Reporting absorbed dose rate in air from Southern part of Ibaraki prefecture related to Fukushima Daiichi Nuclear Power Plant accident

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Abstract. Fukushima Daiichi Nuclear power plant (F1-NPP) accident that occurred in March 2011which dramatically changed the distribution of environmental radioactivity in eastern Japan. Due to this accident enormous amount of radio-caesium released into the environment were estimated as 6-20 pBq. After 10 years of F1-NPP accident, radio-caesium (^{134}Cs ($T_{1/2}$ = 2.06 y) + ^{137}Cs ($T_{1/2}$ = 30.17 y)) remains major concern from a radiological safety perspective. Tsukuba is the central part of southern Ibaraki which is located approximately 180 km southeast of the F1-NPP has been selected to study the dose rate distribution in air. Therefore, the measurement of absorbed dose rate in air was carried out using vehicle mounted 3" x 3" NaI(Tl) scintillation spectrometer (Car-borne survey) in August 2020. The absorbed dose rates in air ranged from 21.14 to 110.58 nGy h^{-1} with an average 49.87 ± 7.87 nGy h^{-1}. The estimated contribution of artificial dose rate in the air were varied from 0.02 to 34.96 %.

KEYWORDS: Fukushima Daiichi Nuclear Power Plant accident, Absorbed dose rate in air, Radiocesium, Car-borne survey

INTRODUCTION

According to the UNSCEAR 2017 report the released total amounts of artificial radionuclides were estimated to be 100-500 PBq of ^{131}I and 6-20 PBq of ^{137}Cs due to F1-NPP accident in March 2011 [1]. While most of these amounts of radionuclides were distributed over the Pacific Ocean and a part of these amounts was deposited on the ground depending on the meteorological conditions [2]. According to the report from the Science Council of Japan, 93 % of the total ^{137}Cs assumed in the simulation model was wet-deposited due to F1-NPP accident [3]. An atmospheric simulation models for release of artificial radionuclides from the F1-NPP were studied for both regional and global atmospheric models. The results of the study indicate the variabilities in the horizontal distribution of the accumulated deposition caused by difference in deposition model treatments [4].

In the years of 2011 and 2012, Nuclear Regulation Authority, Japan had done the distribution of environmental radiation for metropolitan Tokyo was observed by air-borne monitoring after the F1-NPP accident [5]. However, the air borne survey was not sufficient for the detailed discussion of contamination and its associated risks. Therefore, the same authors have carried out absorbed dose rate measurement in air using car-borne survey technique for some important prefectures in Japan e.g. Tokyo, Chiba and Ibaraki, etc. [2]. The continuous monitoring of environmental radiation is very essential to understand the diffusion, deposition, migration and situation of released artificial radionuclides and to assess the external and internal exposure doses for residents.

Ibaraki prefecture is selected and located around 180 km southeast of the F1-NPP. The authors are mainly focused on southern part of Ibaraki prefecture. Since the previous study of the whole Ibaraki prefecture showed the significant exceeding absorbed dose rates were observed in the southern Ibaraki part than the other part of the prefecture. Another hand this study area holds around 60 % of population of Ibaraki prefecture and the selected study area has the very close boundaries between Tokyo metropolitan area, Tochigi, Saitama and Chiba prefectures. Therefore, in this study car-borne survey was carried out to estimate the changes of absorbed dose rate in air of 2015 and 2020.

2 MATERIALS AND METHODS

1.1 Car-borne Survey

A car-borne survey technique is an efficacious method to make a fast assessment of the dose rate in a large area [6]. In this study, car-borne surveys were carried out over asphalt pavements using a 3” x 3” NaI(Tl) scintillation spectrometer with a global positioning system (EMF-211, EMF Japan Co., Osaka, Japan). This survey system combined the NaI(Tl) scintillation spectrometer and a multi-channel analyser (GAMMA-RAD5, AMPTEK, Bedford, MA, USA). The same detector system and all procedures have been used for both 2015 and 2020. The NaI(Tl) scintillation spectrometer was positioned 1 m above the ground surface at the centre of the car. The count rate measurement inside the car was performed every 30 s while the car was moving with a speed around 35 km h^{-1}. During the measurement, the car windows were kept closed. Latitude and longitude at each measurement point were measured at the same time as the count rates. The survey routes were selected as main roads of the towns and cities. The study area and the survey route maps are given figure 1 and 2. The count rates within gamma-ray energies of 50 keV – 3.2 MeV were recorded. The photon peaks of ^{40}K (E_γ = 1.464 MeV) and Tl-208 (E_γ = 2.615 MeV) were used for gamma-ray energy calibration from the channel number and gamma-ray energy before the measurements. The peak positions were determined accurately by smoothing the gamma-ray pulse height distribution.

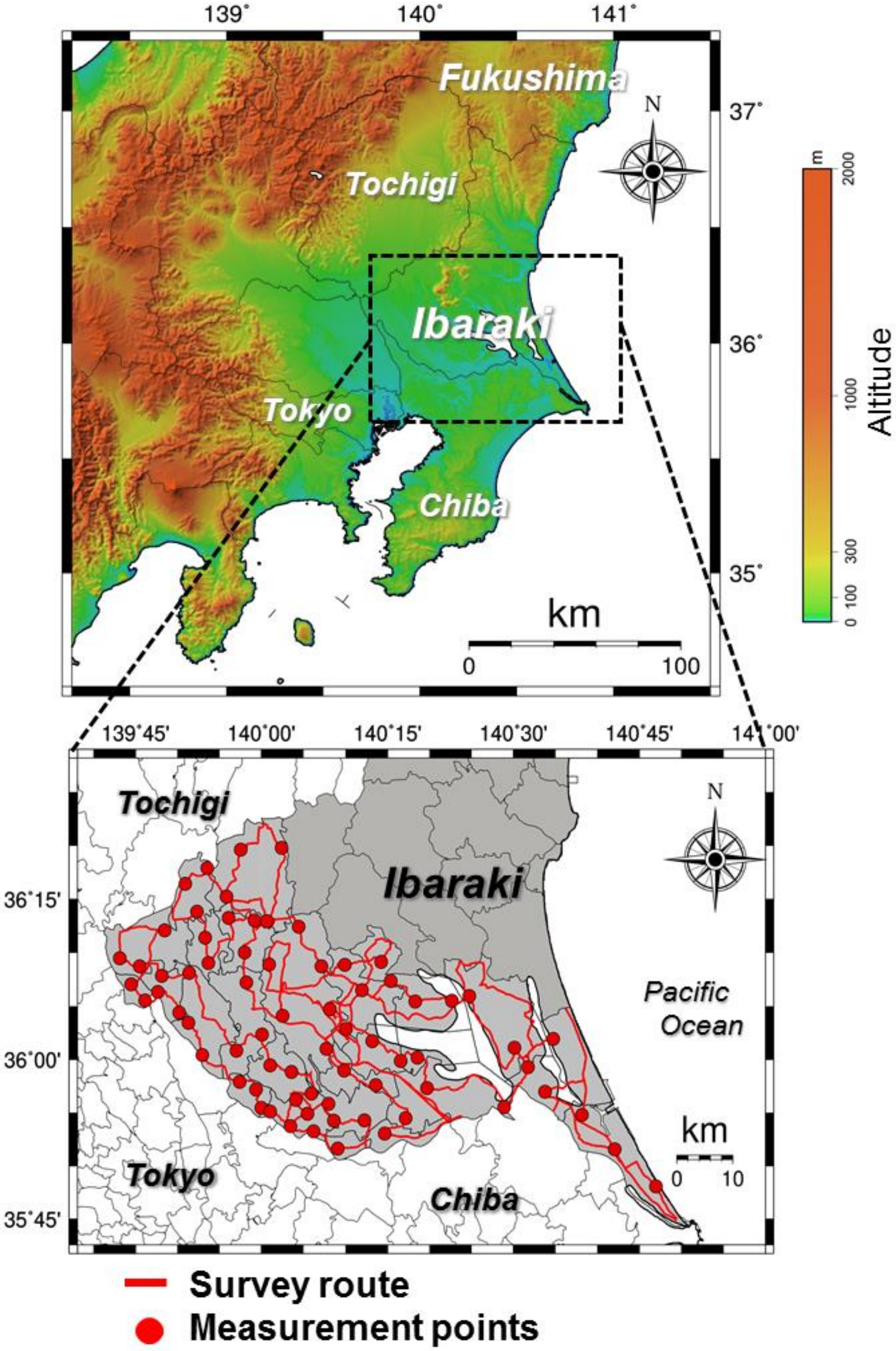
The shielding factor (SF) of the car body was calculated from the correlation between measured count rates inside and outside the car at 72 locations of the southern part of Ibaraki. The fixed measured points are given as red circles in the Figure 2. The measurements were recorded for consecutive 30 s intervals during a total recording period of 2 minutes inside the car. The gamma-ray pulse height distributions were also measured outside the car for 10 minutes at the surface of the bare asphalts. The measured gamma-ray pulse height distributions were then unfolded using the 22 x 22 response matrix method [7] and absorbed dose rates in air were calculated. The dose conversion factor (DCF) (nGy h^{-1}/cps) was calculated from a correlation between calculated dose rates and measured count rates. The absorbed dose rate in air outside the car at 1 m above the ground surface (D_{air}) can be calculated using the following equation:

$$D_{air} = C_{in} \times SF \times DCF \tag{1}$$

Where C_{in} the count rate (cps) inside the car obtained by the measurements for 30 s interval. All obtained data from the car-borne survey were plotted on the distribution of absorbed dose rates in air in southern Ibaraki using a minimum curvature algorithm of GMT [8]. This is the method for interpolating data by presuming a smooth curved surface form the data of individual points.

For more detailed analysis, clear peaks from ^{134}Cs (energy ranges: 0.55-0.65 MeV and 0.75-0.85 MeV), ^{137}Cs (0.65-0.75 MeV), ^{40}K (1.39-1.654 MeV), ^{214}Bi (1.69-1.84 MeV and 2.10-2.13 MeV) and ^{208}Tl (2.51-2.72 MeV) were observed in the energy spectrum after unfolding the gamma-ray pulse height distribution. The absorbed dose rates in air from natural radionuclides (^{40}K, ^{238}U series and ^{232}Th series) and artificial radionuclides (^{134}Cs and ^{137}Cs) were then calculated to estimate the impact from the F1-NPP accident.

Figure 1: A map shows the geographical location of southern part of Ibaraki prefecture in Japan and the survey route (red line) and red circles are fixed points for measuring the absorbed dose rate in air.



3 RESULT AND DISCUSSIONN

The car body SF and DCFs values for 2015 and 2020 were obtained to calculate absorbed dose rates in air shown in Table 1. The SF for 2015 and 2020 were 1.478 and 1.508 respectively. The SF is influenced by the type of car used in a survey, number of passengers and the position of the scintillation spectrometer position inside the car. The coefficient of determination (R^2) from the measurement correlations for 2015 and 2020 were 0.81 and 0.84. The DCFs were obtained from the correlation between count rate outside the car. The DCFs (nGy h^{-1}/cps) was evaluated as 0.146 for both 2015 and 2020 car-borne survey (Table 1).

Table 1: Shielding factors (SFs) and dose conversion factors (DCFs).

Prefecture	Measurement period	n	SF	DCF (nGy h^{-1})
Southern part of Ibaraki	2015	72	1.478	0.146
	2020	72	1.508	0.146

The absorbed dose rates in air (nGy h^{-1}) outside the car 1 m above the ground surface were calculated using both SFs and DCFs (Eq. 1). The changes of absorbed dose rates in air measured in 2015 and 2020 are given Table 2 and Figure 2. The outlier was defined as: <lower quartile-1.5 x distance from upper quartile to lower quartile (IQD) or > upper quartile + 1.5 x IQD (OriginPro, 2020). The absorbed dose rates in air ranged in southern part of Ibaraki prefecture were 32.92-134.49 nGy h^{-1} with a mean of 62.83 ± 1.68 nGy h^{-1} for 2015. The absorbed dose rates in air for 2020 ranged from 21.14-110.58 nGy h^{-1} with a mean of 49.87 ± 7.85 nGy h^{-1}. The significant changes in the absorbed dose rate have been observed from 2015 and 2020. Around 79 % of absorbed dose rate in air have been decreased in southern part of Ibaraki. The previous reported mean value of the absorbed dose rate in air in whole Ibaraki prefecture is also similar to the present study [2].

Table 2: Absorbed dose rates in air in southern part of Ibaraki from measurement by the car-borne survey technique.

			Absorbed dose rate in air (nGy h^{-1})		
Prefecture	Measurement period	n	Mean	SD	Range
Southern part of Ibaraki	2015	2900	62.83	12.68	32.92-134.49
	2020	2997	49.87	7.85	21.14-110.58

In Figure 2, the number of outliers has also been significantly decreased from 2015 to 2020 rates in southern part of Ibaraki. Figure 3 shows the distribution map of absorbed dose rate in air measurement in 2015 and 2020. Higher dose rates exceeding 100 nGy h^{-1} were observed in central and eastern part of the study area in 2015 and drastic reduction of absorbed dose rate in air has been observed in 2020 survey. However, still higher dose rate exceeding 60 nGy h^{-1} were observed in the year 2020 southern Ibaraki survey. This higher dose rate is due to the deposition of artificial radionuclides (^{134}Cs and ^{137}Cs) from the F1-NPP accident and the artificial radionuclide is contributing around 11 % to the absorbed dose rate in the air. The artificial radionuclide deposited locations were tending to higher in the value of observed area less than 200 m altitude from the sea level. Therefore, the western part of the study area which is relatively higher altitude than the eastern part (Figure 3). This similar observation is reported elsewhere for example Izu-Oshima [9].

Table 2: Calculated absorbed dose rates in air in southern part of Ibaraki from measurement in 2015 and 2020.

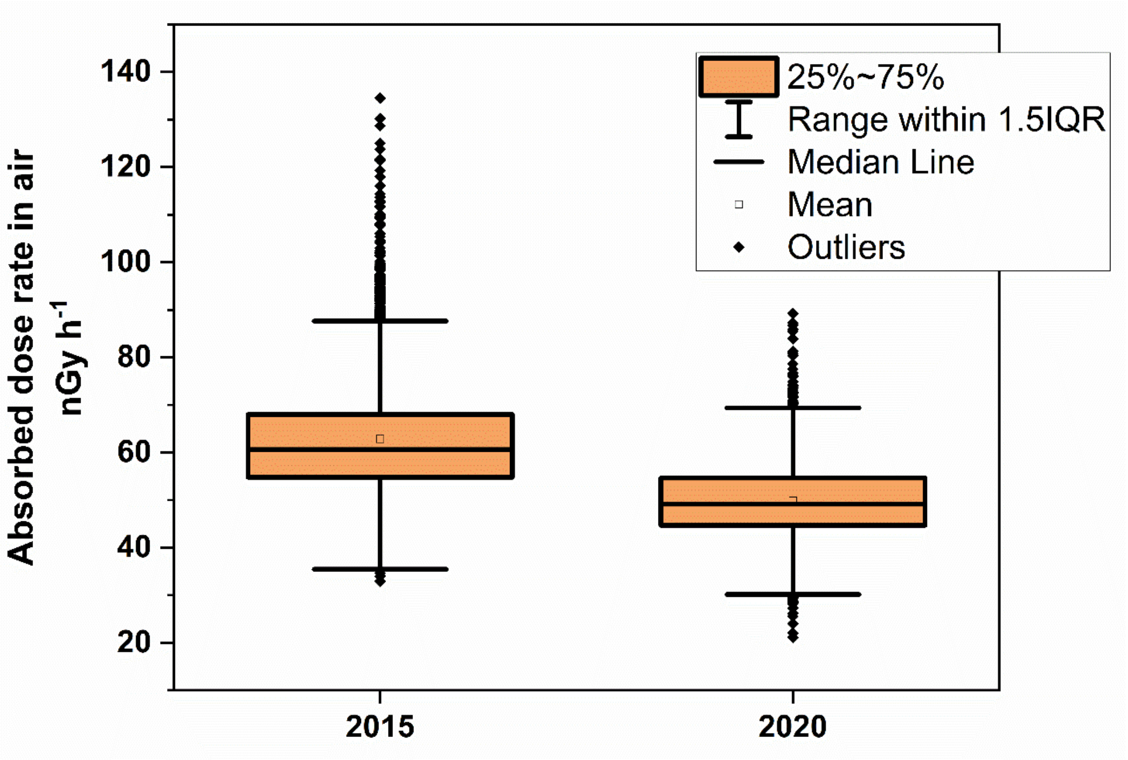
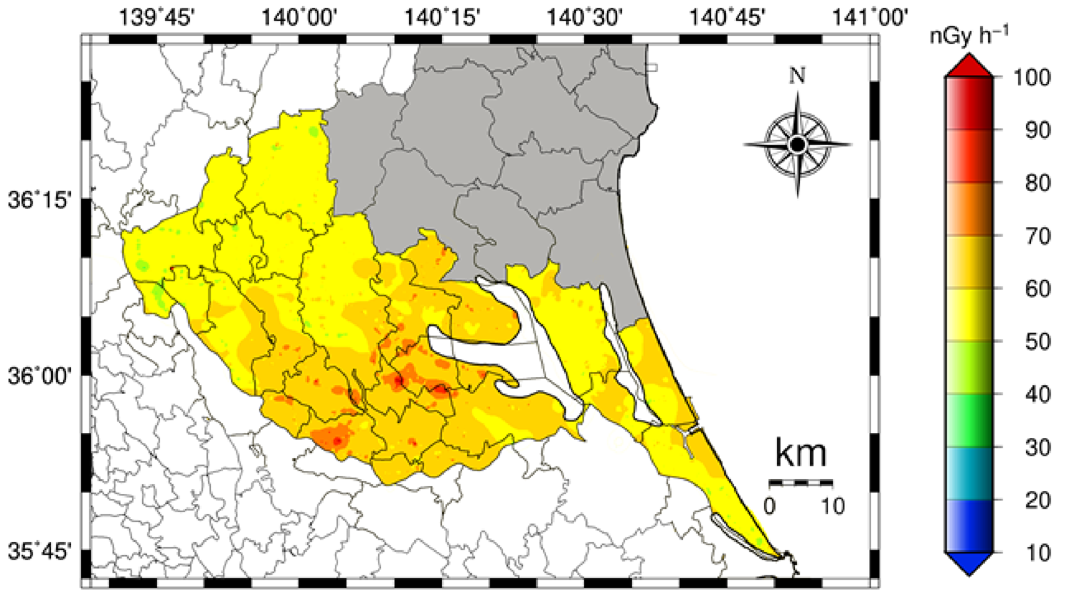
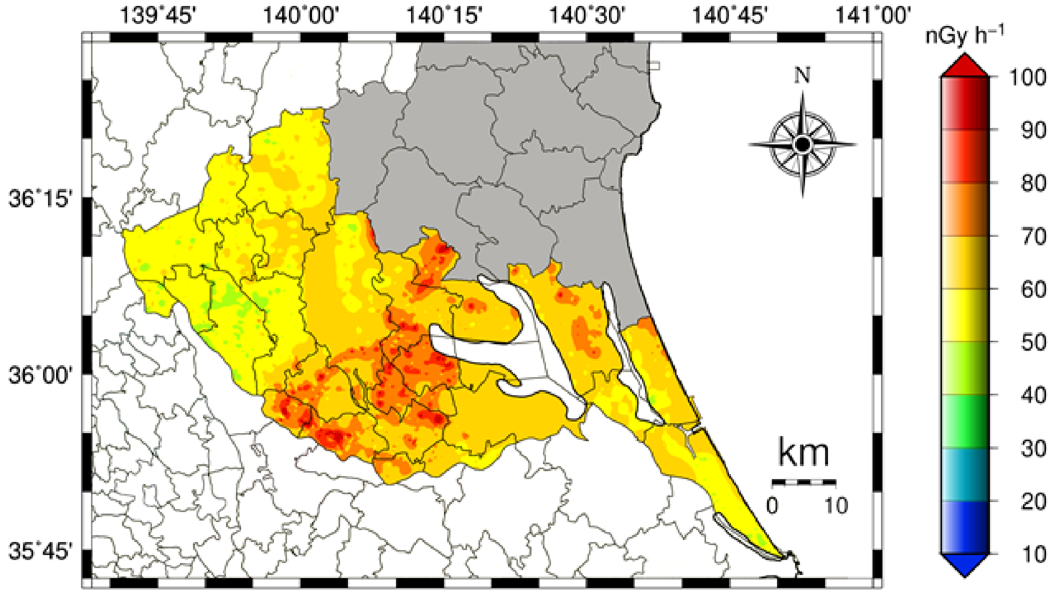


Figure 3: The map shows the comparison of absorbed dose rate distribution between 2015 and 2020 survey results in southern part of Ibaraki prefecture.



2020



2015

CONCLUSION

Car-borne survey with a NaI(Tl) scintillation spectrometer were carried out for southern part of Ibaraki in the year of 2015 and 2020. The absorbed dose rate in air was measured in respective years. The results of the changes in absorbed dose rate in air is revealed exceeding 60 nGy h^{-1} in the central and eastern part of the southern Ibaraki region. These exceeding dose rate could be due to the deposition of artificial radionuclide (^{134}Cs and ^{137}Cs) released from the F1-DNPP accident. The changes of absorbed dose rate in air were compared between in the year of 2105 and 2020. The absorbed dose rate in air is significantly decreased around 79 % from 2015 to 2020. The more detailed study of whole Ibaraki prefecture will be done in near future.

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