RADIATION UNITS AND RADIATION SAFETY

Interaction of Radiation with matter

All radiation possesses energy – inherently as in the case of electromagnetic radiation, or kinetic as in the case of particulate. Absorption of radiation is the process of transferring energy to the medium through which radiation is passing. The transfer of energy to the medium results from ionization or excitation of the medium by the radiation. These mechanisms are important because:

1. Absorption is the principle of radiation detection.
2. The degree of absorption determines shielding and safety requirements.
3. Absorption in body tissue may cause damage.

Units of Radiation Measurement

Ionization is the formation of ions and electrons (or ion pairs) produced by any form of radiation in matter. The discussion of ionizing radiation requires the understanding of two basic units, the *Curie* and the *Roentgen*. The *Curie* measures the degree of radioactivity of a source; the *Roentgen* measures the amount of radiation received by an object exposed to a source of radiation.

Curie

Radioactivity is a property of unstable nuclei resulting in their emission of radiation (either particulate or electromagnetic). The greater the amount of radioactivity of a particular source the greater the amount of radiation emitted. The basic unit of radioactivity is the *Curie* (*Ci*). One Curie of radioactive material disintegrates at the rate of 3.7×10^{10} disintegrations per second (2.2×10^{12} disintegrations per minute). Each disintegration may emit more than one particle or photon, and the energy released per disintegration depends on the nature of the source of radiation. 1 *Ci* is approximately equal to the amount of radioactivity contained in 1 gram of radium. The SI unit of disintegration rate is the *Becquerel* (*Bq*), 1 *Bq* = 1 disintegration/sec.

$$1\,Ci = 3.7 \times 10^{10} \text{ disintegrations/sec}$$

The *Ci* is a very large unit of radioactivity; the sources in the lab range from fractions of a microCurie (μCi) to about 10 milliCurie (mCi).

Roentgen

The cumulative amount of ionization produced by a radiation source is used as a measure of the amount of radiation exposure at a point. The basic unit of radiation exposure is the *Roentgen* ("*R*"). 1 *R* is that amount of ionizing photon radiation that will produce 1 ESU of charge in 1 cm^3 (1.293×10^{-3} grams), or 2.58×10^{-4} coul/kg, of air at STP (0°C and 760 mmHg). It turns out that the amount of energy transferred to air in the process of ionization is 32 eV per ion pair formed, so 1 *R* results in the formation of 1.6×10^{12} ion pairs in one gram of air. This requires the deposition of 87.6 ergs/gm. Thus a Roentgen of radiation may also be measured in terms of the energy deposited in one gram of air.

$$1\ R \rightarrow 87.6 \text{ ergs/gm in air}$$

Radiation Effects

The energy absorbed in tissue from external radiation or by radioactive material deposited in tissue may result in damage – especially in large doses. The basic unit of radiation dose is expressed in terms of energy absorbed per unit mass of tissue. This unit is called the "*rad*" (*Radiation Absorbed Dose*). 1 *rad* = absorbed dose of 100 ergs/gm of tissue. Exposure to 1 *R* of ionizing photons results in an absorbed dose of 0.87 *rad*. The SI unit of absorbed dose is the *Gray* (*Gy*). 1 *Gy* = 1 Joule/kg = 100 *rad*.

The measurement of absorbed dose is complicated by the fact that different sources of radiation at various energies have different biological effects. Generally, the higher the rate of linear energy transfer (*LET*) the greater the damage produced. Radiation absorbed from X–rays, gamma rays, and from beta particles (electrons) have been found to have about the same effect on tissue per *rad* absorbed and are assigned a relative biological effectiveness (*RBE*) or *quality factor* (*Q*) of 1. Radiation absorbed from neutrons and alpha particles have been found to be more damaging to tissue. The *RBE* ranges from 10 for thermal neutrons to 20 for alpha particles. Consequently another unit of radiation exposure is defined: the *rem* (for "*Roentgen Equivalent Man*").

$$1\ rem = 1\ rad \times RBE$$

Radiation Safety

We are continually exposed to "background radiation" from the sun and space and from naturally occurring radioactive materials in the earth's crust and in our bodies (primarily from radioactive isotopes of potassium and carbon). The radiation from these combined sources in the Pasadena area result in a dose of 100-300 millirem per year. Radiation damage effects have been studied for many years. These studies have been evaluated by the National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (BEIR).

The current Caltech regulations for handling radioactive materials and occupational dose limits are based on BEIR reports and are set forth in the following documents:

Radiation Safety Manual

Radiation Safety Training and Reference Manual

Both manuals are available in the sophomore lab. The *TEDE* (total effective dose equivalent) limits set forth in the latter manual are:

5 rem/year for adult radiation workers (TAs)

0.1 rem/year for undergraduate students

Physics 7 experiments are planned to produce radiation levels of less than 2 millirem/hr at any points accessible to the student. These values are checked by ionization chambers, Geiger-Muller counters, and photographic film detectors. However, to be certain of your personal safety and to insure that you obtain the maximum value from each experiment, the following rules must be strictly observed:

1. Make sure you fully understand the procedure.
2. Always consult your TA prior to using a radioactive source or activating a radiation-producing machine.
3. Read and observe safety rules associated with the experiment.
4. No eating or drinking in the lab; wash your hands when you leave the lab.