# Radiation Quantities and Units Definitions

The quantities and units of radiation dose are inherently more complex than those used in toxicology or pharmacology, and additional complexity has resulted from several changes required by evolving concepts in radiation dosimetry. The first widely used physical quantity of radiation was "exposure," related to the ability of x or gamma radiation to ionize air; its unit was the roentgen (R). Exposure was limited to photon radiation with energy less than 2.5 MeV. The quantity "absorbed dose" (D) was introduced because it was applicable to all forms of ionizing radiation and absorbing materials. Absorbed dose is energy deposited per unit mass, and its original unit was the rep (roentgen equivalent-physical); 1 rep equaled 93 ergs per g (0.0093 J per kg) of absorbing material. The rep was replaced with the rad (radiation absorbed dose); 1 rad equaled 100 ergs per g (0.01 J per kg). The "dose equivalent" (H) and its unit, the rem (roentgen equivalent-man), were introduced to account for the different biologic effects of the same absorbed dose from different types of radiation; H is the product of D, Q, and N at a point of interest in tissue, where D is absorbed dose, Q is the quality factor, and N is the product of any other modifying factors. The "effective dose equivalent" was introduced to include the different sensitivities of individual tissues and organs, which are important for internal dosimetry: its unit is the same as the unit of "dose equivalent."

In the 1990 recommendations of the International Commission on Radiological Protection (ICRP 1991), the use of N was dropped and the radiation weighting factor ($W_R$) was substituted for Q. In addition, Systeme International (SI) units have been adopted by ICRP (1977). The unit of dose is now the gray (Gy), and the unit of equivalent dose, effective dose, and associated quantities is the sievert (Sv). Each of those units equals 1 J per kg. In terms of conventional units, 1 Gy = 100 rad and 1 Sv = 100 rem.

SI units have been almost universally adopted internationally and in the US scientific community, but they have not been embraced enthusiastically by the US regulatory and engineering communities. The principal international authority on radiologic quantities and units is the International Commission on Radiation Units and Measurements (ICRU), which maintains administrative offices in the National Council on Radiation Protection and Measurements (NCRP) headquarters in Bethesda, Maryland.

Definitions of various terms, quantities, and units used to describe radioactivity, radiation, and their control are given below. Most have been adapted from "Standards for Protection Against Radiation," Title 10, Part 20, of the Code of Federal Regulations (10 CFR 20). Definitions of effective dose and equivalent dose were adapted from ICRP (1991).

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## DEFINITIONS

**absorbed dose** The energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the rad and the gray (Gy).

**activity** The rate of disintegration (transformation) or decay of radioactive material. The units of activity are the curie (Ci) and the becquerel (Bq).

**As Low As Reasonably Achievable (ALARA)** – Making every reasonable effort to maintain exposures as far below the dose limits as is practical, taking into account economic considerations and other societal concerns.

**becquerel (Bq)** The SI unit of activity. 1 Bq equals 1 disintegration per second.

**byproduct material** As used in the Atomic Energy Act:

(1)
Any radioactive material (except special nuclear material) yielded in, or made radioactive by, exposure to the radiation incident to the process of producing or using special nuclear material; and

(2)
The tailings or wastes produced by the extraction or concentration of uranium or thorium from ore processed primarily for its source-material content, including discrete surface wastes resulting from uranium-solution extraction processes. Underground ore bodies depleted by solution-extraction operations do not constitute byproduct material according to this definition.

**collective dose** The sum of the individual doses received in a given period by a specified population from exposure to a specified source of radiation.

**committed dose equivalent ($H_{T,50}$)** The dose equivalent to organs or tissues of reference (T) that will be received from an intake of radioactive material by a person during the 50-y period after the intake.

**committed effective dose equivalent ($H_{E,50}$)** The sum of the products, for each body organ or tissue that is irradiated, of the applicable weighting factor and the committed dose equivalent to the organ or tissue ($H_{E,50} = \Sigma w_T H_{T,50}$).

**curie (Ci)** The conventional unit of activity. 1 Ci equals $3.7 \times 10^{10}$ disintegrations per second, which equals $3.7 \times 10^{10}$ Bq.

**dose** or **radiation dose** A generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose equivalent.

**dose equivalent ($H_T$)** The product of the absorbed dose in tissue, the quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and the sievert (Sv).

**effective dose (E)** The sum of weighted equivalent doses to all tissues and organs of the body (ICRP 1991). $E = \Sigma w_T H_T$, where $H_T$ is the equivalent dose and $w_T$ is the tissue weighting factor.

**effective dose equivalent ($H_E$)** The sum of the products, for each body organ or tissue that is irradiated, of the dose equivalent to the organ or tissue and the applicable weighting factor ($H_E = \Sigma w_T H_T$).

**equivalent dose ($H_T$)** In radiation protection, the absorbed dose averaged over a tissue or organ rather than a point, as is the case for dose equivalent) and weighted for the radiation quality that is of interest. For this quantity, the weighting factor is called the radiation weighting factor instead of the quality factor, as used in earlier dosimetric quantities.

**external dose** The dose received from radiation sources outside the body.

**exposure** A quantity used to express external ionizing radiation, or to indicate presence of radionuclides or radiation affecting individuals or populations (for example, "exposure" to radionuclides in the environment).

**gray (Gy)** The SI unit of absorbed dose. 1 Gy equals an absorbed dose of 1 J/kg (100 rad).

**internal dose** The dose received from radioactive material taken into the body.

**limits (dose limits)** The permissible upper bounds of radiation doses.

**member of the public** Any person except when that person is receiving an occupational dose.

**quality factor (Q)** The modifying factor that is used to derive dose equivalent from absorbed dose for purposes of radiation protection.

**rad** The special unit of absorbed dose. 1 rad equals an absorbed dose of 100 ergs per gram or 0.01 J per kg (0.01 Gy).

**radiation (ionizing radiation)** Alpha particles, beta particles, gamma rays, x rays, neutrons, high-energy electrons, high-energy protons, and other particles capable of producing ionization in matter. (As used in this report, radiation does not include nonionizing radiation, such as radiowaves, microwaves, visible, infrared, or ultraviolet light.)

**reference man** A hypothetical aggregation of human physical and physiologic characteristics arrived at by international consensus. These characteristics can be used by researchers and public-health workers to standardize results of experiments and to relate biologic insult to a common base.

**relative biological effectiveness (RBE)** The ratio of the absorbed dose of a reference radiation (usually 200 keV x rays) to the absorbed dose of the test radiation required to produce the same degree of biologic effect. The RBE of the test radiation depends on the exact biologic effect in a given species of organism under a given set of exposure conditions.

**rem** The special unit of any of the quantities expressed as dose quivalent. The dose equivalent equals the product of the absorbed dose in rads and the quality factor (1 rem = 0.01 Sv).

**roentgen (R)** The unit of exposure. One roentgen equals the amount of x or gamma radiation required to produce ions carrying a charge of 1 electrostatic unit (esu) per cubic centimeter ($2.58 \times 10^{-4}$ coulomb per kg) of dry air under standard conditions.

**sievert (Sv)** The SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sieverts is equal to the product of the absorbed dose in grays and the quality factor (1 Sv = 100 rem).

**source material** As defined under the Atomic Energy Act:

(1) Uranium, thorium, or any combination of uranium and thorium in any physical or chemical form; or

(2) Ores that contain, by weight, 0.05% or more of uranium, thorium, or any combination thereof. Source material does not include special nuclear material.

**special nuclear material** As defined under the Atomic Energy Act:

(1)
Plutonium, uranium-233, uranium enriched in uranium-233 or in uranium-235, and any other material that the Nuclear Regulatory Commission, pursuant to the provisions of Section 51 of the act, determines to be special nuclear material, but not including source material; or

(2)
Any material artificially enriched by any of the foregoing, but not including source material.

**Total Effective Dose Equivalent (TEDE)** The sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). It is a term used by some organizations to emphasize that the sum of the contributions from external and internal sources is meant. This term is not a part of the recommendations of the ICRP or NCRP. The term *effective dose equivalent,* without the modifier "total," is sufficient to imply contributions from external and internal sources.

**uranium fuel cycle** The operations of milling of uranium ore, chemical conversion of uranium, isotopic enrichment of uranium, fabrication of uranium fuel, generation of electricity by a light-water-cooled nuclear power plant using uranium fuel, and reprocessing of spent uranium fuel to the extent that these activities directly support the production of electric power for public use. Does not include mining operations, operations at waste-disposal sites, transportation of radioactive material in support of these operations, and the reuse of recovered nonuranium special nuclear and byproduct materials from the cycle.

**weighting factor ($w_T$)** For an organ or tissue (T), the proportion of the risk of stochastic effects resulting from irradiation of that organ or tissue to the total risk of stochastic effects when the whole body is irradiated uniformly.

**whole body** For purposes of external exposure, the head, trunk (including male gonads), arms above the elbow, and legs above the knee.

**working level (WL)** Any combination of short-lived radon decay products in 1 L of air that will result in the ultimate emission of alpha-particle energy equal to $1.3 \times 10^5$ MeV ($2.08 \times 10^{-5}$ J per $m^3$). Also equals the total energy emitted by alpha particles from short-lived radon decay products in equilibrium with radon gas in air at a concentration of 100 pCi/L (3.7 kBq per $m^3$).

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