Q 4 N&R Problem Set #5
Written Team Problem Set

This homework assignment is due by **5 pm on Friday 28th of March, 2008**.
Please submit it in the *Drop Box* for your tutorial.
The Drop Boxes are located in the basement of the Burton Tower of McLennan Physics Labs (MP). On the first floor of MP there is a stairway with a bust of Isaac Newton on the 1st floor; the Drop Boxes are at the bottom of the stairs.

	This page must be the first page of the submitted Problem Set.	

Solve the problems in the same team that you have been working with in your tutorials.

	Problem Sets done by a single individual will not be accepted.	

By filling out and signing the form below, I certify that I took an active role in the solution of all the problems of this problem set.

Name (Please Print)	Signature

Designate one member of your team as the *coordinator*. The coordinator will be responsible for assembling the final copy of your solutions and submitting them in the Drop Box on time. The coordinator does NOT need to copy out contributions from members of the team – just stick them together!

The coordinator should fill out this part of the form:

Name of Your PHY138 Tutor	
Tutorial Group	
Tutorial Day	
Tutorial Time	
Coordinator's Name	

Show all your reasoning, and work legibly.
The mark assigned to each section is indicated so :{3}
The total mark assigned to the question is indicated so: **[100]**
I recommend that every member of your team knows how to solve every one of them!

Readings: Supplementary Notes I to V (to §5.4.2)

Important Note: Please follow our suggestions for solving problems. In particular, first solve the problem parametrically (i.e. using symbols that you have defined at the start of the problem). Only when you have obtained a solution in parametric form should you insert the numerical values to obtain a numerical answer (with units!). You will be more easily able to detect any errors; equally important, the long-suffering marker will be more quickly able to give you credit for your work. Failure to follow this suggestion may incur penalty marks.

The Age of the Universe.

Uranium, along with other heavy elements on earth, was created by nuclear fusion reactions in supernovae in the early universe. 99.28% of the naturally occurring Uranium on earth consists of the ^{238}U isotope; the isotope ^{235}U accounts for the remaining 0.72%. Tables that show the decay chains for ^{235}U (the so-called Actinium series) and ^{238}U (the Radium series) are available at http://en.wikipedia.org/wiki/Decay_chain. Atomic masses for this and other problems can be found at http://ie.lbl.gov/toi2003/MassSearch.asp.You will need the numbers in these tables to answer some parts of this question.

A. Making the reasonable assumption that ^{238}U and ^{235}U were originally created in equal numbers, how long ago was the supernova explosion that created them? **[17]**

Decay Energetics.

B. Consider the first decay of ^{238}U to ^{234}Th. Verify the quoted value of alpha particle energy from this decay. **[13]**

Dose from Uranium.

Our bodies contain approximately $2.0\text{x}10^{-5}$ g of Uranium, a mass that is kept fairly constant over time by a balance between ingestion (mainly breathing) and excretion.

C. Estimate the absorbed dose that you receive annually from the ^{238}U in your body. State clearly any assumptions you require.{2}. You need consider only the first decay in the decay chain that involves alpha emission – explain why this is so{3}. **[23]**

D. Now estimate the absorbed dose that you receive annually from the ^{235}U in your body. You will notice that ^{239}Pu is the parent of ^{235}U. Make a numerical argument for ignoring this isotope in your calculation {3}; remember that we are considering only natural sources for the radioisotopes. (In fact, there is some concern about Plutonium contamination from the atmospheric nuclear weapon tests, but that is another story!). Again, you need consider only the first decay in the ^{235}U chain that involves alpha emission – explain why this is so in this case. {2}. **[12]**

E. Finally, estimate the total absorbed dose {1}, the equivalent dose {1}, and the effective dose {1} that you receive annually from the Uranium in your body. **[3]**

***Nuclear Power – the benefit*.**

^{235}U is used to generate nuclear power – and atomic bombs. When a "thermal" neutron (a very slow neutron, whose speed is about that of a molecule in a gas at room temperature) interacts with a nucleus of ^{235}U, the ^{235}U fissions, breaking up into several other nuclei and two or more thermal neutrons. These neutrons can then interact with other ^{235}U nuclei, which in turn produce more neutrons, thus generating a "chain reaction". Controlled chain reactions are used to generate power; uncontrolled chain reactions energize the atomic bomb. One of the main ways the ^{235}U fissions is via: $n + {}^{235}U \rightarrow {}^{236}U \rightarrow {}^{144}Ba + {}^{89}Kr + 3n$
Since the natural occurrence of ^{235}U is so low, nuclear power stations often use enriched uranium, which contains about 3% to 4% of ^{235}U. (The main technical difficulty faced by the Los Alamos scientists who were designing the atomic bomb that was dropped on Japan in 1945, was separating enough of the rarer ^{235}U).

The Pickering Nuclear Generating Station on the shores of Lake Ontario is one of the largest in the world. At peak power, it can generate about 4,000 MW.

F. Approximately what mass of ^{235}U must be converted to energy to allow the Pickering Generating Station to operate at full power for 24 hours? Assume that all of the power produced at Pickering comes from the reaction above (not true, but the other possible reactions produce similar amounts of energy). **[20]**

Nuclear Power - the Dangers.

In April 1986, there was an explosion of a reactor at the Chernobyl Nuclear Power Plant in the Ukraine (then part of the USSR). A large cloud of radioactive elements entered the atmosphere, affecting 5 million people in the USSR, Europe, and even North America. It is estimated that over 10,000 people died of cancer caused by the radiation. Nearby Prypyat, once inhabited by 47,000 people, is now a ghost town.

The radioactivity of milk in many regions rose to 2000 Bq.L^{-1} due to the Iodine-131 in the contaminated grass eaten by cattle. ^{131}I, with a half-life of 8.04 days, is particularly dangerous, as Iodine concentrates in the thyroid gland ; indeed children exposed to this source show an increase in thyroid cancer.

Of course, normal milk, which contains potassium, is mildly radioactive due to the potassium it contains (potassium is, of course, one of milk's health benefits). 1 L of milk contains about 2.00 g of Potassium, of which 0.0117% is the radioisotope ^{40}K.

G. How long after the accident at Chernobyl would the activity of the ^{131}I in the milk have fallen to the "natural" level of the ^{40}K? **[12]**

FOR PRACTICE.

I originally intended to include the following problem. However, I decided that this problem set was probably long enough, so I took pity on you and removed it! Since some of you have asked for more problems to practice on, I retain it here for your consideration. No marks are assigned. It deals with a practical and serious problem of environmental exposure. Once you have made the suggested approximations and assumptions, it is not too hard. However, I will not provide the solution; if you want to check your understanding, talk to your tutor, or come and see me.

The Dangers of Radon In The Home.

As you can see from the tables, one of the products of the ^{238}U decay is ^{222}Rn, which is a chemically inert gas. The Radon seeps out of the ground into the atmosphere, making air radioactive. The average activity of the air is approximately 0.30 pCi.L^{-1} (≈ 11 Bq.m^{-3}) though it varies enormously in different areas of the world.

In homes, ^{222} Rn can be a serious pollutant, since it accumulates in enclosed spaces to reach much higher activities than in the outside air. Indeed ^{222}Rn and its progeny are a major source of the natural radiation background, and an important contributor to cancer. The biological damage is almost entirely caused by the alpha particles from the decay of the ^{222}Rn and its progeny, which attach themselves to dust particles. Alpha particles outside the body are easily stopped by skin, where they deposit their energy. When Radon is breathed into the lungs, the gas and its progeny are quickly distributed throughout the tissues of the body, where the decay alphas are stopped by the tissue where they deposit all of their decay energy. Health Canada recommends that if the radon radioactivity exceeds 200 Bq.m^{-3} in a house, remedial action should be taken (the US EPA limit is 150 Bq.m^{-3}).

Is this a reasonable limit? *To calculate an approximate value for the radiation dose that this limit represents, add the doses received by the skin and by the interior of the body. For the dose delivered to the skin, you will need to know that alphas have a range of about 3 cm in air, and that they are quickly stopped in the skin, which accounts for about 10% of body mass. You will find Problem 66 of chapter 42 in Knight useful for this part. For the dose to the body, assume that the dose comes from an approximately constant volume of air in the lungs that equals, on average, about half the lung volume (the average adult lung has a volume of about 6 litres). You will notice that there are several relatively short-lived alpha decays before a stable isotope is reached. For the sake of simplicity, assume that the total energy deposited by the Radon and its progeny is equivalent to one decay of about 20 MeV.* State clearly any other assumptions you make, the criteria you use for "reasonableness", and your conclusion. **[0]**

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