"Physics & Technology for Future Presidents" by Richard Muller

answer. As I said earlier, each fission of U-235 produces about 200 MeV of energy. Let's convert that to joules (J). 1 eV = 1.6×10^{-19} J, so 200 MeV = 20 0 $\times 10^6 \times 1.6 \times 10^{-19} \approx 3 \times 10^{-11}$ J.

How many do we need for a gigawatt-year of energy? A year[33] is 3×10^7 sec. A gigawatt is 10^9 J/s. So the number of joules in one year is $E = 10^9 \times 3 \times 10^7 = 3 \times 10^{16}$ J.

So the number of fissions needed N is the energy needed divided by the energy per fission: $N = (3 \times 10^{16}$ J$)/(3 \times 10^{-11}$ J per fission$) = 10^{27}$ fissions. So we need 10^{27} atoms of U-235 to produce a gigawatt for a year.

We assumed that all of the energy goes into electric power. But that isn't true—only about a third does. So we really need 3×10^{27} U-235 atoms.

One mole contains 6×10^{23} atoms. So we need $(3 \times 10^{27})/(6 \times 10^{23}) = 5000$ moles. Each mole weighs 235 g (since there are 235 protons and neutrons in each atom). So the weight of U-235 that we need is $5000 \times 235 \approx 10^6$ g = 1 ton of U-235. Uranium has a density of 19 g/cm^3. So the amount of U-235 needed, 10^6 g, is $10^6/19 \approx 50{,}000$ cm^3, which is a cube with sides of 37 cm, a little more than a foot. So remember it this way: the amount of U-235 required is about a cubic foot.

This U-235 is found in natural uranium, but it is only 0.7%—i.e., it is 0.007 of the natural uranium. So the amount of natural uranium it takes to run a nuclear reactor for a year is about 1 ton/0.007 = 140 tons = 140×10^6 g. With a density of 19 g/cm^3, this works out to $(140 \times 10^6)/(19) = 7.4 \times 10^6$ cm^3, which is a cube with sides of about 2 m.

Nuclear Waste

The fission fragments from uranium all come from the uranium, so their weight is comparable. Thus, a year of operation of a nuclear power plant will produce about one ton of fission fragments. There may be a comparable amount of plutonium produced. It is potentially valuable for use as a fuel for other reactors, but it is presently considered (by the United States) to be part of the waste. That was done to avoid the "plutonium economy," mentioned earlier and discussed further in the following. Plutonium is much less radioactive than the fission fragments, since its half-life (24,000 years) is so long. But it lasts for a long time.

If they were concentrated, the fission fragments would take up a few cubic feet of volume. But it is expensive to concentrate such highly radioactive material, and so they are normally mixed in with larger amounts of unspent fuel, primarily U-238. This fuel with its fission fragments makes up the high-level radioactive waste of nuclear energy.

Most of the fission fragments are radioactive. They are the same particles that caused radioactive fallout. Some of them have half-lives of a few seconds. Some have half-lives of years. We already discussed Strontium-90, which makes up 5% of the fission fragments and has a half-life of 28 years.

If the reactor is turned off (by removing the moderator, or by putting in special control rods that absorb neutrons), then the chain reaction stops, but the reactor will still produce heat from the radioactive decay of the remaining fission

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[33] That's the number you get if you take 60 seconds per minute, 60 minutes per hour, 24 hours per day, and 365 days per year: $60 \times 60 \times 24 \times 365 = 3.16 \times 10^7 \approx 3 \times 10^7$ seconds.