Workshop Tutorials for Introductory Physics
Solutions to QI6: **Radiation and the Body**

A. Review of Basic Ideas:

Radiation and the body

Everybody is exposed to **radiation** all the time, from radioactive materials in the ground, the air, and inside us, and **cosmic** radiation from space. This naturally occurring radiation is called **background** radiation.

Normally the **atmosphere** shields us from a lot of cosmic background radiation, but when you're **10 km** up, the background level is somewhat higher. Smokers also have a higher **exposure** to radiation than non-smokers. When tobacco leaves are dried they accumulate small amounts of the **radon** dust which settles on them. The radon and its daughter products are then **inhaled** by the smoker.

People working with **radioisotopes** may wear lead aprons to protect them from radiation, and carry a badge which senses the amount of radiation they are exposed to.

The most difficult radiation to shield against is γ radiation. The high energy photons have no mass or **charge**, and hence are highly penetrating. Dentists and radiologists who use X-ray machines have to be careful to use **lead** shielding. Even **ultraviolet** radiation from the sun can be dangerous, which is why it's important to wear sunscreen if you're outside for any length of time. It is this penetrating nature of high energy photons that makes them so useful for imaging, such as **X-raying**.

Other sorts of radiation are also used for imaging. A PET (**positron** emission tomography) scan uses β^+ radiation. The patient is injected with a radioisotope which emits positrons. A positron is the anti-matter particle of an electron, so when the two collide they **annihilate** each other and some **energy** is released. The energy is released as two **photons** of a specific energy (the mass energy of the particles, from $E = mc^2$), which move off in opposite directions. If the positron was emitted from **radioactive** glucose, for example, we can tell which parts of the body are most active and hence using the most energy. This is extremely useful for looking at the **brain**, which only uses glucose for energy.

Discussion question

The radiation levels inside the building are lower than those outside because the building is well shielded. It has two layers of shielding – one around the reactor itself, and one enclosing the entire building. The natural radiation from cosmic rays and other sources outside cannot get into the building, and the radiation from the reactor inside the building is shielded also, so what remains is lower than the natural levels outside the building.

B. Activity Questions:

1. X-Rays

These are photons in the range of 10^{-10} m. X-rays come about because of atomic processes induced by the energetic electrons shot at the metal target in an x-ray machine. Because of their short wavelength they can pass through objects which are opaque to ordinary light. They can penetrate most tissue, but are absorbed well by bone and can be recorded on photographic film. The different levels of 'greyness' is due to the different abilities of the various tissues to absorb x-rays, the greater the absorption the fewer X-rays get through, and the lighter the film.

2. Measuring Radiation

Two methods of monitoring radiation are the film badge and the Geiger counter.

a. Film Badge: Film badges contain exactly what their name implies -- a piece of photographic film and several types of thin metal strips, which act as absorbers and allow for detection of various energies of radiation. Eg. the attenuation of beta rays depends only on the density of the medium through which it travels and plastic filters of low atomic number can be used to assess beta radiation dose. Cadmium can be used to assess a neutron dose. As the gamma radiation emitted, when neutrons are captured by the cadmium atoms, will blacken the film underneath the cadmium filter. If the radiation beam is only gamma rays then the blackening will be the same under a tin-lead filter and under a cadmium-lead filter. However, the presence of neutrons will produce excess film blackening under the cadmium-lead filter. The amount of exposure to the film determines the amount of radiation exposure that the individual received during that period.

b. A Geiger counter is a device used to detect radiation from a radioactive source. It detects and records the number of radioactive particles. The Geiger counter consists of metal tube filled with a gas at low pressure, such as argon. A wire runs down the centre of the tube and is maintained at a high positive voltage compared with the outer tube, which is negatively charged. The voltage is not sufficient to ionise the gaseous atoms in the tube. When a particle enters the window at one end of the tube it ionises a few gas atoms. The freed electrons are attracted to the central positive wire and ionise other gas atoms as they accelerate towards the wire. A large number of electrons is quickly produced and these produce a voltage pulse at the wire. This pulse is transferred to an electronic counter or to a loudspeaker to be heard as a clicking sound. Counters enable radioactive tracers to be followed as they make their way through complex organisms such as the human body. They are used also to follow radioactive isotopes in chemical reactions.

C. Qualitative Questions:

1. There are three main types of radiation, α, β and γ.

a. The γ particle is the most penetrating because it has neither mass nor charge, hence it interacts relatively weakly with matter.

b. Alpha particles [He nuclei] are very large, but unable to penetrate the human body. Their danger lies in being inhaled or ingested as once inside, they are strongly ionising. They are stopped by air due to collisions with oxygen and nitrogen molecules. In each collision they lose some energy in ionising the air molecules.

c. α emitters are not considered dangerous unless inhaled or ingested because they have very little penetrating power and can usually be stopped by clothing or the air.

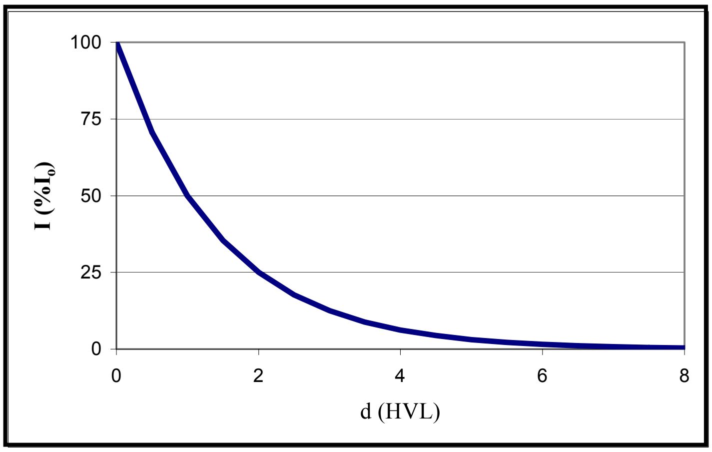
d. γ rays are absorbed by interactions with electrons, so heavy elements, like lead, which have a lot of electrons make good shields against γ rays.

e.

PARTICLE	IONISING ABILITY	PENETRATING ABILITY
Alpha [He nucleus]	Ionises by direct contact with atoms.	Stopped by a few cm. of air or paper. Unable to penetrate the skin because of its large size.
Beta [electron]	Ionise by interaction with atomic electrons in tissue	Because of small mass can penetrate about 1 cm.
Neutron	Does not directly ionise, but transfers their energy to collisions with protons, which then go on to ionise atoms	Very penetrating because of its uncharged nature. Travels hundreds of metres in air.

2. Following the Chernobyl accident the sale of milk was banned. This was because of the fall-out of radioactive isotope ^{90}Sr. This is a reactive metal in the same periodic group as calcium. ^{90}Sr has a relatively long ½ life and is dispersed in varying concentrations throughout the earth's atmosphere and soil. It is readily taken up in the tissues of plants and animals and may enter the human food supply through milk. It is particularly dangerous for growing children as it is easily deposited in the bones and is believed to induce bone cancer.

D. Quantitative Question:



a. The intensity at distance d is $I(d) = I_o\, e^{-\mu d}$.

b. See diagram opposite.

c. Many processes follow this form, such as radioactive decay as a function of time, cooling, and population decay.

d. Each HVL decreases the intensity by 50% or ½. The HVL for Aluminium is 5.0 cm, so 25 cm is 5 HVLs. The reduced intensity is therefore

$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = (\frac{1}{2})^5 = 1/32$ or 3%,

a reduction of 97%.

You can also do this using

$I(25\text{cm}) = I_o e^{-\mu\, 25\text{cm}} = I_o e^{-0.028 \times 25\text{cm}} = 0.03\, I_o$.

e. To reduce the intensity by 75% (reducing to 25% or ¼) using any material you need to use $d = 2 \times$ HVL for that material (½ × ½ = ¼). For lead this is 2 × 1.2 cm = 2.4 cm.

f. To reduce the intensity by 75% using air only (no shielding) you would need 2 × HVL = 200 m of air.

material	HVL (cm)
Lead	1.2
aluminium	5.0
air	10,000