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Linearity Test for Harshaw TLD (Type: TLD-100H) Base on Individual Calibration Method

Luay Abdulsahib Rasool[1], Naashat Raheem Al-Ataby[2], Alaa Fadil Hashim[2]

[1]Nuclear Safety Department, Ministry of Science and Technology, Baghdad, Iraq
[2]Radioecology Department, Ministry of Science and Technology, Baghdad, Iraq

Email address:
luay_abdulsaheb@yahoo.com (L. A. Rasool)

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Abstract: The testing of the individual monitoring instruments is important to demonstrate the performance of the instruments to give accurate measurements in workplace environment. In this research, 18 Thermoluminescence dosimetry (TLD) units were calibrated individually at surface water phantom and exposed with ^{60}Co source at block 32 in Malaysia Nuclear Agency. The TLD were exposed at 5.00 meter distance from the source. The exposed TLD in terms of Personal Dose Equivalent at 10*mm* depth tissue, (Hp (10)) equal to 2.00*mSv*. The exposed TLD then be measured using winRems software from Harshaw TLD reader 6600 plus for defining the calibration factor in term of *mSv/nC*. After that all the 18 unit TLD were tested using linearity testing method and 18 TLD units were exposed with different dose that were 1*mSv*, 5*mSv*, 7*mSv*, 10*mSv*, 15*mSv*, and 20*mSv*. The research is conducted to satisfy two main objectives which was to obtain linear regression coefficient $R^2 \sim 1$ and to show that the ratio of measured value over standard values are within ICRP trumpet acceptance limit curve, which are within (-33% to +50%).

Keywords: Calibration of TLD, Calibration, TLD Dosimetry

1. Introduction

Secondary Standard Dosimetry Laboratory (SSDL) of Malaysia Nuclear Agency (MNA) is a national standard laboratory for ionizing radiation and it is also responsible in supplying, evaluating and analyzing occupational dose for more 20,000 radiation workers in Malaysia. There are more than 2000 radiation workers using Harshaw type thermo luminescence dosimeter (TLD) as their personal dosimeter. TLD is one of the devices when exposed to radiation a visible light will emit from the crystal in the detector and the radiation will be calculated. The amount of light emitted is proportional to the amount of radiation absorbed (dose) by the TL material [1-2]. Radiation dosimetry is basically defined as a measurement, mostly used for the absorbed dose but sometimes used for other relevant quantities like Kerma (kinetic energy released per mass), exposure, equivalent dose or absorbed dose that is produced due to the interaction between radiation and matter. These measurements achieved with the aid of a dosimeter [3]. A dosimeter system is consisting from a dosimeter with a dosimeter reader. The external dosimetry is a measurement of the absorbed dose resulting from any radiation sources which are outside the human body of the exposed workers. The personal dosimeter is used for this type of doses, usually called a "badge", which is worn by the worker all the time they exposing to radiation to ensure that their dose limits is not exceeded, if there is a non-sealed source in the workplace then the radioactive material enters will enter the worker body and will absorbed by his organ or tissues inside his body [4]. Because of this, the internal doses should be taken in our account by using specific monitors, in order to calculate the total effective dose of the body from both internal and external exposure. The absolute dosimeter is used to measure the dose directly without having to be calibrated in a known radiation field on the contrary of relative or secondary dosimeters gives indirect measurements of absorbed dose but needing to calibration by using the primary dosimeter at reference conditions [5] [6]. One of the secondary dosimeter is a TLD that is basically calibrated by using the standard dosimeter (ionization chamber and electrometer). Thermoluminance dosimetry is developed over the years and so many materials are used to see if they are qualified to apply in different areas in dosimetry. Thermoluminance materials are save the information inside their structures when they are exposed after heating these material electrons and holes recombine at luminescence centers as results of this recombination the light is emitted [7] [8] [9]. Light has been measured by using photomultiplier tubes (PMT) that is located inside the reader device and the photons emitted in visible region so they comprise the TL signal [10]. From each trap center one photon was emitted. Therefore, the signal measured is the indicator to the number of the electron/hole pairs and this signal is proportional with the absorbed dose [7] [11].

The basically used of TLDs are for the personal monitoring for the workers who are already works in radiation field with limit more than 0.3 of the equivalent dose limits. A goal from the individual monitoring of the worker is very important to ensure that the worker doesn't exceed the limit of the equivalent dose. They used to measure the absorbed dose of the workers at a specific depth of their bodies, mostly, at 0.07*mm* and 10*mm* (0.07*mm* the effective dose for the skin Hp (0.07) and10*mm* for the dose inside body's organs Hp (10) are measured [12].

In this research, the Thermoluminance dosimeters used for individual monitoring such as LiF (Lithium fluoride) that doped with MgCuP and commercially known as TLD-100H will be examined. At the first, their calibration will be done and then their linearity response will be studied [13].

2. Theory

2.1. Luminescence Phenomenon

Luminescence phenomenon is the process when the material irradiated or absorbs energy emitted photon in the visible region of the electromagnetic spectrum. In the crystal the electron (e) is founds in the valence band (as shown in figure 1-I), when the material is irradiated the electron will moves from the valence to the conduction band, in the conduction band the electron can moves freely [14] [15]. Therefore, the hole (h) remains in the valence band (absence of electron) which also can move inside the crystal, because of the impurities and doping of the crystal the electrons and the holes traps are created in the energy band gap between the valence band and the conduction band, thus the electrons and the holes are trapped at defects (as shown in figure 1-II) [16] [17]. On the other hand, if these traps are deep then the electrons and holes do not have enough energy to escape from the energy gap [18]. By supply the heating on the crystal their energy will be increased and traps will leave and recombine at luminescence centers. As a result of this recombination the light emitted (as shown in figure 1-III) [19].

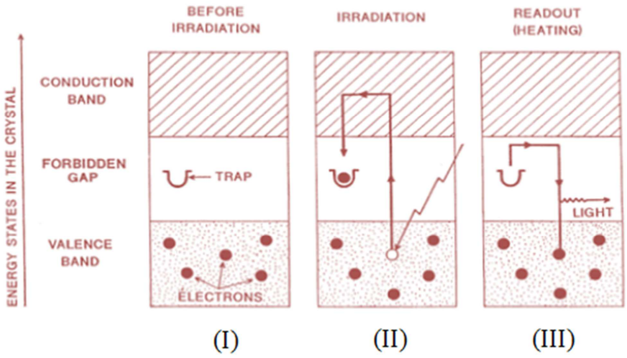

Figure 1. *The thermoluminance dosimetry mechanism.*

The TLD considered one of the integrating detectors that means during the exposure the number of electrons and the holes trapping are the number of the e-/h pairs and every pair emits one photon and the number of photons is equal to the number of charge pairs and it's also proportional to the dose absorbed by the crystal [19].

2.2. Thermoluminance Dosimetry Reader

The schematic diagram and the shape of the TLD reader is shown in figures (2 and 3). The measurement process is done by put the dosimeter in placed on a tray inside the chamber, and then it is heating by heating the coil that is in a good contact with the dosimeter. To reduce the signal produced from the impurities in the air the nitrogen gas is used [20].

Because of the thermoluminescence effect the light is emitted and then passes through the optical filters then enters the PMT through the light guide to measured. The output of the photomultiplier tube (PMT) is proportional to the number of photons generating it is also proportional to the absorbed dose when the output is measured, then the output is converted into pulses which is counted [19]. The device is connected with a computer to measure the output that are either stored in a hard disk or printing by using a printer [20].

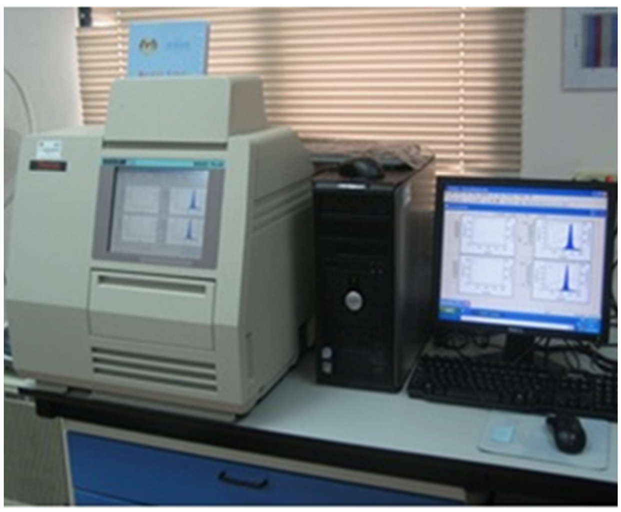

Figure 2. *Automated TLD Card Reader.*

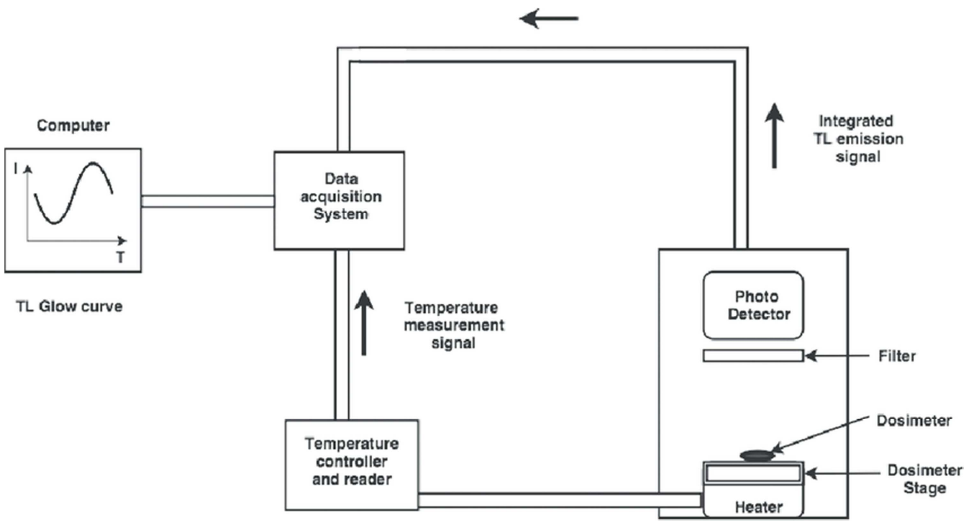

Figure 3. *Schematic of a TLD reader.*

3. Methodology

3.1. Calculate the Exposed Whole Body Dose Rate for Tissue Depth of 10mm, $H'_p(10)$ mSv/Minute from a Relation Below

$$H'_p(10) = K'_{(15/7/2016)}(mGy/min) \times CF_{1.25MeV}(Sv/Gy) \quad (1)$$

Where:
$H'_p(10)$: Personal dose equivalent rate.
K': Kerma rate.
CF: Calibration Factor.
K' at 20/10/2015 is 1.3845*mGy/min*

$$K'_{(15/7/2016)} = K'_{(20/10/2015)} \times e^{\left(\frac{-ln2\times\Delta day}{t_{1/2}(Co-60)}\right)} \quad (2)$$

Δ day = latest date – standard date = 269 day

And,

$$t_{1/2}\ (^{60}\text{Co}) = 1925.20 \text{ day}$$

$$K'_{(15/7/2016)} = 1.2567 mGy/min$$

Then, substitute in eq. (1)

$$H'_p(10) = 1.4452 mSv/min$$

3.2. The Irradiation Time

Calculate the Irradiation Time, t (min) for Each Dose Value, Hp(10) and Record the Reading in Table 1 Below.

Table 1. *The irradiation time corresponding to the personal effective dose.*

No.	$Hp(10)_m$ (mSv)	Irradiation Time (minute)
1	1	0.69
2	5	3.46
3	7	4.84
3	10	6.91
5	15	10.38
6	20	13.84

3.3. Results Analysis:

After the irradiation of all TLD Dosimeters, the TLD Will Be Analyzed Using TLD Automatic Reader, Harshaw 6600 Plus as Shown in Figure 3, Refer to the Working Instruction of the Reader.

3.4. Mathematical Calculations

Record the Reading in Table 2 and Make Some Calculation as Show in Table 3.

Table 2. *The values of the TLDs using the automatic reader (Harshaw 6600 plus).*

TLD Card Number	X, Standard Dose, $Hp(10)_s$ (mSv)	Calibration Factor, (mSv/nC)	Raw Data, (nC)	$Hp(10)_m$ = R (nC) x CF (mSv/nC)		Standard Deviation (STDEV)
				Single Reading	Average, Y	
7513		0.002	549.29	1.09858		
8631	1	0.002	556.99	1.11398	1.16084	0.0948
8604		0.002	634.98	1.26996		
5813		0.002	2803.7	5.6074		
5830	5	0.002	2768.2	5.5364	5.5244	0.0896
7093		0.002	2714.7	5.4294		
7500		0.002	3724.1	7.4482		
5811	7	0.002	3733.4	7.4668	7.3476	0.1904
5805		0.002	3564.5	7.128		
7578	10	0.002	5064.0	10.128	10.2715	0.7680
5807		0.002	4792.6	9.5852		

TLD Card Number	X, Standard Dose, $Hp(10)_s$ (mSv)	Calibration Factor, (mSv/nC)	Raw Data, (nC)	$Hp(10)_m$ = R (nC) x CF (mSv/nC) Single Reading	Average, Y	Standard Deviation (STDEV)
5823		0.002	5550.7	11.101		
5828		0.002	7088.8	14.1776		
5818	15	0.002	7708.0	15.416	15.1278	0.8439
7083		0.002	7895.3	15.79		
8525		0.002	10172	20.344		
7074	20	0.002	10502	21.004	20.61333	0.3463
5630		0.002	10246	20.492		

Table 3. *Some calculation.*

No.	X = $Hp(10)_s$ (mSv)	Y = $Hp(10)_m$ (mSv)	$X^2 = [Hp(10)_s]^2$ (mSv)	$Y^2 = [Hp(10)_m]^2$ (mSv)	X×Y = $Hp(10)_s \times Hp(10)_m$ (mSv)
1	1	1.16084	1	1.3475495	1.16084
2	5	5.5244	25	30.518995	27.622
3	7	7.3476	49	53.987226	51.4332
4	10	10.271	100	105.50371	102.715
5	15	15.127	225	228.85033	226.917
6	20	20.613	400	424.90937	412.2666
SUM	$\sum X = 58$	$\sum Y = 39.43214$	$\sum X^2 = 800$	$\sum Y^2 = 845.117$	$\sum XY = 822.11464$

4. Results

4.1. Plot graph Between Hp(10)m Against Hp(10)s with the Aid of Microsoft Excell Software as Shown in the Figure 4

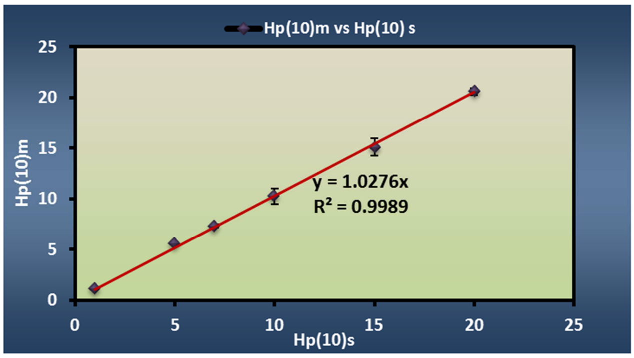

Figure 4. *The plot between the standard values against the measured value.*

4.2. Slop Formula

Find the slop Formula Directly with the Help of Microsoft Excell Software.

4.3. Linearity Factor

Compute the Linearity Factor (R^2) Also Directly by Microsoft Excell Software That Was Equal (0.9989).

4.4. The Measured TLD Are Compared with the Standard TLD for All Values Measured, the Deviation Between the Measured TLD and the Standard TLD Is Computed by Using the Formula [1]

$$\Delta = \frac{(measured\ dose - standard\ dose)}{standard\ dose} \times 100\%$$

Acceptance level of (-33% to +50%) is set for this deviation as mentioned before in the abstract of this research. Six TLD badges were irradiated with $Hp(10)$ of (1mSv – 20mSv) using the average energy of ^{60}Co (1252.5keV). The personal dose equivalent $Hp(10)$ from each card was calculated using the average CF of TLD cards i.e. 0.002mSv/nC. The results are shown in table 4. The percentage deviation of the results is within (16.08% to 0.8%).

Table 4. *The deviation value.*

No.	Standard Dose, $Hp(10)_S$ (mSv)	$Hp(10)_m$ = R (nC) x CF (mSv/nC)	The deviation Δ (%)
1	1	1.16084	16.08
2	5	5.5244	10.488
3	7	7.3476	4.957
4	10	10.2715	2.71
5	15	15.1278	0.846
6	20	20.61333	3

4.5. Compute the Linearity Factor (R^2) by the Mathematical Formula [1]

$$R^2 = \frac{[(N \times \sum XY) - (\sum X \times \sum Y)]^2}{\left[\left((N \times \sum X^2) - (\sum X^2)^2\right) \times \left((N \times \sum Y^2) - (\sum Y)^2\right)\right]}$$

And the value was equal= 0.9988

5. Discussion and Conclusion

In this research, the TLD-100H, fabricated from LiF and doped with Mg, Cu and P, is tested. The reading from TLD value can be determined by multiply the observed reading with the calibration factor for irradiated TLD cards. Then we calculate the linearity factor that was equal R^2~1 which mean that the measured value approaching as near as from the actual value. Then we measured the deviation of the reading of TLD from table 4 that was ranging (16.08% to 0.8%) that's mean the value does NOT exceeded the standard value that is limited by the ICRP (-33% to +50%) and we should be notice that the deviation decreased when the value of the exposure increased that mean the TLD be more efficient in high level exposure. TLD calibration should be done routinely, to ensure a good assessment due to external exposure for individual monitoring.

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