E1

E1.1.1 1.8 pt

1st reading

Ascorbic Acid Concentration (mg)	Volume of DCPIP used (mL)		
	Initial	Final	Difference
Blank	5.00	5.40	0.40
25	5.00	9.60	4.60
50	5.00	11.20	6.20
100	5.00	25.00	20.00
150	5.00	33.90	28.90
200	5.00	51.80	46.80

E1.1.1 (Cont)

2nd reading

Ascorbic Acid Concentration (mg)	Volume of DCPIP used (mL)		
	Initial	Final	Difference
Blank	5.00	5.30	0.30
25	5.00	9.60	4.60
50	5.00	10.90	5.90
100	5.00	25.20	20.20
150	5.00	33.50	28.50
200	5.00	53.50	48.50

E1.1.2 Average reading

0.3 pt

Ascorbic Acid Concentration (mg)	Average volume of DCPIP used (mL)
Blank	0.35
25	4.60
50	6.05
100	20.10
150	28.70
200	47.65

E1.1.3
1.2 pt

1st reading

Ascorbic Acid Irradiation Dose	Volume of DCPIP used (mL)		
	Initial	Final	Difference
0	5.00	31.30	26.30
1	5.00	27.70	22.70
5	5.00	23.30	18.30
10	5.00	16.20	11.20

2nd reading

Ascorbic Acid Irradiation Dose	Volume of DCPIP used (mL)		
	Initial	Final	Difference
0	5.00	31.30	26.30
1	5.00	27.70	22.70
5	5.00	23.50	18.50
10	5.00	15.70	10.70

E1.1.4 Average reading

0.2 pt

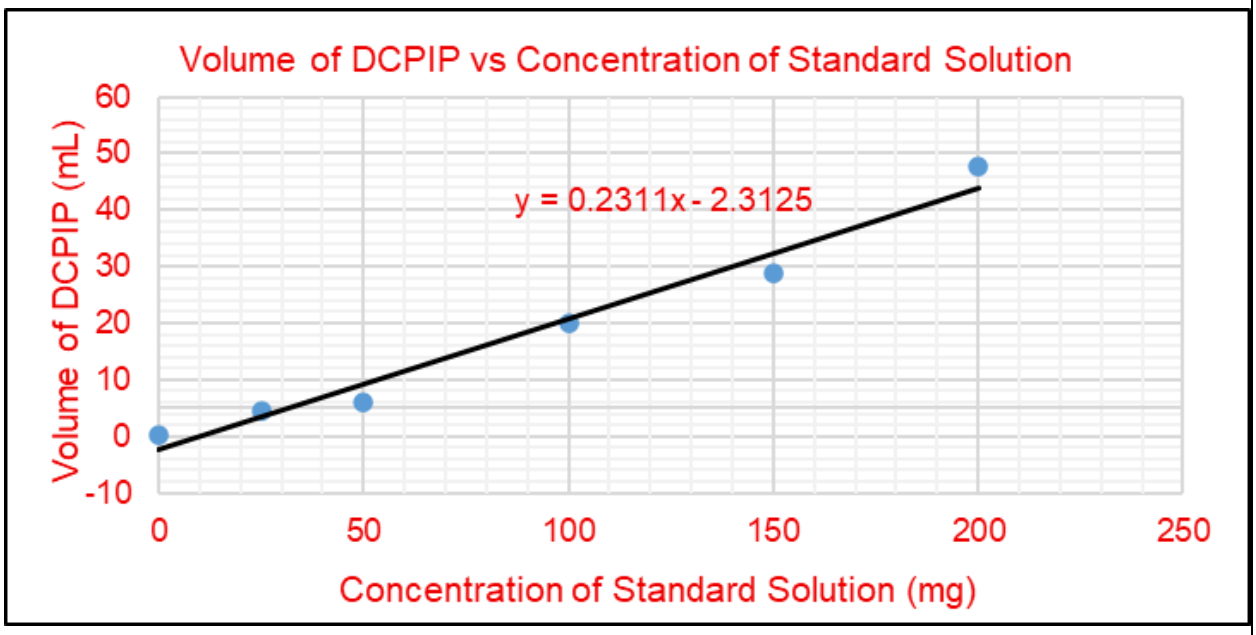
Ascorbic Acid Concentration (mg)	Average volume of DCPIP used (mL)
0	26.30
1	22.70
5	18.40
10	10.95

E1.1.5 0.3 pt	B

E1

E1.2.1

1.0 pt



Axis labelling

Graph usage >80%

Best fit line

Slope (m) = 0.2333

E1.2.2

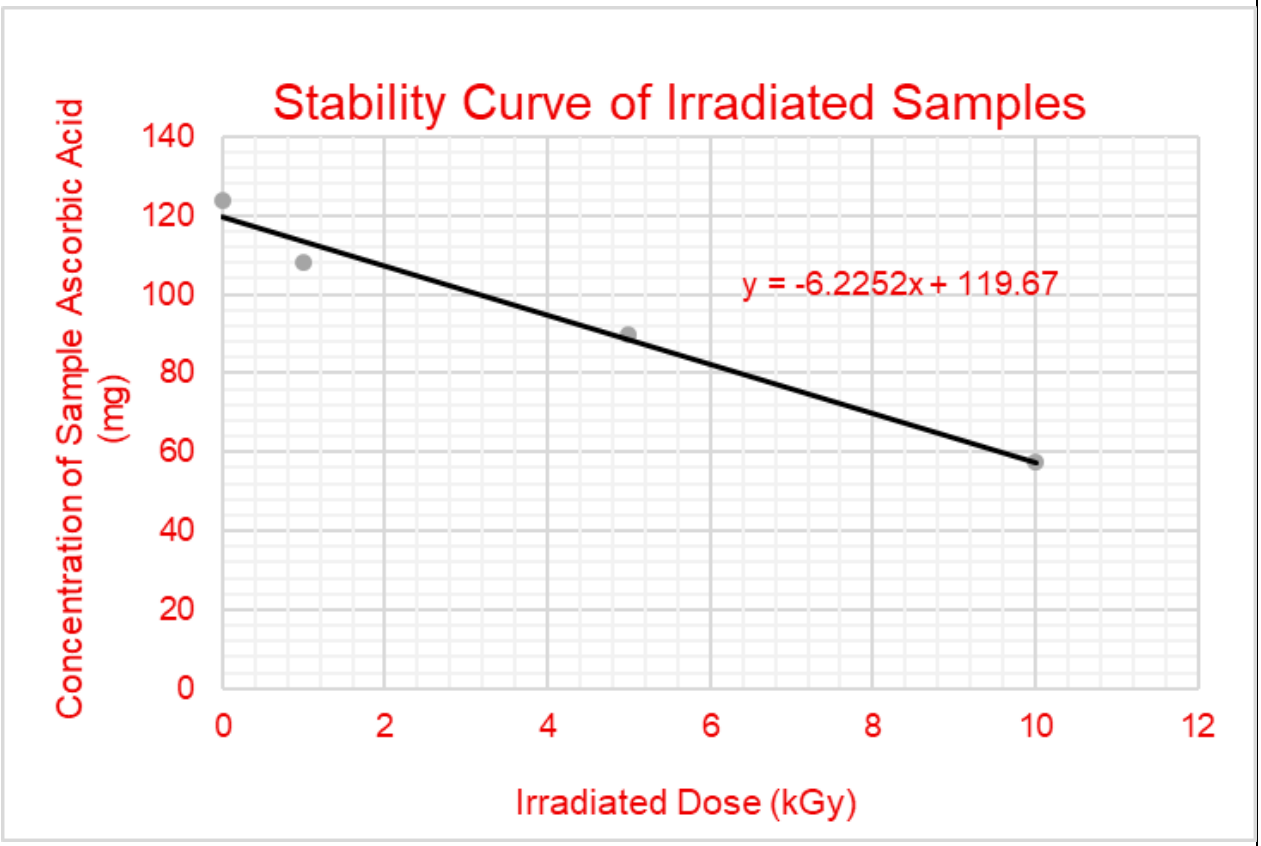
0.4 pt

Ascorbic Acid Irradiation Dose (kGy)	Concentration of Ascorbic Acid (mg)
0	123.81
1	108.23
5	89.63
10	57.39

E1.2.3 0.2 pt	Correct formula used $1\ kGy$ Ascorbic acid solution $\frac{22.70}{26.30} \times 100\% = 86.31\%$ $5\ kGy$ Ascorbic acid solution $\frac{18.40}{26.30} \times 100\% = 69.96\%$ $10\ kGy$ Ascorbic acid solution $\frac{10.95}{26.30} \times 100\% = 41.63\%$

E1.2.4

1.0 pt



Axis labelling

Graph usage >80%

Best fit line

Slope (m) = -5.2892

E1.2.5

0.4 pt

~ 8.4 kGy

E1.2.6 0.6 pt	$0\ kGy$ Standard deviation $SD = \sqrt{\frac{\sum (x_i - \overline{x})^2}{n-1}}$ $SD = \sqrt{\frac{(26.3-26.3)^2+(26.3-26.3)^2}{1}}$ $SD = \sqrt{0.00}$ $SD = 0.00\ mL$ $1\ kGy$ Standard deviation $SD = \sqrt{\frac{(22.7-22.7)^2+(22.7-22.7)^2}{1}}$ $SD = \sqrt{0.00}$ $SD = 0.00\ mL$ $5\ kGy$ Standard deviation $SD = \sqrt{\frac{(18.3-18.4)+(18.5-18.4)^2}{1}}$ $SD = \sqrt{0.02}$ $SD = 0.14\ mL$
E1.2.6 (Cont.)	$10\ kGy$ Standard deviation $SD = \sqrt{\frac{(11.2-10.95)^2+(10.7-10.95)^2}{1}}$ $SD = \sqrt{0.13}$ $SD = 0.35\ mL$

E1.3.1 0.6 pt	$R = k_0 + k_1 \times C$ Express R as $\frac{dC}{dD}$: $$\frac{dC}{dD} = -(k_0 + k_1 \times C)$$ A negative sign is used to indicate the reduction of C as D increases. Rearrange the equation to separate variable C to the left-hand side: $$\frac{dC}{k_0+k_1\times C} = -dD$$ Perform an integration on both sides of the equation: $$\int \frac{dC}{k_0+k_1\times C} = \int -dD$$ $$\frac{\ln k_0+k_1\times C}{k_1} = -D + Integration\ Constant$$ $$\ln k_0 + k_1 \times C = -D \times k_1 + K$$ Where K is a constant tied to the initial system. Exponentiate both sides to isolate C: $$k_0 + k_1 \times C = e^{-k_1 D} \times K$$ Rearrange to solve: $$C = \frac{e^{-k_1 D}\times K - k_0}{k_1}$$ K can be related to the initial concentration C_0, where $D = 0$. As $e^{-k_1 D} = 1$, which means: $$k_0 + k_1 \times C_0 = K$$

E1.3.1 (Cont.)	Hence the equation becomes: $$C = \frac{e^{-k_1 D}\times(k_0+k_1\times C_0) - k_0}{k_1}$$ $$C = \frac{e^{-k_1 D}\times k_0 - k_0}{k_1} + C_0 \times e^{-k_1 D}$$ $$C = \frac{k_0(e^{-k_1 D}-1)}{k_1} + C_0 \times e^{-k_1 D}$$ Final simplification, $$C = \frac{k_0}{k_1}\left(e^{-k_1 D} - 1\right) + C_0 \times e^{-k_1 D}$$

E1.3.2 0.2 pt

With the initial equation of **E1.3.1**,

$$C = \frac{k_0}{k_1}\left(e^{-k_1 D} - 1\right) + C_0 \times e^{-k_1 D}$$

$D = 15\ \mathrm{k}Gy$

$C_0 = 0.025\ \mathrm{M}$

$k_0 = 0.0015\ \mathrm{M}$

$k_1 = 0.12\ \mathrm{k}Gy^{-1}$

$$C = \frac{0.0015}{0.12}\left(e^{-1.8} - 1\right) + 0.025 \times 0.1653$$

$$C = -0.0063\ \mathrm{M}$$

E1.3.3 0.4 pt

With the initial equation of E1.3.1,

$$C = \frac{k_0}{k_1}\left(e^{-k_1 D} - 1\right) + C_0 \times e^{-k_1 D}$$

$$A = \frac{k_0}{k_1} = \frac{0.0015}{0.12}$$

$$A = 0.0125\ \ \mathrm{MkGy}$$

From here we can alter the equation to be:

$$C = A\left(e^{-k_1 D} - 1\right) + C_0 \times e^{-k_1 D}$$

$$C = -A + \left(C_0 + A\right) \times e^{-k_1 D}$$

$$e^{-k_1 D} = \frac{C + A}{C_0 + A}$$

By substituting the values into the equation:

$$D = 2.58\ \mathrm{k}Gy$$

E1.3.4
0.2 pt

With the values and equation given,

$$\frac{dC}{dD} = -\left(k_0 + k_1 \times C\right)$$

$D = 15\ \mathrm{k}Gy$

$C_0 = 0.025\ \mathrm{M}$

$k_0 = 0.0015\ \mathrm{M}$

$k_1 = 0.12\ \mathrm{k}Gy^{-1}$

$$\frac{dC}{dD}(0) = -\left(k_0 + k_1 \times C\right)$$

$$\frac{dC}{dD}(0) = -\left(0.0015 + 0.12 \times 0.025\right)$$

$$\frac{dC}{dD}(0) = -0.0045\ \mathrm{MkGy}^{-1}$$

E1.3.5
0.6 pt

$$C = \frac{k_0}{k_1}\left(e^{-k_1 D} - 1\right) + C_0 \times e^{-k_1 D}$$

First term:

$$\frac{k_0}{k_1}\left(e^{-k_1 D} - 1\right)$$

$$-\frac{k_0}{k_1} \times k_1 e^{-k_1 D} = k_0 e^{-k_1 D}$$

Second term:

$$C_0 \times e^{-k_1 D}$$

$$-k_1 C_0 e^{-k_1 D}$$

Hence:

$$\frac{dC}{dD} = -k_0 e^{-k_1 D} - k_1 C_0 e^{-k_1 D}$$

OR

$$-\frac{dC}{dD} = k_0 + k_1\left(\frac{k_0}{k_1}\left(e^{-k_1 D} - 1\right) + C_0 e^{-k_1 D}\right)$$

$$-\frac{dC}{dD} = k_0 + k_0\left(e^{-k_1 D} - 1\right) + k_1 C_0 e^{-k_1 D}$$

$$\frac{dC}{dD} = -k_0 e^{-k_1 D} - k_1 C_0 e^{-k_1 D}$$

E1.3.6 0.2 pt	With the condition, $\frac{dC}{dD} = -e^{-k_1 D}\left(k_0 + k_1 C_0\right)$ $\frac{dC}{dD}\left(D^*\right) = \frac{1}{2}\frac{dC}{dD}\left(0\right)$ $-e^{-k_1 D^*}\left(k_0 + k_1 C_0\right) = -\frac{1}{2}e^{-k_1(0)}\left(k_0 + k_1 C_0\right)$ $-e^{-k_1 D^*}\left(k_0 + k_1 C_0\right) = -\frac{1}{2}\left(k_0 + k_1 C_0\right)$ $e^{-k_1 D^*} = \frac{1}{2}$
E1.3.7 0.4 pt	$-k_1 D^* = \ln \frac{1}{2}$ $-k_1 D^* = -\ln 2$ $D^* = 5.78\mathrm{k}Gy$

E2.1.1	Complete the following table based on the provided data and information. Write the answers in 2 decimal places for standard deviation and relative uncertainty. Assuming the underlying decay process is Poisson distributed.	2.0 points

Table E2.2 Statistical analysis of the area monitors measurement

Area Monitor	Average Count Rate	Net Count Rate	True Count Rate	Standard Deviation (σ)	Relative Uncertainty (%)
1	15928	15915	79575	126.2	0.79
2	39802	39789	198945	199.5	0.5
3	79590	79577	397885	282.1	0.35
4	8855	8842	44210	94	1.06

0.1 points for each correct answer

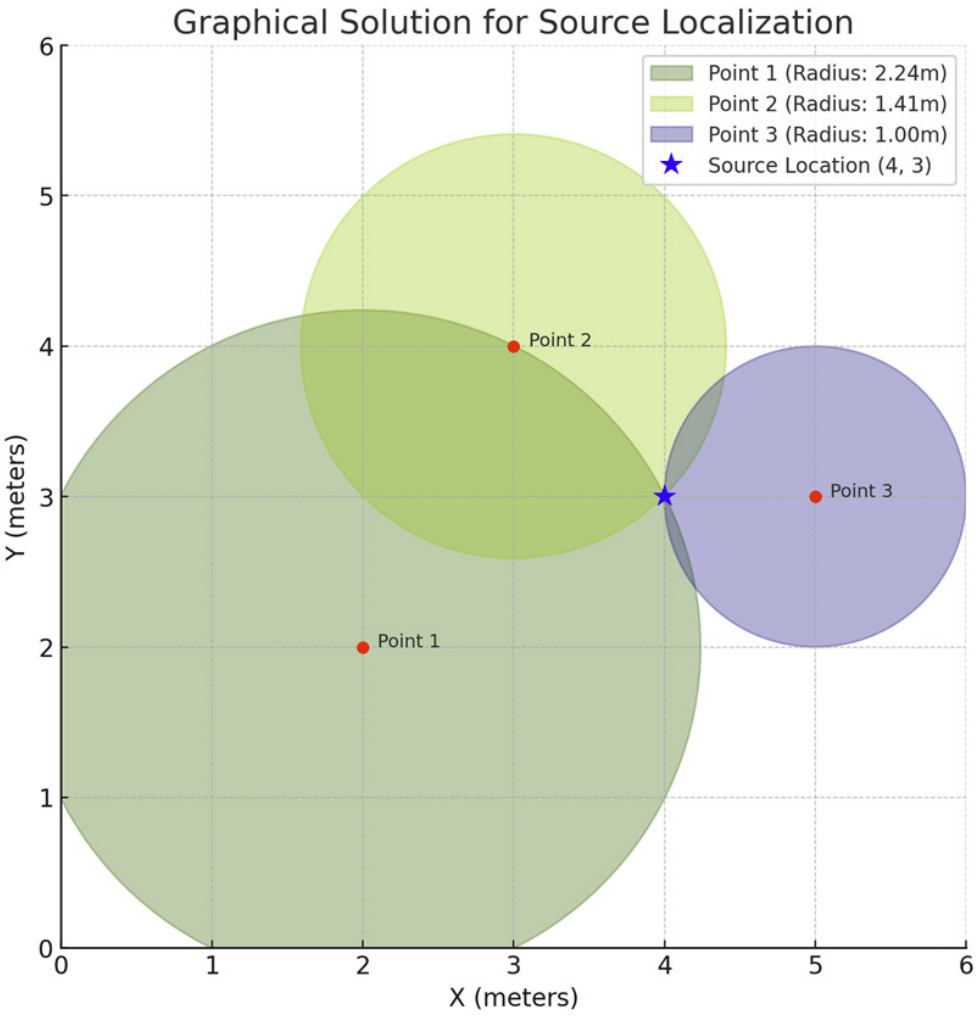
Error within 5% is acceptable

E2.1.2	You observe an unexpected spike of 17000 CPS on area monitor 1 and 9000 CPS on area monitor 4. To determine if the observed spikes are outliers requiring further investigation, use the following criteria: • If $Z > 2$, the spike is considered an outlier and requires further investigation • If $Z \leq 2$, the spike is considered a normal fluctuation and no immediate action is required Calculate the Z-score for the recorded CPS spikes and determine whether each spike should be considered a normal fluctuation or an outlier requiring investigation.	0.4 points
Answer	• Area Monitor 1: Z=32.26; outlier • Area Monitor 4: Z=1.54; normal Answer within 5% error is acceptable	0.2 0.2
	Total	0.4

E2.2.1	Using the true count rate (CPS) values, apply the inverse square law to calculate the distance of the source from monitor 1 to 4. Write the answers in 2 significant figures.	0.6 points
Answer	Source distance from, • Monitor 1: 2.24 m • Monitor 2: 1.41 m • Monitor 3: 1.00 m • Monitor 4: 3.00 m	 0.15 0.15 0.15 0.15
	Total	

E2.2.2	Choose 3 area monitors with the smallest distance to the source. Next, plot and triangulate the position of the missing source (x_s, y_s) on a graph paper. You may assume the source is a point emitter	1.0 points

Plot the data position in the graph to find the source location. Draw a circle around each area monitor to represent the potential source location, source position will be the intersection of the 3 circles.



Marks:

- Correct area monitor positions (0.1 + 0.1 + 0.1 = 0.3 pts)
- Correct circle plot (0.2 + 0.2 + 0.2 = 0.6 pts)
- Correct intersection i.e the source position (0.1 pts)

Final answer: From the graph; the coordinate of (x_s, y_s) is at (4,3)

	Total	

E2.2.3	Verify the missing source coordinates (x_s, y_s) by solving the simultaneous equations of the distance $r^2 = (x_s - x_i)^2 + (y_s - y_i)^2$.	1.0 points
Answer	**Correct substitution for area monitor 1,2,3 equations(0.1 marks each)** Area monitor 1 : $(x_s - 2)^2 + (y_s - 2)^2 = 5 \Rightarrow x_s^2 + y_s^2 - 4x_s - 4y_s + 3 = 0$ (Eq1) Area monitor 2 : $(x_s - 3)^2 + (y_s - 4)^2 = 2 \Rightarrow x_s^2 + y_s^2 - 6x_s - 8y_s + 23 = 0$ (Eq2) Area monitor 3 : $(x_s - 5)^2 + (y_s - 3)^2 = 1 \Rightarrow x_s^2 + y_s^2 - 10x_s - 6y_s + 33 = 0$ (Eq3) **Correct simultaneous equation (max 2 equations - 0.15 marks each)** Option A: Eq1 = Eq2 Option B: Eq1 = Eq3 Option C: Eq2 = Eq3 **Form any two linear equations by subtracting pairs of expanded equations >> show x_s^2 and y_s^2 elimination (0.1 marks each)** Option A: Eq1 – Eq2 $\Rightarrow x_s + 2y_s = 10$ (Linear Eq A) Option B: Eq1 – Eq3 $\Rightarrow 3x_s + y_s = 15$ (Linear Eq B) Option C: Eq2 – Eq3 $\Rightarrow 2x_s - y_s = 5$ (Linear Eq C) **Solve the two linear equations and compute correct x_s and y_s (0.1 marks each)** Example: From linear Eq A $\Rightarrow x_s = 10 - 2y_s$ Substitute into Linear Eq B $\Rightarrow 3(10 - 2y_s) + y_s = 15 \Rightarrow y_s = 3$ $\Rightarrow x_s = 10 - 2(3) = 4$ Final answer: $(x_s, y_s) = (4, 3)$	0.3 0.3 0.2 0.2

	Total	1.0

E2.3.1	If you plan to spend 30 minutes (0.5 hours) at a distance of 1 meter from the radiation source, calculate your total exposure in sieverts. Use the conversion factor: 1mR=10μSv	0.5 points
Answer	Formula: Exposure=Dose Rate x Time • The radiation intensity at 1 meter is 500 mR/h • To find the exposure in μSv for 30 minutes (0.5 hours) • 500 x 0.5 =250 mR Convert mR to μSv: 250 mR x 10 Total exposure=2500 μSv or = 2.5 mSv = 0.0025 Sv	0.1 0.2 0.1 0.1
	Total	

E2.3.2	You are using shielding material that reduces your exposure by 50%. Assuming that you are working at the same distance as in E2.3.1, calculate your total exposure after working for 30 minutes.	0.3 pts
Answer	Formula: Reduced Exposure = Original Exposure x (1- Reduction percentage)	0.1
	= 250 mR x (1- 0.5)	0.1
	= 125 mR	0.1
	Total	

E2.3.3	You need to maintain the same total exposure limit (100 mR) but allowed to move closer to the source. If you move to a distance of 0.5 meters from the source, how much time can you work safely, considering the inverse square law of radiation?	1.0 points
Answer	Using inverse square law, the new dose rate at 0.5m is 2000mR/h	0.5
	Exposure limit = Dose rate x Time, can work for 0.05 hrs (3 minutes)	0.5
	Total	

E2.3.4	As you are dealing with a sealed Cs-137 source, your primary concern is external exposure. However, if the source were unsealed, state 3 ways how Cs-137 could enter your body and lead to internal exposure.	0.3 points
Answer	Inhalation	0.1
	Ingestion	0.1
	Through opening or injury on the skin or wound	0.1
	Total	

E2.3.5	A worker inhales Cs-137 particles with an activity of $1.0 \times 10^{6}\,\mathrm{Bq}$. It is assumed that the inhaled Cs-137 remains lodged in the respiratory tract for the entire year. Given that the dose conversion factor (DCF) for Cs-137 inhalation is $1.3 \times 10^{-8}\mathrm{Sv/Bq}$, calculate the worker's annual committed effective dose (CED) in Sieverts.	0.2 points
Answer	CED= A x DCF = 0.013 Sv	0.2

E2.4.1	Calculate average reading and net reading for each shielding thickness in Table 3 below. Given the background reading is 83.75 cpm. Please answer in two decimal places.	0.8 points

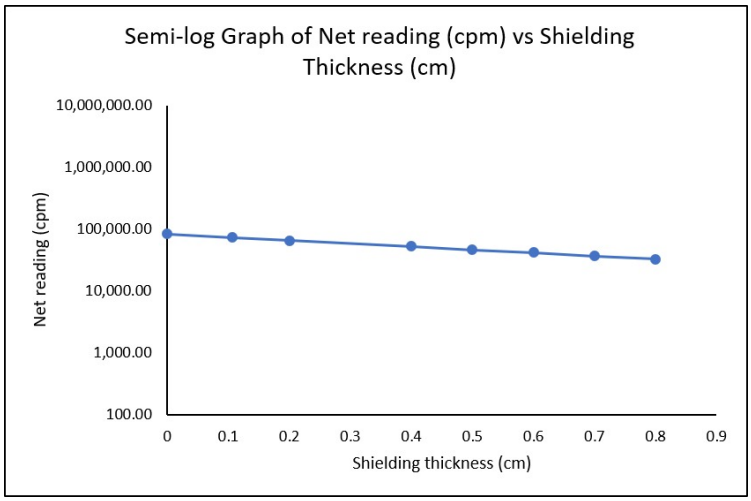
Table 3 Recorded measurements of radioactivity in CPM at different thickness shielding.

Shielding Thickness [cm]	First Reading [cpm]	Second Reading [cpm]	Average [cpm]	Net Reading [cpm]
0	82,900	82,800	82,850.00	82,766.25
0.107	73,000	73,300	73,150.00	73,066.25
0.2	65,900	64,700	65,300.00	65,216.25
0.4	52,900	51,600	52,250.00	52,166.25
0.5	46,800	46,200	46,500.00	46,416.25
0.6	41,700	41,600	41,650.00	41,566.25
0.7	37,100	36,500	36,800.00	36,716.25
0.8	32,800	32,500	32,650.00	32,566.25

0.05 points for each correct answer

Only exact answers are accepted.

E2.4.2	Plot a semi-log graph of Net reading against Shielding thickness.	0.5 points



Plot graph [0.2 points]

Graph title [0.1 points]

Linear Graph [0.1 points]

Axis Labels with unit [0.1 points]

E2.4.3	Based on the graph, if the shielding thickness is 0.3 cm, determine the net reading in cpm.	0.1 points
Answer	Acceptable value in the range: 56,000 - 58,000 cpm	0.1
	Total	

E2.4.4	From the graph, determine the half-value layer (HVL)	0.2 points
Answer	HVL is 0.6 cm. A range between 0.55 and 0.65 cm is acceptable.	0.2
	Total	

E2.4.5	Calculate the linear attenuation coefficient of the lead shielding.	0.1 points
Answer	Linear attenuation coefficient is $1.155\ \mathrm{cm}^{-1}$. 5% error is acceptable.	0.1
	Total	

E2.4.6	Determine the tenth-value layer of the lead shielding.	0.1 points
Answer	TVL=1.994 cm. 5% error is acceptable.	0.1
	Total	

E2.4.7	Determine the mass attenuation coefficient (μ_m) of the lead shielding. The density of lead is 11.35 g/cm^3	0.1 points
Answer	mass attenuation coefficient is $0.102\ \mathrm{cm}^2/\mathrm{g}$. 5% error is acceptable.	0.1
	Total	

E2.4.8	Calculate the required thickness in cm to reduce the count rate to 1% of its initial value. Please answer in one decimal place.	0.2 points
Answer	Thickness is around 4.0 cm. 5% error acceptable	0.2
	Total	

E2.4.9	Calculate the weight (in kg) of the minimum thickness lead shielding required (from the question at E2.4.7) to 1% shield the missing source around 1 m^2 area.	0.3 points
Answer	Mass is 453.6 kg. 5% error is acceptable.	0.3
	Total	

E2.4.10	If a different material such as concrete (density=2.33 g/cm^3, mass attenuation coefficient at 662 keV = 0.07 cm^2/g) were used instead of lead, determine the required thickness of concrete to achieve count rate to 1% of its initial value. Please answer in one decimal place.	0.3 points
Answer	Thickness of concrete is 28.3 cm. Error of around 5% is acceptable	0.3
	Total	