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Practice for use of a polymethylmethacrylate dosimetry system

Pratique de l'utilisation d'un système dosimétrique au polyméthylméthacrylate

Reference number
ISO/ASTM 51276:2002(E)

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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 Subcommittee E10.01, Dosimetry for 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 51276 was developed by ASTM Committee E10, Nuclear Technology and Applications, through Subcommittee E10.01, and by Technical Committee ISO/TC 85, Nuclear Energy.

Annex A1 of this International Standard is for information only.

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 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. The PMMA dosimeter is classified as a routine dosimeter. See ISO/ASTM Guide 51261.

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 Dosimetry[2]

E 178 Practice for Dealing with Outlying Observations[3]

E 275 Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near Infrared Spectrophotometers[3]

E 668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices[2]

E 1026 Practice for Using the Fricke Reference Standard Dosimetry System[2]

2.2 *ISO/ASTM Standards:*

51204 Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing[2]

51205 Practice for Use of a Ceric-Cerous Sulfate Dosimetry System[2]

51261 Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing[2]

51400 Practice for Characterization and Performance of a High-Dose Radiation Dosimetry Calibration Laboratory[2]

51401 Practice for Use of a Dichromate Dosimetry System[2]

51607 Practice for Use of the Alanine-EPR Dosimetry System[2]

51631 Practice for Use of Calorimetric Dosimetry Systems for Electron Beam Dose Measurements and Dosimeter Calibrations[2]

51707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing[2]

2.3 *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 34 The Dosimetry of Pulsed Radiation[4]

ICRU Report 35 Radiation Dosimetry: Electron Beams with Energies Between 1 and 50 MeV[4]

ICRU Report 60 Fundamental Quantities and Units for Ionizing Radiation[4]

3. Terminology

3.1 *Definitions:*

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

3.1.2 *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.

3.1.3 *dosimeter*—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.

3.1.4 *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.

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

[1] This practice is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.01 on Dosimetry for Radiation Processing, and is also under the jurisdiction of ISO/TC 85/WG 3.

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

[3] *Annual Book of ASTM Standards*, Vol 03.06.

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

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

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

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

where:
n = number of dosimeters, and
k_i = individual dosimeter specific absorbance.

3.1.8 *measurement traceability*—the ability to demonstrate 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.

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

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

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

3.1.11 *response*—see *dosimeter response*.

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

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

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

3.1.14.1 *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.

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

$$k = A_\lambda / d \quad (2)$$

3.1.15.1 *Discussion*—In this practice (ISO/ASTM 51276), d is equated to dosimeter thickness (t). If t is essentially constant (within ±1 %), calculation of specific absorbance is unnecessary, and absorbance A may be taken as the dose-related quantity.

3.1.16 *transfer–standard dosimeter*—a dosimeter, often a reference–standard dosimeter, suitable for transport between different locations, used to compare absorbed-dose measurements.

3.2 Definitions of other terms used in this practice that pertain to radiation measurement and dosimetry may be found in ASTM Terminology E 170. Definitions in E 170 are compatible with ICRU 60; that document, therefore, may be used as an alternative reference.

4. Significance and use

4.1 Polymethylmethacrylate dosimetry systems are commonly used 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. Optical absorbance determined at selected wavelengths within these radiation-induced absorption bands is quantitatively related to the corresponding absorbed radiation dose. Examples of appropriate wavelengths used for analysis of specific dosimeters are provided in Table A1.1.

4.3 In the application of a specific dosimetry system, absorbed dose is obtained by using an experimentally determined calibration curve or response function. These are derived by measuring sets of dosimeters irradiated to known absorbed doses that adequately span the range of utilization of the system (see 7.7.2).

4.4 Polymethylmethacrylate dosimetry systems require calibration traceable to national or international standards. See ISO/ASTM Guide 51261.

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 during manufacture. 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 ISO/ASTM Guide 51261.

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. Instrument requirements

5.1 *Components of the PMMA Dosimetry System*—The following are the components of PMMA dosimetry systems to determine absorbed dose:

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 specifying 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 Standard Optical Absorption Filters*, covering more than the range of absorption encountered.

5.1.5 *Calibrated Thickness Gage*.

5.1.6 *Calibrated Thickness Gage Blocks*, covering more than the range of thicknesses encountered.

NOTE 2—For constant thickness dosimeters (see 3.1.15.1) the manufacturer's documentation specifying 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.

5.1.7 Batch calibration curve or response function (see 7.7.6).

6. Performance check of instrumentation

6.1 Check and record 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 instrument specifications to verify adequate performance. (See ASTM Practices E 275 and E 1026.)

6.2 Check the thickness gage before, and, if considered appropriate, after, use to ensure reproducibility and absence of zero drift. Check and record the calibration of the gage at documented intervals. Use gage blocks traceable to national standards for this purpose.

7. Calibration of the dosimetry system

7.1 Prior to use, the dosimetry system (consisting of a specific batch of dosimeters and specific measurement instruments) shall be calibrated in accordance with the user's documented procedure that specifies details of the calibration process and quality assurance requirements. This calibration process shall be repeated at regular intervals to ensure that the accuracy of the absorbed dose measurement is maintained within required limits. Calibration methods are described in ISO/ASTM Guide 51261.

7.2 *Calibration Irradiation of Dosimeters*—Irradiation is a critical component of the calibration of the dosimetry system. Calibration irradiations shall be performed in one of three ways by irradiating the dosimeters at:

7.2.1 An accredited calibration laboratory that provides an absorbed dose (or an absorbed-dose rate) having measurement traceability to nationally or internationally recognized standards, or

7.2.2 An in-house calibration facility that provides an absorbed dose (or an absorbed-dose rate) having measurement traceability to nationally or internationally recognized standards, or

7.2.3 A production or research irradiation facility together with reference- or transfer-standard dosimeters that have measurement traceability to nationally or internationally recognized standards.

7.3 *Measurement Instrument Calibration and Performance Verification*—For the calibration of the instruments, and for the verification of instrument performance between calibrations, see ISO/ASTM Guide 51261 and/or instrument-specific operating manuals.

7.4 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.

7.4.1 The radiation response of PMMA dosimeters may be affected by extremes of environmental or seasonal conditions, such as the absorbed–dose rate and temperature found in some production irradiators. In these circumstances, the use of dosimeter calibrations performed at fixed dose rates and fixed temperatures could result in unacceptably large increases in dosimetric uncertainty. If prior experience, manufacturer's recommendations, or scientific literature suggest that the range of environmental conditions experienced by the dosimeters in the production facility are likely to significantly increase the uncertainties, then the PMMA dosimeters should be calibrated in an environment that encompasses these conditions. This type of calibration may, for example, be carried out using the production irradiator, under the conditions identified, using reference- or transfer-standard dosimeters to determine the calibration doses given (see 7.2.3).

7.5 Absorbed doses shall be specified in terms of absorbed dose in water, or in another specified material appropriate for the particular application.

7.6 Provide the following conditions for the calibration of dosimeters:

7.6.1 Ensure that the shelf-life of the dosimeters, as stated by the manufacturer, has not been exceeded.

7.6.2 Select a well-defined and reproducible position for the dosimeters during irradiation in the calibration field. In the case of a fixed dose rate calibration, select a location in the calibration field in which the variation in absorbed–dose rate within the volume occupied by the dosimeters has been demonstrated to be within ±1 %, a range of 2 %. For variable dose rate calibration in a production irradiator, use a location in the product, or simulated product, in which the variation in total absorbed dose delivered during production has been demonstrated to be within an acceptable range such as ±1 %, a range of 2 %.

7.6.3 If a calibration facility is used, the dose rate shall be traceable to national or international standards. The temperature of the dosimeters, both during and after irradiation, and the fixed dose rate used shall be arranged to be as close as practicable to the average irradiation temperature, average post irradiation temperature/time, and average dose rate conditions occurring in the production facility of interest.

7.6.4 Whatever the irradiation conditions used, the dosimeters shall be surrounded with sufficient PMMA or equivalent material to ensure electron equilibrium conditions.

NOTE 3—As an example, for cobalt-60 gamma irradiations, 3 to 5 mm of PMMA (or equivalent polymeric material, such as solid polystyrene) surrounding the dosimeters on all sides effectively ensures electron equilibrium conditions. In the case of calibrations in a production irradiator, the material should take the form of a block having a minimum wall thickness of 3 mm and containing a cavity, or cavities, located to ensure that the PMMA- and reference- or transfer-standard dosimeters all receive the same dose.

7.7 Calibrate each stock or batch of dosimeters before routine use. If a new stock from the same batch is to be brought into use, recalibration may not be necessary. In this case, however, it must be demonstrated that the existing calibration applies to the new stock, by means of a verification procedure (see Note 4).

NOTE 4—To verify that an existing calibration still applies, irradiate sets of dosimeters at selected doses spanning the range of utilization. The minimum requirement is to irradiate dosimeters at the lower and upper limits of this range, and the mid-point. If the resulting values fit the existing calibration curve (any slight deviations being statistically insignificant), then the calibration is verified.

7.7.1 Use a set of at least four dosimeters for each absorbed dose point (see ISO/ASTM Guide 51261 for guidance on determining sample size).

7.7.2 The number of sets of PMMA dosimeters required to determine the calibration curve of the dosimetry system depends on the dose-range of utilization. Use at least five sets for each factor of ten span of absorbed dose, or at least four sets if the range of utilization is less than a factor of ten. For example, a range of use from 0.2 to 45 kGy would require at least twelve sets. The dose values may be distributed either arithmetically, for a short dose range, or geometrically, for a large range.

NOTE 5—To determine mathematically the minimum number of sets to be used, divide the maximum dose in the range of utilization (D_{max}) by the minimum dose (D_{min}), then, calculate log(base 10) of this ratio:

$$Q = \log (D_{max}/D_{min}) \quad (3)$$

If Q is less than 1, use a minimum of four sets. If Q is greater than 1, calculate the multiple $5 \times Q$, and round this to the nearest integer value. This value represents the minimum number of sets to be used.

7.7.3 Determine the specific absorbance of the dosimeters (see Section 8).

7.7.4 Calculate and document the mean specific absorbance, $\bar{k}$, and the sample standard deviation (S_{n-1}) for each set of four (or more) dosimeters at each dose value.

NOTE 6—The sample standard deviation, S_{n-1}, is calculated from the sample data set of n values as follows:

$$S_{n-1} = \sqrt{\frac{\Sigma(k_i - \bar{k})^2}{n-1}} \quad (4)$$

where:
k_i = i'th value of k.

7.7.5 For calibrations in a production irradiator, document the type, supplier, batch number, date of manufacture, and all other relevant information for the reference- or transfer-standard dosimeters used. Document the code number and title of the measurement practice used, the correction factors used (if applicable), and correlate the measured reference- or transfer-standard doses against the corresponding PMMA dosimeter specific absorbances.

7.7.6 Graphically plot specific absorbance versus absorbed dose, or use a suitable computer code, or both, to derive this relationship in mathematical form. Choose an analytical form (for example, linear, polynomial, or exponential) that provides the best fit to the measured data. See ISO/ASTM Guide 51261.

7.7.7 Examine the resulting calibration curve or response function for goodness of fit (see ISO/ASTM Guide 51707).

7.7.8 Repeat this calibration procedure if any value (or values) deviates significantly from the determined curve, and if discarding this value would result in there being insufficient data to adequately define the curve (see ISO/ASTM Guides 51707 and 51261).

NOTE 7—See ASTM Practice E 178 for guidance on dealing with outliers.

7.7.9 Repeat the calibration procedure at intervals not exceeding twelve months.

8. Procedures

8.1 *Storage and Examination Procedure*:

8.1.1 Store the dosimeters according to the manufacturer's written recommendations.

8.1.2 For each stock or batch of dosimeters, the user shall perform an incoming inspection of a representative sample to, for example, verify batch designation against the manufacturer's certification, pouch integrity, and that the sample's thickness range and pre-irradiation absorbance are within specification.

8.1.3 Immediately prior to use, inspect each dosimeter pouch for imperfections; for example pouch seal integrity. Discard any dosimeters that show unacceptable imperfections that could give rise to erroneous readings.

8.2 *Dosimeter Irradiation Procedure*:

8.2.1 Mark the packaged dosimeters appropriately for identification.

8.2.2 For calibration, use an appropriate procedure as detailed in Section 7.

8.2.3 For general application in industrial process monitoring, place the packaged dosimeters at appropriate locations (see ISO/ASTM Practice 51204).

NOTE 8—For interpretation of absorbed dose, the dosimeters may be irradiated either in the product undergoing processing, in a medium of similar composition, or in simulated product. In each case, the medium should have appropriate dimensions so as to approximate electron equilibrium conditions. Such equilibrium conditions may not exist, however, within dosimeters placed throughout the product under actual processing conditions, particularly near interfaces of different materials. Irradiation under non-equilibrium conditions, such as on the surface of a product package, may nevertheless be sufficient to monitor the absorbed dose delivered to the product and may under certain conditions be related to absorbed dose within the product by correction factors. For a detailed discussion of this subject, see ISO/ASTM Guide 51261 and ISO/ASTM Practice 51204.

8.3 *Post-Irradiation Analysis Procedure*:

8.3.1 Keep the PMMA pieces in their sealed packages until the time for reading.

8.3.2 Inspect each dosimeter pouch for imperfections, for example, pouch violation. Document any imperfections.

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

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

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

8.3.6 Locate the PMMA in the holder in the instrument, taking care to align it properly and position it perpendicular to the analyzing light beam.

8.3.7 Determine the absorbance at the selected analysis wavelength (see Table A1.1).

8.3.8 Measure the thickness of the PMMA in the region traversed by the analyzing light beam (see 3.1.15).

8.3.9 Calculate the specific absorbance (see 3.1.15).

9. Characterization of each stock of dosimeters

9.1 *Reproducibility of Specific Absorbance*:

9.1.1 For each dosimeter stock, the reproducibility of specific absorbance should be obtained by analyzing the sets of dosimeters irradiated during the calibration at each absorbed dose value (see 7.7.2).

9.1.2 Use the sample standard deviations, S_{n-1}, determined during calibration (see 7.7.4) to calculate coefficients of variation (CV) for each absorbed dose value, as follows:

$$CV = \frac{S_{n-1}}{\bar{k}} \times 100\ (\%) \qquad (5)$$

9.1.3 Document these coefficients of variation and note any that are unusually large.

NOTE 9—In general, if any coefficient of variation values are greater than 2 %, then a redetermination of the CV should be considered using a larger sample of dosimeters, or the stock of dosimeters should be rejected. A more complete evaluation of the data set, which includes calculation of a pooled CV, can be found in ISO/ASTM 51707.

9.2 *Post-Irradiation Characterization*:

9.2.1 Under certain conditions, dosimeters may not develop full color immediately after irradiation, or induced color may change with time, and these changes accelerate with increasing temperatures. In order to determine if this is significant in a given application, the following procedure shall be used. Characterize the post-irradiation behavior of each stock of dosimeters by determining specific absorbances at the analyzing wavelength at various times after irradiation at the temperature used. Choose the times to cover the range of post-irradiation measurement times anticipated under typical operational conditions. Keep each dosimeter sealed in its package until measurement; that is, for each set of readings, use a new set of freshly opened dosimeters and do not re-read a dosimeter that was opened and read earlier.

9.2.2 Document any post-irradiation changes.

9.2.3 If specific absorbances measured in accordance with 9.2.1 are found to vary significantly with post-irradiation storage time, then apply correction factors for such time-dependent variations.

9.2.4 This procedure shall be required only once for a given stock of dosimeters, for a given set of irradiation conditions.

9.3 *Other Factors*:

9.3.1 During the characterization, calibration, and use of the dosimetry system, the effects (if any) of temperature, humidity, absorbed dose rate, incident energy spectrum, and background ultraviolet radiation on the dosimeter response shall be considered and taken into account.

NOTE 10—Information regarding the magnitude of such effects on the dosimetric measurements may be obtained from sources such as scientific literature (see Refs **1-25**)[5], dosimeter manufacturers, distributors, and qualified testing organizations.

10. Application of dosimetry system

10.1 Determine the number of dosimeters required for the measurement of absorbed dose on the basis of the dosimetric uncertainty acceptable in a given application. The overall precision may be improved by replicate measurement. See ASTM Practice E 668 for guidance on determining the number of dosimeters required.

10.2 Follow the procedures in accordance with 8.2-8.3.9, inclusive.

10.3 Estimate the absorbed dose from $\bar{k}$ and the system calibration curve or response function.

11. Documentation requirements

11.1 Record the dosimeter manufacturer, type, and batch identification.

11.2 Record or reference the date of calibration, calibration source, and associated instruments used.

11.3 Record any unusual environmental conditions during irradiation, for example extremes of temperature.

11.4 Record all relevant details such as the date of irradiation, the absorbance and thickness data, dosimeter reference identification and irradiation location, the dates on which the irradiated dosimeters were analyzed, the instruments used, the absorbed dose determined, and its uncertainty components.

11.5 File the results in accordance with local requirements such as the record retention plan.

12. Measurement uncertainty

12.1 To be meaningful, a measurement of absorbed dose shall be accompanied by an estimate of uncertainty.

12.2 Components of uncertainty shall be identified as belonging to one of two categories:

12.2.1 *Type A*—those evaluated by statistical methods, or

12.2.2 *Type B*—those evaluated by other means.

12.3 Other ways of categorizing uncertainty have been widely used and may be useful for reporting uncertainty. For example, the terms *precision* and *bias* or *random* and *systematic* (non-random) are used to describe different categories of uncertainty.

12.4 If this ISO/ASTM practice is followed, the estimate of the expanded uncertainty of an absorbed dose determined by a PMMA dosimetry system should be less than 6 % for a coverage factor k=2 (which corresponds approximately to a 95 % level of confidence for normally distributed data).

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