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SPECIFICATION OF RADIATION FIELD AROUND A GAMMA-RAY SOURCE

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Abstract

In this report are discussed the characteristics of a radiation field generated by a small gamma-ray source and the depth-dose curve in a material placed there. The experiments with TLDs and a ^{137}Cs source resulted in a depth-dependence of about 30% decrease by aluminum wall of 100 mg/cm^2, to the contrary of a well-known pattern, i.e. saturation after a rapid build-up for parallel photon beam. In order to investigate the discrepancy, a Monte Carlo code EGS4 was employed to calculate the energy and the fluence of the secondary electrons in an approximate geometery of a spherical gamma-source made of glass in a stainless steel capsule. It was confirmed that the surface dose may be affected considerably by secondary electrons generated in the capsule and/or the air between the source and the detector. The angular distribution of secondary electrons and scattered photons have also been calculated, with which the function of a collimator was also discussed.

1 Introduction

The dependence of the absorbed dose upon the depth in a material or that of the dosimeter response upon the wall thickness, in general, is represented by a well-known pattern, i.e. a rapid increase in a shallower region followed by a saturation and gradual decrease in conjunction with attenuation of primary photons. We can see such depth-dose curves in most textbooks [1,2], the results of experiments with high-energy bremsstrahlung X-rays [3,4] and those of Monte Carlo calculations in the case of parallel-beam exposure. In an actual radiation field generated by a gamma-ray source, however, the experiments with a TLD, OSL (Optically Stimulated Luminescence) element, or a film dosimeter with a relatively thin sensitive layer have resulted in a quite different dependence with the wall thickness.

In this report, the depth-dose relation has been carefully measured with a ^{137}Cs gamma-ray source and commercially available TL elements of 15 mg/cm^2 thick. The results were compared with those calculated by the EGS4 code [5] to specify the radiation field around a point source.

2 Measured Depth-Dose Curve in a Field around a Small Gamma-Ray Source

A ^{137}Cs source with an activity of 220 MBq was used in this experiment which is made of cesium glass covered with a stainless steel capsule of 3.2 mm in diameter, 5.5 mm in height and 0.8 mm in thickness. The source was set on a rod of acrylic resin with a height of 30 cm, and TL elements (UD-802P, Matsushita Electric Co., Ltd.) , $CaSO_4$ and $Li_2B_4O_7$ of 15 mg/cm^2 stuck on a polyimide substrate of 11 mg/cm^2, was placed on a holder of polystyrene foam 30 cm apart from the source. A typical experimental result is shown by dots in Fig.1, where the TL response was plotted against the thickness of aluminum foil attached to the TL element. The variation with the thickness observed was not a build-up but about 30 % decrease in 100 mg/cm^2.

A broken line in the figure represents an approximate calculation [6] under several assumptions of parallel photon beam with an energy of 0.66 MeV, domination of Compton effect, straight trajectory of Compton electron, the same pattern of the energy dissipation by the electron independently of its initial kinetic energy. A saturation at 150 mg/cm^2 or deeper was confirmed in both results, where the electronic equilibrium is considered to be satisfied. The dependence in a shallower region, however, is quite different from each other. The decrease observed in the experiment can never be explained by attenuation of primary photons, which amounts to only a few % for 400 mg/cm^2 aluminum. A forced fit to an exponential function leads to incredibly low photon energy of 26 keV. Additional experiments were carried out with a special attention to the photon scattering, but the initial decrease was unchanged in all the trials.

3 EGS4 Calculations

Thus, EGS4 Monte Carlo code was employed to clarify a radiation field generated by a ^{137}Cs source and to evaluate the energy deposition in TL elements exposed there. A spherical geometry was adopted in this calculation. Namely, the cylindrical gamma-ray source was approximated by a glass sphere with a diameter of 3.2 mm covered by a stainless-steel sphere with a thickness of 0.8 mm. The 0.66 MeV photons are generated uniformly in the glass and emitted isotropically. The air of 30 cm thick surrounds the gamma-ray source, and outward are arranged more than 20 aluminum shells of 0.05 mm thick and TL material.

The energy spectra of both photons and electrons at the outer surface of air sphere, 30 cm apart from the center of the source, are shown in Fig.2. The contribution of secondary electrons is only 0.3% of primary photons, negligibly small with respect to the fluence. From a viewpoint of the energy deposition, however, the electrons play an important role owing to their large value of the conversion factor. This result is recognized more easily in Fig.3, where the upper line represents the depth-dose distribution corresponding to the measured data in Fig.1, and the lower the component by photons. So, the direct contribution of the secondary electrons is represented by a difference between two lines, as shown by dotted area. It may be said that the secondary electrons dominates the absorbed dose in a shallower region, in other words, there might be a mixed radiation field composed of gamma-rays and sesondary electrons.

4 Contaminant Electrons

In radiation therapy using intense gamma-ray sources or electron accelerators, the secondary electrons causing an unexpected excess dose at the surface are called as “contaminant electrons” [7,8]. The expression may be acceptable in the energy deposition, but is not appropriate from a viewpoint of specification of the radiation field. In the case of parallel-beam geometry, the energy fluence near the surface in the upper stream is larger than that in the lower. The difference becomes smaller with increasing the depth, and then reaches zero when the electronic equilibrium is attained. On the other hand, around a gamma-ray source regarded as a point one, the attenuation of the fluence rate by the inverse square law should disturb considerably a balance of the energy fluence of secondary electrons. Because of rapid decrease of the photon intensity with the distance, the fluence rate of secondary electrons in the upper stream is much larger than that in the lower, even in a shallower region. This is considered to be a major reason why the depth-dose curve observed around a gamma-ray source is a different pattern.

5 On the Effect of Collimator

The contamination of secondary electrons brings about an unwilling excess skin dose for radiation therapy. One of the most effective countermeasures is a collimator, of which material and structure have already been determined empirically from a number of experiments. The function of a collimator is discussed here from another approach with Monte Carlo calculations.

The EGS4 user's program was improved to get angular distributions of both photons and electrons incident on the aluminum shell in a spherical geometry. Namely, a thin vacuum layer is set between the air and the first aluminum region to be assigned for a judgement. The energy and the angle with respect to the line normal to the shell, which can be calculated by the current position and the direction cosines, are recorded in the layer as well as the species of the particle. This information gives a contribution of photons or electrons, with an arbitrary angle of incidence and with an arbitrary energy, to the energy deposited in an arbitrary aluminum layer. In Figs. 4 and 5, the energy deposited in the first aluminum shell of 0.05 mm thick by photons and electrons was distributed in the incident angle. The co-ordinates in Fig.5 are both in linear and normal scales, whereas the ordinate of Fig.4 is in a logarithmic scale and the cosine of the incident angle lower than 0.9 is cut in the abscissa. The calculation results mean that not only primary photons directly incident but also secondary electrons with various angles have a contribution to the absorbed dose at the surface. Hence, the depth-dose curve approaches to the pattern for a parallel-beam geometry with the smaller the angle regulation, as shown in Fig.6.

It is in actual so difficult to make such an ideal collimator by the following reason. Any material can easily stop the secondary electrons, but another electrons should inevitably be generated within the collimator itself. It is necessary for an effective collimator to be thick enough to attenuate the primary photons, in order to reduce the electron generation rate in the collimator to be negligibly low.

6 Conclusion

The depth-dose curve obtained with a gamma-ray source and thin TL element is quite different from that theoretically predicted under a parallel beam approximation. The EGS4 calculations supported the experimental results, and gave a great help to specify the radiation field around a point source with respect to the energy deposition in a material. The identity of "contaminant electrons" may be revealed to be a much excess of secondary electrons generated upstream over those downstream. The situation is caused by a rapid decrease in the photon intensity by the inverse square law. It was also pointed out that the collimator would act as a shield of primary photons in order to restrain another electron generation there, rather than as a shield against the contaminant electrons.

References

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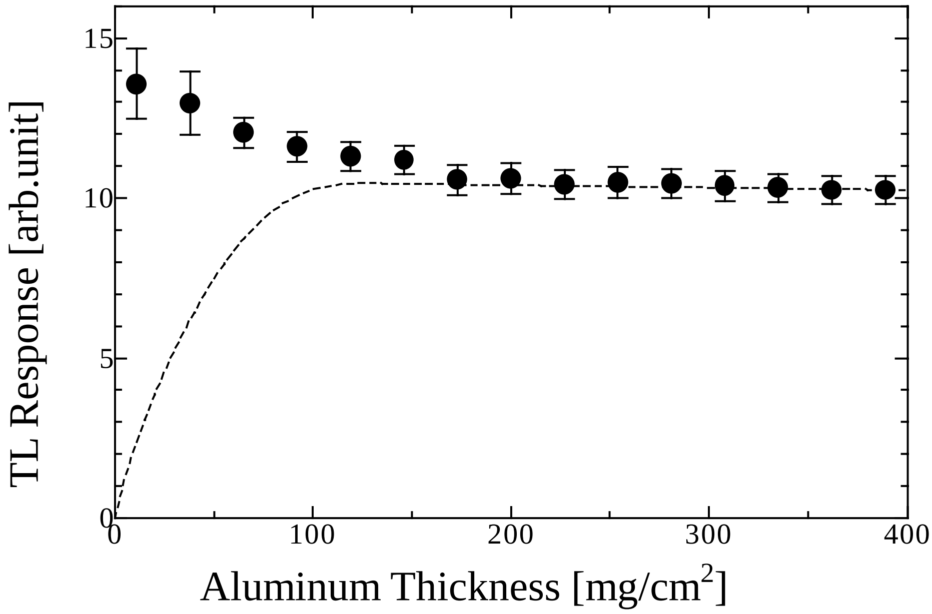

Fig. 1. Dependence of TL response on the thickness of aluminum wall.

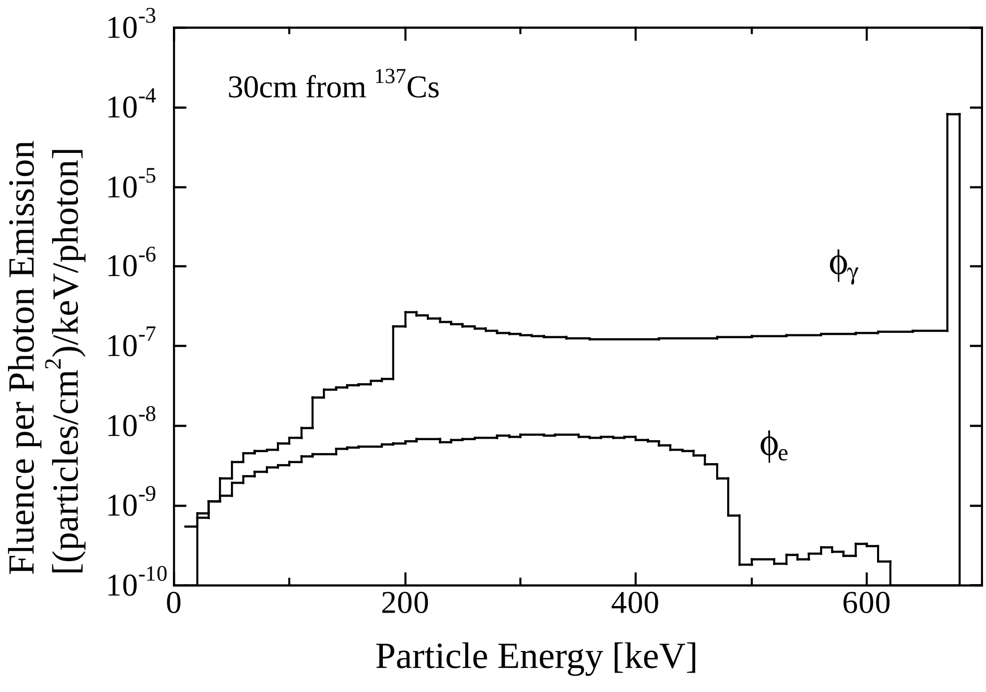

Fig. 2. Energy spectra of photons and electrons at 30cm distance from the source.

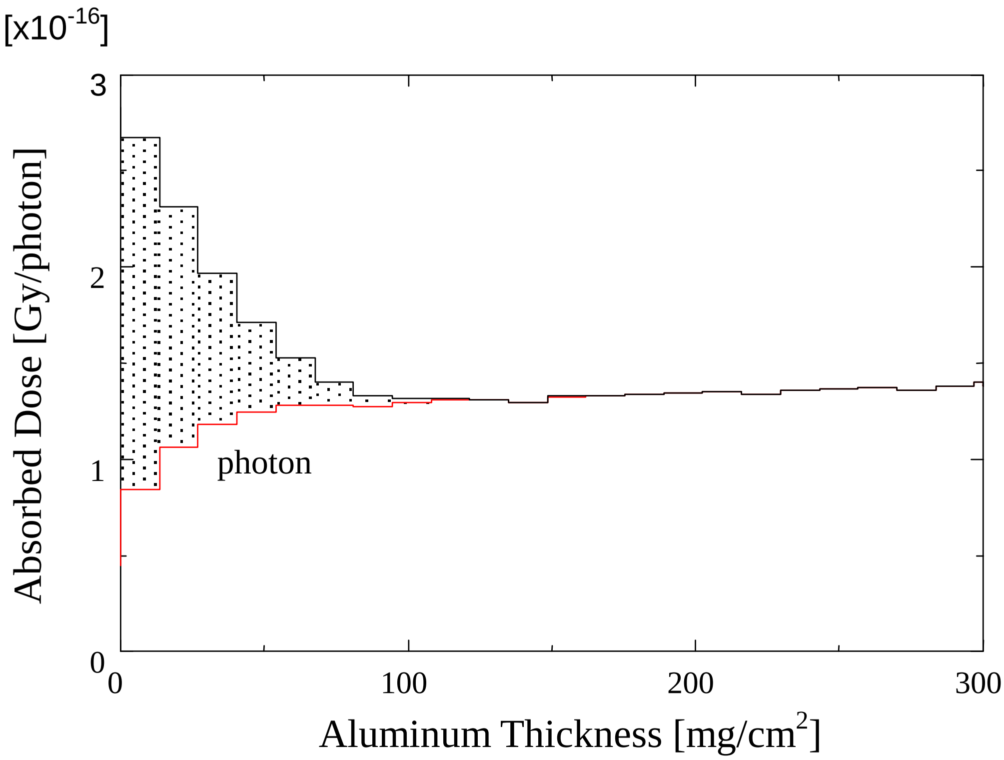

Fig. 3. Depth-dose curve calculated with EGS4.

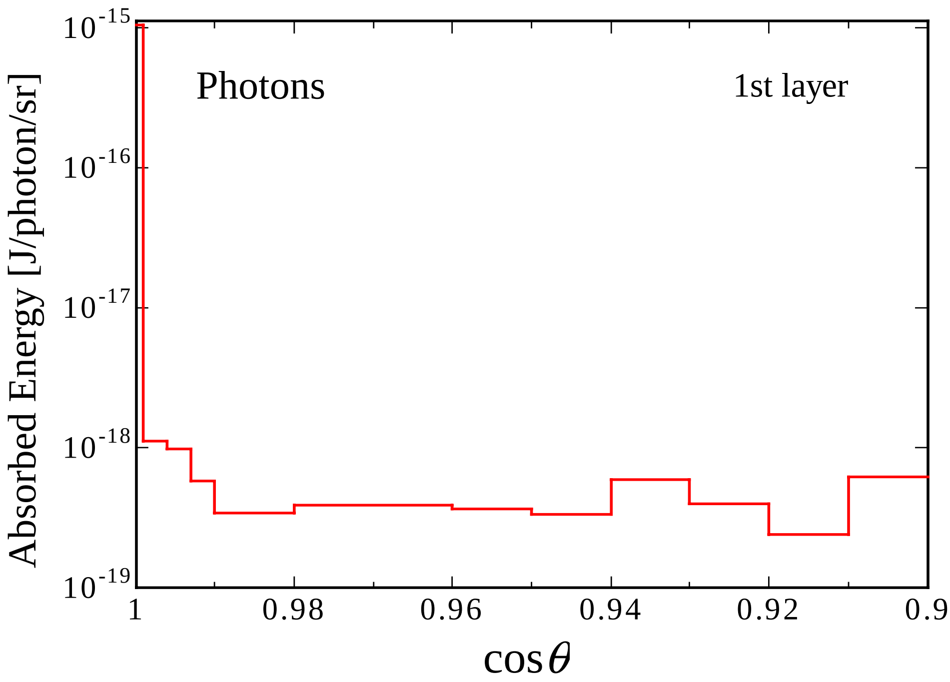

Fig. 4. Distribution of absorbed energy in the angle of photon incidence on the first layer.

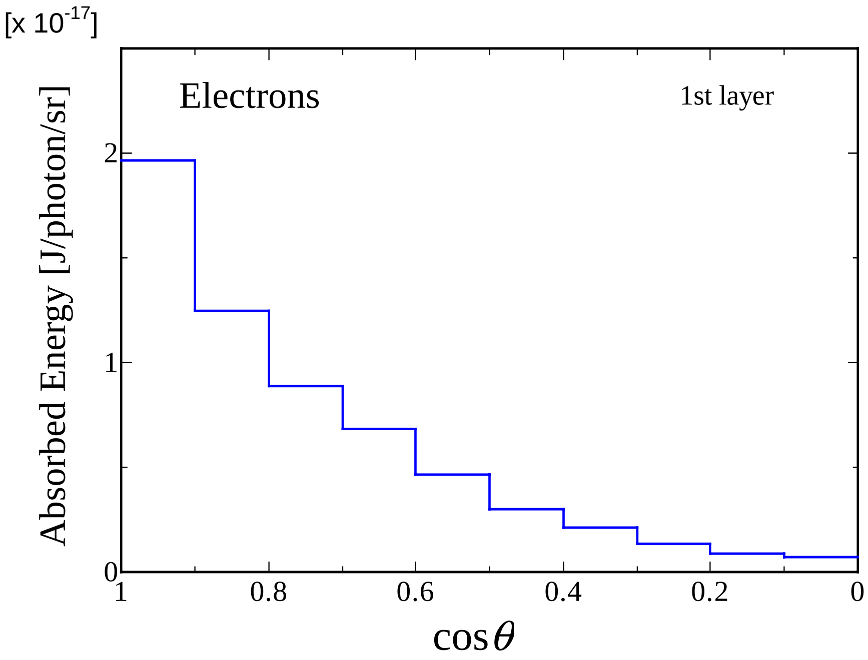

Fig. 5. Distribution of absorbed energy in the angle of electron incidence on the first layer

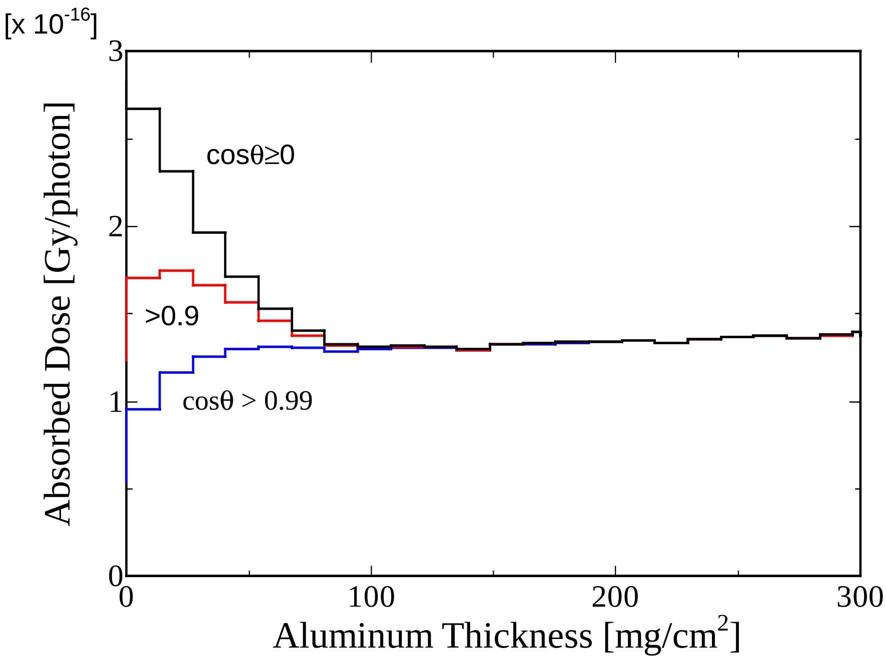

Fig. 6. Depth-dose curves with angle regulation