Ambient dose rate on Mikurashima Island after the Fukushima Daiichi Nuclear Power Plant accident

Keywords: Ambient dose rate; Car-borne survey, Dose distribution map; Mikurashima Island, Annual effective dose.

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ABSTRACT

No detailed ambient dose rate has been reported, either before or after the Fukushima Daiichi Nuclear Power Plant (F1-NPP) accident, for Mikurashima Island, one of the islands within the authority of the Tokyo Metropolitan Government. Thus, the ambient dose rate on Mikurashima Island was observed 4.5 years after the F1-NPP accident. A car-borne survey and a foot patrol survey of the ambient dose rates were conducted over the entire island using a 3-in × 3-in NaI(Tl) scintillation spectrometer. The average ambient dose rate was 27 nGy h^{-1} (12 – 45 nGy h^{-1}) and a higher dose distribution was observed for the northern and eastern areas of Mikurashima Island. However, the impact from the F1-NPP accident (i.e., the presence of artificial radionuclides) was mainly observed for the mountain area of the island (4 – 9 nGy h^{-1}; located about the center to south-southeast direction). Based on the measured ambient dose rate, the estimated annual effective dose after the accident was 0.09 mSv y^{-1}.

抄録

御蔵島（東京都御蔵島村）における空間線量率調査は，福島第一原子力発電所事故以前より現在まで行われていない。そこで，本研究は福島第一原子力発電所事故から約4.5 年経過した御蔵島において，車を用いた走行サーベイおよび歩行サーベイを実施した。測定では 3 インチ×3 インチの NaI(Tl)シンチレーションスペクトロメータを用いて実施した。結果，島内の平均空間線量率は 27 nGy h^{-1}（12 – 45 nGy h^{-1}）であった。また，島内の線量分布は島の北部および東部を中心として高い値を示した。しかし，人工放射性核種由来の空間線量率（4 – 9 nGy h^{-1}）は島の中心部から南東部の山岳部で顕著に観測された。また，走行および歩行サーベイで得られた空間線量率から算出した年間実効線量は 0.09 mSv y^{-1} であった。

INTRODUCTION

Large amounts of artificial radionuclides such as ^{131}I, ^{134}Cs and ^{137}Cs were released to the environment in the March 2011 accident at the Fukushima Daiichi Nuclear Power Plant (F1-NPP). Koo et al. [1] have estimated that 0.7 – 5.0 × 10^{17} Bq of ^{131}I and 1.0 – 5.0 × 10^{16} Bq of ^{137}Cs were released from the reactor buildings in the accident. For the Japanese land deposition, most of the artificial radionuclides deposited on the ground in a northeastern area from the F1-NPP [2] but some were subsequently diffused within an altitude of 0 – 1000 m from ground level and deposited on southern and southwestern areas depending on the topography, wind direction and precipitation field [3,4]. On Izu-Oshima Island (Fig. 1), located 350 km southwest of the F1-NPP, deposition of artificial radionuclides (^{134}Cs and ^{137}Cs) was observed for the entire island [5,6]. Thus, other islands in the Izu Island chain, such as Mikurashima, Miyakejima and Niijima Islands, might also have received radionuclide depositions. However, there is no report for ambient dose rate measured either before or after the F1-NPP accident on Mikurashima Island.

In this paper, a car-borne survey and a foot patrol survey were carried out for all of Mikurashima Island in August 2015, and a detailed dose rate distribution map was drawn using the obtained data. Based on the measured data, the impact on Mikurashima Island by the F1-NPP accident was estimated. In addition, the measured ambient dose rates were separated into dose rates from artificial (^{134}Cs and ^{137}Cs) and natural radionuclides (^{40}K, ^{238}U series and ^{232}Th series) using a 22 × 22 response matrix method [7] in order to provide accurate information about ambient dose rate on Mikurashima Island to local governmental agencies, as such information has not been available previously. Additionally, the annual effective dose was estimated for residents of Mikurashima.

INSTRUMENTS AND METHODS

The measurements of the ambient dose rates (nGy h^{-1}) were carried out in August 2015 on Mikurashima Island which is located 450 km southwest of the F1-NPP (Fig. 1). The weather condition was sunny or cloudy with no rainfall throughout the measurement days. The route map was drawn using the Generic Mapping Tools (GMT) [8)].

The car-borne survey route followed the main roads on this island. It was carried out using a 3-in × 3-in NaI(Tl) scintillation spectrometer (EMF-211, EMF Japan Co., Osaka, Japan). Measurements of the count rates inside the car were performed every 30 s along the route. Simultaneously, latitude and longitude at each measurement point were recorded at the same time with a global positioning system. Car speeds were kept around 30 km h^{-1} (Fig. 2). The car windows were kept closed during measurements. A foot patrol survey was also carried out for the mountain area where the car was unable to travel using the same scintillation spectrometer. The photon peak of ^{40}K (E_{γ} = 1.464 MeV) was used for calibration from the channel number and gamma-ray energy before the measurements.

The shielding effect of the car body was estimated by measuring the count rates inside and outside the car at 15 points (#1 – #15 in Fig. 2) because the count rate used for the dose calculations was measured inside the car. Measurements were recorded over consecutive 30-s intervals during a total recording period of 2 min both inside and outside the car. A shielding factor was calculated from the correlation between count rates inside and outside the car, and the corrected count rates inside the car were obtained by multiplying the data measured by the car-borne survey by this shielding factor. The gamma-ray pulse height distributions were also measured outside the car for 10 min at 20 points (#1 – #20 in Fig. 2). The NaI(Tl) scintillation spectrometer was positioned 1 m above the ground surface for these measurements. The measured gamma-ray pulse height distribution was then unfolded using a 22 × 22 response matrix method [7)] and ambient dose rates were calculated. Next, the calculated dose rates were used to estimate the dose conversion factor (nGy h^{-1}/cps) from a correlation between dose rates and count rates. The count rates measured by the car-borne survey and the foot patrol survey were multiplied by the obtained dose conversion factor and the ambient dose rates for all of Mikurashima Island were calculated.

All obtained data from the car-borne survey and foot patrol survey were plotted using GMT [8)] as a distribution map of ambient dose rate on Mikurashima Island. A minimum curvature algorithm was used for the data interpolation by GMT. This is the method for interpolating data by presuming a smooth curved surface from the data of individual points. For more detailed analysis, the calculated ambient dose rates obtained at 20 points (#1 - #20 in Fig. 2) were separated as being from natural radionuclides (^{40}K, ^{238}U series and ^{232}Th series) or from artificial radionuclides (^{134}Cs and ^{137}Cs) using a 22 × 22 response matrix method [7]. Additionally, the annual effective dose (mSv h^{-1}) was estimated based on measured ambient dose rates by the two surveys. All measurements on Mikurashima Island were carried out with the permission of the Tokyo Metropolitan Government.

RESULTS AND DISCUSSION

Fig. 3a shows the correlation between count rates inside and outside the car obtained at 15 locations (Fig. 2). The shielding factor and the standard uncertainty were calculated to be 1.40 and 0.14, respectively. In many previous reports, the shielding factor was reported to be 1.4 to 1.9 [6, 9-11], and the present shielding factor was at the end of this range. The correlation between dose rate (nGy h^{-1}) calculated from the software using the 22 × 22 response matrix [7] method and total count rate outside the car is shown in Fig. 3b. The dose rate conversion factor and standard uncertainty were evaluated to be 0.163 and 0.013 (nGy h^{-1}/cps). Both the shielding factor and dose rate conversion factor are used to calculate the ambient dose rate (nGy h^{-1}) outside the car (D_{out}) by Eq. (1):

$$D_{out} = C_{in} \times 1.40 \times 0.163 \qquad (1)$$

where C_{in} is count rate (cps) inside the car obtained by the car-borne survey. For the count rate obtained from the patrol survey, only the dose rate conversion factor was utilized to calculate the ambient dose rate.

The average ambient dose rate (range) for all of Mikurashima Island measured in August 2015 was 27 nGy h^{-1} (12 – 45 nGy h^{-1}). The average ambient dose rates (ranges) obtained by car-borne and patrol surveys were 32 (12 – 45 nGy h^{-1}) and 21 (12 – 39 nGy h^{-1}), respectively. There is no report giving measured ambient dose rate for Mikurashima Island; however, the average ambient dose rate of 27 nGy h^{-1} was like that of Izu-Oshima Island (27.0 nGy h^{-1}) measured before the F1-NPP accident [5)] and this reflects the fact that these islands have been mainly formed by the same andesite and basalt rocks. Thus, it could be assumed that the impact on ambient dose rate from the F1-NPP accident was low. Additionally, by comparing the present rate, measured in 2015, to the average ambient dose rate for all of Japan measured before 2011 (50 nGy h^{-1}) [12)], the former rate was 46% lower.

Fig. 4 shows the distribution map of ambient dose rate in air on Mikurashima Island in 2015. This map was drawn using 846 data. Higher ambient dose rates were observed for both northern and eastern areas of this island. That was the same tendency observed for Izu-Oshima Island after the F1-NPP accident[5, 6)] and is reasonable because the F1-NPP is located to the northeast of both islands (Fig. 1), radionuclides associated with the radioactivity plume may have adhered first to the ground in the northern and eastern areas.

Table 1 shows ambient dose rates measured for 20 points on Mikurashima Island. In the northern and eastern areas of the island (#1 – #3, #5, #6, #14, #15 in Fig. 2), generally low dose rates from artificial radionuclides (1 – 6 nGy h^{-1}) were observed. However, higher values for artificial nuclides (4 – 9 nGy h^{-1}) were observed for the mountain area (center to south-southeast direction) (#16 – #20 in Fig. 2). Higher dose rates from natural radionuclides were conversely observed for the northern and eastern areas compared to those of the mountain area. Thus, the higher dose distribution measured for the northern and eastern areas as shown in Fig. 4 might be reflecting the effect of natural radionuclides because the dose rates from artificial radionuclides measured in the mountain area were lower compared with those from natural radionuclides for the northern and eastern areas; the impact from the F1-NPP accident might not be clearly reflected on the dose distribution map.

The standard uncertainties of one time measurement (30 s) can be calculated from the measured value. The obtained range of counts inside the car was 27 – 119 (counts per 30 s) in this study. The standard uncertainty depending on measured counts was calculated to be 1.3 – 2.8 (counts per 30 s). The range of the relative standard uncertainty for 30 s measurements was also given as 2.4% – 4.8%. Here, the respective relative standard uncertainties for the shielding factor and dose conversion factor were calculated to be 10.3% and 8.1%, respectively. The relative standard uncertainties for the traceability of the dose rate and dose calculation procedure by the response matrix method were given as 4.1% (k = 2) (Pony Industry Co., Ltd., Osaka, Japan) and 5.0% (EMF Japan Co., Osaka, Japan), respectively. Thus, the maximum combined relative standard uncertainty to the estimated ambient dose rate in this study was calculated to be 14.6%.

The annual effective dose based on data obtained in August 2015 was calculated using Eq. 2:

$$H = D \times DCF \times (T_{out} + T_{in} \times SF) \times 365 \times 10^{-6} \qquad (2)$$

where H is annual effective dose (mSv y^{-1}), D is the mean ambient dose rate (nGy h^{-1}), DCF is the dose coefficient (0.748 Sv Gy^{-1}) [13], T_{out} and T_{in} are occupancy factors (4 h for outdoors, 20 h for indoors, for residents of Mikurashima Island), SF is dose reduction factor for wooden houses (0.4) [14]. Here, calculated annual effective dose was 0.09 mSv y^{-1}. As the annual effective dose in Japan is 0.33 mSv y^{-1} [15], the annual effective dose after the accident was less than the average in Japan.

CONCLUSION

The car-borne and foot patrol surveys using a NaI(Tl) scintillation spectrometer were carried out on Mikurashima Island in August 2015. The ambient dose rate (range) was found to be 27 nGy h^{-1} (12 – 45 nGy h^{-1}) for the whole island. This value was 46% lower than the average ambient dose rate (50 nGy h^{-1}) of all of Japan obtained before 2011. The higher dose distributions for the northern and eastern areas of the island likely were affected by natural radionuclides. However, the impact from the F1-NPP accident was mainly observed for the mountain area of the island (i.e., center to south-southeast direction). The estimated effective dose rate based on the dose rate measured in August 2015 was 0.09 mSv h^{-1}.

ACKNOWLEDGMENTS

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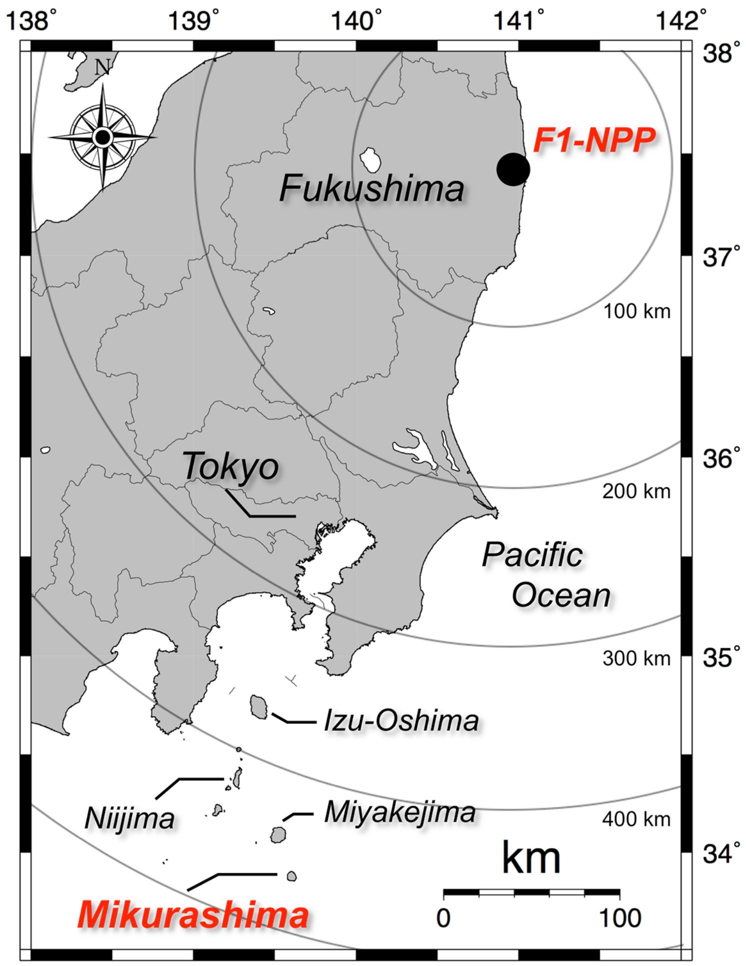

Fig. 1 The location of Mikurashima Island and other islands in the Izu Island chain. These islands are under the authority of the Tokyo Metropolitan Government. The map was drawn using the Generic Mapping Tools [8].

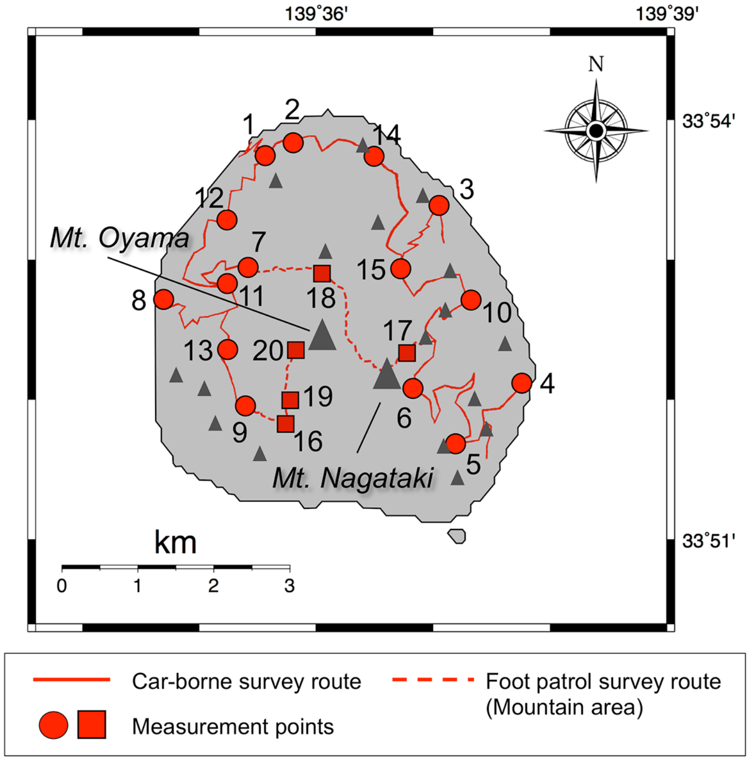

Fig. 2 The survey routes for measuring count rates and measurement points of gamma-ray height distribution on Mikurashima Island. A car-borne survey and a foot patrol survey were carried out using a 3-in × 3-in NaI(Tl) scintillation spectrometer in August 2015. The fixed-point measurements outside the car were also performed for 10 min at 20 locations (#1 - #20).

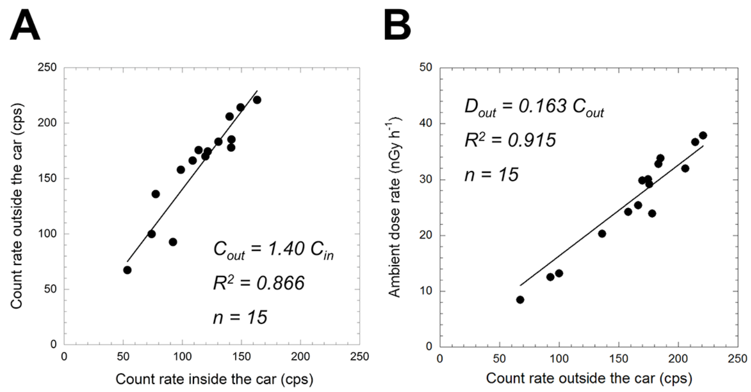

Fig. 3 Correlations between count rates inside and outside the car (a) and between ambient dose rates and count rates outside the car (b). The absorbed dose rates in air were calculated using software of the 22 × 22 response matrix method [7].

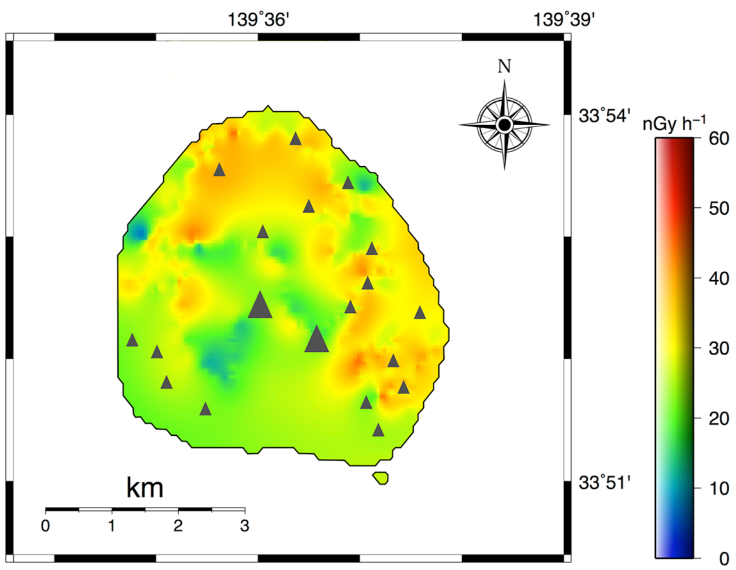

Fig. 4 The distribution map of ambient dose rate on Mikurashima Island measured in August 2015. That map was drawn using 846 data.

Table 1 Measured ambient dose rates on Mikurashima Island.

#*	Latitude (º)	Longitude (º)	Absorbed dose rate in air (nGy h^{-1})		
			All	Natural radionuclides	Artificial radionuclides
1	33.895	139.535	24	23	1
2	33.897	139.597	13	11	2
3	33.889	139.618	8	6	2
4	33.889	139.629	38	38	0
5	33.861	139.619	30	28	2
6	33.868	139.613	24	18	6
7	33.882	139.590	37	37	0
8	33.878	139.578	34	34	0
9	33.865	139.589	30	30	0
10	33.872	139.587	29	29	0
11	33.895	139.608	32	31	1
12	33.882	139.612	33	33	0
13	33.878	139.622	25	24	1
14	33.880	139.587	20	18	2
15	33.888	139.587	13	9	4
16	33.863	139.595	12	8	4
17	33.866	139.596	10	6	4
18	33.872	139.597	14	7	7
19	33.872	139.612	12	6	6
20	33.881	139.600	16	8	8

* Measurement point locations (#) are shown in Fig. 2.