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Note

Investigation of γ-ray Dose Rate in Air at Densely-inhabited District in Fukushima Prefecture

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Air kerma rates by environmental γ-ray at two years after the Fukushima Nuclear Power Station accident were investigated around public facilities in Fukushima City, Koriyama City, Nihonmatsu City and Motomiya City in the Naka-dori area of Fukushima Prefecture. A CsI scintillation survey meter, which is very versatile, was used for measurement. This survey meter was calibrated by means of simultaneous measurement with an NaI(Tl) scintillation spectrometer. The minimum values of air kerma rates at each measurement site were higher than the background levels, and the medians were 0.23-0.35 μGy/h. Using these values and assuming a one year stay at the site, the annual effective dose was evaluated to be 1.5-2.3 mSv. The maximum value was 0.57-1.03 μGy/h, and the annual effective dose by environmental γ-ray was estimated to be 3.7-6.7 mSv without considering the attenuation of the radioactivity.

Key words: dose rate, environmental γ-ray, Fukushima

1. Introduction

Radionuclides were discharged into the environment by the Fukushima Dai-ichi Nuclear Power Station (F1-NPS) accident[1)]. Fukushima Prefecture is divided into three regions, Hama-dori, Naka-dori and Aizu[2)]. In particular, the Naka-dori region is a densely populated area including Fukushima City and Koriyama City, and many people who evacuated from highly polluted areas (Hama-dori area) live in this area. It is very important for residents of a radioactive contamination area to understand the amount of environmental radiation in order to regulate their behavior.

Dose rates in air have been continuously measured by the national government and local self-governing organizations since immediately after the accident[3)]. However, the radioactive plume was diffused unequally by the wind in Fukushima Prefecture and detailed radiation dose data in residential areas were needed[4)]. Dose rates in air in the Naka-dori area derived from these

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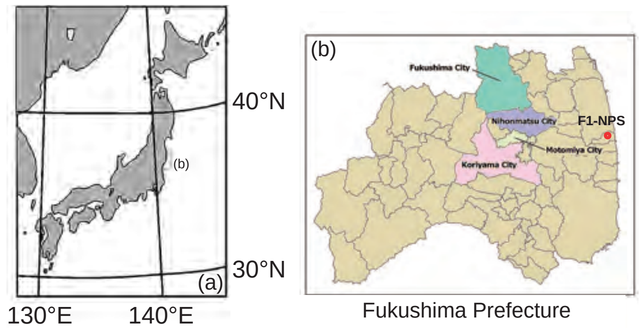


Fig. 1. Maps of investigated area. This figure was made using the Generic Mapping Tools (GMT) created by Wessel and Smith.

investigation results were not always low. Dose rates in air (air kerma rates) by environmental γ-ray were investigated in detail around public facilities in the Naka-dori area two years after the accident, and the results are reported in this study.

2. Materials and Methods

2.1. Measurement sites and survey meters

Fukushima City, Koriyama City, Nihonmatsu City and Motomiya City, which belong to the Naka-dori area of Fukushima Prefecture, were selected as areas to be investigated (Fig. 1). Populations of the cities are 283,000 , 328,000, 56,000 and 30,000 people respectively[4]. Measurements were carried out from April 6 to May 11 in 2013. Measurement sites were set to be within an approximately 700m radius from the center of a monitoring post installed in the respective public facility such as a city office or park, and 60 to 372 points were measured in each city (the number differs among the cities). Most measurement sites were on pavement.

Unsealed surfaces (soil or grass) sites were shown in Fig. 3. In order to calibrate the CsI(Tl) scintillation survey meter (Radi PA-1100, HORIBA, Japan ; measurement range: 0.001-19.99 μSv/h), measurement were carried out at a height of 1 m from the ground surface for 900 seconds with the use of a 3-in×3-in NaI(Tl) scintillation spectrometer (EMF-211, EMF Japan, Japan), and a γ-ray pulse height distribution was obtained. Measurements for calibration were carried out at 14 points. These measurements were estimated by comparison with dose rates in air results obtained from 3-in×3-in NaI(Tl) scintillation spectrometer at the same points. Five measurements were carried out at intervals of 30 seconds around a NaI(Tl) scintillation spectrometer, and then an arithmetic mean of the measured value was derived. An air kerma rate was determined by unfolding the γ-ray pulse height distribution by means of a response matrix method[5]. Measured values obtained by the CsI(Tl) scintillation survey meter were calibrated with this air kerma rate used as a reference.

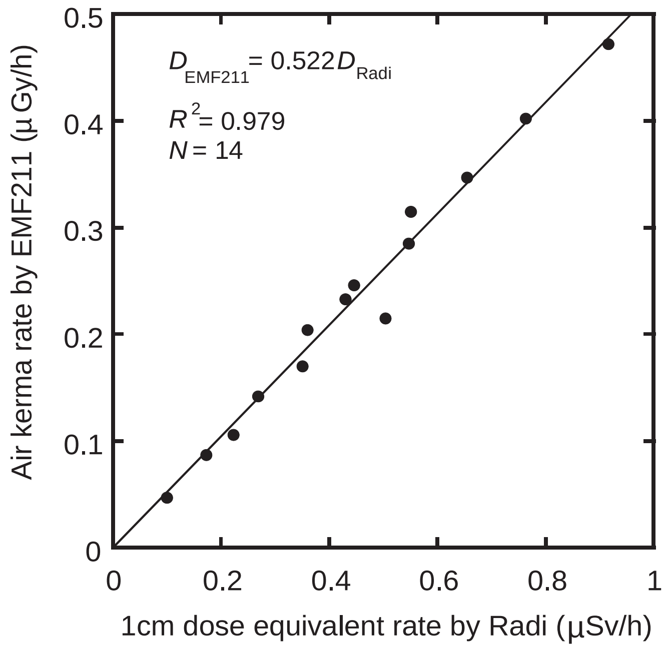


Fig. 2. The relation between air kerma rates obtained by EMF211 and 1cm dose equivalent rates obtained by Radi. (pocket survey meter: Radi PA-1100, HORIBA, Japan)

2.2. Calibration of a CsI(Tl) scintillation survey meter

The relation between air kerma rates obtained by the NaI(Tl) scintillation spectrometer and 1cm dose equivalent rates obtained by the CsI(Tl) scintillation survey meter is shown in Fig. 2. A strong correlation was found between both rates (R^2=0.979), and a regression equation shown below was able to be obtained.

$$D_{EMF211} = 0.522 D_{Radi} \quad (1)$$

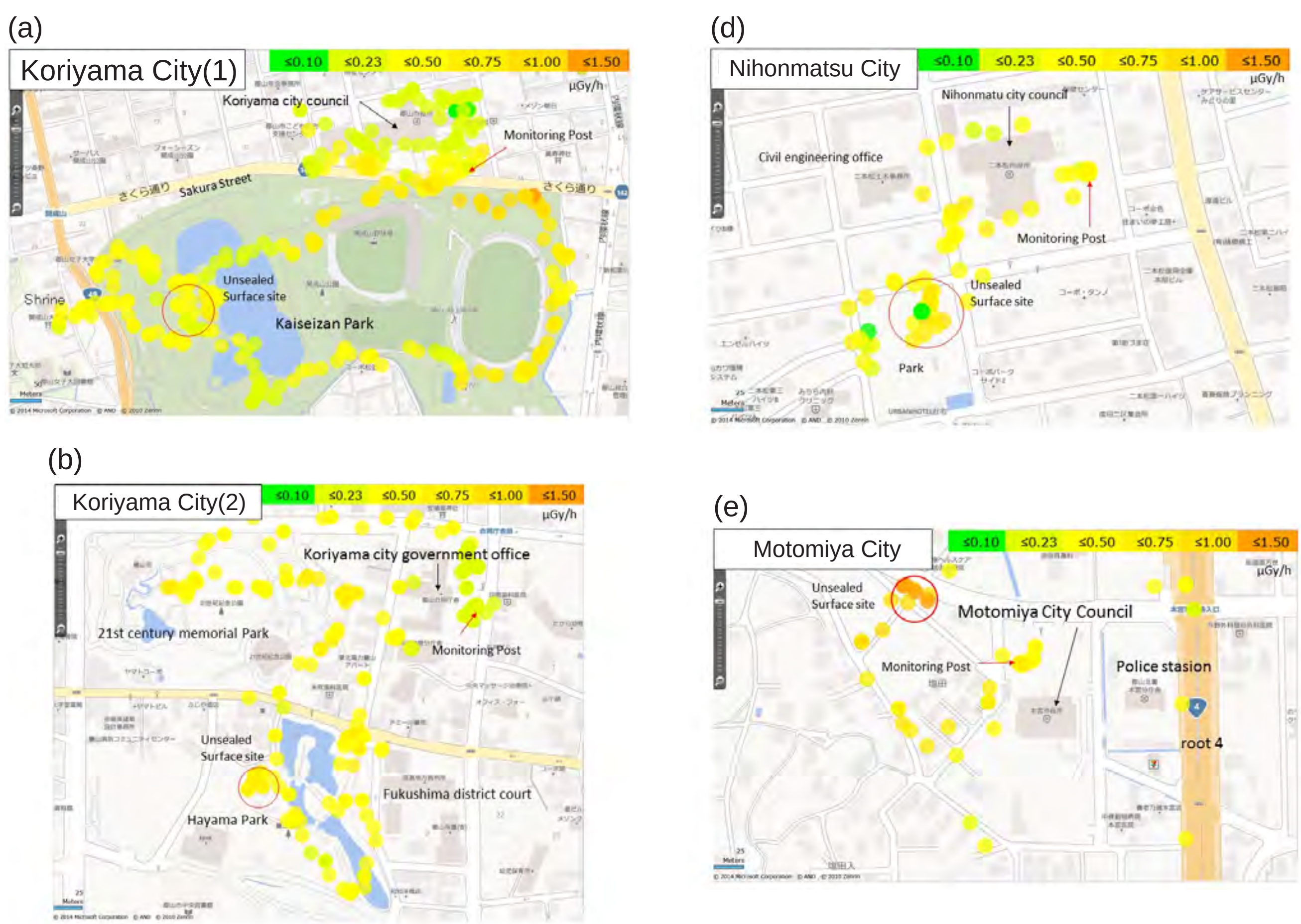
Where, D_{EMF211} is the air kerma rate (μGy/h) obtained by the NaI(Tl) scintillation spectrometer, and D_{Radi} is the 1cm dose equivalent rate (μSv/h) obtained by the CsI(Tl) scintillation survey meter. Therefore, conversion into an air kerma rate can be carried out by multiplying the value obtained by the CsI(Tl) scintillation survey meter by 0.522. The variation coefficient of the CsI(Tl) scintillation survey meter was approximately 2-7%, depending on the measurement site.

3. Results and Discussion

The air kerma rates at the measurement sites are shown in Table 1. Distributions and histograms of air kerma rates at each measurement site are shown in Fig. 3 and Fig. 4. Measurements around the Koriyama City council were

Table 1. Air kerma rates of measured points

City	Number of measuring points	Minimum value (μGy/h)	Maxmum value (μGy/h)	Median (μGy/h)	Measured point
Koriyama City (1)	372	0.13	1.03	0.32	Around Koriyama City hall
Koriyama City (2)	197	0.13	0.68	0.34	Around Koriyama City government office
Fukushima City	286	0.10	0.90	0.28	Around Fukushima Prefecture north health center
Nihonmatsu City	67	0.20	0.83	0.35	Around Nihonmatu City office
Motomiya City	60	0.12	0.57	0.23	Around Motomiya City office



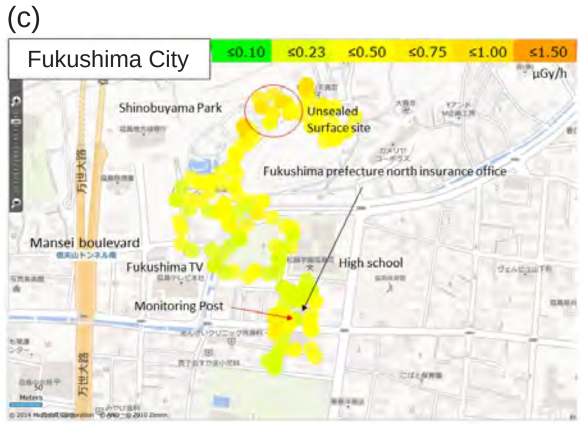


Fig. 3. Distributions of air kerma rates: (a) Koriyama City hall, (b) Koriyama City office, (c) Fukushima Prefecture north health center, (d) Nihonmatu City office and (e) Motomiya City office.

Table 2. Comparion of dose rate between monitoring post and measure values

Area	Dose at post (μSv/h) press report 1)	Dose around the monitoring post (μSv/h)				Post site/average
		post site 2)	minimum	average	maximum	
Koriyama city (1)	0.36	0.27	0.10	0.27	0.77	1.00
Koriyama city (2)	0.23	0.11	0.10	0.27	0.51	0.41
Fukushima city	0.35	0.20	0.07	0.25	0.68	0.80
Nihonmtsu city	0.40	0.17	0.15	0.29	0.62	0.59
Motomiya city	0.19	0.18	0.09	0.18	0.43	1.00

1) The data were measured by Nuclear Regulation Authority and reported by Fukushima Minpo (May 12th 2013)
2) The nearest measuring data from monitoring post

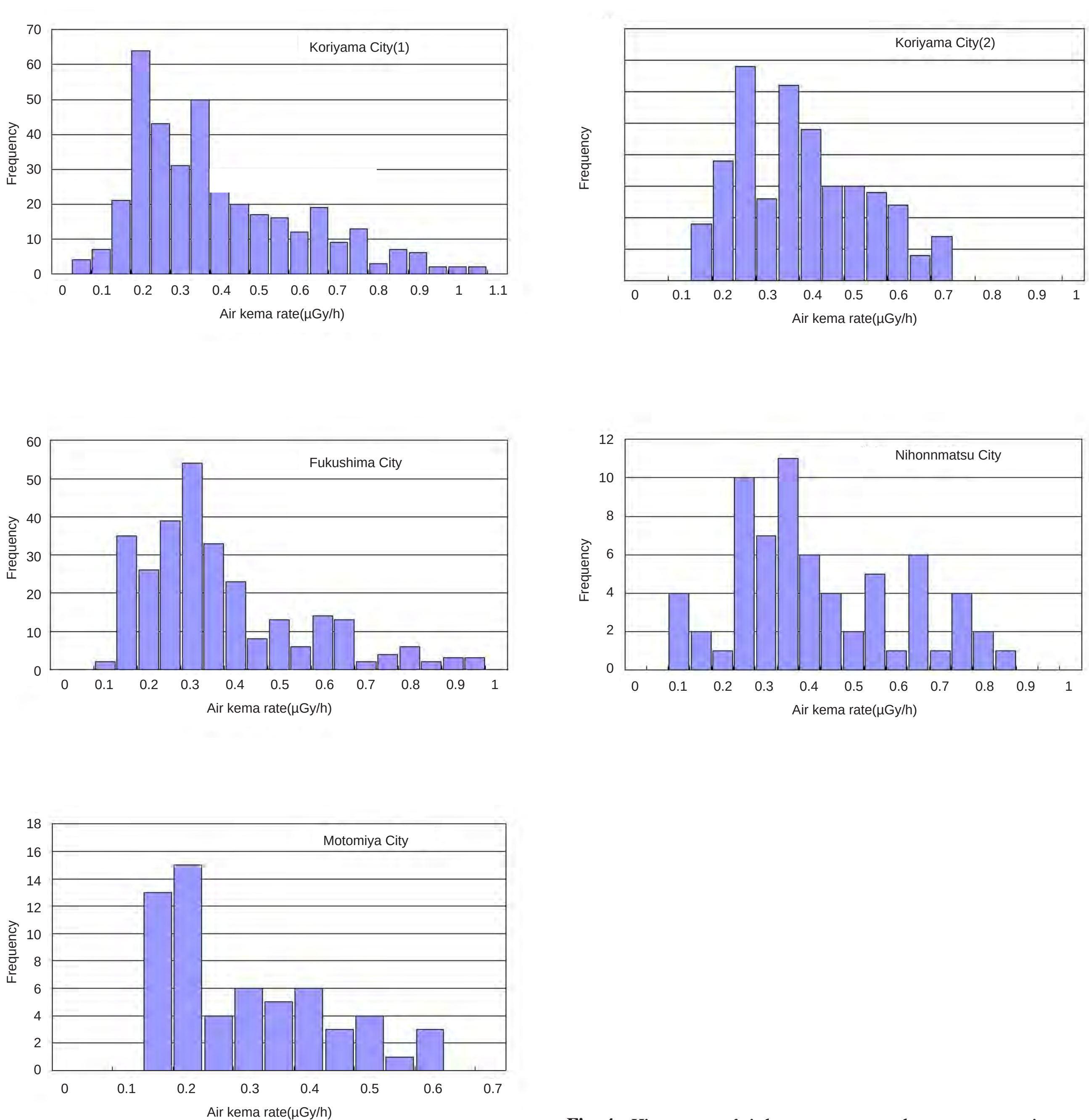


Fig. 4. Histograms of air kerma rates at each measurement site.

Table 3. Estimation dose rate of natural component in Koriyama City, Nihonmatsu City and Motomiya City

Measured site	Total dose rate (nGy/h)	Natural component (nGy/h)
Koriyama City (1)	142	37
Koriyama City (2)	315	39
Koriyama City (3)	215	30
Nihonmatsu City (1)	106	31
Nihonmatsu City (2)	472	19
Motomiya City (1)	347	28
Motomiya City (2)	402	17

carried out at 372 points on May 5, 2013. Measurements around the Koriyama City office were carried out at 197 points on May 10, 2013. Measurements around Fukushima Prefecture north insurance office were carried out at 286 points on May 11, 2013. Measurements around the Nihonmatsu City office were carried out at 67 points on April 6, 2013. Measurements around the Motomiya City office were carried out at 60 points on April 6, 2013.

Although the measurement sites in this investigation were limited to very narrow areas around public facilities, there was a large range of approximately one digit in the measured air kerma rates at all of the measurement sites. The reason is that there were some sites where decontamination had been carried out and a small value was measured. On the other hand, some sites, in particular, the roads in Kaisenzan Park, where decontamination has not been carried out and a large value was measured, were covered with piles of fallen leaves besides the many trees. No measurement site had any points that indicated a value of approximating the natural radiation dose rate level (0.04 μGy/h)[7] of Fukushima Prefecture.

1 cm dose equivalent rates (μSv/h) were used for the measuring dose rates of the monitoring posts. Air kerma rates were calculated by divideng these dose rates by 1.224 Sv/Gy[7]. We compared our measuring data with the values from the monitoring posts. Averages and standard deviations of our measuring data within 700 m from the monitoring posts are shown in Table 2.

The ratios of the average value of measured values within the circumference to the values in five places where a monitoring post was installed were 0.41 to 1.00, and the monitoring posts indicated values equal to or lower than the average value within the circumference. Monitoring posts values published in the newspapers were higher than the measured values in the same places.

As shown in Table 2 and Fig. 4, spatial dose rates within approximately 300m around a monitoring post were about 0.3 to 4 times higher than the values where the monitoring post was installed, and a non-uniform distribution was shown. From this result, the instruction value of a monitoring post does not indicate a representative value at the measurement site, and therefore it is necessary to regard it as only a reference value. It may be important to understand the location of places where the spatial dose rate can be higher than the instruction value of a monitoring post, specify such places, and prevent residents from approaching those places as much as possible.

Table 3 showed the total dose rate and the natural component dose rate which were calculated by the γ-ray pulse height distributions and the results. The doses of the total component were 3.4 to 24.8 (average: 11.9) times higher than those of the natural component. With the use of the median of each measurement site, and the assumption of a one year stay at the site, the annual effective dose was evaluated to be 1.5-2.3 mSv. Furthermore, in the case of using the maximum value, the dose was evaluated to be 3.7-6.7 mSv. Here, 0.748 (Sv/Gy) was used as a conversion factor from the air kerma to the effective dose[7].

4. Conclusions

Dose rates in air by environmental γ-ray were measured around public facilities in densely populated districts approximately two years after the F1-NPS accident. Measured values of air kerma rates varied largely even within a very narrow measurement area. The values dropped to a low level in sites where decontamination had been carried out, while in sites where decontamination has not yet been carried out and in sites where fallen leaves had piled up, values of 0.57 μGy/h or higher and values exceeding 1.03 μGy/h were observed. The annual effective dose by environmental γ-ray converted from this value is approximately 7 mSv.

This study indicated that the measurement method of radiation doses should be considered in estimating the biological effects to the human body because various values are shown depending on equipment and conditions at the measurement point. We need to take that into account beforehand to maintain the safety of residents in Fukushima.

Conflict of Interest Disclosure

The authors have no conflict of interest directly relevant to the content of this article.

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