MEDICAL PHYSICS QUESTIONS FOR MEMBERSHIP EXAMINATION

Edition 11.1

Canadian College of Physicists in Medicine

CANADIAN COLLEGE OF PHYSICISTS IN MEDICINE

LE COLLÈGE CANADIEN DES PHYSICIENS EN MÉDECINE

CCPM Membership Examination **Edition 11.1**

Medical Physics Questions For
Membership Examination
(Edition 11.1)

Questions de Physique Médicale
pour L'Examen d'Admission
(Édition 11.1)

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FOREWORD TO THE ELEVENTH EDITION

This is the eleventh 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 4-part written exam and 3-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 were updated in 2015. The MRI question bank was further updated in 2016. Smaller updates continue to take place each year, so 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 and Renée Larouche 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 Geneviève Jarry, deputy examiner, as well as the many volunteers that help each year. 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,

Alasdair Syme

Halifax, NS, Canada

September 28th 2019

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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. Kahn; 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

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C: Nuclear Medicine

1. Physics in nuclear medicine (3rd Ed): S.R. Cherry, J.A. Sorenson and M.E. Phelps; W.B. Saunders, Philadelphia; 2003
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

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Section A: Radiation Oncology Specialty

You will be required to answer **FIVE** questions from Part III and **FIVE** questions from Part IV. Total time to complete these questions is 2.5 hours. Each question is worth an equal percentage, totaling to 100% for each Part.

CCPM Membership Examination **Edition 11.1**

III RADIATION ONCOLOGY

1. (a) Define linear attenuation coefficient and energy absorption coefficient for photon beams and describe the difference between the two coefficients.
   (b) Prepare a table showing the relationship between the linear, mass, atomic and electronic attenuation coefficients and show suitable units of these coefficients

2. (a) Define and explain the mass energy transfer coefficient and mass energy absorption coefficient.
   (b) Describe and explain the relationship of these two coefficients with the mass attenuation coefficient.
   (c) Express kerma and absorbed dose in terms of the mass energy transfer coefficient and mass energy absorption coefficient, respectively.

3. (a) List the main photon-matter interactions contributing to the mass attenuation coefficient of an x-ray photon.
   (b) On a graph exhibiting atomic number Z vs log photon energy, sketch two curves, one giving equal probability for photo-electric effect and Compton effect and the other equal probability for Compton effect and pair production.

4. (a) Considering photon interactions with matter, describe the photo-electric effect**.**
   (b) Define and derive the F-factor.

5. (a) Considering photon interactions with matter, describe the Compton effect**.**
   (b) Describe how the average kinetic energy of a Compton recoil electron behave as a function of photon energy, over the range of 10 keV to 30 MeV.

6. (a) Considering photon interactions with matter, describe pair production**.**
   (b) Using $E^2 - p^2c^2 = invariant$, calculate the threshold for pair production.

7. Briefly define or explain:
   (a) fluorescent yield
   (b) Auger effect
   (c) internal conversion
   (d) Coster-Kronig effect
   (e) super Coster-Kronig effect
   (f) photoelectrons
   (g) triplet production
   (h) annihilation photon
   (i) characteristic radiation
   (j) Rayleigh scattering.

8. Consider the following photon-matter interactions: photoelectric effect; Compton scattering; and pair production.
   (a) For each, state the dependence of the appropriate attenuation coefficient upon the photon energy $h\nu$ and atomic number Z of the medium.
   (b) For each, briefly describe the processes contributing to the transfer of energy from the photon to the medium that follow the interactions.

9. (a) State the relativistic equations that represent the conservation of energy and momentum and are used in the derivation of the Compton relationship:

$$\lambda' - \lambda = \lambda_c(1 - cos\theta).$$

   (b) Derive the Compton equation for the energy of the recoil electron.

10. (a) Using the Compton relationship, $\lambda' - \lambda = \lambda_c(1 - cos\theta)$, derive expressions for the energy $h\nu'$ of the scattered photon and the kinetic energy T of the recoil electron.
    (b) Show that the energy of the backscattered photon is equal to 255 keV for a high-energy photon.

11. For a photon energy $h\nu$ = 4 MeV incident on lead (Pb), the atomic attenuation coefficients for photo-electric effect ${}_a\tau$, Compton effect ${}_a\sigma$, and pair production ${}_a\kappa$, are:

    ${}_a\tau = 0.567 \times 10^{-24}$ cm^2/atom; ${}_a\sigma = 7.878 \times 10^{-24}$ cm^2/atom; and

    ${}_a\kappa = 5.782 \times 10^{-24}$ cm^2/atom.

    Clearly explaining the steps involved in the calculation, calculate the mass attenuation coefficient μ/ρ, the mass energy transfer coefficient μ_{tr}/ρ, and the mass energy absorption coefficient μ_{ab}/ρ (use the bremsstrahlung fraction g = 0.130, and f_{tr}=0.675 for a 4 MeV photon in Pb).

12. A photon of energy $h\nu$ interacts with lead (Pb):
    (a) Give the general relationship between $h\nu$ and the maximum kinetic energy E_{max} of the free electron produced through photo-electric effect, Compton effect and pair production.
    (b) Assuming $h\nu$ = MeV, calculate E_{max} for the three effects.

13. The Klein-Nishina formula relating the Compton differential cross-section $d\sigma_c/d\Omega$ with the photon scattering angle θ is given by:

$$\frac{d\sigma_c}{d\Omega} = \frac{r_e^2}{2} \times \frac{1+\cos^2\theta}{\left[1+\alpha(1-\cos\theta)\right]^2} \times \left\{1 + \frac{\alpha^2(1-\cos\theta)^2}{\left[1+\cos^2\theta\right]\times\left[1+\alpha(1-\cos\theta)\right]}\right\}$$

where $r_e = 2.818$ fm is the classical electron radius and $\alpha = h\nu/m_e c^2$ with $m_e c^2 = 0.511$ MeV.

(a) Show that for $\alpha = 0$ and any θ, and that for $\theta = 0$ and any α, $d\sigma_c/d\Omega$ transforms into the classical scattering coefficient per electron, $d\sigma_0/d\Omega$.

(b) Show that integrating $d\sigma_0/d\Omega$ over $d\Omega$ yields $\sigma_0 = 66.5\times10^{-30}$ m^2.

(c) Discuss the effect of electron binding on Compton scattering for low photon energies.

14. (a) Define and explain the stopping powers attributed to collision and radiation losses.
(b) Describe the difference between the stopping power and linear energy transfer (LET).

15. (a) Describe the energy and atomic number dependence of the mass collision stopping power S_{coll} for electrons over the energy range 10 keV to 100 MeV.
(b) Describe the energy and atomic number dependence of the mass radiative stopping power s_{rad} for electrons over the energy range 10 keV to 100 MeV.
(c) Sketch on a single graph S_{coll} and S_{rad} for electrons in water and lead in the energy range 10 keV to 100 MeV.

16. (a) Using mass collision and mass radiative stopping power relationships with atomic number and energy, describe the optimum design of a bremsstrahlung target for a high-energy linac.
(b) How does target design effect the quality (i.e. percent depth dose) of the x-ray beam for a given incident electron energy?
(c) Describe how a multi-element target can be used to provide a photon beam of a more desirable spectrum.

17. Briefly define or explain:

(a) guard electrodes
(b) air-equivalent wall material
(c) collection efficiency
(d) stem effect
(e) build-up cap
(f) W for air
(g) leakage current
(h) chamber calibration coefficient
(i) ion pair
(j) initial and general recombination.

18. (a) Draw schematically a parallel-plate (pancake) and a thimble ion chamber, label their main components and show a simple electronic circuit associated with them.
    (b) Describe applications appropriate to a parallel-plate and a thimble ion chamber.

19. Draw a collection efficiency curve for a typical parallel-plate ion chamber irradiated with a continuous photon beam and briefly describe the behavior of the curve as a function of radiation intensity, electrode separation, and photon energy.

20. (a) Describe how absolute dosimetry is accomplished with a free-air ion chamber.
    (b) Describe how absolute dosimetry is accomplished with calorimetry.

21. Briefly define or explain:
    (a) kerma
    (b) absorbed dose
    (c) exposure
    (d) charged particle equilibrium
    (e) terma
    (f) bremsstrahlung
    (g) conversion electrons
    (h) effective atomic number
    (i) delta rays
    (j) fluence.

22. (a) Write kerma and absorbed dose in terms of the photon energy fluence and mass attenuation coefficients both for a homogeneous photon beam with energy $h\nu$ and for a heterogeneous photon spectrum with maximum energy $h\nu_{max}$.
    (b) Briefly describe the Bragg-Gray cavity theory and clearly define the parameters involved.

23. (a) Using labeled diagrams, compare an x-ray tube used for therapy with an x-ray tube used for diagnosis, clearly indicating the key differences.
    (b) Briefly describe quality control protocols for orthovoltage therapy units.

24. (a) Describe the shutter error associated with the timer on Cobalt units, orthovoltage units, and linacs.
    (b) Describe one method to measure the shutter error and derive any equations relevent to this measurement.
    (c) How it is applied in practice when setting treatment times on a Cobalt machine vs a linear accelerator?

25. (a) Estimate the power delivered to the target of an x-ray tube operated at 100 kVp, 50 mA, 3-phase 12-pulse rectified.
    (b) Compare this to the power delivered to the target of a 20 MV linac operated at 50 pps with an electron current pulse width of 7 μs and a height of 50 mA.
    (c) Explain the power differences and what are the consequences?

26. (a) Describe the methods used to produce a clinical electron beam from the pencil beam which exits these accelerators.
    (b) Describe how these beams are collimated.

27. (a) Describe the role and typical properties of flattening filters used in linacs.
    (b) Discuss how flattening filter design affects the quality (i.e. percent depth dose) of the x-ray beam for a given incident electron energy.
    (c) What is the impact of filter design on dose rate?

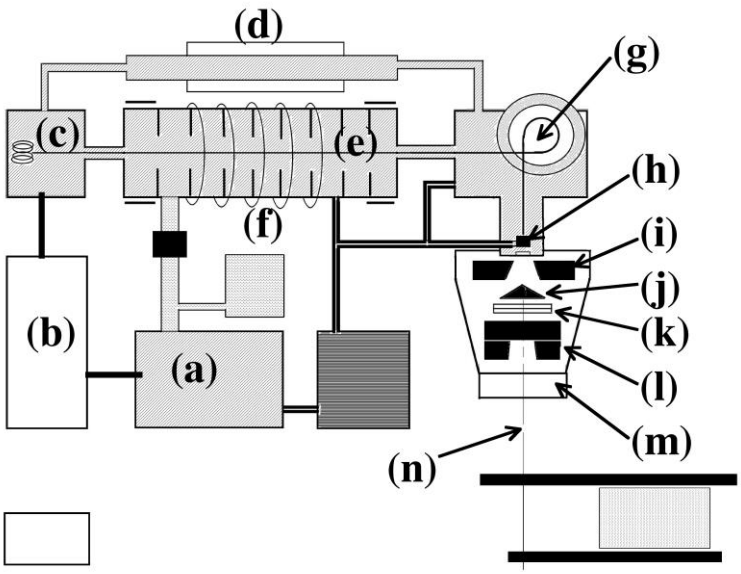
28. (a) Describe how an electron is accelerated to megavoltage energies in a modern linear accelerator.
    (b) Describe how a proton is accelerated to megavoltage energies in a modern cyclotron.

29. Give a range of values and units for the following parameters of a typical linear accelerator:
    (a) peak beam current
    (b) average beam current
    (c) modulator pulse width
    (d) peak modulator current
    (e) radiofrequency of operation
    (f) beam current pulse width
    (g) electron gun voltage
    (h) length of accelerating waveguide
    (i) target material and thickness in a 6 MV linac
    (j) electron kinetic energy in the waveguide.

see next page for (k)

(k) Consider the schematic diagram of a linear accelerator below. Match the label blanks of the major components to the following list:

i) bending magnet
ii) electron gun
iii) flattening filter
iv) focussing coil
v) ionization chamber
vi) isocenter
vii) jaws
viii) microwave power source
ix) multi-leaf collimator
x) primary collimator
xi) pulsed modulator
xii) target
xiii) vacuum pump
xiv) waveguide.



30. (a) Explain why the output (cGy/MU), both in air and in phantom, of a linear accelerator changes with field size.
    (b) Sketch a graph of relative output in air (e.g. S_c) vs. field size for typical 6 MV and 18 MV photon beams, ignoring contaminant electrons.
    (c) Sketch a graph of relative output in phantom (eg. $S_{c,p}$) vs. field size for typical 6 MV and 18 MV photon beams, ignoring contaminant electrons.
    (d) What is the effect of increasing photon energy on the relationship between these factors and field size?
    (e) What is the challenge when measuring relative output in air for a high energy beam?

31. Briefly define or explain:
    (a) Gamma analysis
    (b) DTA
    (c) Flatness
    (d) Symmetry
    (e) Tolerance level
    (f) Action level
    (g) Picket fence
    (h) Winston-Lutz test
    (i) Star shot test
    (j) Acceptance testing vs commissioning

32. Acceptance testing of a linear accelerator with multileaf collimation and electronic portal imaging can be classed into several broad catagories. Five of these catagories are safety, mechanical, dosimetric, imaging, and multi-leaf collimator. Within each catagory, give two examples of a measurement or test, as well as the associated acceptable tolerance specification.

33. (a) What are the typical model parameters used by a radiation therapy treatment planning system which uses a model-based, patient dose calculation algorithm?
    (b) What measurements are typically required and how are these used to estimate model parameters?
    (c) How are the beam model parameters used in three-dimensional patient dose calculations and monitor unit calculations?

34. (a) Describe a common hand-calculation formalism for verifying the monitor units of a 3D conformal treatment plan developed on a treatment planning system. Assume an SAD-setup photon treatment and use of a tissue-phantom ratio table. Explain all parameters involved.
    (b) Explain the concepts of ‘equivalent field size’ and ‘effective radiological pathlength’ in the context of hand calculations for verifying monitor units.
    (c) Briefly describe some general considerations if one wanted to modify the technique to apply to IMRT fields.

35. (a) Describe in detail a protocol for clinical reference dosimetry for an 18 MV beam in a medical linear accelerator using a cobalt-60 calibrated ionization chamber. Include a description of the measurement geometry and conditions, as well as the medium in which the measurement must be made.
    (b) Give the equation used and fully define each parameter.
    (c) How is beam quality specified?

36. Define the following functions used in manual radiation oncology dose calculations, sketch the relevant geometry, and clearly state what beam parameters the functions are influenced by:
    (a) percentage depth dose (PDD)
    (b) tissue-maximum ratio (TMR) and tissue-phantom ratio (TPR)
    (c) off-axis ratio (OAR)
    (d) wedge factor (WF)
    (e) zero-area percentage depth dose.

37. (a) Sketch a PDD for a 6 MV beam with flattening filter, for 100 cm SSD and 10×10 cm^2 field.
    (b) Explain why the PDD function changes with depth (beyond D_{max}).
    (c) Explain the PDD dependence on beam energy.
    (d) Explain the PDD dependence on field size.
    (e) Explain the PDD dependence on SSD.

38. (a) For a large field, 6 MV beam with flattening filter, explain how and why the beam profile changes with depth.
    (b) When a beam of megavoltage photons irradiates a phantom surface, there is dose delivered to the superficial layers of the patient, mainly due to contaminant electrons. Describe the shape of this contaminant electron dose contribution as a function of depth.

39. Describe the following three methods for tissue heterogeneity corrections in dose calculations with photon beams, and give the advantages and disadvantages of each:
    (a) a simple hand calculation approach;
    (b) a pencil-beam dose kernel superposition algorithm approach; and
    (c) a point-dose kernel superposition algorithm approach.

40. Monte Carlo (MC) dose calculation engines are available for many treatment planning systems.
    (a) Discuss the advantages of the MC dose engine over other methods.
    (b) Briefly explain how a particle history is calculated from a collection of pseudo-random numbers.
    (c) Briefly explain how a dose distribution is obtained from a collection of particle histories.

41. The Klein-Nishina formula relating the Compton differential cross-section $d\sigma_c/d\Omega$ with the photon scattering angle θ is given by:

$$\frac{d\sigma_c}{d\Omega} = \frac{r_e^2}{2} \times \frac{1+\cos^2\theta}{\left[1+\alpha(1-\cos\theta)\right]^2} \times \left\{1+\frac{\alpha^2(1-\cos\theta)^2}{\left[1+\cos^2\theta\right]\times\left[1+\alpha(1-\cos\theta)\right]}\right\}$$

    where r_e = 2.818 fm is the classical electron radius and $\alpha = h\upsilon/m_e c^2$ with $m_e c^2 = 0.511$ MeV.
    (a) Describe how this equation could be used by a Monte-Carlo simulation program to model a Compton interaction in a medium. Include the role of a random number generator and the sampling process in your description.
    (b) Describe how the program would decide the trajectory and energy of an electron produced in the interaction.

42. Dose distributions calculated using a Monte Carlo (MC) dose engine are subject to statistical noise.
    (a) Why is statistical noise present in a MC dose distribution?
    (b) Write expressions showing how the relative noise depends upon:
        (i) The number of particle histories;
        (ii) The dose-grid voxel size;
        (iii) The dose as a percentage of prescription dose; and
        (iv) The MC simulation time.
    (c) Sketch a typical cumulative dose volume histogram (DVH) for a planning target volume prescribed to 70 Gy with minimum dose of 67 Gy and maximum dose of 72 Gy. On the same graph sketch the DVH that would be obtained using a MC dose engine with relative statistical noise of 10%.

43. Briefly define or explain:
    (a) kinetic energy of electrons
    (b) contaminant electrons
    (c) R_{50} of an electron beam
    (d) practical range of electrons
    (e) stopping power ratio
    (f) Cerenkov radiation
    (g) Fricke dosimetry
    (h) radiation chemical yield
    (i) thermal defect
    (j) heat capacity.

44. (a) Sketch percentage depth doses for a typical 10×10 cm^2 electron beam, SSD 100 cm, with initial kinetic energies of 6, 12, and 18 MeV.
    (b) Describe, with the aid of a sketch, the shape of the isodose distribution for a 12 MeV electron beam.

45. (a) Sketch percentage depth doses for a 15 MeV electron beam for field sizes 3x3 cm^2, 10x10 cm^2 and 20x20 cm^2. Explain the differences and/or similarities of these three curves.
    (b) Briefly describe what must be considered when electron fields are shaped to substantially reduce their size.

46. (a) Describe the protocol for absorbed dose measurement in an 18 MeV electron beam with a dose calibrated ionization chamber.
    (b) Give the equation used and fully define each parameter.
    (c) Include a description of the measurement geometry and appropriate phantom material.
    (d) How is beam quality specified?

47. (a) Describe the basic physics behind the Optically Stimulated Luminescence (OSL) process.
    (b) Show schematically a typical apparatus for OSL measurements. Clearly label the components.

48. Briefly define or explain:
    (a) pre-irradiation annealing
    (b) post-irradiation annealing
    (c) glow curve (thermogram)
    (d) recombination centre
    (e) storage trap
    (f) activation energy
    (g) supralinearity
    (h) infrared emission of the planchet
    (i) Randall-Wilkins model
    (j) optically stimulated luminescence.

49. (a) Compare thermoluminescent dosimeters with optically stimulated dosimetry and state an advantage and disadvantage for each one.
    (b) Describe the use of thermoluminescent dosimetry or optically stimulated luminescence for patient dose monitoring in external beam therapy.
    (c) Describe calibration and handling techniques for one of these techniques.
    (d) Include a description of the relevance of the measured values when attempting to validate doses calculated on a treatment plan.

50. (a) Name four relative dosimetry techniques other than thermoluminescent or optically stimulated luminescence dosimetry.
    (b) Briefly describe their main characteristics and applications.
    (c) Describe advantages and disadvantages.

51. There are various approaches used in interstitial and intracavitary brachytherapy.
    (a) Describe high-dose rate (HDR) and seed-implant brachytherapy dose delivery methods, including the mechanism of dose delivery and common radioisotopes used.
    (b) Give a clinical application (anatomy and typical dose) for each.
    (c) Explain the advantages offered by remote afterloading compared to manual afterloading, and by manual afterloading compared to insertion of active needles.

52. (a) Describe two brachytherapy sources: one commonly used in remote afterloading systems and one used for manual loading techniques. Include physical construction, and radiation parameters such as half-life, typical activity, energy, and air kerma rate constant.
    (b) Describe a common clinical use of each source. Specify treatment anatomy, planning method and safety considerations.

53. (a) Describe a practical method of calibrating an HDR brachytherapy source after its installation in a clinical remote afterloader. Specify all equipment used.
    (b) Explain how an absorbed dose distribution for a typical brachytherapy source is determined.

54. (a) What are the advantages and disadvantages of high dose rate as compared to low dose rate, for gynaecological brachytherapy?
    (b) How can doses delivered at high dose rate be compared with doses delivered at low dose rate?
    (c) What is a typical dose fractionation scheme for cervix cancer treated with high dose rate brachytherapy?

55. With respect to permanent seed implantation for the treatment of early stage prostate cancer:
    (a) Briefly outline the clinical workflow of a patient who will undergo this treatment, beginning with initial assessment, through to post implant treatment evaluation.
    (b) Describe the steps and tools required for the recommended quality assurance of the radioactive seeds prior to implantation.
    (c) Describe the steps and tools required for the recommended quality assurance of a trans-rectal ultrasound system used for image guidance during the implant.

56. With respect to brachytherapy dose calculations:
    a. Describe the commonly used dose calculation formalism giving definitions and explanations for all quantities.
    b. Describe the conditions under which this formalism can fail to accurately calculate dose.

57. With respect to HDR brachytherapy for prostate cancer:
    (a) Describe how treatment planning is performed.
    (b) Describe how the treatment is delivered.
    (c) Describe four differences in the radiation protection concerns for HDR prostate treatment versus permanent seed implantation.
    (d) Describe the differences in eligibility and selection for patients undergoing HDR brachytherapy versus permanent seed implant.

58. (a) Describe in detail a standard radiation treatment of the breast or chest wall, including the regional lymph nodes. Include considerations of protecting organs at risk, achieving dose homogeniety in three dimensions, and problems associated with beam junctioning.
    (b) State two commonly used total dose and fractionation schemes.

59. Consider the planning, treatment and verification of prostate irradiation.
    (a) Use ICRU 50 and ICRU 62 terminology to describe the appropriate tumour and target volumes.
    (b) State two commonly used total dose and fractionation schemes.
    (c) Describe a typical treatment technique
    (c) Describe 3 possible methods of assessing patient position prior to or during treatment.
    (d) List two organs at risk and for each list tolerance doses and associated toxicity.

60. According to ICRU, the planning target volume (PTV) is a geometric concept that ensures that the prescribed dose is actually delivered to the clinical target volume (CTV). A number of different methods have been proposed to define the magnitude of the CTV to PTV margin. One approach, based on probability distributions, is to distinguish between the random and systematic errors that contribute to geometric deviations. When this approach is employed, the commonly used equation is to define the PTV margin is:

$$PTV = 2.5\ \Sigma + 0.7\ \sigma$$

where Σ is the standard deviation of systematic errors and σ represents the standard deviation of random errors. This equation ensures a minimum dose to the CTV of 95% of the prescription dose in 90% of patients, assuming a penumbra width of 3.2mm.

(a) A number of simplications are assumed in deriving this model. Briefly discuss four of them.
(b) Describe how a dose distribution is modified by random and systematic errors.
(c) For an intra-cranial (ie. brain) tumour treatment, list three sources of geometric deviations and briefly discuss their relative contributions to Σ and σ.
(d) Briefly discuss why this equation does not apply to the determination of a planning organ at risk (PRV) margin.

61. (a) Describe the rationale for total body irradiation (TBI) prior to bone marrow transplantation for leukemia.
(b) Give the dose regimen usually given.
(c) Describe the medical problems encountered during or after TBI.
(d) Describe the theoretical advantages and/or disadvantages of delivering the dose in a single fraction as compared to multiple fractions.
(e) Give two dose constraints for organs at risk.

62. (a) Briefly describe three different techniques used for total body irradiation (TBI), including a technique using a linear accelerator.
(b) For each technique, describe how dose to organs at risk can be reduced.
(c) Briefly describe dosimetric measurements that must be performed before a standard linear accelerator can be used for TBI.

63. (a) State two types of cancer that can benefit from using gating and explain the rational for using gating.
(b) Describe two methods of gating treatment.
(c) Explain the impact of gating on patient preparation, CT-scan protocol and treatment planning.

64. (a) Describe in detail the required changes to, and measurements on, a standard linear accelerator before it can be used to deliver total skin electron irradiation (TSEI).
    (b) Describe one treatment technique currently employed for TSEI.
    (c) State typical doses and fractionations used.

65. (a) List three cranial disease sites or indications for which stereotactic radiosurgery (SRS) is a treatment of choice, and provide a typical dose and fractionation scheme for each.
    (b) List three extra-cranial disease sites or indications for which stereotactic body radiation therapy (SBRT or SABR) is a treatment of choice, and provide the typical dose and fractionation scheme for each.
    (c) Describe the advantages and disadvantages of using stereotactic techniques (SRS/SBRT/SBRT) versus conventional (ie. non-stereotactic) treatments.
    (d) Compare the margin requirements of stereotactic techniques to conventional treatments, and describe the techniques used to achieve tighter margins in SRS/SBRT.

66. (a) Describe three major platforms for performing stereotactic radiosurgery (SRS) and/or stereotactic body radiation therapy (SBRT).
    (b) How do commissioning and quality assurance requirements differ for a linac used for SRS/SBRT compared to a linac used for conventional treatments?

67. (a) Briefly describe the basis of Tomotherapy and explain how intensity modulation is achieved throughout the target volume.
    (b) Sketch and describe the main components of a helical Tomotherapy unit.
    (c) Describe two issues in beam dosimetry that may be more challenging with a tomotherapy unit compared to conventional linac dosimetry.

68. (a) State the rationale for the use of protons for cancer therapy.
    (b) Sketch the relative dose versus depth curve for a 120 MeV proton beam. Show how multiple modulated beams can be combined to produce a more clinically useful depth dose distribution.
    (c) Describe the range of energies that are appropriate for proton therapy.
    (d) Describe two methods for producing clinically useful large laterally uniform fields from the narrow proton beams produced in a typical proton accelerator.

69. Hyperthermia, cryosurgery, photodynamic therapy, and radioimmunotherapy with monoclonal antibodies may be described as alternative treatments for cancer. In each case:
    (a) Briefly describe the basis for the therapy.
    (b) Describe a method of treatment delivery.
    (c) Specify a site treated by the technique.
    (d) Describe a possible problem in utilization.

70. Define or explain, using sketches where applicable, the following:
    (a) CT Simulator;
    (b) bow-tie filter;
    (c) filtered back-projection;
    (d) 4D CT;
    (e) cone-beam CT.

71. Define or explain, using sketches where applicable, the following:
    (a) CT number vs electron density;
    (b) Imaging with megavoltage photon beam;
    (c) Digitally reconstructed radiographs (DRR);
    (d) Beam's-eye view;.

72. (a) Describe and explain the technical operation and physical characteristics of an amorphous silicon electronic portal imager (a-Si EPID) used for megavoltage imaging.
    (b) Describe and explain the main design differences between megavoltage imagers and kilovoltage imagers (mounted on a medical linear accelerator).

73. Compare the use of CT and MRI in radiotherapy treatment planning with reference to resolution, contrast, spatial and geometric uniformity of the images and their ability to:
    (a) Locate bony landmarks;
    (b) Delineate tumour volumes and critical organs (describe tumour extent);
    (c) Give information for tissue inhomogeneity corrections.

74. (a) Describe a typical PET/CT scanner system.
    (b) Describe the main tracer used, it's biological basis for PET imaging, and applicability for oncologic imaging.
    (c) Describe two common clinical disease sites where PET/CT systems are used in a radiation oncology program.
    (d) What technical considerations need to be made to make the most effective use of a PET/CT system for a radiation oncology department (as opposed to a radiology department)?

75. In relation to inverse planning to achieve optimal beam fluences for modulated radiation therapy (IMRT or VMAT), explain:
    (a) objective functions,
    (b) dose objectives,
    (c) dose constraints,
    (d) typical non-stochastic optimization methods,
    (e) typical stochastic optimization methods.

76. Describe the following techniques for delivering modulated treatments, including how modulation is accomplished and comparative advantages and disadvantages:
    (i) static or segmental multileaf collimator (SMLC or 'step and shoot'),
    (ii) dynamic multileaf collimator (DMLC or 'sliding window'), and
    (iii) volumetric modulated arc therapy (VMAT).

77. Describe the following techniques for patient-specific quality assurance of modulated treatments including comparative advantages and disadvantages:
    (i) phantom-based measurement (with ion chamber(s)/film(s)),
    (ii) 2D ion chamber/diode arrays,
    (iii) EPID,
    (iv) independent MU check.

78. In relation to Oncology Information Systems (OIS) being instrumental in running a radiation-oncology department, explain the purpose and use of:
    (a) firewall,
    (b) checksum,
    (c) IPv6,
    (d) RAID,
    (e) DICOM,
    (f) PACS,
    (g) RIS

79. (a) State the rationale for using orthovoltage photons versus electrons, for cancer therapy;
    (b) Sketch percentage depth dose curves for 100 kVp and 270 kVp, assuming FSD=30 cm and appropriate filtration for each beam;
    (c) Describe the main treatment sites where orthovoltage photon beams are typically considered.
    (d) Briefly describe the protocol for absolute dose measurements in an orthovoltage beam with a calibrated ion chamber. State the relevant equation and define the terms.

80. There are multiple volumetric CT-based systems that can be used in image guided radiation therapy. These include kV cone beam CT, MV cone beam CT, kV fan beam CT and MV fan beam CT.
    (a) For a standard pelvis scan, provide approximate dose values for each modality and briefly describe the rationale for the differences.
    (b) Briefly discuss why there are differences in spatial resolution and contrast amongst the different modalities.
    (c) Briefly discuss differences in the susceptibility to and the effects of motion artifacts between the different modalities.

IV RADIATION ONCOLOGY

1. Briefly define or explain:
   (a) stopping power
   (b) half-value layer (HVL)
   (c) tenth-value layer (TVL)
   (d) air kerma
   (e) absorbed dose
   (f) equivalent dose (H_T)
   (g) effective dose (E)
   (h) radiation weighting factor (w_R)
   (i) tissue weighting factor (w_T).
   (j) annual limit on intake (ALI).

2. (a) Describe the concept of linear energy transfer (LET) and its use as a measure of radiation quality.
   (b) How does LET vary with the type and energy of charged particles and with depth in a medium in which charged particles are slowed down?

3. Outline how the linear quadratic radiobiological model describes and explains the variation of relative biological effectiveness and shape of the dose-response curve as a function of radiation type and energy.

4. (a) Define the oxygen enhancement ration (OER) and explain how the presence of oxygen modifies radiation response.
   (b) What is a typical value of OER for a dose of 200 cGy from X-rays?
   (c) Sketch OER as a function of LET.

5. (a) Briefly describe the evidence upon which the ICRP Publication 103 values of radiation weighting factors (w_r) are based.
   (b) What are the radiation weighting factors for photons, electrons, protons, and alpha particles?
   (c) Briefly explain why the radiation weighting factor for neutrons is a continuous function (instead of a single value)?

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

7. Ionization chambers, proportional counters and Geiger-Müeller counters are all gas filled radiation detectors.
   (a) Sketch a graph illustrating the operation of a gas filled detector plotting pulse amplitude against applied voltage. Indicate the regions on this graph which define the different detector types.
   (b) Discuss advantages and disadvantages of these detectors in the the field of radiation protection.
   (c) Give an example of an application for each type of detector (ie. ionization chamber, proportional counter, and G-M counter).

8. In the context of radiation protection:
   (a) Describe the design of an ionization chamber and its associated circuitry when used with an electrometer;
   (b) Describe the use of a portable ionization chamber for a radiation protection survey.

9. Describe:
   (a) A proportional counter;
   (b) The energy discrimination ability of a proportional counter;
   (c) How to calibrate a proportional counter as a tissue equivalent detector.

10. Describe:
    (a) A Geiger-Mueller (G-M) counter;
    (b) How to distinguish between beta and gamma radiation with a G-M counter; and
    (c) How to determine source strength of a beta emitter with a G-M counter.

11. (a) Briefly define or explain:
        (i) thermal neutrons;
        (ii) elastic collision; and
        (iii) recoil proton.
    (b) Describe the measurement of neutrons in the presence of X- or gamma rays.
    (c) Describe a BF_3 detector used to measure equivalent dose from neutrons.

12. (a) Briefly define or explain:
        (i) standard deviation and standard error;
        (ii) precision and accuracy of measurement; and
        (iii) relative and absolute uncertainty.
    (b) Describe the effect of background radiation on the precision of radiation measurements.

13. (a) Give the annual effective dose limits for stochastic effects recommended by ICRP Publication 103 for both occupational and public exposures.
    (b) Explain how effective dose is determined when the whole body is irradiated non-uniformly with a mixed radiation field.
    (c) Give four examples of tissue weighting factors.

14. The Canadian Nuclear Safety Commission specifies effective dose limits for three catagories of people:
    (i) Nuclear energy worker;
    (ii) Pregnant nuclear energy worker; and
    (iii) A person who is not a nuclear energy worker.

    (a) State the effective dose limits for the three groups and compare them to the effective dose from natural background. Include the time periods for which the limits apply.
    (b) Comment on how emergencies may affect dose limits.
    (c) What has been the largest driver of increased exposure to the public over the last 30 years?
    (d) Describe a campaign designed to decrease the population risk associated with the factor identified in (c).

15. (a) The Canadian Nuclear Safety Commission specifies equivalent dose limits. List the organs or tissues for which an equivalent dose limit exists, give the magnitude of the equivalent dose limit in mSv, and the time period for which this limit applies, for:
    (i) Nuclear energy worker;
    (ii) Any other person.
    (b) Briefly describe the five steps the Canadian Nuclear Safety Commission requires a licensee to perform when the licensee becomes aware that an organ or tissue may have exceeded an applicable dose limit.

16. Briefly define or explain:
    (a) detriment in a population
    (b) stochastic effect
    (c) deterministic effect
    (d) linear energy transfer (LET)
    (e) relative biological effectiveness (RBE)
    (f) oxygen enhancement ratio (OER)
    (g) stem cells
    (h) body burden
    (i) therapeutic ratio
    (j) free radicals.

17. A fetus is exposed to a dose of 50 mSv during the 10th week of pregnancy. Describe the possible effect(s) of this exposure and estimate the risk factors associated with each effect.

18. In the context of radiation protection at a radiotherapy facility, briefly define or explain:
    (a) primary barrier
    (b) leakage radiation
    (c) scatter radiation
    (d) secondary barrier
    (e) use factor U
    (f) workload W
    (g) occupancy factor T
    (h) beam stopper
    (i) tenth-value layer at equilibrium (TVL_e)
    (j) ALARA principle.

19. Consider a typical radiation oncology bunker, housing an isocentrically mounted 6MV linear accelerator.
    (a) Give typical values for W, T and U, as well as thicknesses for primary and secondary barriers.
    (b) Explain how the barrier thicknesses are calculated in NCRP 151.
    (c) Explain how the ALARA principle is taken into account when a room is designed.

20. Describe briefly why it is difficult to obtain accurate information on the biological effects on humans at low doses (e.g. 10 mGy) of low-LET ionizing radiations, especially if the dose is accumulated over a long period of time.

21. (a) Describe the concepts of excess absolute risk (EAR) and excess relative risk (ERR) in ICRP 103.
    (b) Describe the steps ICRP 103 uses to move from the concepts of EAR and ERR to tissue weighting factors.

22. Define the following:
    (a) early effects
    (b) late effects
    (c) linear quadratic model
    (d) T_{pot}
    (e) T_{delay}
    (f) α parameter of the LQ model
    (g) β parameter of the LQ model
    (h) accelerated repopulation
    (i) sublethal damage repair
    (j) dose-rate effect

23. (a) Describe the usefulness and limitations of the linear-quadratic model in comparing different dose-time-fractionation schemes used in radiotherapy:
    (b) Using the linear-quadratic model, with d = "*dose per fraction*", and n = "*number of fractions*", derive the equation for biological effective dose:

$$\frac{E}{\alpha} = dn\left(1 + \frac{d}{\alpha/\beta}\right)$$

24. (a) In terms of the linear-quadratic model, describe the range of the α/β ratio for early and late responding tissues and give two examples each of early and late responding tissues.
    (b) With respect to the linear-quadratic model, define and compare the concept of dose in Gy, and $Gy_{\alpha/\beta}$.
    (c) Compare a conventional therapy regimen of 30 fractions of 2 Gy at one fraction per day, 5 days per week with that of a hyperfractionation schedule of 70 fractions of 1.1 Gy given at 2 fractions per day 6 hours apart, 5 days per week. Assume $\alpha/\beta = 2$ for late effects, and $\alpha/\beta = 10$ for early or tumour effects. Express the results in Gy_2 and Gy_{10}, and compare the two regimens in terms of impact on tumour response and normal tissue late response.

25. A cancer center has decided to close for a summer break of 10 working days. The radiation oncologist has concerns that this may effect radiotherapy outcome.
    (a) Give the equation using the linear quadratic model which may be used to assess the effects of this closure, including a term for tumour stem cell proliferation.
    (b) Assume Hodgkins lymphoma has a T_{pot} of 5 days and glioma a T_{pot} of 30 days. Calculate the effective dose reduction factor for each of these tumours in terms of Gy_{10}. Assume fractionation for the lymphoma is 1.8Gy/fraction for 20 fractions and for the glioma is 1.8 Gy/fraction for 28 fractions. Also assume $\alpha = 0.3\ Gy^{-1}$ for both.
    (c) Describe whether closure of the clinic is advisable for either of these tumours.

26. Briefly define or explain the following concepts of tumour radiobiology:
    (a) radiobiological hypoxia
    (b) labeling index
    (c) radioprotector
    (d) spheroid model
    (e) hyperfractionation
    (f) hypofractionation
    (g) anoxic radiosensitizer
    (h) S-phase of cell cycle
    (i) M-phase of cell cycle
    (j) LD_{50}.

27. (a) Sketch a model of a solid tumor at various stages of its growth, showing capillaries and areas of hypoxia and necrosis.
    (b) What is the concentration of oxygen below which cells are generally considered to be radiobiologically hypoxic?
    (c) What is the diffusion distance of oxygen in tissue?
    (d) Describe and contrast chronic hypoxia and acute hypoxia.

28. Describe the "4 R's" in radiobiology and explain their role in fractionated radiotherapy.

29. Cataracts may be classified as delayed somatic effects of radiation.
    (a) Describe how cataracts develop in the lens of the eye as a result of exposure to ionizing radiation.
    (b) Describe the time/dose relationship for cataract production by x- or gamma-rays.
    (c) Describe the threshold for cataract formation and the effect of total dose on the latent period for cataract induction.
    (d) Compare the incidence of cataract following neutron irradiation with that observed following X- or gamma irradiation.

30. (a) Briefly describe the molecular structure of DNA.
    (b) Briefly describe the direct and indirect effects of ionizing radiation on DNA.
    (c) Referring to ICRP 103, comment on the risk of cancer for nuclear energy workers working in the hospital environment who receive their yearly legal limit each year during a 25 year career. Clearly state all assumptions.

31. (a) Describe the genetic effects of radiation in humans and explain the use of the concept of the doubling dose as the unit of measurement of the radiation effect.
    (b) List the main sources of ubiquitous background radiation and medical radiation, and the effective dose per individual they contribute to the general population, as estimated in NCRP 160.
    (c) What is the genetic effect of ionizing radiation in the occupational dose range?

32. Describe the effect of ionising radiation on the embryo and the fetus.

33. Describe the acute effects of whole-body irradiation and give the radiation dose that would produce such effects.

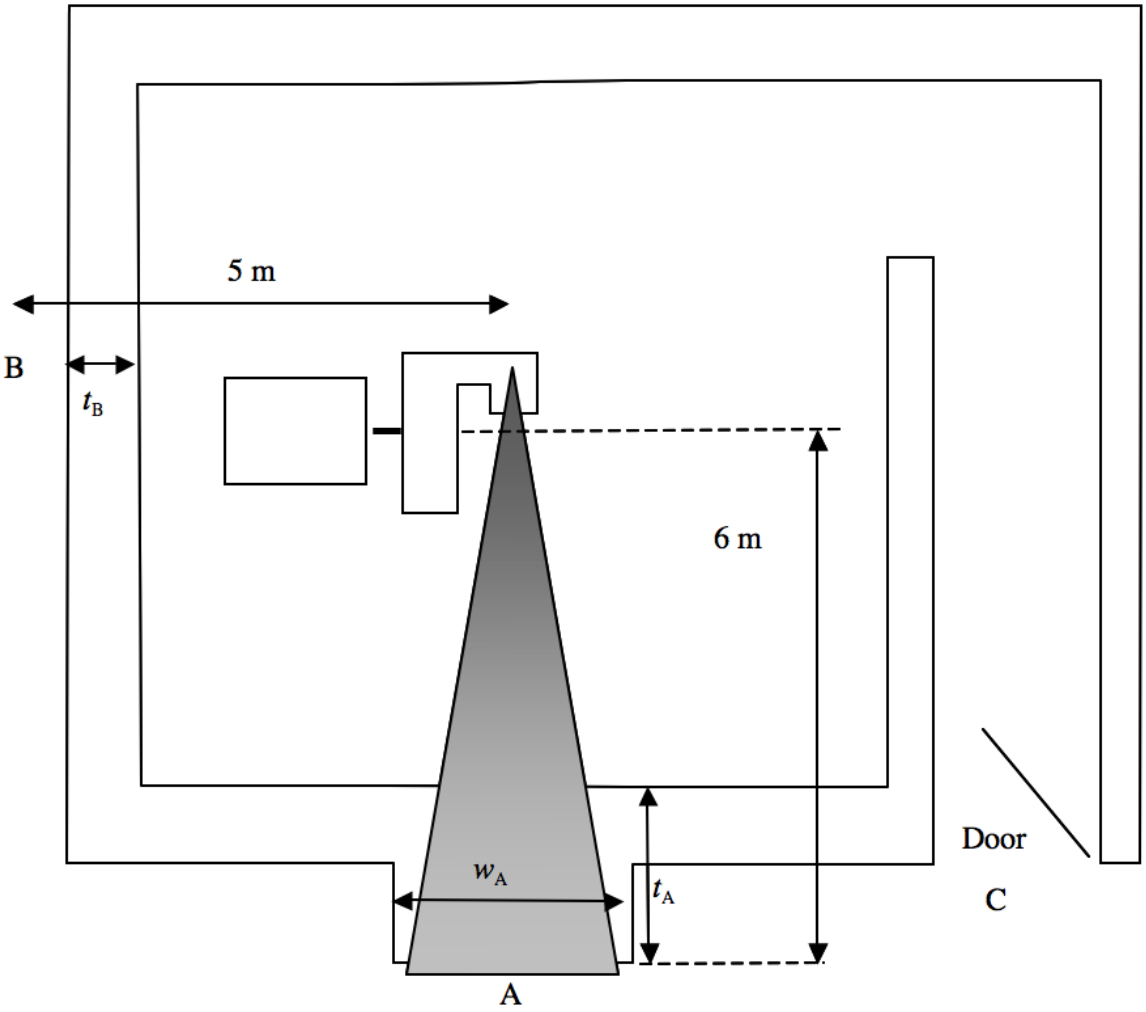
34. (a) Describe a typical cell survival curve, clearly define its parameters and describe its shape.
    (b) With the aid of a sketch, describe and compare typical cell survival curves for aerated cells vs hypoxic cells irradiated with 250 kVp x-rays.
    (c) What is the oxygen enhancement ratio for protons and neutrons?

35. The QUANTEC (Quantitative Analysis of Normal Tissue Effects in the Clinic) effort seeks to provide standardized, outcome-based tolerances for a variety of organ's at risk.
    (a) Describe the general methodology employed in QUANTEC.
    (b) Describe the limitations of QUANTEC
    (c) Describe the lessons learned by the QUANTEC effort.

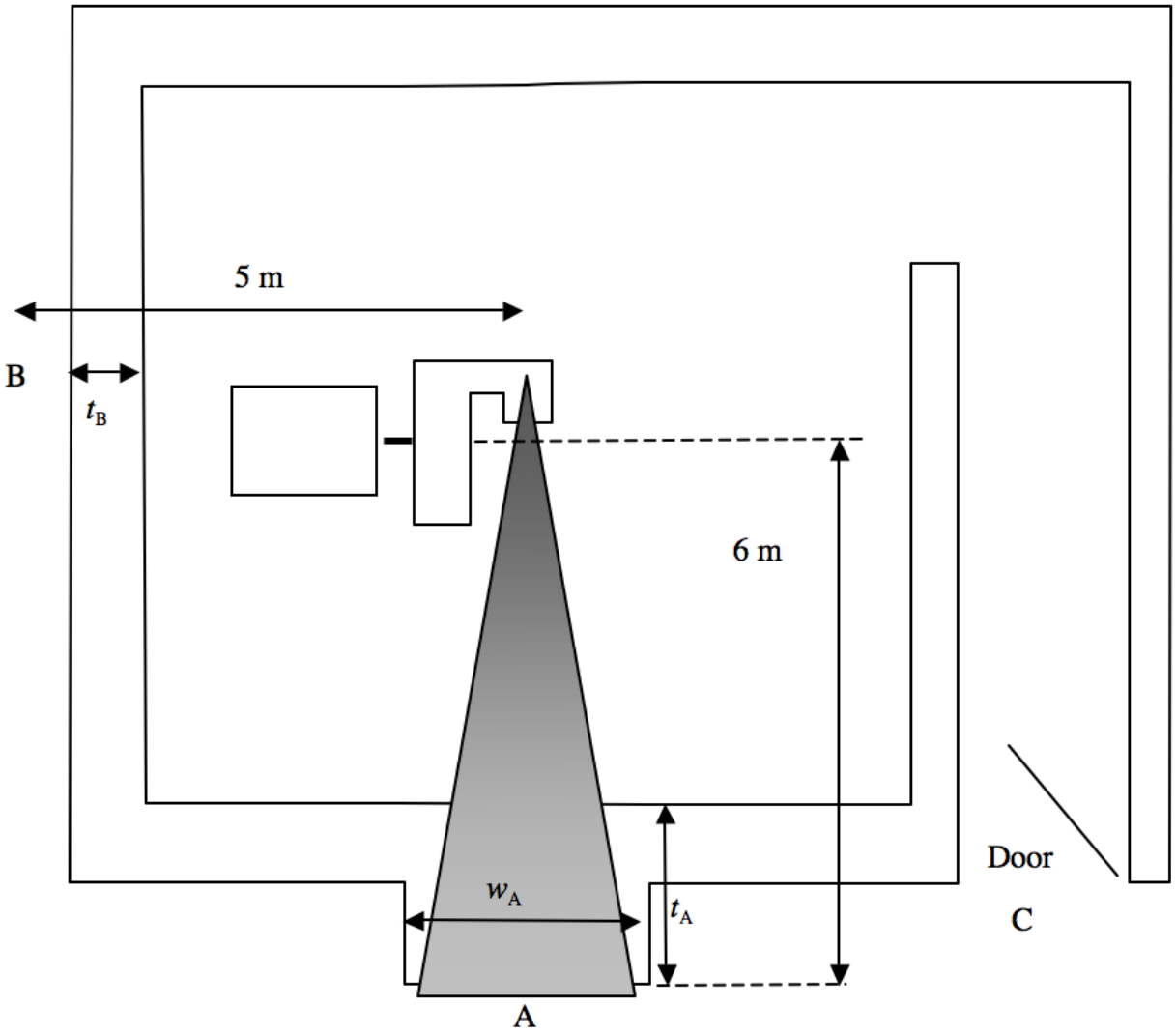
36. Describe the following three Reported Accidental Exposures with New Technologies, given in ICRP 112. For each event, list at least two strategies that, had they been in place, would have reduced the risk of this type of event.
    (a) Case 4. Monitor Unit calculation for the wrong type of wedge. (Epinal);
    (b) Case 5. Computer crashes and the loss of data in IMRT planning. (New York State)
    (c) Case 9. Incorrect manual transfer of treatment parameters. (Glasgow).

37. (a) Describe how a Failure Modes and Effects Analysis could be performed in the radiotherapy setting.
    (b) For each of the following Failure Modes, identify one possible cause and suggest, with reasons, values for Frequency (F), Severity (S) and Detectability (D) parameters
        (i) incorrect vertebra matched during the image guidance procedure for a spinal SBRT treatment;
        (ii) incorrect set of objectives and constraints used in plan optimization; and
        (iii) bolus missed on one fraction out of twenty.
    (c) For each case in (b) above, what preventative measures could be employed to decrease D, (i.e. increase the detectability of the error before it reaches the patient)?

38. You are asked to oversee design and installation of a facility for an 18 MV linear accelerator to be used in the photon (18 MV) and electron mode (6 MeV to 21 MeV).
    (a) Discuss which regulatory agency(ies) and which regulation(s) must be considered and adhered to.
    (b) Describe the CNSC licensing requirements over the lifetime of the linear accelerator.
    (c) List design considerations that might be imposed by special techniques such as intraoperative radiotherapy, total body electron irradiations, and total body photon irradiations.



39. An 18 MV linac (SAD 100 cm, maximum field size at isocentre of 40x40 cm^2) is to be installed in a stand-alone facility on the ground floor as shown in the sketch (not to scale). There are no rooms above the linac. The operator console is at location A, office space is at location B, the treatment room door is shown and all other adjacent areas are unoccupied.
    (a) Discuss the design criteria for a treatment room door and clearly indicate the typical materials and approximate material thicknesses used.
    (b) Clearly describe and identify the location of all safety accessories both inside and outside the room.
    (c) Discuss the area radiation safety survey, and list the equipment to be used. Indicate typical measured values you might expect to measure at points A, B and C (both for door open and door closed), and indicate the nature and location of any warning signs.



40. A dual-energy linac (6 and 18 MV, SAD 100 cm, maximum field size at isocentre of 40x40 cm^2) is to be installed in a stand-alone facility on the ground floor as shown in the sketch (not to scale). There are no rooms above the linac. The operator console is at location A, office space is at location B and all other adjacent areas are unoccupied. Assume that 20 patients are treated per day using 6 MV IMRT, and 10 patients are treated per day using conventional 18 MV techniques. Using the methodology suggested by NCRP 151, and clearly stating all assumptions:
    (a) Calculate the primary barrier thickness (t_A) at Point A for regular concrete.
    (b) Calculate the thickness of the secondary barrier (t_B) at point B for regular concrete. Assume the barrier thickness designed for leakage radiation is sufficient to also shield for scatter (as per NCRP 151).