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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Practice for Dosimetry in Electron and Bremsstrahlung Irradiation Facilities for Food Processing[1]

This standard is issued under the fixed designation E 1431; 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.

ϵ[1] NOTE—Footnote 1 was editorially altered in July 1999.

1. Scope

1.1 This practice describes dosimetric procedures to be followed in facility characterization, process qualification, and routine processing for electron beam and bremsstrahlung irradiation facilities for food processing to ensure that product receives an acceptable range of absorbed doses. Other procedures related to facility characterization, process qualification, and routine product processing that may influence and be used to monitor absorbed dose in the product are also discussed. Information about effective or regulatory dose limits for food products is not within the scope of this practice (see Guides F 1355 and F 1356).

NOTE 1—Dosimetry is only one component of a total quality assurance program for adherence to good manufacturing practices used in the production of safe and wholesome food.

1.2 The electron energy range covered in this practice is from 0.3 MeV to 10 MeV. Such electrons can be generated in continuous or pulse modes.

1.3 The maximum electron energy of bremsstrahlung facilities covered in this practice is 10 MeV. A photon beam can be generated by inserting a bremsstrahlung converter in the electron beam path (See Standard Practice E 1608).

NOTE 2—For guidance in the selection, calibration, and use of specific dosimeters and interpretation of absorbed dose in the product from dose measurements, see the documents listed in E 1261 and practices for individual dosimetry systems listed in 2.1.

NOTE 3—Bremsstrahlung from machine sources and gamma rays from radioactive isotopic sources are similar in characteristics, especially as dosimetry is concerned. See Practice E 1204 for the applications of dosimetry in characterization and operation of gamma-ray irradiation facilities for food processing. For information concerning electron beam irradiation technology and dosimetry, see Practice E 1649.

1.4 *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 Dosimetry[2]

E 177 Recommended Practice for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material[3]

E 456 Terminology for Statistical Methods[3]

E 666 Practice for Calculating Absorbed Dose from Gamma or X Radiation[2]

E 668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices[2]

E 1204 Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing[2]

E 1261 Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing[2]

E 1275 Practice for Use of a Radiochromic Film Dosimetry System[2]

E 1276 Practice for Use of a Polymethylmethacrylate Dosimetry System[2]

E 1310 Practice for Use of a Radiochromic Optical Waveguide Dosimetry System[2]

E 1607 Practice for Use of the Alanine-EPR Dosimetry System[2]

E 1608 Practice for Dosimetry in an X-ray (Bremsstrahlung) Irradiation Facility for Radiation Processing[2]

E 1631 Practice for Use of Calorimetric Dosimetry Systems for Electron Beam Dose Measurements and Dosimeter Calibrations[2]

E 1649 Standard Practice for Dosimetry in an Electron Beam Facility for Radiation Processing at Energies Between 300 keV and 25 MeV[2]

E 1650 Practice for Use of a Cellulose Acetate Dosimetry Systems[2]

E 1707 Guide for Estimating Uncertainties in Dosimetry for Radiation Processing[2]

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

Current edition, which includes substantial revisions to the last previous edition, was approved January 10, 1998. Published June 1998. Originally published as E 1431- 91. International Standard ISO 15562:1998(E) is identical to the last previous edition E 1431- 91.

[2] *ASTM Standards on Precision and Bias for Various Applications*, 4th ed., 1992.

[3] *Annual Book of ASTM Standards*, Vol 12.02.

F 1355 Guide for the Irradiation of Fresh Fruits for Insect Disinfestation as a Quarantine Treatment[4]

F 1356 Guide for the Irradiation of Fresh and Frozen Red Meats and Poultry (to Control Pathogens)[4]

F 1736 Guide for the Irradiation of Finfish and Shellfish to Control Pathogens and Spoilage Microorganisms[4]

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 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

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 per kilogram 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).

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

3.1.1.1 *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.

3. For a photon source under conditions of charged particle equilibrium, the absorbed dose, D, may be expressed as follows:

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

where:

Φ = particle fluence (particles/m^2),

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

μ_{en}/ρ = mass energy absorption coefficient (m^2/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}), and absorbed dose is equal to air kerma.

3.1.2 *average beam current*—time-averaged electron beam current; for a pulsed machine, the averaging shall be done over a large number of pulses.

3.1.3 *beam width*—dimension of the irradiation zone perpendicular to the beam length and direction of the electron beam specified at a specific distance from where the beam exits the accelerator.

3.1.3.1 *Discussion*—For a radiation processing facility with a conveyor system, the beam width is usually perpendicular to the direction of motion of the conveyor (see Fig. 1). Beam width is the distance between the points along the dose profile which are at a defined level from the maximum dose region in the profile (see Fig. 2). Various techniques may be employed to produce an electron beam width adequate to cover the processing zone, for example, use of electromagnetic scanning of pencil beam (in which case beam width is also referred to as scan width), defocussing elements, and scattering foils.

3.1.4 *bremsstrahlung*—broad-spectrum electromagnetic radiation emitted when an energetic electron is influenced by a strong electric field such as that in the vicinity of an atomic nucleus. Practically, 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 **(1,2)**.[6]

3.1.5 *compensating dummy*—simulated product used during routine production runs in process loads that contain less product than specified in the documented product loading configuration, or simulated product used at the beginning or end of a production run, to compensate for the absence of product.

3.1.5.1 *Discussion*—Simulated product or phantom material may be used during irradiator characterization as a substitute for the actual product, material or substance to be irradiated.

3.1.6 *depth-dose distribution*—variation of absorbed dose with depth from the incident surface of a material exposed to a given radiation.

3.1.7 *dose uniformity ratio*—ratio of the maximum to the minimum absorbed dose within the process load. The concept is also referred to as the max/min dose ratio.

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.

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

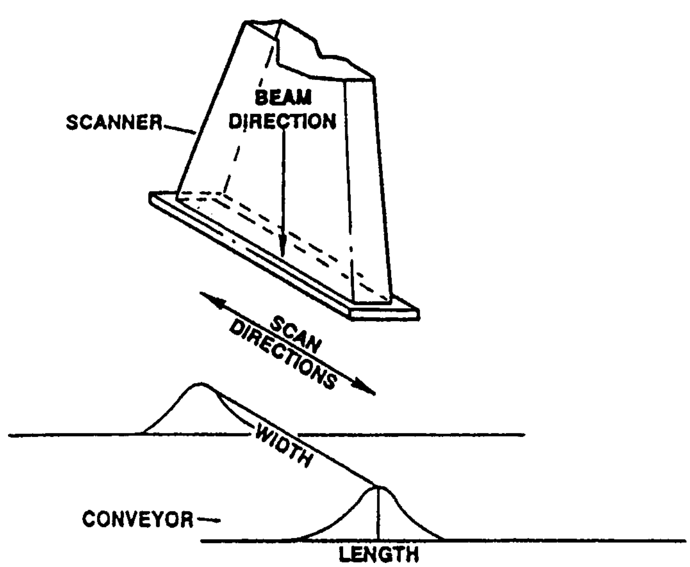

FIG. 1 Diagram Showing Beam Length and Width for a Scanned Beam Using a Conveyor Material Handling System

[4] *Annual Book of ASTM Standards*, Vol 15.09.

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

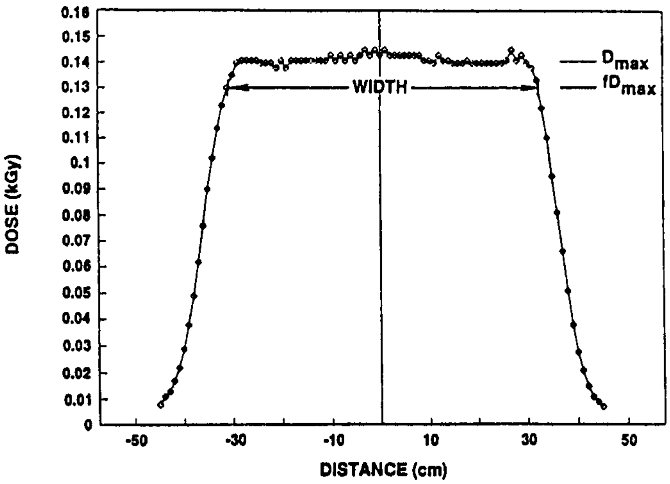

FIG. 2 Example of Electron-beam Dose Distribution Along the Beam Width[4] with the Width Noted at Some Defined Fractional Level *f* of the Average Maximum Dose D_{max}

3.1.9 *electron energy spectrum*—particle fluence distribution of electrons as a function of energy.

3.1.10 *electron range*—penetration distance in a specific, totally absorbing material along the beam axis of the electrons incident on the material (equivalent to practical electron range, R_p).

3.1.10.1 *Discussion*—See Fig. 3—R_p can be measured from experimental depth-dose distributions in a given material. Other forms of electron range are found in the dosimetry literature, eg., extrapolated range derived from depth-dose data and the continuous-slowing-down-approximation range (the calculated pathlength traversed by an electron in a material in the course of completely slowing down). Electron range is usually expressed in terms of mass per unit area ($kg \cdot m^{-2}$), but sometimes in terms of unit thickness (m) for a specified material.

3.1.11 *half-value depth (*R_{50})—depth in homogeneous material at which the absorbed dose has decreased to 50 percent of its maximum value.

3.1.11.1 *Discussion*—See Fig. 3—The half-value depth usually applies to electrons.

3.1.12 *optimum thickness (*R_{opt})—depth in homogeneous material at which the absorbed dose equals the absorbed dose at the surface where the electron beam enters.

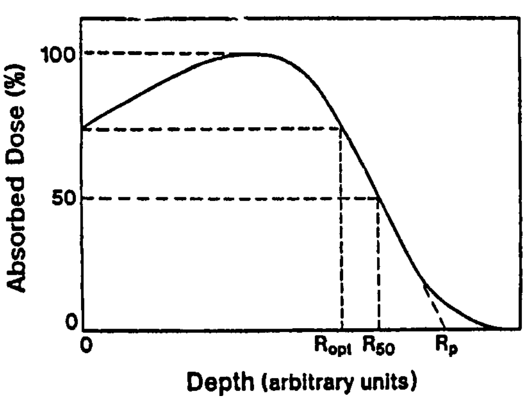

FIG. 3 A Typical Depth Dose Distribution for an Electron Beam

3.1.12.1 *Discussion*—See Fig. 3.

3.1.13 *practical electron range (*R_p)—distance from the incident surface of a homogeneous material where the electron beam enters to the point where the tangent at the steepest point (the inflection point) on the almost straight descending portion of the depth-dose distribution curve meets the depth axis.

3.1.13.1 *Discussion*—See Fig. 3.

3.1.14 *process load*—a volume of material with a specified loading configuration irradiated as a single entity.

3.1.15 *production run*—a series of process loads consisting of materials, or products having similar radiation-absorption characteristics, that are irradiated sequentially to a specified range of absorbed dose.

3.1.16 *reference material*—homogeneous material of known radiation absorption and scattering properties used to establish characteristics of the irradiation process, such as scan uniformity, depth-dose distribution, throughput rate, and reproducibility.

3.1.17 *reference plane*—a selected plane in the radiation zone that is perpendicular to the electron beam axis.

3.2 Definitions of other terms used in this standard that pertain to radiation measurement and dosimetry may be found in Terminology Standard E 170. Definitions in E 170 are compatible with ICRU 33; that document, therefore, may be used as an alternative reference.

4. Significance and Use

4.1 Food products may be processed with accelerator-generated radiation (electrons and bremsstrahlung) to derive public health or economic benefits, or both. Examples include parasite and pathogen control, insect disinfestation, growth and maturation inhibition, and extension of shelf-life. Food irradiation specifications usually include an upper and lower limit of absorbed-dose, and may also include an upper limit on overall average. For a given application, one or both of these values may be prescribed by regulations that have been established on the basis of available scientific data. Therefore, it is necessary to determine the capability of an irradiation facility to process within these absorbed-dose limits prior to the irradiation of the food product. Once this capability is established, it is necessary to monitor and document the maximum and minimum absorbed dose in the irradiated product for each production run to verify compliance with the process specifications with an acceptable level of confidence.

NOTE 4—The Codex Alimentarius Commission **(9)** uses the term "overall average absorbed dose" in discussing broad concepts such as the wholesomeness of foods irradiated to an overall average absorbed dose of less than 10 kGy. The overall average dose should not, however, be used in place of minimum or maximum absorbed doses for specific applications. The CAC confirms this in the following statement from CAC/RCP 19-1979, Annex A: "(T)he design of the facility and the operational parameters have to take into account minimum and maximum dose values required by the process."

NOTE 5—In addition to regulations specifying minimum and maximum absorbed dose limits for a food, some countries have regulations requiring that an overall average dose should not exceed a specified value, which is the mean of the specified minimum and maximum limits. The overall average dose absorbed by the food is the mean value of the measured minimum and maximum absorbed dose values.

4.2 Some food products are processed in the chilled or