



Standard Practice for Use of Cellulose Acetate Dosimetry Systems¹

This standard is issued under the fixed designation E 1650; 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.

ε¹ NOTE—Footnote 1 was editorially altered in July 1999.

1. Scope

1.1 This practice covers the preparation, handling, testing and procedures for the use of cellulose acetate dosimetry systems, and the spectrometric, densitometric, or photometric readout equipment for measuring absorbed dose in materials irradiated by photons and electrons in terms of absorbed dose in water.

NOTE 1—Cellulose acetate dosimeter refers to untinted and tinted cellulose triacetate (CTA) or cellulose diacetate (CDA) film dosimeter.

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

1.2.1 The absorbed dose range for untinted CTA is 5×10^3 to 3×10^5 Gy for photons and electrons,

1.2.2 The absorbed dose range for tinted CDA is 1×10^4 to 1×10^6 Gy for photons and electrons,

1.2.3 The absorbed dose rate for both CTA and CDA is from 0.03 to 4×10^{10} Gy/s,

1.2.4 The radiation energy range for photons is from 0.1 to 50 MeV, and

1.2.5 The radiation energy range for electrons is from 0.2 to 50 MeV.

NOTE 2—In cases where low-energy electrons and charged particles cannot completely penetrate the thickness of standard CTA and CDA films, thin films may be used (1,2).²

1.2.6 The irradiation temperature range is from –10 to 70°C.

1.3 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

E 170 Terminology Relating to Radiation Measurements and Dosimetry³

E 275 Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near Infrared Spectrophotometers⁴

E 666 Practice for Calculating Absorbed Dose from Gamma or X Radiation³

E 925 Practice for the Periodic Calibration of Narrow Band-Pass Spectrophotometers⁴

E 958 Practice for Measuring Practical Spectral Bandwidth of Ultraviolet-Visible Spectrophotometers⁴

E 1026 Practice for Using the Fricke Reference Standard Dosimetry System³

E 1205 Practice for Use of a Ceric-Cerous Sulfate Dosimetry System³

E 1261 Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing³

E 1275 Practice for Use of a Radiochromic Film Dosimetry System³

E 1276 Practice for Use of a Polymethylmethacrylate Dosimetry System³

E 1310 Practice for Use of a Radiochromic Optical Waveguide Dosimetry System³

E 1400 Practice for Characterization and Performance of a High-Dose Gamma Radiation Dosimetry Calibration Laboratory³

E 1401 Practice for Use of a Dichromate Dosimetry System³

E 1538 Practice for Use of the Ethanol-Chlorobenzene Dosimetry System³

E 1540 Practice for Use of a Radiochromic Liquid Dosimetry System³

E 1607 Practice for Use of the Alanine-EPR Dosimetry System³

E 1608 Practice for Dosimetry in an X-Ray (Bremsstrahlung) Irradiation Facility for Radiation Processing³

E 1631 Practice for Use of Calorimetric Dosimetry Systems for Electron Beam Dose Measurements and Dosimeter Calibrations³

¹ This practice is under the jurisdiction of ASTM Committee E-10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.01 on Dosimetry for Radiation Processing.

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² The boldface numbers in parentheses refer to the list of references at the end of this practice.

³ Annual Book of ASTM Standards, Vol 12.02.

⁴ Annual Book of ASTM Standards, Vol 03.06.

E 1649 Practice for Dosimetry in an Electron Beam Facility for Radiation Processing at Energies between 300 keV and 25 MeV³

E 1707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing³

E 1818 Practice for Dosimetry in an Electron Beam Facility for Radiation Processing at Energies Between 80 and 300 keV³

2.2 *International Commission on Radiation Units and Measurements (ICRU) Reports:*⁵

ICRU Report 14—Radiation Dosimetry: X-Rays and Gamma Rays with Maximum Photon Energies Between 0.6 and 50 MeV

ICRU Report 17—Radiation Dosimetry: X-Rays and Gamma Rays at Potentials of 5 to 150 kV

ICRU Report 33—Radiation Quantities and Units

ICRU Report 34—The Dosimetry of Pulsed Radiation

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

ICRU Report 37—Stopping Powers for Electrons and Positrons

ICRU Report 44—Tissue Substitutes in Radiation Dosimetry and Measurement

3. Terminology

3.1 *absorbed dose, (D)*—quantity of ionizing radiation energy imparted per unit mass of a specified material. The SI unit of absorbed dose is the gray (Gy), where 1 gray is equivalent to the absorption of 1 joule per kilogram of the specified material ($\text{Gy} = 1 \text{ J/kg}$). The mathematical relationship is the quotient of $d\bar{\epsilon}$ by dm , where $d\bar{\epsilon}$ is the mean incremental energy imparted by ionizing radiation to matter of incremental mass dm (see ICRU 33).

$$D = d\bar{\epsilon}/dm \quad (1)$$

3.1.1 *Discussion*—The discontinued unit for absorbed dose is the rad ($\text{rad} = 100 \text{ erg/g} = 0.01 \text{ Gy}$). Absorbed dose is sometimes referred to simply as dose.

For a photon source under conditions of charged particle equilibrium (see definition), the absorbed dose, D , may be expressed as:

$$D = \Phi [E (\mu_{\text{en}}/\rho)] \quad (2)$$

where:

Φ = particle fluence (see definition),

E = energy of the ionizing radiation, and

μ_{en}/ρ = mass energy absorption coefficient (see definition).

If bremsstrahlung production within the specified material is negligible, the mass energy absorption coefficient (μ_{en}/ρ) is equal to the mass energy transfer coefficient (μ_{tr}/ρ), and absorbed dose is equal to air kerma.

3.2 *absorbed-dose mapping*—measurement of absorbed dose within a process load using dosimeters placed at specified locations to produce a one-, two- or three-dimensional distribution of absorbed dose, thus rendering a map of absorbed dose values.

3.3 *absorbed-dose rate ($\dot{D}$)*—the absorbed dose in a material per incremental time interval, ie. the quotient of dD by dt .

$$\dot{D} = dD/dt \quad (3)$$

$$SI \text{ unit : Gy} \cdot \text{s}^{-1} \quad (4)$$

3.3.1 *Discussion*—The absorbed-dose rate is often specified in terms of the average value of $\dot{D}$ over long-time interval, for example, in units of $\text{Gy} \cdot \text{min}^{-1}$ or $\text{Gy} \cdot \text{h}^{-1}$.

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

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

3.6 *cellulose acetate dosimeter*—untinted and tinted cellulose triacetate (CTA) or cellulose diacetate (CDA) film dosimeter that undergoes change in optical absorbance or optical density under ionizing radiation.

3.6.1 *Discussion*—This change in absorbance or optical density is related to radiation chemical change in cellulose acetate, plasticizer and tinted dyes, and can be related to absorbed dose in water.

3.7 *charged particle equilibrium*—a condition that exists in a material under irradiation if the kinetic energies, number, and direction of charged particles induced by the radiation are uniform throughout the measurement volume of interest. Thus, the sum of the kinetic energies of the charged particles entering the volume equals the sum of the kinetic energies of the charged particles leaving the volume.

3.7.1 *Discussion*—Electron equilibrium is often referred to as charged-particle equilibrium.

3.8 *dosimeter batch*—quantities 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.

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

3.10 *electron equilibrium*—charged-particle equilibrium for secondary electrons.

3.11 *measurement quality assurance plan*—a documented program for the measurement process that assures 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.

3.12 *measurement traceability*—the ability to demonstrate by means of an unbroken chain of comparisons that a measurement is in agreement within acceptable limits of uncertainty with comparable nationally or internationally recognized standards.

3.13 *net absorbance (ΔA)*—change in measured optical absorbance at a selected wavelength determined as the absolute difference between the pre-irradiation absorbance, A_0 , and the post-irradiation absorbance, A as follows:

$$\Delta A = |A - A_0| \quad (5)$$

3.14 *net optical density, ΔOD* —another expression for “net absorbance.”

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

3.14.1 *Discussion*—This expression is more commonly used for film and plastic dosimeters than for liquid dosimeters.

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

$$\Delta k = \Delta A/d \quad (6)$$

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

3.17 *traceability*—see measurement traceability.

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

4. Significance and Use

4.1 The cellulose acetate (CTA and CDA) dosimetry systems provide a means of measuring absorbed dose in materials (3-17). Under the influence of radiation, chemical reactions take place in the cellulose acetate, plasticizer or dyes in the matrix, changing the optical absorption properties (absorption wavelength (band) and density) (18). Absorbance or optical density values are measured at the selected wavelength using a spectrophotometer, densitometer, or photometer.

4.2 In the use of a specific dosimetry system, absorbed dose is evaluated by the use of a calibration curve or response function traceable to nationally or internationally recognized standards.

4.3 Absorbed dose that is measured is usually specified in water. Absorbed dose in other materials may be evaluated by applying the conversion factors discussed in Guide E 1261.

NOTE 3—For a comprehensive discussion of various dosimetry methods applicable to the radiation types and energies discussed in this practice, see ICRU Reports 14, 17, 34, 35, and 37.

4.4 These dosimetry systems may be used in the industrial radiation processing of various products, for example radiation effects tests, polymer modifications, and sterilization of medical devices.

4.5 The available dynamic ranges indicated in 1.2.1 and 1.2.2 are achieved by using a variety of plasticizer and dye concentrations in the CTA and CDA systems.

4.6 The difference in dose response due to changes in the parameters of the irradiation conditions, such as dose rate, temperature, humidity, and atmosphere should be considered when these are different from the parameters of the calibration.

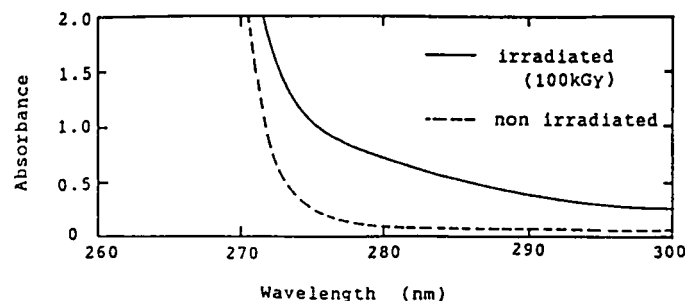
NOTE 4—The dose response of the CTA dosimeter increases linearly with temperature (−10 to 40°C) and relative humidity (20 to 80 %) when irradiated at lower dose-rates (<10 kGy/h) typical of gamma-irradiators. The effects are found to be less severe at the higher dose-rates for electron irradiators (>100 kGy/h). Moreover, as mentioned in Ref 16, these effects are known to vary from batch to batch. All these effects need to be considered before CTA dosimeters can be used routinely for processing (6,9,11,12,16,17, and 20).

5. Apparatus

5.1 The following shall be used to evaluate absorbed dose with cellulose acetate dosimetry systems:

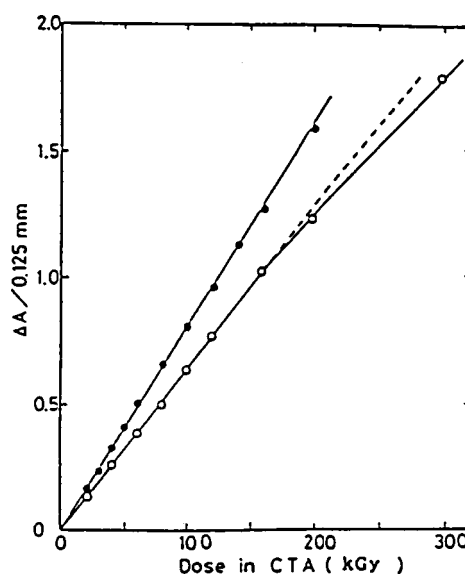
5.1.1 A batch or portion of a batch of cellulose acetate film.

5.1.2 UV/visible spectrophotometer or an equivalent instrument having documentation covering: (1) the analytical wavelength at which absorbance or optical density is measured (see 8.2); (2) the accuracy of wavelength selection, absorbance or optical density reading (see Figs. 1-4 for suitable wavelength—



NOTE 1—The suggested wavelength of 280 nm is chosen due to low absorbance before irradiation (A_0), and linear absorbance (A) increase with dose. (Original drawing by the author of Refs 1,2, and 19).

FIG. 1 Absorption Spectra Before and After Irradiation of Untinted Cellulose Triacetate (CTA) Film with a 2 MeV Electron Beam



NOTE 1—O: electron beam (dose rate: 10^7 /Gy/h, temperature: 15°C, relative humidity: 60 %). ◐: gamma-rays (dose rate: 10^4 /Gy/h, temperature 25°C, relative humidity: 50 to 60 %).

NOTE 2—The ΔA values were measured 2 h after irradiation (19).

FIG. 2 The Relation Between the Increment of Absorbance ΔA /Nominal Thickness (0.125 mm) at 280 nm and Dose in Untinted CTA by Electron and Gamma-Radiation

for example, 280 nm for untinted CTA and 390 nm for dyed CDA); and (3) the spectral wavelength range (in the case of absorption spectral readout as discussed in Ref 16). In addition, stray light rejection is needed. The spectrophotometer or the equivalent instrument should also be able to read the absorbance up to a value of 2.0 at a suitable wavelength with an uncertainty of no more than ± 1 %.

5.1.3 A film holder for spectrophotometer, or equivalent device, should keep the film perpendicular to the analytical beam, or a built-in automatic film feeder at a speed of the order of 0.1 to 1 cm/s with the same specifications of the film holder used for automatic one-dimensional dose profile measurement.

5.1.4 The thickness gage shall be calibrated and traceable to nationally or internationally recognized standards within a