Set 9: Radiation and the Environment

9.1	(a)	Because α particles are much larger (of the same order of size as atoms) than other common radiated particles they collide with many atoms, rapidly losing their kinetic energy. These collisions cause lots of ionisation but the rapid loss of energy means that the α particles do not penetrate very far. β particles are high speed electrons or positrons. Their small size means that they lose energy by collisions with atoms less rapidly. Thus they cause less ionisation but by retaining their energy longer penetrate further. γ rays are high energy photons of electromagnetic radiation. They travel large distances through matter without being absorbed. When absorption occurs electrons are emitted causing ionisation.
	(b)	An α particle is absorbed in the first centimetre of tissue, but causes large amounts of ionisation while doing so. When an α emitter is ingested it can adhere to lung tissue or stomach tissue where it can cause considerable ionisation damage. If the cell reproduction in this tissue is rapid (for example, in the testes and ovaries), the damage is more serious. External sources are usually promptly washed off, but particles lodged internally may continue to do damage over a long period of time.
9.2	(a)	Shielding: When using the source she wears a lead apron and may stand behind a lead screen. Lead is very dense, and high-density material absorbs radiation better than low-density material. Distance: She stands further away from the radioactive source than the patient. Radiation becomes less intense as the distance increases according to the inverse square law, eg. doubling the distance decreases the dose to one quarter.
	(b)	Lead is very dense; high-density material absorbs radiation better than low-density material.
	(c)	See 9.1 part b).
9.3	(a)	Gamma radiation would be used because it is the only radiation that would penetrate far enough.
	(b)	No, healthy tissue would also be affected but cancer cells tend to absorb more radiation.
	(c)	This maintains continuous irradiation of the tumour site while minimising the dose to any surrounding healthy tissue. Some damage will always be caused by the beam on its way to the target tissue but this is now spread over a lot of tissue.
	(d)	No - gamma photons do not cause changes in the nuclei of cells and the absorbed gamma photons are not themselves radioactive.
9.4	(a)	Alpha particles are considered a relatively harmless source outside the body due to their inability to penetrate large distances. However, they are the most ionising form of radiation and as such can use major cell damage if an alpha source is ingested or inhaled.
	(b)	Ventilate the facility well using industrial extractor fans and/or wear face masks.
9.5		The effect of radiation on humans is measured in terms of the quality factor. The quality factor for fast neutrons is 10 compared to 3 for slow neutrons. This is because of the higher energy of the fast neutrons and they will therefore be more harmful.
9.6	(a)	dose equivalent = absorbed dose x quality factor = 36 mGy x 20 = 720 mSv

	(b)	Since beta and gamma have a quality factor = 1, then this absorbed dose would provide a much smaller dose equivalent and therefore be less harmful.
9.7	(a)	A lethal dose of 50/50 suggests that 50% of the people exposed would die within 50 days of exposure.
	(b)	A lethal dose of 100/20 suggests that ALL the people exposed would die within 20 days of exposure.
9.8	(a)	$\text{Absorbed dose} = \frac{\text{energy}}{\text{mass}} = \frac{16.6 \text{ J}}{78.5 \text{ kg}} = 0.206 \text{ Gy}$
	(b)	dose equivalent = absorbed dose x quality factor = 0.206 Gy x 20 = 4.12 Sv
	(c)	Yes – 4 Sv will almost certainly be fatal, causing leukaemia and tumours.
	(d)	$\text{Absorbed dose} = \frac{\text{energy}}{\text{mass}} = \frac{16.6 \text{ J}}{0.6 \text{ kg}} = 27 \text{ Gy}$ so dose equivalent = absorbed dose x quality factor = 27 Gy x 20 = 540 Sv which will cause complete eradication of the exposed tissue, which is probably diseased or damaged tissue anyway so the objective would be achieved. There would be some damage to surrounding tissue also.
9.9		$\text{Absorbed dose per year} = \frac{\text{dose equivalent per year}}{\text{quality factor}} = \frac{1.4 \text{ mSv}}{1} = 1.4 \text{ mGy y}^{-1}$ so energy received per year = absorbed dose per year x mass = 1.4 mGy y^{-1} x 50 kg = 70 mJ y^{-1}
9.10	(a)	Radioactive fallout is the resulting daughter products produced following a nuclear explosion, which is basically the uncontrolled chain reaction of numerous fission processes.
	(b)	These products tend to have extremely long half lives so they are present for years. Such products get absorbed by soil and into the water table, which therefore contaminate crops and animals. People then eat the crops and animals, so the cycle of long term harm continues.
9.11	(a)	Radon is largely produced within the Earth itself and will therefore be found in soil and rocks, such as granite.
	(b)	Radon concentrations where the Earth has been drilled or dug into, or where the Earth has been disturbed, will tend to be highest. So mine sites or areas of recent volcanic activity would be susceptible.
9.12	(a)	$\text{Absorbed dose} = \frac{\text{energy}}{\text{mass}} = \frac{28.7 \text{ J}}{64.2 \text{ kg}} = 0.447 \text{ Gy}$
	(b)	Dose equivalent = absorbed dose x quality factor = 0.447 Gy x 1 = 0.447 Sv
	(c)	No, it is non-fatal but may cause some radiation sickness.
	(d)	Since the quality factor is now x 20, the dose equivalent = 8.94 Sv. She would be unlikely to survive.

9.13	(a)	$^{198}_{79}\text{Au} \rightarrow ^{228-0=198}_{79-(-1)=80}\text{Hg} + ^{0}_{-1}\text{e}$
	(b)	mass of radioisotope = 197.96824 u = 197.924869 u mass of products = 197.96677 u + 0.000549 u] = 197.923399 u mass defect = 197.924869u – 197.923399u = 0.00147 u = 0.00147 x 1.66054 x 10^{-27} kg = 2.44 x 10^{-30} kg E = m x c^2 = 2.44 x 10^{-30} kg x (3 x 10^8 m $s^{-1})^2$ = 2.197 x 10^{-13} J = 2.197 x 10^{-13} J (÷1.60 x 10^{-13} J) = 1.37 MeV
	(c)	Mix the sewage with the gold radioisotope and then use a Geiger Muller counter to monitor the beta radiation as it moves along with the sewage.
9.14	(a)	energy released / second = activity x energy per decay = 100 x 10^6 Bq x 2 x 10^{-13} J = 2.0 x 10^{-5} J s^{-1}
	(b)	Daily absorbed dose = energy ÷ mass = (2.0 x 10^{-5} J s^{-1} x 24hrs x 3600s) ÷ 60 = 0.029 Gy day^{-1}
	(c)	Daily dose equivalent = daily absorbed dose x quality factor = 0.029Gy day^{-1} x 1 = 0.029 Sv day^{-1} = 29 mSv day^{-1}
	(d)	number of days needed to receive a total of $5\text{ Sv} = \frac{5\text{ Sv}}{0.029\text{ Sv day}^{-1}} = 172\text{ days}$ So, there is a 50% chance of surviving almost 6 months
9.15	(a)	Cosmic radiation.
	(b)	Aircrew have less atmosphere to protect them since they are closer to the cosmos than ground based transport industries so they are more susceptible to exposure.
	(c)	The sensitive film suffers a degree of darkening due to the ionising ability of radiation.
	(d)	Alpha particle radiation is not very penetrable and would be almost certainly absorbed by the surrounding air before reaching the film badge.
	(e)	Since beta radiation is made up of fast moving, relatively light particles, the exposure would appear as scattered specks and maybe be more pronounced. However, gamma rays have no mass so their appearance would be more cloudy.
9.16		Potassium iodide tablets can prevent about 99% of the damage to the thyroid gland that would otherwise result from exposure to the radioisotope iodine-131. The gland readily absorbs both radioactive and non-radioactive iodine and normally retains much of this element in either or both forms. If ordinary, non-radioactive iodine is made available, in the form of tablets, which then becomes absorbed by the thyroid before radioactive iodine is present, then the gland will soon become saturated. In this state of saturation, the thyroid can only absorb about 1% as much additional iodine, including radioactive forms that later may become available in the blood – it is said to be blocked. Excess iodine in the blood is rapidly eliminated by the action of the kidneys.
9.17	(a)	Dose equivalent =(7.5 mGy x 1) + (6.0 mGy x 1) + (0.3 mGy x 10) + (1.5 mGy x 3) + (0.15

		mGy x 20) so in one year, dose equivalent = 24 mSv, which is three times too much. Therefore, they should only be allowed to work in the mine for ⅓ of the year (about 121 – 122 days)
	(b)	Assuming that the levels of each type of radiation source remains constant and that the mine workers are of a similar size and body mass.