INTERNATIONAL

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Standard Practice for Use of a Cellulose Triacetate Dosimetry System[1]

This standard is issued under the fixed designation 51650; 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 is a practice for using a cellulose triacetate (CTA) dosimetry system to measure absorbed dose in materials irradiated by photons or electrons in terms of absorbed dose to water. CTA is used as a routine dosimetry system or used for relative dose measurements (that is, non-traceable dose measurements).

1.2 The CTA dosimeter is classified as a type II dosimeter on the basis of the complex effect of influence quantities on its response (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 "Practice for Dosimetry in Radiation Processing" for a CTA dosimetry system. It is intended to be read in conjunction with ISO/ASTM 52628.

1.4 This practice covers the use of CTA dosimetry systems under the following conditions:

1.4.1 The absorbed dose range is 10 kGy to 300 kGy.

NOTE 1—The dosimeter film irradiated to doses exceeding 200 kGy becomes brittle to some degree and must be handled with care. This may limit the practical dose range depending on the type of testing and handling required.

1.4.2 The absorbed-dose rate range is 3 Gy/s to 4×10^{10} Gy·s (**1**).[2]

1.4.3 The photon energy range is 0.1 to 50 MeV.

1.4.4 The electron energy range is 0.2 to 50 MeV.

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:*[3]

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

E3083 Terminology Relating to Radiation Processing: Dosimetry and Applications

2.2 *ISO/ASTM Standards:*[3]

51261 Practice for Calibration of Routine Dosimetry Systems for Radiation Processing

51707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing

51818 Standard Specification for Synthetic Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe

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:*[4]

ICRU Report 85a Fundamental Quantities and Units for Ionizing Radiation

ICRU Report 80 Dosimetry Systems for Use in Radiation Processing

[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. Originally developed as a joint ASTM/ISO standard in conjunction with ISO/TC 85/WG 3.

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

[3] 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.

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

2.4 *ISO Standard:*

12749-4 Nuclear energy—Vocabulary—Part 4: Dosimetry for radiation processing[5]

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[6]

JCGM 200:2008, VIM, International vocabulary of metrology – Basis and general concepts and associated terms[7]

3. Terminology

3.1 *Definitions:*

3.1.1 *cellulose triacetate dosimeter*—piece of CTA film that, during exposure to ionizing radiation, exhibits a quantifiable change in specific net absorbance as a function of absorbed dose.

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*—reproducible, quantifiable change produced in the dosimeter by ionizing radiation.

3.1.3.1 *Discussion*—For CTA dosimeters, the response value (indication) is obtained by measurement of the specific net absorbance.

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

3.1.5 *specific net absorbance (Δk)*—net absorbance, ΔA_λ, at a selected wavelength, λ, divided by the optical pathlength, d, through the dosimeter as follows:

$$\Delta k = \Delta A_\lambda / d \quad (1)$$

3.2 Definitions of other terms used in this practice 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 Terminology 12749-4. Where appropriate, definitions used in these standards have been derived from, and are consistent with definitions in ICRU Report 85a, and general metrological definitions given in the VIM.

4. Significance and Use

4.1 The CTA dosimetry system provides a means for measuring absorbed dose based on a change in optical absorbance in the CTA dosimeter following exposure to ionizing radiation (**2-10**).

4.2 CTA dosimetry systems are commonly used in industrial radiation processing, for example in the modification of polymers and sterilization of health care products.

4.3 CTA dosimeter film can be particularly useful in absorbed dose mapping because it is available in a reel of 100 m whereby the user can cut any length of strip for use. When the CTA film is measured using a strip measurement device with a narrow distance interval (for example, 2 mm), it can provide high resolution results in a linear direction.

4.4 CTA is used to measure relative dose such as depth dose profiles in electron beam and reference phantom tests to assess irradiator changes in gamma.

4.5 When CTA is used as a routine monitoring dosimeter the user must take into consideration the effects of the multiple influence quantities that can affect the result and use appropriate techniques, as discussed herein, for characterizing and mitigating such influences and understanding their contribution to measurement uncertainty. Without such effort the dosimetry system may not meet the user's requirements for dosimetric release of some types of products (for example, health care products).

5. Overview

5.1 CTA dosimeters are manufactured by casting cellulose triacetate with a plasticizer, triphenylphosphate, and solvents, for example, a methylene chloride–methanol mixture (**2, 7**).

5.2 The commercially available dosimeter film is in the format of 8 mm width and 100 m length rolled on a spool, which is described in the informative annex.

5.3 Ionizing radiation induces chemical reactions in CTA and the plasticizer, which create or enhance optical absorption bands in the ultraviolet regions of the electromagnetic spectrum. Optical absorbance at appropriate wavelengths within these radiation-induced absorption bands is quantitatively related to the absorbed dose. ICRU Report 80 provides information on the scientific basis and historical development of the CTA dosimetry systems in current use.

5.4 The difference between the specific net absorbance of un-irradiated and irradiated CTA dosimeter depends on the analysis wavelength used to make the absorbance measurement. Typically, the manufacturer recommends the analysis wavelength that optimizes sensitivity and post-irradiation stability. The analysis wavelengths recommended for some commonly used systems are given in Table A1.1.

5.4.1 The user's choice of calibration method, analysis wavelength, spectral bandwidth, dose range of utilization, and usage procedures, including allowed ranges of influence quantity conditions, shall be documented.

6. Influence quantities

6.1 Factors other than absorbed dose which influence the dosimeter response are referred to as influence quantities. These influence quantities include those related to the dosimeter before, during, and after irradiation and those related to the dosimeter response measurements (see ISO/ASTM Guide 52701). Influence quantities affecting dosimeter response are discussed below.

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

[6] 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).

[7] 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).

6.2 *Pre-Irradiation Conditions:*

6.2.1 *Dosimeter Conditioning and Packaging*—The dosimeter may require conditioning and packaging, particularly for low dose rate irradiation. See 6.3.4.

NOTE 2—Conditioning CTA film and packaging pieces of it in environmentally impermeable pouches under controlled relative humidity conditions will provide for the most consistent dosimeter response.

6.2.2 *Time Since Manufacture*—The pre-irradiation absorbance increases slowly with time presumably due to oxidation on the surface of the film (**7, 11**). The pre-irradiation absorbance of the outer layer(s) of a roll of CTA film may, therefore, increase more than the inner layers; hence, it may be advisable to discard the outer layer(s) of the film. Measure the pre-irradiation absorbance before using the dosimeter. Alternatively, compare the pre-irradiation absorbance to the average value noted at the time of calibration to determine if there is any change that shall be taken into account.

NOTE 3—The pre-irradiation absorbance to be used in the calculation of specific net absorbance will either be the value as measured before irradiation by the user, or a user-determined average value.

6.2.3 *Temperature*—Avoid exposure to temperatures outside the manufacturer's recommended range. The effects of low or high temperatures on the product for short or long durations have not been dutifully examined but the product is a chemical dosimeter and may have some inherent risks, as such. Therefore, store the product under stable temperature conditions such as that of an office or laboratory upon receipt and for the duration of the CTA film's shelf life. Any impact of temperatures during shipping and storage on the product must be taken into account during incoming stock receiving inspection (see Section 8) or the dosimeter calibration (see Section 9), or both.

6.2.4 *Relative Humidity*—It is good practice to store the film in a controlled environment prior to use. Research on this topic generally used unspecified controlled storage conditions. Otherwise, the user must characterize the effect of variable relative humidity storage conditions on the subsequent performance of the dosimeter.

6.2.5 *Exposure to Light*—The dosimeter is insensitive to UV and visible light from normal room lighting; however, exposure to direct sunlight results in an increase in absorbance (**7, 11**).

6.3 *Conditions During Irradiation:*

6.3.1 *Irradiation Temperature*—The dosimeter response is directly correlated to temperature. The variation in dosimeter response from 20 °C to 40 °C is approximately +5 % while the variation from 0 °C to 65 °C is greater than +20 % (**7, 9-12**). Calibration of the film under the conditions of use is recommended to avoid creating a bias in the calibration function due to the irradiation temperature differences between calibration and routine use. However, temperature variation over longer time intervals (months) will lead to a seasonal effect. The amount of this effect is not fully understood and may vary with other influence quantities. Users shall account for this by including a component of uncertainty for temperature variation during irradiation in their uncertainty budget or by re-calibration.

6.3.2 *Absorbed-Dose Rate*—The dosimeter response is affected by the absorbed-dose rate. There is a large variation in response between low and high dose rates of irradiation over the entire absorbed dose range (**4, 7, 8, 9, 13, 14**). The user must select a calibration method that accounts for this fact (see Section 9) and should include a component of uncertainty for dose rate if the rate varies between calibration and routine use.

6.3.3 *Dose Fractionation*—The dosimeter response is affected by dose given in fractions (multiple, separate irradiations) and the effect is greater in high dose rate processes (**14**). The user shall characterize the impact of fractionation on the accuracy of dose measurements or calibrate and use the dosimeter under specified fractionation conditions.

6.3.4 *Relative Humidity*—The dosimeter response is affected by relative humidity during irradiation, particularly at low dose rates and relative humidity extremes (**4, 7, 9, 11, 12**). The user may choose to control relative humidity during calibration and use by sealing the CTA film in impermeable packaging to mitigate this effect. The user shall characterize the effect and account for it as a component of measurement uncertainty.

6.3.5 *Exposure to Light*—The dosimeter is not affected by exposure to normal room lighting. Refer to 6.2.5 for additional information (**7, 11**).

6.3.6 *Radiation Energy*—There is no known effect on dosimeter response. However, the irradiation of 125 micron thick CTA film using electron energies below 300 keV can result in a dose gradient within the film. Refer to ISO/ASTM 51818 for more details on dosimetry considerations when using <300 keV electrons.

6.4 *Post-Irradiation Conditions:*

6.4.1 *Time*—The dosimeter response varies with the time interval between radiation exposure and dosimeter measurement (**4, 7, 10, 11, 12, 14**). After high dose rate irradiation such as electron beam the absorbance might decrease 10 % or more during the first 20 min after irradiation and then increase slowly 3-5 % over the next 3 h. See Fig. A2.1 and Fig. A2.2 in Annex A2. The absorbance increases approximately 6 % or more over 10 days of elapsed time after irradiation with less than 1 % contribution in the last 5 days. See Fig. A2.3 in Annex A2. After low dose rate irradiation using sources such as gamma or X-ray, the absorbance changes more slowly, increasing approximately 2 % after 2 h elapsed time. See Fig. A2.5 in Annex A2 (**7, 11**).

6.4.1.1 A procedure shall be established to control the allowable time interval between irradiation and measurement; for example, a desired measurement time after irradiation (for example, 2 h) with some prescribed allowance for variation (for example, ±15 min). The uncertainty of the measurement of absorbed dose due to the user's allowance for variation in time after irradiation shall be determined and included in the user's measurement uncertainty budget (see ISO/ASTM 51707 for details on uncertainty of measurement).

6.4.2 *Temperature*—The storage temperature after irradiation does have an effect at various points over the time interval after electron beam irradiation. See Fig. A2.2 and Fig. A2.4 in Annex A2 (**7, 9, 11**). After irradiation, store the film in a stable environment.

6.4.3 *Conditioning Treatment*—No advantageous post-irradiation treatment is available or recommended (**4**).

6.4.4 *Relative Humidity (RH)*—The rate of change of the post-irradiation absorbance is affected by relative humidity but the effect is generally less than 1 % in the first 4 h (**7, 9, 11, 12**). After irradiation, store the film in a stable environment.

6.4.5 *Exposure to Light*—If the film is exposed to UV light after the irradiation (such as while traveling on a conveyance system or during removal from the product or apparatus to which it was attached), minimize exposure to UV light and refer to 6.2.5. Apply the same principles when considering any effect after irradiation.

6.5 *Response Measurement Conditions:*

6.5.1 *Exposure to Light*—During measurement the film may or may not be exposed to UV light for periods of time depending on the user's measurement environment. Refer to 6.2.5 and apply the same principles when considering any effect during measurement (**7, 11**).

6.5.2 *Temperature*—The temperature conditions used during routine measurement shall be consistent with the conditions during calibration of the CTA film.

6.5.3 *Relative Humidity*—The relative humidity conditions used during routine measurement shall be consistent with the conditions during calibration of the CTA film.

7. Dosimetry system and its verification

7.1 *Components of the CTA Dosimetry System*—The following are components of a CTA dosimetry system:

7.1.1 *Cellulose Triacetate Dosimeter Film.*

7.1.2 *Spectrophotometer* (or an equivalent instrument), capable of measuring optical absorbance at the analysis wavelength and having documentation specifying the wavelength range, wavelength accuracy, absorbance (photometric) accuracy, and spectral bandwidth.

7.1.2.1 Means of verifying the absorbance accuracy and wavelength accuracy, for example using certified optical filters.

7.1.3 *Holder,* to position the dosimeter reproducibly in, and perpendicular to, the analyzing light beam during absorbance measurement.

NOTE 4—Automatic dosimeter strip reading equipment is commonly used to measure long strips of CTA film (see Table A1.3 for more information).

7.1.4 *Thickness Gauge (optional).*

7.1.4.1 Means of verifying thickness gauge calibration, for example through certified thickness gauge blocks.

7.2 *Measurement Management System,* including the dosimetry system calibration curve resulting from calibration according to ISO/ASTM Practice 51261 (see Section 9).

7.3 *Performance Verification of Instrumentation:*

7.3.1 At user-defined intervals based on risk-assessment, the performance of the spectrophotometer shall be verified, the result(s) documented, and the result(s) compared with the instrument specifications (see ASTM Practice E275).

7.3.1.1 Verify the absorbance accuracy at or near the analysis wavelength (at a minimum) over the full range of the absorbance scale utilized for measurement of the CTA film.

7.3.1.2 Verify the wavelength accuracy at or near the analysis wavelength using calibrated references.

7.3.2 At user-defined intervals based on risk-assessment the calibration of the thickness gauge shall be verified, the result(s) documented, and the result(s) compared with the instrument specifications, if used.

7.3.3 At user-defined intervals based on risk-assessment the calibration of the length (distance) scale of strip measuring equipment, if used, shall be verified, the result(s) documented, and the result(s) compared with the instrument specifications.

8. Incoming dosimeter stock assessment

8.1 User procedures shall be established for the receipt, acceptance, and storage of dosimeters.

8.2 On receiving a new dosimeter stock, the user shall document the manufacturer's batch designation and perform an incoming inspection.

8.2.1 The user shall inspect the CTA film roll for damage and characterize the pre-irradiation absorbance using multiple samples from the leading 0.5 m of film.

8.2.2 The user may verify the film's average thickness against the specification, but it is not required.

NOTE 5—CTA dosimetry system users often accept the manufacturer's stated nominal thickness and do not perform a thickness verification.

8.3 Retain sufficient dosimeter material for additional investigations or for use during calibration, verification, or recalibration.

8.4 Store dosimeters in a dark, dry place with some level of temperature control.

NOTE 6—The monitoring and documentation of storing conditions is recommended (see 6.2).

9. Calibration

9.1 Prior to initial use of each dosimeter stock the dosimetry system shall be calibrated in accordance with ISO/ASTM Practice 51261, and the user's procedures, which shall specify details of the calibration requirements.

9.2 The user's dosimetry system calibration 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—The calibration irradiation of the CTA dosimeters must be performed under conditions similar to those of routine use (see ISO/ASTM 51261 calibration Method 2), unless otherwise justified.

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

10. Routine use

10.1 *Before Irradiation:*

10.1.1 Cut the film into pieces or strips as desired for the use case.

10.1.2 Determine the pre-irradiation absorbance of the film, as applicable, to be used in the calculation of specific net absorbance (see 6.2.2).

10.1.2.1 Measure the pre-irradiation absorbance of each film piece or measure representative samples of film pieces to determine an average pre-irradiation absorbance.

10.1.3 Inspect each film piece for visible physical imperfections in the area of the film that will be measured and do not use pieces with imperfections.

10.1.4 Mark the film piece appropriately for identification purposes on a part of the film that will not interfere with the measurement.

10.1.5 Place the dosimeters at specified locations on the material or fixture for irradiation based on the application requirements.

10.2 *Post-Irradiation Analysis:*

10.2.1 Retrieve the dosimeters.

10.2.2 Store the dosimeters in user-defined location under specified conditions prior to measurement (see 6.4).

10.2.3 Measure the absorbance of dosimeters at a time (see 6.4.1) and under conditions (see 6.5) which take account of potential post-irradiation changes.

10.2.4 Verify instrument performance according to documented procedures (see 7.3).

10.2.5 For each dosimeter, perform the following:

10.2.5.1 Handle the film pieces with care and inspect it for any visible imperfections prior to measurement, and document any imperfections.

NOTE 8—If a dosimeter is found to be scratched, a reliable measurement can sometimes be obtained by repositioning the dosimeter in the spectrophotometer holder, for example by inverting it, so that the scratch is not in the light beam path of the spectrophotometer.

10.2.5.2 If necessary, clean the dosimeter before analysis. An accepted method is wiping the film with a dry, low-lint or lint-free cloth.

10.2.5.3 Position the dosimeter in the holder in the spectrophotometer.

10.2.5.4 Measure and record the absorbance at the selected analysis wavelength (see Table A1.1 for manufacturer's recommendations).

10.2.5.5 Measure the thickness of the dosimeter in the region traversed by the analyzing light beam. Alternatively, the manufacturer's stated average or a user-determined average shall be used.

NOTE 9—When using long strips of film that will be measured at scaled intervals, the user may choose to verify thickness at various points along the length of the strip or qualify the thickness uniformity of the first few meters of film from a roll.

10.2.5.6 Calculate the specific net absorbance using the measured or average thickness, net absorbance, specific absorbance or carry forward the absolute absorbance depending on the user's calibration method and procedures.

10.2.5.7 Determine the absorbed dose from the absorbance and the appropriate calibration curve (see Section 9).

11. Documentation requirements

11.1 Record details of the measurements in accordance with the user's measurement management system.

12. Measurement uncertainty

12.1 All dose measurements need to be accompanied by an estimate of uncertainty. Appropriate procedures are recommended in ISO/ASTM Guide 51707 and Practice 51261 (see also GUM).

12.2 All components of uncertainty should be included in the estimate, including those arising from calibration, dosimeter response reproducibility, instrument variability, and the effect of influence quantities. A full quantitative analysis of components of uncertainty, referred to as an uncertainty budget, is often presented in the form of a table. Typically, the uncertainty budget will identify all significant components of uncertainty, together with their methods of estimation, statistical distributions and magnitudes.

12.3 The estimate of the expanded uncertainty achievable with measurements made using a CTA dosimetry system and used as per this practice is typically of the order of ±6 % to ±8 % for a coverage factor $k = 2$ (which corresponds approximately to a 95 % level of confidence for normally distributed data).

13. Keywords

13.1 absorbed dose; cellulose triacetate; CTA; dose; dosimeter; dosimetry system; electron beam; gamma radiation; ionizing radiation; irradiation; radiation; radiation processing; radiation sterilization

ANNEXES

(informative)

A1. INFORMATION ON (CTA) FILM DOSIMETERS

A1.1 This information is intended to serve as a guide only, since available sources of dosimeters and dosimeter performance may change.

A1.2 A list of available CTA dosimeters is given in Table A1.1.

A1.3 The absorbed dose range is the recommended range. In some cases, it may be possible to extend the lower and upper dose limits with possible consequent loss of dosimetric accuracy.

A1.4 Some suppliers of the film are listed in Table A1.2.

A1.5 Some suppliers of specialized CTA strip reading equipment are shown in Table A1.3.

A1.6 Information on environmental and post-irradiation effects and their possible influence on dosimetric response may be obtained from the supplier and information is published in the references listed in this standard.

TABLE A1.1 Basic properties of available CTA dosimeters

Dosimeter	Nominal Thickness, mm	Analysis Wavelength, nm	Absorbed Dose Range, kGy
FTR-125	0.125	280[A]	10 to 300

[A] Other analysis wavelengths near 280 nm have been suggested and demonstrated **(9)**.

TABLE A1.2 Known suppliers of CTA dosimeters

Type	Supplier Address
FTR-125	FujiFilm Corporation 7-3 Akasaka 9-Chome, Minato-Ku, Tokyo, 107-0052 Japan
FTR-125	GEX Corporation (distribution for Fuji) 7330 S. Alton Way, Suite 12-I, Centennial, CO 80112 USA
FTR-125	Aérial—Centre de Ressources Technologiques (distribution for Fuji) Parc d’Innovation, Rue Laurent Fries, BP 40443 F-67412 Illkirch, Cedex, France

TABLE A1.3 Known suppliers of CTA strip reading equipment

Type	Supplier Address
DosASAP (hardware and software)	Aérial—Centre de Ressources Technologiques Parc d’Innovation, Rue Laurent Fries, BP 40443 F-67412 Illkirch, Cedex, France

A2. FIGURES

A2.1 The figures are for example only and should not be used to estimate correction factors.