

Chemical of the Week

ENVIRONMENTAL NUCLEAR RADIATION

We are exposed to nuclear radiation every day of our lives. Some of this radiation is from natural sources, and some results from human activity. Natural sources include cosmic radiation from space, radiation from lighter, unstable nuclei produced by the bombardment of the atmosphere by cosmic radiation, and radiation from heavy, unstable nuclei produced by the decay of a few long-lived nuclides in the earth's crust. Artificial sources include medical procedures, commercial products that contain radioactive materials, and fallout from nuclear testing.

Nuclear radiation can cause biological damage because it is highly energetic. In passing through matter, nuclear radiation loses its energy by causing ionization in the absorbing material. For this reason, nuclear radiation is called ionizing radiation. In the ionization process, neutral atoms in the absorbing material lose electrons, forming positive ions. Frequently, the ejected electrons possess sufficient energy to cause ionizations in other atoms. The average amount of energy required to ionize an atom is about 35 electron volts. (An electron volt is the amount of energy acquired by an electron accelerated in an electric field of 1 volt. It is equivalent to 1.6×10^{-19} Joule.) The energy of a single particle from a nuclear decay can be as high as 8 million electron volts (8 MeV). This energy is dissipated by producing ions, and an 8-MeV particle can produce 2×10^5 ions.

The magnitude of radioactivity in a sample of radioactive material is expressed using several different units (Table 1). One type of unit focuses on the number of decaying nuclei and is called the *activity*. Activity is expressed in terms of disintegrations per time. The most common unit of activity is the curie (abbreviated as Ci). It is defined as 3.7×10^{10} disintegrations per second. This happens to be the activity of 1 gram of Ra-224, which was discovered by Marie Curie. The SI unit of activity is the becquerel, which is 1 disintegration per second. The other units of radioactivity focus on the effects of radiation on the surroundings. The *exposure* expresses the amount of ionization caused by radioactive material. The common unit of exposure is the roentgen, which is defined as the amount of radiation that produces, in 1 cm³ of dry air, ions having a total charge of 1 electrostatic unit. In SI units, the roentgen is equivalent to 2.58×10^{-4} Coulomb/kg of air. The *absorbed dose* of radioactivity expresses the amount of energy absorbed by a substance exposed to ionizing radiation. One such absorbed dosage unit is the radiation absorbed dose, rad, which is 1×10^{-5} Joule/g. Different kinds of radiation will cause different biological effects for the same amount of energy absorbed. For this reason, the unit called the roentgen equivalent in man, or rem, was introduced. The rem is equal to the rad multiplied by a factor, Q , which accounts for the relative biological effect of radiation on humans. For β and γ radiation (and for X-rays) $Q \approx 1$, while for α particles and fast neutrons, $Q \approx 20$.

Table 1. Units of Nuclear Radiation

Property	Unit		
	Name	Symbol	Definition
Activity	curie	Ci	3.7×10^{10} disintegrations/sec
Exposure	roentgen	R	1 esu/cm ³
Absorbed dose	radiation absorbed dose	rad	1×10^{-5} J/g
Equivalent dose	roentgen equivalent in man	rem	$Q \times \text{rad}$

The ionizing power of radiation depends on the type of radiation. An alpha particle, which is relatively massive, is quite efficient at producing ions, ionizing virtually every atom in its path. Alpha particles lose most of their energy after traveling only a few centimeters in air or less than 0.005 mm in aluminum. A beta particle, which is relatively light, ionizes only a fraction of the atoms in its path. Beta particles travel more than a meter in air or several millimeters in aluminum.

For most humans, much of the absorbed radiation is cosmic radiation. At sea level, the average human absorbs about 26 millirem (mrem) per year. The atmosphere shields the surface of the earth from cosmic radiation, but for each 100-meter increase in elevation, the dosage absorbed increases by about 1.5 mrem per year. A person traveling by commercial jet aircraft can receive as much as 10 mrem on a long flight, such as Los Angeles to London.

When cosmic radiation interacts with the gases in the atmosphere, it causes nuclear transformations that release particles such as neutrons and protons. These neutrons and protons interact with other nuclei in the atmosphere, producing radioactive nuclei, such as carbon-14 and tritium (hydrogen-3). Carbon-14 is responsible for less than 1 mrem per year of absorbed radiation in humans, and tritium only about 1 microrem.

Long-lived radioisotopes in the earth's crust are also a source of absorbed radiation. One of these that is particularly significant is potassium-40, with a half life of 1.3×10^9 years and making up only 0.019% of all potassium. It is significant because potassium is one of the most abundant elements and because it is an essential component of foods. The average absorbed dose for humans from external potassium-40 is about 12 mrem per year, while that from internal potassium-40 is about 20 mrem per year.

For more information about environmental radiation, see "Radioactivity in Everyday Life," an article in the May, 1997 issue of the *Journal for Chemical Education* (page 501).