Standard Terminology Relating to
Radiation Measurements and Dosimetry[1]

This standard is issued under the fixed designation E170; 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 85a on "Fundamental Quantities and Units for Ionizing Radiation," October 2011.[2] Those terms that are defined essentially according to the terminology of ICRU Report 85a 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 85a.[2] This terminology also uses recommended definitions of two JCGM documents,[3] namely "International vocabulary of metrology" (VIM, 2012, unless indicated otherwise) and "Guide to the expression of uncertainty in measurement" (GUM, 2008). Those terms that are defined essentially according to the terminology of these documents will be followed by either VIM or GUM in parentheses.

A term is boldfaced when it is defined in this standard. For some terms, text in italics is used just before the definition to limit its field of application, for example, see **activity**.

1. Referenced Documents

1.1 *ASTM Standards:*[4]

E380 Practice for Use of the International System of Units (SI) (the Modernized Metric System) (Withdrawn 1997)[5]

E722 Practice for Characterizing Neutron Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics

E910 Test Method for Application and Analysis of Helium Accumulation Fluence Monitors for Reactor Vessel Surveillance, E706 (IIIC)

1.2 *Joint Committee for Guides in Metrology (JCGM) Reports:*[3]

JCGM 100:2008, GUM 1995 , with minor corrections, Evaluation of measurement data – Guide to the expression of uncertainty in measurement

JCGM 200:2012, VIM International vocabulary of metrology – Basic and general concepts and associated terms

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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 60 has been superseded by ICRU Report 85a on "Fundamental Quantities and Units for Ionizing Radiation," October 2011. Both of these documents are available from International Commission on Radiation Units and Measurements (ICRU), 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814.

[3] Document produced by Working Groups of the Joint Committee for Guides in Metrology (JCGM). Available free of charge at BIPM website (http://www.bipm.org).

[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] The last approved version of this historical standard is referenced on www.astm.org.

1.3 *ICRU Documents:*[2]
ICRU 60 Fundamental Quantities and Units for Ionizing Radiation, December 30, 1998
ICRU 85a Fundamental Quantities and Units for Ionizing Radiation, October, 2011
1.4 *NIST Document:*[6]
NIST Technical Note 1297 Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, 1994
1.5 *ISO Standard:*[7]
ISO 10012 Measurement management systems – Requirements for measurement processes and measuring equipment

2. Terminology

absorbed dose (*D*)—quotient of $d\bar{\varepsilon}$ by d*m*, where $d\bar{\varepsilon}$ is the mean incremental energy imparted by ionizing radiation to matter of incremental mass d*m*. (ICRU), thus

$$D = d\bar{\varepsilon}/dm \tag{1}$$

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[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] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

DISCUSSION—

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 unit rad (1 rad = 100 erg/g = 0.01 Gy) is still widely used in the nuclear community; however, its continued use is not encouraged. For a photon source under conditions of charged particle equilibrium, the absorbed dose, *D*, may be expressed as follows:

$$D = \Phi \cdot E \cdot \mu_{en}/\rho, \tag{2}$$

where:
Φ = **fluence** (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 (*D˙*)—quotient of d*D* by d*t* where d*D* is the increment of absorbed dose in the time interval d*t* (ICRU), thus

$$\dot{D} = dD/dt \tag{3}$$

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

DISCUSSION—

The absorbed-dose rate is often specified as an average value over a longer time interval, for example, in units of $Gy \cdot min^{-1}$ or $Gy \cdot h^{-1}$.

accuracy—closeness of agreement between a measured **quantity value** and a true quantity value of a **measurand** (VIM).
DISCUSSION—
(1) The concept "accuracy" is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.
(2) The term "accuracy" should not be used for measurement trueness and the term "**precision**" should not be used for "accuracy," which, however, is related to both these concepts.
(3) "Accuracy" is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

activation cross section—**cross section** for a specific direct or compound nuclear interaction in which the product nucleus is radioactive.

DISCUSSION—

Fission and spallation processes produce a statistical ensemble of outgoing nuclear channels, but they are not considered to be activation reactions.

activity (*A*)—*of an amount of radionuclide in a particular energy state at a given time*, quotient of –d*N* by d*t*, where d*N* is the mean change in the number of nuclei in that energy state due to spontaneous nuclear transformations in the time interval d*t* (ICRU), thus

$$A = -dN/dt \tag{4}$$

Unit: s^{-1}

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

$$1 \text{ Bq} = 1 \text{ s}^{-1} \tag{5}$$

DISCUSSION—

The former special unit of activity was the curie (Ci), where

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

The negative sign in Eq 4 is an indication that the activity is decreasing with time. The "particular energy state" is the ground state of the nuclide unless otherwise specified. The activity of an amount of radionuclide 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**.)

aleatory uncertainty—uncertainty representing random uncertainty contributors where there is little possibility of reducing this uncertainty contributor by consideration of a more controlled scenario.

DISCUSSION—

(1) One paradigm decomposes uncertainty into epistemic and aleatory components. This division of uncertainty categories is very dependent upon what question is being posed in a given application. Aleatory uncertainties can be transformed into epistemic uncertainties depending upon the application. The uncertainties underlying a quantity may be classified as aleatory or epistemic according to the goals of the process.

(2) Aleatory uncertainty, also referred to as variability, stochastic uncertainty or irreducible uncertainty, is used to describe inherent variation associated with a quantity or phenomenon of interest. The determination of material properties or operating conditions of a physical system typically leads to aleatory uncertainties; additional experimental characterization might provide more conclusive description of the variability but cannot eliminate it completely. Aleatory uncertainty is normally characterized using probabilistic approaches.

analysis bandwidth—spectral band used in an instrument, such as a densitometer, for a measurement.

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.

DISCUSSION—

For particles at rest, two photons are produced, each having an energy corresponding to the rest mass of an electron (511 keV).

backscatter peak—peak in the observed photon spectrum resulting from large-angle (>110°) Compton scattering of gamma rays from materials near the detector.

DISCUSSION—

This peak is normally below about 0.25 MeV. Also, it will not have the same shape as the full-energy peaks (being wider and skewed toward lower energy).

benchmark neutron field—well-characterized irradiation environment which provides a fluence or fluence rate of neutrons suitable for the validation or calibration of experimental techniques and methods as well as for validation of cross sections and other nuclear data, where following classification for reactor dosimetry has been made:[8]

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

reference neutron field—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—permanent and reproducible neutron field that is characterized to state-of-the-art accuracy in terms of neutron fluence rate and energy spectra, and their associated spatial and angular distributions, where important field quantities need to be verified by interlaboratory measurements.

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[8] The following three definitions are derived from: *Neutron Cross Sections for Reactor Dosimetry*, International Atomic Energy Agency, Laboratory Activities, Vienna, Vol 1, 1978, p. 62 and Vlasov, M., IAEA Program on Benchmark Neutron Fields Applications for Reactor Dosimetry, Report INDC(SEC)-54/L+Dos, IAEA, Vienna, 1976.

DISCUSSION—

A type of neutron field is considered to be a "standard" over a specified energy range and there is only one type of "standard neutron field" for a given energy range. Currently, the ^{252}Cf spontaneous fission field is a "standard neutron field" from 0.5 MeV to 8 MeV. The deuterium-tritium (DT) accelerator field is considered to be the "standard neutron field" from 13.5 to 15 MeV. The thermal Maxwellian and epithermal 1/E slowing-down field are also considered to be "standard neutron fields."

bremsstrahlung—broad-spectrum electromagnetic radiation emitted when an energetic charged particle is influenced by a strong electric field, such as the Coulomb field of an atomic nucleus.

DISCUSSION—

In radiation processing, bremsstrahlung photons are generated by the deceleration or deflection of energetic electrons in a target material. When an electron passes close to an atomic nucleus, the strong Coulomb field causes the electron to deviate from its original motion. This interaction results in a loss of kinetic energy by the electron with the emission of electromagnetic radiation; the photon energy distribution extends up to the maximum kinetic energy of the incident electron. This bremsstrahlung spectrum depends on the electron energy, the composition and thickness of the target, and the angle of emission with respect to the incident electron.

buildup factor—*for radiation passing through a medium*, 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—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.

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—instrument that has been through a **calibration** process at established time intervals.

DISCUSSION—

Measurements carried out by this instrument have metrological traceability to the reference standard if calibration is properly carried out.

calibration—set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards (VIM: 1993).

DISCUSSION—

(1) Calibration conditions include environmental and irradiation conditions present during calibration.

(2) These standards should have metrological traceability to a national or international standard.

(3) To be reliable, calibration should be carried out at regular time intervals – frequency may depend on the final use of the data. Often, the frequency is specified by regulatory authorities.

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

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

DISCUSSION—

Calorimeter is generally designated as a **primary-standard dosimeter**.

certified reference material (CRM)—reference material, accompanied by documentation issued by an authoritative body and providing one or more specified property values with associated uncertainties and traceabilities, using valid procedures (VIM).

DISCUSSION—

"Certified reference material" should be differentiated from "Standard Reference Material" which is a National Institute of Standards and Technology (NIST) trademarked nomenclature.

charged particle equilibrium—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 predominant 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**.

coincidence sum peak—*for gamma spectroscopy*, 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 measurement system.

combined standard uncertainty—**standard uncertainty** that is obtained using the individual standard uncertainties associated with the input quantities in a measurement model (VIM).

DISCUSSION—

In case of correlations of input quantities contributing to the resulting uncertainty, covariances must also be taken into account when calculating the combined standard uncertainty.

Compton edge (E_c)—maximum energy value of electrons of the Compton scattering continuum, which is given by:

$$E_c = E_\gamma - \frac{E_\gamma}{1 + \frac{2E_\gamma}{0.511}} \tag{7}$$

DISCUSSION—

This value 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.

DISCUSSION—

The scattered photon energy, E'_γ (in MeV), is given by

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

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

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

continuum—*for gamma spectroscopy*, 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**.

coverage factor (k)—number larger than one by which a **combined standard uncertainty** is multiplied to obtain an **expanded uncertainty** (VIM).

DISCUSSION—

Coverage factor is typically in the range of 2 to 3.

cross section (σ)—*of a target entity, for a particular interaction produced by incident charged or uncharged particles of a given type and energy*, quotient of N_{int} by Φ, where N_{int} is the mean number of such interactions per target entity subjected to the **fluence** Φ (adapted from ICRU), thus

$$\sigma = N_{int}/\Phi \tag{9}$$

Unit: m^2

DISCUSSION—

The special unit of cross section is the barn, b, where

$$1\,b = 10^{-28}\,m^2 = 10^{-24}\,cm^2 \tag{10}$$

cumulative fission yield—total number of atoms of a specific nuclide produced directly by a fission event and via radioactive decay of the precursors.

DISCUSSION—

This definition is from INDC(NDS)-0534.[9] The fission yield (either independent or cumulative) varies with the energy of the neutron that initiates the fission event. The fission yields for a spontaneous fission event are distinct from those for a thermal or fast neutron-induced fission.

decay constant (λ)—*of a radionuclide in a particular energy state*, quotient of –dN/N by dt, where dN/N is the mean fractional change in the number of nuclei in that energy state due to spontaneous nuclear transformations in the time interval dt (ICRU), thus

$$\lambda = \frac{-\mathrm{d}N/N}{\mathrm{d}t}$$

(11)

Unit: s^{-1}

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[9] Handbook of Nuclear Data for Safeguards: Database Extensions, August 2008.

DISCUSSION—

The quantity (ln 2)/λ is commonly called the half-life, $T_{\frac{1}{2}}$, of the radionuclide, that is, the time taken for the activity of an amount of radionuclide 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)—quotient of $\mathrm{d}\bar{\varepsilon}_d$ by dm, where $\mathrm{d}\bar{\varepsilon}_d$ is that part of the mean incremental energy which produces atomic displacements (that is, excluding the energy that produces ionization and excitation of electrons) imparted by radiation to matter of incremental mass dm, thus

$$D_d = \mathrm{d}\bar{\varepsilon}_d/\mathrm{d}m$$

(12)

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

DISCUSSION—

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

displacements per atom (dpa)—mean number of times each atom of a solid is displaced from its lattice site during its exposure to radiation.

DISCUSSION—

This quantity is calculated from the displacement dose using a dislocation efficiency model such as Kinchin-Pease[10] or Norget-Robinson-Torrens (NRT) model.[11]

displacement threshold energy (E_d)—minimum kinetic energy imparted to a lattice atom to permanently displace it from its initial lattice site.

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[10] Kinchin, G. H., and Pease, R. S., "The Displacement of Atoms in Solids by Radiation," *Reports on Progress in Physics*, Vol 18, 1955, pp. 1-51.
[11] Norgett, M. J., Robinson, M. T., and Torrens, I. M., "A Proposed Method of Calculating Displacement Dose Rates," *Nuclear Engineering and Design*, Vol 33, 1975, pp. 50-54.

DISCUSSION—

This energy refers to the energy required to create the initial Frenkel pair, that is, a vacancy-interstitial defect pair, and is independent of subsequent defect interaction or thermal recombination effects. This energy can have an angle-dependence and, in polyatomic lattices, can be different for different types of lattice atoms. Displacement threshold energies in typical solids are on the order of 10-50 eV.

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