CHUKA **UNIVERSITY**

UNIVERSITY EXAMINATIONS

EXAMINATION FOR THE AWARD OF DEGREE OF MASTER OF MEDICAL PHYSICS

MPHY 851: NUCLEAR MEDICINE

STREAMS: MPHY **TIME: 3 HOURS**

DAY/DATE: THURSDAY 17/04/2025 **2.30 P.M. – 5.30 P.M.**

INSTRUCTIONS

- Answer any Four Questions
- Do not write anything on the question paper
- This is a closed book exam, No reference materials are allowed in the examination room
- There will be No use of mobile phones or any other unauthorized materials
- Write your answers legibly and use your time wisely

QUESTION **ONE (15 MARKS)**

Figure 1 shows a schematic of a collimator, crystal, and photomultiplier tube.

a. Explain briefly how the energy of incoming gamma photons is measured using the scintillation crystal and photomultiplier tube (PMT). **(2 marks)**

b. How does the choice of scintillation material affect energy resolution in SPECT imaging? **(2 marks)**

c. A patient undergoes SPECT imaging using a 99mTc-labeled radiopharmaceutical. The emitted gamma rays (E = 140.5 keV) travel through 4 cm of lung tissue (mass attenuation coefficient μ/ρ = 0.136 cm²/g, density ρ = 0.26 g/cm³) and 2 cm of bone (μ/ρ = 0.150 cm²/g, density ρ = 1.85 g/cm³).

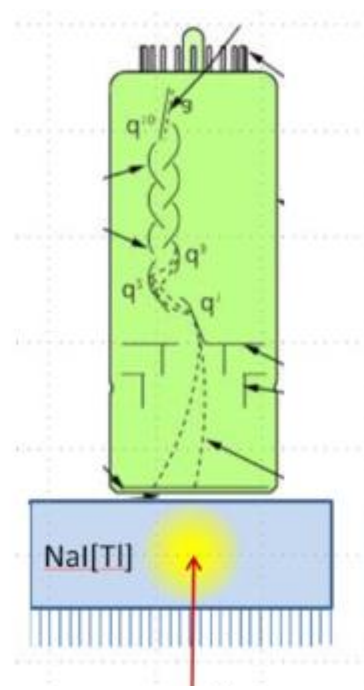

Figure 1

i. Calculate the fraction of gamma rays that are absorbed before reaching the detector. **(3 marks)**

ii. Explain how this attenuation affects image contrast and quantification in SPECT? **(3 marks)**

d. Discuss how the distance between the γ-camera in SPECT Imaging, and the patient affects spatial resolution. Include a labeled diagram in your explanation. **(4 marks)**

e. Apart from distance, describe two other factors that influence spatial resolution in SPECT imaging. **(2 marks)**

QUESTION TWO (15 MARKS)

a. In **Positron Emission Tomography (PET)**, one measures **lines of response** (see Figure 2) produced by the tracks followed by two **gamma rays** released from the **positron-electron**

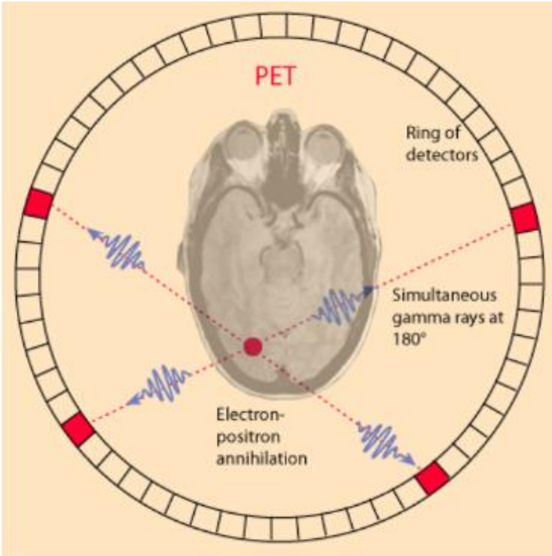

Figure 2: Two lines of response from a positron emission location

In Time-of-Flight (TOF) PET **imaging, the 'time of flight' measurement enables one to determine** where along the line of response the annihilation occurred**.**

i. Describe the process of positron emission in PET and **(3 Marks)**

ii. Explain how positron emission contributes to imaging. **(3 Marks)**

iii. Fluorine-18 (^{18}F) is one of the most commonly used PET radioisotopes.

1. Explain how ^{18}F is produced in a cyclotron**.** **(3 Marks)**
2. Describe its nuclear decay process**,** including the emitted particles and energy. **(2 Marks)**

iv. Calculate the timing resolution required in a PET scanner **to** localize an annihilation event within 1 cm accuracy**. Take the speed of light** $c = 3.0 \times 10^8$ m/s**.** **(4 Marks)**

QUESTION THREE (15 MARKS)

You want to measure insulin (antigen) concentration in a diabetic patient's blood sample using Radioimmunoassay (RIA). Answer the following questions.

(a) What is the basic principle behind the Radioimmunoassay (RIA) technique, and why is it important in medical diagnostics? **(5 Marks)**

(b) What types of antigens and antibodies are required for the assay? **(4 Marks)**

(c) How do you quantitate the concentration of insulin (antigen) in the blood sample using RIA? Outline the step-by-step process. **(4 Marks)**

(d) Identify the commonly used radionuclide in RIA. Explain its physical properties, mode of decay, and how its radiation is detected in the assay. **(2 Marks)**

QUESTION FOUR (15 MARKS)

In vivo non-imaging techniques in nuclear medicine assess organ function by tracking the uptake and decay of radiopharmaceuticals.

a. A patient is administered **10 MBq of iodine-123**, which emits gamma rays with a predominant energy of **159 keV**. Assuming that **25% of the emitted photons are absorbed in the thyroid gland**, calculate the **absorbed dose rate** immediately after administration. Assume the **thyroid gland weighs 20 g**. **(6 Marks)**
b. Using the result from part (a), calculate the **total absorbed dose** in the thyroid gland over a **24-hour uptake period**, ignoring radioactive decay. **(4 Marks)**
c. Gallium-67 is used in nuclear medicine to detect inflammation and chronic infections. It has a **half-life of 3.26 days**. Derive the **exponential decay equation** that represents the percentage of the original **Gallium-67** remaining after **t** days. **(3 Marks)**
d. Using the equation derived in part (c), determine the amount of **Gallium-67** left after **4 days** as a percentage of the initial administered activity. **(2 Marks)**

QUESTION FIVE (15 MARKS)

A laboratory accident results in a 1 μCi intake of ^{32}P **(**beta emitter**)**, which gets uniformly distributed in one of the organs of a patient. The average energy of the emitted beta particles is

570 keV**,** and the organ has a mass of 1800 g. The radiological half-life of ^{32}P is 14 days, and the biological half-life is 257 days**.**

- **i.** Derive and calculate the effective decay constant λ_e for ^{32}P considering both radiological and biological elimination. **(3 Marks)**
- **ii.** Compute the daily dose rate $\dot{D}$ to the organ from this intake. **(4 Marks)**
- **iii.** Determine the dose rate in the organ 28 days after the initial intake. **(3 Marks)**
- **iv.** A reference adult **(70 kg)** is intravenously administered **20 μCi** of ^{32}P. The biological half-life of ^{32}P in the body is **19 days**. If **40% of the intake is uniformly distributed in the whole body**, the initial whole-body activity is:

$$q_0 = 0.40 \times 20\mu Ci = 8\mu Ci$$

Calculate the following:

1. Absorbed dose constant (expressed in **erg/g t** and **Gy/t**) for ^{32}P irradiating the whole body uniformly. **(1 Mark)**
2. Total number of transformations occurring in the whole body over time. **(2 Marks)**
3. Total whole-body dose. **(2 Marks)**

……………………………………………………………………………………………………