Standard Practice for Use of a Polymethylmethacrylate Dosimetry System[1]

This standard is issued under the fixed designation ISO/ASTM 51276; 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 is a practice for using polymethylmethacrylate (PMMA) dosimetry systems to measure absorbed dose in materials irradiated by photons or electrons in terms of absorbed dose to water. The PMMA dosimetry system is generally used as a routine dosimetry system.

1.2 The PMMA dosimeter is classified as a Type II dosimeter on the basis of the complex effect of influence quantities (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 PMMA dosimetry system. It is intended to be read in conjunction with ISO/ASTM Practice 52628.

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

1.4.1 the absorbed dose range is 0.1 kGy to 150 kGy.

1.4.2 the absorbed dose rate is 1×10^{-2} to 1×10^{7} Gy·s^{-1}.

1.4.3 the photon energy range is 0.1 to 25 MeV.

1.4.4 the electron energy range is 3 to 25 MeV.

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced documents

2.1 *ASTM Standards:*[2]

E275 Practice for Describing and Measuring Performance of Ultraviolet and Visible Spectrophotometers

E3083 Terminology Relating to Radiation Processing: Dosimetry and Applications

2.2 *ISO/ASTM Standards:*[2]

51261 Practice for Calibration of Routine Dosimetry Systems for Radiation Processing

51707 Guide for Estimation of Measurement Uncertainty in Dosimetry for Radiation Processing

52628 Practice for Dosimetry in Radiation Processing

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

2.3 *International Commission on Radiation Units and Measurements (ICRU) Reports:*[3]

ICRU Report 80 Dosimetry Systems for Use in Radiation Processing

ICRU Report 85a Fundamental Quantities and Units for Ionizing Radiation

2.4 *ISO Standard:*[4]

12749-4 Nuclear energy — Vocabulary — Part 4: Dosimetry for radiation processing

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

JCGM 100:2008, GUM 1995, with minor corrections Evaluation of measurement date - Guide to the Expression of Uncertainty in Measurement[5]

JCGM 200:2012, VIM International Vocabulary of Metrology - Basic and General Concepts and Associated Terms[6]

[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] Available from International Commission on Radiation Units & Measurements, 7910 Woodmont Ave., Suite 400, Bethesda, MD 20814-3095, http://www.icru.org.

[4] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[5] Document produced by Working Group 1 of the Joint Committee for Guides in Metrology (JCGM WG1), Available free of charge at the BIPM website (http://www.bipm.org).

[6] Document produced by Working Group 2 of the Joint Committee for Guides in Metrology (JCGM WG2), Available free of charge at the BIPM website (http://www.bipm.org).

3. Terminology

3.1 *Definitions:*

3.1.1 *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.

3.1.2 *dosimeter response (indication)*—reproducible, quantifiable change produced in the dosimeter by ionizing radiation.

3.1.2.1 *Discussion*—The dosimeter response value (indication), obtained from one or more measurements, is used in the estimation of absorbed dose.

3.1.2.2 *Discussion*—For PMMA dosimeters, the dosimeter response value (indication) is obtained from measurement of the optical absorbance.

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

3.1.4 *polymethylmethacrylate (PMMA) dosimeter*—piece of specially selected or developed PMMA material, individually sealed by the manufacturer in an impermeable sachet that, when irradiated, exhibits a characterizable change in specific absorbance that can be related to absorbed dose.

3.1.4.1 *Discussion*—The piece of PMMA, when removed from the sachet after irradiation, is also commonly referred to as the dosimeter.

3.1.5 *specific absorbance (k)*—optical absorbance, A_λ, at a selected wavelength λ, divided by the optical path length, d:

$$k = A_\lambda / d \quad (1)$$

3.2 Definitions of other terms used in this standard that pertain to radiation measurement and dosimetry may be found in ISO/ASTM Practice 52628. Other terms that pertain to radiation measurement and dosimetry may be found in ASTM Terminology E3083 and ISO Terminology ISO 12749-4. Where appropriate, definitions used in these standards have been derived from, and are consistent with definitions in ICRU Report 85a, and general metrological definitions given in the VIM.

4. Significance and use

4.1 The PMMA dosimetry system provides a means for measuring absorbed dose based on a change in optical absorbance.

4.2 PMMA dosimetry systems are commonly used in industrial radiation processing, for example in the sterilization of medical devices and the irradiation of foods.

5. Overview

5.1 PMMA dosimeters may be manufactured by various methods. For example, the raw material has historically been cast, extruded, or injection molded. Fundamentally, ingredients required for the promotion and control of polymerization and stability, and, in the case of dyed dosimeters, specified quantities of dyes appropriate for the required range of response, are dissolved in methylmethacrylate, which is then polymerized. The material is then conditioned to adjust the water content, and the response to radiation is verified using appropriate sampling and testing before release for packaging, and ultimately for use.

5.2 Ionizing radiation induces chemical reactions in the material, which create or enhance absorption bands in the visible or ultraviolet regions of the spectrum, or both. Optical absorbance determined at appropriate wavelengths within these radiation-induced absorption bands is quantitatively related to the absorbed dose. ICRU Report 80 provides information on the scientific basis and historical development of the PMMA dosimetry systems in current use.

5.3 The difference between the specific absorbance of unirradiated and irradiated PMMA is dependent upon the wavelength of the light which is used to make the measurement. Typically, the manufacturer specifies the recommended wavelength that optimizes sensitivity and post-irradiation stability. The wavelengths recommended for examples of commonly used systems are given in Table A1.1.

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. (See also ISO/ASTM Guide 52701.) Examples of such influence quantities are temperature and dose rate.

6.2 *Pre-Irradiation Conditions:*

6.2.1 *Dosimeter Conditioning and Packaging*—Pieces of PMMA are pre-conditioned by the manufacturer to optimize water concentration, and sealed in impermeable aluminum foil laminate sachets to maintain that condition.

6.2.2 *Time Since Manufacture*—With appropriate manufacturing, packaging and storage conditions, the shelf-life of some types of PMMA dosimeters has been shown to exceed ten years (**1**).[7]

6.2.3 *Temperature*—Exposure to temperatures outside the manufacturer's recommended range should be minimized to reduce the potential for adverse effects on dosimeter response.

6.2.4 *Relative Humidity*—The effect of humidity is eliminated by the isolation provided by the sachet.

6.2.5 *Exposure to Light*—The effect of light exposure is eliminated by the isolation provided by the sachet.

6.3 *Conditions during Irradiation:*

6.3.1 *Irradiation Temperature*—the dosimeter response is affected by temperature and shall be characterized.

6.3.2 *Absorbed-Dose Rate*—the dosimeter response is affected by the absorbed-dose rate and shall be characterized.

6.3.3 *Dose Fractionation*—the dosimeter response may be affected by incremental exposures and should be characterized.

6.3.4 *Relative Humidity*—the effect of humidity is eliminated by the isolation provided by the sachet.

6.3.5 *Exposure to Light*—the effect of light exposure, if any, is eliminated by the isolation provided by the sachet.

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

6.3.6 *Radiation Energy*—the dosimeter response is dependent upon the radiation energy and the dosimeters shall be irradiated for calibration under the conditions of use.

6.4 *Post-Irradiation Conditions:*

6.4.1 *Time*—the time between irradiation and dosimeter reading shall be standardized and should conform to the manufacturer's recommendations.

6.4.2 *Temperature*—Exposure to temperatures outside the manufacturer's recommended range should be minimized to reduce the potential for adverse effects on dosimeter response.

6.4.3 *Conditioning Treatment*—Post-irradiation treatment is not applicable.

6.4.4 *Relative Humidity*—Prior to opening the sachet, the effect of humidity is eliminated by the isolation provided by the sachet.

6.4.5 *Exposure to Light*—Prior to opening the sachet, any effect of light exposure is eliminated by the isolation provided by the sachet.

NOTE 1—Two categories of post-irradiation change are of concern when devising a practical operational protocol for the use of dosimeters: the changes which occur if the sachet is left unopened; and those which occur after it is opened. It is good practice to assess the post-irradiation change of dosimeters under both of these conditions. Examples of results obtained by a manufacturer are given in (**2**).

6.5 *Response Measurement Conditions:*

6.5.1 *Exposure to Light*—After opening the sachet, exposure to light may affect the response of the dosimeter. Users should follow manufacturer's recommended practices.

6.5.2 *Temperature*—Exposure to temperatures outside the manufacturer's recommended range should be minimized to reduce the potential for adverse effects on dosimeter response.

6.5.3 *Relative Humidity*—After opening the sachet, prolonged exposure to extreme humidity conditions may affect the response of the dosimeter. Therefore, the time between opening the sachet and dosimeter reading should be minimized.

6.5.4 *Handling*—Handle dosimeter by its edges. Skin oils, dirt and debris on the surface of dosimeters that are perpendicular to the analyzing light beam, may affect the absorbance of light, therefore impacting the dose measurement.

7. Dosimetry system and its verification

7.1 *Components of the PMMA Dosimetry System*—The following are components of PMMA dosimetry systems:

7.1.1 *Polymethylmethacrylate Dosimeters.*

7.1.2 *Calibrated Spectrophotometer* (or an equivalent instrument), capable of measuring optical absorbance at the analysis wavelength and having documentation specifying analysis wavelength range, accuracy of wavelength selection and absorbance determination, spectral bandwidth, and stray light rejection.

7.1.2.1 Means of verifying the accuracy of optical absorbance-measurement, for example through the use of certified optical absorption filters, covering more than the range of absorption encountered.

7.1.2.2 Means of verifying wavelength calibration, for example through the use of *certified filters*.

7.1.3 *Holder,* to position the dosimeter reproducibly in, and perpendicular to, the analyzing light beam.

7.1.4 *Calibrated Thickness Gauge.*

7.1.4.1 Means of verifying thickness gauge calibration, for example through the use of certified thickness gauge blocks, exceeding the range of thicknesses encountered.

7.2 *Measurement Management System,* including the dosimeter batch calibration curve resulting from calibration according to ISO/ASTM Practice 51261, and the procedures for use.

7.3 *Performance Verification of Instrumentation:*

7.3.1 At prescribed time intervals, and whenever there are indications of poor performance during periods of use, the wavelength and absorbance scales of the spectrophotometer shall be checked at or near the analysis wavelength, and the results documented. This information should be compared with the instrument specifications to verify adequate performance, and the result documented. (See ASTM Practice E275.)

7.3.2 At prescribed time intervals the calibration of the thickness gauge shall be checked and the result documented. The thickness gauge shall also be checked before, during, and, if considered appropriate, after use, to ensure reproducibility and absence of zero drift.

8. Incoming dosimeter stock assessment

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

8.2 For dosimeters received, the user shall perform an incoming inspection of a representative sample to verify, for example, batch designation against the manufacturer's certification, sachet integrity, and that the sample's thickness range, pre-irradiation absorbance, and radiation response, are within documented specifications.

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

8.4 Store dosimeters according to the manufacturer's written recommendations, or as justified by published data or experience.

NOTE 2—For some industries or uses of PMMA dosimeters, where the dose delivered to product is a defined specification, the monitoring and documentation of storing conditions is recommended in order to prevent storage conditions being a cause of influence quantities.

9. Calibration

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

9.2 The user's dosimetry system calibration procedures 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 3—If prior experience, manufacturer's recommendations, or scientific literature (see Refs **1-29**), suggest that the conditions experienced by the dosimeters are likely to influence dosimeter response and increase the uncertainties beyond what is considered acceptable for the given irradiation application, the calibration irradiation of the dosimeters should be performed under conditions similar to those in routine use (**2**,**27**,**28**).