What Happened from the Accidental Release of Radioactive Materials from the Fukushima Dai-Ichi Nuclear Power Plant on 3.11 in 2011?

Toshiki Iwasaki
Tohoku University, Sendai, Japan

1. Great East Japan Earthquake and Tsunami

The Great East Japan Earthquake occurred at14:46 JST (05:46 UTC) on 11 March 2011 with the epicenter about 130 km off the eastern coast of Miyagi prefecture of Tohoku District (Northeastern Japan). The source region was about 500 km long and 200 km wide. Its magnitude of 9.0 was the one of the five most powerful earthquakes since the start of modern quake record in 1900. Severe tsunami waves due to the quake hit the east coast of East Japan. The quake and tsunami caused 15,880 deaths and left 2,698 people missing, according to the Japanese National Police Agency. The tsunami also hit Fukushima Dai-Ichi Nuclear Power Plant (NPP) of Tokyo Electric Power Company (TEPCO) with its height of more than 10m and damaged it seriously.

2. Atmospheric dispersion

The Fukushima NPP lost all of electric power supplies due to the quake and tsunami. Electric failure stopped the circulation of reactor coolant water and boiled the coolant water away in the unit 1, 2 and 3 reactors. The nuclear fuel suffered meltdown in a few days in the three reactors. Hydrogen explosions occurred on March 12 in unit 1, on March 14 in unit 3, and on March 15 in unit 4. To prevent explosions, reactor ventilations were also conducted. A huge amount of radioactive materials were released for several weeks through the explosions, ventilations and leaks from broken containments. The rough estimate is approximately five times greater than the Three Mile Island accident, but about 10 percent of the Chernobyl accident.

Emission intensity is to be estimated in the Emergency Response Support System (ERSS). In this accident, however, this system could not work well due to the lack of reactor information. Instead, the total releases were inversely estimated with dispersion models from the concentration of radioactive materials at monitoring stations. Monitoring stations are distributed sparsely to estimate the total emission of radioactive materials. We should note the uncertainty of emission intensity in this event.

Radioactive materials flowed following the wind and gradually diluted through turbulent mixing. Aerial materials caused internal exposure, when those were inhaled. In the Fukushima accident, monitoring of areal materials was insufficient to evaluate the actual internal exposure accurately. The radioactive materials fell down into the ground surface due to dry and wet depositions and caused the external exposure. In particular, the wet deposition collected radioactive materials below the cloud and sometimes formed hotspots even far away from the emission source place. In this event, the surface materials increased the risk from external exposure and caused the contaminations of water, soil, farm products and industrial products including construction materials. Many people left their home towns and many farmers lost their farmland.

3. Evacuation orders

The government issued evacuation orders based on concentric circles centered at the source position, without making use of numerical model predictions for evacuation. The evacuation orders were extended gradually, as follows:

March 11: Evacuation order with a 3 km radius and stay-indoors order within 3 to10km.
March 12: Evacuation-order within a 10km radius.
March 14: Evacuation-order within a 20km radius.
March 15: Stay indoors within a 20-30km radius.
March 25: Recommend deliberate evacuation to those who lived within a 20-30km radius.
April 22: Designate evacuation planning zone outside 30km, which was not a circle but strong-radiation areas based on the monitoring results.

Evacuation orders mainly considered internal exposure caused by inhaled radioactive materials. This results from low-level air concentration of radioactive materials. The low-level concentration decreases rapidly with a distance. On the other hand, in the Fukushima accident, serious problems occurred from the surface contamination due to wet deposition even far away from 30 km. The distance of 30 km seems to be insufficient for contamination due to wet deposition. We should make a manual for the wet deposition.

Actual distributions of surface materials had strong directional dependences, reflecting wind direction and precipitation. The distance is determined considering only isotropic diffusions, but not considering wind direction or wet deposition. People in Namie town evacuated from the downtown area near the NPP to the higher radiation area in the suburbs about 30km away from the TPP without any information on the radiation intensity (Investigation Report, 2012: Investigation Committee on the Accident at the Fukushima Nuclear Power Stations).

The government prepared a dispersion model, called SPEEDI (System for Prediction of Environmental Emergency Dose Information) to predict the atmospheric dispersion and depositions in environmental emergency cases. For the Fukushima accident, the model managed to predict the direction of the wind stream with certain accuracy. People in the Namie town would have not evacuated along the stream of radioactive materials, if the model result was available. The government did not disclose the products of numerical models to the public.

4. How to use dispersion models for mitigating hazards of radiation exposure

Later, the government was criticized for neglecting the disclosure of the model products. They were afraid that people get into a "panic" after seeing them. Dispersion model products are subject to various kinds of uncertainties, such as the emission characteristics (time, locations and intensity), turbulent mixing of materials, initial conditions of the atmosphere, atmospheric predictability of chaotic characteristics, and so on. That was another reason that the government hesitated to disclose predictions by dispersion models. In general, dispersion models provide much better information on low-level concentration and wet deposition than the "concentric circles". Thus, model products can be used for issuing evacuation order, if we understand its predictability.

People need information on the low-level concentration of the material, since the inhaled radioactive material causes the internal exposure. The prediction of low-level concentration can be used not to inhale the contaminated air. Its forecast performance is sensitive to orographic condition and turbulent mixing scheme in the dispersion model. The prediction may be dependent on the model and its resolution, even if the weather is predicted accurately.

The wet deposition makes a lot of radioactive hot spots on the ground and contaminates farm products even far away from the source. As a result, it causes external exposure from the ground and internal exposure through having contaminated water and foods. In emergency case, people should prepare for the contamination due to wet deposition in much larger area than the area of preparation for the inhalation. The prediction of wet deposition has a large uncertainty that arises from precipitation forecast as well as wind prediction.

5. Summary

(1) The numerical dispersion models may be useful for the issue of warnings/orders to mitigate both internal and external exposures. Warning/order of evacuation should be issued by making use of numerical dispersion model forecasts.

(2) One important predictor is the low-level concentration of the material, which is inhaled and causes the internal exposure. Its forecast performance is sensitive to turbulent mixing scheme in the dispersion model.

(3) Another predictor is wet deposition, which makes hot spots on the ground even far away from the source. The wet deposition causes external exposures from the ground and internal exposure through water and foods. The prediction of wet deposition has a large uncertainty that arises from precipitation forecast.

(4) The predictability of dispersion models depends on the performance of depending weather prediction models. In addition, dispersion models are subject to the uncertainty from emission scenario of location and time sequence of intensity. Unit emission scenario is useful for us to consider the worst-case, even though emission is unknown.

(5) In order to provide probabilistic information and to consider the worst-case scenario, good tools are ensemble forecasts from weather initial conditions and emission scenario. Multi-model ensemble approach seems to be promising to reduce the uncertainty of the forecast.

(6) Comprehensive advisories are necessary to make an optimal use of model results for crisis management.