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Practice for use of a radiochromic film dosimetry system

Pratique de l'utilisation d'un système dosimétrique à film radiochromique

Reference number
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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.

International Standard ISO 15557 was prepared by the American Society for Testing and Materials (ASTM) Subcommittee E10.01 (as E 1275-93) and was adopted, under a special "fast-track procedure", by Technical Committee ISO/TC 85, *Nuclear energy*, in parallel with its approval by the ISO member bodies.

A new ISO/TC 85 Working Group WG 3, *High-level dosimetry for radiation processing*, was formed to review the voting comments from the ISO "Fast-track procedure" and to maintain these standards. The USA holds the convenership of this working group.

International Standard ISO 15557 is one of 20 standards developed and published by ASTM. The 20 fast-tracked standards and their associated ASTM designations are listed below:

ISO Designation	ASTM Designation	Title
15554	E 1204-93	*Practice for dosimetry in gamma irradiation facilities for food processing*
15555	E 1205-93	*Practice for use of a ceric-cerous sulfate dosimetry system*
15556	E 1261-94	*Guide for selection and calibration of dosimetry systems for radiation processing*
15557	E 1275-93	*Practice for use of a radiochromic film dosimetry system*
15558	E 1276-96	*Practice for use of a polymethylmethacrylate dosimetry system*
15559	E 1310-94	*Practice for use of a radiochromic optical waveguide dosimetry system*
15560	E 1400-95a	*Practice for characterization and performance of a high-dose radiation dosimetry calibration laboratory*
15561	E 1401-96	*Practice for use of a dichromate dosimetry system*

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15562	E 1431-91	*Practice for dosimetry in electron and bremsstrahlung irradiation facilities for food processing*
15563	E 1538-93	*Practice for use of the ethanol-chlorobenzene dosimetry system*
15564	E 1539-93	*Guide for use of radiation-sensitive indicators*
15565	E 1540-93	*Practice for use of a radiochromic liquid dosimetry system*
15566	E 1607-94	*Practice for use of the alanine-EPR dosimetry system*
15567	E 1608-94	*Practice for dosimetry in an X-ray (bremsstrahlung) facility for radiation processing*
15568	E 1631-96	*Practice for use of calorimetric dosimetry systems for electron beam dose measurements and dosimeter calibrations*
15569	E 1649-94	*Practice for dosimetry in an electron-beam facility for radiation processing at energies between 300 keV and 25 MeV*
15570	E 1650-94	*Practice for use of cellulose acetate dosimetry system*
15571	E 1702-95	*Practice for dosimetry in a gamma irradiation facility for radiation processing*
15572	E 1707-95	*Guide for estimating uncertainties in dosimetry for radiation processing*
15573	E 1818-96	*Practice for dosimetry in an electron-beam facility for radiation processing at energies between 80 keV and 300 keV*

Designation: E 1275 – 93

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Standard Practice for Use of a Radiochromic Film Dosimetry System[1]

This standard is issued under the fixed designation E 1275; 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 the handling, testing, and procedure for using a radiochromic film dosimetry system to measure absorbed dose in materials irradiated by photons or electrons in terms of absorbed dose in water.

1.2 This practice applies to radiochromic film dosimeters that can be used within part or all of the specified ranges as follows:

1.2.1 The absorbed dose range is 1×10^{-2} to 1×10^{2} kGy.

1.2.2 The absorbed dose rate is 1×10^{-2} to 1×10^{13} Gy/s **(1–4)**.[2]

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

1.2.4 The irradiation temperature range is −78 to +60°C.

1.3 *This standard does not purport to address all of the safety problems, 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[3]

E 178 Practice for Dealing with Outlying Observations[4]

E 275 Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near Infrared Spectrophotometers[5]

E 668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices[3]

E 1026 Practice for Using the Fricke Reference Standard Dosimetry System[3]

E 1204 Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing[3]

E 1205 Practice for Use of a Ceric-Cerous Sulfate Dosimetry System[3]

E 1261 Guide for Selection and Application of Dosimetry Systems for Radiation Processing of Food[3]

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[6]

ICRU Report 17—Radiation Dosimetry: X Rays Generated at Potentials of 5 to 150 kV[6]

ICRU Report 33—Radiation Quantities and Units[6]

ICRU Report 34—The Dosimetry of Pulsed Radiation[6]

ICRU Report 35—Radiation Dosimetry: Electron Beams with Energies Between 1 and 50 MeV[6]

3. Terminology

3.1 *Definitions:*

3.1.1 *absorbed dose, D*—the quotient of $d\bar{\varepsilon}$ by dm, where $d\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to the matter of mass dm (see ICRU Report 33).

$$D = \frac{d\bar{\varepsilon}}{dm}$$

The special name for the unit for absorbed dose is the gray (Gy):

$$1\ \text{Gy} = 1\ \text{J}\cdot\text{kg}^{-1}$$

Formerly, the special unit for absorbed dose was the rad:

$$1\ \text{rad} = 10^{-2}\ \text{J}\cdot\text{kg}^{-1} = 10^{-2}\ \text{Gy}$$

3.1.2 *analysis wavelength*—wavelength used for calibration and routine application.

3.1.3 *batch*—quantity of dosimeters made from a specific mass of material with uniform composition, fabricated in a single production run, and having a unique identification code.

3.1.4 *calibration curve*—graphical or mathematical relationship between the specific net absorbance and the absorbed dose for a given dosimetry system. The calibration curve can also serve as the response function.

3.1.5 *calibration facility*—combination of an ionizing radiation source and its associated instrumentation that provides uniform and reproducible absorbed dose rates at specific locations and in a specific material traceable to national standards, and therefore, may be used to calibrate the absorbed dose response of routine or other types of dosimeters.

3.1.6 *dosimetry system*—system used for determining absorbed dose, consisting of dosimeters, measurement instrumentation, the calibration curve, reference standards, and procedures for the system's use.

3.1.7 *measurement quality assurance plan*—a docu-

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

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

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

[5] *Annual Book of ASTM Standards*, Vol 14.01.

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

mented program for the measurement process that qualifies the total uncertainty of the measurements (both random and systematic error components); this plan shall demonstrate traceability to national standards and shall show that the total uncertainty meets the requirements of the specific application.

3.1.8 *net absorbance, ΔA*—radiation-induced change in measured absorbance at a selected wavelength(s) determined by subtracting the pre-irradiation absorbance, A_0, from the post-irradiation absorbance, A_I as follows:

$$\Delta A = A_I - A_0$$

This term is also referred to as induced absorbance.

3.1.9 *radiochromic film dosimeter*—specially prepared film containing ingredients that undergo an ionizing radiation-induced change in optical absorbance. This change in optical absorbance can be related to absorbed dose in water.

3.1.10 *specific net absorbance, k*—net absorbance, ΔA, at a selected wavelength(s) divided by the thickness, t, of the dosimeter as follows:

$$k = \Delta A/t$$

3.1.11 *traceability*—ability to show that a measurement is consistent with appropriate national standards through an unbroken chain of comparisons.

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

4. Significance and Use

4.1 The radiochromic film dosimetry system provides a means of determining absorbed dose in materials. Under the influence of ionizing radiation, chemical reactions take place in the radiochromic film creating or enhancing, or both, optical absorption bands. Absorbance is determined at the selected wavelength(s) within these radiation-induced absorption bands. Examples of appropriate wavelengths for analysis for specific dosimetry systems are provided by the manufacturer and in Refs. **3** through **14**.

4.2 In the application of a specific dosimetry system, absorbed dose is determined by use of a calibration curve traceable to national standards.

4.3 The absorbed dose determined is usually specified in water. Absorbed dose in other materials may be determined by applying the conversion factors discussed in Guide E 1261.

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

4.4 Radiochromic film dosimetry systems are commonly applied in the industrial radiation processing of a variety of products, for example, sterilization of medical devices and processing of foods **(11, 13)**.

5. Apparatus

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

5.1.1 *Radiochromic Film Dosimeters.*

5.1.2 *Spectrophotometer or Photometer*, having documentation covering analysis wavelength range, accuracy of wavelength selection, absorbance determination, spectral bandwidth, and stray light rejection.

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

5.1.4 *Calibrated Thickness Gage*, with a precision of ±2 % of the film thickness (at a 95 % confidence level).

NOTE 2—Documentation provided by the manufacturer of the radiochromic film dosimeter with regard to the film thickness and its variability may be substituted for direct measurement of thickness by the user. This information should be verified by the user by analyzing a representative sample of films

NOTE 3—Some radiochromic film dosimeters contain a substrate which is not radiochromic. With such dosimeters the thickness is not measured.

6. Performance Check of Instrumentation

6.1 The performance of the photometer or spectrophotometer shall be checked and documented. (See Practices E 275 and E 1026.)

6.1.1 When using a spectrophotometer, check and document the bias and precision of the wavelength scale and absorbance scale at or near the analysis wavelength(s) at intervals not to exceed one month during periods of use, or whenever there are indications of poor performance.

6.1.2 When using a photometer, check and document the bias and precision of the absorbance scale at intervals not to exceed one month during periods of use, or whenever there are indications of poor performance.

6.1.3 Compare the information obtained in 6.1.1 or 6.1.2 with the original instrument specifications to ensure adequate performance.

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 intervals not to exceed six months. Use gage blocks, traceable to national standards for this purpose.

7. Calibration of Dosimeters

7.1 To calibrate a dosimetry system, use an electron or gamma irradiation facility, as appropriate, whose dose rate is traceable to national standards and which meets the following requirements:

7.1.1 Specify the calibration absorbed dose in terms of absorbed dose in water, or in another material appropriate for the specific application (see 4.3).

7.1.2 Determine the absorbed dose rate of the calibration field by use of a reference or transfer dosimetry system (see Guide E 1261, Practice E 1026, and Practice E 1205).

7.2 Provide the conditions for calibration of dosimeters as follows:

7.2.1 Position the dosimeter in the calibration radiation field in a defined, reproducible location.

7.2.2 When using a gamma-ray source for calibration, surround the dosimeters with a sufficient amount of material to ensure electron equilibrium conditions.

NOTE 4—For example, in determining absorbed dose in water with a ^{60}Co source, approximately 3 to 5 mm of polystyrene (or equivalent polymeric material) should surround the dosimeters in all directions.

7.2.3 Make the calibration field within the volume occupied by the dosimeter(s) as uniform as possible. The variation in absorbed dose rate within the volume should be within ±1 %.

7.2.4 Control (or monitor) environmental factors, such as temperature and humidity, during irradiation of the dosimeters. Take into account any variations of such factors that affect dosimeter response (see 9.1).

7.3 Calibrate each batch of dosimeters prior to routine use.

7.3.1 Use a set of at least five dosimeters for each absorbed dose value (see 9.3 of Practice E 668 for guidance on the selection of an appropriate number of dosimeters).

7.3.2 Irradiate these sets of dosimeters to at least five known absorbed dose values covering the range of utilization in order to determine the calibration curve of the dosimetry system. Measure a minimum of four absorbed dose values per decade of absorbed dose range (see 8.1 and 8.2).

NOTE 5—The determination of zero absorbed dose may be used as an absorbed dose value for determining the calibration curve.

7.3.3 Determine the appropriate response for the dosimeters, either specific net absorbance, k, or net absorbance, ΔA.

7.3.4 Calculate the mean response, $\bar{k}$ or $\Delta\bar{A}$, and the sample standard deviation, s_{n-1}, for each set of five (or more) dosimeters at each dose value.

NOTE 6—The sample standard deviation is calculated from the sample data set of n values as follows:

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

where:

k_i = individual dosimeter response, $(\Delta A_i/t)$, and

$i = 1, 2, \ldots, n$.

7.3.5 Plot the mean response, $\bar{k}$ or $\Delta\bar{A}$, versus absorbed dose and/or derive this relationship using a suitable analytical (mathematical) method. Choose an analytical form (for example, linear, polynominal, or exponential) that provides a best fit to the measured data.

7.3.6 Examine the resulting calibration curve for goodness of fit.

7.3.7 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.

NOTE 7—In general, if a mean specific net absorbance value deviates more than ±2 % from the determined curve, then a redetermination of that datum should be considered. See Practice E 178 for guidance on dealing with outliers.

7.3.8 Repeat the calibration procedure at intervals not to exceed twelve months.

8. Procedures

8.1 *Examination and Storage Procedure:*

8.1.1 Ultraviolet radiation may cause the film to change color. Perform tests to assure that the handling/reading environment does not cause measurable color development. If needed, place ultraviolet filters over fluorescent lights or windows to reduce color development.

8.1.2 Handle the film with tweezers and only on the corners.

8.1.3 Visually inspect the films for imperfections. Gently dust the dosimeters if necessary. Discard any dosimeters that show imperfections that could give rise to erroneous readings.

8.1.4 Identify the dosimeters.

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

8.2 *Irradiation Procedure:*

8.2.1 Determine the pre-irradiation absorbance, A_0, for each dosimeter film at the selected analysis wavelength. This may be done for each dosimeter or by use of an average A_0 determined by reading several dosimeters and documenting the variation.

8.2.2 If necessary, package the dosimeters to provide controlled environmental conditions during irradiation.

8.2.3 Mark the packaged dosimeters appropriately for identification.

8.2.4 For calibration, use an irradiation facility that meets the requirements of Section 7 and follow the procedures in that section.

8.2.5 For general application of the dosimetry system in industrial process monitoring, see Practice E 1204.

NOTE 8—The dosimeters may be irradiated in the product undergoing processing or in a medium of similar composition, or water, of appropriate dimensions so as to approximate electron equilibrium conditions. Such equilibrium conditions may not exist within dosimeters placed throughout the product under actual processing conditions. This particularly is the case near interfaces of different materials. Irradiation under nonequilibrium conditions, such as on the surface of a product package, is often used to monitor the absorbed dose delivered to the product and may be related to absorbed dose within the product by correction factors under certain conditions. For a detailed discussion of this subject, see Guide E 1261.

8.3 *Analysis Procedure:*

8.3.1 Avoid any exposure to ultraviolet radiation that may induce coloration of the dosimeter film (see 8.1.1).

8.3.2 Determine the post-irradiation absorbance, A_1, at the selected analysis wavelength(s).

8.3.3 If appropriate for the dosimeter being used, measure the thickness of each dosimeter film, or use the average thickness provided by the manufacturer and document the variation.

NOTE 9—Certain films may be too thin to allow the accurate determination of thickness using conventional gage technology. In such cases, statistical methods may be employed in order to provide the precision and bias values discussed in Section 12.

8.3.4 Calculate the absorbed dose based on the pre- and post-irradiation absorbances, the thickness, if appropriate, and the calibration curve generated in 7.3.5.

NOTE 10—Examples of radiochromic film dosimeter applications that employ reflectance techniques or alternative methods for determining net and specific net absorbance appear in the literature. The user may choose to refer to these techniques (**15, 16**).

9. Characterization of Each Batch of Dosimeters

9.1 *Reproducibility of Specific Net Absorbance:*

9.1.1 For each batch of dosimeters, the reproducibility of specific net absorbance should be obtained by analyzing the data from the sets of dosimeters irradiated during the calibration at each dose value (see 7.3.2).

9.1.2 Use the sample standard deviations (s_{n-1}) determined during calibration (see 7.3.4) to calculate coefficients of variation (CV) for each absorbed dose value as follows:

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

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

NOTE 11—In general, if the coefficients of variation values are greater than 2 %, then a redetermination of the data should be considered, or the batch of dosimeters should be rejected.

9.2 *Post-Irradiation Characterization:*

9.2.1 Some types of dosimeters may fade or may continue color development after irradiation. This effect may depend on post-irradiation storage conditions such as temperature, humidity, or atmosphere. In order to determine if this is significant in a given application, measure the absorbance at the selected wavelength(s) over the period of anticipated analysis and over the range of expected storage conditions (**7, 8, 14, 15**).

9.2.2 If absorbances measured in 9.2.1 are found to vary significantly with post-irradiation storage time, then apply correction factors for such time-dependent variations, taking into account the calibration curve for that batch of dosimeters, in order to minimize dosimetric errors during routine application.

9.2.3 For a given set of irradiation conditions, this procedure needs to be performed only once for a given batch of dosimeters.

9.3 *Other Factors:*

9.3.1 The effects of temperature, humidity, absorbed dose rate, incident energy spectrum, electron equilibrium and background ultraviolet radiation shall be taken into account (**2, 3, 4, 5, 6, 11, 12, 13, 14, 15**). Appropriate written information regarding the magnitude and effect(s) upon the measurement made by the dosimetry system may be obtained from the scientific literature, dosimeter manufacturer, distributor, irradiation facility operator, or a qualified testing organization.

10. Application of Dosimetry System

10.1 The number of dosimeters required for the measurement of absorbed dose on or within a material is determined by the precision of the dosimetry system and the required precision associated with the application. Appendix X3 of Practice E 668 describes a statistical method for determining this number.

10.2 Follow the procedures in accordance with 8.2 and 8.3.

10.3 Determine the absorbed dose from the mean specific net absorbance values and the system calibration curve that results from following the procedures in accordance with Section 7.

10.4 Record the calculated absorbed dose and all other relevant data as outlined in Section 11.

11. Minimum Documentation Requirements

11.1 Record the dosimeter manufacturer, type, and batch number (code).

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

11.3 Record or reference the irradiation environmental conditions for the dosimeters, including temperature, pressure (if other than atmospheric), relative humidity, and composition of the surrounding atmosphere (if other than air).

11.4 Record the date of irradiation and the dates on which the non-irradiated and irradiated dosimeters are analyzed.

11.5 Record the absorbance and thickness data, if appropriate, and the resulting absorbed dose values.

11.6 Record or reference the precision and bias in the value of the absorbed dose.

11.7 Record or reference the measurement quality assurance plan used for the dosimetry system application.

12. Precision and Bias

12.1 To be meaningful, a measurement of absorbed dose shall be accompanied by an estimate of the uncertainty in the measured value. Factors contributing to the total uncertainty may be separated into two types, precision (random) and bias (systematic). Guide E 1261 discusses sources of uncertainty and lists some of the possible factors that affect precision and bias. Additional information is given in Practice E 668 and Ref. **16**.

12.2 The random and non-random uncertainties involved in measuring absorbed dose using this dosimetry system should be estimated or determined. The overall uncertainty in absorbed dose should be estimated from a combination of these uncertainties, and the procedure for combining these errors should be specifically stated or referenced in all results.

12.3 If care is taken in carrying out this test method, the combined uncertainty of an absorbed dose determined by the dosimetry system should be within ±6 % at a 95 % confidence level. If desired, the random uncertainty of the dosimetry system may be determined by following the statistical procedures described in Practice E 668.

13. Keywords

13.1 absorbed dose; dose measurement; dosimeter; dosimetry; electron beam; gamma radiation; ionizing radiation; quality control; radiation processing; radiochromic dosimetry; radiochromic film

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