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Guide for performance characterization of dosimeters and dosimetry systems for use in radiation processing

Guide standard pour la caractérisation de la performance des dosimètres et des systèmes de dosimétrie pour utilization dans le traitement des radiations

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ISO/ASTM 52701:2013(E)

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Contents

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 E61, 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 52701 was developed by ASTM Committee E61, Radiation Processing, through Subcommittee E61.01 on Dosimetry, and by Technical Committee ISO/TC 85, Nuclear energy, nuclear technologies and radiological protection.

This first edition of ISO/ASTM 52701 cancels and replaces ASTM E2701-09.

ISO/ASTM 52701:2013(E)

An American National Standard

Standard Guide for Performance Characterization of Dosimeters and Dosimetry Systems for Use in Radiation Processing[1]

This standard is issued under the fixed designation ISO/ASTM 52701; 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 guide provides guidance on determining the performance characteristics of dosimeters and dosimetry systems used in radiation processing.

1.2 This guide describes the influence quantities that might affect the performance of dosimeters and dosimetry systems and that should be considered during dosimeter/dosimetry system characterization.

1.3 Users of this guide are directed to existing standards and literature for procedures to determine the effects from individual influence quantities and from combinations of more than one influence quantity.

1.4 Guidance is provided regarding the roles of the manufacturers, suppliers, and users in the characterization of dosimeters and dosimetry systems.

1.5 This guide does not address how the dosimeter/dosimetry system characterization information is to be used in radiation processing applications or in the calibration of dosimetry systems.

NOTE 1—For guidance on the use of dosimeter/dosimetry system characterization information for the selection and use of a dosimetry system, the user is directed to ISO/ASTM Practice 52628.

NOTE 2—For guidance on the use of dosimeter/dosimetry system characterization information for dosimetry system calibration, the user is directed to ISO/ASTM Practice 51261.

1.6 *This guide 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:*[2]

E170 Terminology Relating to Radiation Measurements and Dosimetry

E456 Terminology Relating to Quality and Statistics

E1026 Practice for Using the Fricke Dosimetry System

E1325 Terminology Relating to Design of Experiments

2.2 *ISO/ASTM Standards:*[2]

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

51261 Practice for Calibration of Routine Dosimetry Systems for Radiation Processing

51707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing

52628 Practice for Dosimetry in Radiation Processing

2.3 *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[3]

JCGM 100:2008, VIM , International vocabulary of metrology – Basis and general concepts and associated terms[4]

2.4 *International Commission on Radiation Units and Measurements (ICRU) Reports*[5]

Report 80 Dosimetry Systems for Use in Radiation Processing

Report 85a Fundamental Quantities and Units for Ionizing Radiation

3. Terminology

3.1 *Definitions:*

3.1.1 *calibration curve*—expression of the relation between indication and corresponding measured quantity value. **VIM**

3.1.2 *dosimeter*—device that, when irradiated, exhibits a quantifiable change that can be related to absorbed dose in a given material using appropriate measurement instruments and procedures.

[1] This guide is under the jurisdiction of ASTM Committee E61 on Radiation Processing and is the direct responsibility of Subcommittee E61.01 on Dosimetry, and is also under the jurisdiction of ISO/TC 85/WG 3.

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

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

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

3.1.3 *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 *dosimeter/dosimetry system characteristization*—determination of performance characteristics, such as useful dose range, reproducibilty and the effects of influence quantities, for a dosimeter/dosimetry system under defined test conditions.

3.1.5 *dosimeter response*—reproducible, quantifiable effect produced in the dosimeter by ionizing radiation.

3.1.5.1 *Discussion*—The dosimeter response value, obtained from one or more measurements, is used in the estimation of the derived absorbed dose. The response value may be obtained from such measurements as optical absorbance, thickness, mass, peak-to-peak distance in EPR spectra, or electropotential between solutions.

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

3.1.7 *influence quantity*—quantity that, in a direct measurement, does not affect the quantity that is actually measured, but affects the relation between the indication and the measurement result. **VIM**

3.1.7.1 *Discussion*—In radiation processing dosimetry, this term includes temperature, relative humidity, time intervals, light, radiation energy, absorbed-dose rate, and other factors that might affect dosimeter response, as well as quantities associated with the measurement instrument.

3.1.8 *quality system*—documented organizational structure, responsibilities, procedures, processes and resources for implementing quality management.

3.2 Definitions of other terms used in this standard that pertain to radiation measurement and dosimetry may be found in ASTM Terminology E170. Definitions in ASTM E170 are compatible with ICRU Report 85a; this document, therefore, may be used as an alternative reference. Definitions of other terms used in this standard that pertain to statistics and design of experiments may be found in ASTM Terminologies E456 and E1325, respectively.

4. Significance and use

4.1 Ionizing radiation produces physical or chemical changes in many materials that can be measured and related to absorbed dose. Materials with radiation-induced changes that have been thoroughly studied can be used as dosimeters in radiation processing.

NOTE 3—The scientific basis for commonly used dosimetry systems and detailed descriptions of the radiation-induced interactions are given in ICRU Report 80.

4.2 Before a material can be considered for use as a dosimeter, certain characteristics related to manufacture and measurement of its response to ionizing radiation need to be considered, including:

4.2.1 the ability to manufacture batches of the material with evidence demonstrating a reproducible radiation-induced change,

4.2.2 the availability of instrumentation for measuring this change, and

4.2.3 the ability to take into account effects of influence quantities on the dosimeter response and on the measured absorbed-dose values.

4.3 Dosimeter/dosimetry system characterization is conducted to determine the performance characteristics for a dosimeter/dosimetry system related to its capability for measuring absorbed dose. The information obtained from dosimeter/dosimetry system characterization includes the reproducibility of the measured absorbed-dose value, the useful absorbed-dose range, effects of influence quantities, and the conditions under which the dosimeters can be calibrated and used effectively.

NOTE 4—When dosimetry systems are calibrated under the conditions of use, effects of influence quantities may be minimized or eliminated, because the effects can be accounted for or incorporated into the calibration method (see ISO/ASTM Practice 51261).

4.4 The influence quantities of importance might differ for different radiation processing applications and facilities. For references to standards describing different applications and facilities, see ISO/ASTM Practice 52628.

4.5 Classification of a dosimeter as a type I dosimeter or a type II dosimeter (see ISO/ASTM Practice 52628) is based on performance characteristics related to the effects of influence quantities obtained from dosimeter/dosimetry system characterization.

4.6 The dosimeter manufacturer or supplier is responsible for providing a product that meets the performance characteristics defined in product specifications, certificates of conformance, or similar types of documents. Dosimeter specifications should be developed based on dosimeter/dosimetry system characterization.

4.7 The user has the responsibility for ensuring that the dosimetry requirements for the specific applications are met and that dosimeter/dosimetry system characterization information has been considered in:

4.7.1 determining the suitability of the dosimeter or dosimetry system for the specific application (see ISO/ASTM Practice 52628),

4.7.2 selecting the calibration method (see ISO/ASTM Guide 51261),

4.7.3 establishing dosimetry system operational procedures (see respective dosimetry system practice listed in ISO/ASTM Practice 52628), and

4.7.4 estimating the uncertainty components in the measured dose values (see ISO/ASTM Guide 51707).

4.8 Dosimeter/dosimetry system characterization information provided by manufacturers or suppliers, or available in the literature, should be reviewed by the user to determine the tests that should be performed prior to the use of the dosimeter or dosimetry system. Information on performance characteristics should be verified before using.

5. Dosimeter/dosimetry system characterization

5.1 *Performance Characteristics:*

5.1.1 Some examples of performance characteristics of dosimeters/dosimetry systems that may affect the measurement of absorbed dose are given in Table 1.

5.2 *Measurement Instruments:*

5.2.1 Prior to conducting performance characterization of the dosimeters, it is necessary to establish procedures for the operation of the measurement instruments.

5.2.2 Operating procedures should be developed to control and optimize the performance of all measurement instruments and auxiliary systems, including those used for measuring mass or thickness or used for a post irradiation heat treatment.

5.2.3 The instruments used in a given dosimetry system with specific dosimeters should be calibrated with evidence of traceability and be tested to provide evidence of their suitability for use with the dosimeters. This should include a determination of repeatability and reproducibility for the specific measurement methods to be used.

5.2.4 The influence on measurement values attributable to rounding error, short term instrument drift, etc. over the expected range of use should be determined.

5.2.5 The performance of accessories such as dosimeter holders or dosimeter positioning apparatus within the measurement instrument should be determined.

5.2.6 The supplier of the performance characterization information should provide information on all instrumentation used in the characterization, including relevant performance specifications for the measurement instruments and characterization results.

NOTE 5—Characterization results are specific to the measurement instruments and measurement parameters used for the tests. Results cannot be used with other measurement instruments without adequate data to support equivalency.

5.2.7 Information obtained during the measurement system development to determine optimum or recommended instruments, including precautions to avoid known sources of error, should be made available to potential users.

5.3 *Characterization:*

5.3.1 All dosimeter samples used in the characterization must be representative of dosimeters supplied by the manufacturer/distributor.

5.3.2 The performance of dosimeter/dosimetry system characterization should be conducted in accordance with an experimental design that can effectively assess both individual and combined effects of the influence quantities being tested.

5.3.3 For performance characterization, dosimeters should be irradiated in facilities that can provide highly reproducible dose rates and well-quantified values of influence quantities.

NOTE 6—When studying the effects of irradiation conditions such as temperature or relative humidity, the conditions experienced by the dosimeters must be known within established limits. Dosimeter temperatures should be monitored. Reliance should not be placed on monitoring the air temperature and assuming that there is temperature equilibrium. Difference between dosimeter temperature and air temperature may be associated with dose and may introduce bias in the characterization results over the dose range. For studies on the effects of changes of relative humidity, the time required for the water and oxygen content of the dosimeters to reach equilibrium should be taken into account. It is necessary to validate controlled irradiation conditions to verify that specified conditions can be achieved.

5.3.4 An initial calibration curve may be obtained by irradiating dosimeters over a range of absorbed doses at defined conditions, for example, specified temperature, relative humidity, and absorbed dose rate, and by measuring dosimeter response under defined measurement conditions. The defined conditions for the irradiation should approximate the expected range of values to be encountered during use of the dosimetry system.

NOTE 7—A calibration curve may be developed using a relationship expressed by response = f (dose).

5.4 *Characterization Information:*

5.4.1 Information on dosimeter and dosimetry system characterization carried out by the dosimeter manufacturer or supplier should be documented and made available to potential users.

5.4.2 The user is responsible for the evaluation of the effect of influence quantities or combinations of influence quantities, or both, on the dosimetry system performance over the full range of its intended use.

6. Effect of influence quantities

6.1 *Influence Quantities to be Considered:*

6.1.1 All influence quantities that might affect absorbed-dose determination should be considered. These influence quantities include those related to the dosimeter before, during, and after irradiation and those related to the dosimeter response measurements. Table 2 gives examples of some of these influence quantities.

6.1.2 The influence quantities shown with an asterisk (*) in Table 2 can be controlled by packaging the dosimeter material under specific conditions of relative humidity in light-tight gas-impermeable pouches. When the packaging is essential for

TABLE 1 Examples of performance characteristics of dosimeters/dosimetry systems

Performance Characteristic	Description
Absorbed-dose range	Range over which the dosimetry system can be used within a maximum specified uncertainty
Applicable radiation type and energy	X-radiation, gamma radiation, and electron beam
Effect of influence quantities	Effects from individual influence quantities (see Table 2) and from combinations of more than one influence quantity (see 6.6)
Uncertainty	Achievable maximum level of uncertainty
Spatial resolution	Spatial resolution may be limited by dosimeter size, volume or area over which measurement is taken

TABLE 2 Examples of influence quantities

Category	Section, Influence Quantity	Conditions to be Considered
Pre-irradiation conditions	6.2.1 Dosimeter conditioning and packaging	Conditioning for optimum/stable response
	6.2.2 Time since manufacture	Gradual changes in dosimeter over prolonged time intervals
	6.2.3 Temperature	Long-term & short-term effects at extremes of temperature
	6.2.4 Relative humidity*	Long-term & short-term effects at extremes of humidity
	6.2.5 Exposure to light*	Long-term & short-term effects on dosimeters from light
Condiitons during irradiation	6.3.1 Irradiation temperature	Variation of response with temperature
	6.3.2 Absorbed-dose rate	Variation of response with absorbed-dose rate
	6.3.3 Dose fractionation	Effect on response when irradiation is interrupted
	6.3.4 Relative humidity*	Variation of response with relative humidity
	6.3.5 Exposure to light*	Effect of light on response
	6.3.6 Radiation energy	Variation of response with radiation energy
Post-irradiation conditions	6.4.1 Storage time	Variation of response with time between irradiation & measurement
	6.4.2 Storage temperature	Variation of response with temperature following irradiation
	6.4.3 Conditioning treatment	Deliberate exposure to a conditioning treatment to obtain stable response
	6.4.4 Storage relative humidity*	Variation of response with relative humidity
	6.4.5 Exposure to light*	Effect of light on response
Response measurement conditions	6.5.1 Light	Effect of light during measurement
	6.5.2 Temperature	Effect of temperature during measurement
	6.5.3 Relative humidity	Effect of relative humidity during measurement

* See 6.1.2.

the performance of the dosimeter, the packaging and the dosimeter are sometimes collectively referred to as the dosimeter.

6.1.3 If only one influence quantity is suspected to have an effect on dosimeter performance over the range of dose, the individual effect can be studied by varying its value (see 6.2–6.5).

6.1.4 Due to interactions between influence quantities, combined effects might differ from the summed individual effects. The combined effects of several influence quantities can be explored and estimated efficiently and effectively when the influence quantities are dealt with simultaneously (see 6.6). For example, use of design of experiments provides a systematic approach to experimentation that considers several influence quantities simultaneously (see 6.6.2).

6.2 *Influence Quantities Related to Pre-Irradiation Conditions:*

6.2.1 *Dosimeter Conditioning and Packaging:*

6.2.1.1 Response characteristics of some dosimeters can be optimized or stabilized by conditioning them prior to irradiation. Such conditioning involves storage under controlled conditions of temperature and humidity for specific periods of time. If conditioning is performed to achieve desired level of oxygen content or water content, the dosimeters should be packaged and sealed in gas-impermeable pouches to maintain those conditions. The packaging materials should be specified and the package evaluated for integrity.

6.2.2 *Time since Manufacture:*

6.2.2.1 To determine potential changes in the response for both unirradiated and irradiated dosimeters over the life of a dosimeter batch, dosimeter response testing should be conducted periodically, using dosimeters stored under expected extremes of storage conditions, to determine the extent of this effect.

6.2.3 *Temperature:*

6.2.3.1 The temperature experienced by dosimeters during pre-irradiation storage could affect their response following irradiation; therefore, the effect of long term storage at different temperatures should be determined.

6.2.3.2 The effect on the response of dosimeters exposed for short periods of time to potential extremes of temperatures should also be determined. Shipment during summer and winter represent opposing termperature extremes.

6.2.4 *Relative Humidity:*

6.2.4.1 Changes in relative humidity during storage or shipment of unirradiated non-packaged dosimeters might result in changes in oxygen or water content in the dosimeters that may affect dosimeter response. The response of dosimeters stored or shipped under extremes of relative humidity should be determined and this effect quantified. Packaging dosimeters in gas-impermeable pouches may be used to control and minimize the influence of relative humidity changes on dosimeter response. If pouches are used, the packaging materials should be specified and the packaging effectiveness verified.

6.2.5 *Exposure to Light:*

6.2.5.1 Exposure to light, especially the ultraviolet components from fluorescent lights or sunlight, might affect the dosimeter response. Dosimeters should be exposed to expected light conditions to determine the potential effect. If an effect is found, the dosimeters should be stored, handled, and measured under controlled conditions or supplied and stored in light-protected pouches to prevent such an effect.

6.3 *Influence Quantities Related to Irradiation*—For all the testing described in this section, the response of the irradiated dosimeters should be measured under the same measurement conditions as used for the initial calibration curve. The effect of the influence quantity should be determined for both the dosimeter response and the derived absorbed dose calculated using the initial calibration curve.

6.3.1 *Irradiation Temperature:*

6.3.1.1 The effect of irradiation temperature may be determined by irradiating sets of dosimeters at different temperatures. The testing should address the full intended dose range and anticipated temperature range for the dosimeter material

and include more than the minimum and maximum temperatures at which the dosimeters might be used.

NOTE 8—Testing over a temperature-time profile, rather than at a fixed temperature, may provide information more appropriate for some radiation processing applications. For example, with electron beams, the temperature rise is near adiabatic with dose. If fixed temperatures are not used during the testing, it should be clearly stated whether the test temperatures are peak temperatures, mean temperatures, or effective temperatures based on the temperature-time profile.

6.3.2 *Absorbed-Dose Rate:*

6.3.2.1 The effect of absorbed-dose rate on the dosimeter response should be determined by irradiating sets of dosimeters at different absorbed-dose rates. The selected absorbed-dose rate range will depend on the intended type of facility and application.

NOTE 9—The dosimeter temperature may also change as the absorbed-dose rate is varied making it difficult to separate the contribution from the absorbed-dose rate and from the temperature. Measures taken to control or monitor the dosimeter temperature should be documented.

6.3.2.2 If the dosimeter is intended for use with photons and electrons, irradiation response testing of the dosimeter should be performed and evaluated using both photons and electrons.

NOTE 10—For gamma irradiations, both low, intermediate and high absorbed-dose rate conditions should be evaluated. For electron beams, the absorbed-dose rate depends on the type of electron beam. For a linear accelerator, the dose rate of interest could be either the average absorbed-dose rate, or the instantaneous absorbed-dose rate in a pulse, or both.

6.3.3 *Dose Fractionation:*

6.3.3.1 Absorbed dose may be delivered in two or more increments, due to either intentional or unintentional process interruption. The effects on the dosimeter response of this fractionation of the dose delivery should be investigated

NOTE 11—Dose fractionation testing may bring several influence quantities into play such as temperature effects and post irradiation fading or enhancement.

6.3.4 *Relative Humidity:*

6.3.4.1 The effect of relative humidity on the dosimeter response should be determined by irradiating dosimeters under different values of relative humidity.

NOTE 12—In general, the response of many dosimeter types is dependent on their water or oxygen content, or both, during irradiation, which might vary with the relative humidity. Changes in water or oxygen content might occur rapidly for thin films, requiring only a few minutes, whereas changes for thick dosimeters might occur gradually, requiring hours or days. The water and oxygen content of the dosimeters can be controlled by storing them in an environmentally controlled chamber or over different saturated salt solutions for sufficiently long periods of time to establish equilibrium. The dosimeters should then be irradiated under these conditions (**1**).[6] A manufacturer may establish and implement specific manufacturing conditioning and packaging of the dosimeters to mitigate the effect of this influence quantity.

6.3.5 *Exposure to Light:*

6.3.5.1 The effect on dosimeter response from exposure to light during irradiation should be determined by irradiating some dosimeters in light-protective packages and some exposed to the light conditions expected during irradiation.

6.3.5.2 If a light-protective package is essential for consistent dosimeter performance, for example, for a film sensitive to ultraviolet light, then the packaging should be evaluated for light protection effectiveness.

6.3.6 *Radiation Energy:*

6.3.6.1 Possible effects of the radiation energy on the derived dose value should be taken into consideration.

6.4 *Influence Quantities Related to Post-Irradiation Conditions*—For all the testing described in this section, the response of the irradiated dosimeters should be measured under the same measurement conditions as used for the initial calibration curve. The effect of the influence quantity should be determined for both the dosimeter response and the derived absorbed dose calculated using the initial calibration curve.

6.4.1 *Storage Time:*

6.4.1.1 The post-irradiation stability can be determined by measuring the response of the same dosimeter(s) at different times over a period spanning the shortest and longest time expected between irradiation and measurement. If the process of measuring the dosimeter response alters its response or destroys the dosimeter, it is necessary to irradiate multiple dosimeter sets for each dose point sufficient to provide the data needed to determine the post-irradiation time stability of the dosimeter response.

NOTE 13—For liquid chemical dosimeters in sealed ampoules, the dosimeter material may be consumed in the measurement process. For dosimeters sealed in gas-impermeable pouches to control water or oxygen content, opening the pouch to take the measurement will alter the water or oxygen content of the dosimeter and thus may affect the subsequent dosimeter response measurements.

6.4.1.2 This testing should include the full range of absorbed dose expected to be encountered in routine use.

6.4.1.3 Preliminary measurements over a period of time may be useful for determining the time intervals to be used for the detailed measurements.

NOTE 14—For many dosimeters a rapid change in response can be observed immediately after irradiation followed by a gradual change over a period of time. In some dosimeters, the response can be stabilized by a heat treatment (see 6.4.3.1).

6.4.2 *Storage Temperature:*

6.4.2.1 The effect of the post-irradiation storage temperature on the dosimeter response may be determined by irradiating multiple sets of dosimeters to the same absorbed dose and storing them for specified time intervals at several different temperatures. The response for each set of dosimeters should be measured at the same time after irradiation.

6.4.3 *Conditioning Treatment:*

6.4.3.1 For some dosimeters, post-irradiation response can be stabilized by a conditioning treatment, for example, by exposing the irradiated dosimeters to a specified temperature for a specified time period. If heat treatment is to be utilized, the effects of different temperatures and time intervals after irradiation should be studied and appropriate requirements determined.

6.4.4 *Storage Relative Humidty:*

6.4.4.1 If dosimeters are not supplied in environment secure factory sealed pouches, the effect of the post-irradiation storage

[6] The boldface numers in parentheses refer to the list of references at the end of this standard.