Comparison of the Angular Response of Thermoluminescent and Optically Stimulated Luminescent Personal Dosimeters

Filip Haralambos Apostolakopoulos, Nikola Kržanović, Luka Perazić, Koviljka Stanković

Abstract—**Determination of the angular dependence of thermoluminescent (TL) and optically stimulated luminescent (OSL) dosimeters is of great importance for their application in poly-energetic multidirectional photon radiation fields. In order to determine the angular dependence of the dosimeter responses for different photon energies, the dosimeters were mounted on an ISO water slab phantom, irradiated in two narrow beam X-ray qualities (N-40 and N-80) and in one gamma ray quality (S-Cs), defined in IAEA SRS 16. The angles of incidence ranged from 0° to 60°, with an increment of 20°. Two types of TL dosimeters were used: MTS-N (LiF:Mg,Ti) and MCP-N (LiF:Mg,Cu,P) and one type of OSL dosimeters, InLight (Al_2O_3:C). The two types of TL dosimeters have shown a similar deviation from their 0° responses for all the used radiation qualities, while the OSL dosimeters have shown a greater deviation from the reference values for the gamma radiation quality.**

Index Terms—**Angular dependence, OSL dosimeters, TL dosimeters**

I. INTRODUCTION

The performance of personal dosimeters in real-life poly-energetic multidirectional ionizing radiation fields is of great significance for their application by occupationally exposed individuals. One of the most important characteristics of radiation dosimeters is the angular dependence, which represents the variation in their responses with the angle of incidence of the primary radiation beam. Dosimeters usually exhibit directional dependence due to their constructional details, and physical size.

In this paper, the angular dependence was experimentally determined in laboratory conditions for three different radiation qualities. The most widely used personal dosimeters were tested – thermoluminescent (TL) and optically stimulated luminescent (OSL) dosimeters. In a recent paper, the energy and angular dependence of responses of TL and active electronic personal (EP) dosimeters have been compared for various radiation qualities [1]. The personal dose equivalent Hp(10) is used for the approximation of the effective dose of external exposure, and it represents an operational quantity for personal monitoring [2,3]. The Hp(10) personal dose equivalent is defined for the ICRU tissue at the depth of 10 mm in the human body under the position where the dosimeter is worn by the user and is used for strongly penetrating radiation, such as photons [2]. The measured values of the personal dose equivalent take into consideration attenuation and scattering of the incident photon beams but they differ from one person to another and are position dependent. In anisotropic fields, the values of the personal dose equivalent depend on the orientation of the person wearing the dosimeter in the radiation field [4].

II. MATERIALS AND METHODS

TL dosimeters are passive accumulating dosimeters of ionizing radiation. Radiation produces electron-hole pairs while passing through the thermoluminescent material. The generated charge is trapped on discrete energy levels in the forbidden energy zone of the semiconductor crystal (the traps are formed due to existence of impurities in the crystal structure). The number of trapped electron-hole pairs is proportional to the number of pairs generated inside the crystal by the effects of ionizing radiation. The recombination of electron-hole pairs is induced by heat at a certain temperature. This process is followed by the emission of photons. A photomultiplier tube can then convert these emitted photons into electrical pulses, the count of which reflects the intensity of emitted light, that is proportional to the absorbed dose in the thermoluminescent crystals [5,6]. The TL dosimeter cards (manufactured by Rados) can hold up to four TL crystals under different filters. The used TL dosimeters contained four MCP-N or four MTS-N crystals [7,8].

OSL dosimeters are, like TL dosimeters, passive accumulating dosimeters of ionizing radiation. The basic principle is the same: exposure to ionizing radiation produces electron-hole pairs, which are trapped on discrete energy

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levels of the crystal. The only difference is that the recombination is induced by light, and not by heat. The emitted photons, which are used to obtain the dose information, have a different wavelength than the photons used for the stimulation. Only about 1% of the generated charge in the crystal is used for the dose information, so the OSL dosimeters can be read multiple times [9]. The InLight OSL dosimeters contained four Al_2O_3:C crystals under metal and plastic filters.

The used types of dosimeters were separately mounted on an ISO water slab phantom with polymethyl methacrylate (PMMA) walls. PMMA has a density of 1.19 g/cm^2 and is made of hydrogen (8.05%), carbon (59.99%) and oxygen (31.96%). The phantom was placed on a rotating horizontal wheel with marked angles of incidence. The distance between the source and the water slab phantom was set to 200 cm. In this manner the whole water slab phantom was in the radiation field. In order to keep that distance unchanged during the experiment, the dosimeters were aligned with the vertical axis of rotation of the wheel (Fig. 1). For each radiation quality and each angle of incidence five MCP-N, five MTS-N, and five InLight dosimeters were irradiated separately at a Hp(10) value of 1 mSv.

A spherical ionization chamber was used to measure the values of the air kerma rates of the N-40 and N-80 narrow beam X-ray qualities and the S-Cs gamma radiation quality [10]. The measurements of the air kerma rates have been repeated 10 times for each radiation quality for the duration of 60 s. The personal dose equivalent rate is related to the air kerma rate by the following equation:

$$\dot{Hp}(10) = h_k \, \dot{K}_{air} \tag{1}$$

The conversion coefficients from the air kerma rate to the personal dose equivalent rate for the used radiation qualities are listed in Table I.

TABLE I
CONVERSION COEFFICIENTS FROM THE AIR KERMA RATE TO THE PERSONAL DOSE EQUIVALENT RATE FOR THE N-40, N-80 AND THE S-CS RADIATION QUALITIES [11].

Radiation quality	Mean energy [keV]	Conversion factor [Sv/Gy]
N-40	33	1.17
N-80	65	1.88
S-Cs	662	1.21

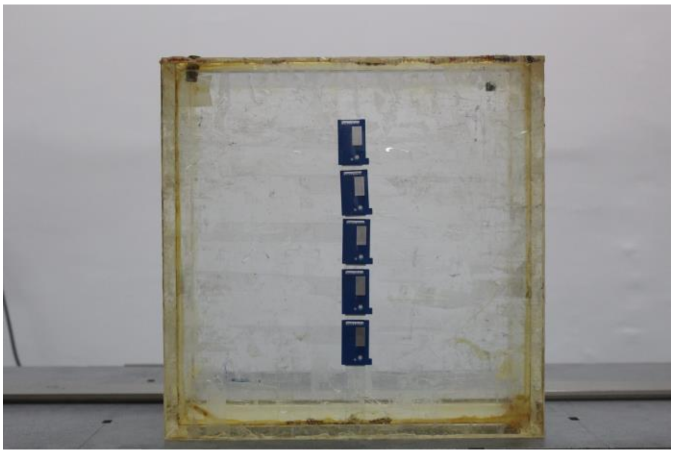

Fig. 1. Five MCP-N dosimeters mounted on the ISO water slab phantom prior to the irradiation.

For the calculation of the measurement uncertainty the Student’s t-distribution was used because the sample size was small (five dosimeters of each type) for all the used radiation qualities. The measurement uncertainty (with the confidence level of 95%) was calculated using the following equation:

$$U = t \frac{s}{\sqrt{n}}, \tag{2}$$

where t is the t-parameter of the Student’s distribution, s represents the standard deviation of the sample, and n represents the sample size [12].

III. RESULTS AND DISCUSSION

After the irradiation, the TL dosimeters were read using a RE 2000 TLD Reader (manufactured by Rados), and the OSL dosimeters were read with a MicroStar InLight Reader (manufactured by Landauer). The angular dependence of the personal dose equivalent was determined for the N-40, N-80 and S-Cs radiation qualities for the angles of 0°, 20°, 40° and 60° [11]. The measured value at 0° was the reference value for all the used dosimeters and all the radiation qualities. The measured values of the Hp(10) personal dose equivalent for the N-40, N-80 and S-Cs radiation qualities, are displayed in Tables II-IV, respectively and are graphically represented on Figs. 2-4, respectively, along with the corresponding measurement uncertainties. Deviation of the measured Hp(10) values from the reference values for the N-40, N-80 and S-Cs radiation qualities are displayed in Tables V-VII, respectively, and are graphically represented on Figs. 5-7, respectively.

TABLE II
MEASURED VALUES OF THE HP(10) PERSONAL DOSE EQUIVALENT IN [MSV] FOR THE MCP-N, MTS-N AND THE INLIGHT DOSIMETERS FOR THE N-40 RADIATION QUALITY AND THE USED ANGLES OF INCIDENCE.

Angle	MCP-N	MTS-N	InLight
0°	0.980	1.014	1.000
20°	0.975	1.037	1.080
40°	0.945	1.018	1.073
60°	0.865	0.920	1.040

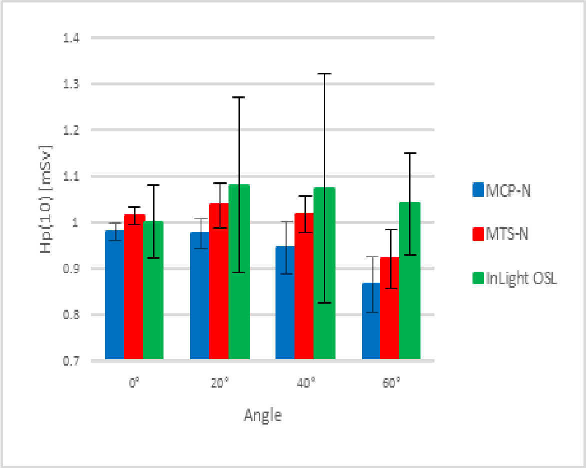

Fig. 2. Graphical representation of the Hp(10) personal dose equivalent in [mSv] for the MCP-N, MTS-N and the InLight dosimeters for the N-40 radiation quality and the used angles of incidence, along with their corresponding measurement uncertainties.

TABLE III
MEASURED VALUES OF THE HP(10) PERSONAL DOSE EQUIVALENT IN [MSV] FOR THE MCP-N, MTS-N AND THE INLIGHT DOSIMETERS FOR THE N-80 RADIATION QUALITY AND THE USED ANGLES OF INCIDENCE.

Angle	MCP-N	MTS-N	InLight
0°	1.101	0.992	1.000
20°	1.117	0.993	1.101
40°	1.060	0.971	1.045
60°	1.000	0.931	0.912

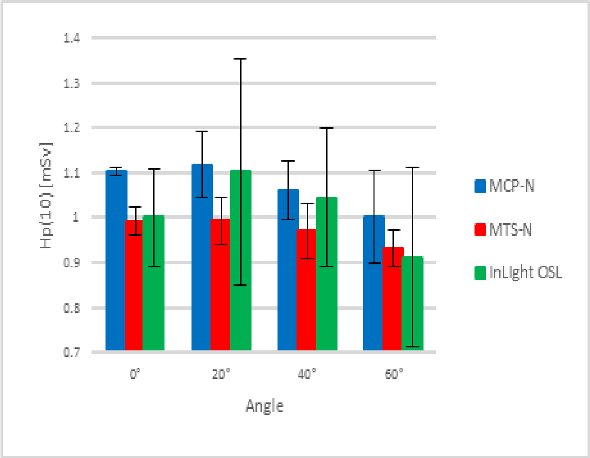

Fig. 3. Graphical representation of the Hp(10) personal dose equivalent in [mSv] for the MCP-N, MTS-N and the InLight dosimeters for the N-80 radiation quality and the used angles of incidence, along with their corresponding measurement uncertainties.

TABLE IV
MEASURED VALUES OF THE HP(10) PERSONAL DOSE EQUIVALENT IN [MSV] FOR THE MCP-N, MTS-N AND THE INLIGHT DOSIMETERS FOR THE S-CS RADIATION QUALITY AND THE USED ANGLES OF INCIDENCE.

Angle	MCP-N	MTS-N	InLight
0°	1.052	1.017	0.966
20°	1.050	1.028	1.060
40°	1.063	1.043	1.096
60°	1.080	1.035	1.036

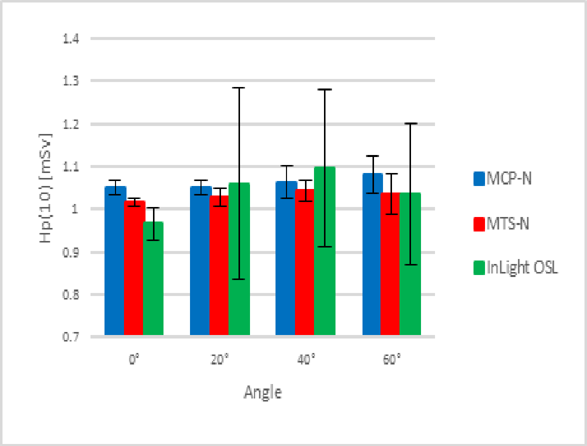

Fig. 4. Graphical representation of the Hp(10) personal dose equivalent in [mSv] for the MCP-N, MTS-N and the InLight dosimeters for the S-Cs radiation quality and the used angles of incidence, along with their corresponding measurement uncertainties.

The maximum measurement uncertainties were 10.32% for the MCP-N dosimeters (calculated for the angle of incidence of 60° and the N-80 radiation quality), 6.36% for the MTS-N dosimeters (calculated for the angle of incidence of 60° and the N-40 radiation quality), and 25.81% for the InLight dosimeters (calculated for the angle of incidence of 20° and the N-80 radiation quality). OSL dosimeters have shown significantly greater measurement uncertainties in comparison to the TL dosimeters.

TABLE V
CALCULATED DEVIATIONS OF THE HP(10) PERSONAL DOSE EQUIVALENT VALUES FROM THE REFERENCE VALUE AT 0° FOR THE MCP-N, MTS-N AND THE INLIGHT DOSIMETERS FOR THE N-40 RADIATION QUALITY AND THE USED ANGLES OF INCIDENCE.

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Angle	MCP-N	MTS-N	InLight
20°	-0.51%	2.27%	8.00%
40°	-3.57%	0.39%	7.30%
60°	-11.73%	-9.27%	4.00%

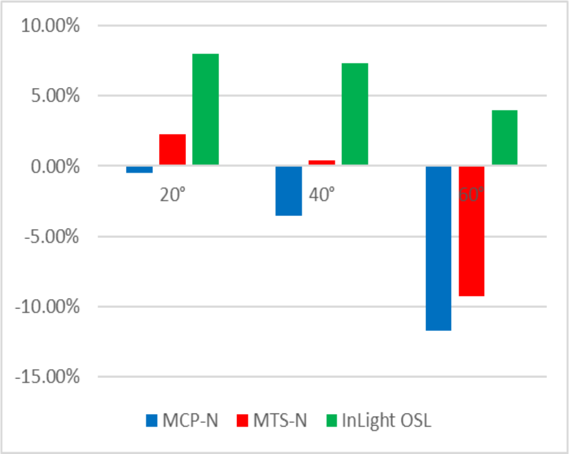

Fig. 5. Graphical representation of the deviations of the Hp(10) personal dose equivalent values from the reference value at 0° for the MCP-N, MTS-N and the InLight dosimeters for the N-40 radiation quality and the used angles of incidence.

TABLE VI
CALCULATED DEVIATIONS OF THE HP(10) PERSONAL DOSE EQUIVALENT VALUES FROM THE REFERENCE VALUE AT 0° FOR THE MCP-N, MTS-N AND THE INLIGHT DOSIMETERS FOR THE N-80 RADIATION QUALITY AND THE USED ANGLES OF INCIDENCE.

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Angle	MCP-N	MTS-N	InLight
20°	1.45%	0.10%	9.17%
40°	-3.72%	-2.12%	4.31%
60°	-9.17%	-6.15%	-9.65%

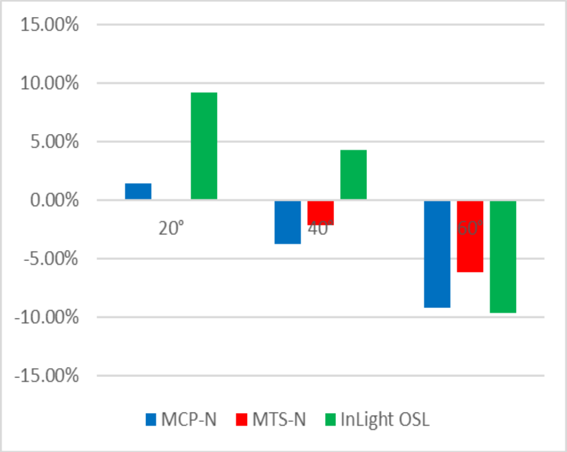

Fig. 6. Graphical representation of the deviations of the Hp(10) personal dose equivalent values from the reference value at 0° for the MCP-N, MTS-N and the InLight dosimeters for the N-80 radiation quality and the used angles of incidence.

TABLE VII
CALCULATED DEVIATIONS OF THE HP(10) PERSONAL DOSE EQUIVALENT VALUES FROM THE REFERENCE VALUE AT 0° FOR THE MCP-N, MTS-N AND THE INLIGHT DOSIMETERS FOR THE S-CS RADIATION QUALITY AND THE USED ANGLES OF INCIDENCE.

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Angle	MCP-N	MTS-N	InLight
20°	-0.19%	1.08%	9.73%
40°	1.05%	2.56%	13.46%
60°	2.66%	1.77%	7.25%

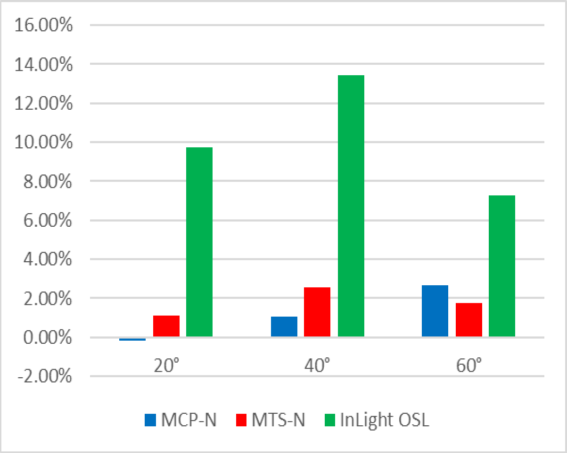

Fig. 7. Graphical representation of the deviations of the Hp(10) personal dose equivalent values from the reference value at 0° for the MCP-N, MTS-N and the InLight dosimeters for the S-Cs radiation quality and the used angles of incidence.

The best performing dosimeters for the 20° angle of incidence were the MCP-N dosimeters with a maximum deviation of 1.45% from the reference value, for the N-80 radiation quality. The MTS-N dosimeters have also performed well, with a maximum deviation of 2.27% for the N-40 radiation quality. At this angle of incidence, the InLight dosimeters have shown a greater overresponse (up to 9.73%) for all the used radiation qualities.

At the angle of incidence of 40° the best performing dosimeters were the MTS-N dosimeters with a maximum deviation of just 2.56% for the S-Cs radiation quality, while the MCP-N dosimeters had a maximum deviation of 3.72% for the N-80 radiation quality. At this angle of incidence as well, the InLight dosimeters had an overresponse (up to 13.46%) for all the used radiation qualities.

At the largest used angle of incidence of 60° MTS-N dosimeters performed best for S-Cs and N-80 radiation qualities with a maximum deviation of 6.15%, while the InLight dosimeters have performed best for the N-40 radiation quality with a deviation of 4.00%. The greatest deviation of MCP-N dosimeters for this angle of incidence was 11.73%.

IV. CONCLUSION

For the angle of incidence of 20° and for all the used radiation qualities, most of the dosimeters showed an overresponse because of the increased distance which the photons cover through the dosimeter crystals. The probability for photons to interact along a linear path segment within the crystal at various angles of incidence can be calculated. However, this is beyond the scope of this paper. For the lower energy narrow X-ray beams the InLight dosimeters showed a lower deviation from the reference value for the angle of incidence of 60° in comparison to the tested TL dosimeters, while for the S-Cs radiation quality the InLight dosimeters showed a significant overresponse in comparison to the TL dosimeters for all the angles of incidence.

Based on the results shown in Tables 2-7 and Figs. 2-7 it can be concluded that the tested MCP-N dosimeters have shown accurate results for all the radiation qualities (maximum deviation of 11.73% from the reference value). This is also true for the MTS-N dosimeters (maximum deviation of 9.27%). The InLight dosimeters had a maximum deviation of 13.46% from the reference value. In addition, it should be taken into account that the InLight dosimeters have shown greater measurement uncertainties in comparison to the TL dosimeters. However, since the TL dosimeters underestimate the dose more often, from a conservative point of view, it could be said that they underperform in comparison to the OSL dosimeters.

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