~~ISO/ASTM 51310:2004 (Reapproved 2012)(E)~~
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 ~~practice covers the procedures for handling, testing, and~~ 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 ~~in water.~~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 ~~10 000 Gy for photons.~~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 ~~for photons~~ is from ~~0.1~~ 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.~~+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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

[1] This ~~guide~~practice is under the jurisdiction of ASTM Committee E61 on Radiation Processing and is the direct responsibility of Subcommittee E61.02 on Dosimetry Systems, and is also under the jurisdiction of ISO/TC 85/WG 3.

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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]

~~E170 Terminology Relating to Radiation Measurements and Dosimetry~~

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

~~E668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices~~

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

~~E1026~~E3083 ~~Practice for Using the Fricke Dosimetry System~~Terminology Relating to Radiation Processing: Dosimetry and Applications

2.2 *ISO/ASTM Standards:*[2]

51261 ~~Guide~~Practice for ~~Selection and~~ Calibration of Routine Dosimetry Systems for Radiation Processing

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

~~5140~~52628 Practice for ~~Characterization and Performance of a High-Dose Radiation Dosimetry Calibration Laboratory~~Dosimetry in Radiation Processing

~~5170~~52701 Guide for ~~Estimating Uncertainties in Dosimetry 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 ~~14~~80 ~~Radiation Dosimetry: X-Rays and Gamma Rays with Maximum Photon Energies Between 0.6 and 50 MeV~~ Dosimetry Systems for Use in Radiation Processing

~~ICRU Report 17 Radiation Dosimetry: X-Rays Generated at Potentials of 5 to 150 kV~~

~~ICRU Report 34 The Dosimetry of Pulsed Radiation~~

ICRU Report ~~60~~85a Fundamental Quantities and Units for Ionizing Radiation

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

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.

~~3.1.4 *dosimetry system*—system used for determining absorbed dose, consisting of dosimeters, measurement instruments and their associated reference standards, and procedures for the system's use.~~

[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.

[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).

3.1.3 ~~*measurement quality assurance plan*—~~*dosimeter response (indication)*—~~documented program for the measurement process that ensures 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.~~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~~pre-irradiation response, R_0, from the post–irradiation response, R:

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

with:

$$R = \frac{A_\lambda}{A_{\lambda ref}}$$

$$R_0 = \left[\frac{A\lambda}{A_{\lambda ref}}\right]_0 \tag{2}$$

$$R = A_\lambda / A_{\lambda ref}$$

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

~~and~~ 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 ~~path~~material at a high index of refraction relative to the material enclosing the optical ~~path.~~material.

3.1.6 *radiochromic optical ~~waveguide~~—waveguide dosimeter*—specially prepared optical waveguide containing ingredients that undergo an ionizing radiation–induced change in photometric ~~absorbance. This change in absorbance~~ absorbance which can be related to absorbed dose ~~into~~ 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.

~~3.1.10 *response function*—mathematical representation of the relationship between dosimeter response and absorbed dose for a given dosimetry system.~~

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 ~~E170~~E3083~~. Definitions~~ and ISO 12749-4. Where appropriate, definitions in ~~E170 are compatible with ICRU 60; that document, therefore, may be used as an alternative reference.~~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 ~~3.1.6~~3.1.4. Examples of appropriate wavelengths for the analysis for specific dosimetry systems are provided by their manufacturers and in Refs (**1-5**).

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

~~4.2 In the application of a specific dosimetry system, absorbed dose is determined by use of a calibration curve traceable to national or international 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 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, and 34.~~

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. Apparatus~~

~~5.1 The following shall be used to determine absorbed dose with radiochromic optical waveguide dosimetry systems:~~

~~5.1.1 *Dosimeters*—A batch or portion of a batch of radiochromic optical waveguide dosimeters.~~

~~5.1.2 *Spectrophotometer or Photometer*—An instrument, either a spectrophotometer equipped with a special dosimeter holder and associated coupling optics (see Ref 7 for an example), or a modified photometer (see Fig. 1 for a block diagram of an instrument that uses a reference wavelength), having documentation covering analysis wavelengths, accuracy of wavelength selection, absorbance determination, spectral bandwidth, and stray light rejection.~~

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

5. ~~Performance check of instrumentation~~ Overview

5.1 ~~Check and document the performance of the photometer or spectrophotometer (see ASTM Practices~~ 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 ~~E275, E925, E958, and E1026).~~ ~~Use reference standards traceable to national or international standards, unless the photometer's or spectrophotometer's design precludes such use.~~to sealing the solution in the tube the beads act as lenses for light during the analysis of the dosimeter's response.

~~6.1.1 When using a photometer, check and document the accuracy of the absorbance scale at intervals not to exceed one month during periods of use, or whenever there are indications of poor performance.~~

~~6.1.2 When using a spectrophotometer, check and document the precision and bias of the wavelength scale and absorbance scale at or near the selected analysis wavelength(s) at intervals not to exceed one month during periods of use, or whenever there are indications of poor performance.~~

~~6.1.3 Document the comparison of information obtained in 6.1.1 or 6.1.2 with the original instrument specification to verify adequate performance.~~

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.

~~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 of Dosimeters*—Irradiation is a critical component of the calibration of the dosimetry system. Calibration 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 When the optical waveguide dosimeter is used as a transfer standard dosimeter, the calibration irradiation may be performed only as stated in 7.2.1, or in 7.2.2 at a facility that meets the requirements in ISO/ASTM Practice 51400.

7.4 *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.

8. Procedure

8.1 *Examination and Storage Procedure:*

8.1.1 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 2—Dosimeters may be stored in UV-opaque material to further avoid the effects noted in 8.1.1.

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

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

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

8.1.5 Store the dosimeters in accordance with the manufacturer's written recommendations.

8.2 *Irradiation Procedure:*

8.2.1 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.

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

8.2.3 Mark the packaged dosimeters appropriately for identification.

8.2.4 Irradiate the dosimeters.

NOTE 3—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 the absorbed dose

~~within the product by correction factors under certain conditions.~~

~~8.3 *Analysis Procedure:*~~

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

~~8.3.2 Determine the post-irradiation response, *R*, at the selected analysis wavelength(s) used for calibration of the dosimetry system.~~

~~8.3.3 Calculate the net response, Δ *R*, as follows:~~

$$\Delta R = R - R_0 \quad (3)$$

~~8.3.4 Determine the absorbed dose from the calibration curve or response function.~~

6. ~~Characterization of each batch of dosimeters~~ 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 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 ~~*Reproducibility of Net Response:*~~ *Pre-Irradiation Conditions:*

6.2.1 *Time Since Manufacture*—~~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~~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~~value.~~).

6.2.2 *Exposure to Light*—~~Use the sample standard deviation (~~Dosimeters are sensitive ~~S_{n-1}) determined during calibration to calculate the coefficient of variation~~ (to ultraviolet light and should be protected~~CV) for each dose value as follows:~~ 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

$$CV = 100 \times \left[\frac{S_{n-1}}{\Delta R}\right] \quad (4)$$

and storage.

6.2.3 *Temperature*—~~Document these coefficients of variation and note any that are unusually large.~~Exposure to temperatures outside the manufacturer's recommended range should be minimized to reduce the potential for adverse effects on dosimeter response.

~~NOTE 4—In general, if the value of the coefficient of variation is greater than ±2 %, then a re-determination of the data should be considered or, in the extreme, the batch should be rejected.~~

6.3 ~~*Effect of Absorbed Dose Rate:*~~ *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 shape (slope) of the calibration curve associated with some radiochromic optical waveguide dosimeters may be~~ the dosimeter response is 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.~~and shall be characterized.

~~NOTE 5—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.~~

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

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*—~~If the absorbed dose rate for a given application differs from the calibration absorbed dose rate, the effect of this difference on dosimeter response shall be taken into account (see ISO/ASTM Guide~~the dosimeter response is dependent upon the radiation energy and the dosimeters shall be irradiated for calibration under the conditions ~~51261).~~of use.

6.4 *Post-Irradiation ~~Characterization:~~Conditions:*

6.4.1 *Time*—~~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.~~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*—~~If the net response measured in~~Dosimeters should be packaged so they ~~9.3.1 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.~~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*—~~For a given set of irradiation conditions, this procedure needs to be performed only once for a given batch of dosimeters.~~ 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 ~~*Other Factors*—~~*Response Measurement Conditions:* ~~The effects of temperature, background ultraviolet radiation, electron~~