MEDICAL PHYSICS QUESTIONS

FOR

MEMBERSHIP EXAMINATION

Edition 13.0

Canadian College of Physicists in Medicine

CANADIAN COLLEGE OF PHYSICISTS IN MEDICINE

LE COLLÈGE CANADIEN DES PHYSICIENS EN MÉDECINE

CCPM Membership Examination **Edition 13.0**

Medical Physics Questions For
Membership Examination
(Edition 13.0)

Questions de Physique Médicale
pour L'Examen d'Admission
(Édition 13.0)

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FOREWORD TO THE THIRTEENTH EDITION

This is the thirteenth edition of the published question bank for the Canadian College of Physicists in Medicine (CCPM) membership exam. This is an exam to enable the CCPM to certify that those who pass the four-part written exam and three-part oral exam are competent in their medical physics subspecialty. Combined with credentialing for the exam, this is an exhaustive process into which a candidate is entering.

All question banks underwent significant updates in 2015 and are reviewed annually for suitability of the exam material. The Magnetic Resonace Imaging question bank was further updated in 2016, the Diagnostic Radiological Physics question bank was further updated in 2021. Significant updates to the Nuclear Medicine subspecialty exam were completed in 2023 with several redundant and/or out-dated questions removed and replaced with current/relevant questions; all the questions were reorganized to improve clarity. Smaller updates have been made to the current version of the Radiation Oncology question bank. Note that it is important to ensure that the correct question bank is downloaded when exam preparation begins! Much work has been invested in producing a comprehensive set of questions since 1984 thanks to the hard work of Past Chief Examiners: Ervin B. Podgorsak, Terry M. Peters, Gino Fallone, Ting-Yim Lee, Katharina E. Sixel, Michael D.C. Evans, Robert Corns, Boyd McCurdy, Renée Larouche, Alasdair Syme and Geneviève Jarry and all those who helped them.

A Preparation Guide now exists and is posted on the CCPM website. The Preparation Guide discusses time management strategies and the typical expected length of hand-written answers.

The College wishes to thank Alexandre Bourque, deputy examiner, as well as the many volunteers that help each year. A special thanks goes to Erin Niven and Marjorie Gonzalez who helped with the comprehensive revision of the Nuclear Medicine question bank.

Candidates preparing for their exam who have comments about the question bank are invited to contact me (chiefexaminer@ccpm.ca).

Best of luck to all of the candidates,

Marcus Sonier
Abbotsford, BC, Canada
September 30th 2024

SUGGESTED TEXTS FOR PREPARATION OF THE EXAMINATION.

It must NOT be assumed that questions will be based solely on materials from these texts.

A: Radiation Oncology

1. The physics of radiation therapy: F. M. Khan; Williams and Williams, Baltimore.
2. Introduction to radiological physics and radiation dosimetry: P.H. Attix; Wiley, New York.
3. The physics of radiology (Fourth Edition.): H.E. Johns and J.R. Cunningham; Charles C. Thomas, Springfield Ill.
4. Modern technology of radiation oncology: J. Van Dyk (Editor); Medical Physics Publishing, Madison Wisconsin.
5. Radiation physics for medical physicists: E.B. Podgorsak; Springer, New York.
6. Radiation oncology physics: a handbook for teachers and students: E.B. Podgorsak (Editor); IAEA, Vienna.
7. Radiobiology for the radiobiologist: E.J. Hall; Lippincott Williams & Wilkins, New York.
8. ICRP publication 103: 2007 recommendations of the international commission on radiological protection, The International Commission on Radiological Protection; New York, 2007
9. NCRP report 147: Structural shielding design for medical x-ray imaging facilities: National Council on Radiation Protection and Measurements; Bethesda MD.
10. NCRP report 151: Structural shielding design and evaluation for megavoltage X- and gamma-ray radiotherapy facilities: National Council on Radiation Protection and Measurements; Bethesda MD.
11. CPQR Technical Quality Control Guidelines. http://www.cpqr.ca/programs/technical-quality-control/
12. ICRP publication 112: Preventing Accidental Exposures from New External Beam Radiation Therapy Technologies, The International Commission on Radiological Protection; New York, 2009

B: Diagnostic Radiology

1. Physics of radiology (2nd Ed.): A. Wolbarst, Medical Physics Publishing, Madison, WI; 2005
2. Review of Radiological Physics (3rd Ed.): W. Huda, R.M. Slone; Lippincott Williams & Wilkins; 2010
3. Essential Physics of Medical Imaging (2nd Ed.): J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, J.M. Boone; Lippincott Williams & Wilkins; (2001)
4. Medical Imaging Signals and Systems: J.L. Prince, J. Links; 2005
5. Medical Imaging Physics (4th Ed.): W.R. Hendee, E.R. Ritenour; Wiley-Liss; 2002
6. Computed Tomography: Fundamentals, System Technology, Image Quality, Applications (2nd Ed.): W.A. Kalender; Wiley-VCH; 2006
7. Ultrasound Physics and Instrumentation (4th Ed): W.R. Hedrick, D.L. Hykes, D.E. Starchman; Mosby; 2004
8. Guidelines for the safe use of diagnostic ultrasound equipment. Prepared by the Safety Group of the British Medical Ultrasound Society Ultrasound 2010; 18: 52–59.
9. Medical electrical equipment – Characteristics of digital X-ray imaging devices – Part 1: Determination of the detective quantum efficiency. International Standard IEC 62220-1

C: Nuclear Medicine

1. Physics in nuclear medicine (4th Ed): S.R. Cherry, J.A. Sorenson and M.E. Phelps; W.B. Saunders, Philadelphia; 2012
2. Nuclear medicine physics: L.E. Williams (Ed); CRC Press, Boca Raton.
3. The physics of radiology (4th Ed.): H.E. Johns and J.R. Cunningham; Charles C. Thomas, Springfield Ill.
4. Introductory physics of nuclear medicine, R. Chandra; Lea & Febiger, Philadelphia.
5. Radiation detection and measurement, G. F. Knoll; John Wiley and Sons, Third Edition, 2000.
6. Basic science of nuclear medicine, R.P. Parker, P.H.S. Smith, D.M. Taylor; Churchill Livingston, New York.

D: Magnetic Resonance

1. Nuclear magnetic resonance imaging in medicine and biology: P.G. Morris; Oxford University Press, Oxford.
2. Magnetic resonance imaging: physical principles and sequence design, R.W. Brown, YN Cheng, E.M. Haacke M.R. Thompson, and R. Venkatesan, A. John Wiley & Sons, 2014.
3. In vivo NMR Spectroscopy: principles and techniques, R. A. de Graaf, John Wiley and Sons, 2007.
4. Questions and answers in magnetic resonance imaging, Second Edition, A.D. Elster and J. H. Burdette, Mosby, 2001.
5. Handbook of MRI pulse sequences, M. A. Bernstein, K. F. King, and X. J. Zhou, Elsevier Academic Press, 2004.
6. MRI: Basic Principles and Applications (4th Ed.); M.A. Brown, R.C. Semelka; Wiley-Blackwell; 2010
7. Principles of Magnetic Resonance Imaging: A Signal Processing Perspective, Z.P. Liang and P.C. Lauterbur, Wiley-IEEE, 1999

Section C: Nuclear Medicine Specialty

You will be required to answer **FOUR** questions from Part III and **FIVE** questions from Part IV. The total time for both Parts is 2.5 hours. Each question in Part III is worth 25%, totaling to 100%. Each question in Part IV is worth 20%, totaling to 100%.

PART III NUCLEAR MEDICINE SPECIALTY

1. Use the invariant $E^2 - p^2c^2 = Inv$ to derive a general relationship for threshold in a nuclear reaction $A(a,b)B$ where *a* and *b* are the incoming and outgoing particles or photons.

2.
   (a) Sketch and briefly discuss the curve E_B/A vs A where E_B is the total binding energy of any nucleus and A is its atomic mass. Indicate and briefly discuss the regions representing fusion and fission on the curve.
   (b) Using the curve sketched in (a), estimate the overall energy (in MeV) released if U238 fissions spontaneously into two equal and stable fragments with the release of four neutrons. What fraction of the U238 mass is converted into energy?
   (c) Assuming the large fission masses in (b) take up negligible Kinetic Energy and that on average, the four neutrons share the available energy equally, calculate the average speed of a neutron, as expressed as a fraction of the speed of light, *v*/*c*.

3. Briefly define or explain:
   (a) activity ***A***
   (b) specific activity ***a***
   (c) carrier-free source
   (d) branching ratio
   (e) energy level width **Γ**
   (f) half-life $t_{½}$
   (g) mean lifetime **τ**
   (h) decay constant **λ**
   (i) decay chain
   (j) daughter activity

4. Briefly define or explain:
   (a) neutron activation
   (b) isomeric transition
   (c) neutron fluence rate
   (d) annihilation photon
   (e) specific ionization
   (f) fission fragments
   (g) nuclear chain reaction
   (h) moderator in nuclear reaction
   (i) artificial radioactivity
   (j) natural radioactivity

5. Briefly define or explain:
   (a) nuclear excited state
   (b) atomic excited state
   (c) fluorescence yield
   (d) average β energy
   (e) isomeric state
   (f) annihilation photon
   (g) internal conversion yield
   (h) characteristic radiation
   (i) bremsstrahlung
   (j) mass deficit

6. Briefly define or explain:
   (a) beta particle
   (b) alpha particle
   (c) ionization
   (d) K-absorption edge
   (e) ion pair
   (f) linear energy transfer (LET)
   (g) half-value layer (HVL)
   (h) positron decay
   (i) electron capture
   (j) internal conversion

7. Discuss α decay in general, give the general relationship for the total energy Q_α liberated in α decay and sketch an energy level diagram for a typical α-decay.

8. Discuss isomeric transition in general, give a typical example with an energy level diagram and explain internal conversion and gamma decay.

9. Discuss the interactions of the particles listed below with both tissues and with high atomic number materials
   (a) alpha particles (kinetic energy: few MeV)
   (b) beta particles (kinetic energy: few MeV)
   (c) thermal neutrons
   (d) fast neutrons.

10. Briefly define or explain:
   (a) nuclear resonance fluorescence
   (b) electron capture
   (c) Mossbauer effect
   (d) characteristic x ray
   (e) triplet production
   (f) Cerenkov radiation
   (g) internal conversion coefficient
   (h) Auger electrons
   (i) mass energy absorption coefficient
   (j) threshold for nuclear reaction

11.
   (a) Sketch the graphs for a typical radioactive nucleus, relating the activity to time t on a semi-log plot and on a linear plot.
   (b) Show the half-life ($t_{½}$) and the mean lifetime (τ) on the time axis and calculate the relationship between τ , $t_{½}$, and the decay constant (λ).

12. Consider a radioactive decay chain, in which a radioactive parent nuclide **P** decays to radioactive daughter nuclide **D** with decay constants λ_P and λ_D respectively:

$$P \xrightarrow{\lambda_P} D \xrightarrow{\lambda_D} G.$$

The activities of parent (A_P) and daughter (A_D) nuclei present at some arbitrary time are

$$A_P = A_{P_0} e^{-\lambda_P t}$$

$$A_D = A_{P_0} \times \frac{\lambda_D}{\lambda_D - \lambda_P}\left(e^{-\lambda_P t} - e^{-\lambda_D t}\right)$$

(a) Sketch on the same graph the activities A_P and A_D vs time t for when $\lambda_P < \lambda_D$.

(b) Calculate the time, tmax, for the maximum in A_D and show that this occurs when $A_P = A_D$

(c) Show for $\lambda_P = \lambda_D(1-\varepsilon)$, where $0 < \varepsilon << 1$, that tmax may be expressed as $t_{\max} \approx 1/(\lambda_P \lambda_D)^{1/2}$.

13. When a radioactive nuclide has a daughter of shorter half-life, it is often possible to separate the two, mechanically or chemically. Several such systems, known as nuclear generators, are in use. Name at least three such systems and sketch the activity of parent and daughter inside the generator with respect to time and assuming:
    (a) no removal of daughter; and
    (b) periodic removal of the daughter. Assume 100% efficiency at removing the daughter from the generator.

14. Suppose a sample of material is bombarded with neutrons and that a radioisotope is produced at a steady rate *Q*. There is initially no radioisotope present and it decays at a rate $-\lambda N$, where *N* is the number of radioactive nuclides present at time *t* and λ is the decay constant.
    (a) Derive the formula for the radioisotope's activity *A* as a function of time *t* during the neutron bombardment.
    (b) What assumption is being made to produce the radioisotope at a steady rate *Q*?

15. Sketch a diagram representing the two most important modes of photon interactions with a medium for photons energies used in nuclear medicine, briefly discuss the two effects, and state the dependence of the appropriate mass attenuation coefficient upon the photon energy and atomic number of the medium.

16. The primary agents that produce damage in cells irradiated by x- or gamma rays are high energy electrons liberated through interactions of photons with whole atoms, orbital electrons or nuclei. Briefly discuss the three most important modes of photon interactions with matter in the photon energy range between 10 keV and 10 MeV describing the general dependence of each mode.

17. Considering the primary imaging photons emitted by Tc-99m and I-131, at what angle of scatter has a Compton-scattered photon lost energy equivalent to the energy resolution at the photopeak energy of a gamma camera using a 0.5" thick NaI(Tl) scintillation detector. Discuss the implications of this for imaging referring specifically to detector photopeak efficiency and the (in)ability of pulse height analysis to discriminate against photons scattered in the patient.

18. Sketch a Poisson distribution that corresponds to the distribution of counts from a radioactive source, where determinations have been made for a fixed period of time. Assume that the true average is 1000 counts per 10 seconds. Indicate on the graph the range in counts in which 66%, 95%, and 99% of the observations should fall.

19.
    (a) Suppose the "true" background radiation level is 100 counts per minute. You wish to measure the background rate and are trying to decide between two methods:
        (i) Measuring the background 10 times using 1 minute intervals and then taking the mean of the 10 readings.
        (ii) Measuring the background once using a 10 minutes interval and then scaling the result to a counts-per-minute rate.

        Show the expected mean value for your measured background and the standard error in the mean is the same. State any assumptions you make.
    (b) Suppose you measured the background with five one-minute measurements and one ten-minute measurement with the results:

        112, 108, 109, 82, 93 and 995.

        Using this data, calculate the best estimate of the background count rate in cpm.

20. A surface is surveyed with a G-M counter for contamination and a small spot of contamination is found which gives a reading of 15,000 counts/min. The normal background reading is 45 counts/minute. The counting rate becomes negligible when a 5 mm plastic absorber is placed over the area. The counting rate for a bismuth-210 beta reference source counted in a similar manner is 9,400 counts/minute but the source is known to emit 32,600 beta particles/minute.
    (a) What is the rate of emission of beta particles from the contaminated surface?
    (b) What factors modify the count rate detected by the G-M detector?

21. A source is to be counted for a time t_G in the presence of background and measured G counts in t_G. A second measurement taken over time t_B for the background alone and measured B counts in t_B. If σ_G and σ_B are the respective standard deviations, derive an expression for the standard deviation σ_r, of the net signal rate: $r = G/t_G - B/t_B$. If the combined time $t = t_G + t_B$ to measure G and B is fixed, then how should the times t_G and t_B available for counting be optimally divided between the two measurements so as to minimize σ_r ?

22. Nuclear medicine imaging procedures are often terminated using "count density" criteria. Making assumptions regarding system spatial resolution of a gamma camera, suggest what count density is required to demonstrate that a 10% change in counts per square centimeter is significant at a 95% confidence level.

23. Let pixels of two digitized scintillation camera images be represented by $X(i,j)$ and $Y(i,j)$, with assumed errors of $\Delta X(i,j)$ and $\Delta Y(i,j)$, respectively. What is the error of a picture element formed by $X(i,j) \times Y(i,j)$, and by $X(i,j) + Y(i,j)$?

24. Draw a 2 × 2 matrix of disease (**D**+ or **D**–) and a diagnostic test (**T**+ or **T**–) for some patient population. Identify true positive, false positive, true negative and false negative cases. Using your table where necessary, clearly define the following:
    (a) sensitivity;
    (b) specificity;
    (c) accuracy
    (d) prevalence (of disease)
    (e) positive predictive value of the test
    (f) negative predictive value of the test

25. Describe in detail how a receiver operating characteristic (ROC) curve is generated and sketch a conventional curve. Label the axes clearly and indicate operating points on the curve corresponding to "*strict*" and "*lax*" thresholds.

26. Outline a method (the "Rating Method") for generating an ROC curve using a single observer and a number of diagnostic images.

27. Provide the full MDA equations for a counting system for the counting of clinical samples (e.g. – blood), of the thyroid, and of wipes. Include definitions and units for the symbols. What parameter changes when the counting system is a GM counter, and why? What is the statistical meaning for the constant term included in the MDA equation?

28. Briefly define or explain:
    (a) meiosis
    (b) interphase
    (c) apoptosis
    (d) growth fraction
    (e) necrosis
    (f) metastasis
    (g) exfoliation
    (h) mitotic index
    (i) mitosis
    (j) hypoxic fraction

29. Briefly define or explain:
    (a) mutation
    (b) DNA
    (c) RNA
    (d) cell cycle
    (e) ploidy
    (f) anaphase
    (g) restitution
    (h) chromatid
    (i) chromosome
    (j) metaphase

30. Briefly discuss the effects of radiation on cellular constituents **other than** DNA and chromosomes.

31. Briefly discuss three types of cell response to radiation:
    (a) apoptosis;
    (b) division delay;
    (c) reproductive failure

32. Molecules can be changed, damaged or inactivated by either *direct* or by *indirect action* of ionizing radiation. Explain what is meant by these terms. Under what circumstances would direct action be the predominant mode of interaction of target molecules? What is the relationship between dose and the production of molecules inactivated by direct action, and how may the size of the target molecules or submolecular structures be calculated from this relationship?

33. Outline the reasons for believing that the principal site of radiation-induced lethal damage is located in the chromosome. Describe how three frequently observed types of chromosome aberration are produced.

34. Discuss the radiation effects on chromosomes and list four specific examples of the damage. Explain the difference between chromosome and chromatid aberrations, and discuss the effects of dose, dose rate, and LET on specific types of chromosome damage.

35.
    (a) Draw a typical radiation survival curve for mammalian cells. Present an equation which is a good fit to curves of this type, and explain its parameters in relation to the understanding of mechanisms of cell killing.
    (b) Briefly discuss how cell survival is determined experimentally.

36. Discuss in detail the cell cycle and give three examples of cell cycle times for mammalian cells. Describe the variation of radiosensitivity of a cell as a function of the position in the cell cycle.

37. Discuss the radiosensitivity for each stage of pregnancy, including the risk of carcinogenesis and other adverse outcomes. What are the threshold doses at which adverse outcomes have been observed in humans? What would be your advice for the following situations:
    (a) A pregnant person in the third trimester is exposed to radiation resulting in a fetal dose of 250 mGy. This person is concerned that the fetus will be lost. What do you advise in this situation?
    (b) A patient has been trying to conceive and is unsure of pregnancy status. If the abdominal region is exposed in very early stages of pregnancy, what organ is used for fetal dose calculation? Assume a fetal dose of 20 mSv is calculated, and it is estimated the patient was 11 days post-conception and is considering terminating the pregnancy. What do you advise in this situation?

38. A patient receives 5.5 GBq of I-131 for treatment of thyroid metastases.
    (a) What precautions must be taken to ensure proper protection of other persons?
    (b) Should the patient's urine be collected? If so, for how long should it be kept and how should it be disposed of? What are the arguments against such collection?

39. Outline a thyroid-screening program suitable for research workers involved in labeling compounds with I-125 and/or I-131.

40. The chairman of the local university physics department is referred to the nuclear medicine department for a bone scan. During the examination he asks a number of questions pertinent to radiation safety. Give your responses to the following questions.
    (a) To which government agencies is the Nuclear Medicine Department responsible for
        (i) procurement of radioisotopes;
        (ii) storage of radioisotopes;
        (iii) radioisotope usage in vivo;
        (iv) disposal of radioactive wastes?
    (b) What are the detrimental effects of radiation at the levels in use in a nuclear medicine department?
    (c) Are there any realistic circumstances in diagnostic nuclear medicine when a potentially dangerous dose of a radiopharmaceutical agent may be administered to a patient?
    (d) What instruments would you want to have available for purposes of monitoring radiation levels, and why?

41.
(a) What radiation safety considerations are particular to breast-feeding mothers?
(b) For what nuclear medicine exams is it recommended that breast feeding be discontinued and for how long?
(c) A mother who received an injection of Tc-99m-pertechnetate has a maximum concentration of tracer in breast milk at 3 hrs measured to be 0.06 MBq/ml. Two additional measurements taken over the next 5 hours suggest a biological half-life of 24 hours. Assuming the infant ingests 150 ml per feeding and feeds every four hours, when is it safe for the infant to start feeding? Assume an effective dose to the newborn of 0.14 mSv/MBq of ingested milk.

42. In health care facilities where radiation is used for diagnostic or therapeutic purposes, protection of four groups of people may need to be considered:
(i) Nuclear Energy Workers (NEW's);
(ii) non-NEW's working in the vicinity of a source radiation;
(iii) clerical and other peripheral staff; and
(iv) public at large.
Specify and justify regulatory and operational dose equivalent limits for the four groups and compare them to the dose equivalent from natural background.

43. Discuss the operating philosophy for radiation protection practices known as ALARA, indicating how it influences interpretation of effective and equivalent dose limits. Describe five radiation-laboratory working practices that are consistent with the ALARA philosophy.

44. A fetus is exposed to a dose of 50 mSv during the 10th week of pregnancy. Discuss the possible effect(s) of this exposure and estimate the risk factors associated with each effect. What is the effective dose limit for occupational exposure of pregnant women who are NEW's?

45. You have been asked to review proposals for human research that will include the administration of diagnostic quantities of radiotracers in clinical use to normal subjects. List, and from the perspectives afforded by the ALARA principle, comment on the principles by which a Human Research and Ethics Committee could, in general, evaluate such proposals.

46. Briefly discuss the principles of radioprotection as they apply to the clinical practice of nuclear medicine. Provide specific examples of the applications of each of these principles.

47. The nuclear medicine department wishes to dispose of its solid waste (syringes, cups, straws, etc) that were used during I-131 treatments. See the *Nuclear Substances and Radiation Devices Regulations* published at the CNSC website for the exemption quantity regulations.
(a) What limits, if any, apply?
(b) What additional considerations should be taken into account?
(c) What alternative approaches could be taken?

48. Briefly describe the methods used to monitor for stray radioactivity following a spill involving 37 MBq of I-131 in liquid form being administered for thyroid therapy. Provide an outline of decontamination procedures in such a situation and describe what future actions, if any, may be necessary.

49. A person arrives at an emergency room complaining of severe abdominal pain, tells the triage nurse he is "radioactive", and then passes out.
    (a) What directions can you provide staff to confirm whether or not the patient is actually radioactive?
    (b) Do you need to investigate this before, during, or after triage?
    (c) Why could this patient be measurably radioactive other than due to a medical procedure?
    (d) Assume that the patient received I-131 therapy for Grave's disease earlier that day with an administered activity of 740 MBq. If asked by emergency room staff, what radiation safety precautions do you instruct them to follow?

50. Briefly define or explain:
    (a) radiation quality
    (b) somatic effects
    (c) stochastic effects
    (d) relative biological effectiveness (RBE)
    (e) maximum permissible dose
    (f) ALARA principle
    (g) absorbed dose
    (h) equivalent dose
    (i) effective dose
    (j) $LD_{50/30}$

51. Briefly define or explain:
    (a) detriment in a population
    (b) quality factor
    (c) collisional stopping power
    (d) LET
    (e) relative biological effectiveness
    (f) exposure
    (g) exposure rate constant
    (h) quenching in a Geiger-Mueller detector
    (i) effective dose
    (j) body burden

52. A 100 MBq of Y-90 is injected into the center of a tumour. Assuming a point-source of Y-90, estimate the initial dose rate from beta-radiation to the surrounding soft-tissues as a function of radius. What is the dose delivered to the tumour? Give your answers in SI units and state any assumptions that you find necessary to make.

53. A patient is given 3.5 MBq of I-131 orally. Assume the uptake to the thyroid is 30%, the average energy of the beta particles is 0.1915 MeV, the biological half-life is 80 days and the mass of the thyroid is 20 grams. Calculate the dose to the thyroid. Justify why the photon contribution to the dose is negligible.

54. What is the full/original MIRD (Medical Internal Radiation Dose) equation? Include definitions and units for the symbols. What are the S-value and residence time parameters? What are the limitations of the MIRD formalism? What are the differences between the MIRD and ICRP internal dose calculation methodologies?

PART IV NUCLEAR MEDICINE SPECIALTY

1. Briefly define or explain:
   (a) dynode
   (b) photocathode
   (c) fluorescence
   (d) crystal light decay constant
   (e) exciton
   (f) valence band
   (g) forbidden zone
   (h) energy gap
   (i) surface barrier detector
   (j) n-type semiconductor

2. Discuss photon energy spectrometry based on scintillation detectors. Sketch a typical pulse height spectrum and define the following features:
   (a) photopeak
   (b) Compton valley, edge and plateau
   (c) x-ray escape peaks
   (d) annihilation escape peak
   (e) coincidence-sum peaks
   (f) backscatter peak
   (g) annihilation peak
   (h) characteristic x-ray peak

3. Briefly define or explain:
   (a) photo-peak
   (b) dynode
   (c) W for air
   (d) glow curve
   (e) Compton edge
   (f) electronic avalanche
   (g) space charge
   (h) quenching
   (i) coincidence loss
   (j) paralyzable and non-paralyzable system

4. A number of different materials are involved in imaging a patient in Nuclear Medicine.
   (a) What are the effective atomic numbers for:
      (i) NaI
      (ii) BGO
      (iii) LSO
      (iv) water
      (v) bone
      (vi) muscle
      (vii) lead
      (viii) tungsten
   (b) What is the relative importance of the photoelectric effect and the Compton effect in the patient and the camera?
   (c) What is the potential impact of photon interactions in the camera head on the image quality?

5. Briefly discuss.
   (a) the calculation of absorbed dose in air from a measurement of ionization in air with an ionization chamber;
   (b) the energy discrimination ability of proportional counters;
   (c) how to distinguish between beta and gamma radiation with a Geiger-Mueller counter;
   (d) how to determine source strength of a beta emitter with a Geiger-Mueller counter.

6. Describe the essential features of a system used for gamma-ray spectroscopy.

7. Draw a typical pulse height spectrum obtained with a Si(Li) detector and an encapsulated Cs-137 gamma source. Identify and explain the main features of the spectrum.

8. Discuss the techniques used for obtaining pulse height distributions from beta emitters by means of liquid scintillation counting.

9. Describe the principle of operation of a scintillation counter. Draw a diagram of a typical counter and clearly label its components. Also sketch a photomultiplier tube and describe its operation.

10. Discuss the photopeak energy resolution in scintillation spectrometry and give typical values for at least three different scintillation materials. Discuss the reasons for the relatively poor energy resolution of scintillation detectors. Sketch a pulse height spectrum obtained with a NaI(Tl) crystal for a Cs-137 gamma source (photon energies: 31.8 keV, 37.3 keV and 662 keV).

11. Describe the principles of operation of semiconductor detectors and discuss their use in radiation protection.

12. Scintillation detectors have a relatively poor energy resolution. As a consequence, semiconductor detectors have been introduced to improve the resolving power of gamma spectrometers. Discuss at least two types of semiconductor detectors used in gamma spectrometry. Why are they not used more routinely in nuclear medicine applications? Describe a semiconductor being used in routine nuclear medicine imaging. What is the energy resolution of this system and what are the potential clinical advantages of this improved energy resolution?

13. Thermoluminescent dosimetry (TLD) is a widely used relative dosimetry technique. Briefly discuss the main characteristics of a typical TLD reader and at least three materials used as radiation sensitive phosphors

14. Describe the operation of three types of personnel radiation monitors that depend on different methods to detect and integrate radiation exposure or dose. Indicate the advantages and disadvantages of each type of detector.

15.
(a) Describe the following radiation detectors based on gas ionization and discuss their relative merits in the field of radiation protection:
(i) ionization chamber;
(ii) proportional counter; and
(iii)Geiger-Mueller counter.
(b) How are these detectors calibrated to give readings in radiation quantities pertinent to radiation protection?

16.
(a) Describe those factors that contribute to dead-time of a detector system.
(b) Define paralyzable and non-paralyzable systems and illustrate each with an example of detector system that is paralyzable and a detector system that is non-paralyzable.
(c) Describe two methods by which dead-time may be determined.
(d) Suppose a nonparalyzable system has a dead time of 1 microsecond. You measure a signal of 200,000 counts in 1 minute. What is the true number of counts?
(e) Describe a clinical nuclear medicine exam in which accurate deadtime correction is essential and explain why.

17.
(a) Discuss these quality control tests for a digital dose calibrator: background, accuracy, linearity, and clock accuracy (include pass/fail criteria, testing options, and frequency of testing). What does it mean if the linearity test fails at the high activity range? At the low activity range?
(b) Discuss these quality control tests for a well counter: background, gain calibration, energy resolution, accuracy, and chi-square (include pass/fail criteria, testing options, and frequency of testing). What does it mean if the chi-square test fails? What would be your next steps?

18. You are performing efficiency and MDA measurements for a well counter for Tc-99m. You have made a source with an activity of 10 kBq. When counting background, you count for 60 seconds using the Tc-99m window and obtain a reading of 250 CPM. When counting the source, you count for 60 seconds and the reading is 495,000 CPM. What is the efficiency and MDA of the well counter for Tc-99m? If the removable contamination limit for Tc-99m in a public area is 30 Bq/cm2, what is the reading in CPM that corresponds to this limit? State any assumptions that you make for your calculations.

19. Briefly define the following NEMA (National Electrical Manufacturers Association) terms as appropriate for a scintillation camera and provide typical values for a modern camera:
    (a) intrinsic spatial resolution
    (b) intrinsic energy resolution
    (c) intrinsic flood field uniformity
    (d) intrinsic spatial linearity
    (e) system alignment
    (f) system spatial resolution with and without scatter
    (g) intrinsic count rate performance
    (h) multiple window spatial registration
    (i) system sensitivity
    (j) detector-detector sensitivity variation

20. In the context of SPECT imaging, briefly define and explain the use or significance of:
    (a) gadolinium source
    (b) coincidence imaging
    (c) flash ADC
    (d) auto-tune
    (e) digital gamma camera
    (f) cross-talk contamination
    (g) pile-up correction
    (h) fan-beam focal length
    (i) holospectral imaging
    (j) truncation artifacts

21. With the aid of diagrams describe components of a single crystal gamma camera. Describe how each of these components may contribute to the degradation of image quality.

22. Discuss the differences between fan-beam and parallel hole collimators for SPECT including a discussion of their respective performance parameters, implications for image reconstruction and attenuation correction techniques.

23. Outline the gamma camera quality control protocol for a multi-head SPECT system with whole body capabilities. Indicate the frequency of the procedures to be performed and briefly describe the techniques used.

24. Draw five examples of abnormal test patterns obtained using a bar phantom, making reference to the type of equipment malfunction involved.

25. What are the sources of intrinsic flood field non-uniformity? What scintillation camera design features serve to minimize such defects?

26. Describe the effects of crystal thickness on intrinsic spatial resolution, system spatial resolution without scatter, and system sensitivity for Tc-99m and I-131. How does crystal thickness affect spatial resolution and sensitivity in PET imaging?

27. Many different factors influence the quality of SPECT images.
    (a) What are the artifacts due to photon attenuation?
    (b) What will be the effect on the SPECT image if a small hot object is placed in the center of the field of view?
    (c) What will be the effect on the SPECT image if a small hot object is placed near the outer edge of the field of view?
    (d) Discuss the advantages and disadvantages of using circular versus non-circular orbit in a SPECT acquisition. What are the possible artifacts in the image?

28. What are the relevant design parameters for collimators used in clinical radionuclide imaging? How do these characteristics affect the performance of the collimator?

29. Sketch and describe the changes in the energy spectrum from a NaI-based detector for Cr-51 (320 keV) if:
    (a) a thicker NaI(Tl) crystal were used;
    (b) a one-inch slab of lucite were interposed between the Cr-51 source and the NaI scintillation detector;
    (c) images of the knee were being acquired using Ga-67 citrate ("spot views") instead of Cr-51
    (d) one-inch slab of lucite were placed behind the Cr-51 source.
    (e) How does the spectrum of Ga-67 change if a LEGP collimator is used instead of a MEGP, what about if a pinhole collimator is used?

30.
    (a) What collimators would you select for each of the following procedures? Explain the reasons for your choice.
        (i) thyroid scintigraphy with Tc-99m-pertechnetate;
        (ii) first-pass angiography;
        (iii) images of the knee using Ga-67 citrate ("spot views")
        (iv) a lung scan to detect metastases in a patient with local recurrence of thyroid cancer treated with radioiodine three days earlier.
    (b) Would you recommend a high-sensitivity collimator coupled with resolution recovery during reconstruction over a high-resolution collimator? Please give your reasons why or why not.

31.
    (a) What are the advantages and disadvantages related with the use of fan-beam collimators in SPECT cameras?
    (b) Why do these collimators have better sensitivity than the standard parallel hole collimators?
    (c) Discuss the use of pinhole collimation in SPECT imaging.

32. Outline and contrast SPECT/CT and SPECT with radioisotope transmission capabilities. Consider hardware, acquisition parameters, reconstruction, cost, and radiation safety; and include a labeled diagram of a SPECT/CT system.

33. Discuss the origins of full or partial ring artifact in a SPECT image. Discuss the limits of planar QC tests in detecting tomographic artifacts. Describe the techniques to discern if a tomographic artifact is intrinsic or extrinsic in origin.

34. Discuss SPECT, SPECT/CT, and CT pulmonary angiography to investigate pulmonary embolism (PE). Discuss the pros and cons of each, and compare the respective patient doses.

35. In the context of positron emission tomography, briefly define and explain the use or significance of:
    (a) line of response
    (b) scatter fraction
    (c) interplane septa
    (d) random coincidence rate
    (e) singles rate
    (f) axial slice width
    (g) 3-D acquisition mode
    (h) single-slice rebinning
    (i) axial acceptance angle
    (j) partial ring geometry

36. Sketch a diagram of a typical PET scanner. Describe individually most important components. Include typical performance parameters.

37. List five major, medically used positron-emitting radionuclides and state their important physical characteristics such as half-life, positron energy, etc. For each isotope listed, provide one associated radiopharmaceutical and its application. Describe typical positron radiopharmaceutical production facility, highlighting problems.

38. Why is F-18 a useful nuclide in PET, given that the fluorine and its compounds are not normal metabolic substrates? What are the clinical applications of F-18 imaging? Provide a minimum of 5 different radiopharmaceuticals spanning oncology, neurology, and cardiology. For each provide a brief description of its use and what it measures.

39. Briefly outline the differences in camera design for PET and SPECT. What detectors are used in both systems and why? Discuss the need for using collimators for PET and SPECT.

40.
(a) Compare the following aspects of PET against SPECT:
(i) spatial resolution;
(ii) sensitivity (including realizable count rates); and
(iii)ability to quantitate radioactivity.
(b) What physical phenomena limit performance of SPECT and PET?

41. Describe the basic operation of a cyclotron and include diagrams. What are the limiting parameters with regards to its design? What are the two common facility shielding designs?

42. Discuss interactions of neutrons with matter. Describe a neutron detector that can be used in the commissioning of a cyclotron. Do cyclotron operating personnel need to be monitored routinely for neutron doses? Why or why not?

43. Describe the CT and MRI attenuation correction methods in PET. Compare and contrast CT attenuation correction in SPECT and PET.

44. Outline the acceptance tests that you would perform on a newly purchased PET system. Provide a general description of the techniques used for each test and the expected results.

45. Discuss the limits of spatial resolution in TOF PET. Discuss 3 current fields of research that could yield an improvement in the spatial resolution of clinically available systems.

46. Briefly define and describe the use or significance of the following to SPECT imaging:
(a) log power spectrum
(b) central slice theorem
(c) sinogram
(d) ramp filter
(e) septal penetration
(f) Ordered Subsets Expectation Maximization
(g) Fast fourier transform
(h) depth dependent resolution recovery
(i) Partial volume effect
(j) Metz filter

47. Briefly define or explain the use of:
(a) bilinear interpolation
(b) Levenberg-Marquardt algorithm
(c) histogram equalization
(d) deconvolution
(e) biexponential fitting
(f) maximum intensity projection
(g) ray tracing
(h) back-propagation neural network
(i) gaussian smoothing
(j) morphological operator

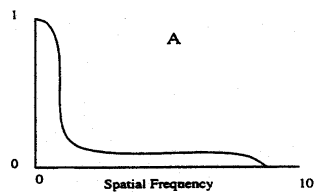
48. In relation to Radiology Information Systems (RIS) in running an imaging department, explain the purpose and use of:
    (a) firewall,
    (b) checksum,
    (c) IPv6,
    (d) RAID,
    (e) DICOM,
    (f) PACS.

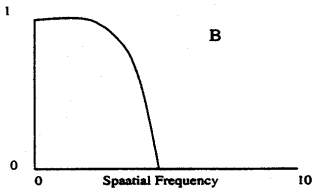
49. Describe in detail, filtered backprojection and iterative techniques for image reconstruction in SPECT. Discuss the advantages and disadvantages of iterative reconstruction compared to filtered backprojection in the context of clinical implementation.

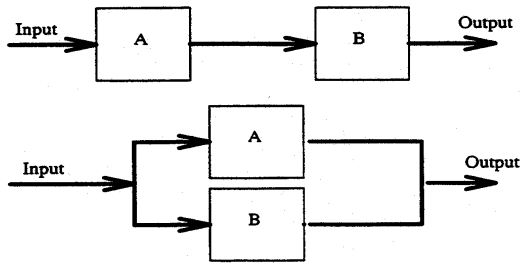
50. Using equations to illustrate your answers where appropriate, answer the following:
    (a) What are two properties of linear imaging systems?
    (b) What is meant by "shift invariant"? Give examples of both "shift variant" and shift invariant systems.
    (c) What is a point response function?

51. Using equations to illustrate your answers where appropriate, answer the following:
    (a) What is the Modulation Transfer Function (MTF) and how is it related to the point response function?
    (b) For a linear cascaded two-stage system with point response function $p_1(x)$ and $p_2(x)$
        (i) What is the total point response function of the system?
        (ii) What is the MTF of the total system?

52. For the systems illustrated graphically below with the corresponding MTF's, what is the MTF for the complete system (i.e., at the output)?







53. Describe a "*contrast-detail*" analysis of an imaging system. Sketch and label a typical contrast-detail graph for a CT scanner. What are the major limitations of this technique?

54. Present the problem of voluntary patient motion (as opposed to cardiac or respiratory motion) during SPECT and dynamic planar imaging. Describe typical algorithms that can be applied for motion correction of planar dynamic, and SPECT acquisitions. Discuss limitations of such algorithms.

55. Why is it important to correct for attenuation in SPECT and PET? Compare the techniques used for non-uniform attenuation correction in SPECT and PET. Discuss the magnitude of the correction required, accuracy of the technique, transmission sources used, algorithms for the attenuation correction, and clinical applications. Prove that the correction is independent of depth for simple PET geometry.

56. Describe techniques for radio-isotope-based non-uniform attenuation correction in SPECT. Sketch the geometries of such systems, discuss reconstruction methods, accuracy of the techniques applications and problems. Compare dual scanning collimated line source technique to collimated line source with fan beam geometry.

57. Why is photon scatter a problem in nuclear medicine? Compare at least three techniques for scatter correction of images.

58. Discuss the difference between filtering in convolution and windowing in Fourier transform reconstruction methodologies. List the advantages and disadvantages of iterative reconstruction vs analytical reconstruction techniques in the context of mathematical/software implementation.

59. What is the application of renal scintigraphy? Provide typical acquisition parameters and describe briefly radiopharmaceuticals used. Discuss image processing and curve analysis methods used in the interpretation of these scans, including background correction techniques and deconvolution analysis. Describe quantitative physiological parameters that can be obtained from renal scintigraphy.

60. Describe image-processing techniques used for automated edge detection and determination of the ejection fraction in planar radionuclide ventriculography. Discuss the reliability, and accuracy of these techniques. Discuss the use of multiple harmonics analysis. What other physiological parameters, can be derived from these images?

61. What is the role of gated SPECT perfusion imaging? What are typical image acquisition parameters? Discuss image-processing techniques used for the automated calculation of the ejection fraction from gated SPECT. Discuss the reliability and accuracy of these algorithms.

62. Describe in detail the bull's eye analysis algorithm applied to the myocardial perfusion tomography including techniques used for the comparison with the normal database.

63. In the context of gated SPECT acquisition, briefly define or explain:
    (a) end-diastolic volume
    (b) list mode
    (c) ejection fraction
    (d) ECG gated frame mode
    (e) premature ventricular contraction (PVC)
    (f) sinus rhythm
    (g) phase analysis
    (h) atrial fibrillation
    (i) bundle branch block
    (j) cardiac output

64. Describe in detail, using diagrams, the acquisition of a gated equilibrium blood pool study. The data from such a study are corrupted when significant arrhythmia is present. Explain how this occurs and suggest methods that can be used to overcome this difficulty.

65. What is the role of an equilibrium gated blood-pool study? Describe the techniques used to estimate ejection fraction. What are the inherent limitations of this technique? What are its advantages and disadvantages in comparison to gated myocardial perfusion imaging for measuring ejection fraction? What is phase analysis and how are these measurements made? What is the role of phase analysis in the management of heart disease?

66. Consider a choice of imaging modality for a patient with suspected coronary artery disease (CAD). Compare coronary angiography, echocardiography, and nuclear medicine. Discuss the information, which can be provided by each of these modalities, cost and availability, and clinical relevance. Could other modalities be potentially useful? Make a case for the role of a nuclear medicine scan in diagnosing CAD.

67. List 5 therapy radiopharmaceuticals currently in use, each with a different radioisotope. Provide their principle photon and particulate emissions, energies, half-lives, and mechanisms for administration. Other than the target tissue/organ, list two tissues/organs that can be clinically concerning for each radiopharmaceutical.

68. Compare and contrast the isotopic properties, radiopharmaceutical distribution, clinical protocols, and image spatial resolution of Tc-99m ECD, Tc-99 HMPAO, and O-15 water for clinical cerebral blood flow protocols