# Changes of Ambient Gamma-ray Dose Rate in Katsushika Ward, Metropolitan Tokyo before and after the Fukushima Daiichi Nuclear Power Plant Accident

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**ABSTRACT (100 words)**

Katsushika Ward in the eastern part of metropolitan Tokyo was the Tokyo area with the highest deposition of artificial radionuclides after the nuclear accident at the Fukushima Daiichi Nuclear Power Plant. A car-borne survey of the air kerma rate was conducted for all of the ward and the results were compared with measurements done in 2005. The mean air kerma rate in 2014 was 59 ± 12 nGy $h^{-1}$ and that was 50% higher than the rate in 2005 ($p < 0.01$). Additionally, the environmental half-life was estimated to be 1.9 years from the transition of ambient equivalent dose rate after the accident for data published by the Katsushika Ward Office.



*Keywords*: Fukushima Daiichi Nuclear Power Plant accident; Katsushika Ward, Tokyo; Car-borne survey; Air kerma rate; Environmental half-life




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## INTRODUCTION

Large amounts of artificial radionuclides such as $^{131}Xe$, $^{131}I$, $^{134}Cs$ and $^{137}Cs$ were released from the reactor buildings to the environment by the accident at the Fukushima Daiichi Nuclear Power Plant (F1-NPP) that occurred in March 2011 [1-3]. While many of these radionuclides were deposited in Iitate Village and Namie Town, both located northwest of the F1-NPP [2], places with high-dose rates occurred throughout eastern Japan, depending on the precipitation field and wind direction [4] at the times of the releases and just after.

In metropolitan Tokyo, the radionuclides were carried to its eastern area by northeast winds on the morning of March 20, 2011, and they were deposited there, between the dates of March 21 to 23, by rainfalls [5]. According to the environmental radioactivity levels obtained by airborne monitoring conducted by the Ministry of Education, Culture, Sports, Science and Technology, the air kerma rate at 1 m above the ground surface and the deposition amount of $^{134}Cs$+$^{137}Cs$ at the surface of the ground measured in Katsushika Ward had the highest values in Tokyo [6]. At the Kanamachi Water Purification Plant, 210 Bq/kg of $^{131}I$ was detected in the purified water on March 22, 2011 and the recommendation to restrict tap water intake by infants was given [7]. Additionally, 88.4 kBq/kg of $^{131}I$ and 14.7 kBq/kg of $^{134}Cs$+$^{137}Cs$ were detected from the sedimentation matter generated by the purification [8].

The authors had previously measured air kerma rates throughout Katsushika Ward in August 2005 and reported the air kerma rates for north and south areas of the ward as 36 nGy $h^{-1}$ and 43 nGy $h^{-1}$, respectively [9]. Air kerma in air is the sum of kinetic energy of all charged particles liberated per unit mass. Absorbed dose rate is defined as the value obtained by subtracting the amount of energy lost by bremsstrahlung from the air kerma rate. For all practical purposes it is equal to the absorbed dose rate in air. After the F1-NPP accident, the Katsushika Ward Office carried out fixed-point observations on a regular basis at seven parks and reported the results [10]. According to that report, mean air kerma rates for those seven parks were 267±63 nGy $h^{-1}$ in June 2011 and 97±36 nGy $h^{-1}$ in May 2014. However, no investigation of radionuclide contamination for the entire ward has been made. It was reasonably expected that the distribution of air kerma rate had changed significantly compared to that before the F1-NPP accident. This paper describes a car-borne survey of the air kerma rate in Katsushika Ward carried out three years after the accident and makes comparisons with measurements performed in 2005. Additionally, the future change in the air kerma rate for the ward is estimated based on the reported fixed-point observation results.

## MATERIALS AND METHODS

Air kerma rates (nGy $h^{-1}$) were measured in March 2014 in Katsushika Ward, a part of Metropolitan Tokyo, Japan (Fig. 1a). A car-borne survey was carried out using a 3-in $\phi$ × 3-in NaI(Tl) scintillation spectrometer (EMF211, EMF Japan Co., Osaka, Japan) with a global positioning system. The car-borne survey technique is a common method for fast assessment of dose rate over an extended territory. Latitude and longitude at each measurement point were measured at the same time as the count rates were recorded. Measurements were made every 30 seconds. The distance of the survey route was 105 km (Fig. 1b). Shielding by the car body was estimated by making measurements inside and outside of the car at five locations. Counting time was set to consecutive 30-second intervals during a total recording period of 2 minutes. For outside measurements, the scintillation spectrometer was positioned 1 m above the ground surface. A preliminary experiment was performed and the shielding factor was found to be 1.31. This factor was used for correction of the measured value so as to represent the outside count rate. Additionally, the pulse height distributions were obtained outside the car for consecutive 30-second intervals during a total recording period of 15 minutes at five locations. The obtained pulse height distributions were unfolded using a 22 × 22 response matrix, and the air kerma rates were obtained [11]. The dose conversion factor was found to be 0.0018 (nGy $h^{-1}$/cpm) by correlation between total count rate and air kerma rate.

All obtained data from the car-borne survey were plotted on a distribution map using generic mapping tools (University of Hawaii, Honolulu, HI, USA). For more detailed analysis, Katsushika Ward was divided into north (A1 in Fig. 1b) and south (A2 in Fig. 1b) areas based on the course of a major river, and mean air kerma rate was calculated for each area. The significance of differences was evaluated using *t*-test by

SPSS (IBM, Tokyo, Japan) and the significant level was set at $p = 0.01$. Those data were then compared with data obtained in 2005.

## RESULTS and DISCUSSION

Fig. 2a shows a distribution map of the air kerma rate from the car-borne survey ($n$ = 1056). A distribution map constructed with data measured in 2005 ($n$ = 272) [9] is shown in Fig. 2b; it uses the same gradation scale. In comparison with the distribution of air kerma rate measurements performed in 2005, the effect of the accident of F1-NPP became evident from this study. Mean air kerma rates in 2014 and 2005 are shown in Table 1, and the newer air kerma rate was 50% higher ($p < 0.01$). The air kerma rates in Katsushika Ward had originally been low because the base geology is a loamy layer typical of the Kanto District. However, the air kerma rates in A2 (Fig. 2b) were 20% higher than those in A1 because the air kerma rates depend on the proportion of asphalt that contains many natural radionuclides [9]. The respective proportions of asphalt for areas A1 and A2 were 80% and 90%. Thus, the air kerma rates in A2 were higher compared to A1. In the air kerma rate distribution of the present survey study, the mean air kerma rate in A1 (Fig. 2a) was 20% higher than that of A2 ($p < 0.01$) (Table 1). This can be explained as due to the presence of artificial radionuclides that were carried by northeast winds as was reported previously [5]. Additionally, the distribution was not uniform and higher air kerma rates were observed in some parts, the southwestern part of A2 to the northeastern part of A1. Moreover, higher air kerma rates were observed across the northern part of Al. A highway (road width: 40 m) and a main road (road width: 25 m) pass through these parts. Within metropolitan Tokyo, these roads have become paths for the winds because of the many high-rise building and density of housing. As described above, since the dispersion of artificial radionuclides is significantly affected by the winds, the radionuclides may have been dispersed along these roads. Whereas higher air kerma rates were observed in 2014 in the ward, the air kerma rates were similar to those measured in 2005 along these roads (Fig. 2a, blue circles). In these locations, the survey car traveled under a viaduct (height: 10 m). Thus, lower air kerma rates might have been obtained because the rainfall containing the artificial radionuclides was obstructed by the viaduct. The histograms of air kerma rates in 2014 and 2005 are shown in Fig. 3. The histograms obtained in 2014 and 2005 did not conform to the normal distribution. The medians of air kerma rates in 2014 were 57 nGy $h^{-1}$ in 2014 and 38 nGy $h^{-1}$ in 2005.

While there are no reports for measurements covering all of Katsushika Ward after the F1-NPP accident, the ambient equivalent dose rate at seven parks (P1-P7 in Fig. 1b) has been regularly observed using a 1-in $\phi$ × 1-in NaI(Tl) scintillation survey meter (TCS-172B, Hitachi-Aloka Medical Co., Tokyo, Japan) at 1 m above the ground surface since May 25, 2011 by the Katsushika Ward Office [10]. The dose conversion factor used was 0.748 Sv $Gy^{-1}$ [12] for converting to the air kerma rate. The air kerma rate from artificial radionuclides was calculated by subtracting background air kerma rate that was obtained in measurements in 2005 (i.e., 39 nGy $h^{-1}$). The change of a representative air kerma rate at P1 is shown in Fig. 4. The origin of the horizontal axis was set to March 21, 2011 when the radioactive plume was observed around Tokyo [5, 13]. The air kerma rate on this start date was reported by the Katsushika Ward Office as 268 nGy $h^{-1}$ [10] and the rate on the measurement date in this study was 55 nGy $h^{-1}$. Here, the decay constant ($\lambda$) and the environmental half-life ($T$) at P1-P7 (Fig. 1b) were calculated using Eq. (1) to estimate the changes in air kerma rate in the future:

$$D = D_L\left(\exp\left(-\lambda_L t\right)\right) \quad , \quad T = 0.693/\lambda_L \qquad (1)$$

where $D$ is air kerma rate from the artificial radionuclides, $D_L$ is initial air kerma rate from long half-life radionuclides and $t$ is elapsed years from the day when the radioactive plume was observed around Tokyo (May 21, 2011). In this evaluation, only long half-life radionuclides were considered to estimate the change in air kerma rate of the future. The calculated decay constant and the environmental half-life are shown in Table 2. These environmental half-lives were shorter than the physical half-life of $^{137}Cs$. Near the F1-NPP, the environmental half-lives were also estimated to be 68-170 days from changes of the absorbed dose rates at 1m above the ground surface [14]. Both the Katsushika and the F1-NPP measurement places were located in high rainfall areas. Additionally, much of their ground surfaces have been paved with asphalt. Since the surface contamination on asphalt is easily washed away by rainfall, those environmental half-lives might be shorter than the physical half-life. If the environmental half-life in

Katsushika Ward was assumed to be 1.9 years (Table 2), the air kerma rate can be expected to drop to that before the accident (i.e., 39 nGy $h^{-1}$) after 1.3 years.

## CONCLUSION

The distribution of air kerma rates in Katsushika Ward three years after the F1-NPP accident was reported in this study. The measured air kerma rates were significantly higher than before the accident and the level could be explained as an effect of the accident. However, it was estimated that the air kerma rate will drop to the natural radiation level after a few years based on calculations using published data from the Katsushika Ward Office.

## ACKNOWLEDGMENTS

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## FIGURES

Figure 1
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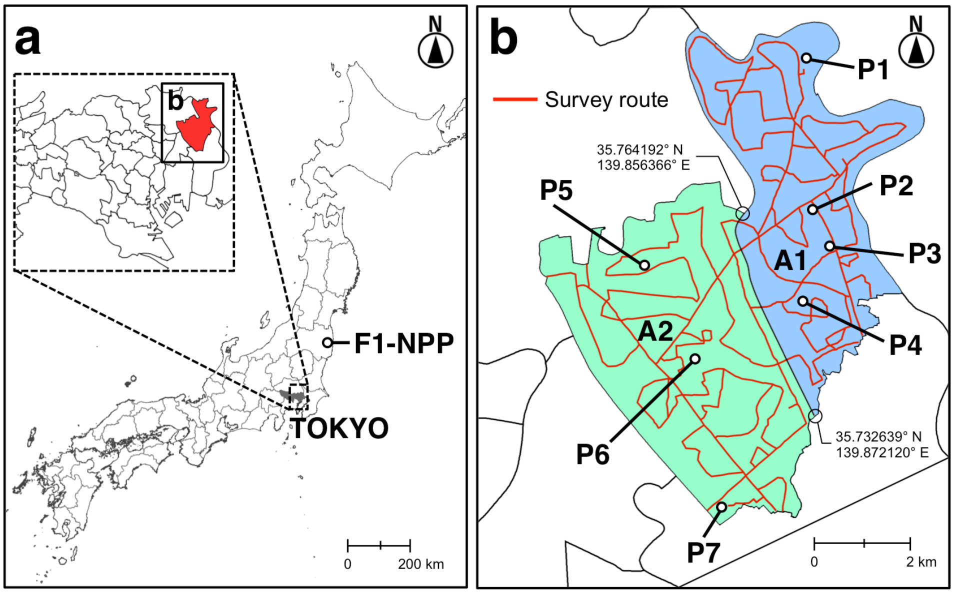


**Fig. 1** The location of Katsushika Ward, Tokyo (**a**) and the survey route for measuring air kerma rate (**b**). The car-borne survey was carried out using a 3-inϕ × 3-in NaI(Tl) scintillation spectrometer in March 2014. Total travel distance was 105 km. North and south areas of Katsushika Ward are indexed as A1 and A2, respectively.



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**Figure 2**
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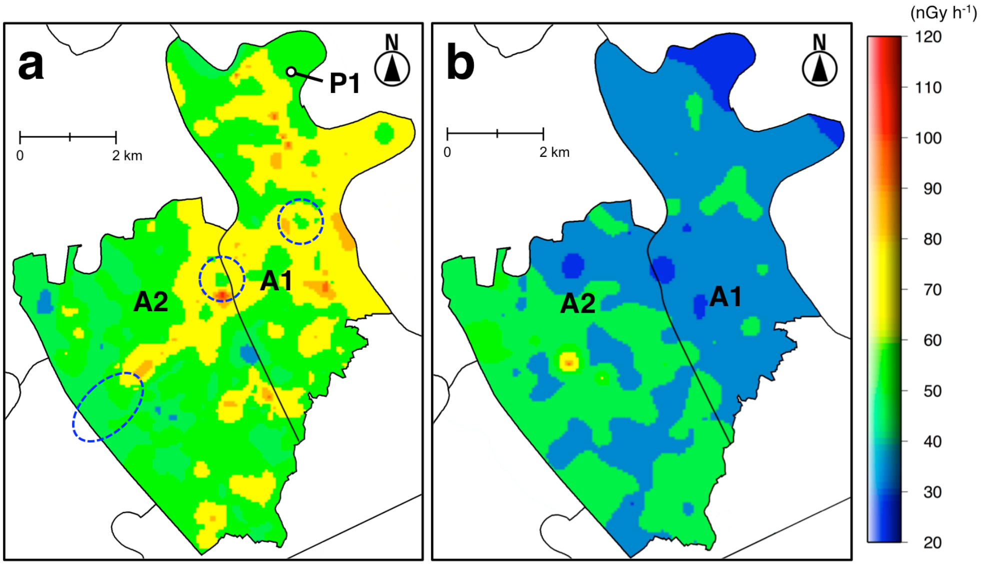


**Fig. 2** The distribution maps of the air kerma rate of the Katsushika Ward measurements done in 2014 (**a**) and 2005 [9] (**b**). The scale range of the distribution map in 2005 was modified to fit the 2014 map.



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**Figure 3**
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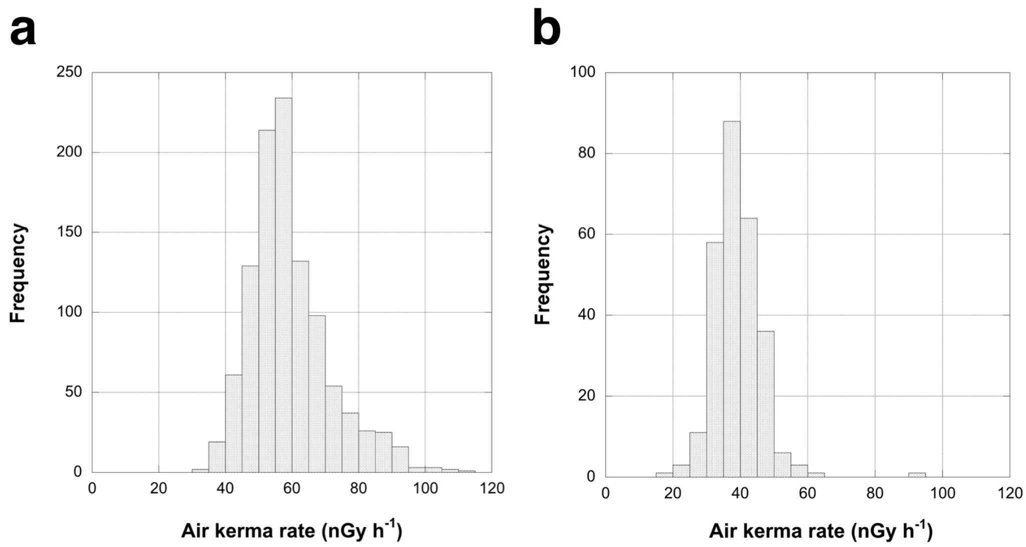


**Fig. 3** The histogram analysis of data obtained in 2014 (**a**) and 2005 [9] (**b**).



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**Figure 4**
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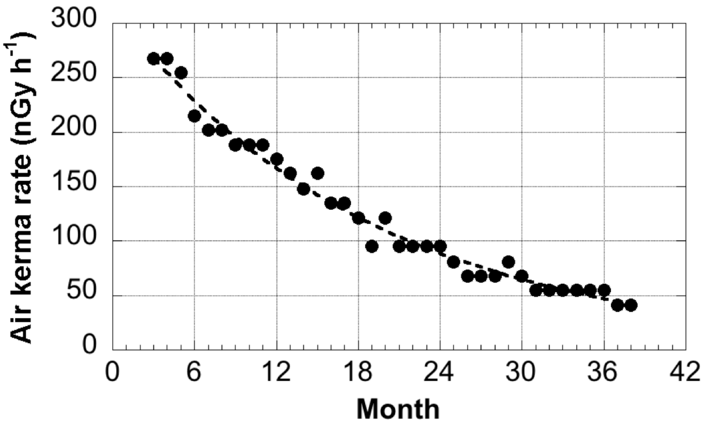


**Fig. 4** Transition of a representative air kerma rate between May 2011 and May 2014 at P1 in Fig. 1b. This figure was drawn using data published by the Katsushika Ward Office [10]. Data were measured using a 1-inϕ × 1-in NaI(Tl) scintillation survey meter (TCS-172B, Hitachi-Aloka Medical Co., Tokyo, Japan).

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Table 1  Air kerma rate in Katushika Ward in 2014 and 2005

| Air kerma rate ($nGy\ h^{-1}$) | Location | | |
|---|---|---|---|
| | Whole area | A1 | A2 |
| May 2014 (*n* = 1056) | | | |
| Mean | 59 | 64 | 56 |
| SD | 12 | 11 | 12 |
| Range | 34-115 | 36-103 | 36-115 |
| August 2005 (*n* = 272) | | | |
| Mean | 39 | 36 | 43 |
| SD | 7 | 5 | 8 |
| Range | 17-91 | 21-50 | 17-91 |

Table 2 Decay constant and the environmental half-life in Katsushika Ward

| Location | Decay constant | Environmental half-life (y) |
|---|---|---|
| P1 | 0.460 | 1.5 |
| P2 | 0.268 | 2.6 |
| P3 | 0.431 | 1.6 |
| P4 | 0.419 | 1.7 |
| P5 | 0.356 | 1.9 |
| P6 | 0.319 | 2.1 |
| P7 | 0.337 | 2.1 |
| Average | 0.370 | 1.9 |