The evaluation of the radiation shielding ability of lead glass

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Abstract. Positron emission tomography (PET) scanning with the tracer 2-[F-18] Fluoro-2deoxy-D-glucose (FDG) is widely used in the clinical PET. However, the photon energy used in the PET scans is considerably higher than that of the X-rays traditionally used in the diagnoses. The radiation protection in the PET institution, therefore, is the remaining problem. Meanwhile, lead glass has attracted considerable attention as a radiation-shielding material for the PET institution. The aim of the present study was to evaluate the radiation-shielding ability of the lead glass against the positron emitters. The shielding ability evaluations were done both in the actual experiments and in the Monte Carlo simulation. The lead glass, the object of evaluation in this study, proved to have sufficient protective effect. The development and the spread of a thinner and lighter lead glass with the same effective dose transmission factor should be expected in the near future.

KEYWORDS: PET; Radiation protection; lead glass; shielding ability; Monte Carlo.

1. Introduction

In recent years, positron emission tomography (PET) is very effective for the diagnosis and management of patients with various types of cancers. PET scanning with the tracer 2-[F-18] Fluoro-2deoxy-D-glucose (FDG) is widely used in the clinical PET, by reason of the increased glucose consumption of cancer cells [1]. However, the energy of photons (two annihilations) used in PET scans is considerably higher than that of the X-rays traditionally used in the diagnoses. A thorough protection against radiation should be necessary for the development of an examination system with a positron emitter. The radiation protection in the PET institution and the guarantee of safety, therefore, are the remaining problems. Meanwhile, lead glass has attracted considerable attention as a radiation-shielding material for the PET institution. The shielding ability can be evaluated based on the effective dose transmission factor and the lead equivalent.

In the present study, the evaluations were done, upon request, of the radiation shielding ability of two kinds of lead glass (Med-X, A: unnamed) made in Pilkington plc. The aim of the present work was to evaluate the shielding ability of the lead glasses against positron emitter such as ^{18}F (511 keV). The shielding ability evaluations were done both in the experiment and the Monte Carlo simulation.

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2. Materials and Methods

2.1 Experimental evaluation

As the radiation source, ^{18}F was used and as the detector was used the ionization chamber-type survey meter (Aloka ICS-311). The measurement stand was made of wood to prevent the influence of scattered radiation. Both the radiation source and the detector were placed at a distance of one meter from the floor. The radiation source was enclosed by lead blocks. The distance between the radiation source and the detector was assumed to be one meter. Two kinds of lead glasses were used: Med-X (glass plate thickness: 8, 10, 12, 15, 18 mm); and A (glass plate thickness: 5, 6, 7, 8 mm). Effective dose rate and time elapsed were measured for tentatively combined glass-plate thickness. The measured values were multiplied by the calibration coefficient for the range correction of ionization chamber-type survey meter. Decay correction for the half life of ^{18}F (109.8 min) was performed. The effective dose transmission factor was calculated using the measured effective dose rate [2]. Furthermore, the lead equivalence of the lead glass was calculated using the effective dose transmission factor measured in this study.

2.2 Simulation evaluation

Simulation evaluation was performed using a Monte Carlo code, EGS4 [3]. Both photons and electrons are transported at random rather than in discrete step. The EGS4 can simulate photon transport in the energy range from 1 keV to several TeV, and electron transport from a few tens of keV up to a few TeV. The cross-section data for photons were taken from PHOTX [4] and the data for electrons and positrons were taken from ICRU report 37 [5]. The numbers of histories of the simulations were basically determined at levels that reduce statistical uncertainties below 5 %.

In the simulation model, deposit energy in an atmospheric layer surrounded with lead block was calculated and the absorbed dose was evaluated. Likewise, the glass plates of different thicknesses were combined for estimation of the transmission factors of the absorbed dose. The radiation source was assumed to be the ^{18}F point source. Positrons were to be emitted from the ^{18}F source. Positron annihilation processes were taken into account in the calculations. The maximum and mean energies of ^{18}F were 634 keV and 250 keV, respectively [6]. The spectrum for the ^{18}F was taken from DECDC [6]. The composition of lead glass was assumed to be Med-X (specific gravity: 4.8, SiO_2 (26.3 %), Al_2O_3 (3.1 %), PbO (52.2 %), CaO (1.0 %), BaO (17.1 %), As_2O_3 (0.2 %), Sb_2O_3(0.2 %)), A (specific gravity: 5.19, SiO_2 (27.0 %), Al_2O_3 (0.5 %), PbO (71.0 %), K_2O (1.5 %)) [7].

3. Result and Discussion

3.1 Experimental evaluation

The relationship between the glass plate thickness and the effective dose transmission factor are shown in **Fig. 1**. Each effective dose transmission factor decreases as the glass plate thickness increases. In the glass plate thickness of 20 mm, 60-70 % of radiation dose was shielded, as shown in the figure. Presently, the thickness of 20 mm is actually used at hospitals. Taking into account the possible attenuation caused by the distance between an operating room and a laboratory, the protective effect should be considered as sufficient from external radiation exposure. Furthermore, in the glass-plate thickness of 60 mm, 95 % of radiation dose is expected to be shielded even at a relatively short distance of around one meter. The difference of 10 % at the maximum in the effective dose transmission factor was observed between Med-X and A. The difference can be explained by the different ratios of lead component in the above-mentioned glass plate composition. “A” is considered to have higher shielding ability which can be confirmed from the lead equivalent as shown in **Table 1**.

Figure 1: Relationship between the glass plate thickness and the effective dose transmission factor.

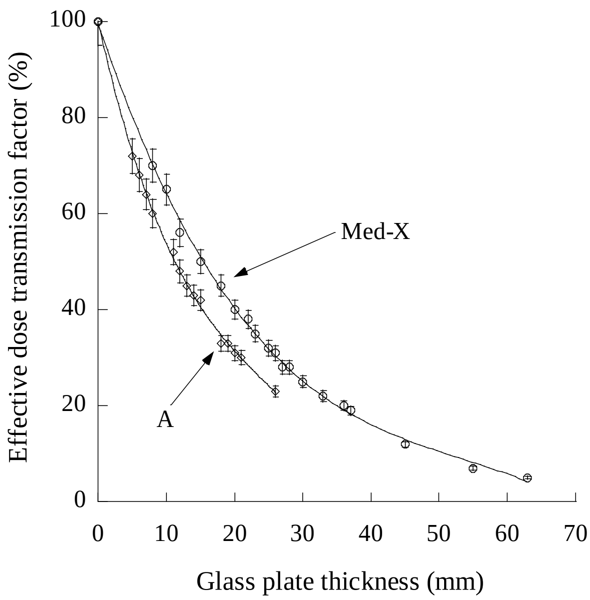


Table 1: Lead equivalent of Med-X and A.

Glass plate thickness (mm)	Lead equivalent (mm)	
	Med-X	A
8	2.85	4.04
12	4.51	5.57
15	5.40	6.63
18	6.28	8.35
20	6.86	8.86
26	8.80	10.92
30	10.26	-
45	12.56	-
63	20.58	-

3.2 Simulation evaluation

In **Fig. 2** and **3** are shown the relationship between the measurement and calculation evaluation of the effective dose transmission factor using Med-X and A. As for both figures, left vertical axis shows the effective dose transmission factor in the actual measurement, and right vertical axis shows the transmission factor of the absorbed dose by calculation. The maximum differences of about 7 % and 10 % were observed in Med-X and A, respectively. These differences are due to the fact that calculations were done under the ideal special condition without the influence of scattered radiation, for instance, in the Monte Carlo simulation. Such difference may be attributed to the smaller number of plots in the simulation evaluation as compared to measurement. The calculation of the present study should be validated since the calculated transmission factors of the absorbed doses tended to be consistent with those of measurements.

Figure 2: Relationship between measurement and calculation evaluation using Med-X. Left vertical axis is effective dose transmission factor with actual measurement. Right vertical axis is a transmission factor of absorbed dose with a calculation.

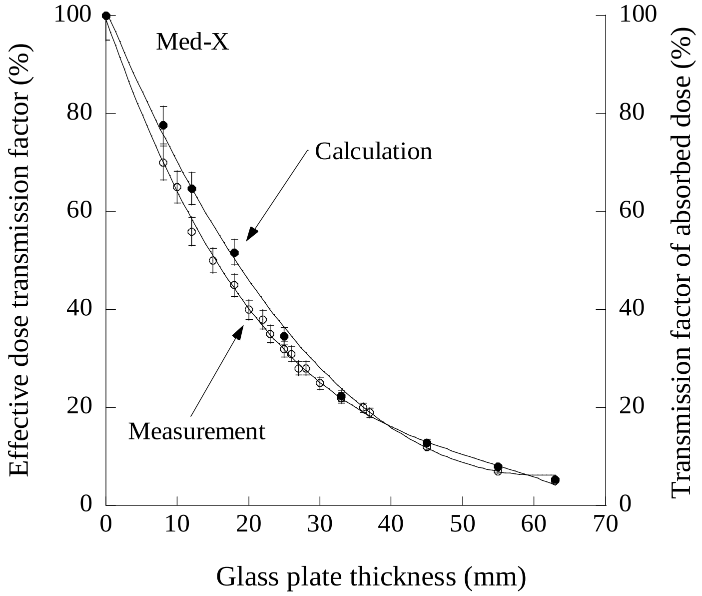
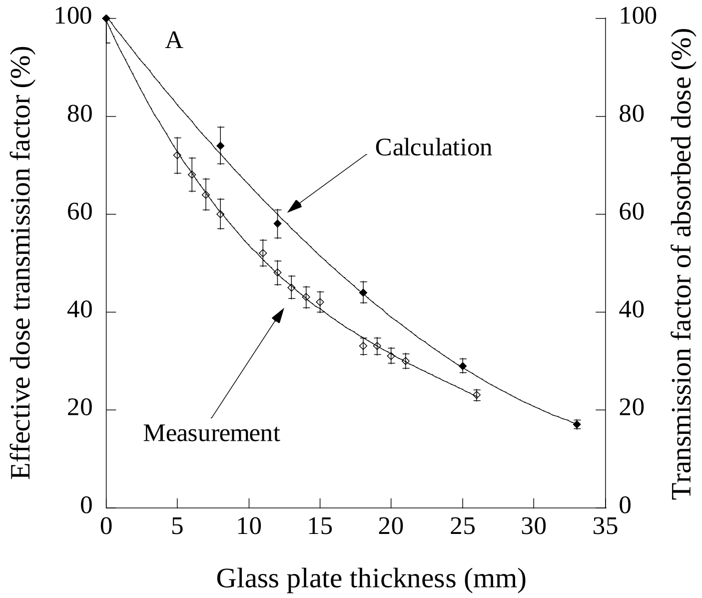


Figure 3: Relationship between measurement and calculation evaluation using A. Left vertical axis is effective dose transmission factor with actual measurement. Right vertical axis is a transmission factor of absorbed dose with a calculation.



4. Conclusion

We concluded that the shielding ability of the A was higher when the two kinds of lead glasses were compared (Med-X, A). Med-X was developed for PET and can be made in a considerably large size. The A was produced mainly for use in the fields of atomic energy with the production ranges not greater than 30×30 cm. In this study the lead glasses were confirmed to have sufficient protection effects. The spread of thinner, lighter lead glass with high lead equivalence even with the same effective dose transmission factor is expected in the near future.

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