1. The total energy released was $E = (17\times10^3\ \text{ton})\left(4.0\times10^9\ \text{J/1 ton}\right) = 6.8\times10^{13}$ J, and according to the mass-energy equivalence ($E = mc^2$), the mass converted was

$$m = \frac{E}{c^2} = \frac{6.8\times10^{13}\ \text{J}}{\left(3.00\times10^8\ \text{m/s}\right)^2} = 7.6\times10^{-4}\ \text{kg} = 0.76\ \text{g}$$

or $m \sim 1$ g and the correct choice is seen to be (d).

2. The energy released in the decay $\text{n}\rightarrow\text{p}+\text{e}^- + \overline{\nu}_e$ is $Q = (\Delta m)c^2 = (m_n - m_p - m_e)c^2$, or combining the proton and electron to form a neutral hydrogen atom, $Q = (m_n - m_{{}^1_1\text{H}_{\text{atom}}})c^2$. We may then use the atomic masses from Appendix B in the textbook to obtain

$$Q = \left(1.008\ 665\ \text{u} - 1.007\ 825\ \text{u}\right)\left(931.5\ \text{MeV/u}\right) = 0.782\ \text{MeV}$$

Alternately, we may use the particle masses (in energy units) from Table 30.2 in the textbook to obtain

$$Q = (m_n - m_p - m_e)c^2 = (939.6\ \text{MeV}/c^2 - 938.3\ \text{MeV}/c^2 - 0.511\ \text{MeV}/c^2)c^2 = 0.789\ \text{MeV}$$

From either approach, we see that the best choice is (a).

5. The annihilation ${}^{0}_{-1}\text{e} + {}^{0}_{+1}\text{e} \rightarrow \gamma$ can conserve energy [2(0.511 MeV) = 1.02 MeV], does conserve charge $[-1+1=0]$, conserves baryon number $[0+0=0]$, and conserves lepton number $[+1-1=0]$. However, the total momentum is zero before annihilation and the momentum of the single photon afterward is $p = 1.02\ \text{MeV}/c \neq 0$. Thus, it cannot occur, and the correct choice is (b).

2. The two factors presenting the most technical difficulties are the requirements of a high plasma density and a high plasma temperature. These two conditions must occur simultaneously.

4. Notice in the fusion reactions discussed in the text that the most commonly formed by-product of the reactions is helium, which is inert and not radioactive.

30.1 The number of fissions required is

$$N = \frac{E}{Q} = \frac{3.30\times10^{10}\ \text{J}}{208\ \text{MeV}}\left(\frac{1\ \text{MeV}}{1.60\times10^{-13}\ \text{J}}\right) = 9.92\times10^{20}$$

The mass of a single ${}^{235}\text{U}$ atom is $m_{\text{atom}} = (235\ \text{u})(1.66\times10^{-27}\ \text{kg/u}) = 3.90\times10^{-25}\ \text{kg}$, so the total mass of ${}^{235}\text{U}$ required is

$$m_{\text{total}} = Nm_{\text{atom}} = \left(9.92\times10^{20}\right)\left(3.90\times10^{-25}\ \text{kg}\right) = 3.87\times10^{-4}\ \text{kg} = \boxed{0.387\ \text{g}}$$

30.3 The energy released in the reaction ${}_0^1\text{n} + {}_{92}^{235}\text{U} \rightarrow {}_{38}^{88}\text{Sr} + {}_{54}^{136}\text{Xe} + 12\,{}_0^1\text{n}$ is

$$Q = (\Delta m)c^2 = \left[m_{{}_{92}^{235}\text{U}} - 11\,m_n - m_{{}_{38}^{88}\text{Sr}} - m_{{}_{54}^{136}\text{Xe}}\right]c^2$$

$$= \left[235.043\,923\text{ u} - 11(1.008\ 665\text{ u}) - 87.905\ 614\text{ u} - 135.907\ 220\text{ u}\right](931.5\ \text{MeV/u})$$

$$= \boxed{126\text{ MeV}}$$

30.12 The energy released in the reaction ${}_1^1\text{H} + {}_1^2\text{H} \rightarrow {}_2^3\text{He} + \gamma$ is

$$Q = (\Delta m)c^2 = \left[m_{{}_1^1\text{H}} + m_{{}_1^2\text{H}} - m_{{}_2^3\text{He}}\right]c^2$$

$$= [1.007\ 825\text{ u} + 2.014\ 102\text{ u} - 3.016\ 029\text{ u}](931.5\ \text{MeV/u}) = \boxed{5.49\text{ MeV}}$$

30.17 Note that pair production cannot occur in a vacuum. It must occur in the presence of a massive particle which can absorb at least some of the momentum of the photon and allow total linear momentum to be conserved.

When a particle-antiparticle pair is produced by a photon having the minimum possible frequency, and hence minimum possible energy, the nearby massive particle absorbs all the momentum of the photon, allowing both components of the particle-antiparticle pair to be left at rest. In such an event, the total kinetic energy afterwards is essentially zero, and the photon need only supply the total rest energy of the pair produced.

The minimum photon energy required to produce a proton-antiproton pair is

$$E_{\text{photon}} = 2(E_R)_{\text{proton}} = 2(938.3\text{ MeV})(1.60\times10^{-13}\ \text{J/MeV}) = 3.00\times10^{-10}\ \text{J}$$

Thus, $f = \dfrac{E_{\text{photon}}}{h} = \dfrac{3.00\times10^{-10}\ \text{J}}{6.63\times10^{-34}\ \text{J}\cdot\text{s}} = \boxed{4.52\times10^{23}\ \text{Hz}}$

and $\lambda = \dfrac{c}{f} = \dfrac{3.00\times10^{8}\ \text{m/s}}{4.52\times10^{23}\ \text{Hz}} = 6.64\times10^{-16}\ \text{m} = \boxed{0.664\ \text{fm}}$