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EGS4 APPLICATION TO DESIGN OF PARALLELL-PLATE FREE-AIR IONIZATION CHAMBER FOR HIGH-ENERGY SYNCHROTRON RADIATION

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Abstract

Energy deposition in two-sized parallell-plate free-air ionization chambers was calculated for 30-200 keV photons with EGS4 to estimate the electron escape fraction for the chambers. For the low-energy x-ray ionization chamber of 5-cm plate separation, the escape increased with energy to 70 keV, decreased from 70 to 100 keV, and above 150 keV rose again. For the high-energy x-ray ionization chamber of 8.5-cm plate separation, the escape became almost below 1% and the charge collection efficiencies calculated based on the Boag's equation were over 99% for the exposure rate below 1 R/s at an applied voltage of 10 kV. Influence of linear polarization was found to be negligible.

1 Introduction

At SPring-8 of 8-GeV synchrotron radiation facility in Japan, monoenergetic photons of the energies up to at least 190 keV are available at the bending magnet beamlines. The exposure rate is at most several tens mGy/s, at which a parallell-plate free-air ionization chamber is expected to be applicable. For high-energy x rays, however, size of plate separation becomes extremely large, which lower the electric field slope. For example, electron range at 100 keV in air is 13.5 cm, which corresponds to 27-cm plate separation necessary. Actually, ionization chambers for up to 250 kV x rays have had 20-cm and 30-cm plate separation at NBS and NPL, respectively[1]. In Japan, as the standard free-air chamber for hard x rays at Electrotechnical Laboratory, 24-cm plate separation has been employed[2]: these facilities have been used for the national standard, in which extremely high accuracy is required. On the other hand, Attix and DeLaVergne have calculated electron ionization losses for various plate separations in a free-air chamber and found that to obtain $< 1\%$ loss a mere 12-cm separation is necessary even for 200 kV x rays[3]. Boag has pointed out that the reason is that the proportion of the total ionization due to photoelectrons declines rapidly with energy, and the Compton recoil electrons have much lower energies[4]. Thus if the high accuracy such as required at the national standard facilities is needless and even 1% accuracy is sufficient, the large plate separation appears not to be necessary. For the detail estimation, Monte Carlo simulation is indispensable.

In this study, energy deposition in ionization chambers was calculated using EGS4 to estimate electron energy loss from the collection plates. Moreover, charge collection efficiency was calculated based on Boag's equation[4] at a voltage applied for various exposure rates.

2 Compton and Photoelectrons

Figure 1 shows the photon attenuation coefficients in air for Compton and photoelectric effect, respectively. Above 30 keV, influence of Compton effect is becoming gradually dominant. Figure 2 shows the energy spectra of Compton electrons for 50- and 100-keV photons, which were calculated based on Klein-Nishina equation. The maximum energies are much smaller than those of photoelectrons. Angular distributions of Compton and photoelectrons for 50- and 100-keV photons are indicated in Figs.3 and 4. The angle of photoelectrons was calculated based on the Sauter distribution[5]. Compton electrons are all ejected below 90 degrees, while some photoelectrons over 90 degrees. From these results, it is expected that in the energy region of 50 to 100 keV where Compton interaction is dominant, plate separation of parallell-plate free-air ionization chamber will not have to be comparable to the electron range of photoelectrons.

3 EGS4 Calculations

In EGS4 calculations, 50- to 200-keV photons were incident to parallell-plate ionization chambers and energy deposition between the collection electrodes was calculated. Beam size used was 5 mm square and cutoff energies of 1 keV and 5 keV were used for photons and electrons, respectively. Statistical errors were all below 1%. Deposited energies obtained were compared with those calculated using the energy absorption coefficients of air. Two kinds of chambers were used: one for $\leq$40 keV[6] and the other for $>$ 40keV. Plate separation, guard electrode length and collection electrode width were 5 cm, 2 cm and 7 cm for $\leq$40 keV, and 8.5 cm, 15 cm and 20 cm for $>$ 40keV, respectively. Collection electrode length was 1 cm for both chambers. Moreover, influence of linear polarization was examined.

4 Results and Discussion

4.1 Ionization chamber for low-energy x rays

Figure 5 shows the comparison between experiment and calculation of the ionization chamber for the low-energy photons. The experimental values are ratios of absorbed doses in the chamber to those in a Si photodiode[7]. The difference of unity and the values on the vertical axis denotes the electron escape fraction. The calculated values decreased to 0.82 at 60 keV, reversely increased to 0.91 at 100 keV and decreased again to 0.56 at 200 keV. Compared with experiments, almost agreement was obtained for BL20B2 beamline, while not agreed for BL38B1. This reason can be attributed to the large beam size of 1 cm by 2 cm used at BL20B2.

Figure 6 shows the result of build-up thickness, that is, the guard electrode length adjusting to the photon energy. Compared with Fig.5, the calculated values significantly increased, which showed the large influence of the buildup region.

To examine the influence of plate separation, guard electrode length and collection electrode width, each length was changed and energy deposition was calculated for 80-keV photons. The result is tabulated in Table 1. In the same way as above, effect of guard electrode length was found to be the greatest, which is 11%. Consequently, the difference of experiment and calculation at BL38B1 in Fig.5 is principally attributed to the modelling of the build-up air layer that exists outside of the chamber.

4.2 Ionization chamber for high-energy x rays

Figure 7 indicates the EGS4 calculation result of ionization chamber for the high-energy x rays. Under 150 keV, the electron energy losses became below 1%. At 200 keV, however, electron escape fraction rises to 4% because even the Compton electron energies become large and then longer buildup layer is required. Influence of scattering from the chamber wall was not found owing to an EGS4 calculation.

Charge collection efficiency f of the present model was calculated based on the Boag's equation[4]:

$$f = \frac{1}{1 + \frac{1}{6}\zeta^2}$$

$$\zeta = m(\frac{d^2\sqrt{q}}{V})$$

m=36.7
d: Plate separation (cm)
q: Ionization rate (esu/cm^3/s)
V: Applied voltage (V)

The equation and parameters are applicable in the range $f > 0.7$. Figure 8 shows the efficiencies calculated at the applied voltage of 10 kV. An efficiency of > 99% is obtained up to 1 R/s, which is adequate exposure rate at the bending-magnet beamlines.

Angle of secondary electrons ejected in the photon interaction depends on the direction of linear polarization. Photoelectrons are easy to be ejected in the plane including photon electric field[5]. On the other hand, Compton electrons tend to be strongly scattered vertically to the plane: both effects compensate each other. Consequently, owing to EGS4 calculations considering linear polarization, large influence was not also found clearly.

5 Conclusions

Calculations with EGS4 have showed that the electron escape fraction is below 1-2% at a plate distance of 8.5 cm for 50- to 150-keV photons. The charge collection efficiencies at 10 kV were also over 99% owing to a theoretical calculations. The distance of 8.5 cm is much shorter than the twice of the electron range of 26.5 cm at 150 keV.

References

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Table 1: Influence of guard electrode length, width and plate separation at 80 keV. Energy deposition was normalized at the maximum.

Guard electrode length (cm)	Width (cm)	Plate separation (cm)	Deposited energy
2	7	5	0.815
9	7	5	0.917
9	18	5	0.935
9	18	9	0.987
9	18	18	1.000

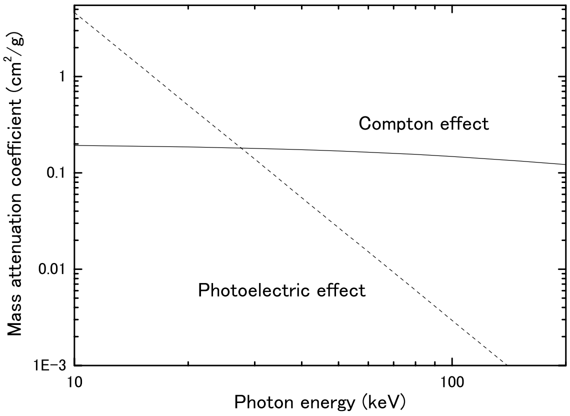

Figure 1: Proportion of Compton and photoelectric effect in air.

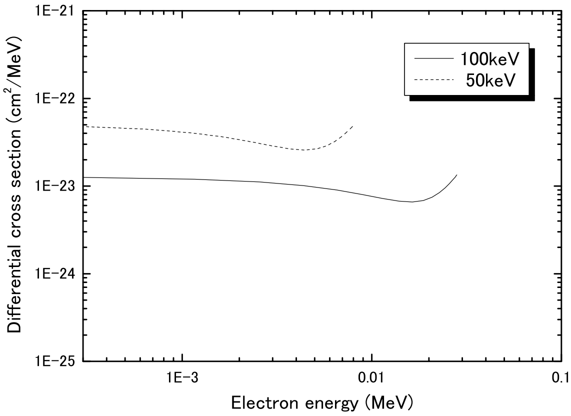

Figure 2: Energy of Compton electrons.

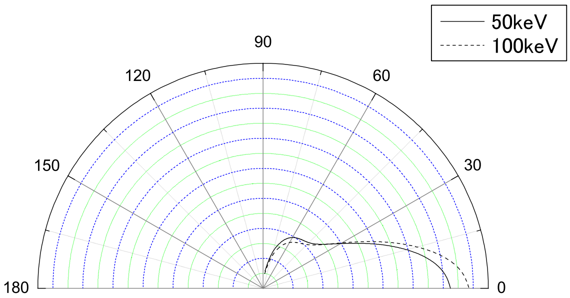

Figure 3: Angular distribution of Compton electrons.

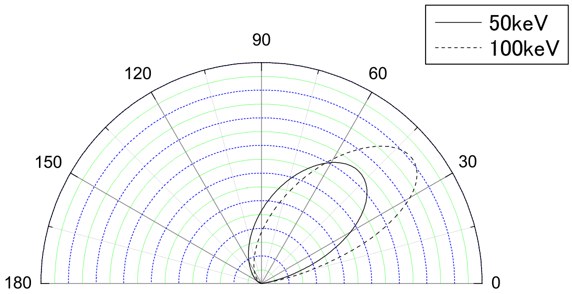

Figure 4: Angular distribution of photoelectrons.

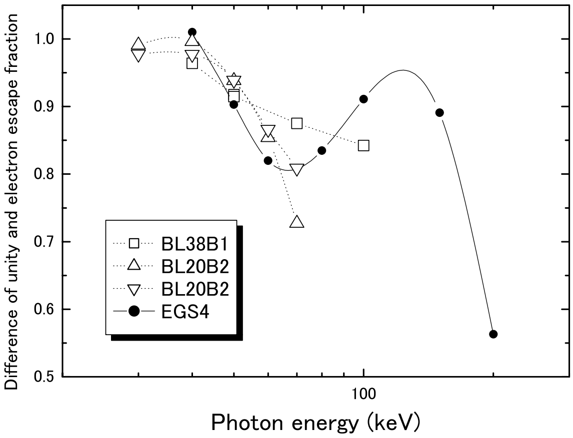

Figure 5: Comparison of experiments and calculation for low energy x-ray ionization chamber.

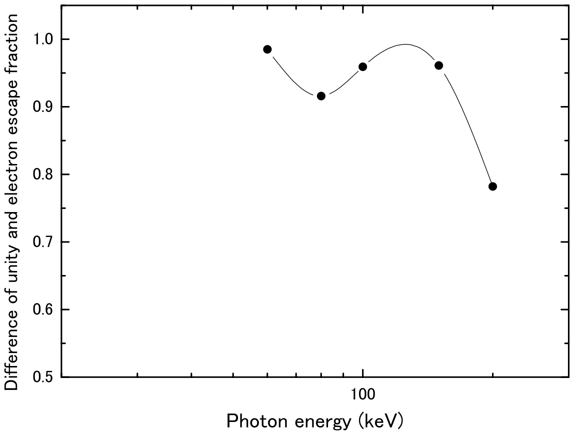

Figure 6: Calculations for build-up layer of adequate thickness.

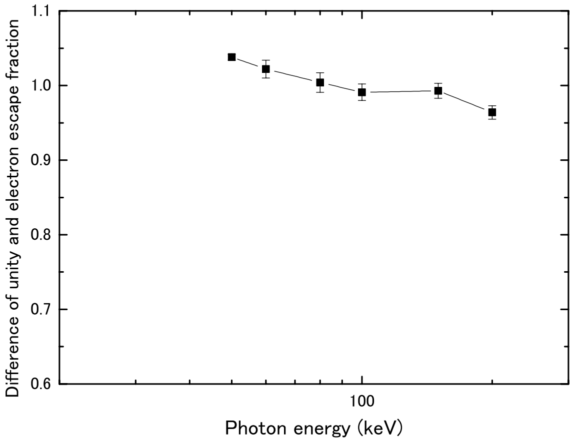

Figure 7: Calculations for high energy x-ray ionization chamber.

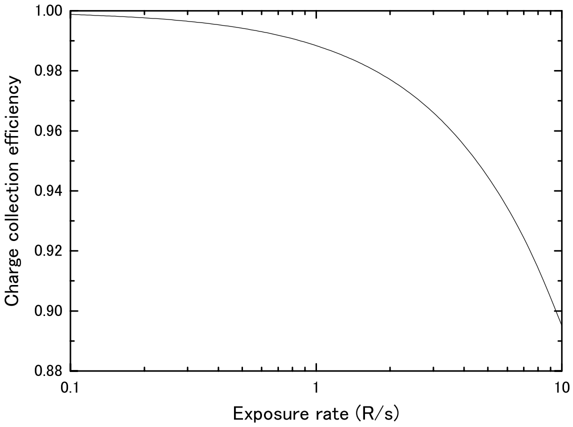

Figure 8: Analytical calculation of charge collection efficiency based on Boag's equation for high energy x-ray ionization chamber at 10 kV.