Influence of the PMMA and the ISO Slab Phantom for Calibrating Personal Dosemeters

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INTRODUCTION

Wide agreement has been reached among the main Bodies and Organizations involved in standardization of radiation protection to define as operational quantity for individual monitoring of external exposure, the personal dose equivalent, $H_p(d)$ (1,2,3). However, as $H_p(d)$ is defined in the human body, it is not a measurable quantity. In practice, it has to be estimated from the indication of an individual dosemeter, which is worn on the trunk and calibrated on a suitable phantom. The calibration phantom should provide a backscatter contribution, similar to that of the part of the body where the dosemeter is worn. Since its definition in 1985 (4), several reports have been published to clarify and define the experimental set up to be used for the calibration of dosemeters in terms of the above-mentioned quantity. Although the ICRU sphere was first considered to be a good phantom, its practical use presented so many difficulties that it was rejected. On the other hand, other phantoms such as the PMMA slab phantom of different sizes or the IAEA cubic water phantom were adopted. In 1992, ICRU, in its report 47 (5), gave a list of five different phantoms that were being used by several laboratories and were considered to be accurate enough within an accepted overall uncertainty in most radiation protection measurements of 30 %. ICRU 47 also included a new quantity to be used for calibration, which is defined as $H_p(d)$ in a phantom which has the composition of ICRU tissue and the same size and shape as the calibration phantom. In the following text, this phantom will be named as the ICRU phantom. Nevertheless, to achieve uniformity in calibration procedures, ICRU 47 recommended the 30 cm x 30 cm x 15 cm PMMA slab phantom. However, recently, the International Organization for Standardization (ISO), in ISO 4037-3 (3), has proposed another phantom, which will be named, in this text, the ISO phantom, which consists of a 30 cm x 30 cm x 15 cm water phantom with PMMA walls (front wall 2.5 mm thick). Many studies, such as the works from Grosswendt (6) and Gualdrini and Morelli (7), have analysed the characteristics of several practical calibration phantoms by means of Monte Carlo codes for photon transport. Calculations confirm that the new ISO phantom is a better substitute of the ICRU phantom than the PMMA phantom, mainly at low photon energies. The values for the personal dose equivalent for the ISO phantom are found to be very close to those calculated for the theoretical ICRU phantom, thus indicating that, in practice, backscatter correction factors are not needed in this new phantom.

In 1995, the secondary calibration Laboratory from the Institute of Energy Technology (INTE) at the Technical University of Catalonia in Barcelona, Spain, agreed with the Spanish National Laboratory to adopt the ICRU recommended PMMA phantom, and to improve calibration procedure accuracy by introducing a correction factor for backscatter differences in PMMA and ICRU tissue (8). Such corrections were of the order of 8 % for the low-energy X-ray qualities. In 1999, before implementing the new ISO standard the INTE laboratory carried out the present work, whose aim was to estimate the influence of both phantoms when calibrating personal dosemeters with photons in the range 33 keV, 1.5 MeV.

MATERIAL AND METHODS

The study was performed in the INTE secondary Standard Dosimetry Laboratory using the ISO reference radiation qualities defined in ISO 4037-1 (9), corresponding to the X-ray narrow spectrum series and ^{137}Cs. The X-ray beams were produced in a Rich Seifert ISOVOLT 320D X-ray system for dosimetry whose output stability was controlled with a PTW monitor chamber.

The study aimed at analysing the influence of the calibration procedure in the measurement of $H_p(10)$ and $H_p(0.07)$, for the TL dosemeter, used by the INTE approved personal dosimetry service and for the EPD2 electronic personal dosemeter manufactured by SIEMENS. The TLD holder had a 2-mm-thick PVC back surface, whereas the SIEMENS device had a metal case.

Calibration procedure 1:

This procedure is based on the use of the PMMA phantom, which is recommended by ICRU 47 as a practical calibration phantom for personal dosemeters. The phantom is situated at a source-point of test distance of 2.5 m, which ensures a complete irradiation of the phantom. Dosemeters are held to the surface using double-sided stick paper on the front surface. When calibrating, four TLD holders were placed on the front face, centred within an 11-cm diameter circle and irradiated at the same time. Because of its size, only one unit of the electronic device could be calibrated at once.

As described in reference (8), a correction factor, k'_p , for backscatter differences in a PMMA and an ICRU slab phantom was introduced when calibrating TLDs. k'_p was calculated according to the following expression:

$$k'_p = \frac{B_m^{ICRU}}{B_m^{PMMA}} = \frac{(K_m)_{ICRU}}{(K_m)_{PMMA}}, \qquad (1)$$

where B_m^{ν} is the backscatter factor, at a given radiation quality, on a phantom of material m, in a media ν and $(K_m)_\nu$ is the kerma in a media m on the surface of a semi-infinite phantom of material ν. In expression (1), m is the dosemeter material, therefore, for tissue equivalent detectors, as variations of k'_p in air and tissue are within 1%, the following simplification is adopted:

$$k'_p = \frac{(K_{ICRU})_{ICRU}}{(K_{ICRU})_{PMMA}}. \qquad (2)$$

In the energy range considered in this study, the kerma ratio indicated in equation (2) can be substituted by air collision kerma ratio, which in turn can be approximated to dose equivalent at 0 mm depth on the PMMA and on the ICRU tissue slab phantom. Values of k'_p for monoenergetic photon have been obtained from Grosswendt data (6) as the ratio of the dose equivalent in the two phantoms. Values of $\overline{k'_p}$ for the considered X-ray qualities have been calculated by integrating our experimental energy spectral distribution of air kerma:

$$\overline{k'_p} = \frac{\int_0^{E_{max}} K_{air,E}\, k'_p\, dE}{\int_0^{E_{max}} K_{air,E}\, dE} \qquad (3)$$

Radiation quality [1]	**Mean energy (keV)**	**Calibration area diameter** [2] **(cm)**	$h_{pK}(10)$ **(Sv/Gy)**	$h_{pK}(0.07)$ **(Sv/Gy)**	$\overline{k_{p'}}$
N-40	33	16	1.17	1.27	0.925
N-60	48	11	1.65	1.55	0.922
N-80	65	11	1.88	1.72	0.932
N-100	83	11	1.88	1.72	0.943
N-120	100	11	1.81	1.67	0.954
N-150	117	11	1.73	1.61	0.959
N-200	164	12	1.57	1.49	0.966
N-250	207	13	1.48	1.42	0.975
N-300	248	15	1.42	1.38	0.979
S-Cs	662	15	1.21	1.25	0.981

Table 1. Radiation qualities used in the comparison of the performance of the PMMA and the ISO phantoms, conversion coefficients and backscatter correction factors. [1] Radiation qualities produced in accordance to ISO 4037-1. [2] Diameter of the area of the front face, where the dose is approximately within 98 % of the dose in the centre of the phantom (3).

Table 1 lists the radiation qualities chosen for this comparison, the corresponding mean energy averaged over the fluence experimental spectra, the conversion coefficients from air kerma to the personal dose equivalent in a depth of 10 mm and 0.07mm for the ICRU phantom, $h_{pK}(10)$ and $h_{pK}(0.07)$ (3) and the calculated $\bar{k}_p'$ values.

When procedure 1 is used, the calibration factor for the TL dosemeters, N_{TLD}, is defined as:

$$N_{TLD} = \frac{h_{pK}(d) K_a}{\bar{k}_p' M}, \qquad (4)$$

where:
$h_{p,K}$ (d) is the conversion coefficient from air kerma, K_a, to the dose equivalent $H_p(d)$,
M is the corrected dosemeter reading in arbitrary units,
K_a is the air kerma free in air, in the point of test, when there is no phantom.

Previous measurements showed that the SIEMENS dosemeter did not detect the backscatter radiation in the considered energy range. Therefore, the laboratory established that for electronic devices, which usually had thick cases, no backscatter correction would be applied, thus the calibration factor, N_{EPD2}, is calculated as:

$$N_{EPD2} = \frac{h_{pK}(d) K_a}{M}. \qquad (5)$$

Calibration procedure 2:

The experimental set-up is the same as in procedure 1, with the exception of the ISO phantom used in the calibration. As it is accepted that this phantom does not need any special correction for backscatter differences, the calibration factor for any type of personal dosemeter, when applying procedure 2, is obtained by using the same expression as in (5):

$$N_{ISO} = \frac{h_{pK}(d) K_a}{M}. \qquad (6)$$

RESULTS

Tables 2 and 3 show the calibration factors obtained with procedure 1 and 2, respectively for the TLD and the Siemens EPD2. The ratio of the calibration factors corresponding to each calibration procedure, for $H_p(10)$ and $H_p(0.07)$, is also tabulated. Each calibration factor has been calculated, using as dosemeter reading, M, the mean value of the four TLDs or the mean value of three consecutive readings in the electronic dosemeter. The uncertainty associated with the calibration procedures has been estimated following the ISO guide (3). The uncertainty components (k=1) that have been considered in the study are

- $\bar{k}_p'$**:** 1.5%,
- dosemeter reading: 0.85 % for TLDs, 0.2 % for $H_p(10)$ and 0.8 % for $H_p(0.07)$ in the Siemens detector,
- experimental set-up (positioning, output stability) : 1.5 %,
- dose equivalent coefficients: 2 %,
- air kerma reference measurement: 1.6 %.

The overall uncertainties (k=1) associated to the different calibration factors are of the order of 3.4 % for N_{TLD} and 3.1% for N_{EPD2} and for $N_{ISO.}$ The uncertainty budget of the ratio of calibration factors between the two calibration procedures (columns 4 and 7 of tables 2 and 3) does not include the uncertainty for the dose equivalent coefficients nor for the air kerma reference measurement, since these parameters affect in the same way both calibration procedures. Therefore, the uncertainty of the ratio of the two calibration factors is of the order of 2.9 % for the TLD and of 2.4 % for the EPD2 (k=1).

Radiation quality	**$H_p(10)$**			**$H_p(0.07)$**		
	N_{TLD} (mSv/a.u)	**N_{ISO} (mSv/a.u)**	**N_{TLD}/N_{ISO}**	**N_{TLD} (mSv/a.u)**	**N_{ISO} (mSv/a.u)**	**N_{TLD}/N_{ISO}**
N-40	0.766	0.762	1.01	0.163	0.155	1.05
N-60	0.320	0.315	1.02	0.178	0.170	1.05
N-80	0.243	0.237	1.02	0.181	0.174	1.04
N-100	0.218	0.216	1.01	0.179	0.173	1.04
N-120	0.216	0.209	1.03	0.178	0.176	101
N-150	0.210	0.203	1.03	0.182	0.178	1.02
N-200	0.210	0.205	1.03	0.190	0.185	1.02
N-250	0.202	0.200	1.01	0.185	0183	1.02
N-300	0.201	0.196	1.03	0.189	0.187	1.01
S-Cs	0.208	0.203	1.02	0.207	0.204	1.01

Table 2: Calibration factors for $H_p(10)$ and $H_p(0.07)$ for the TL dosemeter of the INTE aproved personal dosimetry sevice, which uses LiF as sensitive material. Comparison between procedure 1 with a PMMA phantom (N_{TLD}) and procedure 2 with an ISO phantom (N_{ISO}). (a.u stands for arbitrary units and corresponds to the TL reader number of counts for a given thermal treatment and sensitivity).

エラー! ブックマークが定義されていません。 **Radiation quality**	**$H_p(10)$**			**$H_p(0.07)$**		
	N_{EPD2}	**N_{ISO}**	**N_{EPD2}/N_{ISO}**	**N_{EPD2}**	**N_{ISO}**	**N_{EPD2}/N_{ISO}**
N-40	0.99	0.99	1.00	0.93	0.93	1.00
N-60	1.09	1.09	1.00	0.93	0.93	1.00
N-80	0.91	0.91	1.00	0.93	0.93	0.99
N-100	0.99	0.99	0.99	1.00	1.00	1.00
N-120	1.13	1.13	1.00	1.10	1.10	1.02
N-150	1.08	1.08	1.00	1.04	1.04	1.01
N-200	0.95	0.95	0.99	0.92	0.92	0.97
N-250	0.92	0.92	1.00	0.92	0.92	1.01
N-300	0.89	0.89	1.00	0.90	0.90	1.00
S-Cs	0.99	0.99	1.00	1.00	1.00	1.00

Table 3: Calibration factors for $H_p(10)$ and $H_p(0.07)$ for an EPD2 SIEMENS personal electronic dosemeter. Comparison between procedure 1 with a PMMA phantom (N_{EPD2}) and procedure 2 with an ISO phantom (N_{ISO}). (N_{EPD2} and N_{ISO} are dimensionless because the dosemeter reading is in mSv).

For the TLD, the mean value of the calibration factor ratio and the corresponding standard deviation, in the studied energy range, was 1.02±0.01 for $H_p(10)$, and, 1.03±0.02 for $H_p(0.07)$. These results indicate a very good agreement, within uncertainties, between the two calibration procedures. Table 2 highlights that, for the TLD holder and material used in the comparison, the introduction of a backscatter correction factor, k'_p, improves the coherence between procedures 1 and 2, mainly for $H_p(10)$ and the low energy qualities from N-40 to N-100. However, at higher energies, and for $H_p(0.07)$ calibration, no significant improvement associated with this correction could be proved. In all the radiation qualities, the calibration factor obtained with the PMMA phantom has been greater than the calibration factor from the ISO phantom, which implies that the correction factors proposed by our Laboratory overestimate the contribution of this radiation component. In particular, for ^{137}Cs, as it is suggested by ISO, no backscatter correction should be used when calibrating with a PMMA phantom.

For the SIEMENS device, the mean value of the calibration factor ratio, in the studied energy range, was 0.996±0.003 for $H_p(10)$, and, 1.00±0.01 for $H_p(0.07)$. Thus demonstrating a perfect coincidence between the two phantoms. This result confirms that the selected electronic personal dosemeter is not sensitive to backscatter and therefore the same calibration factor would be found when calibrating free-in-air.

CONCLUSIONS

The results of this work indicate that although, theoretically, the ISO water phantom is a better substitute of the ICRU phantom, in practice, the differences between PMMA an ISO phantoms are not significant. This conclusion ensures that, in case of changing from the calibration procedure recommended by ICRU to the procedure recommended by ISO, it will not imply any important changes in former dose estimate. This statement which has been proven to be true for specific radiation qualities is even more clear in realistic mixed radiation fields. The accepted photon energy response for personal dosemeters is of the order of ± 30% ^{137}Cs response, thus making negligible the influence of the calibration phantom for the dose assessment. To this effect, from a radiation protection point of view, any of the proposed calibration procedures ensures a satisfactory estimate of the effective dose and therefore the compliance with the established limits.

However, for type testing and for the comparison of the performance of several dosemeters, it is very desirable to achieve international uniformity in calibration procedures. This principle which is general in metrology has been emphasised by ISO and ICRU. Since ISO and IEC recommend the water phantom with PMMA walls for personal dosemeter calibration, accredited laboratories should gradually adopt the new criteria to favour international harmonization and uniform proficiency testing results. One of the advantages of the ISO proposal is that, irrespective of the dosemeter material, the backscatter contribution at the point of measurement is very similar to the backscatter of a theoretical ICRU phantom, thus eliminating the need of estimating the backscatter correction. Nevertheless, the water phantom is more cumbersome and difficult to manipulate than the solid phantom. Precautions have to be taken to guarantee a flat front surface and to prevent leaks and pressure changes in the phantom.

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