1)

b	i	(ratio of area of detector to surface area of sphere) ratio = $\frac{0.0015}{4\pi(0.18)^2}$ ✓ 0.0037 ✓ (0.00368)	2

b	ii	activity = 0.62/(0.00368 × 1/400) give first mark if either factor is used. 67000 ✓ Bq accept s^{-1} or decay/photons/disintegrations s^{-1} but not counts s^{-1}✓ (67400 Bq)	3

c		(use of the inverse square law) $\frac{I_1}{I_2} = \left(\frac{r_2}{r_1}\right)^2$ or calculating k = 0.020 from I = k/x^2 ✓ $I_2 = 0.62 \times \left(\frac{0.18}{0.28}\right)^2$ ✓ 0.26 counts s^{-1} ✓(allow 0.24-0.26)	3

2)

		The mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC).		
	QWC	**Descriptor**	**Mark range**	
	High Level (Good to excellent)	The candidate refers to all the necessary apparatus and records the count-rate at various distances (or thicknesses of absorber). The background is accounted for and a safety precaution is taken. The presence of an α source is deduced from the rapid fall in the count rate at 2 – 5 cm in air. The presence of a γ source is deduced from the existence of a count-rate above background beyond 30 -50 cm in air (or a range in any absorber greater than that of beta particles, e.g. 3 – 6 mm in Al) or from the intensity in air falling as an inverse square of distance or from an exponential fall with the thickness of a material e.g. lead. *The information should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.*	5-6	If more than one source is used or a different experiment than the question set is answered limit the mark to 4

	Intermediate Level (Modest to adequate)	The candidate refers to all the necessary apparatus and records the count-rate at different distances (or thicknesses of absorber). A safety precaution is stated. The presence of an α source is deduced from the rapid fall in the count rate at 2 – 5 cm in air and the γ source is deduced from the existence of a count-rate beyond 30 -50 cm in air (or appropriate range in any absorber, e.g. 3 -6 mm in Al). Some safety aspect is described. One other aspect of the experiment is given such as the background. *The grammar and spelling may have a few shortcomings but the ideas must be clear.*	3-4	To get an idea of where to place candidate look for 6 items: 1.Background which must be used in some way either for a comparison or subtracted appropriately 2.Recording some data with a named instrument
	Low Level (Poor to limited)	The candidate describes recording some results at different distances (or thicknesses of absorber) and gives some indication of how the presence of α or γ may be deduced from their range. Some attempt is made to cover another aspect of the experiment, which might be safety or background. *There may be many grammatical and spelling errors and the information may be poorly organised.*	1 - 2	3.Safety reference appropriate to a school setting – not lead lined gown for example 4.Record data with more than one absorber or distances 5.α source determined from results taken 6.γ source determined
		The description expected in a competent answer should include a coherent selection of the following points. apparatus: source, lead screen, ruler, γ ray and α particle detector such as a Geiger Muller tube, rate-meter or counter and stopwatch, named absorber of varying thicknesses may be used. safety: examples include, do not have source out of storage longer than necessary, use long tongs, use a lead screen between source and experimenter. measurements: with no source present switch on the counter for a fixed period measured by the stopwatch and record the number of counts or record the rate-meter reading with the source present measure and record the distance between the source and detector (or thickness of absorber) then switch on the counter for a fixed period measured by the stopwatch and record the number of counts or record the rate-meter reading repeat the readings for different distances (or thicknesses of absorber).		from results taken this is a harder mark to achieve it may involve establishing an inverse square fall in intensity in air or an exponential fall using thicknesses of lead if a continuous distribution is not used an absorber or distance in air that would just eliminate β (30-50cm air / 3-6mm Al) must be used with and without the source being present or compared to background
		use of measurements: for each count find the rate by dividing by the time if a rate-meter was not used subtract the background count-rate from each measured count-rate to obtain the corrected count-rate longer recording times may be used at longer distances (or thickness of absorber). plot a graph of (corrected) count-rate against distance (or thickness of absorber) or refer to tabulated values plot a graph of (corrected) count-rate against reciprocal of distance squared or equivalent linear graph to show inverse square relationship in air analysis: the presence of an α source is shown by a rapid fall in the (corrected) count-rate when the source detector distance is between 2 – 5 cm in air the presence of a γ source is shown if the <u>corrected</u> count-rate is still present when the source detector distance is greater than 30 cm in air (or at a range beyond that of beta particles in any other absorber, e.g. 3 mm in Al) the presence of a γ source is best shown by the graph of (corrected) count-rate against reciprocal of distance squared being a straight line through the origin		

3)

(a) α-particles not able to penetrate air between source and window .... B1 [1]

(b) (i) rapid drop in count rate B1
for small thicknesses (up to 2 mm)
OR most β's stopped by few mm of aluminium B1

(ii) very slow drop-off in count rate B1
for thicknesses greater than 2 mm
OR γ much higher penetration than β .... B1 [4]
(do not allow 'γ not stopped by aluminium')

4)

Analysis, conclusions and evaluation (15 marks)

(a) gradient = $-\rho\eta$
y-intercept = $\ln R_0$ or $\log_e R_0$ [1]

(b)

ln (R/s^{-1})	**Errors in ln R**
6.620 or 6.62	± 0.02 – 0.03
6.363 or 6.36	± 0.03
6.064 or 6.06	± 0.05
5.799 or 5.80	± 0.06
5.521 or 5.52	± 0.08
5.247 or 5.25	± 0.10 – 0.11

Column heading for ln (R); ln R calculated. All correct for one mark. [1]
2 or 3 dp scores one mark as shown. [1]
Errors in ln R: Ignore no. of sf in errors. [1]

(c) **(i)** Points plotted correctly. All six within half a small square required for this mark. [1]
Error bars in ln R plotted correctly. Check x = 0.0300 m. Allow ecf. [1]

(ii) Line of best fit. Must be within tolerances. [1]
Worst acceptable straight line. Line should be clearly labelled. [1]

(iii) Gradient of best-fit line. Must be negative. [1]
Award this mark if in range –54.0 to –56.0.
If out of range, check the read offs. Work to half a small square.
The triangle used should be greater than half the length of the drawn line.

Error in gradient [1]
Method of determining absolute error. Expect to see difference between gradient from best-fit line and the worst acceptable line correctly evaluated.

(d) Value of η [1]
Award mark for method η = candidate's gradient/11300 evaluated.
Error in η [1]
Method of determining absolute error.
Unit of η: $\mathbf{m^2\ kg^{-1}}$. [1]

(e) Value of x in the range **0.0410 m to 0.0425 m** [1]

If x in the range **0.0410 m to 0.0425 m**, then method of determining error in x. [1]

[Total: 15]

Q5.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	**Either** • The GM-tube has a low efficiency for γ-ray detection **Or** there is an increased area exposed to γ-rays • (So) placing the tube side on to the radiation would increase the count rate **Or** • The γ-radiation could be detected anywhere inside the GM-tube • So placing the tube side on to the radiation would reduce the uncertainty in the distance measurement	(1) (1) (1) (1)	For low efficiency, accept GM tube poor at detecting γ-rays.	2

Question Number	Acceptable Answer		Additional Guidance	Mark
(ii)	• Record the count (at least) twice and then determine an average count rate **Or** record the count for a much longer time • This reduces the effect of (random) errors in the measurement of the count rate	(1) (1)		2

Q6.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	An explanation that makes reference to the following:			
	• use a GM tube and counter to measure the number of counts in a known time	(1)	Answers may refer to the use of a ratemeter instead of a counter	
	• place a piece of aluminium a few mm thick between the source and the detector	(1)		
	• α and β will not penetrate aluminium but γ will	(1)		
	• so the source that is unchanged is Co 60 and the one with a decreased count is Ra 226	(1)		
	<u>OR</u> use a GM tube and counter to measure the number of counts in a known time			
	• place a strong magnet near the source	(1)		**(4)**
	• α and β will be deviated but γ will not	(1)		
	• so the source that is unchanged is Co 60 and the one with a decreased count is Ra 226	(1)		

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	An explanation that makes reference to a precaution and the reason for it • make sure the source remains at a distance of at least 30 cm from your body to minimise exposure OR make sure the source is always pointed away from you to minimise exposure OR only use one source at a time to minimise exposure • the sources emit ionising radiation which can be harmful to your cells	(1) (1) (1) (1)		**(2)**

Q7.

Question Number	Answer	Mark
	Log expansion of $R = R_0 e^{-\mu x}$ (1) μ identified as (-) gradient (1) Gradient calculated (1) Use of $R = R_0 e^{-\mu x}$ **Or** use $x_{½} = \frac{\ln 2}{\mu}$ (1) Half-value thickness = 1.5 cm (1) Conclusion consistent with half-value thickness (1) **OR** Log expansion of $R = R_0 e^{-\mu x}$ (1) ln R_0 identified as intercept (1) Intercept read from graph (1) $R_0/2$ calculated and x read from graph (1) Half-value thickness = 1.5 cm (1) Conclusion consistent with half-value thickness (1) <u>Example of calculation</u> $\ln R = \ln R_0 - \mu x$ $\mu = -\left(\frac{5.20 - 6.85}{3.5\text{ cm}}\right) = 0.471\text{ cm}^{-1}$ $\frac{R_0}{2} = R_0 e^{-0.471\text{ cm}^{-1} x}$ $\therefore \ln 2 = 0.471\text{ cm}^{-1} x$ $\therefore x = 1.47\text{ cm}$	**(6)**
	Total for Question	**6**

Q8.

Question Number	Answer		Mark
(a)(i)	Top line correct Bottom line correct <u>Example of calculation</u> $^{60}_{27}\text{Co} \rightarrow ^{60}_{28}\text{Ni} + ^{0}_{-1}\beta^{-} + ^{0}_{0}\bar{\nu}_e$	**(1)** **(1)**	**2**
(a)(ii)	The mass of the Ni nucleus is much larger than total mass of the other two particles	**(1)**	**1**
(b)	Use of $\lambda = \frac{\ln 2}{t_{½}}$ Use of $A = A_0 e^{-\lambda t}$ t = 6.0 (years) <u>Example of calculation</u> $\lambda = \frac{\ln 2}{5.27 \times 3.16 \times 10^7\ \text{s}} = 4.16 \times 10^{-9}\ \text{s}^{-1}$ $1.85 \times 10^{14}\text{Bq} = 4.07 \times 10^{14}\ \text{Bq}\ e^{-4.16 \times 10^{-9} \times t}$ $\therefore t = \frac{\ln\left(\frac{4.07 \times 10^{14}\ \text{Bq}}{1.85 \times 10^{14}\ \text{Bq}}\right)}{4.16 \times 10^{-9}\ \text{s}^{-1}} = 1.886 \times 10^8\ \text{s}$ $\therefore t = \frac{1.894 \times 10^8\ \text{s}}{3.16 \times 10^7\ \text{s year}^{-1}} = 5.996$ years	**(1)** **(1)** **(1)**	**3**
(c)	Required % transmission calculated Distance x read from graph for required transmission x =1.1 cm, so shielding would be insufficient **OR** Required % transmission calculated % transmission read from graph for 1.0 cm shielding % transmission ≈ 33%, so shielding would be insufficient <u>Example of calculation</u> Required % transmission $\leq \frac{1.2 \times 10^{14}\ \text{Bq}}{4.0 \times 10^{14}\ \text{Bq}} \times 100\% = 30\ \%$ From graph, for required % transmission thickness of shielding = 1.1 cm,	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**3**
	Total for question		**9**