An American National Standard

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 classified 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 ASTM Practice E2628).

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 ASTM E2628 "Practice for Dosimetry in Radiation Processing" for a PMMA dosimetry system. It is intended to be read in conjunction with ASTM E2628.

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 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

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

E2628 Practice for Dosimetry in Radiation Processing

E2701 Guide for Performance Characterization of Dosimeters and Dosimetry Systems for Use in Radiation Processing

2.2 *ISO/ASTM Standards:*[2]

51261 Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing

51707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing

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

ICRU Report 60 Fundamental Quantities and Units for Ionizing Radiation

ICRU Report 80 Dosimetry Systems for Use in Radiation Processing

2.4 *ISO Reports:*[4]

GUM Guide to the Expression of Uncertainty in Measurement, 1995.

VIM International Vocabulary of Basic and General Terms in Metrology, 2008

3. Terminology

3.1 *Definitions:*

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

3.1.1.1 *Discussion*—in radiation processing dosimetry standards, the term *dosimeter response* is generally used rather than "indication". Thus, a calibration curve is an expression of the relation between the dosimeter response and the corresponding measured quantity value.

3.1.2 *dosimeter*—a device that, when irradiated, exhibits a quantifiable change that can be related to absorbed dose in a given material using appropriate measurement instruments and procedures.

3.1.3 *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.

3.1.4 *dosimeter response*—reproducible, quantifiable effect produced in the dosimeter by ionizing radiation.

NOTE 1—For PMMA dosimeters, the specific absorbance is the dosimeter response.

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

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[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 and Measurements, 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814, U.S.A.

[4] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, http://www.iso.org

3.1.6 *measurement management system*—set of interrelated or interacting elements necessary to achieve metrological confirmation and continual control of measurement processes.

3.1.7 *polymethylmethacrylate (PMMA) dosimeter*—piece of specially selected or developed PMMA material, individually sealed by the manufacturer in an impermeable sachet, that during exposure to ionizing radiation exhibits a characterizable change in specific optical absorbance as a function of absorbed dose.

NOTE 2—The piece of PMMA, when removed from the sachet after irradiation, is also commonly referred to as the dosimeter.

3.1.8 *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.

3.1.9 *response*—see *dosimeter response*.

3.1.10 *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.

3.1.11 *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 practice that pertain to radiation measurement and dosimetry may be found in ASTM Terminology E170. Definitions in E170 are compatible with ICRU Report 60; that document, therefore, may be used as an alternative reference.

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 and/or ultraviolet regions of the spectrum. 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 ASTM Guide E2701.) 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)**.[5]

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.

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.

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

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 3—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.

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 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.

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 Guide 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 4—If prior experience, manufacturer's recommendations, or scientific literature (see Refs **1-28**), suggest that the conditions experienced by the dosimeters are likely to influence dosimeter response and increase the uncertainties significantly, the calibration irradiation of the dosimeters should be performed under conditions similar to those in routine use **(2,27,28)**.

9.3 Multiple calibration curves may be required to accommodate particular dose ranges or post-irradiation measurement intervals.

10. Routine use

10.1 *Before Irradiation*:

10.1.1 Ensure that the dosimeters are selected from an approved batch stored according to user's procedures and manufacturer's written recommendations, and that they are within shelf life and calibration expiration dates.

10.1.2 Inspect each dosimeter sachet for external imperfections, for example sachet seal integrity and presence of PMMA piece. Discard any dosimeters that show unacceptable imperfections.

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

10.1.4 Place the unopened dosimeters at specified locations for irradiation.

10.2 *Post-Irradiation Analysis Procedure*:

10.2.1 Retrieve the dosimeters.

10.2.2 Maintain the PMMA pieces in their sealed packages in an approved location under specified conditions prior to measurement. See 6.4 and 6.5.

10.2.3 Specific absorbance of dosimeters should be measured within a specified time interval (see 6.4.1 and Ref **(26)**) and under conditions (6.5) which take account of potential post-irradiation changes.

10.2.4 Verify instrument performance according to documented procedures. See 7.3.

10.2.5 Inspect each dosimeter sachet for imperfections, for example, compromised sachet integrity. Document any imperfections.

10.2.6 For each dosimeter, perform the following:

10.2.6.1 Open the package and remove the PMMA piece, handling it by its edges.

10.2.6.2 Inspect the PMMA piece for any imperfections, such as scratches. Document any imperfections.

NOTE 5—If a dosimeter is found to be scratched, a reliable measurement can usually be obtained by repositioning the PMMA piece, for example by inverting it, so that the scratch is not in the light beam path of the spectrophotometer.

10.2.6.3 If necessary, clean the PMMA piece before analysis. An accepted method is wiping with paper tissue moistened with an appropriate solvent such as ethanol or propanol.

10.2.6.4 Position the PMMA piece in the holder in the instrument, taking care to align it properly and to position it perpendicular to the analyzing light beam.

10.2.6.5 Measure and record the absorbance at the selected analysis wavelength (see Table A1.1 for manufacturer's recommendations).

10.2.6.6 Measure the thickness of the PMMA piece in the region traversed by the analyzing light beam.

10.2.6.7 Calculate the specific absorbance.

10.2.6.8 Determine the absorbed dose from the specific absorbance and the appropriate calibration curve (see 9.3).

11. Documentation requirements

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

12. Measurement uncertainty

12.1 All dose measurements need to be accompanied by an estimate of uncertainty. Appropriate procedures are recommended in ISO/ASTM Guides 51707 and 51261 (see also GUM).

12.1.1 All components of uncertainty should be included in the estimate, including those arising from calibration, dosimeter variability, instrument reproducibility, and the effect of influence quantities. A full quantitative analysis of components of uncertainty is 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.

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

13. Keywords

13.1 absorbed dose; dose; dosimeter; dosimetry system; electron beam; gamma radiation; ionizing radiation; irradiation; PMMA; polymethylmethacrylate; radiation; radiation processing; radiation sterilization

ANNEX

(informative)

A1. INFORMATION ON POLYMETHYLMETHACRYLATE (PMMA) DOSIMETERS

A1.1 This information is intended to serve as a guide only, since available sources of dosimeters and dosimeter performance may change.

A1.2 A general list of available PMMA dosimeters is given in Table A1.1.

TABLE A1.1 Basic properties of available PMMA dosimeters

Dosimeter Type	Nominal Thickness, mm	Analysis Wavelength, nm	Absorbed Dose Range, kGy
Harwell Red 4034	3	640	5 to 50
Harwell Amber 3042	3	603 or 651	1 to 30
Harwell Gammachrome YR®	2	530	0.1 to 3
Radix W	1.5	280 or 320	1 to 150

A1.3 Note that the absorbed dose ranges are recommended ranges. In some cases it may be possible to extend the lower and upper dose limits with possible consequent loss of dosimetric accuracy.

A1.4 Some suppliers are listed in Table A1.2.

A1.5 The radiation response of some types of PMMA dosimeters is known to be dependent on water content, so these dosimeters are normally supplied in sealed leak-tight packages. These packages protect the dosimeters, ensure a stable water content, and prevent undue exposure to light before absorbance measurements.

A1.6 Information on environmental and post-irradiation effects and their possible influence on dosimetric accuracy may

TABLE A1.2 Some suppliers of polymethylmethacrylate (PMMA) dosimeters

Dosimeter	Address
Harwell	Harwell Dosimeters Ltd., 540 Becquerel Ave., Harwell S&I Campus DIDCOT Oxfordshire, OX11 OTA, England
Radix	Radia Industry Co., Ltd., 168 Ooyagi Takasaki Gunma 370-0072, Japan

be obtained from the suppliers.

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