Standard Terminology Relating to Radiation Measurements and Dosimetry[1]

This standard is issued under the fixed designation E 170; 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.

INTRODUCTION

This terminology generally covers terms that apply to radiation measurements and dosimetry associated with energy deposition and radiation effects, or damage, in materials caused by interactions by high-energy radiation fields. The common radiation fields considered are X-rays, gamma rays, electrons, alpha particles, neutrons, and mixtures of these fields. This treatment is not intended to be exhaustive but reflects special and common terms used in technology and applications of interest to Committee E10, as for example, in areas of radiation effects on components of nuclear power reactors, radiation hardness testing of electronics, and radiation processing of materials.

This terminology uses recommended definitions and concepts of quantities, with units, for radiation measurements as contained in the International Commission on Radiation Units and Measurements (ICRU) Report 60 on "Fundamental Quantities and Units for Ionizing Radiation," December 30, 1998.[2] Those terms that are defined essentially according to the terminology of ICRU Report 60 will be followed by ICRU in parentheses. It should also be noted that the units for quantities used are the latest adopted according to the International System of Units (SI) which are contained in Appendix X1 as taken from a table in ICRU Report 33.[2] This terminology also uses recommended definitions of two ISO documents[3], namely "International Vocabulary of Basic and General Terms in Metrology." (VIM, 1993) and "Guide to the Expression of Uncertainty in Measurement" (GUM, 1995). Those terms that are defined essentially according to the terminology of these documents will be followed by either VIM or GUM in parentheses.

1. Referenced Documents

1.1 *ASTM Standards:* [4]

E 380 Practice for the Use of the International System of Units (SI) (The Modernized Metric System)[5]

E 456 Terminology Relating to Quality and Statistics

E 706 Master Matrix for Light-Water Reactor Pressure Vessel Surveillance Standards, E 706(0)

E 722 Practice for Characterizing Neutron Energy Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics

E 910 Test Method for Application and Analysis of Helium Accumulation Fluence Monitors for Reactor Vessel Surveillance, E706 (IIIC)

1.2 *ISO Standards:*[3]

GUM Guide to the Expression of Uncertainty in Measurement, ISO 1995

VIM International Vocabulary of Basic and General Terms in Metrology, ISO 1993

1.3 *ICRU Documents:*[2]

ICRU 33 Radiation Quantities and Units

ICRU 60 Fundamental Quantities and Units for Ionizing Radiation, December 30, 1998

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[1] This terminology is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.93 on Editorial.

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[2] ICRU Report 33 has been superceded by ICRU Report 60 on "Fundamental Quantities and Units for Ionizing Radiation," December 30, 1998. Both of these documents are available from International Commission on Radiation Units and Measurements (ICRU), 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814.

[3] Available from International Organization for Standardization (ISO), 1 Rue de Varembe, Case Postale 56, CH-1211, Geneva 20, Switzerland, http://www.iso.ch.

[4] 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.

[5] Withdrawn.

1.4 *NIST Document:*[6]

NIST Technical Note 1297 Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, 1994

2. Terminology

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 $d\bar{\varepsilon}$ by dm, where $d\bar{\varepsilon}$ is the mean incremental energy imparted by ionizing radiation to matter of incremental mass dm. (ICRU)

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

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

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

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).

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 if, in addition, charged particle equilibrium exists.

absorbed dose rate, $\dot{D}$—the absorbed dose in a material per incremental time interval, that is, the quotient of d *D* by d *t* (see ICRU Report 33).

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

SI unit: $Gy \cdot s^{-1}$.

DISCUSSION—The absorbed-dose rate is often specified in terms of the average value of *D* over longer time intervals, for example, in units of $Gy \cdot min^{-1}$ or $Gy \cdot h^{-1}$.

accuracy—the closeness of agreement between a measurement result and an accepted reference value (see Terminology E 456).

activation cross section—the cross section for processes in which the product nucleus is radioactive (see **cross section**).

activity, *A*—of an amount of radioactive nuclide in a particular energy state at a given time, the quotient of d*N* by d*t*, where d*N* is the expectation value of the number of spontaneous nuclear transitions from that energy state in the time interval d*t* (ICRU).

$$A = dN/dt \quad (4)$$

Unit: s^{-1}

The special name for the unit of activity is the becquerel (Bq).

$$1\ Bq = 1\ s^{-1} \quad (5)$$

DISCUSSION—The former special unit of activity was the curie (Ci).

$$1\ Ci = 3.7 \times 10^{10}\ s^{-1} \text{ (exactly)}. \quad (6)$$

The "particular energy state" is the ground state of the nuclide unless otherwise specified. The activity of an amount of radioactive nuclide in a particular energy state is equal to the product of the decay constant for that state and the number of nuclei in that state (that is, $A = N\lambda$). (See **decay constant**.)

analysis bandwidth—spectral band used in a photometric instrument, such as a densitometer, for the measurement of optical absorbance or reflectance.

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

annihilation radiation—gamma radiation produced by the annihilation of a positron and an electron. For particles at rest, two photons are produced, each having an energy corresponding to the rest mass of an electron (511 keV).

backscatter peak—a peak in the observed photon spectrum (normally below about 0.25 MeV) resulting from large-angle (>110°) Compton scattering of gamma rays from materials near the detector. This peak will not have the same shape as the full-energy peaks (being wider and skewed toward lower energy).

benchmark neutron field—a well-characterized neutron field which will provide a fluence of neutrons for validation or calibration of experimental techniques and methods and for validation of cross sections and other nuclear data. The following classification of benchmark neutron fields for reactor dosimetry has been made:[7]

controlled neutron field—a neutron field physically well-defined, and with some spectrum definition, employed for a restricted set of validation experiments.

reference neutron field—a permanent and reproducible neutron field less well characterized than a standard field but accepted as a measurement reference by a community of users.

standard neutron field—a permanent and reproducible neutron field with neutron fluence rate and energy spectra, and their associated spatial and angular distributions characterized to state-of-the-art accuracy. Important field quantities must be verified by interlaboratory measurements and calculations.

buildup factor—for radiation passing through a medium, the ratio of the total value of a specified radiation quantity (such as absorbed dose) at any point in that medium to the contribution to that quantity from the incident uncollided radiation reaching that point.

cadmium ratio—the ratio of the neutron reaction rate measured with a given bare neutron detector to the neutron reaction rate measured with an identical neutron detector enclosed by a particular cadmium cover and exposed in the same neutron field at the same or an equivalent spatial location.

[6] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, USA, http://www.nist.gov

[7] *Neutron Cross Sections for Reactor Dosimetry*, International Atomic Energy Agency, Laboratory Activities, Vienna, 1978, Vol 1, p. 62.

Discussion—In practice, meaningful experimental values can be obtained in an isotropic neutron field by using a cadmium filter approximately 1 mm thick.

calibrated instrument—an instrument for which the response has been documented upon being directly compared with the response of a standard instrument, both having been exposed to the same radiation field under the same conditions; or one for which the response has been documented upon being exposed to a standard radiation field under well-defined conditions.

calibration source or field—see **electron standard field, γ-ray standard field,** and **X-ray standard field.**

calorimeter—an instrument capable of making absolute measurements of energy deposition (or absorbed dose) in a material through measurement of its change in temperature and a knowledge of the characteristics of its material construction.

certified reference material—a material that has been characterized by a recognized standard or testing laboratory, for some of its chemical or physical properties, and that is generally used for calibration of a measurement system, or for development or evaluation of a measurement method.

Discussion—Certification of a reference material can be obtained by one of the following three established routes of measurement of properties: (*1*) using a previously validated reference method; (*2*) using two or more independent, reliable measurement methods; and (*3*) using an *ad hoc* network of cooperating laboratories, technically competent, and thoroughly knowledgeable with the materials being tested. The certified reference materials provided by the United States National Institute of Standards and Technology are called Standard Reference Materials.

charged particle equilibrium—a condition that exists in an incremental volume within a material under irradiation if the kinetic energies and number of charged particles (of each type) entering that volume are equal to those leaving that volume.

Discussion—When electrons are the predominatnt charged particle, the term "electron equilibrium" is often used to describe charged particle equilibrium. See also the discussions attached to the definitions of kerma and absorbed dose in E 170.

coincidence sum peak—a peak in the observed photon spectrum produced at an energy corresponding to the sum of the energies of two or more gamma- or x-rays from a single nuclear event when the emitted photons interact with the detector within the resolving time of the detector.

Compton edge (E_c)—the maximum energy value of electrons of the Compton scattering continuum. The energy value of the Compton edge is

$$E_c = E_\gamma - \frac{E_\gamma}{1 + \frac{2E_\gamma}{0.511}} \quad (7)$$

which corresponds to 180° scattering of the primary photon of energy E_γ (MeV). For a 1 MeV photon, the Compton edge is about 0.8 MeV.

Compton scattering—elastic scattering of a photon by an atomic electron, under the condition of conservation of momentum, that is, the vector sum of the momenta of the outgoing electron and photon is equal to the momentum of the incident photon. The scattered photon energy, E'_γ, is given by

$$E'_\gamma = \frac{E_\gamma}{1 + \frac{E_\gamma (1 - \cos\theta)}{0.511}} \quad (8)$$

where E_γ is the incident photon energy in MeV and θ is the angle between the direction of the primary and scattered photon. The electron energy, E_e, is equal to $E_\gamma - E'_\gamma$.

continuum—the smooth distribution of energy deposited in a gamma detector arising from partial energy absorption from Compton scattering or other processes (for example, Bremsstrahlung). See **Compton scattering.**

cross section, σ—the quotient of P by Φ, where P is the probability of the interaction for one target entity when subjected to the particle fluence Φ (ICRU).

$$\sigma = P/\Phi \quad (9)$$

Unit: m^2

The special unit of cross section is the barn, *b*.

$$1 \text{ b} = 10^{-28} \text{ m}^2 \quad (10)$$

decay constant, λ—of a radioactive nuclide in a particular energy state, the quotient of dP by dt, where dP is the probability of a given nucleus undergoing a spontaneous nuclear transition from that energy state in the time interval dt (ICRU).

$$\lambda = dP/dt \quad (11)$$

Unit: s^{-1}

Discussion—The quantity (ln 2)/λ is commonly called the half-life, $T½$, of the radioactive nuclide, that is, the time taken for the activity of an amount of radioactive nuclide to become half its initial value.

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

displacement dose (D_d)—the quotient of d $\bar{\varepsilon}_d$ by dm, where d $\bar{\varepsilon}_d$ is that part of the mean energy imparted by radiation to matter which produces atomic displacements (that is, excluding the part that produces ionization and excitation of electrons) in a volume element of mass dm.

$$D_d = d\,\bar{\varepsilon}_d/dm \quad (12)$$

Unit: $J \cdot kg^{-1}$

Discussion—A more common unit is **displacements per atom (dpa)**, (see definition).

displacements per atom (dpa)—the mean number of times each atom of a solid is displaced from its lattice site during an exposure to displacing radiation, as calculated following standard procedures (see **displacement dose**).

dosimeter—a device that, when irradiated, exhibits a quantifiable change that can be related to absorbed dose in a given material using appropriate measurement instrument(s) and procedures.

dosimetry system—a system used for determining absorbed dose, consisting of dosimeters, measurement instruments