Annual Report of Iwate Medical University
Center for Liberal Arts and Sciences
No. 56（2021）, 111–116.

X-ray-dose-rate measurement using an ionization diode and a digital voltmeter

Eiichi SATO[a], Yasuyuki ODA[b], Sohei YOSHIDA[c], Satoshi YAMAGUCHI[c],
Kunihiro YOSHIOKA[c], Manabu WATANABE[d]

[a] Honorary Professor of Physics, Iwate Medical University, 2-14-6 Kawaramachi, Wakabayashi, Sendai, Miyagi 984-0816, Japan
[b] Department of Physics, Iwate Medical University, 1-1-1 Idaidori, Yahaba, Iwate 028-3694, Japan
[c] Department of Radiology, School of Medicine, Iwate Medical University, 2-1-1 Idaidori, Yahaba, Iwate 028-3694, Japan
[d] Department of Surgery, Toho University Ohashi Medical Center, 2-22-36 Ohashi, Meguro, Tokyo 153-8515, Japan

（Accepted December 10, 2021）

Abstract

To measure X-ray dose rate, we developed a dosimeter with an ionization diode. Ionization currents flowing through the diode with an aluminum cap are converted into voltages using a current-to-voltage amplifier and amplified by a voltage-to-voltage amplifier. The amplifier output was measured using a digital voltmeter with a 2-s-timeconstant integrator for smoothing. The standard dose rate was measured using a readily available semiconductor dosimeter and had a value of 306 μGy/s at 0.6 m from the X-ray source, a tube current of 1.0 mA, and a tube voltage of 100 kV. Next, the absolute dose rate of the ionization gap was determined by one and two-point calibrations. Using the ionization diode and two-point calibration, the dose rate was proportional to the tube current and to the 1.9th power of the tube voltage.

***Keywords*：** ionization chamber, aluminum diode, aluminum window, X-ray dose rate, digital voltmeter

1. Introduction

To construct several photon-counting energy-dispersive X-ray computed tomography (CT) scanners [1-3], we measure the dose rate to calculate the incident dose for the object using a dosimeter with a triode-type ionization chamber. Several ionization chambers were developed [4-6] corresponding to the radiographic objectives, we usually use an ionization triode with a tri-axial coaxial cable.

The silicon X-ray diode (Si-XD) is a photodiode selected for detecting X-ray photons, and we developed several dosimeters [7,8] and high-sensitivity CT scanners [9,10]. However, the ionization triodes are used to measure the standard dose, since the energy dependence of sensitivity is small.

The major objectives of our research are as follows: to develop an ionization diode with an aluminum cap, to reduce electric noises, and to measure the dose rate using a digital voltmeter. Therefore, we constructed an X-ray dosimeter with an ionization diode and measured the dose rates with changes in the tube voltage and current.

2. Experimental methods

Figure 1 shows the block diagram including the electric circuit of an X-ray dosimeter using an ionization diode. X rays are irradiated to the ionization diode, the ionization current flowing through the diode and a 5.0-m-length coaxial cable is converted into the voltage using a current-to-voltage (I-V) amplifier with a 1-ms-timeconstant integrator, and the I-V output is amplified by a voltage-to-voltage (V-V) amplifier with a 1 ms integrator. Subsequently, the V-V output is input to a digital voltmeter (Advantest, ADCE7351E) through a 2 s integrator for smoothing. The applied voltage for the ionization diode was +200 V and supplied using a DC-DC converter (Bellnix, BYH05-200S01). The DC output of 3.7 V was supplied to a dual operational amplifier (Texas Instruments, LMC662) using a battery. To reduce electric noises from the ionization diode and the coaxial cable, we used a condenser. Two amplifiers, two integrators, the converter, and the battery were set in a 1.0-mm-thickness aluminum (Al) box.

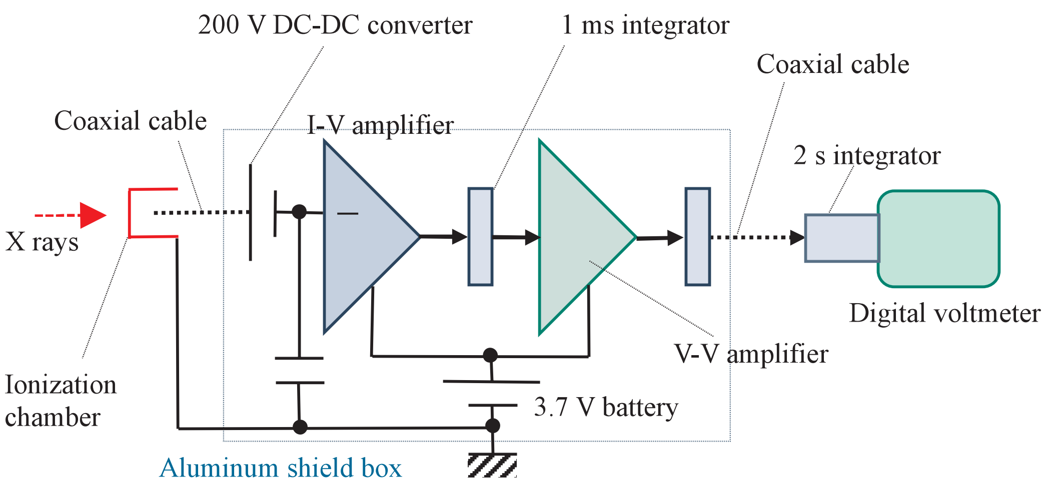


Fig. 1. Block diagram including the electric circuit of the dosimeter with an ionization diode.

The absolute dose rate was determined using a dosimeter (RaySafe, X2) with a detector (RaySafe, R/F) placed 0.6 m from the X-ray source. The ionization diode was also set to 0.6 m from the source, and the dose rate was determined by one and two-point calibrations.

3. Results

The standard-absolute dose rates are shown in Fig. 2. The X-ray dose rate from a glass-window tube increased in proportion to the 1.9th power of the tube voltage using the rates of 50 and 100 kV [Fig. 2(a)]. The dose rate was proportional to the tube current, and the rate was 306 μGy/s at a voltage of 100 kV and a current of 1.0 mA [Fig. 2(b)].

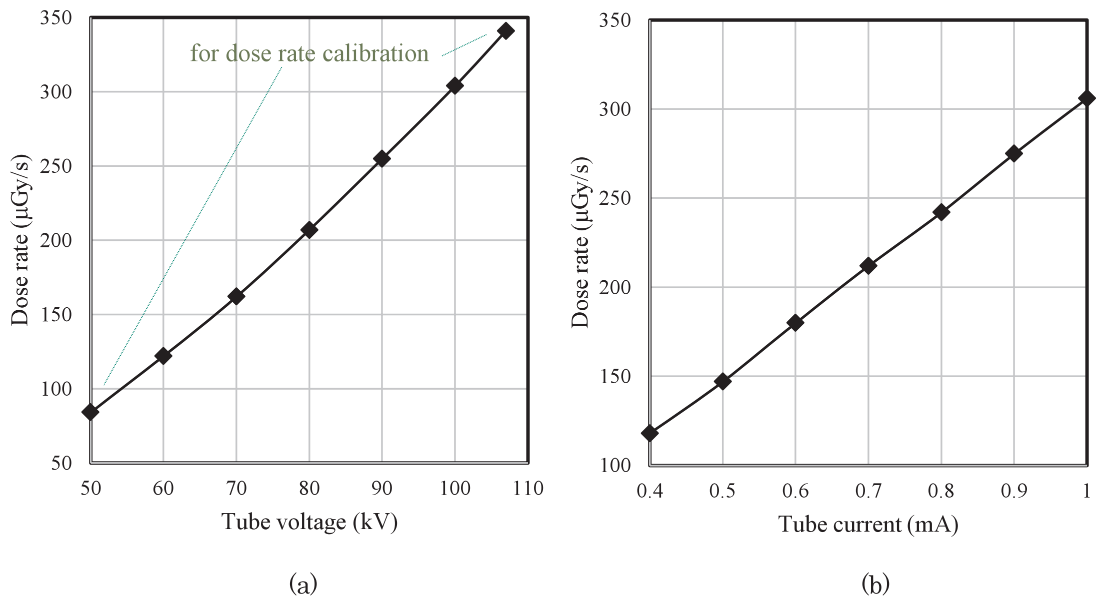


Fig. 2. X-ray dose rates measured using a semiconductor dosimeter at 0.6 m from the X-ray source. (a) Tube voltage dependence at a tube current of 1.0 mA and (b) tube current dependence at a tube voltage of 100 kV.

Fig. 3 indicates the output from the V-V amplifier. When the tube voltage was increased, the output voltage increased in proportion to the 2.4th power of the tube voltage [Fig. 3(a)]. Subsequently, the output increased in proportion to the tube current [Fig. 3(b)] and was 73.0 mV at a tube voltage of 100 kV and a tube current of 1.0 mA.

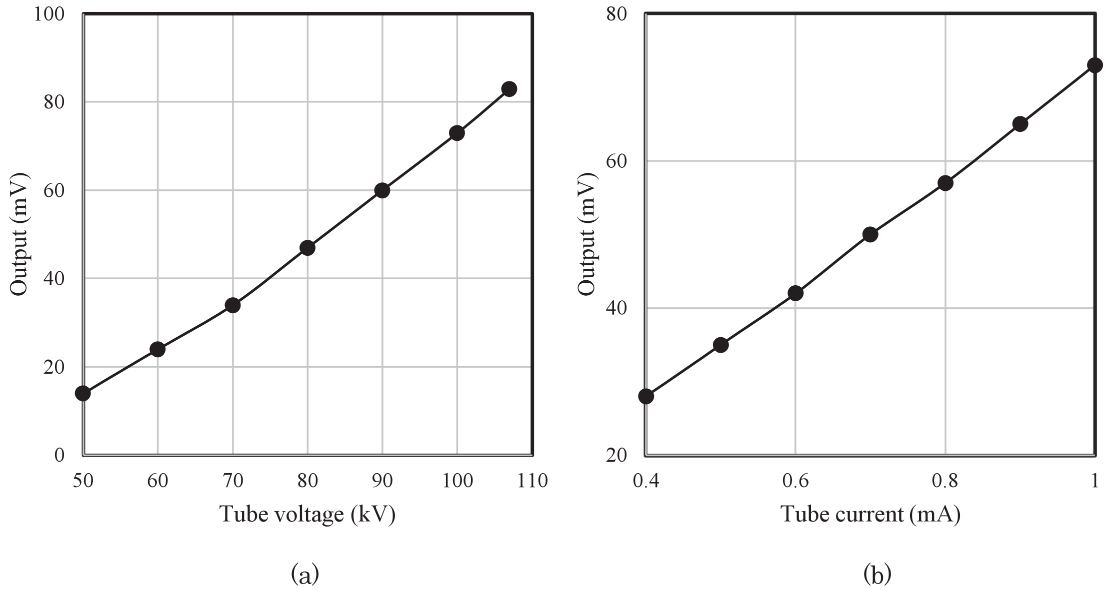
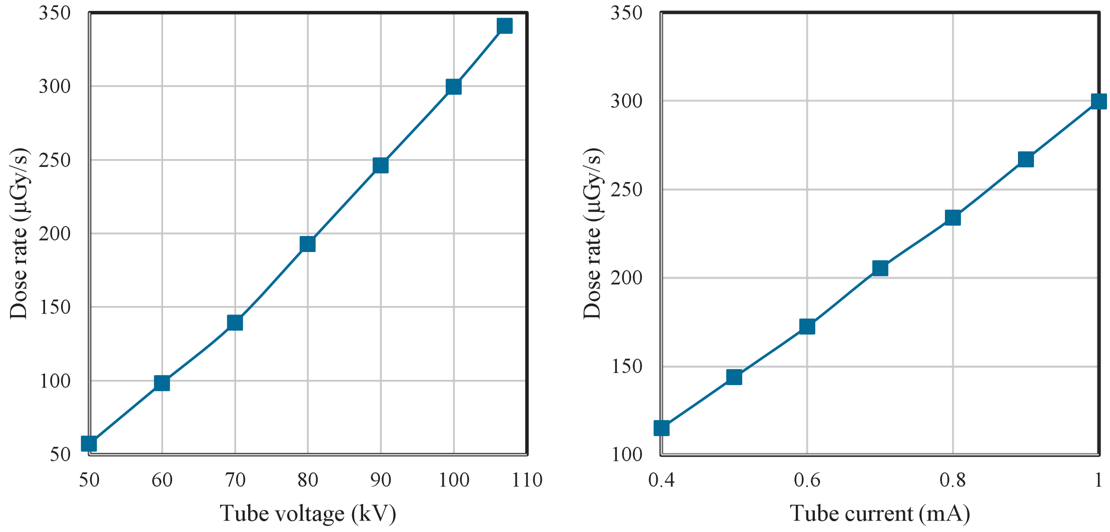


Fig. 3. Variations of amplifier output measured using an ionization diode at 0.6 from the X-ray source. (a) Tube voltage dependence at a tube current of 1.0 mA and (b) tube current dependence at a tube voltage of 100 kV.

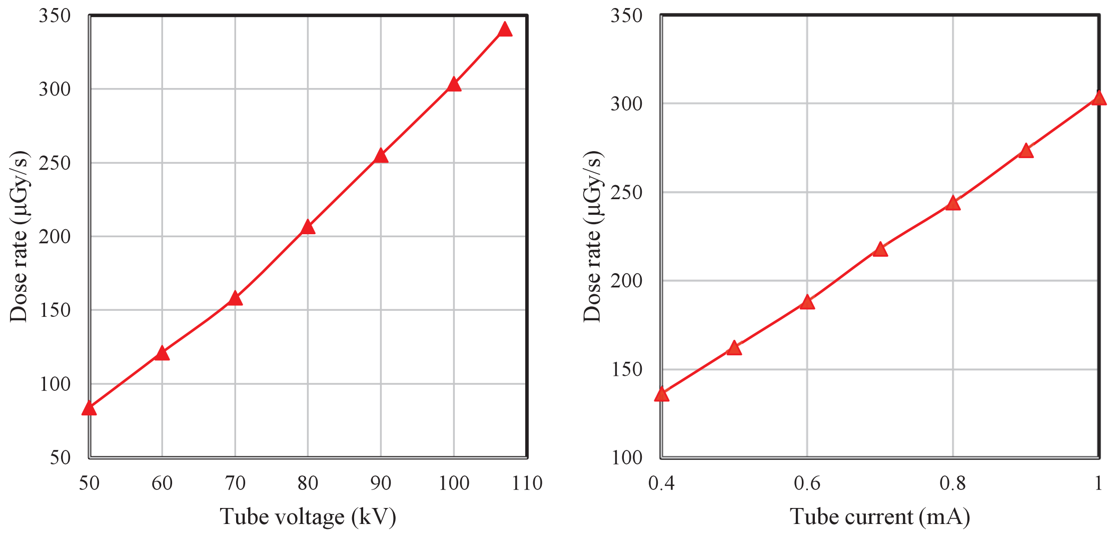
The X-ray dose rate measured using the ionization diode is shown in Fig. 4, and one-point calibration was conducted to roughly determine the absolute dose using the dose rate of 341 μGy/s in Fig 2. The dose rate increased in proportion to the 2.4th power of the tube voltage [Fig. 4(a)] and was proportional to the tube current [Fig. 4(b)].



(a) (b)

Fig. 4. X-ray dose rates determined using one-point calibration. (a) Variations with the tube voltage and (b) variations with the tube current.

Figure 5 shows the X-ray dose rate determined by two-point calibration [cf. Fig. 2]. The dose rate increased with increasing tube voltage, and the minimum and maximum dose rates corresponded to the standard dose rates [Fig. 5(a)]. Although the dose rate was proportional to the tube current, the low dose rate at a tube current of 0.4 mA did not correspond to the rate in Fig. 2.



(a) (b)

Fig. 5. X-ray dose rates determined using two-point calibration. (a) The tube voltage dependence and (b) the tube current dependence.

4. Discussion

We used an ionization diode instead of the triode and measured the dose rate. Using two-point calibration, we measured a minimum dose rate of 84.1 μGy/s at 0.6 m from the X-ray source, a tube current of 1.0 mA, and a tube voltage of 50 kV. Using an ionization diode with the aluminum cap, the ionization volume and the incident-window thickness were approximately 1 mL and 0.5 mm, respectively, extremely low-energy photons were absorbed by the window, and the volume should be increased to increase the sensitivity.

When a high voltage of 200 V was applied, the dark currents flowed between the high-voltage point and the ground. Therefore, the high voltage to ground distance should be maximized, and a high-resistivity electric substrate should be selected. In this experiment, although we used a coaxial chamber with a 0.5-mm-thidkness window, a thimble-diode chamber made of conductive plastic can be made and used.

The ionization triode with a tri-axial cable is complex, and it is difficult to make the chamber. Compared with triode, the diode chamber can easily be made, and it is easy to use the dosimeter in the physical experiment in our university. The background output from the amplifier may vary according to the room temperature, humidity, and atmospheric pressure, it is important to maintain the stable background output to measure the dose with high accuracies.

5. Conclusions

We constructed an X-ray dosimeter with an ionization diode and measured the dose rate with changes in the tube voltage and current. The dose rate increased in proportion to the 1.9th power of the tube voltage at a tube current of 1.0 mA using two-point calibration. The dose rate was proportional to the tube current at a tube voltage of 100 kV.

Acknowledgments

This work was supported by Grants from JSPS (17K10371, 17K09068, 17K01424, and 17H00607). This was also supported by a Grant-in-Aid for Strategic Medical Science Research (S1491001 and 2014–2018) from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

References

[1] Sato, E., Kosuge, Y., Yamanome, H., Mikata, A., Miura, T., Oda, Y., Ishii, T., Hagiwara, O., Matsukiyo, H., Watanabe, M., Kusachi, S.: Investigation of dual-energy X-ray photon counting using a cadmium telluride detector with dual-energy selection electronics, Rad. Phys. Chem. 130, 385–390 (2017).

[2] Matsukiyo, H., Sato, E., Oda, Y., Ishii, T., Yamaguchi, S., Sato, Y., Hagiwara, O., Enomoto, T., Watanabe, M., Kusachi, S.: Investigation of quad-energy photon counting for X-ray computed tomography using a cadmium telluride detector, Appl. Radiat. Isot. 130, 54–59 (2017).

[3] Moriyama, H., Sato, E., Oda, Y., Yoshida, S., Hagiwara, O., Enomoto, T., Watanabe, M.: Measurement of humanbody-window spectra using a white power light-emitting diode and its application to high-spatial-resolution computed tomography, Proc. SPIE 11073, 1107321-1-6 (2019).

[4] AlMasri, H., Funyu, A., Kakinohana, Y., Murayama, S.: Investigation of thermal and temporal responses of ionization chambers in radiation dosimetry, Rad. Phys. Tech. 5, 172–177 (2012).

[5] Kato, T., Arai, K., Sagara, T., Kato, R., Yamazaki, Y., Oyama, S.: Patient-specific quality assurance for proton depth dose distribution using a multi-layer ionization chamber in a single-ring wobbling method,

Rad. Phys. Tech. 12, 305–311 (2019).

[6] Sato, E., Ichikawa, M., Chiba, T., Oda, Y., Yoshida, S., Yamaguchi, S., Yoshioka, K.: X-ray-dose-rate measurement using an ionization gap and a digital voltmeter, Ann. Rep. Iwate Med. Univ. Center Lib. Arts Sci. 55, 6–10 (2020).

[7] Yamaguchi, S., Sato, E., Ieko, Y., Ariga, H., Yoshioka, K.: A capacitor dosimeter with disposable silicon-diode substrates for 4-MV X-ray beam detection in radiation therapy, Phys. Open 2, 100026 (2020).

[8] Yamaguchi, S., Sato, E., Ieko, Y., Ariga, H., Yoshioka, K.: Development of a dose-rate dosimeter for x-ray CT scanner using silicon x-ray diode, Rev. Sci. Instrum. 92, 053103 (2021).

[9] Arakawa, Y., Sato, E., Kogita, H., Hamaya, T., Nihei, S., Numahata, W., Kami, S., Oda, Y., Hagiwara, O., Matsukiyo, H., Osawa, A., Enomoto, T., Watanabe, M., Kusachi, S., Sato, S., Ogawa, A.: Investigation of X-ray photon-counting using ceramic-substrate silicon diode and its application to gadolinium imaging, Jpn. J. Appl. Phys. 53: 072201-1–5 (2014).

[10] Sato, Y., Sato, E., Ehara, S., Oda, Y., Hagiwara, O., Matsukiyo, H., Enomoto, T., Watanabe, M., Kusachi, S.: Development of a dual-energy silicon X-ray diode and its application to gadolinium imaging, Radiat. Meas. 77, 12–17 (2015).