ABSORBED DOSE RATE IN AIR IN METROPOLITAN TOKYO BEFORE THE FUKUSHIMA DAIICHI NUCLEAR POWER PLANT ACCIDENT

K. Inoue[1], M. Hosoda[2,*], M. Fukushi[1], M. Furukawa[3] and S. Tokonami[4]
[1]Department of Radiological Sciences, Tokyo Metropolitan University, 7-2-10 Higashiogu, Arakawa-ku, Tokyo 116-8551, Japan
[2]Hirosaki University Graduate School of Health Sciences, 66-1 Hon-cho, Hirosaki, Aomori 036-8564, Japan
[3]Graduate School of Engineering and Science, University of the Ryukyus, 1 Senbaru, Nishihara, Okinawa 903-0213, Okinawa, Japan
[4]Institute of Radiation Emergency Medicine, Hirosaki University, 66-1 Hon-cho, Hirosaki, Aomori 036-8564, Japan

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The monitoring of absorbed dose rate in air has been carried out continually at various locations in metropolitan Tokyo after the accident of the Fukushima Daiichi Nuclear Power Plant. While the data obtained before the accident are needed to more accurately assess the effects of radionuclide contamination from the accident, detailed data for metropolitan Tokyo obtained before the accident have not been reported. A car-borne survey of the absorbed dose rate in air in metropolitan Tokyo was carried out during August to September 2003. The average absorbed dose rate in air in metropolitan Tokyo was 49 ± 6 nGy h^{-1}. The absorbed dose rate in air in western Tokyo was higher compared to that in central Tokyo. Here, if the absorbed dose rate indoors in Tokyo is equivalent to that outdoors, the annual effective dose would be calculated as 0.32 mSv y^{-1}.

INTRODUCTION

Large amounts of artificial radionuclides such as ^{131}I, ^{134}Cs, and ^{137}Cs were released from the reactor buildings to the natural environment by the accident at the Fukushima Daiichi Nuclear Power Plant (F1-NPP) due to the Great East Japan Earthquake that occurred on March 11, 2011(1). In metropolitan Tokyo which is located 220 km southeast of the plant, these radionuclides were deposited there between March 21 to 23, by rainfalls(2). According to the survey results of airborne monitoring carried out in September 2011 for Tokyo by the Ministry of Education, Culture, Sports, Science and Technology, Japan, high deposition amounts of ^{134}Cs and ^{137}Cs at the ground surface and 1 m above the ground surface were observed in eastern Tokyo(3). Additionally, amounts tended to be high in the extreme western part of Tokyo which is mostly forested land. On the homepage of the Tokyo Metropolitan Government, the survey results of measured radiation dose rates at 100 locations in Tokyo, which were carried out in June 2011 have also been published(4).

Data obtained before the accident are needed to more accurately assess the effects of radionuclide contamination from the accident. However, there is only one reported database of absorbed dose rates in air obtained before the F1-NPP accident and it was prepared by the National Institute of Radiological Sciences(5). According to that database, the arithmetic mean absorbed dose rate in air (n = 19) was 32.5 nGy h^{-1} at 1 m above the ground surface in Tokyo. But, more detailed data are needed to evaluate the impact of the accident in Tokyo in detail.

The authors had collected detailed data of absorbed dose rates in air in Tokyo (excluding the Pacific Ocean islands that are within the Tokyo Government's jurisdiction) by performing a car-borne survey before the F1-NPP accident. In this report, the trend and distribution of the absorbed dose rate in air from the natural radionuclides that were observed before the accident were reported.

MATERIALS AND METHODS

The absorbed dose rates in air (nGy h^{-1}) from the natural radionuclides such as ^{40}K, ^{238}U series and ^{232}Th series were measured on August 25, 27 (cloudy with intermittent rain showers; total precipitation, 27 mm) and 29, and September 1 and 2, 2003 in metropolitan Tokyo, excluding the island chain (Figure 1a). The car-borne survey route encompassed all municipalities (i.e. wards and cities within the metropolitan area). Main roads were used to the extent possible, primarily centered on residential areas. A 2-in × 2-in NaI(Tl) scintillation survey meter (S-1857, Applied

*Corresponding author: m_hosoda@cc.hirosaki-u.ac.jp

Engineering Inc., Tokyo, Japan) was used. Latitude and longitude at each measurement point were measured with a global positioning system at the same time. The measurements were made every minute. The shielding effect of the car body was estimated by measuring the count rate for one minute inside and outside of the car at 27 locations (Figure 1b).

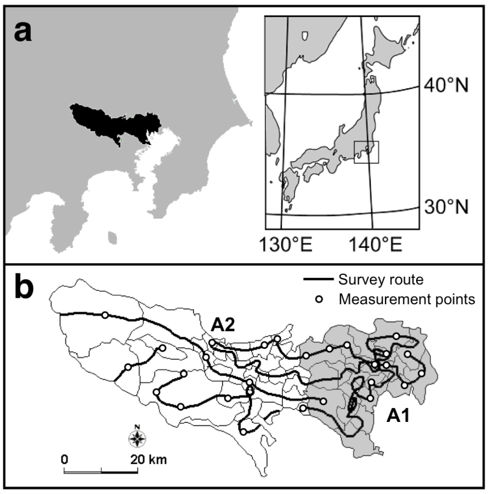

Figure 1. The location of metropolitan Tokyo (a) and survey route for measuring absorbed dose rate in air (b).

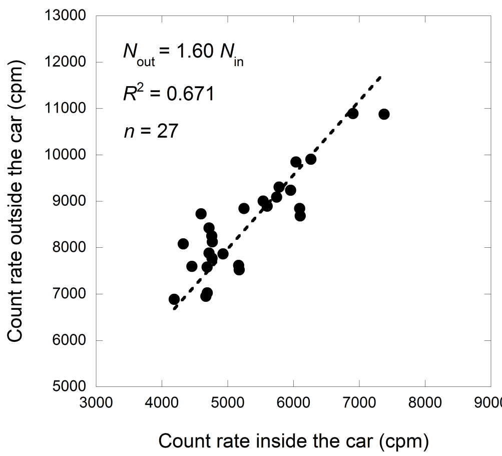

Figure 2. Correlation between count rates inside and outside the car.

A preliminary experiment was performed to determine the correlation between the count rates measured inside and outside the car and a better correlation (R^2 = 0.671) was obtained as shown in Figure 2. Based on this correlation the obtained following linear approximation equation was used to estimate the count rates inside and outside the car (N_{out}):

$$N_{out} = 1.60 \times N_{in} \qquad (1)$$

where N_{in} (cpm) is the count rate inside the car. The obtained pulse height distributions were unfolded using a 22 × 22 response matrix, and the absorbed dose rates in air were obtained[6]. The dose conversion factor was found to be 0.053 nGy h^{-1}/cpm by correlation between total count rate and absorbed dose rate in air. All of the obtained data from the car-borne survey were plotted on a distribution map using a inverse distance weighting technique. For more detailed analysis, metropolitan Tokyo was divided into east (A1 in Figure 1b) and west (A2 in Figure 1b) areas based on the municipalities. The significance of differences was evaluated using *t*-test by SPSS (IBM, Tokyo, Japan) and the significance level was set at $p = 0.050$.

A mean annual effective dose (mSv y^{-1}) was also calculated using the following equation:

$$E = D \times 10^6 \times f \times 24 \text{ (hr)} \times 365 \text{ (day)} \qquad (2)$$

where E is mean annual effective dose (mSv y^{-1}), D is mean absorbed dose rate in air (nGy h^{-1}), and f is dose coefficient (0.748 Sv Gy^{-1}) in this study[7]. Here, the absorbed dose rate indoors was assumed to be equivalent to that outdoors.

RESULTS

Figure 3 shows the distribution of absorbed dose rate in air obtained from all over metropolitan Tokyo. The mean absorbed dose rate (range) was 49 ± 6 nGy h^{-1} (18 – 76 nGy h^{-1}). Figure 4 shows the distribution map of the absorbed dose rate in air obtained from the car-borne survey (n = 669). The absorbed dose rate in air at A2 was higher compared to that A1 (p = 0.016). The mean absorbed dose rates (range) at A1 (n = 335) and A2 (n = 334) were 47 ± 6 nGy h^{-1} (18 - 61 nGy h^{-1}) and 52 ± 6 nGy h^{-1} (34 – 76 nGy h^{-1}), respectively. Especially, the highest absorbed dose rate in air was observed in part of the most western city C2 (Figure 4) and the lowest value was observed in part of one eastern ward C1. The absorbed dose rates in air at C1 and C2 were 61 ± 3 nGy h^{-1} and 40 ± 8 nGy h^{-1}, respectively. Annual mean effective dose for all of metropolitan Tokyo was 0.32 mSv y^{-1}. The annual effective doses in C1 and C2 were 0.26 and 0.40 mSv y^{-1}, respectively; thus there was a 1.5-fold difference between C1 and C2.

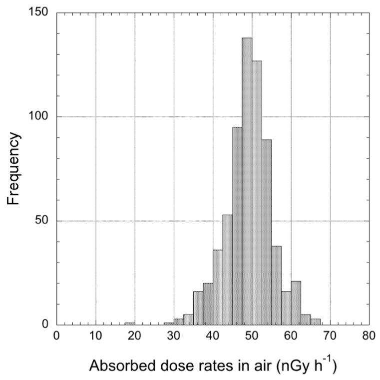

Figure 3. The histogram analysis of data obtained in 2003.

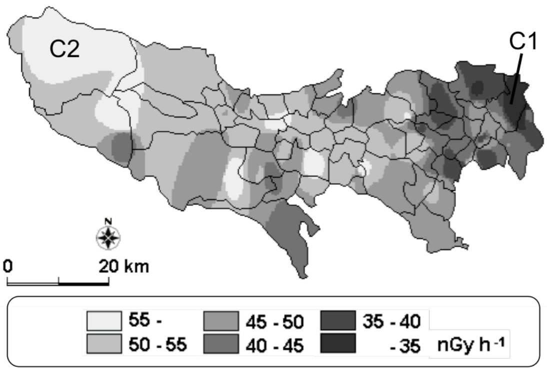

Figure 4. The distribution map of the absorbed dose rate in air in metropolitan Tokyo obtained in 2003.

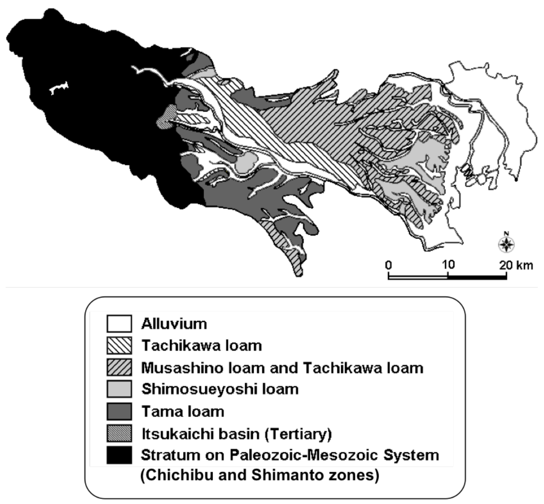

Figure 5. The geological map of Metropolitan Tokyo[8].

DISCUSSION

In this paper, the detailed distribution of the absorbed dose rates in air in Tokyo obtained from the authors' car-borne survey done in 2003 was reported (Figure 4). The mean absorbed dose rate in air after the accident of F1-NPP has been reported by the Tokyo Metropolitan Government to be 61 ± 24 nGy h^{-1} (30 – 200 nGy h^{-1})[4]. Compared to the mean absorbed dose rate in air before the accident (i.e., 49 ± 6 nGy h^{-1}), after the accident the rate was a maximum of 4.1 times higher.

The distribution of absorbed dose rate in air in Tokyo before the accident was significantly different for the two east-west areas A1 and A2. This result was like the trend of the previous report. Especially, the absorbed dose rate in air in the eastern area C2 has had the highest value observed in Tokyo (104 nGy h^{-1})[5].

Based on the geological map of metropolitan Tokyo shown in Figure 5, it is possible to describe the distribution of absorbed dose rate in air obtained as due to the difference in geology. The geology of western Tokyo where C2 showed the highest absorbed dose rate in air is the oldest layer (Chichibu and Shimanto zones) in Tokyo and it was formed in Mesozoic and Paleozoic eras (250 million years ago - 590 million years ago). This area has mainly formed by black shale that is one of the sedimentary rocks and 98% of this area has covered with forest. Generally, older layers tend to show higher dose rates. Thus, absorbed dose rates in air obtained from the western side showed higher value compared to other areas[9]. The layers located in the middle of Tokyo such as Tama loam (13 million - 40 million years ago), Shimosueyoshi loam (60 thousand - 13 million years ago), Musashino loam (30 thousand - 60 thousand years ago) and Tachikawa loam (10 thousand - 30 thousand years ago) were formed much more recently. In the areas of these layers, lower absorbed dose rates were observed compared to that of C2 because these loams came from activity periods in which mafic volcanic rock was formed[9]. On the other hand, the he eastern Tokyo area A1 is alluvial and it was deposited very recently, 4000 to 5,500 years ago. In addition, the land around Tokyo Bay is landfill that was created mainly after 1900s. Although observed absorbed dose rate in air will be different depending on the type of soil that has been used for the landfill, the absorbed dose rate in air is generally low when the age of the soil layer is young[9].

From the authors' results before the accident, the arithmetic anural effective dose in Tokyo was 0.32 mSv y^{-1} (0.26 - 0.40 mSv y^{-1}). Since the annual effective dose of the national average reported by the National Institute of Radiological Sciences is 0.33 mSv y^{-1}[5], the present result was similar. On the other hand, when the annual effective dose after the accident was estimated by assuming the absorbed dose rate in air of 200 nGy h^{-1}[4] and the environmental half-life of 68-170 days[10], it was 0.34 - 0.68 mSv y^{-1}. The annual effective dose would be increased 1.1 to 2.1 times compared to that before the accident.

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