Designation: ~~E170 – 14~~ E170 – 14a

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 ISO documents[3], namely "International Vocabulary of Basic and General Terms in Metrology." (VIM, 2008) 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.

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]
E456 Terminology Relating to Quality and Statistics
E706 Master Matrix for Light-Water Reactor Pressure Vessel Surveillance Standards, E 706(0) (Withdrawn 2011)[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 *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 2008

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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.

Current edition approved ~~Sept. 1, 2014~~Oct. 15, 2014. Published ~~October 2014~~November 2014. Originally approved in 1963. Last previous edition approved in ~~2010~~2014 as ~~E170 – 10.~~E170 – 14. DOI: ~~10.1520/E0170-14.~~10.1520/E0170-14A.

[2] ICRU Report 60 has been superceded 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] 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] 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

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

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

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 ($\dot{D}$)—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 measurement result and an accepted reference value (see Terminology E456).

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

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

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

DISCUSSION—

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

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

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**.)

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

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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

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—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—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—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 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.

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 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—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—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

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

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

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

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

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

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

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

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

Unit: m^2

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

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

DISCUSSION—

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

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

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

$$\lambda = \frac{-\mathrm{d}N/N}{\mathrm{d}t} \tag{11}$$

Unit: s^{-1}

DISCUSSION—

The quantity (ln 2)/λ is commonly called the half-life, $T_{1/2}$, 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 $d\bar{\varepsilon}_d$ by d*m*, 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 d*m*, thus

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

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

DISCUSSION—

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

displacements per atom (dpa)—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—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—system used for determining absorbed dose, consisting of dosimeters, measurement instruments and their associated reference standards, and procedures for the system's use.

effective cadmium cut-off energy (E_c**)—**energy at which a specified cadmium container performs like a theoretically perfect filter and, therefore, has the following properties:

(1) for all energies below E_c, no neutron reactions occur, and

(2) for all energies above E_c, neutron reactions occur at the same rate as if the cadmium were not present.

DISCUSSION—

E_c varies with cadmium thickness, geometry of the container, angular distribution of incident neutrons, and ambient temperature.

*efficiency***—**see **total efficiency** and **full-energy peak efficiency**.

electron equilibrium—charged-particle equilibrium for electrons.

electron standard field—electron field whose particle energy and direction, spatial uniformity, and particle fluence rate uniformity are well established and reproducible.

energy calibration—process of establishing the relationship between photon or particle energy and channel number in the spectrometer. The energy calibration may be as simple as building a table of two or more energy-channel pairs or as complex as using a least squares algorithm to establish a function describing the energy versus channel relationship.

epithermal neutrons—general classification of neutrons with energies above those of thermal neutrons; or frequently, neutrons with energies in the resonance range, between the thermal limit and some upper limit, such as 0.1 MeV (see **thermal neutrons**).

DISCUSSION—

The term "epithermal neutrons" is generally used in thermal neutron systems when two groups of neutrons are considered. The term is not used to describe high energy neutrons in other types of systems such as fast or fusion reactors.

equivalent fission fluence—fluence of fission spectrum neutrons that would give a detector or material response for a particular reaction equal to that in a given neutron field.

equivalent 2200 m/s fluence (Φ_o**)—**measure of the thermal neutron fluence made with a l/v detector and using the 2200 m/s cross section, thus

~~$\Phi_o = n v_o t$ (13)~~

$$\Phi_o = n v_o t \quad (13)$$

where:

n = neutron density,
v_o = 2200 m/s, and

t = exposure time of the detector.

equivalent monoenergetic neutron fluence ($\Phi_{eq}(E_o)$)—characterizes an incident energy fluence spectrum, $\Phi(E)$, in terms of the fluence of monoenergetic neutrons at a specific energy, E_o, required to produce the same displacement kerma, K_o, in a specific material (for example, silicon) as $\Phi(E)$.

Discussion—

In applying this definition, total kerma is divided into two parts, ionization and displacement kerma (see Practice E722).

escape or pair production peak—peak in a gamma ray spectrum resulting from the pair production process within the detector, annihilation of the positron produced, and escape from the detector of one or more of the annihilation photons (see **pair production** and **annihilation radiation**).

single escape peak—gamma ray spectrum peak corresponding to escape of one of the annihilation photons from the active volume of the detector. The energy of the single escape peak is equal to the original gamma ray energy minus 511 keV.

double escape peak—gamma ray spectrum peak corresponding to escape of both of the annihilation photons from the active volume of the detector. The energy of the double escape peak is equal to the original gamma ray energy minus 1.022 MeV.

exposure *(X)***—**quotient of dq by dm, where dq is the absolute value of the mean total charge of the ions of one sign produced when all electrons and positrons liberated or created by photons incident on a mass dm of dry air are completely stopped in dry air (ICRU), thus

$$X = \mathrm{d}q/\mathrm{d}m \quad (14)$$

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

Discussion—

Formerly, the special unit of exposure was the röntgen (R), where

$$1\ \mathrm{R} = 2.58 \times 10^{-4}\ \mathrm{C{\cdot}kg^{-1}}\ \text{(exactly)} \quad (15)$$

exposure rate ($\dot{X}$)—quotient of dX by dt, where dX is the increment of exposure in the time interval, dt (ICRU), thus

~~$\dot{X} = \mathrm{d}X/\mathrm{d}t$ (16)~~

$$\dot{X} = \mathrm{d}X/\mathrm{d}t \quad (16)$$

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

fast neutrons—term for designating neutrons of energy exceeding some threshold that must be specified (typically 0.1 or 1 MeV); often associated with those neutrons predominantly responsible for displacement damage of materials in neutron radiation fields.

fission chamber—ionization chamber containing one or more surfaces coated with fissionable material.

fluence (Φ)—quotient of dN by da, where dN is the number of particles incident on a sphere of cross-sectional area da (ICRU), thus

$$\Phi = \mathrm{d}N/\mathrm{d}a \quad (17)$$

Unit: $\mathrm{m^{-2}}$

Discussion—

In order to distinguish this quantity from the energy fluence, this term is sometimes referred to as "particle fluence." The fluence may also be expressed as the time integral of the fluence rate.

fluence rate (φ)—quotient of dΦ by dt, where dΦ is the increment of fluence in the time interval dt (ICRU), thus

$$\varphi = \frac{\mathrm{d}\Phi}{\mathrm{d}t} = \frac{\mathrm{d}^2N}{\mathrm{d}a\ \mathrm{d}t} \quad (18)$$

Unit: $\mathrm{m^{-2} \cdot s^{-1}}$

Discussion—

In order to distinguish this quantity from the energy fluence rate, this term is sometimes referred to as "particle fluence rate." The term **flux density**