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Energy and angular dependence of the personal dosemeter in use at ITN-DPRSN

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Abstract

In this paper the characterization of the dosimetry system and of the personal dosemeter in terms of the stability of the reader calibration factors and of the linearity of the response for the 137Cs reference radiation is presented. The energy and angular dependence of the whole body dosemeter are also shown. The energy dependence was determined performing irradiations with the X-ray narrow series beams N30, N40, N60, N80, N100, N120 and with the gamma reference radiations of 137Cs and 60Co [ISO 4037-1, 1996. X and Gamma Reference Radiation for Calibrating Dosemeters and Doserate Meters and for Determining Their Response as a Function of Photon Energy—Part 1: Radiation Characteristics and Production Methods. International Organization for Standardization, Geneva] in terms of Hp(10) incident on the ISO water slab phantom. The angular dependence of the dosemeter was determined for the angles 0°, ±20°, ±40° and ±60° with normal using the above mentioned radiation fields. All irradiations were performed at the Laboratório de Metrologia das Radiações lonizantes of ITN-DPRSN. The experiments presented in this paper show the thermoluminescence dosimetry (TLD) system is stable and presents a linear behaviour over and extended dose range. The measurements allowed the determination of the energy dependence at normal incidence and of the angular dependence of the dosemeter currently in use. Further studies are being carried out in order to implement correction factors for supralinearity and low energy measurements.

Keywords: Type testing; Reading system stability; Dosemeter characterization

1. Introduction/scope

The characterization of a personal dosemeter in terms of its energy and angular dependence is generally called type testing and is performed in standard conditions (ISO 4037-1, 1996; ISO 4037-3, 1999). The type testing experiments provide an important set of parameters to better understand the behaviour of the dosemeter.

The thermoluminescence dosimetry (TLD) system in use at the Individual Monitoring Service (IMS) of ITN-DPRSN is based on two Harshaw 6600 readers and on the Harshaw 8814 dosemeter card and holder. The IMS presently provides whole body dosemeters to 3000 workers in the medical, industrial and research fields of activity, evaluated on a monthly basis.

The whole body dosemeter in use has no algorithm implemented to correct for the energy dependence. However, the system's performance was successfully tested in the intercomparison organized by EURADOS that took place in 1999 (Bartlett et al., 2000) and with irradiations performed at other laboratories in Europe.

In this paper the dosimetry system is characterized in terms of the distribution of the individual element correction coefficients (ECC) of the cards issued to customers, of the stability of the reader calibration factors and of the linearity of the response. The energy and angular dependence of the personal dosemeter in reference conditions is also determined. The results are tested for compliance with national requirements (DL 167, 2002) and with the standard IEC 61066 (IEC 61066, 2006).

2. Materials and methods

The TLD system for individual monitoring is based on two Harshaw 6600 readers and on the Harshaw 8814 dosemeter card and holder. One of the readers incorporates a ^{90}Sr/^{90}Y irradiator used for the determination of ECC and for experiments that

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do not require special irradiation conditions. The TL card contains two elements of LiF:Mg,Ti (TLD-100) detectors for the measurement of the operational quantities, the personal dose equivalents $H_p(10)$ and $H_p(0.07)$.

Nearly 15 600 two-element dosemeter cards are available from different batches, purchased at different times. The TLD cards follow an initialization procedure before they are considered ready to be used, that consists of three cycles of irradiation and readout where the last reading cycle is used for the determination of the individual ECC. All cards have been individually calibrated and are identified as calibration, quality control, field, zero and bad cards, following the suggestions found in the reader and software manuals (Harshaw-Bicron, 1992, 1994) and criteria defined in-house.

Both readers are calibrated using calibration dosemeters that are irradiated at the Laboratório de Metrologia das Radiações Ionizantes (LMRI) of ITN-DPRSN with respect to $H_p(10)$ and $H_p(0.07)$, using a ^{137}Cs beam incident on the ISO water slab phantom. The phantom is a 30 cm × 30 cm × 15 cm PMMA container filled with water, where the front face consists of a 2.5 mm thick plate and the other phantom sides are 10 mm thick (ISO 4037-1, 1996 and ISO 4037-3, 1999).

The readers are calibrated every month at the beginning of each monitoring period for the determination of the reader calibration factors (RCF). The stability of the reading system over the last 5.5 years was determined by calculating the annual average of the RCF, since 2002 till 2007 (July).

Linearity measurements were carried out using field cards chosen at random. Sets of 10 dosemeters were irradiated to the following dose values: 0.1, 0.5, 1, 5, 10, 50, 100, 500, 1000 and 5000 mSv, in terms of $H_p(10)$ in ^{137}Cs.

The energy dependence of the dosemeter was determined for the X-ray narrow series N30, N40, N60, N80, N100, N120, and for the gamma radiation beams of ^{137}Cs and ^{60}Co. Build-up layers of 2 and 4 mm PMMA were respectively used in the ^{137}Cs and ^{60}Co irradiations to ensure electronic equilibrium. For each irradiation eight dosemeters were always irradiated to 10 mSv, in terms of $H_p(10)$. The angular dependence was also studied for the same reference radiations for the following angles: 0°, ±20°, ±40° and ±60° with normal.

The results were compared with the maximum allowed variation ranges mentioned in the national requirements and in the IEC 61066.

3. Results and discussion

3.1. ECC distribution

A total number of 15 600 cards (approx.) are available from different batches as they were purchased at different times. The distribution of the number of cards by ECC intervals is shown in Fig. 1.

ECC for TLD elements in position (ii) or $H_p(10)$ are represented by the grey distribution. Similarly ECC for the elements in position (iii) or $H_p(0.07)$ are represented by the white distribution. Although the total number of cards originated from different batches, the ECC seem to follow a normal distribution pattern.

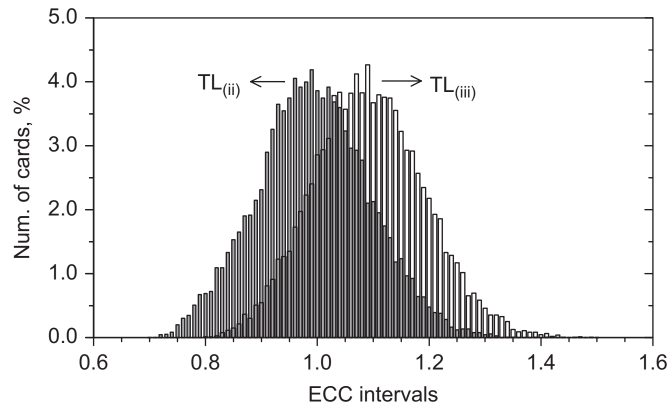

Fig. 1. ECC distribution of the total number of available cards (approx. 15 600): grey pattern—position (ii) that corresponds to $H_p(10)$; white pattern—position (iii) that corresponds to $H_p(0.07)$.

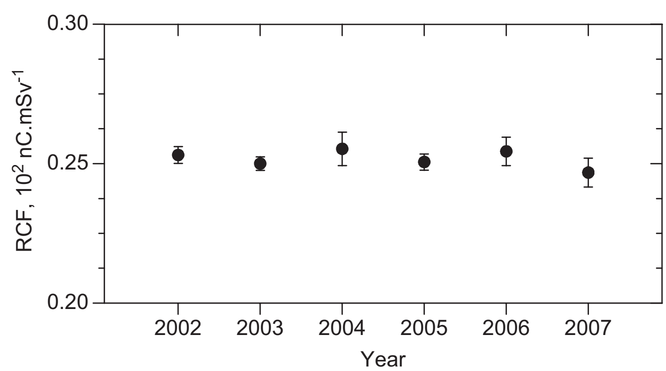

Fig. 2. Annual averages of the RCF, since 2002 until 2007 (July).

Calibration, quality control and zero cards are used at the IMS for different purposes: calibration cards for the determination of the RCF; quality control and zero cards are interspaced with field cards during readout sessions for the assessment of the reader's stability during readouts (Alves et al., 2006a). Only field cards with ECC in the range [0.71, 1.32] are issued to customers. Considering the allowed variation range for the field cards and assuming the ECC follow a normal distribution, the uncertainty associated with the ECC is 10.2% (Bartlett et al., 2000; Fantuzzi et al., 2006).

3.2. RCF stability

The RCF for each operational quantity and for each reader are evaluated on a monthly basis. An analysis of the monthly behaviour since November 2001 to April 2004 is available elsewhere (Alves et al., 2006b).

Annual averages of the RCF values obtained for $H_p(10)$ and for one of the readers, since 2002 until 2007 (July) are presented in Fig. 2, where the error bars are $\pm 1\sigma$ values. The results in Fig. 2 show that the annual RCF values present a stable

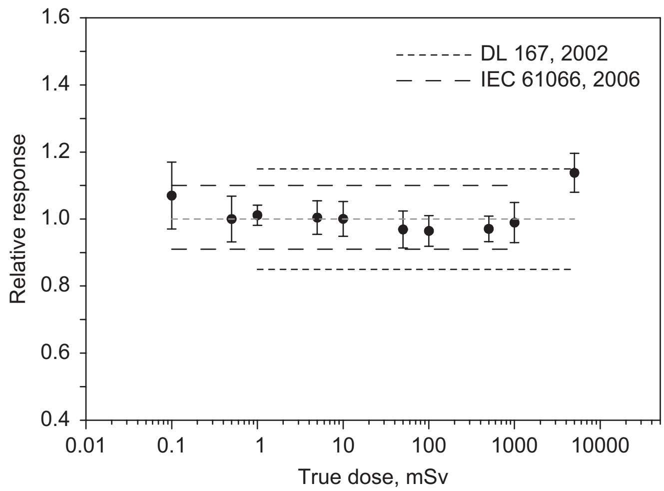

Fig. 3. Linearity curve for 0.1 mSv to 5 Sv dose range. Irradiations performed in the ^{137}Cs radiation beam.

Table 1
Linear regression parameters considering two dose ranges

Range (mSv)	Slope	Intercept	R^2
0.1–1000	0.99	−0.89	0.99993
0.1–5000	1.14	−25.44	0.9992

behaviour, with an average variation of 1.3% over the 5.5 years studied.

3.3. Linearity

A linearity curve represented in terms of the relative response of $H_p(10)$ is presented in Fig. 3, where the error bars are $\pm 2\sigma$ values. A logarithmic scale was used because of the wide dose range that covers several orders of magnitude. In Fig. 3 maximum variation guides (dashed lines) corresponding to different dose ranges are also shown. The short dash guides correspond to the ±15% for the dose range (1 mSv, 5 Sv) as stated in the national requirements. The longer dashed guides are the −9% and +11% for the dose range (0.1 mSv,1 Sv) mentioned in the IEC 61066 standard.

Within the experimental uncertainty the response remained at unity for the (1 mSv, 1 Sv) dose range. However, the readings of 5 Sv irradiation set showed a result higher than expected. For this reason two linear regressions curves were determined, corresponding to two dose ranges (0.1 mSv, 5 Sv) and (0.1 mSv, 1 Sv), and the results are presented in Table 1.

The results in Fig. 3 and in Table 1 show that the reading system presents a linear behaviour, even for the widest dose range studied. However, the slope, the intercept as well as the quality of the fit are improved if the (0.1 mSv, 1 Sv) dose range is considered. This may be due to the onset of supralinearity for doses higher than 1 Sv.

If the 5 Sv value is considered in the linear regression, both the slope and the intercept increase suggesting an increase in the light efficiency process typical of the supralinear behaviour of LiF:Mg,Ti (McKeever et al., 1995).

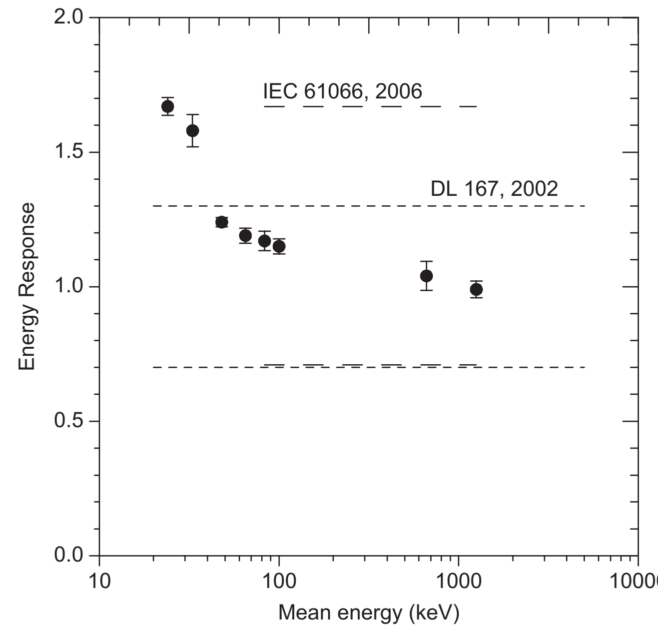

Fig. 4. Energy dependence for normal incidence normalized to ^{137}Cs.

The reading system complies with national requirements but a correction factor should be applied to account for the onset of supralinearity.

In reference to the IEC 61066, the system also has a linear behaviour in accord to the (−9%, 11%) response variation for dose values varying in the (1 mSv, 1 Sv) range.

Further studies are needed for a better understanding of the dosemeter's response in the region of 50–5000 mSv, to confirm the slight underestimation of the dose, followed by the determination of the beginning and extent of the supralinear region and the onset of the saturation region. Saturation of the reading system effects has also been suggested by others (Gilvin et al., 2007), although for the hypersensitive material LiF:Mg,Cu,P. A lower number of cards will be used instead of 10, due to the large residual signal observed after the readouts (∼ 10 mSv for the cards irradiated with 5000 mSv) and due to the irreversible damage that might be induced in the TLD trap system if the saturation level is reached.

3.4. Energy dependence

The energy dependence of the response at normal incidence, normalized to that of ^{137}Cs is presented in Fig. 4 for $H_p(10)$ (error bars are $\pm 1\sigma$ values). The ±30% guides mentioned in the national requirements for the (20 keV, 5 MeV) energy interval (short dashed lines) as well as the −29% and +67% guides (longer dashed lines) mentioned in the IEC 61066 for the energy interval 80 keV to ^{60}Co are also presented.

It can be observed in Fig. 4 that all the results are within the IEC 61066 allowed variation range. However, the low energies of N30 and N40 are outside the ±30% range for the energy interval mentioned in the national requirements.

Both measured values overestimate the true dose value. From a radiation protection point of view, such a measurement would still be on a "safe-side", though reporting a result

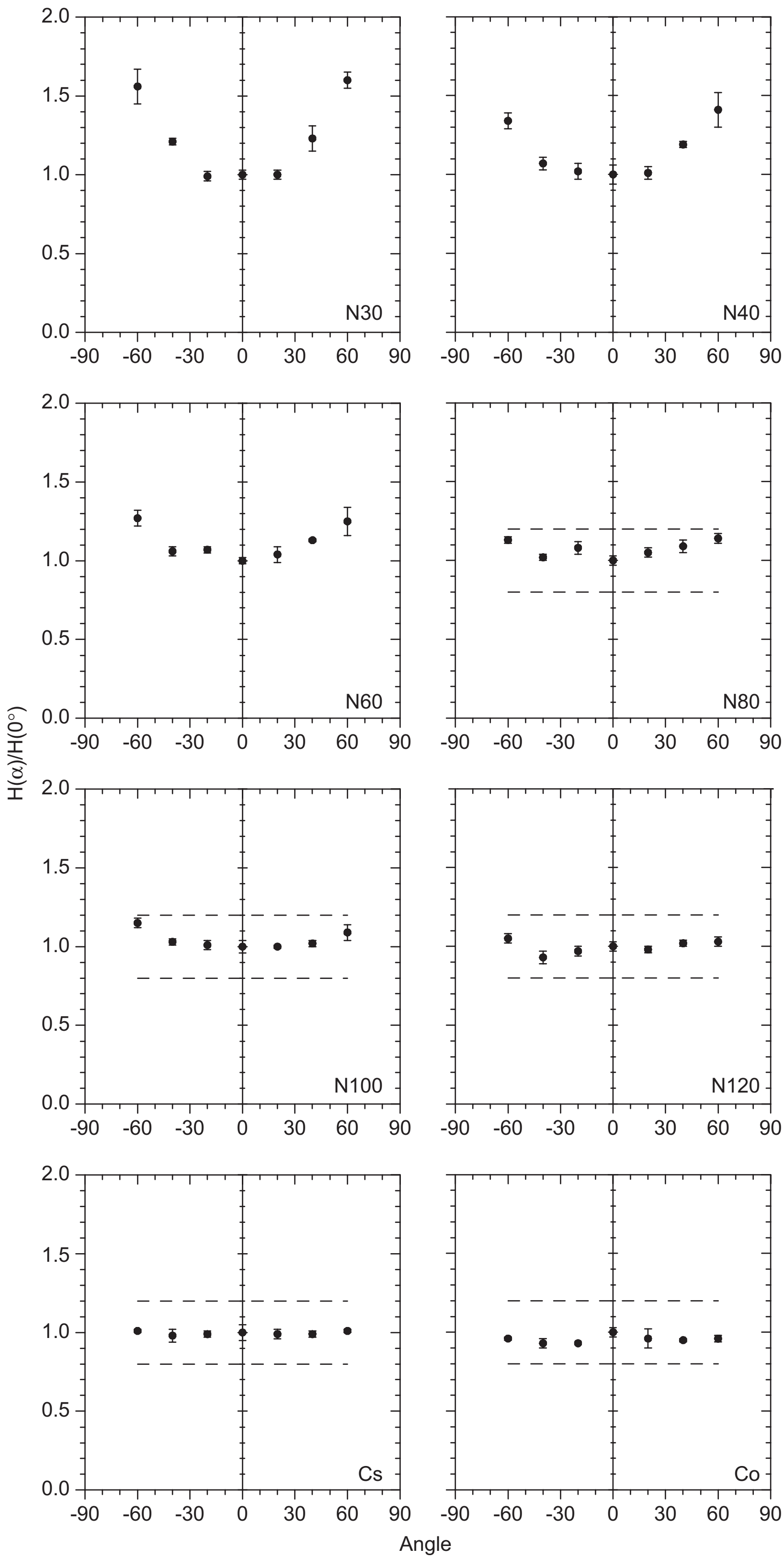

Fig. 5. $H_p(10)$: angular dependence for all irradiation beams studied.

higher than the actual dose value received by the worker. The highest variation observed (around 65%) was obtained for N30.

In general, and due to the energy dependence characteristics of LiF:Mg,Ti, all irradiations with energy below that of ^{137}Cs show a higher relative response and the measured results overestimate the true dose to different extents. The worst cases are those of N30 and N40.

So that all measured values fall within the requested guides, two alternatives are available: the consideration of a correction factor that would equally shift the curve down; or the implementation of an algorithm e.g. based on the quotient of $H_p(10)$ and $H_p(0.07)$ since both readings are simultaneously performed with this dosemeter. Other though more expensive alternatives exist, e.g., changing the dosemeter's holder filtration and/or replacing the sensitive element with a phosphor with better energy dependence, for instance like LiF:Mg,Cu,P (Gilvin et al., 2007; Freire et al., 2007)

3.5. Angular dependence

The angular dependence was determined for the same energies represented in Fig. 4, at ±20°, ±40° and ±60° with normal and the measurements were normalized to normal incidence. The results for the angular dependence are presented in Fig. 5 for $H_p(10)$ (error bars are $\pm 1\sigma$ values).

In this figure ±20% guides for mean energies higher than 60 keV (higher than ISO N80) are represented in the graphs, as national requirements state the angular dependence for $H_p(10)$ should be bellow 20% for angles up to 60° and for energies higher than 60 keV. Within the experimental uncertainty, all the graphs shown in Fig. 5 present a symmetrical behaviour.

Although the ISO N30 to N60 are out of the scope of this requirement, for N40 and N60 (respectively, with mean energies of 33 and 48 keV) the ±60° value is the only value out of the requirement. Whereas for the N30 beam, both ±60° and ±40° values are out of the allowed variation.

The IEC 61066 allows a variation range of (0.71, 1.67) for 0° to ±60° and for mean energies between 80 keV and ^{60}Co. All the results are within this range, even the low energies ISO N30 to N60 which are out of the energy interval.

4. Conclusions

In this paper several experiments were carried out in order to better characterize the response of the dosemeter and the dosimetry system (e.g. distribution of the ECC for the total population of cards, stability of the average RCF over a 5.5 y period, linearity of the response, energy and angular dependences of the dosemeter).

It was observed that the distribution of the ECC of the total card population follows a gaussian shaped curve and that the uncertainty associated to the ECC of the field cards is 10.2%. Over the 5.5 y period, the annual RCF varied 1.3% which indicates that the reading system is reliable and stable.

The linearity of the reading system was characterized in an extended dose range from 0.1 mSv to 5 Sv. The system complies with the requirements, however a correction factor for supralinearity should be considered.

The energy dependence results show that the low energy measurements are overestimated, particularly N30 and N40. At present no correction factor is being applied for these cases. In order to overcome and correct this, a correction factor needs to be implemented or the dosemeter modified (changes in holder filtration or another sensitive element) to meet the national requirement of ±30% for all energies. However, it does comply with the IEC 61066 requirement.

Concerning the angular dependence of the dosemeter, all energies comply with the national requirement of ±20% for mean energies higher than 60 keV. The same applies to the IEC 61066 requirement.

The experiments presented herein allowed the determination of a set of parameters related to the dosemeter and dosimetry system's stability, linearity, energy and angular dependences.

Further studies on the energy correction factor of the dosemeter are needed as well as on the dose response curve for the determination of the supralinearity and saturation regions.

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