A new laser thermoluminescence dosimetry system for the determination of the personal dose equivalent $H_p(10)$ and the irradiation conditions

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Introduction

For the purpose of radiation protection additional information about the irradiation conditions may be important if a personal dose above a specified threshold is detected. The objective of the development of a new personal dosemeter therefore is to determine the personal dose equivalent with the necessary accuracy and, also, to provide infomation about the irradiation conditions. To fulfil these requirements, a new laser-heated TL dosemeter (TLD) system, commercially available and produced by International Sensor Technology Inc. has been modified. A new algorithm based on linear programming (1, 2) is applied to improve the dose determination. A TL-sheet is inserted into the dosemeter badge to allow information to be obtained about the irradiation conditions.

Laser TLD system

The unique feature of the dosemeter (Figure 1) used in the laser TLD system is a $CaSO_4$:Tm imaging sheet (image area: 9 mm × 15 mm). The sheet determines the direction of incident radiation by the "shadow" projected by two metal plugs (ø: 1,5 mm, length: 3,8 mm, lead alloy), one arranged above and the other below the sheet. Four $CaSO_4$:Tm elements (3,5 mm × 3,5 mm) (3), each with different filtering, are used to calculate the personal dose equivalent $H_p(10)$, including an estimate of the mean energy of the incident photon radiation. The following four filters are used: plastic material 1,17 mm and 3,30 mm thick, tin 1,40 mm thick and stainless steel 0,25 mm thick.

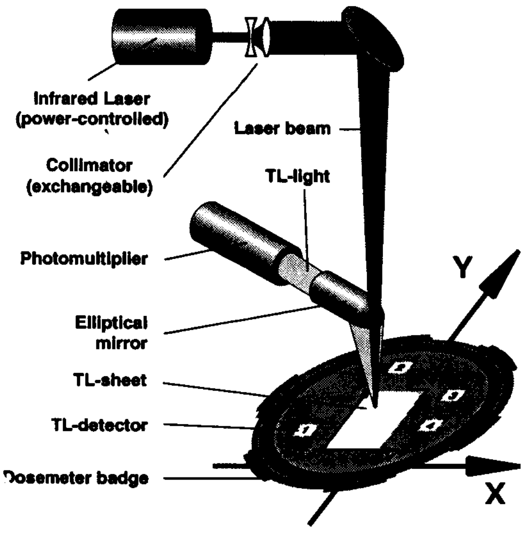

Figure 1. Schematic diagram of the laser TLD system. For evaluation of the TL elements and the sheet, the dosemeter is moved in an x-y plane to place each element in the beam of a power-controlled 10 W CW CO_2 laser (4, 5). A shutter (not shown) is opened for element reading and annealing only. Two types of beam-shaping optics (collimators) are automatically moved into the laser beam. The first type produces a 4 mm × 4 mm uniform heating beam used to read the single elements and anneal both the single elements and the imaging sheet (4, 5). The second type produces a small spot for reading the imaging element with a high spatial resolution (0,3 mm in both the x and the y direction).

Determination of the personal dose equivalent $H_p(10)$

All TL-elements of the dosemeter are calibrated using gamma radiation of ^{137}Cs. The dosemeter is read to determine the personal dose equivalent $H_p(10)$ over an energy range from 17 keV to 1250 keV and over an angular range from 0° to 60° (Figure 2). For dose determinations, information about irradiation conditions is not necessary, because an algorithm based on linear programming is used (1, 2). The algorithm determines the lowest (H_{min}) and the highest (H_{max}) dose values compatible with the signals of the four single elements. The geometric mean of the extreme dose values, H_{min} and H_{max}, is taken as the dose value M_p of the dosemeter. The response matrix (1, 2) used for the calculations consists of the four single element responses to X-ray radiation of the ISO narrow spectrum series (N-30 to N-300) and to gamma rays of ^{137}Cs and ^{60}Co and angles of 0°, 30°, 45° and 60° on an ISO water slab phantom. The maximum difference between the irradiated dose and the dose measured for $H_p(10)$ by this dosemeter determined with linear programming is less than ± 16 % for mixed photon fields in an energy range of 26 keV to 1250 keV and an angular range of 0° to 60° (2).

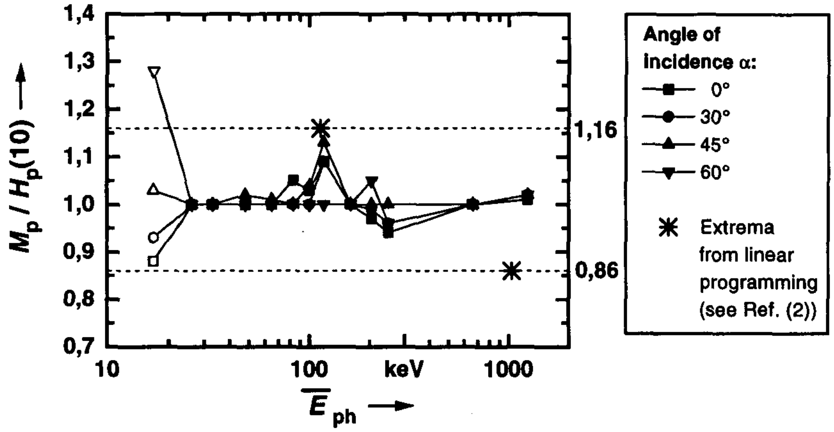

Figure 2. Dosemeter response to $H_p(10)$ using a linear programming algorithm to calculate the dose based on the responses of the four single elements. The radiation energy range is obtained with X-rays of the ISO narrow spectrum series (N-20 to N-300) and gamma rays of ^{137}Cs and ^{60}Co. The open symbols denote irradiation conditions outside the range defined by the response matrix. The dashed lines indicate a deviation of the response of + 16% / − 14 % from unity. The small angular dependence is a result of specially designed filters. $\overline{E}_{ph}$ is the mean photon energy.

Direction of incident radiation

The direction of radiation incidence is determined by scanning a $CaSO_4$ imaging element when the measured personal dose equivalent exceeds a specified threshold. The collimator in the laser beam path will scan the sheet with a 0,3 mm spatial resolution (both in x and y direction). The sheet is annealed by scanning with the large (4 mm × 4 mm) heating beam. The imaging sheet has sufficient sensitivity to provide incident radiation direction information for X-ray (30 kV - 300 kV tube potential) doses higher than or equal to 0,2 mSv.

The direction of incident radiation is inferred from the "shadow" projected by the two lead alloy plugs (one arranged above and the other below the sheet) onto the sheet. If the incident radiation is perpendicular to the sheet, a circular shadow is produced on the image. Non-perpendicular irradiation produces an oval shadow (Figure 3). The two plugs are staggered to distinguish radiation incident from the front or back of the dosemeter.

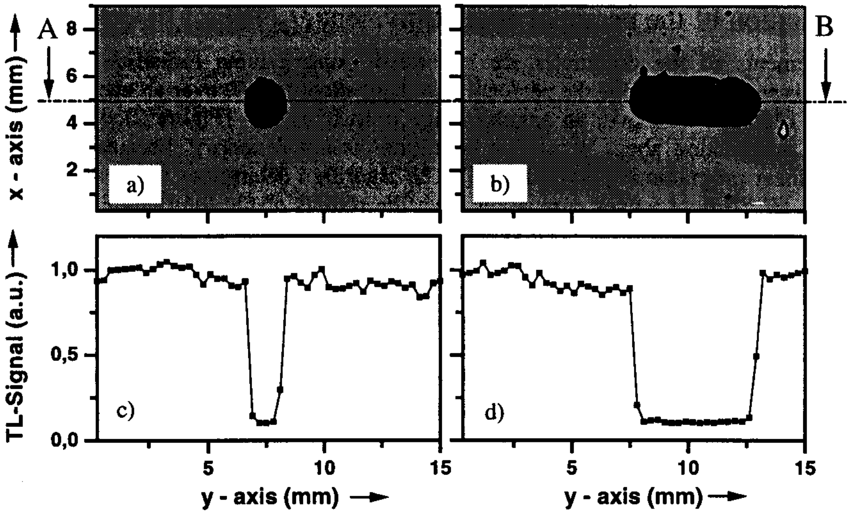

Figure 3. Contour (a, b) and cross section (c, d) plots of the dose distribution of a $CaSO_4$ imaging sheet (9 mm × 15 mm) after irradiation with 1 mSv 60 kV X-rays. The contour plots show that the shadow of the metal plug is circular (a) and oval (b), when irradiation takes place perpendicular or at 45°, respectively, to the imaging sheet. The cross section plots (c, d) show the dose distribution along the line AB as shown in figures a and b.

Conclusions

The laser-heated TLD system has a unique 2-dimensional dose image based on TLD, which provides information about the direction of incident irradiation. The system also allows the personal dose equivalent $H_p(10)$ to be determined with sufficient accuracy for a wide range of the photon energy and the angle of incidence. Besides the features of the system shown here, it also allows the personal dose equivalent H_X to be determined and the mean energy of the incident photon field(s) to be estimated.

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