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IRSN
INSTITUT
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ET DE SÛRETÉ NUCLÉAIRE

Fukushima-Daiichi Accident:
Main contamination events

The contamination of Honshu Island

The ground contamination of Japan's main island by the Fukushima-Daiichi nuclear accident was essentially due to four episodes: that of 12 March, that of 14-16 March, that of 18 March and that of 20-21 March. These episodes are analysed below in the light of the various measurements in the environment, particularly ^{137} Cs activity concentration measurements [Tsuruta *et al* (2014)].

Events of 12 March and 18 March (Figure 1a and 1 c)

On 12 March, some hours after the explosion of Reactor N°1 (at 6:36 UTC [1]), a radioactive plume was detected and measured during its journey along the coast towards the North of Hamadori (Points J, I and H). 25 km from the power plant (Point J), a maximum of 575 Bq/m^3 of ^{137} Cs was measured between 12:00 and 14:00, consistent with the observed dose rate increases. In total, over the duration of the event, the activity concentration integrated at Point J was about 2660 Bq/m^3. During its journey along the coast, the plume did not leach, thereby limiting the contamination of the ground. North of the Fukushima Prefecture, the plume was no longer measured. It took a North-Northeast direction away from the coast leading to the detection of ^{137}Cs in Alaska on 18 March [Thakur *et al* (2013)].

The event of 18 March was comparable to that of 12 March, measured in terms of its duration and activity. A maximum of up to 440 Bq/m^3 was measured at Station J and values greater than 100 Bq/m^3 persisted there for 7 hours. The plume measured appears to be narrower than that of 12 March and did not reach Station H, but their paths look similar.

These two events are responsible for the dry deposits on the eastern tip of the Miyagi prefecture. A deposit of about 15 kBq/m^2 of ^{137}Cs was measured.

[1] All times are given in Universal Time (9 hours must be added to obtain the local Japanese time).

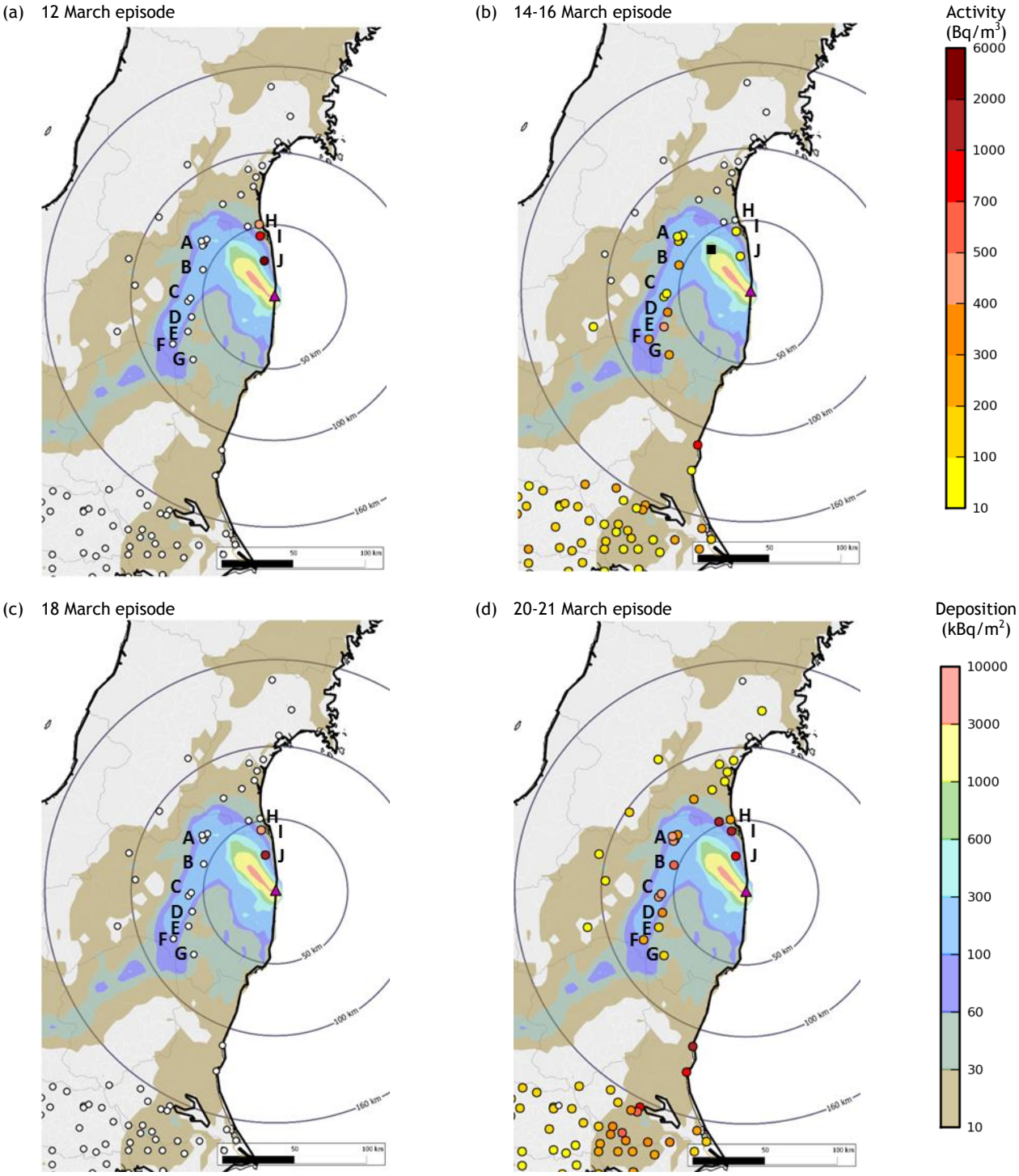

Figure 1: Activity concentration measurements of ^{137}Cs integrated over various time sequences (coloured circles) superimposed on the total ^{137} Cs deposits measured. Episode of 12 March at 19:00 (a) - Episode of 14-16 March (b) - Episode of 18 March (c) - Episode of 20 March (d). The black square in Figure (b) indicates the location of Idate.

Event of 14-16 March

This event is marked by turning winds and by a rainfall that generated significant contamination of the Japanese territory.

On the evening of the 14th of March, a first radioactive plume was transported by winds towards the southwest first along the coast (366 Bq/m^3 measured at Tokai). It then came inland and reached the Tokyo area. At Tsukuba, 153 Bq/m^3 were measured between 23:00 on 14 March and 2:00 on 15 March. This plume was not subjected to leaching by rain. Observations show that the wind then gradually turned towards the west and then the northwest. Plumes probably travelled through the reliefs located to the west of the power plant (at an altitude of 900m on average, Mount Otakine reaches 1193 m) to be measured in the Nakadori Valley (Stations A to G). The increase in the dose rate values at the stations located about twenty kilometres west of the plant, coupled with the analysis of the winds measured by the meteorological observation stations of the AMEDAS network, validate this assumption. The South of the Valley was first struck on 15 March between 2:00 and 3:00 (Point E) and the maximum value of 330 Bq/m^3 was measured between 3:00 and 4:00. Plumes were detected in the north of the valley at 6:00 (Point B). The activity concentrations were higher in the South of the valley than in the north, where they peaked at 138 Bq/m^3 in Nihonmatsu (Station B). Very light winds probably favoured the stagnation of the plumes, which were measured until noon in the southern part and up until 17:00 in the northern part. In the Fukushima Basin (Point A), the measured activities were much less significant than elsewhere in the valley. They peaked at 33 Bq/m^3 at 13:00.

In the valley, precipitations were observed as from 8:00. The AMEDAS data indicate that light rainfall started locally earlier without having been measured because they were below the detection threshold of the pluviometer (0.5 mm/h). Rain likely started at 6:00 am at Idate (black square in Figure 1 b) and between 4:00 and 5:00 in Koriyama. They then progressed towards the Southeast, becoming generalised and more intense. Rain generated deposits in the valley (of the order of 100-300 kBq/m^2 of ^{137} Cs), particularly along a strip located to the northwest of the plant, identified as one of the most contaminated areas of the Japanese territory (about 850 kBq/m^2 to ^{137}Cs were measured at Idate, located at the edge of the maximum deposit zone).

At about 17:00, the wind turned again and pushed the plumes to the south, along the coast where they were detected up until the 16th of March at 15:00.

The cross-analysis of all available measurements for this episode provided new perspectives and helped to clarify the events.

The deposits in the valley occurred on 15 March: the plumes were transported there before those that hit Fukushima and Idate. Leaching began at 5:00 in Koriyama and Shirakawa (Stations C and F). At Idate, leaching took place between 6:00 and 9:00; at Fukushima (Station A), it took place between 7:00 am and 10:00 am.

It is interesting to note, for stations where all observations were available, that the deposits occurred at the beginning of the rainy episode when rainfall was sometimes too low to be measured. This explains why this event has long been misunderstood.

Some Japanese teams (JAEA, MRI, etc.) hypothesised that the deposition in the valley was due to deposition by the fog. Yet both in the North and South of the Valley, the AMEDAS observations indicate that there was no fog. At the centre of the valley, in Koriyama (Point C), the presence of fog has not been completely confirmed because the observations are not available. Nevertheless, the hypothesis of a deposition generated by light precipitation is favoured.

The hypothesis of a deposition by orographic fog remains however credible to explain the contamination on the side of the Nikko Mountains and on the mountains of the Gunma prefecture, as suggested by Hososhima and Kaneyasu (2015), although there were no simultaneous fog and plume measurements in this area.

The orders of magnitude of the activity concentrations measured near the ground, compared to increases in the dose rate and deposits measured at the Fukushima (Point A) and Koriyama (Point C) stations as well as other stations, suggests that the deposition is largely due to the leaching of the plume of which much of the activity would have been located at high altitude. This hypothesis cannot be corroborated by observations, but it raises the delicate question of the vertical distribution of plumes and the impact of Japan's complex orography on their evolution. Only modelling tools can help to answer this question.

Events of 20-21 March

From 20 to 21 March, several radioactive plumes were detected in the Tokyo metropolitan area, north-northwest of the power plant and in the Nakadori Valley.

- **Tokyo Metropolitan Area Contamination**

On 20 March at 2:00 am, a plume coming from the Pacific Ocean was first measured at Tokai (110 km south of the facility) and then over the entire Tokyo metropolitan area, propagating westward. A maximum of 40 Bq/m^3 was observed at the southern end of Ibaraki prefecture (Katori). The plume was very spread out and was possibly released earlier (modelling suggests that the plume could have been released on the 19^{th} of March) and transported over Honshu Island after passing over the Pacific Ocean. It was continuously observed (a few Bq/m^3) over a large area of the Kanto plain up until 19:00 when another more concentrated and much finer plume propagated. This second plume probably lightly touched the coast south of the power plant as from 16:00. At 19:00, an activity concentration of 420 Bq/m^3 of ^{137}Cs was measured in Tokai. Further south, the activity concentrations also increased. Rainfall observed as from 21:00 leached the plume along the coast towards Tokai and more to the southwest. The dose rate measurements suggest that the bulk of the plume was located south of Tokai when the first rains began. The maps of the total deposits measured perfectly match the location of the plume at the time of the rain.

- **Contamination of the region North-West of the power plant and of the Nakadori Valley**

Along the coast, to the North and then the North-West, a plume was measured as from 1:00 on 20 March, until 3:00 the next day. A maximum of 360 Bq/m^3 was measured at Soma (Point I) on 20 March at 11:00 am. The plume was probably split and followed two different directions. Part appears to have been transported towards the North-East, where it would be leached between the north of the Miyagi Prefecture and the south of the Iwate Prefecture, leading to deposits of around 10-30 kBq/m^2. The trajectory of this plume is not confirmed by measurements. The other part of the plume was transported towards the Fukushima Basin (Point A) where 45 Bq/m^3 of ^{137}Cs were measured on 20 March at 6:00. This represents almost twice the maximum contamination observed during the episode of 14-16 March. The plume then spread to the south of the valley where it was blocked and stagnated. It continued to be measured up until 23:00. Scattered showers were observed, but they were not followed by an increase in the measured dose rate, suggesting that the deposition by rain was negligible compared to that of the episode of 14-16 March.

It is noteworthy that the detection of the plume was not accompanied by an increase in the dose rate at all of the stations that had been impacted by wet deposition during the episode of 14-16 March. The measurements by radionuclides performed at Chiba and Tokai show that the proportion of iodine, tellurium and of rare gases was lower for this episode than during previous events. This partly explains the fact that the dose rate levels did not increase.

Finally, over the entire territory, the importance of the dry deposition should not be forgotten either. For example, during the event of 20-21 March, the light winds over the island of Honshu were able to cause the stagnation of the plumes responsible for a non-negligible dry deposition. The order of magnitude estimated from the activity concentration measurements was of the order of a few kBq/m^2 of dry deposit.

Hososhima, M., Kaneyasu, N., 2015. Altitude-dependent distribution of ambient gamma dose rates in a mountainous area of Japan caused by the Fukushima nuclear accident. Environ. Sci. Technol. 49, 3341–3348. doi:10.1021/es504838w

Thakur, P., Ballard, S. et Nelson, R. (2013). "An overview of Fukushima radionuclides measured in the northern hemisphere." Science of The Total Environment **458–460**: 577-613

Tsuruta, H., Oura, Y., Ebihara, M., Ohara, T. et Nakajima, T. (2014). "First retrieval of hourly atmospheric radionuclides just after the Fukushima accident by analyzing filter-tapes of operational air pollution monitoring stations." Sci. Rep. **4**.