dose is important. A short dose of 1000 rem (10 Sv) is nearly always fatal. A 400-rem (4-Sv) dose in a short period of time is fatal in 50% of the cases. However, the body possesses remarkable repair processes, so that a 400-rem dose spread over several weeks is not usually fatal. It will, nonetheless, cause considerable damage to the body.

The effects of low doses over a long time are difficult to determine and are not well known as yet.

CONCEPTUAL EXAMPLE 31–11 **Limiting the dose.** A worker in an environment with a radioactive source is warned that she is accumulating a dose too quickly and will have to lower her exposure by a factor of ten to continue working for the rest of the year. If the worker is able to work farther away from the source, how much farther away is necessary?

RESPONSE If the energy is radiated uniformly in all directions, then the intensity (dose/area) should decrease as the distance squared, just as it does for sound and light. If she can work four times farther away, the exposure lowers by a factor of sixteen, enough to make her safe.

EXAMPLE 31–12 **Whole-body dose.** What whole-body dose is received by a 70-kg laboratory worker exposed to a 40-mCi ${}^{60}_{27}\text{Co}$ 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? ${}^{60}_{27}\text{Co}$ 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.)

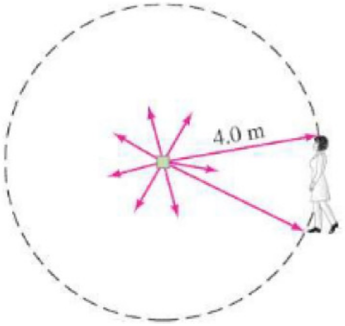

FIGURE 31–14 Radiation spreads out in all directions. A person 4.0 m away intercepts only a fraction: her cross-sectional area divided by the area of a sphere of radius 4.0 m. Example 31–12.

APPROACH Of the given energy emitted, only a fraction passes through the worker, equal to *her* area divided by the total area over a full sphere of radius 4.0 m (Fig. 31–14).

SOLUTION The total γ-ray energy per decay is $(1.33 + 1.17)\,\text{MeV} = 2.50\,\text{MeV}$, so the total energy emitted by the source per second is

$$(0.040\,\text{Ci})(3.7 \times 10^{10}\,\text{decays/Ci}\cdot\text{s})(2.50\,\text{MeV}) = 3.7 \times 10^{9}\,\text{MeV/s}.$$

The proportion of this intercepted by the body is its 1.5-m^2 area divided by the area of a sphere of radius 4.0 m (Fig. 31–14):

$$\frac{1.5\,\text{m}^2}{4\pi r^2} = \frac{1.5\,\text{m}^2}{4\pi(4.0\,\text{m})^2} = 7.5 \times 10^{-3}.$$

So the rate energy is deposited in the body (remembering that only 50% of the γ rays interact in the body) is

$$\begin{aligned} E &= \left(\tfrac{1}{2}\right)(7.5 \times 10^{-3})(3.7 \times 10^{9}\,\text{MeV/s})(1.6 \times 10^{-13}\,\text{J/MeV}) \\ &= 2.2 \times 10^{-6}\,\text{J/s}. \end{aligned}$$

Since $1\,\text{Gy} = 1\,\text{J/kg}$, the whole-body dose rate for this 70-kg person is $(2.2 \times 10^{-6}\,\text{J/s})/(70\,\text{kg}) = 3.1 \times 10^{-8}\,\text{Gy/s}$. In the space of 4.0 h, this amounts to a dose of

$$(4.0\,\text{h})(3600\,\text{s/h})(3.1 \times 10^{-8}\,\text{Gy/s}) = 4.5 \times 10^{-4}\,\text{Gy}.$$

Since QF $\approx$ 1 for gammas, the effective dose (Eq. 31–10b) is 450 μSv or (see Eq. 31–9):

$$(100\,\text{rad/Gy})(4.5 \times 10^{-4}\,\text{Gy})(1) = 45\,\text{mrem} = 0.45\,\text{mSv}.$$

NOTE This 45-mrem effective dose is almost 50% of the normal allowed dose for a whole year (100 mrem/yr), or 1% of the maximum one year allowance for radiation workers. This worker should not receive such a dose every day and should seek ways to reduce it (shield the source, vary the work, work farther away, etc.).