A new film badge for the measurement of the personal dose equivalent $H_p(10)$ using the gliding-shadow method

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Introduction

The gliding-shadow method (1) is a novel design principle for filters of a personal dosemeter badge which allows the energy and angular dependence of the dosemeter response to be considerably reduced. This is demonstrated with the aid of a new film dosemeter, because film dosemeters are used worldwide in routine individual monitoring predominantly because of their advantages in dose record documentation and in the retrospective investigation of the conditions of exposures. The new film badge was developed and optimized for the new measurand $H_p(10)$.

The gliding-shadow method

In the new film badge, filters are used which have been designed and optimized using the gliding-shadow method. With the gliding-shadow method a filter F of the size of detector D is placed at a certain distance d in front of the detector (see fig. 1). In the case of normal incident radiation, the shadow of the filter exactly hits the detector (fig. 1, on the left). If the direction of radiation incidence changes to oblique angles, the shadow of the filter glides apart and parts of the detector are exposed to unattenuated radiation (fig. 1, middle). The more oblique the angle of incidence becomes, the more the shadow glides beside the detector (fig. 1, on the right). Obviously, the response of the detector increases with increasing angle of incidence, depending on the distance and the thickness of the filter. The variation in the response of a detector shielded in this way is contrary to the variation of the response of detectors shielded with conventional filters, where the filter is much larger than the detector and very close to it ($d \cong 0$). Consequently, the combination of a conventional filter with a filter designed by the gliding-shadow method enables the construction of a personal dosemeter with a low variation of the response even at large angles of incidence over a wide energy range.

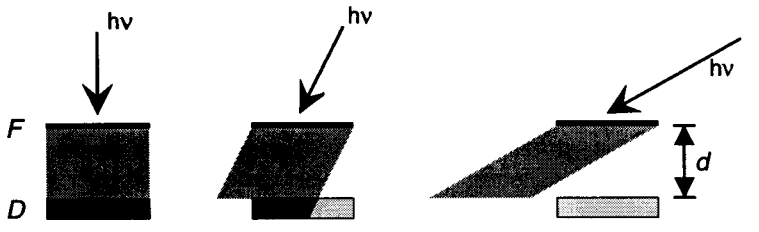

Figure 1. *Principle of the gliding-shadow method: with increasing oblique angle of incidence, the shadow of the filter F glides beside detector D depending on the distance d between filter and detector.*

Design of the new film badge

Due to the strong energy dependence of the response of the bare film, a satisfactorily low variation of the response cannot be achieved with a single filter, even if the gliding-shadow

method is used. It has, however, been found that two filters, a metal filter and a plastic filter, are sufficient. Fig. 2 shows the setup of the two optimized filters. The filters are of circular symmetry in relation to a vertical axis through the center of the respective filter and are designed for a diameter of 8 mm of the detector which is the area on the film directly below the filter. The metal filter is made up of two concentric discs, each consisting of an Sn and Pb layer. A PE disc serves as a spacer between both discs. The plastic filter consists of a thin PE layer (0,5 mm) with a PE ring 2 mm thick arranged below. Thus the gliding shadow is replaced by a gliding illuminated area. This design is necessary, because, at low energies, the bare film itself has nearly the required response to $H_p(10)$ at normal incidence, and only at oblique incidence is an additional shielding necessary to simulate the additional attenuation due to the longer path through the 10 mm ICRU tissue layer in the definition of $H_p(10)$.

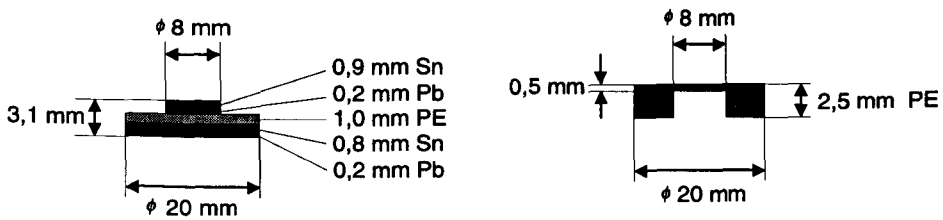

Figure 2. Design of the metal filter (on the left) and of the plastic filter (on the right) in the new film badge. A set of identical filters is placed below the film.

Results and conclusions

The performance of the dosemeter was tested using X-ray fields of the ISO narrow spectrum series with mean photon energies ranging from 17 keV to 250 keV, gamma radiation of ^{137}Cs and ^{60}Co, and high-energy photon fields of 4,4 MeV and 6,7 MeV. The X-ray irradiations were carried out on slab phantoms (size 30 cm × 30 cm × 15 cm) according to ISO/CD 4037-3 at a distance of 250 cm from the focus of the X-ray tube, the irradiations with ^{137}Cs and ^{60}Co at a distance of 100 cm from the gamma source and the irradiations in the high-energy photon fields at a distance of 50 cm from the source. The angle of incidence α ranged from normal incidence (0°) to 75°.

The conventional true value of the personal dose equivalent for the ISO water slab phantom, $H_p(10)$, was calculated from the air collision kerma K_a using appropriate conversion coefficients from ISO/CD 4037-3. The dose values, H_{pla} and H_{met}, were obtained by first measuring the optical density on the film behind the plastic filter and the metal filter as mean values over areas 8 mm in diameter which are fixed irrespective of the angle of incidence. In the second step, these values of the optical density were converted to the dose values using calibration curves and corrections for the background. The calibration curves of H_{pla} were obtained with X-rays with a mean photon energy of 37 keV, and those of H_{met} with gamma radiation of ^{137}Cs.

The measured dose value M_p of the whole dosemeter results from a linear combination (2, 3) of the measured values, H_{pla} and H_{met}:

$$M_p = 1{,}05 \cdot H_{met} + 0{,}82 \cdot H_{pla}$$

In fig. 3 the response, i. e. the ratio $M_p / H_p(10)$, is shown as a function of the mean photon energy and of the angle of incidence. The response shows a maximum deviation of ± 34% (dashed lines) from unity over an energy range from 17 keV (N-20) to 1250 keV (^{60}Co) and

over an angular range from 0° to 60°. For angles of incidence of 75°, most of the measured data are within or slightly outside the range of ± 34% except for energies of 17 keV (N-20) and 48 keV (N-60). In the case of high-energy photon radiation with energies of 4,4 MeV and 6,7 MeV, the dosemeter shows an overresponse of between 70% and 110%.

From the ratio H_{pla} / H_{met} of the measured values, an estimation of the mean energy of the incident photon radiation is possible for energies up to about 300 keV.

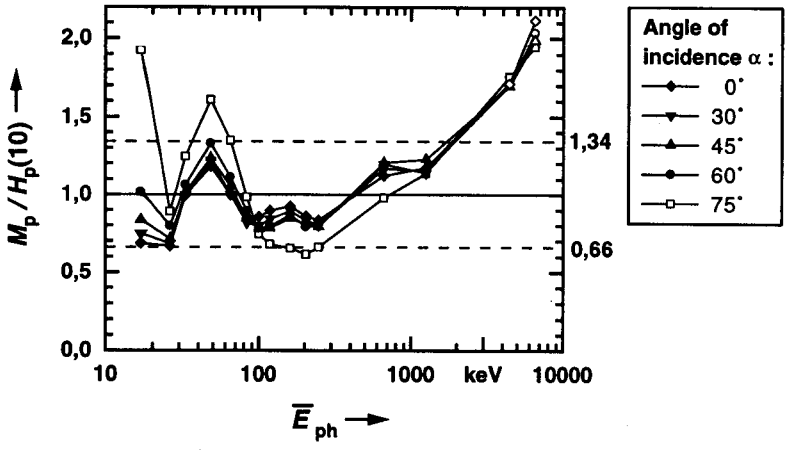

Figure 3. Response of the new film dosemeter to $H_p(10)$ as a function of the mean photon energy $\overline{E}_{ph}$ for different angles of incidence α. The dashed lines indicate a deviation of the response of ± 34% from unity. The open symbols denote irradiation conditions outside the suggested rated range of use, which is 17 keV - 1250 keV for the energy and 0° - 60° for the angle of incidence.

All these results can be obtained by a fully automated read-out procedure, because the measuring positions of the densitometer are fixed. The whole dosemeter is enclosed by a lead shielding frame to prevent incorrect measurements due to radiation incident parallel to the film plane. In addition, the badge contains two small filters which are not used to determine the dose but to detect beta radiation, and four lead pins to determine the direction of the incident radiation.

It is also possible to design other dosemeters, e. g. TL-dosemeters, using the new gliding-shadow method, and to calculate other measurands for the personal dose equivalent by exchanging the coefficients for the linear combination.

Acknowledgement

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