Name: Josh whitehead Homework #2 UID: u1069843

1. From careful measurements scientists have determined that the total energy output of the Sun is 3.86×10^{23} kJ/s. All of this energy is produced by a series of approximately 10 nuclear fusion reactions occurring inside the core of the Sun. For the sake of simplicity, let's approximate all of those reactions by one of the more important solar fusion reactions

$$^{2}H + {}^{1}H \rightarrow {}^{3}He + \gamma$$

From the Sun's energy output and the Q-value for this fusion reaction, determine how many tons of hydrogen (both ^{2}H and ^{1}H) are fused per second inside the core of the Sun. Measured masses of the nuclei are ^{2}H = 2.014102 amu, ^{1}H = 1.007825 amu, and ^{3}He = 3.016030 amu. Use 1 ton = 2200 lb = 998.8 kg. (1 point)

$$Q = -931.5\,(3.01603 - 2.014102 - 1.007825) = 5.493055\text{ MeV}$$

$$Q = 5.493055\,\cancel{\text{MeV}}\,\frac{\text{kJ}}{6.242\times10^{15}\,\cancel{\text{MeV}}} = 8.80015\times10^{-16}\text{ kJ} \text{ — one rxn}$$

$$\#\text{ of rxn: } \frac{3.86\cdot10^{23}}{8.80015\times10^{-16}} = 4.39\times10^{38}\text{ rxns}$$

$$\frac{m_{H}}{\text{rxn}}: 1.661\times10^{-27}\,\frac{\text{kg}}{\text{amu}}\cdot(2.014102 + 1.007825) = 5.01942\times10^{-27}\,\frac{\text{kg H}}{\text{rxn}}$$

$$\rightarrow 4.39\times10^{38}\,\cancel{\text{rxn}}\cdot 5.01942\times10^{-27}\,\frac{\text{kg}}{\cancel{\text{rxn}}} = 2.20\times10^{12}\text{ kg H}$$

$$2.20\times10^{12}\,\cancel{\text{kg}}\text{ H}\cdot\frac{1\text{ ton}}{998.8\,\cancel{\text{kg}}} = \boxed{2.20\times10^{9}\text{ tons H}}$$

Name: Josh Whitehead Homework #2 UID: U1069343

2. The uranium enrichment process uses, as raw material, natural uranium or uranium recovered through reprocessing, and produces two products: enriched uranium with a ^{235}U content higher than that in natural uranium (0.72 %); and depleted uranium with a ^{235}U content lower than that in natural uranium, which is considered as waste. Answer the following questions about the material balance in the enrichment process.
   a. Assume that natural uranium is the only raw material input into the enrichment process and that the ^{235}U content in waste is 0.3%. How many tons of natural uranium are needed to produce 27 tons of 4% enriched uranium? In this case, how many tons of depleted uranium will be generated? (1 point)

$$F = P\frac{(x_P - x_W)}{(x_F - x_W)} = 27 \text{ ton } \frac{(0.04 - 0.003)}{(0.0072 - 0.003)} = \boxed{237.857 \text{ tons natural U}}$$

$$W = F - P = 237.857 - 27 = \boxed{210.857 \text{ ton waste}}$$

Name: Josh Whitehead Homework #2 UID: U1067343

3. The uranium enrichment process uses, as raw material, natural uranium or uranium recovered through reprocessing, and produces two products: enriched uranium with a ^{235}U content higher than that in natural uranium (0.72 %); and depleted uranium with a ^{235}U content lower than that in natural uranium, which is considered as waste. Answer the following questions about the material balance in the enrichment process.
   a. Assume that, in addition to natural uranium, uranium recovered through reprocessing is used as a raw material input into the enrichment process. Provided that the ^{235}U content in the recovered uranium is 0.8% and that 25 tons of this uranium is supplied, how many tons of natural uranium are needed to produce 27 tons of 4% enriched uranium? In this case, how many tons of depleted uranium will be generated? (1 point)

F_1 = recovered

F_2 = natural

$$F_1 = P_1 \frac{(x_P - x_w)}{(x_F - x_w)}$$

$$P_1 = F_1 \frac{(x_F - x_w)}{(x_P - x_w)} = 25 \frac{(0.008 - 0.003)}{(0.04 - 0.003)} = 3.378 \text{ ton}$$

$$P_2 = 27 - P_1 = 23.6216 \text{ ton}$$

$$\therefore F_2 = 23.6216 \frac{(0.04 - 0.003)}{(0.0072 - 0.003)} = \boxed{208.0952 \text{ tons natural U}}$$

$$W = (208.0952 + 25) - 27 = \boxed{206.0952 \text{ tons depleted U}}$$

Name: Josh Whitehead Homework #2 UID: V10693343

4. The uranium enrichment process uses, as raw material, natural uranium or uranium recovered through reprocessing, and produces two products: enriched uranium with a ^{235}U content higher than that in natural uranium (0.72 %); and depleted uranium with a ^{235}U content lower than that in natural uranium, which is considered as waste. Answer the following questions about the material balance in the enrichment process.

   a. Compare the above two cases and explain the natural uranium saving effect of recycling uranium recovered through reprocessing and its impact on the amount of wastes generated during the mining and enrichment processes. (1 point)

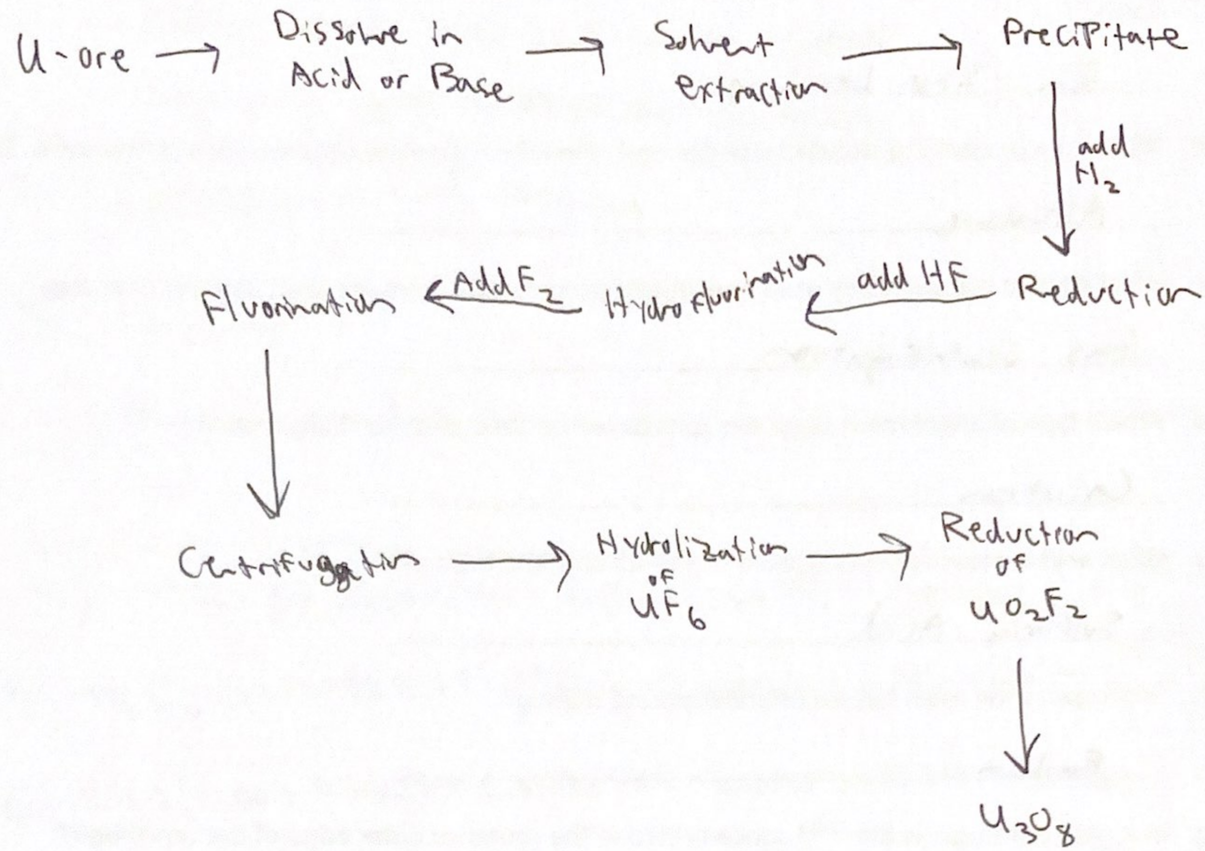
~~25 tons~~

~~By using the recycled uranium almost 30 tons~~

Incorporating the reprocessed U as a starting material allows us to use less natural U to get the same amount of product. Almost 30 tons of ~~the~~ natural U ~~was~~ was not needed. By recycling after each cycle, we would also decrease the amount of waste produced

Name: Josh Whitehead Homework #2 UID: U1069343

5. Make a flow diagram to show how U-ore is converted to enriched $^{235}U_3O_8$. (1 point)



Name: Josh Whitehead Homework #2 UID: U1069343

6. Write in the blank the short answer to the following questions (2 points):
   a. What type of mining should be used when the U-ore is several km beneath the surface of the Earth?

      In - Situ Leaching

   b. What type of leaching should be performed when the carbonate concentration of the ore is 5%?

      Alkaline

   c. What type of commercially used enrichment process consumes the least amount of energy?

      Gas Centrifugation

   d. Which type of enrichment separates ions based on their mass to charge ratio?

      Calutron

   e. What acid is most commonly used to extract uranium from ore?

      Sulfuric Acid

   f. What gas is the main hazard of underground mining?

      Radon

   g. In a gas centrifuge, is the ^{235}U concentrated in the center or outer edge of the centrifuge?

      outer edge

   h. What does ADU stand for?

      Ammonium Diuranate

   i. What is the main element used to make fuel cladding?

      Zirconium

   j. Is it safe to store and transport uranium as UF_6 (yes or no)?

      No

7. What are the four steps of making a UO_2 fuel pellet. Specifically state where the binding and lubricating agents are added and what they do to help in the fuel pellet production. (1 point)

Name: Josh Whitehead Homework #2 UID: U1069343

1.) Mixing UO_2 powder with binding and lubricating agents

- Binding agent helps hold powder together
- Lubricating agent helps powder compress

2.) Compaction or cold pressing

3.) Sintering

4.) Precision grinding

8.) a.) $-931.5(7.016003434 - 6.0151228874 - 1.008665) = \boxed{7.251218 \text{ MeV}}$

b.) $-931.5(6.0151228874 + 1.008665 - 1.008665 - 6.0151228874) = \boxed{0 \text{ MeV}}$

c.) $-931.5(1.00727647 + 6.01888589 - 6.0151228874 - 1.008665) = \boxed{-2.2118 \text{ MeV}}$

d.) $-931.5(5.012057 + 2.01410177784 - 6.0151228874 - 1.008665) = \boxed{-2.20848 \text{ MeV}}$

e.) $-931.5(4.00260325413 + 3.01604928132 - 6.0151228874 - 1.008665)$ $= \boxed{4.78358 \text{ MeV}}$

8. Consider the following possible reactions, all of which create the compound nucleus ^7Li,

$$^1n + {}^6Li \rightarrow {}^7Li^* \rightarrow \begin{cases} {}^7Li + \gamma & a \\ {}^6Li + n & b \\ {}^6He + p & c \\ {}^5He + d & d \\ {}^3H + \alpha & e \end{cases}$$

a) What is the Q-value of each reaction? (1 point)

Name: Josh Whitehead Homework #2 UID: U1069343

9. Consider the following possible reactions, all of which create the compound nucleus ^7Li,

$$^1n + {}^6Li \rightarrow {}^7Li^* \rightarrow \begin{cases} a\ {}^7Li + \gamma & Q > 0 \\ b\ {}^6Li + n & Q = 0 \\ c\ {}^6He + p & Q < 0 \\ d\ {}^5He + d & Q < 0 \\ e\ {}^3H + \alpha & Q > 0 \end{cases}$$

a) What is the kinematic threshold energy? (1 point)

$$E_x^{Th} = -\frac{m_y + m_Y}{m_y + m_Y - m_x} Q$$

Not needed for $Q > 0$

$$\therefore E_{x_c}^{Th} = -Q_c \cdot \frac{m_p + m_{6He}}{m_p + m_{6He} - m_n} \boxed{= 2.582571 \text{ MeV}}$$

$$E_{xd}^{Th} = -Q_d \cdot \frac{m_d + m_{5He}}{m_d + m_{5He} - m_n} \boxed{= 2.578675 \text{ MeV}}$$

Name: Josh whitehead Homework #2 UID: U1069343

10. Consider the following possible reactions, all of which create the compound nucleus ^{7}Li,

$$^{1}n + {}^{6}Li \rightarrow {}^{7}Li^{*} \rightarrow \begin{cases} {}^{7}Li + \gamma \\ {}^{6}Li + n \\ {}^{6}He + p \quad c \\ {}^{5}He + d \quad d \\ {}^{3}H + \alpha \end{cases}$$

a) Based on your answers to 3 and 4 above, what is the minimum kinetic energy of the products? (1 point)

$(E_Y + E_{\bar{Y}})_{min} = Q + (E_x^{Th})_{min}$

c) $-2.21182 + 2.582571 = \boxed{0.37075 \text{ MeV}}$

d.) $-2.20848 + 2.578675 = \boxed{0.370191 \text{ MeV}}$

Name: Josh Whitehead Homework #2 UID: U1069343

11. Consider the following possible reactions, all of which create the compound nucleus ^{19}F,

$$^{3}H + {}^{16}O \rightarrow {}^{19}F^{*} \rightarrow \begin{cases} {}^{18}F + n & a \\ {}^{17}O + d & b \\ {}^{18}O + p & c \end{cases}$$

a) What is the Q-value of each reaction? (1 point)

a.) $-931.5\,(m_n + m_{18F} - m_{16O} - m_{3H})$

$Q = -931.5 \cdot (m_y + m_Y - m_x - m_X)$

$= -931.5\,(1.008665 + 18.0009373 - 15.99491462 - 3.016049281)$

$\boxed{\approx 1.268331 \text{ MeV}}$

b.) $-931.5\,(2.01410177 8 + 16.99913176 - 15.99491462 - 3.016049281)$

$\boxed{\approx -2.114116 \text{ MeV}}$

c.) $-931.5\,(1.007276647 + 17.9991596 1 - 15.99491462 - 3.016049281)$

$\boxed{\approx 4.217663 \text{ MeV}}$

Name: Josh whitehead Homework #2 UID: V10693443

12. Consider the following possible reactions, all of which create the compound nucleus ^{19}F,

$$^{3}H + {}^{16}O \rightarrow {}^{19}F^{*} \rightarrow \begin{cases} {}^{18}F + n & Q > 0 \\ {}^{17}O + d & Q < 0 \\ {}^{18}O + p & Q > 0 \end{cases}$$

a) What is the kinematic threshold energy of the triton? (1 point)

$$E_{x}^{Th} = -Q \cdot \frac{m_y + m_{\bar{y}}}{m_y + m_{\bar{y}} - m_x}$$

$$= 2.11416 \cdot \frac{2.014101778 + 16.99913176}{2.014101778 + 16.99913176 - 3.016049281}$$

$$\boxed{= 2.51276 \text{ MeV}}$$

Name: Josh Whitehead Homework #2 UID: U1069343

13. Consider the following possible reactions, all of which create the compound nucleus ^{19}F,

$$^{3}H + {}^{16}O \rightarrow {}^{19}F^{*} \rightarrow \begin{cases} {}^{18}F + n & a \\ {}^{17}O + d & b \\ {}^{18}O + p & c \end{cases}$$

a) What is the coulomb barrier threshold energy of the triton? (1 point)

$$E_x^c \simeq 1.2 \frac{Z_x Z_X}{A_x^{1/3} + A_X^{1/3}}$$

$$a: \quad 1.2 \frac{1 \cdot 8}{3^{1/3} + 16^{1/3}} = 2.422963 \text{ MeV}$$

Name: Josh Whitehead Homework #2 UID: U1068343

14. Consider the following possible reactions, all of which create the compound nucleus ^{19}F,

$$^{3}H + {}^{16}O \rightarrow {}^{19}F^{*} \rightarrow \begin{matrix} {}^{18}F + n \\ {}^{17}O + d \\ {}^{18}O + p \end{matrix}$$

a) Based on your answers for 4 – 6, what is the minimum energy that the tritium needs for the different reaction products to be produced? (1 point)

$E_{min} = E(E_x^{Th}, E_x^{C})_{max}$

$= 2.51276 \text{ MeV} = E^{Th}$

$= 2.422963 \text{ MeV} = E^{C}$

$E_x^{Th} > E_x^{C}$

$\boxed{\therefore \text{ min } E = 2.51276 \text{ MeV}}$