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CALCULATION OF DOSIMETER RESPONSE FOR IN-HUMAN-PHANTOM MEASUREMENT TO LOW-ENERGY PHOTONS

N. Nariyama[a], A. Konnai[b], S. Ohnishi[b] and N. Odano[b]

[a]Japan Synchrotron Radiation Research Institute, Kouto 1-1-1, Sayo, Hyogo 679-5198, Japan

[b]National Maritime Research Institute, Shinkawa 6-38-1, Mitaka, Tokyo 181-0004, Japan

e-mail:nariyama@spring8.or.jp

Abstract

To estimate local dose given by synchrotron radiation and radiation through shield defect, dose distribution measurement using a human phantom is planned. For the measurement, it is preferable that dosimeters inserted in the phantom are equivalent to each organ material. For the estimation, mass energy-absorption coefficients were compared between thermoluminescent dosimeters (TLDs) and the organ materials used in the phantom for 10-200 keV photons. The calculated energy response is known not to agree with the actual response for some TLDs. The true responses in the organ materials were estimated by using the discrepancy between the measured and calculated responses in the air. Moreover, by considering other dosimetric factors such as sensitivity, it was concluded that LiF is suitable in the most organs and Mg_2SiO_4 is fitting for bone.

1. Introduction

When exposed to beam-shape radiation such as synchrotron radiation and radiation emitted through shield defect, dose is given to local area of the body. In the condition, conversion factors for effective dose assuming total-body irradiation is not applicable and personal dosimeters are not effective if the position the radiation hit is not clear.

For the narrow-beam irradiation, Pelliccioni has calculated organ doses and effective dose for 30 keV to 1 MeV photons using a FLUKA code[1)]. For synchrotron radiation, Nordstrom et al. have calculated dose rate to human organs for 33-, 66- and 99-keV x rays[2)]. Monte-Carlo transport codes increasingly become useful and standard tool for the calculations, and recently a combination with a voxel phantom has made more detail dose-distribution calculation possible[3)]. As for the photon transport calculation between keV and MeV regions, satisfactory accuracy is expectable. For complex geometry such as simulated with a voxel phantom, however, validity of the algorithm used in the calculation codes has to be checked experimentally, for example, by using a human phantom with complex geometries. Moreover, it is useful that the dose distribution obtained can be interpreted almost straightforward for the actual body dose.

In this study, for the estimation of calculation codes combined with a mathematical phantom, a human phantom was prepared and the physical data of the material used was calculated. Using the data, suitable dosimeters for the dose measurement in the phantom were chosen considering the material equivalence and sensitivity.

2. Materials and method

2.1 Human phantom

A human phantom produced is a torso with a head, which simulates a typical Japanese male. The picture is shown in Fig. 1. Main organs such as lungs, liver, kidneys and bones are included. The phantom is sliced horizontally at seven heights and slits for dosimeters are made at each surface. Figure 2 depicts a slice surface, showing lungs. For stomach and oesophagus, hungry condition is assumed.

The CT values of the phantom are shown in Table 1. In ICRP 1990 Recommendations, tissue-weighting factors are assigned to 12 organs and remainder for effective dose[4)]. Constituents of lung, bladder, liver, bone, spleen, kidney and pancreas are distinguished from that of soft tissue and the other organs are considered to be equivalent to the soft tissue, while the positions are marked.

Physical data of mass photon attenuation coefficients, mass energy-absorption coefficients and electron stopping power were calculated corresponding to the CT values of the phantom between 10 keV and 1.5 MeV. The results of mass photon attenuation coefficients and mass energy-absorption coefficients are tabulated in Figs. 3 and 4. The values of electron stopping power were almost the same at all the CT values.

The values of mass energy-absorption coefficients were compared with those for body tissues tabulated in ICRU Report 46[5)]. For liver, the values of the phantom almost agreed with the reference values. On the other hand, for bladder and soft tissue, the values of the phantom became smaller below 100 keV.

2.2 Conditions required for dosimeters

To measure dose distribution in the phantom, dosimeters are set inside and irradiated. As for the radiation field, conditions required for the dosimeters are that the dosimeters does not disturb electron and photon fields and the required correction should be as low as possible: thin and small size and equivalence to each organ are preferable. The degree of the equivalence is estimated by photon energy-absorption coefficients in the energy region of ten to hundreds keV.

For dosimeter selection, high sensitivity and wide-range linearity are also important because the dose in and near the beam is very strong but far from the beam very low dose has to be detected. In this context, thermoluminescent dosimeters (TLDs) of LiF:Mg,Ti (TLD-100), LiF:Mg,Cu,P (GR-200), Mg_2SiO_4:Tb (MSO) and CaF_2 were investigated as the candidate for the practical dosimeters.

3. Results and discussion

Figure 5 shows the comparison of energy-absorption coefficients of the TLDs to those of some organ materials with CT values: LiF is equivalent to most organs. On the other hand, Mg_2SiO_4 is equivalent to bone and CaF_2 is too heavy material even in bone.

Actually, it is known that some TLD responses do not agree with those calculated. Figure 6 shows the comparison of the measured and the calculated energy responses of LiF:Mg,Ti, LiF:Mg,Cu,P and Mg_2SiO_4 in the air at 10-40 keV[6,7)]. The measured response of LiF:Mg,Cu,P is lower below 40 keV and the discrepancy increases with decreasing energy. On the other hand, the measured response of Mg_2SiO_4 became higher than that calculated. The response of LiF:Mg,Ti is enhanced slightly; however, the degree is not so large. Photon attenuation is considered for all the TLDs.

It is difficult to measure directly the energy response in a material other than the air accurately. As a result, the response discrepancy between the experiment and calculation in the phantom material was assumed to equal to that in the air. This supposition will be correct because electrons from the surrounding material do not influence the absorbed dose in the TLDs for the low-energy photon irradiation. Based on the assumption, the responses in Fig. 5 were modified, of which the result is indicated in Fig. 7. The response of LiF:Mg,Cu,P became more similar to the soft tissue below 100 keV and the discrepancy between Mg_2SiO_4 and bone increased slightly.

For the dosimetric characteristics, sensitivities of LiF:Mg,Cu,P and Mg_2SiO_4 are much higher than that of LiF:Mg,Ti. Linearity of LiF:Mg,Cu,P extends to 10 Gy at 30 keV[7)] and for Mg_2SiO_4 supralinearity appears at about 1 Gy for ^{60}Co gamma rays. For both TLDs, thin chips without glass are available.

4. Conclusions

To most of the organs, LiF TLDs are applicable; especially, LiF:Mg,Cu,P is suitable for soft tissue below 100 keV. To bone, Mg_2SiO_4 is adjustable, while LiF:Mg,Ti is also equivalent by similar degree below 30 keV. Using these dosimeters, absorbed doses in the TLDs can be converted to those in the organs without large correction factors.

References

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Table 1 CT value of each organ

CT value	Organ
-7	Soft tissue
10	Bladder
30	Pancreas, Kidney
40	Heart, Bronchi, Brain
50	Spleen
70	Liver
90	Skeleton-cartilage

Fig. 1 Human phantom

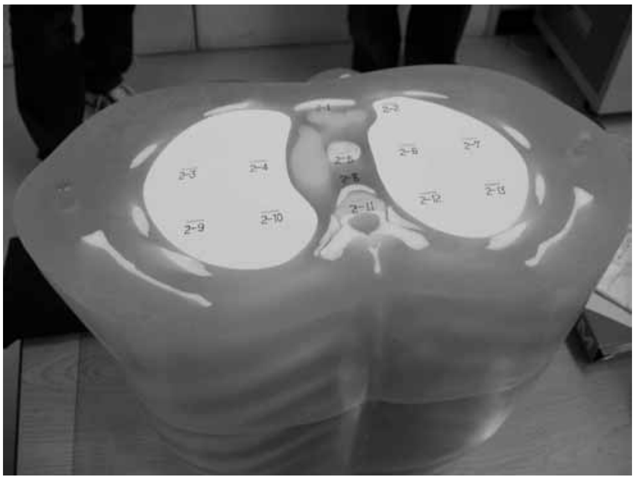

Fig. 2 Cross section of the phantom

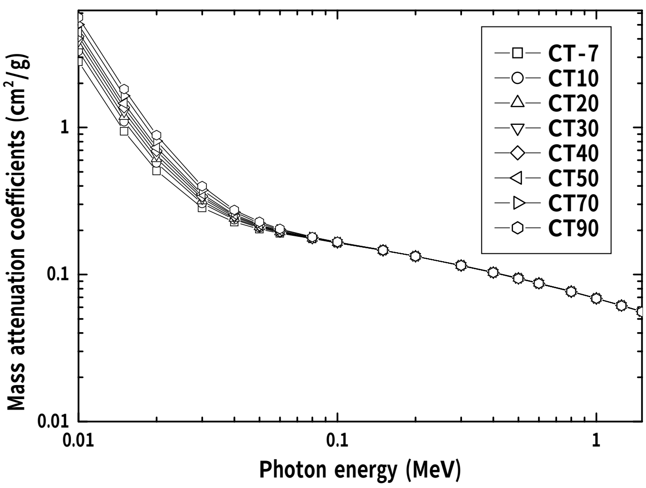

Fig. 3 Comparison of mass attenuation coefficients

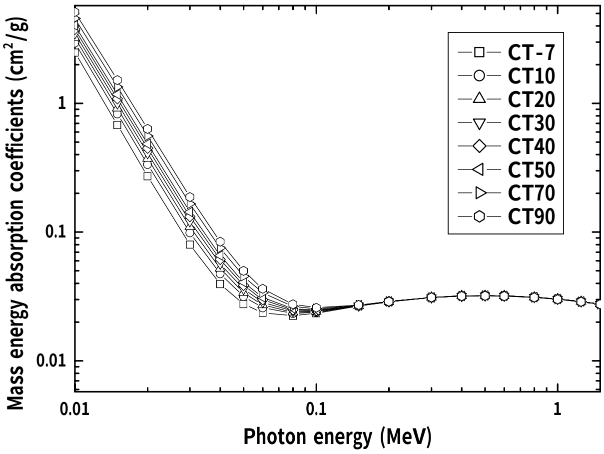

Fig. 4 Comparison of mass energy-absorption coefficients

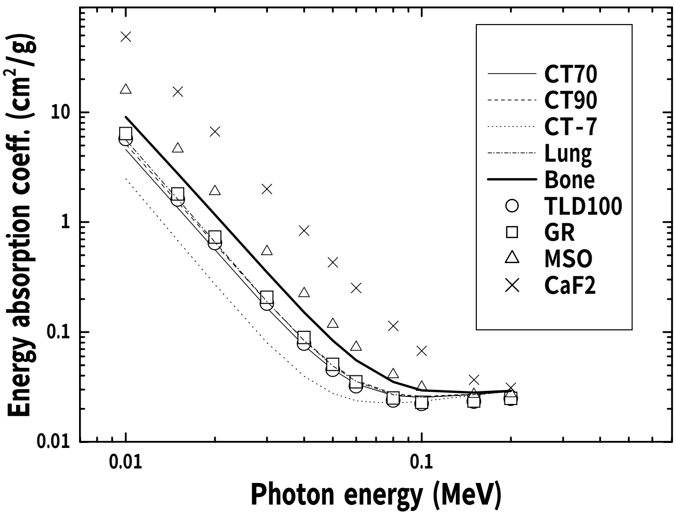

Fig. 5 Comparison of mass energy-absorption coefficients between the organ materials and TLDs

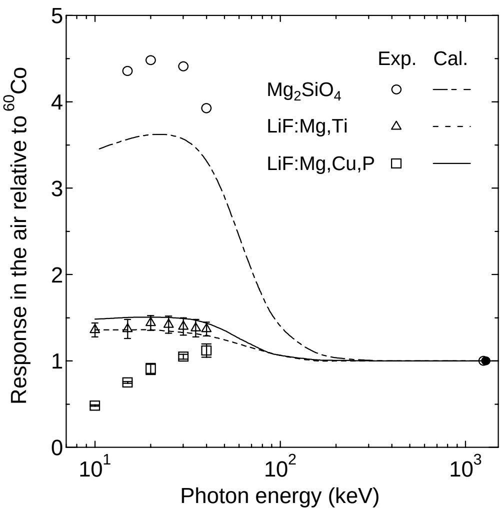

Fig. 6 TLD responses in the air measured with synchrotron radiation[7)]

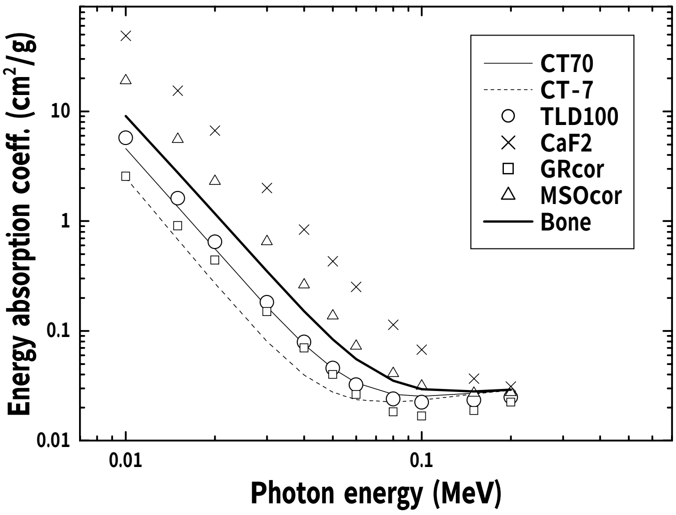

Fig. 7 Modified TLD responses