13. RADIOACTIVITY & RADIATION PROTECTION

Revised Sept. 1991 with assistance from N.A. Greenhouse.

The International Commission on Radiation Units and Measurements (ICRU) recommends the use of SI units. Therefore we list SI units first, followed by cgs (or other common) units in parentheses, where they differ.

• **Unit of activity** = becquerel (curie):

1 Bq = 1 disintegration s^{-1} [= $1/(3.7 \times 10^{10})$ Ci]

• **Unit of absorbed dose** = gray (rad):

1 Gy = 1 joule kg^{-1} (= 10^4 erg g^{-1} = 100 rad)

= 6.24×10^{12} MeV kg^{-1} deposited energy

• **Unit of exposure**, the quantity of x- or γ- radiation at a point in space integrated over time, in terms of charge of either sign produced by showering electrons in a small volume of air about the point:

= 1 coul kg^{-1} of air (roentgen; 1 $R = 2.58\times10^{-4}$ coul kg^{-1})

= 1 esu cm^{-3}(= 87.8 erg released energy per g of air)

Implicit in the definition is the assumption that the small test volume is embedded in a sufficiently large uniformly irradiated volume that the number of secondary electrons entering the volume equals the number leaving. This unit is somewhat historical, but appears on many measuring instruments.

• **Unit of equivalent dose** (for biological damage) = sievert [= 100 rem (**r**oentgen **e**quivalent for **m**an)]: Equivalent dose in Sv = absorbed dose in grays × w_R, where w_R (radiation weighting factor, formerly the quality factor Q) expresses long-term risk (primarily cancer and leukemia) from low-level chronic exposure. It depends upon the type of radiation and other factors, as follows [1]:

Table 13.1: Radiation weighting factors.

Radiation	w_R
X- and γ-rays, all energies	1
Electrons and muons, all energies	1
Neutrons < 10 keV	5
10–100 keV	10
> 100 keV to 2 MeV	20
2–20 MeV	10
> 20 MeV	5
Protons (other than recoils) > 2 MeV	5
Alphas, fission fragments, & heavy nuclei	20

• **Natural annual background**, all sources: Most world areas, whole-body equivalent dose rate ≈ (0.4–4) mSv (40–400 millirems). Can range up to 50 mSv (5 rems) in certain areas. U.S. average ≈ 3.6 mSv, including ≈ 2 mSv (≈ 200 mrem) from inhaled natural radioactivity, mostly radon and radon daughters (0.1–0.2 mSv in open areas. Average is for a typical house and varies by more than an order of magnitude. It can be more than two orders of magnitude higher in poorly ventilated mines).

• **Cosmic ray background** in counters (Earth's surface): ~ 1 min^{-1} cm^{-2} sr. For more accurate estimates and details, see the Cosmic Rays section (Sec. 14 of this *Review*.

• **Fluxes** (per cm^2) to deposit one Gy, assuming uniform irradiation:

≈ (**charged particles**) $6.24\times10^9/(dE/dx)$, where dE/dx (MeV g^{-1} cm^2), the energy loss per unit length, may be obtained from the Mean Range and Energy Loss figures.

≈ 3.5×10^9 cm^{-2} minimum-ionizing singly-charged particles in carbon.

≈ (**photons**) $6.24\times10^9/[Ef/\lambda]$, for photons of energy E (MeV), attenuation length λ (g cm^{-2}) (see Photon Attenuation Length figure), and fraction $f \lesssim 1$ expressing the fraction of the photon's energy deposited in a small volume of thickness $\ll \lambda$ but large enough to contain the secondary electrons.

≈ 2×10^{11} photons cm^{-2} for 1 MeV photons on carbon ($f \approx 1/2$).

(Quoted fluxes are good to about a factor of 2 for all materials.)

• **Recommended limits to exposure (whole-body dose):***

CERN: 15 mSv yr^{-1}

U.K.: 15 mSv yr^{-1}

U.S.: 50 mSv yr^{-1} (5 rem yr^{-1})†

• **Lethal dose**: Whole-body dose from penetrating ionizing radiation resulting in 50% mortality in 30 days (assuming no medical treatment) 2.5–3.0 Gy (250–300 rads), as measured internally on body longitudinal center line. Surface dose varies due to variable body attenuation and may be a strong function of energy.

For a recent review, see E. Pochin, *Nuclear Radiation: Risks and Benefits* (Clarendon Press, Oxford, 1983).

* The ICRP recomendation [1] is 20 mSv yr^{-1} averaged over 5 years, with the dose in any one year ≤ 50 mSv.

† Many laboratories in the U.S. and elsewhere set lower limits.

Reference:

1. ICRP Publication 60, *1990 Recommendation of the International Commission on Radiological Protection* Pergamon Press (1991).