24. Why is the recommended maximum radiation dose higher for women beyond the child-bearing age than for younger women?

25. Radiation is sometimes used to sterilize medical supplies and even food. Explain how it works.

26. What is the difference between absorbed dose and effective dose? What are the SI units for each?

* 27. How might radioactive tracers be used to find a leak in a pipe?

Problems

(NOTE: Masses are found in Appendix B.)

31–1 Nuclear Reactions, Transmutation

1. (I) Natural aluminum is all $^{27}_{13}\text{Al}$. If it absorbs a neutron, what does it become? Does it decay by β^+ or β^-? What will be the product nucleus?

2. (I) Determine whether the reaction $^2_1\text{H} + ^2_1\text{H} \rightarrow ^3_2\text{He} + \text{n}$ requires a threshold energy.

3. (I) Is the reaction $\text{n} + ^{238}_{92}\text{U} \rightarrow ^{239}_{92}\text{U} + \gamma$ possible with slow neutrons? Explain.

4. (II) Does the reaction $\text{p} + ^7_3\text{Li} \rightarrow ^4_2\text{He} + \alpha$ require energy, or does it release energy? How much energy?

5. (II) Calculate the energy released (or energy input required) for the reaction $\alpha + ^9_4\text{Be} \rightarrow ^{12}_6\text{C} + \text{n}$.

6. (II) (*a*) Can the reaction $\text{n} + ^{24}_{12}\text{Mg} \rightarrow ^{23}_{11}\text{Na} + \text{d}$ occur if the bombarding particles have 10.00 MeV of kinetic energy? (d stands for deuterium, ^2_1H.) (*b*) If so, how much energy is released?

7. (II) (*a*) Can the reaction $\text{p} + ^7_3\text{Li} \rightarrow ^4_2\text{He} + \alpha$ occur if the incident proton has kinetic energy = 2500 keV? (*b*) If so, what is the total kinetic energy of the products?

8. (II) In the reaction $\alpha + ^{14}_7\text{N} \rightarrow ^{17}_8\text{O} + \text{p}$, the incident α particles have 7.68 MeV of kinetic energy. (*a*) Can this reaction occur? (*b*) If so, what is the total kinetic energy of the products? The mass of $^{17}_8\text{O}$ is 16.999131 u.

9. (II) Calculate the Q-value for the "capture" reaction $\alpha + ^{16}_8\text{O} \rightarrow ^{20}_{10}\text{Ne} + \gamma$.

10. (II) Calculate the total kinetic energy of the products of the reaction $\text{d} + ^{13}_6\text{C} \rightarrow ^{14}_7\text{N} + \text{n}$ if the incoming deuteron (d) has KE = 36.3 MeV.

11. (II) Radioactive $^{14}_6\text{C}$ is produced in the atmosphere when a neutron is absorbed by $^{14}_7\text{N}$. Write the reaction and find its Q-value.

12. (II) An example of a "stripping" nuclear reaction is $\text{d} + ^6_3\text{Li} \rightarrow \text{X} + \text{p}$. (*a*) What is X, the resulting nucleus? (*b*) Why is it called a "stripping" reaction? (*c*) What is the Q-value of this reaction? Is the reaction endothermic or exothermic?

13. (II) An example of a "pick-up" nuclear reaction is $^3_2\text{He} + ^{12}_6\text{C} \rightarrow \text{X} + \alpha$. (*a*) Why is it called a "pickup" reaction? (*b*) What is the resulting nucleus? (*c*) What is the Q-value of this reaction? Is the reaction endothermic or exothermic?

14. (II) (*a*) Complete the following nuclear reaction, $\text{p} + ? \rightarrow ^{32}_{16}\text{S} + \gamma$. (*b*) What is the Q-value?

15. (II) The reaction $\text{p} + ^{18}_8\text{O} \rightarrow ^{18}_9\text{F} + \text{n}$ requires an input of energy equal to 2.453 MeV. What is the mass of $^{18}_9\text{F}$?

31–2 Nuclear Fission

16. (I) Calculate the energy released in the fission reaction $\text{n} + ^{235}_{92}\text{U} \rightarrow ^{88}_{38}\text{Sr} + ^{136}_{54}\text{Xe} + 12\text{n}$. Use Appendix B, and assume the initial kinetic energy of the neutron is very small.

17. (I) What is the energy released in the fission reaction of Eq. 31–4? (The masses of $^{141}_{56}\text{Ba}$ and $^{92}_{36}\text{Kr}$ are 140.914411 u and 91.926156 u, respectively.)

18. (I) How many fissions take place per second in a 200-MW reactor? Assume 200 MeV is released per fission.

19. (II) The energy produced by a fission reactor is about 200 MeV per fission. What fraction of the rest mass of a $^{235}_{92}\text{U}$ nucleus is this?

20. (II) Consider the fission reaction $^{235}_{92}\text{U} + \text{n} \rightarrow ^{133}_{51}\text{Sb} + ^{98}_{41}\text{Nb} + ?\text{n}$. (*a*) How many neutrons are produced in this reaction? (*b*) Calculate the energy release. The atomic masses for Sb and Nb isotopes are 132.915250 u and 97.910328 u, respectively.

21. (II) How much mass of $^{238}_{92}\text{U}$ is required to produce the same amount of energy as burning 1.0 kg of coal (about 3×10^7 J)?

22. (II) Suppose that the electric average power consumption, day and night, in a typical house is 950 W. What initial mass of $^{235}_{92}\text{U}$ would have to undergo fission to supply the electrical needs of such a house for a year? (Assume 200 MeV is released per fission, as well as 100% efficiency.)

23. (II) What initial mass of $^{235}_{92}\text{U}$ is required to operate a 650-MW reactor for 1 yr? Assume 40% efficiency.

24. (III) Assuming a fission of $^{236}_{92}\text{U}$ into two roughly equal fragments, estimate the electric potential energy just as the fragments separate from each other. Assume that the fragments are spherical (see Eq. 30–1) and compare your calculation to the nuclear fission energy released, about 200 MeV.

31–3 Nuclear Fusion

25. (I) What is the average kinetic energy of protons at the center of a star where the temperature is 10^7 K? [*Hint*: use Eq. 13–8.]

26. (II) Show that the energy released in the fusion reaction $^2_1\text{H} + ^3_1\text{H} \rightarrow ^4_2\text{He} + \text{n}$ is 17.59 MeV.

27. (II) Show that the energy released when two deuterium nuclei fuse to form ^3_2He with the release of a neutron is 3.27 MeV.

28. (II) Verify the Q-value stated for each of the reactions of Eqs. 31–6. [*Hint*: be careful with electrons.]

29. (II) Calculate the energy release per gram of fuel for the reactions of Eqs. 31–8a, b, and c. Compare to the energy release per gram of uranium in fission.

30. (II) How much energy is released when $^{238}_{92}\text{U}$ absorbs a slow neutron (KE ≈ 0) and becomes $^{239}_{92}\text{U}$?

31. (II) If a typical house requires 950 W of electric power on average, what minimum amount of deuterium fuel would have to be used in a year to supply these electrical needs? Assume the reaction of Eq. 31–8b.