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Practice for use of a thermoluminescence-dosimetry system (TLD system) for radiation processing

Pratique pour l'utilisation d'un système de dosimêtrie par thermoluminescence (système TLD) pour le traitement par irradiation

Reference number
ISO/ASTM 51956:2013(E)

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Case postale 56 • CH-1211 Geneva 20
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ASTM International,100 Barr Harbor Drive, PO Box C700,
West Conshohocken, PA 19428-2959, USA
Tel. +610 832 9634
Fax +610 832 9635
E-mail khooper@astm.org
Web www.astm.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75% of the member bodies casting a vote.

ASTM International is one of the world's largest voluntary standards development organizations with global participation from affected stakeholders. ASTM technical committees follow rigorous due process balloting procedures.

A pilot project between ISO and ASTM International has been formed to develop and maintain a group of ISO/ASTM radiation processing dosimetry standards. Under this pilot project, ASTM Committee E61, Radiation Processing, is responsible for the development and maintenance of these dosimetry standards with unrestricted participation and input from appropriate ISO member bodies.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. Neither ISO nor ASTM International shall be held responsible for identifying any or all such patent rights.

International Standard ISO/ASTM 51956 was developed by ASTM Committee E61, Radiation Processing, through Subcommittee E61.02, Dosimetry Systems, and by Technical Committee ISO/TC 85, Nuclear energy, nuclear technologies and radiological protection.

This third edition cancels and replaces the second edition (ISO/ASTM 51956:2005), which has been technically revised.

An American National Standard

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:*

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:*

[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.

6.4.1 *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.

10.1.2 Preparation of the TLDs for irradiation may require cleaning, annealing, or encapsulation, or combinations thereof, depending on the type and form of the TL phosphor.

10.1.3 Reusable TLDs require careful treatment during annealing in order to obtain reliable results in dose measurements. The annealing procedure should include a reproducible temperature cycle of the annealing oven, accurate timing of the annealing period, and a reproducible cooling rate.

10.1.4 Ensure that the dosimeters are selected from an approved batch stored according to user's procedures. These procedures should be based on manufacturer's written recommendations or user specific performance characterization results.

10.1.5 Use only dosimeters that are within shelf life and calibration expiration dates.

10.1.6 Inspect each dosimeter and discard any dosimeters that indicate possible damage.

10.1.7 Bare TLDs should not be handled with the bare fingers; dirt or grease on their surfaces can affect their response and can contaminate the heating chamber of the TLD reader. A vacuum pen or tweezers coated with TFE-fluorocarbon should be used in handling. If required, the TLDs can be cleaned by using procedures similar to those described Annex A1 for LiF dosimeters.

10.1.8 Mark the dosimeters appropriately for identification, or if preferred, and if provided by the manufacturer, use the unique reference or bar-code of the dosimeter.

10.1.9 If the TLD reader uses hot gas to heat the TLDs, nitrogen should be used.

10.1.10 TLDs shall be read out with the same reader using the same readout techniques and reader parameters. The calibration is valid only for that batch used in that particular reader. Readers that are different from the one used for calibration, including those of the same make and model, do not necessarily indicate the same response for TLDs irradiated to the same absorbed dose.

10.2 *Irradiation:*

10.2.1 Place the dosimeters at the specified locations for irradiation.

10.3 *Post-Irradiation Analysis Procedure:*

10.3.1 Retrieve and account for all dosimeters, verifying the placement location of each dosimeter.

10.3.2 Inspect each dosimeter for imperfections. Document any imperfections.

10.3.3 Maintain the TLDs under specified conditions prior to measurement.

10.3.4 Verify instrument performance according to documented procedures (see 7.3).

10.3.5 TLDs should be measured during an interval (see 6.4.1) and under conditions (see 6.5) which account for potential post-irradiation changes. If appropriate, perform post irradiation heat treatment per established procedure.

11. Summary of requirements for performance testing of a TLD system

11.1 The performance of a specific TLD system should be evaluated to determine its suitability for use in a specific radiation processing application (see ISO/ASTM 52701). Acceptable performance of the TLD system should be verified before applying the system in a particular application.

11.2 Performance tests should be repeated whenever a significant change is made in the TLD system or in the specific application. Examples of such changes are: a change in the physical form or type of phosphor in the TLD, a change in any critical component or in any adjustable readout factor of the TLD reader, or a change in the irradiation source characteristics.

11.3 A particular performance test may be omitted if widely accepted documentation exists in the scientific and technical literature to show that the performance of the TLD system is satisfactory for that specific requirement. For example, if previously accepted studies document that a particular TLD has no absorbed-dose rate dependence for the expected conditions of irradiation, then performance testing for absorbed-dose rate dependence of that TLD system is unnecessary. All reports of test results should include appropriate references that substantiate the performance of the system and thereby justify the omission of such performance tests.

11.4 If a particular TLD system fails to meet the performance specification of any performance test, then use of that TLD system is not recommended. Such a system may be used only if appropriate corrections to the TLD response can be determined sufficiently well in order that the results of the specific processing application can be determined within the required uncertainty.

11.5 The number of TLDs used for each test should be sufficient to ensure that the test results are significant at the 95 % confidence level.

12. Documentation requirements

12.1 Record details of the measurements in accordance with the user's measurement management system.

13. Measurement uncertainty

13.1 All dose measurements need to be accompanied by an estimate of uncertainty. Appropriate procedures are recommended in ISO/ASTM Guide 51707 (see also GUM).

13.2 All components of uncertainty should be included in the estimate, including those arising from calibration, dosimeter reproducibility, instrument reproducibility, and the effect of influence quantities. A full quantitative analysis of components of uncertainty may be referred to as an uncertainty budget, and is then often presented in the form of a table. Typically, the uncertainty budget will identify all significant components of uncertainty, together with their methods of estimation, statistical distributions and magnitudes.

13.3 The estimate of the expanded uncertainty achievable with measurements made using a routine dosimetry system such as the TLD system is typically of the order of ±6 % to ±13 % for a coverage factor k = 2 (which corresponds approximately to a 95 % level of confidence for normally distributed data).

13.4 The uncertainties in the calibration and absorbed-dose measurement of a routine TLD dosimetry system depend on the specific dosimetry system employed and on the specific application. See Annex A1 for an example of the use of LiF chips.

14. Keywords

14.1 absorbed dose; dosimeter; dosimetry system; gamma radiation; ionizing radiation; irradiation; radiation processing; thermoluminescence dosimeter; thermoluminescence dosimetry system; TLD; ICS 17.240

ANNEX

(informative)

A1. RECOMMENDED PROCEDURES FOR APPLICATION OF LiF CHIPS

A1.1 Scope

A1.1.1 The procedures in this annex cover the use of lithium fluoride TLDs in the form of reusable solid chips. This is done for illustrative purposes and is not meant to imply that other types of phosphors, and physical forms of this or other phosphors, are not suitable for use in radiation processing dosimetry. Each type and form of TLD requires a different application procedure (see Refs **(1-10)** for descriptions of various types of TLDs). LiF chips have some significant advantages over some other types and forms of TLDs. Some of these advantages include radiation absorption characteristics reasonably similar to water and ease of handling compared to powders. One disadvantage in using LiF TLDs is a moderate fading of the TLD response after irradiation. The TLDs discussed here are for the natural isotopic ratio of ^{6}Li and ^{7}Li. Single isotope ^{6}Li and ^{7}Li type TLDs are generally used in neutron dosimetry and are not addressed in this practice.

A1.2 Dosimeter preparation

A1.2.1 Always handle chips gently and in a manner that will minimize mechanical stress as well as the possibility of scratching or chipping the dosimeter. Never touch the chips with bare fingers to avoid getting dirt or oils on them. The recommended handling tool is a vacuum pen; however, tweezers may be used. The contact points of all handling tools should be coated with TFE-fluorocarbon if possible.

A1.2.2 Between normal uses, the TLDs should be rinsed with analytical-grade anhydrous methyl alcohol and allowed to dry by evaporation (**11**). More thorough cleaning of the TLDs should not be necessary under normal use. Water should not be used.

A1.2.3 Keep the chips as clean as possible at all times so that additional cleaning can be avoided. Clean the chips only if necessary since the process can contribute to the aging (decrease in sensitivity) of the phosphor. If additional cleaning is necessary, the following procedure is recommended.

A1.2.3.1 Wash the chips in approximately 50°C trichloroethylene for 2 min. An ultrasonic cleaner may be used.

A1.2.3.2 Wash the chips in reagent grade anhydrous methyl alcohol for 2 min. An ultrasonic cleaner may be used.

A1.2.3.3 Place the chips between two layers of paper towels and allow to dry by evaporation.

A1.2.4 Anneal the chips for 1 h at 400°C followed by rapid cooling. This annealing is essential after irradiation at high absorbed doses to avoid changes in dose sensitivity. For annealing, place the chips in a tray or container of a material that will not react with them at the annealing temperature, such as high-temperature borosilicate glass. Do not use aluminum.

A1.3 Effects of storage and transportation

A1.3.1 Minimize the storage and transportation time of the dosimeters either between preparation and irradiation or between irradiation and readout. Protect the dosimeters from ultraviolet light and elevated temperatures during storage or transportation. Apply corrections for any effects on dosimeter response caused by the duration and conditions of the storage or transportation, or both. Changes in humidity have not been shown to affect the response of LiF chips.

A1.4 Irradiation procedures

A1.4.1 Procedures for using the TLDs during calibration or production irradiations depend on conditions within each individual facility and on the requirements of the radiation processing application. However, precautions on handling, exposure to light, and exposure to temperature variations apply. The procedures described in Section 10 are applicable.

A1.4.2 For photon irradiation, surround the chips with sufficient amount of material to achieve approximate electron equilibrium conditions in the dosimeters.

A1.5 Readout

A1.5.1 Pre-readout cleaning of the chips should be done only if necessary (see A1.2.3). LiF chips may require annealing at low temperatures (approximately 100°C) between irradiation and readout to remove unstable low temperature peaks in the response output. This procedure is necessary only if the entire response output glow curve (current versus temperature) is used. For readers with adjustable temperature discrimination levels or when using the peak-height response, the pre-readout annealing procedure is not needed.

A1.5.2 Reader parameters should be adjusted to give reproducible responses over the absorbed doses measured. For readers that use resistively heated planchets to heat the TLDs, a heating rate of approximately 30 Celsius degrees per second should be satisfactory. The TLD chips should have been heated to a temperature of about 350°C at the end of the heating cycle. For readers that use hot (nitrogen) gas to heat the TLDs, a gas temperature of about 350°C and heating times between 15 and 30 s should be satisfactory.

A1.5.3 TLD response can be measured as the peak height of the light output versus temperature curve, or as integrated light output over the heating cycle. For heating cycles that are very reproducible, the peak height of the light output versus temperature curve may be used. However, the integrated light output is usually conveniently obtained and is satisfactory in most cases. When hot gas readers are used, integrated light output should be used; the heating profile (and therefore the peak light output) depends on the orientation of the TLD in the reader chamber, which usually cannot be controlled. For readers in which the digital data (charge or current vs temperature) can be obtained, the data may be analyzed offline and various methods may be used to compare results.

A1.5.4 Most TLD readers are furnished with a light source that may be used to check the stability of the reader. This procedure provides a check of the reader stability only for the light measuring section and its associated electronics; it does not test the performance and stability of the heating and temperature measuring section. Therefore, the use of calibration-check TLDs, irradiated to known doses, is recommended.

A1.6 Absorbed dose measurement uncertainty

A1.6.1 Examples of the uncertainty analysis of a typical LiF chip system employed in radiation processing are given in Table A1.1 and Table A1.2. These tables identify the sources of uncertainties and give estimates of their magnitudes. A basic assumption for these data is that the TLD system has been characterized and used in accordance with the recommended procedures in this practice. Therefore, as indicated in Footnote *A* in Table A1.1, certain potential sources of uncertainty are expected to be insignificant in this case.

TABLE A1.1 Estimates of uncertainties for typical LiF system utilized as individual chips

Source of Uncertainty	Type A (%)	Type B (%)
^{60}Co source calibrated dose value	0.74	0.47
Determination of calibration curve	0.10	1.00
Time between irradiation and readout: fading correction	0.5	1.00
Correction for attenuation in equilibrium material	. . .	2.00
Reproducibility of individual dosimeter response	1.00	. . .
Interspecimen scatter	1.00	. . .
Absorbed dose rate dependence	[A]	[A]
Energy dependence	[A]	[A]
Effect of time between preparation and readout	[A]	[A]
Directional dependence	[A]	[A]
Temperature before, during, and after irradiation	[A]	[A]
Humidity dependence	[A]	[A]
Effect of size of TLD	[A]	[A]
Combined separately in quadrature	1.68	2.49
Total combined in quadrature	3.00	
Total combined X 2	6.0	

[A] For purposes of this uncertainty analysis, it is assumed that the TLD system is utilized in such a way as to make these uncertainties negligible. However, this assumption may not be valid under all conditions of use for radiation processing dosimetry. A careful examination of all possible sources of uncertainty must be made for the irradiation conditions and TLD system employed in each specific application.

A1.6.2 The uncertainties are estimated by the methods discussed in ISO/ASTM Guide 51707 and GUM, that is, by classification as Type A and Type B, according to how they are evaluated. The values in the tables are given at the one standard deviation level (Type A; determined by standard statistical methods) or the equivalent one standard deviation level (Type B; determined by all other methods). Table A1.1 gives uncertainties for the TLDs used as individual chips, that is, the identity and calibration response history is maintained for the entire period of use of each chip. Table A1.2 gives uncertainties for the TLDs used in a batch mode with no chip identity maintained and a group calibration responses utilized.

A1.6.3 The uncertainties are assumed to be uncorrelated. They are combined in quadrature and multiplied by a coverage factor of two to provide an expanded (or overall) uncertainty that corresponds approximately to a 95 % level of confidence for normally distributed data. If there are known correlations among any of the uncertainties, then that must be accounted for. The method of combining uncertainties that is used should be reported in the dosimetry measurement results.