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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Practice for Use of Thermoluminescence-Dosimetry (TLD) Systems for Radiation Processing[1]

This standard is issued under the fixed designation E 1956; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers procedures for the use of thermoluminescence dosimeters (TLDs) utilized as routine dosimeters to determine the absorbed dose in a material irradiated by ionizing radiation. Examples of materials useful as TLDs include LiF, CaF_2, $CaSO_4$, $Li_2B_4O_7$, and Al_20_3. Although some elements of the procedures have broader application, the specific area of concern is radiation processing of materials such as blood products, food, and insects for sterile release programs. This practice is applicable to the measurement of absorbed dose in materials irradiated by gamma rays, X rays, and electrons. Source energies covered are from 0.1 to 50 MeV photons and electrons. The range of absorbed dose covered is approximately from 1 to 10^5 Gy (10^2 to 10^7 rad), and the range of absorbed dose rates is approximately from 10^{-2} to 10^{10} Gy/s (1 to 10^{12} rad/s). Absorbed dose and absorbed dose-rate measurements in materials subjected to neutron irradiation are not covered in this practice.

1.2 Procedures for the use of TLDs for determining absorbed dose in radiation-hardness testing of electronic devices are given in Practice E 668.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *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:*

E 170 Terminology Relating to Radiation Measurements and Dosimetry[2]
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[3]
E 456 Terminology Relating to Quality and Statistics[3]
E 668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices[2]
E 1204 Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing[2]
E 1261 Guide for Selection and Calibration of Dosimetry Systems of Radiation Processing[2]
E 1431 Practice for Dosimetry in Electron and Bremsstrahlung Irradiation Facilities for Food Processing[2]
E 1702 Practice for Dosimetry in a Gamma Irradiation Facility for Radiation Processing[2]
E 1707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing[2]

2.2 *International Commission on Radiation Units and Measurements (ICRU) Reports:*

ICRU Report 14— Radiation Dosimetry: X Rays and Gamma Rays with Maximum Photon Energies Between 0.6 and 50 MeV[4]
ICRU Report 17— Radiation Dosimetry: X Rays Generated at Potentials of 5 to 150 kV[4]
ICRU Report 33— Radiation Quantities and Units[4]
ICRU Report 34— The Dosimetry of Pulsed Radiation[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *absorbed does, D*—Quantity of ionizing radiation energy imparted per unit mass of specified material. The SI unit of absorbed dose is the gray (Gy), where 1 gray is equivalent to the absorption of 1 J per kilogram of the specified material (1 Gy = 1 J/kg). The mathematical relationship is the quotient of $d\bar{\epsilon}$ by dm, where $d\bar{\epsilon}$ is the mean energy imparted by ionizing radiation to the matter in a volume element and dm is the mass of matter in that volume element.

$$D = \frac{d\bar{\epsilon}}{dm} \quad (1)$$

3.1.1.1 *Discussion*—The discontinued unit of absorbed dose is the rad (1 rad = 100 erg/g = 0.01 Gy). Absorbed dose is sometimes referred to simply as dose.

For a photon source under conditions of charged particle equilibrium, the absorbed dose, D, may be expressed as:

$$D = \phi E \frac{\mu_{en}}{\rho} \quad (2)$$

[1] This practice is under the jurisdiction of ASTM Committee E-10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.01 on Dosimetry for Radiation Processing.

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[2] *Annual Book of ASTM Standards*, Vol 12.02.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

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

where:

ϕ = particle fluence,
E = energy of the ionizing radiation, and
$\frac{\mu_{en}}{\rho}$ = mass energy absorption coefficient.

If bremsstrahlung production within the specified material is negligible, the mass energy absorption coefficient, μ_{en}, is equal to the mass energy transfer coefficient, μ_{tr}, and absorbed dose is equal to kerma.

3.1.2 *absorbed-dose rate*—the absorbed dose per unit time interval.

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

3.1.3.1 *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.

3.1.4 *calibration conditions*—the normal environmental conditions prevailing during routine calibration irradiations such as the ambient temperature, humidity, and lighting.

3.1.5 *calibration curve*—graphical representation of the dosimetry system's response function.

3.1.6 *calibration facility*—combination of an ionizing radiation source and its associated instrumentation that provides a uniform and reproducible absorbed dose, or absorbed dose rate, traceable to national or international standards at a specified location and within a specific material, and that may be used to derive the dosimetry system's response function or calibration curve.

3.1.7 *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.

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

3.1.9 *electron equilibrium*—a condition that exists in a material under irradiation if the kinetic energies, number, and direction of electrons induced by the radiation are uniform throughout the measurement volume of interest. Thus, the sum of the kinetic energies of the electrons entering the volume equals the sum of the kinetic energies of the electrons leaving the volume.

3.1.9.1 *Discussion*—Electron equilibrium is often referred to as charged-particle equilibrium (see Terminology E 170 and ICRU Report 33).

3.1.10 *measurement quality assurance plan*—a documented program for the measurement process that assures on a continuing basis that the overall uncertainty meets the requirements of the specific application. This plan requires traceability to, and consistency with, nationally or internationally recognized standards.

3.1.11 *measurement traceability*—the ability to demonstrate and document periodically that the measurement results from a particular measurement system are in agreement within acceptable limits of uncertainty with comparable measurement results obtained with a nationally or internationally recognized standard.

3.1.12 *primary standard dosimeter*—dosimeter of the highest metrological quality, established and maintained as an absorbed dose standard by a national or international standards organization.

3.1.13 *process load*—a volume of material with a specified loading configuration irradiated as a single entity.

3.1.14 *quality assurance*—all systematic actions necessary to provide adequate confidence that a measurement is performed to a predefined level of quality.

3.1.15 *reference dose location*—a position that has a reproducible and documented relationship relative to the maximum or minimum absorbed-dose positions (see Practice E 1204).

3.1.16 *reference standard dosimeter*—dosimeter of high metrological quality, used as a standard to provide measurements traceable to, and consistent with, measurements made using primary standard dosimeters.

3.1.17 *response function*—mathematical representation of the relationship between dosimeter response and absorbed dose for a given dosimetry system.

3.1.18 *routine dosimeter*—dosimeter calibrated against a primary, reference, or transfer standard dosimeter and used for routine absorbed dose measurement.

3.1.19 *simulated product*—a mass of material with attenuation and scattering properties similar to those of the product, material or substance to be irradiated.

3.1.19.1 *Discussion*—Simulated product is used during irradiator characterization as a substitute for the actual product, material or substance to be irradiated. When used in production runs, it is sometimes referred to as compensating dummy. When used for absorbed-dose mapping, simulated product is sometimes referred to as phantom material.

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

3.1.21 *transfer standard dosimeter*—dosimeter, often a reference standard dosimeter, intended for transport between different locations for use as an intermediary to compare absorbed dose measurements.

3.1.22 *thermoluminescence dosimeter (TLD)*—a TL phosphor, alone, or incorporated in a material, used for determining the absorbed dose in materials. For example, the TL phosphor is sometimes incorporated in a TFE-fluorocarbon matrix.

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

3.1.24 *thermoluminescence dosimeter (TLD) response*—the measured 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.

3.1.25 *thermoluminescence (TL) phosphor*—a material that stores, upon irradiation, a fraction of its absorbed dose in various excited energy states. When thermally stimulated, the material emits this stored energy in the form of photons in the ultraviolet, visible, and infrared regions.

3.1.26 *TLD preparation*—the 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 Terminology E 170. Definitions in Terminology E 170 are compatible with ICRU Report 33; that document, therefore, may be used as an alternative reference.

4. Significance and Use

4.1 Ionizing radiation is used to produce various desired effects in products. Examples include the sterilization of medical products, processing of food, sterilization of insects for sterile release programs, modification of polymers, irradiation of electronic devices, and curing of inks, coatings, and adhesives **(1, 2)**[5]. The absorbed doses employed vary according to the application. The doses cover a range from about 1 Gy to more than 100 kGy. Examples of TLDs and applicable dose ranges are given in Table 1.

TABLE 1 Types of TLDs

TLD Type	Applicable Dose Range, Gy	References
Lithium Fluoride; Magnesium & Titanium doped (LiF: Mg, Ti)	$1 - 10^5$	**(7, 8)**
Calcium Fluoride; Manganese doped (CaF_2: Mn)	$10^{-2} - 10^4$	**(9)**
Calcium Sulfate; Dysprosium doped ($CaSO_4$: Dy)	$10^{-4} - 10^6$	**(10)**
Lithium Borate; Manganese doped ($Li_2B_4O_7$: Mn)	$10^{-3} - 10^4$	**(11)**
Aluminum Oxide; Magnesium & Yttrium doped (Al_2O_3: Mg,Y)	$10^2 - 10^4$	**(12)**

4.2 Regulations for sterilization of medical products, irradiation of blood products, and radiation processing of food exist in many countries. These regulations may require that the response of the dosimetry system be calibrated and traceable to national standards **(3, 4, 5, 6)**. Adequate dosimetry, with proper statistical controls and documentation, is necessary to ensure that the products are properly processed.

4.3 Proper dosimetric measurements shall be employed to ensure that the product receives the desired absorbed dose. The dosimeters shall be calibrated. Calibration of a routine dosimetry system may be carried out directly in a nationally or internationally recognized standards laboratory by standardized irradiation of routine dosimeters. It also may be carried out through the use of a local (in-house) calibration facility or in a production irradiator. All possible factors that may affect the response of dosimeters, including environmental conditions and variations of such conditions within a processing facility, should be known and taken into account. The associated analytical instrumentation shall also be calibrated.

NOTE 1—For comprehensive discussions of various applicable dosimetry methods see Guide E 1261 and ICRU Reports 14, 17, and 34.

5. Apparatus

5.1 *The TLD system* consists of the TLDs, the equipment used for preparation of the TLDs, and the TLD reader.

5.2 *The calibration facility* delivers a known quantity of radiation to materials under certain prescribed environmental and geometrical conditions. Its radiation source is usually a radioactive isotope, commonly either ^{60}Co or ^{137}Cs, whose radiation output has been calibrated by specific techniques to some specified uncertainty (usually to within ±5 %) and is traceable to nationally or internationally recognized standards.

5.3 *The storage facility* provides an environment for the TLDs before and after irradiation, that is light tight and that has a negligible background absorbed-dose rate. A TLD stored in the facility for the longest expected storage period should absorb no more than 1 % of the lowest absorbed dose expected to be measured in its intended applications.

5.4 *The environmental chamber* is used in testing the effects of temperature and humidity on TLD response. The chamber should be capable of controlling the temperature and humidity within ±5 % over the range expected under both calibration and application conditions.

6. Handling and Readout Procedures

6.1 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 the procedures in accordance with Appendix X1.

6.2 TLDs, especially those 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, either before or after 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.

6.3 Preparation of the TLDs for irradiation consists of cleaning the TL phosphor (if required), annealing (if reusable TLDs are employed), and encapsulating the TL phosphor. Reusable TLDs require careful treatment during annealing in order to obtain the best 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.

6.4 For low absorbed-dose measurements (<1 Gy), dry nitrogen should be passed through the heating chamber of the TLD reader during readout. This suppresses the spurious TL response that occurs in most forms of TLDs as a result of absorbed oxygen on the phosphor surface. If the TLD reader uses hot gas to heat the TLDs, nitrogen should be used.

6.5 Calibration-irradiated TLDs and all subsequent application-irradiated TLDs from the same batch 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

[5] The boldface numbers in parentheses refer to the list of references at the end of this standard.