



Standard Guide for Dosimetry in Radiation Research on Food and Agricultural Products¹

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1. Scope

1.1 This guide covers the minimum requirements for dosimetry and absorbed-dose validation needed to conduct research on the irradiation of food and agricultural products. Such research includes establishment of the quantitative relationship between the absorbed dose and the relevant effects in these products. This guide also describes the overall need for dosimetry in such research, and in reporting of the results.

1.2 This guide is intended for use by research scientists in the food and agricultural communities, and not just scientists conducting irradiation research. It, therefore, includes more tutorial information than most other ASTM dosimetry standards for radiation processing.

1.3 This guide is in no way intended to limit the flexibility of the experimenter in the experimental design. However, the radiation source and experimental set up should be chosen such that the results of the experiment will be beneficial and understandable to other scientists, regulatory agencies, and the food and agricultural communities.

1.4 The effects produced by ionizing radiation in biological systems depend on a large number of factors which may be physical, physiological, or chemical. Although not treated in detail in this guide, quantitative data of environmental factors that may affect the absorbed-dose response of dosimeters, such as temperature and moisture content in the food or agricultural products should be reported.

1.5 The overall uncertainty in the absorbed-dose measurement and the inherent absorbed-dose range within the specimen should be taken into account in the design of an experiment.

1.6 The guide covers research conducted using the following types of ionizing radiation: gamma rays, bremsstrahlung X-rays, and electron beams.

1.7 This guide does not include other aspects of radiation processing research, such as planning of the experimental design. Dosimetry must be considered as an integral part of the experimental design.

1.8 The guide does not include dosimetry for irradiator characterization, process qualification and routine dosimetry;

these subjects are described in Practices E 1204, E 1431, E 1608, E 1649, and E 1702. The selection and calibration of dosimetry systems is specified in Guide E 1261.

1.9 *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 Dosimetry²
- E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods³
- E 275 Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near Infrared Spectrophotometers⁴
- E 456 Terminology Relating to Quality and Statistics⁵
- E 666 Practice for Calculating Absorbed Dose from Gamma or X Radiation²
- E 668 Practice for Application of Thermoluminescence Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation Hardness Testing of Electronic Devices²
- 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 System²
- E 1204 Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing²
- E 1261 Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing²
- E 1275 Practice for Use of a Radiochromic Film Dosimetry System²
- E 1431 Practice for Dosimetry in Electron and Bremsstrahlung Irradiation Facilities for Food Processing²
- E 1539 Guide for the Use of Radiation-Sensitive Indicators²

¹ This guide is under the jurisdiction of ASTM Committee E-10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E 10.01 on Dosimetry for Radiation Processing.

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² Annual Book of ASTM Standards, Vol 12.02.

³ Annual Book of ASTM Standards, Vol 04.02.

⁴ Annual Book of ASTM Standards, Vol 03.06.

⁵ Annual Book of ASTM Standards, Vol 14.02.

E 1540 Practice for Use of a Radiochromic Liquid Dosimetry System²

E 1607 Practice for Use of the Alanine-EPR Dosimetry System²

E 1608 Practice for Dosimetry in an X-ray (Bremsstrahlung) Facility for Radiation Processing²

E 1649 Practice for Dosimetry in Electron Beam Facility for Radiation Processing at Energies between 300 keV and 25 MeV²

E 1702 Practice for Dosimetry in a Gamma Irradiation Facility for Radiation Processing²

E 1707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing²

F 1355 Guide for the Irradiation of Fresh Fruits for Insect Disinfestation as a Quarantine Treatment⁶

F 1356 Guide for the Irradiation of Fresh and Frozen Red Meats and Poultry (to Control Pathogens)⁶

F 1640 Guide for Packaging Materials for Foods to be Irradiated⁶

F 1736 Guide for the Irradiation of Finfish and Shellfish to Control Pathogens and Spoilage Microorganisms⁶

2.2 International Commission on Radiation Units and Measurements (ICRU) Reports⁷

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

ICRU 17, Radiation Dosimetry: X-rays Generated at Potentials of 5 to 150 kV

ICRU 30, International Comparison of Radiological Units and Measurements Quantitative Concepts and Dosimetry in Radiobiology

ICRU 33, Radiation Quantities and Units

ICRU 34, The Dosimetry of Pulsed Radiation

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

2.3 NCRP Publications⁸

NCRP Report No. 69, Dosimetry of X-Ray and Gamma-Ray Beams for Radiation Therapy in the Energy Range 10 keV to 50 MeV, December 1981

2.4 Methods for Calculating Absorbed Dose and Dose Distribution⁹

ZTRAN Monte Carlo Code

Integrated Tiger Series (ITS) Monte Carlo Codes

Energy Deposition in Multiple Layers (EDMULT) Electron Gamma Shower (EGS43)

Monte Carlo Codes

3. Terminology

3.1 Definitions:

3.1.1 *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/kg of the specified material (1 Gy = 1 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).

$$D = \frac{d\bar{\epsilon}}{dm}$$

DISCUSSION :

1. The discontinued unit for absorbed dose is the rad (1 rad = 100 erg/g = 0.01 Gy),
2. Absorbed dose is sometimes referred to simply as dose, and
3. For a photon source under conditions of charged particle equilibrium, the absorbed dose, D , may be expressed as follows:

$$D = \phi[E(\mu_{en}/\rho)]$$

where:

ϕ = particle fluence (particles/m²),

E = energy of the ionizing radiation (J), and

μ_{en}/ρ = mass energy absorption coefficient (m²/kg)

4. 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 kerma.

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

$$\dot{D} = \frac{dD}{dt}$$

Unit: Gy · s⁻¹

DISCUSSION—The absorbed dose rate can be specified in terms of average value of D over long-time intervals, for example, in units of Gy · min⁻¹ or Gy · h⁻¹.

3.1.3 *bremsstrahlung*—broad-spectrum electromagnetic radiation emitted when an energetic electron is influenced by strong electric field, such as that in the vicinity of an atomic nucleus. Particularly, bremsstrahlung is produced when an electron beam strikes any material (converter). The bremsstrahlung spectrum depends on the electron energy, the converter material and its thickness, and contains energies up to the maximum kinetic energy of the incident electrons.

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

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

DISCUSSION—Electron equilibrium often is referred to as charged-particle equilibrium.

3.1.6 *dosimeter*—device that, when irradiated, exhibits a quantifiable change in some property of the device, which can be related to absorbed dose in a given material using appropriate analytical instrumentation and techniques.

3.1.7 *dosimeter response*—the reproducible, quantifiable radiation effect produced by a given absorbed dose.

⁶ Annual Book of ASTM Standards, Vol 15.09.

⁷ Available from the International Commission on Radiation Units and Measurements, 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814 USA.

⁸ Available from the National Council on Radiation Units and Measurements, 7910 Woodmont Ave., Bethesda, MD 20814 USA.

⁹ Available from the Radiation Shielding Information Center (RSIC) Oak Ridge National Laboratory (ORNL) P.O. Box 2008, Oak Ridge, TN 37381 USA.

3.1.8 *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.

3.1.9 *electron equilibrium*—charged particle equilibrium for electrons.

3.1.10 *equilibrium absorbed dose*—the absorbed dose in a finite volume within the material in which the condition of approximate electron equilibrium exists.

3.1.11 *irradiator turntable*—device used to rotate the sample during the irradiation to improve the dose uniformity ratio.

DISCUSSION—Some research irradiators use turntables instead of a transport or conveyor system for the purpose of dose homogeneity improvement.

3.1.12 *phantom material*—a mass of material with attenuation and scattering properties similar to those of the product, material, or substance to be irradiated.

DISCUSSION—Phantom material may be used during the accelerator or irradiator characterization, or during absorbed-dose mapping as a substitute for the actual product, material or substance to be irradiated. When used in routine production runs, sometimes it is referred to as compensating dummy.

3.1.13 *primary-standard dosimeter*—a dosimeter of the highest metrological quality, established and maintained as an absorbed dose standard by a national or international standards organization (see Guide E 1261).

3.1.14 *quality assurance*—all systemic actions necessary to provide adequate confidence that a calibration, measurement, or process is performed to a predefined level of quality.

3.1.15 *reference-standard dosimeter*—a dosimeter of high metrological quality, used as a standard to provide measurements traceable to, and consistent with measurements made using primary standard dosimeters.

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

3.1.17 *routine dosimeter*—dosimeter calibrated against a primary-, reference-, or transfer-standard dosimeter and used for routine absorbed-dose measurement (see Guide E 1261).

3.1.18 *simulated product*—a mass of material with attenuation and scattering properties similar to those of the product, material or substance to be irradiated.

3.1.19 *traceability*—the documentation demonstrating 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.

3.1.20 *transfer-standard dosimeter*—a dosimeter often a reference standard dosimeter suitable for transport between different locations, used to compare absorbed-dose measurements (see Guide E 1261).

3.1.21 *uncertainty*—a parameter associated with the result of a measurement, that characterizes the dispersion of the values that reasonably could be attributed to the measurand or derived quantity.

DISCUSSION—(1) The parameter, for example, may be a standard deviation (or a given multiple of it), or the half-width

or an interval having a stated level of confidence. (2) Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of a series of measurements and can be characterized by experimental standard deviations. The other components, which also can be characterized by standard deviations, are evaluated from assumed probability distributions based on experience or other information. (3) It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion. (4) The term overall uncertainty associated with a measurand should take into account all components of error.

3.1.22 *validation*—establishment of documented evidence, which provides a high degree of assurance that a specified process will consistently produce a product meeting its predetermined specifications and quality attributes.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *absorbed-dose mapping*—measurement of absorbed-dose within the irradiated specimen 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.

3.2.2 *dose uniformity ratio*—ratio of the maximum to the minimum absorbed dose within the irradiated specimen. The concept also is referred to as the max/min dose ratio.

3.2.3 *secondary radiation*—electrons or photons produced by the action of primary radiation on matter, such as Compton recoil electrons, photoelectric electrons, and pair-production electrons.

3.2.4 *target dose*—absorbed dose delivered to a specific location in, or on the specimen that results in an acceptable absorbed-dose distribution within the rest of the specimen.

3.2.5 *transit dose*—absorbed dose delivered to product, material, or substance as it moves from the load/unload position to the irradiate position, and back to the load/unload position.

4. Significance and Use

4.1 This guide is intended to provide direction on the dosimetry aspects of experiments in food and agricultural research. Research concerning the effectiveness of irradiation of food and agricultural products to achieve a defined benefit necessarily involves very different operating parameters from one study to another. For example, the absorbed dose required to sterilize fruit flies is much lower than the doses required to inactivate some bacterial pathogens in meat, or to decontaminate spices. Furthermore, the kind and design of the facility, including type of radiation source that may be used in these studies are often very different. Yet the investigators must report to the scientific community sufficient information to characterize adequately their studies so that these studies can be repeated by another competent researcher, and so that the absorbed dose may be reproduced properly during the conduct of the experiment.

4.2 Ideally, an experiment should be designed to irradiate