National Examination December 2016
98-Phys-B1, Radiation Physics
Three (3) Hours Duration

Notes

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer a clear statement of any assumptions made.
2. This is an **Open Book** exam.
3. Any non-communicating calculator is permitted. You must indicate the type of calculator being used, i.e. write the name and model designation of the calculator, on the first left hand sheet, of the exam work book.
4. This exam has 7 questions, for a total of **87** points.
5. You are required to answer only eighty (80) points worth of questions. That is, the full mark is **80** points.
6. Total worth of each question is given with the question or its parts.
7. Duration: Three (3) Hours

Marking Scheme

Subdivision of marks are shown in question's parts.

Q.1 13 points.

Q.2 9 points.

Q.3 8 points.

Q.4 10 points.

Q.5 19 points.

Q.6 10 points.

Q.7 18 points.

QUESTION 1. Nuclear fission, biological effects of radiation, radioactivity

On April 13, 2016, *The Telegraph* newspaper reported that "1,000 large tanks have been filled with discarded cooling water, which has been cleansed of caesium and strontium but not of tritium" from the Fukushima damaged nuclear power plant. Keeping in mind that the Fukushima's reactors are light-water cooled:

(a) (3 points) State how these isotopes (caesium[1], strontium, and tritium) are produced in the reactor.

(b) (2 points) Which isotope of caesium is of most concern? State why?

(c) (2 points) Which isotope of strontium is of most concern? State why?

(d) (1 point) Iodine is known to be also released following a reactor accident. Why was not it mentioned as being present in the discarded cooling water?

(e) (1 point) Why was the discarded cooling water cleansed of caesium and strontium but not of tritium?

(f) (2 points) Explain the hazard caused by exposure to tritium, considering its decay process and its half-life.

(g) (2 points) The biological half-life of caesium is 70 days, while its physical half-life is 30.17 years, what is its effective half-life?

QUESTION 2. Safety and protection, nuclear interactions

The equivalent does rates, outside the radiation shield of a proton cyclotron vault used to produce positrons for positron-emission tomography, are reported to be 5 μSv/h gamma rays, 10 μSv/h thermal neutrons and 12 μSv/h fast neutrons.

The positrons are produced by bombarding water enriched in ^{18}O with protons. Gallerani et al.[2] reported that this reaction produces an intense fast-neutron field.

(a) (2 points) Name the isotope produced by the $H_2{}^{18}O(p,n)$ reaction, and explain why it is a positron emitter.

(b) (1 point) How are neutrons produced in a proton accelerator?

(c) (1 point) Explain how a thermal-neutron dose results from the fast-neutron field.

(d) (1 point) Explain how gamma-rays are produced in such facility.

(e) (1 point) Why no proton dose is reported above?

(f) (3 points) Estimate the radiation exposure in Gy/hr for each of the above reported dose equivalents.

[1] Cesium.

[2] Neutron production in the operation of a 16.5 MeV PETrace cyclotron, Progress in Nuclear Energy, Volume 50, Issue 8, November 2008, pp. 939-943.

QUESTION 3. Non-ionizing radiation

A radio station transmits at a power of 50 kW. Making a reasonable assumption about the directionality of its radiation emission, determine:

(a) (2 points) the mean power density at a distance of 50 km,

(b) (2 points) the maximum electric field strength at 50 km,

(c) (3 points) the maximum magnetic field strength at 50 km, and

(d) (1 point) the listening range of the radio station.
Hint: for a radio station that uses a non-directional antenna with a maximum transmitter power of 1 kW, the maximum reliable reception range at night in a very congested frequencies environment is 50 km.

QUESTION 4. Radiation interactions

Inverse Compton scattering is the process in which a charged particle transfers part of its energy to a photon.

If a photon of original wavelength λ_i is bombarded by an electron moving at speed v, so that the photon is perfectly backscattered, the final photon wavelength, λ_f will be given by:

$$\lambda_f = \left[\left(\lambda_i \sqrt{\frac{1 - v/c}{1 + v/c}} \right) + \lambda_0 \right] \sqrt{\frac{1 - v/c}{1 + v/c}} \qquad (1)$$

where $\lambda_0 = 2h/m_e c$, with h being Planck's constant, m_e the electron rest mass, and c the speed of light.

(a) (1 point) Show that $2h/m_e c$ has the dimensions of a wave length, λ_0.

(b) (1 point) Compare the value of λ_0 to the wave length $\lambda_i = 10$ μm of a carbon dioxide laser photon.

(c) (2 points) Under what conditions can equation (1) be expressed as:

$$\lambda_f \approx \lambda_i \left[\frac{(1 - v/c)}{2} \right] \qquad (2)$$

(d) (2 points) Calculate the electron velocity, v, needed to generate 10 MeV photons.

(e) (2 points) What is the total energy of the electron corresponding to v, including the rest mass energy.

(f) (1 point) What is the kinetic energy of the electron corresponding to the calculated value of v?

(g) (1 point) What is the voltage required to accelerate the incident electrons to the speed v calculated above.

QUESTION 5. Detection of radiation, radiation instrumentation, radiation protection

The following equation represents a typical fission reaction:

$$n + {}^{235}U \longrightarrow {}^{236}U^{*} \longrightarrow {}^{92}Kr + {}^{142}Ba + 2\ n + \gamma$$

(a) (1 point) What is the neutron energy at which this fission is most probable?

(b) (2 points) Name two types of detectors that are most efficient for measuring the incident neutrons in the above reaction.

(c) (2 points) Sketch the energy spectrum of the neutrons produced by this reaction, indicating the value of the most probable energy.

(d) (2 points) Name a type of detector that can be used to measure the spectrum of the produced fission neutrons, and explain how it works.

(e) (2 points) How is the radiation dose produced by neutrons measured?

(f) (4 points) Describe an effective arrangement to shield against the radiation produced in the above fission reaction: give material and approximate thickness.

(g) (2 points) State (in percentage terms) how this energy is distributed among the reaction products (Kr, Ba, neutrons and gamma rays).

(h) (2 points) The fission products, ^{92}Kr and ^{142}Ba, are unstable. Explain.

(i) (2 points) What is the most likely mode of decay of ^{92}Kr and ^{142}Ba?

QUESTION 6. (10 points) **Radiation safety and standards**

A small northern Canadian, not connected to the electrical grid, is presented with a proposal to install a small modular reactor (SMR) of about 100 MW to meet some of the electrical demands of the town. On the other hand, a citizen group in town is advocating the use of renewable energy to supply this power. You were asked by the mayor of the town to present the town's council with an expert view of the available options to supply the power needs of the town. In the form of a memo, present the requested report to the mayor, keeping in mind that the obligation of a professional engineer is to "hold paramount the safety, health and welfare of the public and the protection of the environment". Your memo should be about 1000 words ($\approx$ two single-spaced pages) long.

QUESTION 7. Radioactive decay, dosimetry

Graves is an autoimmune disease that causes thyroid's overactivity.

This disease is treated with ^{131}I.

A patient receives 100 MBq of this isotope, which has a radiological half-life of eight (8) days and a biological half-life of two (2) days. The thyroid's uptake is 60%, and the uptake of the isotope can be assumed to be immediate. Assume that the mean beta and gamma energies per disintegration of ^{131}I are 192 keV and 370 keV, respectively. The dose rate in an infinitely large homogeneous tissue containing a uniform distribution of ^{131}I at an activity of 1 Bq/kg is 27.72×10^{-15} kg Sv/(Bq s) for beta rays and 48.55×10^{-15} kg Sv/(Bq s) for gamma rays. The weight of the patient's thyroid is estimated to be 16 g.

(a) (1 point) Why iodine in particular is used to treat a thyroid disease?

(b) (3 points) How long will it take for the activity of ^{131}I in the body to decrease to one-eighth ($\frac{1}{8}$) of its initial value.

(c) (2 points) Determine the cumulative (integral) activity of ^{131}I absorbed in the body in Bq s.

(d) (2 points) Estimate the absorbed fraction of ^{131}I gamma in the thyroid, using the data provided in the table below:

Absorbed fraction of a gamma emitter uniformly distributed in the thyroid per gram

Photon Energy	Absorbed Fraction
100 keV	1.44×10^{-3}
200 keV	1.55×10^{-3}
500 kev	1.66×10^{-3}

(e) (4 points) Calculate the absorbed gamma cumulative dose to the thyroid from this treatment.

(f) (4 points) Calculate the absorbed beta cumulative dose to the thyroid from this treatment.

(g) (2 points) Which type of radiation (beta or gamma) is most suited for treating the Graves' disease? Justify your answer by the results of the above calculations and on physical grounds.