Chapter 31
Nuclear Energy; Effects and Uses of Radiation

31-4 Passage of Radiation Through Matter; Radiation Damage

Radiation includes alpha, beta, and gamma rays; X rays; and protons, neutrons, pions, and other particles.

All these forms of radiation are called ionizing radiation, because they ionize material that they go through.

This ionization can cause damage to materials, including biological tissue.

31-5 Measurement of Radiation—Dosimetry

Radiation damages biological tissue, but it can also be used to treat cancer and other diseases.

It is important to be able to measure the amount, or dose, of radiation received. The source activity is the number of disintegrations per second, often measured in curies, Ci.

$$1\ \text{Ci} = 3.70 \times 10^{10}\ \text{disintegrations per second}$$

The SI unit for source activity is the becquerel (Bq):

$$1\ \text{Bq} = 1\ \text{disintegration/s}$$

31-5 Measurement of Radiation—Dosimetry

Another measurement is the absorbed dose—the effect the radiation has on the absorbing material.

The rad, a unit of dosage, is the amount of radiation that deposits energy at a rate of 1.00×10^{-2} J/kg in any material.

The SI unit for dose is the gray, Gy:

$$1\ \text{Gy} = 1\ \text{J/kg} = 100\ \text{rad}$$

EXAMPLE 31–10 **Radioactivity taken up by cells.** In a certain experiment, 0.016 μCi of ${}^{32}_{15}\mathrm{P}$ is injected into a medium containing a culture of bacteria. After 1.0 h the cells are washed and a 70% efficient detector (counts 70% of emitted β rays) records 720 counts per minute from the cells. What percentage of the original ${}^{32}_{15}\mathrm{P}$ was taken up by the cells?

31-5 Measurement of Radiation—Dosimetry

TABLE 31–1 Relative Biological Effectiveness (RBE)

Type	RBE
X- and γ rays	1
β (electrons)	1
Protons	2
Slow neutrons	5
Fast neutrons	≈ 10
α particles and heavy ions	≈ 20

The effect on tissue of different types of radiation varies, alpha rays being the most damaging. To get the effective dose, the dose is multiplied by the relative biological effectiveness.

31-5 Measurement of Radiation—Dosimetry

If the dose is measured in rad, the effective dose is in rem; if the dose is grays, the effective dose is in sieverts, Sv.

Natural background radiation is about 0.3 rem per year. The maximum for radiation workers is 5 rem in any one year, and below 2 rem per year averaged over 5 years.

A short dose of 1000 rem is almost always fatal; a short dose of 400 rem has about a 50% fatality rate.

38. (I) 350 rads of α-particle radiation is equivalent to how many rads of X-rays in terms of biological damage?

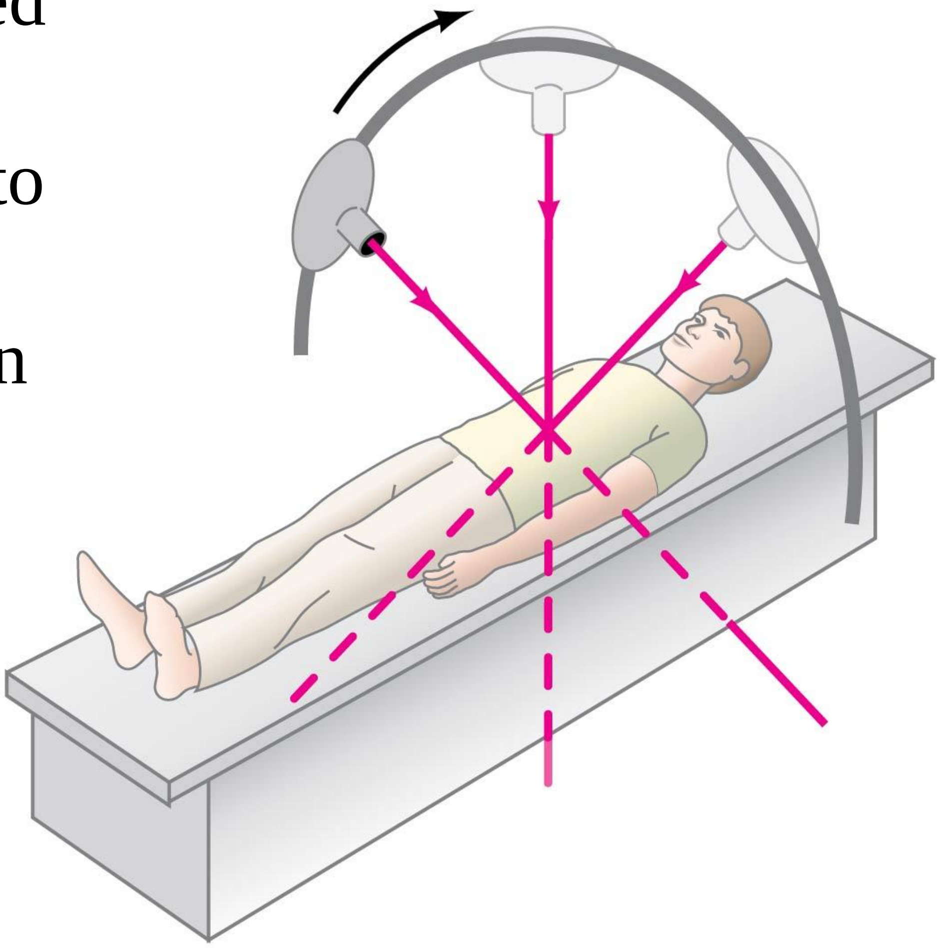
40. (II) How much energy is deposited in the body of a 65-kg adult exposed to a 2.5-Gy dose?

EXAMPLE 31–12 **Whole-body dose.** What whole-body dose is received by a 70-kg laboratory worker exposed to a 40-mCi $^{60}_{27}\mathrm{Co}$ source, assuming the person's body has cross-sectional area 1.5 m^2 and is normally about 4.0 m from the source for 4.0 h per day? $^{60}_{27}\mathrm{Co}$ emits γ rays of energy 1.33 MeV and 1.17 MeV in quick succession. Approximately 50% of the γ rays interact in the body and deposit all their energy. (The rest pass through.)

EXAMPLE 31–13 **Radon exposure.** In the U.S., yearly deaths from radon exposure (the second leading cause of lung cancer) are estimated to be on the order of 20,000 and maybe much more. The Environmental Protection Agency recommends taking action to reduce the radon concentration in living areas if it exceeds 4 pCi/L of air. In some areas 50% of houses exceed this level from naturally occurring radon in the soil. Estimate (*a*) the number of decays/s in $1.0\ m^3$ of air and (*b*) the mass of radon that emits 4.0 pCi of $^{222}_{86}Rn$ radiation.

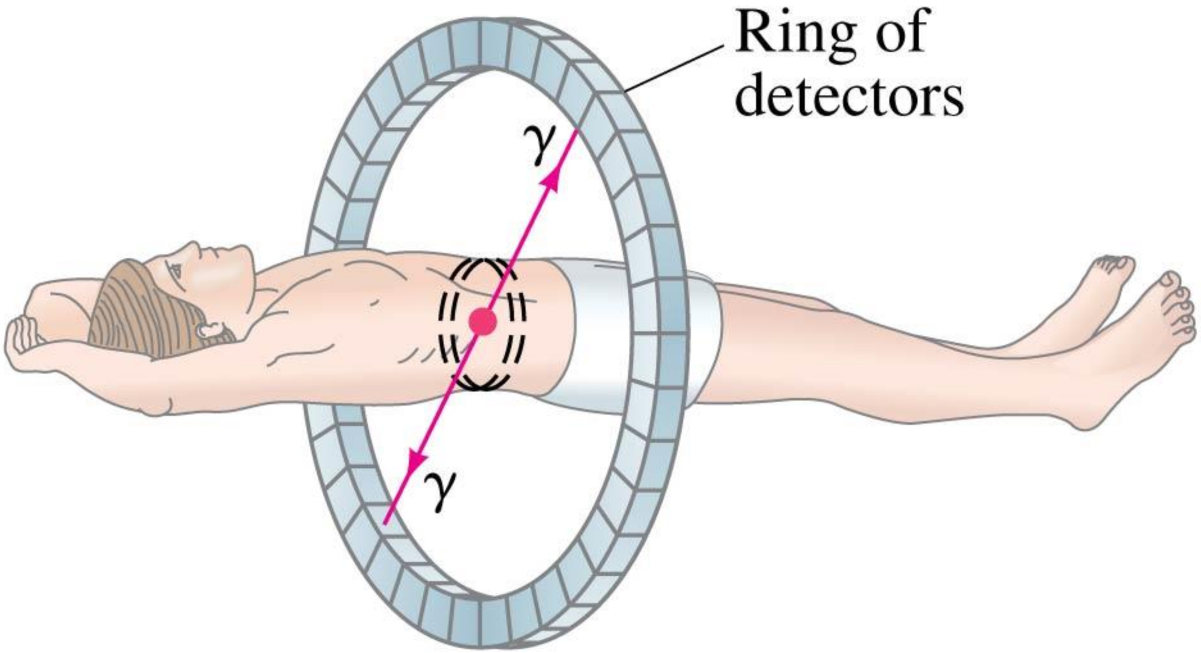
31-6 Radiation Therapy

Cancer is sometimes treated with radiation therapy to destroy the cells. In order to minimize the damage to healthy tissue, the radiation source is often rotated so it goes through different parts of the body on its way to the tumor.



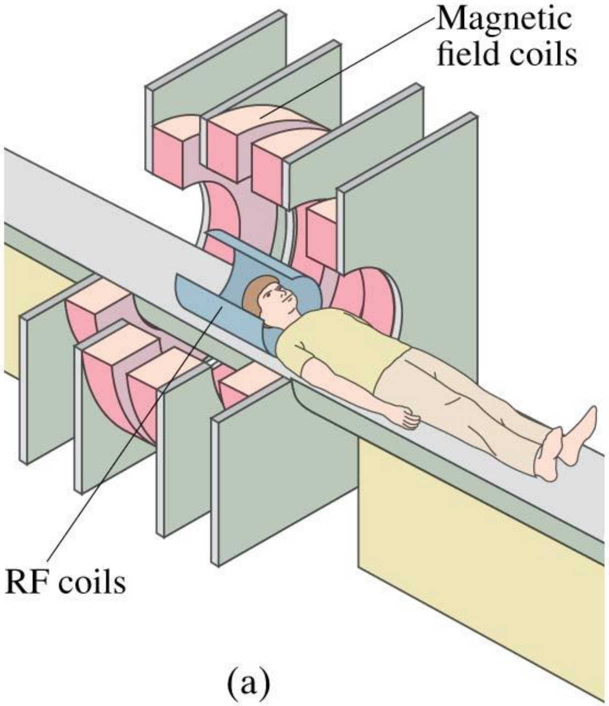
31-8 Emission Tomography: PET and SPECT

Radioactive tracers can also be detected using tomographic techniques, where a three-dimensional image is gradually built up through successive scans.



31-9 Nuclear Magnetic Resonance (NMR) and Magnetic Resonance Imaging (MRI)

The object to be examined is placed in a static magnetic field, and radio frequency (RF) electromagnetic radiation is applied.



(a)

(b)

41. (II) A cancer patient is undergoing radiation therapy in which protons with an energy of 1.2 MeV are incident on a 0.20-kg tumor. (*a*) If the patient receives an effective dose of 1.0 rem, what is the absorbed dose? (*b*) How many protons are absorbed by the tumor? Assume RBE ≈ 1.

44. (II) A 1.6-mCi source of $^{32}_{15}P$ (in $NaHPO_4$), a β emitter, is implanted in a tumor where it is to administer 32 Gy. The half-life of $^{32}_{15}P$ is 14.3 days, and 1.0 mCi delivers about 10 mGy/min. Approximately how long should the source remain implanted?

46. (II) $^{57}_{27}Co$ emits 122-keV γ rays. If a 65-kg person swallowed 1.55 μCi of $^{57}_{27}Co$, what would be the dose rate (Gy/day) averaged over the whole body? Assume that 50% of the γ-ray energy is deposited in the body. [*Hint*: Determine the rate of energy deposited in the body and use the definition of the gray.]