**FIGURE 31–8** Devastation around Chernobyl in Russia, after the nuclear power plant disaster in 1986.

The accidents at Three Mile Island, Pennsylvania (1979), and at Chernobyl, Russia (1986), have illustrated some of the dangers and have shown that nuclear plants must be constructed, maintained, and operated with great care and precision (Fig. 31–8). Finally, the lifetime of nuclear power plants is limited to 30-some years, due to buildup of radioactivity and the fact that the structural materials themselves are weakened by the intense conditions inside. "Decommissioning" of a power plant could take a number of forms, but the cost of any method of decommissioning a large plant is very great.

So-called **breeder reactors** were proposed as a solution to the problem of limited supplies of fissionable uranium. A breeder reactor is one in which some of the neutrons produced in the fission of $^{235}_{92}U$ are absorbed by $^{238}_{92}U$, and $^{239}_{94}Pu$ is produced via the set of reactions shown in Fig. 31–1. $^{239}_{94}Pu$ is fissionable with slow neutrons, so after separation it can be used as a fuel in a nuclear reactor. Thus a breeder reactor "breeds" new fuel† $\left(^{239}_{94}Pu\right)$ from otherwise useless $^{238}_{92}U$. Since natural uranium is 99.3 percent $^{238}_{92}U$, this means that the supply of fissionable fuel could be increased by more than a factor of 100. But breeder reactors have the same problems as other reactors, plus other serious problems. Not only is plutonium considered to be a serious health hazard in itself (radioactive with a half-life of 24,000 years), but plutonium produced in a reactor can readily be used in a bomb, increasing the danger of nuclear proliferation and theft of fuel by terrorists to produce a bomb.

Nuclear power presents risks. Other large-scale energy-conversion methods, such as conventional oil and coal-burning steam plants, also present health and environmental hazards; some of them were discussed in Section 15–12, including air pollution, oil spills, and the release of $CO_2$ gas which can trap heat as in a greenhouse to raise the Earth's temperature. The solution to the world's needs for energy is not only technological, but economic and political as well. A major factor surely is to "conserve"—to not waste energy and use as little as possible. "Reduce, reuse, recycle."

**EXAMPLE 31–5** **Uranium fuel amount.** Estimate the minimum amount of $^{235}_{92}U$ that needs to undergo fission in order to run a 1000-MW power reactor per year of continuous operation. Assume an efficiency (Chapter 15) of about 33%.

**APPROACH** At 33% efficiency, we need $3 \times 1000\,\text{MW} = 3000 \times 10^6\,\text{J/s}$ input. Each fission releases about 200 MeV (Eq. 31–5), so we divide the energy for a year by 200 MeV to get the number of fissions needed per year. Then we multiply by the mass of one uranium atom.

**SOLUTION** For 1000 MW output, the total power generation needs to be 3000 MW, of which 2000 MW is dumped as "waste" heat. Thus the total energy release in 1 yr ($3 \times 10^7$ s) from fission needs to be about

$$\left(3 \times 10^9\,\text{J/s}\right)\left(3 \times 10^7\,\text{s}\right) \approx 10^{17}\,\text{J}.$$

If each fission releases 200 MeV of energy, the number of fissions required is

$$\frac{\left(10^{17}\,\text{J}\right)}{\left(2 \times 10^8\,\text{eV/fission}\right)\left(1.6 \times 10^{-19}\,\text{J/eV}\right)} \approx 3 \times 10^{27}\ \text{fissions}.$$

The mass of a single uranium atom is about $(235\,\text{u})\left(1.66 \times 10^{-27}\,\text{kg/u}\right) \approx 4 \times 10^{-25}\,\text{kg}$, so the total uranium mass needed is

$$\left(4 \times 10^{-25}\,\text{kg/fission}\right)\left(3 \times 10^{27}\ \text{fissions}\right) \approx 1000\,\text{kg},$$

or about a ton.

**NOTE** Since $^{235}_{92}U$ makes up only 0.7% of natural uranium, the yearly requirement for uranium is on the order of a hundred tons. This is orders of magnitude less than coal, both in mass and volume (coal releases $2.8 \times 10^7\,\text{J/kg}$).

† A breeder reactor does *not* produce more fuel than it uses.