Name: Josh Whitehead Homework #3 UID: U1069343

1. How many elastic scatters, on average, are required to slow a 1-MeV neutron to below 1 eV in ^{56}Fe? (1 point)

$$n = \frac{1}{\xi} \ln\left(\frac{E_1}{E_2}\right) \qquad \xi = 1 + \frac{\alpha}{1-\alpha} \ln(\alpha)$$

$$\alpha = \frac{(A-1)^2}{(A+1)^2}$$

$$\therefore \quad \alpha = \frac{55^2}{57^2} = 0.931056$$

$$\downarrow$$

$$\xi = 1 + \frac{0.931056}{1-0.931056} \ln(0.931056) = 0.035293$$

$$n = \frac{1}{0.035293} \ln\left(\frac{1000000}{1}\right) \boxed{= 391 \text{ scatters}}$$

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2. How many neutrons per second are emitted spontaneously from a 1 mg sample of ^{252}Cf? (1 point)

Table 6.2 $\longrightarrow$ $2.3 \times 10^{12} \frac{n}{g \cdot sec} \longrightarrow 2.3 \times 10^{12} \frac{n}{g \cdot sec} \cdot 0.001\,g$

$= 2.3 \times 10^{9} \frac{n}{sec}$

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3. In a particular neutron-induced fission of ^{235}U, 4 prompt neutrons are produced and one fission fragment is ^{121}Ag. (1 point)

$92-47=45$

a) What is the other fission fragment?

$$^{235}_{92}U + {}^{1}n \longrightarrow 4({}^{1}n) + {}^{121}_{47}Ag + \boxed{^{111}_{45}Rh}$$

b) How much energy is liberated promptly (i.e., before the fission fragments being to decay)?

$$\cancel{E = mc^2 \rightarrow E_p = (M_{235U} + m_n - M_{121Ag} - M_{111Rh} - 4(m_n))c^2}$$

$$E_p = Q_{value}$$

$$= -931.5\,(M_{111Rh} + 4M_n + M_{121Ag} - M_n - M_{235U})$$

$$= -931.5\,(110.911643 + 4(1.008665) + 120.920125 - 1.008665 - 235.0439281)$$

$$\boxed{= 173.4128 \text{ MeV}}$$

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4. In a particular neutron-induced fission of ^{235}U, 4 prompt neutrons are produced and one fission fragment is ^{121}Ag.
   a) If the total initial kinetic energy of the fission fragments is 150 MeV, then what is the initial kinetic energy of each? (1 point)

$$^{235}U + {}^{1}n \longrightarrow {}^{121}Ag + 4({}^{1}n) + {}^{111}Rh$$

$$\cancel{E_{ff} = E_p - E_n \rightarrow E_n = 173.4128 - 150 = 23.41279 \text{ MeV}}$$

$$\frac{E_H}{E_L} = \frac{m_L}{m_H} \rightarrow E_H = (E_{ff} - E_H)\frac{M_{Rh}}{M_{Ag}}$$

$$\downarrow$$

$$E_H = E_{ff}\frac{M_{Rh}}{M_{Rh} + M_{Ag}}$$

$$\downarrow$$

$$E_H = 150 \cdot \frac{110.911643}{110.911643 + 120.920125}$$

$$\boxed{\begin{array}{l} E_H = 71.76215 \text{ MeV} \\ E_L = 78.23785 \text{ MeV} \end{array}}$$

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5. Consider the following fission reaction:

$$^{1}n + ^{235}U \rightarrow ^{90}Kr + ^{142}Ba + 4(\,^{1}n) + 6\gamma$$

Where ^{90}Kr and ^{142}Ba are the initial fission fragments.

a) What is the fission product chain created by each of these fission fragments? (1 point)

$$^{90}Kr \xrightarrow{\beta^-} {}^{90}Rb \xrightarrow{\beta^-} {}^{90}Sr \xrightarrow{\beta^-} {}^{90}Y \xrightarrow{\beta^-} {}^{90}Zr$$

$$^{142}Ba \xrightarrow{\beta^-} {}^{142}La \xrightarrow{\beta^-} {}^{142}Ce$$

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6. Consider the following fission reaction:

$$^{1}n + {}^{235}U \rightarrow {}^{90}Kr + {}^{142}Ba + 4({}^{1}n) + 6\gamma$$

Where ^{90}Kr and ^{142}Ba are the initial fission fragments.

a) How much energy is liberated promptly? (1 point)

$Q = -931.5\left(M_{Ba} + 4M_n + M_{Kr} - M_n - M_U\right)$

$= -931.5\left(141.916433 + 4(1.008665) + 89.9195279 - 1.008665 - 235.0439281\right)$

$\boxed{= 169.5071 \text{ MeV}}$

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7. Consider the following fission reaction:

$$^{1}n + {}^{235}U \rightarrow {}^{90}Kr + {}^{142}Ba + 4({}^{1}n) + 6\gamma$$

Where ^{90}Kr and ^{142}Ba are the initial fission fragments.

b) What is the total energy eventually emitted? (1 point)

$$\cancel{6e^-} + {}^{90}Kr + {}^{142}Ba \longrightarrow {}^{90}Zr + {}^{142}Ce + \cancel{6}\beta^- + 6(\bar{\nu})$$

$$\therefore Q_2 = -931.5\left(M_{Zr} + M_{Ce} - M_{Kr} - M_{Ba}\right)$$

$$= -931.5\left(89.9046987\text{6} + 141.9092502 - 89.9195279 - 141.916433\text{3}\right)$$

$$= 20.50412 \text{ MeV}$$

$$E_{tot} = Q_p + Q_2 = 20.504112 + 169.5071 \; \boxed{= 190.0112 \text{ MeV}}$$

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8. How much ^{235}U is consumed per year (in g/y) to produce enough electricity to run a 100-W light bulb? Compare that to the amount of coal needed per year (in g/y). Note that coal has a heat content of about 12 GJ/ton. You can assume a conversion efficiency of 33% for thermal energy into electrical energy for both the coal and nuclear plants. (1 point)

Coal: $C = 0.33 \cdot 12\,000\,000\,000 \frac{J}{ton} \approx 3.96 \times 10^{9} \frac{J}{ton}$

$\rightarrow 100 \frac{J}{sec} \cdot \frac{1\ ton}{3.96\times10^{9}\ J} \approx 2.525\times10^{-8} \frac{ton}{sec} \cdot \frac{907185\ g}{ton} = 0.0229087 \frac{g}{sec}$

$\approx 722540.7803 \frac{g}{Yr}$

^{235}U assume $200 \frac{MeV}{fission} \longrightarrow 200 \frac{MeV}{fission} \cdot \frac{1.60218\times10^{-13}\ J}{1\ MeV}$

$\approx 3.204\times10^{-11} \frac{J}{fiss} \rightarrow 100 \frac{J}{sec} \cdot \frac{1\ fiss}{3.204\times10^{-11}\ J} = 3.1208\times10^{12} \frac{fiss}{sec}$

$\approx 3.1208\times10^{12} \frac{atom}{sec} \cdot \frac{1\ mol}{6.022\times10^{23}\ atom} \cdot \frac{235.0439281\ g}{1\ mol}$

$\approx 1.218\times10^{-9} \frac{g}{sec}$ $\cancel{\approx 3.84175\times10^{-2} \frac{g}{Yr}}$

$\approx \frac{3.8418\times10^{-2} \frac{g}{Yr}}{0.33}$

$\downarrow$

$\boxed{\approx 0.116417 \frac{g}{Yr}}$

$\frac{m_u}{Yr} \ll \frac{m_c}{Yr}$

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9. An accident in a fuel reprocessing plant, caused by improper mixing of ^{235}U, produced a burst of fission energy liberating energy equivalent to the detonation of a 7 kg of TNT (4.2 GJ/ton = 4.6 kJ/g). About 80% of the fission products were retained in the building.
   a) How many fissions occurred? (1 point)

$$\text{assume} \approx 200 \frac{MeV}{fission} \rightarrow 0.8 \cdot 200 = 160 \frac{MeV}{fiss} \cdot \frac{1.6022 \times 10^{-16}\ kJ}{1\ MeV}$$

$$= 2.56352 \times 10^{-14} \frac{kJ}{fiss}$$

$$E_{tot} = 4.6 \frac{kJ}{g} \cdot 7000\,g = 32200\ kJ$$

$$\rightarrow 32200\ \cancel{kJ} \cdot \frac{1\ fiss}{2.56352 \times 10^{-14}\ \cancel{kJ}} = \boxed{1.25609 \times 10^{18}\ fissions}$$

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10. A broad beam of neutrons is normally incident on a homogeneous slab 6-cm thick. The intensity of neutrons transmitted through the slab without interaction is found to be 30% of the incident intensity. (1 point)

a) What is the total interaction coefficient for the slab material?

$$I^{\circ}(6) = 0.3\, I^{\circ}(6)$$

$$I^{\circ}(x) = I^{\circ}(0)\, e^{-\mu_t x}$$

$$\rightarrow \frac{0.3\, \cancel{I^{\circ}(0)}}{\cancel{I^{\circ}(0)}} = e^{-\mu_t x} \rightarrow \frac{\ln(0.3)}{-6} = \boxed{\mu_t = 0.200662134 \ \frac{1}{cm}}$$

b) What is the average distance a neutron travels in this material before undergoing an interaction?

$$\bar{x} = \frac{1}{\mu_t} \boxed{= 4.9835 \ cm}$$

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11. Calculate the macroscopic cross-section for the capture of thermal neutrons by carbon dioxide. (1 point)

$\cancel{\mu_i = \sigma_i \frac{\rho N_a}{A}}$ $\mu_i = \sum N^j \sigma^j_i$

^{16}O - 99.757 | ^{12}C - 98.94
^{17}O - 0.03835 | ^{13}C - 1.06
^{18}O - 0.2045 |

$\cancel{N^{CO_2} = 2N}$ $N^O = 2N^{CO_2}$
$N^C = N^{CO_2}$

σ_γ | ^{16}O — 0.0019
^{17}O — 0.00384
^{18}O — 0.00016
^{12}C — 0.0034
^{13}C — 0.00137
} b

$$N^{CO_2} = \frac{0.001977 \cdot 6.022\times10^{23}}{12.011 + 2(15.999)}$$

$$N^{CO_2} = 2.705\times10^{19} \ \frac{atom}{cm^3}$$

$1b = 10^{-24}\ cm^2$

$$\mu = 2.7052\times10^{19}\Big[0.0106 \cdot 1.37\times10^{-27} + 0.9894 \cdot 3.4\times10^{-27} + 2 \cdot 0.002045 \cdot 1.6\times10^{-28}$$
$$+ 2 \cdot 0.0003835 \cdot 3.84\times10^{-27} + 2 \cdot 0.99757 \cdot 1.9\times10^{-28}\Big)$$

$$\boxed{= 1.0175\times10^{-7}\ cm^{-1}}$$

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12. In a liquid metal fast breeder reactor, no neutron moderation is desired, and sodium is used as a coolant to minimize fission-neutron thermalization. How many scatters with sodium, on the average, would it take for 2-MeV neutrons to reach an average thermal energy of 0.025 eV? (1 point)

$$n = \frac{1}{\xi} \ln\left(\frac{E_1}{E_2}\right) \qquad \xi = 1 + \frac{\alpha}{1-\alpha} \ln(\alpha)$$

$$\alpha = \frac{(A-1)^2}{(A+1)^2}$$

^{23}Na = only naturally occuring Isotope

$$\therefore \alpha = \frac{22^2}{24^2} = 0.840277778$$

$$\rightarrow \xi = 0.08448899$$

$$\rightarrow n = \frac{1}{0.08448899} \ln\left(\frac{2000000}{0.025}\right) \boxed{\approx 215 \text{ scatters}}$$

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13. What atom-% enrichment of uranium is needed to produce a thermal fission factor of 1.85? (1 point)

$$\eta = \nu \frac{\bar{\Sigma}_f^F}{\bar{\Sigma}_a^F} = \frac{\nu^{235} N^{235} \bar{\sigma}_f^{235}}{N^{238}\bar{\sigma}_a^{238} + N^{235}\bar{\sigma}_a^{235}} = 1.85$$

$\sigma_f^{235} = 505.9$

$\sigma_a^{235} = 592.6$

$\sigma_a^{238} = 2.382$

$\nu = 2.437$

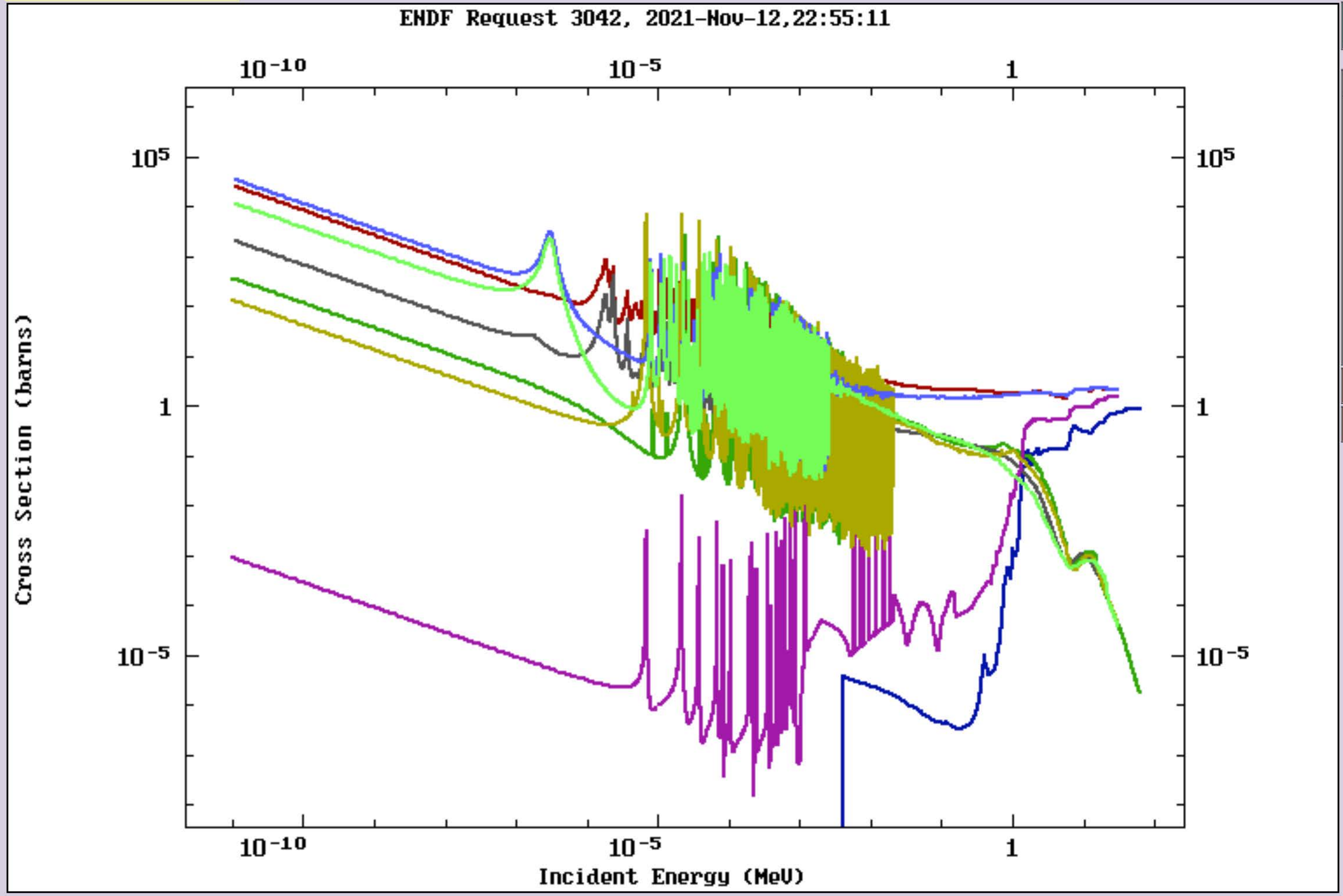
$$\rightarrow \frac{N^{238}}{N^{235}} = \frac{\nu^{235}\sigma_f^{235}}{\eta\,\sigma_a^{238}} - \frac{\sigma_a^{235}}{\sigma_a^{238}} = 30.9911$$

$$N^{238} = 1 - N^{235}$$

$$\therefore \frac{1-N^{235}}{N^{235}} = 30.9911 \rightarrow N^{235} = \frac{1}{1+30.9911} = 0.3126$$

$$\boxed{= 3.126\%}$$

Cross Section



EXFOR | Find and add to the plot experimental data

- Select data for plotting [all] [none]
  - 1) ENDF/B-VIII.0: TH-232(N,F)
  - 2) ENDF/B-VIII.0: TH-232(N,G)TH-233
  - 3) INDEN.0-beta: U-233(N,F)
  - 4) INDEN.0-beta: U-233(N,G)U-234
  - 5) ENDF/B-VIII.0: U-238(N,F)
  - 6) ENDF/B-VIII.0: U-238(N,G)U-239
  - 7) INDEN.0-beta: PU-239(N,F)
  - 8) INDEN.0-beta: PU-239(N,G)PU-240
- 9) Use my data [example][2]
- Use my control file [init] [help]

See: plotted data (12499Kb) out: e6 json+p

Log: XY | X | Y | Lin: XY | X | Y | Auto-range: XY | X | Y | Page: >> | << | Zoom: <> | >< | Grid: VH | 0 | V | H | Pts: Txt | Box | PL | Print

Reset | Repaint | Legend | Authors | Info+ | PostScript | Plotting options: [+] | Clipboard: Copy

Shift legend: x= 10 y= 10 | Split: 0 1:xy;2:y | Marker: | Plot data or ratio: 0 0:data; 1:ratio to dataset-1; 2:ratio to 2-nd, etc.

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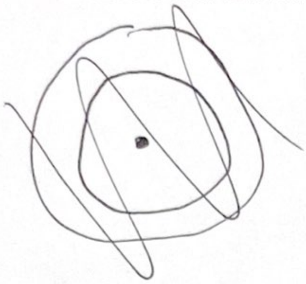
15. The Canadians prefer to use heavy water to cool their reactors. Hence, in a Canadian swimming pool reactor that has a flux of 3 x 10^{16} thermal neutrons $m^{-2}s^{-1}$ at 1 m from the reactor core. (1 point)

a) Assuming a parallel beam of neutrons diffusing up to the surface of the pool where the neutron flux is measured to be 10^8 n $m^{-2}s^{-1}$, calculate the thickness of the heavy water layer.



$$\cancel{\phi^0(r) = \frac{S_p}{4\pi r^2} \rightarrow \phi^0(1) = 3\times10^{16} = \frac{S_p}{4\pi}}$$

$$\rightarrow S_p = 3.7699\times10^{17}$$

$$\cancel{\phi^0(r) = \frac{S_p}{4\pi r^2} \rightarrow r = \left(\frac{S_p}{\phi^0(r)\cdot 4\pi}\right)^{1/2}}$$

$$\cancel{R = \left(\frac{3.7699\times10^{17}}{10^8\cdot 4\cdot\pi}\right)^{1/2} = \boxed{17320.5\ m}}$$

$$\phi = \phi_0 e^{-\frac{x}{L}} \rightarrow x = -L\ln\left(\frac{\phi}{\phi_0}\right) \qquad L = \frac{D}{\Sigma_\gamma} = \frac{1}{3\Sigma_s\Sigma_\gamma}$$

$$\Sigma_s = N^{D_2O}\left(2\cdot\sigma_s^{2H}\cdot 1 + 0.99757\cdot\sigma_s^{16O} + 0.0003835\cdot\sigma_s^{17O} + 0.002045\cdot\sigma_s^{18O}\right)$$

$$= 0.41855 \qquad \Sigma_\gamma = 4.01635\times10^{-5} \rightarrow \underline{L = 140.82\ cm}$$

$$x = -140.82\ln\left(\frac{10^8}{3\times10^{16}}\right) = 2748.707\ cm$$

$$\boxed{= 27.487\ m}$$

b) Why can these Canadian reactors use a lower enrichment of Uranium than normal water cooled reactors?

D_2O has a smaller scattering cross-section than H_2O so the neutrons stay as high energy neutrons longer and can interact with ^{238}U and decay to ^{239}Pu which is fissile