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IMPROVEMENT IN THE ENERGY CHARACTERISTICS OF A VACUUM IONIZATION CHAMBER

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1 Introduction

We are developing an irradiation accelerator as an irradiation processing system that can carry out high dose rate irradiation. In irradiation processing, large d oses on the order of 1k - 10kGy need to be irradiated to sterilize microorganisms and kill insects. Our plan is to introduce a system that combines an irradiation quantity control device and a real-time dose monitor to ensure irradiation at correct dose levels.

There are currently no radiation measuring instruments capable of measuring high does rate radiation in real time. For this reason, the only method available is to estimate the irradiated radiation dosage from the acceleration pipe current of the accelerator. To address this problem, we are developing a radiation detector capable of measuring high dose rate radiation (10kGy/s), to precisely verify radiation levels.

We have already developed a detector capable of measuring high dose rate irradiation [1]. The detector was achieved by decompressing the inside of an ionization chamber and producing a vacuum ionization chamber to control the re-combination of ions, which was made possible by reducing the size of the ionization medium under study. It has shown good prospects for high dose rate measurement. However, the above size reduction can conceivably result in relatively larger contributions of emitted secondary electrons from the electrodes and changes to the energy characteristics.

In this paper, we explain how the rate of discharge of secondary electrons (emitted from the electrodes of the above-mentioned vacuum ionization chamber) is made to agree with the ionization characteristics in the air, in order to precisely measure the absorbed dose.

2 Theory

Although it is difficult to measure the absorbed dose in a substance directly, the absorbed dose can be measured indirectly by measuring the exposure dose. This is because, fortunately, the exposure dose has a proportional relationship to the energy transfer in the air. More specifically, the exposure dose is defined by the amount of ionized electric charges created in the air, and the amount of ionization has a distribution (Fig. 1) that depends on the energy of the radiation. Therefore, a highly precise measurement can be achieved by matching the sensitivity distribution (energy characteristics) of the radiation detector at each radiated energy, with the ionization quantity distribution in the air. The developed vacuum ionization chamber detects radiation by collecting the secondary electrons emitted from the electrons and electrons created by the ionization of air in the ionization chamber. Therefore, we considered that the energy characteristics of a vacuum ionization chamber can be improve by matching the distribution of the amount of emitted secondary electrons at each radiated energy, with the ionization quantity distribution in the air.

Below, we describe the relationship between the secondary electrons and electrodes, and the theory underlying the electrode design. Although both the ionization of the air and the secondary electrons result from the radiation (X-rays) hitting the substance, the electrodes being solids means that the range is short and a part of the secondary electrons produced within the electrodes are unable to reach the electrode surfaces. This leads to changes in the secondary electron distribution. Because this masking effect particularly affects low-energy secondary electrons, we control the discharge of the secondary electrons for X-rays having energy levels of several hundred keV or less (Fig. 2). In other words, we obtain a secondary electron discharge distribution that emphasizes the high-energy side.

The amount of discharge of the secondary electrons is fixed, i.e., the electronic state is achieved in electronic equilibrium, when the thickness of the substance is sufficiently thick in the relationship between the range of the secondary electrons in the substance and the thickness of the substance. When the electrodes are thin, on the other hand, we cannot satisfy the condition of balancing the electrons for high-energy radiation. In this case, we control the quantity of the emitted secondary electrons. We can obtain a secondary electron discharge distribution that emphasizes the low-energy side by adjusting the thicknesses of the electrodes (Fig. 3).

The secondary electron discharge distribution differs depending on the substance, Fortunately, there are various materials suitable for emphasizing the low-energy size, and various materials suitable for emphasizing the high-energy side. For this reason, by properly discerning multiple substances and by adjusting the thickness and going through the layers, we can design electrodes having a secondary electron discharge distribution matching the ionization quantity distribution in the air, and can improve the energy characteristics of the vacuum ionization chamber.

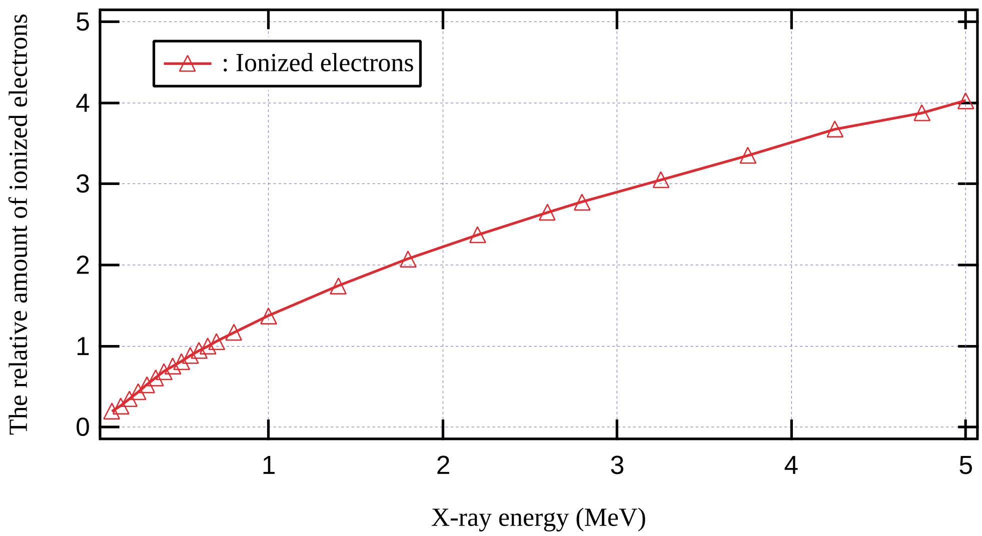

Figure 1: The amount of ionization of a distribution that depends on the energy of the radiation.

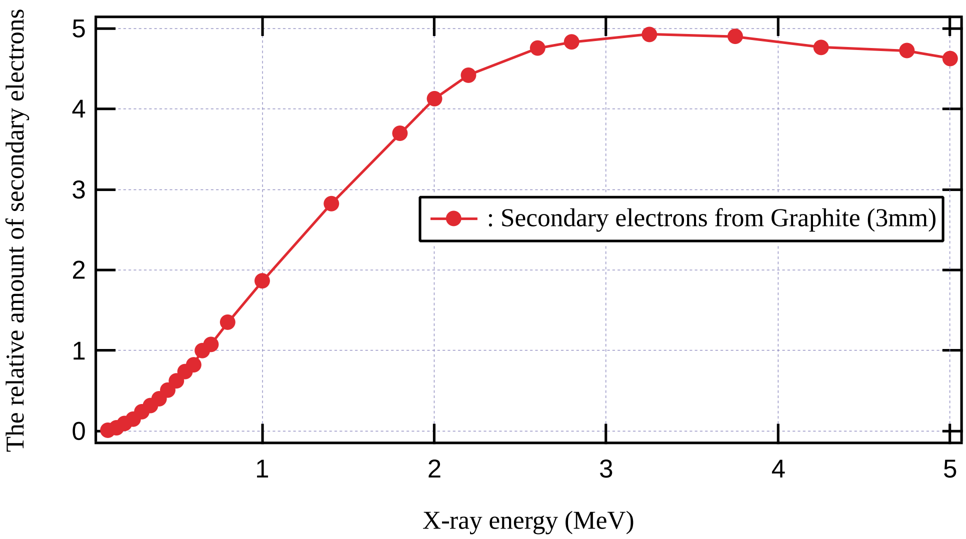

Figure 2: A secondary electron discharge distribution that emphasizes the high-energy side (Graphite).

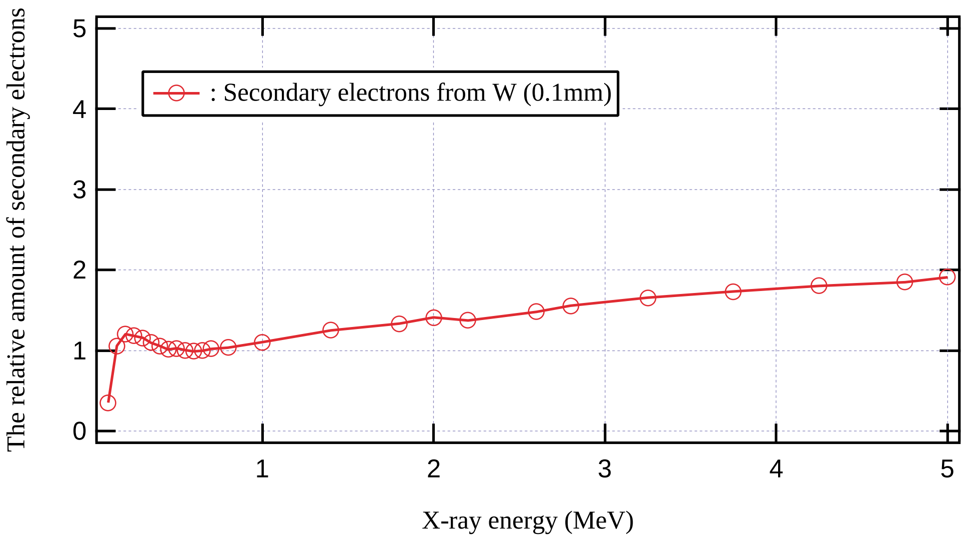

Figure 3: A secondary electron discharge distribution that emphasizes the low-energy side (W).

3 Simulation

We calculated the amount of electrons emitted from the side opposite the electrodes when X-rays were irradiated to one point of an infinite board using EGS4 (Electron Gamma Shower Version 4). The electrodes were employed the three types of the materials, which were iron with a comparatively high sensitivity near 100keV, tungsten with a high sensitivity in the domain of several hundred keV, and graphite with a high sensitivity in the domain beyond. When these materials were added to three layers, we changed the thickness of each electrode, computed the secondary electron discharge distribution for each thickness, and made comparisons with the distribution of a rate constant of 1cm dose equivalent, which showed the ionization density in the air, namely ionization quantity distribution.

The evaluated system is shown in Fig. 4. Because secondary electrons emitted by low-energy X-rays have a low energy, they are likely to be trapped by other electrodes. Accordingly, we positioned the electrodes on the side opposite the X-ray irradiation side to raise the sensitivity for low-energy X-rays (in Fig. 4, (1): graphite, (2): tungsten, and (3): iron). The energy range in which the simulation was performed was assumed as 100keV - 5MeV, which is the energy range of bremsstrahlung was generated by accelerator (Note: most of the X-rays of 100keV or less were not generated. See Fig. 5. When the bremsstrahlung were 5MV, the spectrum was shifted further to the high-energy side.) The set of thicknesses of the individual electrodes in which the simulation was performed is shown in Table 1.

To evaluate the simulation results, we standardized the secondary electron discharge distribution of each substance and the ionization quantity distribution. Here, we assumed the value of 660keV (which is the gamma ray energy of Cs-137) to be 1, which was used in the correction (JIS standard Z4333) of the ionization chamber.

The set of electrodes best matching the ionization quantity distribution was graphite: 0.3mm, tungsten: 0.1mm, and iron: 0.02mm. Figure 6 shows a comparison of secondary electron discharge distribution and ionization quantity distribution (rate of 1cm dose equivalent) graphs for the ideal set of optimum electrodes.

We also compare the relative value of the output current of the ionization chamber. The output current is proportional to the inner product of the energy characteristics of bremsstrahlung spectrum and the ionization chamber. Figure 5 shows that the ratio of the inner product of the bremsstrahlung spectrum of 4MV and the energy characteristics of the optimum electrodes, and the inner product of the bremsstrahlung spectrum and the ionization characteristics in the air, was 0.96. Consequently, we can see that the output current value by the optimum electrodes agrees well with the output of a typical ionization chamber, even in the presence of sensitivity to X-rays with a wide-range energy distribution like bremsstrahlung. That is, the proposed electrodes enable high-precision measurement independent of the energy of the radiation under measurement.

Table 1 The set of thicknesses of the individual electrodes.

Material of electrode	Thickness of electrode
Graphite	5 - 0.1 (mm)
W	0.1 - 0.01 (mm)
Fe	0.05 - 0.001 (mm)

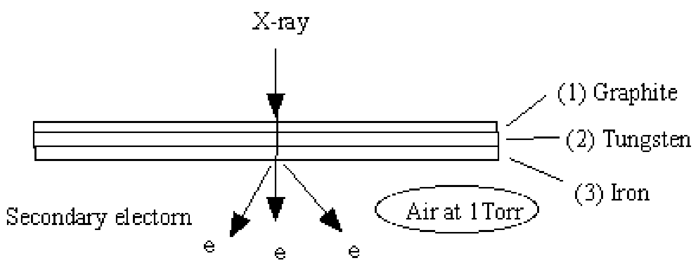

Figure 4: The evaluated system for EGS4 simulation.

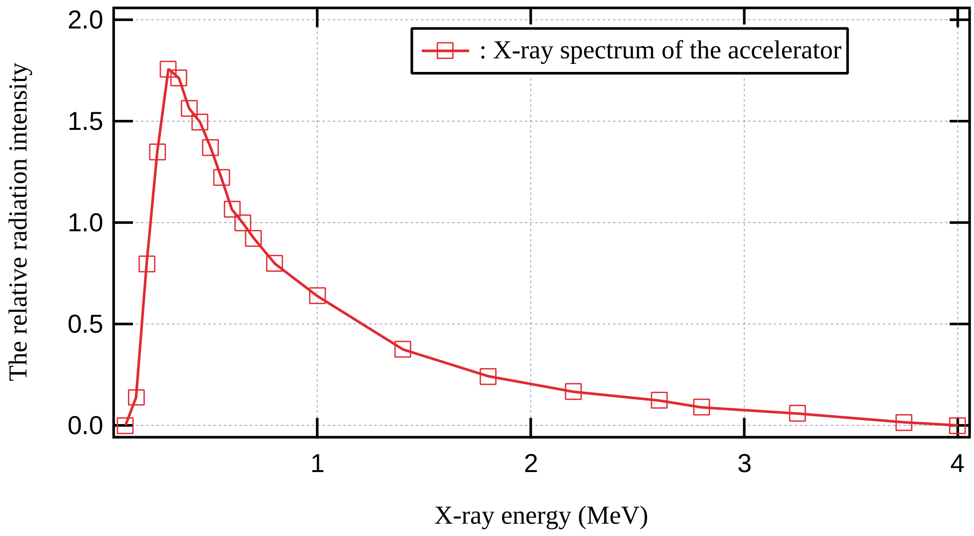

Figure 5: The X-ray spectrum of 4MV by the accelerator.

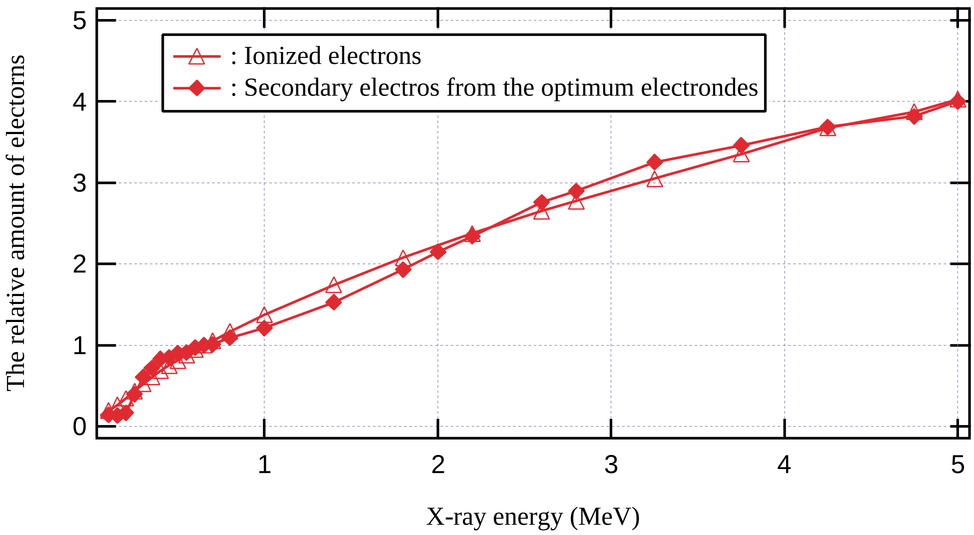

Figure 6: A comparison of secondary electron discharge distribution from the ideal set of optimum electrodes and ionization quantity distribution.

4 Verification Experiment

To check the validity of the electrode design by simulation, a prototype was manufactured (Fig. 7) and an irradiation test was performed at the Japan Atomic Energy Research Institute in Takasaki using their Co-60 radiation source. The irradiation test measurements were made at atmospheric pressure and at a low vacuum (1Torr), which was decompressed the gas pressure in the ionization chamber, and were then compared to derive the amount of ionization of the air and the amount of secondary electrons emitted from the electrodes. The irradiation conditions are shown in Table 2.

Here, the simulation model was also improved in accordance with the structure of the prototype (including air (ionization medium) and electrodes. See Fig. 8.), and the amount of ionization of the air and the amount of secondary electrons emitted from the electrodes were evaluated.

The measurement results are shown in Figs. 9 and 10. (In this irradiation test, since the dose rate, which was a maximum of about 0.15kGy/min, was no high dose rate, results with linearity were obtained with no saturation of the pressure in the ionization chamber at atmospheric pressure.) If we compare the slope of the output at atmospheric pressure and in the low vacuum state, we can see that the difference is as great as 26.8 times. In the low vacuum state, on the other hand, the quantity of the ionization medium decreases to 1/760, and the contribution of the ionization of air becomes 1/760 compared with the state at atmospheric pressure. From the above, the ratio of the amount of ionization in the vacuum ionization chamber output and the amount of secondary electron discharge is 1 to 28.4

$$\begin{aligned} 26.8 : 1 &= 760 \times a + b : a + b \\ a : b &= 1 : 28.4 \end{aligned} \tag{1}$$

where a is the contribution of the amount of ionization in the vacuum ionization chamber, and b is the contribution of the secondary electrons emitted from the electrodes.

Similarly, as a result of the simulation, the ratio of the number of secondary electrons emitted from the electrodes, and the amount of ionization, was as follows: (the number of secondary electrons)/(the amount of ionization) = 26.1, and the test could be reproduced in an accuracy of 97%.

Above, it was verified that this simulation can imitate a vacuum ionization chamber with a sufficient accuracy. Therefore, the electrode design using EGS4 can be said to be appropriate.

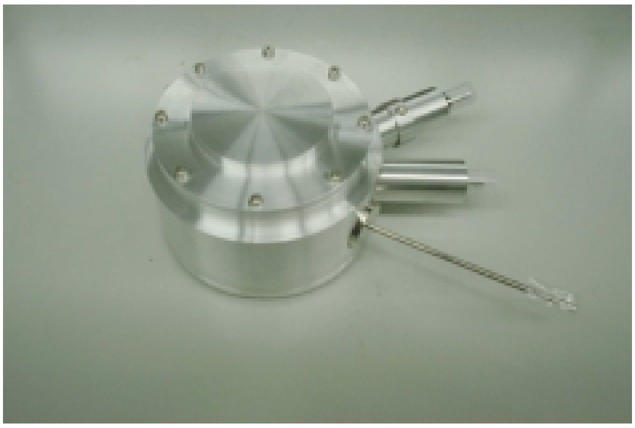

Figure 7: The photograph of a prototype detector.

Table 2 The irradiation conditions.

radiation source	Co-60
Dose rate	0 - 0.15 (kGy/min)
Pressure in ionization chamber	760 (Atmosheric pressure), 1 (Torr)
Applied voltage	200 (V)

5 Conclusion

The following conclusions were obtained as a result of the study.

1. By adding electrodes made of various materials to the layers, the distribution of the secondary electrons could be made to agree with the distribution of the amount of ionization of the air, and the energy characteristics of the vacuum ionization chamber could be improved.

2. A verification test confirmed the validity of the electrode design using EGS4.

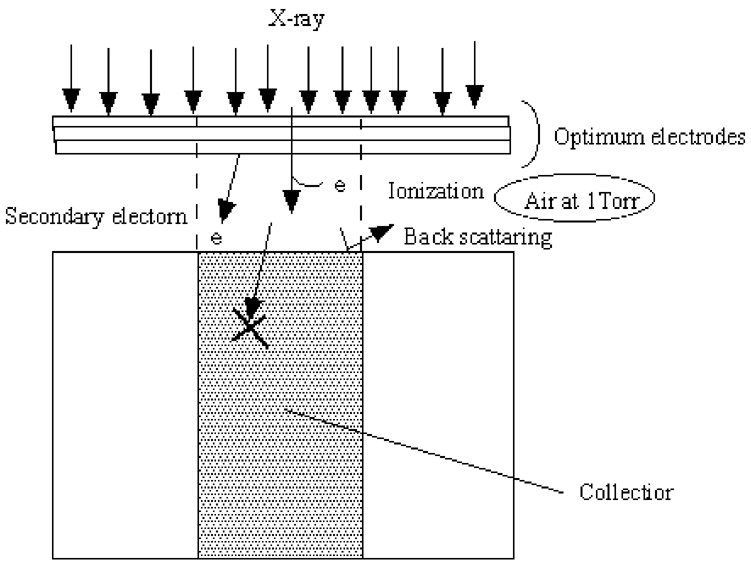

Figure 8: The improved evaluated system for EGS4 simulation.

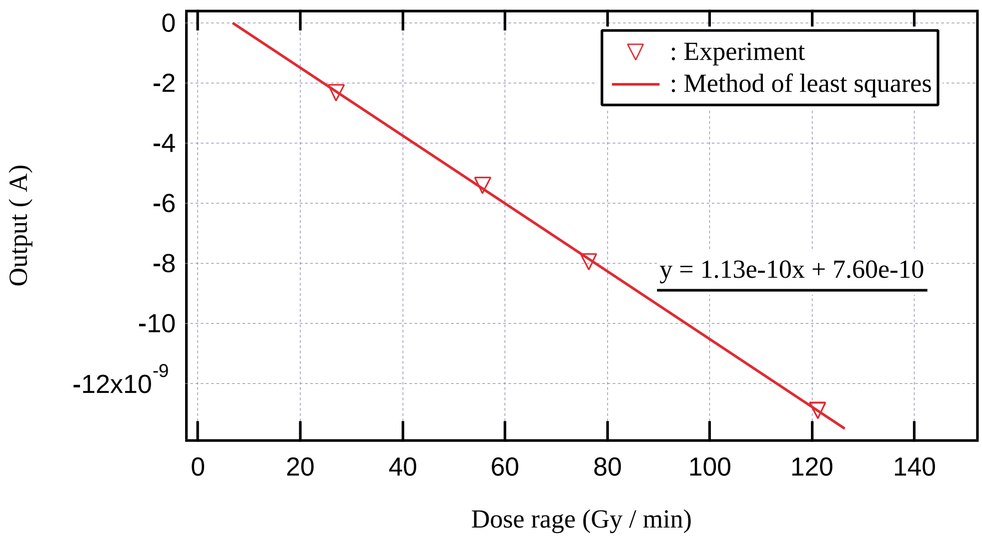

Figure 9: The measurement result at atmospheric pressure.

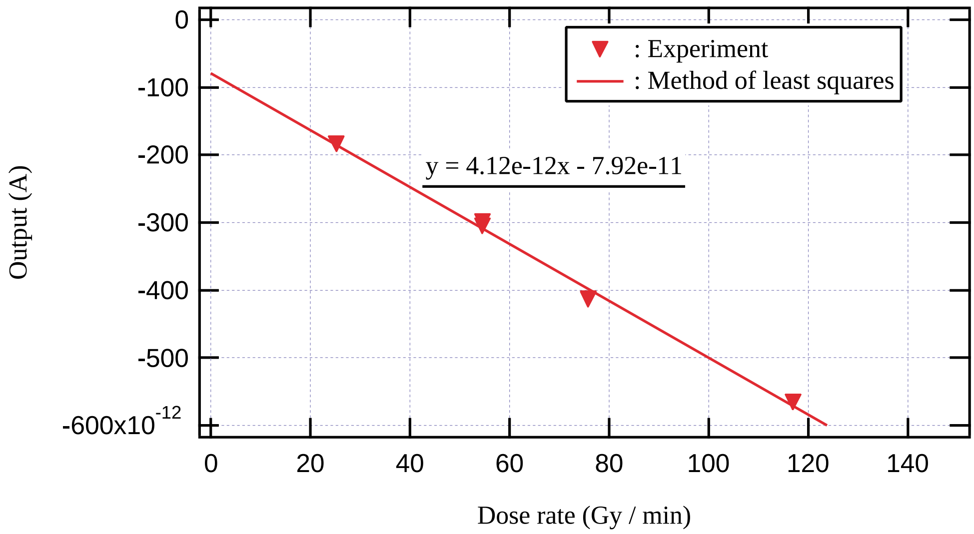

Figure 10: The measurement result at 1Torr.

References

1) R. Nishiura et al., Proceedings of the Eighth International Conference on Nuclear Engineering, 8414, (1999).