SOLUTIONS
RADIOLOGICAL FUNDAMENTALS PRACTICE PROBLEMS
FOR TECHNICAL MAJORS

Note: Two DOE Handbooks are used in conjunction with the practice questions and problems below to provide preparatory material for the NPS Radiological Fundamentals Subject.

DOE HANDBOOK: GENERAL EMPLOYEE RADIOLOGICAL TRAINING

Part 3 of 3 – "Student's Guide", Parts A through E

1. Define ionizing radiation and list the four basic types of ionizing radiation.

Ionizing radiation has enough energy to remove electrons from electrically neutral atoms.

There are four basic types of ionization radiation:
Alpha particles
Beta particles
Neutrons
Gamma rays.

2. Define radioactive contamination.

Contamination is uncontained radioactive material in an unwanted location.

3. Describe the difference between radiation and radioactive contamination.

Exposure to radiation does not result in contamination of the worker. A worker's clothes or skin can only become contaminated if it comes in contact with radioactive contamination.

4. What are the two basic sources of radiation? Give examples of each.

Natural background sources:

Cosmic radiation
Radon
Terrestrial radiation
Materials present in our bodies.

Man-made sources:

Medical uses such as X-rays and nuclear medicine treatments
Tobacco products
Building materials
Domestic water supply.

5. Describe an individual's risk associated with occupational exposure to radiation.

The risks associated with occupational doses are very small and considered acceptable when compared to other occupational risks.

6. Describe the risk of heritable effects associated with occupational exposure to radiation.

The risk of heritable effects from ionizing radiation is considered to be very small when compared to other naturally occurring heritable effects and is difficult to detect over the natural background rate of birth defects.

7. Describe the basic practices used to maintain exposure to radiation ALARA.

Time – reduce the amount of time spent near a source of radiation
Distance – stay as far away from the source as possible
Shielding – Shielding is placed between workers and the source.

8. What are the annual radiation dose estimates for the following occupations?

Airline flight crew member	***400-600 mrem***
Nuclear power plant worker	***300 mrem***
Medical personnel	***70 mrem***

DOE HANDBOOK: NUCLEAR PHYSICS AND REACTOR THEORY-VOLUME 1 OF 2

Module 1 - "Atomic and Nuclear Physics"

Topic 5 – "Radioactivity"

1. Define activity, curie, radioactive decay constant, and radioactive half-life. Include equations where applicable.

Activity: the *rate* of nuclear decay of a substance. $\mathbf{A = \lambda N}$.

Curie (Ci): unit of activity equal to 3.7 x 10^{10} disintegrations per second

Radioactive decay constant: The probability that a nuclide will decay per unit time. It is a constant for a given radioactive nuclide. $\lambda = \ln 2 / t_{1/2}$.

Radioactive half-life: the amount of time required for the activity (or atomic concentration) of a sample to reach half its initial value.

2. What is the curie content of 1 mg of Mn-56? The half-life of Mn-56 is 2.578 hrs.

$$\mathbf{A = \lambda N}$$

$$\mathbf{N = (1mg)\left(\frac{1g}{1{,}000\,mg}\right)\left(\frac{1\ mole}{56\,g}\right)\left(\frac{6.02x10^{23}\ atoms}{1\,mole}\right) = 1.075x10^{19}\ atoms}$$

$$\mathbf{\lambda = \frac{\ln 2}{t_{1/2}} = \left(\frac{0.69315}{2.578\,hrs}\right)\left(\frac{1\,hr}{60\,min}\right)\left(\frac{1\,min}{60\,sec}\right) = 7.469x10^{-5}\ sec^{-1}}$$

$$\mathbf{A = \left(7.469x10^{-5}\ sec^{-1}\right)\left(1.075x10^{19}\ atoms\right)\left(\frac{1\,Ci}{3.70x10^{10}\ \frac{atoms}{sec}}\right) = 2.17x10^{4}\ Ci}$$

3. A sample of Co-60 in a 250 mL sample bottle is known to have an activity of 3.4 Ci. What is the concentration of Co-60 in the bottle, expressed as g/L ? The half-life of Co-60 is 5.271 yrs.

$$\mathbf{A = \lambda N \quad \Rightarrow N = \frac{A}{\lambda}}$$

$$\mathbf{N = (3.4\,Ci)\left(\frac{5.271\ yrs}{\ln 2}\right)\left(\frac{3.70x10^{10}\ \frac{atoms}{sec}}{1\,Ci}\right)\left[\frac{(365)(24)(3600)\,sec}{1\,yr}\right] = 3.017x10^{19}\,atoms}$$

$$\mathbf{[Co\text{-}60] = \frac{N}{V}}$$

$$\mathbf{[Co\text{-}60] = \left(\frac{3.017x10^{19}\ atoms}{250\,mL}\right)\left(\frac{1\,mole}{6.02x10^{23}\ atoms}\right)\left(\frac{60\,g}{1\,mole}\right)\left(\frac{1{,}000\,mL}{1\,L}\right) = 0.0120\ {}^{g}\!/\!{}_{L}\ .}$$

4. Calculate the activity of 1 Ci of N-16 (half-life is 7.13 sec) after one, two, three, four, five, six, and seven half-lives. At what time (expressed in half-lives and seconds) is the activity essentially zero?

$$\mathbf{A = A_o e^{-\lambda t} = A_o e^{-\left(\ln 2 / t_{1/2}\right)t} \ \text{or}\ \left(\frac{1}{2}\right)^{\left(t / t_{1/2}\right)} \ \text{or}\ \left(\frac{1}{2}\right)^{(\#\ of\ half-lives)}}$$

A (Ci)	(t / $t_{1/2}$)	t (sec)
1	0	0
0.5	1	7.13
0.25	2	14.26
0.125	3	21.39
0.0625	4	28.52
0.03125	5	35.65
0.015625	6	42.78
0.0078125	7	49.91

The activity is essentially zero at approximately 5 $t_{1/2}$ or 35.65 sec.

5. Define radioactive equilibrium.

Radioactive equilibrium exists when the production rate of a radioactive substance equals the removal rate of the substance.

<u>Topic 6 – "Neutron Interactions"</u>

1. Describe scattering of neutrons with nuclei in general. Then describe elastic scattering and inelastic scattering of neutrons.

Neutron scattering occurs when a nucleus is bombarded by a neutron and then emits a neutron. The initial and final neutrons do not have to be the same, and the net effect is that a neutron will appear to have "bounced off" the nucleus.

Elastic scattering: A neutron bombards a nucleus, a neutron is released from the nucleus, but <u>no</u> gamma ray is emitted.

Inelastic scattering: A neutron bombards a nucleus, a neutron is released from the nucleus, but a gamma ray <u>is</u> emitted.

<u>Topic 9 – "Interaction of Radiation with Matter"</u>

1. What is the difference between charged particle interactions and uncharged particle interactions?

A charged particle interacts with surrounding nuclei by electric field interactions. The charged particle can completely remove electrons from surrounding atoms in a process called ionization.

An uncharged particle can only ionize surrounding atoms by direct collision since they have no electric field. A photon, which is also uncharged, can undergo photoelectric effect, Compton scattering, or pair production to ionize surrounding atoms.

2. Describe an alpha particle. How does it interact with matter? Why does it have a short range in matter? What can stop alpha particles? Would a flux of alpha particles incident upon a person be a risk to the person's internal organs if the source was external? Why or why not?

An alpha particle is the nucleus of a helium atom. It is produced by an unstable nucleus that undergoes alpha-decay. It consists of two protons and two neutrons. It has a +2 charge.

Since an alpha is charged, it undergoes charged particle interactions, specifically ionization. For each interaction an alpha undergoes, it loses some finite amount of energy.

Because of its high mass and relatively high charge, an alpha particle's ionizing power is very high. Alphas therefore lose their energy in a very short distance as they travel through matter.

A few centimeters of air or a piece of paper stop alpha particles.

A person externally exposed to alpha particles would not experience any damage to his/her internal organs because the range of alphas in the body (or any matter) is extremely small (only a few microns in the body; a micron is a millionth of a meter, or a thousandth of a millimeter). The outer layer of skin (which is mainly dead skin cells) would completely absorb the energy from the alpha particles. However, if the person inhaled or ingested the source of alpha particles (e.g., radon gas), the person could experience damage to his/her internal organs.

3. Describe a beta-minus particle. How does it interact with matter? Compare its range to an alpha particle's range. What can stop beta-minus particles?

A beta-minus is an electron that has been ejected at a high velocity (and therefore, high energy) from an unstable (radioactive) nucleus. It has a very tiny mass compared with an alpha particle which has a mass more than 7,000 times larger than the mass of a beta. The beta-minus has a charge of –1e, where e is the fundamental charge on an electron.

A beta-minus undergoes charged particle interactions, such as ionization.

The range of beta-minus particles is longer than the range of alphas, but is much shorter than the range of gammas or neutrons.

A few mm of a light metal such as aluminum foil will stop beta-minus particles.

4. Describe a neutron. What is the typical source of neutrons? How does a neutron interact with matter? Compare its range to an alpha particle's range. What type of material is more effective at attenuating neutrons?

Neutrons are uncharged particles with almost the same mass as a proton.

Neutrons primarily come from nuclear fission but can also come from decay of unstable (radioactive) nuclei.

Neutrons undergo elastic scattering, inelastic scattering, and absorption. Neutron absorption can, in turn, result in radiative capture, particle ejection, or fission.

Since it is uncharged, a neutron's range is much, much longer than an alpha particle's range. Neutron radiation is considered penetrating radiation. It will damage the internal organs of a person externally exposed.

Hydrogenous materials (i.e., materials which contain H as part of the chemical formula) are the best at attenuating neutrons. Examples include water, oil, and paraffin (polyethylene).

5. Describe a gamma ray. How does it interact with matter? Compare its range to an alpha particles range. What material can attenuate gamma rays? How much material is required?

Gamma rays are electromagnetic radiation, just like microwaves, radio and TV waves, or visible light, but with much higher energy. Gamma rays are indistinguishable from X-rays except for their source: gamma rays come from nuclear decays or nuclear reactions (like fission) and X-rays come from de-exciting or deaccelerating electrons. Gamma rays have no mass and no charge.

Gamma rays interact with matter by the Photoelectric Effect, Compton Scattering, and Pair Production.

A gamma ray's range is much, much longer than an alpha's range. Gamma radiation is also considered to be penetrating radiation.

Several feet of concrete, several meters of water, or several inches of lead will attenuate gamma radiation.