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Calculation of Equivalent Dose Rate of Bremsstrahlung X-rays Generated by Rigaku-200EGM X-Ray Generator

Dang Quyet Pham*, Thi Tu Anh Trinh**
* Nuclear Research Institute, 01 Nguyen Tu Luc, Dalat, Vietnam
Email: quyetpd@gmail.com
**Office of National Assembly Delegations and People Councils, 02 Tran Hung Dao, Dalat, Vietnam
Email: anhttt@dlu.edu.vn

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Abstract:

The Rigaku-200EGM X-ray generator works in the high-voltage range of 70-200 kV. The generator includes a tungsten (W) anode, an irradiation angle of 40^0, and filters of Be and Al with thicknesses of 1 mm and 2 mm, respectively. In this paper, we present the calculation of the equivalent dose rate at 60 cm from the focus of the generator, produced by the continuous spectra. According to the calculation results, Bremsstrahlung X-rays mainly contribute to the equivalent dose of the Rigaku-200EGM generator. According to the calculation results, Bremsstrahlung X-rays mainly contribute to the equivalent dose of the Rigaku-200EGM generator. At the same time, the results show that the equivalent dose rate generated by the generator does not increase proportionally to the square of the high voltage but rather is a parabolic function of the high voltage, which agrees with the experimental data of Rigaku.

Keywords **— Dose rate, Rigaku-200EGM, X-ray generator, square of high voltage**

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1. INTRODUCTION

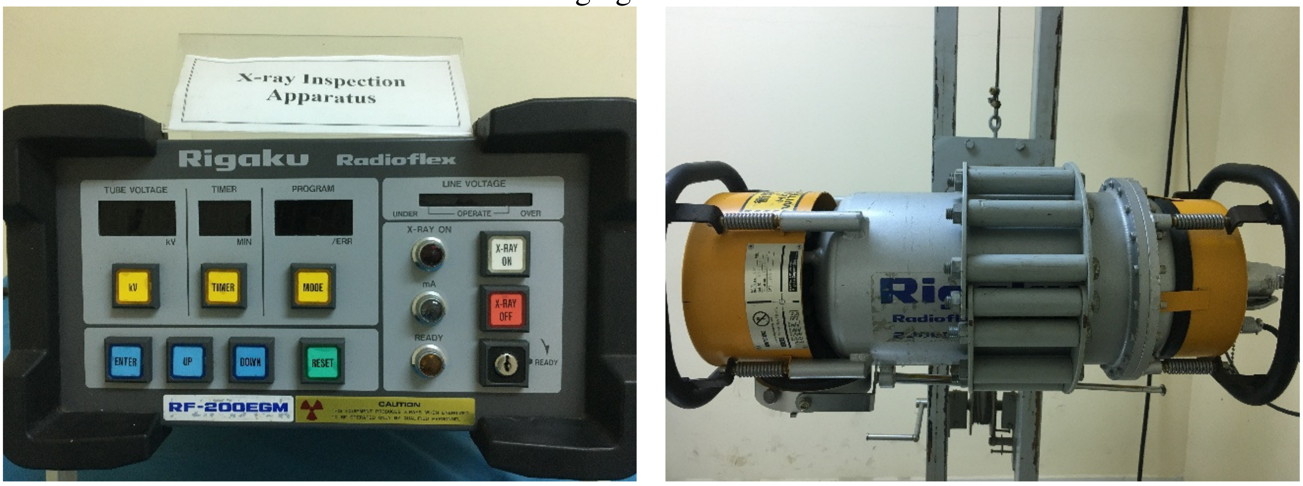
Equivalent dose rate is the product of the radiation weighting factor and the amount of radiation energy absorbed per unit time, measured in (μGy/h) or (Sv/h) [1]. Assessing the equivalent dose rate from a radiation source, such as an isotope source or X-ray generator, is essential for radiation protection, medical imaging, and industrial applications that require safe exposure settings [2]. For X-rays, the radiation weighting factor is one [1]. The equivalent dose rate (dose rate) from the X-ray generator depends on several parameters, including high voltage (in kV), current (in mA), exposure time (in s), and the distance from the focus of the anode (target) (in cm) [3]. The X-ray generator dose rate has two components: Bremsstrahlung and characteristic X-rays. For a tungsten target operated at 70-200 kV, Bremsstrahlung X-rays contribute over 80% of the dose rate [4-5]. The computation begins with determining the energy spectrum of the X-rays produced [3]; the X-ray spectrum represents the distribution of the number of photons created as a function of their energy E. The shape of the emitted X-ray spectrum will depend upon the anode material, the high voltage applied, and the effects of any filters placed in the X-ray beam [6]. Once the spectrum is established, the average energy of the X-ray spectrum can be determined using the integral ratio method described in reference [7].

The Rigaku-200EGM X-ray generator was installed at the Training Center of the Dalat Nuclear Research Institute in Vietnam for training purposes. The focus was on optimizing high voltage, current, irradiation time, and distance from the focus to the object to examine for defects in welded joints. The goal of this study is to offer calculations of the equivalent dose rate of continuous spectra generated by the Rigaku-200EGM X-ray generator in the high-voltage range of 70-200 kV.

2. MATERIALS AND METHODS

2.1. Materials

In this study, we used the Rigaku-200GM X-ray generator donated by Rigaku Corporation to generate the X-ray beam. The generator employs a tungsten (W) target with a target angle of 45° to optimize the geometry for effective X-ray emission while minimizing self-absorption. An X-ray exposure field of 40° is used to concentrate the X-ray beam for a thorough inspection of materials [8]. In addition, this device has Be and Al filters with thicknesses of 1 mm and 2 mm, respectively. The Be filter is widely used, mainly as the material for the X-ray tube window to maximize transmission of the X-ray beam, while the Al filters are placed at or near the X-ray port, sometimes in thin sheets. They primarily absorb soft X-rays up to around 10–15 keV—those that add dose but little imaging information. Al filters harden the beam by removing low-energy photons, increasing the average photon energy. These filtration layers ensure that emitted X-rays have the necessary quality and intensity for precise measurements. These filtration layers collectively ensure that emitted X-rays possess the desired quality and intensity for precise measurements. Figure 1 illustrates the two primary components of the Rigaku X-ray generator used in this study.



a) b)

Fig. 1. Rigaku-200EGM X-ray generator: a) controller, b) X-ray tube

2.2. Theoretical calculation for the X-ray dose rate

The X-ray dose rate due to a X-ray generator produces at a interested point [9] is calculated according to the following formula:

$$\dot{H} = \frac{4.77\times10^{6} \times i \times T_e \times \eta \times \left(\frac{\mu_{en}}{\rho}\right)_{air}}{d^{2}} \qquad (1)$$

where $\dot{H}$ is the X-ray dose rate (in mSv/min), i is the current (in mA), T_e is the electron energy (in keV), is η the Bremsstrahlung radiation yield, $(\mu_{en}/\rho)_{air}$ is the mass energy absorption coefficient of the air corresponding to X-rays with energy $\overline{E}_X$ (in cm^2/g), and d is the distance from the focus of the generator to the interested point (in cm).

3. RESULTS AND DISCUSSION

3.1. Calculation of average energy of Bremsstrahlung radiation spectrum

To obtain the average value of the bremsstrahlung X-ray spectra, we first determine the mass attenuation coefficients of the X-ray energy levels for the Be and Al filters. Next, we calculate the attenuation coefficients of Be and Al for thicknesses of 1 mm and 2 mm, respectively, using the exponential decay law. Table 1 displays the corresponding X-ray energy levels in the machine's high-voltage operating range (70-200 kV), as well as the X-ray attenuation coefficients for Be and Al filters with thicknesses of 1 mm and 2 mm, respectively. Figure 2 depicts the Rigaku-200EGM's X-ray spectra at 60 cm (from the generator focus) for high voltages of 70, 80, 100, 150, and 200 kV, using Be (1 mm) and Al (2 mm) filters.

Table 1. Attenuation coefficients of Be and Al filters for X-ray energy levels.

No.	U_0 [kV]	$(\mu/\rho)_{Be}$ [cm²/g], [10]	W_{Be}	$(\mu/\rho)_{Al}$ [cm²/g], [10]	W_{Al}
1	1	6.04×10^{2}	2.91×10^{-49}	1.19×10^{3}	1.24×10^{-278}
2	5	4.37×10^{0}	4.46×10^{-1}	1.93×10^{2}	4.41×10^{-46}
3	10	6.47×10^{-1}	8.87×10^{-1}	2.62×10^{1}	7.06×10^{-7}
4	20	2.25×10^{-1}	9.59×10^{-1}	3.44×10^{0}	1.56×10^{-1}
5	30	1.79×10^{-1}	9.67×10^{-1}	1.13×10^{0}	5.44×10^{-1}
6	40	1.64×10^{-1}	9.70×10^{-1}	5.69×10^{-1}	7.36×10^{-1}
7	50	1.55×10^{-1}	9.72×10^{-1}	3.68×10^{-1}	8.20×10^{-1}
8	60	1.49×10^{-1}	9.73×10^{-1}	2.78×10^{-1}	8.61×10^{-1}
9	70	1.45×10^{-1}	9.74×10^{-1}	2.06×10^{-1}	8.95×10^{-1}
10	80	1.40×10^{-1}	9.74×10^{-1}	2.02×10^{-1}	8.97×10^{-1}
11	90	1.35×10^{-1}	9.75×10^{-1}	1.76×10^{-1}	9.09×10^{-1}
12	100	1.33×10^{-1}	9.76×10^{-1}	1.70×10^{-1}	9.12×10^{-1}
13	150	1.19×10^{-1}	9.78×10^{-1}	1.38×10^{-1}	9.28×10^{-1}
14	200	1.09×10^{-1}	9.80×10^{-1}	1.22×10^{-1}	9.36×10^{-1}

Note: W_{Be} and W_{Al} are the attenuation coefficients of Be and Al, respectively

Karamer describes the expression for determining the spectrum intensity of Bremsstrahlung X-rays [11], combining this expression with the attenuation coefficients of Be and Al, as given in Table 1. Figure 2 displays the computed Bremsstrahlung X-ray spectra for the Rigaku-200EGM X-ray generator.

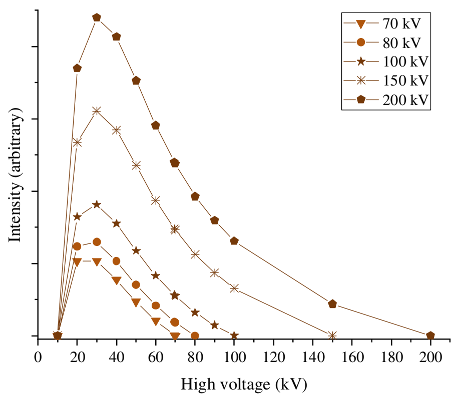


Fig. 2. X-ray spectra at 60 cm produced by the Rigaku-200EGM with filters of Be (1 mm) and Al (2 mm)

The Bremsstrahlung radiation spectrum is continuous spectrum, so we used the integral ratio method described in reference [7] to calculate its average energy. Table 2 displays the results of calculating the average energy of the X-ray spectra.

Table 2. Calculated average energy of Bremsstrahlung radiation spectrum at 60 cm from focus of Rigaku-200EGM generator

Te [keV]	70	80	100	150	200
$\bar{E}_X$ [keV]	33.62	36.71	42.15	54.59	63.65

Calculation of X-ray dose rate of Rigaku-200EGM generator. By using Eq. (1), the equivalent dose rates of the Rigaku-200EGM X-ray generator's continuous spectra at 60 cm from the generator's focus are calculated and listed in Table 3.

Table 3. Calculated X-ray dose rate at 60 cm from focus of Rigaku-200EGM generator

No.	T_e [keV]	η, [12]	[cm²/g], [10]	$\dot{H}$ [mSv/min]	$\dot{H}$ _cor. [mSv/min]
1	70	7.45×10^{-3}	11.26×10^{-2}	389	115*
2	80	8.43×10^{-3}	8.81×10^{-2}	394	116
3	100	1.03×10^{-2}	6.02×10^{-2}	412	122
4	150	1.47×10^{-2}	3.38×10^{-2}	493	146
5	200	1.87×10^{-2}	2.77×10^{-2}	684	202

Note: $\dot{H}$ _cor. and * are the corrected equivalent dose rate and the value provided by Rigaku

In the last column of Table 3, we corrected the computed results by a factor of 0.3 to compare them with the results provided by Rigaku (115 and 250 mSv/min for 70 and 200 kV, respectively). This factor is contributed by the correction factors, including single-phase voltage [13], node angle, take-off angle, and X-ray absorption coefficient by the W target [14].

Figure 3, we assumed that if the dose rate increases proportionally with the square of the high-voltage (black line, square item), it is seen that, although with the same value (115 mSv/min) at the starting point of 70 kV, the values of the dose rate assumed to increase proportionally with the square of the high-voltage increase more rapidly even at the end point of 200 kV, this value increases almost four times compared to the data provided by Rigaku as well as the data calculated by us. As a result, it can be confirmed that the dose rate generated by the Rigaku-200EGM X-ray generator does not increase proportionally with the square of the high voltage.

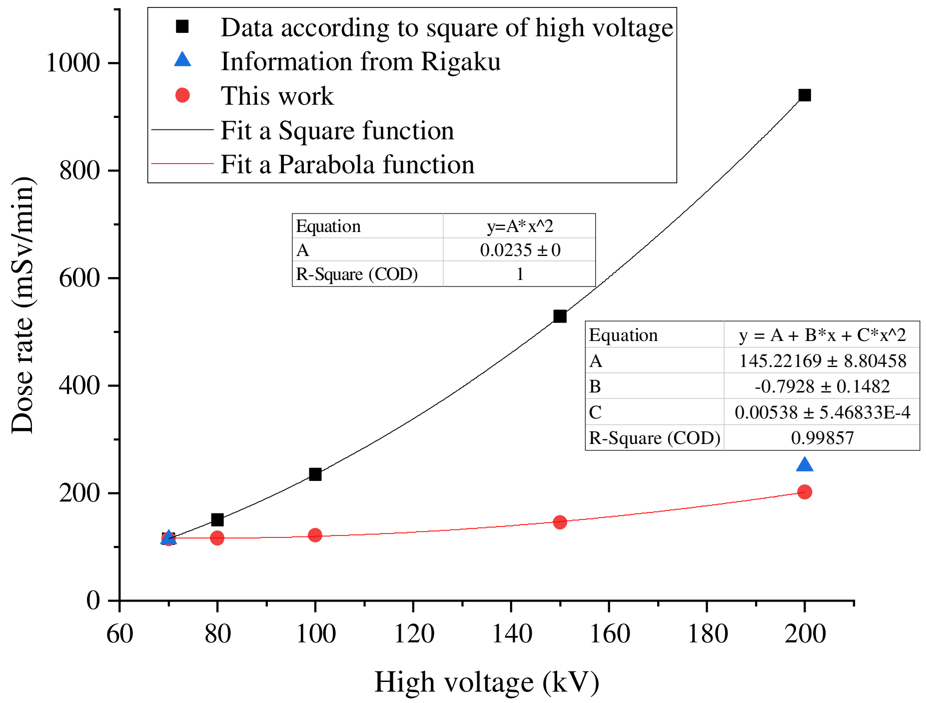


Fig. 3. Dose rate generated by the Rigaku-200EGM X-ray generator as a parabolic function of high voltage

As shown in Figure 3, the equivalent dose at a position 60 cm from the focal point of the Rigaku-200EGM X-ray generator is a parabola function of the high voltage. This result is in good agreement with the result provided by Rigaku; the dose rate value at 200 kV calculated by us is slightly smaller than the value provided by Rigaku, which can be explained by the contribution of characteristic radiations ($K_\alpha \approx 59$ keV) of the W target, which has not been calculated in our study.

4. CONCLUSION

The dependence of the X-ray equivalent dose rate on the high voltage of the Rigaku-200EGM X-ray generator was studied, and the calculated results were in good agreement with the values provided by Rigaku. The dose rate does not increase in proportion to the square of the high voltage. This study will be useful in training students and personnel in the field of nuclear radiation. However, further studies are also needed to clarify the contributions of components such as anode angle, take-off angle, X-ray absorption coefficient, and characteristic X-rays in the target of the generator.

REFERENCES

1. Annals of the ICRP Publication 103, Elsevier Ltd. 2007.
2. U.S. Government Printing Office, 1968, Committee on commerce United States senate, Ninetieth congress, Second session.
3. A. A. Oglat, *Comparison of X-ray films in term of kVp, mA, exposure time and distance using radiographic chest phantom as a radiationquality,* Journal of Radiation

Research and Applied Sciences. 15(4) (2022) 100479-100483.

4. N. A. Dyson, X-rays in atomic and nucler physics, Cambridge University Press. 1990.
5. V. White, Selman's the fundamentals of imaging physics of radiobiology, Charles C Thomas. 2020.
6. H. Aichinger, J. Dierker, S. Joite-Barfub, M. Sabel, Radiation exposure and image quality in X-ray diagnostic radiology, Springer. 2012.
7. K. S. Krane, Introductory nuclear physics, John Wiley & Sons. 1988.
8. Rigaku, Cat.No.6061A1/ 6062A1/ 6063A1 Portable industrial X-ray inspection apparatus – Radioflex 200EGM/ 250EGM/ 300EGM instruction manual - Manual No. ME16013C04 (Fouth edition). Japan: Rigaku Corporation. 2004.
9. R. Antoni, L. Bourgois, Applied physics of external radiation exposure: Dosimetry and radiation protection, Springer. 2017.
10. J. H. Hubbell, S. M. Seltzer, Tables of X-ray mass attenuation coefficients and mass energy-absorption coefficients 1 keV to 20 MeV for elements Z = 1 to 92 and 48 additional substances of dosimetric interest, NIST. 1995.
11. L. Reimer, Scanning electron microscopy: Physics of image formation and microanalysis, Springer. 1998.
12. J. E. Martin, Physics for Radiation Protection: A handbook, Wiley-VCH Verlag GmbH & Co. KGaA. 2006.
13. S. C. Bushong, Radiologic science for technologists: physics, biology, and protection, Elsevier. 2017.
14. H. Ebel, *X-ray tube spectra,* X-ray spectro. 28 (1999) 255-266.

Competing Interest: The authors have declared that no competing interest exists.

Ethical approval: This study does not contain any studies with human or animal subjects performed by any of the authors.

Author Contributions: The first draft of the manuscript was written by Pham Dang Quyet and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

