

22.01 Problem Set 7 Homework Solutions

1. (4 points) Pure crystalline silicon ingots are irradiated in the MIT reactor to produce n-type semiconductor material for industry. Describe the nuclear reaction that occurs in silicon to produce the “doped” silicon. Be specific.

Crystalline silicon has the following isotopes with abundances in percent: ^{28}Si (92.23%), ^{29}Si (4.67%), and ^{30}Si (3.10%). Neutron activation of ^{28}Si goes to ^{29}Si and of ^{29}Si goes to ^{30}Si . Both of these isotopes are not n-type dopants and are both stable and will not decay to anything else.

The neutron activation of ^{30}Si gives ^{31}Si , which will β^- decay 100% of the time to ^{31}P . This phosphorus is now going to give the n-type doped silicon crystal.

2. (5 points) For cells that show a linear dose response relationship when plotted as log survival vs dose, explain why D_0 is considered to be the “mean lethal dose”.

The equation that describes a linear dose response relationship for survival is:

$$SF = e^{-D/D_0} \quad (13.14)$$

When the dose, D , equals D_0 , this is the dose that will give a cell survival of 37%. When looking at the Poisson distribution and saying that it takes a mean of 1 hit per cell to kill the cell and seeing the number of hits of 0, survival, the distribution gives:

$$P(n) = \frac{e^{-\bar{n}} \cdot e^{-n}}{n!} = \frac{e^{-1} \cdot e^{-0}}{0!} = .37$$

which is the same as the 37% we get from the survival curve. Hence this tells us that D_0 is the mean dose for cell death as described by a mean of 1 hit per cell to kill target theory.

3. (5 points) Calculate the effective dose to an individual who has received the following exposures:

- 5 mGy alpha to the lung
- 10 mGy thermal neutron, to the skin
- 5 mGy gamma, whole body
- 100 mGy beta to the thyroid.

The effective dose is defined by multiplying the absorbed dose by a weighing factor for the type of dose and where that dose in the body was deposited. Solving the following equation for each type of dose to the body:

$$E = \sum_{R,T} w_R w_T D_{R,T}$$

	Radiation	D (mGy)	w _R	w _T	E (mSv)
Lung	Alpha	5	20	0.12	12
Skin	Thermal Neutron	10	5	0.01	.5
Whole body	Gamma	5	1	1.0	5
Thyroid	Beta	100	1	0.05	5
				Total	22.5

Therefore the total effective dose is **22.5 mSv**.

4. (6 points) If the absolute risk of lung cancer from radon exposure is 5×10^{-3} /person-year/Sv, calculate the annual number of lung cancer cases expected in a population of 150×10^6 persons from exposure to 4 pCi/L of indoor radon. The dose conversion factor for lung epithelial cells is 0.75 Gy/WLM. State any assumptions you need to make.

We need to calculate the effective dose to the lung from this exposure to indoor radon. Converting to the working level, WL:

$$4 \frac{\text{pCi}}{\text{L}} \cdot \frac{\text{L}}{100 \text{ pCi}} = 0.04 \text{WL}$$

We will assume a 365-day exposure time, or 8760 hours. Calculating the working – level months (WLM):

$$\text{WLM} = \frac{\text{WL} \cdot \text{exposure}(\text{hrs})}{170 \text{hrs}} = \frac{0.04 \times 8760}{170} = 2.06$$

Now calculating for the absorbed dose and then finding the effective dose and equivalent dose by taking in the weighing factors for alpha particles and for lung as the target organ:

- Physical dose = 2.06 WLM * 0.75 = 1.54 Gy
- $H_T = QD_{T,R} = (20) \cdot (1.54) = 30.92 \text{ Sv}$
- $E = w_T H_T = (0.12)(30.92) = 3.71 \text{ Sv}$

The number of annual number of lung cancer cases expected in a population is then:

$$5 \times 10^{-3} \frac{\text{Sv}}{\text{person} \cdot \text{year} \cdot \text{Sv}} \cdot 3.71 \text{Sv} \cdot 150 \times 10^6 \text{ person} = 2,782,500 \text{ yr}^{-1}$$

5. (6 points) Given the following cell survival data:

<u>X rays</u>		<u>α-particles</u>	
Dose (cGy)	Surviving fraction (%)	Dose (cGy)	Surviving fraction (%)
0	100	0	100
330	60	100	45
620	28	200	15
826	12	400	2.5
1239	1.7	600	0.45
1653	0.11	800	0.06
2479	0.0009	1200	0.0015

- a. Estimate the RBE of the α -particles relative to the x-rays. Explain how you determined the RBE.

The plot of the data is attached at end of problem. RBE is determined by looking at the surviving fraction and seeing what dose of alpha particles and x-rays give the same biological effect. It is defined as:

$$RBE = \frac{D_{REF}}{D_{test}} = \frac{D_{x-rays}}{D_{alpha}}$$

- At 10% survival:

$D_{x-rays} \approx 880$ cGy, $D_{\alpha} \approx 250$ cGy, therefore, **RBE ≈ 3.52**

- At 1% survival:

$D_{x-rays} \approx 1310$ cGy, $D_{\alpha} \approx 500$ cGy, therefore, **RBE ≈ 2.62**

You can use any SF of the curve to determine the RBE.

- b. Estimate the D_0 value for the alpha particles and the x-rays.

D_0 is the 37% survival. For alpha particles, since the curve is linear we can read off the 37% survival at approximately **110 cGy**.

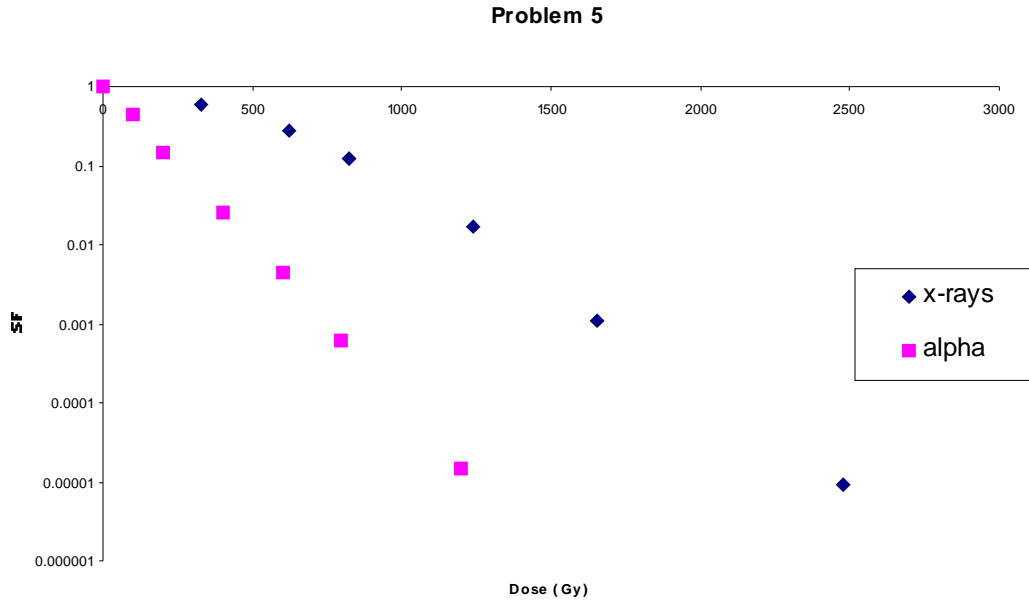
For x-rays, we need to work with the linear portion of the curve. The linearity begins around an SF of .01 with a dose of 1310 cGy and going down to SF of 0.0037 gives a dose of 1500 cGy. Therefore D_0 for x-rays is **190 cGy**.

- c. What is the extrapolation number, n, for the x-rays?

Extrapolation of the linear portion of the survival curve for x-rays gives **n ≈ 28** .

- d. Is the RBE higher or lower at 10% survival than at 1% survival? Give an explanation for this.

It is **higher**, because the dose difference from x-rays compared to alpha particles is larger for 10% survival than 1% survival. This is due to the repair shoulder of the x-ray curve where we see that much more x-ray dose is needed for the same survival as for alpha particles because we have cell repair from low LET radiation.



6. (4 points) A 50 cm^3 sample of water is given a dose of 2 Gy from 2 MeV protons. If the yield of OH radicals is $G = 1.44$ per 100 eV, how many OH radicals are produced in the sample?

First, we need to calculate the total energy deposited in the sample:

$$2 \frac{\text{J}}{\text{kg}} \cdot 0.05 \text{ kg} \cdot \frac{1 \text{ eV}}{1.6 \times 10^{-19} \text{ J}} = 6.25 \times 10^{17} \text{ eV}$$

Therefore the total OH radicals produced in the sample is:

$$\frac{1.44}{100 \text{ eV}} = \frac{x}{6.25 \times 10^{17} \text{ eV}} \Rightarrow x = 9 \times 10^{15} \text{ radicals}$$