ISO/ASTM 51956:2013(E)

Standard Practice for Use of a Thermoluminescence-Dosimetry System (TLD System) for Radiation Processing[1]

This standard is issued under the fixed designation ISO/ASTM 51956; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision.

1. Scope

1.1 This practice covers procedures for the use of thermoluminescence dosimeters (TLDs) to measure the absorbed dose in materials irradiated by photons or electrons in terms of absorbed dose to water. Thermoluminescence-dosimetry systems (TLD systems) are generally used as routine dosimetry systems.

1.2 The thermoluminescence dosimeter (TLD) is classified as a type II dosimeter on the basis of the complex effect of influence quantities on the dosimeter response. See ISO/ASTM Practice 52628.

1.3 This document is one of a set of standards that provides recommendations for properly implementing dosimetry in radiation processing, and describes a means of achieving compliance with the requirements of ISO/ASTM 52628 "Practice for Dosimetry in Radiation Processing" for a TLD system. It is intended to be read in conjunction with ISO/ASTM 52628.

1.4 This practice covers the use of TLD systems under the following conditions:

1.4.1 The absorbed-dose range is from 1 Gy to 10 kGy.

1.4.2 The absorbed-dose rate is between 1×10^{-2} and 1×10^{10} Gy s^{-1}.

1.4.3 The radiation-energy range for photons and electrons is from 0.1 to 50 MeV.

1.5 This practice does not cover measurements of absorbed dose in materials subjected to neutron irradiation.

1.6 This practice does not cover procedures for the use of TLDs for determining absorbed dose in radiation-hardness testing of electronic devices. Procedures for the use of TLDs for radiation-hardness testing are given in ASTM Practice E668.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced documents

2.1 *ASTM Standards:*[2]

E170 Terminology Relating to Radiation Measurements and Dosimetry

E666 Practice for Calculating Absorbed Dose From Gamma or X Radiation

E668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices

2.2 *ISO/ASTM Standards:*[2]

51261 Practice for Calibration of Routine Dosimetry Systems for Radiation Processing

51608 Practice for Dosimetry in an X-Ray (Bremsstrahlung) Facility for Radiation Processing

51649 Practice for Dosimetry in an Electron-Beam Facility for Radiation Processing at Energies Between 300 keV and 25 MeV

51702 Practice for Dosimetry in Gamma Irradiation Facilities for Radiation Processing

51707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing

51939 Practice for Blood Irradiation Dosimetry

51940 Guide for Dosimetry for Sterile Insect Release Programs

52628 Practice for Dosimetry in Radiation Processing

52701 Guide for Performance Characterization of Dosimeters and Dosimetry Systems for Use in Radiation Processing

2.3 *Joint Committee for Guides in Metrology (JCGM) Reports:*

JCGM 100:2008, GUM 1995, with minor corrections, Evaluation of measurement data—Guide to the Expression of Uncertainty in Measurement[3]

[1] This practice is under the jurisdiction of ASTM Committee E61 on Radiation Processing and is the direct responsibility of Subcommittee E61.02 on Dosimetry Systems, and is also under the jurisdiction of ISO/TC 85/WG 3.

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[2] For referenced ASTM and ISO/ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Document produced by Working Group 1 of the Joint Committee for Guides in Metrology (JCGM/WG 1). Available free of charge at the BIPM website (http://www.bipm.org.

JCGM 200:2008, VIM, International Vocabulary of Metrology—Basis and general concepts and associated terms[4]

2.4 *ISO Standard:*

ISO 10012 Measurement Management Systems—Requirements for Measurement Processes and Measuring Equipment[5]

2.5 *International Commission on Radiation Units and Measurements (ICRU) Report:*

ICRU Report 85a Fundamental Quantities and Units for Ionizing Radiation[6]

3. Terminology

3.1 *Definitions:*

3.1.1 *annealing*—thermal treatment of a TLD prior to irradiation or prior to readout.

3.1.1.1 *Discussion*—Pre-irradiation annealing of TLDs is usually done to erase the effects of previous irradiation and to readjust the sensitivity of the phosphor; pre-readout annealing usually is done to reduce low-temperature TLD response.

3.1.2 *calibration*—set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards.

3.1.2.1 *Discussion*—Calibration conditions include environmental and irradiation conditions present during irradiation, storage and measurement of the dosimeters that are used for the generation of a calibration curve. To achieve stable environmental conditions, it may be necessary to condition the dosimeters before performing the calibration procedure.

3.1.3 *calibration curve*—expression of the relation between indication and corresponding measured quantity value. **(VIM)**

3.1.4 *charged-particle equilibrium*—condition in which the kinetic energy of charged particles (or electrons), excluding rest mass, entering an infinitesimal volume of the irradiated material equals the kinetic energy of charge particles (or electrons) emerging from it.

3.1.4.1 *Discussion*—When electrons are the predominant charged particles, the term "electron equilibrium" is often used to describe charged-particle equilibrium.

3.1.5 *dosimeter batch*—quantity of dosimeters made from a specific mass of material with uniform composition, fabricated in a single production run under controlled, consistent conditions, and having a unique identification code.

3.1.6 *dosimeter stock*—part of a dosimeter batch held by the user.

3.1.7 *dosimetry system*—system used for measuring absorbed dose, consisting of dosimeters, measurement instruments and their associated reference standards, and procedures for the system's use.

3.1.8 *electron equilibrium*—charged-particle equilibrium for electrons. See *charged-particle equilibrium.*

3.1.9 *measurement management system*—set of interrelated or interacting elements necessary to achieve metrological confirmation and continual control of measurement processes. **(ISO 10012)**

3.1.10 *quality assurance*—all systematic actions necessary to provide adequate confidence that a calibration, measurement, or process is performed to a predefined level of quality.

3.1.11 *reference standard dosimetry system*—dosimetry system, generally having the highest metrological quality available at a given location or in a given organization, from which measurements made there are derived.

3.1.12 *routine dosimetry system*—dosimetry system calibrated against a reference standard dosimetry system and used for routine absorbed dose measurements, including dose mapping and process monitoring.

3.1.13 *thermoluminescence dosimeter (TLD)*—TL phosphor, alone or incorporated in a material, used for determining the absorbed dose to materials.

3.1.13.1 *Discussion*—For example, the TL phosphor is sometimes incorporated in a TFE-fluorocarbon matrix.

3.1.14 *thermoluminescence dosimeter reader (TLD reader)*—instrument used to measure the light emitted from a TLD consisting essentially of a heating element, a light-measuring device, and appropriate electronics.

3.1.15 *thermoluminescence dosimeter response (TLD response)*—light emitted by the TLD and read out during its heating cycle consisting of one of the following: *(a)* the total light output over the entire heating cycle, *(b)* a part of that total light output, or *(c)* the peak amplitude of the light output.

3.1.16 *thermoluminescence phosphor (TL phosphor)*—material that stores, upon irradiation, a fraction of its absorbed dose in various excited energy states and when thermally stimulated, it emits this stored energy as ultraviolet, visible, and infrared lights.

3.1.17 *TLD preparation*—procedure of cleaning, annealing, and encapsulating the TL phosphor prior to irradiation.

3.2 Definitions of other terms used in this standard that pertain to radiation measurement and dosimetry may be found in ASTM Terminology E170. Definitions in ASTM Terminology E170 are compatible with ICRU Report 85a; that document, therefore, may be used as an alternative reference.

4. Significance and use

4.1 In radiation processing, TLDs are mainly used in the irradiation of blood products (see ISO/ASTM Practice 51939) and insects for sterile insect release programs (see ISO/ASTM Guide 51940). TLDs may also be used in other radiation processing applications such as the sterilization of medical

[4] Document produced by Working Group 2 of the Joint Committee for Guides in Metrology (JCGM/WG 2). Available free of charge at the BIPM website (http://www.bipm.org.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[6] Available from International Commission on Radiation Units and Measurements, 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814, USA.

products, food irradiation, modification of polymers, irradiation of electronic devices, and curing of inks, coatings and adhesives. (See ISO/ASTM Practices 51608, 51649, and 51702.)

4.2 For radiation processing, the absorbed-dose range of interest is from 1 Gy to 100 kGy. Some TLDs can be used in applications requiring much lower absorbed doses (for example, for personnel dosimetry), but such applications are outside the scope of this practice. Examples of TLDs and applicable dose ranges are given in Table 1. Information on various types of TLDs and their applications can be found in Refs (**1-10**).[7]

5. Overview

5.1 During the irradiation of certain crystalline materials, for example, LiF, CaF_2, $CaSO_4$, $Li_2B_4O_7$, and Al_2O_3, the filling of electron and hole traps between the ground state and the conduction band results in stored energy that can be released as luminescence during subsequent heating. TLD systems provide a means of determining absorbed dose to materials by measuring this luminescence by the controlled heating of the irradiated crystalline material. The amount of luminescence emitted by the TL phosphor upon heating can be directly related to absorbed dose by a calibration.

5.2 TLDs can be reused by subjecting the irradiated TLDs to an annealing process at a higher temperature to release all the electron and hole traps.

6. Influence quantities

6.1 Factors other than absorbed dose which influence the dosimeter response are referred to as influence quantities and are discussed in the following sections. Examples of such factors are temperature, relative humidity, light and dose rate (see ISO/ASTM Guide 52701). See Refs (**1-10**) for examples of the types and magnitudes of the effects for different TLDs.

6.2 *Pre-Irradiation Conditions:*

[7] The boldface numbers in parentheses refer to the bibliography at the end of this standard.

TABLE 1 Types of TLDs and applicable dose ranges[A]

Type of TLD	Linear Dose Range, Gy	Supralinear Dose Range, Gy
LiF: Mg, Ti	10^{-5} – 1	1 – 10^3
LiF:Mg, Cu, P	10^{-6} – 10	NA
CaF_2: Mn	10^{-5} – 10	10 – 10^3
CaF_2:Dy	10^{-5} – 6	6 – 5 × 10^2
CaF_2:Tm	10^{-5} – 1	1 – 10^4
Al_2O_3:C	10^{-6} – 1	1 – 30
Al_2O_3:Mg, Y	10^{-3} – 10^4	NA
BeO	10^{-4} – 1	1 – 10^2
MgO	10^{-4} – 10^4	NA
$CaSO_4$: Dy and $CaSO_4$:Tm	10^{-5} – 10	10 – 5 × 10^3
$Li_2B_4O_7$: Mn	10^{-4} – 10^2	10^2 – 10^4
$Li_2B_4O_7$: Cu	10^{-5} – 10^3	NA
MgB_4O_7:Dy and MgB_4O_7:Tm	10^{-5} –50	50 – 5 × 10^3

[A] This table is taken from Ref (**6**). Ranges are approximate, and may vary with batch. Supralinearity refers to a region where the slope of the response versus dose curve is greater than that for the linear region.

6.2.1 *Dosimeter Packaging*—The TLD response is not usually influenced by the water content, so the TLDs are not usually supplied in vapor tight pouches. They may be supplied in light tight pouches to minimize the effect of light.

6.2.2 *Time Since Manufacture*—There is no known influence of time since manufacture on TLDs when stored under recommended conditions. However, it is recommended that users carry out periodic performance verification of response over the time the dosimeter batch is used.

6.2.3 *Temperature*—Exposure to extreme temperature during shipment and storage at the user's facility might affect the TLD response. Manufacturer should be consulted for specific recommendation for dosimeter shipment and storage.

6.2.4 *Relative Humidity*—The TLD response is not usually affected by environmental changes in humidity.

6.2.5 *Exposure to Light*—TLDs with high sensitivity should be packaged to protect them from light such as sunlight or fluorescent light which have an appreciable ultraviolet component. Prolonged exposure to ultraviolet light before irradiation can cause spurious TLD response or enhanced post-irradiation fading. Incandescent lighting should be used for the TLD preparation and readout areas. However, brief exposures of a few minutes to normal room fluorescent lighting is not likely to significantly affect the TLD response except for low dose measurements (<1 Gy) or measurements with high-sensitivity TLDs. TLDs, especially those with high sensitivity, should be protected from light having an appreciable ultraviolet component.

6.3 *Conditions During Irradiation:*

6.3.1 *Irradiation Temperature*—Irradiation temperature is expected to influence dosimeter response. It is recommended to calibrate the dosimetry system under the conditions of use (in-plant calibration) in order to mitigate the effect of temperature on dosimeter response.

6.3.2 *Absorbed-dose Rate*—Absorbed-dose rate might influence dosimeter response. It is recommended to calibrate the TLD system under the conditions of use (in-plant calibration) in order to mitigate any possible effect of dose rate on dosimeter response.

6.3.3 *Dose Fractionation*—Dose fractionation might influence the TLD response. It is recommended to calibrate the TLD system under the conditions of use (in-plant calibration) in order to mitigate any possible effect of dose fractionation.

6.3.4 *Relative Humidity*—For most types of TLDs, the amount of water in the dosimeter does not influence the response.

6.3.5 *Exposure to Light*—TLDs with high sensitivity should be protected from light such as sunlight or fluorescent light which have an appreciable ultraviolet component. Prolonged exposure to ultraviolet light during irradiation can cause spurious TLD response or enhanced post-irradiation fading.

6.3.6 *Radiation Energy*—Since the atomic number of many TLDs is higher than the atomic number for water, the absorbed dose to water must be calculated from knowledge of the irradiation field and the composition of the dosimeter material (see ASTM Practice E666).

6.4 *Post-Irradiation Conditions:*

6.4.1 *Time*—Some TLDs may take significant time for the electron and hole traps to stabilize after irradiation. Such dosimeters may require an extended post irradiation time period (for example, 24 h) to stabilize sufficiently for measurement purposes.

6.4.2 *Temperature*—Temperature after irradiation might influence the TLD response. Dosimeter manufacturer should be consulted for specific recommendation for storage of irradiated dosimeters.

6.4.3 *Relative Humidity*—The TLD response is not usually affected by the water content.

6.4.4 *Exposure to Light*—Dosimeters are sensitive to UV light, including the UV component in sunlight and facility lighting. Dosimeters should be protected against light exposure.

6.5 *Response Measurement Conditions:*

6.5.1 Requirements for post irradiation conditions apply to conditions of measurement.

7. Dosimetry system and its verification

7.1 *Components of the Thermoluminescence Dosimetry (TLD) System*—The following are components of TLD systems:

7.1.1 *Thermoluminescence Dosimeters (TLDs)*—TLDs are available from commercial suppliers in different forms such as loose powder, chips or crystals encapsulated in glass or plastic.

7.1.2 *Instrumentation*—The thermoluminescence dosimeter (TLD) reader is a special instrument used to measure TLDs. It consists of a heating element that subjects the TLD to a carefully controlled heating program that allows the freed electrons and holes from traps to recombine with the emission of characteristic light. The emission of light as a function of temperature produces a glow curve that is measured by the TLD reader and related to the absorbed dose.

7.1.3 *Procedures for Its Use.*

7.2 *Measurement Management System* specifying details of the preparation and handling of the TLDs and the verification, calibration and quality assurance requirements for the TLD system shall be in place.

7.3 *Performance Verification of Instrumentation:*

7.3.1 At prescribed time intervals, or in the event of suspected performance issues during periods of use, measurement instruments should be checked against their calibration standards.

7.3.2 Implementation of a daily check program intended to verify instrument performance before and after measurement sessions is also recommended.

8. Incoming dosimeter stock assessment

8.1 A protocol shall be established for the purchase, receipt, acceptance and storage of dosimeters.

8.2 The user shall perform an incoming inspection and acceptance testing for each shipment of dosimeters received. Samples should be selected from all or as many incoming boxes as is possible.

8.2.1 Verify and document details such as batch ID, quantity, date received, miscellaneous descriptions (such as average mass) and status of any shipping controls (such as temperature device's indication of whether temperature limits may have been exceeded during shipping).

8.2.2 Perform random sampling per documented procedures to verify dosimeter integrity.

8.2.3 It is also recommended that the user conduct dosimeter response testing at or near the planned high, medium and low doses either to determine that the batch samples respond within expectation or to verify the batch response of a new dosimeter stock against the results obtained with samples from a prior stock.

8.3 Retain sufficient dosimeters for additional investigations, for use during verification or for recalibration.

8.4 Store dosimeters according to the manufacturer's recommendations, or specific user determined practices.

9. Calibration

9.1 Prior to initial use of each batch of dosimeters, the dosimetry system shall be calibrated in accordance with ISO/ASTM Practice 51261 and the user's procedures, which should specify details of the calibration and quality assurance requirements.

9.2 The user's dosimetry system calibration shall take into account the influence quantities associated with pre-irradiation, irradiation, and post-irradiation conditions applicable to the process in the user's facility (see Section 6).

NOTE 1—Successful calibration of a TLD system requires use of calibration conditions that approximate those expected to be encountered during use. If large seasonal temperature differences are anticipated, then the calibration should be conducted during periods that may better reflect the middle of the temperature range expected to be encountered over the life of the calibration. Periodic or seasonal calibration verification is also recommended to determine any effects of seasonal variation and confirm continued use of a batch specific calibration.

9.3 Multiple calibration curves can be used instead of using a single calibration curve over the entire dose range as a means of reducing the level of calibration uncertainty.

9.4 If reusable TLDs are irradiated (for either calibration or production use) to high single or accumulated absorbed-dose levels (>10^2 Gy) recalibration may be required after each anneal-irradiation cycle because of possible changes in absorbed-dose sensitivity (**7**). If the TLD system being used is subject to this effect, it is recommended that each TLD in the batch be irradiated only once until the entire batch has been used after which the entire batch can be annealed and a new calibration performed. In addition, because of possible changes in batch response uniformity due to high absorbed-dose irradiations, periodically repeat the tests.

10. Routine use

10.1 *Before Irradiation:*

10.1.1 TLDs may be used either as reusable or as single-use dosimeters. Single-use dosimeters are irradiated once, read out, and then discarded; they are generally used as received from the manufacturer. Dosimeters that are reused are cycled repeatedly through an anneal-irradiation-readout procedure.