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TECHNICAL MATERIAL

Estimation of the characteristics of gamma-ray dose measurements with an experimental wireless dose monitoring system

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Real-time and wireless monitoring of gamma-ray emission by radioisotopes can aid radiation workers to respond quickly and decrease their exposure to gamma-ray emission. The purpose of this study is to compare an experimental wireless dose monitoring system with a wired system and to estimate their performances using gamma-ray emitting nuclides. Type 4 and 5 pocket geigers were used as radiation detectors in this study. These devices use silicon PIN photodiode sensors. The type 4 device was connected by a wire to an iPad Mini, while the type 5 device was connected to a personal computer *via* a Bluetooth wireless module, which is controlled by an Arduino UNO R3. We estimated their sensitivities and ambient dose equivalent rate characteristics using radioisotope point sources of Cobalt-60, Cesium-137, and Barium-133. The sensitivity of the type 5 device was 3.88 cpm/(μSv/h). Regarding the dose rate characteristics of type 5, linearity from 0.1 to 4 μSv/h was obtained. The sensitivity of type 5 was found to be slightly lower in the following two cases: a) while using Cobalt-60 (probably owing to high gamma-ray energy) and b) operating in a low dose rate range. It is concluded that both systems can be practically used for management of nuclear medical examination sites.

Keywords: monitoring system; Bluetooth wireless module; gamma rays; silicon PIN photo diode sensor

1. Introduction

Because nuclear medicine workers often operate in proximity to sources of ionizing radiation, it is necessary for their exposure to the radiation [1]. Awareness of a risk of exposure in real time can allow the workers to make a timely choice, i.e., to remain near the source or to distance themselves from the source of emission; thus, they can reduce their dose to the ionizing radiation as needed.

Passive personal dosimeters such as glass badges are typically used to measure workers' exposure, but these devices are not equipped with displays; thus, the dosages remain unknown for some time. In contrast, even though electronic personal dosimeters can allow for real-time monitoring of doses, the nuclear medicine workers may be unable to access this information in real time since they may not be able to use their hands during the examinations. However, use of a real-time dose monitoring system that continually sends the information wirelessly to a monitor can solve these problems. Although these systems already exist [2-7], they have not been widely adopted owing to their high cost.

The purpose of this study is to compare a wireless dose monitoring system with a wired system which are inexpensive and to estimate their characteristics using gamma-ray emitting nuclides.

2. Material and methods

2.1. Radiation detector

In this study, we used pocket geigers (Radiation Watch JAPAN, Japan) as radiation detectors [6-8] since they are inexpensive but accurate. They use silicon p-intrinsic-n (PIN) photodiode sensors, and six different versions exist owing to the differences in operating systems (OS) and power supplies that they can be connected to. In this study, we used a type 4 and 5 pocket geigers. Type 4 can be connected to iPhones, iPads, and iPod Touch devices through a wire. An image of the type 4 pocket geiger is shown in **Figure 1**.

Type 5 pocket geigers can be connected to peripheral interface controllers and microcomputers, and they can send data wirelessly to personal computers. Both types 4 and 5 use the same semiconductors as detectors, but there are differences between them, particularly with

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regard to the OS and electronic circuits that they use. In this study, we developed a transmitter that could send measurement data from type 5 devices to a personal computer, which would be subsequently used as a monitor. The transmitter was controlled by an Arduino. A photograph of the type 5 pocket geiger and the transmitter is shown in **Figure 2**; this system comprised an Arduino UNO R3 used as the microcomputer, a Bluetooth communication module (SBDBT; Running Electronics, Japan), and a Bluetooth USB adapter (BSBT4D100BK, Buffalo, Japan) for both the Bluetooth module and power supply.

Figure 1. Photograph of a wired type 4 pocket geiger.

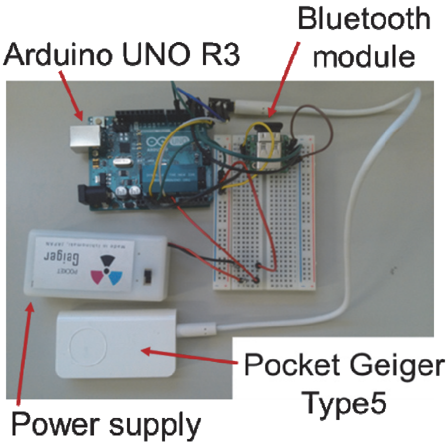

Figure 2. Photograph of a type 5 pocket geiger and a wireless transmitter system.

The sample code provided on the Radiation Watch homepage [9] was the control code that was written onto the Arduino for the gamma-ray measurements. Values were obtained approximately every 0.18 s; these values were transmitted to the receiver and displayed on the personal computer's monitor. Bluetooth 4.0 was used as the wireless standard.

2.2. Radiation source

^{60}Co (3.84 × 10^4 Bq), ^{137}Cs (2.8 × 10^6 Bq), and ^{133}Ba (7.20 × 10^4 Bq) were used as the radiation sources in this study.

2.3. Estimation of characteristics

2.3.1 Communication distance

We examined the communicable distance of the proposed system. Data was transmitted every second using a program of Arduino for communication testing without any obstructions between the transmitter and receiver. The transmitter was placed in a radiography examination room, while the receiver was placed outside; the distance between them was 5.5 m. Data was transmitted using the same program while keeping the door closed.

2.3.2 Geometry of estimation

The experimental setup is shown in **Figure 3**. To reduce the radiation scattered from the experiment table, a radiation source and a dosimeter were placed on a piece of cardboard. A sheet of graph paper was placed on the top of a cardboard box with a height of 16 cm. To reduce the amount of background radiation, we shielded the dosimeter with a lead block and a lead plate.

Figure 3. Experimental setup as viewed from (a) above and from (b) the side.

2.3.3 Sensitivity

Using the ^{137}Cs source, we estimated the ratio of the counting rate of each detector (measured in cpm) to the theoretical ambient dose equivalent rate [μSv/h] using the radioactivity to ambient dose equivalent rate conversion coefficient [μSv m^2 MBq^{-1} h^{-1}] [10].

2.3.4 Characteristics of the ambient dose equivalent rate

We measured the ambient dose equivalent rate ($\hat{H}$*(10)) for both the type 4 and 5 pocket geigers using the theoretical ambient dose equivalent rates for ^{60}Co, ^{137}Cs, and ^{133}Ba. The dose rate was varied by changing the distance between the source and the detector from 5 to 40 cm at 5 cm intervals.

3. Results and discussion

3.1. Communication distance

The potential communication distance of the wireless monitoring system was up to 41 m in the absence of shields and obstacles. According to the instruction manual of BSBT4D100BK, the maximum communication distance is 100 m [11]. It is possible that the observed distance did not reach the maximum value because of the characteristics of the power supply of the device and environmental factors. Communication was possible in both indoor and outdoor areas even if the doors of the radiation inspection room were closed.

3.2. Sensitivity

Table 1 shows the count rate per ambient dose equivalent rate; we found that the count rate for type 4 was 1.16 times that of type 5. Although the two detectors used the same PIN photo diode, they had different reverse bias voltages; 40 V was applied in type 4, but only 33 V was applied in type 5. In this system, the reverse bias voltage could not be adjusted. Fujibuchi et al., reported that the sensitivity of their detector increased with increasing reverse bias voltage [12]. Thus, the difference of reverse bias voltages is believed to account for the difference in the sensitivities of the two devices.

Table 1. Sensitivities of the type 4 and 5 pocket geigers.

	Sensitivity [cpm/(μSv/h)]
Type 4	4.48
Type 5	3.88

3.3. Characteristics of the ambient dose equivalent rate

Figure 4 shows the ambient dose equivalent ratio characteristics of the type 4 pocket geiger, and **Figure 5** shows the characteristics of the type 5 pocket geiger. The results indicate that the value displayed by these devices is proportional to the theoretical values and that both type 4 and 5 show linearity in the range of 0.1–4 μSv/h. However, the slope of the line varied for each nuclide; the tendencies of ^{137}Cs and ^{133}Ba are close to 1, but the ^{60}Co is ~0.6.

Using Ba-133 as the source, we observed that the theoretical dose rate and the ambient dose equivalent H*(10) measured by the type 4 pocket geiger at low dose rates were not consistent. It is important to note that while theoretical dose rate estimation does not account for scattered radiation, real measurements will include this background noise. Thus, it is likely that the discrepancy between the theoretical and observed doses at low rates is due to the presence of the large noise.

The energies of the ^{60}Co gamma rays were 1.17 and 1.33 MeV. These energies are higher than those of ^{137}Cs and ^{133}Ba. High energy gamma rays have small absorption coefficients, and are less likely to interact

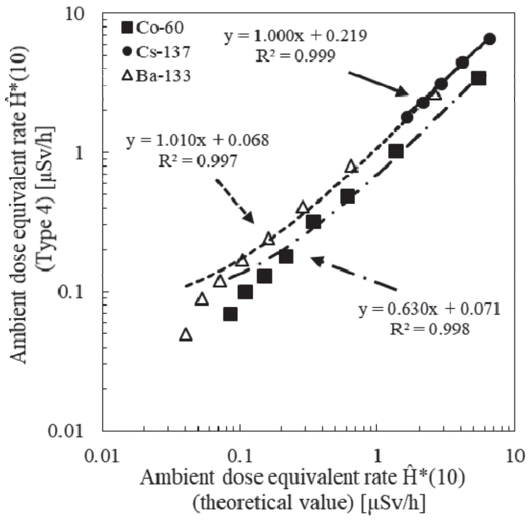

Figure 4. Ambient dose equivalent rate. Characteristics of the type 4 pocket geiger.

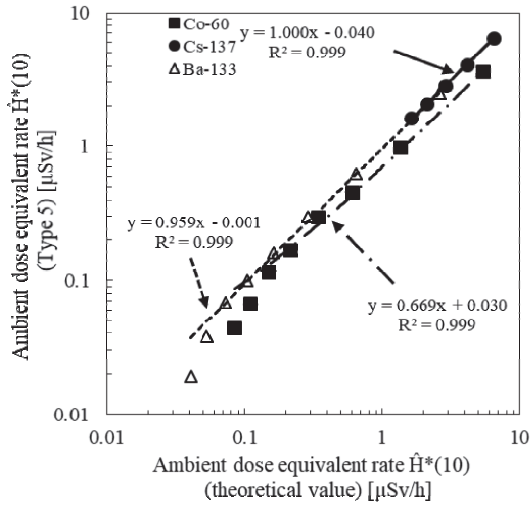

Figure 5. Ambient dose equivalent rate. Characteristics of the type 5 pocket geiger.

with detectors. As such, it is likely that the result obtained for ^{60}Co was significantly lower than the actual value.

The tendencies of ^{137}Cs and ^{133}Ba were almost the same; thus, their energy dependences are considered to be small in the range of gamma-ray energies from ^{137}Cs and ^{133}Ba. Because the energies of ^{137}Cs and ^{133}Ba (81–662 keV) overlap with those of common radionuclides used for nuclear medicine practices (71–511 keV), as shown in **Table 2**, we believe that the prototype wireless dose monitoring system can be used effectively in nuclear medicine.

The ratios of ambient dose equivalent rate measured by type 4 and 5 pocket geigers are shown in **Figure 6**. Even though both detectors use the same semiconductor detector, the measured type5 to type4 dose rate ratio was small at low dose rates. As the dose rate increased, the ratio approached 1. The low dose rates (low signal) for both the output signal and SNR of type 5 system could be lower for the following two reasons: a) a low

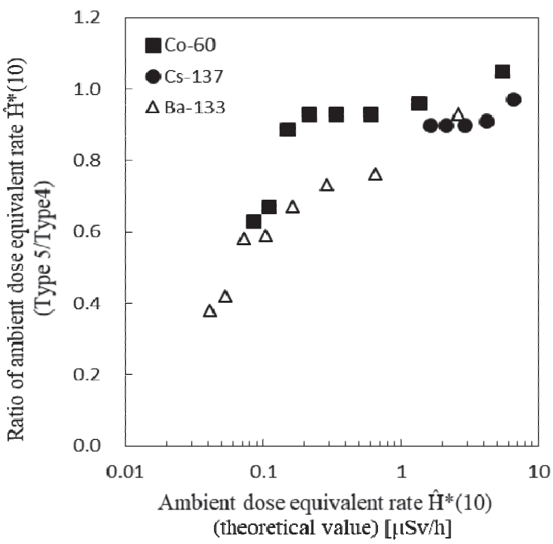

Figure 6. Ratio of ambient dose equivalent rate between the type 4 and 5 pocket geigers.

sensitivity (Table 1) and b) a high discrimination level. The former decreases the detected signal, and the latter decreases the signal relative to a high background noise (problematic since the total signal could be subtracted by the "discrimination level" voltage).

Table 2. Nuclides used in nuclear medicine practice.

	Nuclide	gamma-ray energy [keV]
SPECT	^{99m}Tc	141
	^{111}In	171, 245
	^{123}I	159
	^{131}I	364
	^{211}Tl	71.8
PET	^{11}C	511
	^{13}N	511
	^{15}O	511
	^{18}F	511
This study	^{60}Co	1170, 1330
	^{137}Cs	662
	^{133}Ba	81, 303, 356

4. Conclusion

In this study, we have estimated the basic characteristics of two types of pocket geigers, a wireless system and a wired system. Both systems showed linearity in the range of 0.1–4 μSv/h, within the energy domain commonly encountered in nuclear medicine examination. Moreover, it can be concluded that while the sensitivity of type 4 is less than that of type 5, both detectors are practical and effective for managing nuclear medical examination sites.

In this study we used a radiation source with low activity, but nuclear medicine examination uses high radioactivity. Thus, future work could involve characteristic estimation at high dose rates.

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