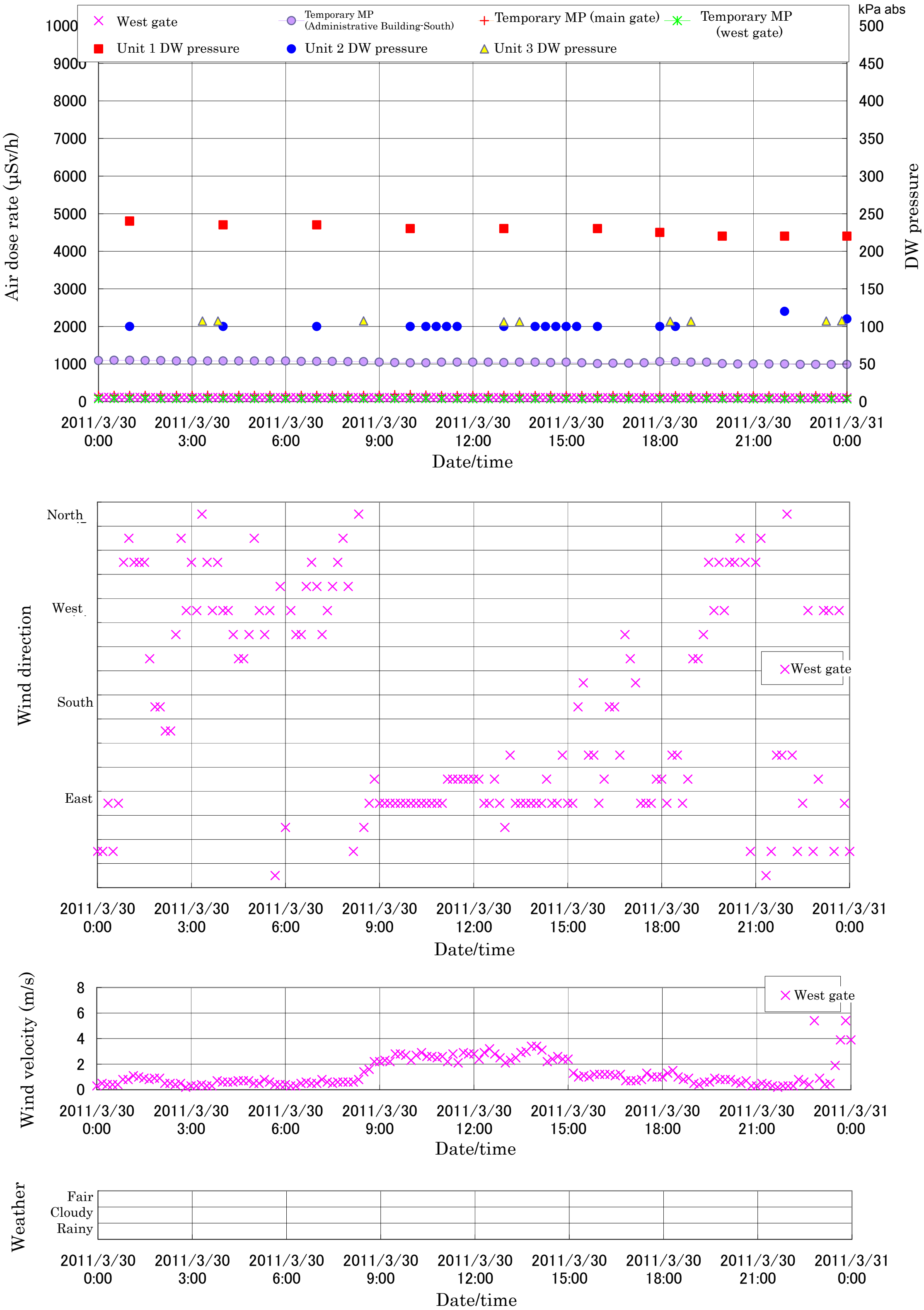


Figure 24. Change in Air Dose Rate (March 30)

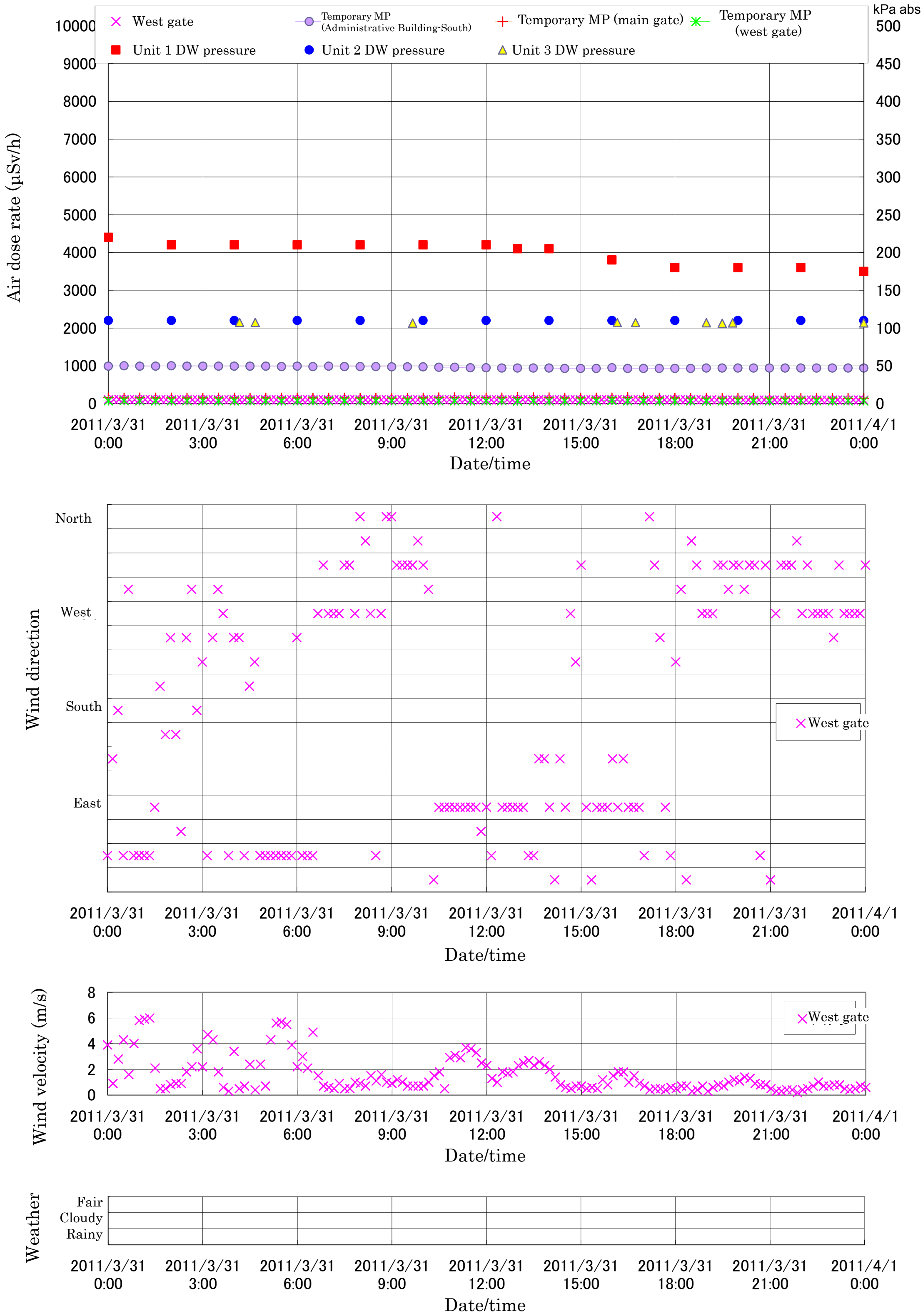
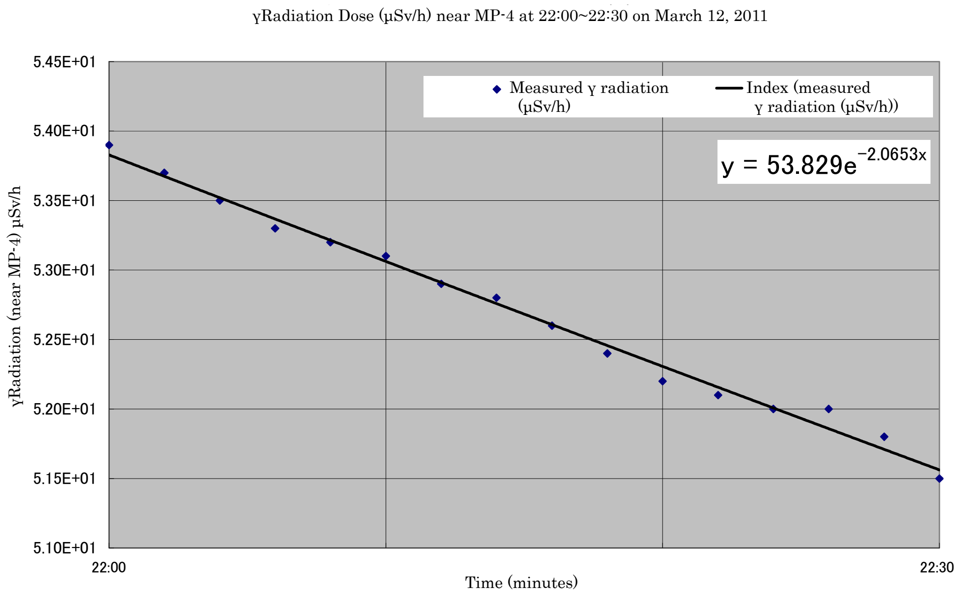
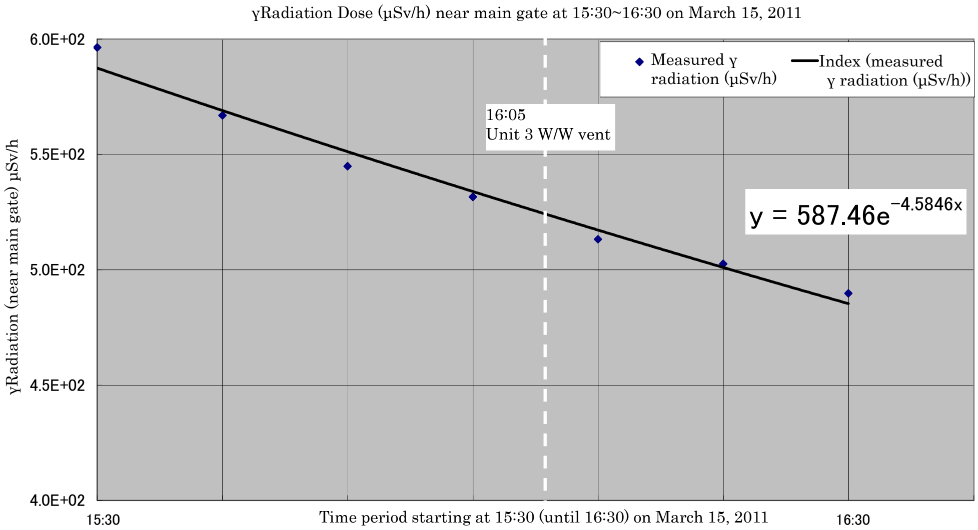


Figure 25. Change in Air Dose Rate (March 31)





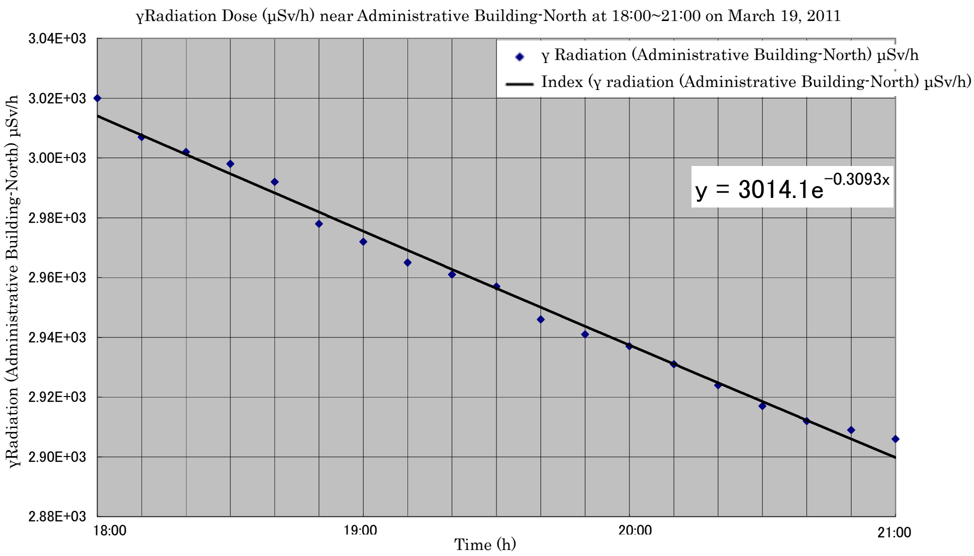


Figure 26. Error of Measurement in Air Dose Rate

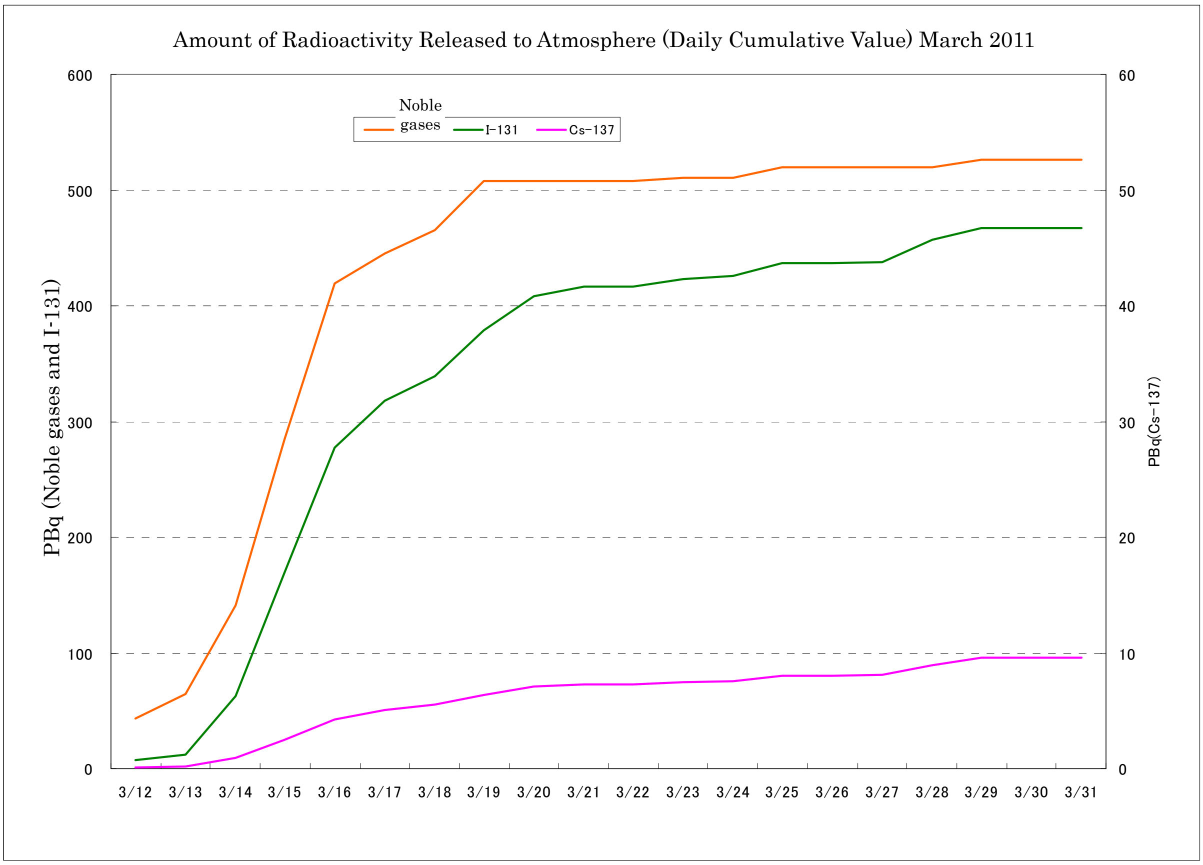
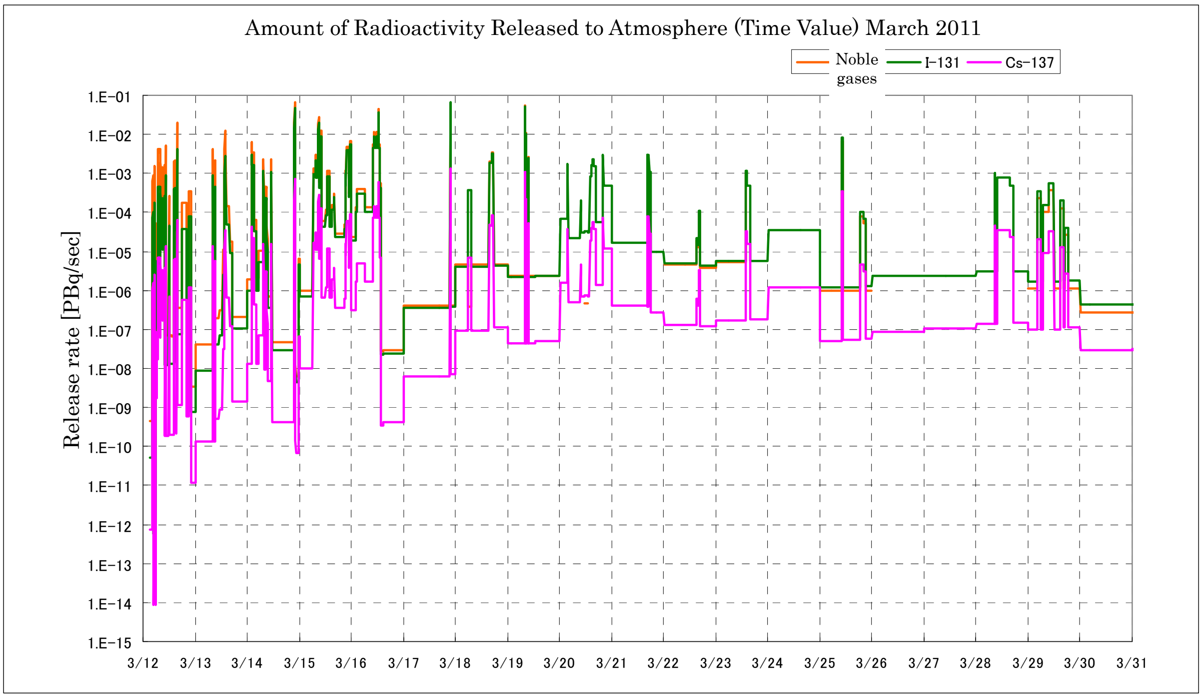
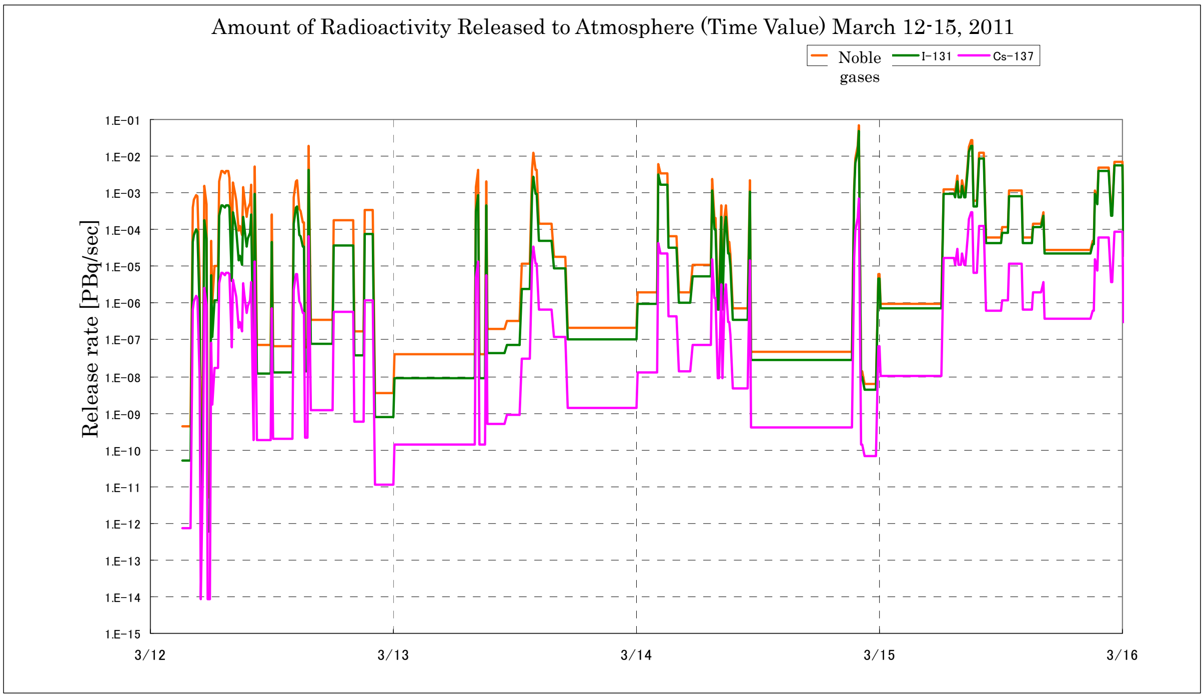


Figure 27. Time Variation (Cumulative Value for Amounts Released)



(a) Time Variation (Release Rate PBq/s)



(b) Time Variation (Release Rate PBq/s) (3/12-3/15)

Figure 28. Time Variation of Release Rate

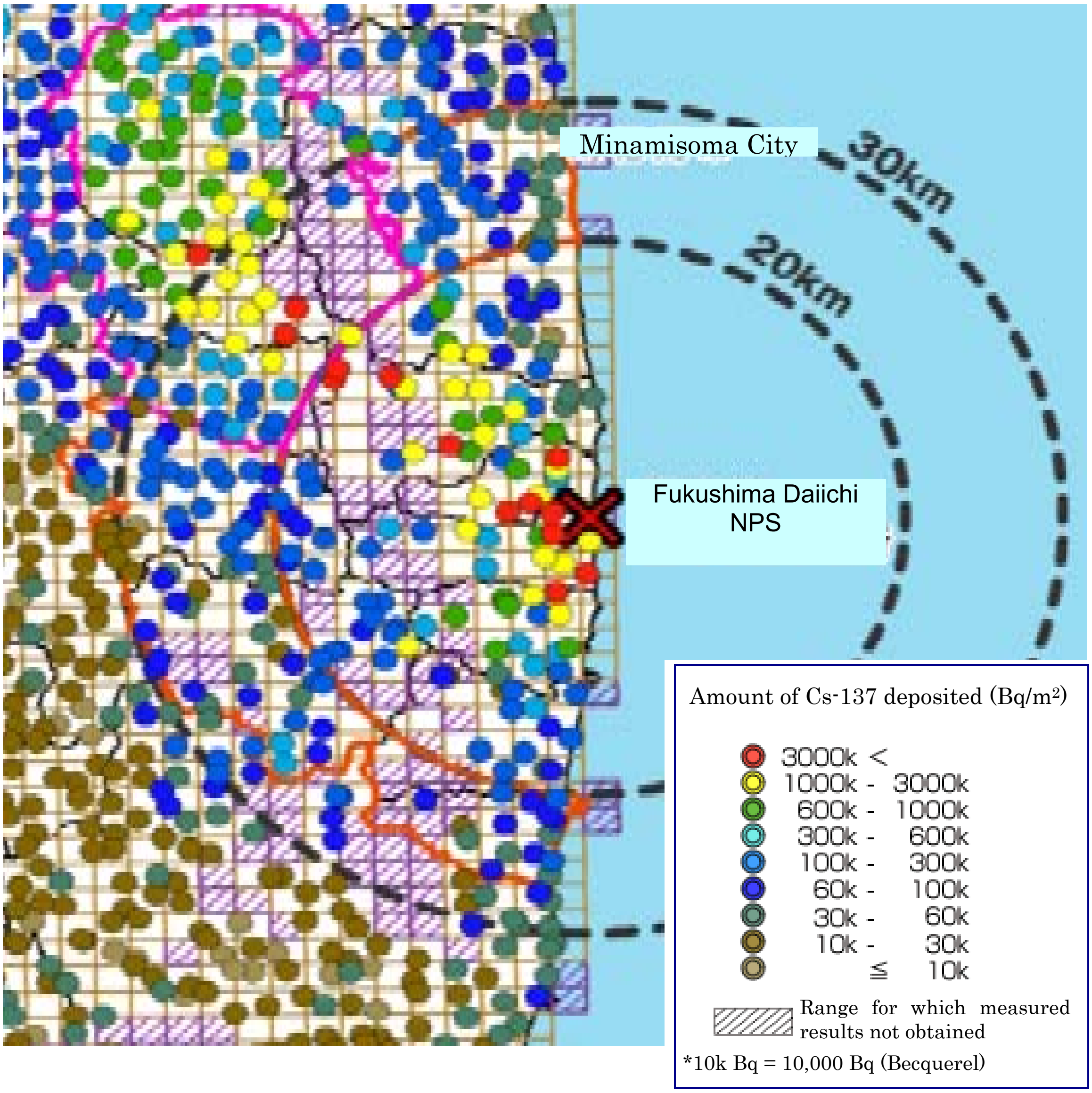


Figure 29. Survey Results of Cs-137 Deposition Status by Ministry of Education, Culture, Sports, Science and Technology

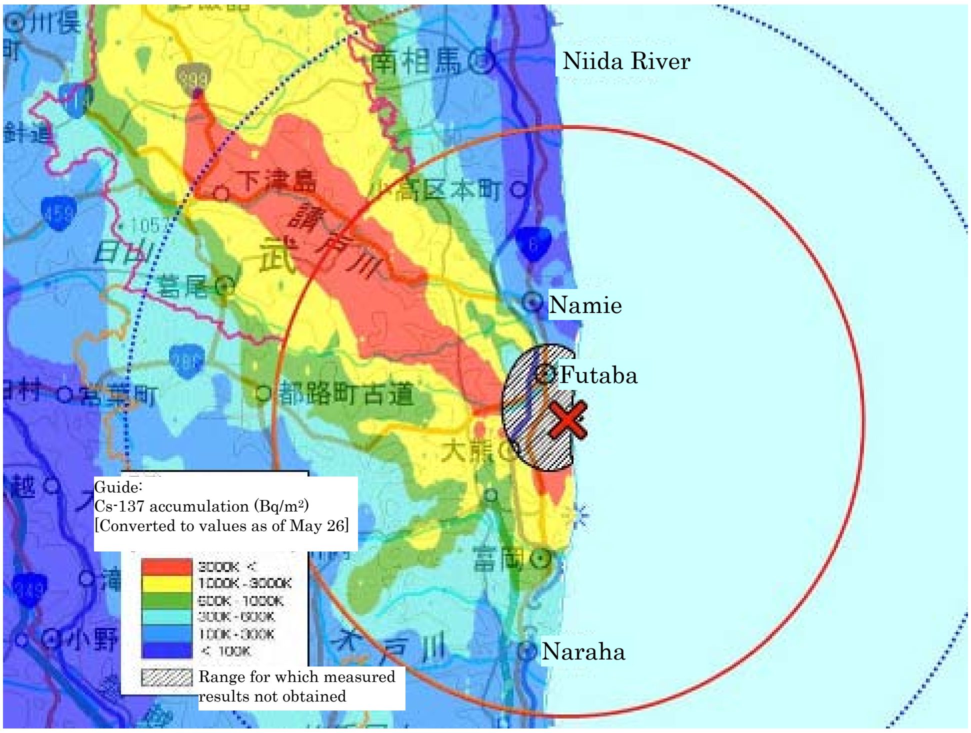


Figure 30. Results of Aircraft Monitoring by Ministry of Education, Culture, Sports, Science and Technology (Cs-137 Deposition Status)
(Source: Distribution Map of Radiation Dose, etc. by Ministry of Education, Culture, Sports, Science and Technology, website: http://ramap.jaea.go.jp/map/)

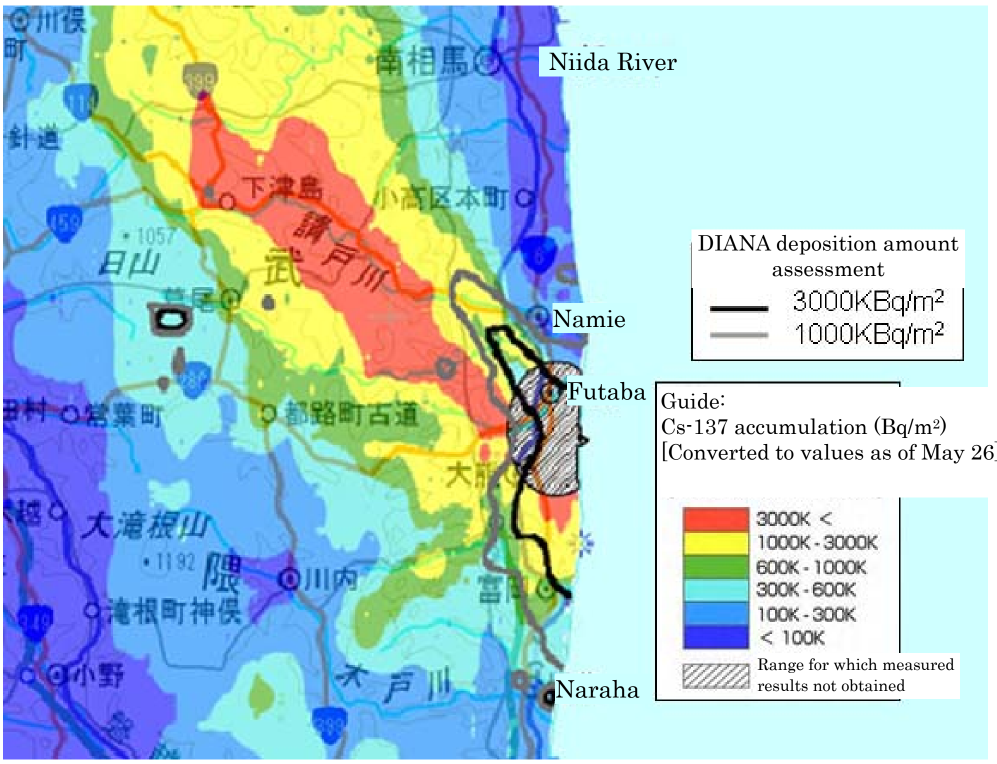


Figure 31. Comparison of DIANA Assessment Results and Survey Results by the Ministry of Education, Culture, Sports, Science and Technology (Cs-137 Deposition Status)

Figure 32. Image from Fukuichi Live Camera (Around 10:00 on March 15)

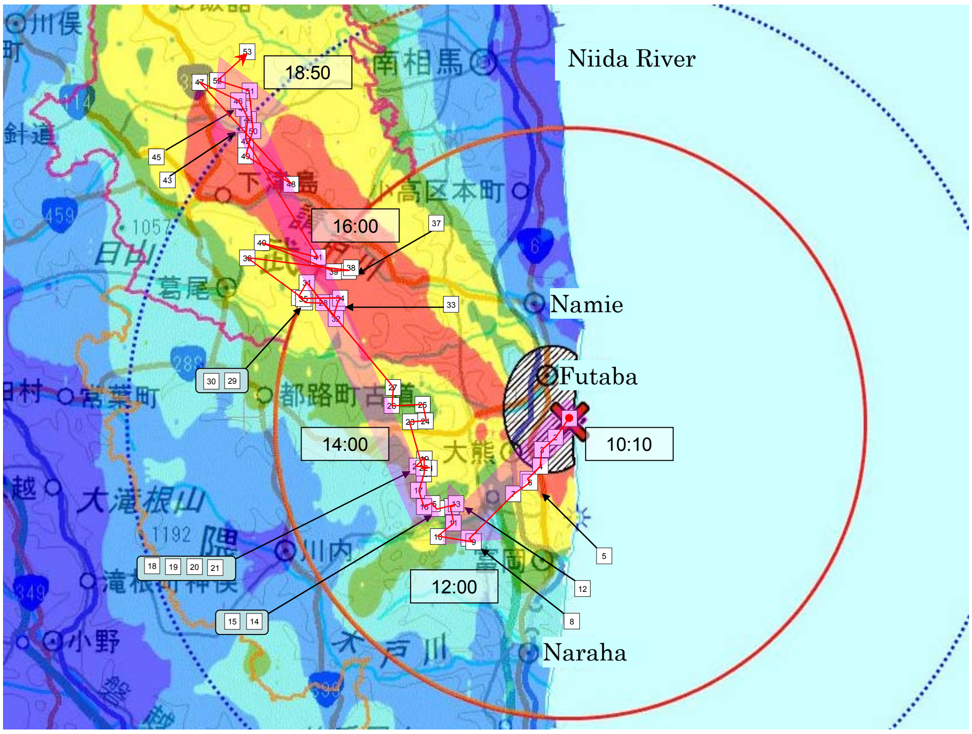


Figure 33. Path of Plume Released during Unit 2 Building Release after 10:00 on March 15

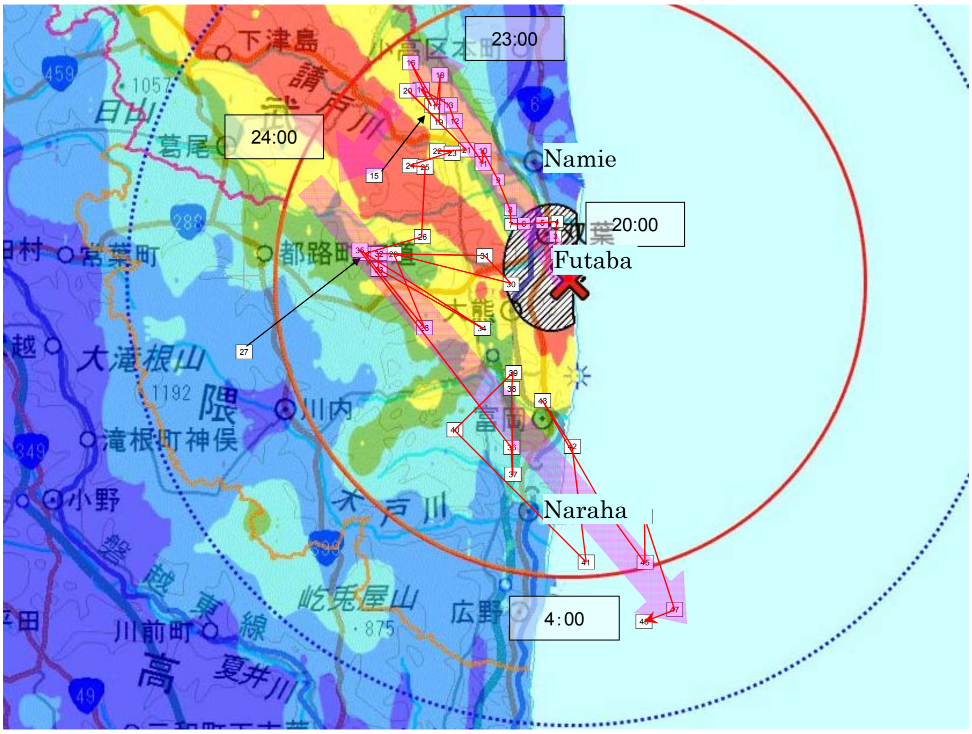
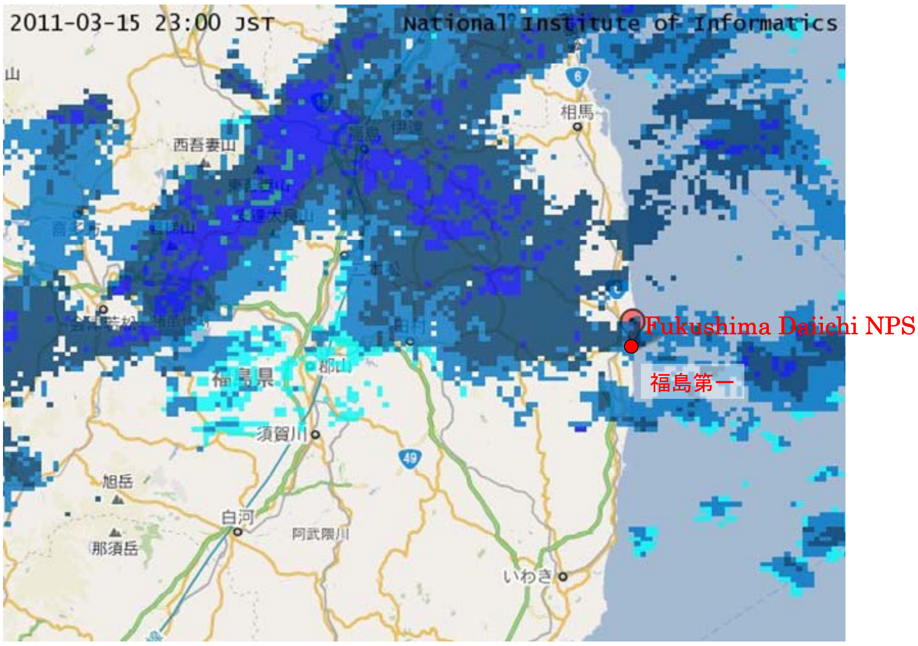
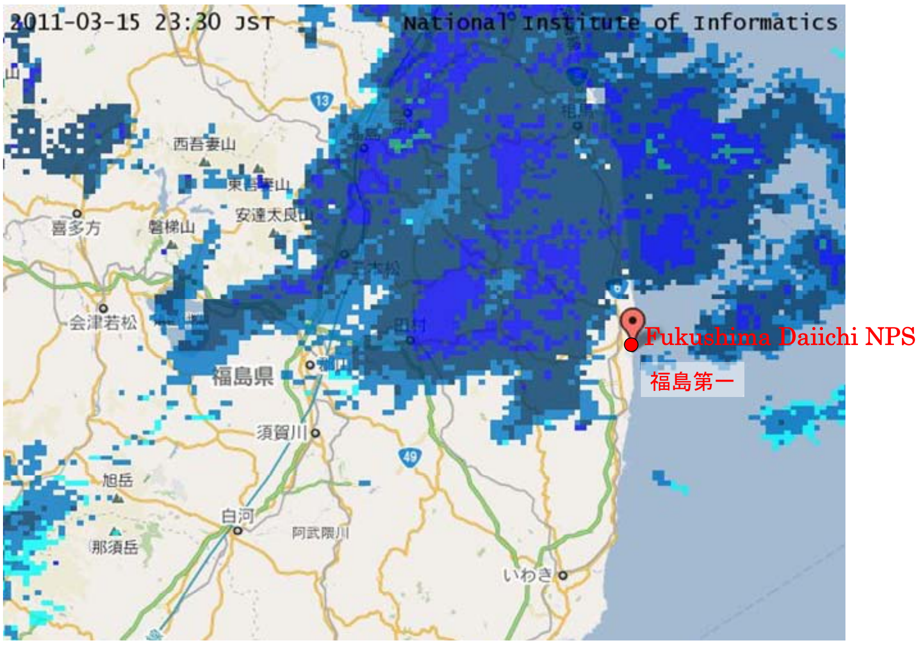


Figure 34. Path of Plume Released during Unit 2 Building Release after 20:00 on March 15

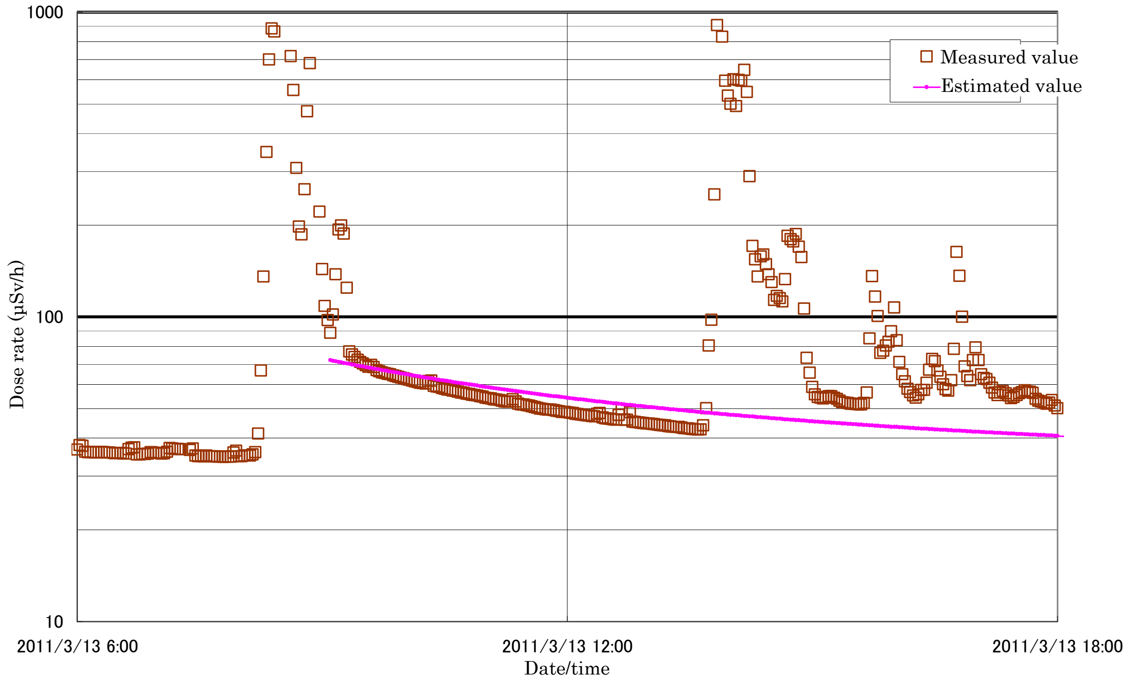


Rain Cloud Conditions in Fukushima Prefecture at 23:00 on March 15
(Source: National Institute of Informatics website:
http://agora.ex.nii.ac.jp/earthquake/201103-eastjapan/weather/data/radar-20110311/)

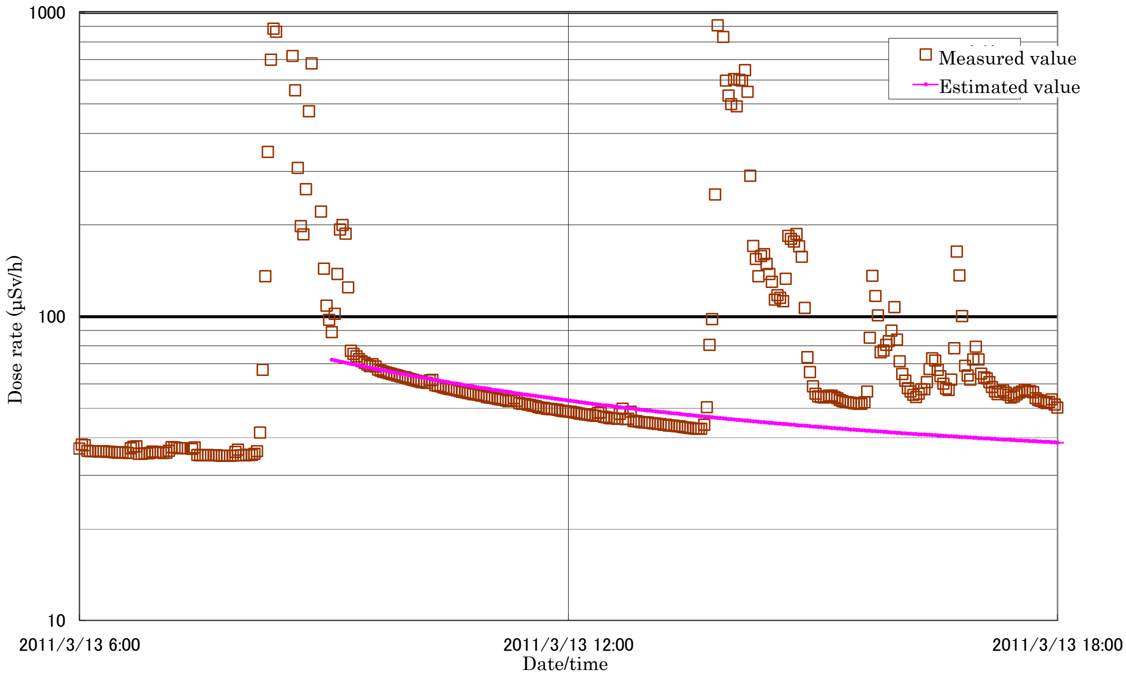


Rain Cloud Conditions in Fukushima Prefecture at 23:30 on March 15
(Source: National Institute of Informatics website:
http://agora.ex.nii.ac.jp/earthquake/201103-eastjapan/weather/data/radar-20110311/)

Figure 35. Rain Cloud Conditions in Fukushima Prefecture around 23:00 on March 15

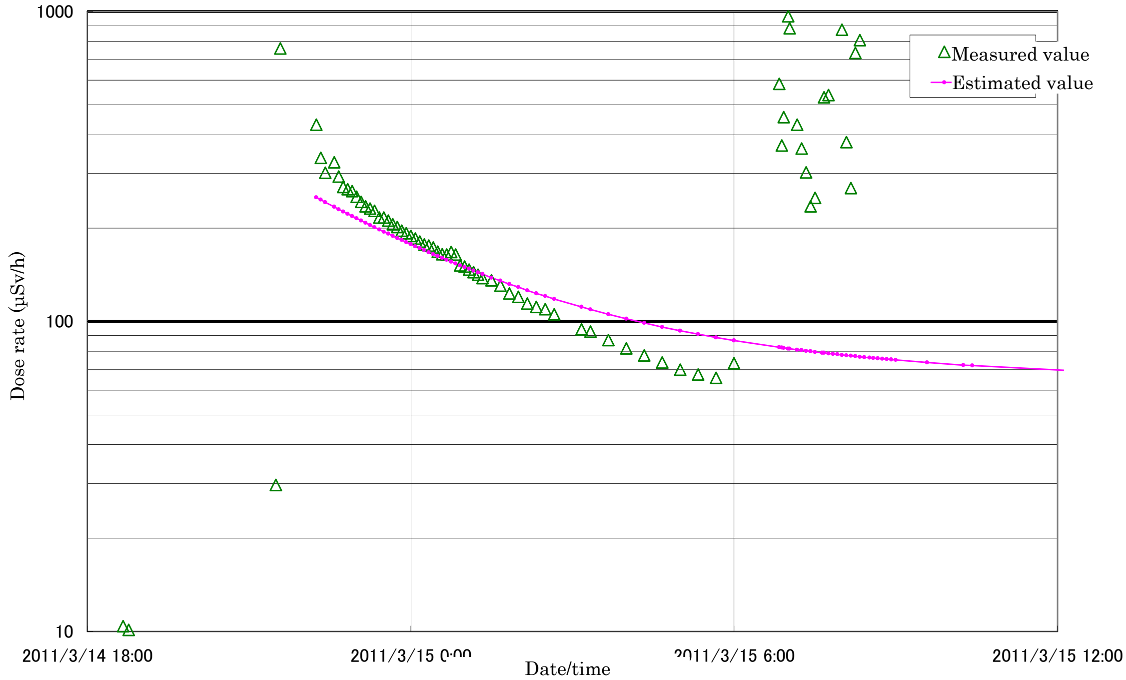


(a) Case Where Ratio of Iodine to Cesium is set at 2:1

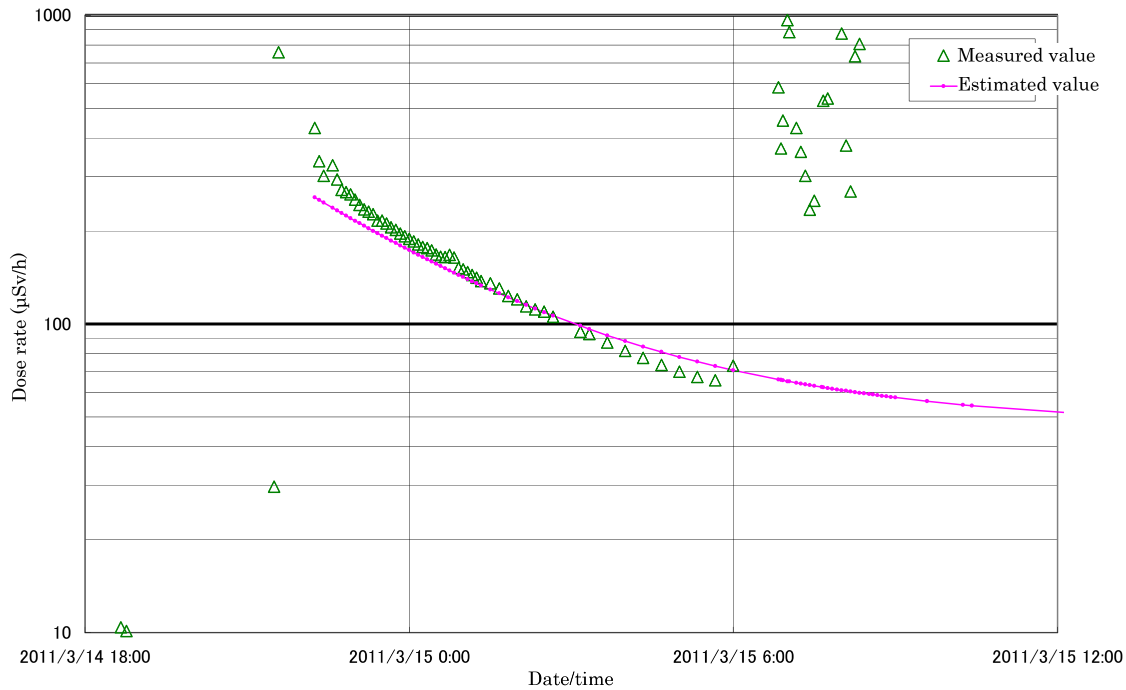


(b) Case Where Ratio of Iodine to Cesium is set at 10:1

Figure 36. Estimate of Ratio of Susceptibility of Radioactive Nuclides to Release (At time ①)

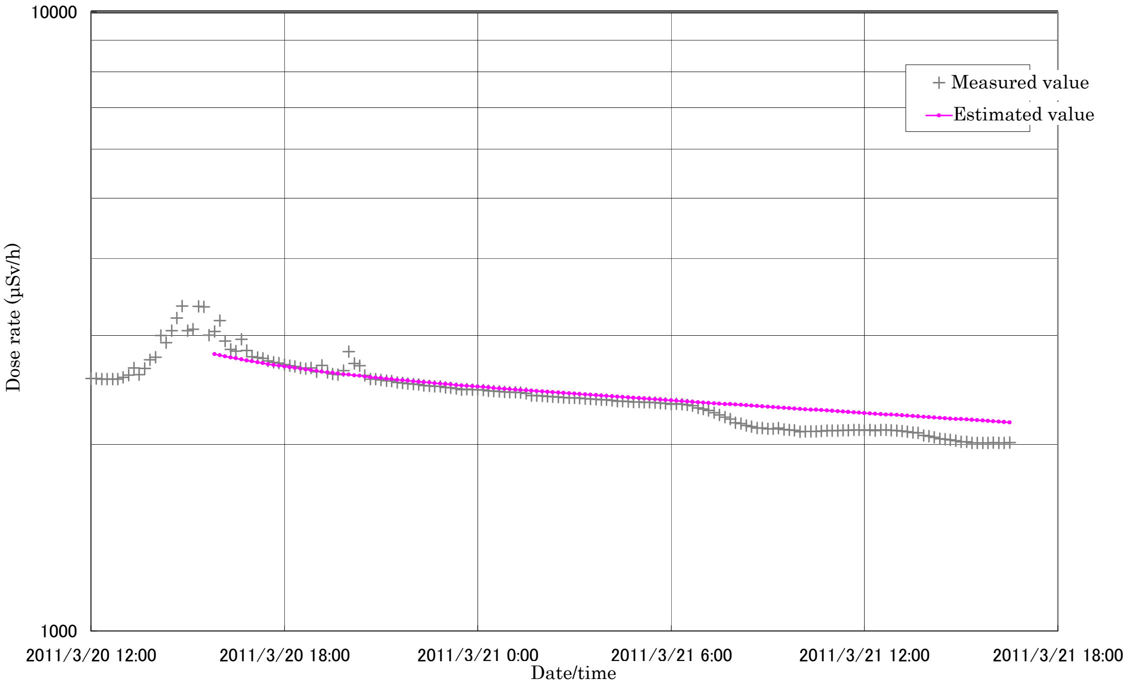


(a) Case Where Ratio of Iodine to Cesium is set at 2:1

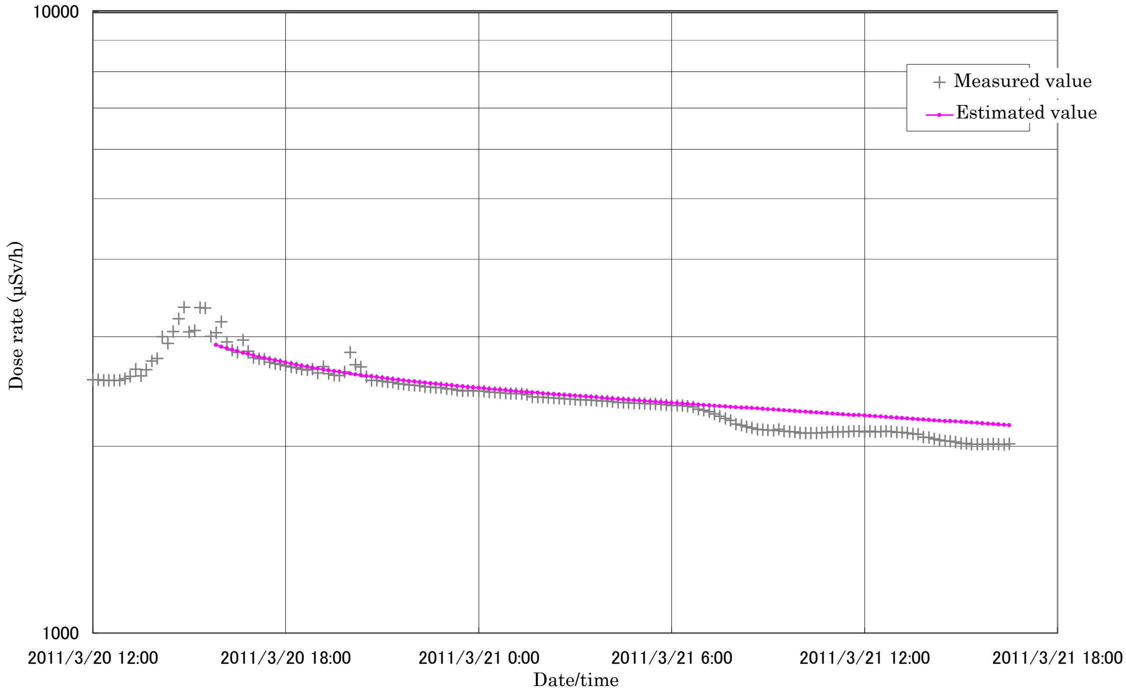


(b) Case Where Ratio of Iodine to Cesium is set at 10:1

Figure 37. Estimate of Ratio of Susceptibility of Radioactive Nuclides to Release (At time ②)

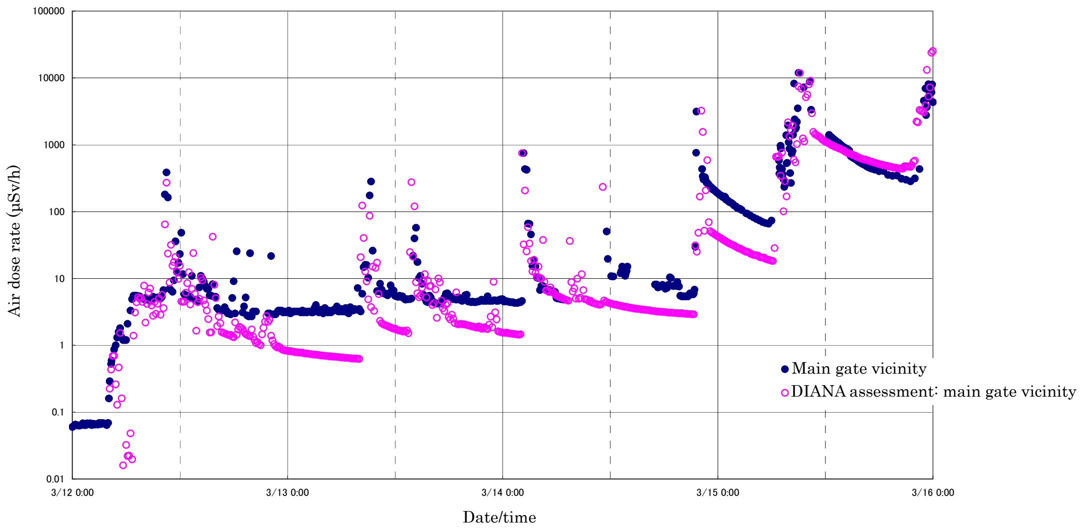


(a) Case Where Ratio of Iodine to Cesium is set at 2:1

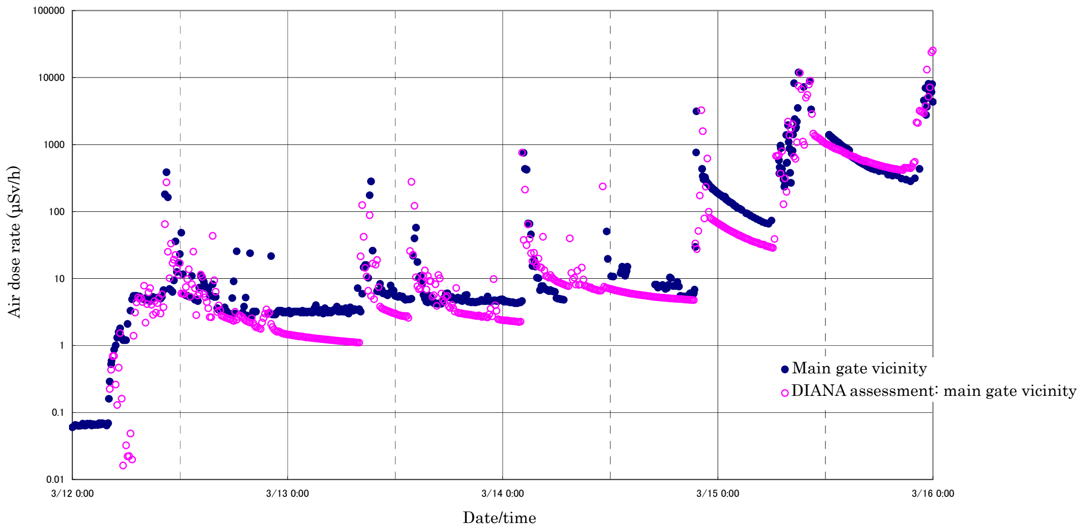


(b) Case Where Ratio of Iodine to Cesium is set at 10:1

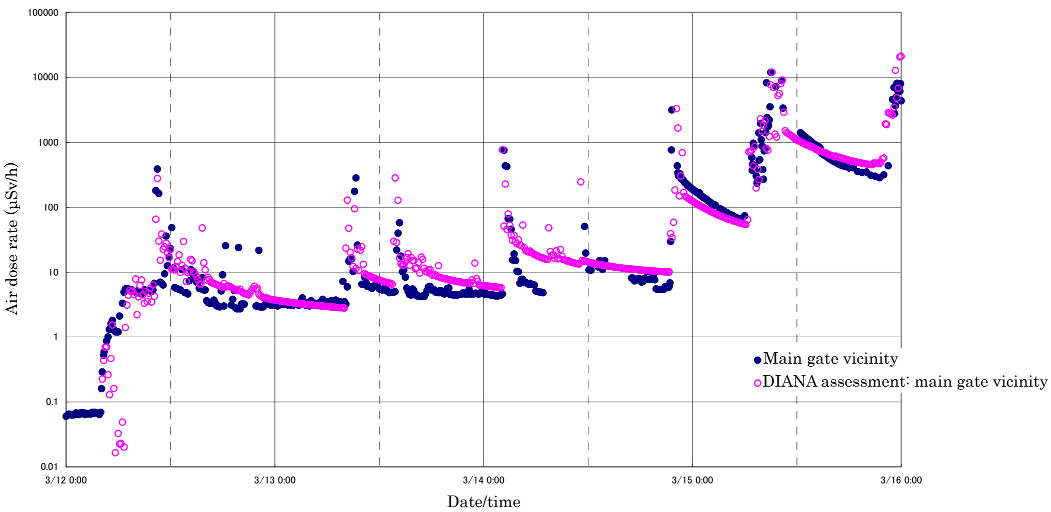
Figure 38. Estimate of Ratio of Susceptibility of Radioactive Nuclides to Release (At time ③)



(a) Case Where Ratio of Noble Gases, Iodine and Cesium is set at 100:1:0.1



(b) Case Where Ratio of Noble Gases, Iodine and Cesium is set at 100:2:0.2



(c) Case Where Ratio of Noble Gases, Iodine and Cesium is set at 100:10:1

Figure 39. Comparison of DIANA Assessment and Actual Measured Values for Air Dose Rate

Assessed Values for April and Afterwards

From April on, assessments have been conducted based on the concentration of airborne radioactive material (dust concentration) as described below.

Table 1. Monthly Assessment Results

	Cs-134+Cs-137 amounts released (PBq/month)	Measured data used in assessment (Total value of Cs-134+Cs-137)
Mar	Approx. 20	Current assessment
Apr	4×10^{-3}	These assessments used the concentration of airborne radioactive material in vicinity of west gate (dust concentration) (assessed using the mean value for all days in each month)
May	1×10^{-3}	
Jun	9×10^{-4}	
Jul	7×10^{-4}	1×10^{9}Bq/h (6/20-6/28) ⇒7.44×10^{-4}PBq/month
Aug	1×10^{-4}	2×10^{8}Bq/h (7/26-8/12) ⇒1.49×10^{-4}PBq/month
Sep	1×10^{-4}	2×10^{8}Bq/h (8/28-9/17) ⇒1.44×10^{-4}PBq/month
Oct	7×10^{-5}	1×10^{8}Bq/h (10/3-10/13) ⇒7.44×10^{-5}PBq/month
Nov	4×10^{-5}	6×10^{7}Bq/h (11/1-11/10) ⇒4.32×10^{-5}PBq/month
Dec	4×10^{-5}	6×10^{7}Bq/h (11/26-12/6) ⇒4.46×10^{-5}PBq/month

(Dates in parentheses indicate the period of days for sampling the measured data.)

[Assessment Method]

○April~June: Assessments were conducted based on the concentration of airborne radioactive material (dust concentration) in the vicinity of the west gate. These assessments used the same methods as employed in July and August (see Appendix for more details).

○July~August: Assessments were conducted under the following conditions as based on the concentration of airborne radioactive material (dust concentration) in the vicinity of the west gate (see Appendix for more details).

○September~: Assessments were conducted based on the concentration of airborne radioactive material (dust concentration) in the upper part of the reactor building and other locations.

Assessments and measured data are posted at places displayed below the heading “Status of Fukushima Daiichi & Daini Nuclear Power Stations Since the Great East Japan Earthquake” on the Tokyo Electric Power Company website.

○ “Press Release” → “Other Distributed Press Material”
(Assessment methods are published in the “Methods for Assessing Amount of Radioactive Material Released under Current Conditions from Reactor Buildings at Units 1~3 of the Fukushima Nuclear Power Station” released on November 26, 2011)

○ “Radiation Doses in Area Surrounding Power Stations” → “Results of Analysis of Nuclides from Radioactive Material in the Area Surrounding Fukushima Daiichi Nuclear Power Station” → “Atmosphere within Power Station Premises”

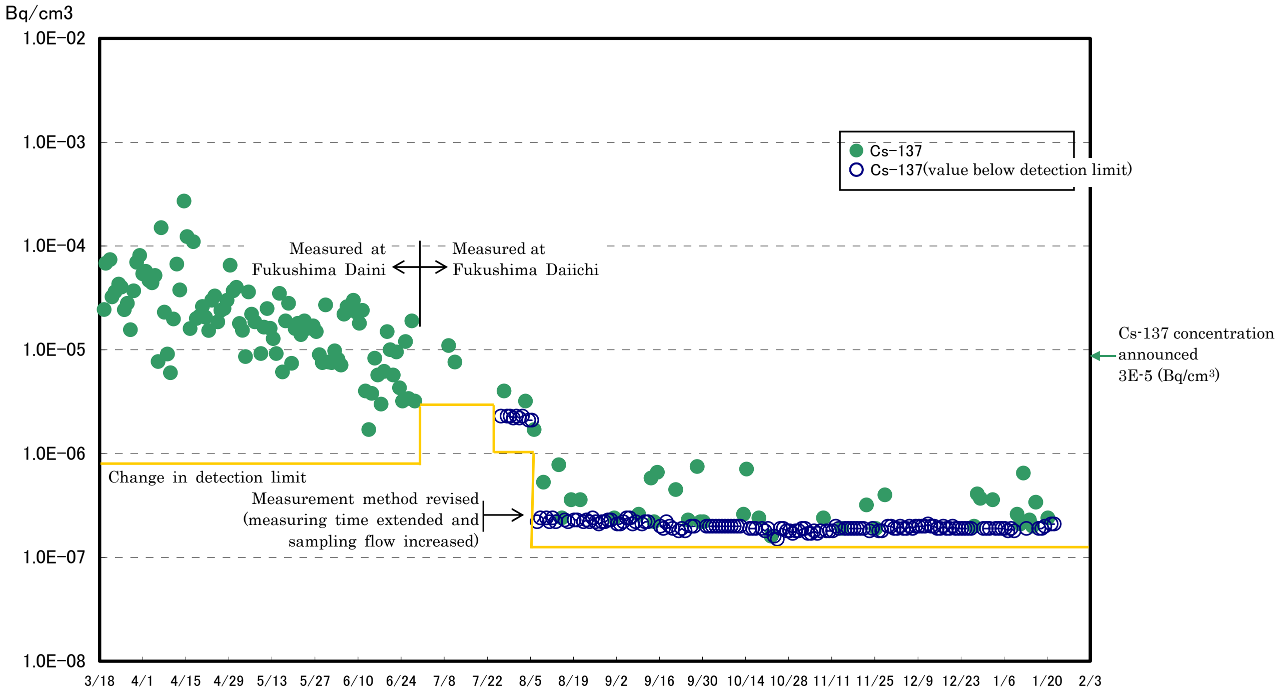


Figure 1. Concentrations of Airborne Radioactive Materials within Site

Estimation of Amount Released Based on Actual Measurements of Radioactive Material Concentrations

With regard to radioactive material released from a reactor building, the amounts released were estimated as follows, which correspond to the measured values of radioactive material concentrations within the power station premises.

1. Estimation Method

Using a concentration distribution graph (prepared for each atmospheric stability per unit release rate) which was prepared beforehand in accordance with the dispersion formula given in the “Guidelines for Weather Conditions Related to Safety Analysis of Power Reactor Facilities,” the concentration per unit release amount (1 Bq/s) at the assessment points were read, and the measured values in the surrounding area were divided by the read value to calculate the amount released.

Using the distribution graph for concentrations (Bq/cm^3) shown in the attached figure, the concentration is read for each unit release amount (1 Bq/s) under the following conditions.

<Conditions for reading distribution graph>

Weather conditions: Wind velocity 1.0m/s and atmospheric stability D (Set under moderate conditions (intermediate state) for ease of dispersion)

Release points: Ground surface (set as conditions on the safe side in the vicinity of the power station)

Assessment spots: 1km downwind (vicinity of west gate of the power station 1km to the west of the reactor building)

As all measured values (Cs-134 and Cs-137) for concentrations of airborne radioactive materials in the vicinity of the west gate of the power station are conservatively regarded as having been released from the power station, the total amount released (Bq/s) from Units 1, 2 and 3 is calculated by dividing the measured values for concentrations (Bq/cm^3) by the concentration for each of the aforementioned unit release amounts (1 Bq/s).

2. Calculation Example (Amount for April)

Using the attached distribution graph, the concentration per unit release amount (1 Bq/s) can be read as approximately 7×10^{-5} Bq/m^3 (approx. 7×10^{-11} Bq/cm^3).

If all measured values[Note 1] (approx. 9.5×10^{-5} Bq/cm^3) for airborne radioactive material concentrations in April in the vicinity of the power station west gate are conservatively regarded as having been released from the power station, then the total amount released from Units 1, 2 and 3 will be approximately 4×10^{-3} PBq/month based on the calculation below using the aforementioned concentration per 1 Bq/s and the measured values for airborne radioactive material concentrations in the vicinity of the west gate.

$$9.5\times10^{-5}(Bq/cm^3) \div 7\times10^{-11}((Bq/cm^3)/(Bq/s)) = 1.4\times10^{6}(Bq/s)$$
$$= 4\times10^{-3}\ (PBq/month)$$

Note 1: The measured values are posted at places displayed below the heading “Status of Fukushima Daiichi & Daini Nuclear Power Stations since the Great East Japan Earthquake” on the Tokyo Electric Power Company website.

○ “Radiation Doses in Area Surrounding Power Stations” → “Results of Analysis of Nuclides from Radioactive Material in the Area Surrounding Fukushima Daiichi Nuclear Power Station” → “Atmosphere within Power Station Premises”

End

Attached Figure

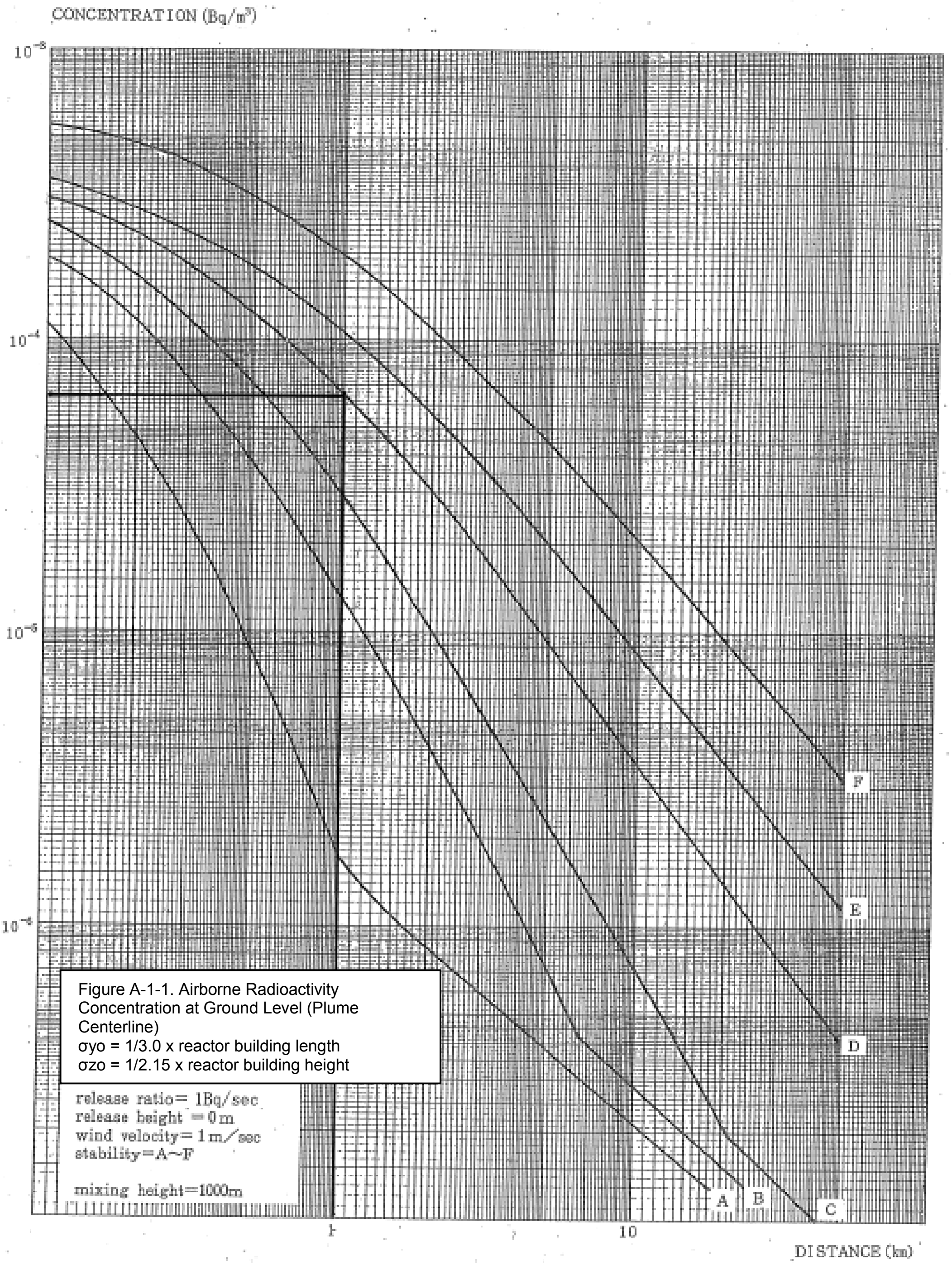


Figure: Distribution of Airborne Radioactivity Concentration at Ground Level

Attachment 2

Impact Due to Primary Containment Vessel Venting

1 Introduction

Units 1~4 at the Fukushima Daiichi Nuclear Power Station lost their ultimate heat sink and coolant injection function due to the massive tsunami following the Tohoku-Chihou-Taiheiyou-Oki Earthquake.

The result was a rise in pressure of the primary containment vessel due to steam released from the reactor. Moreover, pressurization also developed due to hydrogen generated from a reaction between the steam and fuel clads (zircaloy) which had increased in temperature. In this process, fuel damage also occurred, and radioactive material was released into the primary containment vessel.

To lower the primary containment vessel pressure, operations were attempted to depressurize the primary containment vessel by means of venting at each unit. In these venting operations, radioactive material was released to the atmosphere along with steam and hydrogen. Accordingly, this document discusses the release of radioactive material accompanying the venting operations, and examines the relationship to contamination in the area northwest of the Fukushima Daiichi Nuclear Power Station.

2 Primary Containment Vessel Vent Valve Operation

There are two lines through which steam discharges by means of venting, one line from the suppression chamber (S/C) and the second line from the dry well (D/W). When venting is conducted, the necessary valve operations are performed in order to construct either (or both) of these lines. At any of these units, after the vent valve (MO valve) is opened, the AO valve (large valve or valvula), which is on every line, is opened. Configurations of the vent lines are shown in Attached Figures 1-1 and 1-2.

In addition, the ventings implemented at Units 1~3 are shown in Attached Table 1.

3 Discussion of Operation of Vent Valve at Each Unit and Amounts of Radioactive Material Released

3.1 Unit 1

○Venting after 10:00 on March 12 (S/C vent valve valvula operated)

Unit 1 where a station blackout (SBO) resulted from the tsunami strike on March 11 lost function of the isolation condenser (IC), and it is believed that core damage was sustained early due to the loss of function for removing heat from the core, and that a leak occurred from the gas phase area of the reactor pressure vessel (RPV) boundary, which resulted in D/W pressure rising. Following the rise in D/W pressure, the procedures for venting under conditions without any available power source were reviewed, and, although it was confirmed that the S/C vent valve valvula could be opened manually, doses in the field were high and the operation to open the valvula could not be performed. Consequently, while also proceeding with preparations for operations to open the S/C vent valve large valve remotely, operations were conducted at 10:17, 10:23, and 10:24 on March 12 from the main control room (MCR) to open the S/C vent valve valvula with the expectation of there being residual pressure in the instrumentation air system (IA system). Because the same operation did not decrease the D/W pressure, it could not be determined from the D/W pressure behavior whether the S/C vent valve valvula opened or not. During the same time frame, because the dose rate near the main gate rose temporarily (approximately 400μSv/h) (Figure 6 in the main document), it is believed that radioactive material was released along with steam into the atmosphere. As for the route through which the plume was released, when the time of the vent valve operation and the time when the dose rate rose are taken into account, it is believed that there were both a possibility that the S/C vent valve valvula opened and there was a release to the extent that a decrease in D/W pressure was not able to be seen as well as a possibility that there was a direct release from the building to the atmosphere, but the release path is not known. On the basis of change in the air dose rate, this assessment was conducted on the assumption that radioactive material was released from the stack. The assessment results for noble gases, iodine and cesium in the plume released during the same time frame are shown in Attached Table 2. When compared with the assessment results in section 4.1 of the main document, the amount released to the atmosphere during the same time frame was found not to have been controlling. Also, the path of the plume as projected based on wind direction, wind velocity and atmospheric stability is shown in Attached Figure 2-1. The boxed numerals in the diagram plot the maximum dose rate occurring every 10 minutes according to the movement of the plume, and show the path of the plume. In this diagram, the results of soil sampling, which were conducted by the Ministry of Education, Culture, Sports, Science and Technology (Figure 30 in the main document), were also superimposed. Although the plume released during the same time frame passed directly through the vicinity of the high contamination area northwest of the Fukushima Daiichi Nuclear Power Station, because the assessed results obtained show that the amount of radioactive material in the plume was not controlling as stated above, it is believed that the contribution to soil contamination was small.

○Venting after 14:00 on March 12 (S/C vent valve large valve operated)

After 14:00 on March 12, an operation was conducted to open the S/C vent valve large valve, and, because of the fact that a decrease in D/W pressure was confirmed and that steam was confirmed above the stack by video from the Fukuichi live camera (Attached Figure 5-1), it is believed that steam was released by means of this venting. As shown in Figure 6 of the main document, at the times when the venting was performed, the dose rate was being measured by monitoring cars positioned near the main gate and MP-8, and the air dose rate near the main gate rose to 10μSv/h. So, based on change in the air dose rate, it was assessed that radioactive material had been released from the stack. The assessment results for noble gases, iodine and cesium released during the venting are shown in Attached Table 2. When compared with the assessment results in section 4.1 of the main document, the amount released to the atmosphere by means of venting is believed not to have been controlling. Also, in Attached Figure 2-2, the path of the plume as projected based on wind direction, wind velocity and atmospheric stability is shown (figure superimposing the path of the plume onto Figure 30 of the main document). The plume did not pass directly over the area of high contamination northwest of the Fukushima Daiichi Nuclear Power Station, and, because the assessed results obtained show that the amount of radioactive material released accompanying the venting was not controlling as stated above, it is believed that the contribution to soil contamination from the venting was small.

3.2 Unit 2

○Venting after 21:00 on March 14 (S/C vent valve valvula operated)

At Unit 2, taking into account the situation at Unit 1, it was anticipated that venting would eventually be necessary, so preparations were advanced, and, at 11:00 on March 13, the small generator for temporary lighting in the main control room was used to energize the solenoid valve to perform an operation to open the S/C vent valve large valve. However, the primary containment vessel pressure was lower than the rupture disc operating pressure (427kPa[gage]), and the situation continued in which venting was not conducted. At 11:01 on March 14, the impact of the building explosion at Unit 3 disconnected the circuit for energizing the solenoid valve and the S/C vent valve large valve was closed, so, while proceeding to restore venting by means of the S/C vent valve large valve, an operation was performed to open the S/C vent valve valvula at around 21:00 on March 14. Even after that, the D/W pressure rose, and, although it was inconceivable that depressurization could be achieved, the dose rate near the main gate rose (approximately 3,000μSv/h) (Figure 8 in main document) during the same time frame, so it is believed that radioactive material was released along with steam into the atmosphere. With regard to the route through which the plume was released, when the time of the vent valve operation and the time when the dose rate rose are taken into account, it is believed that there were both a possibility that the operation to open the S/C vent valve valvula caused a release to the extent that a decrease in D/W pressure was not able to be seen as well as a possibility that there was a direct release from the building to the atmosphere, but the release path is not known. This assessment was conducted as there having been radioactive material released from the stack on the basis of change in the air dose rate. The assessment results for noble gases, iodine and cesium in the plume released during the same time frame are shown in Attached Table 2. When compared with the assessment results in section 4.1 of the main document, the amount released to the atmosphere was found not to have been controlling. Also, the path of the plume as projected based on wind direction, wind velocity and atmospheric stability is shown (figure superimposing the path of the plume onto Figure 30 of the main document) in Attached Figure 3. The plume released during the same time frame did not pass directly over the area of high contamination northwest of the Fukushima Daiichi Nuclear Power Station, and because the assessed results obtained show that the amount of radioactive material in the plume was not controlling as stated above, it is believed that the contribution to soil contamination from the plume was small.

○Venting after 00:00 on March 15 (D/W vent valve valvula operated)

Even after that, because the D/W pressure continued rising, an operation was performed at 0:02 on March 15 to open the D/W vent valve valvula, but, several minutes later, it was confirmed to be closed and the a decrease in D/W pressure was not confirmed. Also, because of the fact that the dose rate near the main gate did not vary during the same time frame, it was inferred that no radioactive material was released and that there was no release of steam to the atmosphere from the vent valve operation.

3.3 Unit 3

○Venting after 9:00 on March 13 (S/C vent valve large valve operated)

At Unit 3, taking into account the situation at Unit 1, it was anticipated that venting would eventually be necessary, so preparations for venting were advanced, and, at 8:41 on March 13, an operation was performed to open the S/C vent valve large valve. During the venting, because of the fact that a decrease in D/W pressure was confirmed (At the Emergency Headquarters, it was determined that venting had been performed at around 9:20 on the same day.) and that steam above the stack was confirmed by video from the Fukuichi live camera (Attached Figure 5-2), it was determined that steam had been released by means of this venting. Also, as shown in Figure 7 of the main document, at the time when the venting was performed, the dose rate was being measured by monitoring cars positioned near the main gate, MP-1 and MP-4, and the dose rate rose to several hundred μSv/h near the main gate and MP-4. So, on the basis of change in the air dose rate, the assessment was conducted as there having been radioactive material released from the stack. The assessment results for noble gases, iodine and cesium released during the venting are shown in Attached Table 2. When compared with the assessment results in section 4.1 of the main document, it was found that the amount released to the atmosphere by means of venting was not controlling. Also, the path of the plume as projected from wind direction, wind velocity and atmospheric stability is shown (figure superimposing the path of the plume onto Figure 30 of the main document) in Attached Figure 2-1. The plume released during the same time frame did not pass directly over the area of high contamination northwest of the Fukushima Daiichi Nuclear Power Station, and because the assessed results obtained show that the amount of radioactive material released accompanying the venting was not controlling as stated above, it is believed that the contribution to soil contamination from the venting was small.

○Venting after 12:00 on March 13 (S/C vent valve large valve operated)

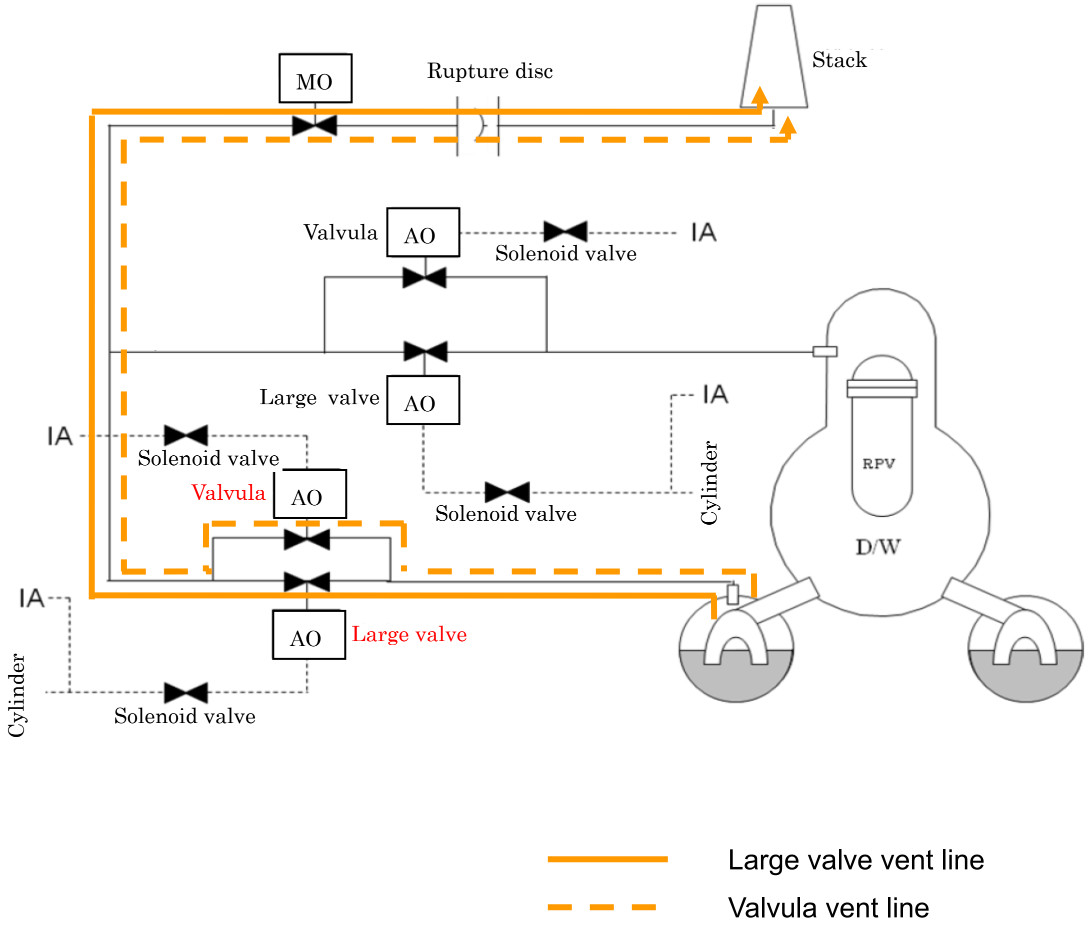
After 12:00 on March 13, an operation was conducted to open the S/C vent valve large valve. Because of the fact that a decrease in D/W pressure was confirmed and that steam was confirmed above the stack by video from the Fukuichi live camera (Attached Figure 5-3), it was determined that steam had been released by means of this venting. As shown in Figure 7 of the main document, at the times when the venting was performed, the dose rate was being measured by monitoring cars positioned near the main gate, MP-1 and MP-4, but, because a rise was not confirmed in the dose rate close to the time of the vent valve operation, it was assumed that the release was to an extent that did not vary the air dose rate, and it was assessed that radioactive material had been released from the stack. The assessment results for noble gases, iodine and cesium released during the venting are shown in Attached Table 2. When compared with the assessment results in section 4.1 of the main document, the amount released to the atmosphere due to venting was found not to have been controlling. Also, the path of the plume as projected based on wind direction, wind velocity and atmospheric stability is shown (figure superimposing the path of the plume onto Figure 30 of the main document) in Attached Figure 4-2. The plume released during the same time frame did not pass directly over the area of high contamination northwest of the Fukushima Daiichi Nuclear Power Station, and, because the assessed results obtained show that the amount of radioactive material released accompanying the venting was not controlling as stated above, it is believed that the contribution to soil contamination from the venting was small.

Even after these times, S/C vent valve large valve and valvula operations were performed. As shown in Figures 7~12 and 14 in the main document, at the times when vent valve operations were conducted, the air dose rate was being measured by monitoring cars (with the exception of venting after 5:00 on March 18), but rises in the dose rate were not confirmed for any of the vent valve operations. The assessment results for noble gases, iodine and cesium released by venting are shown in Attached Table 2. With regard to venting conducted after 12:00 on March 13, when it was assumed that the release was to an extent that did not vary the air dose rate and when it was assessed that radioactive material had been released from the stack, it was found that the amount released was smaller than that released from venting conducted after 9:00 and 12:00 on the same day, and that the amount released during venting decreased each time from the time before. With regard to the venting performed on March 14 and later, changes were not confirmed in the air dose rate, and the amount released by means of venting decreased each time from the time before as stated above, so the amount of radioactive material released accompanying venting conducted on March 14 and later was conservatively regarded as having been the same amount as released from venting conducted after 20:00 on March 13, and the amounts released were not assessed. With regard to any of the ventings as well, when compared against the assessment results in section 4.1 of the main document, it is believed that the amounts released to the atmosphere were not controlling. Also, the paths of plumes as projected based on wind direction, wind velocity and atmospheric stability are shown (figure superimposing the path of the plume onto Figure 30 of the main document) in Attached Figures 4-3 thru 4-9. As is shown in the same figures, none of the plumes passed directly over the area of high contamination northwest of the Fukushima Daiichi Nuclear Power Station, and it is believed that the contribution to soil contamination due to these ventings was small. Although the plume released from the venting conducted after 11:00 on March 20 passed close to the area of high contamination northwest of the Fukushima Daiichi Nuclear Power Station, the assessed results obtained show that the amount of radioactive material released during the venting was not controlling, so it is believed that the contribution to soil contamination from the venting was also small.

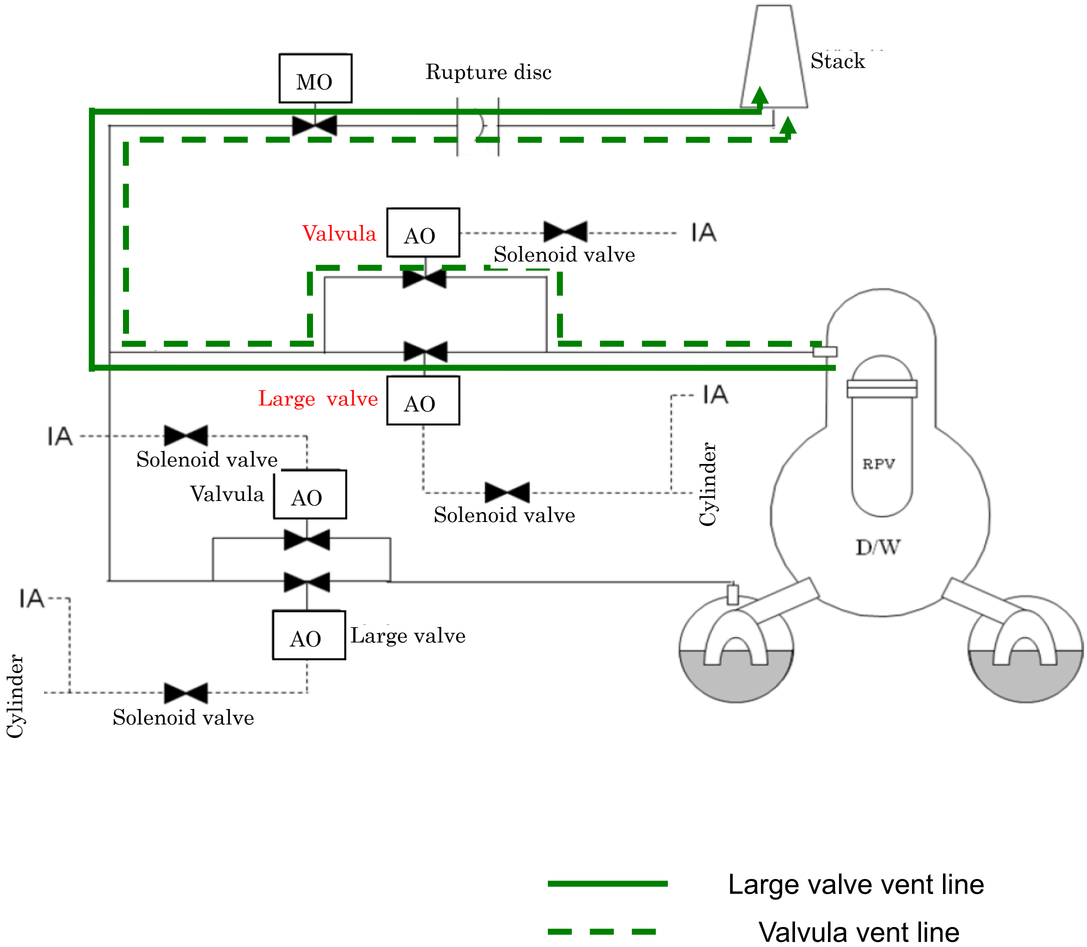
4 Summary of Radioactive Material Releases by Means of Venting

When compared with the assessment results in section 4.1 of the main document, the amount of radioactive material released to the atmosphere accompanying venting conducted at Units 1~3 was not controlling. This is believed to be because the radioactive material released during venting decreased a considerable extent due to the scrubbing effect. Also, the radioactive material released accompanying venting is believed to have contributed little to the soil contamination northwest of the Fukushima Daiichi Nuclear Power Station.

End



Attached Figure 1-1. S/C Vent Lines



Attached Figure 1-2. D/W Vent Lines

Attached Table 1. Ventings Implemented

Unit	Date/time	Vent valve operated	Time when valve confirmed to be closed
Unit 1	After 10:00 on March 12	S/C vent valve valvula	(Open state could not be confirmed)
	After 14:00 on March 12	S/C vent valve valvula large valve	Unknown (D/W pressure started to rise around 15:00 on March 12)
Unit 2	After 21:00 on March 14	S/C vent valve valvula	Around 23:35 on March 14
	After 0:00 on March 15	D/W vent valve valvula	Several minutes after opening operation
Unit 3	After 9:00 on March 13	S/C vent valve valvula large valve	11:17 on March 13
	After 12:00 on March 13	S/C vent valve valvula large valve	Unknown (D/W pressure started to rise around 15:00 on March 13)
	After 20:00 on March 13	S/C vent valve valvula large valve	16:00 on March 15
	After 6:00 on March 14	S/C vent valve valvula	16:00 on March 15
	After 16:00 on March 15	S/C vent valve valvula large valve	21:00 on March 17
	Around 2:00 on March 16	S/C vent valve valvula	Around 18:30 on April 8
	After 21:00 on March 17	S/C vent valve valvula large valve	5:30 on March 18
	After 5:00 on March 18	S/C vent valve valvula large valve	11:30 on March 19
	After 11:00 on March 20	S/C vent valve valvula large valve	Around 18:30 on April 8

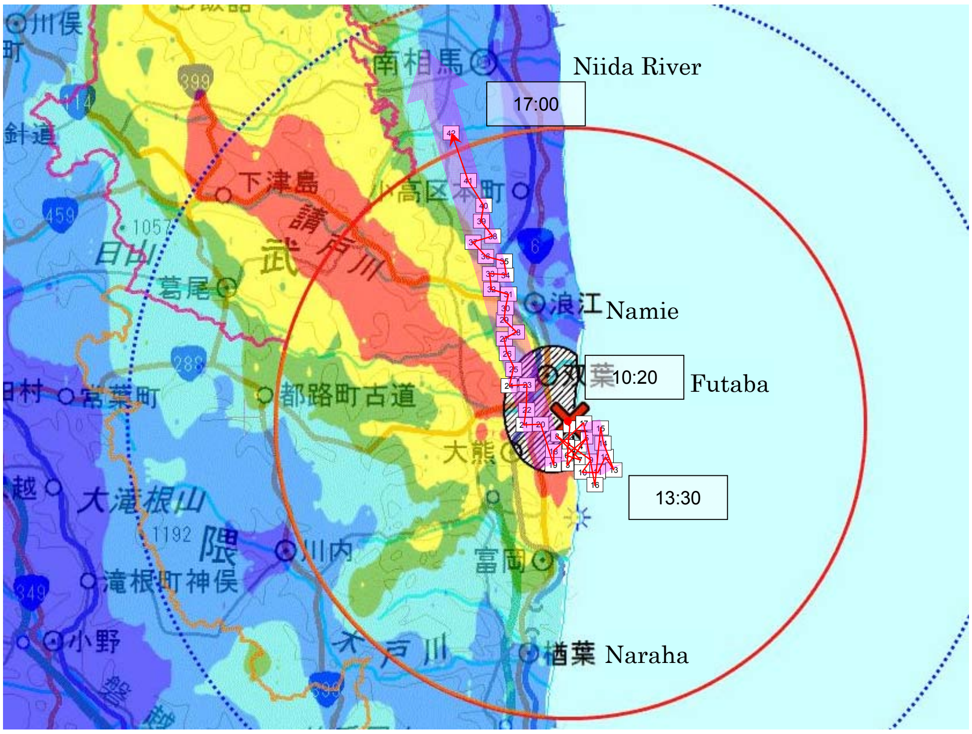
Attached Table 2. Amounts Released During Vent Valve Operations

Unit	Date/time	Event	Amount released (PBq)			
			Noble gases	I-131	Cs-134	Cs-137
1	After 10:00 on March 12	Location of release unknown	3	0.5	0.01	0.008
	After 14:00 on March 12	Primary containment vessel vent	4	0.7	0.01	0.01
2	After 21:00 on March 14[Note 1]	Location of release unknown	60	40	0.9	0.6
3	After 9:00 on March 13 [Note 1]	Primary containment vessel vent	1	0.3	0.005	0.003
	After 12:00 on March 13 [Notes 1、2]	Primary containment vessel vent	0～0.04	0～0.009	0～0.0002	0～0.0001
	After 20:00 on March 13 [Notes 1、2]	Primary containment vessel vent	0～0.003	0～0.001	0～0.00002	0～0.00002
	After 6:00 on March 14 [Note 3]	Primary containment vessel vent	0～0.003	0～0.001	0～0.00002	0～0.00002
	After 16:00 on March 15 [Note 3]	Primary containment vessel vent	0～0.003	0～0.001	0～0.00002	0～0.00002
	Around 2:00 on March 16 [Note 3]	Primary containment vessel vent	0～0.003	0～0.001	0～0.00002	0～0.00002
	After 21:00 on March 17 [Note 3]	Primary containment vessel vent	0～0.003	0～0.001	0～0.00002	0～0.00002
	After 5:00 on March 18 [Note 3]	Primary containment vessel vent	0～0.003	0～0.001	0～0.00002	0～0.00002
	After 11:00 on March 20 [Note 3]	Primary containment vessel vent	0～0.003	0～0.001	0～0.00002	0～0.00002

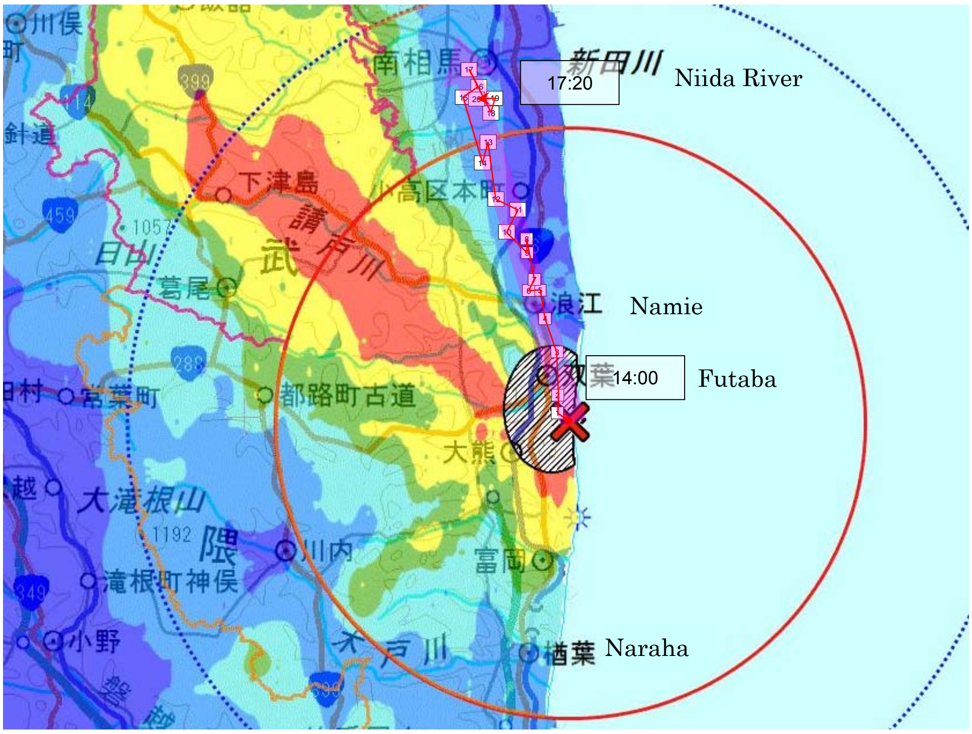
Note 1: It is believed that Units 1~3 released radioactive material directly to the atmosphere from the primary containment vessel due to the building explosions and opening of blowout-hole panels. Because it is difficult to separate the releases resulting from venting and releases directly from the primary containment vessel in making an assessment, building explosions occurring after or venting implemented after a building explosion or blowout panel opened are assessed as comprising also radioactive material released directly from the primary containment vessel in addition to radioactive material released from venting and building explosions.

Note 2: Because peaks do not appear in the dose rate, it is assumed in making the assessment that there was a release to the extent that it did not effect any variation in the dose rate.

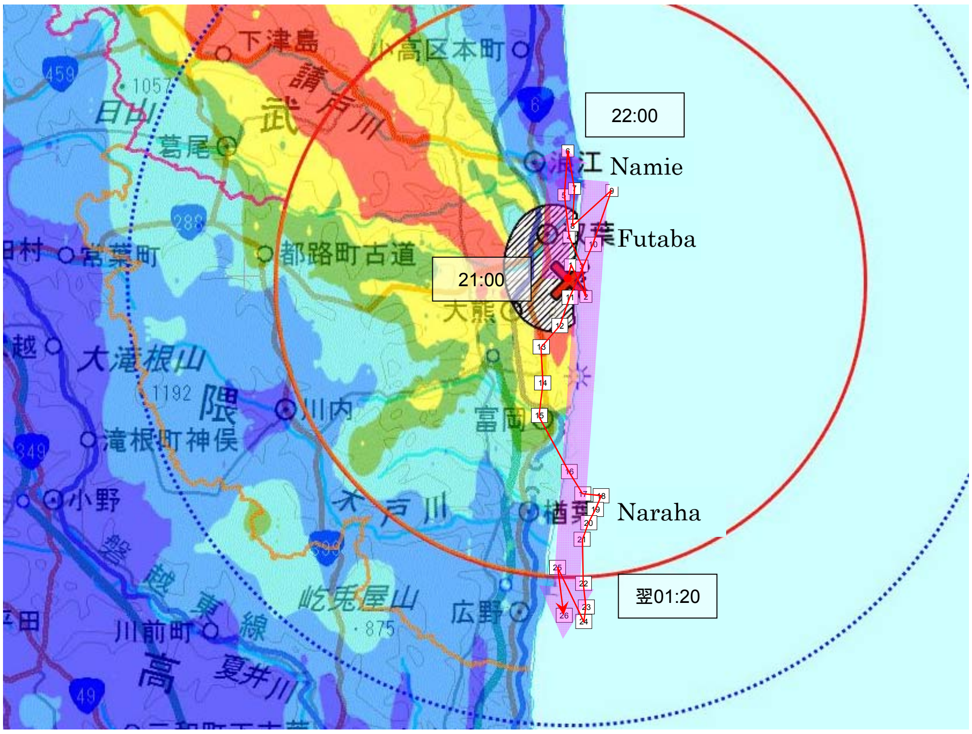
Note 3: With regard to the venting of Unit 3, it has been found that the amount released at the time of venting decreases with each time a based on the assessment results of venting which was conducted three times on March 13. Fluctuations in the air dose rate have not been confirmed in regard to venting conducted on or after March 14, so it is possible that the release of radioactive material was even less, and this is regarded as being the same as the amount released during venting after 20:00 on March 13. The reason for this is that deposits which had accumulated up to that point raised the background value, resulting in an oversized amount released according to an estimation method which uses a value of 1% for the background value.



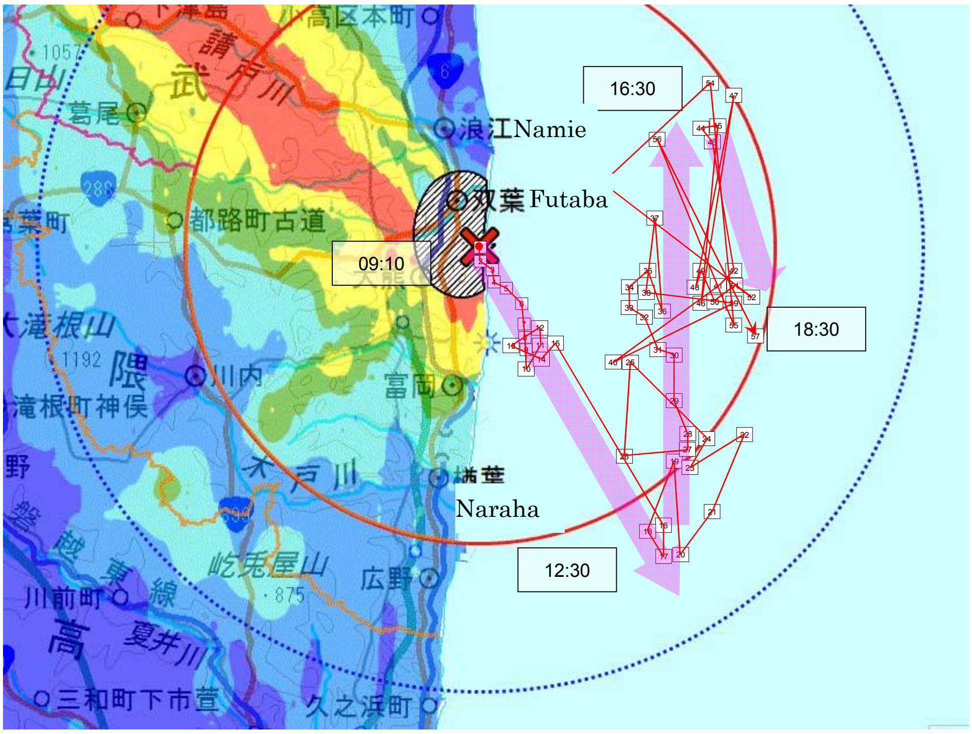
Attached Figure 2-1. Path of Plume Released after 10:00 on March 12



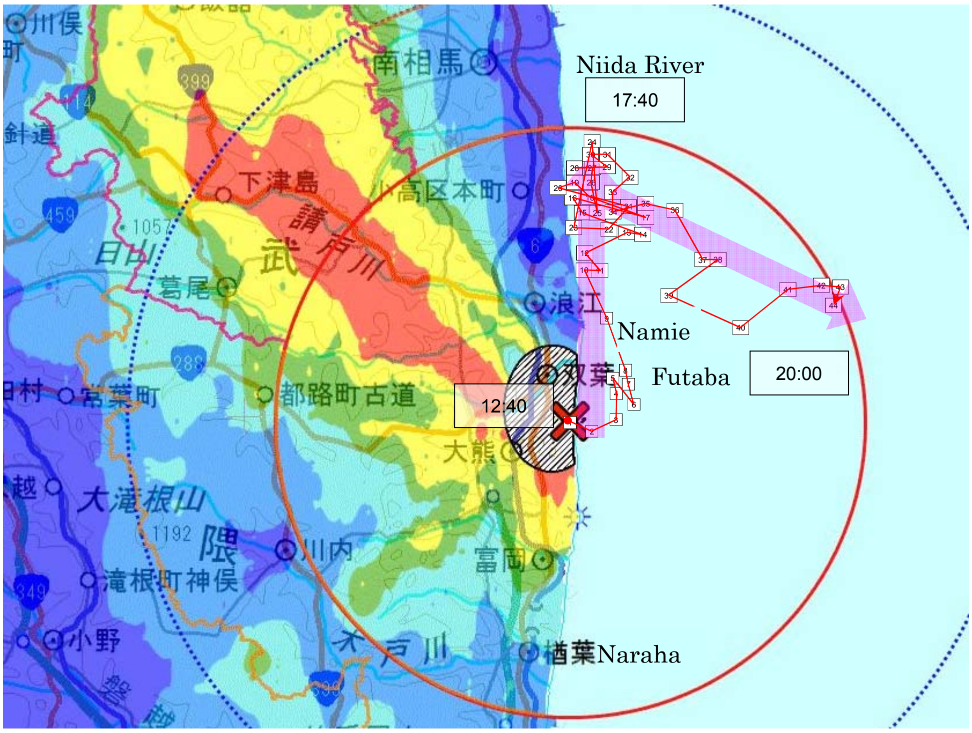
Attached Figure 2-2. Path of Plume Released During Venting of Unit 1 after 14:00 on March 12



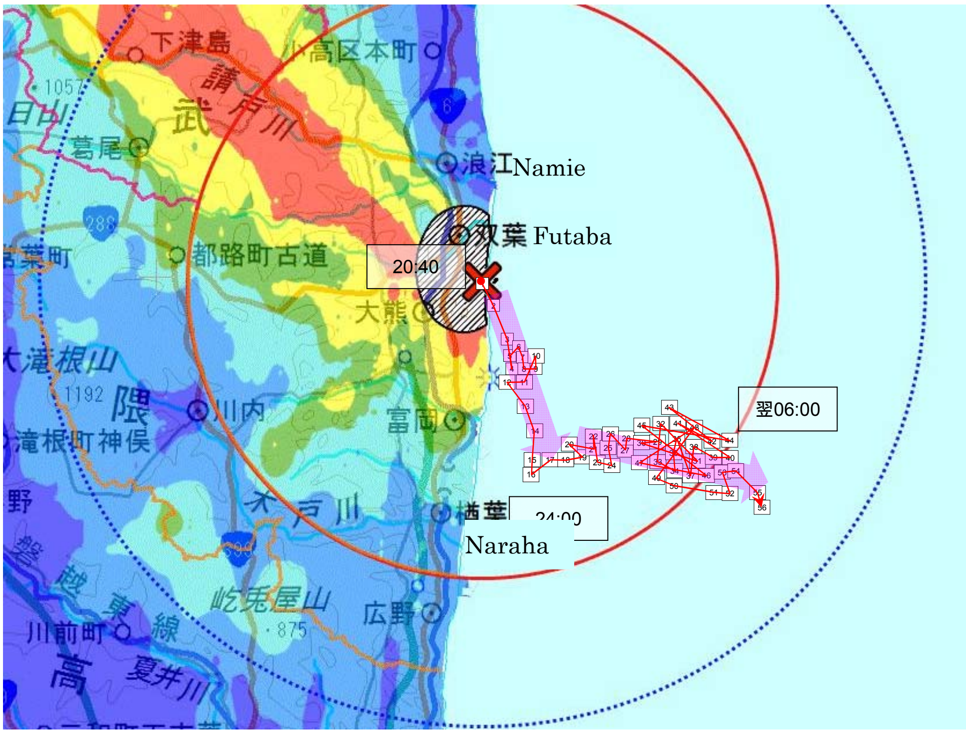
Attached Figure 3. Path of Plume Released after 21:00 on March 14



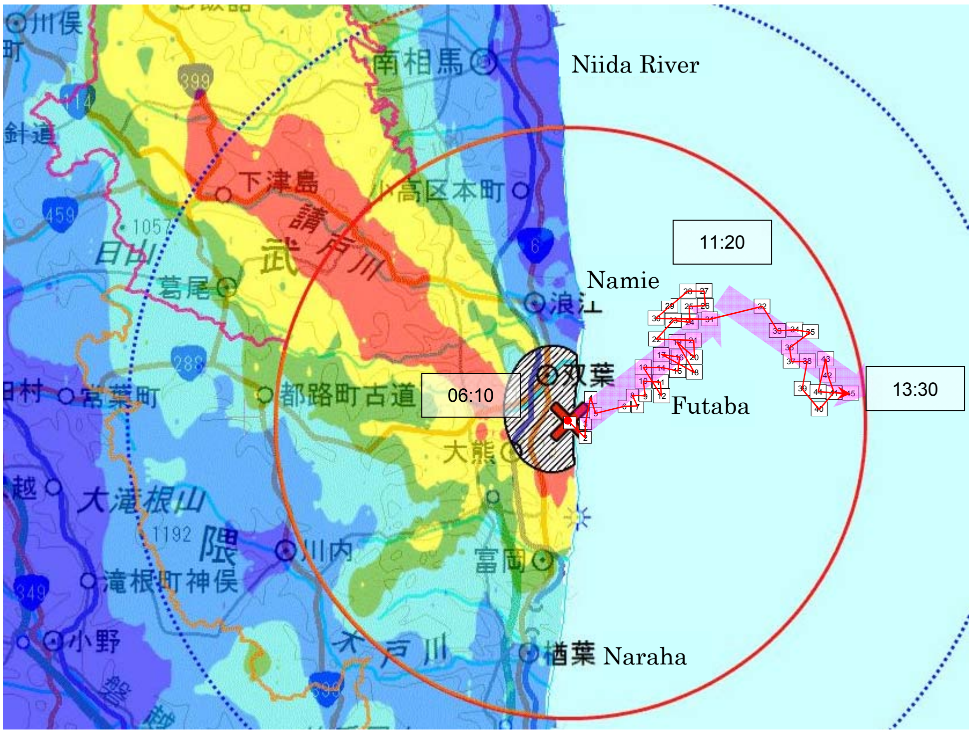
Attached Figure 4-1. Path of Plume Released During Venting of Unit 3 after 9:00 on March 13



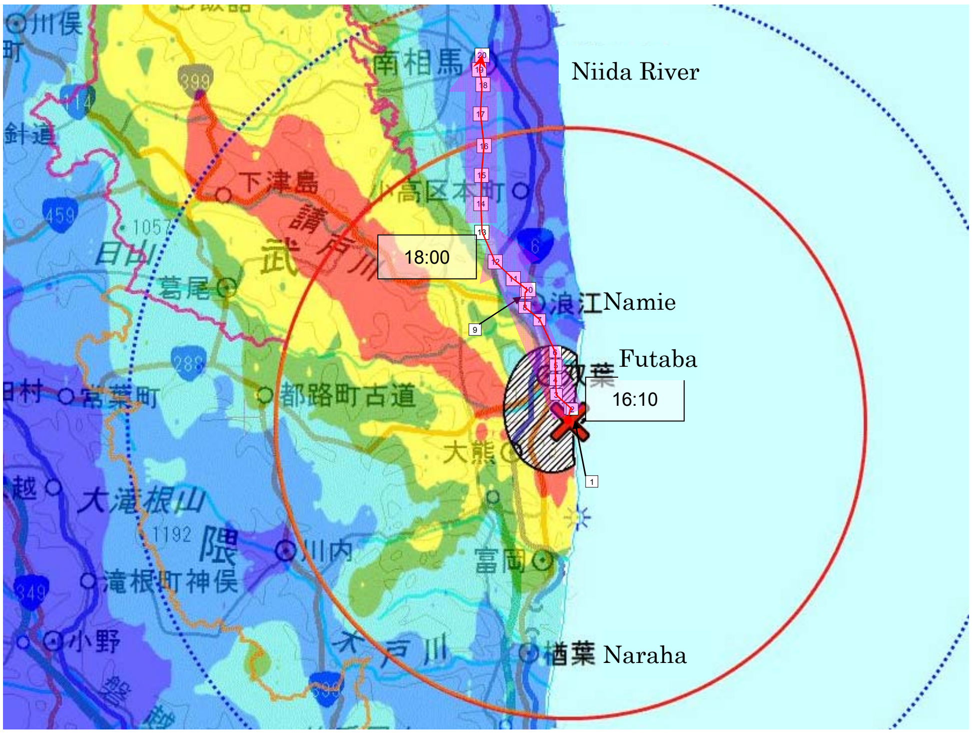
Attached Figure 4-2. Path of Plume Released During Venting of Unit 3 after 12:00 on March 13



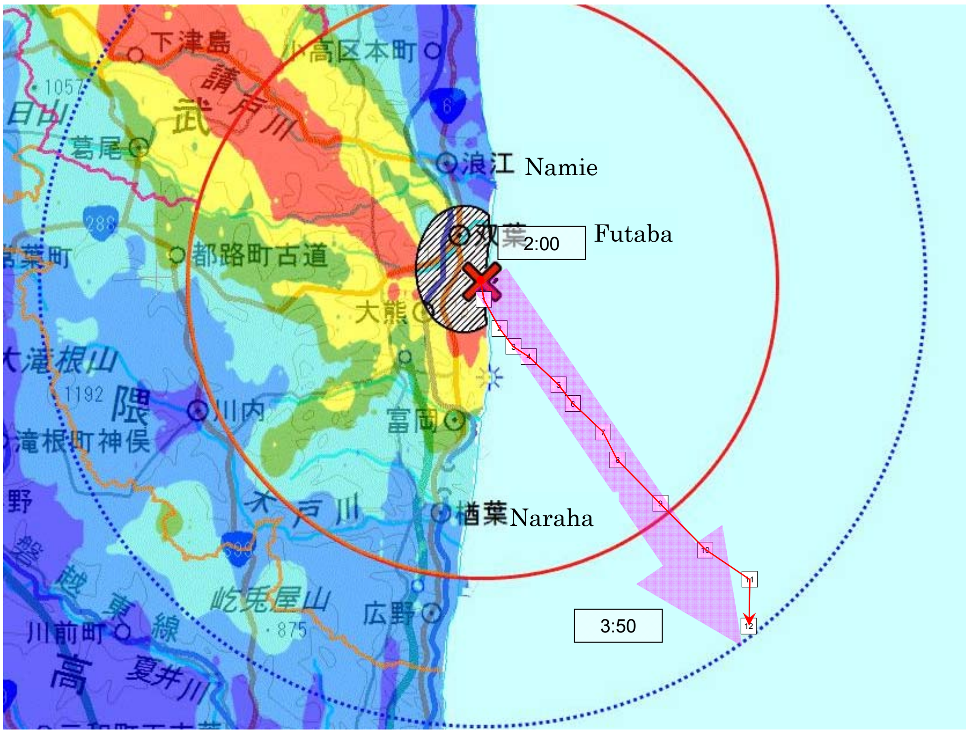
Attached Figure 4-3. Path of Plume Released During Venting of Unit 3 after 20:00 on March 13



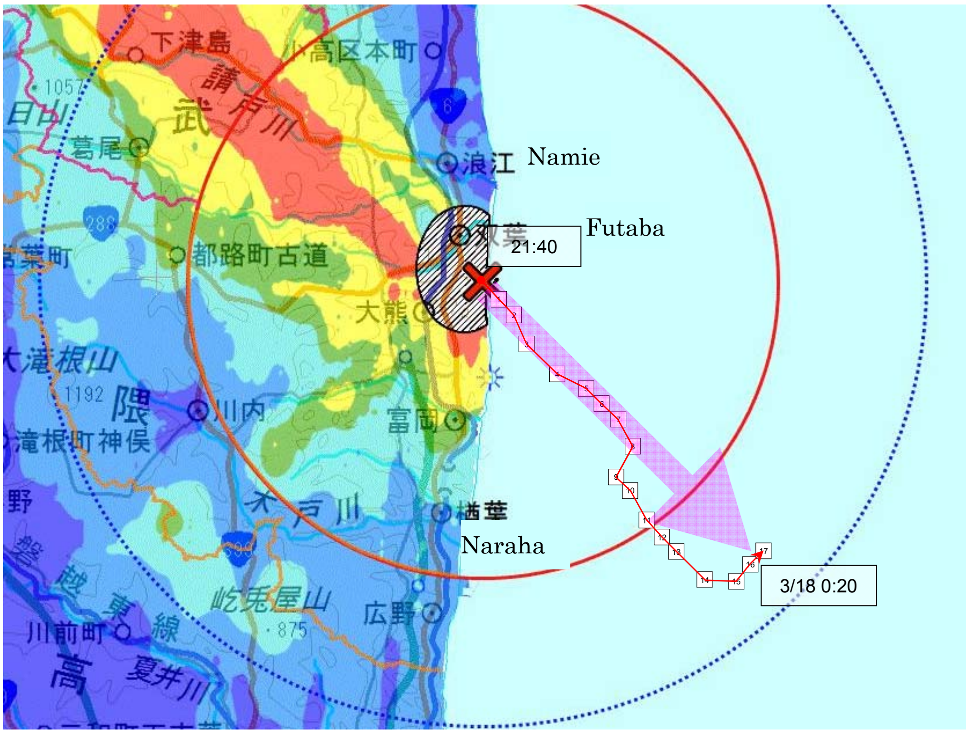
Attached Figure 4-4. Path of Plume Released During Venting of Unit 3 after 6:00 on March 14



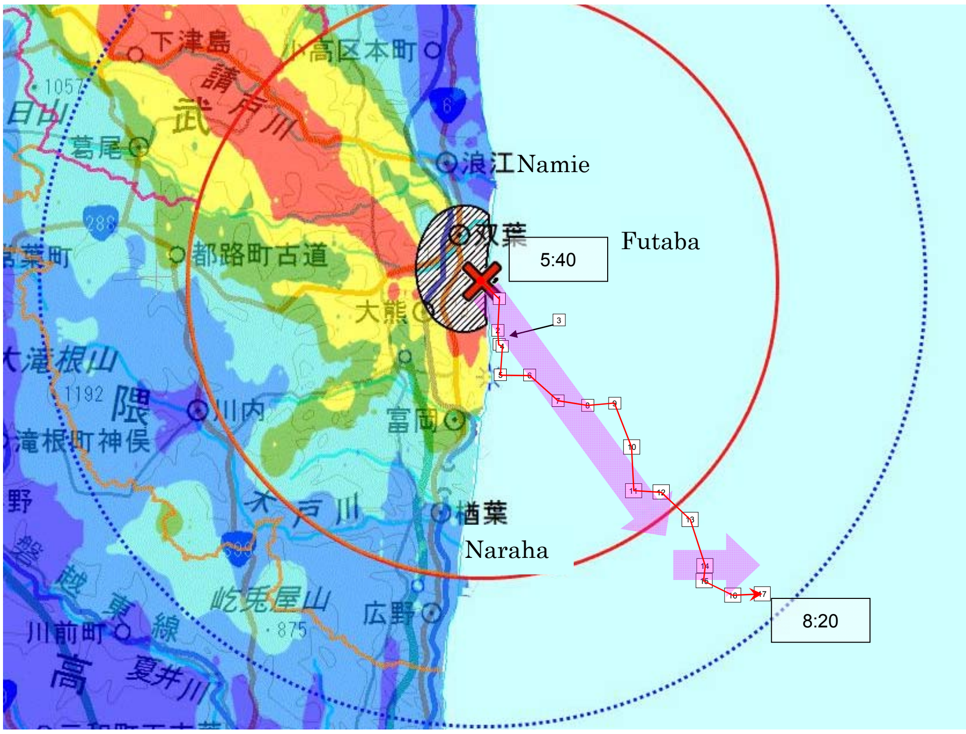
Attached Figure 4-5. Path of Plume Released During Venting of Unit 3 after 16:00 on March 15



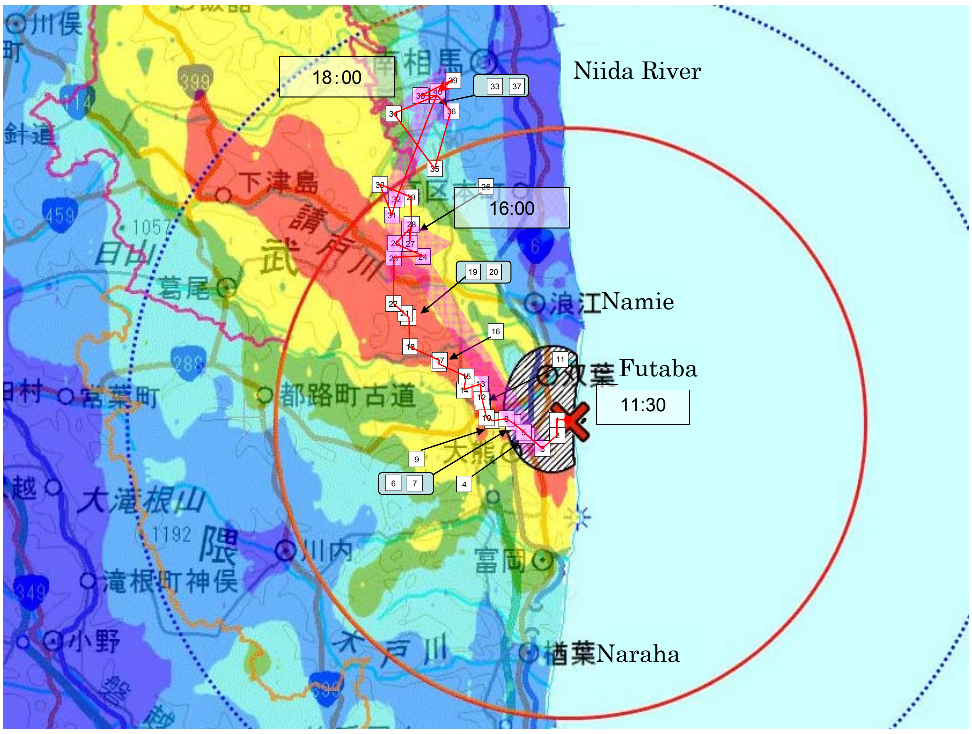
Attached Figure 4-6. Path of Plume Released During Venting of Unit 3 after 2:00 on March 16



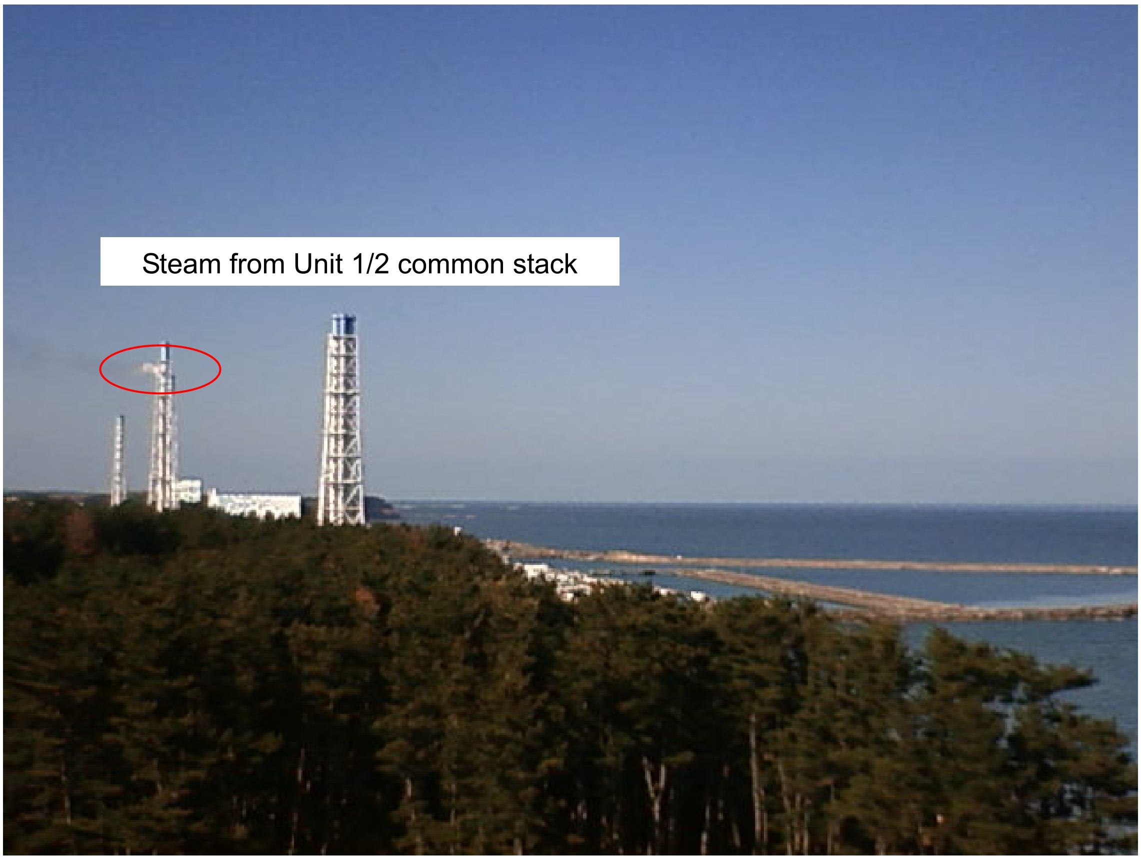
Attached Figure 4-7. Path of Plume Released During Venting of Unit 3 after 21:00 on March 17



Attached Figure 4-8. Path of Plume Released During Venting of Unit 3 after 5:00 on March 18

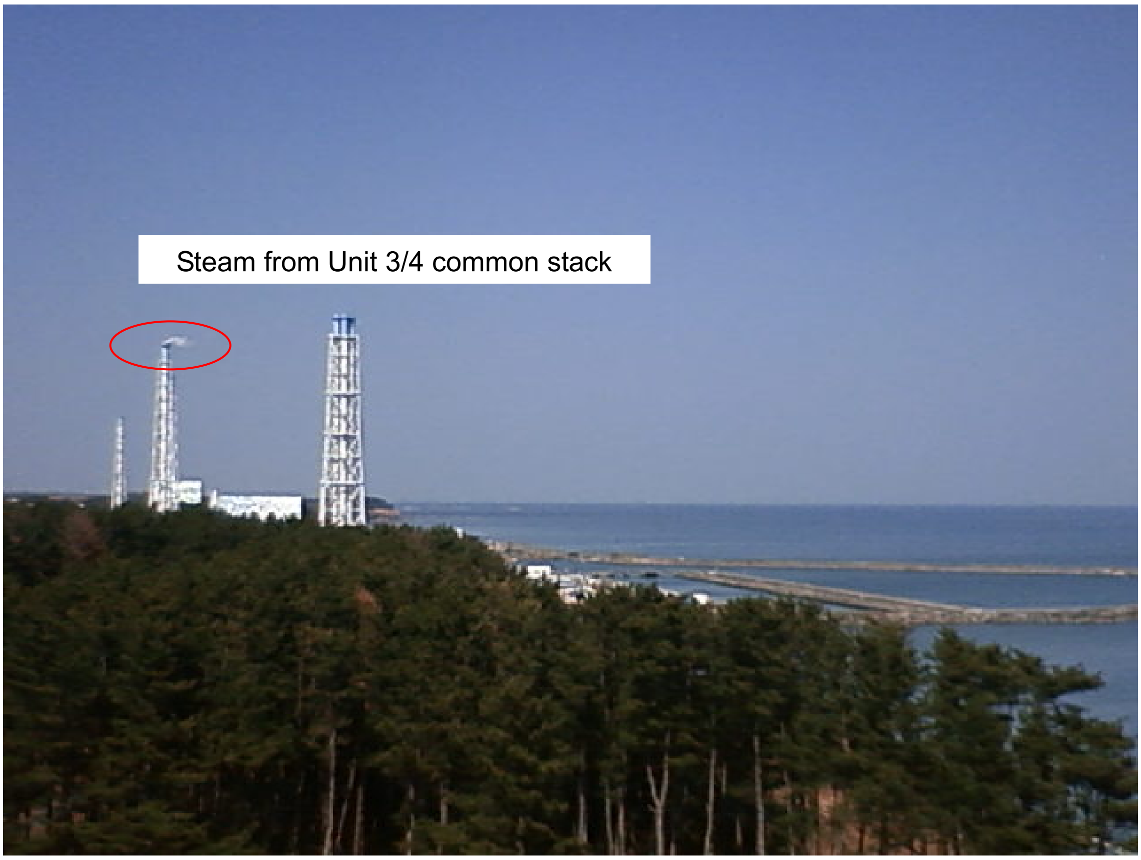


Attached Figure 4-9. Path of Plume Released During Venting of Unit 3 after 11:00 on March 20



Attached Figure 5-1. Image from Fukuichi live camera (~15:00 on March 12)

Attached Figure 5-2. Image from Fukuichi live camera (~10:00 on March 13)



Attached Figure 5-3. Image from Fukuichi live camera (~13:00 on March 13)

Attachment 3

Discussion of Leakage from Primary Containment Vessel

1 Discussion of Leakage Route from Primary Containment Vessel

At Units 1~3 of the Fukushima Daiichi Nuclear Power Station, the primary containment vessels were exposed to a high temperature and high pressure environment as a result of the accident, and based on the subsequent pressure behavior of the primary containment vessel and other factors, it has been determined that leaks developed from the primary containment vessels. Here, the purpose is to conduct an estimation of the locations of leaks from the primary containment vessels.

1.1 Important Sources of Information about Primary Containment Vessel Leakage Routes

(1) Knowledge Acquired from the Perspective of Primary Containment Vessel Design

The extent of leakage when the PCV is exposed to a high temperature and high pressure environment differs depending on the design of the primary containment vessel (PCV), so design information is believed to contribute to estimation of the locations of leaks from the PCV.

(2) Other Knowledge Acquired from Information Confirmed in the Vicinity of the PCV Boundary and Other Sources

Information, such as that pertaining to the soundness of the PCV boundary, state of contamination inside and outside the reactor building (R/B) and other data based on field investigations and other sources in addition to the aforementioned, is believed to contribute to estimation of the principal locations of leaks from the PCV.

1.2 Knowledge Acquired from the Perspective of PCV Design (Attached Figure 1)

(1) Flanged Portions

・Outward-Opening Flanges

With top head flanges, traversing in-core probe (TIP) system penetrations, control rod drive (CRD) system hatches, suppression chamber (S/C) manholes and other outward-opening flanges, excessive pressure acting upon the PCV interior may open the flange, and high-temperature steam coming into direct contact with organic sealing material (silicon rubber) may result in deterioration of the organic sealing material. With respect to “pressure receiving area/(gross-sectional area of flange bolt × flange bolt length),” the hatches mounted on the PCV are structured so that the top head flange is the easiest to open, followed by the S/C manhole. There is a high likelihood that these flanges may develop leaks due to the deterioration of the organic sealing material.

・Inward-Opening Flanges

Equipment hatches and other inward-opening flanges are structured so that the flange closes as a result of PCV internal pressure, and when compared to the outward-opening flanges, it is difficult to conceive of an event in which high-temperature steam would come into direct contact with the organic sealing material, producing deterioration.

(2) Personnel Air Locks

Personnel air locks are inward-opening double-entry door structures. The door is suppressed by a latch mechanism, and the flange face does not have a metal touch. Accordingly, there is a high likelihood that high temperature steam may come into contact directly with the organic sealing material, deteriorating the sealing material.

(3) Electrical Wiring Penetrations

There is knowledge from high temperature and high pressure testing of canister-type electrical wiring penetrations that organic sealing material deteriorates under conditions of 400C and/or 700kPa[gage], and major leaks have developed. Accordingly, there is the possibility that such penetrations may become paths for leaks when the penetration has a history of high temperature or high pressure.

At Unit 1, all of the electrical wiring penetrations have already been replaced with a module-type that has a high degree of leaktightness.

(4) Bellows

When stainless steel (SUS 304) bellows are mounted on vent piping and some piping penetration parts, the seawater injected into the PCV may cause stress-corrosion cracking or pitting of the bellows, resulting in a path for leaks.

(5) Vacuum Breaker

The vacuum breaker on Unit 1 is connected to the vent piping outside the S/C. If a high temperature state were to result, there is a likelihood that leaks may occur from valve seals, cover gaskets and other such areas.

1.3 Other Knowledge Acquired from Information Confirmed in the Vicinity of the PCV Boundary and Other Sources

1.3.1 Steam Confirmed on First Floor of Unit 1 R/B

On June 3, 2011, an outflow of steam was confirmed from penetration seals on the piping floor of the atmospheric control system in the southeastern part of the first floor of the Unit 1 R/B (Attached Figure 2). The PCV internal temperature on June 3 was 100□, and the floor below the location where steam was flowing out was the torus, so it has been inferred that steam flowing out had flowed into the torus from either the S/C or dry well (D/W). However, it was difficult to identify whether the location of the steam leak was the S/C or D/W.

1.3.2 Steam Confirmed to be Emitted from Area Directly Above Unit 2 Reactor

On September 17, 2011, when video was taken at the time dust was sampled at the opening of the blowout panel on the Unit 2 R/B, it was confirmed that steam was being generated from a portion directly above the reactor (Attached Figure 3). At that point in time, it could not be confirmed from where exactly the steam was leaking, but it was inferred from the video taken that the location of the steam leak was the vicinity of the reactor well head of the upper part of the PCV top head flange, which is located on the upper part of the reactor. Also, because of the fact that the temperature of the spent fuel pool was not high (approximately 34C on September 17, 2011), the confirmed steam is believed to have leaked from the PCV. The structure of the PCV top head flange (or reactor well head) for both Units 1 and 3 is the same as on Unit 2, and it is believed that at both Units 1 and 3, the same PCV leakage path may exist as has been inferred at Unit 2.

Moreover, according to the results of air dose measurements taken inside the R/B which are currently being ascertained, the high dose (approximately 200mSv/h) confirmed on R/B floor 5 has not been confirmed on floor 4 or a lower floor (Attached Figure 4). When it is taken into account that the R/B structure has been maintained at Unit 2 and that there is conceivably a correlation between dose distribution and the leak path, it is suggested that leak from the fifth floor was the main leak.

1.3.3 Confirmed Thermal Imagery from Above Unit 3

On March 20, 2011, thermal imagery was taken using an infrared thermographic device and other equipment from the sky above the Unit 3 R/B by the Technical

Research and Development Institute of the Ministry of Defense. From the results, it has been ascertained that there was a comparatively high-temperature region directly above the reactor on the refueling floor of Unit 3 after the R/B exploded (Attached Figure 5). The location in question is thought to be in the vicinity of the reactor well head of the upper part of the PCV top head flange, and it has been suggested that it was possible steam flowed out from this location.

1.3.4 Survey Results of Triangular Corners in Underground Levels of R/Bs at Units 2 and 3

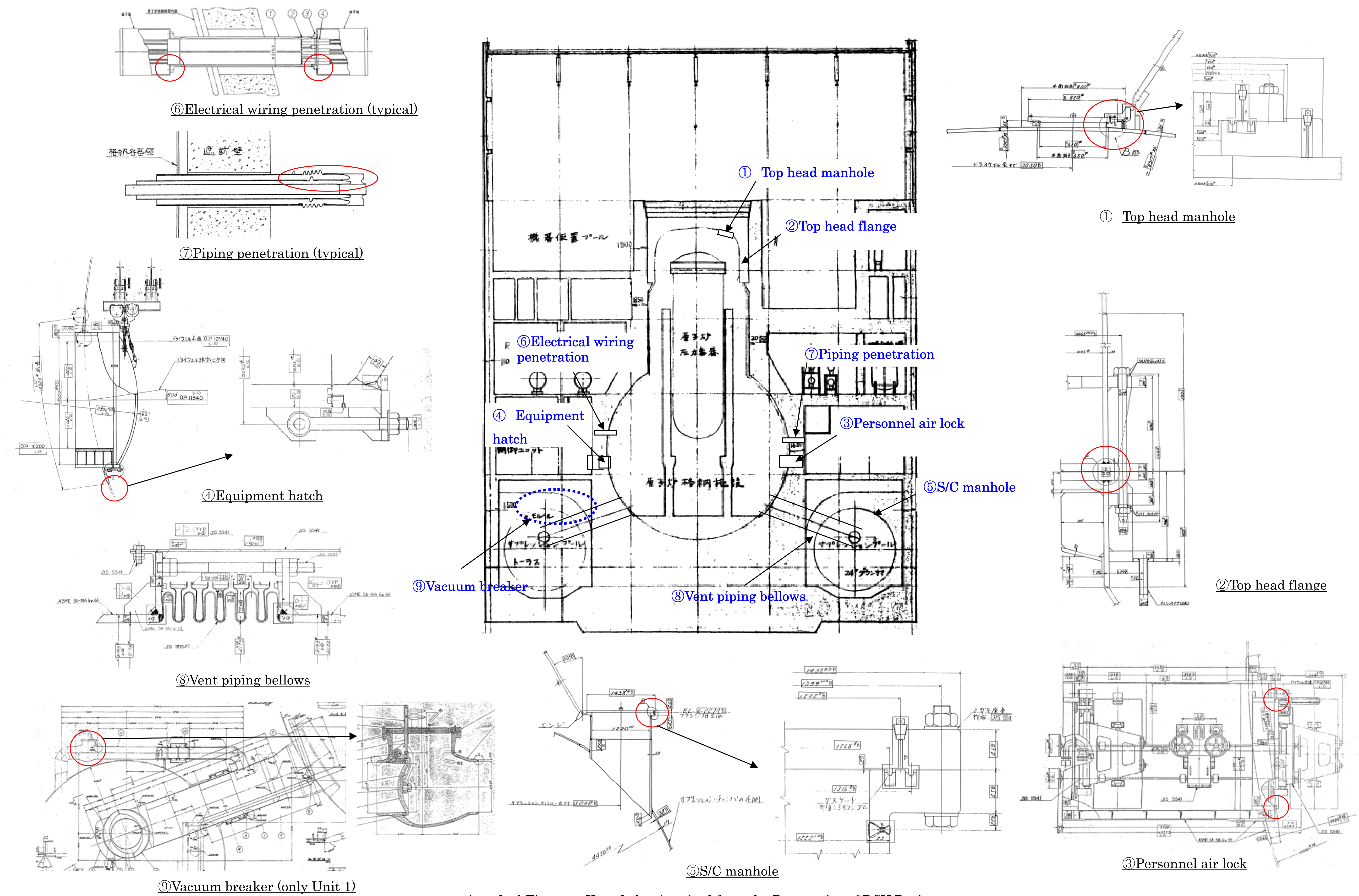
On March 14, 2012, a field survey was conducted of the R/B underground levels and other areas in order to investigate the torus. The results showed that the ambient dose in triangular corners was approximately 15~30mSv/h. These values are either the same as on the first floor of the R/B as shown in Attached Figures 4 and 6 or even lower values, and it has been confirmed that no peeling of paint has been confirmed on the fifth floor of the Unit 2 R/B (Attached Figure 7). This is believed to be due to steam leakage from the torus to the triangular corner areas having been limited, and it suggests the possibility that there was steam leakage from the upper part of the PCV earlier than leakage from the lower levels.

1.3.5 Survey Results of Unit 2 R/B Torus

On April 18, 2012, a survey runner was used to conduct a field survey of the interior of the Unit 2 torus. From the results, no major leaks, deformations or damage were confirmed within the range inspected by camera. In particular, the results of an inspection using camera of the exterior of the S/C manhole, which was cited as an assumed location for leakage from the perspective of PCV design in section 1.2 (1), no major leaks, deformations or damage were confirmed, nor were there any indications confirmed that an explosion had occurred. Taking into account the fact that D/W pressure was tending upward at the time the field survey was conducted, it is believed that the airtightness of the gas phase area inside the Unit 2 primary containment vessel was high, and it is inferred that there was also a small possibility of a gas phase leak in addition to the liquid phase leak from the S/C manhole.

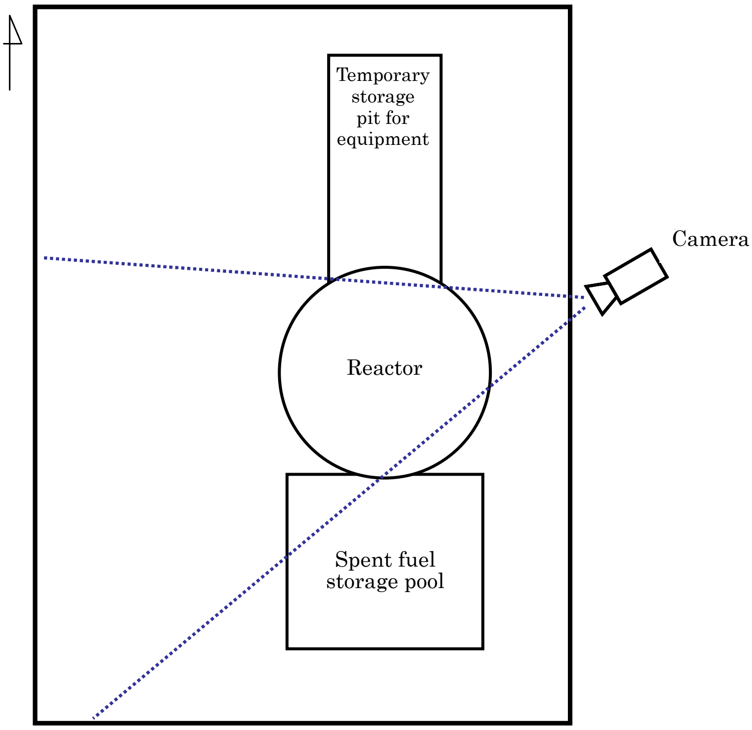
2 Summary

At Units 1~3, it is believed that the binding portion (top head flange) of the PCV head, the binding portion of hatches where equipment and people go in and out as well as other sealed portions where silicon rubber and other such materials are used for leakproofing may have been exposed to high temperatures and their functionality decreased. At the current stage, it is difficult to identify the locations of the leaks. However, if magnitude and other factors pertaining to leaks from the gas phase area are taken into consideration, it is believed that the leaks may have mainly occurred from sealed portions of the top head flanges.



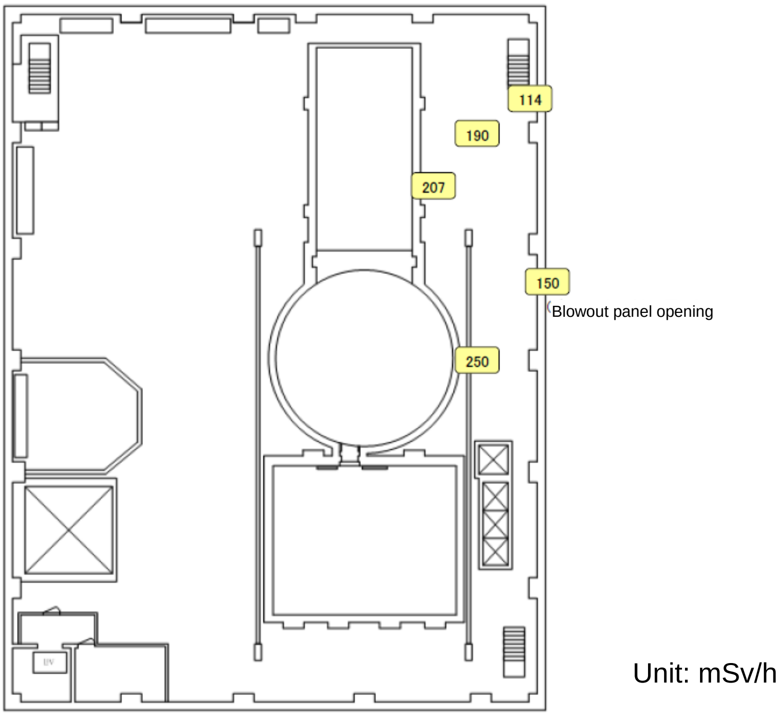
Attached Figure 1. Knowledge Acquired from the Perspective of PCV Design

Attached Figure 2. Steam Released from Floor
Penetration on Unit 1 R/B First Floor
(Photo taken on June 3, 2011)

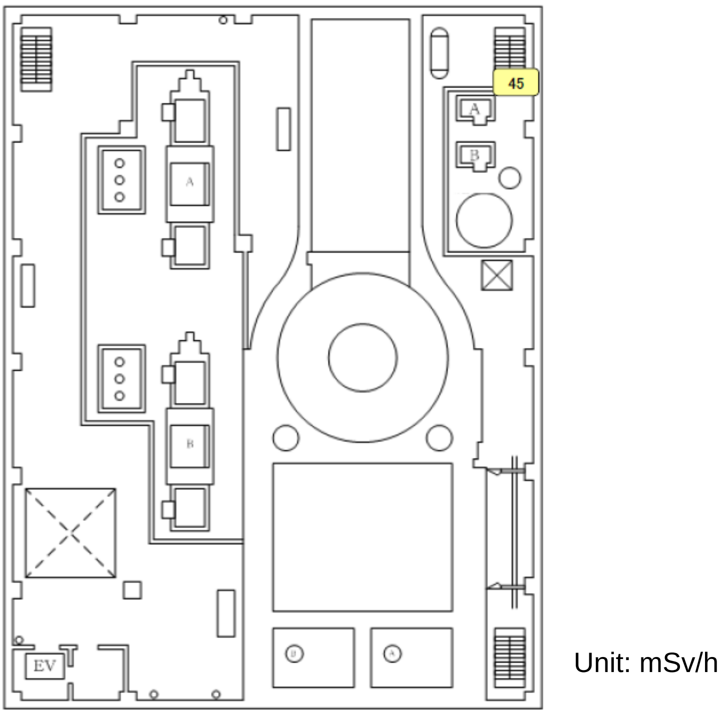


Schematic Representation of Fifth Floor of Unit 2 R/B at Fukushima Daiichi Nuclear Power Station

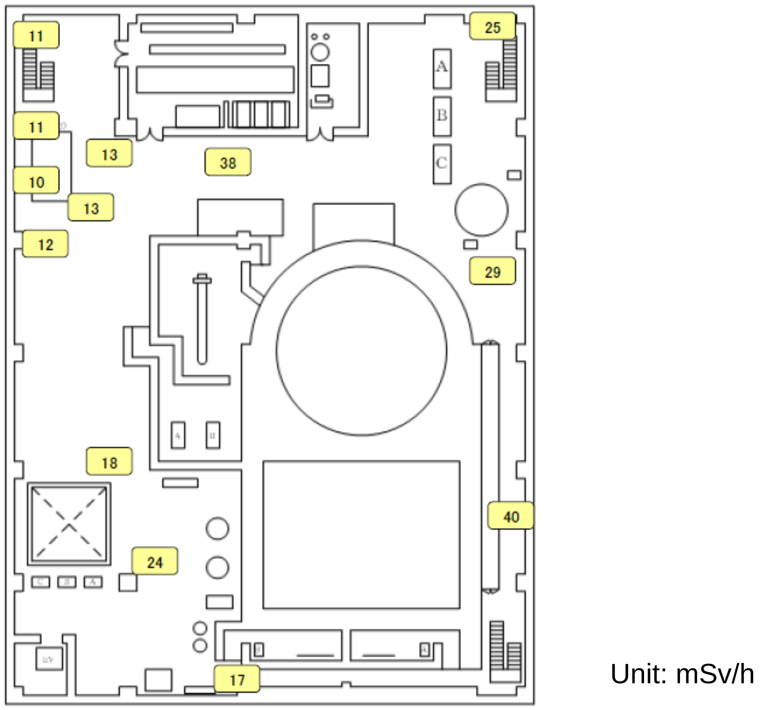
Attached Figure 3. Confirmation of Steam Generation on Fifth Floor of Unit 2 R/B
(Photo taken on September 17, 2011)



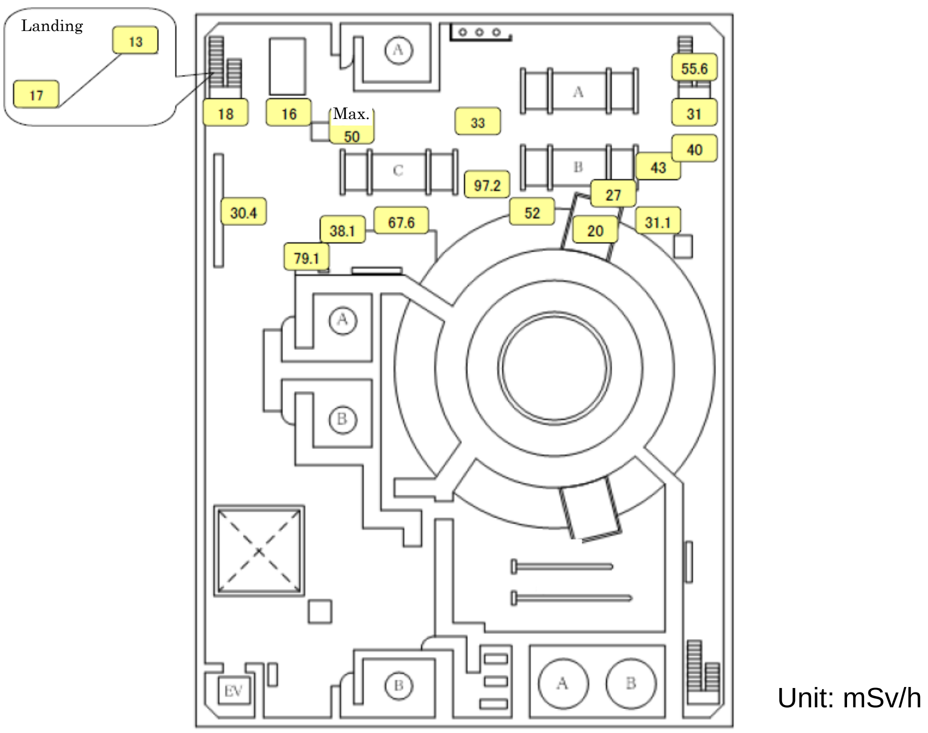
Attached Figure 4－1. Air Dose inside Unit 2 R/B (5th Floor)



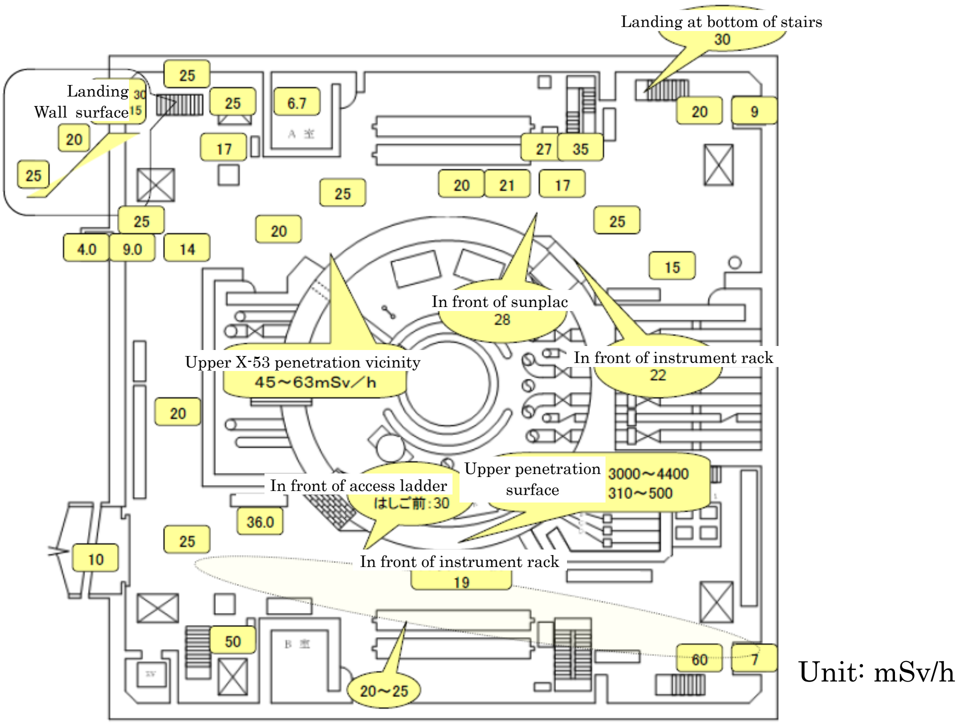
Attached Figure 4－2. Air Dose inside Unit 2 R/B (4th Floor)



Attached Figure 4－3. Air Dose inside Unit 2 R/B (3rd Floor)



Attached Figure 4－4. Air Dose inside Unit 2 R/B (2nd Floor)



Attached Figure 4－5. Air Dose inside Unit 2 R/B (1st Floor)

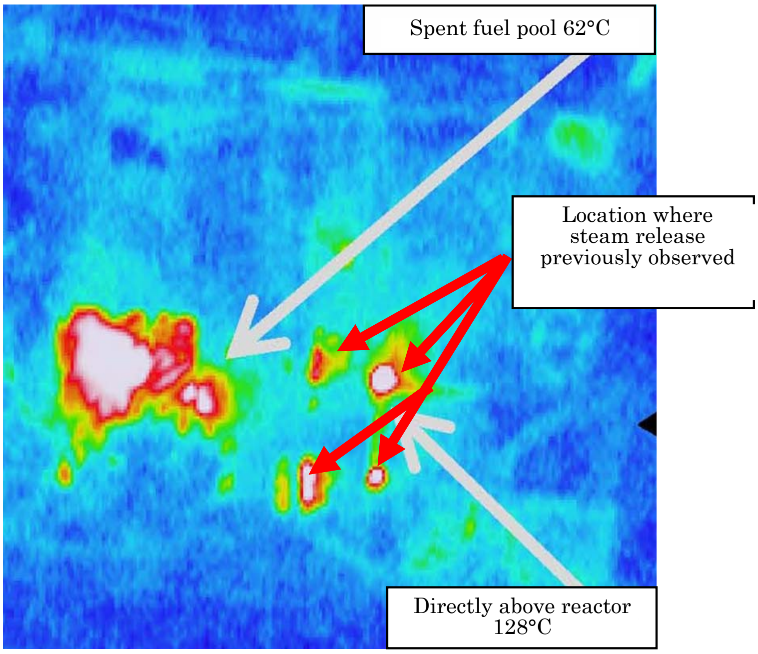
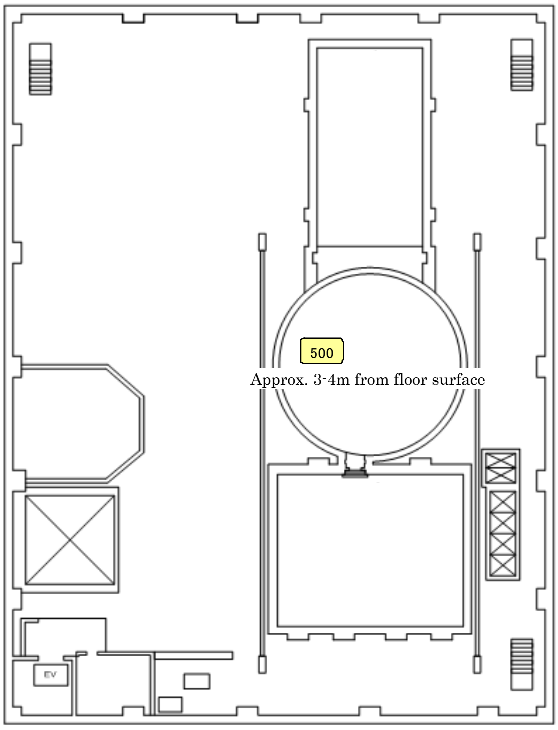


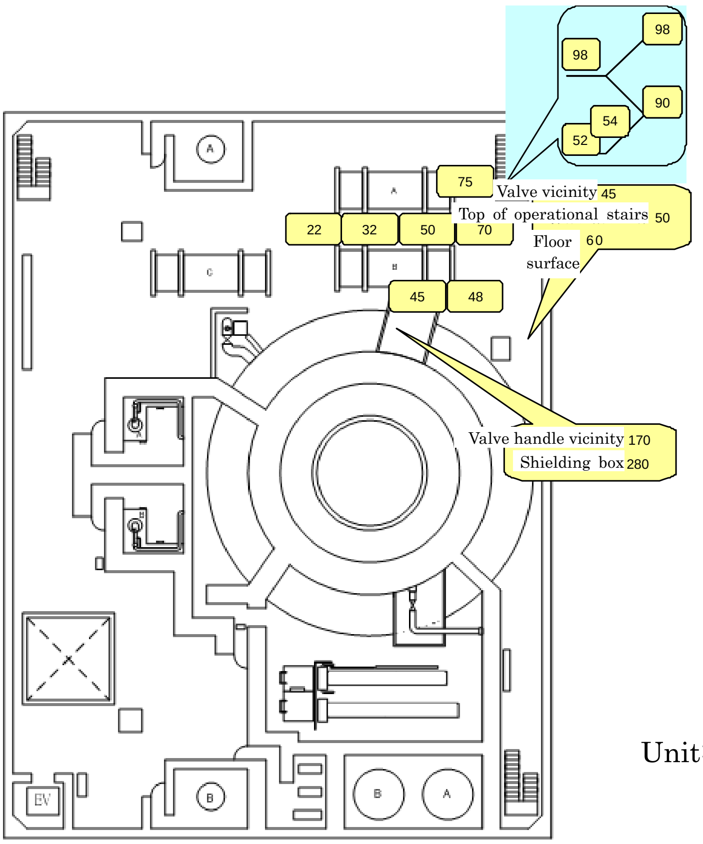
Photo by Technical Research and Development Institute, Ministry of Defense

Attached Figure 5: Thermal Imaging Photo Taken above Unit 3 R/B
(Photo taken on March 20, 2011)



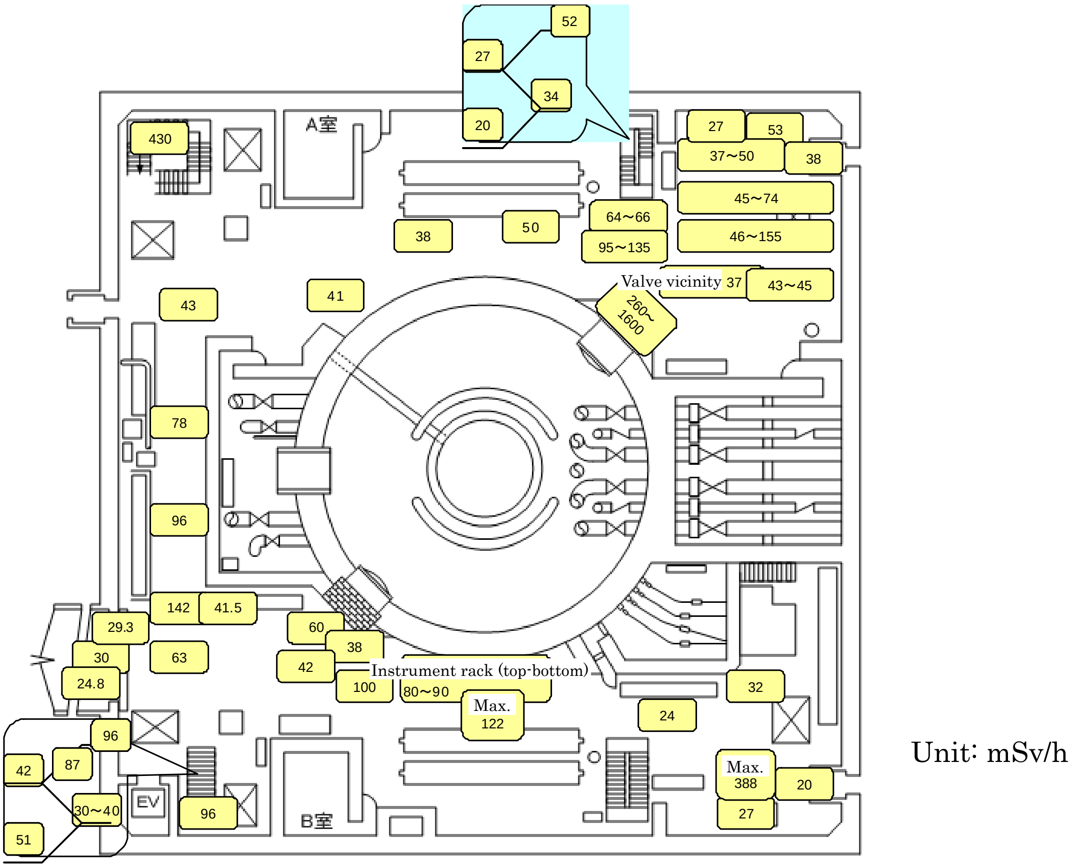
Unit: mSv/h

Attached Figure 6－1. Air Dose inside Unit 3 R/B (5th Floor)

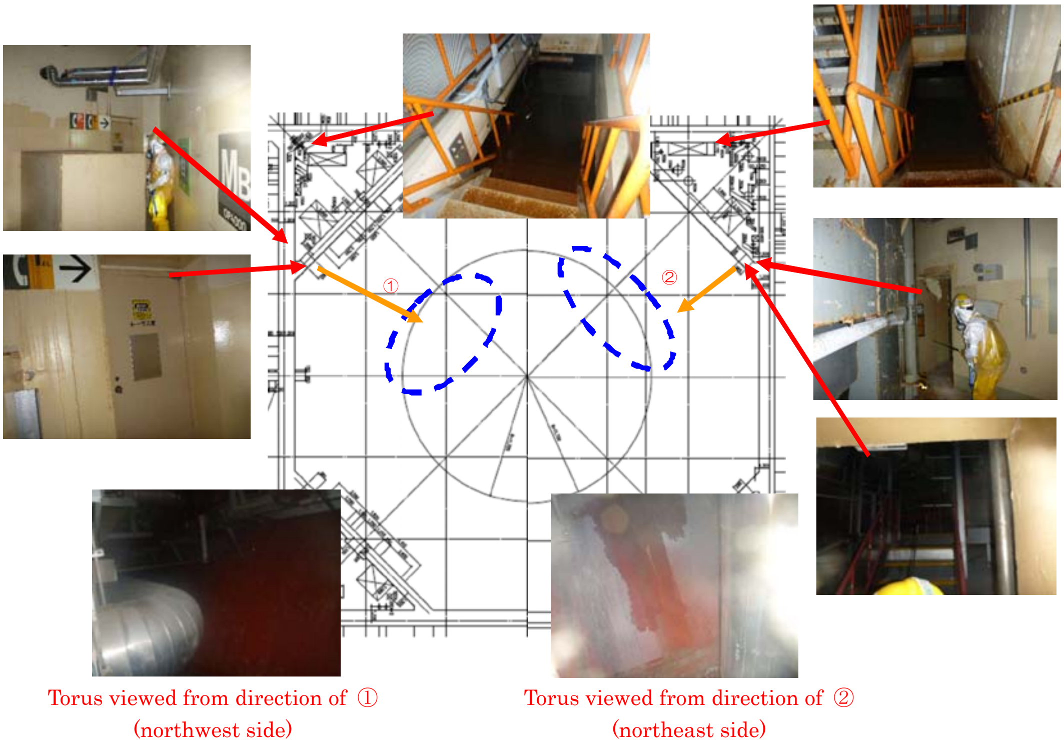


Unit: mSv/h

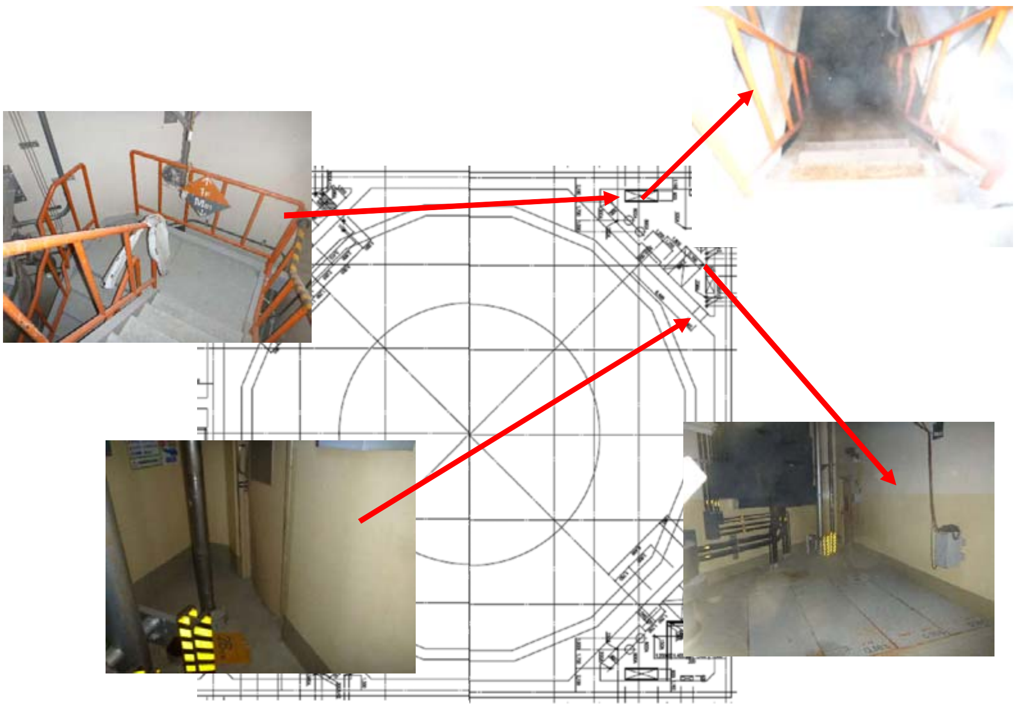
Attached Figure 6－2. Air Dose inside Unit 3 R/B (2nd Floor)



Attached Figure 6－3. Air Dose inside Unit 3 R/B (1st Floor)



Attached Figure 7－1. Survey Results of Torus and Underground Levels in Unit 2 R/B
(Photo taken on March 14, 2012)



Attached Figure 7－2. Survey Results of Torus and Underground Levels in Unit 2 R/B
(Photo taken on March 14, 2012)