ISO/ASTM 51310:2022(E)

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

This standard is issued under the fixed designation ISO/ASTM 51310; 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 a radiochromic optical waveguide dosimetry system to measure absorbed dose in materials irradiated by photons and high energy electrons in terms of absorbed dose to water. The radiochromic optical waveguide dosimetry system is generally used as a routine dosimetry system.

1.2 The optical waveguide dosimeter is classified as a Type II dosimeter on the basis of the complex effect of influence quantities (see ISO/ASTM Practice 52628).

1.3 This document is one of a set of standards that provides recommendations for properly implementing dosimetry in radiation processing, and describes a means of achieving compliance with the requirements of ISO/ASTM 52628 for an optical waveguide dosimetry system. It is intended to be read in conjunction with ISO/ASTM Practice 52628.

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

1.4.1 The absorbed dose range is from 1 Gy to 20 000 Gy.

1.4.2 The absorbed dose rate is from 0.001 Gy/s to 1000 Gy/s.

1.4.3 The radiation photon energy range is from 1 MeV to 10 MeV.

1.4.4 The radiation electron energy range is from 3 MeV to 25 MeV.

1.4.5 The irradiation temperature range is from –78 °C to +60 °C.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

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

2. Referenced documents

2.1 *ASTM Standards:*[2]

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

E925 Practice for Monitoring the Calibration of Ultraviolet-Visible Spectrophotometers whose Spectral Bandwidth does not Exceed 2 nm

E958 Practice for Estimation of the Spectral Bandwidth of Ultraviolet-Visible Spectrophotometers

E3083 Terminology Relating to Radiation Processing: Dosimetry and Applications

2.2 *ISO/ASTM Standards:*[2]

51261 Practice for Calibration of Routine Dosimetry Systems for Radiation Processing

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

52628 Practice for Dosimetry in Radiation Processing

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

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

ICRU Report 80 Dosimetry Systems for Use in Radiation Processing

ICRU Report 85a Fundamental Quantities and Units for Ionizing Radiation

[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.

Current edition approved December 10, 2021. Published April 2022. Originally published as ASTM E 1310–89. Last previous ASTM edition E 1310–98$^{\varepsilon 1}$. ASTM E 1310–94 was adopted by ISO in 1998 with the intermediate designation ISO 15559:1998(E). The present International Standard ISO/ASTM 51310:2022(E) is a revision of the last previous edition ISO/ASTM 51310:04(2012)(E).

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

2.4 *ISO Standard:*[4]

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

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

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

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

3. Terminology

3.1 *Definitions:*

3.1.1 *analysis wavelength*—wavelength used in a spectrophotometric instrument for the measurement of optical absorbance or reflectance.

3.1.2 *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.

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

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

3.1.3.2 *Discussion*—For optical waveguide dosimeters, the dosimeter response value (indication) is the net response obtained from measurements of the optical absorbance.

3.1.4 *net response, ΔR*—radiation–induced change in the relationship of measured absorbance at a specific wavelength determined by subtracting the pre-irradiation response, R_0, from the post–irradiation response, R:

$$\Delta R = R - R_0 \tag{1}$$

with:

$$R = A_\lambda / A_{\lambda ref}$$
$$R_0 = [A\lambda / A_{\lambda ref}]_0 \tag{2}$$

where:

A_λ = optical absorbance at the analysis wavelength, λ, and
$A_{\lambda ref}$ = optical absorbance at a reference wavelength, λ_{ref}.

3.1.5 *optical waveguide*—device that contains an optical material at a high index of refraction relative to the material enclosing the optical material.

3.1.6 *radiochromic optical waveguide dosimeter*—specially prepared optical waveguide containing ingredients that undergo an ionizing radiation–induced change in photometric absorbance which can be related to absorbed dose to water (**1**, **2**).[7]

3.1.7 *reference wavelength, λ_{ref}*—wavelength selected for comparison with the analysis wavelength. This wavelength is chosen to minimize effects associated with optical coupling and other geometric variations in the dosimeter.

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

4. Significance and use

4.1 The radiochromic optical waveguide dosimetry system provides a means of measuring absorbed dose in materials. Under the influence of ionizing radiation such as photons, chemical reactions take place in the radiochromic optical waveguide creating and/or modifying optical absorbance bands in the visible region of the spectrum. Optical response is determined at selected wavelengths using the equations in 3.1.4. Examples of appropriate wavelengths for the analysis for specific dosimetry systems are provided by their manufacturers and in Refs (**1-5**).

4.2 These dosimetry systems commonly are applied in the industrial radiation processing of a variety of products, for example, the sterilization of medical devices and radiation processing of foods (**4-6**).

NOTE 1—For additional information on dosimetry systems used in radiation processing, see ICRU Report 80.

5. Overview

5.1 Radiochromic optical waveguide dosimeters may be manufactured by various methods. For example, consisting of a solution held in a fluorinated ethylenepropylene (FEP) tube by means of glass beads inserted in the ends of the tube. In addition to sealing the solution in the tube the beads act as lenses for light during the analysis of the dosimeter's response.

5.2 The FEP tube has a lower index of refraction than the radiation-sensitive solution, creating an optical waveguide. Light entering through one end will tend to move through the solution to the other end, reflecting off the wall of the tube.

5.3 The response is measured as a ratio of the absorbance at the wavelength of interest to the absorbance at a reference wavelength that is minimally affected by the radiation-induced changes of the solution inside the tube.

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. Examples of such

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

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

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

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

factors are temperature and dose rate. An in-situ calibration may help to account for the influence quantities and reduce their associated uncertainty along with batch to batch variations. (See ISO/ASTM Guide 52701.)

6.2 *Pre-Irradiation Conditions:*

6.2.1 *Time Since Manufacture*—The initial absorbance and response variation tends to increase with time and may affect the shelf-life. Storing the dosimeters in a refrigerator (about 4 °C) helps minimize these effects. See manufacturer's recommendations. It is recommended that users carry out performance verification of pre-irradiation absorbance and post-irradiation response stability over the useful life of the dosimeter batch. Regular verification of the calibration may be required. (See 7.3).

6.2.2 *Exposure to Light*—Dosimeters are sensitive to ultraviolet light and should be protected by protective packaging or a holder if available; dosimeters without protective packaging or holder might be affected. The manufacturer should be consulted for specific recommendations for dosimeter shipment and storage.

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.

6.3 *Conditions During Irradiation:*

6.3.1 *Irradiation Temperature*—The dosimeter response is affected by temperature and shall be characterized by the user. It is recommended to calibrate the dosimetry system under the conditions of use (in-situ calibration) in order to mitigate the effect of temperature on dosimeter response. (**7**).

6.3.2 *Exposure to Light*—Dosimeters should be packaged so they are not affected by exposure to ultraviolet light; for example, a dosimeter may be wrapped in or inserted into an opaque material.

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

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

6.3.4.1 *Discussion*—The shape (slope) of the calibration curve associated with some radiochromic optical waveguide dosimeters may be affected by the absorbed dose rate for a given application. If an application requires an absorbed dose rate that is significantly different from the absorbed dose rate used in calibrating the dosimetry system, significant error may be introduced into the determination of absorbed dose.

NOTE 2—Appropriate documented information regarding the magnitude and effect(s) due to absorbed dose rate may be obtained from the scientific literature (**8, 9**), dosimeter manufacturer, distributor, irradiation facility operator, or a qualified testing organization.

NOTE 3—The use of electron scavengers in the formulation of the dosimeter can reduce or eliminate the absorbed dose rate effect (**8, 9**).

6.3.5 *Orientation*—the dosimeter response may be affected by the orientation during irradiation or during readout for low dose applications and shall be characterized. It is recommended to measure the initial absorbance of each dosimeter and to mark the dosimeter for repeatable orientation of measurement after irradiation.

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.

NOTE 4—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. 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. If the net response measured varies significantly with post-irradiation storage time, 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. For a given set of irradiation conditions, this procedure needs to be performed only once for a given batch of dosimeters.

6.4.2 *Exposure to Light*—Dosimeters should be packaged so they are not affected by exposure to ultraviolet light; for example, a dosimeter may be wrapped in or inserted into an opaque material.

NOTE 5—Appropriate written information regarding the magnitude and effect(s) upon the measurement made by the dosimetry system may be obtained from the scientific literature (**3-5**), (**8-12**), dosimeter manufacturer, distributor, irradiation facility operator, or a qualified testing organization.

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

6.5 *Response Measurement Conditions:*

6.5.1 *Exposure to Light*—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 avoided to reduce the potential for adverse effects on the dosimeter response.

6.5.3 *Handling*—Handle dosimeters by the middle of the tubing of the Optical Waveguide, not by the ends.

7. Dosimetry system and its verification

7.1 *Components of the Radiochromic Optical Waveguide Dosimetry System*—The following are components of radiochromic optical waveguide dosimetry systems:

7.1.1 *Radiochromic Optical Waveguide Dosimeters*—A batch or portion of a batch of radiochromic optical waveguide dosimeters.

7.1.2 *Calibrated Spectrophotometer or Photometer*—An instrument, either a spectrophotometer equipped with associated coupling optics (see Ref (**13**) for an example), or a modified photometer (see Ref (**2**) for an example), capable of measuring optical absorbance at the analysis and reference wavelengths and having documentation specifying analysis wavelength range, accuracy of wavelength selection and absorbance determination, spectral bandwidth, and stray light rejection.

7.1.3 *Holder,* to position the dosimeter reproducibly in line with the analyzing light beam.

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

7.3 *Performance Verification of Instrumentation:*

7.3.1 At prescribed time intervals, and whenever there are indications of poor performance during periods of use, the wavelength and absorbance scales of the spectrophotometer or photometer shall be checked at or near the analysis and reference wavelengths, and the results documented. This information should be compared with the instrument specifications to verify adequate performance and the result documented. (see Practices E275, E925, and E958).

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 manufacturer's certification, dosimeter integrity, pre-irradiation absorbance and radiation response are within documented specifications.

8.2.1 Exposure to ultraviolet (UV) radiation may cause the dosimeter to change color. Perform tests to ensure that the handling and reading environment does not cause measurable color development. If needed, place UV filters over fluorescent lights or windows to reduce color development.

NOTE 6—Dosimeters may be stored in UV–opaque material to further avoid the effects noted in 8.2.1.

8.2.2 Handle the dosimeter along the sides, never at the ends. Handling should be kept to a minimum.

8.2.3 Visually inspect the dosimeters for imperfections (for example, loss of end fittings). Discard any dosimeters that show imperfections.

8.2.4 Identify the dosimeters with an appropriate code that can be related to the manufacturer, type, and batch.

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 of the dosimetry system

9.1 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, 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 7—If prior experience, manufacturer's recommendations, or scientific literature (see Refs **(1-6, 8-14)**, suggest that the conditions experienced by the dosimeters are likely to influence dosimeter response and increase the uncertainties beyond what is considered acceptable for the given irradiation application, the calibration irradiation of the dosimeters should be performed under conditions similar to those in routine use **(5, 11, 12)**.

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

9.4 *Reproducibility of Net Response:*

9.4.1 Determine the reproducibility of net response for each batch of dosimeters by analyzing the data from the sets of dosimeters irradiated during the calibration process at each dose value.

9.4.2 Use the sample standard deviation (S_{n-1}) determined during calibration to calculate the coefficient of variation (CV) for each dose value as follows:

$$CV = 100\ \% \times \left[\frac{S_{n-1}}{\Delta R} \right] \tag{3}$$

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

NOTE 8—In general, if the value of the coefficient of variation is greater than ±2 %, then a redetermination of the data should be considered or, in the extreme, the batch should be rejected.

10. Routine use

10.1 *Pre-Irradiation Procedure:*

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 for imperfections and determine the pre-irradiation response, R_0, for each dosimeter at the selected analysis wavelength(s). This may be done for each dosimeter or by use of an average R_0 determined by reading several dosimeters and documenting the uncertainty, provided this practice meets the precision requirements for the application. Discard any dosimeters that show unacceptable imperfections.

10.1.3 Where necessary, package the dosimeters in a UV-opaque material.

10.1.4 Mark the packaged dosimeters appropriately for identification.

10.1.5 Place the dosimeters at specified locations for irradiation.

10.2 *Post-Irradiation Analysis Procedure:*

10.2.1 Retrieve the dosimeters and avoid any exposure to ultraviolet radiation that may induce coloration of the dosimeter (see 6.3.2).

10.2.2 Verify instrument performance according to documented procedures. See 7.2.

10.2.3 For each dosimeter, perform the following:

10.2.3.1 Determine the post-irradiation response, R, at the selected analysis wavelength(s) used for calibration of the dosimetry system within the specified time interval (see 6.4.2) and under conditions (6.5) which take account of potential post-irradiation changes.

10.2.3.2 Calculate the net response, ΔR, as follows: