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TYPE TESTING THE MODEL 6600 PLUS AUTOMATIC TLD READER

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The Harshaw Model 6600 Plus is a reader with a capacity for 200 TLD cards or 800 extremity cards. The new unit integrates more functionality, and significantly automates the QC and calibration process compared to the Model 6600. The Model 6600 Plus was tested against the IEC 61066 (1991–2012) procedures using Harshaw TLD-700H and TLD-600H, LiF:Mg,Cu,P based TLD Cards. An overview of the type testing procedures is presented. These include batch homogeneity, detection threshold, reproducibility, linearity, self-irradiation, residue, light effects on dosemeter, light leakage to reader, voltage and frequency, dropping and reader stability. The new TLD reader was found to meet all the IEC criteria by large margins and appears well suited for whole body, extremity and environmental dosimetry applications, with a high degree of dosimetric performance.

INTRODUCTION

The Harshaw Model 6600 Plus is an automatic reader capable of handling 200 TLD dosemeters or 800 extremity dosemeters in a single loading. The unit uses hot nitrogen gas as a non-contact heating medium to heat the TLDs. A linearly ramped time–temperature profile can be programmed independently for each of the four TLD chips, and the gas temperature is held within $\pm 1^{\circ}$C[1]. This instrument has a servomotor control transport which ensures precise positioning of the TLD card with respect to the heater jets and photomultiplier tubes, especially important for reproducibility of readings[2]. Other features include an optional extremity dosemeter barcode identification compatible with the EXTRAD[3] and DXTRAD[4] systems and an optional ^{90}Sr/Y internal irradiator. Glow curves are displayed graphically, along with light intensity, temperature and channel scaling. The Model 6600 Plus works with an external personal computer to control the reader that provides storage/retrieval of the TLD reading results.

TYPE TESTING PROCEDURES AND RESULTS

The Model 6600 Plus was tested against the IEC 61066 (1991–2012)[5] standard using Harshaw LiF:Mg,Cu,P based TLD Cards: TLD-700H for elements 1, 2 and 3, and TLD-600H for element 4, with chip thickness of 0.38, 0.38, 0.25 and 0.38 mm, respectively.

Calibration

All cards were calibrated. The reader was calibrated before each test readout. The calibration was performed by using the reader's auto-calibration function (Anneal, Expose and Read). The irradiation dose level was set to 2 mSv.

Batch homogeneity

One hundred dosemeters were prepared, irradiated to 1 mSv ^{137}Cs equivalent and read. The criteria require that no two dosemeters in the batch differ from one another by >30%, i.e.

$$\frac{E_{\max}-E_{\min}}{E_{\min}} \leq 0.3.$$

The results show <0.08 for all material types, which is well below the requirement.

Reproducibility

Each test cycle consisted of reading a card twice to clear it, irradiating it to 10 mSv ^{137}Cs equivalent, and reading it again. Ten cards were used and the test cycle repeated 10 times with each card. The standard requires that the relative standard deviation be ≤7.5% for each card for repeatability and each irradiation for uniformity. The values of the standard deviation after applying the ECCs (Element Correction Coefficients), for repeatability and uniformity, are in the range of 0.9–3%. The system easily passed this test.

Linearity

Five groups of five cards were cleared, placed into Harshaw TLD 8840 holders and irradiated to 0.1, 1, 10, 100 mSv and 1 Sv, of ^{137}Cs, respectively. The requirement is

$$0.90 \leq \frac{\overline{E}_j \pm I_j}{C_j} \leq 1.10, \qquad (1)$$

where $\overline{E}_j$ is the average evaluated dose equivalent, I_j is the half-width of the confidence interval, C_j is the

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Table 1. Dose-response performance from 0.1 to 1000 mSv for each channel of the Model 6600 Plus.

	$\frac{\overline{E}_j \pm I_j}{C_j}$ Delivered dose (mSv)				
	0.1	1.0	10	100	1000
Channel 1	1.00–1.07	0.97–1.04	0.99–1.01	0.96–0.99	0.99–1.05
Channel 2	0.99–1.05	1.01–1.02	0.99–1.01	0.97–1.05	1.01–1.08
Channel 3	1.00–1.04	1.01–1.03	0.98–1.02	0.98–1.02	1.04–1.07
Channel 4	1.01–1.06	0.99–1.01	0.98–1.02	0.99–1.01	1.05–1.07

irradiated dose equivalent and j is the jth dosemeter. The results are displayed in Table 1.

Detection threshold

The test was performed by reading 20 cleared cards and computing the dose equivalent. The standard deviation of the measurement $\left(s_{\overline{E}}\right)$was multiplied by 2.0, which is the 95% confidence interval for 19° of freedom. The standard requires that the resulting value be ≤0.1 mSv (100 μSv). A maximum of 2 μSv is reported, thus passing the test.

Self-irradiation

The IEC criteria require that after a storage period of 30 d in a lead house, the zero point shall not exceed a value of 0.1 mSv. The equation used is

$$\left(\overline{E}+I\right)-C_{\mathrm{b}} \leq H, \tag{2}$$

where $\overline{E}$ is the mean of the evaluated value, C_{b} is the background radiation during storage and I is the confidence interval. The system easily passed this test with 0.03 mSv.

Residue

Ten cards were exposed to 100 mSv, ^{137}Cs equivalent and cleared. The detection threshold test was then repeated. The requirement is that:

$$\mathrm{t}_n \cdot s_{\overline{E}} \leq 100\ \mu Sv \tag{3}$$

The same cards were then dosed to 2 mSv, ^{137}Cs equivalent and read again. The standard requires that the readings do not exceed ±10% of the applied dose, using a 95% confidence interval. The results are displayed in Table 2.

Table 2. Residue for each channel of the Model 6600 Plus.

	$t_n \cdot s_{\overline{E}}$(μSv)	$\frac{\overline{E} \pm I}{2}$
Channel 1	4.1	1.05–1.08
Channel 2	2.0	0.97–0.99
Channel 3	0.6	0.98–0.99
Channel 4	1.4	1.04–1.06

Effects of light exposure on the dosemeter

Twenty dosemeters were cleared and assembled. Ten dosemeters (Group A) were placed under a fluorescent light containing two 15 W bulbs, used at a distance of 4 cm and giving a measured light of 800 W m^{-2}. The remaining 10 dosemeters (Group B) were placed in the dark at the same environmental background for 24 h. The zero point drifting:

Table 3. Effects of light exposure on zero point drift (Column 2) and response change (Column 3).

	$\left(\overline{E}_{\mathrm{A}}-\overline{E}_{\mathrm{B}}\right) \pm I$(μSv)	$\frac{\overline{E}_{\mathrm{A}}}{\overline{E}_{\mathrm{B}}} \pm I$
Channel 1	−1.6–0.5	0.99–1.03
Channel 2	−3.2–8.1	0.99–1.01
Channel 3	−0.3–0.9	0.98–1.00
Channel 4	−1.3–3.9	0.98–1.01

$$\left(\overline{E}_{\mathrm{A}}-\overline{E}_{\mathrm{B}}\right) \pm I \tag{4}$$

is required to be less than ±0.1 mSv (100 μSv). The same 20 dosemeters were then cleared, assembled again and irradiated to 10 mSv. Group A was placed under light and Group B was placed in the dark for 1 week. The difference between the two groups:

$$\frac{\overline{E}_{\mathrm{A}}}{\overline{E}_{\mathrm{B}}} \pm I \tag{5}$$

shall be less than ±10%. The system passed by a large margin. See Results displayed in Table 3.

Primary power supply voltage and frequency

Five groups of 10 cards were cleared and dosed to 10 mSv, ^{137}Cs equivalent. The first group (B) of 10 cards was read under normal reader conditions. The second group was read with voltage that was 12% lower and frequency that was 2% below normal conditions (105 V per 58 Hz). The third group was read with voltage that was 10% higher and frequency

Table 4. Performance for each channel of the Model 6600 Plus under various primary power supply voltage and frequency test conditions.

	$\frac{\overline{E}_n}{\overline{E}_B} \pm I,\ n = 2, 3, 4$ and 5			
	105 V/58 Hz	132 V/58 Hz	132 V/62 Hz	105 V/62 Hz
Channel 1	1.00–1.02	0.99–1.02	1.00–1.02	0.99–1.01
Channel 2	0.98–1.00	0.98–1.01	0.99–1.02	0.99–1.01
Channel 3	0.99–1.00	0.99–1.01	0.98–1.00	0.98–1.00
Channel 4	0.99–1.01	0.99–1.01	0.99–1.01	0.99–1.01

that was 2% below normal conditions (132 V per 58 Hz). The fourth group was read with voltage that was 10% higher and frequency that was 2% above normal conditions 132 V per 62 Hz). The last group was read with voltage that was 12% lower and frequency that was 2% above the normal conditions (105 V per 62 Hz). The average readings of groups two, three, four and five must not differ by more than ±5% from that of the first group. The results are displayed in Table 4.

Transient voltage

Three groups of 10 cards were cleared and dosed to 10 mSv, ^{137}Cs equivalent. The first group (C) was read under the normal reader condition. The second group (A) was read under a transient low voltage condition, i.e. the voltage was set 10% below the nominal, then in 1 s decreased to 20% below the nominal and held for 1 s, then returned to 10% below the nominal for 2 s. The third group (B) was read under a transient high voltage condition, i.e. the voltage was set to 10% above the nominal, then in 1 s increased to 20% above the nominal and held for 1 s, then returned to 10% above the nominal for 2 s. The standard requires that, under the voltage transient increase or decrease, the average reading must not differ by more than ±5% from that under normal conditions. The results are displayed in Table 5.

Table 5. Performance for each channel of the Model 6600 Plus under transient voltage test conditions.

	$\frac{\overline{E}_A}{\overline{E}_C} \pm I$ 108/96/108 V	$\frac{\overline{E}_B}{\overline{E}_C} \pm I$ 132/144/132 V
Channel 1	0.99–1.02	0.99–1.01
Channel 2	0.98–1.01	0.98–1.01
Channel 3	0.98–1.00	0.98–0.99
Channel 4	0.99–1.01	0.98–1.01

Effects of climatic conditions on the reader

Eight test conditions are required in this test. In each condition, the reader is evaluated for its zero point drifting and the response changes. The zero point drifting:

$$(\overline{E}_n - \overline{E}_B) \pm I \quad (6)$$

is required to be less than ±0.1 mSv (100 μSv) and the response changes:

$$\frac{\overline{E}_n}{\overline{E}_B} \pm I \quad (7)$$

shall be less than ±10%. A total of 18 groups of 10 cards were cleared and 9 of the 18 groups were irradiated to 10 mSv, ^{137}Cs equivalent. Test condition 1 was groups B_1 (not irradiated) and B_2 (irradiated) read under the normal condition. Condition 2 was the readout performed after 60°C and 65% relative humidity (RH) for 2 h. Condition 3 was 40°C and 65% RH for 2 h. Condition 4 was −10°C and 65% RH for 2 h. Condition 5 was 10°C and 65% RH. Condition 6 was 20°C and 90% RH for 24 h. Condition 7 was 20°C and 90% RH for 6 h with power on. Condition 8 was 20°C and 5% RH for 24 h. Condition 9 was 20°C and 5% RH for 6 h with the power on. The results are displayed in Tables 6 and 7.

Dropping effect on dosemeter

Two groups of 10 cards were cleared and irradiated to 10 mSv, ^{137}Cs equivalent. Group A was dropped from a height of 1 m onto a concrete surface. Group B was not dropped, and kept as a reference. Both groups were read on a Model 6600 Plus. The difference between the two groups

$$\frac{\overline{E}_A}{\overline{E}_B} \pm I \quad (8)$$

shall be less than ±10%. Less than 3% was reported.

Dropping effect on reader

To determine the effect on the reader after being dropped 1 cm, 20 cards were cleared and dosed to 10 mSv, ^{137}Cs equivalent. Ten cards (Group B) were read under normal conditions. Then, after dropping the reader 1 cm onto a wood surface, then the remaining 10 cards (Group A) were read. The

Table 6. Zero point drift for each channel of the Model 6600 Plus under climatic test conditions.

	$(\overline{E}_n - \overline{E}_B) \pm I(\mu Sv),\ n = 2, 3, \ldots, 9$							
	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6	Condition 7	Condition 8	Condition 9
Channel 1	1–3	−4–1	−1–1	−3–0	−4 to −1	−4 to −1	3–5	−2–1
Channel 2	0–1	−4 to −2	−2–0	−3 to −2	−4 to −2	−6 to −1	0–4	−4 to −1
Channel 3	−1–0	−4 to −2	−3 to −2	−4 to −3	−4 to −3	−4 to −2	0–1	−3 to −1

Table 7. Response change for each channel of the Model 6600 Plus under climatic test conditions.

	$\frac{\overline{E}_n}{\overline{E}_B} \pm I,\ n = 2, 3, \ldots, 9$							
	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6	Condition 7	Condition 8	Condition 9
Channel 1	0.93–0.97	0.92–0.95	0.93–0.96	0.92–0.95	0.90–0.93	0.91–0.95	0.93–0.97	0.94–0.98
Channel 2	1.02–1.05	0.99–1.01	1.01–1.04	0.99–1.01	0.99–1.01	0.99–1.02	1.01–1.04	1.01–1.03
Channel 3	1.01–1.03	0.99–1.01	1.01–1.03	1.00–1.03	1.00–1.03	0.99–1.01	1.01–1.03	1.02–1.04
Channel 4	0.95–0.98	0.93–0.96	0.94–0.97	0.93–0.96	0.94–0.97	0.92–0.95	0.96–0.98	0.97–1.00

standards require that the mean values after dropping must not differ by more than ±10% from that of the normal condition. Less than 4% was reported.

Effects of reader light leakage

Two groups of 10 cards were cleared. Group A was read with a fluorescent lamp measuring 800 W m^{-2} illuminating the reader. Group B was read under the normal lab condition. The change of the reader background:

$$(\overline{E}_A - \overline{E}_B) \pm I \tag{9}$$

shall not be >20 and 6.4 μSv was the reported maximum.

Reader stability

Thirty cards were cleared, then dosed to 10 mSv, ^{137}Cs equivalent. After 14 d, the first group of 10 cards (Group C) was read. The next day the second group of 10 cards (Group A) was read. After another 6 d the final group of 10 cards (Group B) was read. Group A must not differ by more than ±5% from Group C. Group B must not differ by more than ±10% from Group C. The results are displayed in Table 8.

Table 8. Reader Stability for each channel of the Model 6600 Plus.

	$\frac{\overline{E}_A}{\overline{E}_C} \pm I$	$\frac{\overline{E}_B}{\overline{E}_C} \pm I$
Channel 1	0.98–1.03	0.99–1.03
Channel 2	0.99–1.01	0.98–1.01
Channel 3	0.99–1.02	0.99–1.02
Channel 4	0.99–1.01	1.00–1.02

CONCLUSION

The Harshaw Model 6600 Plus automatic TLD reader was found to meet the criteria of the Type Test IEC 61066 (1991–2012) by large margins. Equipped with the ability to read both cards and extremity dosemeters, in addition to automatic calibration features, and a built-in $^{90}Sr/Y$ source, this reader is well suited for whole body, extremity and environmental dosimetry applications, with a high degree of dosimetric performance.

REFERENCES

1. Moscovitch, M., Szalancy, A., Bruml, W. W., Velbeck, K. J. and Tawil, R. A. *A TLD system based on gas heating with linear time-temperature profile*. Radiat. Prot. Dosim. **34**, 361–364 (1990).
2. Velbeck, K. J., Szalancy, A. and Bruml, W. W. *An automatic, medium capacity, controlled linear heating TLD system methodology for performance evaualtion*. In: Proceedings of the Tenth International Conference on Solid State Dosimetry (1992).
3. Tawil, R. A., Velbeck, K. J., Rotunda, J. E., Gooley, R., Moscovitch, M. and Wu, C. F. *A system for extremity monitoring*. Radiat. Prot. Dosim. **47**, 445–450 (1993).
4. Duftschmid, K. E., Majevski, M., Michler, E. and Tawil, R. A. *A new TL finger ring dosimetry system with automated ring identification*. Radiat. Prot. Dosim. **66**, 111–112 (1996).
5. International Electrotechnical Commission, International Standard. *Thermoluminescence dosimetry systems for personal and environmental monitoring*. CEI IEC 61066, First edition 1991–2012 (Geneva: IEC).