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Experience of type testing Harshaw advanced TLD system to new IEC-61066 standard

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Abstract

The recently released IEC 61066:2006 standard "Thermoluminescence Dosimetry Systems for Personal and Environmental Monitoring" is a new guideline for type testing a TLD dosimetry system. A few main changes made in this standard include harmonizing the reference radiation and calibration with ISO standards, integrating the basic uncertainty analysis, and aligning IEC uncertainty requirements on dosimetry systems with those stated in ICRP Publication 75. We tested to this standard with an advanced Harshaw TLD system: Model 8800 Plus Reader and LiF:Mg,Cu,P dosemeter. This work describes the more than 10 tests in four major categories and provides the learning experience in uncertainty analysis.

Keywords: IEC-61066; TLD; Harshaw

1. Introduction

The IEC 61066:1991 "*Thermoluminescence dosimetry systems for personal and environmental monitoring*" has been widely used as guidelines in type testing TLD dosimetry systems. It has been recently replaced by its second edition published in 2006. The main changes are in four aspects: 1. specify the use of operational quantities; 2. harmonize the reference radiation and calibration with ISO standards; 3. integrate the basic uncertainty analysis; and 4. align IEC uncertainty requirements on dosimetry system with those stated in ICRP Publication 75. This work is focused on the last two aspects.

In radiation protection dosimetry, the typical dose values are small and fluctuate statistically. Therefore, the coefficient of variation (COV) of the reported dose is an important indicator of the dosimetry system. However, this coefficient of variation fluctuates itself from measurement to measurement. To make this measured COV as close as the true system COV, the more measurements the better. But in reality, it would be very costly in any type test. So what is the least possible number of measurements, which represents a satisfactory certainty, to perform in a type test? Based on the work carried out by Brunzendorf and Behrens, by applying the statistic analysis of the uncertainty, the IEC 61066:2006 standard limits the number of irradiations necessary to combine the tests and use their common references. It also optimizes the number of dosemeters used in each test instead of setting them the same. The important quantity COV is estimated at one or a few test conditions from a limited number of measurements. The interpretation of the results is a learning process for the authors.

As discussed in Brunzendorf and Behrens' work, the checking on if the COV (σ) exceeds the acceptance limit (σ_{max}) is answered by checking the standard deviation $s < \sigma_{max}$ or not. Due to the nature of fluctuation for s, the confidence of $s < \sigma_{max}$ concluded the $\sigma < \sigma_{max}$ is significantly depending on the number of measurements (n) when the measurement is less than 25. To make the type test requirement simple and not increase the number of measurements, parameter c from χ^2-test is introduced when less than 4 data points (w) measured. To further improve the type test protocol, c_1 and c_2 are then introduced, whereas, $s/\sigma_{max} < c_1$ shall be fulfilled for all expect no more than 2 data points (no more than 2 outliers allowed), these two points can not be adjacent, and $s/\sigma_{max} < c_2$ is required. Values of c, c_1 and c_2 are provided for various numbers of data points and measurements in their paper.

2. TLD Dosimetry System

All dosimeters are read on the Harshaw TLD Model 8800 Plus Reader, equipped with the built-in ^{90}Sr/Y beta source. The dosemeter is a standard Harshaw TLD LiF:Mg,Cu,P card, composed of four TL elements. The element arrangement is TLD-100H of 0.36mm, TLD-700H of 0.36mm, TLD-700H of 0.25mm and TLD-600H of 0.36mm, respectively, on element position i, ii, iii and

iv. The readout protocol is: preheat at 165^0C for 10 sec and then read in 13 seconds with heating rate of 15^0C to 260^0C. Unless specified, all irradiations are obtained by the use of this beta source.

3. Type Tests and Results

There are five major test categories and numbers of subcategories specified for the dosimetry system, dosemeter and reader in the new standard, as tabulated in the first two columns of table 4. In this work, the tests performed are: Coefficient of Variation; Non-linear Response; Overload, After-effects and Reusability; Radiation Energy and Angle of Incidence; Additivity of the Indicated Value; Ambient Temperature; Light Exposure and Primary Power Supply.

Coefficient of Variation

The requirements are that the statistical fluctuations of the indicated value should meet: a. 15% for H < 0.1 mSv; b. $(16-\frac{H}{0.1mSv})\%$ for 0.1 mSv ≤ H < 1.1 mSv and c. 5% for H ≥ 1.1 mSv.

Non-linear Response

It is required that the deviation of the dose response should within the range of –9% to 11% over the entire measuring range of 0.1 mSv ≤ H ≤ 1 Sv for photon or beta reference radiation.

These two tests are combined. There are nine groups. Each group contains 5 dosemeter. The groups are irradiated to 0, 0.1, 0.3, 0.3, 1, 3, 10, 100 and 1050 mSv, respectively. Each indicated value, COV and uncertainty is identified according to the standard. The system passed tests and the results are shown in figure 1 and table 1.

Overload, After-effects and Reusability

In this test it is required that a. the system displays an overload message if the dosemeter was irradiated with a dose of $10H_{up}$ or 10 Sv; b. the dosemeter still meets the requirements after a high dose and necessary treatment. c. reuse testing meets all the requirements of this standard.

Four groups of dosemeters are used. The first group is a reference and dosed to 0.3 mSv. The second group is dosed to high dose of 5 Sv. The third group is dosed to 0.1 mSv and the fourth group is first dosed to 10 mSv, followed by annealing and then dosed again to 0.1 mSv. The reader, set to stop when dose reading is higher than 1 Sv, stops and data is marked after reading the second group. The results of the after-effects and reusability are shown in table 2 and 3. They are well below the limit for COV and the range of -9% to 11% for dose.

Radiation Energy and Angle of Incidence for Hp(10) or H(10) Dosemeters and for Hp(0.07) Dosemeters*

These are two sub-category tests. For the Hp(10) dosemeter, the deviation of the relative response at various photon energies and angles within the rated ranges should meet the requirement for Hp(10). For the Hp(0.07) dosemeter, the indicated Hp(10) value due to beta radiation with energies up to the energy equivalent of $^{90}Sr/^{90}Y$ shall be less than 0.1* Hp(0.07).

A range of photon and beta energy and angular tests were performed previously. Their photon energy spans from 17 keV to 1.2 MeV and angles are up to 60 degrees. Data are re-analyzed to verify whether they meet this standard. There are three sets of independent tests. In the first set, there are 5 dosemeters each in 13 data points, which yields c_1 = 1.34 and c_2 = 1.82. The second set has 3 dosemeters each in 24 data points, which yields c_1 = 1.48 and c_2 = 2.08. And for the third set, 4 dosemeters each in 5 data points are tested for beta, which yields c_1 = 1.0 and c_2 = 1.5. The analyzed results are shown in Figures 2 and 3.

One outlier of COV is observed for Hp(0.07) at 50 keV and 140^0 angular, figure 2. All dose responses are within the limits except for a few under-responding points at 60 degrees angle. $0.71-U_{C,com} \le \left(\frac{\bar{E}_i}{\bar{E}_{r,0}} \pm U_{com}\right)\cdot\frac{C_{r,0}}{C_i} \le 1.67+U_{C,com}$

Additivity of the Indicated Value

It is required that the indicated value of the dosimetry system is additive for mixed irradiations, and that $\frac{\Delta E}{E}=\frac{E_K+E_L-E_{K+L}}{E_{K+L}}$ and $-9\% \le \frac{\Delta E}{E} \le 11\%$ are met. The mixture can be in dose value, energy, angle or radiation type.

The test is carried out using an in-house ^{137}Cs and $^{90}Sr/Y$ sources and results are well within ±5%.

Light Exposure (Dosemeter)

The variation of the response due to a change of light exposure within its rated range shall be within a –9% to 11% range. Two groups, one exposed to sunlight and one to normal lab lighting, are compared. They are within ±2%.

Dose Build up, Fading, Self Irradiation and Response to Natural Radiation (Dosemeter)

The requirements are: the variation of the response due to dose build up and fading shall not exceed a –9% to 11% range; the coefficient of variation at the lower limit of the measuring range should meet the specified requirement; the indicated value due to self irradiation and natural radiation shall not differ by more than the lower limit of the measuring range during the maximal rated measuring time. The work is presented on a separated paper.

Reader Stability (Reader)
Ambient Temperature (Reader)
Light Exposure (Reader)
Primary Power Supply (Reader)

The response deviation due to reader stability, or temperature, light exposure, change of power supply voltage and frequency with their rated range should be within –9% to +11% and the coefficient of variation at the lower limit of the measuring range shall fulfil the specified requirements.

In the reader stability test, the reader is only calibrated at the beginning of the test. Twenty dosemeters are irradiated and readout every week up to 15 weeks.

The temperature and light tests are performed outdoors under a bright sunlight at midday in the summer of Ohio, US (42^0C, 48% RH) and in normal lab condition of (23^0C and 58% RH).

In the power supply test, the voltage is changed from -15% to 10% and the frequency is varied -2% to 2%.

All tests are carried out at a lower dose level of 0.7 mSv. At each data point, the COV is identified to verify the $\frac{s_i}{\overline{E}_i} < requirment$ is met. The relative response $\frac{\overline{E}_i}{\overline{E}_2} \pm U_{com}$ is calculated and verified to within 0.98 to 1.02 with the exception of the high temperature test which went to 1.04. The overall result shows it is well below the limit of -9% to 11% range.

It is also required that the total of all variation of the response from the environment should meet $\sqrt{\sum\left(\frac{1}{r_q}-1\right)^2} \leq 20\%$. Our results from the tests performed show the TLDs of these four elements are within 3 – 4%.

4. Summary

In this work, we have practiced on the concept of the basic uncertainty analysis technique on how to deal with the statistical fluctuation in coefficient of variation (COV). Harshaw TLD Model 8800 Plus Reader and LiF:Mg,Cu,P dosemeters are type tested. This system passed the test. Table 4 summarizes the type test categories, requirements and test results

Acknowledgments

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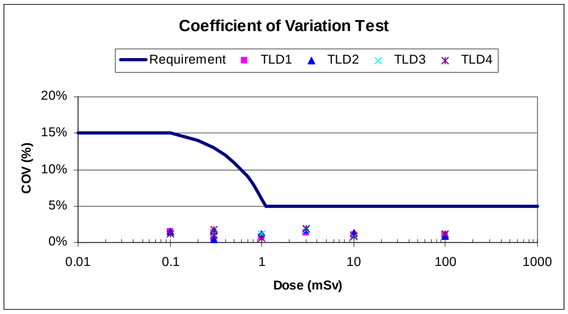

Figure 1: Results of COV in Coefficient of Variation and Non-linear Response Tests.

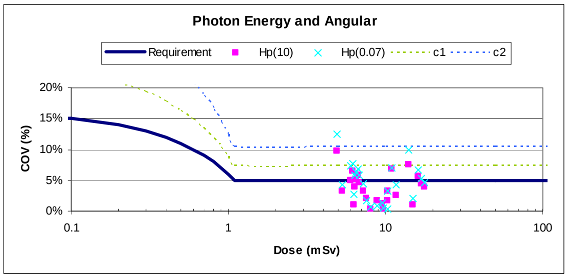

Figure 2: Results of COV in Photon Radiation Energy and Angle Test

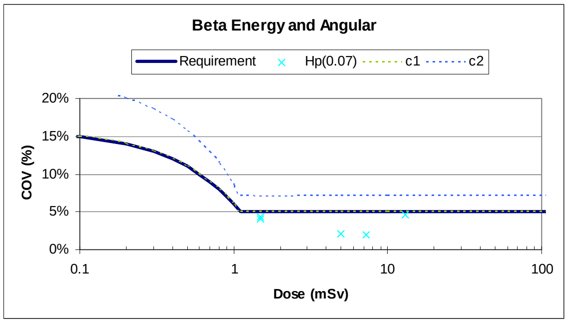

Figure 3: Results of COV in Beta Radiation Energy and Angle Test

Table 1. Results of dose response in Non-linear Response Test.

Exposed (mSv)	$\left(\frac{\overline{E_i}}{\overline{E_{r,0}}} \pm U_{com}\right) \cdot \frac{C_{r,0}}{C_i}$			
	TLD1	TLD2	TLD3	TLD4
0.1	1.03 1.00	1.04 1.01	1.02 0.99	1.01 0.98
0.3	1.01 0.97	1.02 0.98	1.03 0.99	1.02 0.97
0.3	1.01 0.99	1.01 0.99	1.02 0.98	1.02 0.98
1	0.99 0.96	1.02 0.99	1.03 0.99	1.00 0.97
3	1.00 0.96	1.02 0.97	1.04 0.99	1.01 0.96
10	0.99 0.96	1.00 0.97	1.03 1.00	1.00 0.97
100	1.00 0.97	0.98 0.96	1.04 1.00	1.02 0.99
1050	1.03 0.98	1.00 0.97	1.07 1.02	1.03 0.99

Table 2: Results of COV in After-effects and Reusability Test.

Exposed (mSv)		σ_{max}	**COV (σ)**			
			TLD1	TLD2	TLD3	TLD4
Reference	0.3	13%	0.5%	1.3%	1.2%	1.3%
After Effect	0.1	15%	1.4%	1.0%	1.0%	1.3%
Reusability	0.1	15%	1.5%	0.9%	1.3%	1.8%

Table 3: Results of dose response in After-effects and Reusability Test

Exposed (mSv)		$\left(\frac{\overline{E}_i}{\overline{E}_{r,0}} \pm U_{com}\right) \cdot \frac{C_{r,0}}{C_i}$ TLD1	TLD2	TLD3	TLD4
Reference	0.3	1.01 0.99	1.01 0.99	1.01 0.99	1.01 0.99
After Effect	0.1	1.03 1.01	1.04 1.02	1.02 0.99	1.02 0.99
Reusability	0.1	1.04 1.02	1.04 1.02	1.00 0.98	1.02 0.98

Table 4: Summary of test categories, requirements and results

Category	**Sub-category**	**Requirement**	**Result**
Radiation Performance Requirement and Tests (Dosimetry System)	Coefficient of Variation	Each COV within range	Pass
	Non-linear Response	$0.91 \le \left(\frac{\overline{E}_i}{\overline{E}_{r,0}} \pm U_{com}\right) \cdot \frac{C_{r,0}}{C_i} \le 1.11$	Pass
	Overload, After-effects and Reusability	$0.91 \le \left(\frac{\overline{E}_i}{\overline{E}_{r,0}} \pm U_{com}\right) \cdot \frac{C_{r,0}}{C_i} \le 1.11$ and Each COV within range	Pass
	Radiation Energy and Angle of Incidence for Hp(10) or H*(10) Dosemeters	$\left(\frac{\overline{E}_i}{E_{r,0}} \pm U_{com}\right) \cdot \frac{C_{r,0}}{C_i}$	Pass with a few exception of 60 Degrees Angle
	Radiation Energy and Angle of Incidence for Hp(0.07) Dosemeters	Each COV within range.	
	Radiation Incidence from the Side of an Hp(10) or Hp(0.07) Dosemeters	Not Tested	
Additivity of the Indicated Value (Dosimetry System)		$\frac{\Delta E}{E} = \frac{E_K + E_L - E_{K+L}}{E_{K+L}}$ $-9\% \le \frac{\Delta E}{E} \le 11\%$	Pass
Environmental Performance Requirements and Tests	Ambient Temperature and Relative Humidity (Dosemeter)	Separate work	Pass
	Light Exposure (Dosemeter)	Separate work	Pass
	Dose Build up, Fading, Self Irradiation and Response to Natural Radiation (Dosemeter)	Separate work	Pass
	Sealing (Dosemeter)	Not Tested	
	Reader Stability (**Reader**)	$0.91 \le \left(\frac{\overline{E}_i}{\overline{E}_{r,0}} \pm U_{com}\right) \cdot \frac{C_{r,0}}{C_i} \le 1.11$ and Each COV within range	Pass
	Ambient Temperature (**Reader**)	$0.91 \le \left(\frac{\overline{E}_i}{\overline{E}_{r,0}} \pm U_{com}\right) \cdot \frac{C_{r,0}}{C_i} \le 1.11$ and Each COV within range	Pass
	Light Exposure (**Reader**)	$0.91 \le \left(\frac{\overline{E}_i}{\overline{E}_{r,0}} \pm U_{com}\right) \cdot \frac{C_{r,0}}{C_i} \le 1.11$ and Each COV within range	Pass
	Primary Power Supply (**Reader**)	$0.91 \le \left(\frac{\overline{E}_i}{\overline{E}_{r,0}} \pm U_{com}\right) \cdot \frac{C_{r,0}}{C_i} \le 1.11$ and Each COV within range	Pass
	General Interpretation of the Results	$\sqrt{\sum \left(\frac{1}{r_q} - 1\right)^2} \le 20\%$	Pass with performed tests
Electromagnetic Performance Requirements and Tests (Dosimetry System)		See CE compliance document, Report No. EMR2082	
Mechanical Performance Requirements and Tests	Drop (Dosemeter)	Separate work	Pass
	Vibration	N/A to Reader > 15 Kg	N/A