For full credit, make your work clear. Show formulas used, essential steps, and results with correct units and significant figures. Points shown in parenthesis. For TF and MC, choose the best answer.

1. (2) T F Nuclear isotopes are nuclei of some element that differ in mass and charge.

2. (2) T F In any spontaneous nuclear decay reaction, the total mass of the products is less than the mass of the parent nucleus.

3. (6) A $^{232}$Th (thorium) nucleus contains _______ protons and _______ neutrons and _______ nucleons.

4. (4) Identify the element whose nuclei have 84 nucleons and 48 neutrons.

5. (4) Carbon-14 forms naturally in Earth’s atmosphere due to a nuclear transmutation of which element $X$, according to the reaction, $n + X \rightarrow ^{14}_6$C + p ?
   a. oxygen (O) b. nitrogen (N) c. boron (B) d. silicon (Si)

6. (12) A common isotope of beryllium is $^9_4$Be, with a mass of 9.012182 u.
   a) (8) Calculate the total binding energy for one $^9_4$Be nucleus, in MeV.
   b) (4) Calculate the binding energy per nucleon for $^9_4$Be, in MeV.

7. (4) Here is a radioactive decay by alpha emission: $X \rightarrow ^{84}_{36}$Kr + $\alpha$
   What is the parent nucleus, $X$? Give the element symbol and mass number.

8. (4) Here is a radioactive decay by $\beta^-$ emission: $^{60}_{27}$Co $\rightarrow X + \beta^- + \bar{\nu}$
   What is the daughter nucleus, $X$? Give the element symbol and mass number.
9. (3) If a nucleus decays by $\beta^+$ emission, daughter nucleus will have mass number
   
a. one lower than that of the parent nucleus.
   b. equal to that of the parent nucleus.
   c. one higher than that of the parent nucleus.

10. (3) If a nucleus $\frac{3}{2}X$ decays by $\gamma$-emission, the daughter nucleus will have atomic number
    

11. (2) Which type of radiation is the most penetrating and causes the most biological damage?
    
a. alpha particles  b. beta particles.  c. gamma rays.

12. (16) Potassium-40 makes up 0.0117 per cent of natural potassium, and decays by beta emission with a half-life of $1.277 \times 10^9$ years. A banana has 320 mg of natural potassium, whose average mass is 39.0983 u.
   a) (6) How many atoms of potassium (all isotopes) are in this banana?
   b) (4) How many atoms of potassium-40 are in this banana?
   c) (6) What is the radio-activity (decays/s) due to the potassium-40 in this banana?

13. (8) A radioactive sample has an initial activity of 32.0 decays/s. After 18.0 days, the activity has diminished to 2.00 decays/s. Calculate the half-life for this material.
14. (8) Tritium is an isotope of hydrogen ($^3$H) with a mass of 3.016049 u. It decays spontaneously by $\beta^-$ emission with a half-life of 12.33 years. The reaction is $^3$H $\rightarrow$ $^3$He + $\beta^-$ + $\bar{\nu}$.

Calculate the energy released (the $Q$) in the reaction in MeV. (See eqn. sheet for masses.)

15. (18) The ratio of carbon-14 to carbon-12 atoms in living things is about $1.3 \times 10^{-12}$. Carbon-14 has a half-life of 5730 years and the decay constant is $\lambda = 3.83 \times 10^{-12}$ s$^{-1}$. 2.00-grams of carbon in a sample of ancient wood has a radio-activity of 5.0 decays/minute.

a) (6) About how many C-14 atoms were present in this wood sample when the tree died?

b) (6) About how many C-14 atoms are now present in the wood sample?

c) (6) How much time has passed since the tree died, in years?
16. (6) Consider the reaction, \( ^{2}\text{H} + ^{2}\text{H} \rightarrow ^{0}\text{n} + X \), where \( X \) is some unknown.

a) (2) The type of reaction is a. \( \alpha \)-decay.  b. \( \beta \)-decay.  c. \( \gamma \)-decay.  d. fusion.  e. fission.

b) (4) What is \( X \)?

17. (6) Consider the reaction, \( n + ^{235}_{92}\text{U} \rightarrow ^{142}_{60}\text{Nd} + ^{74}_{32}\text{Ge} + X \), where \( X \) is some unknown.

a) (2) The type of reaction is a. \( \alpha \)-decay.  b. \( \beta \)-decay.  c. \( \gamma \)-decay.  d. fusion.  e. fission.

b) (4) What is \( X \)?

18. (6) Consider the reaction, \( ^{238}_{92}\text{U} \rightarrow X + ^{4}_{2}\text{He} \), where \( X \) is some unknown.

a) (2) The type of reaction is a. \( \alpha \)-decay.  b. \( \beta \)-decay.  c. \( \gamma \)-decay.  d. fusion.  e. fission.

b) (4) What is \( X \)?

19. (12) One sequence of fusion reactions in the Sun is equivalent to the reaction, \( 4^{1}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + 2e^{+} + 2\nu + 2\gamma \), with an energy output \( Q = 26.7 \text{ MeV} \). Suppose you can make a reactor based on this reaction, to supply a continuous power of 5.00 kW to your house for 1.00 year.

a) (6) How many of the given reactions must take place during one year?

b) (6) What mass of hydrogen fuel would the reactor consume per year?

Score = __________/126.
Energy, power and mass in nuclear reactors:

Half-life and decay constant

Chapter 30 Equations

Nuclides:

\[ A = N + Z, \quad (\text{mass, neutron, proton numbers}) \]

\[ \Delta E = [(\text{mass of parts}) - (\text{mass of nuclide})]c^2 \]

\[ Q = [M_{\text{parent}} - M_{\text{products}}]c^2 \]

Half-life and decay constant

\[ N = N_0e^{-\lambda t} \quad (\text{decay of parent nuclei}) \]

\[ t = \frac{1}{\lambda} \ln(N/N_0) \quad (\text{time when N nuclei remain}) \]

\[ \lambda T_1 = \ln 2 \quad (\text{decay constant, half-life}) \]

\[ \#(^{14}_{6}C)/\#(^{12}_{6}C) = 1.3 \times 10^{-12} \quad (\text{live carbon ratio}) \]

Chapter 31 Equations

Reactions:

\[ Q = [M_{\text{reactants}} - M_{\text{products}}]c^2 \quad (\text{reaction energy}) \]

\[ Q > 0 \quad (Q = \text{mass converted to energy}) \]

\[ Q < 0 \quad (|Q| = \text{threshold energy}) \]

Energy, power and mass in nuclear reactors:

\[ E = mc^2 \quad (\text{Einstein’s mass-energy equivalence}) \]

\[ E = NQ \quad (\text{energy} = (\# \text{ of reactions}) \times (\text{reaction energy})) \]

\[ M = Nm \quad (\text{mass used} = (\# \text{ of reactions}) \times (\text{reaction mass})) \]

\[ E_{\text{out}} = eE_{\text{in}} \quad (\text{output energy} = (\text{efficiency}) \times (\text{input energy})) \]