Chapter 01: Mathematics and Statistics
Waterstram-Rich: Nuclear Medicine and PET/CT: Technology and Techniques, 8th Edition

MULTIPLE CHOICE

1. The radiation intensity from a point source of ^{99m}Tc is 9 mR/hr at 3 m from the source. If the distance is changed to 9 m, what is the new radiation intensity?
   a. 0.5 mR/hr
   b. 1.0 mR/hr
   c. 2.0 mR/hr
   d. 3.0 mR/hr

   ANS: B
   The inverse square law results in the radiation intensity quadrupling if the distance from the source is halved, or it results in the radiation intensity decreasing to one fourth of its value if the distance is doubled.

   REF: p. 4

2. A technologist is sitting near a bone mineral densitometer, which is a point source of x-rays. If the x-ray intensity at 1 m from the x-ray beam is 0.20 mR/hr, to what distance from the x-ray beam should the technologist move to decrease total weekly exposure to the occupational limit of 2 mR for a 40-hour workweek?
   a. 0.5 m
   b. 1.5 m
   c. 2.0 m
   d. 2.5 m

   ANS: C
   The inverse square law results in the radiation intensity quadrupling if the distance from the source is halved, or it results in the radiation intensity decreasing to one fourth of its value if the distance is doubled. The unit of intensity is mR/hr, but a 40-hour workweek must be taken into consideration when calculating the final answer.

   REF: p. 4

3. 10 mCi is equal to how many becquerels?
   a. 370 Bq
   b. 370 kBq
   c. 370 MBq
   d. 370 GBq

   ANS: C
   1 curie = 3.7×10^{10} disintegrations per second [dps], and in Système International d'Unités (SI units), 1 Bq = 1 dps; therefore, 1 Ci = 37 GBq and 1 mCi = 37 MBq. In this problem, activity in Bq =

$$10\,\text{mCi} \times \left[10^{-3}\,\frac{\text{Ci}}{\text{mCI}}\right] \times \left[3.7 \times 10^{10}\,\frac{\text{Bq}}{\text{Ci}}\right].$$

REF: p. 5

4. 20 mCi is equal to how many becquerels?
   a. 0.74 GBq
   b. 0.37 GBq
   c. 0.54 GBq
   d. 0.20 GBq

ANS: A
1 curie = 3.7×10^{10} disintegrations per second [dps], and in SI units 1 Bq = 1 dps; therefore, 1 Ci = 37 GBq and 1 mCi = 37 MBq. In this problem, activity in Bq =

$$20\,\text{mCi} \times \left[10^{-3}\,\frac{\text{Ci}}{\text{mCI}}\right] \times \left[3.7 \times 10^{10}\,\frac{\text{Bq}}{\text{Ci}}\right].$$

REF: p. 5

5. The dose equivalent for occupational whole-body exposure is commonly limited to 50 mSv. How many rem is this?
   a. 5000 rem
   b. 500 rem
   c. 50 rem
   d. 5 rem

ANS: D
To convert the dose equivalent in the new SI units of 1 cSv into the old unit of rem:
Dose equivalent = $1\,\text{cSv} \times 10^{-2}\,\frac{\text{Sv}}{\text{cSv}} \times \frac{100\,\text{rem}}{\text{Sv}} = 1\,\text{rem}.$

REF: p. 6

6. A source of $^{131}\text{I}\left[t_{\frac{1}{2}} = 8.05\,\text{d}\right]$ is delivered to the nuclear medicine department calibrated for 100 mCi at 8:00 AM on Monday. If this radioactivity is injected into a patient at noon on Tuesday, what radioactivity will the patient receive?
   a. 80 mCi
   b. 85 mCi
   c. 90 mCi
   d. 95 mCi

ANS: C
Solving the differential equation yields the radioactive decay law: $A = A_0 e^{-\lambda t}$ where A = activity at time t, A_0 = activity at starting time, λ = decay constant, t = time since starting time. The *decay constant* λ is the fraction of atoms that decay per (small) time interval, and has units of 1 over time (e.g., 1/hr) or inverse time (hr^{-1}). The typical radioactive decay calculation required in nuclear medicine specifies three of the four variables (A, A_0, λ, t) in the decay equation, requiring that the fourth unknown variable be solved for.

REF: p. 10

7. A patient was injected with ^{131}I on Monday at 10:00 AM. On Tuesday at 10:00 AM, the thyroid probe was placed over the thyroid and produced 100,000 counts. On Thursday at 10:00 AM, the probe showed 25,000 counts. What is the effective half-life in this patient's thyroid?
   a. 12 hours
   b. 24 hours
   c. 48 hours
   d. 72 hours

ANS: B
Typically the patient's organ excretes the radiopharmaceutical with some biologic half-life t_B while the radioactivity also decays physically with a **physical half-life** that is denoted as t_P. The counts observed by the gamma camera follow an exponential decay law based on the ***effective half-life*** t_E, where: $\frac{1}{t_E} = \frac{1}{t_P} + \frac{1}{t_B}$ or, in a format that is much easier for calculation purposes, $t_E = \frac{t_P \times t_B}{(t_P + t_B)}$. The effective half-life is always less than or equal to the smaller of t_P or t_B.

REF: p. 15

8. A ^{99}Mo-^{99m}Tc generator is eluted Monday at 7:00 AM, producing 1.8 Ci of ^{99m}Tc in the eluate vial, in 20 ml saline. What volume of eluate should be withdrawn from the eluate vial into a syringe in order to inject a patient with 20 mCi of ^{99m}Tc at 3:00 PM? (Given the half-life of ^{99m}Tc is 6.02 hours.)
   a. 0.56 ml
   b. 0.66 ml
   c. 0.76 ml
   d. 0.86 ml

ANS: A
The radioactive decay law can be algebraically rearranged (dividing both sides of the decay equation by A_0) as: $A/A_0 = e^{-0.639\left[t/t\frac{1}{2}\right]}$. After solving for the half-life, the concentration (radioactivity per volume) in the eluate vial is then determined and the volume needed to be withdrawn into the syringe can be calculated from the equation activity = concentration × volume: A = C × V.

REF: p. 10

9. If the HVL for some radionuclide in lead is 0.30 mm, what thickness of lead shielding is necessary to reduce the radiation exposure from 8 mR/hr to 1 mR/hr?
   a. 0.30 mm
   b. 0.45 mm
   c. 0.60 mm
   d. 0.90 mm

ANS: D
It is common to follow the method used in radioactive decay and define a half-value layer (HVL) as that thickness of material that absorbs 50% of the photons. The HVL is the analog of $t_{/2}$in radioactive decay. One HVL transmits 50% of the photons. The equation of photon attenuation then can be expressed as: $I = I_0e^{-\mu x} = I_0e^{-0.693 \times (x/HVL)}$ and a relationship exists between μ and HVL, given by μ = 0.693/HVL. Remember the units of *x* and HVL must be the same, and remember that this equation calculates the *transmitted* intensity.

REF: p. 16

10. The linear attenuation coefficient in lead for ^{99m}Tc gamma rays (140 keV) is 23 cm^{-1}. What percentage of these gamma rays will be absorbed by a lead apron that contains 0.60 mm of lead?
a. 75%
b. 50%
c. 25%
d. 12.5%

ANS: A
The intensity of the transmitted radiation is given by:

$$I = I_0e^{-\mu x}$$

where μ is the linear attenuation coefficient, or the fraction of the beam absorbed in some (very small) thickness *x*. The linear attenuation coefficient μ is the analog of the decay constant λ in radioactive decay. The linear attenuation coefficient μ depends on the type of absorbing material and the energy of the photons.

REF: p. 15

11. A new gamma camera/computer system that uses a new method of calculating cardiac ejection fraction (EF) is installed in a nuclear medicine department. The department decides to calculate EF for the next 25 patients on both the old gamma camera and the new gamma camera before discontinuing the use of the old camera. In the future, if it is desirable to convert the new EF value to that which would have been obtained on the old gamma camera (e.g., to assess if the patient's EF had changed), the mathematical analysis to be used is called a(n)
a. independent *t*-test.
b. linear regression.
c. standard error.
d. chi-square.

ANS: B
The least squares method, or linear regression, calculates the best-fit values for *y*-intercept (*a*) and slope (*b*) in the best-fit straight line: $y = a + bx$. The line of identity is often drawn on regression graphs when the *same* parameter, here the ejection fraction, is being plotted on both the *x* and *y* axes. The line of identity facilitates an evaluation of whether the two methods (the *x* and *y* axes) are predicting the same result for ejection fraction. If the two methods produce the same value for ejection fraction, then the regression line should be the same as the line of identity.

REF: p. 20

12. What is the standard deviation of 40,000 counts?
   a. 4000 counts
   b. 2000 counts
   c. 400 counts
   d. 200 counts

   ANS: D
   Counting statistics, meaning the number of counts expected from a sample, follow the Poisson distribution. In the Poisson distribution, the standard deviation (σ_C) for any number of counts *(C)* is fixed at the square root of *C:*

$$\sigma_c = \sqrt{C}$$

   This fixed definition of standard deviation does not exist in Gaussian distributions; essentially only counting statistics are Poisson.

   REF: p. 24

13. What is the coefficient of variation of 40,000 counts?
   a. 2%
   b. 1%
   c. 0.5%
   d. 0.25%

   ANS: C
   The standard deviation can be expressed as a percentage of the mean value, which is frequently called the percent standard deviation, or coefficient of variation (CV):

$$CV = \left(\frac{\sigma}{\bar{x}}\right) \times 100$$

   In this problem, the counts would be substituted for the mean in the equation.

   REF: p. 25

14. How many counts should be acquired into each pixel of a nuclear medicine flood image if it is desired to be 95% confident that the true count in each pixel is within 1% of the measured counts in each pixel?
   a. 100,000 counts
   b. 40,000 counts
   c. 10,000 counts
   d. 4000 counts

   ANS: B
   Counting statistics, besides being Poisson, are also described by a Gaussian distribution as long as the number of counts is greater than about 30. Hence, given some number of counts *C*, the standard deviation is automatically known. It is also known that 68% of repeat measures of the sample fall within C ± $\sqrt{C}$ and 95% of repeat measures of the sample fall within C ± $2\sqrt{C}$ and so on (95% confidence = C ± $2\sigma_c$ = C ± $2\sqrt{C}$).