Introduction to Nuclear Engineering & Health Physics
MECH5103 & MECH6300
Fall 10/5/2021
Quiz 1

PART 1: According to whether each of the following statements is True (T) or False (F), please circle T , F or write the word TRUE or FALSE adjacent to the question. Be sure that your response is clearly legible. Alternatively, make a numbered list with T/F designations.

1. ***T F*** The average energy of the beta particles emitted from a radioactive material is about 1/3 of the maximum beta particle energy.

$^{1}_{1}P + ^{0}_{-1}e \rightarrow ^{1}_{0}n + ^{0}_{0}\nu + Q$

2. ***T F*** Following electron capture, other than a neutrino, no particles are emitted from the nucleus.

3. ***T F*** ? Deterministic effects of radiation exposure, such as formation of cataracts and skin reddening (erythema), can be completely avoided if the exposure is below a threshold dose.

4. ***T F*** Alpha particles emitted from a source have discrete energies, while beta particles exhibit a continuous energy spectrum.

? 5. ***T F*** The U. S. Nuclear Regulatory Commission (NRC) is the sole agency that can license and regulate a commercial nuclear power plant in the USA.

6. ***T*** ***F*** X-rays and gamma rays are identical and the only difference is in the place of their origin. Gamma rays are ejected from the nucleus while the X-rays are ejected from the extra-nuclear, electronic structure.

7. ***T*** ***F*** The fate of beta particles and positrons are essentially the same, except that the positron has a positive charge and the beta particle a negative charge.

8. ***T*** ***F*** Bremsstrahlung may occur when a heavy charged particle, such as an alpha particle, is deflected in the electric field of a nucleus or, to a lesser extent, in the field of an atomic electron. Beta particle !

9. ***T*** ***F*** An absorber having a linear thickness slightly greater than the range of the charged particle will completely stop all particles from penetrating the absorber.

10. ***T*** ***F*** The decay constant, λ, represents a probability. Even if the half-life of a radioactive material is reported as 100 days, any one of the atoms of the material can have a half-life from less than one day up to infinity.

11. ***T*** ***F*** Being much more massive, alpha particles are more penetrating than beta particles.

? 12. ***T*** ***F*** Cancer is an undesirable outcome of acute radiation exposure for which the probability increases in a linear manner with increasing exposure and exhibits no threshold.

13. **T** **F** Stopping power refers to the linear rate of energy loss by an electron due to excitation and ionization.

?

14. **T** **F** The best absorbers used to shield electrons and beta particles should be made of low Z materials (e.g., aluminum rather than lead) because the production of bremsstrahlung radiation is directly proportional to Z.

$P \propto Z^2$

15. **T** **F** The density thickness of an absorber is directly dependent on the density of the absorbing material.

Part II: Multiple Choice Questions. Answer all questions. Circle the correct answer on this page.

1. Ionization and excitation

A? B?

(A) are the names of two processes required for neutrino emission

(B) represent the methods for charged particles to lose energy passing through an absorber

(C) are used to compare the energy absorption of different materials

(D) are necessary for bremsstrahlung radiation

(E) none of the above

(F) all of the above

2. The *range* of a beta particle in an absorber

(A) represent the total path length of the trajectory of the particle

(B) is different depending upon the sign of the beta particle

(C) reflects the distance of penetration of a charged particle

(D) all of the above

(E) none of the above

3. In the case of alpha decay of $^{A}X_{Z}$ where Z is the atomic number and A is the mass number,

(A) A remains the same and Z increases

(B) Z remains the same and A decreases

(C) A and Z both decrease

(D) A decreases and Z remains the same

(E) none of the above

4. Which of the following may *accompany* radioactive decay?

?

B? D?

(A) Characteristic x-rays

(B) Gamma rays

(C) Annihilation radiation

(D) All of the above

(E) None of the above

5. Which of the following is true?

A ? secular equilibrium is established when $\lambda_{parent} >> \lambda_{decay\ product}$

B activity of parent and decay product are virtually equal in secular equilibrium

C the decay product exhibits the same half-life as the parent in transient equilibrium.

D All of the above

E None of the above

6. A radionuclide has a decay constant equal to 0.693 hr^{-1}. The fraction of atoms that DECAY in 2 hours is:

(A) 0.167
(B) 0.250
(C) 0.500
(D) 0.667
(E) 0.750

$\lambda = 0.693 \frac{1}{hr}$

$N_t / N_0 = 0.25$

$t_{\frac{1}{2}} = 1$

$N_t = N_0 \cdot e^{-0.693 \cdot 2}$

7. A certain isotope has a decay constant of 0.5 day^{-1} which means

$\lambda = 0.5$

$t = \frac{0.693}{0.5}$

=

(A) $t_{½} = 2.0$ day
(B) $t_{½} = 0.5$ day
(C) $t_{½} = 2.0$ day
(D) $t_{½} = 1.4$ day
(E) none of the above

8. From a practical point of view

(A) X-rays and gamma rays are identical and the only difference is in their energy. Gamma rays are always much more energetic than X-rays.

(B) X-rays and gamma rays are identical and the only difference is in the place of their origin. Gamma rays are produced within the nucleus while the X-rays are produced in the extra-nuclear structure.

(C) X-rays and the gamma rays are identical and the only difference is in the place of their origin. Gamma rays are produced in the extra-nuclear structure while the x-rays are produced within the nucleus.

(D) None of the above

Part III: Solve only *2* of the *3* following questions. Show all your work and please include *units* so I can award appropriate credit. Neat handwriting is also greatly appreciated.

1. The hands of a worker are exposed for 5 seconds to a beam

of 1 MeV beta particles of intensity 3 x 10^8 cm^{-2} sec^{-1} . What is the linear range in tissue (in units of cm or mm) for these beta particles? (r_{tissue}= 1 g cm^{-3}) Use the range-energy curve to check your result.

$E = 1.92R^{0.725}$	R<= 0.3 g/cm^2
$R= 0.407E^{1.38}$	E<= 0.8 MeV
$E = 1.85R + 0.245$	R ³ 0.3 g/cm^2
$R = 0.542E – 0.133$	E ³ 0.8 MeV

2. Most of the radioactive pharmaceutical used in medical imaging, diagnosis and treatment have short half-lives so waste materials can be stored at the hospital and, after sufficient time, can be disposed as non-radioactive waste. Typically, the time needed to store the radioactive waste at the hospital is about 10 half-lives. For example, $^{99}Tc_{43}$ has a half-life of only 6.02 hr. How long must radioactive waste containing $^{99}Tc_{43}$ be stored so that 99.9% of the activity has decayed?

$\lambda = \frac{0.693}{6.02}$ $=$

$t = \frac{\ln(0.001)}{-\lambda}$

$N_t = N_0 \cdot e^{-\lambda t}$ $\quad e^{-\lambda t} = 0.001$ $= 60\,hr$

3. The conditions established for <u>secular</u> equilibrium indicate that the activity of the decay product is equal to that of the parent after approximately 7 half-lives of the decay product. What is the actual numerical value of the activity of the decay product (relative to that of the parent) at that time? The following equations may be helpful.

$$N_2 \cong \frac{\lambda_1}{\lambda_2} N_1^0 (1 - e^{-\lambda_2 t})$$
$$N_1 \cong N_1^0$$

$A_1^0 = \lambda_1 N_1^0$

$A_2 = \lambda_2 N_2$

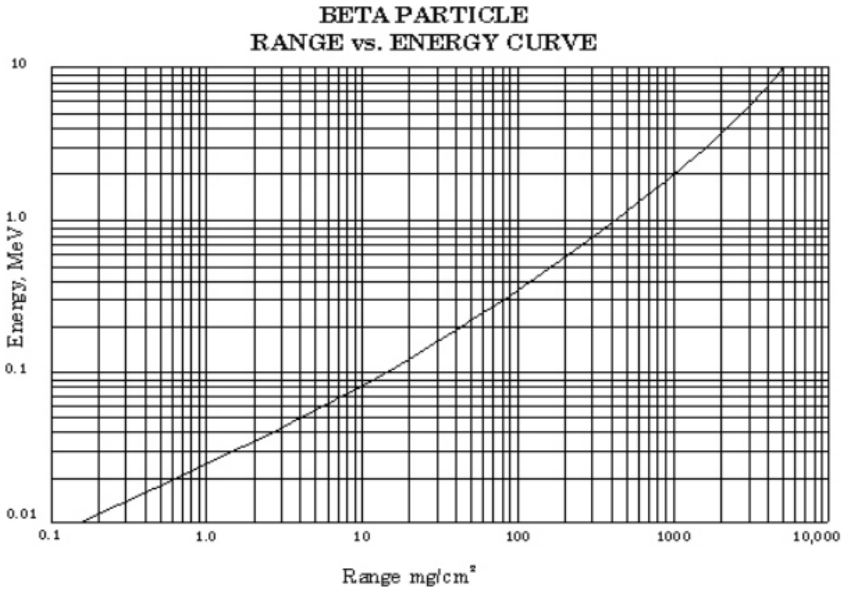
$= (\lambda_1 N_1^0)(1 - e^{-\lambda_2 t})$

$= A_1^0 (1 - e^{-\lambda_2 t})$

$\frac{A_2}{A_1^0} = 1 - e^{-\lambda_2 t}$

$= 1 - e^{-\frac{0.693}{t} \cdot 7t}$

$= 0.9922$


BETA PARTICLE
RANGE vs. ENERGY CURVE
Energy, MeV
10
1.0
0.1
0.01
0.1
1.0
10
100
1000
10,000
Range mg/cm²