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CHARACTERIZATION OF AN ACTIVE DOSEMETER ACCORDING TO IEC 61526:2010

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The active personal dosemeter, RaySafe i2, allows the measurement and record of Hp(10) in real time, every second, via wireless technology for real-time display on a portable computer and/or a local network. The system seems particularly attractive for individual monitoring at clinical facilities where high intensity and varying radiation fields may occur, as it enables the user to acknowledge and optimize the dose and dose rate values in real time for each procedure. Prior to its use, the system was characterized at the Metrology Laboratory of Ionizing Radiation of IST-LPSR aiming at the metrological characterization of the system in accordance with IEC 61526:2010 for metrological control purposes and to verify the technical specifications stated by the manufacturer.

INTRODUCTION

The active personal dosemeter, RaySafe i2, allows the measurement and record of Hp(10) via local area wireless technology for real-time display, e.g. on a portable computer and/or a local network.

The radiation detection and performance data provided by the manufacturer is scarce as it only mentions the dose range limits of operation and the maximum uncertainty tolerance and there is no information about what type of detector is used and its position on the dosemeter. The relevant information about the personal dosemeter specifications is given in Table 1.

This RaySafe i2 dosemeter system of four detectors was acquired in the framework of project PTDC/SAU-ENB/115792/2009 for use in computed tomographic fluoroscopy. Prior to its use the system was tested at the Metrology Laboratory of Ionizing Radiation (LMRI) of IST-LPSR aiming the metrological characterization of the system in accordance with IEC 61526:2010[(1)], using chapter 9 of the standard, called ‘Radiation performance requirements and tests’. The characterization consisted, in the study, of the response and relative response of the dosemeter using N-100 (defined in ISO 4037-1[(2)]) as reference radiation. The system was tested for dose and dose rate linearity, angular dependence (0°, ±45°, ±60°, ±80°), energy dependence, homogeneity and reproducibility, considered essential performance tests for any personal dosemeter for use in radiation protection.

METHODS

Tests performed with the personal dosemeter (numbered from 1 to 4) were done according the proposed ISO 4037 irradiation geometry[(3)]. The personal dosemeter was positioned at 2 m from the X-ray tube focus or from the source, in the case of Cs-137. An ISO water phantom was positioned at the back of the dosemeter, centered. For the measurements with Cs-137 a build-up plate with 2 mm thickness was positioned in front of the dosemeter according to ISO 4037 specifications. The radiation qualities used on this test are the ones described in ISO 4037[(2)], namely the narrow spectra series from 30 to 120 kV. The ISO narrow spectra series specifications of LMRI are presented in Table 2.

The dosemeter performs a measurement each second and registers it on internal memory, which can be downloaded into a data sheet for data analysis. In all the results presented, the error bars represent the uncertainty of each data point, calculated according to GUM[(4)], for a level of confidence of approximately 95%.

RESULTS

Dose rate linearity

For this study, the radiation quality used was the N-100 and the dose rates applied to the dosemeter were 40 μSv/h, 80 μSv/h, 160 μSv/h, 400 μSv/h, 800 μSv/h, 1.6 mSv/h, 4 mSv/h, 8 mSv/h, 16 mSv/h and 40 mSv/h. The relative response results for the set of four dosemeters are shown in Figure 1. Each point represents about 120 measurements (i.e. 120 seconds) of the dosemeter. The gray area represents the limits of variation of the relative response according to IEC 61526:2010.

For the lower dose rates, below 400 μSv/h, the relative response of the dosemeters starts to spread and to exceed the limits proposed by the standard. As the dose rate continuous to decrease, this behavior is more clearly stated.

Homogeneity

Prior to the linearity results obtained, the response, *R*, of the all set of dosemeters was calculated and the results are presented in Figure 2. The results on the response for the four dosemeters tested show above 0.4 mSv/h a constancy on the response with response differences between 31 and 44%. Below 0.4 mSv/h, this behavior increases and over-responses of 2.3, 1.9 and 1.7, and response differences of 90% and 114% at 0.08 mSv/h and 0.04 mSv/h, for Dosemeters 1 and 3, respectively, were obtained. For each data point the number of measurements is about 120.

From the results presented in Figure 2, it is clear that the set of four dosemeters have some heterogeneity on their response results and significant changes appear at lower dose rates.

Accumulated dose

For six independent series of measurements, the dose measured by the personal Dosemeter 1 was

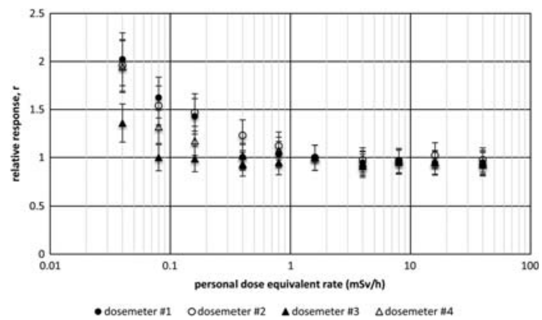

Figure 1. Results on the dose rate linearity of the all set of dosemeters.

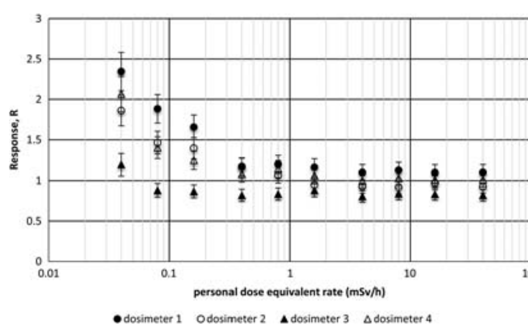

Figure 2. Response results of the overall dosemeters.

Table 1. i2 technical specifications[5].

Characteristic	Range and limits of variation
Operational quantity	Hp(10)
Energy range	33–101 keV
	N-40 to N-100: ±20%
	N-100 to N-120: ±30%
Dose range	1–10 Sv within ±5%
Dose rate range	40 μSv/h to 150 mSv/h within ±10%
	150 mSv/h to 300 mSv/h within ±20%
Angular dependence	±5° within ±5%
	±50° within ± 30%
	±90° within +200%/−100%
Reproducibility	10% or 1 μSv

Table 2. ISO narrow spectra radiation characteristics at LMRI.

Beam code	Voltage (kV)	Mean energy (keV)	Filtration (mm)/material	1st HVL (mm)
N-30	30	24	4.0 Al	1.17 Al
N-40	40	33	4.0 Al + 0.21 Cu	0.083 Cu
N-60	60	48	4.0 Al + 0.6 Cu	0.23 Cu
N-80	80	65	4.0 Al + 2.0 Cu	0.60 Cu
N-100	100	83	4.0 Al + 5.0 Cu	1.13 Cu
N-120	120	100	4.0 Al + 5.0 Cu + 1.0 Sn	1.60 Cu

integrated during 103 seconds and compared with the true value. For this, the radiation quality used was the N-100 and the dose rate applied to the dosemeter was 5 mSv/h.

On the only dose point tested of 0.14 mSv, the accumulated dose differs by +29% relatively to the true value. The standard expresses its limits of variation in relative response, and with only on dose point tested, it was not possible to calculate the relative response. Even then, this value obtained is above the statement of the manufacturer, which uses ±5% as an indication for limitation in the dose measurement in all range of doses indicated in Table 1.

Energy dependence

The energy dependence of the relative response of the personal dosemeter was characterized using the narrow spectra series from ISO 4037 for 30, 40, 60, 80, 100 and 120 kV, described in Table 2, and also for Cs-137, with energy photon emission of 662 keV. The reference radiation to calculate the relative response was the N-100, and the results are presented in Figure 3. For each data point, the number of measurements ranges from 100 to 150. The gray area represents the limits of variation of the relative response according to IEC 61526:2010.

The energy dependence of the relative response ranges from 0.65 (N-40 and Cs-137) up to 1.26 (N-80). For an average energy of 24 keV (N-30), the relative response of the personal dosemeter is about 0.27.

Angle dependence

The angle dependence of the personal dosemeter was investigated for the following angles: 0°, ±45°, ±60°, ±80°, using N-100 radiation quality for the test performance. The results are presented in Figure 4. For each angle the dose rate was 5 mSv/h. For each data point, the number of measurements is 120 and the gray area represents the limits of variation of the relative response according to IEC 61526:2010.

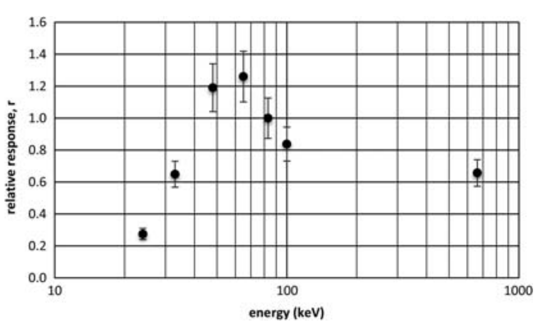

Figure 3. Results for energy dependence of the personal dosemeter.

Angle dependence behavior is similar for all four dosemeters. The relative response at −80° and +80° is not symmetric.

Even the manufacturer states that the range of energies measured by the dosemeter has its maximum at 101 keV, the same study was made using Cs-137 and the results are presented also in Figure 4.

For Cs-137, the angle dependence of the relative response is within −15% and +5%, also not symmetric behavior at ±80°.

Reproducibility

The reproducibility was obtained by irradiating six times for a period of 100 seconds (100 measurements), a single dosemeter (Dosemeter 1) at the same dose rate of 5 mSv·h^{-1} for N-100 radiation quality.

The results show good consistency of the relative response with differences not more than 2.5% with uncertainties between 6.4 and 6.7% (k = 2).

Statistical fluctuations

From the results on the linearity test, the statistical fluctuations were calculated and the results are presented in Figure 5. The gray area represents the limits of variation of the relative response according to IEC 61526:2010.

The statistical fluctuations represent the degree of dispersion on the results of the dosemeter measurement. It is calculated by dividing the standard deviation by the average of a set of measurements. The results show high statistical fluctuations below 80 μSv/h outside the limits indicated in the standard.

DISCUSSION AND CONCLUSIONS

This work has two main objectives. The first objective is to evaluate the dosemeter performance and

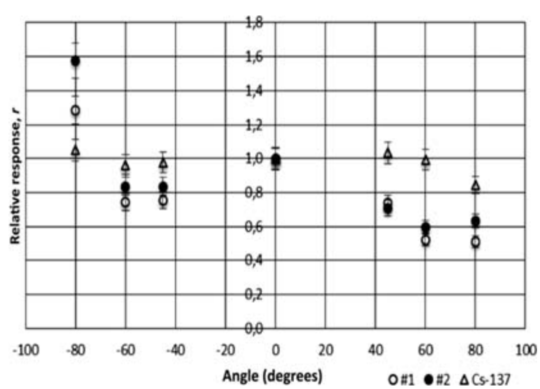

Figure 4. Angle dependence of the personal Dosemeters 1 and 2, relative response at 5 mSv/h for N-100. For Cs-137 radiation quality, the relative response of Dosemeter 1 is also presented.

compare it with the manufacturer specifications as described in Table 1. The second objective is to evaluate the dosemeter performance and compare it with the standard IEC 61526:2010 specifications, described in Table 3, in order to get metrological control approval.

The i2 personal dosemeter has some useful advantages that are the ability to assess the dose rate and dose in real time, which is a very powerful tool for radiation protection management of exposed workers and optimization procedures.

It is evident that the dosemeter has a reliable response to higher energies, namely, Cs-137, with a possible broader applications.

It is concluded that for dose rate linearity at 400 μSv/h and above, the results agree with the requirements of the standard. Below this dose rate, the dosemeters fail on the requirements of the standard. The manufacturer specifications are more restricted than the standard, only above 800 μSv/h the results agree with the statement of the manufacturer.

From the test of accumulated dose, performed only for one value of accumulated dose, 0.143 mSv, the results show that the dosemeter response is

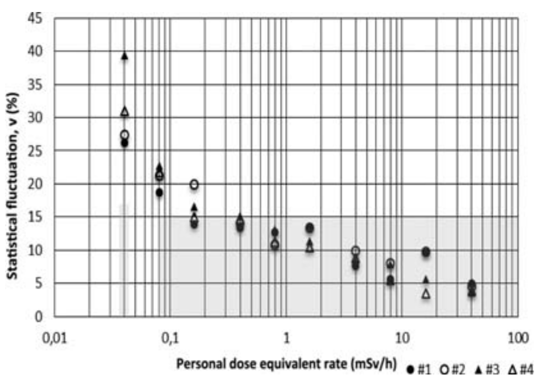

Figure 5. Results on the dose rate statistical fluctuations.

$R = 1.29 \pm 0.14$. This result, for this particular dose point test, is far from the manufacturer statement that gives a range of ±5% for the true value.

The response homogeneity of the set of dosemeters reveals, above 0.4 mSv/h, dispersions between 31 and 44%. Below 0.4 mSv/h, this behavior increases and over-responses of 2.3, 1.9 and 1.7 and response amplitudes between 90% and 114% are obtained.

The energy dependence of the relative response ranges from −73% to +26%. The standard allows −29 to +67% plus the expanded uncertainty of the true value of personal dose equivalent, $H_p(10)$, which for the LMRI and for the radiation qualities used is 4.4%. The dosemeter relative response agrees with the standard specifications for the N-60, N-80, N-100 and N-120 radiation qualities. With the specifications of the manufacturer, only the N-60, N-100 and N-120 radiation qualities are inside the boundaries stated.

The angular dependence relative response of Dosemeter 1, ranges from −49% to +29% and for Dosemeter 2 ranges from −40% to +58%. The standard allows from −29% to +67% plus the expanded uncertainty of the true value (4.4%). In both dosemeters tested, a significant asymmetry of the relative response appears at ±80° and in both dosemeters the relative response at +60° and +80° is outside the boundaries of the standard. The results for Cs-137 show relative responses between −15% and +5%, well inside the permitted range of the standard.

The results on reproducibility show 2.5% of dispersion, which is good, with standard deviations of 6%, which agree with the statement of the manufacturer of 10%.

The statistical fluctuations, ν, range from 39 to 3.5%. Below 80 μSv/h, the higher values are observed outside the requirements of the standard.

Considering linearity of the dose and dose rate response and statistical fluctuations, it is clear that at lower dose rates the dosemeters are not appropriate as active personal dosemeter according to the standard.

Table 3. Radiation characteristics of $H_p(10)$ dosemeters for X and gamma radiation according to IEC 61526:2010 standard.

Characteristics under test or influence quantity	Minimum rated range of influence quantity	Limit of variation of instrument parameter or relative response for whole rated range
Variation of the relative response due to dose and dose rate	100 μSv to 1 Sv and 0.5 μSv/h to 1 Sv/h	−17 to +25%
Statistical fluctuation, ν:	$H_0 \leq H < 11\ H_0$	$16 - (H/H_0)$%
personal dose equivalent	$H \geq 11\ H_0$	5%
Statistical fluctuation, ν:	$\dot{H} < 10$ μSv/h	20%
personal dose equivalent rate	10 μSv/h $\leq \dot{H} < 60$ μSv/h	$(21 - H/(10$ μSv/h$))$%
	$\dot{H} \geq 60$ μSv/h	15%
Radiation energy and angle of incidence	80–1.5 MeV or 20–150 keV 0° to 60° from reference direction under consideration	−29% to +67%

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