57. A shielded γ-ray source yields a dose rate of 0.052 rad/h at a distance of 1.0 m for an average-sized person. If workers are allowed a maximum dose of 5.0 rem in 1 year, how close to the source may they operate, assuming a 40-h work week? Assume that the intensity of radiation falls off as the square of the distance. (It actually falls off more rapidly than $1/r^2$ because of absorption in the air, so your answer will give a better-than-permissible value.)

58. Radon gas, $^{222}_{86}\text{Rn}$, is formed by α decay. (*a*) Write the decay equation. (*b*) Ignoring the kinetic energy of the daughter nucleus (it's so massive), estimate the kinetic energy of the α particle produced. (*c*) Estimate the momentum of the alpha and of the daughter nucleus. (*d*) Estimate the kinetic energy of the daughter, and show that your approximation in (*b*) was valid.

59. Consider a system of nuclear power plants that produce 3400 MW. (*a*) What total mass of $^{235}_{92}\text{U}$ fuel would be required to operate these plants for 1 yr, assuming that 200 MeV is released per fission? (*b*) Typically 6% of the $^{235}_{92}\text{U}$ nuclei that fission produce $^{90}_{38}\text{Sr}$, a β^- emitter with a half-life of 29 yr. What is the total radioactivity of the $^{90}_{38}\text{Sr}$, in curies, produced in 1 yr? (Neglect the fact that some of it decays during the 1-yr period.)

60. In the net reaction, Eq. 31–7, for the proton–proton cycle in the Sun, the neutrinos escape from the Sun with energy of about 0.5 MeV. The remaining energy, 26.2 MeV, is available within the Sun. Use this value to calculate the "heat of combustion" per kilogram of hydrogen fuel and compare it to the heat of combustion of coal, about 3×10^7 J/kg.

61. Energy reaches Earth from the Sun at a rate of about 1400 W/m^2. Calculate (*a*) the total power output of the Sun, and (*b*) the number of protons consumed per second in the reaction of Eq. 31–7, assuming that this is the source of all the Sun's energy. (*c*) Assuming that the Sun's mass of 2.0×10^{30} kg was originally all protons and that all could be involved in nuclear reactions in the Sun's core, how long would you expect the Sun to "glow" at its present rate? See previous Problem.

62. Some stars, in a later stage of evolution, may begin to fuse two $^{12}_{6}\text{C}$ nuclei into one $^{24}_{12}\text{Mg}$ nucleus. (*a*) How much energy would be released in such a reaction? (*b*) What kinetic energy must two carbon nuclei each have when far apart, if they can then approach each other to within 6.0 fm, center-to-center? (*c*) Approximately what temperature would this require?

63. An average adult body contains about 0.10 μCi of $^{40}_{19}\text{K}$, which comes from food. (*a*) How many decays occur per second? (*b*) The potassium decays produce beta particles with energies of around 1.4 MeV. Calculate the dose per year in sieverts for a 50-kg adult. Is this a significant fraction of the 3.6 mSv/year background rate?

64. When the nuclear reactor accident occurred at Chernobyl in 1986, 2.0×10^7 Ci were released into the atmosphere. Assuming that this radiation was distributed uniformly over the surface of the Earth, what was the activity per square meter? (The actual activity was not uniform; even within Europe wet areas received more radioactivity from rainfall).

65. A star with a large helium abundance can burn helium in the reaction $^{4}_{2}\text{He} + {}^{4}_{2}\text{He} + {}^{4}_{2}\text{He} \rightarrow {}^{12}_{6}\text{C}$. What is the Q-value for this reaction?

66. A 1.0-μCi $^{137}_{55}\text{Cs}$ source is used for 2.0 hours by a 75-kg student in a physics lab. Radioactive $^{137}_{55}\text{Cs}$ decays by β^- decay with a half-life of 30 years. The average energy of the emitted betas is about 190 keV per decay. The β decay is quickly followed by a γ with an energy of 660 keV. Assuming the student absorbs *all* emitted energy, what effective dose (in rem) is received during lab?

67. A large amount of $^{90}_{38}\text{Sr}$ was released during the Chernobyl nuclear reactor accident in 1986. The $^{90}_{38}\text{Sr}$ enters the body through the food chain. How long will it take for 90% of the $^{90}_{38}\text{Sr}$ released during the accident to decay? See Appendix B.

68. Three radioactive sources have the same activity, 25 mCi. Source A emits 1.0-MeV γ rays, source B emits 2.0-MeV γ rays, and source C emits 2.0-MeV alphas. What is the relative danger of these sources?

69. A 70-kg patient is to be given a medical test involving the ingestion of $^{99m}_{43}\text{Tc}$ (Section 31–7) which decays by emitting a 140-keV gamma. The half-life for this decay is 6 hours. Assuming that about half the gamma photons exit the body without interacting with anything, what must be the initial activity of the Tc sample if the whole-body dose cannot exceed 50 mrem? Make the rough approximation that biological elimination of Tc can be ignored.

Answers to Exercises

A: $^{138}_{56}\text{Ba}$.

B: 3 neutrons.

C: 2×10^{17}.