Measuring Radiation: Terminology and Units

This resource is part of Science for Democratic Action vol. 8 no. 4*, which includes a Glossary of Radiation-Related Terms, and information on Measuring Radiation: Devices and Methods. Also see the associated* Energy & Security no. 14 *on Ionizing Radiation.*

(*Some of the terms used below are defined in IEER's Glossary*)

Ionizing radiation is emitted when radioactive substances decay. Radioactive decay occurs when the nucleus of an atom spontaneously decays by emitting a particle (an alpha particle, an electron, or one or more neutrons).

The four forms of ionizing radiation are alpha particles, beta particles, gamma rays, and, indirectly, neutrons. All have enough energy to ionize atoms, in other words, remove one or more of the atom's electrons.

An alpha particle consists of two protons and two neutrons, the equivalent of the nucleus of a helium atom. Alpha particles readily ionize material they contact and transfer energy to that material's electrons. An alpha particle can travel several millimeters in air, but in general its range decreases with increasing density of the medium. For example, alpha particles do not penetrate the outer layer of human skin, but if inhaled, alpha particles can damage lung tissue.

A **beta particle** is an electron or a positron and is much lighter than an alpha particle. Thus, it takes beta particles a longer distance than alpha particles to lose energy. A medium-energy beta particle travels about one meter in air and one millimeter in body tissue.

Gamma rays are electromagnetic radiation. A radioactive element may emit gamma rays (in discrete bundles, or quanta, called **photons**) if the nucleus remaining after alpha or beta decay is in an excited state. Gamma rays can penetrate much more deeply than alpha or beta particles; a high-energy gamma ray photon may pass through a person without interacting with tissue at all. When gamma rays interact with tissue, they ionize atoms. The term "X rays" is also sometimes used for the gamma rays emitted in the process of radioactive decay that are at the lower end of the energy spectrum of electromagnetic radiation resulting from radioactive decay.

Neutrons are neutral particles that have no electric charge. Unlike alpha and beta particles, they do not interact with electrons or cause ionization directly. Neutrons can, however, ionize indirectly in a variety of ways: elastic collisions, inelastic scattering, nonelastic scattering, capture reactions, or spallation processes. These processes variously result in the emission of gamma rays, beta radiation, and, in the case of spallation, more neutrons. For a more detailed explanation, see *Health Effects of Exposure to Low Levels of Ionizing Radiation (BEIR V report)*, National Academy Press, 1990, pp. 15-17.

Measuring Radioactivity

Ionizing radiation can be measured using units of electron volts, ergs, and joules. The **electron-volt** (abbreviated eV) is a unit of energy associated with moving electrons around. An electron is “tightly bound” in a hydrogen atom (one proton and one electron). It takes energy to move this electron away from the proton. It takes 13.6 electron-volts of energy to move this electron completely away from the proton. We say then that the atom is “ionized.” In the jargon, the “ionization energy” of the tightly bound electron in hydrogen is 13.6 electron volts.

Electrons are very light objects, so we don’t expect an electron-volt to represent very much energy. One electron-volt is only 1.6 x 10^{-19} joules of energy, in other words, 0.16 billion-billionth of a joule. One **joule** (abbreviated J) is equivalent to the amount of energy used by a one-watt light bulb lit for one second. The energy associated with the radioactive decay ranges from thousands to millions of electron-volts per nucleus, which is why the decay of a single nucleus typically leads to a large number of ionizations.

The radioactivity of a substance is measured in the number of nuclei that decay per unit time. The standard international unit or radioactivity is called a becquerel (abbreviated Bq), which is equal to one disintegration per second (dps). Radioactivity is also measured in curies, a historical unit based on the number of disintegration per second in one gram of radium-226 (37 billion). Hence 1 curie = 37 billion Bq. One picocurie (a trillionth of a curie) = 0.037 Bq, and 1 Bq = 27 picocuries. Radioactivity is also measured in disintegration per minute (dpm). One dpm = 1/60 Bq.

Specific activity measures the radioactivity of a unit weight of substance. The units are curies per gram or becquerels per gram. This allows us to compare whether a substance is more or less radioactive than another. The specific activity of a radionuclide is inversely proportional to its atomic weight and its half-life.

Environmental and biological measurements of radioactivity are generally expressed as concentrations of radioactivity in soil, water, air, or tissue. Examples of units include picocuries per liter, becquerels per cubic meter, picocuries per gram, and disintegrations per minute per 100 square centimeters. One picocurie (abbreviated pCi) is 10^{-12} (or 0.000000000001) curie. Sometimes, the weight of a radioactive material per unit of soil or tissue might be given and expressed in parts per million, or ppm, can be expressed in terms of mass. This can be converted into radioactivity units, since we know the specific activities of various radionuclides. Disintegrations per minute per 100 square centimeters (dpm/100 cm^2) is a unit commonly used to measure the surface contamination of an object, such as concrete or metal.

Measuring Dose

Placing your body near a radioactive source results in exposure. To evaluate the hazard from this exposure one must compute the absorbed dose. This is defined as the energy imparted to a defined mass of tissue. Dose is generally not uniform over the body. A radioactive substance can be selectively taken up by different organs or tissue.

Radiation doses are often calculated in the units of rad (short for **r**adiation **a**bsorbed**d**ose). One rad is 100 ergs/gram, in other words, 100 ergs of energy absorbed by one gram of a given body tissue. An erg is one-ten-millionth of a joule. One hundred rad equals one Joule/kilogram (J/kg), which also equals one **Gray** (Gy), the standard international unit for measuring radiation dose. Suppose time is involved? Then we are talking about dose rate (or dose per unit time). An example of the units for dose rate is millirad/hour. In everyday terms, a joule (and even more so, an erg) is a rather small amount of energy. But in terms of ionization potential of molecules or elements, a joule is a huge amount of energy. One joule of ionizing radiation can cause tens of thousands of trillions of ionizations.

The roentgen measures the amount of ionization in the air caused by radioactive decay of nuclei. In non-bony biological tissue, one roentgen is the equivalent of about 0.93 rad. In air, one roentgen equals 0.87 rad. Dials that show calibration in mR/hr are reading milliroentgen per hour.

Physically speaking, the most elementary way to measure the effect of radiation is to measure the amount of energy deposited in a given weight of material. However, the deposition of energy is only one aspect of the potential of radiation to cause
biological damage. The damage caused per unit of deposited energy is greater when it is deposited over a shorter distance. Hence an alpha particle, which would deposit its entire energy over a very short distance, causes far more damage per unit of energy than a gamma ray, which deposits its energy over a longer track. The weight of biological matter in which the energy is deposited is also important. The sensitivities of different organs also vary. The concept of relative biological effectiveness (RBE) has been created to try to capture the relative efficiency of various kinds of radiation in producing biological damage.

The RBE varies according to the organ exposed, the age of exposure, and other factors. A single factor, called the quality factor, for converting deposited energy in rad is used for regulatory purposes, even though this represents a considerable simplification of real life risks. For beta and gamma radiation, the quality factor used is 1, that is 1 rad = 1 rem. Alpha radiation is far more damaging per unit of energy deposited in living tissue. Currently, the quality factor for alpha is 20 (multiply rad of alpha radiation by 20 to get rem). We say “currently” because the quality factor for alpha radiation has changed over the years. The current quality factor generally used for neutrons is 10.

Dose conversion factors (DCFs) are used to convert an amount of radioactivity (expressed in curies or becquerels) breathed or ingested by a person into a dose (expressed in rems and sieverts). The DCFs used for regulatory purposes are derived from a combination of a variety of experimental data and mathematical models.

Some units used in measuring ionizing radiation and radiation dose

Unit	Description
Rem (roentgen equivalent man)	A unit of eq of radiation account the effectivenes ionizing rad ways in whi energy to hu in rem equa multiplied b (Q). For bet the quality f that is, rem radiation, th

	taken as 20, times rads. measure of neutrons, Q 10.
Sievert (Sv)	A unit of eq equal to 100
Rad (radiation absorbed dose)	A unit of ab radiation. R amount of e tissue.
Gray (Gy)	A unit of ab equal to 100 of depositio
Curie (Ci)	The traditio radioactivity radioactivity radium-226
Becquerels (Bq)	The standar radioactivity disintegratio
Disintegrations per second (dps)	The number (e.g. alpha (gamma ray nucleus of a second. One (disintegrati

Sources: *Nuclear Wastelands*, Makhijani et al., eds., Cambridge: MIT Press, 1995; *Science for Democratic Action, vol. 6 no. 2, November 1997*; Radiation Protection: A Guide for Scientists and Physicians, 3rd Ed., Jacob Shapiro, Cambridge: Harvard University Press, 1990.