Physics In Modern Medicine

November 16, 2009

Fall 2009

Take-home Final Exam

Name________________________

Part	
Problem #1	/ 20
Problem #2	/ 50
Problem #3	/20
Problem #4	/ 50
Problem #5	/ 10
Total	/ 150

Assigned on Monday November 16, 2009 in class.
Due Monday, November 23, by Noon, EST.

Late exams will be penalized 10 points/half day.

Ground rules: The total credit for the exam is 150 points. Be sure to start by reading all the questions carefully so you understand what you are being asked to do, and answer all parts. Explain your reasoning and show all of your work--don't simply write down numerical answers for the mathematical parts. This is crucial--failure to explain answers or show your reasoning will result in my inability to give you full credit, especially if you only write down a wrong numerical answer. Pay attention to the appropriate units, prefixes (like kilo, milli, micro and Mega), significant figures and powers of ten for full credit. You **must include units** for physical quantities. Even if you aren't sure about how to completely answer each part, put down as much work as you can, as clearly as possible, for partial credit. I will give partial credit for *everything relevant and correct* you have written down! The solutions to the final exam may be typed or neatly written. The solutions to the exam may be electronically submitted. The solutions to the problems should be as complete as possible.

The exam is open book and open notes. You may only consult the textbooks by Kane and Wolbarst as well as any class notes or the class lecture slides. You may not communicate in any way with any other person during the exam, and you may not consult the web (for those of you that know my exam style, doing so would be pointless anyway.) You may, of course, use a calculator during the exam.

1. *Applications of Nuclear Physics*

a. Determine the decay products for the radioactive elements and list them in the table below. Relevant nuclear data may be found at http://hyperphysics.phy-astr.gsu.edu/hbase/pertab/pertab.html#c1. Note, elements that are listed as EC (which stands for electron capture) are another radioactive decay process that will lead to an eventual gamma ray emission.

Isotope	**Decay product**	**PET**	**MRI**	**Cancer therapy**	**Radioisotope imaging**
Carbon-11 (6 protons/ 5 neutrons)					
Carbon-12 (6 protons/ 6 neutrons)					
Carbon-13 (6 protons/ 7 neutrons)					
Gold-196 (79 protons/ 117 neutrons)					
Fluorine-19 (9 protons/ 10 neutrons)					
Fluorine-18 (9 protons/ 9 neutrons)					
Gallium-67 (31 protons / 36 neutrons)					
Gallium-72 (31 protons / 37 neutrons)					
Cobalt-60 (27 protons/33 neutrons)					

b. Which of the isotopes above would be useful for the applications shown? There may be more than one possible choice, or the answer may be "none". Explain your selections by describing the ways you decided each category (which are good for PET, etc.)

2. Radiation therapy & safety

a. What is the effective half-life of the radioactive isotope ^{35}S in the testis (male reproductive gland)? Assume a physical half-life of 87.1 days and a biological half-life of 623 days.

b. What is the decay particle emitted by ^{35}S (it decays to ^{35}Cl)?

c. Compute the daily dose to a testis with mass 18 grams from a uniformly distributed internal 6660 Bq source activity of ^{35}S and assume the 48.8 keV decay particles are completely absorbed.

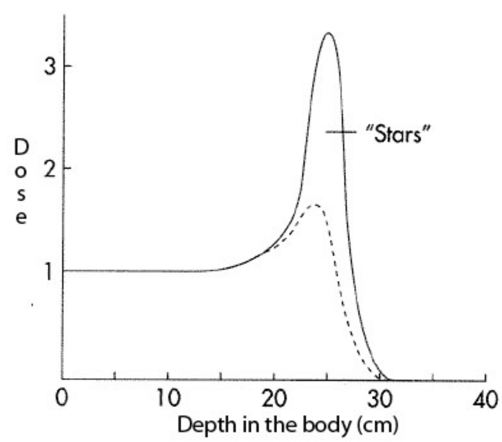
d. What would the daily dose be to the testis if instead of ^{35}S you used Palladium (^{46}Pd)? (Assume that you have the same mass administered as ^{35}S and that the activity and half-life are 14 MBq and 17days respectively. ^{46}Pd decays by emitting 21keV gamma rays.)

e. Explain the differences of using Palladium versus Sulfur to treat, say testicular cancer.

3. *Brachytherapy*

a. One kind of brachytherapy involves using catheters inserted into the body near the tumor to deliver a radioactive fluid very close to the tumor, thus enabling very high doses of radiation to be targeted to the tumor for short times (since the fluid can be removed easily). The limit on exposure to radiation for tissues not in the treatment area is limited by the Nuclear Regulatory Commission (the relevant U.S. regulatory body) to 0.5 Sv (50 rem) dose equivalent. What are the health consequences of this level of exposure to ionizing radiation of tissues not in the treatment area? Explain any assumptions you have made.

b. Shown below is the radiation dose vs. depth curve for the exotic charged particles known as pions. The dashed line shows the radiation dose due to pions alone, while the solid line adds in the extra dose to "stars"—densely ionizing particles released by pions near the end of their travel. Use this plot to explain what advantages pions would have over x-rays for performing external beam radiation therapy.



4. Radionuclide imaging

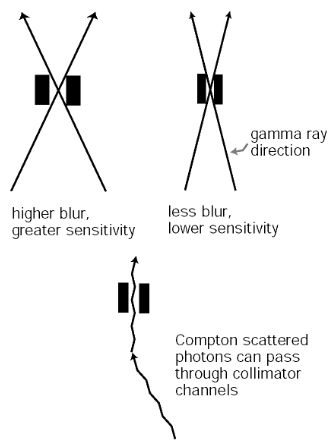
a. Indium-111 (^{111}In) is a radioactive isotope that decays by emitting only gamma rays, with energies in the range 171 to 245 keV. Its physical half-life is 2.8 days. Assuming that it has low toxicity, explain why this isotope would be a good choice for radionuclide imaging. Explain your answer fully making reference to its physical properties.

b. Imagine a solution of ^{111}In has an initial source activity of 5 MBq. How much source activity remains after one week? After 2 weeks?

c. Compute the fraction of 200 keV gamma rays that are transmitted by 15 cm of soft tissue, approximated as having the same linear attenuation coefficient at this energy as water: 0.136 cm^{-1}. (I chose 200 keV to lie in the midrange of emitted gamma ray energies for this radioisotope.) What fraction does a layer of lead shielding 5mm thick transmit? At this photon energy, the linear attenuation coefficient of lead is 10.2 cm^{-1}.

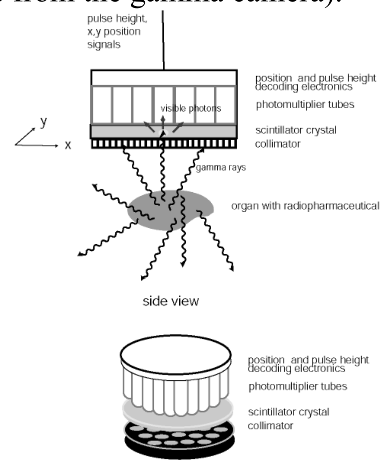
d. Explain why the calculations from parts b & c are important and relevant to the use of ^{111}In in imaging.

e. A gamma camera is a large angle detector that is used to image the location of gamma rays emitted by the body from injected radiopharmaceuticals. The blur and sensitivity of gamma cameras depends upon depth of the radioactive source in the body (distance from the detector). Use the images below to make a sketch explaining whether blur and sensitivity increase or decrease with increasing/decreasing depth in the body (distance from the gamma camera).



(b)

Amador Fig. 6-5



(a)

Amador Fig. 6-5

5. Magnetic Resonance Imaging

Magnetic resonance imaging can be used to monitor the temperature increases achieved by focused ultrasound surgery. (Focused US surgery involves using a focused beam of high intensity ultrasound to heat up and destroy tissue. This method can be used to destroy breast, prostate or brain tumors deep within the body noninvasively. For example, a beam of ultrasound can be focused so that only regions near a tumor are exposed to high intensities.) MR can be used to monitor because the difference in energy between proton spin UP and DOWN states varies in proportion to the temperature change (be sure to explain why as part of your answer) of the tissue that contain the protons. Explain a scheme how one might use this effect to monitor the temperature change in an MRI image taking during focused ultrasound therapy.