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Note

# A Comparison Study of Commercially Available Survey Meters for Measurement of Gamma-rays.

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In this study, we investigated the response of six models of commercially available survey meters for measurement of radiation dose rate of the background on the Bunkyo-cho campus of Hirosaki University. The 1 cm equivalent dose rate at nine places on the campus for the low to high dose rates ranged from 20 to 110 nSv/h. Even for the same measurement location, the readings differed greatly among the survey meters. For four of the models, the arithmetic mean of the relative standard deviation of the 1cm equivalent dose rate exceeded 10%. From the relationship between the absorbed dose rate in air obtained by the NaI(Tl) scintillation spectrometer and the 1cm equivalent dose rate of each survey meter, it was judged that the scintillation type survey meter showed good linearity and had only a small variation in the readings for natural radiation level. These results suggested that it is important to confirm beforehand both the variation and the response sensitivity of the readings of the survey meter, even within the natural radiation dose rate of the background.

*Key words:* 1cm equivalent dose rate, survey meter, natural background radiation, scintillation spectrometer

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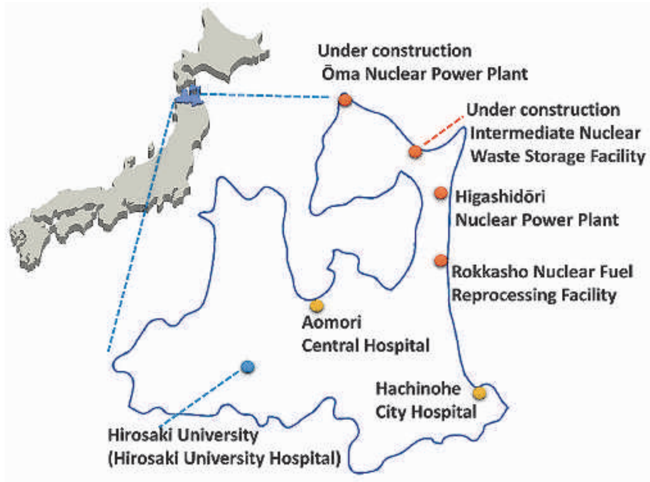


**Fig. 1.** Location of Hirosaki University, nuclear power and power-related facilities and institutes for secondary radiation emergency medicine (Aomori Central Hospital and Hachinohe City Hospital). Hirosaki University Hospital is the local tertiary radiation emergency medicine institution in Aomori prefecture.

**Table 1.** Summary of specifications of each survey meter

| ID | Detecting unit | Detection range | | |
|---|---|---|---|---|
| A | Si semiconductor | 0.05 μSv/h to 9.99 μSv/h | γ-rays | Home radiation meter |
| B | GM | 0.04 μSv/h (At 5 min measurement) to 9.99 μSv/h | β-rays, γ-rays | Simple ambient dose rate monitor |
| C | NaI(Tl) scintillator | 0.01 μSv/h to100 mSv/h | γ-rays 60 keV to 1.3 MeV | For measurement of γ-rays |
| D E | CsI(Tl) scintillator | 0.001 to 19.99 μSv/h | γ-rays 60 keV to 1.25 MeV | For measurement of ambient dose rate |
| F | NaI(Tl) scintillator | Background to 30 μSv/h | γ-rays 50 keV to3 MeV | For measurement of dose rate |
| G | CdTe semiconductor | 0.01 μSv/h to 10 mSv/h | γ-rays, X-rays 20 keV to 1.5 MeV | Mini spectrum meter |

## 1. Introduction

Large quantities of radionuclides were released into the environment in the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident of March 2011[1]. The interest of ordinary citizens towards radiation in the environment has increased since the accident and some have worries about personal radiation dose levels. Many simple survey meters are commercially available to measure personal radiation levels[2, 3]. Survey meters that are widely used in Japan for professional medical and scientific studies are the GM (Geiger-Müller) survey meter for measurement of beta-rays (and X-, and gamma-rays) and the NaI(Tl) survey meter for measurement of X- and gamma-rays. GM survey meter is used in measurement of surface contamination well, and the reading for it is in units of counts per minute (CPM; CPM is a measure of the detection rate of ionization events per minute). NaI(Tl) survey meter is used in measurement of radiation dose rate, and the reading for it is in units of μSv/h or μGy/h. The detection unit in generally available survey meters is a GM tube, a semiconductor or a scintillator, and such devices can be purchased on the internet. Generally, survey meters were calibrated by the checking source to show the appropriate value before sale.

A number of nuclear power and power-related facilities are in Aomori Prefecture (Fig. 1), and Hirosaki University, therefore, has launched an educational program on radiation emergency medicine for medical specialists in such facilities and hospitals in the prefecture and for personnel working in administrative agencies[4]. This training course includes a practical exercise on radiation measurement and making a dose rate distribution map. In the previous two implementation of the exercise, measurements of estimation for absorbed dose rate in air in Hirosaki City (September 2012) and on the campus of Hirosaki University (June 2013) were carried out[5, 6]. According to these reports, artificial radionuclides derived from the FDNPP accident were not found. We investigated the response of commercially available survey meters for natural radiation dose rate of the background as a part of the Education Program for

**Table 2.** 1cm equivalent dose rate (nSv/h) of each survey meter (A to G) and absorbed dose rate in air (nGy/h) calibrated using the 3-inch × 3-inch NaI(Tl) scintillation spectrometer (EMF) and relative standard deviation at each measurement location (Nos. 1 to 9)

| | No.1 | No.2 | No.3 | No.4 | No.5 | No.6 | No.7 | No.8 | No.9 |
|---|---|---|---|---|---|---|---|---|---|
| | 1cm equivalent dose rate (nSv/h) (RSD %) | | | | | | | | |
| A | 60 ± 10 (17%) | 50 ± 0 (0%) | 57 ± 12 (20%) | 80 ± 17 (22%) | 97 ± 15 (16%) | 60 ± 10 (17%) | 67 ± 21 (31%) | 67 ± 15 (23%) | 73 ± 15 (21%) |
| B | 70 ± 17 (25%) | 93 ± 21 (22%) | 107 ± 6 (5%) | 97 ± 12 (12%) | 97 ± 6 (6%) | 83 ± 6 (7%) | 110 ± 0 (0%) | 100 ± 10 (10%) | 90 ± 10 (11%) |
| C | 20 ± 0 (0%) | 23 ± 5 (25%) | 23 ± 6 (25%) | 23 ± 6 (25%) | 33 ± 6 (17%) | 27 ± 6 (22%) | 33 ± 6 (17%) | 33 ± 6 (17%) | 30 ± 0 (0%) |
| D | 34 ± 1 (4%) | 39 ± 2 (6%) | 38 ± 2 (8%) | 41 ± 2 (5%) | 44 ± 2 (4%) | 42 ± 4 (10%) | 50 ± 3 (6%) | 53 ± 3 (6%) | 51 ± 4 (8%) |
| E | 32 ± 2 (9%) | 38 ± 2 (6%) | 40 ± 1 (3%) | 40 ± 3 (7%) | 44 ± 2 (5%) | 43 ± 2 (5%) | 50 ± 2 (4%) | 54 ± 3 (5%) | 55 ± 2 (3%) |
| F | 38 ± 4 (11%) | 40 ± 0 (0%) | 43 ± 5 (12%) | 47 ± 5 (11%) | 47 ± 5 (11%) | 53 ± 5 (10%) | 62 ± 4 (7%) | 57 ± 5 (9%) | 65 ± 5 (8%) |
| G | 24 ± 13 (56%) | 54 ± 15 (28%) | 56 ± 32 (57%) | 38 ± 26 (68%) | 68 ± 18 (26%) | 50 ± 28 (57%) | 80 ± 7 (9%) | 60 ± 23 (38%) | 70 ± 24 (35%) |
| EMF | Absorbed dose rate in air (nGy/h) | | | | | | | | |
| | 16 ± 0.5 | 24 ± 0.7 | 24 ± 0.7 | 27 ± 0.8 | 28 ± 0.8 | 30 ± 0.9 | 33 ± 1.0 | 36 ± 1.1 | 37 ± 1.1 |

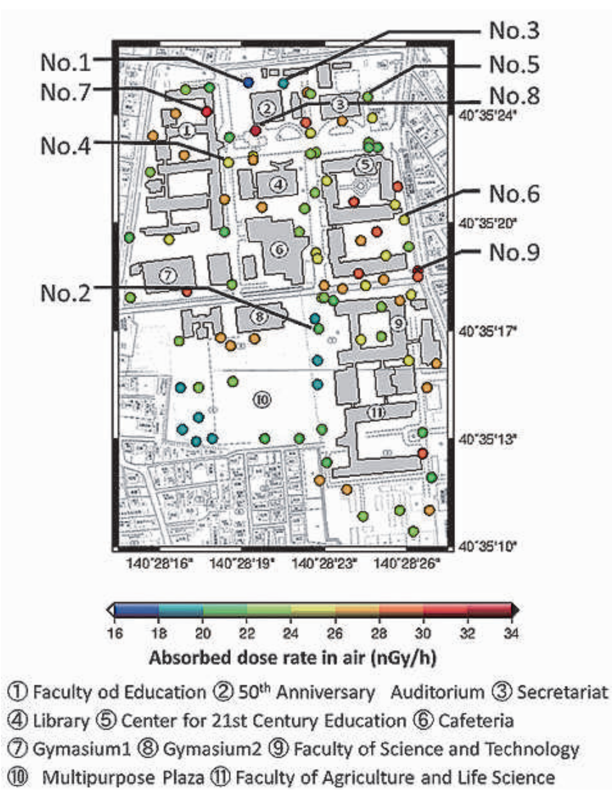


**Fig. 2.** Nine measuring locations and distribution map[2] of absorbed dose rate in air on the Bunkyo-cho Campus of Hirosaki University.

Professionals in Radiation Emergency Medicine. Our findings are reported here.

## 2. Materials and Methods

### *2.1. Measurements of ambient dose rate by survey meters*

A summary of the specifications of the seven survey meters (six models), designated A-G, used to measure the 1cm equivalent dose rate in this study is shown in Table 1. Items described are the detecting unit, detection range, measurable radiation and energy range. Survey meters D and E were also used to confirm instrumental error. All survey meters have been calibrated by $^{137}$Cs checking source. The seven survey meters were used for the measurement on May 12, 2014 on the Bunkyo-cho campus of Hirosaki University. Based on previous findings for the distribution map of absorbed dose rate in air that the rates were divided into low, intermediate and high level absorbed dose rates, nine measurement locations were chosen to have three in each dose rate category. The measurement was conducted at a 1 m above the ground surface. The weather was sunny throughout the entire measurement period and unaffected by rain.

Since the time constant was different for each survey meter, measurements were carried out 3-9 times at intervals of two minutes or more. The number of measurements were 3, 3, 3, 7-9, 7, 6, and 4-5 for survey meters A to G, respectively. The value was recorded as 0.05 μSv/h for survey meter A when the displayed measurement value was shown as < 0.05 μSv/h which was the lowest value that could be displayed on survey meter A. Student's t-test was used for the statistical comparisons of the 1cm equivalent dose rate of survey

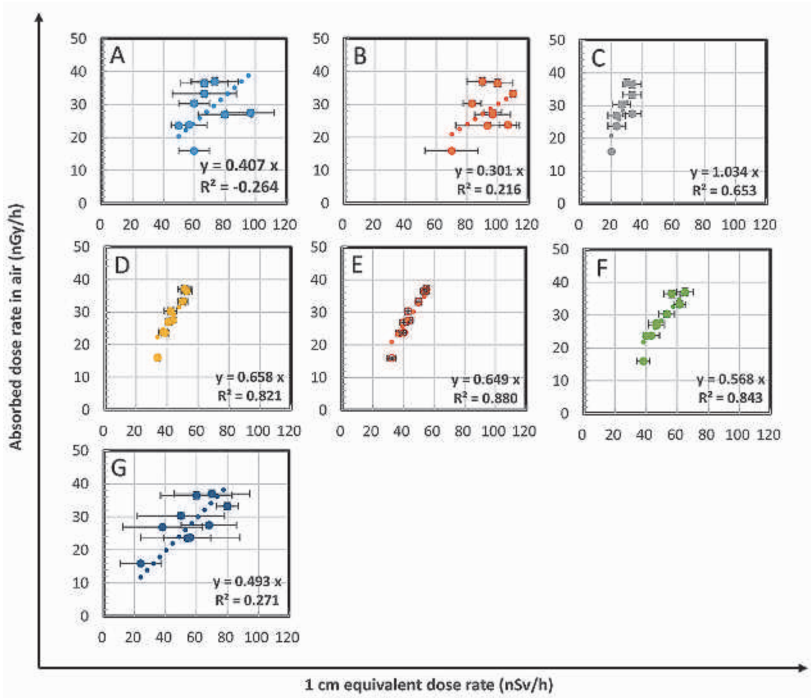


**Fig. 3.** Relationship between absorbed dose rate in air calibrated using the 3-inch × 3-inch NaI(Tl) scintillation spectrometer and 1 cm equivalent rate obtained by the seven survey meters.

meters D and E and p-values less than 0.05 were considered to indicate statistically significant differences.

*2.2. Estimation of conversion factor from 1cm equivalent dose rate to absorbed dose rate in air*

We estimated conversion factors (Gy/Sv) from 1cm equivalent dose rate (Sv/h) to absorbed dose rate in air (Gy/h) to investigate response sensitivity of each survey meter. Conversion factors obtained were assessed by the relative error and relative standard deviation (RSD). Absorbed dose rate in air obtained by a 3-inch × 3-inch NaI(Tl) scintillation spectrometer (EMF211, EMF-Japan, Japan) was used as the reference dose rate. This measurement was conducted at the same locations as for the survey meter measurements and at 1 m above the ground surface. Measurement time was set as 900 s. The obtained gamma-ray pulse height distributions were unfolded by a 22 × 22 response matrix for the evaluation of absorbed dose rate in air[7]. The statistical errors for air kerma rate obtained using this software depend on the integral air kerma (nGy) at each measurement point[8], and this were evaluated in this study as 3%. This calculation software assumed that the fallout formed an infinite plane source on the ground.

## 3. Results and Discussion

Based on absorbed dose rate in air obtained by the NaI(Tl) scintillation spectrometer, we numbered the measurement locations from No. 1 to No. 9 in ascending order (Fig. 2). These values were similar to data that Hosoda *et al* showed[2]. The 1cm equivalent dose rate (nSv/h) and RSD (%) in the nine locations obtained by each survey meter and absorbed dose rate in air (nGy/h) obtained by NaI(Tl) scintillation spectrometerare shown in Table 2. The 1 cm equivalent dose rate ranged from 20-110 nSv/h and we observed that the indicated values differed greatly among the survey meters even for the same measurement location. For the nine measurement locations, the arithmetic mean ± standard deviation of RSD(%) of the 1cm equivalent dose rate was 18 ± 8, 11 ± 8, 16 ± 10, 6 ± 2, 5 ± 2, 9 ± 4, and 42 ± 19% for survey meters A to G, respectively. The variation of measurements of survey meters A, B and C exceeded 10%. Moreover, survey meter G had variation of 42% and it was considered the least reliable. For survey meter A, the arithmetic mean ± standard deviation of the RSD was 21 ± 3% and variation of the measurements tended to be large even if data were eliminated that were less than 0.05 μSv/h (that data includes one in locations No.1, 6, and 7 and two in locations No.2 and 3). Furuta and Kusama[9] have reported that three survey meters among 11 models that they evaluated using a $^{137}Cs$ radiation source (about 0.4 μSv/h) had large RSDs of the measurements. Statistically significant differences ($P < 0.05$) were found between D and E only at location No.3, but this difference

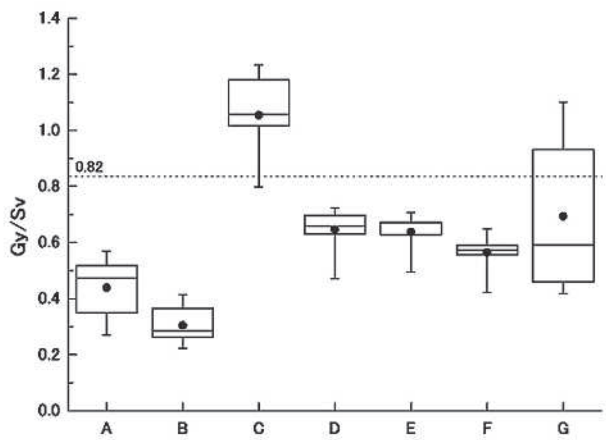


**Fig. 4.** Relationship between absorbed dose rate in air calibrated using the 3-inch × 3-inch NaI(Tl) scintillation spectrometer and 1 cm equivalent rate obtained by the seven survey meters.

was about 2 nGy/h and that was probably negligible in practical use considering the count error of the survey meters. At location No.3, the mean value ± standard deviation of measurements of survey meters D and E was 38 ± 3 and 40 ± 1 nSv/h, respectively, and we thought these were statistically significant differences because variation of the measurements was small.

Figure 3 shows the relationship between absorbed dose rate in air calibrated using the NaI(Tl) scintillation spectrometer and the 1 cm equivalent dose rate obtained by the seven survey meters. Furthermore, conversion factors from the 1cm equivalent dose rate (Sv/h) to absorbed dose rate in air (Gy/h) (straight line regression formula) and the coefficient of determination $R^2$ are also shown in Figure 3. Judging from $R^2$, between the absorbed dose rate in air and the 1 cm equivalent dose rate we found: a strong positive correlation for survey meters D, E and F; a positive correlation for survey meter C; a weak positive correlation for survey meters B and G; and no correlation for survey meter A. For survey meters C, D, E and F that had positive or strong positive correlations, the detecting units were fundamentally scintillation types.

Arithmetic mean ± standard deviation of the conversion factor was 0.44 ± 0.11, 0.30 ± 0.06, 1.05 ± 0.2, 0.65 ± 0.08, 0.64 ± 0.06, 0.56 ± 0.06, and 0.69 ± 0.3 for survey meters A-G, respectively, and the data are shown in Figure 4 as a box plot. Moriuchi *et al*[10] reported that the conversion factor from the absorbed dose rate in air (Gy/h) to the 1cm equivalent dose rate (Sv/h) was 1.224 (Sv/Gy) in natural background radiation. We calculated that the conversion factor from the 1cm equivalent dose rate to absorbed dose rate in air was 0.82 (Gy/Sv) using the conversion factor (Sv/Gy). The relative value of the conversion factors from the survey meters for the conversion factor (0.82) was 53, 37, 129, 79, 78, 69, and 85% for survey meters A to G, respectively. Compared to this relative value, the readings of survey meter C were underestimated. Readings of other survey meters were overestimated, and so these survey meters function suitably for radiation management on the conservative side. The relative value of survey meters A and B were overestimated and measurements with them could be viewed as less reliable. The detecting unit of survey meter A which showed a large arithmetic mean of the RSD (18%) was a Si semiconductor, and its 1cm equivalent dose rate represents the counted gamma-rays that entered the detecting unit per unit time multiplied by a calibration factor. We thought that accuracy decreased for the reading results because this coefficient was set much higher than the reliable calibration factor. Also, survey meter B had a rather high arithmetic mean of RSD (11%), too. Detecting unit of survey meter B was the GM tube and survey meter B calculated the 1cm equivalent dose rate by the same method as survey meter A, so the accuracy readings was thought to be decreased by a calibration factor. Survey meters D, E and F showed conversion factors that had a small variation and were close to 0.82; they were all scintillation-type survey meters.

## 4. Conclusion

We investigated the response of seven survey meters of six model types for measurement of the natural radiation dose rate of the background on the Bunkyo-cho Campus of Hirosaki University. Each survey meter had different response sensitivity for the 1cm equivalent dose rate and four models had poor repeatability. From the relationship between the absorbed dose rate in air obtained by the NaI(Tl) scintillation spectrometer and the 1cm equivalent dose rate of each survey meter, we found that the scintillation-type survey meters showed good linearity and small variation of the reading values. Overall, we found that some commercially available survey meters were inaccurate. Therefore, commercially available survey meters need to be calibrated by comparing the data obtained from a spectrometer in advance, even in the case of measurements for the natural radiation background level.

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