Radiation units summary

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1 Radiation units

1.1 Activity

Activity is the number of radioactive events per second, typically given in becquerel (Bq) or curie (Ci). 1 Bq is defined as 1 event per second and 1 Ci is defined to be 37 GBq (approximately the activity of 1 g of ^{226}Ra):

$$\begin{aligned} 1\,\text{Bq} &= 1\,\text{events/s} \\ 1\,\text{Ci} &= 3.7 \times 10^{10}\,\text{events/s} \end{aligned}$$

$$1\,\text{Ci} = 37\,\text{GBq}$$

1.2 Absorbed dose

The dose a material receives is the energy it absorbs from a radioactive source per unit mass of the dosed material. Common units of absorbed dose are the gray (Gy) and rad, defined as follows:

$$\begin{aligned} 1\,\text{Gy} &= 1\,\text{J/kg} \\ 1\,\text{rad} &= 100\,\text{ergs/g} \end{aligned}$$

$$1\,\text{Gy} = 100\,\text{rads}$$

1.3 Exposure

Exposure characterizes the level of radioactivity in some area independently of the material the radiation is incident on, unlike absorbed dose. One exposure unit (X unit) is the quantity of X- or gamma radiation that ionizes 1 C of total charge in a kilogram of air. The more commonly used exposure unit is the roentgen (R), defined to ionize 1 statcoulomb of total charge in a cubic centimeter of standard air:

$$\begin{aligned} 1\,\text{X unit} &= 1\,\text{C/kg air} \\ 1\,\text{R} &= 1\,\text{SC/cm}^3\,\text{air} \end{aligned}$$

$$1\,\text{X unit} = 3881\,\text{R}$$

To convert between from exposure in R to absorbed dose in rads for a general material m, the exposure must be scaled by the ratio $0.877(\mu/\rho)_m/(\mu/\rho)_{air}$, as in Cember Eq. 6.12. Here μ is the energy absorption coefficient (the inverse of the absorption length) and ρ is the material density. In general, μ depends on the radiation type and energy.

1.4 Equivalent dose

Dose equivalent normalizes each type of radiation to its propensity to cause biological damage, or its relative biological effectiveness (RBE). It is computed as

$$\text{Dose equivalent H} = \text{absorbed dose D} \times \text{quality factor Q}.$$

Quality factors for different kinds of radiation can be found in Table 7.3 in Cember's Introduction to Health Physics. For x-rays, gamma rays, and beta rays, Q = 1; for alpha particles, Q = 20. The SI unit of equivalent dose is the sievert (Sv), defined to be the dose equivalent of 1 Gy for radiation with a quality factor Q = 1. The more common unit is the roentgen equivalent in man (rem), defined to be 0.01 Sv so that 1 roentgen deposits approximately 1 rem in human biological soft tissue:

$$\begin{aligned} 1\,\text{Sv} &= 1\,\text{Gy with Q} = 1 \\ 1\,\text{rem} &= 0.01\,\text{Sv} \\ \\ 1\,\text{rem} &\leftrightarrow 1\,\text{rad (x-rays)} \\ 1\,\text{rem} &\leftrightarrow 0.877\,\text{R (x-rays, air)} \end{aligned}$$

The last two lines convert rem (equivalent dose) to rad (absorbed dose) and roentgen (exposure), respectively.

1.5 Effective dose

Effective dose accounts for the nonuniform sensitivity of different parts of the body by including a weighting factor for each area according to Table 1 (taken from Table 8.1 in Cember).

The total effective dose is the weighted sum of local doses. When the entire body uniformly receives the same dose, the total effective dose reduces to the dose to each area of the body.

2 Occupational limits

Occupational limits are defined in terms of effective doses. Radiation attenuates as it penetrates the body, so the effective dose to each kind of tissue is computed for an appropriate attenuation length. The following categories are relevant:

Tissue	weight
Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surface	0.03
Remainder	0.30

Table 1: Tissue weighting factors

- Deep dose equivalent (DDE): dose equivalent at 1 cm penetration of soft tissue
- Lens dose equivalent (LDE): dose equivalent at 0.3 cm penetration into the eye
- Shallow dose equivalent (SDE): dose equivalent at 0.007 cm penetration (beneath dead skin)
- Total effective dose equivalent (TEDE): computed only from DDE in the case of no internal sources (e.g., from ingestion)

The annual occupational limits for radiation workers are as follows:

$$\begin{array}{rcl} \text{TEDE} & < & 5\,\text{rem} \\ \text{LDE} & < & 15\,\text{rem} \\ \text{DDE for any single tissue} & < & 50\,\text{rem} \\ \text{SDE for skin and each extremity} & < & 50\,\text{rem} \end{array}$$

The limit on total effective dose equivalent is smaller than the other limits because it incorporates the tissue weighting factors. For example, a deep dose equivalent of 50 rem to the thyroid is only an effective deep dose equivalent of $50\,\text{rem} \times 0.03 = 1.5\,\text{rem}$.

These limits are only to provide a general sense of scale; it is unacceptable for members of the ACME experiment to receive doses approaching the legal occupational limits. As another reference, the background level of radiation is approximately 300 mrem.