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The air dose rate around the Fukushima Dai-ichi Nuclear Power Plant: its spatial characteristics and temporal changes until December 2012

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ABSTRACT

Distribution maps of air dose rates around the Fukushima Dai-ichi Nuclear Power Plant were constructed using the results of measurement obtained from approximately 6500 locations (at most) per measurement period. The measurements were conducted 1 m above the ground using survey meters in flat and spatially open locations. Spatial distribution and temporal change of the air dose rate in the area were revealed by examining the resultant distribution maps. The observed reduction rate of the air dose rate over the 18 months between June 2011 and December 2012 was greater than that calculated from radioactive decay of radiocesium by 10% in relative percentage except decontaminated sites. This 10% difference in the reduction of the air dose rate can be explained by the mobility of radiocesium in the depth direction. In the region where the air dose rate was lower than 0.25 μSv h^{-1} on June 2011, the reduction of the air dose rate was observed to be smaller than that of the other dose rate regions, and it was in fact smaller than the reduction rate caused by radioactive decay alone. In contrast, the reduction rate was larger in regions with higher air dose rates. In flat and spatially open locations, no significant difference in the reduction tendency of air dose rates was observed among different land use classifications (rice fields, farmland, forests, and building sites).

1. Introduction

Soon after the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident in March 2011, many groups measured the dose rates in the air (hereinafter referred to as the "air dose rate") at various locations around the FDNPP using their measuring instruments; these individually obtained data were reported separately. In addition, the instruments used for these measurements were varied and the procedure to obtain the air dose rate was not standardized. Therefore, these data were not suitable to use for constructing a single map of the dose rate distribution. However, some comprehensive monitoring activities were performed. For example, the air dose rates over wide areas in Fukushima Prefecture were measured by Fukushima University soon after the accident (Yamaguchi et al., 2011), and aircraft-based monitoring was conducted by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the United States Department of Energy (DOE) in May 2011 (MEXT and DOE, 2011). These data provided valuable information on the contamination conditions around the FDNPP; nevertheless, further comprehensive environmental monitoring was desirable to obtain sufficient data in terms of both quality and quantity.

In order to take effective and appropriate countermeasures to the environmental impacts caused by radioactive fallout from the FDNPP accident, in June 2011 the MEXT commissioned the Japan

Abbreviation: FDNPP, Fukushima Dai-ichi Nuclear Power Plant; GIS, geographic information system; JAEA, Japan Atomic Energy Agency; MEXT, Ministry of Education, Culture, Sports, Science, and Technology; GPS, global positioning system.

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Atomic Energy Agency (JAEA) to assume a leading role in a comprehensive investigation of the affected land environment. Thus, the dose rate distribution mapping project began. One of the activities of the project was to construct a reliable distribution map of the air dose rate using standardized methods. A series of three campaigns to measure the air dose rate was completed by the end of the year 2012.

Measurements were conducted at approximately 2200 locations around the FDNPP from June to July 2011 in the first campaign (Saito et al., 2014), at approximately 1000 locations in the Tohoku and Kanto regions from December 2011 to May 2012 in the second campaign, and at approximately 6500 locations in an area with a radius of approximately 80 km around the FDNPP in 2012 in the third campaign, which consisted of two measurement periods implemented in September and December of that year.

By analyzing these basic data that were systematically obtained at many locations over several different periods, the air dose rate characteristics, including the changes in the distribution over time, will be discerned. In particular, air dose rate data periodically obtained at exactly the same location are valuable for investigation of the time-dependent weathering effects. Air dose rate data from radiation monitoring stations are continuously obtained at same locations; however, the monitoring stations are often situated at locations that are not suitable for the investigation of weathering effects. They are often set up on artificial foundations or located near or on artificial structures. Findings obtained by present study can be utilized for predicting the air dose rate distribution in the future in natural environments and for the repatriation program for evacuees.

In this paper, we report the distribution maps of the air dose rates measured between December 2011 and December 2012 in the second and third campaigns, and discuss their temporal and spatial change in comparison with the results of the first campaign from June 2011, which have been reported separately (Saito et al., 2014).

2. Materials and methods

2.1. Region and locations of measurements

In the first campaign from June 4 to July 8, 2011, measurements were made in the region within a 100-km radius of the FDNPP and other areas in Fukushima Prefecture. For the measurements, this area was divided into 2 km × 2 km grids for the areas within an 80 km radius of the FDNPP and into 10 km × 10 km grids for the areas more than 80 km from the FDNPP. Consequently, these measurements were obtained from approximately 2200 locations (Saito et al., 2014).

Before the beginning of the second campaign, aircraft-based and other monitoring showed that quite large regions in east Japan had been contaminated by radionuclides released from the FDNPP. Therefore, reliable and detailed dose rate measurements on land were required to estimate the impacts. Thus, in the second campaign, measurements were made between December 13, 2011 and May 29, 2012, in and around the region where the air dose rate at 1 m above the ground was found to be greater than 0.2 μSv h^{-1} according to previous aircraft-based and other monitoring. Consequently, the investigated region extended approximately 300 km from the FDNPP over 11 prefectures, including Iwate, Miyagi, Fukushima, Ibaraki, Tochigi, Gunma, Chiba, Saitama, Tokyo, Kanagawa, and Yamanashi.

The region was divided into 5 km × 5 km grids for those regions where the air dose rate was greater than 0.2 μSv h^{-1} and into 10 km × 10 km grids for those where the dose rate was less than that. In each grid, one specific location, typically in a public place, was selected as the site for making the measurement. Whenever possible, locations that were used for dose rate measurement during the first campaign were chosen for making the measurements in subsequent campaigns also. The same measurement points within 80-km radial area centered around the FDNPP were selected in each of the three campaigns as often as possible.

Uninhabited regions, such as mountain forests were excluded from this investigation. In each grid, as often as possible, a location with undisturbed flat terrain and without large obstacles within a 5 m radius was selected for the air dose rate measurements.

The air dose rate measurements were made above soil, but not above surfaces paved with asphalt or concrete, because the purpose of present study was to measure the air dose rate resulting from radioactive materials deposited onto ground soil. Because the radioactive fallout resulting from the accident may have adhered to trees and plants in forested regions, measurement locations where vegetation cover was minimal were selected. Places near gutters through which rainwater flows were also avoided for the measurements because radioactive materials could accumulate in these places and cause a locally inhomogeneous distribution of the air dose rate.

At each selected location, we confirmed that the variation in the air dose rates was within a factor of several within at least 3 m × 3 m around the exact measurement location.

Some places were difficult to access due to the closure of roads damaged by the Great East Japan earthquake in 2011. Consequently, the air dose rate measurements in the second campaign were made at 1016 locations.

The second campaign clarified the features of the dose rate distribution over wide regions in east Japan. The results confirmed that repeating dose rate measurements within a 80-km radial area centered around the FDNPP will be important from the point of view of long-term effects of the accident, because highly contaminated areas are mostly concentrated in that region.

In the third campaign, measurements were made twice in the area within an 80-km radius of the FDNPP. The first part of measurements was made from August 14 to September 7, and the second from November 5 to December 7, 2012. For these measurements, the area within 80 km of the FDNPP was divided into 1 km × 1 km grids, and one specific location in each grid was selected as the measurement site. The other conditions were the same as those in the second campaign. Some planned locations for measurement were difficult to access because of road closures, dense vegetation, and other factors. Consequently, air dose rate measurements were made at 6551 locations during the first part and at 6549 locations during the second part of the third campaign.

2.2. Measurement using survey meters

The gamma-ray spectrum obtained in the field environment is, in principle, different from that in a calibration room where the survey meters were calibrated because the lower-energy components of the spectrum are expected to be greater in the field environment. In particular, recognition of this effect is important in cases where decontamination work was carried out. Therefore, to obtain an accurate air dose rate, the output of the survey meter should be energy compensated by taking into account its gamma-ray energy response. The instruments used in these campaigns were photon-energy compensated and calibrated within a year in laboratories traceable to the Japanese primary standard.

For measurements of the air dose rate in terms of the ambient dose, NaI(Tl) scintillation survey meters (TCS-171B or TCS-172B) and an ionization-chamber type survey meter (ICS-323C) manufactured by Hitachi–Aloka Medical, Ltd., were used depending on the magnitude of the air dose rate in the field. The ionization-chamber type survey meter was used in the field for air dose rates of >30 μSv h^{-1}.