Radioactivity Units

U^{238} and its daughter ^{234}Th each contain about the same number of atoms per gram—approximately 2.5×10^{21}. Their half-lives, however, are greatly different; ^{238}U has a half-life of 4.5×10^9 years while ^{234}Th has a half-life of 24.1 days. Thorium^{234}, therefore, is transforming 6.8×10^{10} times faster than ^{238}U. When using radioactive material, the radiations are the center of interest. In this context, therefore, 15 mg of ^{234}Th is about equivalent in activity to 1 g of ^{238}U. These examples show that when interest is centered on radioactivity, the gram is not a very useful unit of quantity. To be meaningful, the unit for quantity of must be based on the number of radioactive decays occurring within a prescribed time in the radioactive material. This quantity—the number of decays within a given time-is called the activity.

- Two units for measuring the activity are used. The SI unit is called the Becquerel, symbolized by Bq, and is defined as follows:
- 1-The becquerel is that quantity of radioactive material in which one atom is transformed per second (tps).
- 1 Bq = 1 tps = 1 dps.
- 2-The curie, symbolized by Ci, is the unit for quantity of radioactivity that was used before the adoption of the SI units and the becquerel. The curie, which originally was defined as the activity of 1 g of ^{226}Ra, is now more explicitly defined as : the activity of that quantity of radioactive material in which 3.7×10^{10} atoms are transformed in one second.The curie is related to the becquerel by
- 1 Ci = 3.7×10^{10} Bq.

Specific Activity

- We note that the becquerel (or curie) used as a unit of quantity, does not
- imply anything about the mass or volume of the radioactive material in which the specified number of transformations occur. The concentration of radioactivity, or
- the relationship between the mass of radioactive material and the activity, is called the specific activity. Specific activity is the number of becquerels (or curies) per unit mass or volume. The specific activity of a carrier-free (pure) radioisotope-a radioisotope that is not mixed with any other isotope of the same element-may be calculated as
- follows:
- If λ is the transformation constant in units of reciprocal seconds, then the number of transformations per second and, hence, the number of becquerels in an aggregation of N atoms, is simply given by λN.
- If the radionuclide under consideration weighs 1 g, then, according to Eq below the number of atoms is given by

$$N = \frac{6.02\ X 10^{23}\ atom/mol}{A\ g/mol}\ X\ W.g$$

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- by using the relationship between the specific activity and weight of an isotope in terms of the isotope's half-life .
- Prove the specific activity is :SA= λN.

$$SA = \frac{4.18\times 10^{23}}{A\times T} --------(a)$$

Note that Eq. (a) is valid only if *T are given in time units* of seconds. A more convenient form for calculating specific activity may be derived by making use of the fact that there are 3.7 × 10^{10} tps in 1 g of ^{226}Ra. The specific activity, therefore, of ^{226}Ra is 3.7 × 10^{10} Bq/g. The ratio of the specific activity of any radionuclide, SA_i, to that of ^{226}Ra is

,

$$\frac{SA_i}{3.7\times 10^{10}\ \frac{Bq}{g}} = \left(\frac{4.18\times 10^{23}\ A_i \times T_i}{4.18\times 10^{23}\ A_{Ra}\times T_{Ra}}\right)$$

$$SA_i = 3.7\times 10^{10}\ \frac{A_{Ra}\times T_{Ra}}{A_i \times T_i}\ \frac{Bq}{g}$$

where A_{Ra}, the atomic weight of ^{226}Ra, is 226, A_i is the atomic weight of the radioisotope whose specific activity is being calculated, and T_{Ra} and Ti are the half-lives of the radium (1600 year) and the radionuclide i.

- H.W: A solution of Hg(NO3)2 tagged with 203Hg has a specific activity of 1.5×10^5 Bq/mL. If the concentration of mercury in the solution is 5
- mg/mL.
- (a) what is the specific activity of the mercury Hg?
- (b) what fraction of the mercury in the $Hg(NO_3)_2$ is ^{203}Hg?
- Hint : 5.8×10^{-8}

H.W: If 2 g of carbon from a piece of wood found in an ancient temple is analyzed and found to have an activity of 10 transformations/minute/gram, what is the age of the wood if the current specific activity of ^{14}C in carbon is assumed to have been constant at 15 transformations/minute/gram?

Hint: the half-life for 14C is 5730 years (**a**) The specific activity of the mercury is

and the speci

$$SA(\text{Hg}) = \frac{1.5 \times 10^5 \text{ Bq/mL}}{5 \text{ mg Hg/mL}} = 0.3 \times 10^5 \frac{\text{Bq}}{\text{mg}} \text{ Hg}.$$

$SA(^{203}\text{Hg})$ (**b**) The weight-fraction of mercury that is tagged is given by

$$\frac{SA(\text{Hg})}{SA(^{203}\text{Hg})},$$

The weight fr

$$\frac{0.3 \times 10^8 \text{ Bq/g Hg}}{5.2 \times 10^{14} \text{ Bq/g } ^{203}\text{Hg}} = 5.8 \times 10^{-8} \text{ g Hg}$$

Solution

The fraction of the original ^{14}C remaining today is, according to Eq. (4.18),

$$\frac{A}{A_0} = \frac{10}{15} = e^{-\lambda t}.$$

Since the half-life for ^{14}C is 5730 years

$$\lambda = \frac{0.693}{5730 \text{ years}} = 1.21 \times 10^{-4} \frac{1}{\text{yr}}$$

$$\frac{10}{15} = e^{-1.21 \times 10^{-4} t}$$

$$t = 3.35 \times 10^3 \text{ years}.$$

Units of Radiation Exposure

Roentgen (R)

The roentgen is a unit used to measure a quantity called exposure. This can only be used to describe an amount of gamma and X-rays, and only in air. One roentgen is equal to depositing in dry air enough energy to cause 2.58E-4 coulombs per kg.

Rad (radiation absorbed dose)

The rad is a unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. One rad is defined as the absorption of 100 ergs per gram of material. The unit rad can be used for any type of radiation, but it does not describe the biological effects of the different radiations.

Rem (roentgen equivalent man)

The rem is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of thousandths of a rem, or mrem. To determine equivalent dose (rem), you multiply absorbed dose (rad) by a quality factor (Q) that is unique to the type of incident radiation.

RAD Units

Quantity	Name	Symbol	SI Unit
Exposure	roentgen	R	air kerma (Gya) C/kg
Absorbed Dose	rad	rad	gray (Gy1)
Effective Dose	rem	rem	seivert (Sv)
Radioactivity	curie	Ci	becquerel (Bq)

Calculating SI units

R x 0.01 = Gya

rad x 0.01 = Gy1

rem x 0.01 = Sv

Ci x 3.7 x10^{10} = Bq

R = 2.58 x 10^{-4} = C/kg

Naturally Occurring Radiation

- There are three sources for naturally occurring sources of radiation

1-The oldest source is cosmic radiation, which is believed to have originated at the birth of the universe, about 13–14 billion years ago.

2-A second source is from primordial radioactive elements that were created when the earth was born about 4.5 billion years ago.

3-A third source of naturally occurring radioactivity and radiation is cosmogenic radioactivity. The production of cosmogenic radioactivity is an ongoing process as cosmic radiation interacts with the atmosphere to produce radionuclides.

4- Another transient source of radioactivity was a naturally occurring nuclear reactor for example Oklo reactor.

Serial Transformation

- They were members of a long series of isotopes of various elements,

- Uranium, the most abundant of the radioactive elements in this mixture, consists of three different isotopes: about 99.3% of naturally occurring uranium is ^{238}U, about 0.7% is ^{235}U, and a trace quantity (about 5×10^{-3} %) is ^{234}U. The ^{238}U and ^{234}U belong to one family, the uranium series, while the ^{235}U isotope of uranium is the first member of another series called the actinium series. Uranium is ubiquitous in the natural environment and is found in the soil at average concentrations of about 3 ppm (parts per million) by weight, which corresponds to =74 mBq/g soil.
- Uranium forms extremely stable compounds with phosphorous. Phosphate-rich soil, therefore, contains uranium at concentrations much higher than average, from about 7 ppm to about 125 ppm Medium-grade uranium ore contains about 1000–5000 ppm uranium, while the uranium concentration in high-grade ore is about 10,000–40,000 ppm.

- Thorium, another ubiquitous naturally occurring radioactive element, is about 4 times more abundant in nature than uranium. The most abundant thorium isotope, ^{232}Th, is the first member of still another long chain of successive radionuclides.
- A third common characteristic among the three natural radioactive series is lead. In the case of the uranium series ^{206}Pb; in the actinium series, it is ^{207}Pb; and in the thorium series, it is ^{208}Pb.
- The artificial neptunium series differs in this characteristic too from the natural series; the terminal member is stable bismuth, ^{209}Bi.
- In addition to the four chains of radioactive isotopes described above, a number of other groups of sequentially transforming isotopes are important to the health physicist and radiobiologist. Most of these series are associated with nuclear fission,

Secular Equilibrium

The quantitative relationship between radionuclides in secular equilibrium may be derived in the following manner:

$^{90}_{36}Kr$ 33s$\rightarrow$ $^{90}_{37}Rb$ 2.74min$\rightarrow$ $^{90}_{38}Sr$ 28.8 yr $\rightarrow$ $^{90}_{39}Y$ 64.2hr$\rightarrow$ $^{90}_{40}Zr$

$$A \xrightarrow{\lambda_A} B \xrightarrow{\lambda_B} C$$

where the half-life of isotope A is very much greater than that of isotope B. The decay constant of A, λ_A, is therefore much smaller than λ_B, the decay constant for B. C is stable and is not transformed. Because of the very long half-life of A relative to B, the rate of formation of B may be considered to be constant and equal to K. Under these conditions, the net rate of change of isotope B with respect to time, if NB is the number of atoms of B in existence at any time t after an initial number, is given by

Rate of change = Rate of formation − Rate of transformation, that

$$\frac{dN_B}{dt} = K - \lambda_B N_B$$

Interaction of Radiation with Matter

In order for health physicists to understand the physical basis for radiation dosimetry and the theory of radiation shielding, they must understand the mechanisms by which the various radiations interact with matter
the several radiations, depends on the type and energy of the radiation as well as on the nature of the absorbing medium.

Beta Particles (beta rays)
Range–Energy Relationship

The attenuation of beta particles (beta rays is used synonymously with beta particles) by any given absorber may be measured by interposing successively thicker absorbers between a beta source and a suitable beta detector, such as a Geiger–Muller counter(Fig. 1), and counting the beta particles that penetrate the absorbers. When this is done with a pure beta emitter, it is found that the beta-particle counting rate decreases rapidly at first, and then, as the absorber thickness increases, it decreases slowly. Eventually, a thickness of absorber is reached that stops all the beta particles; the Geiger counter then registers only background counts due to environmental radiation. If semilog paper is used to plot the data and the counting rate is plotted on the logarithmic axis while absorber thickness is plotted on the linear axis, the data approximate a straight line, as shown in Figure 2.

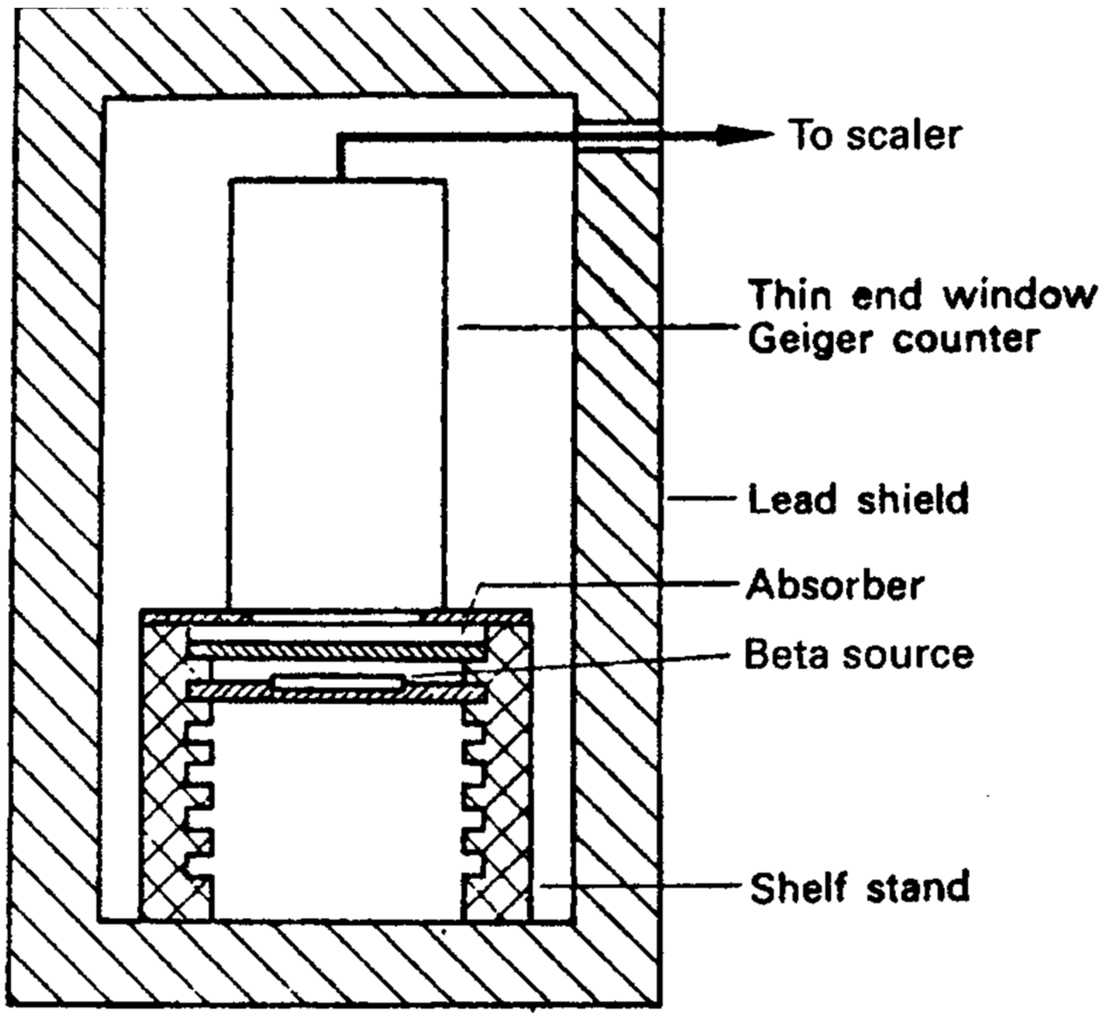

Figure 1. Experimental arrangement for absorption measurements on beta particles

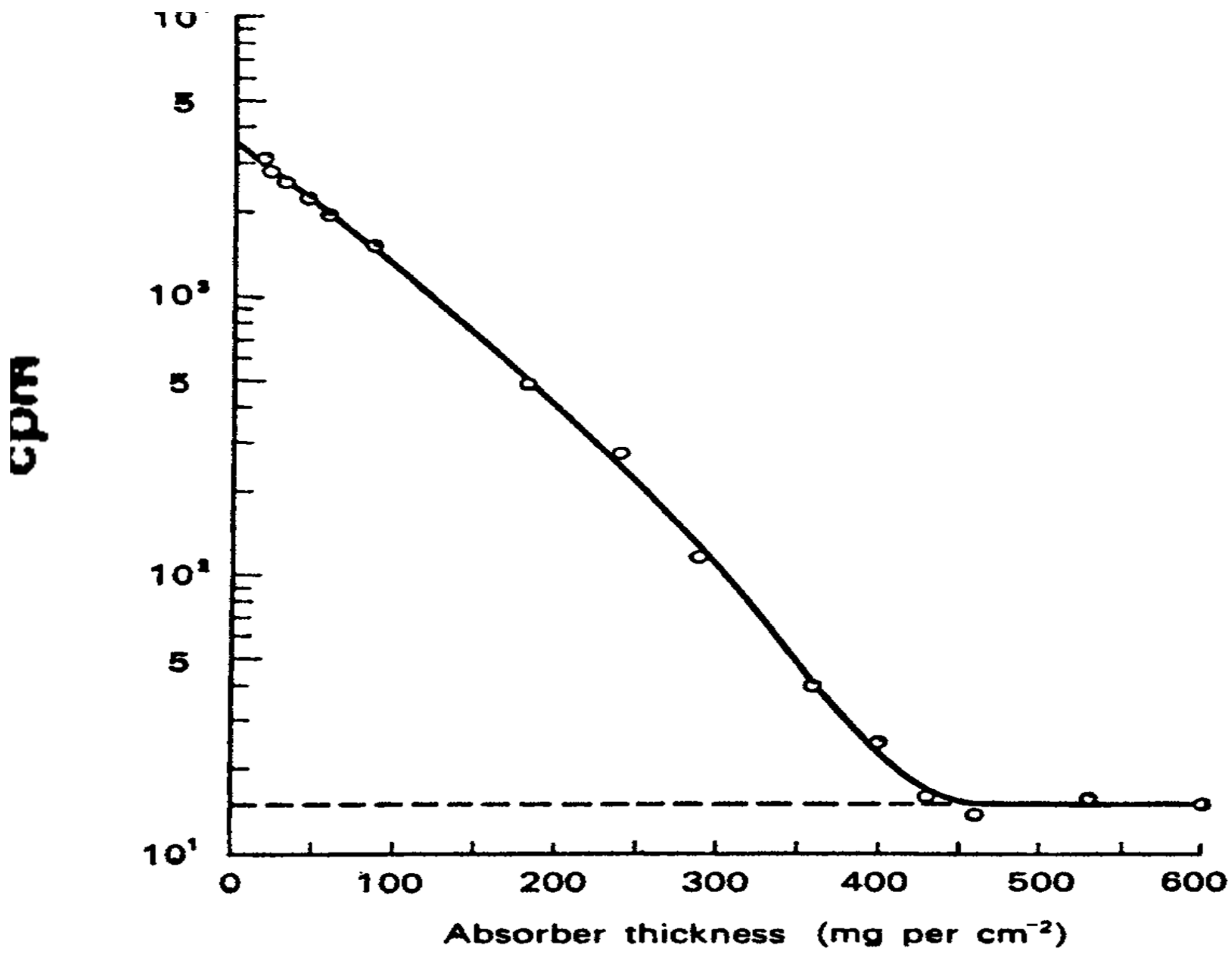

Figure 2: Absorption curve (aluminum absorbers) of ^{210}Bi beta particles, 1.17 MeV.

The endpoint in the absorption curve, where no further decrease in the counting rate is observed, is called the *range* of the beta in the material of which the absorbers are made., a useful relationship is that the absorber half thickness (that thickness of absorber which stops one-half of the beta particles) is about one-eighth the range of the beta. Since the maximum beta energies for the various isotopes are known, by measuring the beta ranges in different absorbers, the systematic relationship between range and energy shown in Figure 3 is established. Inspection of Figure 3 shows that the required thickness of absorber for any given beta energy decreases as the density of the absorber increases. Detailed analyses of experimental data show that the ability to absorb energy from beta particles depends mainly on the number of absorbing electrons in the path of the beta—that is, on the areal density (electrons/cm^2) of electrons in the absorber, and, to a much lesser degree, on the atomic number of the absorber. For practical purposes, therefore, in the calculation of shielding thickness against beta particles, the effect of atomic number is neglected. (It should be pointed out that, for reasons to be given later, beta shields are almost always made from low-atomic-numbered materials.) Areal density of electrons is approximately proportional to the product of the density of the absorber material and the linear thickness of the absorber, thus giving rise to the unit of thickness called the *density thickness*. Mathematically, density thickness

$$t_d \, g/cm^2 = \rho \, g/cm^3 \times t_l \, cm. \text{---------} (w)$$

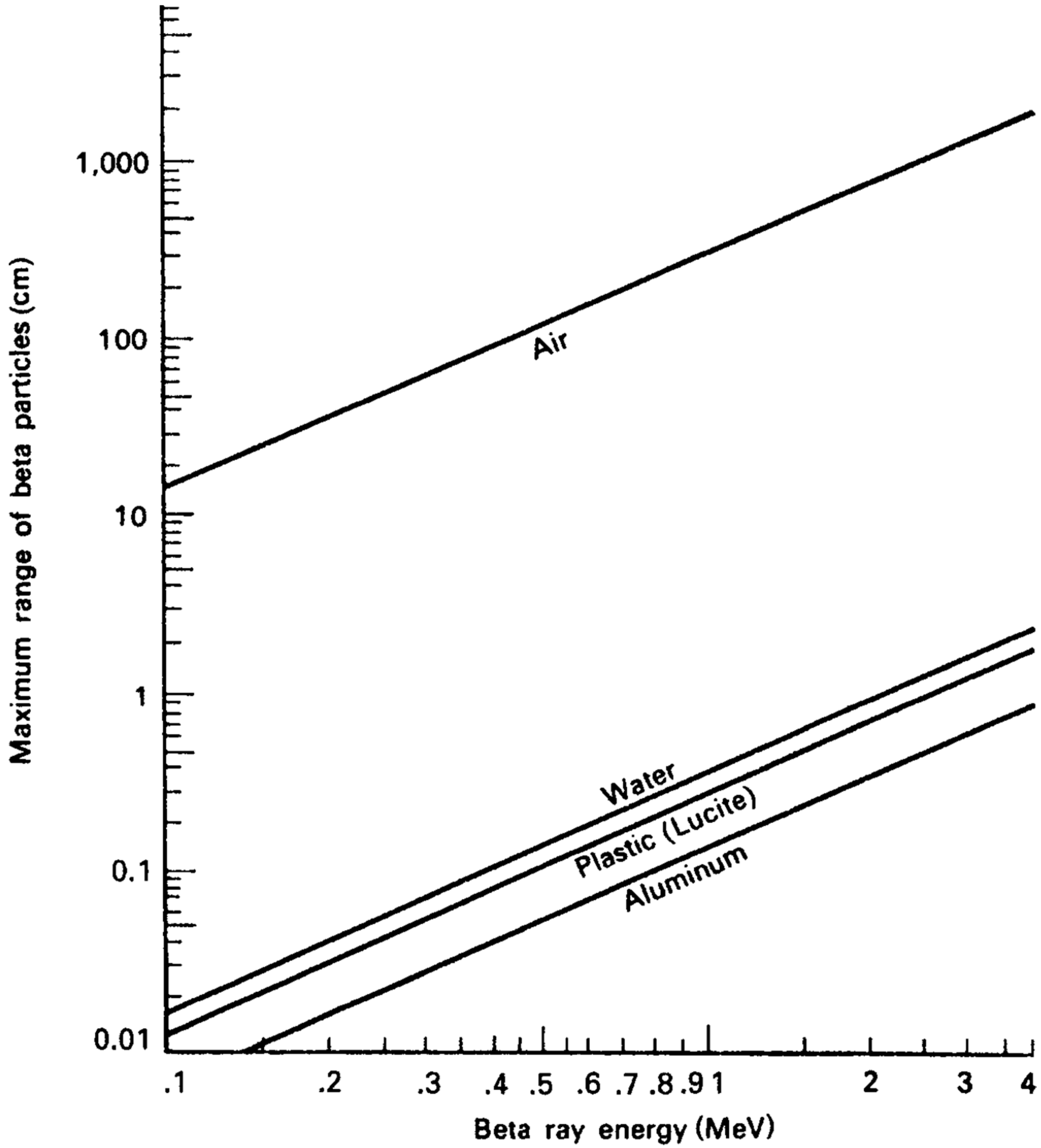

Figure 3. Range–energy curves for beta particles in various substances. (Adapted from Radiological Health Handbook. Washington, DC: Office of Technical Services; 1960.)

If a sheet of Plexiglas whose density is 1.18 g/cm^3 is to have a beta absorbing quality very nearly equal to that of the 1-cm-thick sheet of aluminum-that is, 2.7 g/cm^2-its linear thickness is found, from Eq. (w), to be

$$t_1 = t_d/\rho = 2.7 g/cm^2 / 1.8 g/cm^3 \quad = 2.39 \text{ cm.}$$

The quantitative relationship between beta energy and range is given by the following experimentally determined empirical equations:

$$E = 1.92R^{0.725} \qquad R \leq 0.3 \text{ g/cm}^2 \qquad \text{(a)}$$

$$R = 0.407E^{1.38} \qquad E \leq 0.8\text{MeV} \qquad \text{(b)}$$

$$E = 1.85R + 0.245 \qquad R \geq 0.3 \text{ g/cm2} \qquad \text{(c)}$$

$$R = 0.542E - 0.133 \qquad E \geq 0.8\text{MeV} \qquad \text{(d)}$$

where

R = range, g/cm^2 and

E = maximum beta energy, MeV.

An experimentally determined curve of beta range (in units of density thickness expressed as mg/cm^2) versus energy is given in Figure 4.

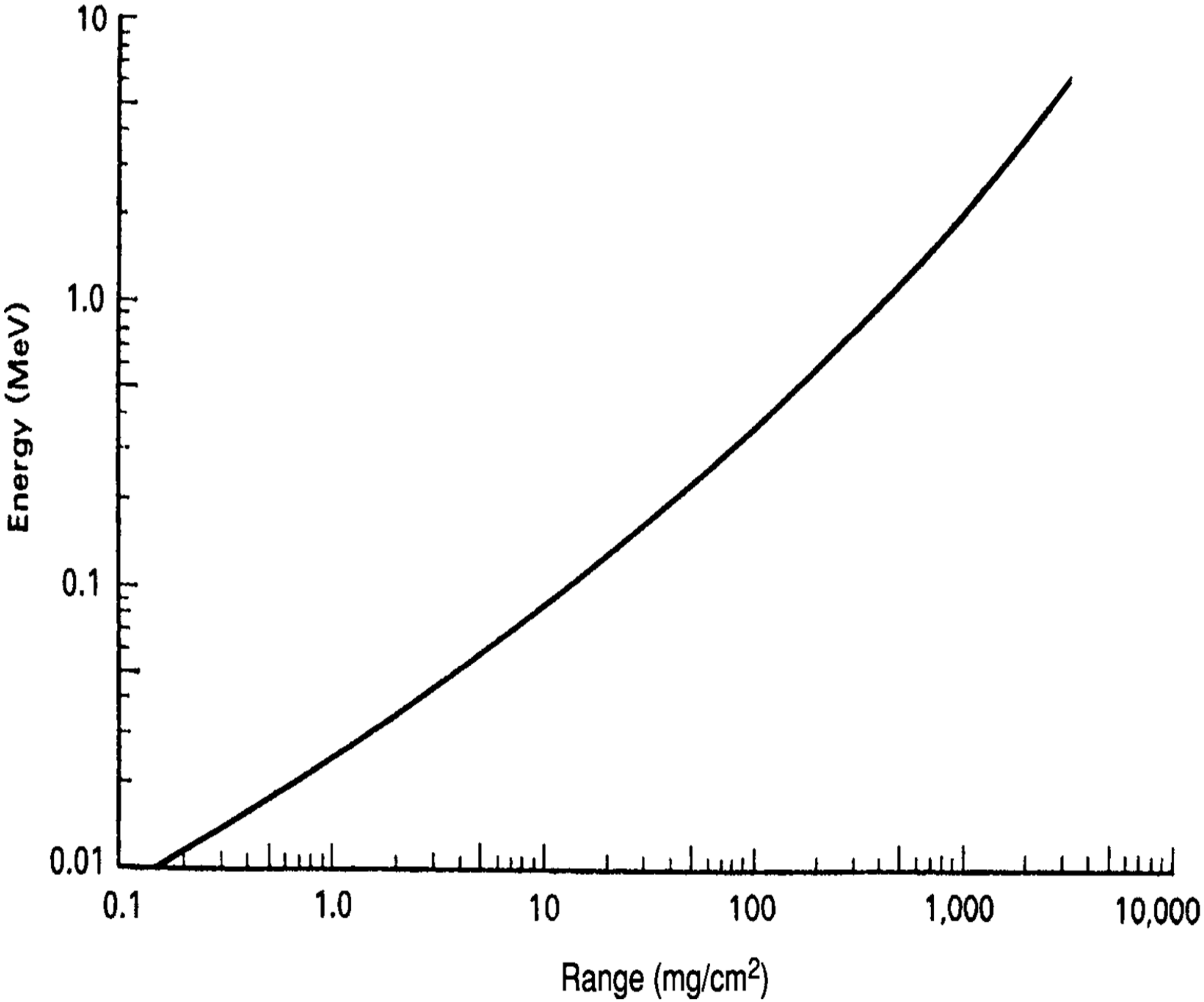

Figure 4. Range–energy curve for beta particles and for monoenergetic electrons. (Adapted from Radiological Health Handbook. Washington, DC: Office of Technical Services; 1960.)