



Standard Terminology Relating to Radiation Measurements and Dosimetry¹

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 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 documents³, 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

- E380 Practice for the Use of the International System of Units (SI) (The Modernized Metric System)⁵
- E456 Terminology Relating to Quality and Statistics

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 June 1, 2010. Published August 2010. Originally approved in 1963. Last previous edition approved in 2009 as E170 – 09a. DOI: 10.1520/E0170-10.

² ICRU Report 33 has been superseded 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. The last approved version of this historical standard is referenced on www.astm.org.

E706 Master Matrix for Light-Water Reactor Pressure Vessel Surveillance Standards, E 706(0)

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 1993

1.3 *ICRU Documents*:²

ICRU 33 Radiation Quantities and Units

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

1.4 *NIST Document*:⁶

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

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

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

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

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/m²),

E = energy of the ionizing radiation (J), and

μ_{en}/ρ = **mass energy absorption coefficient** (m²/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 dD by dt (see ICRU Report 33).

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

SI unit: Gy·s⁻¹.

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

accuracy—the closeness of agreement between a measurement result and an accepted reference value (see Terminology E456).

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 dN by dt , where dN is the expectation value of the number of spontaneous nuclear transitions from that energy state in the time interval dt (ICRU).

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

Unit: s⁻¹

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

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

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

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, $A = \lambda N$). (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.

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.

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

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.

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 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 in E170.

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: m²

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 $(\ln 2)/\lambda$ is commonly called the half-life, $T_{1/2}$, 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 $d\bar{\epsilon}_d$ by dm , where $d\bar{\epsilon}_d$ 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 .

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

Unit: J · 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 and their associated reference standards, and procedures for the system's use.

effective cadmium cut-off energy (E_c)—the 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—an electron field whose particle energy and direction, spatial uniformity, and particle fluence rate uniformity are well established and reproducible.

energy calibration—a 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—a 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—the 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 —a measure of the thermal neutron fluence made with a 1/v detector and using the 2200 m/s cross section.

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

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—a 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—the 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—the 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 —the quotient of dQ by dm , where the value of dQ is the absolute value of the total charge of the ions of one sign produced in air when all the electrons (negatrons and positrons) liberated by photons in air of mass dm are completely stopped in air (ICRU).

$$X = dQ/dm \quad (14)$$

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

DISCUSSION—Formerly, the special unit of exposure was the röntgen (R).

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

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

$$\dot{X} = dX/dt \quad (16)$$

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

fast neutrons—a 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—an ionization chamber containing one or more surfaces coated with fissionable material.

Fricke dosimetry system—consists of a liquid chemical dosimeter (composed of ferrous sulfate or ferrous ammonium sulfate in aqueous sulfuric acid solution), a spectrophotometer (to measure optical absorbance) and its associated reference standards, and procedures for its use.

DISCUSSION—

(1) It is considered to be a reference-standard dosimetry system.

(2) Sodium chloride is usually added to dosimetric solution to minimize the effects of organic impurities.

full-energy peak—the peak in an energy spectrum recorded by a photon detector that occurs when the full energy of an

incident photon is absorbed by the detector. This is sometimes referred to as the photopeak.

full-energy peak efficiency—the ratio of the net count rate in the full-energy peak to the emission rate of the photons from a sample giving rise to the peak. The value is dependent on the source-detector-shield geometry and the photon energy. This is sometimes referred to as the photopeak efficiency.

gamma-ray standard field—a gamma ray field produced by a particular radioactive nuclide (such as ^{60}Co) that is well established and reproducible as to the absorbed dose rate produced in a specific material at a designated location within the field at any given time.

G value—see **radiation chemical yield**.

half-life—see **decay constant**.

helium accumulation fluence monitor (HAFM)—a passive neutron dosimeter whose measured reaction product is helium. The neutron fluence is obtained by dividing the helium concentration by the spectrum-averaged cross section (see **spectrum-averaged cross section**). (See also Test Method E910 and ASTM Master Matrix E706)

influence quantity—quantity that is not the measurand but that affects the result of the measurement (VIM).

instrument calibration traceability—property of the measuring instrument whereby the measurements made by it can be related to a stated reference through its calibration at acceptable time intervals against that reference, usually a national or international standard, or against a secondary standard which has been in turn calibrated against a reference standard.

integral neutron fluence—the fluence of neutrons integrated over all energies.

$$\Phi = \int_0^\infty \Phi(E) dE \quad (17)$$

ionization—a process in which a charged particle is created from a parent atom or molecule or other bound state.

ionizing radiation—any type of radiation consisting of *charged* particles or *uncharged* particles, or both, that as a result of physical interaction, creates ions by either primary or secondary processes. (For example, *charged* particles could be positrons or electrons, protons, or other heavy ions, and *uncharged* particles could be X rays, gamma rays, or neutrons.)

kerma, K —the quotient of dE_{tr} by dm , where dE_{tr} is the sum of the initial kinetic energies of all the charged particles liberated by uncharged particles in a mass dm of material (ICRU).

$$K = dE_{tr}/dm \quad (18)$$

The special name of the unit of kerma is the gray (Gy).

$$1 \text{ Gy} = 1 \text{ J} \cdot \text{kg}^{-1} \quad (19)$$

DISCUSSION—For uncharged radiation of energy E (excluding rest energy), the kerma, K , may also be written as:

$$K = \Phi \left[E \left(\frac{\mu_{tr}}{\rho} \right) \right] \quad (20)$$

where:

μ_{tr}/ρ = mass energy transfer coefficient and the term

$$\left[E \left(\frac{\mu_{tr}}{\rho} \right) \right] \quad (21)$$

is called the kerma factor. Φ is the **particle fluence** (see definition).

Since E_{tr} is the sum of the kinetic energies of charged ionizing particles liberated by the uncharged ionizing particles, it also includes the energy that these particles radiate in bremsstrahlung (ICRU).

It may often be convenient to refer to a value of kerma or kerma rate for a specified material in free space, or inside a different material. In such a case, the value will be that which would be obtained if a small quantity of specified material were placed at the point of interest.

For the purpose of dosimetry it may be convenient to describe the field of indirectly ionizing particles in terms of kerma rate for a suitable material.

For measurements of kerma, the mass element should be so small that its introduction does not appreciably disturb the field of uncharged ionizing particles; however, if this is not so, appropriate corrections must be applied.

Equality of absorbed dose and kerma is approached to the degree that charged particle equilibrium exists and bremsstrahlung is negligible.

mass energy-absorption coefficient, μ_{en}/ρ —of a material for uncharged ionizing particles, the product of the mass energy transfer coefficient, μ_{tr}/ρ , and $(1-g)$, where g is the fraction of the energy of secondary charged particles that is lost to bremsstrahlung in the material (ICRU).

$$(\mu_{en}/\rho) = (\mu_{tr}/\rho)(1 - g) \quad (22)$$

Unit: $\text{m}^2 \cdot \text{kg}^{-1}$

mass energy-transfer coefficient (μ_{tr}/ρ)—of a material for uncharged ionizing particles, the quotient of dE_{tr}/EN by ρdl , where E is the energy of each particle (excluding rest energy), N is the number of particles, and dE_{tr}/EN is the fraction of incident particle energy that is transferred to kinetic energy of charged particles by interactions in traversing a distance dl in the material of density ρ (ICRU).

$$(\mu_{tr}/\rho) = 1/\rho EN \cdot dE_{tr}/dl \quad (23)$$

Unit: $\text{m}^2 \cdot \text{kg}^{-1}$

mass stopping power, S/ρ —of a material for charged particles, the quotient of dE by ρdl , where dE is the energy lost by a charged particle in traversing a distance, dl , in the material of density ρ (ICRU).

$$S/\rho = (1/\rho) dE/dl \quad (24)$$

Unit: $\text{J} \cdot \text{m}^2 \cdot \text{kg}^{-1}$

($\text{eV} \cdot \text{m}^2 \cdot \text{kg}^{-1}$ is also used).

DISCUSSION— S is the linear stopping power. For energies at which nuclear interactions can be neglected, the mass stopping power is

$$S/\rho = 1/\rho (dE/dl)_{\text{col}} + 1/\rho (dE/dl)_{\text{rad}} \quad (25)$$

where:

$(dE/dl)_{\text{col}} = S_{\text{col}}$ = the linear collision stopping power

$(dE/dl)_{\text{rad}} = S_{\text{rad}}$ = the linear radiative stopping power.

measurand—specific quantity subject to measurement (VIM).

measurement quality assurance plan—a documented program for the measurement process that ensures that the expanded uncertainty consistently meets the requirements of

the specific application. This plan requires traceability to nationally or internationally recognized standards.

measurement system—the specific combinations of instrumentation, operator, and procedure used to make a particular measurement.

molar linear absorption coefficient (ϵ_m)—a constant relating the spectrophotometric absorbance, A_λ , of an optically absorbing molecular species at a given wavelength, λ , per unit pathlength, d , to the molar concentration, c , of that species in solution:

$$\epsilon_m = A_\lambda / (d \times c) \quad (26)$$

SI Unit: $\text{m}^2 \text{mol}^{-1}$

DISCUSSION—The measurement is sometimes expressed in units of $\text{L mol}^{-1} \text{cm}^{-1}$.

multigroup cross section—average particle fluence-weighted cross section in an energy interval of a multigroup model. (See also **multigroup model**).

$$\sigma_i = \int_{E_i}^{E_{i+1}} \Phi(E) \sigma(E) dE / \int_{E_i}^{E_{i+1}} \Phi(E) dE \quad (27)$$

multigroup model—subdivision of an energy spectrum into a number of subintervals: (E_i , E_{i+1}), where: $i = 1, 2, \dots n$.

multigroup particle fluence—particle fluence in the energy intervals of a multigroup model (see also **multigroup model**).

$$\Phi = \int_{E_i}^{E_{i+1}} \Phi(E) dE \quad (28)$$

national standard—an artifact, such as a well-characterized instrument or radiation source, that embodies the international definition of primary physical measurement standard for national use.

national standards laboratory—the laboratory which maintains a nation's measurement standards, such as the National Institute of Standards and Technology in the United States.

net count rate—the count rate recorded in a spectrometer after correcting for background and coincidence events.

neutron activation detector—a neutron fluence sensing device, well-characterized with respect to geometry, mass, composition and cross section which produces activity with a sufficiently long half life to permit its measurement after withdrawal from the neutron field.

neutron fluence—see **particle fluence**.

neutron fluence rate—see **particle fluence rate**. **neutron flux**—see **particle fluence rate**.

neutron spectrum—see **particle fluence spectrum**.

nuclide—a species of an atom characterized by its mass number, atomic number, and its nuclear energy state.

1/E fluence—that fluence in the portion of the neutron spectrum produced by moderating media for which the fluence per unit energy, ideally, is inversely proportional to the neutron energy.

1/v detector—a detector made of a nuclide whose cross section for a particular reaction of interest (for example, (n, γ), (n, p), (n, α)) varies as the reciprocal of the velocity of the impinging neutrons. The 1/v property of the detector is valid only over a restricted energy range and usually below 10 keV (see **2200 m/s cross section**).

pair production—a process that corresponds to the creation of an electron-positron pair by the interaction of a gamma ray in the field of a nucleus. The energy of the gamma ray must exceed 1.022 MeV (twice the rest mass of an electron).

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

$$\Phi = \frac{dN}{da} \quad (29)$$

Unit: m^{-2}

DISCUSSION—The fluence may also be expressed as the time integral of the fluence rate.

particle fluence rate, ϕ —the quotient of $d\Phi$ by dt , where $d\Phi$ is the increment of particle fluence in the time interval dt (ICRU).

$$\phi = \frac{d\Phi}{dt} = \frac{d^2N}{da dt} \quad (30)$$

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

DISCUSSION—The term **particle flux density** may be used but the term fluence rate conforms to the adoption of a uniform set of terms and units as prescribed by ICRU and SI units. Historically, the term *neutron flux* has been understood to mean neutron flux density (fluence rate). This term still is widely used in the nuclear community.

particle fluence spectrum, $\phi(E)$ —the quotient of $d\phi$ by dE , where $d\Phi$ is the fluence of particles in the interval E to $E + dE$.

$$\phi(E) = \frac{d\Phi}{dE} \quad (31)$$

Unit: $\text{m}^{-2} \cdot \text{eV}^{-1}$

DISCUSSION—The term **particle spectrum** is commonly used in E10 standards to indicate particle fluence spectrum. It should not be confused with the particle density spectrum, defined as *the quotient of the volumetric density of particles in dE by dE ($\text{m}^{-3} \cdot \text{eV}^{-1}$)*.

particle number—the number of particles emitted, transferred or received (ICRU).

precision—the closeness of agreement between measurements obtained under prescribed conditions (see Terminology E456).

DISCUSSION—Precision is a quantitative description of the dispersion characteristics of the results of a set of measurements. The precision of a measurement, under a certain set of prescribed conditions, can be referred to as “repeatability” or “reproducibility.” See **repeatability** and **reproducibility**.

primary-standard dosimeter—a dosimeter of the highest metrological quality, established and maintained as an absorbed-dose standard by a national or international standards organization.

quality assurance—all systematic actions necessary to provide adequate confidence that a calibration, measurement, or process is performed to a predefined level of quality.

radiation chemical yield, $G(x)$ —the quotient of $n(x)$ by $\bar{e}$ where $n(x)$ is the mean amount of a specified entity, x , produced, destroyed, or changed by the mean energy, $\bar{e}$,

imparted to the matter (see ICRU Report 33).

$$G(x) = (n(x)/\bar{\epsilon}) \quad (32)$$

SI Unit: mol J⁻¹

DISCUSSION—This is often referred to as G value. The former special unit was (100 eV)⁻¹. For example, for the Fricke dosimeter, G(Fe³⁺) is 15.5 (100 eV)⁻¹ or 1.61 μmol·J⁻¹ for ⁶⁰Co gamma rays.

radioactivation—an interaction process in which the product nucleus becomes radioactive.

reaction rate—the number of a given reaction that occur per target nucleus per unit time. When appropriate this term may be interpreted as a probability of reaction per unit time.

reference neutron field—see **benchmark neutron field**.

reference-standard dosimeter—a dosimeter of high metrological quality, used as a standard to provide measurements traceable to measurements made using primary-standard dosimeters.

repeatability (of results of measurements)—closeness of the agreement between the results of successive measurements of the same measurand carried out subject to all of the following conditions: the same measurement procedure, the same observer, the same measuring instrument, used under the same conditions, the same location, and repetition over a short period of time (**VIM**).

DISCUSSION—These conditions are called 'repeatability conditions.' Repeatability may be expressed quantitatively in terms of the dispersion characteristics of the results, for example, precision.

reproducibility (of results of measurements)—closeness of agreement between the results of measurements of the same measurand, where the measurements are carried out under changed conditions such as differing principle or method of measurement, observer, measuring instrument, location, conditions of use, or time (**VIM**).

DISCUSSION—A valid statement of reproducibility requires specification of the conditions changed. Reproducibility may be expressed quantitatively in terms of dispersion characteristics of the results, for example, precision. In this context, results of measurement are understood to be corrected results.

routine dosimeter—dosimeter calibrated against a primary-, reference-, or transfer-standard dosimeter and used for routine absorbed-dose measurement.

saturation activity—the number of disintegrations per unit time for the steady-state condition in which the rate of production of a nuclide is equal to the rate of loss by radioactive decay or nuclear transmutation.

shape calibration—a process of establishing a relationship between the expected peak shape and energy. The shape calibration may be as simple as the user supplying a few peak full-width at half maximum (FWHM)/energy (or channel) pairs or as complex as using a least squares algorithm to establish several parameters characterizing the peak width and its deviation from a pure Gaussian. Shape calibration may be an explicitly defined function of an analysis program or implicitly done in connection with some other operation (typically the energy calibration).

solid-phase chemical dosimeter—plastic, dyed plastic, or glass whose optical density, usually in the visible range,

changes when exposed to ionizing radiation. Examples that are in use include dyed polymethylmethacrylate (red perspex), undyed poly(vinyl) chloride (PVC), dyed polyamide (blue dye in Nylon matrix), and dyed polychlorostyrene (green dye in chlorostyrene matrix). It is generally considered to be a secondary standard dosimetry system.

solid state track recorder (SSTR)—a plastic, mineral, or emulsion material that records the passage of energetic ionizing particles as latent tracks that may be chemically enlarged or developed for microscopy or other techniques.

DISCUSSION—Track characteristics, such as track density, length, or diameter, can be used to obtain reaction rate, dose, energy spectrum, or other types of data (see **track etch technique**).

spectrum averaged cross section, $\bar{\sigma}$ —the cross section averaged over the energy distribution of the neutron fluence, where the energy limits of integration are chosen according to the neutron spectrum and reaction cross section considered. It is defined as:

$$\bar{\sigma} = \frac{\int \sigma(E) \Phi(E) dE}{\int \Phi(E) dE} \quad (33)$$

standard instrument—a measuring instrument intended to define, represent physically, maintain, or reproduce the unit of measurement of a quantity (or a multiple or submultiple of that unit) in order that other measuring instruments may be calibrated against it by comparison (see **calibrated instrument**).

standard neutron field—see **benchmark neutron field**.

standard uncertainty—uncertainty of the results of a measurement expressed as a standard deviation (**GUM**).

thermal neutrons—neutrons in thermal equilibrium with the medium through which they are traveling or diffusing.

thermoluminescence dosimeter (TLD)—a dosimeter made of a material that stores energy when irradiated by ionizing radiation and then releases that energy in the form of visible light when heated. The light output of heated TLD is measured photometrically. TLDs are secondary-standard dosimetry systems. Examples of commonly available TLDs include lithium fluoride (LiF), calcium fluoride with various trace activators (such as CaF₂ : Mn and CaF₂ : Dy), calcium sulfate (CaSO₄ : Mn and CaSO₄ : Dy), and lithium borate (Li₂B₄O₇ : Mn).

threshold neutron activation detector—a device containing a particular nuclide that is not significantly activated by neutrons below a certain threshold energy.

total efficiency—the ratio of the net count rate for all energies in a gamma ray spectrometer system to the gamma ray emission rate of monoenergetic photons from a sample. The value is dependent on the source-detector-shield geometry and the photon energy. If gamma rays of more than one energy are emitted by the source, it may be necessary to determine a separate total efficiency for each such energy.

traceability—property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties (**VIM**).

DISCUSSION—The unbroken chain of comparisons is called a 'traceability chain.'

track etch technique—a measurement method consisting of a dielectric material that records the passage of energetic heavy ionizing particles as latent tracks that can be developed or enlarged by various chemical methods and observed by microscopy methods or other techniques.

transfer-standard dosimeter—a dosimeter, often a reference-standard dosimeter suitable for transport between different locations, used to compare absorbed-dose measurements.

2200 m/s cross section, $\sigma(v_0)$ —the neutron cross section at $v_0 = 2200$ m/s (E is about 0.0253 eV).

true value—value of measurand that would be obtained by a perfect measurement.

DISCUSSION—True values are by nature indeterminate and only an idealized concept. The terms “true value of a measurand” and “value of a measurand” are viewed as equivalent.

uncertainty—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 (**VIM**) (NIST).

DISCUSSION—1. The parameter may be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence.

2. Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of a series of measurements and can be characterized by experimental standard deviations, are evaluated from assumed probability distributions based on experience or other information.

3. It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion.

4. The derived expanded uncertainty associated with a measurand should take into account all components of uncertainty.

X-ray standard field—an X-ray field that is well characterized as to the exposure rate, or absorbed dose rate produced in a specified material, at a specified location within the field for a given tube voltage, current, and filtration.

APPENDIXES

(Nonmandatory Information)

X1. RECOMMENDED QUANTITIES AND UNITS

TABLE X1.1 ICRU Recommended Quantities and Units (from ICRU 33)

Quantity		Unit Symbols	
Name	Symbol	SI	SI Restricted Name ^A
Particle number	N	1	
Particle fluence	Φ	m^{-2}	
Particle fluence rate ^B	ϕ	$\text{m}^{-2} \text{s}^{-1}$	
Mass energy transfer coefficient	μ_{tr}/ρ	$\text{m}^2 \text{kg}^{-1}$	
Mass energy absorption coefficient	μ_{en}/ρ	$\text{m}^2 \text{kg}^{-1}$	
Total mass stopping power	S/ρ	$\text{J m}^2 \text{kg}^{-1}$	
Radiation chemical yield	G(x)	mol J^{-1}	
Absorbed dose	D	J kg^{-1}	Gy
Absorbed dose rate ^B	$\dot{D}$	$\text{J kg}^{-1} \text{s}^{-1}$	Gy s ⁻¹
Kerma	K	J kg^{-1}	Gy
Kerma rate ^B	$\dot{K}$	$\text{J kg}^{-1} \text{s}^{-1}$	Gy s ⁻¹
Exposure	X	C kg^{-1}	
Exposure rate ^B	$\dot{X}$	$\text{C kg}^{-1} \text{s}^{-1}$	
Activity ^B	A	s^{-1}	Bq
Decay constant	λ	s^{-1}	

^AThe symbol for the special name for the SI unit restricted to specified quantities.

^BDay (d), hour (h), and minute (min) may be used instead of second (s).

X2. COMMENTARY ON UNITS

TABLE X2.1 Old and New Radiation Units

Quantity	SI Unit	Old Unit
activity	becquerel (Bq) (1/second)	curie (Ci) 1 Ci = 3.7×10^{10} Bq
absorbed dose and kerma	gray (Gy) (joule/kilogram) J/kg	rad 1 rad = 0.01 Gy
exposure	coulomb/kilogram (C/kg)	roentgen (R) 1 R = 2.58×10^{-4} C/kg

X2.1 The units associated with physical quantities defined or used in definitions in this standard are SI (The International System of Units). For a detailed discussion of SI units, see Practice E380.

X2.2 In recent years, the several traditional units having special names in radiation measurements and dosimetry have been replaced by others. In particular, this applies to the units for activity, kerma, absorbed dose, and exposure. Activity previously expressed in curies is now expressed in becquerels. The unit for kerma and absorbed dose has changed from rad to

gray. Exposure expressed now in the unit named roentgen should more properly have the units of coulomb per kilogram.

X2.3 It is recommended that the use of the old units for quantities with special names be avoided; however, if it is deemed necessary to use them for clarity, then values of quantities should be expressed first in the new units followed by values in the old units in parentheses. Table X2.1 summarizes the relationship between the old and new units for the quantities of interest.

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