



Standard Practice for Use of a Polymethylmethacrylate Dosimetry System¹

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ε¹ NOTE—Footnote 1 was editorially altered in June 1999.

1. Scope

1.1 This practice covers procedures for using hermetically-sealed polymethylmethacrylate (PMMA) dosimeters for measuring absorbed dose in materials irradiated by photons or electrons in terms of absorbed dose in water.

1.2 This practice covers systems that permit absorbed dose measurements under the following conditions:

1.2.1 The absorbed dose range is 0.1 to 100 kGy.

1.2.2 The absorbed dose rate is 1×10^{-2} to 1×10^7 Gy·s⁻¹.

1.2.3 The radiation energy range for photons is 0.1 to 50 MeV, and for electrons 3 to 50 MeV.

1.2.4 The irradiation temperature is -78 to +50°C.

1.3 *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 Dosimetry²

E 178 Practice for Dealing with Outlying Observations³

E 275 Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near Infrared Spectrophotometers⁴

E 668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices²

E 1026 Practice for Using the Fricke Reference Standard Dosimetry System²

E 1204 Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing²

E 1205 Practice for Use of a Ceric-Cerous Sulfate Dosimetry System²

E 1261 Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing²

E 1400 Practice for Characterization and Performance of a High-Dose Radiation Dosimetry Calibration Laboratory²

E 1401 Practice for Use of a Dichromate Dosimetry System

E 1607 Practice for Use of the Alanine-EPR Dosimetry System²

E 1631 Practice for Use of Calorimetric Dosimetry Systems for Electron Beam Dose Measurements and Dosimeter Calibrations²

E 1707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing²

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 MeV⁵

ICRU Report 17—Radiation Dosimetry: X Rays Generated at Potentials of 5 to 150 kV⁵

ICRU Report 33—Radiation Quantities and Units⁵

ICRU Report 34—The Dosimetry of Pulsed Radiation⁵

ICRU Report 35—Radiation Dosimetry: Electron Beams with Energies Between 1 and 50 MeV⁵

3. Terminology

3.1 Definitions:

3.1.1 *absorbed dose (D), n*—quantity of ionizing radiation energy imparted per unit mass of a specified material. The SI unit of absorbed dose is the gray (Gy), where 1 gray is equivalent to the absorption of 1 joule 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 incremental energy imparted by ionizing radiation to matter of incremental mass dm (see ICRU Report 33).

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

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

3.1.2 *absorbed-dose rate ($\dot{D}$), n*—the absorbed dose in a

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² Annual Book of ASTM Standards, Vol 12.02.

³ Annual Book of ASTM Standards, Vol 14.02.

⁴ Annual Book of ASTM Standards, Vol 14.01.

⁵ Available from International Commission on Radiation Units and Measurements, 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814.

material per incremental time interval, that is, the quotient of dD by dt (see ICRU Report 33).

$$\dot{D} = \frac{dD}{dt} \quad (2)$$

Unit: $\text{Gy} \cdot \text{s}^{-1}$.

3.1.2.1 *Discussion*—The absorbed-dose rate is often specified in terms of average value of $\dot{D}$ over long-time intervals, for example, in units of $\text{Gy} \cdot \text{min}^{-1}$ or $\text{Gy} \cdot \text{h}^{-1}$.

3.1.3 *analysis wavelength, n*—wavelength used in a spectrophotometric instrument for the measurement of optical absorbance.

3.1.4 *calibration curve, n*—graphical representation of the dosimetry system's response function.

3.1.5 *calibration facility, n*—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.

3.1.6 *dosimeter, n*—a device that, when irradiated, exhibits a quantifiable change in some property of the device which can be related to absorbed dose in a given material using appropriate analytical instrumentation and techniques.

3.1.7 *dosimeter batch, n*—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 *dosimeter response, n*—the reproducible, quantifiable radiation effect produced by a given absorbed dose.

3.1.9 *dosimeter stock, n*—part of a dosimeter batch held by the user.

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

3.1.11 *electron equilibrium, n*—a condition that exists in 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 (see ICRU Report 33).

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

3.1.12 *measurement quality assurance plan, n*—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.

3.1.13 *mean specific absorbance ($\bar{k}$), n*—average value of k for a set of dosimeters irradiated to the same absorbed dose, under the same conditions.

$$\bar{k} = \frac{1}{n} \sum_{i=1}^n k_i \quad (3)$$

where:

n = number of dosimeters, and

k_i = individual dosimeter specific absorbance.

3.1.14 *polymethylmethacrylate (PMMA) dosimeter, n*—piece of specially selected or specially developed PMMA material that exhibits characterizable ionizing radiation-induced changes in specific optical absorbance as a function of absorbed doses, individually sealed by the manufacturer in a hermetically sealed pouch.

3.1.14.1 *Discussion*—The PMMA piece, when removed from the pouch, is still referred to as the dosimeter.

3.1.15 *reference standard dosimeter, n*—a dosimeter of high metrological quality, used as a standard to provide measurements traceable to and consistent with measurements made using primary standard dosimeters (see Guide E 1261).

3.1.16 *response, n*—see *dosimeter response*.

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

3.1.18 *routine dosimeter, n*—dosimeter calibrated against a primary-, reference-, or transfer-standard dosimeter and used for routine absorbed-dose measurement (see Guide E 1261).

3.1.19 *simulated product, n*—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 routine 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 *specific absorbance (k), n*—absorbance, A , at a selected wavelength divided by the optical path length, d , through the dosimeter, as follows:

$$k = A/d \quad (4)$$

3.1.20.1 *Discussion*—In this practice (Practice E 1276), d is equated to dosimeter thickness (t). If t is virtually constant (within $\pm 1\%$), calculation of specific absorbance is unnecessary, and absorbance A may be taken as the dose-related quantity.

3.1.21 *traceability, n*—the documentation demonstrating by means of an unbroken chain of comparisons that a measurement is in agreement within acceptable limits of uncertainty with comparable nationally or internationally recognized standards.

3.1.22 *transfer standard dosimeter, n*—a dosimeter, often a reference standard dosimeter, suitable for transport between different locations, used to compare absorbed-dose measurements (see Guide E 1261).

3.1.23 *uncertainty, n*—a parameter associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand or derived quantity.

3.1.23.1 *Discussion*—The parameter may be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated confidence.

3.1.23.2 *Discussion*—Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of series of measurements and can be characterized by experimental standard deviations. The other components, which also can be characterized by standard deviations, are evaluated from assumed probability distributions based on experience or other information.

3.1.23.3 *Discussion*—It is understood that the result of the measurement is the best estimate of the value of the measurement, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion.

3.2 Other appropriate terms may be found in Terminology E 170.

4. Significance and Use

4.1 Polymethylmethacrylate dosimetry systems are commonly applied in industrial radiation processing, for example, in the sterilization of medical devices and the processing of foods. In these applications, doses fall mostly within the 0.1 to 100 kGy working range of the family of PMMA dosimeters.

4.2 Properly selected PMMA dosimeter materials provide a means of directly estimating absorbed doses in near water-equivalent substances, such as plastics, cotton, paper, gut, and rubber. The doses are normally expressed in terms of dose in water (see 4.7). Under the influence of ionizing radiation, chemical reactions take place in the material, creating and/or enhancing absorption bands in the visible and/or ultraviolet regions of the spectrum. Absorbance is determined at selected wavelengths within these radiation-induced absorption bands. Examples of appropriate wavelengths used for analysis of specific dosimeters are provided in Table X1.1.

4.3 In the application of a specific dosimetry system, absorbed dose is determined by using an experimentally derived calibration curve. The calibration curve is determined by measuring sets of dosimeters irradiated to known absorbed doses that adequately span the range of utilization of the system (see 7.5.2).

4.4 Polymethylmethacrylate dosimetry systems require calibration traceable to national or international standards. See Guide E 1261.

4.5 During calibration and use, possible effects of conditions such as temperature, light exposure, energy spectrum, and absorbed dose rate are taken into account.

4.6 Unprotected PMMA dosimeter material is sensitive to changes in humidity, and cut pieces are therefore individually sealed in water impermeable pouches at the manufacturing stage. They must be kept in these sealed pouches during irradiation.

4.7 Absorbed dose in materials other than water may be determined by applying conversion factors in accordance with Guide E 1261.

NOTE 1—For a comprehensive discussion of various dosimetry methods applicable to the radiation types and energies discussed in this practice, see ICRU Reports 14, 17, 34, and 35.

5. Apparatus

5.1 *Components of the PMMA Dosimetry System*—The following shall be used to determine absorbed dose with PMMA dosimetry systems:

5.1.1 *Polymethylmethacrylate Dosimeters*.

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

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

5.1.4 *Calibrated Thickness Gage*.

5.1.5 Calibrated thickness gage blocks covering the range of thicknesses encountered.

NOTE 2—For constant thickness dosimeters (see 3.1.20.1) documentation provided by the manufacturer of the PMMA dosimeter with regard to the thickness and its uniformity must first be verified by the user for a representative sample, and may then be substituted for direct measurement by the user.

5.1.6 Calibration curve on response function see 7.5.6.

6. Performance Check of Instrumentation

6.1 Check and document the uncertainties of the wavelength and absorbance scales of the spectrophotometer at or near the analysis wavelength at documented time intervals during periods of use, or whenever there are indications of poor performance. Compare and document this information with the original instrument specifications to verify adequate performance. (See Practices E 275 and E 1026.)

6.2 Check the thickness gage before, during, and after use to assure reproducibility and lack of zero drift. Check and document the calibration of the gage at documented time intervals. Use gage blocks traceable to national standards for this purpose.

7. Calibration of Dosimeters

7.1 Calibration of PMMA dosimeters can be accomplished by irradiating the dosimeters in a calibration facility, or by irradiating the dosimeters, along with reference or transfer standard dosimeters in a production irradiator (see Guide E 1261).

7.2 The gamma- or electron-beam facility used may be an accredited calibration facility that provides an absorbed-dose rate measured by reference or transfer standard dosimeters, or it may be a production irradiator. If a production irradiator is used, the absorbed doses delivered to the calibration dosimeters shall be determined by means of reference or transfer standard dosimeters irradiated together with the dosimeters to be calibrated, under conditions that ensure that the calibration- and corresponding reference- or transfer-standard dosimeter sets receive the same dose, under the same environmental conditions.

NOTE 3—The radiation response of PMMA dosimeters may be affected by extremes of environmental or seasonal conditions, such as absorbed dose rate and temperature found in some production irradiation (see Ref.