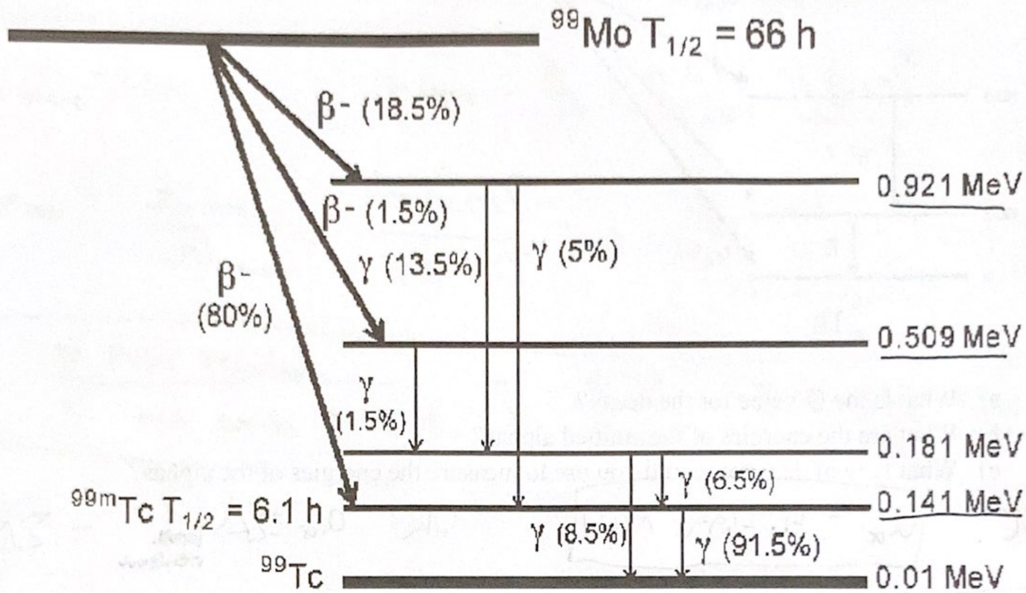
Radiation Interactions Final Exam **Name:** Josh Whitehead

1. (5 pts) Consider the following decay scheme:



a) What are the maximum beta energies for the decay of ^{99}Mo to the 3 energy levels in ^{99}Tc?

b) If a 22g mouse was injected with 2.4 x 10^5 Bq of ^{99}Mo that distributed evenly throughout the body, what is the average whole-body dose rate considering only the beta particles?

a.) $E_{max} = Q - E_{level}$ nndc: $Q_{\beta^-} = 1.358$ MeV

$\rightarrow 1.358 - 0.921 = \boxed{0.437 \text{ MeV}}$

$1.358 - 0.509 = \boxed{0.849 \text{ MeV}}$

$1.358 - 0.141 = \boxed{1.217 \text{ MeV}}$

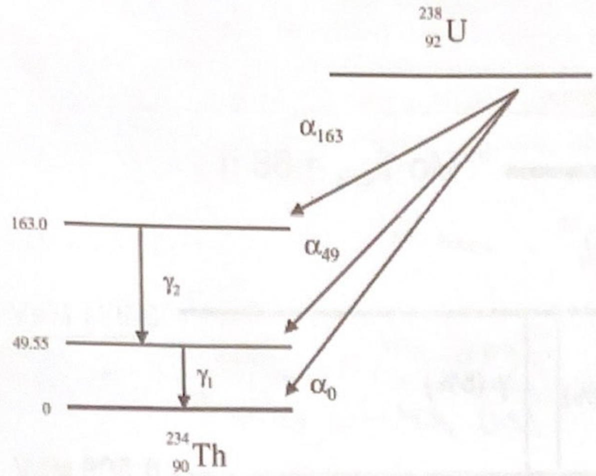
b.) $D = 1.6\times10^{-10}\, \Delta t\, E\, \frac{A}{m}$ $A = 2.4\times10^5$ Bq

$m = 22$ g

$\rightarrow \dot{D} = \frac{1.6\times10^{-10}\, E A}{m}$ $E = Q_{\beta^-} = 1.358$ MeV

$= \frac{1.6\times10^{-10}(1.358)(2.4\times10^5)}{22}$ $\boxed{= 2.37033\times10^{-6}\ \frac{Gy}{sec}}$

2. (5 pts) Consider the following decay scheme:



a) What is the Q-value for the decay?
b) What are the energies of the emitted alphas?
c) What type of detector would you use to measure the energies of the alphas?

a.) NNDC: $\boxed{Q_\alpha = 4.2699 \text{ MeV}}$ OR $Q_\alpha = \sum \Delta_{\text{react reactant}} - \sum \Delta_{\text{Prod}}$

$= 47.3077 - 2.4249 - 40.613$

$= 4.2698$ ✓

b.) $E_\alpha =$ 0.163 MeV
0.04955 MeV
0 MeV

$E_{\alpha, max} = Q_\alpha - E_\alpha = \left. \begin{array}{l} 4.2699 - 0.163 \\ 4.2699 - 0.04955 \\ 4.2699 - 0 \end{array} \right\} \begin{array}{l} = 4.1069 \text{ MeV} \\ = 4.22035 \text{ MeV} \\ = 4.2699 \text{ MeV} \end{array}$

c.) $\boxed{\text{Semiconductor}}$

3. (10 pts) You have a thin circular detector with a radius of 3 cm that is 1.5 meters away from a point source. What is the fraction of the activity that intersects with the detector? You measure the counts per second for a 30 min exposure to be 4.5 x 10^4, what is the efficiency of the detector if the point source emits 5 x 10^6 511 keV photons/s assuming there is no detector dead time? What is the standard deviation of the measurement we would quote if there were a 90% probability it contains the true mean?

$\Omega_{sphere} = 4\pi$ $\qquad \Omega_{detect} = \frac{A}{r^2} = \frac{\pi R^2}{r^2} = \frac{\pi (0.03)^2}{1.5^2}$

$\rightarrow$ frac: $\frac{\Omega_{detect}}{\Omega_{sphere}} = \frac{\pi (0.03)^2}{4\pi (1.5)^2} = 0.0001 \boxed{= 0.01\ \%}$

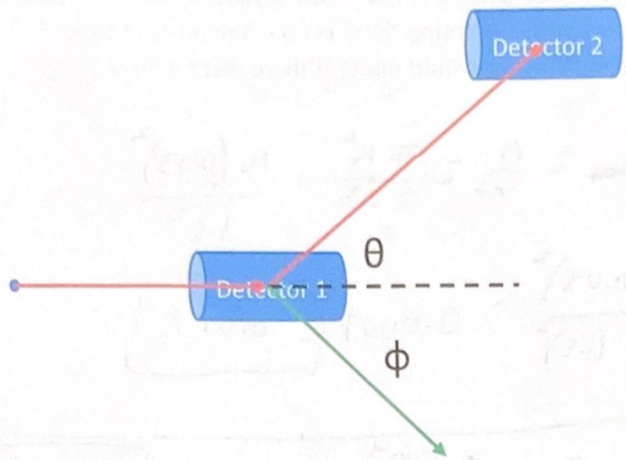
$\text{Eff} = \frac{\#\text{ Pulse recorded}}{\#\text{ rad quanta emitted}} = \frac{4.5\times10^4}{5\times10^6} = 0.009 \boxed{= 0.90\ \% \text{ for 511 keV}}$

for 90%: $x \pm 1.64\sigma = x \pm 1.64\sqrt{x}$

$= 4.5\times10^4 \pm 1.64\sqrt{4.5\times10^4} = 4.5\times10^4 \pm$ ~~[illegible]~~ 347.90

$\boxed{= 4.5\times10^4 \pm 347.90}$

4. (5 pts) Consider the following set up:



a) If you have a ^{137}Cs point source, at what angle would you place detector 2 to observe a scattered photon of 400 keV?

b) What would be the energy and angle of the scattered electron?

table 1.6.1

$E_{\gamma'} = 400$ keV

$E_\gamma = 661.657$ keV

$m_e c^2 = 511$ keV

a.) $\frac{1}{E_{\gamma'}} - \frac{1}{E_\gamma} = \frac{1-\cos\theta}{m_e c^2}$

$\rightarrow \cos\theta = 1 - 511\left(\frac{1}{E_{\gamma'}} - \frac{1}{E_\gamma}\right) = 1 - 511\left(\frac{1}{400} - \frac{1}{661.657}\right) = 0.494803$

$\theta = \cos^{-1}(0.4948) = 1.053188 \boxed{= 60.34°}$

b.) $T_e = E_\gamma - E_{\gamma'} = 661.657 - 400 \boxed{= 261.657 \text{ keV}}$

$\tan\phi = \frac{\sin\theta}{\left(1 + \frac{E_\gamma}{511}\right)\cos\theta} = 0.765314$

$\phi = \tan^{-1}(0.765314) = 0.65323$

$\boxed{= 37.43°}$

5. (10 pts) Calculate the stopping power (dE/dx) of 30 MeV $^{12}C^{6+}$ particle interacting with Aluminum? Given the SRIM output graph the Bragg peak for this interaction. At what distance is the maximum energy deposition?

$$\frac{-dE}{dx} = \underbrace{4\pi N_A r_e^2 m_e c^2}_{0.3071 \frac{MeV\,cm^2}{g}} \rho \frac{Zq^2}{A\beta^2}\left(\ln\left(\frac{W_{max}}{I}\right) - \beta^2\right)$$

$\rho = 2.26 \frac{g}{cm^3}$

$A = 12$

$Z = 6$

$q = 6$

$$\beta = \left[1 - \left(\frac{931.5}{931.5 + \frac{E}{A}}\right)^2\right]^{1/2}$$

$$\gamma = \frac{1}{(1-\beta^2)^{0.5}}$$

$$W_{max} = 2 m_e c^2 (\gamma\beta)^2$$

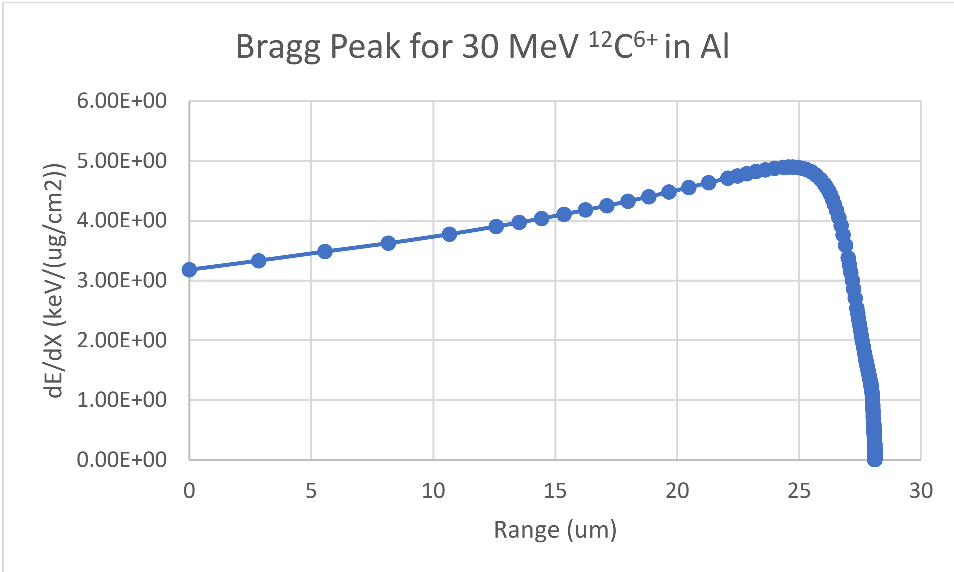
$$\frac{I}{Z} = (12 + 7Z^{-1})\,eV = \left[\frac{\left(12 + \frac{7}{Z}\right)}{1000000}\right] MeV$$

$$\frac{dE}{dx} = 51587.07 \cancel{}$$

$$\boxed{= 51587.07 \frac{MeV}{cm}}$$

The maximum energy deposition occurs @ about ~~[illegible]~~

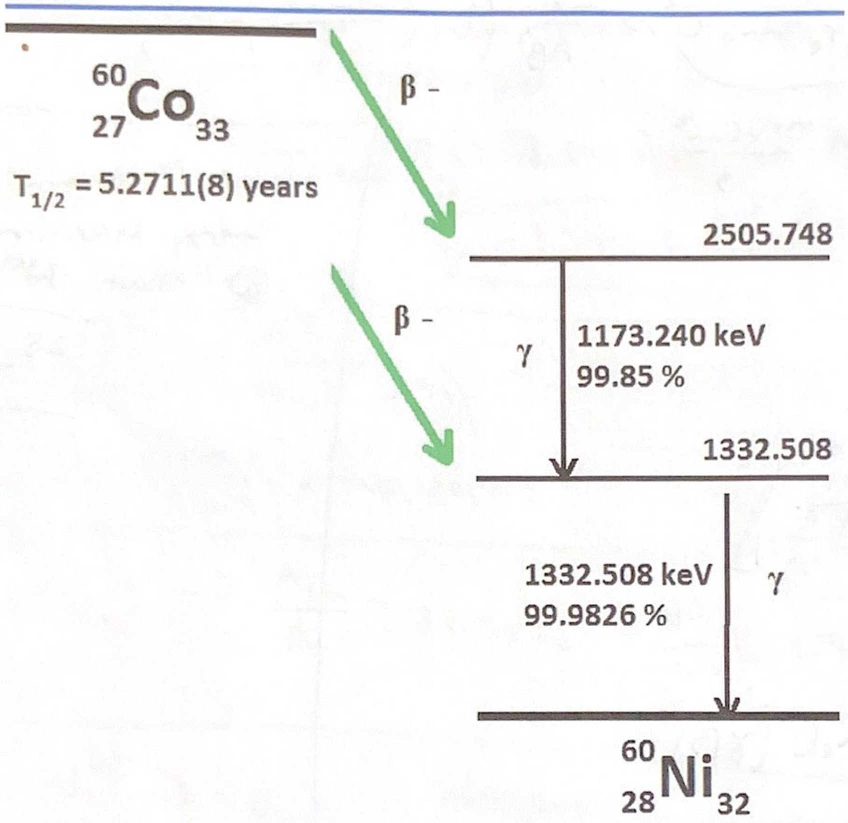
$\boxed{25\,\mu m}$


Bragg Peak for 30 MeV ¹²C⁶⁺ in Al
6.00E+00
5.00E+00
4.00E+00
3.00E+00
2.00E+00
1.00E+00
0.00E+00
dE/dX (keV/(ug/cm2))
0
5
10
15
20
25
30
Range (um)

6. (15 pts) You have a 20 mCi point source of ^{60}Co (decay scheme below). What is the dose rate at 0.25 cm and 30 cm from the source? How much lead shielding do you need to reduce the dose rate at 30 cm by 95%? (Use the attenuation coefficient for the 1332 keV photon). What detector would you use to measure the dose rate?

dose $\neq$ exposure

$1R \approx 0.95$ rad



$\text{Exposure} = \dfrac{\Gamma \lambda_d N t}{r^2}$

$\Gamma = 13.2 \dfrac{R\,cm^2}{mCi\,h}$

$\lambda_d N = 20\,mCi$

$r = 0.25,\ 30$

Use Inorganic Scintillator like NaI(Tl)

$0.25\,cm: \dfrac{Exp}{t} = \dfrac{13.2(20)}{0.25^2} = 4224 \dfrac{R}{hr} \approx \boxed{4012.8 \dfrac{rad}{hr}}$

$30\,cm: \dfrac{Exp}{t} = \dfrac{13.2(20)}{30^2} = 0.2933 \dfrac{R}{hr} \approx \boxed{0.2787 \dfrac{rad}{hr}}$

$\boxed{4.422\ cm\ \text{lead needed}}$

$I = I_0 \exp(-\mu_t x) \rightarrow x = \dfrac{\ln\left(\frac{I}{I_0}\right)}{-\mu_t}$

$I = 0.05 I_0 \quad \therefore x = \dfrac{\ln\left(\frac{0.05 I_0}{I_0}\right)}{-0.6774}$

$\mu_m = 0.06$

$\mu_t = 0.06 \left(11.29 \dfrac{g}{cm^3}\right) = 0.6774$

7. (10 pts) Consider the following nuclear reaction: $^{103}Rh(p,n)^{103}Pd$

a) Calculate the Q-Value for this reaction

b) Calculate the Coulomb (lab) barrier for this reaction

c) Calculate the threshold energy in the lab system required for the production of ^{103}Pd

d) At what energy will this reaction begin?

a.) $Q = \sum \Delta_{Prod} - \sum \Delta_{react} = (-88.0317) + (7.2889711) + (87.4570) - (8.0713171)$

$\boxed{= -1.35705 \text{ MeV}}$

b.) $V_C = \dfrac{1.44 Z_{Pr} Z_T}{1.2 (A_{Pr}^{1/3} + A_T^{1/3})} = \dfrac{1.44 (1)(45)}{1.2 (103^{1/3} + 1)} = 9.494425$

$A_{CN} = A_T + A_{Pr} = 103+1$

$V_C^{lab} = \left(\dfrac{103+1}{103}\right) \cdot 9.494425$ ~~9.494425 MeV~~ $\boxed{9.586604 \text{ MeV}}$

c.) $E_{th} = -Q \dfrac{A_{CN}}{A_T} = +1.35705 \cdot \dfrac{104}{103} = \boxed{1.370225 \text{ MeV}}$

d.) $V_C^{lab} > E_{th} \therefore$ ~~reaction will~~

rxn will occur at energies higher than 9.586604 MeV

8. (10 pts) A measurement of possible ^{57}Co contamination on an air filter is made on a daily basis. The measurement consists of placing the filter in a counting system with an absolute gamma ray counting efficiency of 5% at 122 keV for a period of 60 min. You count the air filter for 60 minutes and obtain 225 counts/min. If a background count of 60 minutes resulted in 200 counts/min can you positively say there was ^{57}Co contamination on the air filter?

$N_S = N_T - N_B = (225 - 200)\,60 = 1500$ Counts

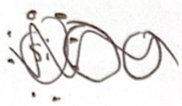
$L_C = 2.326\sqrt{200 \cdot 60} = 254.8$ Counts

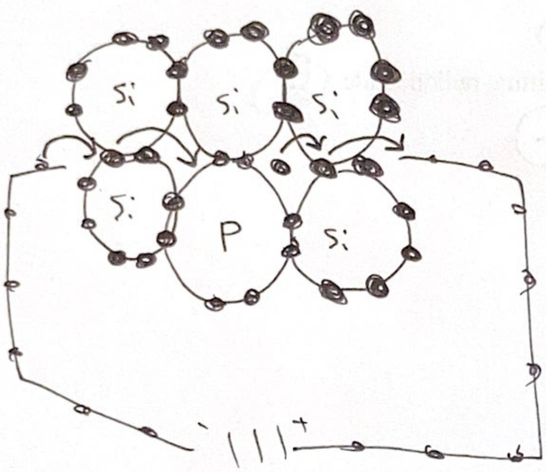
$N_S \gg L_C \quad \therefore$ Yes

9. (10 pts) Describe with illustrations how an n-type semiconductor detector functions.

An n-type semiconductor has Si doped with P.

P has 1 extra valence electron so the e^- is free to move around which can produce current





10. (5 pts) Match each detector to an appropriate application:

Ion Chamber 1

Geiger Mueller Detector 2

Proportional Detector 3

High Purity Germanium Detector 4

Liquid Scintillation Counter 5

Survey a lab bench for contamination 5

Measure count rate of a thin sample of a beta emitting radionuclide 3

Measure the dose of a high activity source 1

Determine the identity of an unknown gamma emitting radionuclide 4

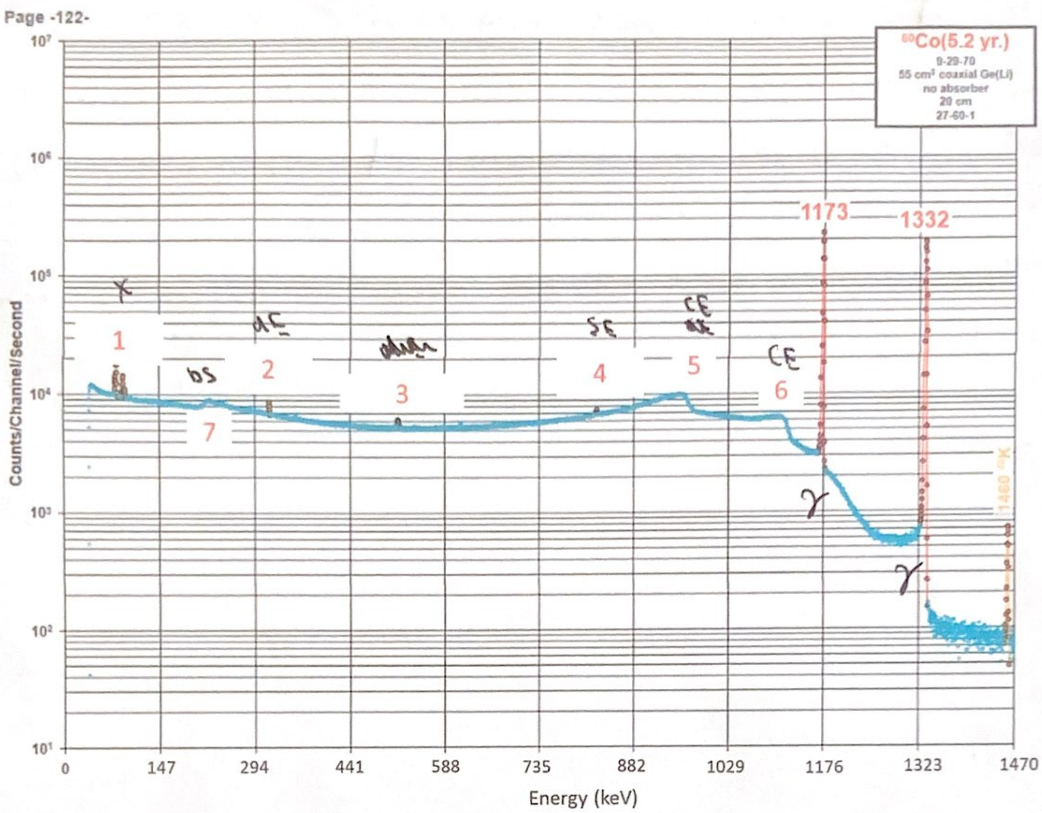
To measure ultra-trace alpha contamination 2

11. (5 pts) Illustrate and describe how a NaI(Tl) scintillator works.

NaI (Tl) is an inorganic scintillator.

The radiation interacts with NaI and produces a flash of light. The crytal is doped with Tl so the emitted light is in the visible range. The impurity provides an energy level in the forbidden area to provide the proper energy of γ

12. (10 pts) Below is the HPGe spectra for ^{60}Co. Identify and explain the labeled artifacts in the spectrum.



1.) X-ray – γ interacts with shield (high Z) and produces lower energy X-rays

2.) Double escape – occurs at (E_γ – 1.02 MeV $\approx$ 312 keV) the γ produces e^-, e^+ pair which can annihilate and produce 2 more γ which both escape

3.) no escape ~~noise~~ – γ produces e^+, e^- and the annihilate but don't escape but have lower energy than incident γ

4.) Single escape – Same as double escape but only one γ escapes occurs @ E_γ – 0.511 MeV

5.) Compton Edge – occurs @ E_γ – 255 due to Compton scattering of incident γ

6.) Compton edge

7.) back scatter – γ hits shield and scatters back to detector