RADIOLOGICAL PHYSICS

Raphex 2004

EXAMINATION

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❖ Preface ❖

RAPHEX 2004 was prepared by members of the Radiological and Medical Physics Society of New York (RAMPS, Inc.), the New York chapter of the American Association of Physicists in Medicine (AAPM). Contributors to this exam were:

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If you are taking RAPHEX under exam conditions, your proctor will give you instructions.

- ❖ You have 3 HOURS to complete both sections: the GENERAL section, and your SPECIALTY section.
- ❖ Non-programmable calculators may be used.
- ❖ Choose the most complete and appropriate answer to each question.

We urge residents to review the exam with their physics instructors.

Any comments or corrections are appreciated and should be sent to:

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G1. 5 rem is equivalent to _____ mSv.

A. 0.05
B. 0.5
C. 5
D. 50
E. 500

G2. In order to convert exposure (R) to absorbed dose (mGy), the factor for diagnostic x-rays and muscle tissue by which exposure is multiplied is closest to _____ .

A. 0.1
B. 5
C. 9
D. 20
E. 90

G3. Exposure is _____ :

A. The energy absorbed in a given mass of a medium.
B. The air kerma of a photon beam.
C. Measured in Sv.
D. The ionization in a given mass of air.

G4–7. Match the following units with the quantities below: (Answers may be used more than once or not at all.)

A. Bq
B. Sv
C. C/kg
D. Gy
E. J

G4. Absorbed dose
G5. Activity
G6. Exposure
G7. Dose equivalent

G8. The energy equivalent of an electron at rest is _____ .

A. 0.51 keV
B. 930 keV
C. 0.51 MeV
D. 1.02 MeV
E. 930 MeV

General

❖ Questions ❖

G9–12. Match the following:

A. Electron
B. Positron
C. Neutron
D. Alpha particle
E. Proton

G9. Emitted by the cathode of an x-ray tube.
G10. The particle responsible for MR Imaging.
G11. Assuming A–E have the same energy, the _____ has the shortest path length in water.
G12. Is indirectly ionizing.

G13. ^{131}Iodine and ^{125}Iodine have:

A. Have different chemical properties.
B. Have different Z values.
C. Occupy different columns on the periodic table.
D. Have the same number of neutrons.
E. None of the above.

G14. All of the following are true **except**: Tritium ^{3}H _____ hydrogen ^{1}H.

A. is an isotope of
B. has more neutrons than
C. has more electrons than
D. is chemically identical to

G15. $^{59}_{27}Co$ has _____ neutrons and mass number _____ .

A. 59 27
B. 59 32
C. 32 27
D. 27 59
E. 32 59

G16. When an electron is removed from an atom, the atom is said to be:

A. Radioactive.
B. Ionized.
C. Inert.
D. Metastable.

G17. In an atomic nucleus, the binding energy per nucleon:

A. Is not affected by the process of radioactive decay.
B. Is independent of Z.
C. Is maximum for low and high values of Z.
D. Increases after decay to the ground state.

G18. Compared with an atom of argon (Z=18), potassium (Z=19) is:
A. Much more reactive.
B. Slightly less reactive.
C. Much less reactive.
D. About equally reactive.

G19. After 10 half-lives, the fraction of activity remaining is _____ .
A. $1-(1/2)^{10}$
B. $1-e^{-0.693 \times 10}$
C. $(1/2)^{10}$
D. $e^{-0.693 \times 10}$
E. C and D

G20. A radioactive source of strength 47.0 $mGy.m^2.h^{-1}$ and half-life of 74 days will decay to _____ $mGy.m^2.h^{-1}$ after 222 days.
A. 23.5
B. 11.8
C. 5.9
D. 2.9
E. 1.5

G21. A batch of ^{125}I seeds for a prostate implant is required to have an activity of 0.50 mCi/seed at the time of the implant. If the seeds arrive 5 days early, their activity will be _____ mCi/seed on arrival. (Half-life = 60 days.)
A. 0.47
B. 0.53
C. 0.59
D. 0.62
E. 0.77

G22. If the biological and physical half-lives of a radiotracer are both 2 hours, the effective half-life is _____ hours.
A. 0.25
B. 0.5
C. 1.0
D. 2.0
E. 4.0

G23. During nuclear decay, energetic particles are emitted. The maximum energy of these particles is a function of the:
A. Mass defect.
B. Neutron capture cross section.
C. Spin orientation of the particles.
D. Decay constant.

G24. Which of the following is/are true regarding positron emission?

1. It is accompanied by neutrino emission.
2. It cannot occur unless the energy levels of the parent and daughter differ by 0.51 MeV.
3. It is followed by annihilation and emission of two 0.51 MeV photons.
4. It consists of monoenergetic positrons.

A. 1, 3
B. 2, 4
C. 4 only
D. 1, 2, 3, 4
E. None of the above

G25. Which of the following is/are true regarding electron capture?

1. It can compete with positron emission in isotopes with an excess of protons.
2. It can result in characteristic x-ray emission.
3. It can result in Auger electron emission.
4. It can result in the emission of a neutrino.

A. 1, 3
B. 2, 4
C. 4 only
D. 1, 2, 3, 4

G26. Two nuclides have the following properties:

	Nuclide I	Nuclide II
Atomic number	Z	Z+1
Mass number	A	A

Nuclide I may transform into Nuclide II by:

A. Beta plus decay.
B. Beta minus decay.
C. Alpha decay.
D. Isomeric transition.

G27. Heavy radioactive nuclei (mass number A > 200) decay most frequently with the emission of a(n) _____ .

A. Beta particle
B. Gamma ray
C. Auger electron
D. Alpha particle

G28. Characteristic x-rays may be emitted following:

1. Internal conversion
2. Beta minus decay
3. Electron capture
4. Alpha decay

A. 1, 3
B. 2, 4
C. 4 only
D. 1, 2, 3, 4
E. None of the above

G29. During an isomeric transition, all of the following may be emitted, **except:**

A. Auger electron.
B. Beta particle.
C. Characteristic x-rays.
D. Internal conversion electrons.
E. Gamma rays.

G30. Positron emission occurs in radionuclides which have an excess of:

A. Electrons.
B. Positrons.
C. Neutrons.
D. Protons.
E. Mesons.

G31. When $^{35}_{17}Cl$ undergoes an (n,α) reaction, the product is _____ .

A. $^{32}_{15}P$
B. $^{33}_{15}P$
C. $^{34}_{16}S$
D. $^{33}_{17}Cl$

G32. Which of the following is produced in a cyclotron?

A. ^{137}Cs
B. ^{18}F
C. ^{192}Ir
D. ^{40}K

G33. Radionuclides created by placing a sample in the neutron flux of a reactor generally emit ______ following decay.

A. Beta plus particles
B. Alpha particles
C. Beta minus particles
D. Gammas
E. C and D

G34. Which of the following occurs one month after a radium source (half-life 1600 years) is sealed in a tube with its daughter radon (half-life 3.8 days)?

A. Transient equilibrium
B. Secular equilibrium
C. Equilibrium has not yet occurred
D. Equilibrium will never be established with these isotopes

G35. 10 Ci is equal to _____ .

A. 3.7 Bq
B. 270 Bq
C. 2.7 MBq
D. 37 MBq
E. 370 GBq

G36. Which of the following is *not* a unit used to describe the strength of a radioactive source?

A. MBq
B. μCi
C. mg Ra equ
D. Gy m^2 hr^{-1}
E. Amu

G37. The exposure rate constant for ^{137}Cs is 3.3 $R.cm^2.mCi^{-1}.h^{-1}$.
The exposure rate at 3 m from a patient with a temporary insertion of 163 mCi (ignoring tissue attenuation) is _____ .

A. 60 R/hr
B. 0.36 R/hr
C. 36 mR/hr
D. 6 mR/hr

G38. An ^{192}Ir source from a high dose rate afterloader has a dose rate of 1.75 R/hr at 1 m. It is placed at the center of a container of radius 30 cm._____ TVLs of shielding are required to reduce the exposure rate at the surface of the container to less than 2 mR/hr.

A. 1
B. 2
C. 4
D. 7
E. 10

G39. Regarding x-ray tubes, all of the following are true **except:**

A. The filament emits electrons by thermionic emission.
B. Electrons travel from the anode to the cathode.
C. The kVp is the peak voltage applied between the anode and the cathode.
D. When electrons strike the target, characteristic x-rays and Bremsstrahlung are emitted.
E. The target is angled and rotated to increase its heat capacity.

G40. The ratio of energy converted to heat versus energy converted to x-ray production in a typical diagnostic x-ray target is *about* _____ .

A. 1:1000
B. 1:100
C. 1:1
D. 100:1
E. 1000:1

G41–44. Consider an atom with the following binding energies:

K shell	30 keV
L shell	4.0 keV
M shell	0.7 keV

Match the energies of possible emissions with the types, for incident electrons of 50 keV.

A. Characteristic x-rays only
B. Bremsstrahlung only
C. Both
D. Neither

G41. 49.3 keV
G42. 26.0 keV
G43. 54.0 keV
G44. 4.7 keV

G45. The maximum photon energy in an x-ray spectrum is determined by:

A. the inherent and added filtration.
B. the target material.
C. the kVp.
D. the maximum mA.
E. none of the above.

G46. The minimum photon energy in an x-ray spectrum is determined by the:

A. Inherent and added filtration.
B. Target material.
C. kVp.
D. Maximum mA.
E. None of the above.

G47. In a typical x-ray beam, the 2nd HVL _____ the 1st HVL.

A. is always greater than
B. is always less than
C. is the same as
D. could be greater than or less than

G48. For a typical diagnostic x-ray beam, the HVL is measured in _____ .

A. mm Pb
B. cm W
C. mm Al
D. cm Cu

G49. The effective photon energy of an x-ray beam can be increased by:

A. Increasing the tube current.
B. Decreasing the filtration.
C. Increasing the mAs.
D. Increasing the tube voltage.
E. None of the above.

G50–52. Match the following with the descriptions below:

A. Gamma rays
B. Ultraviolet
C. Infrared
D. Radiowaves
E. Visible light

G50. Has the longest wavelength.
G51. Has the shortest wavelength.
G52. Has the 2nd highest energy.

G53. The frequency of a photon of wavelength 10^{-5}cm is _____ Hz.
(Velocity of light $c = 3 \times 10^8$ m s^{-1})

A. 30
B. 3000
C. 3×10^5
D. 3×10^{15}
E. 3×10^{25}

G54. The energy of a photon of wavelength 10^{-5}cm is _____ eV.
(Planck's constant = 4.14×10^{-15} eV.s; c = 3×10^{8} m.s^{-1})
A. 1.8×10^{-3}
B. 12.4
C. 8.1×10^{2}
D. 1.24×10^{8}
E. 3.6×10^{4}

G55. An exposure rate of 50 mR/hr is measured at a distance of 1 m from a source of radiation. The exposure rate will be 2 mR/hr at _____ m.
A. 25
B. 20
C. 15
D. 5
E. 2

G56. The relationship between HVL and linear attenuation coefficient μ is _____ .
A. HVL = 0.5 μ
B. HVL = $e^{-\mu}$
C. HVL = $e^{0.693x\mu}$
D. 0.693 = μ × HVL

G57. A monoenergetic photon beam has a linear attenuation coefficient of 0.1 cm^{-1} in tissue. After travelling through 5 cm of tissue, the fraction of the initial intensity remaining is _____ .
A. 0.61
B. 0.50
C. 0.43
D. 0.38
E. 0.05

G58. Houndsfield numbers in a CT image are linearly related to the:
A. Mass attenuation coefficient.
B. Linear attenuation coefficient.
C. Electron density of the patient.
D. Number of photoelectric interactions per cm.

G59. The reason for the differential contrast between bone and soft tissue in a diagnostic radiograph is due primarily to:
A. Compton interactions.
B. Pair production.
C. Photoelectric effect.
D. Coherent scatter.

G60. Carbon (Z=6, A=12) is about _____ times as likely as hydrogen (Z=1, A=1), per unit mass, to undergo a photoelectric interaction.

A. 216
B. 144
C. 36
D. 1/6
E. 1/36

G61. A photoelectric interaction occurs between an 9.0 keV photon and a K shell electron. A 4.0 keV photoelectron is emitted. The binding energy of the K shell is ______ keV.

A. 4.0
B. 5.0
C. 9.0
D. 13.0
E. Cannot tell from information given.

G62. Following a photon interaction with matter, a photon is detected. It could be any of the following **except:**

A. Characteristic x-ray following photoelectric interaction.
B. Scattered photon following Compton interaction.
C. Annihilation photon following pair production.
D. Scattered photon following photoelectric interaction.

G63. The type of interaction in which a 100 keV photon is scattered with half its initial energy, and an electron is emitted with the remaining energy would be:

A. Classical scatter.
B. Photoelectric.
C. Pair production.
D. Compton.

G64. Two materials with Z values of 7 and 14 are irradiated by a photon beam. The ratio of Compton interactions per unit mass is approximately:

A. 1:4.
B. 1:2.
C. 1:1.
D. 2:1.
E. Dependent on the photon energy.

G65. Compton scatter:

A. Takes place with inner shell, bound electrons.
B. Is an interaction with the nucleus.
C. Is more likely at energies just below the K edge.
D. Decreases in probability as photon energy increases.
E. Is responsible for the efficiency of lead as a diagnostic room shielding material.

G66. Compton scattered electrons can be emitted at:

A. Any angle.
B. 0°–90° with the incident photon.
C. 30°–120° with the incident photon.
D. 90°–180° with the incident photon.

G67. Pair production can occur for which of the following photon energies?

1. 1.02 keV
2. 0.51 MeV
3. 1.02 MeV
4. 2.51 MeV

A. 1, 2, 3, 4
B. 2, 3, 4
C. 3, 4
D. 4 only

G68. If a 6 MeV photon undergoes pair production, which of the following is true?

A. Two 0.51 MeV photons will be emitted.
B. A 4.98 MeV photon is scattered.
C. 6 MeV is shared as kinetic energy between a positron and an electron.
D. Two positrons are emitted at 180° to each other.

G69–72. Match the most appropriate interaction to the description. (answers can be used more than once.).

A. Coherent scatter
B. Photoelectric
C. Compton
D. Pair production

G69. Chiefly responsible for loss of contrast in a diagnostic radiograph.
G70. No energy is transferred or locally absorbed.
G71. Probability of interaction, per unit mass, depends on Z^3.
G72. Probability of interaction increases as energy increases.

G73. Which of the following is true?

A. At any given photon energy, only one type of interaction is possible.
B. Compton, photoelectric, and pair production all decrease in probability with energy.
C. The most likely interaction in soft tissue at 100 keV is photoelectric.
D. The most likely interaction in soft tissue at 1.5 MeV is Compton.

G74. The 2.2 MevV betas from ^{90}Sr will travel about _____ in tissue and _____ in air. (ρ_{air} = 0.0013 g/cm^3).

A.	1 cm	8 m
B.	2 cm	4 m
C.	1 cm	80 m
D.	2 cm	220 m
E.	4.4 cm	34 m

G75. In PET imaging, the image is created from:

A. Positrons emitted from the patient which strike the detectors.
B. Annihilation photons.
C. Protons.
D. Photoelectrons emitted when the positrons interact with tissue.

G76. The rate of energy loss of a particle depends on which of the following?

1. Energy
2. Mass
3. Velocity
4. Charge

A. 1, 3
B. 2, 4
C. 1 only
D. 4 only
E. 1, 2, 3, 4

G77. Electrons lose energy when passing through matter by:

1. Production of Bremsstrahlung.
2. Photoelectric interactions.
3. Collisions with other electrons.
4. Production of delta rays.

A. 1, 2
B. 3, 4
C. 1, 3, 4
D. 1, 2, 3
E. 1, 2, 3, 4

G78. All of the following are directly ionizing radiation **except:**

A. Protons.
B. Alpha particles.
C. Beta particles.
D. Neutrons.
E. Positrons.

G79. Two x-ray films, each with optical density of 1.0, are placed on top of one another. The fraction of incident light transmitted through the "sandwich" is:

A. 0.2
B. 0.02
C. 0.01
D. 0.001

G80. Grids are used in diagnostic radiology to _____

A. Reduce patient dose.
B. Allow a lower kVp to be used.
C. Reduce scatter to the film.
D. Reduce scatter dose to the patient.

G81. Which of the following is true regarding MRI?

A. The MRI signal differentiates between tissues on the basis of their Z values.
B. MRI can image metabolic activity.
C. MRI scans have better resolution than plane radiographs.
D. Patients with tungsten prostheses cannot undergo MRI scans.

G82. A paper states that a certain result (95% survival at 5 years) has a p value of 0.01. This means that:

A. The result is true 0.01% of the time.
B. There is a probability of 1 in 100 that this result was obtained by chance.
C. The result is true for 99% of the population.
D. There is a1% probability that the result is typical of the population.

G83. A radioactive sample is counted, yielding a value of 900 counts. If this were repeated, the value would fall between ____ and ____ 95% of the time.

A. 870 930
B. 840 960
C. 850 950
D. 895 905
E. 612 1188

G84. A CT image consists of 200 slices, each 512 × 512 pixels, each pixel having a 16-bit pixel depth. The size of the file is _____ .

A. 500 kB
B. 5 MB
C. 10 MB
D. 50 MB
E. 100 MB

G85–88. Match the following annual radiation levels with the sources listed. (answers may be used more than once.).

A. 50 mSv
B. 10 mSv
C. 2 mSv
D. 1 mSv
E. 0.5 mSv

G85. Average dose to a member of the population from radon.
G86. Maximum recommended dose to a radiation worker.
G87. Average dose to a member of the population from medical uses of radiation.
G88. Maximum recommended dose to a member of the public (*frequent* exposure).

G89. The *average* total annual dose to a member of the public from background and man-made radiation is ____ mSv.

A. 5.0
B. 3.5
C. 1.5
D. 0.4
E. 0.2

G90–91. The following effects are:

A. Stochastic
B. Deterministic
C. Both
D. Neither

G90. Induction of cancer from exposure to radiation.
G91. Skin burns from prolonged fluoroscopic exams.

G92. According to BEIR V, the *additional* risk of cancer death from a 0.1 Sv (10 rem) exposure to a population of 100,000 people would be about _____ %.

A. 0.01
B. 0.1
C. 1.0
D. 10.0

G93. If a physician receives an average whole body dose of 0.05 mSv from a procedure involving interventional fluoroscopy, _____ of these procedures can be performed each week.

A. 5
B. 10
C. 20
D. 40
E. 80

G94. All of the following are used in x-ray machine room shielding calculations in the United States, **except:**

A. Occupancy factor and Use factor.
B. Weekly dose limit to workers or public.
C. Workload.
D. Beam energy.
E. Instantaneous dose rate.

G95. Ion chamber readings are corrected for temperature and pressure because:

A. The chamber's calibration factor is stated at 22°C and 760 mmHg.
B. As temperature increases, the gas in the chamber expands, resulting in a higher collected charge.
C. As pressure increases, the gas in the chamber is compressed, resulting in a lower collected charge.
D. All of the above are true.

G96. Personnel monitors must have all of the following features, **except:**

A. No energy dependence over the range of radiation encountered.
B. Negligible loss of stored signal over 1 month of wear, and time taken to process detector.
C. Must be unaffected by normal fluctuations in environment (temperature, pressure, humidity).
D. Ability to differentiate between different energies and types of radiation.

G97. A unit dose radioisotope is delivered to a hospital. The vendor supplies a calibration of its activity. Regulations require the hospital to do all of the following, **except:**

A. Wipe test the package before opening it.
B. Treat the packaging material as low-level radioactive waste.
C. Quantify any residual activity left following use of the radioisotope.
D. Keep logs of receipt, use, and disposal (or storage) of all radioisotopes.

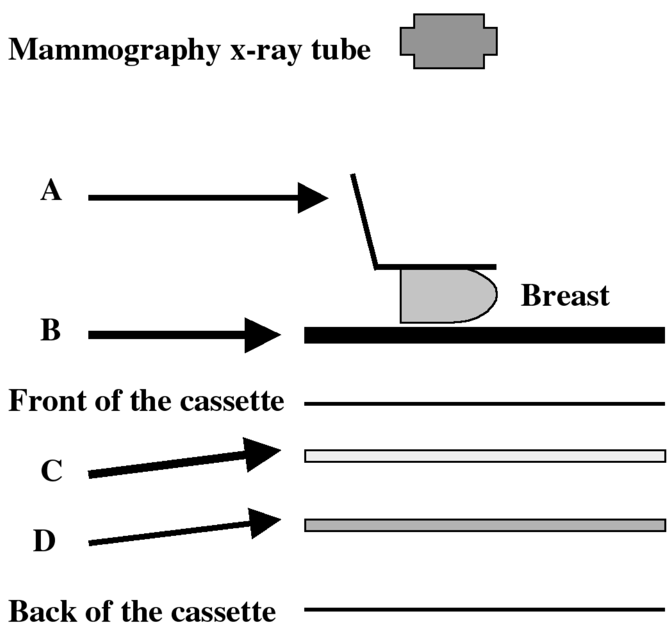
Diagnostic
❖ Questions ❖

D1. In diagnostic x-ray equipment, **tube A** has a 12° anode angle and **tube B** has a 7° anode angle. Relative to tube B, tube A:

A. Limits the size of the usable x-ray field due to cutoff of the beam.
B. Provides a smaller effective focal spot size for the same filament size.
C. Is desired for cineangiographic and neuroangiographic equipment.
D. Provides better spatial resolution.
E. Is desirable for large field-of-view coverage.

D2. Concerning radiographic equipment, variation of the effective focal spot size in the image receptor field:

A. Occurs along the anode-cathode direction.
B. Occurs perpendicular to the anode-cathode dimension.
C. Is the highest at the center of the image receptor.
D. Shows shortening of the projected focal spot size toward the cathode side of the field.
E. Causes less blur for structures placed under the cathode side of the field.



D3–5. Match the following components of a mammography screen-film system in the above figure

D3. Film ___________
D4. Anti-scatter grid ___________
D5. Screen ___________

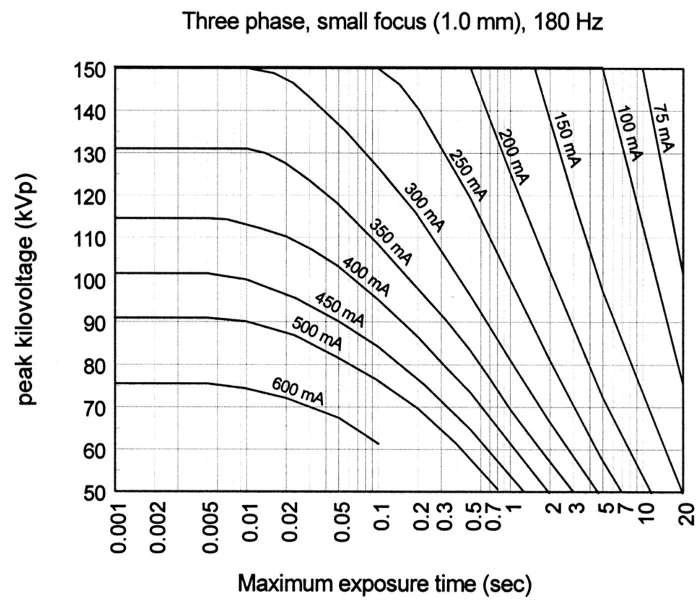
D6. Concerning diagnostic x-ray equipment, leakage radiation is:
A. Radiation that escapes the tube housing when the unit is off.
B. Radiation that escapes the tube housing during the exposure.
C. Radiation that leaks from the power cables.
D. Radiation that is transmitted through the cassette.

D7. Off-focus radiation in x-ray tubes:
A. Results from a small fraction of electrons scattering from the target and striking the filament cup.
B. Is a high-intensity x-ray source over the face of the cathode
C. Can be reduced by placing a grid between the collimator and the filter
D. Increases geometric blurring and image background fog

D8. The difference between kVp and keV is the difference between:
A. Exposure and dose.
B. Monoenergetic and heterogeneous photon beams.
C. Potential difference and energy.
D. Gamma-rays and x-rays.
E. Ionizing and non-ionizing radiation.

D9. The energy of *characteristic radiation* emanating from a tube operating at 100 kVp is determined by:
A. The elemental composition of the target.
B. Whether a single phase or three phase, or high- frequency generator is used.
C. Rectification of the secondary potential.
D. The tube current.
E. The space charge compensation circuit.

D10. A typical *filament* current for an extremity x-ray examination is ______ mA.
A. 5
B. 50
C. 250
D. 500
E. 5000



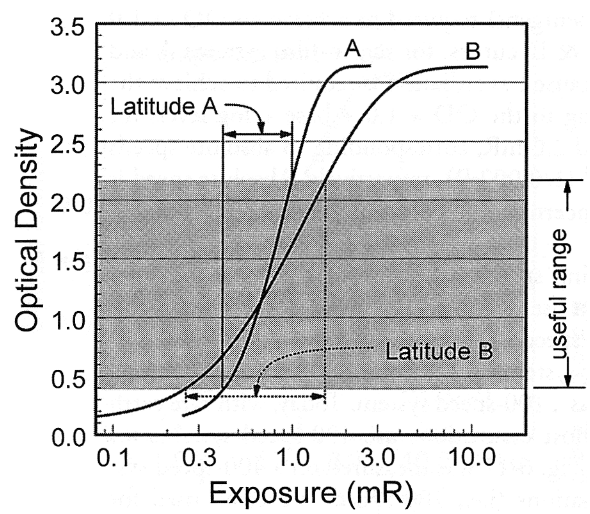
D11–13. For the x-ray tube rating chart above, the following *single* exposures are allowed. **(Answer A if allowed, B if not allowed.)**

D11.	_____	110 kVp,	400 mA,	1.5 sec
D12.	_____	80 kVp,	350 mA,	0.2 sec
D13.	_____	60 kVp,	500 mA,	0.7 sec

D14–18. For the characteristic curves of screen-film systems in this figure, match the following:

A. System A
B. System B
C. Both systems
D. Neither system

D14. System that has higher contrast
D15. System that is likely to have a higher retake rate
D16. System typically used for chest radiography
D17. System typically used in mammography
D18. System recommended for personnel dosimetry



D19. For the sensitometric strip in the above figure, which of the following is true?

A. It is obtained using a wide range of x-ray exposures to the film.
B. It is used to evaluate the film-processor daily performance.
C. Steps 8 and 14 will show equal increase in density if the developer temperature is increased.
D. Step 21 density will appear in the toe region of the film characteristic curve.

D20–23. For the following examinations, select the most appropriate image receptor:

A. Double screen, long latitude double-emulsion film
B. Cesium iodide scintillator, photocathode
C. Single screen, single-emulsion film
D. High-speed, high-contrast double screen, double-emulsion film
E. Cesium iodide scintillator, thin film transistor

D20. Mammography
D21. Chest radiography
D22. Digital radiography (DR)
D23. Fluoroscopy

D24. Concerning intensifying screens used in film screen radiography, which of the following is true?

A. Screen quantum detection efficiency is higher for thinner screens.
B. Detail screens have low MTF values.
C. Gadolinium oxysulfide screens are commonly used for screen-film mammography.
D. Cesium iodide screens are commonly used in conventional screen-film radiography

D25. A scatter removing grid has the following characteristics:
Parallel grid strips, strip height = 1.2 mm, strip thickness = 0.04 mm,
width of interspaces between grid strips = 0.12 mm.

A. The grid focal distance is in the 75–110 cm range.
B. The grid interspacing is made of lead.
C. The grid ratio is 3:1.
D. This grid is ideal for mammography imaging.
E. This grid would provide better scatter cleanup compared with a 5:1 grid.

D26–30. For quality assurance in diagnostic radiology, match each test tool with the appropriate test:

A. Focal spot size
B. mR/mAs
C. HVL
D. Light/x-ray congruence
E. Fluoroscopic resolution

D26. Aluminum filters
D27. Line pair or mesh pattern
D28. Lead markers or coins
D29. Ion chamber dosimeter
D30. Slit camera

D31. Concerning linear blurring tomography, which of the following is **false**?

A. It uses a conventional grid.
B. It achieves a section thickness of about 2 mm using a wide angle.
C. It requires a higher patient x-ray exposure than a plain film.
D. It requires long exposure times for thin sections.
E. It yields very high contrast images for thin sections.

D32. The typical lead equivalent in lead aprons used in fluoroscopy rooms is about _____ .

A. 0.1 mm
B. 0.5 mm
C. 0.5 cm
D. 1.0 cm

D33. Changes in **subject** contrast are affected by changes in:

1. Film-screen contact
2. Tissue atomic number
3. Object-film distance
4. Beam quality
5. Development time and temperature

A. 1.
B. 3 and 5.
C. Only 2.
D. Both 2 and 4.
E. All of the above.

D34–38. One of the five changes listed below will be made to the technique factors for a multislice CT scanner capable of obtaining 4 slices per rotation. All other factors will remain the same. **(Answers may be used more than once.)**

A. Raise tube current from 100 to 300 mA.
B. Change tube voltage from 120 to 80 kV.
C. Switch from 256 to 512 acquisition matrix.
D. Switch from 5 mm to 2.5 mm acquisition slice thickness.
E. Decrease table speed from 30 mm/rotation to 15 mm/rotation for the original 5 mm slice acquisition.

D34. Which change will lead to decreased patient dose?
D35. Which change will lead to higher (high contrast) resolution?
D36. Which change will lead to reduced partial volume effects?
D37. Which change will lead to the greatest reduction in noise (standard deviation of CT number) when a water phantom is scanned?.
D38. Which change will lead to a pitch less than one?

D39. Concerning radiation doses associated with thoracic CT applications, which of the following is true?

A. Doses of 20–50 mGy at the body surface are typical for conventional thoracic CT.
B. Multislice CT of the heart for calcium scoring can deliver up to five times the typical thoracic CT dose levels.
C. Dose rates for typical CT angiography are in the same range as those for typical thoracic CT.
D. Using electron beam CT for cardiac calcium scoring, the breast dose is substantially lower than that from a typical thoracic CT.
E. All of the above

D40. The patient surface dose from a typical adult abdominal CT series is about:

A. 200–300 times more than that of a typical chest radiograph.
B. 20–30 times that of the mean glandular dose of a typical craniocaudal mammogram.
C. 10–20 times that of a typical abdominal radiograph.
D. Equal to the dose from 2–5 minutes of abdominal fluoroscopy.
E. All of the above.

D41. The contrast resolution of CT is approximately ________%.

A. 0.3 to 0.6
B. 1.0 to 2.0
C. 2.0 to 3.0
D. 4.0 to 5.0
E. 5.0 to 10.0

D42. A CT image is abnormally noisy; this could be from:
- A. Using a higher than normal kVp.
- B. Using a thicker than normal slice width.
- C. Using a smoothing reconstruction algorithm.
- D. Using a lower than normal mAs.

D43. Mammographic resolution as measured at the chest wall should not be less than _____ .
- A. 1 lp/mm
- B. 6 lp/mm
- C. 11 lp/mm
- D. 18 lp/mm
- E. 25 lp/mm

D44. Current full-field digital mammography receptors have a limiting resolution that is ________ that for screen-film mammography.
- A. much higher than
- B. the same as
- C. slightly less than
- D. significantly less than
- E. 5% of

D45. Resolution in mammography is lowest at the:
- A. Top of a 6 cm compressed breast.
- B. Top of a 3 cm compressed breast.
- C. Center of the breast.
- D. Bottom of a 6 cm compressed breast.
- E. Bottom of a 3 cm compressed breast.

D46. When reading mammograms, which of the following is recommended?
- A. Have at least 3000 cd/m^2 luminance viewboxes.
- B. Always have masking available.
- C. Always have a "hot light".
- D. Have illumination levels less than 50 lux in the room.
- E. All of the above.

D47. Currently, MQSA requires the AEC in mammography to be calibrated such that radiographs of 2, 4, and 6 cm thick phantoms give an OD within _______ of the average OD.
- A. ±0.01 OD
- B. ±0.15 OD
- C. ±0.30 OD
- D. ±1.00 OD
- E. No specific requirement

D48. Single screen/single emulsion film is used in mammography because it:
A. Improves contrast.
B. Improves resolution.
C. Reduces average glandular dose.
D. Allows use of small tabletop film processors.
E. Costs less.

D49. A technologist notices that a DR (or CR) spine image appears low in contrast on the review workstation. The most appropriate action is:
A. Lower the kVp setting and repeat x-ray exposure.
B. Lower the mAs setting and repeat x-ray exposure.
C. Increase the AEC density control and repeat exposure.
D. Do not repeat; change the brightness/contrast or window level settings and save modified image.
E. Do nothing, since DR (or CR) is totally automatic.

D50. A technologist notices that a DR (or CR) spine image appears unacceptably noisy on the review workstation. The most appropriate action is:
A. Decrease the AEC density control and repeat exposure.
B. Increase the AEC density control and repeat exposure.
C. Do not repeat; apply a smoothing filter and save modified image.
D. Do not repeat; change the brightness/contrast or window level settings and save modified image.
E. Do nothing, since DR (or CR) is totally automatic.

D51. The limiting resolution for typical screen-film systems is about 6 lp/mm. The typical limiting resolution for a 35 × 43 cm flat panel detector system using a 150 micrometer detector aperture is ________ lp/mm.
A. 1
B. 3
C. 6
D. 10
E. 20

D52. A certain digital radiography system can be operated in system speed modes of 400, 800 or 1200. Typical screen-film systems have a speed of about 400. Which of the following is true?
A. In 1200 speed mode, the images will probably be noisy.
B. In 400 speed mode, the images will probably be noisy.
C. Regardless of speed chosen, patient exposure will be lower in DR than in screen-film.
D. DR limiting spatial resolution will be lower in 1200 speed mode than in 400 speed mode.
E. 400 speed mode should be chosen for pelvimetry.

D53. The appearance of an overexposed DR (or CR) image will be:
A. Too dark.
B. Too light.
C. Very low contrast.
D. Noisy.
E. Good.

D54. The quality factor (or radiation weighting factor) is essentially a simplified version of the:
A. *f*-factor.
B. Linear Energy transfer (LET).
C. Relative Biological Effectiveness (RBE).
D. Effective dose equivalent.
E. Exposure to dose conversion factor.

D55. If the absorbed dose of ^{60}Co γ-rays required to kill 50% of HeLa cells in culture is 3 Gy and the absorbed dose of ^{211}At α-rays required to kill 50% of the same cell population under the same conditions is 0.3 Gy, then the RBE of ^{211}At α-rays relative to ^{60}Co γ-rays is:
A. 0.1.
B. 0.3.
C. 3.
D. 10.
E. 30.

D56. In cells and tissues, most of the low-LET radiation damage to DNA is caused indirectly, that is, by:
A. Hydrogen and hydroxyl free radicals produced from water.
B. Low-energy Compton- scattered photons.
C. Elastic nuclear interactions.
D. Local heating effects of the radiation on DNA molecules.
E. Producing Bremsstrahlung radiation which chemically alters the DNA.

D57. Except for effects on the embryo/fetus, the threshold dose equivalent for non-stochastic (deterministic) radiation effects on most tissues of the body is:
A. A few milliSieverts.
B. A few Sieverts.
C. A few hundreds Sieverts.
D. A few thousands Sieverts.
E. A few hundred thousands Sieverts.

D58. In the United States, the mean background effective dose equivalent (natural plus artificial) is approximately:

A. 3,500 mSv/year.
B. 350 mSv/year.
C. 35 mSv/year.
D. 3.5 mSv/year.
E. 0.35 mS/year.

D59. The 1997 NRC regulations regarding release criteria for radionuclide therapy patients states that such patients can be released from the hospital when the projected dose equivalent to individuals around the patient is less than or equal to:

A. 5 mSv.
B. 50 mSv.
C. 500 mSv.
D. Individual age multiplied by 10 rem.
E. Individual age multiplied by 0.1 rem.

D60. The current "best" estimate (BEIR V value) for the lifetime risk factor for radiogenic fatal cancer is approximately:

A. 1 excess cancer/million people/Sievert.
B. 10 excess cancers/million people/Sievert.
C. 1000 excess cancers/million people/Sievert.
D. 10,000 excess cancers/million people/Sievert.
E. 100,000 excess cancers/million people/Sievert.

D61. A patient is examined with an x-ray fluoroscope using auto brightness control. The source to skin distance, SSD = 65 cm. The source to image intensifier distance SID = 90 cm. The patient's entrance air kerma rate (EAKr) is 20 mGy/min when the 14 cm FOV image intensifier is used and the x-ray beam is collimated to the full FOV. If the *SID is increased to 120 cm* ***without changing SSD,*** the EAKr:

A. Increases by a factor of approximately 2.6.
B. Increases by a factor of approximately 1.8.
C. Increases by a factor of approximately 1.3.
D. Is unaffected.
E. Decreases by a factor of approximately 1.3.

D62. A patient is examined with an auto brightness, triple mode FOV, image intensifier x-ray fluoroscope. The patient's entrance air kerma rate (EAKr) is 20 mGy/min when the 14 cm FOV is used and the x-ray beam is collimated to the full FOV, the patient's EAKr:

A. Increases more than 30% when the FOV is decreased to 10 cm (full field collimation).
B. Increases more than 30% when the FOV is unchanged and the beam is collimated to 10 cm × 10 cm.
C. Is unaffected by FOV and collimation changes.
D. Decreases more than 30% when the FOV is unchanged and the beam is collimated to 10 cm × 10 cm.
E. Decreases more than 30% when the FOV is decreased to 10 cm (full field collimation).

D63. In order to reduce the radiation dose to both patients and personnel, a radiologist chooses to use the C-arm fluoroscopy unit in the lowest dose mode. The most significant effect on image quality is:

A. High contrast resolution increases.
B. High contrast resolution decreases.
C. Low contrast resolution increases.
D. Low contrast resolution decreases.
E. None of the above.

D64. Two modes of a multi-mode image intensifier system are described as follows:

	Resolution	Brightness gain
Mode A	4.4 1p/mm	5500
Mode B	3.6 1p/mm	10000

What is the most likely input diameter size (in inches) of each?

	Mode A	Mode B
A.	9	6
B.	6	9
C.	6	12
D.	12	9
E.	12	6

D65. The major differences between fluoroscopy and standard radiography include all of the following **except:**

A. Focal spot size.
B. Spatial resolution.
C. Tube current.
D. Tube potential.
E. Source-to-skin distance.

D66. ^{18}Fluorine used in FDG imaging is produced by:
A. Neutron bombardment of ^{17}F in a nuclear reactor.
B. Elution from a fluorine generator.
C. A (p,n) reaction in a cyclotron.
D. High-energy electron bombardment of a sulfur target using a betatron.

D67. Which detector system is most appropriate and accurate for measuring the activity of a pure beta source:
A. Ionization chamber.
B. Geiger Mueller tube.
C. NaI well scintillation counter.
D. Thermoluminescent dosimeter.
E. Liquid scintillation counter.

D68. The window setting used on a gamma camera for ^{99m}Tc is set with the center at 140 keV with a width of ±14 keV, i.e., 20%. The reason for this is:
A. The energy spread is a consequence of the statistical broadening when amplifying the initial energy deposition event in the NaI crystal.
B. The 140 keV gamma ray emission of ^{99m}Tc is not truly monoenergetic but the center of a spectrum of emissions.
C. The higher and lower Gaussian tails are a consequence of Compton scattering within the patient.
D. The result of additional scattered photons generated in the collimator.
E. A consequence of patient motion during scanning.

D69. When counting an ^{125}I source of unknown activity, the multi-channel analyzer shows a peak at 60 keV, in addition to the main peak at 30 keV. This is due to:
A. Compton scatter.
B. Pulse pile-up.
C. Bremsstrahlung.
D. Collimator scatter.
E. A characteristic x-ray.

D70. How many counts must be collected in an instrument with zero background to obtain an error limit of 1% with a confidence interval of 95%?
A. 1000
B. 3162
C. 10,000
D. 40,000
E. 100,000

D71. Some dedicated PET scanners can perform both 2-D and 3-D scans. The difference is:

A. 2-D scans acquire transaxial images and cannot display coronal or sagittal images.
B. 3-D scans acquire the data directly in coronal or sagittal planes.
C. 2-D scans acquire the data one slice at a time, whereas 3-D scans acquire all slices simultaneously.
D. Only 3-D scans can be corrected for attenuation.
E. 2-D scans have septa in front of the detectors to reduce events from scattered photons.

D72–76. In nuclear medicine imaging, match the following quality control procedures with the relevant choice:

A. Gamma camera resolution
B. Gamma camera field uniformity
C. Photopeak window of the pulse height analyzer
D. Dose calibrator linearity
E. Dose calibrator constancy

D72. Checked daily using a uniform flood source.
D73. Checked daily using standardized long half-life source.
D74. Checked quarterly by measuring the decay of ^{99m}Tc over 72 hrs or more.
D75. Checked daily by placing a small amount of a known source of radioisotope in front of the camera.
D76. Checked weekly using a bar phantom.

D77. A cold spot artifact appears in a scintillation camera image. The artifact could be caused by all of the following **except:**

A. The energy spectrum of one of the photomultiplier tubes is out of calibration.
B. The photomultiplier tube is defective.
C. The patient is wearing metallic jewelry.
D. An out-dated uniformity correction is used.
E. The wrong collimator was used.

D78. Most diagnostic nuclear medicine scans are performed with an image acquisition setting of 8 bits per pixel., This means that the maximum number of counts per pixel is 2^8 or 256. The minimum detectable count difference which is significant at the 2σ level is about _____%.

A. 15
B. 12.5
C. 9
D. 6
E. 3

D79. Most PET scans consists of two parts: an **emission** scan and a **transmission** scan. What is the purpose of these two processes?

A. Emission provides an image of the activity distribution; transmission normalizes the emission image for variations in detector block sensitivity.
B. Emission provides an image of the body attenuation map; transmission provides an image of the activity distribution.
C. Emission provides an image of the activity distribution; transmission provides a map of the attenuation.
D. Emission provides an image of the activity distribution; transmission is used to determine the precise amount of activity that should be administered to the patient.
E. Emission provides an image of the activity distribution; transmission corrects the emission image for photon attenuation and scatter within the couch assembly.

D80. All of the following radioactive sources with an initial activity of 30 mCi can be discarded after one year, except:

A. ^{201}Tl.
B. ^{99m}Tc.
C. ^{18}F.
D. ^{57}Co.
E. ^{123}I.

D81. Which of the following **does not** require the use of a collimator?

A. SPECT scan.
B. PET scan.
C. Measuring gamma camera system uniformity with a ^{57}Co flood source.
D. Sentinel lymph node detection.
E. First pass cardiac scan.

D82. An imaging system has the following individual MTF values. The system's total MTF is ______.

Film = 0.8, Screen = 0.7, Focus = 0.5

A. 0.12.
B. 0.28.
C. 0.5.
D. 0.8.
E. 2.0.

D83. The attenuation coefficient (decibels/cm) of ultrasound is largest in:

A. Liver.
B. Lung.
C. Fat.
D. Blood.
E. Skull bone.

D84. If the ultrasound intensity is attenuated by 50% in a pulse-echo experiment, the relative intensity of the pulse to the echo is _______dB.

A. 2
B. 3
C. 6
D. 10
E. 50

D85. When operating in the Doppler mode:

A. One can employ a pulse-echo or continuous wave technique.
B. The frequency shifts are independent of the ultrasound frequency.
C. Meaningful information can only be obtained from moving interfaces.
D. The principal application is measurement of midline shifts of the brain.
E. Only qualitative measurements can be obtained.

D86. "Duplex" ultrasound refers to:

A. Simultaneous recording of A lines from two transducers.
B. Doubling the pulse repetition frequency to enhance resolution.
C. Anatomical images and a selectable Doppler window gate simultaneously displayed.
D. Simultaneous measurement of ultrasound attenuation and acoustic impedance.

D87. Multiple reflections that occur between two strong reflectors along the ultrasonic path with progressively weaker bands in the image is best described as:

A. Propagation speed error.
B. Acoustic speckle.
C. Ghost image.
D. Reverberation.
E. Side lobe energy.

D88. Concerning multifrequency (broad-bandwidth) Ultrasound transducers, all of the following are true **except:**

A. They have bandwidths close to 80% of the central frequency.
B. With 5 MHz central frequency, they can receive 3–7 MHz frequencies.
C. They are used in harmonic imaging.
D. They use non-resonance transducer material.

D89. Concerning ultrasound harmonic imaging the following are true **except:**

A. Harmonic images are formed from integral multiples of the transducer fundamental frequency.
B. The transmitted frequencies and the returned harmonics have the same frequency but different intensity.
C. No harmonics are generated at near field.
D. Harmonic pulses travel half the distance of the fundamental pulse.
E. Harmonic imaging improves lateral resolution.

D90. In MRI, calcium deposits in an acute hemorrhage can cancel the T_2 shortening effects of the blood degradation products because of ______ properties.

A. Diamagnetic
B. Paramagnetic
C. Magnetization transfer
D. Hysteresis
E. Solidification

D91. For the spin-lattice relaxation time, the lattice is:

A. the x,y,z coordinate system.
B. tissue.
C. an imaginary frame.
D. a set of adjacent nuclei.
E. the digital image matrix.

D92. A spin echo sequence used with a TE of 200 msec and TR of 3 seconds will result in an image that is primarily _______ weighted.

A. T_1
B. Proton density
C. T_2
D. T_1/T_2
E. Magnetization transfer

D93. A gadolinium contrast agent will most likely cause one of the following:

A. Decreased proton density signal.
B. Increased proton density signal.
C. Increased T_2.
D. Increased T_1.
E. Decreased T_1.

D94. The dominant artifact affecting image quality *most* often in the phase encoding direction is:

A. Wrap around.
B. Aliasing.
C. Motion.
D. RF zipper.

D95. When changing from a 256 × 256 matrix (SNR_1) with 2 NEX to a 256 × 128 matrix (SNR_2) with 1 NEX and the phase encoding along the 128 matrix dimension (with everything else fixed), the SNR relationships will be:
(NEX refers to number of excitations per phase encode step)

A. $SNR_1 = 1/2\ SNR_2$.
B. $SNR_1 = 1/4\ SNR_2$.
C. $SNR_1 = SNR_2$.
D. $SNR_1 = 2\ SNR_2$.
E. $SNR_1 = 4\ SNR_2$.

T1. In the formula for calculating the monitor unit setting for a single direct spine field treated at 100 cm SSD, the value of "A" is _____ .

MU = (dose/fraction) / (cGy/MU at SSD) × A

A. TMR (tissue-maximum ratio)
B. TPR (tissue-phantom ratio)
C. PDD/100 (percent depth dose)
D. SAR (scatter-air ratio)
E. TAR (tissue-air ratio)

T2. The ratio: (dose rate at depth d) / (dose rate at depth d_{max}) measured at the same point, and for the same field size, is the _____ .

A. TMR
B. TPR
C. PDD
D. SAR
E. TAR

T3. In megavoltage photon beams, the tissue-maximum ratio (TMR) varies with all of the following factors **except:**

A. Field size.
B. SSD.
C. Depth.
D. Photon energy.

Questions T4—T9 refer to the following data tables for 6 MV photons. (PDD are for 100 cm SSD.)

		Field Size				
	Depth (cm)	5 × 5	10 × 10	15 × 15	20 × 20	25 × 25
PDD	3	95.3	95.8	95.4	95.6	95.6
	8	72.0	75.0	76.3	77.3	77.9
	10	64.2	67.6	69.2	70.3	71.1
	15	47.7	51.6	53.7	55.4	56.4
	20	36.7	39.2	41.5	43.4	44.5
TMR	3	0.978	0.984	0.981	0.982	0.982
	8	0.809	0.842	0.857	0.869	0.877
	10	0.745	0.784	0.804	0.818	0.828
	15	0.602	0.647	0.675	0.697	0.713
	20	0.487	0.530	0.560	0.586	0.605
Output (cGy/MU) at depth = 1.6 cm, SSD = 100 cm		0.950	1.000	1.038	1.055	1.069
Output (cGy/MU) at depth = 1.6 cm, SAD = 100 cm		0.980	1.032	1.071	1.089	1.103

T4. To deliver 200 cGy to a depth of 3.0 cm in a 14 × 8 cm supraclavicular field set up at 100 cm SSD, with a small corner block (tray factor = 0.96), the MU setting is _____ .

A. 235
B. 230
C. 224
D. 217
E. 210

T5. If the field in question T4 above were set up at 100 cm SAD, with the isocenter at d=3.0 cm, the MU setting would be _____ .

A. 230
B. 225
C. 212
D. 205
E. 202

T6. The maximum tissue dose in question T4 above is _____ cGy.

A. 200
B. 205
C. 209
D. 217
E. 225

T7. With the isocenter at d=3 cm , as in question T5 above (isocentric set up), the dose at d=10 cm is _____ cGy.

A. 123
B. 139
C. 159
D. 182
E. 195

T8. Parallel opposed lung fields, 13.0 × 17.5 cm, are treated at 100 cm SAD, d=10 cm, to a total dose of 180 cGy/fraction. The MU setting per field is _____ .

A. 105
B. 100
C. 98
D. 95
E. 93

T9. In question T8 above, if the beam energy is 6 MV, the maximum tissue dose in the treated volume will be about _____ % greater than the prescribed dose at the isocenter.

A. 0
B. 2
C. 6
D. 12
E. 18

T10. A patient is treated to the thigh with isocentric AP/PA fields using 6 MV photons. If the machine is broken and the patient has to be switched to another linac with 4 MV photons, all of the following would be expected **except:**

A. Slightly increased skin dose.
B. Increased dose homogeneity.
C. Decreased depth of d_{max}.
D. Increased MU.

T11. The factor that most influences the change in PDD with SSD is the change in:

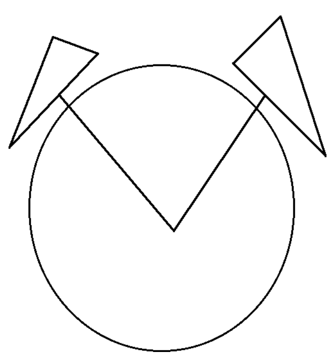
A. Beam energy as distance increases.
B. Scatter in tissue.
C. Attenuation in the patient.
D. Inverse square.
E. Scatter in air.

T12. Given a square field and an elongated rectangular field of the same *area*, which would you expect to have the greater percent depth dose for 4 MV photons?

A. The square.
B. The rectangle.
C. They have the same depth dose.

T13. According to the "rule of thumb" for wedge angle vs. hinge angle, the wedge that would give the most homogeneous dose distribution in the diagram below is ____ degrees.

Hinge Angle = 60°



A. 15
B. 30
C. 45
D. 60

T14. All of the following are advantages of a dynamic wedge over a physical wedge, **except:**

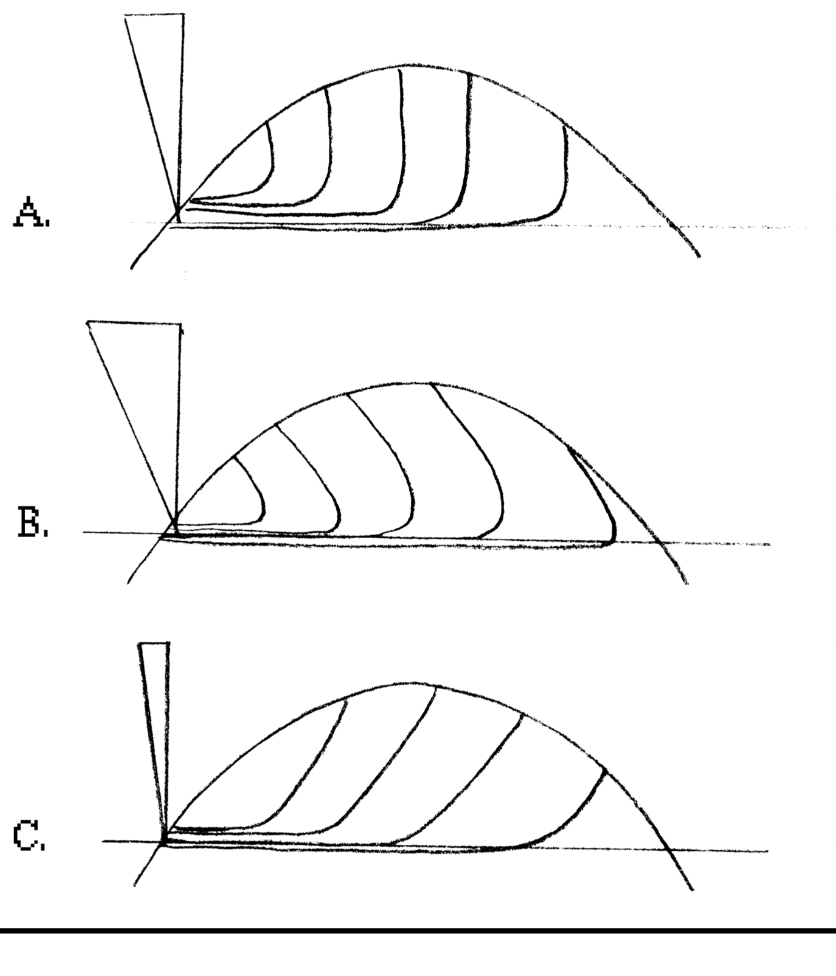
A. Same depth dose as the open beam.
B. Field height is not limited.
C. Therapists do not have to lift a heavy wedge.
D. Less dose outside the field (e.g., to contralateral breast).
E. Wedge transmission factor is independent of field width.

T15. A wedge transmission factor is 0.75. The monitor unit setting is _____ times that calculated for the open beam.

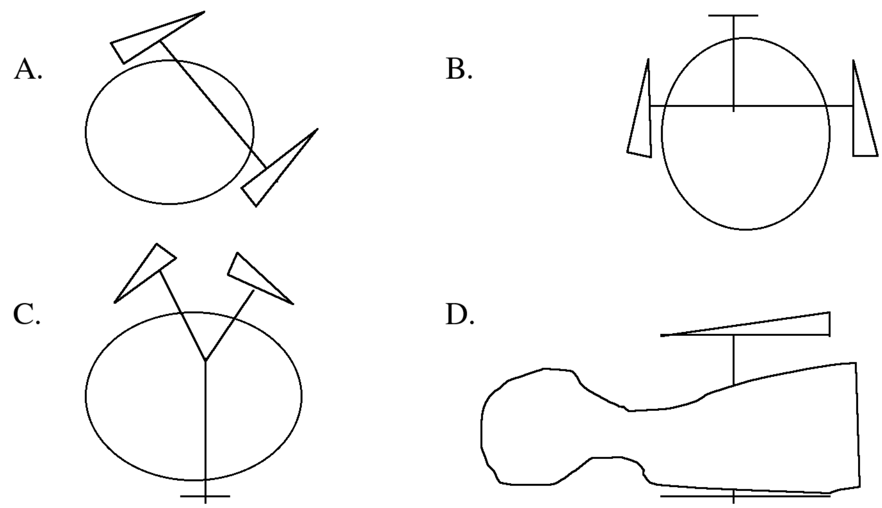
A. 0.25
B. 0.75
C. 1.33
D. 1.75
E. 2.33

T16. Which one of the wedged isodose curves shown, when combined with a similar opposed wedged field , would deliver the most homogeneous dose to the breast volume?

A.
B.
C.



T17. Which one of the following plans has the wedges in the correct orientation?

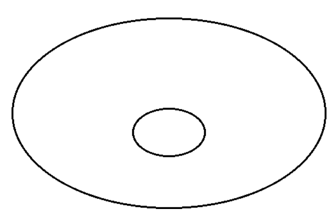


A.
B.
C.
D.

T18. The purpose of a "beam spoiler" in a photon beam is to:

A. Increase dose in the build build-up region.
B. Reduce the PDD at 5 cm depth.
C. Filter out scattered electrons, to reduce the skin dose.
D. Reduce the energy of a photon beam.
E. Increase the TMR beyond d_{max}.

T19.



The PTV shown can be treated with 4-fields (AP/PA and Lats) or conventional 360° rotation. Assuming no field shaping is used, compared with the 4-field plan the rotation plan:

A. Conforms better to the shape of the PTV.
B. Requires fewer monitor units.
C. Delivers a much more homogeneous dose to the PTV.
D. Treats a larger volume of normal tissue.

T20. In a photon beam, skin dose, as a percent (%) of dose at d_{max}, *increases* with all of the following **except:**
- A. Increasing obliquity.
- B. Use of bolus.
- C. Decreased SSD.
- D. Decreasing field size.

T21. As photon energy *increases:* surface dose ________ and depth of d_{max} _____ .
- A. increases, increases
- B. decreases, increases
- C. increases, decreases
- D. decreases, decreases

T22. Surface dose is likely to increase with all of the following **except:**
- A. Lower electron beam energy.
- B. Use of bolus.
- C. Use of a spoiler.
- D. Obliquity.

T23. In a *single isocenter* 4-field breast plan (i.e., using half-blocked fields for the tangents, supraclav, post axilla) the tangents are given a collimator rotation of 10° degrees to align with the chest wall. In order to match the supraclav field to the tangents, without creating a cold area at the match, the supraclav field requires a _____ .
- A. a couch rotation of 90° and a gantry rotation of 10°.
- B. a gantry rotation of 10° only.
- C. a gantry rotation of 350° only.
- D. a gantry angle of 0°, with light field edges matched on the skin.
- E. a collimator rotation of 10 and a gantry angle of 0°.

T24. Adjacent single direct fields of heights 25 cm and 28 cm are matched at 6.0 cm depth. The gap to be left on the skin between the light field edges is _____ cm.
- A. 0.8
- B. 1.0
- C. 1.6
- D. 2.4
- E. 3.2

T25. The collimator rotation required to align 25 × 25 cm cranial fields with a direct spinal axis field of height 36 cm is _____ degrees.
- A. 3.5
- B. 5
- C. 7
- D. 10
- E. 17

T26. A possible *disadvantage* of using parallel parallel-opposed 18 MV photons for treating a volume which includes superficial nodes is:

A. Increased skin dose.
B. Higher total dose at d_{max}.
C. Insufficient dose in the build-up region.
D. Higher dose rate.

T27. All of the following are true regarding 10MV photons **except:**

A. Penumbra is sharper than for 4 MV beam.
B. The depth of d_{max} is approx. 2.0 cm.
C. Attenuation is approx. 2.5% per cm.
D. The PDD for a 10 × 10 cm beam at 10 cm depth is 74%.

T28. A patient's whole brain is treated isocentrically to 3000 cGy using 6 MV photons. If the calculation was done using 8.5 cm depth, but the patient's separation was in fact 15.0 cm, the dose received was about _____ cGy.

A. 2700
B. 2970
C. 3030
D. 3090
E. 3300

T29. Flattening filters in photon beams are designed to optimally flatten the beam at _____ cm depth.

A. d_{max}
B. 5
C. 10
D. 20

T30. The depth of d_{max} for an 18 MV photon beam is 3.5 cm. For parallel parallel-opposed 15 × 15 cm fields, with a separation of 20 cm, the *minimum* depth at which 95% of the mid-plane dose occurs is _____ cm.

A. 3.4
B. 3.0
C. 1.5
D. 0.5
E. 0.2

T31. A photon field is calculated for treatment at 100 cm SSD. Due to an error in the ODI (optical distance indicator) the treatment is delivered at 98.8 cm SSD. The dose received by the patient at d_{max} is _____ .

A. 3.6% low
B. 2.4% low
C. 1.2% low
D. 1.2% high
E. 2.4% high.

T32. For superficial x-ray units, increasing all of the following will increase the PDD **except:**

A. Additional filtration.
B. Field size.
C. SSD.
D. kVp.
E. mA.

T33. Superficial x-rays, compared with 6 MeV electrons, _____ .

A. Have a lower skin dose.
B. Deliver less dose to underlying tissues.
C. Require thicker shielding.
D. Have a sharper penumbra .

T34. Which of the following is **not true** for CT images of the torso used directly for computerized treatment planning?

A. The patient must be scanned in the treatment position.
B. A flat insert is required for the CT table.
C. The CT image is a gray scale representation of the relative linear attenuation coefficient of each pixel.
D. CT numbers must be converted into electron densities before pixel-by-pixel inhomogeneity corrections can be made.
E. Triangulation points or surface marks are unnecessary since the isocenter can be related to internal organs.

T35. Which of the following lists tissues in order of increasing Hounsfield (CT) number?

A. Bone, muscle, fat, lung.
B. Lung, fat, muscle, bone.
C. Lung, muscle, fat, bone.
D. Fat, lung, muscle, bone.
E. Bone, fat, muscle, lung.

T36. Triangulation points tattooed on the skin are used to reproduce a patient's position daily. These tattoos are likely to be *most* reliable for treating _____ .

A. Glioma
B. Prostate
C. Breast
D. Lung

T37. Heterogeneity corrections are greatest for _____ .

A. 10 cm lung, and 6 MV photons
B. 10 cm lung, and 18 MV photons
C. 3 cm bone, and 6 MV photons
D. 3 cm bone and 10 MV photons

T38. The dose under a 1.5 cm width cord block (5 HVL thickness) in a 6 MV photon beam at 5 cm depth is approximately _____ % of the dose in the open beam.

A. 3
B. 7
C. 15
D. 25
E. 50

T39. In an irregular field calculation, the increase in MU setting to account for blocking will be greatest for:

A. 10 MV photons, at a depth of d_{max}.
B. 4 MV photons, at a depth of d_{max}.
C. 10 MV photons, at a depth of 10 cm.
D. 4 MV photons, at a depth of 10 cm.
E. 4 MV photons, at a depth of 5 cm.

T40. A film with a magnification of 1.4 has a block drawn on it that measures 3.5 cm on the film. The actual size of this block on a tray at 65 cm, and the projected size on the patient's skin at 100 cm SSD are _____ cm and _____ cm, respectively.

A. 0.75, 0.85
B. 1.1, 2.5
C. 1.3, 1.8
D. 1.6, 2.5
E. 2.5, 3.1

T41. At what SSD will the maximum field size of 40 cm diverge to 56 cm?

A. 196 cm
B. 156 cm
C. 140 cm
D. 128 cm
E. 116 cm.

T42. On an 80 cm SAD ^{60}Co unit, a 15 × 15 cm isocentric field set up at 10 cm depth measures _____ × _____ cm on the skin.

A. 13.1
B. 13.5
C. 14.1
D. 14.6

T43. The *approximate* maximum dose to a patient's contralateral breast from tangential breast fields delivering a total dose of 5000 cGy is of the order of:

A. 2500 cGy.
B. 250 cGy.
C. 25 cGy.
D. 5 cGy.
E. Negligible.

T44. The component of dose to the fetus of a pregnant patient undergoing radiotherapy that *cannot* be modified by additional custom shielding is _____:

A. Head leakage.
B. Collimator scatter.
C. Internal scatter.
D. Scatter from blocks and blocking tray.

T45. A TBI patient is treated at 400 cm SSD. If the linac is calibrated to deliver 1.0 cGy/MU at d_{max}, 100 cm SSD, approximately how many MU are required to deliver 100 cGy from one field at d_{max} to the TBI patient?

A. 4000
B. 1600
C. 800
D. 400
E. 200

T46. All of the following will improve dose homogeneity for TBI **except:**

A. Using the highest photon beam energy available together with a beam spoiler.
B. Using AP and PA beams instead of opposed laterals.
C. Using tissue compensators for the extremities.
D. Using the shortest SAD consistent with adequate field size at the patient.
E. Adding compensating material over the lung area.

T47. For stereotactic radiosurgery, accuracy and reproducibility should generally be on the order of _____ mm.

A. 7
B. 5
C. 2
D. 0.5

T48. The gamma knife could be incorporated into the treatment of all of the following sites **except:**

A. Certain patients with two brain mets, each measuring 2.0 cm in diameter.
B. A 1.5 cm intra-auricular accoustic neuroma.
C. A newly diagnosed GBM measuring 5 cm.
D. A 1.0 cm surgically inaccessible arteriovenous malformation.

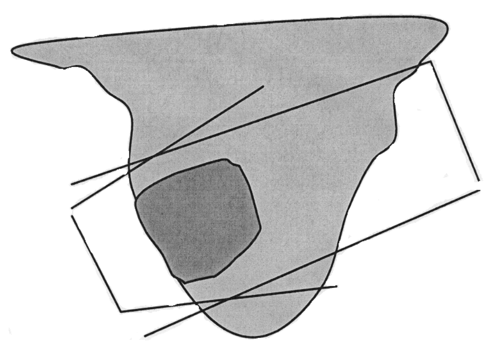
T49. Advantages of a multi-leaf collimator over cerrobend blocks for field shaping include all of the following, **except:**

A. Decreased time to generate field shaping.
B. Adjustments to field shaping are faster.
C. Faster set-up (no tray to attach to head of machine).
D. More conformal.

T50. Which one of the following is *required* for generating a conformal treatment plan?

A. GTV
B. CTV
C. PTV
D. Internal margin
E. Set-up error.

T51. A lumpectomy site in the breast is treated with parallel parallel-opposed 6 MV photon fields, as shown below. On the DVH, 10% of the PTV receives less than 90% of the prescribed dose. The most probable reason for this is:



A. The field arrangement and choice of angles could be improved.
B. The fields are not wide enough to cover the PTV.
C. The beam energy is too low.
D. The PTV is drawn up to the skin, and includes the build-up region.

T52. A radiotherapy department has a choice of 6, 10, and 18 MV photons. For IMRT prostate plans, _____ MV photons are chosen, because:

A. 6, this delivers the most homogeneous dose to the PTV.
B. 10, this delivers a lower neutron dose than 18 MV, but acceptable dose to normal tissues.
C. 18, this delivers the lowest neutron dose and the lowest normal tissue dose outside the PTV.
D. 10, although this delivers the highest neutron dose, it gives the best dose distribution, and the neutron dose is clinically acceptable.

T53. Potential advantages of IMRT include all of the following **except:**

A. Dose conformity for irregularly shaped volumes.
B. The possibility of dose escalation.
C. Reduced normal tissue morbidity at conventional doses.
D. Ability to treat a volume with a concave surface, conformally.
E. Simpler verification of dose calculation and delivery.

T54. In IMRT inverse planning for treatment with the “step and shoot” technique, all of the following are specified by the human planner (i.e., not by the computer), **except:**

A. Beam angles.
B. Number of beams.
C. Beam weights.
D. Dose constraints for contoured volumes.
E. PTV contour on CT images.

T55. Reasons for fusing an MRI scan with a CT scan for treatment planning brain tumors include all of the following **except:**

A. Some brain lesions have areas of infiltration that are better visualized on MRI .
B. CT is less subject to geometrical distortion than MRI.
C. Image fusion should be more accurate than estimating contours on CT using a hard copy of the MRI.
D. The CT image is required for heterogeneity corrections.

T56. All of the following are true regarding PET used in treatment planning, **except:**

A. PET/CT can aid in treatment target definition.
B. PET images can show areas of metabolic activity.
C. ^{18}F, a cyclotron produced positron emitter, is used in most PET studies.
D. Registration of PET and CT images can be a problem, which the combined PET/CT unit is designed to solve.
E. An advantage of the combined PET/CT unit is that it makes gating unnecessary.

T57. Orthogonal films of a gynecological applicator are required for dosimetry planning. AP and lateral films are taken, but the lateral film has very poor contrast. All of the following solutions may provide films with acceptable contrast **except:**

A. Retake lateral, reducing the collimator setting to the minimum area possible.
B. Retake lateral using a higher ratio grid.
C. Retake lateral with increased mAs.
D. Take orthogonals at 45° and 315° instead of 0° and 90°.

T58. Proton beam therapy has a potential advantage over photon beam therapy because:

A. Monoenergetic protons have an ideal depth dose distribution for treating deep-seated tumors such as the prostate.
B. Protons have an exponential depth dose similar to that of neutrons.
C. Protons have a lower RBE, and hence are less damaging to normal tissue.
D. Protons exhibit a sharp fall-off in dose beyond the PTV, which spares normal tissue.

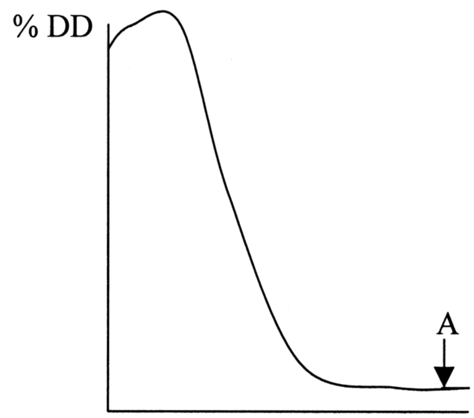
T59. A 10 × 10 cm 9 MeV electron field has the 90% depth dose at approximately _____ cm depth.

A. 2.1
B. 2.7
C. 3.6
D. 4.5
E. 9.0

T60. To ensure adequate coverage of the treatment volume with an electron beam, it is important to remember that:

A. All isodose curves decrease in width with depth.
B. All isodose curves increase in width with depth.
C. The 90% isodose increases and the 20% isodose decreases in width with depth.
D. The 90% isodose decreases and the 20% isodose increases in width with depth.

T61.



The part of the electron depth dose curve labeled A on the diagram is mainly due to:
A. Electrons with the highest energy which have the greatest range.
B. Bremsstrahlung x-rays created by electron interactions with tissue.
C. Characteristic x-rays generated by electrons striking the collimators.
D. Bremsstrahlung x-rays created by electron interactions with high Z components in the head.

T62. A cervical neck node is to receive a boost with 16 MeV electrons using a 3.0 cm circular cut-out in a 6 × 6 cm cone. This field must be treated at 115 cm SSD to avoid the shoulder. All of the following are true, **except:**
A. The electron output (cGy/MU) is reduced compared to an open 6 × 6 cm cone.
B. The penumbra width will increase, compared to that at 100 cm SSD.
C. The depth of the 90% isodose will be less than that of the open 6 × 6 cm cone.
D. The output at 115 cm SSD will be $(100/115)^2$ times that at 100 cm SSD.

T63. The output for an electron cone is 1.02 cGy/MU. The MU required to deliver 200 cGy to the 95% isodose level is _____ MU.
A. 196
B. 206
C. 218
D. 222
E. 235

T64. A chest wall of thickness 1.2 cm overlies lung of density 0.33 g cm^{-3}. If 0.5 cm of bolus is placed on the skin, use the 6 MeV electron depth dose table below to estimate the *approximate depth in lung* of the 50% isodose.

Depth (cm)	0	0.5	1.2	1.5	1.7	2.0	2.3	4.0
PDD	77	95	100	97	90	70	50	3

A. 0.3
B. 0.6
C. 0.9
D. 1.8
E. 2.9

T65. A batch of ^{125}I seeds is ordered for a prostate implant. On arrival, the activity is 0.455 mCi/seed. The activity will be 0.420 mCi/seed after _____ days.
A. 14
B. 10
C. 7
D. 5
E. 2

T66. The dose rate in cGy/hr in air at 1 m from a radioactive source is closest numerically to the source strength expressed in units of:
A. mCi.
B. Ci.
C. GBq.
D. Air Kerma Strength.
E. mg Ra equivalent.

T67. The exposure rate constant is:
A. 0.957 for all photon-emitting radionuclides.
B. The dose rate in tissue at 1 m from a point source.
C. 8.25 R-cm^2/mCi-hr for 1 mg Ra equivalent of any radionuclide.
D. The value that must be entered under "Transport Index" for mailed packages.

T68. For a Fletcher applicator with loading of 15-10-10 mg-Ra equ in the tandem and 15 mg-Ra equ in each ovoid, a lateral displacement of 0.2 cm in the location of point A would cause about a __________ % change in the dose rate at that point.
A. 0.1
B. 1
C. 2
D. 10
E. 30

T69. A patient has a temporary implant containing 20 mCi of ^{192}Ir. (Γ = 4.6 R-cm^2/mCi-hr). The exposure rate at 2.5m from the sources is _____ mR/hr.

A. 5.5
B. 3.2
C. 1.5
D. 0.5
E. 0.05

T70. A permanent implant has a half-life of 17 days. After 51 days, _____ times the initial activity remains, and _____ % of the total dose has been delivered.

A. 0.125, 87.5
B. 0.25, 75.0
C. 0.125, 12.5
D. 0.875, 87.5
E. 0.25, 25.0

T71. When reconstructing the 3-D positions of a tandem and ovoid from orthogonal films, it is often difficult to identify the R and L ovoids on the lateral film. All of the following can be helpful, **except:**

A. Using different dummy markers in each ovoid.
B. Rotating the orthogonal films a few degrees (e.g., gantry angles of 10° and 100° until the ovoids are separated on the lateral view).
C. Taking films at gantry angles of 45° and 315°.
D. The ovoid with the larger diameter is the one closest to the film cassette.

T72. The Patterson-Parker system cannot be used for a single plane breast implant, using equal strength ^{192}Ir seeds placed on a 1 cm grid, because:

A. The system requires unequal strength sources at the periphery and in the center.
B. Patterson-Parker only applies to radium and cesium sources.
C. The ends cannot be "crossed.".
D. The system applies only to permanent, not temporary, seed implants.

T73. When ^{192}Ir sources are sent from the manufacturer to a hospital, all of the following are true, **except:**

A. The container must be D.O.T approved.
B. The "Transport Index" must be measured, and written on the label.
C. A radioactive source warning label must be attached to the container.
D. The maximum dose rate on the surface of the container must be stated on the label.
E. The activity and radionuclide must be stated on the label.

T74. According to NRC regulations, sealed radioactive sources must be leak tested **except** when:

A. The activity is below 5.0 mCi.
B. They are "in storage" (i.e., not in use).
C. They emit photons only.
D. They have been shown not to leak for the previous 2 years.

T75. A lead apron would be effective shielding for a brachytherapy procedure with which of the following radionuclides?

A. ^{137}Cs
B. ^{125}I
C. ^{192}Ir
D. A and B
E. All of the above.

T76. All of the following are true of ^{192}Ir **except:**

A. It can be used in the form of strands of seeds for temporary implants.
B. It is the radionuclide most often used in High Dose Rate Afterloaders.
C. It is created by neutron activation in a reactor.
D. Mean energy is about 350 keV.
E. Half-life = 60 days.

T77. A radionuclide which emits photons of average energy 21 keV and has a 17-day half-life is:

A. ^{125}I.
B. ^{103}Pd.
C. ^{137}Cs.
D. ^{198}Au.
E. ^{192}Ir.

T78. The dose in tissue at 1.0 cm depth from the surface of a vaginal cylinder, expresed as a percent of the surface dose, is:

A. Greatest for the largest diameter cylinder.
B. Greatest for the smallest diameter cylinder.
C. Independent of cylinder diameter.

T79. The ICRU rectal point in a gynecological insertion using tandem and ovoids is defined as:

A. The point on the rectal marker closest to the tandem at its superior end.
B. The most posterior and superior point on the radio-opaque packing.
C. A point 0.5 cm posterior to the radio-opaque packing, centered at the ovoids.
D. A point 2 cm posterior and 2 cm superior to the external os, as visualized on the lateral film.
E. A point 1 cm posterior and 1 cm inferior to the external os, as visualized on the lateral film.

T80. An HDR treatment has a total treatment time of 282 seconds on May 1st. Assuming the ^{192}Ir source has not been changed, the treatment will take _____ seconds on May 15th.

A. 322
B. 302
C. 296
D. 264
E. 247

T81. An HDR treatment planning system uses optimization to deliver an even dose at a radius of 1 cm from a bronchial applicator. The dwell times will be:

A. Higher at the ends than in the center.
B. Alternately high and low.
C. All approximately equal.
D. Higher in the center than at the ends

T82. The long-term success of intravascular brachytherapy (IVBT) depends on all of the following **except:**

A. The relative doses delivered to the innermost lumen wall and the adventitia.
B. Not exceeding a maximum dose to the innermost lumen wall.
C. Achieving an axially symmetric dose relative to the vessel adventitia.
D. The rate of dose delivery during the procedure.
E. Treating the full dose to a distance proximal and distal to the balloon-injured area.

T83. Which of the following is the most important advantage of brachytherapy over teletherapy?

A. There is no repair of sublethal injury.
B. A more homogeneous dose is delivered.
C. The oxygen enhancement ratio is reduced.
D. The volume of normal tissue treated is minimized.
E. Radiation exposure to personnel is less.

T84. When a linear accelerator is used in the *electron* mode, the electron beam passes through each of the following components **except:**

A. Accelerator tube.
B. Bending magnet.
C. Target.
D. Primary collimator.
E. Monitor chamber.

T85. On a linac with a nominal dose rate of 300 MU/min, a treatment requires a monitor unit setting of 150 MU. This means that:

A. The timer will terminate the beam after exactly 30 seconds.
B. The timer constantly monitors the true dose rate, and terminates the beam after the time calculated to deliver 150 MU.
C. The monitor chamber collects charge as the beam passes through it, and terminates the beam after a charge equivalent to 150 monitor units has been collected.
D. The beam is terminated after 150 R has been collected in the chamber.

T86. Bending magnets are needed in linear accelerators:

A. To rotate the electron beam so that it points towards the isocenter.
B. Only in the photon mode.
C. Only for linacs with the waveguide mounted perpendicular to the gantry rotation axis.
D. Only in the electron mode.
E. With dual energy photons only.

T87. Regarding neutrons, which of the following is **false**?

A. Neutrons are produced in therapy linacs operating at nominal energies of 10 MeV and above.
B. Additional shielding for neutrons is required for linacs operating at nominal energies of 15 MeV and above.
C. High-Z materials are the most effective neutron moderators.
D. Neutrons have a high RBE because they give rise to secondary protons.
E. Neutrons are more readily attenuated by concrete than by an equal mass of lead.

T88. Most of the neutrons produced by a high-energy linac are produced:

A. In the patient.
B. In the floor and walls of the room.
C. In the electron mode rather than the photon mode.
D. In the head of the linac.

T89. A superficial x-ray unit has an HVL of 2 mm Al. Which of the following will cause the greatest increase in dose rate at the patient's surface?

A. Increasing the filtration by 1 mm.
B. Increasing the beam current from 8 to 12 mA.
C. Changing the kVp from 100 to 80.
D. Increasing the SSD from 15 to 18 cm.

T90. The AAPM's TG-40 report on Quality quality Assurance assurance requires all of the following Q/A measures, **except:**

A. Verification by spot check of the activity of seeds used for permanent implants.
B. Daily output checks of all photon and electron beams on a linac.
C. Annual verification of depth dose data and profiles for all photon and electron beams on a linac.
D. Monthly verification of photon beam symmetry.

T91. The protocol currently recommended by the AAPM for calibrating megavoltage therapy units is:

A. SCRAD.
B. The Nordic protocol.
C. TG-51.
D. ICRU Report 21.

T92. Calculation of the *primary barrier* thickness for a linac in a radiotherapy department requires all of the following factors **except:**

A. Workload.
B. Photon energy.
C. Wall material.
D. Recommended dose limit for staff on other side of wall.
E. Head leakage.

T93. Which of the following provides the greatest amount of shielding?

A. 7 half-value layers of concrete.
B. 6.0 cm lead for a beam with HVL 12 mm.
C. 2 tenth tenth-value layers of lead.
D. 1 TVL of lead and 1 TVL of concrete.

T94. A ^{60}Co source is stuck in the "on" position, delivering 100 cGy/min at the isocenter. The therapist enters the room to rescue the patient, and spends 1 minute at a distance of 1 meter from the isocenter (with the beam pointing towards the floor). The dose received by the therapist is approximately _____ times the recommended weekly dose limit.

A. 0.1
B. 1.0
C. 10
D. 100
E. 1000

T95. TLD ring badges are worn in addition to a whole-body film badge for brachytherapy procedures because:

A. The film badge cannot discriminate between different types and energies of radiation.
B. The recommended dose limit for the hands is higher than for the whole body, and requires a separate measurement.
C. The ring badge acts as a backup for the film badge in case the film badge is damaged during processing.
D. TLD is uniquely sensitive to the particles emitted from brachytherapy sources.
E. The skin of the hands has a lower recommended dose limit than the whole body.

T96. The radiation detector used to monitor a patient after removal of an ^{192}Ir seed implant must be:

1. Calibrated annually
2. Able to integrate dose
3. Capable of detecting background levels of radiation
4. A solid rather than a gas-filled detector

A. 1, 3
B. 2, 4
C. 1, 2, 3, 4
D. 4 only

T97. Which of the following is/are *always* required to have a state license in order to work in a radiotherapy department?

1. Attending physician
2. RSO
3. Therapist
4. Physicist

A. 1, 2
B. 1, 3
C. 1, 2, 3
D. 1, 2, 3, 4
E. 1 only

RADIOLOGICAL PHYSICS

Raphex 2004

EXAM ANSWERS

Published for:

RAMPS

(Radiological and Medical Physics Society of New York)

❖ Preface ❖

The RAPHEX 2004 Exam Answers book provides a short explanation of why each answer is correct, along with worked calculations where appropriate. An in-depth review of the exam with the physics instructor is encouraged.

In cases where more than one answer might be considered correct, the most appropriate answer is used. Although one exam cannot cover every topic in the syllabus, a review of RAPHEX exams/answers from three consecutive years should cover most topics.

We hope that residents will find these exams useful in reviewing their radiological physics course.

RAPHEX 2004 Committee

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G1. D 1 rem = 1 cSv = 10 mSv.

G2. C The *f* factor (roentgen-to-rad conversion factor) for muscle tissue ranges from 0.921 at 10 keV to 0.960 at 150 keV. 1 rad is equal to 10 mGy.

G3. D Exposure is equal to the total charge of ions of one sign produced in a unit mass of air. Units were formerly roentgen, R, and are now C/kg in the SI system.

G4. D 1 Gy = 1 J/kg.

G5. A 1 Bq = 1 disintegration/sec.

G6. C C/kg is the SI unit. 1R = 2.58×10^{-4} C/kg in air.

G7. B 1 Sv = 1 Gy × Q where Q is a quality factor which depends on the type and energy of the radiation, and its RBE.

G8. C This can be found from Einstein's equation: $E = mc^2$.

G9. A

G10. E

G11. D

G12. C

G13. E Isotopes of an element have the same Z (number of protons or electrons) but different numbers of neutrons and, hence, different A (mass number). Chemically, all isotopes of the same element are identical.

G14. C Tritium has one proton, two neutrons and one electron; hydrogen has one proton and one electron. Isotopes of an element have different numbers of neutrons, but the same numbers of protons and electrons, and hence are chemically identical.

General

❖ Answers ❖

G15. E 59, the mass number (A), is the number of protons (Z) plus the number of neutrons (N). 27 is the atomic number (Z). In an electrically neutral atom, this is equal to the number of electrons.

G16. B An atom is said to be ionized when an orbital electron is removed, leaving a net positive charge.

G17. D Radioactive decay to the ground state results in a more stable atom, and hence the binding energy per nucleon increases.

G18. A The number of electrons required to *fill* the nth shell of an atom is $2n^2$;. i.e., K = 2, L = 8, M = 18, etc. However, the order of shell and subshell filling is such that the maximum number of electrons in the *outer* shell can be no more than 8. Argon has 8 electrons in the M shell, and is thus inert. For potassium, the next electron must go into the N shell. Atoms with a single electron in the outer shell are very reactive.

G19. E After n half-lives, the fraction of initial activity remaining is $(1/2)^n$. It can also be expressed as $e^{-\lambda t}$, where $\lambda = 0.693/T_{1/2}$. Substituting $n \times T_{1/2}$ for t gives $e^{-0.693n}$.

G20. C 222 days is 3 half-lives. The source strength is $47.0 \times (0.5)^3 = 5.9$ mGy.m^2.h^{-1}.

G21. B $A_t = A_0 \exp(0.693 \times t/60)$, where t = 5.

G22. C $1/T_{eff} = [1/T_p + 1/T_b]$.

G23. A The energy available for particles emitted from an unstable nucleus is the difference between the masses of the initial nucleus and the daughter nucleus plus any emitted particles. This mass can be converted into units of energy using $E = mc^2$. The mass of a nucleus is less than the sum of its protons and neutrons by an amount called the mass defect, which is greatest for the most stable nuclei.

G24. A Positrons, like betas, have a spectrum of energies. Two 511 keV annihilation photons are emitted when the positron looses its kinetic energy and combines with an electron.

G25. D Positron emission and electron capture often compete as a decay process in the same radionuclide with an excess of protons. In electron capture, an electron, usually from the K shell, combines with a proton to form a neutron and an emitted neutrino. The K shell vacancy causes characteristic x-rays and auger electrons to be emitted.

G26. B In beta minus decay Z increases by one, but A remains the same.

G27. D An example is $^{226}Ra \rightarrow {}^{222}Rn$.

G28. A These are the only processes listed that create a vacancy in an electron shell.

G29. B The nucleus emits a gamma ray which can sometimes interact with the orbital electrons and emit an internal conversion electron. If this occurs, it can be followed by a characteristic x-ray, or an Auger electron.

G30. D Nuclei with excess protons decay by positron emission, whereas nuclei with an excess of neutrons decay by beta minus emission.

G31. A The addition of one neutron and the loss of an alpha particle (2 two neutrons, 2 two protons) means that there is one less neutron, and there are two less protons, i.e., three less nucleons. Thus A becomes 35 − 3 = 32, and Z becomes 17 − 2 = 15.

G32. B ^{18}F is a positron emitter used in PET. ^{137}Cs is a reactor fuel by-product, created by fission. ^{192}Ir is created by bombarding ^{191}Ir with neutrons in a reactor. ^{40}K is a naturally occurring isotope of potassium, present in the human body.

G33. E Examples are $^{59}Co + n = {}^{60}Co$; $^{191}Ir + n = {}^{192}Ir$. Both of these radionuclides emit betas and gammas, of which the gammas are used clinically in teletherapy and brachytherapy.

G34. B Secular equilibrium occurs when a long-lived parent decays to a short-lived daughter in a sealed container. After about 4 half-lives of the daughter equilibrium is established, and the parent and daughter appear to decay with the same half-life.

G35. E 1 Bq = 1 disintegration/second. 1 Ci = 3.7×10^{10} disintegrations/sec.
10 Ci = 37×10^{10} Bq = 370 GBq.

G36. E Amu stands for Atomic mass unit.

G37. D Exposure rate = (Exp rate const.) × A / r^2. = 3.3 R cm^2/mCi.hr × 163 mCi × $1/(300)^2$ cm^2 = 6×10^{-3} R/hr.

G38. C Exposure rate at 30 cm = Exposure rate at 1 m × $(100/30)^2$ = 1.75 × 11.11 = 19.4 R/hr with no shielding. 4 TVLs will reduce this by a factor of 10^4 to 1.9 mR/hr.

G39. B Electrons travel to the anode, or target.

G40. D X-ray production is a very inefficient process, and steps must be taken to dissipate the large amount of heat generated.

G41. B

G42. C

G43. D

G44. B Possible characteristic x-ray energies are found by taking the energy differences between electron shells. Bremsstrahlung ("braking radiation"), which is energy lost by the electron in the field of the nucleus, can have any energy up to that of the incident electron.

G45. C The maximum Bremsstrahlung energy in keV is equal to the maximum energy of the incident electrons, i.e., to the kVp applied across the tube.

G46. A The minimum photon energy depends on the filtration.

G47. A This is due to beam hardening as the beam passes through the first HVL.

G48. C

G49. D Decreasing filtration lets through more low energy photons, and decreases the effective energy of the beam. The mA and mAs have no effect on beam energy.

G50. D

G51. A

G52. B

G53. D $c = \lambda\nu$. Thus, $\nu = c/\lambda = 3 \times 10^8\ ms^{-1}/10^{-7}$ m.

G54. B $E = h\nu = hc/\lambda$, where h = Planck's constant.
Thus, $E = (4.14 \times 10^{-15}$ eV.s) $\times (3 \times 10^8\ m.s^{-1}) / 10^{-7}$ m = 12.4 eV.

G55. D By the inverse square law: $I_1/I_2 = (d_2/d_1)^2$. I_1 = 50 mR/hr, I_2 = 2 mR/hr, d_1 = 1 m.

G56. D

G57. A $I_x = I_0\ e^{-\mu x}$; $\mu = 0.1\ cm^{-1}$; x = 5.0 cm; $I_x = e^{-0.5} = 0.61$.

G58. B CT number = $1000 \times [(\mu_{material} - \mu_{water}) / \mu_{water}]$ where μ is the linear attenuation coefficient.

G59. C The Z^3 dependence of the photoelectric effect is responsible for the bone-tissue contrast in a diagnostic radiograph, along with the difference in density between tissue and bone.

G60. A The probability of the photoelectric effect per unit mass is proportional to Z^3.

G61. B The energy of the photon is totally absorbed by the electron, which uses 5.0 keV to overcome its binding energy, leaving 4.0 keV as the energy of the emitted photoelectron.

G62. D In a photoelectric interaction the incident photon is completely absorbed. A photoelectron is emitted, but the vacancy it leaves gives rise to a characteristic x-ray.

G63. D

G64. C The probability of a Compton interaction per unit mass is independent of Z, since it depends on the electron density, which is fairly constant for all materials except hydrogen.

G65. D The probability of Compton interactions decreases with increasing photon energy.

G66. B The Compton photon can be scattered at any angle, but the emitted electron is limited to 0°–90° with the direction of the incident photon.

G67. C The threshold for pair production is, as the name suggests, the energy required to create two electrons at rest, i.e., 2×0.51 MeV.

G68. A From the initial 6 MeV, 1.02 MeV is used to create a positron and an electron, and the remaining 4.98 MeV is divided between the particles as kinetic energy. After losing its kinetic energy, the positron will annihilate with an electron at rest, emitting two annihilation photons each of energy 0.51 MeV.

G69. C

G70. A

G71. B

G72. D

G73. D Compton is most probable between 25 keV and 25 MeV.

G74. A Betas travel about 0.5 cm per MeV in unit density material. In air, they will travel about 1/0.0013 or 800 times as far.

G75. B PET (Positron Emission Tomography) relies on coincidence counting of the annihilation photons that are emitted in opposite directions from the point where a positron and electron annihilate. The positron emitter is labeled to a substance that is taken up by, or metabolized by, the tissue to be imaged. ^{18}F can be tagged to materials that are metabolized by the body. For example, it can be used to observe activity in different areas of the brain.

G76. E Increased mass and charge, and slower velocity all contribute to a greater rate of energy loss.

G77. C The photoelectric interaction is a photon interaction with matter.

G78. D Neutrons are *indirectly* ionizing: their energy is given to charged particles, such as protons, which then directly ionize the atoms along their paths.

G79. C — Optical density is the logarithm of the incident intensity divided by the transmitted intensity. Optical density is therefore additive. Thus, 1.0 + 1.0 = 2.0 is the optical density of the sandwich, and $1/10^2$ or 0.01 of the incident light is transmitted.

G80. C — Grids tend to increase patient dose (for the same optical density on the film), but they intercept scatter generated by interactions in the patient, which would reduce contrast.

G81. B — Only ferromagnetic metals cause problems in the high magnetic field of the MR scanner. Differences in hydrogen content, not Z, are imaged by MRI. Plane film has much better resolution than CT or MRI.

G82. B

G83. B — The standard deviation $\sigma = N^{1/2} = 900^{1/2} = 30$.
68% of the measurements fall within $\pm\sigma$ of the mean, and 95% within $\pm 2\sigma$ of the mean.
$2\sigma = 60$. $900 \pm 2\sigma = 840 - 960$.

G84. E — 16 bits equals 2 bytes. $2 \times 512 \times 512 \times 200 = 104857600$ bytes = 100 MB.

G85. C

G86. A

G87. E

G88. D

G89. B — The average annual doses are as follows: (in mSv/yr)
Radon 2.0; Diagnostic 0.39; Nuclear Medicine 0.14; Natural background other than radon (cosmic, internal, fallout) 1.0.

G90. A — Cancer induction is probabilistic, i.e., there is a certain probability of inducing cancer from a dose of radiation, but the severity of the effect is not dose related.

G91. B — Skin reactions to radiation are an example of a deterministic, or non-stochastic effect: there is a threshold, and severity is dose related.

G92. C BEIR V (1990) states that the excess cancer deaths in a population of 100,000 persons exposed to 0.1 Sv would be about 770 males or 810 females.

G93. C The recommended whole body dose limit for radiation workers is 50 mSv/yr, or 1.0 mSv/wk.

G94. E The instantaneous dose *rate* is not a factor in barrier thickness calculations. However, the total dose in a week must be kept below the recommended limit for workers or the general public, depending on who will occupy the area.

G95. A B and C result in *lower* and *higher* charge collection, respectively. The temperature-pressure correction gives the reading which would have been measured with the chamber at standard temperature and pressure.

G96. A Although LiF thermoluminescent detectors have little energy dependence, film (which is widely used in personnel monitoring) has a greater response to low energy because of the high Z components in the emulsion. By using various filters over portions of the film, and comparing the developed film densities in each area, an estimate of doses in different energy ranges can be obtained.

G97. B If the packaging material reads background, it can be disposed of as regular trash, provided all radioactive warning labels have been removed or obliterated.

D1. E — A large anode angle (about 12 to 15 degrees) with large filament size x-ray tube provides large field coverage but increased geometric blur, hence spatial resolution degradation. It is necessary for general radiographic work. A small anode angle (about 7 to 9 degrees) is desirable for small field-of-view image receptors, such as in cineangiographic and neuroangiographic equipment, where field coverage is limited by the image intensifier diameter.

D2. A — The length of the effective focal spot varies with the position in the image plane in the anode-cathode direction. It shortens because of the line-focus principle toward the anode side of the field while it lengthens towards the cathode side. Less geometric blur will be seen for structures positioned towards the anode side of the field.
The effective focal spot size does not change appreciably with position in the width dimension of the field (perpendicular to the anode-cathode).

D3. C

D4. B

D5. D — In mammography, the screen is positioned in the back of the cassette so that x-rays travel through the cassette cover (front) and film before interacting with the phosphor. X-rays are more likely to interact near the phosphor surface closest to the film emulsion. This reduces the distance traveled by the light, minimizing its spread and thereby preserving spatial resolution. The grid is placed before the cassette to reduce scatter radiation reaching the film.

D6. B — Leakage radiation is radiation that escapes the tube housing during the exposure. It penetrates the tube lead shielding and has a high effective energy. Federal regulations limit the leakage radiation exposure rate to 100 mR/hour at one meter from the focal spot when the x-ray tube is operated at the maximum kVp and the highest possible continuous current (typically 3 to 5 mA at maximum kVp).

D7. D — Off-focus radiation results from electrons in the x-ray tube that strike the anode outside the focal spot area. These electrons create a low-intensity x-ray source over the face of the anode. Off-focus radiation increases patient exposure, geometric blurring and background fog. A small lead collimator placed near the tube output port can reduce off-focus radiation by intercepting x-rays that are produced at a large distance from the focal spot.

D8. C — kVp is kilovolt peak, a potential difference; keV is kilo electron volts, a unit of energy.

D9. A — The characteristic radiation is solely determined by the target material. If the energy of the electrons does not exceed the binding energy of the target electron, characteristic radiation will not be produced.

D10. E The filament current is typically around 2 to 10 Amps = 2000 to 10000 mA. The *tube current,* on the other hand, is around 1 to 5 mA for fluoroscopy and 200 to 1000 mA for radiography using short pulses.

D11. B Find the intersection of the kV and time requested. The maximum mA allowed can be determined by interpolation of the mA curves to either side of the point. If the requested mA is greater than the maximum allowable mA, the exposure cannot be achieved.

D12. A See D11.

D13. B See D11.

D14. A Screen film system A has higher contrast than system B, because it has a steeper slope. System A shows a reduced range of x-ray exposures that deliver the optical densities in the usable range. This means it has lower latitude than system B.

D15. A Because of its lower latitude, it is more difficult to achieve proper exposures with system A. These systems contribute to higher retake rates.

D16. B System B has wide latitude, which enables one to achieve adequate contrast of both mediastinum and lung fields.

D17. D While mammography requires high contrast screen/film systems because it is a single screen/ film system, it requires higher radiation exposure.

D18. D Films used for personnel monitoring do not employ screens. Both systems A and B have screens. The maximum exposures allowed by these systems (1.6 mR and 3.0 mR) are too low for personnel dosimetry.

D19. B A film-processor quality control program is required in radiography and mammography. The daily sensitometric strip, shown in the question, is obtained by exposing a film (taken from a box reserved for quality control) using a calibrated sensitometer with a light spectral output similar to the screen phosphor.
Steps 1–8 will show greater response to an increase in developer temperature.
Step 14 (high density) shows that almost all silver bromide grains were used and that an increase in temperature will not increase the density as much as for the lower density steps.
Step 21 shows very high density and is likely to appear in the shoulder part of this film's characteristic curve.

D20. C Mammography requires very high resolution with acceptable dose, i.e., one screen, one emulsion.

D21. A Chest radiography, the most frequently performed clinical exam, requires acceptable dose and long latitude to see the wide range of attenuating structures encompassed.

D22. E Flat panel digital radiography employs thin film transistor (TFT) arrays that convert light energy to an electric signal. The TFT is not very sensitive to x-rays, therefore, a scintillator such as CsI is used to convert x-ray energy to visible light, which then strikes the TFT detector.

D23. B In fluoroscopy virtually all modern image intensifiers use cesium iodide for the input phosphor. CsI has the unique property of forming long, needle-like crystals, which function as light pipes, channeling the visible light emitted within the crystals to the photocathode with minimal lateral spread. As a result, CsI can be quite thick, resulting in high absorption efficiency, while still maintaining high resolution.

D24. C Screen quantum detection efficiency is higher for thick screens, which contain more fluorescent material. Detail screens are thin screens associated with less light diffusion in the body of the screen, hence less blur and better resolution. Cesium iodide is an excellent scintillator used in fluoroscopy and digital radiography; however it is too sensitive to moisture to be used for screen-film radiography.

D25. E The grid ratio is equal to the strip height/width of interspacing (1.2 mm/0.12 mm = 10:1). Higher grid ratios have better scatter cleanup efficiency. For parallel grids the focal length is infinity. The interspacing between the grid strips is made of low atomic number material such as cardboard or carbon fiber. Grid ratios in mammography are 4:1 or 5:1.

D26. C

D27. E

D28. D

D29. B

D30. A

D31. E Wide-angle tomography produces thin sections, which have low contrast. This is because all the anatomy above and below the section in focus is blurred across the image with an effect similar to fog. The patient exposure is higher because most of the time the x-ray beam is passing through the patient at an angle, i.e., the patient is effectively thicker.

D32. B 0.5 mm Pb will reduce the x-ray intensity by 95% to 99%, depending on the kVp.

D33. D Changes in subject contrast are a function of variations in tissue and beam quality. Lower subject contrast is expected at increased beam energy (higher quality, less photoelectric effect), smaller tissue thickness, lower tissue density, and lower atomic number. Other film/screen and processor variations will affect radiographic contrast (overall image contrast) but not subject contrast.

D34. B kVp is commonly lowered to reduce the dose in pediatric patients.

D35. C Switch from 256 to 512 acquisition matrix.
This change will reduce the pixel size by a factor of two in each of the two in-plane dimensions.

D36. D Switch from 5 mm to 2.5 mm acquisition slice thickness.
Each voxel will now be half as large in the z-dimension, thereby reducing partial volume effects.

D37. A Raise tube current from 100 to 300 mA.
Tripling the mA will triple the number of detected photons. The reduction in table speed will increase the detected photons by a factor of two. Going to a larger matrix (smaller pixel) will increase noise.

D38. E Decrease table speed from 30 mm/rotation to 15 mm/rotation for the original 5 mm slice acquisition. The pitch for a 4-slice machine is defined as table speed in millimeter per rotation divided by 4 times the acquired slice thickness. The pitch is initially $30/(4 \times 5) = 1.5$. If the table speed is reduced to 15 mm/rotation, the pitch will be $15/(4 \times 5) = 0.75$, whereas if the acquired slice thickness is reduced to 2.5 mm, the pitch will be $30/(4 \times 2.5) = 3.0$.

D39. E All of the above are true. Exposures of 20 to 50 mGy at the body surface are typical for conventional thoracic CT. Multislice CT of the heart for calcium scoring can deliver up to five times the typical thoracic CT levels because multiple exposures are required to gather data during different periods of the cardiac cycle. Dose rates for typical CT angiography at 20 to 40 mGy are in the same range as the typical thoracic CT. When using electron beam CT for cardiac calcium scoring the breast dose is substantially lower than that from typical thoracic CT because the x-ray beam originates behind the patient.

D40. E All of the above are true. The typical surface dose from an adult abdominal CT scan using multiple adjacent CT slices is in the range of 20 to 50 mGy.

D41. A Contrast resolution is the ability of an imaging system to reveal small differences in the transmission of an x-ray beam. Modern CT units can see contrast differences as little as 0.3%. Screen-film systems can see differences of about 5%.

D42. D Increasing kVp or slice width will decrease noise because of higher voxel dose. The smoothing algorithm will decrease noise. A lower mAs increases noise.

D43. C 11 lp/mm.
With a bar line-pair pattern on a 4.5 cm high phantom, the high contrast spatial resolution produced by a mammography unit should be at least 11 lp/mm with the bars perpendicular to the anode-cathode axis and 13 lp/mm with the bars parallel to the anode-cathode axis.

D44. D Current commercial full field mammography units have image receptors which are capable of resolving 5 to 7 lp/mm, whereas screen-film receptors designed for mammography can often resolve 15 to 20 lp/mm.

D45. A Geometric blur increases with magnification, so resolution is lowest at highest magnification, i.e., top of thickest breast.

D46. E A, B, C, D are recommendations of the ACR accreditation program. B and C are MQSA requirements.

D47. B For the x-ray unit settings normally used, the OD for 2, 4, and 6 cm phantoms must be within ±0.15 OD of the average of the three. This became effective October 28, 2002.

D48. B The primary reason for single-screen, single emulsion systems is to reduce blur from crossover and halation. It will result in increased patient dose.

D49. D Increases in kVp, mAs have little effect on image contrast in DR/CR, as the DR/CR system rescales the contrast according to the processing algorithm used. Most DR/CR systems allow the technologist to adjust the brightness and contrast (or window/level) and/or change the processing algorithm before sending the image to a dedicated display workstation or a PACS system. In general, exposures should not be repeated in DR/CR because of brightness or contrast concerns.

D50. B DR/CR systems cannot compensate for excessive noise due to quantum mottle, i.e., dose too low. If unacceptable, the view needs to be repeated with a higher exposure to the image receptor (and to the patient).

D51. B For a full size, 35 × 43 cm field, most DR/CR systems have a resolution of 2.5 to 4 lp/mm, lower than traditional screen/film systems. A 150 micrometer aperture should be able to resolve 0.15 mm objects. This is equivalent to 1/(2 × 0.15) lp/mm or about 3 lp/mm.

D52. A Radiologists are used to the noise of 400 speed systems, but at 1200 speed the images will probably be unacceptably noisy. Speed (sensitivity) is defined in the same way for DR as for screen-film. Spatial resolution is independent of speed for digital imaging systems.

D53. E Overexposed images are generally very good in DR/CR because they will be low in noise. The system will rescale the brightness and contrast so they will appear properly exposed.

D54. C The quality factor (QF), nowadays also known as the radiation-weighting factor (w_r), reflects differences between different types of radiation in producing biological damage, as does the relative biological effectiveness (RBE). The quality factor is essentially a “typical” value of the RBE assigned to a particular radiation. While less rigorous radiobiologically than the RBE, the use of the QF is in principle straightforward—multiply the absorbed dose by the quality factor to calculate the corresponding dose equivalent.

D55. D The relative biological effectiveness (RBE) quantitatively expresses differences between different types of radiation in producing biological effects. The RBE of a “test” radiation is defined as the ratio of the absorbed dose of a “standard” low-LET radiation such as ^{60}Co γ-rays or 250-kVp x-rays to produce a specific biological effect under specific conditions to that of the test radiation to produce the same effect under the same conditions. In this question, the effect is killing 50% of HeLa cells in culture and therefore the RBE = 3 Gy/0.3 Gy, = 10.

D56. A Because cells and tissues are comprised mostly (80% to 90%) of water, most of the interactions of radiation will be with water molecules and produce water ions and then water free radicals. Such highly reactive free radicals (electrically neutral atoms or molecules having an unpaired electron) may ultimately react with and chemically alter DNA and thus precipitate the cascade of molecular events, which are ultimately manifested as cellular radiation damage.

D57. B For most (though not all) tissues of the body, acute non-stochastic (deterministic) effects of radiation (which are distinct from long-term, low-dose stochastic effects such as carcinogenesis) do not appear below dose equivalents of at least one Sievert (100 rem).

D58. D As tabulated and published by such authoritative groups as the Biological Effects of Ionizing Radiation (BEIR) Committee and the National Council on Radiation Protection and Measurements (NCRP), the current "best" estimate of the *average* background radiation (naturally occurring and artificial) in the United States is approximately 3.5 mSv/year, (350 mrem/year).

D59. A Historically, the Nuclear Regulatory Commission (NRC) and Agreement States required patients receiving radionuclide therapy to remain hospitalized until the retained activity in the patient was less than 1110 MBq (30 mCi) or the dose rate at 1 m from the patient was less than 0.05 mSv/hr (5 mrem/hr). The new NRC regulations, revised 10CFR 35.75 effective May 1997, allow for the release from medical confinement of patients if the expected total effective dose equivalent (TEDE) to individuals exposed to the patient is not likely to exceed 0.5 rem (500 mrem). Compliance with this dose limit may be demonstrated using either (a) a default table in Regulatory Guide 8.39 for activity (e.g., less than 33 mCi of iodine-131 retained by the patient) or dose rate (e.g., less than 7 mrem/hr at 1 m from an ^{131}I-containing patient) or (b) patient-specific kinetic data using effective half-times or residence times, dose rate measurements and a patient-specific projected dose calculation.

D60. E As tabulated and published by the Report of Biological Effects of Ionizing Radiation (BEIR) Committee ("BEIR V") in 1990 and based on the linear, no-threshold dose-response model, current "best" estimate (BEIR V value) for the <u>lifetime risk</u> factor for radiogenic fatal cancer is approximately 800 excess cancers/million people/rem, rounded off to 1000 excess cancers/million people/rem, or 100,000 excess cancers/million people/Sievert.

D61. B A constant dose rate is needed at the image intensifier at any SID. Increasing the SID requires an increased output from the X-ray tube. Using the inverse square law, the ratio is $(120/90)^2 \approx 1.8$.

D62. A Decreasing the FOV decreases the geometric light amplification factor of the image intensifier. More radiation is therefore needed to produce the required output light level. Also, less scatter is produced (and reaches the image intensifier) when the beam is collimated. A small increase in EAKr is needed to offset this effect.

D63. D For a smaller number of detected photons/mm^2 the contrast-diameter curve for detectable objects moves away from the origin. The most significant effect is the inability to detect small objects with low contrast.

D64. B The 6 in. mode must have the higher resolution. The ratio of brightness gains equals the ratio of the magnification gains, which is the ratio of the input areas; $(6 \times 6)/(9 \times 9) = 1:2.25$

D65. D The focal spots for fluoroscopy are typically 0.3 or 0.6 mm; those for standard radiography are usually 1.0 to 1.2 mm. The spatial resolution for fluoroscopy is usually limited by the TV system to 1.8 to 2.5 lp/mm, while radiography has resolutions of 4 to 8 lp/mm. The tube current for fluoroscopy is usually 1 to 3 mA in order to limit anode heating for the long exposure times of 3 to 10 minutes; because of the short exposure times (less than 1 second) of radiography, tube currents of 200 to 800 mA can be used. Tube potentials are the same for both procedures. SSDs in fluoroscopy are usually 18 to 20 inches, while the SSDs for radiographs are typically about 25 inches (except for chest radiographs).

D66. C ^{18}F is produced by bombarding an ^{18}O target with a proton beam in a cyclotron.

D67. E A liquid scintillation counter, in which the sample is dissolved in a liquid scintillant is the only accurate method. The other methods are inaccurate, because the activity determination of a pure beta source is extremely position and geometry sensitive.

D68. A Photons, which impinge upon the crystal, lose energy by Compton scattering and the photoelectric effect. Both processes convert the gamma-ray energy into electron energy. On average, approximately one electron-hole pair is produced per 30 eV of gamma-ray energy deposited in the crystal. These electrons result in the release of visible light when trapped in the crystal. These light quanta are collected and amplified by photomultiplier tubes. The statistical fluctuation in the number of light quanta collected and their amplification is what causes the spread in the detected energy peak, even when most of the ^{99m}Tc photons deposit exactly 140 keV in the NaI crystal.

D69. B A second peak is seen at twice the energy of the main peak. Pulse pile-up occurs when two photons impinge upon the detector at the same time, resulting in an event being recorded as if it had twice the energy of the initial photon.

D70. D A 95% confidence interval means the counts must fall within two standard deviations (SD) of the mean (N).
Error limit = 1% = 2 SD/N, but SD = $N^{1/2}$.
Thus, 0.01 = $2(N^{1/2})/N = 2/N^{1/2}$.

D71. E The septa reduce a large fraction of the cross-plane coincidences, in order to reduce coincidence events from scattered photons. Both 2-D and 3-D scans acquire all axial slice data simultaneously, and can reformat the data to display sagittal or coronal images.

D72. B

D73. E

D74. D

D75. C

D76. A

D77. E The wrong collimator would increase septal penetration and increase or decrease camera sensitivity, but could not produce a cold spot in the image.

D78. B The standard deviation $\sigma = \sqrt{N}$ where N is the average number of counts per pixel. The minimum detectable count difference would occur when the counts are highest, i.e., 256. $2\sigma = 2\sqrt{256} = 32$.
Expressed as a % percent of 256 this is 32/256 × 100% = 12.5%. According to Poisson statistics, a pixel with a number of counts that differs by more than 12.5% from the average occurs less than 5% of the time.

D79. C The emission scan provides an image of the distribution of radioactivity within the patient. The intensity of the emission image depends upon the point-to-point thickness of the patient. For this reason a transmission image is performed with an external 511 keV ^{68}Ge transmission source (or alternatively a ^{137}Cs source or CT unit), so as to measure the attenuation profile of the patient (with couch). Answer A refers to the daily quality assurance procedure, which is performed without a patient or couch in the field-of-view. Although the thickness of the patient may affect the duration of the emission scan, it would not, ordinarily, be used to determine the amount of activity to be administered to the patient. Although the transmission scan does correct for attenuation in the couch, the main source of photon attenuation is the patient.

D80. D The remaining activity for any of the sources is 30 mCi multiplied by $(1/2)^n$, where n = number of half-lives in one year. To be discarded, the source activity should reach background level. For ^{57}Co, which has a half-life of about 273 days, the source activity after one year is still too high to be discarded. For all other sources in the list the remaining activity would be negligible after one year taking into consideration the half lives for these sources; ^{201}Tl is about 3 days, ^{99m}Tc is 6 hours, ^{18}F is 110 minutes, ^{123}I is 13 hours.

D81. B Collimation is necessary in all procedures except in PET.

D82. B The total MTF is the product of the individual MTF values: 0.8 × 0.7 × 0.5 = 0.28.

D83. B Air is a strong attenuator of ultrasound, particularly in alveolar structures.

D84. B The ratio of I_1 to I_2 is 2, Relative intensity of the pulse to the echo dB = 10 log $I_1/I_2 = 10 \times \log 2 = 10 \times 0.3 = 3$.

D85. A Continuous and pulsed Doppler are both available. Meaningful information is displayed by moving *and* non-moving interfaces (e.g., normal vasculature versus clot).

D86. C Duplex ultrasound refers to the simultaneous acquisition of dynamic *B scan* grayscale information and Doppler information within a predetermined "gate".

D87. D This is the definition of reverberation.

D88. D Similar to resonance frequency (conventional) transducers, multifrequency transducers (also known as non-resonance or broad-bandwidth transducers) use PZT as a transducer material. Multifrequency transducers operate with a range of frequencies around the central frequency (±40% or 80% range). With a ±40% range the operational sensitivity of a 5-MHz frequency transducer is 3 to 7 MHz. Because harmonic imaging requires receivers capable of receiving multifrequency values, non-resonance transducers are suitable for this application.

D89. B Harmonic frequencies, which are integral multiples of the transducer fundamental frequency, are generated in tissue near mid field along the beam. They are caused by wave distortion. No harmonics are generated in the near field because the wave has not traveled far enough to distort. With increased depth far field harmonics will be attenuated faster than they are being generated. Because they originate from reflecting boundaries, harmonics travel half the distance traveled by the fundamental pulse and would have a stronger signal from deeper structures. Harmonics appear closer to the center of the returning beam with minimal side lobes, hence improved lateral resolution and better gray-scale contrast.

D90. A Calcium, because of its paired nuclear spins, exhibits a diamagnetic property that has the effect of diminishing the local magnetic field. Paramagnetic agents, such as methemoglobin, augment the local magnetic field. In certain situations, these properties offset, and the image does not exhibit the expected appearance of a hemorrhage.

D91. B The lattice is the environment in which the spins exist.

D92. C This range of TE (relatively long) and TR (long) results in T_2 weighting.

D93. E Gadolinium, a paramagnetic agent, will cause a decrease in the T_2 time because of magnetic inhomogeneities causing a more rapid phase dispersion of the transverse magnetization. It also interacts with the lattice of the tissues, causing a decrease in the T_1 time; thus, the answer E.

D94. C The phase encode gradient is applied with varying strengths throughout the acquisition; algorithms assume no motion. Since even a slight motion will cause a substantial amount of phase shift, most of the motion artifacts are manifested in the phase encode gradient direction.

D95. C The voxel volume is doubled, therefore related to volume differences, $SNR_2 = 2\ SNR_1$ (SNR is directly proportional to voxel volume). However, the *total* number of excitations is *decreased* by a factor of 4 (from 2 NEX to 1 NEX is 2X, and 256 excitations to 128 excitations (phase encoding) is 2x); therefore, related to the #excitations, $SNR_2 = 1/2\ SNR_1$ (the SNR is directly proportional to the square root of the number of excitations). The overall relative SNR of the images is therefore equal because of offsetting variables.

Therapy
❖ Answers ❖

T1. C

T2. A

T3. B

T4. D — The equivalent square of 14 × 8, using 4A/P, is 10.2; use 10.
MU = [dose/fx]/[(cGy/MU at SSD) × TF × (PDD/100)]
= 200 / (1.0 × 0.96 × 0.958) = 217 MU.

T5. D — Equ sq = 10.3. MU = dose/[(SAD output) × TF × TMR]
= 200/(1.032 × 0.96 × 0.984) = 205 MU.

T6. C — Dose at d1/Dose at d2 = PDD1/PDD2. Dose at d_{max} = 200 × (100/95.8) = 209 cGy.

T7. B — For an isocentric setup:
Dose at d2/Dose at d1 = [TMR(d2)/TMR(d1)] × $(dist1/dist2)^2$
Dose at d10/200 = (0.784/0.984) × $(100/107)^2$
Dose at d10 = 139 cGy.

T8. A — Equivalent square of 13 × 17.5 = 15.
MU = [dose/fx]/[(cGy/MU at SAD) × TMR]
= 90/(1.071 × 0.804) = 105 MU.

T9. C — The maximum dose occurs at d_{max}. The only reasonable answer for this energy and separation is 106% of the midplane dose. To calculate the exact value, use the formula:

Dose at depth2 = Dose at depth1 × [TMR(d2)/TMR(d1)] × $[dist\ 1/dist2]^2$
Entrance dose = 90 × (1.0/0.804) × $(100/91.6)^2$ = 133.4 cGy.
Exit dose = 90 × (0.597/0.804) × $(100/108.4)^2$ = 56.9 cGy.
Total dose at d_{max} = 190.3 cGy = 1.057 × 180 cGy.

T10. B — At lower energy, the total dose at d_{max} will increase, as a percent of the dose at the isocenter.

T11. D — Percent depth dose is a combination of two factors: patient attenuation (which is independent of distance but varies with depth) and inverse square fall-off between d_{max} and depth. The longer the SSD, the smaller the inverse square factor. Thus PDD increases with increasing SSD.

T12. A Scatter from the corners of the rectangle has farther to travel to the field center than scatter from the periphery of the square and will contribute less to the depth dose.

T13. D Wedge angle = 90° − (Hinge angle/2) = 90° − 30° = 60°.
This holds if the surface is perpendicular to the beam axis; in practice, the wedge angle may also have to compensate for an air gap.

T14. E With a dynamic wedge the wedge factor (measured on the beam axis) is a function of both the starting and ending moving jaw position, i.e., both field width and offset.

T15. C The standard definition of the wedge transmission factor (WTF) is: (dose with wedge / dose without wedge) measured at the same point on the beam axis.
MU with wedge = MU open / WTF. [Note that off-axis wedge factors can also be defined, for use with half-blocked or asymmetric wedged fields, and may be required for hand calculations.]

T16. A In this case, the wedges are used as missing tissue compensators. For parallel-opposed fields, the most homogeneous distribution is achieved when the wedge turns the isodose lines so that they are perpendicular to the beam axis. The optimal wedge angle can be found by viewing the isodoses from each beam individually.

T17. C All the other wedges are reversed.

T18. A If only high-energy photons are available and superficial structures would be underdosed, spoilers may be used. The ideal is to maintain a low skin dose and increase dose in the build-up region, to emulate a lower energy beam. However, while it is impossible to exactly mimic a lower energy beam with a spoiler, the build-up characteristics may be preferable to using bolus, which could result in too high a skin dose.

T19. D Full rotation will treat an oval-shaped volume, but one that is longer in the AP aspect, and thus does not conform well to the PTV shown. (Two lateral arcs would conform better to this shape.) Also, while the 4-field plan could use different field shaping for each pair of fields, in the rotating plan any field shaping will not conform optimally at all angles.

T20. D As field size increases, skin dose increases.

T21. B

T22. A — Lower energy electrons have more skin sparing than higher energy electrons. This is the opposite of the case with photons.

T23. A — Answer D will match the dose on the skin, but create a cold triangle at depth.

T24. C — gap = (1/2)[coll1 + coll2] × (match depth/SAD) = 0.5 × 53 × 6/100 = 1.6 cm.

T25. D — The angle required to rotate the brain fields so that their inferior edge matches the divergence of the upper border of the spine field is: $\tan^{-1}$ [(36/2)/100] = 10°.

T26. C — For parallel-opposed fields the higher the photon energy, the more homogeneous the dose profile below d_{max}, and the lower the skin dose. A possible disadvantage is that d_{max} is deeper, so tissue in the build-up region can be underdosed. If tissue between the surface and d_{max} needs to be treated, the actual dose profile should be examined. The depth at which 95% of the midplane dose occurs, for parallel-opposed fields, is generally much less than the depth of d_{max}, but this depends on field size and separation, and should be calculated for each case.

T27. A — Penumbra is sharper for lower energy photons (except for ^{60}Co, because of the large source diameter).

T28. D — There is 1 cm less attenuation in each beam, so the dose is increased by approx. 3%.

T29. C — Flattening filters cannot flatten the beam equally at all depths, and tend to over-flatten at d_{max}, and under-flatten at d20.

T30. C — See answer to T26 above.

T31. E — Due to the inverse square law, the dose is $(100/98.8)^2$ = 1.024 times that intended.

T32. E — The mA has no effect on energy or depth dose, only on dose rate.

T33. D — For A–C the opposite is true.

T34. E — Although the isocenter of a plan can be related to internal structures, it must also be related to reproducible surface landmarks (preferably triangulation points) in order to position the patient correctly for treatment.

T35. B The Hounsfield number is $1000 \times [(\mu_{tissue} - \mu_{water}) / \mu_{water}]$ where μ refers to the linear attenuation coefficient of the material *at the CT beam quality.* Thus, the Hounsfield number for water is 0. Materials with negative Hounsfield numbers have linear attenuation coefficients less than water, and those with positive Hounsfield numbers have linear attenuation coefficients greater than water.

T36. A Tattoos on skin overlying the skull are likely to be reproducible, unless edema is present. The prostate is subject to movement due to bladder and rectal filling, and can therefore move with respect to skin marks. Breathing may cause lung lesions to move with time, and gating can be used to synchronize treatment with part of the breathing cycle. In breast treatment, tattoos—especially those at the lateral aspect—can move with arm position.

T37. A In a lower energy beam, the attenuation per centimeter is greater, so the difference between soft tissue and lung will be greatest. The corrections for bone and lung are approximately the same, per centimeter, but in opposite directions. The path length in lung is generally greater than in dense bone, so lung corrections usually have the greatest impact.

T38. C Five HVLs is equivalent to 3% transmission. The additional dose is due to scatter from the surrounding tissue.

T39. D In megavoltage photon beams, the fraction of dose at a point which is due to scatter is greatest for the lowest energy and greatest depth. Since scatter is removed by secondary blocking, the greatest effect on the MU setting will therefore be seen for low energy and large depths.

T40. D By similar triangle geometry: 3.5 cm at 140 is equivalent to $3.5 \times (65/140) = 1.6$ cm at 65, and $3.5 \times (100/140) = 2.5$ cm at 100.

T41. C By similar triangle geometry: SSD2/SSD1 = FS2/FS1.
SSD2/100 = 56/40.

T42. A By similar triangle geometry: FS on skin at 70 = FS at $80 \times (70/80) = 13.1$ cm.

T43. B Each field contributes about 2.5% of the prescribed dose: the lateral field contributes internal scatter, and the medial field contributes dose from the physical wedge. If a dynamic wedge is used, this will reduce the contralateral breast dose by almost one half.

T44. C The relative amounts of the dose contributions listed vary with distance from the field edge, and somewhat with field size, energy, and depth. Photons below 10 MeV should be used if possible, to reduce the neutron dose. See AAPM Report 50: Fetal Dose from Radiotherapy with Photon Beams.

T45. B Using the inverse square law, the MU will be: $100 \times (400/100)^2 = 1600$ MU.

T46. D As SAD increases, PDD increases, thus increasing dose homogeneity for parallel-opposed fields.

T47. C Accuracy should be better than conventional RT, due to the small size of the volume treated. Head frames improve registration between imaging scans, treatment planning, and treatment delivery.

T48. C Stereotactic radiosurgery, with either a linac or a gamma knife, is designed to treat small, accurately localized volumes while spreading out the entrance and exit doses over a large volume, and thus reducing the normal tissue dose. For volumes larger than 2 cm, multiple "shots" can be used, but for volumes larger than 3 cm, the number of shots required makes the normal tissue dose too great. A 5 cm GBM is better treated with conventional RT.

T49. D Cut blocks can be made to fit any desired shape, and have edges which diverge to match beam divergence, whereas MLCs give a stepped edge. Dosimetrically, the stepping is most marked at the 50% isodose level, and smoother at the 90% level. Also, if daily setup variation is taken into account, the stepping effect may become blurred to some extent.

T50. C While the GTV and CTV may aid the physician in determining the PTV (e.g., if the PTV has a fixed margin around the GTV), only the PTV is *required* for generating a treatment plan. The maximum and minimum doses in the PTV, as well as doses to critical organs, are generally the criteria used for choosing between plans.

T51. D If the PTV really extends to the skin, a lower energy, and possibly bolus, would be needed to give adequate coverage. For a DVH to be meaningful, the PTV needs to be carefully drawn to include only the tissue that needs to be treated to full dose. A PTV drawn up to the skin will always include a lower dose region of build-up, the size of which will increase with increasing photon energy.

T52. B IMRT plans can require 3 to 5 times the MU for a conventional plan, so the neutron leakage dose is a consideration. At 18 MV, the neutron leakage is 0.15%, versus 0.04% at 10 MV. However, a higher photon energy will deliver less dose to normal tissue outside the PTV. 10 MV is therefore a good compromise: a good dose distribution and a low neutron dose.

T53. E Currently, a disadvantage of IMRT is the complexity of, and time taken to perform, verification of dose calculation and delivery.

T54. C In inverse planning for IMRT, each beam is divided into "beamlets." The algorithm weights each beamlet to optimize the dose distribution consistent with the specified dose constraints to the volumes of interest.

T55. D Although CT images are required for heterogeneity corrections, these are not necessary for partial brain plans, since the thickness of dense bone in the skull makes very little difference to the effective depth of the photon beams.

T56. E Various radiotracers can be used with PET to image different biochemical processes. For example, FDG is metabolized by lung mets, and can be used to detect lung mets that might not be seen on CT, or to verify that a mass seen on CT is tumor. Thus PET can increase—or sometimes decrease—the target volume. However, even with the improvement in anatomical registration offered by a combined PET/CT unit, breathing can cause misregistration. Gating can improve registration, by matching PET and CT images from the same part of the breathing cycle, and thus can potentially reduce the size of the PTV.

T57. C Increasing mAs will make the film darker, but have no effect on contrast. Contrast is improved by reducing scatter. Reducing the collimator setting to the minimum necessary field of view usually has the greatest effect. If different grids are available, the one with the greatest grid ratio will "clean up" the most scatter. If these two techniques still don't work, for patients with very large lateral separations one solution is to take orthogonal R and L ant obliques, making use of the somewhat reduced separation.

T58. D Monoenergetic protons exhibit a depth dose curve with a narrow Bragg peak—a high rate of energy loss near the end of their range. This peak is too narrow to cover most tumors, so a range of energies are used to "scan" the Bragg peaks across the treatment volume. This increases the entrance dose somewhat, but maintains a sharp depth dose fall-off just beyond the treated volume, while still keeping a lower entrance dose than that obtained for photons.

T59. B As a rule of thumb, the depth of the 90% isodose is about E/3 cm.

T60. D This is important when (a) ensuring adequate coverage of the tumor volume with the 90% isodose curve at depth, (b) avoiding adjacent structures with the penumbra, and (c) abutting electron and x-ray fields.

T61. D When electrons interact with high Z components in the head of the linac, bremsstrahlung and a smaller number of characteristic x-rays are produced. This bremsstrahlung "tail" increases with increasing energy, but is usually between 2% and 5%.

T62. D For electrons, output can be corrected by the inverse square law only when the *virtual* SSD (generally not 100 cm) is used in the equation. For very small inserts, it is best to measure the output for the actual cut-out and SSD to be used.

T63. B MU = dose per fraction / [output × (PDD/100)] = 200/[1.02 × 0.95] = 206.

T64. D The chest wall is at a depth of 1.7 cm (1.2 + 0.5 cm bolus). If the lung were unit density, the 50% line would be at a total depth of 2.3 cm or 0.6 cm depth in lung. However, the lung has a density of 0.33 times that of soft tissue, so the isodoses beyond the chest wall are at increased depth. A good approximation is to scale the depth of the isodose in lung by 1/electron density, in this case 0.6/0.33 = 1.8 cm. (This is approximate, as it does not take into account the different scattering properties of the two media). Lung corrections should always be considered when choosing between a single direct electron beam and tangents to treat the chest wall.

T65. C A_t / A_0 = 0.420/0.455 = exp–(0.693 × t/60). This gives t=7 days.
[As a good approximation: the daily decay is exp–(.693/60), or about 1%.
0.420/0.455 = 0.922, so 7%=7 days is the best answer.]

T66. D Units of Ci and Bq are related to the number of disintegrations/second of the source. Air Kerma Rate (AKR) has units of dose rate. The recommended units of Air Kerma Strength are $\mu Gy m^2 h^{-1}$, but this can be converted to $cGy\ m^2 h^{-1}$, i.e., cGy/hr at 1 m.

T67. C The exposure rate constant is different for each radionuclide, and is the exposure rate for a given activity at a given distance, usually per mCi at 1 cm, or per Ci at 1 m.
One "mg Ra equivalent" is the quantity of a radionuclide which has the same exposure at 1 cm as 1 mg of radium.

T68. D This can be calculated roughly using the inverse square law: $(2/2.2)^2 = 0.83$, i.e., 17%. If all sources were 2.0 cm from point A, this would be the exact answer; however, since most sources are further away, the answer is about 10%.

T69. C Exposure rate = $\Gamma . A/r^2$. = 4.6(R cm^2/mCi-hr) × 20 mCi /$(250)^2$ cm^2 = 0.00147 R/hr.

T70. A 51 days is 3 half-lives, so the activity has decayed to $(1/2)^3 = 0.125$ times the initial value. The fraction of the total dose delivered is (1.0 − 0.125) = 0.875.

T71. D The ovoid *closest to the x-ray tube* will project larger on the film. However, this is a very small effect, typically a difference of about 1 mm, and may not be helpful in determining which ovoid is which.

T72. A The Patterson-Parker system is a set of rules which, if followed, delivers an even dose (within prescribed limits) to a plane at a given "treating distance" from the implant. It requires a higher activity (mCi/cm) at the periphery than in the center, to counteract the inverse square effect. For implants with equal activity per seed, the rules do not apply.

T73. D The Transport Index (TI), which is the maximum dose rate at 1 m, must be stated on the label, along with the radionuclide and its activity; the surface dose rate is not required on the label.

T74. B Sources that are not in use, but which are in storage, do not have to be leak tested every 6 months.

T75. B Standard lead aprons, as used in diagnostic x-ray departments, contain about 0.5 mm lead. While this may reduce diagnostic x-rays by about 95%, it is much less effective as photon energy increases. The HVLs in lead are as follows: ^{137}Cs (660 keV): 5.5 mm. ^{192}Ir (380 keV avg): 2.5 mm. ^{125}I (28 keV avg): 0.025 mm.

T76. E Half-life = 74 days.

T77. B Palladium-103 is used for prostate seed implants.

T78. A Because of the inverse square law, the depth dose at a given depth from the surface of an applicator increases as the diameter of the applicator increases. For this reason, and also to deliver an even dose to the mucosal surface, the largest diameter appropriate for the patient is generally used.

T79. C Rectal markers can sometimes give a lower dose if they are not positioned at the anterior rectal wall. The ICRU point is asumed to be the highest dose to the rectum.

T80. A The treatment time increases by the inverse of the source decay. Decay time = 14 days. Half-life = 74 days. Time = 282 sec × exp (0.693 × 14/74) = 322 sec.

T81. A A point at a radius of 1 cm near the center of the source array is closer to more sources than a point at the same radius near the end of the array. For this reason the ends of the array are weighted up to compensate for this effect.

T82. D The dose gradient across a vessel is important. A clinically acceptable dose to the adventitia cannot be associated with a damaging dose to the innermost lumen. Similarly, the dose to the innermost lumen must not be above or below the therapeutic range. The therapeutic dose pattern should be reasonably symmetrical along the length of the irradiated area, and should extend proximally and distally beyond the balloon-injured area, to avoid a "candy wrapper" effect (i.e., restenosis at the margins). The rate of dose delivery, typically 2 or 3 minutes for beta sources, 20 minutes for gamma sources, is not a critical factor in the success of IVBT.

T83. D Because the inverse square law causes a rapid fall-off of dose rate near a source, normal tissues around a brachytherapy implant can generally be spared to a greater extent than with an external beam that traverses normal tissue before reaching the tumor.

T84. C The target is used only in the photon mode.

T85. C When the linac is calibrated, 1 MU is adjusted to be equivalent to a specific absorbed dose at a reference point, e.g., 1 cGy at the isocenter, at depth d_{max} for a 10×10 cm field. The monitor chamber monitors the beam during treatment, by collecting charge as the beam passes through the chamber. Thus, variations in absolute dose rate do not affect the dose delivered. Symmetrical segments of the chamber are also used to monitor beam symmetry during treatment.

T86. A The accelerator tube is generaly mounted parallel to the floor, and the bending magnet bends the beam of electrons exiting from the accelerator through 90° or (270°) to point at the isocenter.

T87. C Hydrogenous materials (e.g., concrete, polyethylene) and boron are effective neutron moderators.

T88. D Most neutrons are generated by interactions between high-energy photons and high Z components in the head of the linac.

T89. B Dose rate increases proportionately with mA. The other factors will all reduce the dose rate.

T90. B Photon beams should be checked daily, and electrons at least twice a week.

T91. C This is the report No. 67 of AAPM Task Group 51, published in 1999 (Protocol for Clinical Reference Dosimetry of High-Energy Photon and Electron Beams).

T92. E If the barrier is thick enough for the primary beam, it is more than adequate to attenuate head leakage when the beam is pointing away from the barrier, since head leakage is less than 0.1% of the useful beam. Secondary barriers, however, should take leakage into account.

T93. A 7 HVLs attenuate by a factor of $1/2^7 = 0.008$. B is only 5 HVLs. C and D are the same: 2 TVLs will reduce intensity by a factor of 1/100 regardless of the attenuating material.

T94. B The dose rate at a distance of 1 m lateral to the beam direction, scattered from the patient, is about $1/1000^{th}$ of the dose rate at the isocenter, or about 100 mrem/min. The recommended whole body dose limit is 5 rem/yr (50 mSv/yr), or 100 mrem/wk (1 mSv/wk).

T95. B The hands usually receive a higher dose than the trunk in brachytherapy procedures and should be monitored separately. The recommended dose limit for the hands is 500 mSv per year (10 times the whole body limit), according to NCRP Report #116, Limitation of Exposure to Ionizing Radiation (1993).

T96. A The detector will measure background if all the seeds have been removed. Measurement of dose rate, not integrated dose, is required in this case.

T97. E Most, but not all, states require therapists to be licensed. Few states require medical physicists to be licensed. Attending physicians must be licensed to practice medicine, and additionally a radioactive materials license is usually (but not always) required to perform brachytherapy. The RSO is usually a physicist, but can be a physician.