Nuclear Radiation Measurement using Thermoluminescence Technique

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Abstract: In this study, the standard Thermoluminescence dosimetric (TLD) material ($CaSO_4$:Dy) in the form of Teflon discs have been studied for their thermoluminescence property. The TL sensitivity of the $CaSO_4$:Dy Teflon discs has been investigated while irradiating them with gamma radiation emitted from ^{60}Co radioactive source. The discs were calibrated with different radiation exposure and the unknown radiation exposure was estimated using this method. Known $CaSO_4$;Dy discs were collected from the Defence Laboratory DRDO, Jodhpur in the form of Teflon discs which were annealed by putting them in an oven for 4 to 6 hours at 300 ^{0}C. The TL integral count and TL glow curve of the discs were recorded by a TLD Reader. On the basis of the obtained data from our observations using TLD Reader the TL sensitivity of $CaSO_4$:Dy in units of AU/R/mg (Arbitrary unit per Roentgen per milligram) were estimated, where 1 Roentgen is the quantity of X-radiation or gamma radiation that produces an electrical charge of 2.58×10^{-4} Coulomb in a kg of air at standard temperature and pressure (STP). Future prospects of the $CaSO_4$:Dy Teflon discs are discussed.

Keywords: Thermoluminescence, $CaSO_4$:Dy Teflon discs, Radiation, Exposure, Glow curve

1. INTRODUCTION

Thermoluminescence (TL) is a form of luminescence that is exhibited by an insulator or a semiconductor which is observed when the solid is thermally stimulated. TL is thermally stimulated emission of light following the absorption of energy from radiation [1]. The TL characteristics of a material are expressed by a few parameter such as order of kinetics, activation energy and frequency factor. The knowledge of these parameters is essential for the understanding of TL process occurring in a phosphor. There are many experimental techniques developed on the basis of glow curve shape, heating rate, phosphorescence decay etc. [2]. During the TL process, part of energy absorbed by the material is re-emitted during heating in form of light. The plot of the TL intensity (light output) as a function of rising temperature exhibits one or more peaks is called a glow curve. The glow curve provides a useful tool for studying the traps and trapping parameter (such as trap depth E, kinetic order b, frequency factor etc.).[3].

Calcium Sulphate singly doped with dysprosium is an important TLD material which is commercially available as TLD-600. CaSO4:Dy TL material is known to have a very high sensitivity to gamma radiation. Their main dosimetric glow peak is at 220 ^{0}C, with two unstable low temperature peaks at 80 and 120 ^{0}C. At absorbed dose levels above the limit of linearity (i.e.30 Gy for Dy doped TL material, where Gy stands for Gray and 1 Gray is equal to 100 rads and 1 rad is equal to the deposition of 100 ergs of energy per gram of a tissue (100 erg/gm)) a higher temperature peak appears at approximately 250 ^{0}C.

This peak dominates up to the saturation absorbed dose of 1000 Gy for Dy. The spectral emission peak of the Dy-activated TL material is at 478 and 571 nm. At normal ambient temperature the dark fading of the 220 ^{0}C glow peak of the Dy activated TL material is low. Dark fading is the unintentional release of an electron before readout. The glow curve of $CaSO_4$:Dy is shown in Fig. 1.

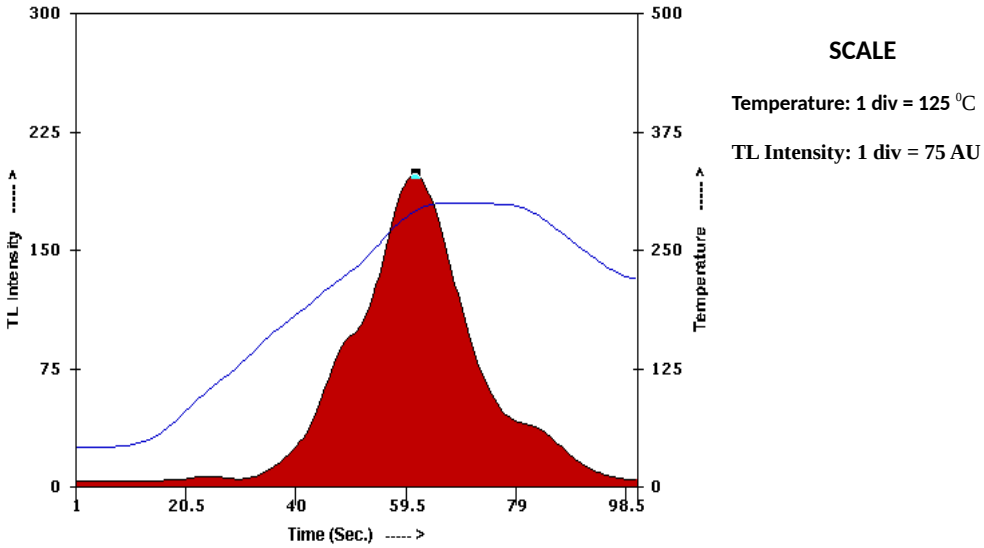

Fig. 1: Graph showing the glow curve of $CaSO_4$:Dy

2. MATERIALS AND METHODS:

Fifty (50) standard TL discs were acquired from old stock of TLD unit of Defence Laboratory, Jodhpur, and have been utilized in this study.

2.1: Sample preparation (annealing):

To ensure complete readout of stored data the TL discs were annealed before taking radiation measurements. All 50 TL discs, were annealed in automatic oven at 270 ^{0}C for four hours and allowed to cool to normal temperature to ensure that the TL discs are free from pre-irradiation.

2.2: TL measurement setup:

A PC controlled TLD Reader (Model: TL1009I, Make: M/S Nucleonix System Pvt. Ltd., Hyderabad, India) was used for investigating the TL property of the material under study. The system has two essential parts; (a) The integral TLD reader and, (b) Personnel computer system with TL data acquisition and analysis software. Entire electronic hardware of the integral TL reader consists of low voltage (LV) and high voltage (HV) supplies, temperature controller and thermocouple amplifier circuits, microcontroller based data acquisition circuits, photomultiplier tube (PMT), heater transformer, PMT current to frequency (I to F) converter and kanthal strip for sample loading with drawer assembly, all are kept in a single enclosure. The TL light output from the sample is detected by the PMT, which is amplified and recorded. The PMT is powered with HV. The recorder continuously records the measured luminescence against time scale or temperature scale or both. Here heating is done by resistive heating method, in which electric current is passed through a planchet so as to raise the sample temperature in a controlled manner.

2.2: Experimental procedure:

2.2.1: Sample exposure with gamma radiation:

The prepared samples (annealed discs) were irradiated in calibrated gamma radiation field of average energy (1.25 MeV) emitted from ^{60}Co sources of Industrial Gamma Radiation Exposure Device (IGRED), Model: Techops-741 at Defence Laboratory, Jodhpur. The radiation from ^{60} ₂₇ is nearly mono-energetic, being made up of two photon energies, 1.17 MeV and 1.33 MeV, giving an average of 1.25 MeV (Technical report, 1987). Here gamma radiation has been used for irradiating the sample. The desired exposure rate and accordingly the irradiation time for the samples were calculated using the standard and calibrated radiation field data provided by Bhabha Atomic Research Centre (BARC), Mumbai. Standard Radiation Field data:

Standard Radiation Field data:

- Source: ^{60}Co, $T_{1/2}$ = 5.27 years (1924 days)
- Exposure rate at 53.3 cm from the source: 118.949 R/h as on 25/07/2012

Calculation of exposure data for sample irradiation:

- Date of experiment: 08/06/2018
- Total time elapsed since calibration: 08/06/2018 – 25/07/2012
  = (06 years) = 2173 days
- Exposure rate $X(t) = X(o).\exp-[(0.693x\ t)/T_{1/2})]$
  $X(t) = 118.949 \times \exp-[(0.693x2173)/1924] = 55.34$ R/h as on08/06/2018
- Exposure rate at 50 cm from the source = $55.34 \times (53.3/50)^2 = 61.80$ R/h

Table 1: Sample Exposure time for different exposure

Sample Exposure time	**Exposure (R)**
30 sec	0.51
1 min	1.03
5 min	5.15
10 min	10.3
50 min	51.5

Five TL Discs for each exposure were packed in an opaque paper and immobilized at 50 cm from the source of the radiation calibration unit and exposed as per calculated exposure time given in Table 1.

2.2.2: Thermoluminescence Measurement:

Teflon discs of $CaSO_4$:Dy was properly kept on the heating element of the TL Reader. After inserting the heating unit at measurement position, the TL measurement sequence was run, glow curve obtained and the TL output data stored in an appropriate file of the computer system of the unit. The integral count within the glow curve was recorded for each TL disc. This procedure was repeated for all five discs of background measurement and the discs for each set of exposure.

2.2.3: Observations:

The TL Integral counts of the $CaSO_4$:Dy Disc for background and exposure are shown in Table 2.

Table 2: TL measured data of $CaSO_4$:Dy

TL Measured Data of $CaSO_4$:Dy Disc (Standard TL Dosimeter)							
Sr. No.	Background TL Counts (A)	Exposure (Roentgen) -R	TL Output (Integral Counts)-AU			Average TL Integral Counts (AU)-(B)	Net TL Integral Counts (B-A)
			Reading-1	Reading-2	Reading-3		
1	877	0.51	1458	1733	1775	1655	778
2	877	1.03	2442	2446	2592	2493	1616
3	877	5.15	10740	9923	12464	11042	10165
4	877	10.3	23283	22600	22014	22632	21755
5	877	51.5	109108	107077	80532	98906	98029
6	877	Unknown (U1)	4181	4362	4624	4389	1788
7	877	Unknown (U2)	27916	25539	23607	25687	12628

The TL emission of CaSo4:Dy disc at different radiation exposure plotted using analysis software of the TLD reader unit and shown in Fig. 2.

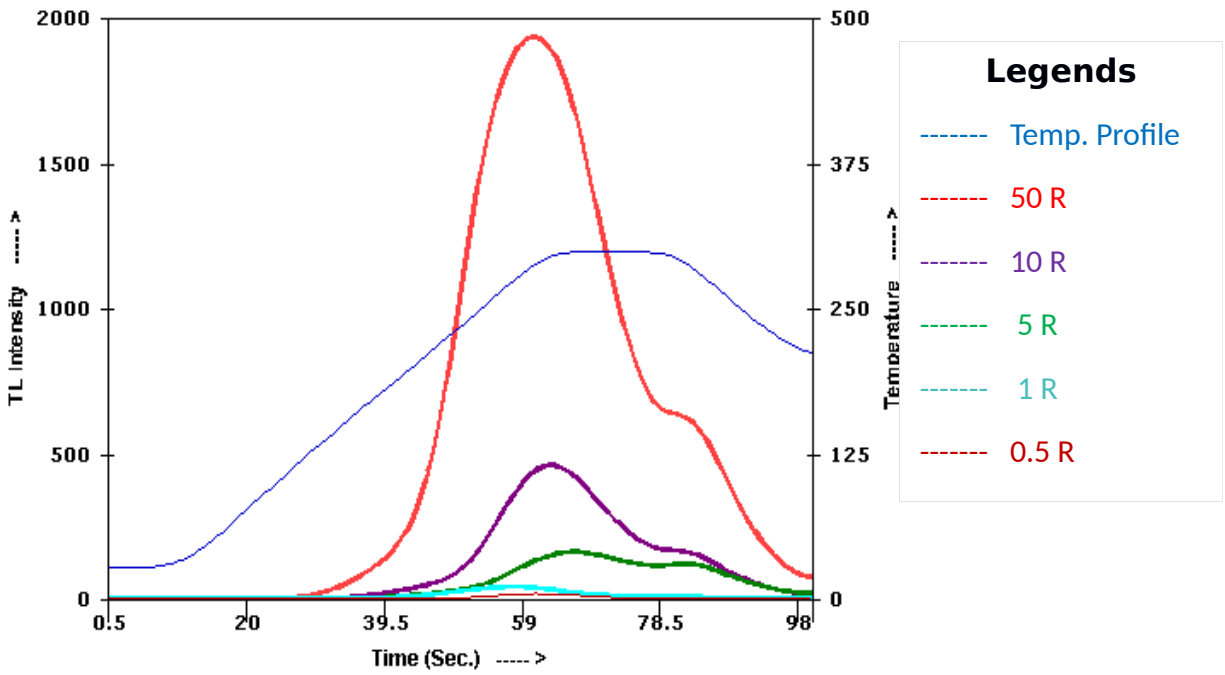

Fig. 2: Graph showing irradiated experimental glow curve of $CaSO_4$:Dy

3. RESULT AND DISCUSSIONS:

3.1: Calibration and TL Sensitivity:

A graph between radiation exposure and net TL integral counts is plotted in Fig. 3. The TL output is found to be directly proportional to the amount of radiation with which the TLD Discs are exposed. TL response of $CaSO_4$:Dy is found to be linear within the studied exposure range 0.5 to 50 R. A linear fitted equation is shown on the graph itself. For the TLD reader used in this study, the TL sensitivity of $CaSO_4$: Dy disc is found to be 1907 Arbitrary Unit (AU)/R.

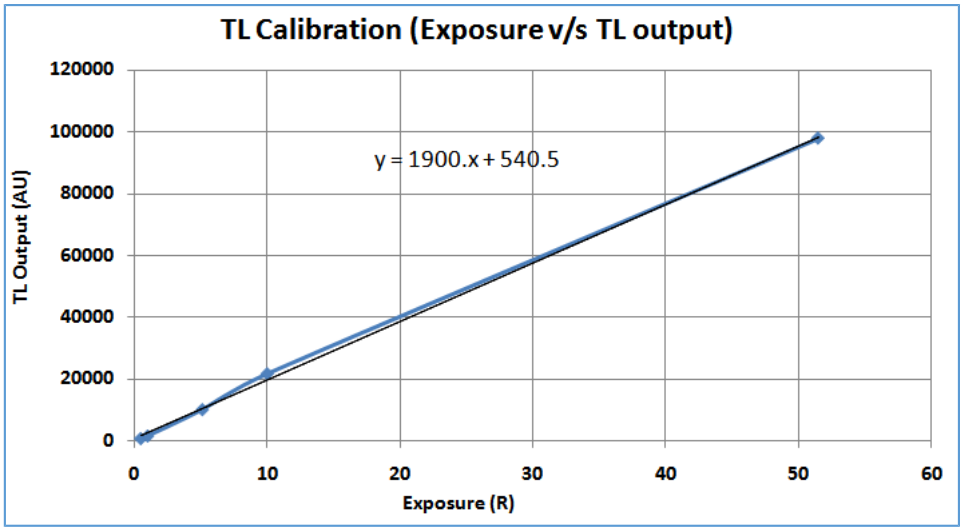

Fig. 3: Calibration Graph (Exposure v/s TL Output)

3.2: Calibration Factor:

From the above graph, the calibration factor of the TL disc as inverse of the slope of the straight line is estimated to be 0.5243 mR/AU. This calibration factor can be used for estimating the unknown exposure received by the TLD disc.

3.3: Measurement of Unknown Dose:

Two sets of $CaSO_4$:Dy discs (five discs in each set) were exposed with unknown gamma doses and their TL was measured under the identical setup of the TLD reader used during the calibration. The exposure measured by this TL technique vis-a-vis the unknown test exposure is given in Table 3. The percentage error in unknown dose estimation using CaSo4:Dy TL material is found to be within 10%, which is acceptable for radiation protection dose estimation.

Table 3: Unknown dose estimation using $CaSO_4$:Dy Disc

Sample ID	TL output (AU)-A	Calibration Factor (mR/AU)-B	Estimated Unknown Exposure (mR) = A X B	Declared Exposure (mR)	% Error
U1	3512	0.5243	1841	1648	-10.48%
U2	24810	0.5243	13008	12446	-4.32%

4. CONCLUSIONS:

The TL property of $CaSO_4$:Dy disc has been studied for nuclear radiation measurement. It has linear TL response in the exposure range required for public as well as personnel radiation dosimetry below 50R. Thermoluminescence is a passive radiation detector, which stores the radiation information for longer period and can be read whenever required. Radiation dosimetry using CaSo4:Dy has been established as routine passive dosimetry system for occupational radiation worker and for environmental monitoring.

5. FUTURE PROSPECTS:

Though radiation dosimetry using $CaSO_4$:Dy TL material has been established, the radiation dose measurement at R level is still a challenge. TL study on novel materials can be explored for low level radiation measurement.

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References

[1] A F Mckinlay, *Thermoluminescence Dosimetry;* 1986, ISBN 0-85274-520-6.

[2] Dr. Vij and N. Singh, *Luminescence and related properties of II-VI semiconductors*; Classes of Luminescence; ISBN 1-56072-433-1.

[3] Dr. Hitesh Mandavia, *Thermoluminescence study of ceramic tiles materials*; ISBN 978-93-84044-78-7, 2015.