Commentary

Impacts of Fukushima Daiichi NPP Accident through Atmospheric Environment

–First Step Toward Grasping Comprehensive Overview of Environmental Impact–

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Currently, measurements are conducted on the site to reveal the environmental impact of radioactive materials released during the accident. Meanwhile, there has not been any public explanation on the overall impact. At any stage of an accident, it is required for the off-site counter measures to grasp the overall accident scenario and communicate to the society about its serious environmental impacts.

I. Introduction

In the northwestern direction from Fukushima Daiichi Nuclear Power Plant, higher air dose rate than other areas continues to be detected at the point of early May 2011, when this paper was written. In the Kanto region, which is more than 100–200 km away from the accident site, increase in air dose rate was detected on March 15 and 16, 2011 and radioactivity was detected from tap water and agricultural products after March 21. In contrast, relatively lower air dose rate was detected in the coastal areas of Minamisoma even if it was relatively close to the accident site.

Although these measurements were published by organizations, such as the national government, raw data with different qualities are published as lists without temporal or spatial uniformity from several organizations. There has not been any public explanation about the overall influence of the accident even after two months. In particular, during the first two weeks after the accident, there has been virtually no information about the situation of the radioactive material release from the plant. Meanwhile, environmental contamination by the radioactivity released due to the unprecedented accident in Japan was constantly being detected in various locations. Combined with the strong reactions from other countries, starting from the United States, it is deemed that the fragmentary information in fact caused the speculation and social confusion. The situation was such that even the specialists in the field of environment had to gather the information from the websites of relevant organizations and media reports and carefully analyze them to merely obtain a vague understanding of the scale of the accident or how the environmental impact was progressing.

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While the release of radioactive material into the ocean is also causing a major impact, this paper will focus on its release into the atmosphere and examine the environmental impact of the accident from an analytical perspective. Following are the important perspectives for considering the impacts of the accident for a short duration. (1) The types and quantity of the radioactive nuclides that were released from the accident facility and their time course. (2) The concentration of radioactive materials and the quantity of deposition on the ground surface in the affected areas (contamination of soil, water, and agricultural products) due to the atmospheric transport phenomenon. (3) External exposure through radiation from the radioactive materials in the atmosphere (cloud shine) and the internal exposure through inhalation. (4). External exposure from the nuclides deposited on the ground surface (ground shine). In this study, the impact of the accident on the atmospheric transport will be surveyed provisionally from these perspectives.

Further, the perspectives on the internal exposure caused by the resuspension of nuclides deposited on the ground or by transfer to agricultural products will be indispensable to consider their long-term impacts. Moreover, it is important to grasp the impacts of these accidents and to plan and implement the measures based on them in timely and appropriate manner. The aspects whether the results contributed toward securing the safety of the local residents, whether information was disclosed properly, whether it contributed to avoiding confusion among people in Japan and people in foreign countries. It is inevitable that lessons learned objectively and multilaterally should be introduced in the future. Although prediction should be avoided, since this manuscript was written when the information was not yet sufficiently organized, please note that there is a limitation in distinguishing between facts and predictions.

II. Release into the Atmosphere from the Accident Facility

It is clear that the total absence of information provided by the facility on the radioactive nuclides released into the atmosphere, its amount (rate), form of the release (position and whether it was continuous or intermittent), and the time course of these release source was the major obstacle in estimating the environmental impact outside the facilities and devising a response plan. It is imperative to fully examine whether the necessity and importance of these information for the emergency measures outside the facility was not sufficiently recognized. If it was recognized, why was the necessary information not collected? Or was the method or competence for gathering such information lacking? This chapter will outline how to estimate the release information based on the limited information, such as incomplete environmental monitoring, result in the situation where no information can be expected from the facility. This chapter also includes the estimation result published by the Nuclear Safety Commission.

1. Monitoring Data of Facilities

If the radioactive material is released via exhaust stack, the release rate can be estimated from the exhaust stack monitor. However for this accident, absolutely no information was obtained from the exhaust stack monitor; whether this was due to power loss is unknown. Moreover, there is also no measurement result of the air dose rate from the permanent monitoring post on the premises boundary. During March, only dose rate at every 10 min from generally one location (mainly the main gate or the west gate) by a monitoring car was obtained.

Although measurers faced difficulty due to exposure and contamination, the information derived is insufficient for quantitative understanding of the release source information and its time course; thus, only the broad tendency of the release could be determined. Measurement was not conducted during the early stage of the accident, and during March 14 to 16, which is considered to be the crucial time for the impact assessment, the measurement location was reduced and not restored or expanded in the following two weeks when a large amount of release into the atmosphere were deemed to be continuing. After April, dose rate was measured at the monitoring post on the boundary of the premises. However, this monitoring at the time when the release rate is significantly lower and with its minimum value at 1 μSv/h only confirms that no as substantial release was observed as was in March; this information cannot be used for estimating the scale of the ongoing release. Outside the premises of the facility, Fukushima Prefecture has more than 20 observation stations. However, no necessary information for planning measures against dose rate or weather was obtained from these, presumably due to the effect of the earthquake and blackout.

Figure 1 shows the measurement results of air dose rate at the premises boundary (~1 km from the reactor building(R/B)) published by the company operating the power plant [1)]. The dose rate increased considerably before March 16. Particularly before the morning of March 15, it corresponds with the phenomena that are deemed to be accompanied by release. In the figure, the period of time when the wind direction was toward the ocean was calculated based on the wind data measured along with the dose rate monitoring. The wind data was measured 2–3 m above the ground. Considering the uneven terrain, it is necessary to evaluate whether the measured wind direction represents the wind of the whole site. It shows that before the morning of March 15, there were many cases wherein the dose rate did not increase even during the period when the onshore breeze continued. Therefore, it is assumed that the release was intermittent and accompanied the phenomena that triggered release.

In contrast, frequent increase of dose rate during the time period with onshore wind direction was observed after March 16. The dose rate increase while plume is passing greatly differs depending on whether the center of the plume passes in the vicinity of the measurement point or is at a distance while passing. The measurement from the Tokaimura criticality accident clearly demonstrated this phenomenon. When this result is considered along with the fact that the wind direction near the ground surface constantly changes due to the fluctuation

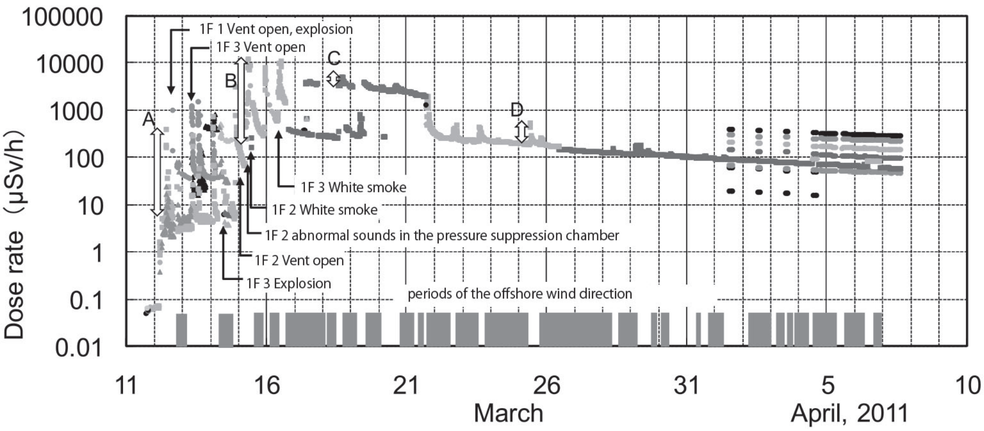

Figure 1 Monitoring results of the air dose rate around the premises boundary by the company operating the plant [1)]

of atmospheric turbulence and the changes in meteorological field through time, the short-term changes in dose rate shows that the axis of plume crossed the measurement point (if plume is compared to a clock hand and the release point its fulcrum, then this phenomenon is similar for the sweeping second hand). By considering all these aspects, we fairly assume that the release continuously occurred after March 16. The effect of the changes in wind direction is applicable to the measurements before the morning of March 15. Thus, the shape of dose rate transition does not necessarily represent the mode of release (the pattern of changes of release late through time).

Based on these discussions, it is assumed that although estimating the release mode from the dose rate data of the premises boundary is difficult, it is highly likely that the release rate at that point of time can be estimated from the amount of increase of dose rate determines. Figure 1 shows that if a timeline is obtained by picking up the size of each peak, then it's envelop can be regarded as the envelop of release mode at a good approximation. Although the analysis result based on this view is not considered herein, the release was relatively small until the evening of March 14, reached its peak on March 15, and gradually decreased throughout late March. At that point, the release was 3 or 4 orders of magnitude smaller than the maximum amount. However, the difference in the nuclide composition that contributes to the dose rate was not considered in this approximation. In the future, there is a possibility that other information about the release source could be obtained from the characteristics of dose rate change, such as the decrease of ground shine components or the ratio between sky and ground shine components.

2. Estimation of Release Source Information Based on Remote Data

On April 12, the Nuclear Safety Commission disclosed that the provisional estimation of I-131 and Cs-137 from the beginning of the accident to April 5 are 1.5×10^{17} and 1.2×10^{16} Bq, respectively[2]. Together with the estimations published by the Nuclear and Industrial Safety Agency (NISA) (1.3×10^{17} and 6.1×10^{15} Bq)[3], these estimations became the basis for the provisional assessment of level 7 of International Nuclear Event Scale. This information from the Nuclear Safety Commission is available for the period until the date the information is published as an academic paper[4]. This paper will only discuss the outline. Please refer to the references for figures.

This estimation is obtained as the necessary release rate for reproducing the concentration of measured radioactive nuclide in the atmosphere via atmospheric diffusion calculation using SPEEDI and WSPEEDI. In other words, in atmospheric diffusion calculation, unit release is postulated (for instance, each nuclide is released at 1 Bq/h), and the release rate is obtained by dividing the concentration obtained from measurement by the concentration obtained from calculation (in this case equivalent to the dilution rate). However, the estimation on March 15 was conducted using the measurement and calculation of the ground shine dose rate of the deposited nuclide on the surface in the northwest direction from the accident facility because the atmospheric concentration that can be used for the release rate estimation was unavailable.

Thus, change in the release rate of I-131 was in the range of 10^{14} Bq/h until March 14, on the order of 10^{16} Bq/h at a certain time in March 15, 10^{14} Bq/h until around March 24, and decreased to less than 10^{13} Bq/h by March 27. Then, the release rate increased once to ~10^{14} Bq/h by the end of March and decreased in the following few days to 10^{12} Bq/h. This tendency of change is similar to the aforementioned release rate variation estimated from the dose rate from the area around the boundary of premises. Although its ratio relative to I-131 increased as the time elapsed, the variation pattern of Cs-137 was almost similar.

Estimations using similar methods were conducted previously. For instance, results that are consistent with the estimations made later with other methods were obtained for the Chernobyl Accident[5)], the accidental release caused by burning medical Cs-137 in Europe[6)], and the JCO Accident[7)]. It is a relatively robust method; although, performing a detailed estimation is impossible in principle.

However, there is a possibility that this estimation method may cause significant uncertainty. In atmospheric dispersion calculations, error originating mainly from the errors in wind field and atmospheric turbulence field is contained and the position of plume and its arrival time obtained from calculation do not necessary correspond to actual measurements. Moreover, the estimation accuracy is affected depending on whether the measurement captured the main part of the plume. In this case, since the number of atmospheric concentration measurement values is extremely limited, the accuracy of estimating the release rate and the details of grasping the time variation are limited. Thus, the published values should be regarded as provisional, and future examination is required to validate its accuracy.

From this perspective, the fact that little information on the concentration in the atmosphere was obtained via emergency monitoring during the early stage of the accident, combined with the lack of dose rate monitoring in the vicinity of the area as discussed earlier, is a serious shortcoming for comprehending the accident scale from the perspectives of release rate estimation and environmental impact, and more importantly, from the perspective of protecting local residents from internal exposure. For off-site countermeasures, it is difficult to understand why the measurement of the concentration in the atmosphere was not conducted for more than a week after the accident within the framework of emergency monitoring. There is a possibility that the measurement was conducted but data were not obtained; the authors cannot ascertain this presently.

III. State of Atmospheric Diffusion

1. Outline

The dose rate in the premises changes according to the changes in wind direction at the point of May; thus, it is inferred that release into the atmosphere is ongoing. However, its release rate is deemed to be small. Therefore, the atmospheric diffusion situation can be evaluated until around March 25 when the release rate is large, which mostly determined the environmental impacts. This paper only discusses that period; however, the impact of the release into the atmosphere during other periods cannot be ignored.

To facilitate easy understanding of the impact, it is categorized into the following three categories. (1) Contamination by diffusion and deposition within 20 km range (short-distance impact). (2) Impact on the areas several dozen kilometers northwest from the facility (northwestern-area impact). (3) Impact on large areas, including the central Fukushima prefecture, Tohoku region, and Kanto region.

Regarding the short-distance impact, sufficient monitoring information has not been disclosed; therefore, understanding the progress of contamination when large-quantity release was observed and the current state of contamination distribution are insufficient. The dose rate in the area within 20 km range was disclosed by the Ministry of Education, Culture, Sports, Science and Technology for the first time in April, and then several measurements were added[8)] (mainly ground shine reflecting the soil contamination). The results showed that the high-contamination area with over 100 μSv/h and the area with <1 μSv/h, which are mainly around the shore on the north side of the site are mixed, showing strong localization of contamination, determined from the direction the plume extended from the accident facility, the release rate at that moment, and whether there was precipitation. Detailed measurement and analysis is required in the future to determine these factors.

2. Contamination in Northwestern Direction

In the coastal area, the land and sea breeze circulation becomes dominant when the barometric gradient of the general field becomes smaller. In the area of Fukushima Daiichi Nuclear Power Plant, the wind that was breezing toward the ocean in the evening turns to south in the early morning, followed by the direction changes to southwest, west, and then to northwest from afternoon to evening. Such clockwise wind direction change is frequent in that area. Moreover, this was combined with the valley wind along the slopes and valleys of the Abukuma mountain range to be considered to cause the transport toward inland. During the period with large release rate, such phenomena were considered to have occurred on March 15 and 20. Particularly on March 15, the release rate is estimated to be 1 to 2 orders of magnitude larger than those observed on other days. The transportation to the inland area by the sea breeze and the valley wind occurring at that time, and the stagnation caused by the weak wind at night are factors that influence the formation of contaminated area. However, the actual time when the radioactive materials that contributed to the northwestern contamination were released on March 15 is not understood so far.

Moreover, precipitation was observed from the evening of that day to the next day. Although it was raining at the night of March 15 in Fukushima City, it snowed before the dawn of March 16 when the temperature lowered. It is likely that in the Abukuma mountain range at higher altitudes, it was snowing during the night of March 15. The deposition of radioactive materials when there is precipitation (wet deposition) causes significantly higher surface contamination than deposition without precipitation (dry deposition). Excluding the radioactive material in the form of large-size particle that can deposit due to the gravity, only the radioactive materials in the air that is in contact with the ground surface deposit in the dry deposition. Deposition of the radioactive material aloft must wait for the vertical transport by the atmospheric turbulence. Thus, in the dry deposition, the radioactive materials in the air close to the ground surface makes major contribution. In contrast, in the wet deposition, precipitation captures the radioactive material in the air and carries them down to the ground. Therefore, all the radioactive materials in the atmosphere, except for the noble gases, possibly contribute to the deposition.

Considering the time course of γ ray dose rate caused by ground shine, it can be concluded that the contaminated area in the northwest direction were caused by the coincidence of the following three conditions, namely, the high release late on March 15, local wind circulation and precipitation. This contaminated area in the northwestern direction (ground shine caused by deposition) were understood at the latest by the early morning of March 16 as the result of SPEEDI calculation that considered the damage on Unit 2 pressure suppression chamber conducted by the Government Nuclear Emergency Response Headquarters (calculation No.41 by the secretariat to the Government Nuclear Emergency Response Headquarters) [9], and a spatial distribution that is close to the actual contamination situation was obtained. Moreover, SPEEDI calculation conducted at the dawn of March 15 allowed the Local Nuclear Emergency Response Headquarters to predict a high probability of diffusion toward northwestern direction in the afternoon of the same day (calculation No.3 of the Local Nuclear Emergency Response Headquarters) [10].

3. Large Area Impact

The most conspicuous large area impacts during the period under discussion are the following: (1) Northward impact on March 12 (dose rate increase at Onagawa). (2) Impact on Kanto region and other regions between March 15 and 16. (3) Impact on the same area between March 20 and 22. This section will discuss the impact on Kanto direction of (2) and (3).

Figure 2 shows the result of atmospheric transport calculation of these two examples using a numerical model [7]. The analytical meteorological data JRA 25 by the Meteorological Agency and the Central Research Institute of Electric Power Industry were used as the input to calculate the three-dimensional distribution of wind and turbulence using the non-hydrostatic atmospheric model MM5 and the Lagrangian diffusion model to obtain the concentration field. The purpose of both calculations was to understand the outline of the atmospheric transport, and their calculation results of atmospheric concentration are provisional because the calculation only considered the atmospheric transport process without deposition; therefore, they may differ from the actual concentration distribution.

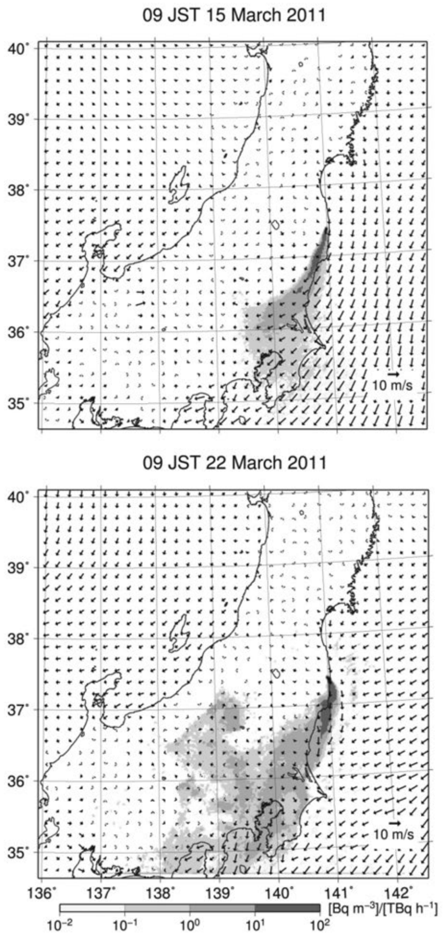

Figure 2 Example of calculation result of the surface atmospheric concentration with an assumption of continuous release of non-depositing radioactive materia at the rate of 1 TBq/h. (Top: 09:00, March 15, 2011. Bottom: 09:00, March 22)

It is well known that there often occurs a typical wind pattern at the Pacific coast on the eastern side of the Abukuma mountainous region located between the southern part of the Tohoku region and the northern part of the Kanto region, where Fukushima Daiichi Nuclear Power Plant is located. When there is a low or a stationary front on the south coast of Honshu causing a north-high pressure pattern, the Abukuma Mountains become a barrier for the wind system, in which a southward wind blows along the coast line in the lowest atmospheric layer with a depth of 0.5–1 km. This wind turns into the northeastern wind at the area near Tokai mura, where the Abukuma mountain range ends and Kanto Plain opens out. As such wind is commonly accompanied by a maritime stable temperature stratification, it has a tendency to have less diffusive mixing and maintain high concentration. Moreover, another characteristic is that, in Kanto Plain, this wind system is frequently accompanied by precipitation caused by the depression or by the front.

Both the periods (2) and (3) occurred with this situation. During the period (2), precipitation was weak and occurred only in limited areas. Therefore, it is assumed that the impact of the wet deposition was less. The plume that affected the Kanto region on March 15 was considered from the travel time to be released in the late night of the day before and the early morning of the March 15. It is likely that its release rate was relatively small in comparison with the plume that affected the northwestern direction. WSPEEDI calculation result indicating such a situation was already obtained by the Ministry of Education, Culture, Sports, Science and Technology and the Japan Atomic Energy Agency at the point of March 15 [8)], and its result was similar to the calculations made later by the authors. Thus, it is assumed that while the values of concentration contours were undetermined, the overview of distribution and its progress with time were almost identical the actual situation.

In contrast, during the period (3), transport by the aforementioned wind system continued for a long period. Moreover, strong rain continued during March 21 and 22, leading to the impact in a large area by the deposition of radioactive materials. Although the size of the impacted area and its level must be assessed based on field measurements, a comprehensive analysis where the actual measurement is supplemented by atmospheric transport calculations is necessary to cover the large-impact area.

IV. Further Concerns

Regarding the impact of the radioactive materials released in the atmosphere following the accident, its quantitative and spatial details are still insufficiently understood. To comprehend these based on actual measurements in the future will be the first stage of environmental remediation.

First, it is the external exposure dose by cloud shine and internal exposure dose caused by inhalation during the passing of the plume. Judging from the dose rate measured throughout Japan and the concentration in the atmosphere, it is estimated that the impact in the large area is small. However, it is necessary to evaluate the radiological dose through calculation (dose reconstruction), such as one with SPEEDI, after determining the release rate and verify that that value is sufficiently small. Its necessity is particularly high for the early stage of the accident when there is less measurement data related to concentration in the atmosphere and the area near the accident facility.

Moreover, contamination of the ocean is a chief concern. The release of retained water in early April (no distinction of nuclides; 1.5×10^{11} Bq) and the leakage near the water intake of

Unit 2 during the same period (total of main nuclides; 4.7×10^{15} Bq) are being evaluated as its cause. The impact of the contamination will be monitored for a long time. However, the release/leakage in aquatic form is not only the cause of the ocean contamination. We must consider the facts that the amount released in the atmosphere was 1–2 orders of magnitude larger than these amounts, the time the radioactive materials released in the atmosphere were moving toward the ocean was longer than that toward the land, and the radioactive materials in the atmosphere above the ocean will eventually deposit on the sea. It is clear that the true source of marine contamination in a relatively large area is the release into the atmosphere. Although we wish it is only the insufficient research by the authors, it is worrying that any public comment on this situation from a responsible organization cannot be found. If an undisclosed measurement results are revealed or the above mentioned problems are to be examined only according to the suggestion by a third party or a foreign agency, it cannot be seen as an attitude to faithfully understand the overall view of the environmental impact of the accident and it will be hard to regain trust from the researchers of the related fields and the members of academic societies.

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