Designation: E666 − 21

Standard Practice for
Calculating Absorbed Dose From Gamma or X Radiation[1]

This standard is issued under the fixed designation E666; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This practice presents a technique for calculating the absorbed dose in a material from knowledge of the radiation field, the composition of the material, (**1-5**)[2,3] and a related measurement. The procedure is applicable for X and gamma radiation provided the energy of the photons fall within the range from 0.01 to 20 MeV.

1.2 A method is given for calculating the absorbed dose in a material from the knowledge of the absorbed dose in another material exposed to the same radiation field. The procedure is restricted to homogeneous materials composed of the elements for which absorption coefficients have been tabulated. All 92 natural elements are tabulated in (**2**). It also requires some knowledge of the energy spectrum of the radiation field produced by the source under consideration. Generally, the accuracy of this method is limited by the accuracy to which the energy spectrum of the radiation field is known.

1.3 The results of this practice are only valid if charged particle equilibrium exists in the material and at the depth of interest. Thus, this practice is not applicable for determining absorbed dose in the immediate vicinity of boundaries between materials of widely differing atomic numbers. For more information on this topic, see Practice E1249.

1.4 Energy transport computer codes[4] exist that are formulated to calculate absorbed dose in materials more precisely than this method. To use these codes, more effort, time, and expense are required. If the situation warrants, such calculations should be used rather than the method described here.

1.5 *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.*

1.6 *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:*[5]

E170 Terminology Relating to Radiation Measurements and Dosimetry

E668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices

E1249 Practice for Minimizing Dosimetry Errors in Radiation Hardness Testing of Silicon Electronic Devices Using Co-60 Sources

2.2 *International Commission on Radiation Units and Measurements (ICRU) Reports:*[6]

ICRU Report 18 Specification of High Activity Gamma-Ray Sources

ICRU Report 21 Radiation Dosimetry: Electrons with Initial Energies Between 1 and 50 MeV

ICRU Report 34 The Dosimetry of Pulsed Radiation

ICRU Report 51 Radiation Quantities and Units in Radiation Protection Dosimetry

ICRU Report 60 Radiation Fundamental Quantities and Units for Ionizing Radiation

[1] This practice is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.07 on Radiation Dosimetry for Radiation Effects on Materials and Devices.

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[2] The boldface numbers in parentheses refer to the list of references appended to this practice.

[3] See also ICRU Report 80. For calculation of absorbed dose in dosimetry systems and materials used in radiation processing, mass attenuation coefficients and mass-energy absorption coefficients for key elements, compounds and materials used in radiation processing dosimetry over the photon range from 100 keV to 20 MeV are given in Appendix 1 of that report.

[4] Information on and packages of computer codes can be obtained from The Radiation Safety Information Computational Center, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6362. This information center collects, organizes, evaluates, and disseminates shielding information related to radiation from reactors, weapons, and accelerators and to radiation occurring in space.

[5] For referenced 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.

[6] Available from International Commission on Radiation Units and Measurements (ICRU), 7910 Woodmont Ave., Suite 400, Bethesda, MD 20841.

ICRU Report 80 Dosimetry Systems for Use in Radiation Processing

ICRU Report 90 Key Data for Ionizing-Radiation Dosimetry: Measurement Standards and Applications

3. Terminology

3.1 *energy fluence spectrum, ψ(E)*—the product of the particle fluence spectrum (see Terminology E170) and the particle energy. In this standard, the particles referred to are photons. The energy fluences spectrum is the same as the energy fluence per unit energy.

3.2 *energy fluence, ψ*—the integral of the energy fluence spectrum over the complete range of particle energies that are present.

3.3 *mass-depth and mass-thickness, t*—the product of a length traversed in a material and the mass density of the material. The mass-depth and the mass-thickness have dimensions of mass per unit area.

4. Significance and Use

4.1 The absorbed dose is a more meaningful parameter than exposure for use in relating the effects of radiation on materials. It expresses the energy absorbed by the irradiated material per unit mass, whereas exposure is related to the amount of charge produced in air per unit mass. Absorbed dose, as referred to here, implies that the measurement is made under conditions of charged particle (electron) equilibrium (see Appendix X1). In practice, such conditions are not rigorously achievable but, under some circumstances, can be approximated closely.

4.2 Different materials, when exposed to the same radiation field, absorb different amounts of energy. Using the techniques of this standard, charged particle equilibrium must exist in order to relate the absorbed dose in one material to the absorbed dose in another. Also, if the radiation is attenuated by a significant thickness of an absorber, the energy spectrum of the radiation will be changed, and it will be necessary to correct for this.

NOTE 1—For comprehensive discussions of various dosimetry methods applicable to the radiation types and energies and absorbed dose rate ranges discussed in this method, see ICRU Reports 34 and 80.

5. Calculation of Absorbed Dose

5.1 The absorbed dose, D, at a point may be expressed as:

$$D = I \int_0^\infty \psi(E)[\mu_{en}(E)/\rho]\mathrm{d}E \quad (1)$$

where $\psi(E)$ is the energy fluence per unit energy at the point of interest; $\mu_{en}\ (E)/\rho$ is the mass energy absorption coefficient (**2**); and I is a normalizing factor. If all of the variables in Eq 1 are expressed in SI units, I = 1. In this case the units for D are Gy (J kg^{-1}), of $\psi(E)$, are m^{-2} , of μ_{en}/ρ are m^2·kg^{-1}, and of E are J. For an alternative use of the normalizing factor I, see Appendix X2. For further information on the use of energy absorption coefficients to calculate absorbed dose see the discussion in Attix (**1**). The energy fluence spectrum, $\psi(E)$, is that which is incident at the point where the dose is to be determined. In practice, the limits of integration are the limits of energy over which $\psi(E)$ is of a significant magnitude. If material intervenes between the source and the point of dose determination, then the spectrum used in the calculation must be the output spectrum of the source modified by the absorbing effects of the intervening material. The values of $\mu_{en}(E)/\rho$ are found in the tables of Ref 2.

NOTE 2—For units and terminology in reports of data, E170 and ICRU Reports 51 and 60 may be used as guides.

5.2 If the material in which the absorbed dose is to be calculated is a homogeneous combination of materials not listed in the tables of Ref 2, $\mu_{en}(E)/\rho$ is determined as follows:

5.2.1 From Ref 2, obtain values of $\mu^i_{en}(E)/\rho$ for each component, i.

5.2.2 Determine the mass fraction, w_i, for each component.

5.2.3 Calculate $\mu_{en}(E)/\rho$ from the following equation:

$$\mu_{en}(E)/\rho = \sum_i w_i[\mu^i_{en}(E)/\rho] \quad (2)$$

5.2.4 Values of $\mu_{en}(E)/\rho$ must be determined for each value of E for which $\psi(E)$ is significant, where E is the photon energy.

5.3 The integral contained in Eq 1 is evaluated numerically. The values of $\mu_{en}(E)/\rho$ in Ref 2 are tabulated for specific energies. In evaluation of the integral referred to in actual practice, it is often desirable to choose energy intervals that would not correspond to the tabulated values in Ref 2. In such cases, the appropriate value of $\mu_{en}(E)/\rho$ for the chosen energies should be determined by an acceptable interpolation procedure. The range of energy over the total photon spectrum is divided into energy intervals or bins. The width of these bins is somewhat flexible but should be chosen small enough so as not to distort the shape of the spectrum. For the purpose of selecting appropriate values of $\mu_{en}(E)/\rho$, the energy value selected for each energy interval can be taken either as that energy at the beginning or midpoint of each energy interval over the entire spectrum.

5.4 The energy fluence spectrum, $\psi(E)$, is commonly given in arbitrary units and may be normalized to some source parameter. If a standard or calibrated dosimeter is used, then the integral in Eq 1 must be calculated for the material from which this dosimeter is constructed. The value of I is then given by the observed dose, D, measured by the dosimeter, divided by the value of the integral.

6. Estimating the Absorbed Dose in One Material from That Measured in Another Material

6.1 If the absorbed dose is known in one material, A, then the absorbed dose can be estimated in another material, B, using the method described in this section.

6.1.1 The absorbed dose observed in A occurs at some depth in the region of material A; similarly, it is desired to know the absorbed dose in material B at some depth in the region of material B. If it is presumed that we know the surface energy fluence spectrum $\psi_o(E)$ (the energy fluence spectrum incident on the surface of materials A and B) then the energy fluence spectrum $\psi(E)$ to be used in Eq 1 must be related to the known