# Physics Recreations: Radiation Exposure

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## 1 Introduction

It is well known that exposure to radiation can adversely affect human health. In this paper we'll review several concepts involving radioactivity, radiation exposure, and the effect of radiation on human beings. This is part of a larger field called *health physics*.

## 2 Activity

*Activity* is a measure of the number of decays in a sample of radioactive material per unit time. The SI unit of activity is called the *becquerel* (Bq), and is equal to one radioactive decay per second.

Other units of activity are the *curie* (Ci; 1 Ci $= 3.7 \times 10^{10}$ Bq), and the *rutherford* (rd; 1 rd $= 10^6$ Bq).

## 3 Exposure

*Exposure* is a measure of the amount of ionizing radiation (such as X-rays or $\gamma$ rays). Historically the unit of measure of exposure is the *röntgen* (R), which is defined as the amount of ionizing radiation needed to produce 1 statcoulomb of positive and negative electric charge in 1 cubic centimeter of dry air. The corresponding SI unit is the coulomb per kilogram (C/kg), which is the amount of ionizing radiation needed to produce 1 coulomb of positive and negative charge in 1 kilogram of dry air. The conversion factor between the two units is 1 R $= 2.58 \times 10^{-4}$ C/kg.

## 4 Absorbed Dose

*Absorbed dose* is a measure of how much ionizing radiation energy is absorbed per unit mass of material (the "material" is usually human tissue). The SI unit is the *gray* (Gy), and is equal to the absorbtion of 1 joule of energy per kilogram of material.

Another unit of absorbed dose is the *rad*, which is equal to 0.01 Gy.

A *Geiger counter* is an instrument for measuring radiation rates, typically in units of mrad/hr. Multiplying the Geiger counter reading by the exposure time gives the total absorbed dose.

# 5 Dose Equivalent

*Dose equivalent* is a measure of the biological effect of radiation. The SI unit of dose equivalent is the *sievert* (Sv), and is equal to 1 joule of absorbed energy per kilogram of material.

Another unit of dose equivalent is the *rem* (which stands for "röntgen equivalent man"); 1 rem is equal to 0.01 Sv.

To compute the dose equivalent, we multiply the absorbed dose by a dimensionless *quality factor* $Q$, which accounts for how damaging a particular type of radiation is to human tissue. Mathematically,

$$\text{dose equivalent} = Q \times (\text{absorbed dose}). \tag{1}$$

Dimensionally, $\mathrm{Sv} = Q \times \mathrm{Gy}$, or $\mathrm{rem} = Q \times \mathrm{rad}$.

Table 1 gives some common quality factors for different types of radiation. For neutron radiation, the quality factor is a function of energy, as shown in Fig. 1.

The typical background level due to natural radiation is about 2.4 mSv. The effect of dose equivalents on humans for acute exposure (less than an hour or so) is summarized in Table 2.

If you find yourself in a radiation environment with a Geiger counter, you can multiply the Geiger counter reading $G$ (in mrad/hr) by the exposure time (in hours) to get the absorbed dose; converting this from mrad to grays and then multiplying by the quality factor $Q$ gives the dose equivalent in sieverts:

$$\text{dose equivalent} = G\,(\mathrm{mrad/hr}) \times t\,(\mathrm{hr}) \times (10^{-5}\,\mathrm{Gy/mrad}) \times Q. \tag{2}$$

(Changing the conversion factor to $10^{-3}$ rad/mrad would give the dose equivalent in *rems* instead.) Comparing the result with Table 2 then gives you an idea of how much danger you're in.

Table 1. Quality factors, $Q$.

| Radiation Type | $Q$ |
|---|---|
| X-, $\gamma$, or $\beta$ radiation | 1 |
| protons | 2 |
| protons (high-energy) | 10 |
| neutrons | (Fig. 1) |
| neutrons (unknown energy) | 10 |
| $\alpha$ radiation | 20 |

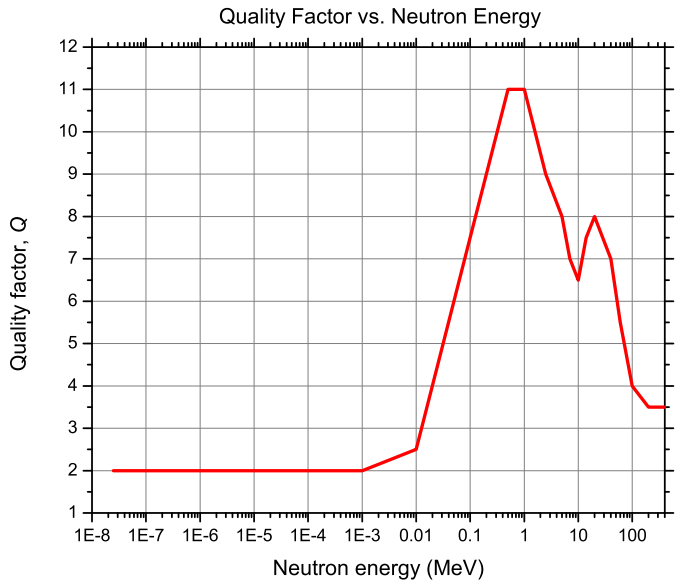


Figure 1: Quality factor for neutron radiation as a function of energy.

Table 2. Dose equivalent effects on humans (acute exposure).

| Dose Equivalent | | |
|---|---|---|
| Sv | rem | Effect |
| 1 | 100 | nausea |
| 2–5 | 200–500 | hair loss, hemorrhage, sometimes death |
| $> 3$ | $> 300$ | death in 50% of cases in 30 days |
| $> 6$ | $> 600$ | survival unlikely |