Designation: E 1818 – 96^ε1

An American National Standard

Standard Practice for Dosimetry in an Electron Beam Facility for Radiation Processing at Energies Between 80 and 300 keV[1]

This standard is issued under the fixed designation E 1818; 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 June 1999.

1. Scope

1.1 This practice covers dosimetric procedures to be followed to determine the performance of low energy (300 keV or less) single-gap electron beam radiation processing facilities. Other practices and procedures related to facility characterization, product qualification, and routine processing are also discussed.

1.2 The electron energy range covered in this practice is from 80 keV to 300 keV. Such electron beams can be generated by single-gap self-contained thermal filament or plasma source accelerators.

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 Dosimetry[2]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[3]

E 456 Terminology Relating to Quality and Statistics[3]

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

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

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

2.2 *International Commission on Radiation Units and Measurements (ICRU) Reports:*[4]

ICRU Report 33 Radiation Quantities and Units

ICRU Report 37 Stopping Powers for Electrons and Positrons

2.3 *Methods for Calculating Absorbed Dose and Dose Distribution:*[5]

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 Definitions of terms used in this practice may be found in Terminology E 170 and ICRU Report 33.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *absorbed dose (D), n*—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 Report 33).

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

3.2.1.1 *Discussion*—The discontinued unit for absorbed dose is the rad (1 rad = 100 erg/g = 0.01 Gy). Absorbed dose is sometimes referred to simply as dose.

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

Current edition approved June 10, 1996. Published August 1996. International Standard ISO 15573:1998(E) is identical to this practice.

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

[3] *Annual Book of ASTM Standards*, Vol 14.02.

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

[5] Available from the Radiation Shielding Information Center (RSIC), Oak Ridge National Laboratory (ORNL), P.O. Box 2008, Oak Ridge, TN 37831.

3.2.2 *air gap*, *n*—the distance between the product plane and the electron beam window.

3.2.3 *backscatter*, *n*—the term used to describe additional absorbed dose caused by scatter of the primary electron beam from nearby material.

3.2.4 *beam current*, *n*—time-averaged electron beam current delivered from the accelerator.

3.2.5 *beam length*, *n— non-scanned electron beam*, the active length of the cathode assembly in vacuum parallel to the product flow and perpendicular to the beam width.

3.2.6 *beam power*, *n*—the product of the average electron beam energy and the average beam current (unit kW).

3.2.7 *beam width*, *n—non-scanned electron beam*, the active width of the cathode assembly in vacuum perpendicular to the product flow and beam length.

3.2.8 *bulk processing rate*, *n*—mass throughput rate based on the output power in watts of the electron beam, the mass of the irradiated material and the dose. Expressed in kilogray kilograms per kilowatt hour or Megarad pounds per kilowatt hour.

3.2.9 *depth-dose distribution*, *n*—variation of absorbed dose with depth from the incident surface of a material exposed to a given radiation (see Fig. 1 for calculated values).

3.2.10 *dose uniformity ratio*, *n*—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.

3.2.11 *dosimeter*, *n*—a 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.

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

3.2.13 *electron energy*, *n*—kinetic energy of the accelerated electron beam (units—eV (electron volts)). Often, acceleration voltage in kV is used to characterize beam energy in keV. The maximum energy of the beam inside the accelerator is equal to the acceleration voltage but expressed in keV units. The beam energy at the product surface is less than the maximum energy inside the accelerator due to losses in the beam path, such as the window and the air gap.

3.2.14 *traceability*, *n*—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.

3.2.15 *practical electron range*, *n*—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.

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

3.2.17 *production run*, *n— continuous-flow irradiation*, 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.

3.2.18 *product plane*, *n*—the plane corresponding to the top surface of the product being irradiated.

3.2.19 *self-shielded accelerator*, *n*—an electron beam source that is integrally designed with radiation shielding, product transport system, and irradiation chamber.

3.2.20 *single-gap accelerator*, *n*—an electron beam source consisting of a vacuum tube and a high voltage power supply that can accelerate a dispersed beam of electrons from a high voltage potential to ground potential in one stage.

3.2.21 *surface area rate coefficient (K)*, *n*— a quantity relating area irradiated per unit time to beam current and absorbed dose. Typically this value is expressed in kGy meters^2 per milliampere minute, or Megarad feet^2 per milliampere minute. Calculated values using Monte Carlo simulation are shown in Table 1. In the literature, this processing rate concept is sometimes called the processing coefficient.

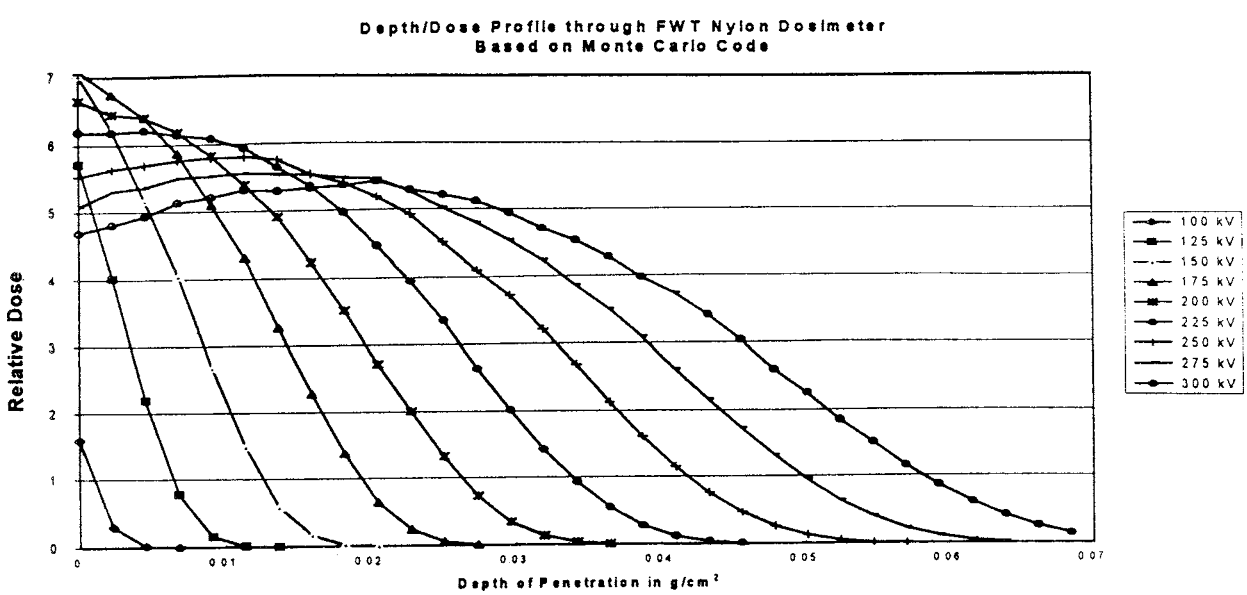

FIG. 1 Depth Dose Curves (0.5 mil Ti Window, 0.5 in. Air Gap)

TABLE 1 Calculated *K* Values at the Product Surface

Electron Beam Acceleration Voltage	Kilogray Metres^2/ Milliampere Minute $(K)^A$	Megarad Feet^2/Milliampere Minute $(K)^A$
100 kV	6.0	6.5
125 kV	14.9	16.0
150 kV	24.3	25.1
175 kV	23.4	25.2
200 kV	23.3	25.1
225 kV	22.7	24.4
250 kV	21.4	23.0
275 kV	18.7	20.1
300 kV	18.5	19.9

[A] Based on Monte Carlo Integrated Tiger Series simulation, assuming Far West (FWT 60-00) film dosimeters and 12.7 mm (0.5 in.) air gap.

3.2.22 *uncertainty*, *n*—a parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand or derived quantity (see Guide E 1707).

4. Significance and Use

4.1 A variety of processes use low energy electron beam accelerators to modify product characteristics. Dosimetry requirements, the number and frequency of measurements, and record keeping requirements will vary depending on the type and end use of the products being processed. In many cases dosimetry may be used in conjunction with physical, chemical, or biological testing of the product. In many cases reference standards may be developed, comparing dosimetry results with other quantitative product testing; for example, sterility, gel fraction, melt flow, modulus, molecular weight distribution, or cure analysis tests can be used to determine radiation dose in specific relevant materials. Wherever possible, the results of quantitative physical testing should be used in conjunction with dosimetry in commercial radiation processing applications.

4.2 Radiation processing specifications usually include a minimum or maximum absorbed dose limit, or both. For a given application these limits may be set by government regulation or by limits inherent to the product itself.

4.3 Critical process parameters must be controlled to obtain reproducible dose distribution in processed materials. The electron beam energy (in eV), beam current (in mA), spatial distribution of the beam, and exposure time or process line speed all affect absorbed dose (see Section 5). In some liquid-to-solid polymerization applications (often referred to as radiation curing), the residual oxygen level during irradiation must be controlled to achieve consistent results. A high level of residual oxygen can affect product performance in these curing applications, but it will not affect the absorbed dose.

4.4 Before any radiation process can be utilized, it must be validated to determine its effectiveness. This involves testing of the process equipment, calibrating the measuring instruments, and demonstrating the ability to deliver the desired dose within the desired dose range in a reliable and reproducible manner. The desired improvements, as well as any undesirable effects due to radiation damage to a specific product, should be understood.

5. Dosimetry System

5.1 The documents listed in Section 2 provide detailed information on the selection and use of appropriate dosimetry systems for gamma-ray and electron beam irradiation. Due to the limited depth of penetration of low energy electron beams and the narrow air gaps that are inherent in self-shielded equipment, thin film dosimeters are usually preferred over thicker systems (see Refs **1-3**,[6] Practices E 1275 and E 1650, and Guide E 1261).

6. Installation Qualification and Testing

6.1 *Equipment Testing*—The first phase of qualifying an irradiation facility is to determine that the processing equipment performs in accordance with design specifications. The process should include mechanical and electrical testing of the electron beam accelerator and related processing equipment, and should include, but not be limited to, the following:

6.1.1 Operation of all safety interlocks,

6.1.2 Operation of all system interlocks,

6.1.3 An extended demonstration of system performance at specified ratings,

6.1.4 Operation of the system over the full range of voltage and beam current,

6.1.5 Radiation survey at maximum operating voltage and current,

6.1.6 Mechanical inspection of the system,

6.1.7 Electrical inspection of the system,

6.1.8 Performance of the inert gas system, if applicable,

6.1.9 Performance of the ozone exhaust system, if applicable, and

6.1.10 Testing and calibration of product handling system over the full performance range.

6.2 The second phase of qualifying an irradiation facility is to characterize the performance of the equipment using dosimetry. The purpose of these measurements is to qualify the dose delivering characteristics of the equipment for performance acceptance and for future reference. The process should include, but not be limited to, the following:

6.2.1 *Surface Area Rate Measurements*— minimum of five measurements over the voltage range of interest with at least five dosimeters equally spaced across the width of the beam at the product plane at a nominal dose level. The surface area rate measurement should be repeated at a typical operating voltage level at several different beam current levels to establish and test the linearity between beam current and surface dose (see Appendix X1).

6.2.2 *Beam Uniformity Measurements*—minimum of one dosimeter per 2.5 cm over full width. Three measurements should be made at the product plane (see Appendix X1).

6.2.3 *Depth-dose Measurements*—A minimum of three measurements should be made at each voltage covering the voltage range of interest measured with the dosimetry stack at the product plane (see Appendix X1).

7. Frequency of Dosimetric Measurements

7.1 Initial facility performance evaluation dosimetry should be conducted in accordance with Section 6.

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