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ORNL-TM-2034, Vol. II

# REACTOR OPERATOR STUDY HANDBOOK
(Programmed Instruction Version)
## VOLUME II - RADIATION SAFETY AND CONTROL

R. A. Costner, Jr.
E. N. Cramer
R. L. Scott, Jr.

Editors

C. D. Cagle
S. D. Sheppard

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ORNL-TM-2034

Contract No. W-7405-eng-26

OPERATIONS DIVISION

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JANUARY 1968

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# REACTOR OPERATOR STUDY HANDBOOK
(Programmed Instruction Version)

## Volume II - Radiation Safety and Control

As a part of the Reactor Operator Training Program of Operations Division, Oak Ridge National Laboratory, five areas of instruction have been programmed for individual study. They are:

| | | |
|---|---|---|
| Volume I | - | Elementary Mathematics Review |
| Volume II | - | Radiation Safety and Control |
| Volume III | - | Reactor Physics |
| Volume IV | - | Heat Theory and Fluid Flow |
| Volume V | - | Instrumentation and Controls |

These programmed studies are a part of a course in reactor operation that includes classwork, lectures, and on-the-job training. At the end of the course, the operator trainee is tested for competence in all areas of reactor operations before being certified to operate a particular reactor.

It is suggested that the programs be studied in the sequence given above; however, sequential dependence has been minimized so that they may be studied either individually or as an integrated group.

The authors and editors would like to especially acknowledge the patience and assistance of the members of the Operations Division clerical staff who worked on this report; namely, Gladys Carpenter, Linda Hierhager, Milinda Compton, and Joanne Lamartine.

## INSTRUCTIONS

The material contained in this manual has been prepared using a technique called "programmed instruction". This technique of instruction consists of:

1. Presenting ideas or information in small, easily digestible steps called "frames".
2. Allowing you to set your own pace.
3. Encouraging response in an active way so that you have a stronger impression of the idea presented.
4. Letting you know immediately if your answer is right, thus reinforcing your impression.
5. Presenting many clues at first to help you arrive at the correct answer. (As you progress, the number of clues is reduced.)

A few sample frames are found on the next page. These will be used to illustrate the proper use of "programmed instruction". Most frames will require you to respond by filling in a blank, or blanks, to complete a sentence. Other frames will give you a choice of several responses. A few frames are for informational purposes only and require no response. The correct response to a given frame is always found on the right side of the page adjacent to the following frame. When reading a frame, a sheet (or strip) of paper should be used to cover the area below the dotted line which follows the frame. After completely reading a frame, you should write your response on a piece of paper. Next, move the paper down the page until you reach the next dotted line or turn the page. This will uncover the next frame and the correct response for the frame you have just completed. Compare your response with the correct response. If they do not match, read that frame again before moving on to the next one; do not proceed until you understand the information in the frame you are reading. If the responses do match, proceed to the frame you have just uncovered.

At the end of each section, there are self-test questions for review. If you miss one of the self-test questions, repeat the pertinent frames. It is not enough to respond correctly as you proceed through the material; you must remember correctly at the end of the program and even later. You should attempt to complete each section once you have started.

## Sample Frames

i. Programmed instruction is a method of presenting information in short paragraphs called "frames". These _____ usually contain only one or two concepts for the student to grasp.

- - - - - - - -

ii. By requiring you to think of the appropriate response and to write that _____ on a piece of paper, you take an active part in the program, and thereby reinforce your learning.

frames

- - - - - - - -

iii. This method of instruction, called _____ _____, allows you to proceed with the material at a rate which you determine for yourself.

response

- - - - - - - -

iv. Programmed instruction provides the appropriate response immediately and thus should reinforce the student's _____.

programmed instruction

- - - - - - - -

learning

# SECTION II-1

# ATOMS

## 1.1 Parts Defined

In this section we shall briefly review atoms and the smaller particles of which they are composed.

- - - - - - -

1. Matter is anything which has physical form. Your desk is matter, the paper you are now reading, the air you are breathing, the building you are in, etc.; in fact, you are _____.

- - - - - - -

2. All matter is composed of very small objects called atoms. The fact that there are different kinds of matter is accounted for by the fact that there are different kinds of _____. matter

- - - - - - -

3. The different kinds of atoms are called elements. That is, the element carbon is composed of atoms with one set of properties; the element oxygen is composed of atoms with another set of properties, etc. The atoms of the element iron are different from the (atoms, elements) of the (atom, element) oxygen. atoms

- - - - - - -

4. Since matter is composed of atoms, does this mean that an atom is the smallest piece of matter? The answer is no because atoms can also be broken into smaller particles. It is these small pieces of an atom which we will be studying throughout the remainder of this program. atoms, element

- - - - - - -

5. Of what is an atom composed? <u>All</u> atoms are composed of protons, neutrons, and electrons. Is an oxygen atom composed of the same types of particles as an iron atom? (Yes, No)

- - - - - - -

6. The iron atom and the oxygen atom are both made up of protons, neutrons, and electrons. The difference is that an iron atom has more of these particles and they are arranged in a different manner than those in the oxygen atom. Yes

- - - - - - -

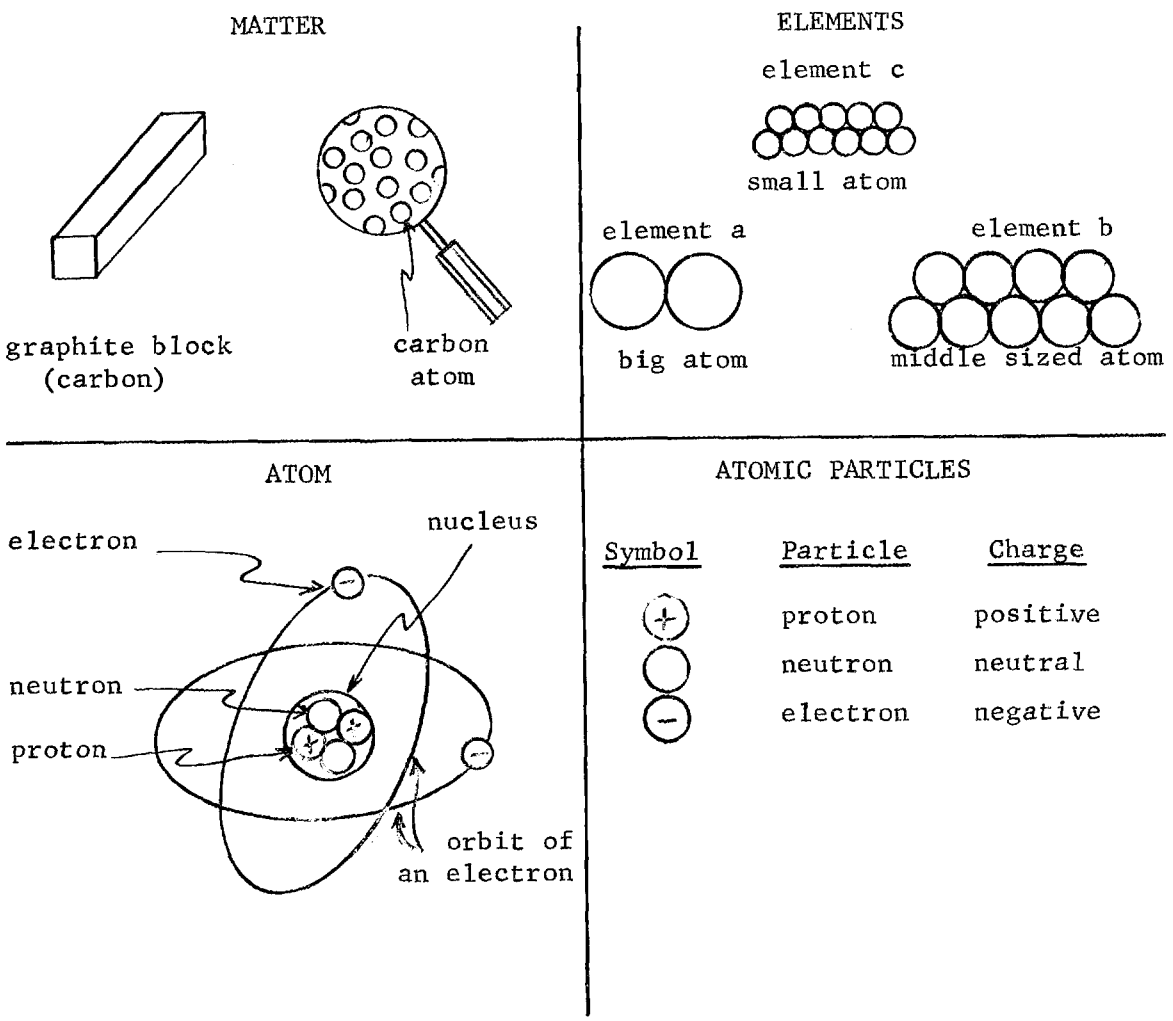



Fig. II-1. The Parts of Matter

## 1.2 Characteristics of Protons, Neutrons, and Electrons

7. What are the differences between these atomic particles? One major difference is in the electrical charges. A proton has a positive charge, the electron has a negative charge, and the neutron has no charge. So, these atomic particles do not have the same kind of electrical _____.

charge

---

8. Another major difference is in the mass. The proton and the neutron have approximately the same mass, but the electron has a much smaller mass. The mass of the proton is about 1836 times greater than the mass of an electron.

---

9. The proton has a (positive, negative) electrical charge. The electron has a (neutral, negative) electrical charge. Which particle is uncharged? (proton, electron, neutron)

---

10. The positively charged protons and the uncharged neutrons form the densely packed nucleus of the atom. The negatively charged electrons revolve in "orbits" around the densely packed _____.

positive, negative, neutron

---

11. The nucleus of the atoms contains _____ and _____.

nucleus

---

12. The negatively charged electrons revolve in orbits around the _____.

protons, neutrons

---

13. Because an atom normally has the same number of negatively charged orbital electrons as it has positively charged protons in the nucleus, the normal atom's net electrical charge is zero; that is, the atom is uncharged. Both the neutron and the normal atom are _____.

nucleus

- - - - - - -

14. The charges of the electron and proton are equal but opposite; that is, equal in electrical strength, but opposite in sign.

uncharged

- - - - - - -

15. The positive electrical charge of the _____ balances the negative charge of the _____.

- - - - - - -

16. The _____ of an atom is composed of protons and neutrons.

protons, electrons

- - - - - - -

17. To give you an idea of the makeup and size of the atom, let us consider an atom of the element hydrogen. The hydrogen atom is composed of only one proton in the nucleus with just one orbital electron. (Note that the nucleus of the hydrogen atom is the only exception to the statement made in Frame 16.) If the atom were enlarged until the proton was about the size of a golf ball, we would find the electron about one-fifth of a mile away. From this example, it should be apparent that atoms (and consequently matter) are mostly empty space.

nucleus

- - - - - - -

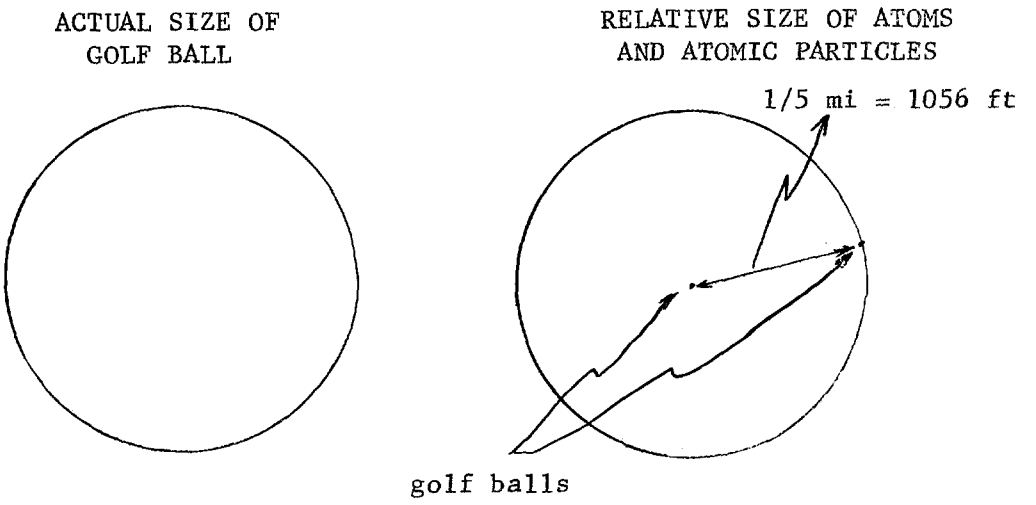



Fig. II-2. Relative Atomic Sizes

- - - - - - -

18. The proton and neutron, which will weigh approximately the same, are each about 1836 times heavier than the _____.

- - - - - - -

19. It should be apparent that most of the weight of the atom is located within the (orbit, nucleus). electron

- - - - - - -

20. The weight of the electron is so small compared to the weight of the proton or neutron that it is generally ignored when the weight of the atom is considered. The <u>atomic weight</u>, therefore, is usually stated on the basis of the total weight due to the (element, protons) and (electrons, neutrons). nucleus

- - - - - - -

21. The weight of the atom is so small when expressed in pounds or ounces or grams that for convenience a different unit is used. This unit is the atomic mass unit (which may be abbreviated as amu). For instance, the weight of a hydrogen atom (proton) is 1 amu.

protons, neutrons

- - - - - - -

It might interest you to know that 1 amu is equivalent to $1.7 \times 10^{-24}$ grams, or 0.000,000,000,000,000,000,000,000,003 lbs.

- - - - - - -

22. The number of protons in the nucleus of an atom is very important. Why? Because the number of protons (called the atomic number) determines what kind of atom it is, in addition to making a significant contribution to the weight of the atom. In other words, the number of protons in the nucleus of a particular atom determines whether it is an atom of the element hydrogen, oxygen, iron, etc. A hydrogen atom and a helium atom do not have the same number of (protons, electrons) in the nucleus.

- - - - - - -

23. A hydrogen atom has one proton in its nucleus. A helium atom has two protons and two neutrons in its nucleus. All atoms with one proton in the nucleus are atoms of the element hydrogen. All atoms with two protons in the nucleus are atoms of the element _____.

protons

- - - - - - -

24. About 99.985% of the hydrogen atoms which occur in nature do not have neutrons in the nucleus. However, about 0.0149% of the hydrogen atoms which occur in nature have one neutron in the nucleus. Occasionally we find a hydrogen atom which has two neutrons in its nucleus. So, although atoms of hydrogen may have zero, one, or two (electrons, neutrons), they can never have more than one _____ and still be an atom of the element hydrogen.

helium

- - - - - - -

25. Atoms of the same element which have different atomic weights are called isotopes of that element; for example, the most common isotope of hydrogen has only one proton. A less common isotope of hydrogen has one proton and one neutron. Isotopes of the same element have a different number of _____.

neutrons, proton

- - - - - - -

26. Different isotopes of the same element have the same number of _____ but different numbers of _____.

neutrons

- - - - - - -

27. Atoms with the same number of protons but different atomic weights are called _____ of an element.

protons, neutrons

- - - - - - -

## 1.3 Self Test

isotopes

28. All matter is composed of (neutrons, atoms). All atoms are composed of _____, _____, and _____. (If you made an incorrect response, repeat Frames 1 through 5.)

- - - - - - -

29. The nucleus of an atom contains the (positively, negatively) charged protons and uncharged (electrons, neutrons). The negatively charged _____ move in orbits around the nucleus. (If you made an incorrect response, repeat Frames 6 through 16.)

atoms,
protons,
neutrons,
electrons

- - - - - - -

30. Protons have about the same mass as (neutrons, electrons) and are about 1836 times heavier than (neutrons, electrons). (If you made an incorrect response, repeat Frames 17 through 21.)

positively,
neutrons,
electrons

- - - - - - -

31. Each atom of an element has the same number of _____ in the nucleus as the others. Isotopes of an element also have the same number of _____ but a different number of _____. (If you made an incorrect response, repeat Frames 22 through 27.)

neutrons,
electrons

- - - - - - -

protons,
protons,
neutrons

# SECTION II-2
# RADIOACTIVE MATERIAL AND RADIATION

## 2.1 Unstable Atoms

In this section we shall discuss nuclear radiation and the unstable atoms which emit radiation.

- - - - - - -

1. Most of the atoms found in matter have stable nuclei (nuclei is the plural of nucleus). However, some nuclei have an excess amount of energy usually because they contain either too many protons or too many neutrons. These excited nuclei usually become so violent in trying to get rid of their excess energy that they throw away one or more of their atomic particles and thus transform themselves into entirely different kinds of atoms.

- - - - - - -

2. This transformation of the excited atom to another kind of atom is called radioactive decay. Radioactive decay occurs when an excited nucleus gets rid of (ejects) an atomic particle, some combination of atomic particles, or energy in the form of photons. That is, an excited nucleus, by ejecting an atomic particle, gets rid of its excess _____.

- - - - - - -

3. The ejection of an atomic particle by a radioactive atom is almost always accompanied by the release of another form of energy (similar to light and heat) called a gamma photon. So, a radioactive atom gives up its excess energy by the ejection of atomic particles and the release of a _____ photon. energy

- - - - - - -

Note that the word "radioactivity" is sometimes used when "radioactive decay" should be used. Radioactivity is a general term and includes in its common usage radioactive decay, the results of the decay (that is radiation), and other reactions such as an instantaneous transition of an atom (e.g., the absorption of a neutron and the simultaneous emission of a gamma photon).

gamma

- - - - - - -

4. Since we call the transformation process radioactive decay, let us call the excited atom (or nucleus) a radioactive atom because it is the atom which will be transformed by _____ _____. We have already referred to nonradioactive nuclei as "stable" nuclei, which is the usual term used.

- - - - - - -

5. The gamma photon and particles which are released or ejected from a radioactive atom are called radiation. Radiation is emitted by (stable, radioactive) atoms.

radioactive decay

- - - - - - -

6. There are several different combinations of atomic particles which are emitted from radioactive atoms. However, we shall concern ourselves only with the three most common types of particle radiation. They are the alpha particle ($\alpha$), the beta particle ($\beta$), and the neutron (n); the last one is much less common than the first two.

radioactive

- - - - - - -

7. The excess energy emitted by a radioactive atom normally takes the form of an _____ particle, _____ particle, or _____, and a _____ photon.

- - - - - - -

It should be noted that some radioactive isotopes do not emit gamma photons with the particles.

alpha,
beta,
neutron,
gamma

- - - - - - -

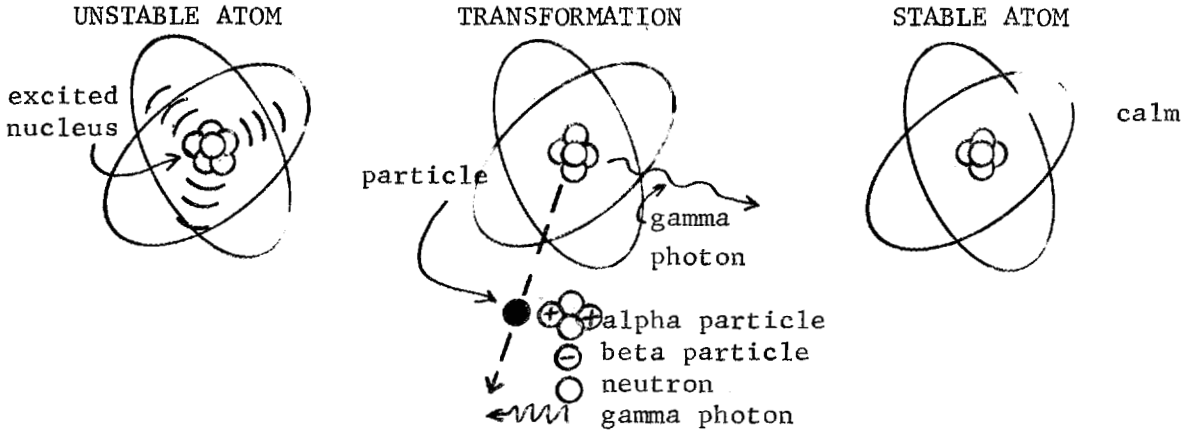



Fig. II-3. Radioactive Decay

- - - - - - -

## 2.2 Types of Radioactive Decay

8. We are already familiar with a neutron, and we certainly are familiar with the properties of heat and light, so we have some idea about the gamma photon. The question to ask now is "what is an alpha particle, and what is a beta particle?"

- - - - - - -

9. Let us consider the alpha particle first. An alpha particle is a helium-atom nucleus. It is a particle which is made up of two protons and two neutrons. The atomic weight of an alpha particle is almost _____ amu's.

- - - - - - -

10. Since the alpha particle is only the nucleus of the helium atom, it has no orbital electrons. Therefore, it has a net electrical charge of two. This net electrical charge of two is (positive, negative). 4

- - - - - - -

11. When a radioactive atom emits an alpha particle, it gives up two protons and two neutrons. Therefore, the atom's atomic weight (increases, decreases) by (2, 4). positive

- - - - - - -

12. The number of protons which the radioactive atom had in its nucleus (increases, decreases) by (2, 4). decreases, 4

- - - - - - -

13. Since the number of protons in the nucleus of the radioactive atom has changed, the atom has been transformed into an atom of a different element. (See Fig. II-4.) decreases, 2

- - - - - - -

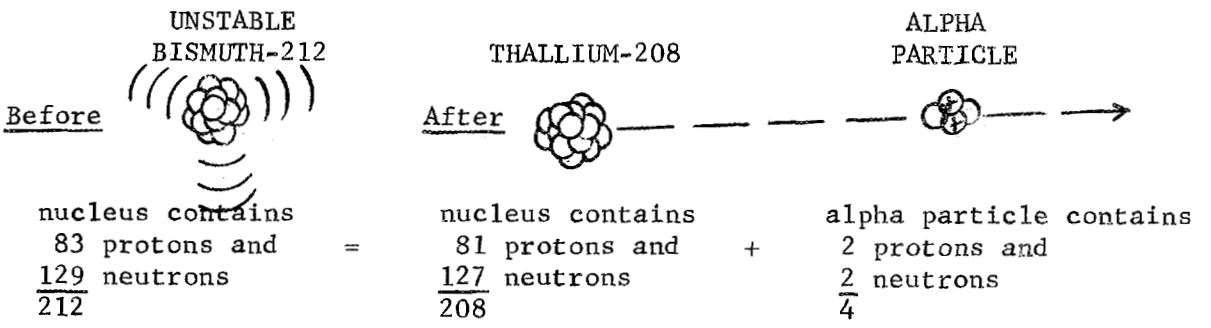



Fig. II-4. Radioactive Decay by Alpha-Particle Emission

- - - - - - -

14. The beta particle, like the alpha particle, is also emitted from the _____ of a radioactive atom.

- - - - - - -

15. In fact, the beta particle is an <u>electron</u> which has been ejected from the _____ of a _____ atom. — nucleus

– – – – – – –

16. This appears to conflict with what you learned earlier, that electrons are not found in the nucleus of an atom; they are found in _____ around the _____. — nucleus, radioactive

– – – – – – –

17. You also learned that the nucleus of an atom contains only positively charged _____ and uncharged _____. Then, from where did the negatively charged beta particle come? — orbits, nucleus

– – – – – – –

18. Occasionally, an uncharged neutron in the nucleus of an excited atom will disappear and a positively charged proton and negatively charged electron will appear. The proton will stay in the nucleus, but the electron is ejected. — protons, neutrons

– – – – – – –

19. This electron which is ejected from the nucleus of an atom is called a _____ particle.

– – – – – – –

20. One difference between the electron and the beta particle is that the electron normally moves in an orbit around the _____, whereas the beta particle is emitted from the nucleus when a _____ disappears and a _____ and a beta particle appear in its place. — beta

– – – – – – –

21. When beta decay occurs, a neutron in the nucleus disappears and a proton and an electron are formed. The uncharged neutron has become two oppositely charged particles. The negatively charged electron is emitted as a beta particle, and the positive proton stays in the nucleus. The total number of protons in the nucleus, therefore, (increases, decreases).

nucleus, neutron, proton

- - - - - - -

22. Since the newly formed proton stays in the nucleus, this also transforms the atom into an atom of a different element. You remember the radioactive decay of Bismuth-212 by alpha particle emission, don't you? Well, let us consider the radioactive decay of Bismuth-212 by beta particle emission by looking at Figure II-5 and comparing it to Figure II-4.

increases

- - - - - - -

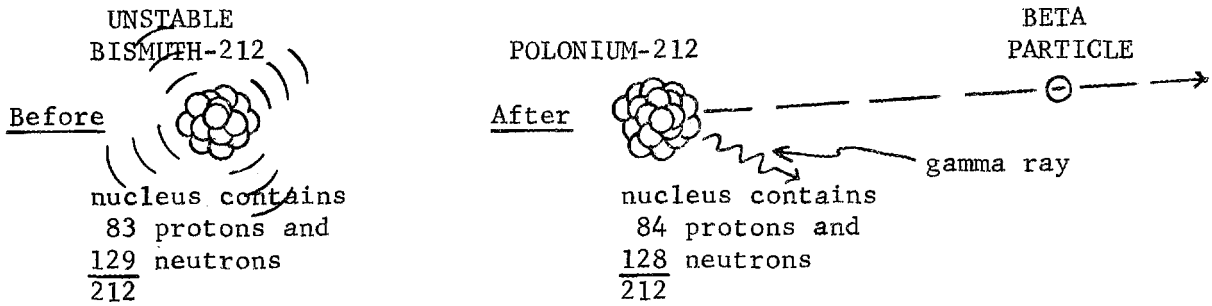



Fig. II-5. Radioactive Decay by Beta-Particle Emission

- - - - - - -

23. The result of beta-particle emission is that the nucleus of the radioactive atom loses one neutron and gains one proton and therefore transforms itself into a different element. The atomic weight of this atom (does, does not) change.

- - - - - - -

Remember, we said that since the weight of the proton or neutron was about 1836 times greater than the weight of an electron, we could ignore the weight of the electron.

does not

- - - - - - -

24. When a beta particle is emitted, the nucleus loses one neutron but it gains one proton so the atomic weight does not change; however, the positive charge of the nucleus (increases, decreases) by one.

- - - - - - -

25. It is apparent that when an alpha or beta particle is emitted from the nucleus of an atom, the positive charge (number of protons or atomic number) of the nucleus changes. Consequently, the atom is transformed into a different element. Does the charge of a nucleus change when a neutron is emitted? (Yes, No) Why?

increases

- - - - - - -

26. Does the charge or weight of an atom change when a gamma ray is emitted? The gamma photon (like heat, light, and radio signals) is an electromagnetic wave which is uncharged and weightless. Therefore, the emission of a gamma photon by an atom (would, would not) change its weight or charge.

No, because a neutron is uncharged; only the atomic weight changes

- - - - - - -

27. Let us summarize the information that we have about radiation.

    a. There are two kinds of radiation--charged and uncharged.

    b. The two charged radiations which we have studied are _____ particles and _____ particles.

    c. The two uncharged radiations which we have studied are _____ and _____ photons.

    d. The neutron is an uncharged particle with an atomic weight of 1 amu.

    e. The gamma ray is an uncharged, weightless electromagnetic wave.

    f. The beta particle is a negatively charged electron which has been emitted from the nucleus of an atom.

    g. The alpha particle is a helium-atom nucleus. It is a big radiation particle with a positive charge of two and a weight of 4 amu.

would not

- - - - - - -

28. Since the source of radiation is radioactive atoms, a good question to ask is "what is the source of radioactive atoms?" There are naturally occurring radioactive atoms and artificially produced radioactive atoms. It does not matter that one kind of radioactive material occurs naturally and the other is artificially produced; they both may emit the same kinds of _____.

alpha, beta, neutrons, gamma

- - - - - - -

29. The nuclei of most elements found in nature are stable. However, there are some naturally radioactive nuclei such as uranium-238 and bismuth-212. Artificially radioactive nuclei can be produced in several ways. We call this artificially produced radioactivity <u>induced</u> radioactivity because the nucleus becomes unstable as a result of a change that we induce or cause to happen.

radiation

– – – – – – –

30. The most common method of _____ radioactivity is by placing the material in or near a reactor core where there are many neutrons. An atom of the material absorbs (swallows up) one of the neutrons and is transformed as a result of this absorption into an unstable atom with excess energy.

– – – – – – –

31. This unstable atom then tries to return to a stable state by emitting energy in the form of _____.

inducing

– – – – – – –

32. We will have more to say about artificially produced or _____ radioactivity a little later.

radiation

– – – – – – –

33. Radioactive material is material which contains unstable atoms. It makes no difference whether this material occurs naturally or is artificially produced; it will still emit _____.

induced

– – – – – – –

radiation

## 2.3 Radioactive Contamination

34. Now that we have some idea about radioactive atoms and radiation, the next question is, "what is radioactive contamination?"

- - - - - - -

35. Contamination is material in a place where it is not wanted. For example, the floor of your kitchen at home may be contaminated with mud; your coffee may be contaminated with cream (if you like black coffee).

- - - - - - -

36. Radioactive contamination is radioactive material which is an impurity in an otherwise nonradioactive system. That is, radioactive contamination results when radioactive material has been deposited in any place where it is not desired--particularly any place where its presence may be harmful. Therefore, radioactive contamination is an impurity which is a source of _____.

- - - - - - -

37. Radioactive contamination is radioactive material in an otherwise "clean" system. This contamination is a source of _____, as is all radioactive material. radiation

- - - - - - -

38. There are two types of radioactive contamination. The two types are transferable contamination and nontransferable contamination. Radioactive contamination which can be easily spread or transferred is called (transferable, nontransferable) contamination. radiation

- - - - - - -

39. Transferable contamination can be easily spread or transferred to other pieces of equipment, to other areas of a building, to other persons, etc. Nontransferable contamination (can, cannot) be easily spread. — transferable

- - - - - - -

40. So, radioactive contamination which can be easily spread is called _____ radioactive contamination. — cannot

- - - - - - -

41. Transferable contamination is generally detected by wiping some of the radioactive material onto a clean filter paper and detecting _____ coming from the previously clean paper. — transferable

- - - - - - -

42. It makes no difference whether the material is transferable contamination or nontransferable contamination; if the material is radioactive, it will emit _____. — radiation

- - - - - - -

43. Suppose we detect radiation being emitted from a piece of filter paper that has been wiped across the floor. We would say that the floor is contaminated with _____ radioactive contamination. — radiation

- - - - - - -

44. If we spray paint over this contaminated spot and allow the paint to dry, the transferable contamination is no longer easily spread and has become _____ radioactive contamination. — transferable

- - - - - - -

This example is used to illustrate the terms; however, it should be noted that the above procedure is not considered good practice.

nontransferable

- - - - - - -

45. We could now wipe a clean filter paper across the painted floor, and we would find that we could not detect any radiation coming from the filter paper because no radioactive (radiation, contamination) was transferred to the filter paper.

- - - - - - -

46. We may, however, be able to detect radiation from the floor where the paint was applied. The radioactive contamination which is being held in place by the paint is emitting this _____.

contamination

- - - - - - -

47. It should be recognized that if the paint becomes chipped or is removed, the nontransferable contamination may again become _____ contamination.

radiation

- - - - - - -

This is one of a number of reasons why the procedure described in Frame 41 is not considered good practice.

transferable

- - - - - - -

48. Now, let us suppose that we have a reactor-core tool which has some transferable contamination on the surface. We clean it thoroughly, using wet rags. We then wipe the tool with a clean filter paper. The filter paper is checked and we detect no _____.

- - - - - - -

49. The wet rags are checked and we do detect radiation. This would indicate that the _____ radioactive contamination has been transferred from the tool to the wet rags. — radiation

– – – – – – –

50. We are now convinced that all of the _____ radioactive contamination has been _____ to the wet rags. — transferable

– – – – – – –

51. However, we find that radiation is still coming from the tool. We have not painted the tool; and we are reasonably sure that no chemical bonding action could have taken place, so there is no transferable contamination due to these two causes. In addition, the _____ contamination has been removed by the wet rags. — transferable, transferred

– – – – – – –

52. What could be the source of the radiation which is coming from the tool? The transferable contamination was removed by wet rags; we did not paint the tool so as to confine any transferable contamination, and we are sure no chemical bonding action has taken place. (Think--then proceed to the next frame.) — transferable

– – – – – – –

53. The radiation coming from the tool is radiation which is being emitted by radioactive atoms in the material of which the tool is made. That is, some of the atoms of which the tool is made were at one time or another artificially made radioactive by exposure to neutrons. If the tool is made of iron, then some of the _____ atoms are radioactive.

– – – – – – –

54. If we were to take a piece of iron and place it near a reactor core where there are many, many neutrons, some of the iron atoms would absorb some of the neutrons and would be converted from stable atoms to (radioactive, transferable) atoms. — iron

- - - - - - -

55. We have <u>induced</u> (artificially produced) radioactive iron atoms. The piece of iron is now a source of (radiation, atoms). — radioactive

- - - - - - -

56. The radiation coming from the piece of iron is being emitted by radioactive (iron, stable) atoms. — radiation

- - - - - - -

57. We could wipe a clean filter paper across this piece of iron and we would find that none of the radioactive _____ atoms were transferred to the filter paper. — iron

- - - - - - -

58. However, if we were to scrape the piece of iron with a file, we would probably find that some of the _____ atoms were transferred to the file. — iron

- - - - - - -

59. Because the filings containing radioactive iron atoms are no longer attached to the original piece of iron, they can be easily spread or transferred. Therefore, they have become _____ radioactive contamination on the file. — radioactive or iron

- - - - - - -

60. This piece of iron which was made a source of radiation due to neutron bombardment has now become a source of transferable radioactive _____ due to the filing. transferable

- - - - - - -

61. There is another example of how the piece of iron, which is a source of radiation, could become a source of radioactive contamination. If the iron were to rust, the oxidation (rusting) would not change the radioactivity of the iron atoms and small radioactive rust particles could drop off or be brushed off while the piece of iron was being handled. The radioactive rust particles, even while they were still on the piece of iron, would be considered _____ radioactive contamination. contamination

- - - - - - -

62. From these examples, it should be recognized that you may have a source of radiation without having contamination. However, if you have radioactive contamination, you do have a source of _____. transferable

- - - - - - -

## 2.4 Self Test

radiation

63. An atom which has an excess of energy in its nucleus is a (stable, radioactive) atom. By emitting radiation this atom transforms itself by a process called _____ decay. (If you made an incorrect response, repeat Frames 1 through 5.)

- - - - - - -

64. The excess energy emitted by a radioactive atom is called _____, and usually takes the form of an _____ particle, a _____ particle, a neutron, and/or a _____ photon. (If you made an incorrect response, repeat Frames 4 through 7.)

radioactive, radioactive

– – – – – – –

65. An alpha particle is a helium atom's _____ and is composed of two _____ and two _____. When an atom ejects an alpha particle, its atomic weight (increases, decreases) by (2, 4). (If you made an incorrect response, repeat Frames 8 through 13.)

radiation, alpha, beta, gamma

– – – – – – –

66. A beta particle is an _____ which has been ejected from the (nucleus, orbit) of a radioactive atom. In order for beta decay to occur, a (neutron, proton) in the nucleus must disappear and a proton and an _____ must appear. (If you made an incorrect response, repeat Frames 14 through 21.)

nucleus, neutrons, protons, decreases, 4

– – – – – – –

67. When beta decay occurs, the number of protons in the nucleus (increases, decreases). The atomic weight (does, does not) change. (If you made an incorrect response, repeat Frames 22 through 24.)

electron, nucleus, neutron, electron

– – – – – – –

68. Is an atom transformed into a different element when alpha emission occurs? (Yes, No) When beta emission occurs? (Yes, No) When neutron emission occurs? (Yes, No) When gamma photon emission occurs? (Yes, No) (If you made an incorrect response, repeat Frames 25 and 26.)

increases, does not

– – – – – – –

69. Naturally occurring and artificially produced radioactive materials emit the same kinds of (contamination, radiation). (If you made an incorrect response, repeat Frames 28 through 30.)

Yes,
Yes,
No,
No

- - - - - - -

70. Radioactive _____ results from the presence of a radioactive impurity. This radioactive contamination is a source of _____, as is all radioactive material. (If you made an incorrect response, repeat Frames 31 through 33.)

radiation

- - - - - - -

71. Radioactive contamination which is easily spread or transferred is called _____ radioactive contamination. That which is not easily spread is called _____ radioactive contamination. (If you made an incorrect response, repeat Frames 33 through 37.)

contamination,
radiation

- - - - - - -

72. We generally detect transferable radioactive contamination by wiping across a suspected surface with a clean _____ _____; if the surface has transferable radioactive contamination, we will detect _____ coming from this previously clean _____ _____. (If you made an incorrect response, repeat Frames 38 through 44.)

transferable,
nontransferable

- - - - - - -

73. Can you have a source of radiation without having any radioactive contamination? (Yes, No) (If you made an incorrect response, repeat Frames 45 through 59.)

filter paper,
radiation,
filter paper

- - - - - - -

74. Can you have radioactive contamination without having any radiation? (Yes, No) (If you made an incorrect response, repeat Frames 45 through 59.)

Yes

- - - - - - -

75. A tool which is free of transferable contamination may be a source of radiation due to _____ radioactive contamination or _____ within it. (If you made an incorrect response, repeat Frames 45 through 59.)

No

- - - - - - -

nontransferable, radioactivity

# SECTION II-3

# IONIZATION

## 3.1 Ions

This section is devoted to the effects of radiation on matter and how matter can be used as radiation shields.

- - - - - - -

1. Before continuing, let us make a quick review of a few items. Matter is composed of elements of which the smallest piece which retains its identity is called an atom. An atom consists of a nucleus, which contains all of the _____ and _____, and which is surrounded by _____ in orbits about the nucleus.

- - - - - - -

2. Neutrons and gamma photons are uncharged. Protons have a charge which is (positive, negative). The electron's charge is _____.

   protons, neutrons, electrons

- - - - - - -

3. The normal atom is electrically uncharged because it has as many electrons in orbit as there are _____ in the nucleus. The negative charges of the _____ balance the _____ charges of the _____.

   positive, negative

- - - - - - -

4. If we were to remove an electron from a normal atom, the atom would have a positive charge because of the charge from one unmatched _____. Such an atom would be called an ion.

   protons, electrons, positive, protons

- - - - - - -

5. If we were to remove a second electron from this atom, two protons would be unmatched, and it would have a _____ _____ of two. proton

- - - - - - -

6. Figure II-6 below shows how a helium atom might possibly appear (if we could see it) in the neutral and positively charged states. In case 1, the uncharged atom has two protons and two neutrons in the nucleus and two electrons in orbit which balance the charge of the protons. The net charge is zero, so it is a neutral (or uncharged) atom. positive charge

- - - - - - -

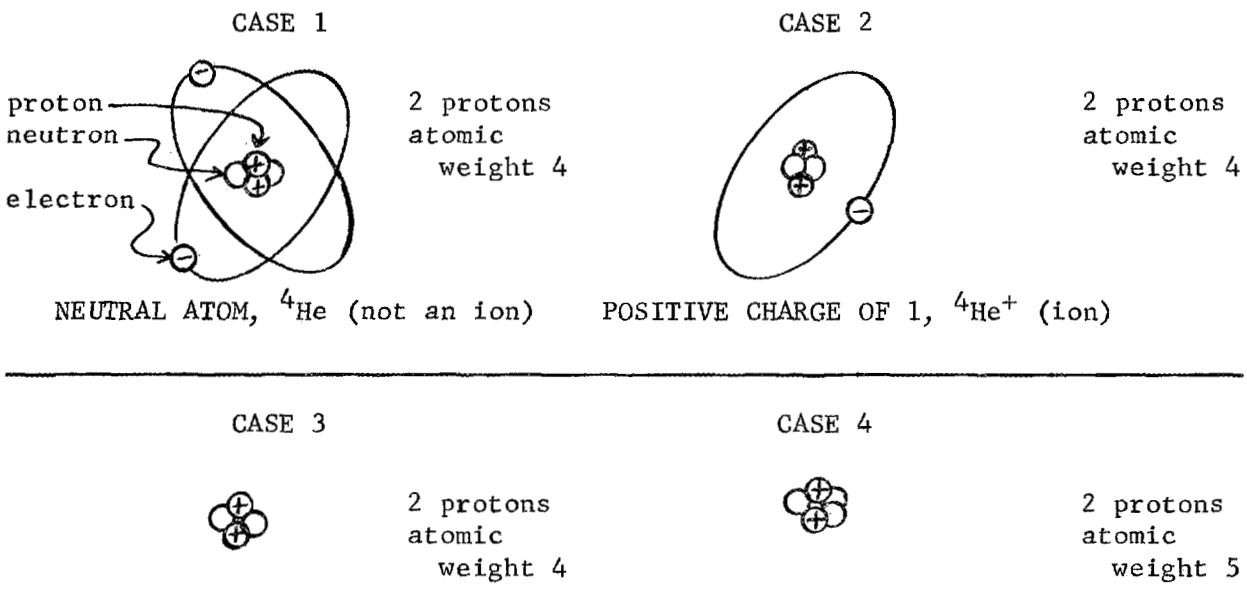



Fig. II-6. Ions

- - - - - - -

7. In case 2, the atom has two protons and two neutrons in the nucleus and only one electron in orbit. This atom has a (positive, negative) charge of 1.

- - - - - - -

8. The atoms in case 3 and case 4 have lost all of their orbital electrons. They are, in fact, nuclei of atoms of the element _____. positive

- - - - - - -

9. In case 3, the atom has lost both of its electrons and so the remaining nucleus has a _____ charge of _____. helium

- - - - - - -

10. Do you recognize the nucleus in case 3? Yes, we have talked before about this positively charged helium-atom nucleus. It is also called an _____ particle. positive, 2

- - - - - - -

11. In case 4, the nucleus is still a helium nucleus because it has the same number of _____ as the nuclei of the other helium atoms. alpha

- - - - - - -

12. Since the nucleus in case 4 has a different number of neutrons, it is a different _____ of helium. protons

- - - - - - -

13. The atoms in cases 2, 3, and 4 have one characteristic which is the same. That is, they each have unmatched protons and therefore have positive _____. isotope

- - - - - - -

14. Atoms which have unmatched protons or electrons are called <u>ions</u>. The atom shown in case 1 is neutral (uncharged) and therefore is not an _____. charges

- - - - - - -

15. The atoms shown in cases 2, 3, and 4 have positive _____ and are called _____. ion

- - - - - - -

16. When the positively charged atom and the electron which has been separated from the atom are considered as a pair, they are called an <u>ion pair</u>. When only the positively charged atom is considered, it is called an _____. charges, ions

- - - - - - -

17. An <u>ion pair</u> is a charged atom and an electron which has been _____ from the atom. ion

- - - - - - -

18. Now, since you have added <u>ion</u> and <u>ion pair</u> to your vocabulary, let us add ionization. Ionization is the process by which ions or ion pairs are created. separated or removed

- - - - - - -

19. So, when electrons are removed or separated from an atom, we call the charged atom an _____. When we speak of both the charged atom and the separated electron, we use the term _____ _____. We call the process _____.

- - - - - - -

ion,
ion pair,
ionization

## 3.2 Radiation and Ionization

20. What causes ionization? Since we have been talking about radiation, it is logical for you to assume that _____ causes ionization.

- - - - - - -

21. Ionization is caused by radiation. Electrons are removed or separated from the atom by radiation, thus creating _____ pairs. radiation

- - - - - - -

22. As radiation passes through matter, some of its energy is transferred to the matter; this can result in removing electrons from atoms. When it does, this removal of electrons from atoms is called _____. ion

- - - - - - -

23. Ionization is a result of the transfer of energy from _____ to the atoms of which matter is composed. ionization

- - - - - - -

24. Let us look just a little closer at this process, ionization. When we do, we might ask the question, "How does radiation cause ionization?" radiation

- - - - - - -

25. One way by which radiation can cause ionization is by direct collision with the atom. If the radiation, as it passes through matter, should collide or interact with an atom, an electron might leave its orbit--thus becoming separated from the atom. If this occurs an _____ pair is created.

- - - - - - -

26. If you have ever played pool, you have witnessed this type of direct collision reaction. The cue ball hits the pool ball and glances off. The pool ball goes one way, the cue ball goes another. This is an example of the direct collision reaction (see Figure II-7).

ion

- - - - - - -

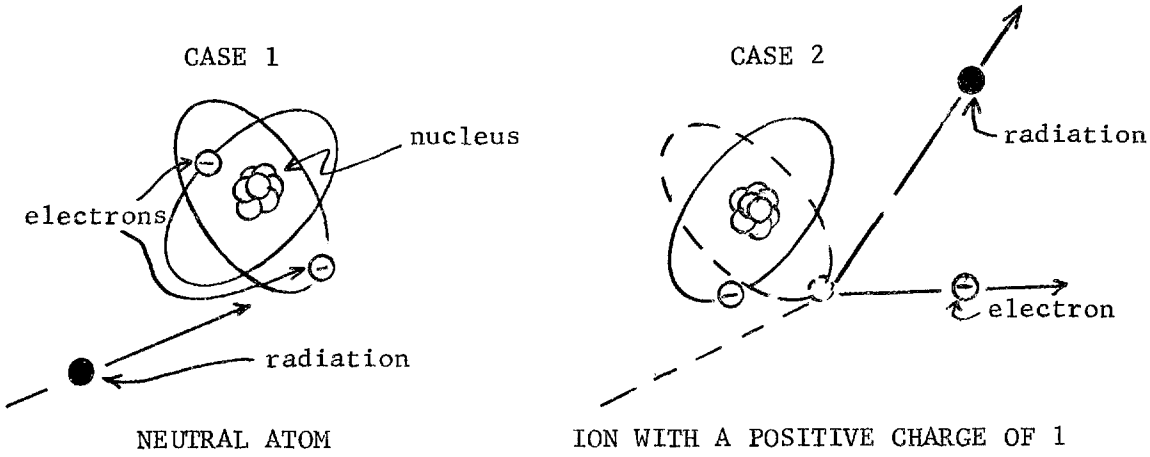



Fig. II-7. Ionization by Direct Collision

- - - - - - -

27. For radiation consisting of charged particles, the direct collision reaction is <u>not</u> the most likely method of creating ion pairs. One reason is that atoms are mostly <u>empty space</u>. (Remember the analogy of the golf balls separated by >1000 ft.) The most likely method by which radiation consisting of charged particles causes ionization is by electrical <u>attraction</u> or <u>repulsion</u>. (Unlike charges attract each other; like charges repel each other.)

- - - - - - -

28. Ion pairs are created by radiation consisting of charged particles principally by electrical _____ or _____.

- - - - - - -

29. Charged particles are surrounded by an electric field. It is the electric field of the charged particles which interacts with (mutual action upon) the electric field of the orbital electrons causing them to leave their orbits. Thus, ionization by charged radiation is the result of the interaction of the _____ field of the charged radiation with the electric field of the atom's orbital _____ (see Figure II-8).

attraction, repulsion

- - - - - - -

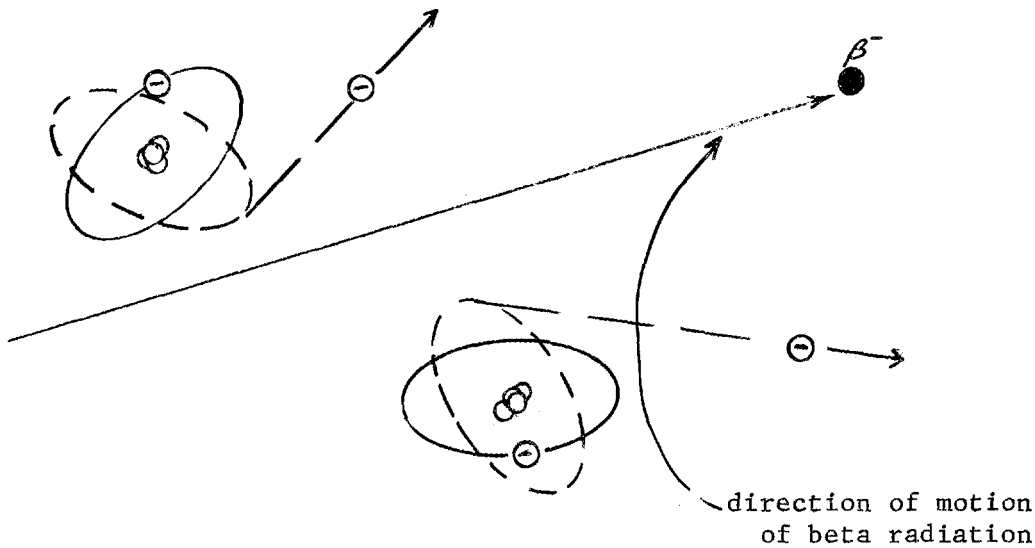



Fig. II-8. Ionization of Atoms by Charged Particle Radiation

- - - - - - -

30. Uncharged radiation does not have an _____ _____ and must therefore cause ionization primarily by direct _____.

electric, electrons

- - - - - - -

31. Positive electrical charges attract negative electrical charges, and vice versa. Therefore, it is apparent that an electron might be attracted out of its orbit by a radiation particle which has a _____ charge.

electric field, collision or interactior

- - - - - - -

32. Positive charges repel positive charges, and negative charges repel negative charges. Therefore, a negatively charged radiation particle might _____ an electron out of its orbit. positive

- - - - - - -

33. This method of causing ionization by electrical attraction or repulsion is characteristic of (charged, uncharged) radiation. repel

- - - - - - -

34. Uncharged radiation does not possess an electric field; consequently, neutrons and gamma photons cause ionization by (repulsion, collision). charged

- - - - - - -

## 3.3 Range

collision

35. Suppose you could shrink in size so that you could see an alpha particle traveling past you. If you could see the reactions taking place, you would see, as the alpha particle passed by, many electrons leave their atoms and try to follow the alpha particle (because of the alpha particle's positive charge). As each electron left its atom, you would notice the alpha particle slow down just a little, and eventually it would stop. When the alpha particle stopped, the electrons would be attracted to it. Two of these electrons would choose an orbit and start circling around the particle. The alpha particle has now become an uncharged _____ atom. It can no longer cause ionization to take place.

- - - - - - -

36. By use of an instrument called a cloud chamber, the path (usually called a "track") of a charged particle can be observed. Figure II-9 shows what would be observed if we had a cloud chamber and a source of alpha particles. helium

- - - - - - -

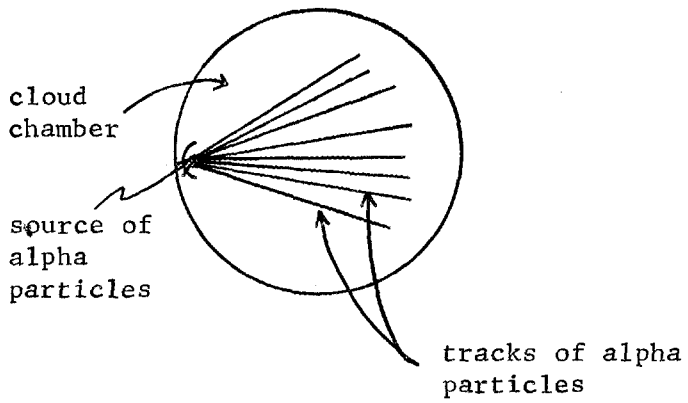



Fig. II-9. Alpha Particle Tracks

- - - - - - -

37. Notice how the tracks terminate after the alpha particle has traveled a certain distance. All of the particles stop at about the same distance from the source. This distance is normally referred to as the "range" and is characteristic of charged radiation.

- - - - - - -

38. The distance which charged radiation can travel in a particular material and cause ionization is normally referred to as the _____.

- - - - - - -

39. Ionization tracks caused by a source of uncharged radiation do <u>not</u> terminate at about an equal distance from the source. In other words, uncharged radiation does not have a definite _____. range

- - - - - - -

40. If your car has a full 20-gallon gas tank and will get 15 mi per gallon, then the range of your car is 300 mi (20 gal x 15 mpg), as long as the tank is not refilled. Charged particles lose a small amount of energy each time they create an ion pair and eventually "run out of gas". The distance the charged particle travels before running out of "gas" is called the _____. range

- - - - - - -

You may be interested to know that the basic unit of energy used when speaking of radiation is the electron volt (ev). The electron in the illustration will have gained 1 electron volt (ev) of energy by the time it reaches the positive plate. range

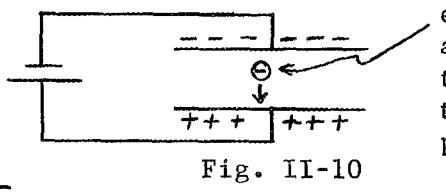



Fig. II-10

- - - - - - -

41. A beta particle loses energy at the rate of ~1 Mev in traveling 12 ft in air (Mev, or million electron volts, is a unit or measure of energy). The <u>range</u> of a beta particle with 1 Mev of energy (gas) is 12 ft in air (1 Mev x 12 ft/Mev). The difference in <u>range</u> between the various types of charged particles is similar to the difference in gas mileage between a Volkswagen and a Cadillac--the lighter car generally travels farther on the same amount of gas. This is best illustrated by comparing ranges of a beta ($\beta$) particle and an alpha ($\alpha$) particle, which are included in Table II-0.

- - - - - - -

Table II-1. Ranges of 1 Mev Particles (in in.) in Several Materials

| Particle and Charge | Air | Water, Tissue | Concrete | Lead |
|---|---|---|---|---|
| $\alpha^{++}$ (alpha) | 0.2 | ~0.0002 | | |
| $\beta^{-}$ (beta) | 144.0 | 0.14 | 0.075 | 0.012 |
| $p^{+}$ (proton) | 0.9 | | | |
| $d^{+}$ (proton + neutron) | 0.6 | | | |

42. According to Table II-1, the 1 Mev beta particle travels about 12 ft in air, while the alpha particle travels only _____.

– – – – – – –

43. The <u>range</u> of a charged particle may then be defined as the distance it can travel and still cause _____. — 0.2 in. (less than 1/4 of an in.)

– – – – – – –

44. Since charged particles have this characteristic of range, it should be obvious that if we wish to shield this type of radiation, all we need to do is to use a thickness of material slightly greater than the _____ of that particle in that material. — ionization

– – – – – – –

45. For example, from Table II-1 we see that the range of alpha particles in water (or human tissue) is 0.0002 in. and the range of beta particles in water is _____. — range

– – – – – – –

46. All of the ionization which the beta particle can cause will take place in the water if we use more than _____ in. of water as shielding. — 0.14 in.

– – – – – – –

47. The range of the beta particle in water is much greater than the range of the alpha particle. Therefore, if we use enough water to shield for the beta particle, we also shield for the _____ _____.

0.14 (or any greater value)

- - - - - - -

48. We should recognize from this example that a source of charged particle radiation can easily remain under paint, blotting paper, tools, and of course, a puddle of water, and then be uncovered when least expected or desired.

alpha particle

- - - - - - -

49. Why is there such a big difference in the ranges of the beta and alpha particles? There are two reasons. First, the alpha particle has twice as much electrical charge as the beta particle. That is, the electric field is larger and stronger and thus interacts with more atoms as it moves through matter. Second, the larger alpha particle travels slower. (For example, a 1-Mev beta particle will travel ~42 times as fast as a 1-Mev alpha particle.) Therefore, the alpha particle stays in one area for a longer period of time. Consequently, the alpha particle's electric field interacts with more atoms for a longer period of time.

- - - - - - -

50. Since radiation particles with the same amount of energy will create the same number of ion pairs, it is apparent that the alpha particle will create its ion pairs in a shorter distance of material penetrated. That is why the alpha particle has a shorter range than the beta particle. So, for charged radiation particles of the same energy, the one which has more (charge, neutrons) and travels (slower, faster)--thus spending (more, less) time in one area--will ionize matter along a shorter distance.

- - - - - - -

51. If we consider radiation particles with the same amount of energy, the one which creates the most ion pairs per inch of material penetrated will have the shortest range. If an alpha particle and a beta particle have the same energy, the (alpha, beta) particle will have the longest range.

charge, slower, more

- - - - - - -

52. The term "specific ionization" is used to describe the ionizing ability of radiation by specifying the "number of ion pairs created per centimeter of travel". Thus, if the alpha particle has a large specific ionization, the number of ion pairs created per centimeter must be (large, small).

beta

- - - - - - -

53. An alpha particle produces about 50,000 to 100,000 ion pairs per centimeter of path in air, while in the same distance the beta particle produces about 30 to 300 ion pairs. The specific ionization of an _____ particle is greater than that of the _____ particle.

large

- - - - - - -

54. Radiation, whether it is charged or uncharged, gives up some of its energy each time an ion pair is created. The kind of radiation which could be expected to give up its energy in a short range is (charged, uncharged) radiation.

alpha, beta

- - - - - - -

55. We learned earlier that atoms are mostly empty space because of the large orbits of the _____.

charged

- - - - - - -

56. Consequently, what we think of as a solid object (for example, your desk, which we call matter) is in reality mostly _____ space. electrons

- - - - - - -

57. Since matter is mostly empty space, gamma photons and neutrons (uncharged radiation) can easily penetrate a considerable distance between the widely-spaced atoms before an interaction occurs. empty

- - - - - - -

58. Uncharged radiation is therefore more penetrating than charged radiation because, unlike charged radiation, uncharged radiation must actually collide with the electrons in order to give up some or all of its _____.

- - - - - - -

59. Since _____ radiation is less likely to lose energy, it is more _____ than _____ radiation. energy

- - - - - - -

60. Uncharged radiation does not have a range because, in general, its individual units (such as gamma photons) lose most or all of their energy in one interaction, so is not continuously slowed down. Charged radiation, however, is continuously interacting with matter and is therefore being continuously slowed down. Charged radiation does have a _____. Uncharged radiation does not have a _____. uncharged, penetrating, charged

- - - - - - -

range, range

## 3.4 Shielding

61. Since charged radiation has a range, we can shield this type of radiation by using a thickness of material slightly greater than the _____ of the radiation in that material.

- - - - - - -

62. Uncharged radiation does not have a range and therefore cannot be completely shielded as was the _____ radiation. range

- - - - - - -

> It should be noted that in the process of stopping one type of radiation with a particular type of shield, other radiation may be produced. The latter radiation may be more penetrating than the original radiation. It is a good procedure to always check the radiation level after you construct a shield.

charged

- - - - - - -

63. However, the intensity of the uncharged radiation can be reduced. If a particular thickness of material reduces the intensity to one-tenth or 10% of its original value, we call this thickness the "tenth-value layer", or TVL. A tenth-value layer will reduce the intensity of the uncharged radiation to _____ of its original value.

- - - - - - -

64. The intensity of uncharged radiation can be reduced to one-_____ its original tensity by a _____ _____ _____ of a shielding material. one-tenth

- - - - - - -

65. This thickness of material usually will completely shield any accompanying charged-particle radiation because charged radiation is much less penetrating than _____ radiation.

tenth, tenth-value layer or TVL

- - - - - - -

66. If, for example, one TVL is used, the intensity will be reduced from 100% to 1/10 of 100% or 10%. It will be reduced by an additional TVL to _____%.

uncharged

- - - - - - -

67. Now the intensity has been reduced to 1%. If another TVL is used, the intensity will be further reduced from 1% to _____%.

1

- - - - - - -

68. So, although uncharged radiation cannot be completely eliminated, it can be _____ to a tolerable level.

0.1

- - - - - - -

69. Figure II-11 is a graph of the radiation intensity vs tenth-value layers. From this graph, we see that after the uncharged radiation has penetrated four TVL's, only _____% of its original intensity is left.

reduced

- - - - - - -

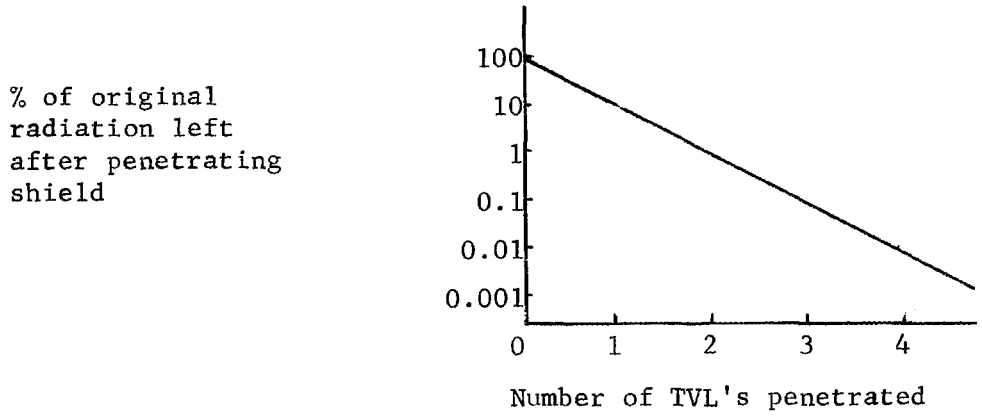



Fig. II-11. Reduction of Intensity of Uncharged Radiation

– – – – – – –

70. Although four TVL's will reduce the radiation intensity to 0.01% of its original value, the intensity might still be harmful. For example, four TVL's would reduce a 1,000,000 mrem/hr radiation level to _____ mrem/hr; but this is still a high radiation level. 0.01

– – – – – – –

The unit mrem/hr is a unit of radiation intensity.

– – – – – – –

## 3.5 Self Test 100

71. An atom which loses some of its electrons becomes charged. The charge is (positive, negative) because of the unmatched _____. (If you made an incorrect response, repeat Frames 1 through 13.)

– – – – – – –

72. The separation of electrons from atoms is called _____. The charged atom and separated electron are called an _____ _____. The charged atom is called an _____. (If you made an incorrect response, repeat Frames 14 through 19.)

positive, protons

- - - - - - -

73. The removal of electrons from atoms by either direct collision or electric attraction or repulsion are the methods by which _____ causes _____. (If you made an incorrect response, repeat Frames 20 through 25.)

ionization, ion pair, ion

- - - - - - -

74. (Charged, Uncharged) radiation causes ionization principally by electrical attraction or repulsion while (charged, uncharged) radiation can cause ionization only by close interaction. An electric field is a characteristic of (charged, uncharged) radiation. (If you made an incorrect response, repeat Frames 26 through 36.)

radiation, ionization

- - - - - - -

75. The distance a charged particle can penetrate matter and still cause ionization is called the _____ of the particle. Does uncharged radiation have this characteristic? (Yes, No) (If you made an incorrect response, repeat Frames 36 through 41.)

Charged, uncharged, charged

- - - - - - -

76. For the same energy, an alpha particle will have a (shorter, longer) range than a beta particle. (If you made an incorrect response, repeat Frames 42 through 49.)

range, No

- - - - - - -

77. An alpha particle has a much shorter range than a beta particle with the same energy. The reason for this is that the (alpha, beta) particle has more charge and travels (faster, slower). (If you made an incorrect response, repeat Frames 50 through 55.)

shorter

– – – – – – –

78. Since it does not have a definite range, the most penetrating type of radiation is (uncharged, charged) radiation. Since it does have a range, the most easily shielded radiation is (charged, uncharged) radiation. (If you made an incorrect response, repeat Frames 56 through 67.)

alpha, slower

– – – – – – –

79. Uncharged radiation cannot be shielded against completely, but the intensity can be reduced. Two TVL's reduce the intensity to _____ of its original value. (If you made an incorrect response, repeat Frames 63 through 71.)

uncharged, charged

– – – – – – –

1/10 x 1/10
or 1/100
or 1%

## SECTION II-4

## RADIATION UNITS

In this section we shall discuss the units used to describe a quantity of radioactive material, a quantity of radiation effect, and rates of producing these effects.

– – – – – – –

### 4.1 The Curie

1. The excess energy of a radioactive atom is emitted in the form of _____ which may be an _____ particle, a _____ particle, or a _____ photon.

– – – – – – –

2. Naturally occurring and artificially produced radioactive materials emit the same kinds of (contamination, radiation).

radiation, alpha, beta, gamma

– – – – – – –

3. Can you have radioactive contamination without having any radiation? (Yes, No)

radiation

– – – – – – –

4. Since the primary effect of radiation on matter is ionization, which can be measured, it is ionization which is measured in order to determine the quantity of radiation. The quantity of radiation present is determined by measuring the amount of _____ produced by the radiation.

No

– – – – – – –

5. Since different kinds of radiation cause ionization by different methods, various instruments are used which take advantage of these different methods in order to measure the _____ produced by the _____. ionization

- - - - - - -

6. There are also units which are used to describe quantities of radiation. A unit is a standard of measurement (for example, inches, feet, yards, and miles are units of length). So, to measure radiation, we must have various kinds of instruments; and to describe quantities of radiation, we must establish units of radiation. ionization, radiation

- - - - - - -

7. The "curie" is such a unit. However, instead of representing a quantity of <u>radiation</u>, it represents a quantity of radioactive <u>material</u>. Radioactive material, you remember, is material from which (radiation, curie) is emitted.

- - - - - - -

8. The unit "curie" is that amount of radioactive material in which $3.7 \times 10^{10}$ (37 billion or $3.7 \times 10{,}000{,}000{,}000$) atoms disintegrate every second. Notice that this is <u>radioactive</u> material and thus may be mixed in with any amount of nonradioactive material. radiation

- - - - - - -

For those of you who may wish to review methods of writing large numbers:

$10^1 = 10$

$10^2 = 100$

$10^3 = 1000$

$10^{10} = 10{,}000{,}000{,}000$

$\frac{1}{10^1} = \frac{1}{10} = 0.1 = 10^{-1}$

$\frac{1}{10^2} = \frac{1}{100} = 0.01 = 10^{-2}$

$\frac{1}{10^3} = \frac{1}{1000} = 0.001 = 10^{-3}$

$\frac{1}{10^{10}} = \frac{1}{10{,}000{,}000{,}000} = 0.000000001 = 10^{-10}$

9. The disintegration of an atom is the radioactive decay of an atom; therefore, each disintegration results in the emission of _____ which can cause ionization.

- - - - - - -

10. That amount of radioactive material in which $3.7 \times 10^{10}$ atoms disintegrate every second is called a _____. radiation

- - - - - - -

11. In a curie of radioactive material, 37 billion ($3.7 \times 10^{10}$) atoms disintegrate every _____. curie

- - - - - - -

12. Disintegrations per minute (usually referred to as dis/min or dpm) is a unit describing the actual number of atoms disintegrating each minute. A 100 d/m source, then, has _____ atoms disintegrating each minute. second

- - - - - - -

13. D/m is an abbreviation for _____ _____ _____. 100

- - - - - - -

14. Since radiation is emitted equally in all directions from a radioactive source, the radiation from all of the disintegrations does not pass through the detection instrument (see Figure II-12). In addition, the detection instrument does not count all of the radiation which passes through it; it is not 100% effecient. The number of disintegrations per minute which are detected by the instrument is called the counts per minute or c/m. disintegrations per minute

- - - - - - -

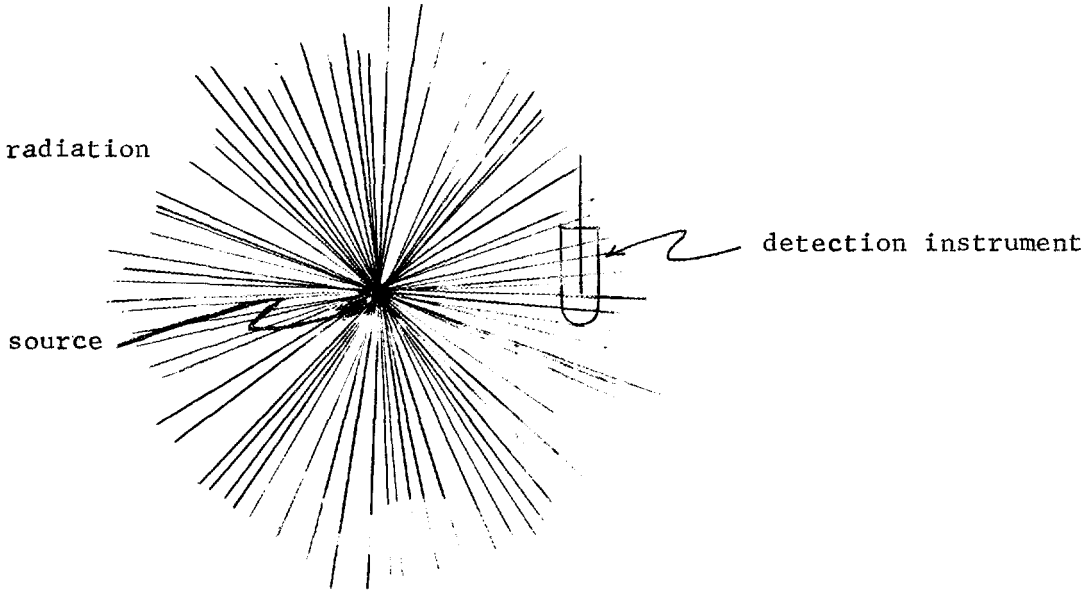



Fig. II-12. Radiation Detection

- - - - - - -

15. Do the number of d/m usually equal the number of c/m detected from the same source? (Yes, No)

- - - - - - -

16. The number of c/m is usually much less than the number of d/m because all of the d/m are not _____ by the detecting instrument. — No

- - - - - - -

17. Suppose we have a radiation detection instrument which actually detects one disintegration per minute for each ten disintegrations per minute which occur in the source. If 100 disintegrations per minute occur in a source, what would be the number of c/m? What would be the number of d/m? — detected or measured or recorded

- - - - - - -

If we had a source with a strength of one-millionth ($1/10^6$) of a curie, we would have $3.7 \times 10^4$ d/sec; or, since there are 60 sec in each minute, this same source would have $3.7 \times 10^4 \times 60$ or $222 \times 10^4$ dpm. The detection instrument which counts only one d/m for each 10 d/m would register only $22.2 \times 10^4$ c/m. 10, 100

- - - - - - -

18. If we have a radioactive source which has 1000 d/m, we will find that for this same instrument the number of c/m would be 100. The point is, this particular instrument can detect only _____% of the disintegrations which are occurring in the source.

- - - - - - -

19. So, if this instrument records 1000 c/m, we must divide by 1/10 (10%) or multiply by 10 in order to determine the actual number of disintegrations which are occurring. In this case, the d/m is _____. 10

- - - - - - -

20. The number which we use to divide into counts per minute to obtain disintegrations per minute is called the "overall counter factor". In the example just described, the overall counter factor is _____ counts per disintegration (c/d). 10,000

- - - - - - -

overall counter factor $= \frac{c/m}{d/m} =$ counts/disintegration $\frac{1}{10}$ or 0.1

- - - - - - -

21. If our radiation detection instrument records 2 c/m and the overall counter factor of the instrument is 0.1, the actual number of d/m is _____.

- - - - - - -

The overall counter factor can be broken down into a combination of other factors. If a source produces 100 d/m and if the radiation resulting from 20 d/m passes through the detector, we say the "geometry factor" is 20/100 or 0.2. If the detector actually counts only 90% (0.9) of the radiation entering the counter, we say the "counter efficiency factor" is 0.9. In this case, the "overall efficiency factor" is equal to the "geometry factor" times the "counter efficiency factor" (0.2 x 0.9 = 0.18). 20

- - - - - - -

22. In Figure II-13, let each radiation line stand for an equal number of disintegrations per minute and assume that 88% of the radiation entering the detector is counted.

The number of c/m is 99.

The geometry factor is _____.

The counter efficiency factor is _____.

The overall counter factor is _____ c/d.

The source has _____ d/m.

- - - - - - -

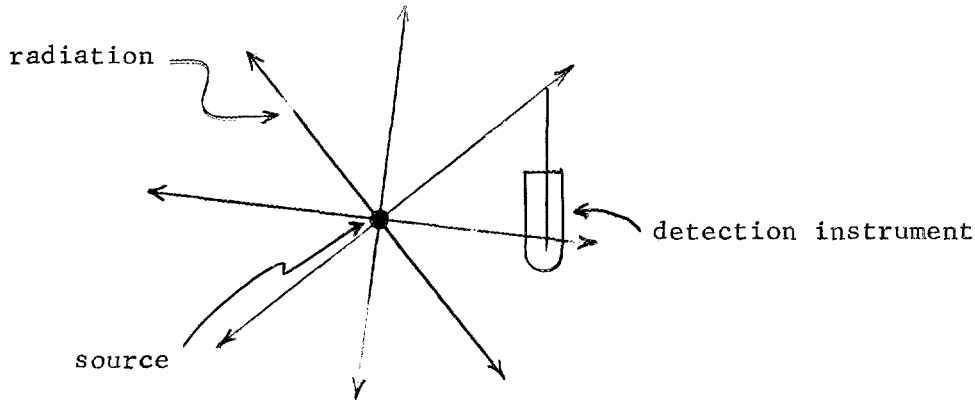



Fig. II-13. Radiation Detection

- - - - - - -

23. If the overall counter factor is known and does not vary, c/m can be converted to _____ per minute.

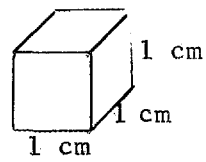
1/8 or 0.125,
0.88
1/8 x 0.88 = 0.11
$\frac{99}{0.11} = \frac{9900}{11} =$ 900
disintegrations

- - - - - - -

The frames you have just completed describe the method by which the "overall counter factor" of an instrument is determined. That is, we take a source for which we know the number of d/m and we let the instrument register the number of c/m. By dividing c/m by d/m we obtain the overall counter factor of that particular instrument. Then, when we have a source for which the number of d/m <u>is</u> <u>not</u> known (for example, a piece of filter paper which has been wiped across an object contaminated with transferable contamination), we can place this piece of filter paper in the instrument, divide the c/m registered by the instrument by the overall counter factor and determine the actual number of d/m occurring on the filter paper.

- - - - - - -

24. Suppose we have a 1 milliliter sample of water containing radioactive material. (1 ml = 1 $cm^3$ = a cube with each side 1 cm in length. The actual size of 1 $cm^3$ is shown at the side of the page.) If for this 1-ml sample, 5,000 counts per minute are registered on an instrument which has an overall counter factor of 0.1, the actual number of disintegrations per minute occurring in this ml of water is _____ $\frac{d/m}{ml}$.




- - - - - - -

25. Since there are 50,000 disintegrations occurring each minute in this 1-ml sample of water, there are 833 disintegrations occurring each second. (There are 60 seconds in each minute, so 50,000 d/m divided by 60 sec/min equals 833 d/sec.) What fraction of a curie of radioactive material do we have in this 1-ml sample of water? 50,000

- - - - - - -

We said earlier that one curie is that amount of radioactive material in which $3.7 \times 10^{10}$ d/sec occur. Since our water sample has 833 d/sec occurring, the fraction of a curie may be found by dividing 833 d/sec by $3.7 \times 10^{10}$ d/sec. $\frac{833 \text{ d/sec}}{3.7 \times 10^{10} \text{ d/sec/curie}} = 0.0225 \times 10^{-6}$ curies. Since $10^{-6}$ curies is a microcurie, we have 0.0225 microcuries.

- - - - - - -

26. The curie is a unit which represents a <u>quantity of radioactive material</u>. The curie does not tell us anything about the ionization caused by the radiation emitted, nor does it tell us anything about the effect of this radiation on the human body.

- - - - - - -

## 4.2 The Roentgen

27. A unit which tells us something about the effects of radiation that is being emitted from radioactive material is the "roentgen". The roentgen, usually abbreviated by the letter <u>r</u>, is a <u>quantity</u> of (radiation effect, radioactive material); the curie is a quantity of (radiation, radioactive material).

- - - - - - -

28. The roentgen is the quantity of gamma radiation which will cause 2.08 x $10^9$ (2,080,000,000) ion pairs to be formed in one cubic centimeter of air. You do not have to remember this number.

radiation
effect,
radioactive
material

- - - - - - -

29. Thus, the r is a unit which represents the amount of ionization per cubic centimeter caused by _____ radiation in _____ only.

- - - - - - -

## 4.3 The Rad

gamma,
air

30. The definition of the roentgen places severe limitations on the interpretation of radiation measurements, since it describes only the amount of ionization caused by gamma radiation in air. We must use another unit to describe the amount of ionization caused by any radiation in any material. The rad is this more general unit which can be applied to all types of radiation.

- - - - - - -

31. One rad of radiation will deposit 100 ergs of energy in one gram of the material which is being irradiated. So, if one gram of air receives 500 ergs of energy from the radiation, the quantity of radiation is five _____.

- - - - - - -

Notice we used the words "deposit" and "energy". The "energy deposited" by radiation is an expression for the "amount of ionization caused" and both expressions mean the same thing. For example, you know that as a charged particle passes through air it creates ion pairs. The creation of each of these ion pairs requires about $5.4 \times 10^{-11}$ ergs. The radiation therefore gives up this amount of energy to the air each time it creates an ion pair; in other words, it deposits its energy in the air.

Notice also that we are talking in terms of much larger units of energy than before. Where we were speaking of single particles or photons having an energy in the Mev range, we are now talking of very many particles or rays depositing ergs of energy. It takes 624,000 Mev to equal one erg. (You are not required to remember these numbers.)

rad

- - - - - - -

32. It should be reemphasized here that the ionization produced by the radiation (as a result of the energy transfer) is the property which is actually measured. The amount of ionization produced in the probe (detection compartment) of a radiation detection instrument is then expressed by the instrument meter in the unit _____.

- - - - - - -

33. The radiation unit which satisfactorily describes the amount of ionization caused by any kind of radiation in any material is the _____. rad

- - - - - - -

34. Although the rad is a unit which represents a quantity of radiation, it does not tell us how much damage radiation does to the human body. To determine the damage radiation can cause to the human body, we must know the kind of radiation (alpha, beta, gamma, neutron, etc.) as well as the quantity. That is, we cannot tell what effect 30 or 40 rad will have on the human body until we know the _____ of radiation. rad

- - - - - - -

35. We must know the kind of radiation in order to determine the amount of damage to the human body because each kind of radiation affects the human body in a different way. For example, a gamma photon may strike an atom, thus creating an ion pair and then move on through the body. However, a fast neutron might strike an atom, thus creating an ion pair, and at the same time become absorbed by the stable nucleus--thus converting the stable nucleus to a radioactive nucleus which in turn will emit radiation to cause more ionization. So in the case of the fast neutron we have secondary damage occurring because of the radioactive atom formed. From this example, it should be apparent that one rad of fast neutrons can cause more biological damage than one rad of gamma radiation. In fact, one rad of fast neutrons can cause ten times as much _____ damage as one rad of gamma radiation. kind or type

- - - - - - -

36. One rad of slow neutrons will cause approximately two and one-half times more biological damage than one rad of gamma rays. Fast neutrons cause nearly five times as much damage as slow neutrons because of the higher energy of the recoil particles after collision. The ability of both slow and fast neutrons to cause more damage than gamma radiation is attributed to secondary effects. biological

- - - - - - -

## 4.4 The Relative Biological Effectiveness of Radiation (RBE)

37. What we have said is that some kinds of radiation can more effectively produce biological damage than others. So, by knowing what kind of radiation is present we have an idea of the biological effect that radiation can cause. The term which is used to describe the bioligical effectiveness of radiation is the RBE which is an abbreviation for Relative _____ Effectiveness.

- - - - - - -

The "relative" in the RBE comes from the fact that the damage caused by one rad of gamma radiation is the basis of comparison. That is, since one rad of slow neutrons causes two and one-half times as much biological damage as one rad of gamma radiation, the slow neutrons are 2.5 times more biologically effective (damaging) relative to the gamma radiation. Therefore, the RBE of slow neutrons is 2.5. Naturally, the RBE of gamma radiation is 1. Biological

- - - - - - -

38. The relative biological effectiveness (RBE) represents the ability of each kind of radiation to cause damage to human tissue relative to the same quantity (in rad) of gamma radiation. Since the ability of radiation to cause biological damage is related to that of the gamma radiation, the RBE of gamma radiation is _____.

- - - - - - -

Table II-2. RBE Factors 1

| Kind of Radiation | RBE |
|---|---|
| Gamma | 1.0 |
| Beta Particles | 1.0 |
| Thermal Neutrons | 2.5 |
| Fast Neutrons | 10.0 |
| Alpha Particles | 10.0 |
| Protons | 10.0 |
| Deuterons | 20.0 |

- - - - - - -

39. Table II-2 lists the RBE factor for several different kinds of radiation. The RBE of gamma radiation is _____ while the RBE of alpha particles and fast neutrons is _____.

- - - - - - -

40. Since the RBE of fast neutrons is 10, this means that one rad of fast neutrons will cause 10 times (more, less) biological damage than one rad of gamma radiation. 1, 10

- - - - - - -

41. To determine the amount of damage to human tissue caused by a specified amount of a particular kind of radiation, our first step is to multiply the quantity of radiation, expressed in rad, times the _____; this step will give the gamma-radiation absorbed dose which will produce the same biological damage as the specified amount of the particular kind of radiation. more

- - - - - - -

4.5 The Roentgen Equivalent Man (Rem) RBE

42. It is now time to introduce you to another unit--the roentgen equivalent man or rem. The rem is a unit which represents the amount of absorbed dose (rad) in tissue which will result in the same biological damage as would be produced by an equal number of rem of gamma radiation. For example, one rad of fast neutron radiation will cause the same biological damage as 10 rem of gamma radiation because 1 rad multiplied by the _____ of fast neutrons, which is 10, is equal to 10 rem.

- - - - - - -

43. Therefore, to determine the tissue dose in rem (which will help us determine the amount of biological damage) we must know the quantity of radiation expressed in rad, and we must know the _____ of radiation so that the proper _____ factor can be applied. RBE

- - - - - - -

Notice that we have not said that determining the total dose in rem gives us the biological damage automatically. It does not. We must specify the particular type of tissue in which this dose is absorbed. A particular dose in rem will cause more biological damage in some types of tissue than in other types. kind or type, RBE

- - - - - - -

44. The rem is a tissue dose unit and is equal to the quantity of radiation expressed in _____ multiplied by the _____.

- - - - - - -

45. One rad of gamma radiation (will, will not) cause the same amount of damage to human tissue as one rad of alpha particle radiation.

rad, RBE

- - - - - - -

Rem cannot be added to rad. Rad multiplied by the RBE equals rem. If you are exposed to several kinds of radiation, the total tissue dose can be determined by converting each to rem and adding. For example, 1 rad of gamma plus 1 rad of alpha particle radiation is equivalent to a tissue dose in rem of

1 (rad of gamma) x 1 (RBE of gamma) plus

1 (rad of alpha) x 10 (RBE of alpha)

which is equal to 1 rem of gamma plus 10 rem of alpha. So the total tissue dose from 1 rad of gamma plus 1 rad of alpha is 11 rem.

will not

- - - - - - -

46. One rem of gamma radiation (will, will not) cause the same amount of damage to human tissue as one rem of alpha particle radiation to the same tissue.

- - - - - - -

47. One rem of gamma radiation plus one rad of alpha particles (is, is not) equal to 2 rem of tissue dose.

will

- - - - - - -

48. Actually, for day-to-day operation, a radiation dose of one rem is very high. However, radiation doses of 0.001 rem are not uncommon. For this reason, another dose unit which is useful is the mrem or <u>millirem</u> which is equivalent to 1/1000 rem (0.001 rem).

is not

– – – – – – –

49. The radiation units rad and rem (or mrad and mrem) are dose units. That is, if one rad of radiation is being absorbed each hour, then the dose rate is one rad per hour (one rad/hr). If the tissue dose rate is 1 mrem per hour (1 mrem/hr) then in one hour, a total tissue dose of _____ _____ will be received.

– – – – – – –

50. To illustrate the difference between <u>dose</u> (or total dose) and <u>dose rate</u>, let us assume you are driving in your car at a speed of 15 miles per hour. In one hour, you will travel 15 miles. In two hours you will travel 30 miles. If you associate the dose rate with the speed which is 15 miles per hour, then the total dose (distance traveled) in 1 hour is 15 miles. The car speed (dose rate) after 2 hours is still _____ _____. The distance traveled (total dose) after 2 hours is _____.

1 mrem

– – – – – – –

51. The difference between dose and dose rate should be clearly understood. An individual could be exposed to a <u>large</u> dose rate but receive only a <u>small</u> dose if the exposure time was small. That is, dose rate (in $\frac{\text{mrem}}{\text{hr}}$) x time (in hours) = _____ (_____).

15 miles per hour,
30 miles

– – – – – – –

52. If a man works 8 hrs in a radiation field of 5 mrem/hr, his total dose is _____ mrem. — dose (in mrem)

– – – – – – –

53. If a man works 6 min (0.1 hr) in a radiation field of 400 mrem/hr, his total dose is _____. — 40

– – – – – – –

54. If, in an emergency situation, a man enters a 1.2 rem/hr (1200 mrem/hr) field for only 2 minutes, he receives a total dose of _____. — 40 mrem

– – – – – – –

55. How long could a man be in a 5 rem/hr field and not exceed a 100 mrem dose? — 40 mrem

– – – – – – –

56. A man needs to close a hand valve in an area where the slow neutron radiation has been measured at 4 rad/hr. How long does he have to do the job and not exceed 100 mrem total dose? — 1.2 min or 72 sec

– – – – – – –

## 4.6 Self Test — 36 sec

57. A curie is a quantity of _____ material in which $3.7 \times 10^{10}$ atoms _____ every _____. (If you made an incorrect response, repeat Frames 7 through 11.)

– – – – – – –

58. Dpm and d/m are abbreviations for _____ _____ _____. Cpm and c/m are abbreviations for _____ _____ _____. The difference between d/m and c/m is that d/m is the actual number of _____ each minute, whereas c/m is just the number of _____ actually _____ each minute. (If you made an incorrect response, repeat Frames 12 through 18.)

radioactive, disintegrate, second

- - - - - - -

59. The number which is used to divide counts per minute (from an instrument) to obtain disintegrations per minute is called the _____ _____ factor. (If you made an incorrect response, repeat Frames 19 through 24.)

disintegrations per minute, counts per minute, disintegrations, disintegrations, detected or counted

- - - - - - -

60. The roentgen (r) is a quantity of _____ radiation which will cause a certain amount of ionization in one cubic centimeter of _____. (If you made an incorrect response, repeat Frames 27 through 29.)

overall counter

- - - - - - -

61. The radiation unit which represents the amount of ionization by any radiation in any material is the _____. (If you made an incorrect response, repeat Frames 30 through 33.)

gamma, air

- - - - - - -

62. To determine the amount of tissue dose, we must know the _____ and _____ of radiation. (If you made an incorrect response, repeat Frames 34 through 36.)

rad or mrad

- - - - - - -

63. The RBE is an abbreviation for _____ _____ _____, and indicates the (damaging, penetrating) ability of radiation relative to that of gamma radiation in tissue. (If you made an incorrect response, repeat Frames 37 and 38.)

quantity, kind

- - - - - - -

64. To determine the amount of tissue dose caused by radiation, we multiply the quantity of radiation in _____ by the _____ to obtain _____. (If you made an incorrect response, repeat Frames 40 through 44.)

relative biological effectiveness, damaging

- - - - - - -

65. Rem is an abbreviation for _____ _____ _____. (If you made an incorrect response, repeat Frame 44.)

mrad, RBE, mrem

- - - - - - -

66. One rem of gamma radiation (will, will not) cause the same amount of biological damage to tissue as one rem of alpha particle radiation to the same tissue. (If you made an incorrect response, repeat Frames 45 through 47.)

roentgen equivalent man

- - - - - - -

67. Usually 1/1000 rem or 0.001 rem is called a _____. (If you made an incorrect response, repeat Frame 48.)

will

- - - - - - -

68. Rem and rad are (dose, dose rate) units. Rem/hr and rad/hr are (dose, dose rate) units. Dose rate x time = _____. (If you made an incorrect response, repeat Frames 49 through 51.)

millirem

- - - - - - -

dose, dose rate, dose or total dose

# SECTION II-5

# HEALTH HAZARDS OF RADIATION

In this section we shall discuss the health hazards due to radiation and the radiation doses (and dose rates) at which the health hazard becomes significant.

– – – – – – –

## 5.1 Radiation Review

1. The distance charged particles can penetrate matter while causing ionization is called their _____. (Section II-3, Frames 35 through 40.)

– – – – – – –

2. An alpha particle has a much (shorter, longer) range than a beta particle with the same energy. (Section II-3, Frames 50 through 55.) — range

– – – – – – –

3. Radiation is either charged or uncharged. Radiation which is _____ does not have a definite range; therefore, it is the most penetrating type. (Section II-3, Frames 55 through 65.) — shorter

– – – – – – –

4. Uncharged radiation cannot be shielded completely, but its intensity can be reduced. Two tenth-value layers will reduce the intensity to _____ of its original value. (Section II-3, Frames 65 through 75.) — uncharged

– – – – – – –

5. The radiation unit which represents the amount of ionization caused by any radiation in any material is the _____. (Section II-4, Frames 30 through 35.)

$\frac{1}{10} \times \frac{1}{10}$ or $\frac{1}{100}$ or 1%

- - - - - - -

6. The RBE factor represents the damaging ability of radiation to human tissue and is an abbreviation for _____ _____ _____. (Section II-4, Frames 35 through 40.)

rad or mrad

- - - - - - -

7. To help determine the amount of damage to human tissue caused by radiation, we multiply the quantity of radiation in mrads by the _____ to obtain _____. (Section II-4, Frames 40 through 45.)

relative biological effectiveness

- - - - - - -

8. Mrem and mrad are (dose, dose rate) units. Mrem/hr and mrad/hr are (dose, dose rate) units. Dose rate x time = _____. (Section II-4, Frames 50 through 55.)

RBE, mrem

- - - - - - -

9. To determine a tissue dose (in mrem), you must know the radiation intensity expressed in mrad/hr, and you must know the kind of radiation to which you are being exposed so that the proper RBE factor can be used. By multiplying the number of mrad/hr by the RBE factor, the tissue dose rate in mrem/hr is obtained. You must also know the length of time the exposure will last. What has just taken several words to say can be represented by an equation. That is:

$$\text{mrem} = \left(\frac{\text{mrem}}{\text{hr}}\right) \times (\text{time}) = \left(\frac{\text{mrad}}{\text{hr}}\right) \times (\text{RBE}) \times (\text{time})$$

(Section II-4, Frames 50 through 55.)

dose, dose rate dose or total dose

- - - - - - -

10. If you are working in an area where the radiation intensity is 2 mrad/hr of fast neutrons (RBE = 10), then the radiation damage dose rate in mrem/hr is 2 mrad/hr x 10 = 20 mrem/hr. The tissue dose rate after 2 hours is _____. The tissue dose after 2 hours is _____.

- - - - - - -

| | |
|---|---|
| If you do not want to receive more than a specific amount of tissue dose (mrem), then you must know the dose rate and from this determine the length of time for that dose to be accumulated. | 20 mrem/hr, 40 mrem |

- - - - - - -

11. If the tissue dose rate is 20 mrem/hr, then in 1 hour you will accumulate 20 mrem of tissue dose. In 2 hours you will accumulate 40 mrem of tissue dose. If you do not want to receive more than 10 mrem of tissue dose, how long may you stay in an area where the radiation tissue dose rate is 20 mrem/hr? (5 minutes, 30 minutes, 1 hour, 2 hours)

- - - - - - -

## 5.2 Penetration Effects

30 minutes

12. A question which may have occurred to you by now is, "Will an exposure to radiation be harmful?" To answer this question, we must know four things:
    (1) What was the dose in mrad or mrem?
    (2) What kind of radiation caused the dose?
    (3) What parts of the body received the radiation dose?
    (4) Was the dose received all at once, or was it extended over a long period of time?

- - - - - - -

13. We have already learned how to determine the tissue dose in mrem. All we have to do is to multiply mrad/hr by the _____ to obtain mrem/hr then multiply mrem/hr by the _____ to obtain the accumulated tissue dose in rem.

RBE,
time (in hrs)

- - - - - - -

But, we must know the kind of radiation that caused the dose so that we use the correct RBE factor.

- - - - - - -

14. In order to detect and measure the different kinds of radiation, specific types of instruments must be used. The proper use of these instruments enables us to determine the type of _____ which is present.

radiation

- - - - - - -

15. Some of the various instruments detect more than one type of radiation at the same time. Others are designed to detect only one type under almost all conditions, but even these instruments will respond to one (or more) other types of radiation in extreme conditions. However, by proper use of the various instruments--along with small amounts of shielding to block the less penetrating types of radiation--the dose rate in _____ caused by the different types of radiation can be determined.

- - - - - - -

Although the determination of the type and quantity of radiation present is normally the function of personnel specifically trained for this purpose (Health Physics personnel), these people may not be immediately available during emergencies when immediate action is necessary. For this reason, we should become familiar with all of the radiation-detection instruments. It should also be emphasized that when there is any uncertainty as to the type of radiation present, we should test for all types.

rad/hr or rem/hr

- - - - - - -

16. Figure II-13 shows the penetration into the human body by gamma ($\gamma$) radiation as compared to alpha ($\alpha$) and beta ($\beta$) particle penetration.

- - - - - - -

17. From this figure we see that after the gamma radiation has penetrated the human body to a depth of about 25 in., there is still about _____% of the gamma radiation present.

- - - - - - -

18. Figure II-13 shows that 5 Mev alpha particles will penetrate the body to a depth of _____in., and the beta particles to a depth of _____in. 10

- - - - - - -

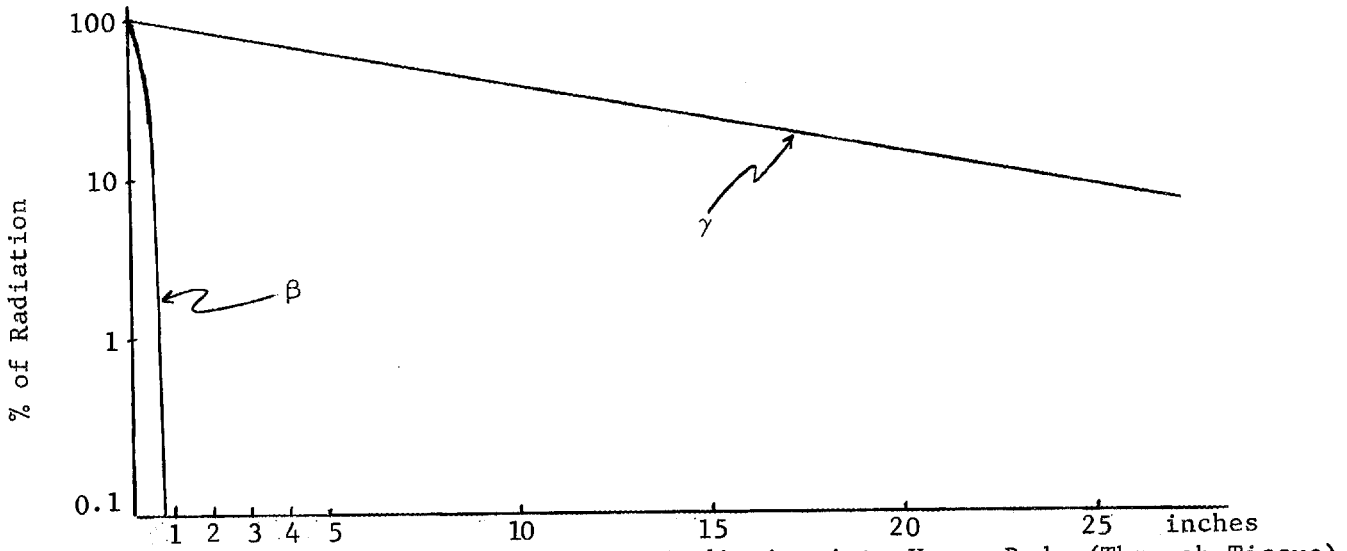



Illustration of Penetration of Gamma Radiation into Human Body (Through Tissue)

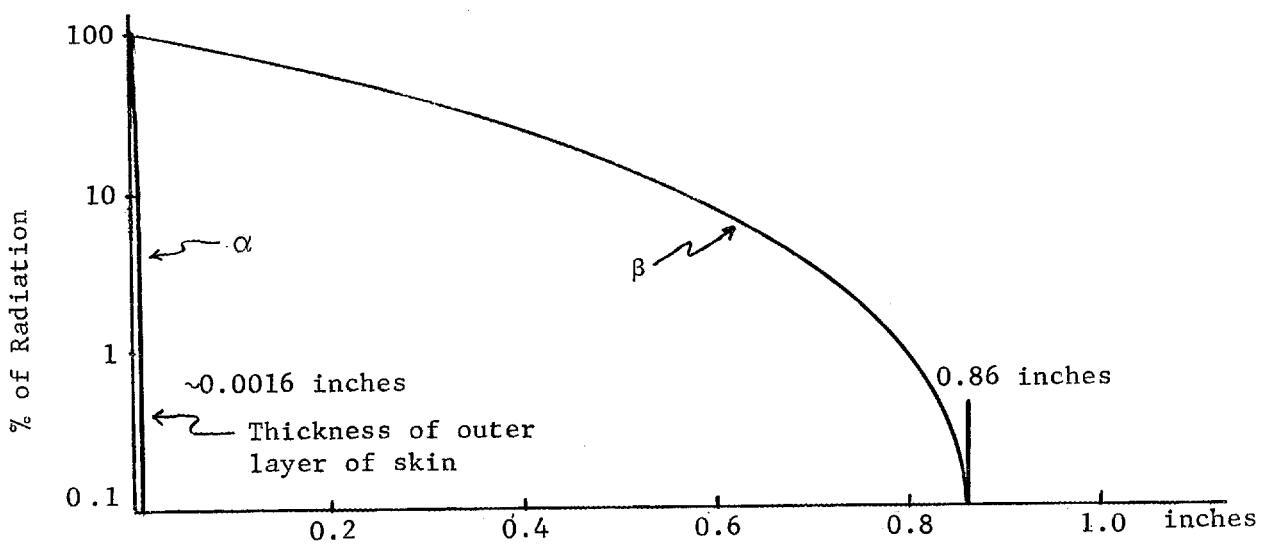



Illustration of the Relative Penetration of High Energy α and β Particles (~5 Mev) into Human Body (Through Tissue)

Fig. II-14. Penetrating Ability of Radiation

19. The thickness of the outer protective layer of skin is about 0.0016 in. Because of this dense layer, an alpha particle generally does not reach the soft tissue below in which the alpha particle has a somewhat longer range. Usually, therefore, a source of alpha radiation will present no serious hazard to an individual's health, provided the source is on the outside of the body. (If the source is very intense, skin damage will occur. Also, if the energy of the alpha particles is 7.5 Mev or greater, the particle can penetrate the outer protective layer.) 0.0016, 0.86

- - - - - - -

The thickness of this sheet of paper is about 0.002 in., only slightly thicker than the outer layer of skin.

- - - - - - -

20. Whereas, in general, alpha particle radiation cannot completely penetrate the protective layer of skin, beta particle radiation is more penetrating and capable of producing serious burns in the layers below.

- - - - - - -

## 5.3 Effects from Ingested Sources

21. In general, alpha particles and beta particles which originate outside the body do not penetrate deeply enough to reach vital tissues and organs. However, if the source of these radiations is (inside, outside) the body, there is a much greater probability that these particles will reach some vital tissue or organ.

- - - - - - -

22. A source of radiation which is inside the body--internal source--causes more (ionization, tissue damage) than the same source outside the body--external source. inside

- - - - - - -

Even if you picked "tissue damage", this is probably a good time for a review. The answer "ionization" is not correct, since the radiation from the source will cause the same amount of ionization no matter where the source is located; but ionization inside the body will cause tissue damage. If the radiation does not reach the tissue (and deposit energy in the tissue) there is no dose. (For example, your clothing would probably shield you from alpha particles.)

Another thing to remember is that some types of tissue are more sensitive than others. For example, the skin might be relatively unharmed by a certain dose (or amount of energy absorbed) but that same dose might cause serious damage to one of the important internal organs. However, it makes no difference what kind of radiation deposits energy in a given internal organ. Any given tissue dose to an internal organ (in rem) will result in a given amount of tissue damage whether the radiation depositing the energy comes from an alpha or beta source inside the body or from a gamma source outside the body. tissue damage

- - - - - - -

23. There are several reasons why radiation from sources inside the body cause more tissue damage than that from sources outside the body. How many reasons can you think of? (List your reasons--then proceed to the next frame.)

- - - - - - -

24. If the source of radiation is inside the body, the internal organs will not be shielded by the outer protective layers of skin; also, the internal organs will be exposed to the damaging radiation _____ hours a day, every day of the week.

- - - - - - -

25. Therefore, probably the most important reason why a source which is not very dangerous outside the body can be dangerous inside the body is that you cannot walk away from it. 24

- - - - - - -

26. A radiation source emits radiation in all directions. (Remember the geometry factor of a detection instrument as discussed in Section II-4, Frames 14 through 21.) If a radioactive source is outside the body, you will be exposed to only a fraction of the radiation emitted because of the geometry factor (in addition to the reduced time of exposure). If that source of radiation gets inside the body, you will then be exposed to _____ of the radiation emitted by the source.

- - - - - - -

27. Another reason why we should prevent sources of radioactive material (or radiation) from getting inside the body is that the sources may accumulate (or concentrate) in certain tissues or organs. For example, if the radioactive material is radioactive iodine (which emits beta and gamma radiation), the thyroid gland can be damaged because iodine has a tendency to _____ in the _____ _____. all

- - - - - - -

28. Besides iodine concentration in the thyroid gland, other examples of radioactive material concentration are plutonium and strontium accumulation in the bones. The point is that the damaging capabilities of internal sources of radiation are greater because of this tendency to _____ in various organs.

accumulate or concentrate, thyroid gland

- - - - - - -

29. How do these sources of radiation get into the body? If the source of radiation were in the form of transferable contamination, it could enter your body when you breathe, eat, or drink. If the contamination were on your hand and you were cut, the contamination could enter through the wound into your blood stream.

accumulate or concentrate

- - - - - - -

30. It should be obvious from what has just been said, that if you work with material which is a source of transferable radioactive contamination, you should use every control measure available to prevent the spread of contamination. Effective control of contamination will limit the possibility of radiation sources getting _____ the body.

- - - - - - -

Effective control of radioactive contamination should always be exercised because of the health hazard to those people working with such materials as well as to those people in surrounding areas who are unaware of the presence of radioactive contamination (and may not be taking precautions against this health hazard).

inside or into

- - - - - - -

31. Assuming, therefore, that we will take every precaution to prevent radioactive material from getting inside our bodies, let us continue our discussion of the damaging effects of radiation from sources outside the body.

- - - - - - -

## 5.4 Radiation Sensitivity of Body Organs

32. The next thing we need to know to help us determine the effect on our health caused by external radiation is, "What parts of the body were exposed to the radiation?" We need to know this because some parts of the body are more sensitive to radiation than other parts. That is, some parts of the body are more easily _____ by radiation than others because they are more sensitive to the radiation.

- - - - - - -

Damage to some tissue may be more serious than damage to other tissue depending on the importance of the tissue to the health of the body. The portions of the body which are the least sensitive to radiation are the muscles and full-grown bones. The parts of the body which are the most easily damaged by radiation are the bone marrow, reproductive organs, eyes, and gastro-intestinal tract (large digestive organs).

damaged

- - - - - - -

33. Although the bone is one of the least radiation-sensitive parts of the body, the bone marrow is one of the _____ sensitive parts of the body.

- - - - - - -

34. The parts of the body which are of intermediate sensitivity to radiation are the skin, liver, and lungs. So, you see when we consider the radiation damage to man, we must consider the _____ to radiation of specific organs of the body.

most or more

- - - - - - -

35. The intestines, bones, and skin exhibit different sensitivities to radiation. Can you list these according to their sensitivity? List the most easily damaged first, and so on. _____ _____ _____

sensitivity

- - - - - - -

36. If the entire body is exposed to radiation, <u>all organs</u> will be affected. Therefore, more damage will occur if the (hand, whole body) is exposed.

intestines, skin, bones

- - - - - - -

37. The exposure of the entire body to a large penetrating radiation dose might be fatal, since radiation would be absorbed by all parts of the body and thus all organs would be affected. The same dose could be received on the hand or foot and the overall health of the individual might not be seriously affected, although a local injury may occur.

whole body

- - - - - - -

38. When exposure to radiation is necessary, it is wise to protect as much of the body as possible.

- - - - - - -

## 5.5 Radiation Dose Rate

39. There is a fourth question which must be answered in order to determine the effect of radiation on an individual's health. "Was the radiation dose received all at once, or was it extended over a long period of time?"

- - - - - - -

40. The question is important because a dose which has been spread over many years may not produce any noticeable effect due to the damage rate not exceeding the recovery rate. If that same total dose were received in a few seconds, considerable harm would result. There are many things for which this type of time relationship is true. For example, a quart of wine may be sipped on for a long period of time without any noticeable effects, but can you imagine the effect if you were to drink that quart in less than 5 minutes? So, although the dose is important, the length of _____ for the dose to be accumulated must be considered.

- - - - - - -

41. We should now have some idea of the things which we must know in order to evaluate the "harmfulness" of radiation. These things are the dose rate, measured in _____, the exposure time, the kinds of radiation, and the portions of the body exposed to the radiation. time

- - - - - - -

42. Since we have considered the factors which influence the damage caused by radiation, let us now consider some quantities of radiation which we might receive. For example, man has always been exposed to radiation from cosmic rays; radiation from naturally radioactive material found in the soil, air, and water; and radiation from natural radioactive isotopes which are present inside the body, such as carbon-14 and potassium-40. These sources of radiation are referred to as environmental sources of radiation. Table II-3, which follows, lists the average dose which an individual might receive from these environmental sources in a period of one year.

rad/hr or rem/hr

---

Table II-3. Average Dose of Radiation to Soft Tissues and Gonads from Environment Sources*

| Radiation Sources | Dose Per Year (Rem) |
|---|---|
| Natural Background | |
| External radiation | |
| Cosmic rays | 0.028 |
| Local gamma rays | 0.047 |
| Radon in air | 0.001 |
| Internal radiation | |
| Potassium-40 | 0.019 |
| Carbon-14 | 0.001 |
| Radon and disintegration products | 0.002 |
| Subtotal | 0.098 |
| Man-Made Contributions | |
| Medical radiology | 0.100 |
| Shoe-fitting fluoroscopic machines | 0.001 |
| Luminous watch and clock dials | 0.001 |
| Occupational exposure | 0.002 |
| Television sets | 0.001 |
| Fallout from weapons tests | 0.001 |
| Subtotal | 0.106 |
| Total | 0.204 |

*From Report of the United Nations Scientific Committee on the Effects of Atomic Radiation (1958) and Medical Research Council report on "Hazards to Man of Nuclear and Allied Radiation" (1956).

43. As you can see from Table II-3, the average dose in one year to an individual from environmental sources is _____ rem or _____ millirem.

0.204, 204

- - - - - - -

Note that the man-made contribution to the exposure dose is about the same as that from natural background sources. Some references indicate that the soft X-rays emitted from TV sets are about 1 mrad/hr at one foot.

- - - - - - -

44. The 204-millirem dose received by the average individual from environmental sources in one year is equivalent to a daily dose of about _____ millirem.

1/2 or 0.5

- - - - - - -

45. The values for the yearly dose and daily dose from environmental sources should be remembered, since these values may be used as a basis of comparison when and if larger doses or dose rates are encountered. The yearly environmental radiation dose is _____ mrem. The daily dose is about _____ mrem.

$$\left(\frac{204 \text{ mrem/yr}}{365 \text{ days/yr}} = 0.56 \frac{\text{mrem}}{\text{day}}\right)$$

- - - - - - -

46. It appears that the human body can withstand the effect of small, but continuous, doses of radiation because the body can repair the damage at a rate faster than the damage occurs. However, frequent (for example, daily) exposures to radiation doses several thousand times that from natural sources may result in serious injury if continued for a long period of time.

204, 0.5

- - - - - - -

47. Frequent overexposure of the body to radiation may result in such things as interference with the blood circulation, malignant tumors, cataracts, scar formation, shortening of the life span, etc. Obviously, _____ of the body to radiation is something which should be avoided.

overexposure

- - - - - - -

48. The question now becomes, "What is the radiation dose which is considered to be an overexposure?"

- - - - - - -

49. Table II-4 shows that dose which may be accumulated over a long period of time without any significant effect occurring. Any dose greater than those listed may therefore be considered an "overexposure".

- - - - - - -

Table II-4. Personnel Exposure Limits (in rem)

| Organ | Recommended Maximum Weekly Dose | Maximum Permissible Dose (rem) | | |
|---|---|---|---|---|
| | | Quarterly (13 weeks) | Annual | Accumulated Dose N = present age |
| Total body, head and trunk, eye lens, gonads, blood-forming organs | 0.1 | 3 | 12 | 5(N-18) |
| Skin of whole body, thyroid | 0.6 | 10 | 30 | 30(N-18) |
| Hands, forearms, feet, ankles | 1.5 | 25 | 75 | 75(N-18) |
| Bone | | $\frac{30}{4n}$* | $\frac{30}{n}$ | $\frac{30}{n}$(N-18) |
| Other body organs | | 5 | 15 | 15(N-18) |

*Applies to internal exposure; n is one (1) for radiation from radium isotopes and for gamma radiation; otherwise, it is equal to five (5).

50. The dose which is recommended as the maximum allowable weekly dose for the total body or the most sensitive body organ is _____ rem or _____ millirem.

– – – – – – –

51. Note that the recommended maximum allowable dose of 100 mrem for a 5-day work week is equivalent to 20 mrem per day. This is approximately _____ times the dose which is received from environmental sources every day. (You may wish to refer to Frame 45.) 0.1, 100

– – – – – – –

52. If a person is exposed to a whole body radiation dose greater than 100 millirem in one week, he has exceeded the recommended weekly radiation exposure. 40

– – – – – – –

The record of the person who has received greater than a 100-millirem exposure must be investigated to find out how much dose he has received in the past. The point is that a dose greater than this amount might be considered an overexposure if he has been continuously exposed to the recommended maximum weekly dose over a long period of time. The amount he received which was in excess of this recommended maximum weekly dose would have to be taken into account also.

– – – – – – –

53. If you receive an exposure of 150 millirem in one week, does this mean that your blood will stop circulating or scars will start to form? No, your blood will not stop circulating and no scars will form, even though you have received a dose which exceeds the recommended weekly dose by _____ millirem.

– – – – – – –

It has been estimated that as much as 500 millirem per day could be received for many months without any decrease in an individual's efficiency and without any large scale drop in life span. In other words, no noticeable effects will occur. 50

- - - - - - -

54. According to Table II-4, the limit for the accumulated dose in one year (after the age of 18) should not exceed _____ to the total body or the most sensitive body organs.

- - - - - - -

55. This means that the average rate of accumulation should not exceed 5 rem per year, and the limit for any single year is 12 rem. For example, a person 29 years of age may have received an exposure dose of 10 rem the preceding year, which we will assume gave him a total accumulated exposure dose of 60 rem. Since the recommended limit for dose accumulation is 5 rem per year, this individual should not be allowed any additional exposure until he becomes 30 years of age because the recommended limit is 5(N-18) or 5(30-18), which is 5(12) or 60 rem. 5 rem

- - - - - - -

56. However, if his total accumulated exposure dose were only 55 rem, he is within the recommended limit. A 32-year old worker with no previous on-the-job exposure might receive over 5 rem in one year and still be well within the 5(N-18) requirement as long as he receives less than _____ in one single year.

- - - - - - -

57. If he has been working with radiation and his previous exposure is unknown, it must be assumed that he has received the full amount permitted by the formula for previous years. 12 rem

- - - - - - -

58. The 100 mrem dose per week is recommended as the weekly dose limit because, at this rate, in 50 weeks (2 weeks vacation) an individual will not exceed the recommended average annual exposure dose of _____ rem.

- - - - - - -

As we have just seen, a person who receives an exposure of 100 mrem per week will automatically receive his yearly limit; therefore, he would have no reserve for nonroutine situations. This can be a serious handicap to operating groups whose work requires that personnel be routinely exposed to radiation; these personnel could easily accumulate 100 mrem per week unless special efforts are made. Therefore, it is the ORNL Reactor Operations Department policy to limit the weekly exposure for departmental personnel to 50 mrem/wk. (It is interesting to note that the average exposure to operators in the Reactor Operations Department for the year 1961 was 1.05 rem or about 20 millirem per week.) 5

- - - - - - -

59. Occasionally, large overexposures occur as a result of incidents or emergencies. The probable results of such overexposures are summarized in Tables II-5 and II-6.

- - - - - - -

Table II-5. Results of Large Accumulated Overexposures*

| Dose Rate in Rem Per Day | Exposure Time | Probable Effects |
|---|---|---|
| 500 | 2 days | About 100% deaths |
| 100 | | Deaths begin after about 15 days |
| 60 | 10 days | Some deaths, crippling disabilities |
| 10 | 365 days | Some deaths |
| 3 | Few months | No drop in efficiency |
| 0.5 | Several months | No large-scale drop in life span |

*Radiological Health Handbook, 1960 Revision, p. 183.

- - - - - - -

60. Table II-5 shows that some deaths can be expected if the dose rate is 10 rem/day for 365 days; this results in a total dose of _____rem. It also shows that 100% deaths can be expected if the dose rate is 500 rem/day for 2 days; this results in total dose of _____ rem.

- - - - - - -

61. The fact that 100% deaths occur with a dose of 1000 rem received in 2 days, whereas only some deaths occur with a larger total dose of 3650 rem received in 365 days illustrates that, while the total dose is important, so also is the _____ _____.

3650, 1000

- - - - - - -

62. It appears that the human body can repair some types of radiation damage. Judging from Table II-5, if the dose rate is not too large, the body may be able to repair the damage at about the same rate it occurs.

dose rate or exposure time

- - - - - - -

63. When the radiation damage rate exceeds the body _____ rate, the damage rate is excessive. In this case, noticeable and undesirable effects occur.

- - - - - - -

64. Radiation damage to the skin or bone marrow from a low-level exposure is repairable to some extent. However, damage to the brain or kidneys appears not to be repairable; this type of damage accumulates (or is said to be "cumulative"). Examples of nonrepairable injuries (permanent) are shortening of the life span, genetic effects, or scar formation. repair

- - - - - - -

65. While Table II-5 shows the results of large doses accumulated over a period of time, Table II-6 shows the results of large overexposures which occur in a relatively short time (a period of hours or less). Note that for a "one-shot" dose of 200 to 400 rem, the percentage of deaths is _____.

- - - - - - -

Table II-6. Results of Large "One-shot" (Acute) Exposures*

| Dose in Rem | Probable Effects |
|---|---|
| 0 - 50 | Almost undetectable. |
| 50 - 100 | Temporary minor blood changes, possible nausea. |
| 100 - 200 | Vomiting, complete recovery in a few weeks. |
| 200 - 400 | Vomiting, loss of hair, small percentage of deaths, survivors recover in a few months. |
| 400 - 500 | Vomiting and nausea in all personnel on first day, 50% chance of survival, survivors recover in about 6 months. |
| 1000 | No recovery (death). |

*See also tables on pages 182-3 in Radiological Health Handbook (1960 Edition), and on pages B-14 and B-15 in Radiation Safety and Control Pocket Manual (June 1, 1961).

66. According to Table II-6, a "one-shot" dose of 400 to 500 rem gives the chances of survival as _____%, while a dose of 1000 rem results in ____% deaths. small

- - - - - - -

This 400 - 500 rem dose is commonly called the "Median Lethal Dose" or "$LD_{50}$". 50, 100

- - - - - - -

67. For a single exposure dose of up to 25 rem, we can expect the effects to be almost _____.

- - - - - - -

68. No official maximum exposures have been set for rescue teams or any other deliberately exposed persons for "extreme emergencies". However, some groups have suggested that 25 rem might be taken during an extreme emergency, since the results of a single-exposure dose of 25 rem is almost undetectable. (An extreme emergency would include such things as a national emergency, an act of life saving, or a situation where exposure is required to prevent the release of large quantities of radioactive material which could endanger the health of personnel in surrounding areas or the population at large.) undetectable

- - - - - - -

It is recognized that some self-sacrifice may be desired or necessary in extreme emergencies such as those described, but this is a matter of personal decision. (It is a matter of personal decision whether to volunteer to take the necessary dose, but it is not necessarily a matter of personal decision whether an extreme emergency does exist.) In such cases, those persons to be exposed should be made fully aware of the possible consequences before their self-sacrificial exposure. That is why you are being given this information now, while you have time to think.

- - - - - - -

69. In an extreme emergency, a dose which might be taken with almost undetectable results is _____ rem.

- - - - - - -

70. Although Table II-6 indicates that the results of 25 rem are almost _____, it is recommended that a dose this large be received only once in a lifetime. 25

- - - - - - -

71. After a person has been exposed to such a dose, an attempt should be made to limit his future exposure so as to reduce his accumulated total exposure (as soon as practical) to the recommended limit for his age as determined by the equation: total dose = _____. undetectable

- - - - - - -

72. Even though a 25-rem dose might be taken (once in a lifetime) with almost undetectable results, your exposure dose should always be kept at a minimum. 5(N-18)

- - - - - - -

## 5.6 Self Test

73. An individual who is working in a gamma-radiation field where the intensity is 10 rad/hr will receive a tissue dose of 25 rem in _____ hours. (If you made an incorrect response, repeat Frames 10 and 11.)

- - - - - - -

74. The kind of radiation an individual is exposed to must be known in order to determine the penetrating ability and the _____ factor. The characteristics of the radiation determine the type of _____ which must be used to detect it. (If you made an incorrect response, repeat Frames 13 through 16.)

2.5 or two and one-half

- - - - - - -

75. Which radiation (gamma, alpha) penetrates the body's outer protective layer of skin? Which radiation (alpha, beta) is more penetrating and capable of producing serious burns? (If you made an incorrect response, repeat Frames 17 through 20.)

RBE, instrument

- - - - - - -

76. A source of radiation which is inside the body causes more (ionization, tissue damage) than the same source outside the body. (If you made an incorrect response, repeat Frames 21 through 23.)

gamma, beta

- - - - - - -

77. If radioactive material gets inside the body, radiation exposure will last for (8, 24) hours a day. (If you made an incorrect response, repeat Frames 24 and 25.)

tissue damage

- - - - - - -

78. If a radiation source is outside the body, you will be exposed to only a fraction of the total radiation emitted by that source because of the geometry factor (in addition to the reduced time of exposure). If the radiation source gets inside the body, you will be exposed to _____% of the radiation emitted by the source. (If you made an incorrect response, repeat Frame 26.) 24

- - - - - - -

79. An internal source of radioactive iodine is very hazardous because iodine has a tendency to _____ in the thyroid gland. (If you made an incorrect response, repeat Frames 27 and 28.) 100

- - - - - - -

80. Can you think of three ways by which sources of radiation may get into the body? _____, _____, and _____. (If you made an incorrect response, repeat Frame 29.) accumulate or concentrate

- - - - - - -

81. The quantity of radioactive material getting inside the body can and must be limited by using effective _____ measures. (If you made an incorrect response, repeat Frames 30 and 31.) breathing, eating, drinking, wound

- - - - - - -

82. Some parts of the body are more sensitive to radiation than others; that is, they are more easily _____ by radiation. List the intestines, bones, and skin in the order of sensitivity. The most easily damaged should be listed first. _____, _____, and _____. (If you made an incorrect response, repeat Frames 31 through 35.)

control

- - - - - - -

83. The overall health of an individual will be affected more if a radiation exposure is to the (arm, whole body). (If you made an incorrect response, repeat Frames 36 through 38.)

damaged, intestines, skin, bones

- - - - - - -

84. The effect of radiation on an individual's health depends on the dose, the _____ _____, the _____ of radiation, and the _____ of the body exposed. (If you made an incorrect response, repeat Frames 39 through 41.)

whole body

- - - - - - -

85. The average dose from environmental sources of radiation which a person receives in one year is about _____ millirem. This is equivalent to an average daily dose of about _____ millirem. (If you made an incorrect response, repeat Frames 42 through 45.)

exposure time, kind or type, parts or portions

- - - - - - -

86. A large overexposure is not desirable because it may _____ the life span. (If you made an incorrect response, repeat Frames 46 and 47.)

204, one-half

- - - - - - -

87. The recommended maximum weekly dose to the most sensitive body organs for the Laboratory is _____ millirem. For the Reactor Operations Department, this recommended limit has been lowered to _____ millirem. (If you made an incorrect response, repeat Frames 48 through 58.) — decrease

- - - - - - -

88. If you receive an exposure in one week of 500 mrem, does this mean a scar may form? (Yes, No) (If you made an incorrect response, repeat Frame 53.) — 100, 50

- - - - - - -

89. The <u>average rate</u> of accumulation of absorbed dose to the total body should not exceed _____ rem per year, although the limit for any <u>single</u> year is _____ rem. (If you made an incorrect response, repeat Frames 54 through 58.) — No

- - - - - - -

90. If several people are exposed to a radiation dose rate of 10 rem/day, after 365 days some deaths can be expected. However, after 2 days at 500 rem/day, _____% deaths can be expected. (If you made an incorrect response, repeat Frames 54 and 61.) — 5, 12

- - - - - - -

91. Radiation damage is not cumulative if the body can _____ this damage. Radiation damage to the skin or bone marrow from a low-level exposure is _____ to some extent. (If you made an incorrect response, repeat Frames 62 through 64.) — 100

- - - - - - -

92. For a "one-shot" dose of 200 to 400 rem, the percentage of deaths is _____. For a one-shot dose of 400 to 500 rem, the chances of survival are 50%, while a one-shot dose of 1000 rem would result in _____% deaths. (If you made an incorrect response, repeat Frames 65 and 66.)

repair, repairable

- - - - - - -

93. Since the results are almost undetectable, a dose which might be taken (in a single, once-in-a-lifetime exposure) during an <u>extreme emergency</u> is _____ rem. (If you made an incorrect response, repeat Frames 67 through 69.)

small, 100

- - - - - - -

94. A dose of 25 rem (in a single exposure) should not be received more than once in a _____. (If you made an incorrect response, repeat Frames 70 and 72.)

25

- - - - - - -

lifetime

# SECTION II-6

## RADIATION PROTECTION METHODS

In this section we shall discuss the methods you can use to protect yourself from external sources of radiation. Specifically, we shall discuss methods of reducing the dose rate and the exposure time.

- - - - - - -

### 6.1 Review

1. Radioactive _____ is radioactive material which is an impurity in its environment. (Section II-2, Frames 34 through 37.)

- - - - - - -

2. Can you have radioactive contamination without having any radiation? (Yes, No) (Section II-2, Frames 48 through 62.)

contamination

- - - - - - -

3. The removal of electrons from an atom by direct interaction or electrical attraction and repulsion are the methods by which _____ causes _____. (Section II-3, Frames 20 through 24.)

No

- - - - - - -

4. Ionization by electrical attraction or repulsion is caused by (charged, uncharged) radiation, but direct interaction is necessary for (charged, uncharged) radiation to cause ionization. An electric field is a characteristic of (charged, uncharged) radiation. (Section II-3, Frames 25 through 35.)

radiation, ionization

- - - - - - -

5. The distance a charged particle can penetrate matter while causing ionization is called the _____ of the particle. Does uncharged radiation have a characteristic range? (Yes, No) (Section II-3, Frames 35 through 40.)

charged, uncharged, charged

- - - - - - -

6. If they both have the same energy, an alpha particle will have a (shorter, longer) range than the beta particle. (Section II-3, Frames 41 through 48.)

range, No

- - - - - - -

7. Radiation is either charged or uncharged. Radiation which is _____ does have a definite range; therefore, it is the most easily shielded. Radiation which is _____ does not have a definite range; therefore, it is the most penetrating type. (Section II-3, Frames 55 through 62.)

shorter

- - - - - - -

8. Uncharged radiation cannot be shielded completely, but the intensity can be reduced. A shield two TVL's thick will reduce the intensity to (1%, 2%, 10%, 20%) of its original value. (Section II-3, Frames 63 through 70.)

charged, uncharged

- - - - - - -

9. Radiation is emitted equally in all directions from a radioactive source; therefore, the probes of most detectors (can, cannot) count the radiation from all of the atoms which are disintegrating. (Section II-4, Frame 14 and Figure II-11.)

1% because 1/10 x 1/10 = 1/100 or 1%

- - - - - - -

10. The number which is divided into an instrument reading in counts per minute to obtain disintegrations per minute is called the (geometry, overall counter). (Section II-4, Frames 20 through 24.)

cannot

- - - - - - -

11. 1/1000 rem or 0.001 rem is known as a _____. (Section II-4, Frame 48.)

overall counter

- - - - - - -

12. Rem and rad are (dose, dose rate) units. Rem/hr and rad/hr are (dose, dose rate) units. Dose rate x time = _____. (Section II-4, Frames 49 through 51.)

millirem or mrem

- - - - - - -

13. An individual working in a 10 mrad/hr gamma-radiation field will receive a total tissue dose of 25 mrem in _____ hours. (Section II-4, Frames 10 and 11.)

dose, dose rate, dose

- - - - - - -

14. Which radiation (gamma, alpha) can penetrate the body's outer protective layer of skin? Which radiation (alpha, beta) is more penetrating and capable of producing serious burns? (Section II-5, Frames 17 through 20.)

2.5

- - - - - - -

15. Some parts of the body are more sensitive to radiation than others. List the head, skin, and hands in the order of sensitivity, with the most sensitive part first.

_____, _____, _____.

(Section II-5, Frames 32 through 35.)

gamma, beta

- - - - - - -

16. The effect of radiation on an individual's health depends on the dose, the _____ _____, the _____ of radiation, and the _____ of the body exposed. (Section II-5, Frames 39 and 41.)

head, skin, hands

- - - - - - -

17. The average dose from environmental sources of radiation which a person receives in one year is about 204 mrem. This is equivalent to an average daily dose of about _____ mrem. (Section II-5, Frames 42 through 45.)

exposure time kind or type, parts or portions

- - - - - - -

18. Since the results are almost undetectable, a dose which might be taken (in a single once-in-a-lifetime exposure) during an extreme emergency is _____ rem. (Section II-5, Frames 67 through 72.)

1/2

- - - - - - -

## 6.2 Planning, to Reduce Exposure

19. A question which is of primary concern for those of us who work with radiation is, "How can a radiation exposure dose be minimized?" Since dose = dose rate x exposure time, we can reduce the dose by reducing either the _____ _____, the _____ _____, or both.

25

- - - - - - -

20. The purpose of reducing the dose rate or the exposure time is to _____ the _____.

dose rate, exposure time

- - - - - - -

21. How can the exposure time be reduced? Unless the work to be done is routine (and routine procedures have been developed), careful and complete planning is necessary. Careful planning for a job would require that information be obtained on such things as the urgency of doing the job, how much radiation the individuals have already been exposed to, the type of radiation hazard involved, the dose rates, and many other things. Complete planning for a job would require that all steps be planned before starting the work. Complete and careful planning will, first of all, reduce unnecessary exposure time due to indecision as to "what to do next". Second, it will insure that the different techniques (or methods) of reducing exposure time are considered. The best technique (or combination of techniques) for the job can then be selected.

reduce or minimize, dose

- - - - - - -

22. One technique by which the exposure time can be reduced is by using several persons in sequence to do a job. For example, if a job requires one hour to complete and the dose rate is 100 mrem/hr; then if five persons are available, each individual should work no more than _____ minutes and receive a maximum dose of _____ mrem.

- - - - - - -

23. Another technique by which the exposure time can be reduced is by the use of tools which are designed and fabricated to do a special job quicker than could be done with the tools normally available. Still another technique would be for the workers to practice doing the job using nonradioactive, full-scale models of the equipment.

12, 20

- - - - - - -

24. Careful and complete _____ can help minimize the exposure time (and consequently the exposure dose). Three of the techniques which might be considered as part of this planning are: using several _____ in sequence; using special _____; and by _____ prior to doing the job.

- - - - - - -

## 6.3 Reducing the Dose Rate

planning, people or persons, tools, practice or practicing

25. We have considered some methods used to reduce the exposure time. Let us now consider the other half of the equation (dose = dose rate x exposure time) and discuss methods to reduce the dose by reducing the dose _____.

- - - - - - -

26. The dose rate (and thus the dose) can be minimized by at least three methods: adding some shielding material, waiting a period of time (for the radioactive material to decay), or moving to a greater distance away from the source of the radiation.

rate

- - - - - - -

27. By placing shielding material around the radiation source (or at least between you and the radiation source), the radiation will be absorbed entirely or partially by the shielding material. In other words, the radiation will cause ionization in the _____ _____ and not in you.

- - - - - - -

28. Therefore, the radiation dose rate to which your body will be exposed can be reduced by using _____ _____. shielding material

- - - - - - -

29. By the nature of radioactive decay, the number of atoms which are radioactive decreases continuously if no replacement is made. This is true even if this decrease is too slow to notice after a period of a week or two. Therefore, another way of reducing the dose rate is to allow a longer time for _____. shielding material

- - - - - - -

When a pie is taken out of the oven, you have to allow a little decay (cooling) time before you eat it; otherwise, you would burn your mouth. Unfortunately, unlike the cooling of the hot pie (which we can speed up by putting the pie in a refrigerator), we cannot change the rate of radioactive decay. decay

- - - - - - -

30. The farther we move away from the source of radiation, the less radiation we receive. Remember the discussion of the geometry factor for a detector. Consequently, another way by which we can reduce the dose rate (to which we are exposed) is to increase the _____ between us and the source.

- - - - - - -

31. In addition to reducing the exposure time by careful and complete planning, you can also reduce the dose rate (to which you are exposed) by the use of _____ material; by allowing a longer decay _____; and by moving a greater _____ away from the source of radiation.

distance

- - - - - - -

32. Thus you can reduce your radiation dose by reducing the exposure _____, the dose _____, or both.

shielding, time, distance

- - - - - - -

33. In any situation involving radiation, you should take advantage of any shielding which is available, even if there is shielding for only a part of your body.

time, rate

- - - - - - -

34. An example of the use of partial body shielding would be working from behind a thick, solid object (such as a concrete wall) with only the head and hands; or even better, only the hands exposed to the radiation. A metal or concrete post might be used also. Of course, if you do not have any work which has to be done in an area where there is radiation--get out.

- - - - - - -

35. Whenever you are working with radiation, you should consider the possibility of using at least some _____ _____ shielding.

- - - - - - -

36. Let us consider a few more details of the way shielding reduces the dose rate and consequently, the total _____.

partial body

- - - - - - -

37. There are two kinds of radiation, charged and uncharged. The shielding of charged radiation is relatively easy. All that is necessary is to use a thickness of material slightly greater than the _____ of the radiation in that material. dose

- - - - - - -

38. The ranges of some charged particles (with an energy of 1 Mev) are again listed in Table II-7. Note that the range of an alpha particle in air is about 1/5 of an inch, while the range of the beta particle in air is about 12 feet. range

- - - - - - -

Table II-7. Ranges of 1 Mev Charged Particles (in Inches)

| Particle and Charge | Air | Water | Concrete | Lead |
|---|---|---|---|---|
| $\alpha^{++}$ | 0.2 | 0.0002 | | |
| $\beta^{-}$ | 144.0 | 0.14 | 0.075 | 0.012 |

- - - - - - -

39. It might be interesting at this point to look at some graphs which show the variation in shielding required as the energy of the radiation increases. See Figures II-15 and II-16.

- - - - - - -

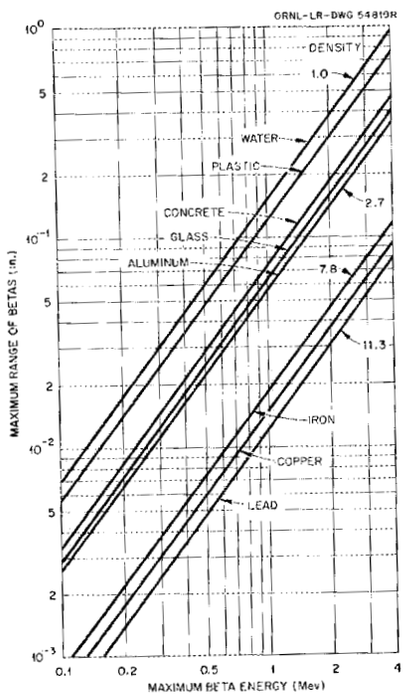



Fig. II-15. Beta-Radiation Shielding

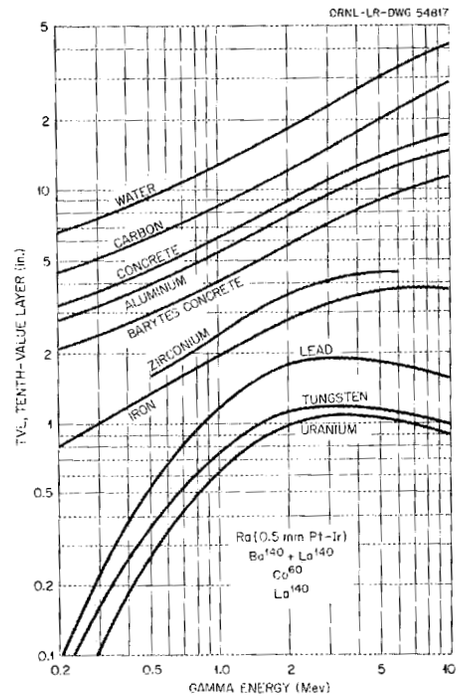



Fig. II-16. Narrow-Beam Gamma Radiation Attentuation

— — — — — — —

40. You may wonder why Figure II-16 shows that the thickness of lead, tungsten, and uranium required to make a TVL is less for 10-Mev gamma photons than for 2-Mev gamma photons. For heavy shielding materials, the thickness required for a TVL decreases for gamma photons having energies about 2 or 3 Mev. This is because with these high-density materials, gamma photons with energies >2 Mev are lost through an absorption process called pair production (a gamma photon spontaneously becomes a $\beta^-$ and $\beta^+$, a pair).

— — — — — — —

41. Since, at energies above 2 Mev, more gamma photons are lost because of an increased probability of _____ production, a TVL of lead for 8-Mev gamma photons is (greater, less) than for 2-Mev gamma photons.

— — — — — — —

42. A piece of aluminum 1/3 in.-thick will stop any beta particle (with less energy than about 4 Mev). So, if we keep a piece of aluminum 1/3-in. thick between us and the source of beta radiation, all of the beta radiation will be absorbed in the aluminum and none will reach us to cause any body damage. We would place the aluminum shield material as close to the source as we could get it.

pair, less

- - - - - - -

43. Only a few radioactive materials release alpha particles which have an energy greater than 4 Mev; therefore, alpha particles generally have a range less than an inch in air. (However, an 8-Mev alpha particle would travel almost 3 in. in air.) A thin piece of aluminum about 0.001-in. thick or a piece of paper about 0.002-in. thick is satisfactory to shield most alpha particles.

- - - - - - -

44. This page which you are now reading is about 0.002-in. thick--therefore, this piece of paper is satisfactory to use for shielding _____ particles.

- - - - - - -

45. Since a thin piece of aluminum 0.001-in. thick is all that is needed to shield most alpha particles, a piece of aluminum 1/3-in. thick, used to shield beta particles, (is, is not) adequate for shielding (alpha, neutron) particles.

alpha

- - - - - - -

46. To shield alpha particles, an ordinary sheet of paper is adequate. A piece of aluminum about 1/3 in. thick is adequate to shield both _____ and _____ particles.

is, alpha

- - - - - - -

47. Other things which will shield or absorb alpha particles are plastic bags, clothing, rubber gloves, wood blocks, aluminum, etc. To shield or absorb beta radiation, the material (can, must) be (thinner, thicker) than that used for alpha particles.

alpha, beta

- - - - - - -

48. Shielding uncharged radiation is an entirely different problem from that of shielding (charged, gamma) radiation.

must, thicker

- - - - - - -

49. As you should remember, uncharged radiation does not have an electric field surrounding it as does the charged radiation. Uncharged radiation must therefore interact directly with an atom in order to give up some or all of its energy. Since matter (atoms) is mostly empty space, uncharged radiation can penetrate deeply into matter (by passing between the nuclei and electrons) before an interaction occurs.

charged

- - - - - - -

50. Because uncharged radiation is more penetrating than charged radiation, (more, less) shielding material will be required for uncharged radiation.

- - - - - - -

51. Generally, therefore, when we wish to shield against a source of both charged and uncharged radiation, we (will, will not) have more than taken care of the charged radiation if we shield against the uncharged radiation. more

- - - - - - -

52. The complete absorption by a shielding material of all of the uncharged radiation is not possible. However, by using a sufficient thickness of some shielding material, the radiation intensity may be _____ to a tolerable level. will

- - - - - - -

53. In general, the thickness of shielding material required will depend upon the density of the material. More thickness is required for a less dense material. Less thickness is required for more dense material. reduced

- - - - - - -

## 6.4 Shielding--Tenth-Value and Half-Value Layers

54. Table II-8 gives the thickness of common material which will reduce the intensity of gamma ($\gamma$) radiation a specified amount. As you should remember, the TVL (tenth-value layer) is that thickness of material which will reduce the intensity of radiation to 10% or 1/10 of its original intensity. The HVL (half-value layer or half-thickness) is that thickness of material which will reduce the intensity to 50% or 1/2 of its original intensity. (Another name commonly used for HVL is "half-thickness".)

- - - - - - -

Table II-8. Shielding Effectiveness for 2- to 4-Mev Gamma Rays

| | Water (in.) | Concrete (in.) | Lead (in.) |
|---|---|---|---|
| Half-value layer (HVL) | 7.8 | 3.3 | 0.6 |
| Tenth-value layer (TVL) | 26.0 | 11.0 | 2.0 |

- - - - - - -

55. As you can see from the table, the half thickness (HVL) is about 0.3 (three-tenths) the tenth-value layer (TVL); the actual number is 0.3013 if you wish to be more accurate. All of these values are important, and it would be to your benefit to memorize them. You could memorize the TVL values and then remember that you can multiply the TVL value by _____ to obtain the _____.

- - - - - - -

56. Shielding calculations using TVL and HVL are easy to do; and to show this, we need only to work a few problems. Let us suppose that a radiation source produces a reading of 10 rad/hr on a detector which is 3 ft away. We will assume that we know that the source emits 0.9-Mev gamma photons and that although it also emits beta particles we do not know if the beta particles are getting through the container in which the source is sealed. We will also assume that there are no secondary complicating effects. Now let us further assume that for some reason or another, we <u>do not</u> want a radiation dose rate at that spot greater than 10 mrad/hr (0.01 rad/hr). Since 1 TVL of lead for 0.9-Mev gamma photons is 1 in. (see Figure II-16), we can place 1 in. of lead in front of the radiation source; and we find that the dose rate drops from 10 rad/hr to 1 rad/hr because 1 TVL of shielding material will reduce the dose rate to _____ of its original value.

0.3, HVL

- - - - - - -

There are a few things that you should think about before you continue. The dose rate of 10 rad/hr at 3 ft may be due to a combination of gamma and beta radiation because, as you know, beta particles (with an energy of 1 Mev) will travel about 12 ft in air; so some beta radiation could reach the spot 3 ft from the source. (Even 8-Mev alpha particles could not be causing any direct radiation dose.) Now, if the dose rate had dropped below 10% of 10 rad/hr when we put the TVL of lead in place, we could assume that part of the 10 rad/hr was due to beta radiation and the rest gamma. But for the rest of the problem, let us assume that all of the radiation is gamma radiation.

10% or 1/10

- - - - - - -

57. The 1 in. of lead (one TVL) had reduced the radiation level from 10 rad/hr to 1 rad/hr. By using another piece of lead 1-in. thick, the radiation level is reduced to _____ rad/hr or _____ mrad/hr.

- - - - - - -

58. The use of a third TVL of lead will reduce the radiation dose rate still further from 100 mrad/hr to _____ mrad/hr.

0.1, 100

- - - - - - -

59. The total thickness of lead required to reduce the dose rate from 10 rad/hr to 10 mrad/hr was _____ in. of lead,

10

- - - - - - -

60. If we now want to reduce the radiation level from 10 mrad/hr to 5 mrad/hr, we can use _____ in. of lead. (HVL = 0.3 x TVL)

3 because 3 TVL's were used, so 3 x 1 in. = 3 in.

- - - - - - -

You could use another TVL, one inch, and reduce the level to 1 mrad/hr, which is below the 5 mrad/hr level and thus a much safer value. But, it may be that we do not have room for another inch of lead or maybe our support for the shielding cannot stand that much more weight. It is convenient to estimate the required thickness of shielding by thinking of the number of TVL or HVL required. 0.3

- - - - - - -

61. There are various ways to show how much of a reduction in radiation intensity can be accomplished by using TVL and HVL. For example:

$$10 \text{ rad/hr} \times \frac{1}{10} = 1 \text{ rad/hr}$$

$$1 \text{ rad/hr} \times \frac{1}{10} = 0.1 \text{ rad/hr (or 100 mrad/hr)}$$

$$100 \text{ mrad/hr} \times \frac{1}{10} = 10 \text{ mrad/hr}$$

We could, of course, do this in one step rather than in three steps. For example:

$$\frac{10 \text{ rad/hr}}{10 \times 10 \times 10} = \frac{10 \text{ rad/hr}}{1000} = 0.01 \text{ rad/hr (or 10 mrad/hr)}$$

Each factor of 10 reduction (10 in the denominator) could be obtained by using _____ in. of lead, which is the thickness of one _____ for 0.9-Mev gamma radiation.

- - - - - - -

62. A mathematician would write the equation which describes the reduction in radiation intensity as: 1, TVL

$R_o\left(\frac{1}{10}\right)^x = R_1$; where $R_o$ is the original or initial radiation intensity without any shielding material; and where $R_1$ is the intensity to which the radiation level has been reduced by the use of shielding material.

$x = \frac{\text{total thickness of shielding used in inches}}{\text{TVL value in inches of the material used}}$; that is, x = the number of TVL used.

- - - - - - -

63. To illustrate the use of the equation, $R_1 = R_o\left(\frac{1}{10}\right)^x$, let $R_o$ = 10 rad/hr of gamma radiation and use 3 TVL of lead as shielding material. $R_1$, the radiation intensity to which 10 rad/hr is reduced by using 3 in. of lead (3 x 1 in. = 3 in.), is:

$$R_1 = 10\ \frac{\text{rad}}{\text{hr}}\left(\frac{1}{10}\right)^3 = \frac{\text{rad}}{\text{hr}}\left(\frac{1}{10} \times \frac{1}{10} \times \frac{1}{10}\right) = \frac{10\ \text{rad/hr}}{10 \times 10 \times 10} =$$

10 mrad/hr, which is the same answer we got before. If x = 4 for this same problem, what would $R_1$ be equal to?

\- - - - - - -

For x = 4, $R_1$ = 1 mrad/hr because $R_1$ =

$$10\ \frac{\text{rad}}{\text{hr}}\left(\frac{1}{10}\right)^4 = 10\ \frac{\text{rad}}{\text{hr}}\left(\frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10}\right) \text{ or}$$

$$\frac{10\ \text{rad/hr}}{10 \times 10 \times 10 \times 10} = 1\ \text{mrad/hr}$$

1 mrad/hr

\- - - - - - -

64. A mathematician would write the equation for half-thickness value as: $R_1 = R_o\left(\frac{1}{2}\right)^y$; where y is the number of HVL. So if $R_o$ is 10 rad/hr of gamma radiation and we use 10 HVL of lead as shielding material, what will the value $R_1$ be? $R_1 = 10\ \text{rad/hr}\left(\frac{1}{2}\right)^{10}$ = _____ mrad/hr.

\- - - - - - -

$$10\ \text{rad/hr}\left(\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}\right)$$

$$= \frac{10\ \text{rad/hr}}{2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2} =$$

$\frac{10\ \text{rad/hr}}{1024}$, which is equal to 0.0098 rad/hr or about 10 mrad/hr.

9.8 or ~10

\- - - - - - -

65. By knowing the values of the tenth-value layers (TVL) and half-value layers (HVL) and using the shielding equations, the amount of material necessary to reduce the radiation dose rate to a tolerable level can be determined.

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66. You are removing a sample from an experiment hole and the experimenter has calculated that the radiation level at 1 ft should be 25 rads of 0.9-Mev gamma radiation, no beta or alpha. You wish to build a shield of lead blocks to shield the sample while it decays. In order to allow a radiation intensity no greater than 12.5 mrad at 1 ft, the total thickness of the lead would have to be at least _____ in. (Reduce the intensity by using enough TVL and HVL to do the job.)

- - - - - - -

67. We could have calculated the above problem with logarithms as follows: $R_o\left(\frac{1}{10}\right)^x = R_1$, where we calculate x, the number of TVL used. Rewrite the equation as $\frac{R_o}{R_1} = \frac{1}{\left(\frac{1}{10}\right)^x} = \frac{10^x}{1^x} = 10^x$. 3.3 in.

By logarithms: $\log 25 - \log 0.0125 = x(\log 10)$

$1.3979 - 8.0969 - 10 = x$ (the log of 10 is 1)

Subtract:

$$\begin{array}{r} 11.3979 - 10 \\ \underline{8.0969 - 10} \\ 3.3010 \end{array} = x$$

We need, then, 3.3 TVL of lead at 1 in. each. Shielding thickness is _____ in.

- - - - - - -

68. If you had no lead but had 8-in.-thick concrete blocks, how many blocks thick would the shielding need to be? Refer to Table II-8 for TVL for concrete. — 3.3 in.

- - - - - - -

69. If the shielding is three blocks thick, the gamma radiation will be reduced to (exactly, less than, more than) 12.5 mrem. — 3 blocks

- - - - - - -

## 6.5 Radioactive Decay — less than

70. The greater the radiation dose rate is, the greater the shielding thickness must be to reduce the dose rate to a tolerable level. However, there may be occasions when the radiation dose rate of an object is so high that we do not want to approach it even to provide shielding. In this case, if we leave the object and return after a sufficiently long time, we will find that the radiation dose rate has decreased. The decrease in radiation intensity is due to _____ _____.

- - - - - - -

71. You will recall that "radioactive decay" is the process by which an atom gets rid of excess energy and becomes more stable by emitting _____. — radioactive decay

- - - - - - -

72. The radiation emitted by a source results from the disintegration (or decay) of the radioactive atoms in the source. Since most radioactive atoms decay to nonradioactive (or stable) atoms, if no replacement is made the number of radioactive atoms will (decrease, increase) and so must the radiation intensity. — radiation

- - - - - - -

73. There is an equation which can be used to determine the gamma radiation dose rate one foot from a source if you know the number of curies of radioactive material in the source and if the source is small enough (so that we can consider all of the radiation as coming from a single point). The equation is: rad/hr at 1 ft = 6 CE, where C is the number of curies and E is the energy (Mev) of the gamma photons.

decrease

- - - - - - -

74. Let us calculate the dose rate 1 ft away from a source containing 1 curie of $^{16}N$ radioactive atoms which emit gamma photons with an energy of 6 Mev. The dose rate would be equal to _____.

- - - - - - -

75. You have a 10-millicurie $^{226}Ra$ source used to check the response of G-M survey meters. The $^{226}Ra$ emits a 0.19-Mev gamma photon. If it is held 1 ft from your hand, the dose rate to your hand is _____ mrem/hr.

36 rad/hr

- - - - - - -

76. The interval of time which we wait for the radiation intensity to decrease due to the radioactive decay of the atoms is commonly referred to as the <u>decay time</u>.

1.14

- - - - - - -

77. The longer we allow the radioactive material to decay (longer decay time), the more the radiation intensity will be reduced. That is, the radiation dose rate will decrease as the _____ _____ increases.

- - - - - - -

A common example of using decay time to reduce the radiation intensity is the practice of withdrawing an experiment from the neutron flux several days before it will be removed from the reactor. Also, some isotope samples would be withdrawn from the flux ahead of the shipping time to allow for the decay of the short half-life aluminum-28 that is in the container.

decay time

- - - - - - -

78. The decay time necessary for 50% (1/2) of the radioactive atoms to decay is generally referred to as the half-life ($T_{1/2}$) of that particular radioactive isotope. So, if at 12:00 noon we have a source which contains 100 radioactive atoms and at 1:00 p.m. there are only 1/2 as many (i.e., 50) radioactive atoms left, then we can say that radioactive isotope has a _____ _____ of (1 hr, 30 min).

- - - - - - -

79. Since at 12 noon we had 100 radioactive atoms and at 1:00 p.m. we only had half as many (50), then at 1:00 p.m. there will be only _____ as much radiation being emitted.

half-life, 1 hr

- - - - - - -

80. If the radiation dose rate from a source was 10 rad/hr, after one half-life the radiation dose rate will be _____ rad/hr.

half or 50%

- - - - - - -

The mathematical equation for the half thicknesses, which was given when we were talking about shielding, is also applicable in considering decay time--provided there is only one particular radioactive isotope present. That is: $R_o \left(\frac{1}{2}\right)^t = R_1$ where $R_o$ is the original dose rate; where $R_1$ is the dose rate after decay; and where t is the number of half lives. 5

- - - - - - -

81. So now we see that there are two methods by which a radiation dose rate of 10 rad/hr can be reduced to 5 rad/hr. We can use a thickness of shielding material equal to the _____-_____ value, or we can wait a period of time equal to the _____ _____.

- - - - - - -

Here is a brief table which lists the half-lives of some radioactive isotopes which are quite frequently dealt with in reactor operation. half-thickness, half-life

- - - - - - -

Table II-9. Half Lives

| Radioisotope | Half-Life |
|---|---|
| Argon-41 | 1.82 hours |
| Aluminum-28 | 2.3 minutes |
| Cobalt-60 | 5.2 years |
| Iodine-131 | 8.05 days |
| Nitrogen-16 | 7.4 seconds |
| Sodium-24 | 15.0 hours |
| Uranium-235 | $7.1 \times 10^8$ years |

- - - - - - -

82. Assume that a quantity of a radioactive isotope such as aluminum-28 causes a gamma radiation dose rate of 100 mrad/hr at a point 10 ft from the source. (Al-28 emits 1.78-Mev gamma photons and has a 2.3-min half-life.) After waiting 2.3 minutes, we will notice that the radiation intensity has dropped from 100 mrad/hr to _____ mrad/hr.

- - - - - - -

83. After waiting a period of time equivalent to 2 half-lives (4.6 minutes), we will find that the radiation dose rate has decreased from 100 mrad/hr to _____ mrad/hr. $\frac{100}{2} = 50$

- - - - - - -

84. After waiting a period of 6.9 minutes, what is the dose rate? _____ mrad/hr. $\frac{100}{2 \times 2} = 25$

- - - - - - -

12.5 mrad/hr because $\frac{6.9}{2.3} = 3$, and $\frac{100}{2 \times 2 \times 2} = 12.5$ 12.5

- - - - - - -

85. One way we could write a problem like this if it is not too long and difficult is to write it down like this:

100 mrad/hr x $\frac{1}{2}$ = 50 mrad/hr after the first 2.3 min
50 mrad/hr x $\frac{1}{2}$ = 25 mrad/hr after the second 2.3 min
25 mrad/hr x $\frac{1}{2}$ = 12.5 mrad/hr after the third 2.3 min
12.5 mrad/hr x $\frac{1}{2}$ = _____ mrad/hr after the fourth 2.3 min

- - - - - - -

86. If these radiation readings are plotted on graph paper as a function of the time, the results would be as shown in Figure II-17. 6.25

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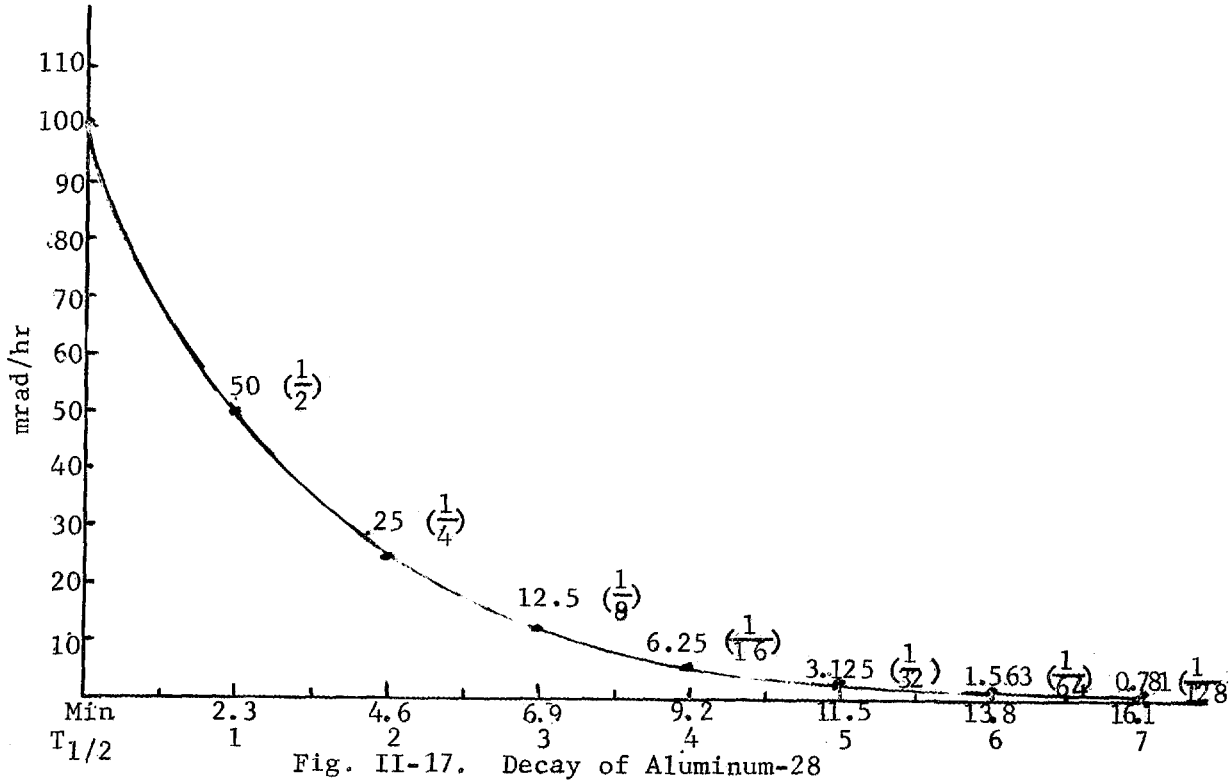


Fig. II-17. Decay of Aluminum-28

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87. Note that after about 3.3 half lives (7.6 minutes) the radiation level has decreased to 10 mrad/hr (about 10% of its original intensity). After 7 half lives, the radiation level has decreased to <u>less</u> than 1% of its original intensity.

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88. If we plot this same information on the type of graph paper shown in Figure II-18 (called semi-log paper), the line representing the decay will be straight.

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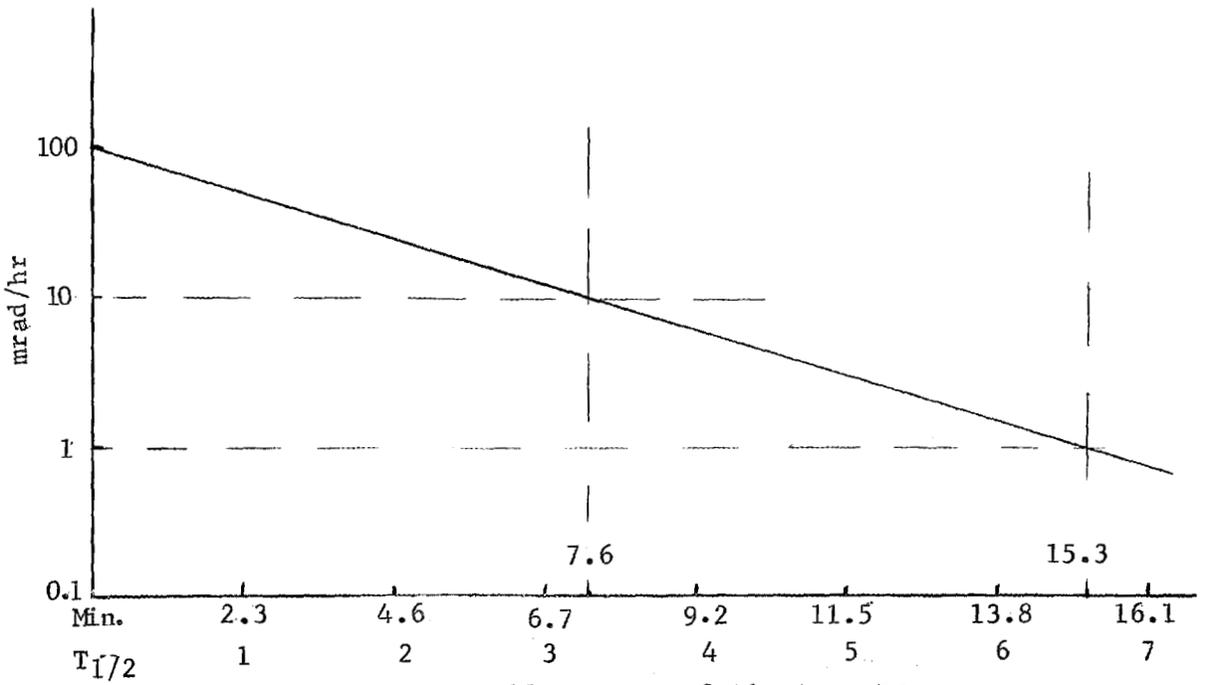


Fig. II-18. Decay of Aluminum-28

We can see that the radioactive decay of an isotope is a curve on plain graph paper. By using semi-log-type graph paper, the same information appears as a straight line. Note that on the plain graph which follows, after about 7 half-lives, it appears that the dose rate is zero; but this is not true as can clearly be seen by looking at the semi-log graph which shows that after 10 half-lives, the dose rate is still about 0.1 mrad/hr. The point is the information on the semi-log graph after 7 half-lives can still be analyzed, but the information after 7 half-lives on the plain graph cannot because it appears to be zero.

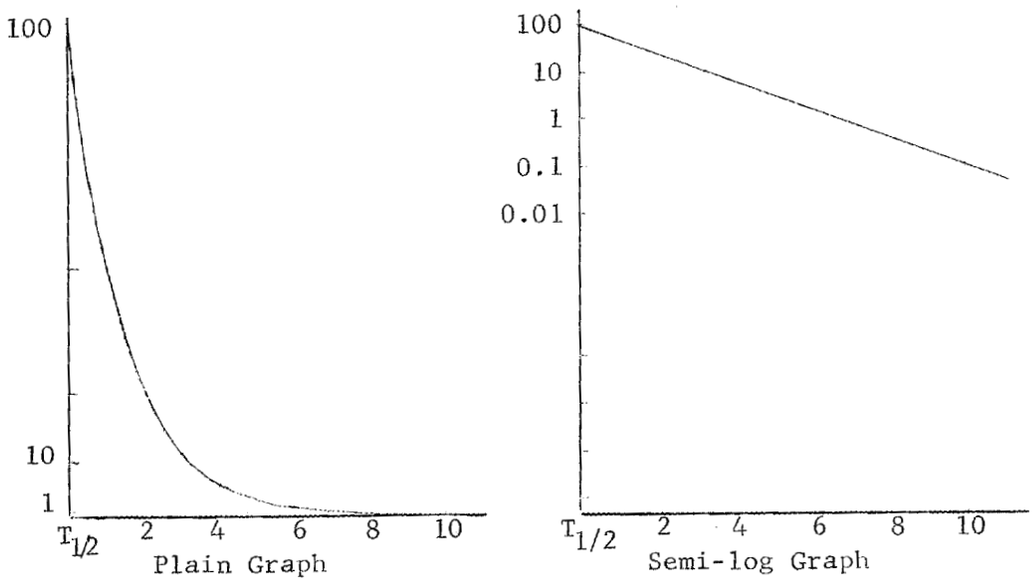


Fig. II-18a.

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89. Figure II-19 is a semi-log plot of percent radiation dose rate (or activity or number of atoms) as a function of the number of half-lives. This graph may be used to find the amount the radiation intensity from any radio-isotope sample has decreased after a period of time if we know what the value of the half-life is for that radioisotope.

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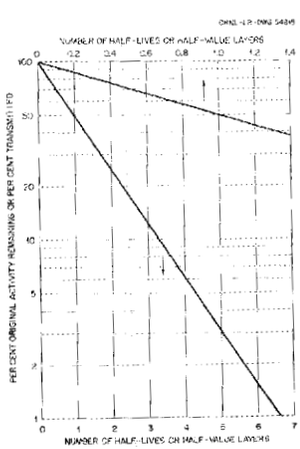


Fig. II-19.

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This graph cannot be used if there is more than one radioisotope present, since there will be more than one $T_{1/2}$ value. When there are two or more radioisotopes present with different $T_{1/2}$ values (and therefore with different decay rates), the curve representing the decay of several isotopes is much more complicated.

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90. As you can see from the graph, at the end of one half-life (whether it is 1 minute or 1 year), the radiation intensity will have decreased to _____% of its original value.

- - - - - - -

The radiation intensity (dose rate) has decreased to 50% because the number of radioactive atoms has decreased to 50%. So, whether the quantity you are interested in is counts per minute, mrad/hr, or the number of radioactive atoms present, after 1 $T_{1/2}$ each of these quantities will have decreased 50%.

50%

- - - - - - -

91. Again it should be pointed out that at the end of about 4 half-lives (actually 3.3) the radiation will have been reduced to less than 10% of its original rate. At the end of about 7 half-lives (actually 6.6) the radiation will have been reduced to less than _____%.

- - - - - - -

92. Although the initial dose rate may be reduced to less than 1% by waiting an interval of time equal to about 7 half-lives, the initial dose rate may be so great that even 1% is still a very damaging dose rate. For example, if the initial dose rate is 100,000 rem/hr, after 7 half-lives, the dose rate would still be about _____ rem/hr. At this dose rate, exposure for 1 hr will still result in death. 1

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93. Another point to keep in mind is that the dose rate may be large or small; but if the half-life is long, for example days or months, then you cannot expect a large decrease in the radiation intensity in a few (hours, years). 1000

- - - - - - -

94. If there is more than one radioactive isotope present, the decrease in the radiation dose rate will not be represented by a straight line on semi-log paper. The total radiation from two radioisotopes at any particular time is the sum of the radiation from the separate radioisotopes; and it is this sum which is detected by an instrument or to which the body will be exposed. Figure II-20 shows how a radiation reading from a combination of the isotopes nitrogen-16 and aluminum-28 would decrease. The line representing the total radiation shows what might be detected by an instrument; this line is the sum of the dose rates from both radioisotopes. hours

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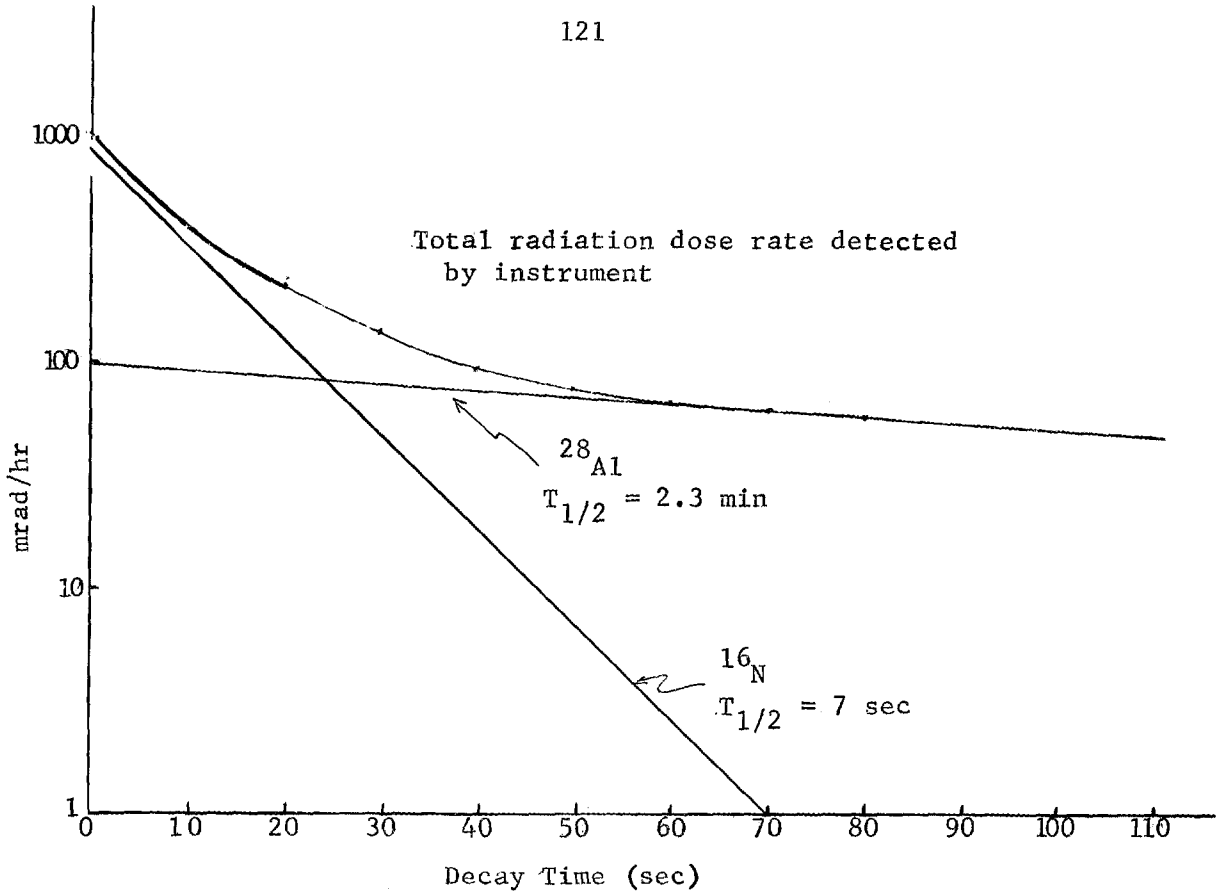


Fig. II-20. Decay of Two Radioisotopes

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Nitrogen-16 and aluminum-28 are both produced in reactors like the LITR, ORR, and HFIR. The nitrogen-16 comes from irradiation of water and the aluminum-28 from irradiation of structural material of the reactors.

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95. Inspection of this graph shows that initially (when t = 0) the dose rate was 1000 mrad/hr - 100 mrad/hr due to $^{28}Al$ and 900 mrad/hr due to $^{16}N$. After about 70 sec (about ten $^{16}N$ half-lives), the dose rate due to the $^{16}N$ has become insignificant. However, the dose rate is still about 70 mrad/hr due to the $^{28}Al$. By allowing a total decay time of 16.1 minutes, the total dose rate would be about _____ mrad/hr.

- - - - - - - -

After 70 seconds, the dose rate from $^{16}N$ can be ignored. The 16.1 minutes is equal to 7 $T_{1/2}$ values for $^{28}Al$; after a period of 7 half-lives, the radiation will have been reduced to a little less than 1% of its original value. So, since initially we had 100 mrad/hr due to the $^{28}Al$, after 7 $T_{1/2}$ we will have only about 1 mrad/hr. 1

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## 6.6 Shielding with Distance

96. Now that we have discussed shielding and decay time, we should discuss distance. The third method by which the radiation dose rate to the body can be reduced is to move away from the source of radiation. That is, the dose rate to the body can be decreased by increasing the _____ between you and the source.

- - - - - - -

97. A similar effect is experienced with a 40-watt light bulb mounted on the ceiling. An individual trying to read a book will find that the lighting is better the closer he gets to the lamp. But as he moves away from the lamp, the book becomes harder to read because there is less light (radiation) falling on the pages of the book. This occurs because the same amount of light is now covering a greater area; so the amount falling on the pages of the book is less. Let us take a look at Figure II-21, which illustrates how this geometry effect occurs. distance

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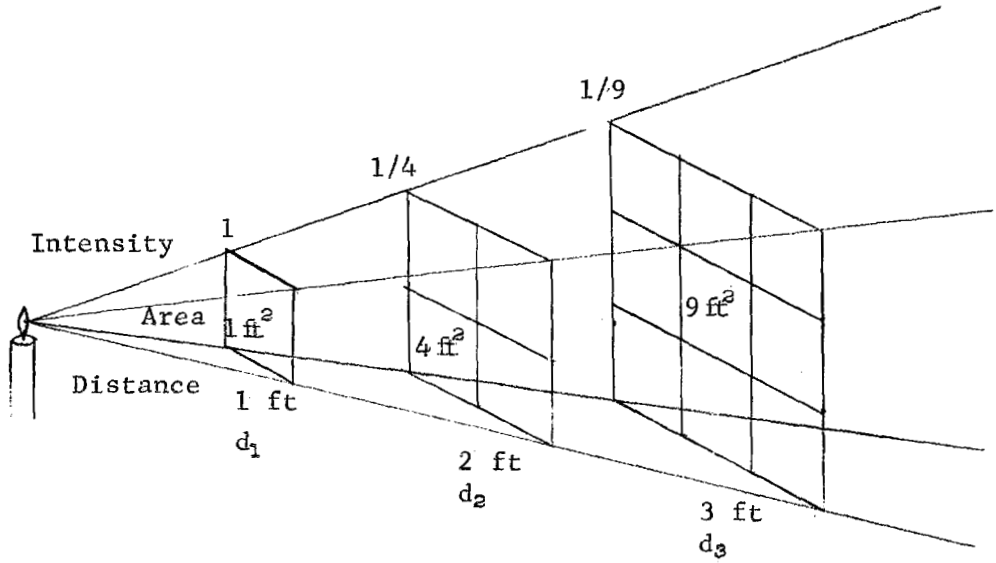


Fig. II-21. Geometry Effect

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98. At a distance $d_1$, 1 foot, from a point source (candle) a certain amount of radiation (light) will fall on 1 sq ft of area (the book's page). However, at a distance $d_2$, 2 feet, that same amount of radiation is now spread out over an area of 4 square feet. So the amount of radiation (or light) which falls on a square foot of area is much <u>less</u> at a distance of (one foot, two feet) than it is at a distance of (one foot, two feet).

- - - - - - -

> You may wonder how we know that the amount of light which covers 1 sq ft at a distance 1 ft from the candle would have to cover 4 sq ft at a distance of 2 ft. Remembering that the same amount of light goes out in all directions, compare the surface area of a sphere with a 1-ft radius to the surface area of a sphere with a 2-ft radius.
> (Surface area = $4\pi$ x radius$^2$.)

two feet,
one foot

- - - - - - -

99. The fact that, even with no absorption, the amount of radiation (or light) which falls on a certain area <u>decreases</u> as the distance from the source <u>increases</u> is due to the "geometry effect". A mathematician would say that the amount of light falling on a certain area varies <u>inversely</u> with distance.

- - - - - - -

100. So, by moving away from a source of radiation, the amount of radiation (dose rate) which hits your body (about 5 or 6 sq ft of area) will (increase, decrease).

- - - - - - -

| |
|---|
| You must take care that in an actual situation, such as working on the ORR tank top, while trying to get away from one source you do not back into another source. |

decrease

- - - - - - -

101. If you know or can determine the radiation dose rate at either a distance $d_1$ or $d_2$ and know or measure the distances $d_1$ and $d_2$; then by using a mathematical equation you can calculate the radiation dose rate at the other position. The mathematical equation is:

$$(\text{dose rate at } d_1)\ (\text{the distance } d_1)^2 = (\text{dose rate at } d_2)\ (\text{the distance } d_2)^2$$

- - - - - - -

Whether the dose rate is in units of rad/hr or rem/hr, the equation still works.

You can readily see that if you know or can determine the values of any three of the variables ($d_1$, $d_2$, dose rate at $d_1$, or dose rate at $d_2$), the fourth variable can be determined. For example, you may know the distance $d_1$, the dose rate at $d_2$, and the distance $d_2$. By using the equation, you can calculate the dose rate at $d_1$.

- - - - - - -

102.. Working a problem might be helpful. Calculate the dose rate at $d_1$ if:

$d_1 = 1$ ft (dose rate at $d_1$) = ?

$d_2 = 2$ ft (dose rate at $d_2$) = 40 mrem/hr

$$(\text{dose rate at } d_1)(d_1)^2 = (\text{dose rate at } d_2)(d_2)^2$$

$$(\text{dose rate at } d_1)(1)^2 = (40)(2)^2$$

$$(\text{dose rate at } d_1) = \frac{40 \times 2^2}{1} = \frac{40 \times 4}{1} = \underline{\qquad}\text{ mrem/hr.}$$

- - - - - - -

103.. The equation: (dose rate at $d_1$)$(d_1)^2$ = (dose rate at $d_2$)$(d_2)^2$ is sometimes referred to as the "inverse square law" equation because the dose rate is <u>inversely</u> proportional to the <u>square</u> of the distance from the source. To illustrate what this means, let us review the problem we just worked. We saw that at a distance of 2 ft the dose rate was $160/2^2 = 160/4 = 40$ mrem/hr; that is, the intensity <u>decreased</u> by a factor of four as the distance increased by a factor of two (i.e., <u>inversely</u> proportional to the distance <u>squared</u>). 160

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104. If we now calculate the dose rate at a distance of 4 ft, we will get:

$$\text{dose rate at 4 ft} = \frac{(160 \text{ mrem/hr})(1)^2}{4^2} = \frac{160 \text{ mrem/hr}}{16};$$

so the dose rate at 4 ft is 10 mrem/hr. So now we should begin to see the influence of distance: At 1 ft the dose rate was 160 mrem/hr, at 2 ft it was _____ mrem/hr, at 3 ft it would be 17.8 mrem/hr, and at 4 ft it was _____ mrem/hr. This should indicate to you what is meant when we say the dose rate is inversely proportional to the square of the _____.

40, 10, distance

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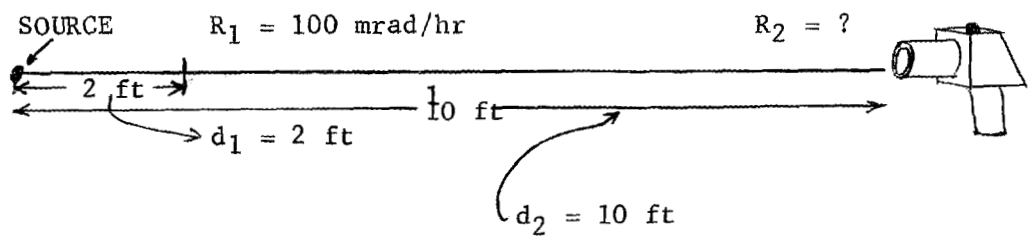
105. Let us assume you are standing 2 ft away from a point source of radiation and the dose rate at this point is 100 mrad/hr. Calculate what the dose rate would be at a distance 10 ft away from the source.




Let $R_1$ stand for the dose rate at $d_1$ and $R_2$ the dose rate at $d_2$. Then the equation:

$$(\text{dose rate at } d_1)(d_1)^2 = (\text{dose rate at } d_2)(d_2)^2 \text{ becomes}$$

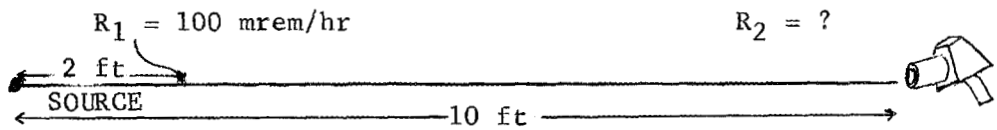
$$(R_1)(d_1)^2 = (R_2)(d_2)^2$$

Since we know that $R_1$ = 100 mrad/hr, $d_1$ = 2 ft, and $d_2$ = 10 ft, we can substitute these values into the equation in order to find the value of $R_2$. So we have $(100 \text{ mrad/hr})(2)^2 = (R_2)(10)^2$, which is the same as

$$R_2 = \frac{100 \text{ mrad/hr } (2)^2}{(10)^2} = \frac{(100 \text{ mrad/hr})(4)}{100} = _____$$

- - - - - - -

106. Using the same symbols ($R_1$, $R_2$, $d_1$, and $d_2$), assume $R_1$ = 100 mrem/hr, $d_1$ = 2 ft, $d_2$ = 20 ft, and find $R_2$. To help you with the problem you could draw a picture: 4 mrad/hr




The radiation dose rate at $d_2$ = _____ mrem/hr.

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$$(R_1) \times (d_1)^2 = (R_2) \times (d_2)^2$$
$$100 \text{ mrem} \times 2^2 = R_2 \times 20^2$$
$$\text{So, } R_2 = \frac{100 \text{ mrem} \times 4}{400} = \frac{400 \text{ mrem}}{400} = 1 \text{ mrem.}$$

1

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107. Now from these problems you should recognize that the <u>more</u> distance there is between you and the source of radiation, the (more, less) radiation you will be exposed to.

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108. The main reason that the dose rate from a radiation source gets larger the closer we get to it is due to the (geometry effect, air shielding). less

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109. Since you now can work with $1/d^2$ equation, we will derive the equation. You do not need to spend a lot of time trying to memorize all of this, but you may wish to see the derivation of the equation. First of all, let us again look at Figure II-20, which shows light spreading out from a candle. The radiation (light) which is emitted can be considered to fall on the inside surface of an imaginary sphere (ball) which has its center at the light source. The surface area geometry effect

of any sphere (ball) is $4\pi r^2$, where r is the radius. In this case, the radius is the distance (d) from the light source to the surface of the sphere. The next thing to remember is that the total amount of radiation is spread out over the entire surface of the sphere, regardless of the size of the sphere. The more surface there is, the less radiation there will be striking each square foot. We can put this information in the form of the equation:

(Radiation per sq ft at $d_1$)(area of sphere at $d_1$) is equal to
(Radiation per sq ft at $d_2$)(area of sphere at $d_2$)

Each of these are equal to the total amount of radiation coming from the source.

Let $R_1$ = the radiation per sq ft at $d_1$
$4\pi(d_1)^2$ = the area of sphere at $d_1$
$R_2$ = the radiation per sq ft at $d_2$
$4\pi(d_2)^2$ = the area of sphere at $d_2$
Then the equation becomes:

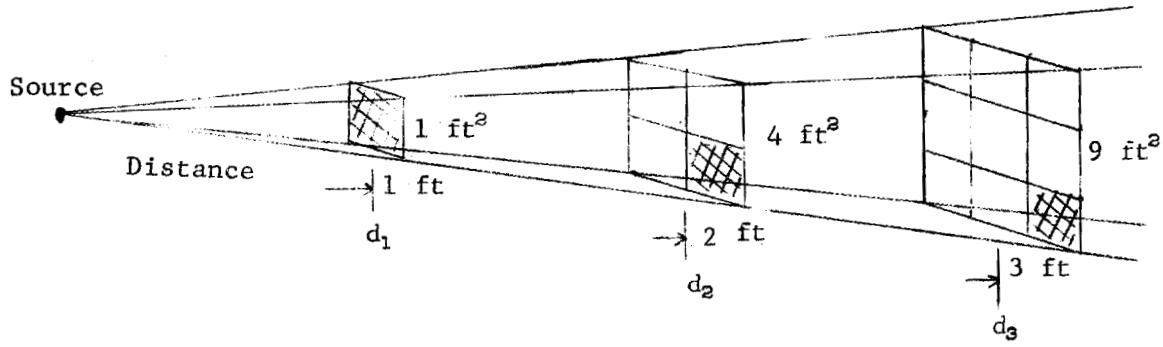
$$(R_1)(4\pi d_1^2) = (R_2)(4\pi d_2^2) \text{ or } 4\pi(R_1)(d_1^2) = 4\pi(R_2)(d_2^2)$$

This is equal to:

$$(R_1)(d_1^2) = \frac{(R_2)(d_2^2)(4\pi)}{(4\pi)} = (R_2)(d_2^2)$$

- - - - - - -

110. Refer to the figure below.




If the shaded area at $d_1$ (1 ft) receives a dose rate $R_1$ equal to 100 mrad/hr, then at $d_2$ = 2 ft the radiation reading will be $R_2 = R_1 \ (d_1^2/d_2^2)$ or $R_2 = \frac{100 \times 1^2}{2^2} = \frac{100}{4} = 25$ mrad/hr.

At $d_3$ = 3 ft, $R_3 = \frac{100 \times 1^2}{3^2} = \frac{100}{9} = 11.1$ mrad/hr

$R_1$ (at a distance of 1 ft) $= \frac{100 \text{ mrad/hr}}{1} = \frac{100 \text{ mrad/hr}}{1}$

$R_2$ (at a distance of 2 ft) $= \frac{100 \text{ mrad/hr}}{4} = \frac{25 \text{ mrad/hr}}{1}$

$R_3$ (at a distance of 3 ft) $= \frac{100 \text{ mrad/hr}}{9} = \frac{11.1 \text{ mrad/hr}}{1}$

Note how the dose rate decreases as the _____ from the source _____ because the total amount of radiation is received by a larger _____.

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111. What we have been talking about is a point source; that is, we have been assuming that the source is shaped compactly like a small ball or point. However, there are other shapes of radiation sources which a reactor operator might encounter. For instance, another radiation source which is pretty common is one which is shaped like a long, slender rod (sometimes referred to as a "line" source). A long crack in the biological shielding surrounding a reactor might be an example of a line source.

distance, increases, area

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112. The decrease in dose rate with distance from a line source is different than the decrease from a point source. Whereas the equation for the point source was $R_1 \times d_1^2 = R_2 \times d_2^2$, we cannot derive such a simple equation for the decrease in dose rate with distance from a line source.

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113. If the line were infinite (i.e., had no end or limit in either direction), we could derive and use the equation:

$$R_1 \times d_1 = R_2 \times d_2$$

This equation would tell us that the dose rate is inversely proportional to just the _____ from an infinite line source (not the square of the distance as was true for a point source).

- - - - - - -

114. To illustrate how the dose rate really decreases with distance from several types of sources, we will assume each source results in a dose rate of 100 mrad/hr at 1 ft from the source. We will further assume that the decrease in dose rate is only due to geometry. The dose-rate decrease with increased distance is shown in Figure II-22. distance

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115. This figure shows us that the $1/d^2$ law works for sources other than point sources if they are far enough away. The figure also shows that the dose rate from a line source as long as 10 ft does not decrease nearly as slowly with distance as does that from an infinitely long line source (which follows the 1/d law). Of course, the sources required to obtain all the curves shown in Figure II-22 would not contain the same number of curies.

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The point is that the change of dose rate (from different shaped sources) with distance does not follow any one simple law. When entering a marked "radiation zone" or an area where the radiation dose rate is not continuously monitored, the best thing to do is to use a radiation detecting instrument after making sure it is working properly. (Briefly, a "radiation zone" is an area where special measures are taken to control the radiation exposure to personnel due to external sources; this term will be defined in more detail later.)

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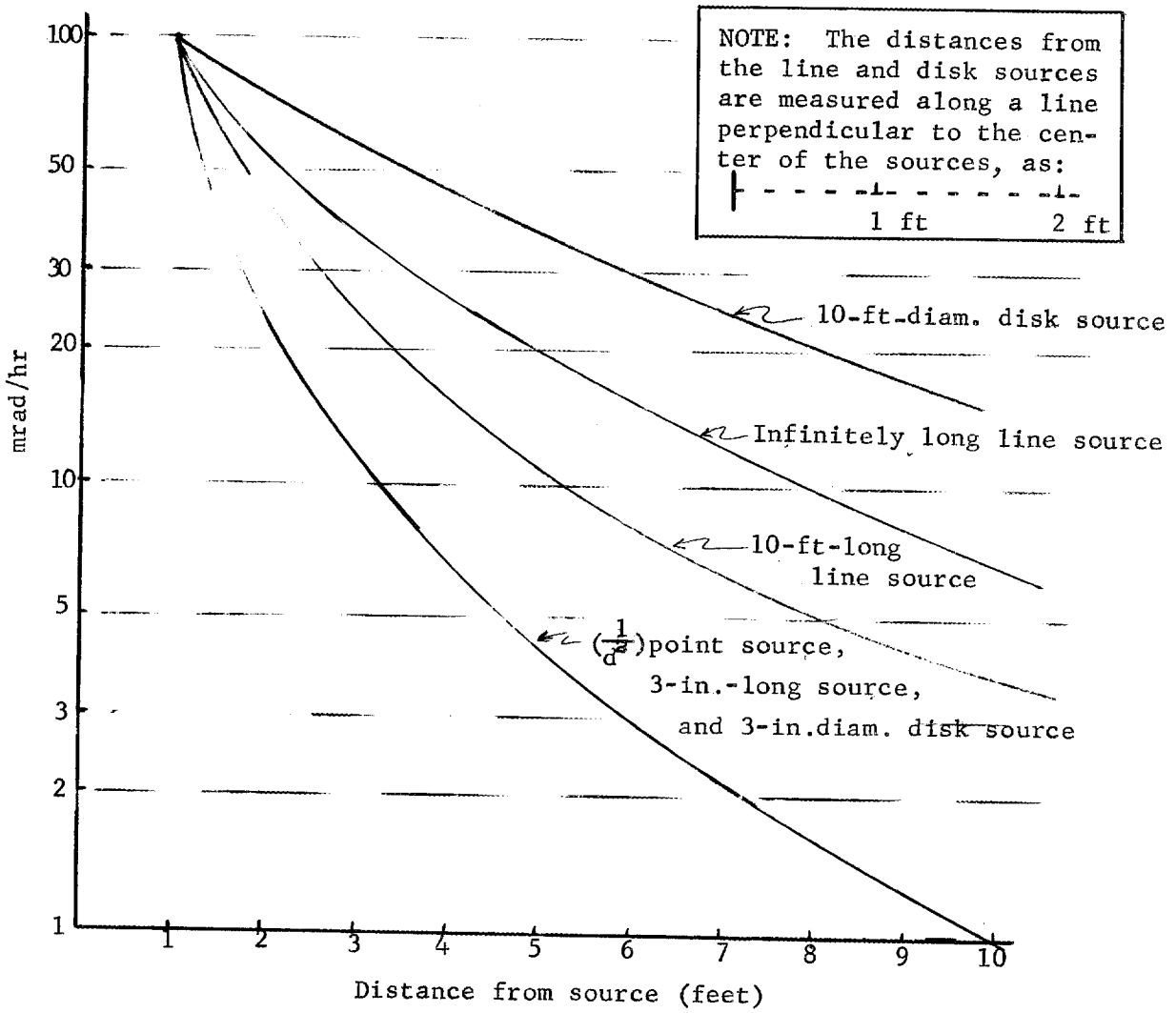


Fig. II-22. Radiation Dost Versus Distance From Source

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116. Now, let us try a hard problem and call upon some of the knowledge which you have acquired by now. Let us apply what we have learned about shielding materials and the $1/d^2$ law and calculate the radiation dose rate from a radioactive isotope sample which is in a lead container. Assume that the dose rate 1 ft from the sample was measured in air before the sample was put into the container and was found to be 100 rad/hr. One-half of this dose rate was found to be due to beta radiation; the other half was due to gamma radiation. Now let us begin to determine the radiation dose rates ($R_1$, $R_2$, and $R_3$) at the various distances from the sample as shown in Figure II-23.

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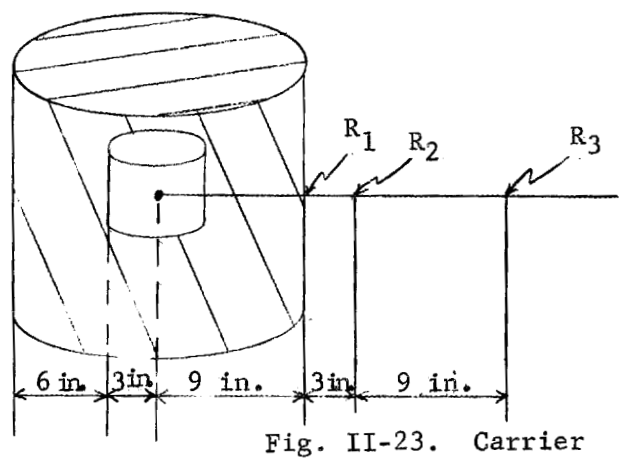


Fig. II-23. Carrier

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117. You will recall from Fig. II-17 that the range of a 4-Mev-beta particle in lead is less than 0.2 in. Since there is 6 in. of lead shielding provided by the container, all of the beta radiation will be absorbed in the lead; and there will be no beta radiation outside the container. Thus, with the source in the container, we can forget the beta radiation. This allows us to consider a dose rate from the source, without shielding, of only _____.

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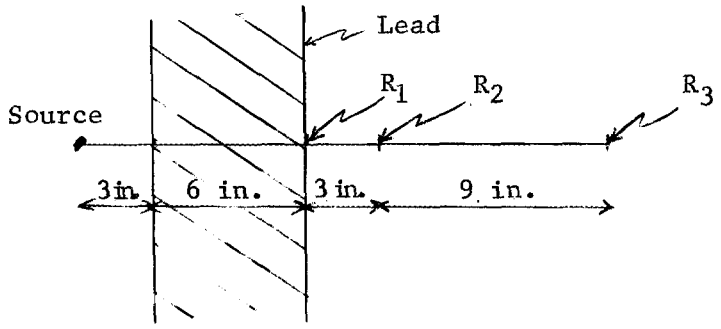
118. A diagram of the problem would look like: 50 rad/hr




$R_2$ is 50 rad/hr without the lead shielding.

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119. With the 6 in. of lead shielding (three TVL's for the most difficult to shield gamma radiation), the dose rate of $R_2$ is reduced to at least _____.

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Since 6 in. of lead shielding is 3 TVL, $\frac{50 \text{ rad}}{\text{hr}}\left(\frac{1}{10}\right)^3 = \frac{50 \text{ rad/hr}}{1000} = 0.050$ rad/hr = 50 mrad/hr. You should remember that if you take the sample out of the carrier, both the beta and the gamma radiation will be unshielded; and the dose rate 1 ft away will be 100 rad/hr.

0.05 rad/hr
or 50 mrad/hr

- - - - - - -

120. With the lead shielding in place, the $R_2$ will be 50 mrad/hr, and this is at a distance 1 ft from the source. Now let us use the $1/d^2$ equation and find the value of $R_1$. Since $R_2$ is 50 mrad at 1 ft (12 in.) from the source and $R_1$ is 9 in. from the source, the equation becomes:

$$R_1 = 50 \times \frac{(12)^2}{9^2} = 50 \times \left(\frac{12}{9}\right)^2 = 50 \times \left(\frac{4}{3}\right)^2 = 50 \times \frac{16}{9} = \frac{800}{9} = 88.9$$

- - - - - - -

121. Now figure out the dose rate $R_3$, which is 21 in. from the source. $R_3$ is equal to about _____ mrad/hr.

- - - - - - -

$$R_3 = 50 \text{ mrad} \times \frac{(12)^2}{(21)^2} = 50 \times \left(\frac{12}{21}\right)^2 = 50 \times \left(\frac{4}{7}\right)^2 = 50 \times \frac{16}{49} = \frac{800}{49} = 16.3$$

16

- - - - - - -

122. Review the problem you have just finished after you have read and thought about the following things.

a. The distances used are those to the radioactive sample, not to the carrier because the "sample" is the _____, not the carrier. Always keep this in mind.

b. If the source is not in the center of the carrier, the dose rates will be (the same, different) on different sides of the carrier.

c. Near the source, the dose rate may be due to a combination of beta and gamma radiation. (For example, the range of a 1-Mev beta particle in air is about 12 ft.) However, the shielding material used for gamma radiation will most likely (reflect, absorb, scatter) all of the beta radiation also.

d. When trying to shield a source of gamma photons of unknown energy, use the TVL for the gamma photons of the most difficult energy to shield.

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123. If you have a source of unknown strength in a shield and are trying to estimate the dose rate from the unshielded source, you should remember the following things.

source, different, absorb

a. The maximum dose rate you can detect anywhere at the shield surface should be used in any calculations.

b. Remember that when the source is removed from the shield, there may be a large dose rate due to beta particles.

c. Remember that if you are using the TVL of lead for 2- to 3-Mev gamma rays, the shield <u>may</u> be reducing the dose rate much more than you have calculated; therefore, the dose rate from the unshielded source will be higher than you have estimated.

d. The <u>precise</u> value of the radiation dose rate at the surface of a shield or carrier usually cannot be measured because the detecting part of a radiation detector may be as much as one or two inches inside of the detecting instrument.

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124. We have now considered the three factors which can be used in reducing the radiation dose to the human body. These factors are time, _____, and _____.

- - - - - - -

125. In actual practice, it is not always practical to provide additional shielding or to use distance to reduce the dose rate. Therefore, total exposure to individuals must be limited by limiting the individual's exposure _____ by administrative control measures. (This is necessary for work in areas where, in spite of shielding, the dose rate remains high.)

distance, shielding

- - - - - - -

126. An area where administrative control measures involve, primarily, the limiting of exposure to external radiation is called a "radiation zone"; these measures are based, primarily, on limiting exposure time.

time

- - - - - - -

127. The procedure for marking and establishing radiation zones is indicated in Table II-10.

- - - - - - -

Table II-10. Procedure for Establishing Radiation Zones

| Dose Rate Range | Immediate Action | Follow-up Action |
|---|---|---|
| 3 mrem/hr to 6 mrem/hr | Post low-level tags if the accumulated daily dose to personnel may be 20 mrem. | Periodic review. |
| 6 mrem/hr to 1 rem/hr | Post warning signs or tags. | Rope off the area if the accumulated weekly dose may be 1 rem. |
| 1 to 3 rem/hr | Post warning signs or tags; rope off. | Erect a barricade which provides absolute exclusion of personnel if the accumulated weekly dose in the area may be 12 rem. Lock or block entrance. |
| Over 3 rem/hr | Post warning signs, tags, and erect a temporary barricade; lock and/or block all entries. | |

128. Only those persons who are authorized by supervision may enter a radiation zone. Laboratory procedures specify that under certain conditions, this authorization may be given by regulations which are posted at the entrance to a radiation zone. Under other conditions, however, Laboratory procedures require that authorization must be given in writing in the form of a Radiation Work Permit.

- - - - - - -

129. Authorization by supervision is required for individuals to enter a _____ _____. This authorization may (under conditions specified by Laboratory procedure) be given by _____ posted at the entrance or by a _____ _____ _____.

- - - - - - -

Since the procedures (specifying the conditions that govern the type of authorization which is required) are subject to change, the conditions will not be discussed here in detail.

radiation zone, regulations, Radiation Work Permit

- - - - - - -

## 6.7 Self Test

130. A radiation exposure dose can be reduced by reducing either the dose _____ or the exposure _____. (If you made an incorrect response, repeat Frame 19.)

- - - - - - -

131. The radiation exposure time can be reduced by careful and complete _____ of the work to be done and by using several _____ in _____. (If you made an incorrect response, repeat Frames 21 through 24.)

rate, time

- - - - - - -

132. Three methods by which the radiation dose can be minimized are _____, _____, and _____. (If you made an incorrect response, repeat Frames 25 and 26.)

planning, persons, sequence

- - - - - - -

133. By using shielding material, ionization caused by radiation will occur in the _____ _____ and not in you. (If you made an incorrect response, repeat Frames 27 and 28.)

distance, time, shielding

- - - - - - -

134. The number of radioactive atoms and, consequently, the radiation intensity will decrease (if no replacement is made) by allowing some time for _____. (If you made an incorrect response, repeat Frame 29.)

shielding material

- - - - - - -

135. The farther we move away from a source of radiation, the (more, less) radiation we will receive. Consequently, we can reduce the dose rate (to which we are exposed) by increasing the _____ from the source. (If you made an incorrect response, repeat Frame 30.)

decay

- - - - - - -

136. The radiation exposure time can be reduced by careful and complete _____ and by using several _____ to complete a job. The dose rate (to which you are exposed) can be minimized by _____, _____, and decay _____. Reducing the exposure time, the dose rate, or both will (reduce, increase) the exposure dose. (If you made an incorrect response, repeat Frames 31 and 32.)

less, distance

- - - - - - -

137. Where radiation is involved, you should take advantage of any shielding available. If there is shielding for only a part of your body, at least attempt _____ body shielding. (If you made an incorrect response, repeat Frames 33 through 35.)

planning, persons, shielding, distance, time, reduce

- - - - - - -

138. Shielding charged radiation may be accomplished by using a thickness of material slightly greater than the _____ of the radiation in that material. (If you made an incorrect response, repeat Frames 37 and 38.)

partial or some

- - - - - - -

139. Although a 1-Mev beta particle will travel about 12 ft in air, we can limit the distance a beta particle travels from its source by using a thin piece of material as _____. (If you made an incorrect response, repeat Frame 42.)

range

- - - - - - -

140. A thin piece of aluminum used to shield beta radiation will also shield out any _____ radiation. (If you made an incorrect response, repeat Frames 45 and 46.)

shielding

- - - - - - -

141. To shield alpha particles, we can use bags, clothing, gloves, wood, aluminum, glass, etc. To shield or absorb beta radiation, the material will have to be (thinner, thicker) than that used for alpha radiation. (If you made an incorrect response, repeat Frame 47.)

alpha

- - - - - - -

142. Uncharged radiation (can, cannot) penetrate deeply into matter; therefore, it is (more, less) difficult to shield than charged radiation. (If you made an incorrect response, repeat Frames 48 through 51.) — thicker

- - - - - - -

143. In general, the thickness of shielding material required will depend upon its density. Greater thickness is required for a less _____ material. (If you made an incorrect response, repeat Frames 53 and 54.) — can, more

- - - - - - -

144. The TVL of lead for shielding 2- to 3-Mev gamma radiation is 2 inches. The HVL of lead is about _____ of the TVL value. (If you made an incorrect response, repeat Frames 54 and 55.) — dense

- - - - - - -

145. A dose rate of 100 mrad/hr (due to 2- to 3-Mev gamma radiation) can be reduced to 1 mrad/hr by using _____ inches of lead, which is equivalent to _____ TVL thicknesses. (If you made an incorrect response, repeat Frames 56 through 59.) — 0.3

- - - - - - -

146. A dose rate of 20 mrad/hr (due to 2- to 3-Mev gamma radiation) can be reduced to 5 mrad/hr by using _____ HVL, or _____ inches of lead. (If you made an incorrect response, repeat Frame 60.) — 4, 2

- - - - - - -

147. One TVL will reduce a dose rate of 20 rad/hr to _____ rad/hr. In the equation, $R_o\left(\frac{1}{10}\right)^x = R_1$, what does x represent? What does $R_1$ represent? (If you made an incorrect response, repeat Frames 61 and 62.)

2,
1.2

- - - - - - -

Answers to Frame 148:
2,
x = number of TVL used
$R_1$ = level to which the initial radiation intensity is reduced

- - - - - - -

148. If $R_o$ = 1000 rad/hr, and we use 3 TVL, calculate $R_1$ using the equation $R_1 = R_o\left(\frac{1}{10}\right)^x$. (If you made an incorrect response, repeat Frame 63.)

- - - - - - -

149. If $R_o$ = 1000 rad/hr, and we use 3 HVL, calculate $R_1$. (If you made an incorrect response, repeat Frames 64 and 65.)

$R_1$ = 1 rad/hr

- - - - - - -

150. The process by which a radioactive atom gets rid of excess energy and becomes more stable is known as radioactive _____. By allowing some decay time, the number of radioactive atoms and, consequently, the radiation intensity will (increase, decrease). (If you made an incorrect response, repeat Frames 71 through 76.)

125 rad/hr

- - - - - - -

151. The time necessary for 50% (1/2) of the radioactive atoms to decay is referred to as the _____ _____ ($T_{1/2}$) of that particular isotope. (If you made an incorrect response, repeat Frame 77.)

decay,
decrease

- - - - - - -

152. If a radiation dose rate is 40 mrad/hr at 1:00 p.m. and at 3:00 p.m. the dose rate is 10 mrad/hr, what is the half-life of that source of radiation? (If you made an incorrect response, repeat Frames 80 through 86.) — half-life

- - - - - - -

153. At the end of one half-life the radiation intensity will decrease to _____% of its original value. (If you made an incorrect response, repeat Frame 91.) — 1 hour

- - - - - - -

154. If the half-life of the isotope in a radiation source is equal to 1 month, then we (can, cannot) expect a significant decrease in the radiation intensity from the source at the end of 1 hour of decay time. (If you made an incorrect response, repeat Frame 94.) — 50

- - - - - - -

155. If there are two radioisotopes in a radiation source, the radiation intensity due to the source will be equal to (that due to the most rapidly decaying isotope, the sum of the two). (If you made an incorrect response, repeat Frames 95 and 96.) — cannot

- - - - - - -

156. The dose rate from a radiation source will be less at (4 feet, 5 feet) from the source because the same amount of radiation must be spread over a _____ area. (If you made an incorrect response, repeat Frames 97 through 102.) — the sum of the two

- - - - - - -

157. For a point source of radiation, the equation, $R_1(d_1)^2 = R_2(d_2)^2$ can be used to calculate radiation doses at various distances. If at a distance of 2 ft the dose rate is 100 mrad/hr, then at a distance of 10 ft, the dose rate will be equal to _____ mrad/hr. (If you made an incorrect response, repeat Frames 102 and 103.)

5 feet, larger

- - - - - - -

158. The equation $R_1(d_1)^2 = R_2(d_2)^2$ is sometimes referred to as the "_____ _____ _____" equation because the dose rate is inversely proportional to the square of the distance from the source. (If you made an incorrect response, repeat Frames 104 and 105.)

4

- - - - - - -

159. If $R_1$ = 144 mrad/hr at a distance of 1 ft from a point source: the dose rate at 2 feet is _____ mrad/hr;
the dose rate at 3 feet is _____ mrad/hr;
the dose rate at 4 feet is _____ mrad/hr.
(If you made an incorrect response, repeat Frames 106 and 107.)

inverse square law

- - - - - - -

160. The more distance there is between you and the source of radiation, the (more, less) radiation you will receive. That is, the radiation intensity is less the (closer, farther) you are to/from the source. (If you made an incorrect response, repeat Frames 107 and 108.)

36, 16, 9

- - - - - - -

161. Because of the geometry effect, the radiation dose rate decreases as the _____ from the source _____ because the radiation is spread out over a larger _____. (If you made an incorrect response, repeat Frame 111.)

less, farther

- - - - - - -

162. If, for a point source of gamma radiation, the dose rate at a distance of 1 ft is 1 rad/hr,

the dose rate at 18 in. = _____mrad/hr;
the dose rate at 2 ft = _____mrad/hr;
the dose rate at 180 in.= _____mrad/hr.

If 3 TVL of shielding are used, the radiation at a distance of 1 ft from the source is _____mrad/hr. (If you made an incorrect response, repeat Frames 117 and 118.)

distance, increases, area

- - - - - - -

163. Authorization by supervision is required for individuals to enter a _____ _____. This authorization may (under conditions specified by Laboratory procedure) be given by _____ posted at the entrance or by a _____ _____ _____. (If you made an incorrect response, repeat Frames 122 through 127.)

444, 250, 4.4, 1

- - - - - - -

radiation zone, regulations, Radiation Work Permit

# SECTION II-7

## RADIOACTIVE CONTAMINATION - PROTECTIVE MEASURES

In this section we shall discuss the methods you can use to prevent radioactive material from getting into your body. In particular, we shall discuss the hazards due to radioactive contamination.

- - - - - - -

### 7.1 Review

1. Radioactive material which results in a state of impurity is called radioactive _____. This material is a source of _____, as is all radioactive material. (Section II-2, Frames 34 through 37.)

- - - - - - -

2. Radioactive contamination which can be easily spread or transferred is called _____ radioactive contamination. That which cannot be so easily spread is called _____ radioactive contamination. (Section II-2, Frames 28 through 40.)

contamination, radiation

- - - - - - -

3. You might have a source of radiation without having any radioactive contamination. Can you have radioactive contamination without having any radiation? (Yes, No) (Section II-2, Frames 48 through 62.)

transferable, nontransferable

- - - - - - -

4. A curie is a quantity of radioactive material in which $3.7 \times 10^{10}$ atoms _____ every second. (Section II-4, Frames 7 through 11.)

No

- - - - - - -

5. The abbreviation dpm (d/m) stands for _____ _____ _____; the abbreviation cpm (c/m) stands for _____ _____ _____. (Section II-4, Frames 12 through 18.)

disintegrate or decay

- - - - - - -

6. Which kind of charged radiation (alpha, beta) cannot completely penetrate the outer protective layer of human skin? Which kind of charged radiation is capable of producing serious burns deep into skin tissue? (Section II-5, Frames 17 through 20.)

disintegrations per minute, counts per minute

- - - - - - -

7. Alpha particles and beta particles from <u>internal</u> sources might give up all of their energy to vital tissues and organs of the body. Therefore, radiation from sources inside the body causes more (disintegrations, damage). (Section II-5, Frames 21 and 22.)

alpha, beta

- - - - - - -

8. If a radiation source gets inside the body, exposure will last for (8, 24) hours a day. (Section II-5, Frames 24 and 25.)

damage

- - - - - - -

9. If a radiation source is outside the body, you will be exposed to only a fraction of the total radiation emitted by that source due to the geometry effect (as well as to the decreased exposure time). If the radiation source gets inside the body, you will be exposed to ____% of the radiation emitted by the source. (Section II-5, Frame 26.)

24

- - - - - - -

10. Another factor which makes some radioactive material more hazardous when inside the body is illustrated by iodine which has a tendency to _____ in the thyroid gland. (Section II-5, Frames 27 and 28.) — 100

- - - - - - -

11. List three ways by which sources of radiation can get into the body. (Section II-5, Frame 29.) — accumulate, collect, or concentrate

- - - - - - -

12. You can and should limit the amount of radioactive material getting into the body by exercising effective _____ measures. (Section II-5, Frames 30 and 31.) — breathing, eating, drinking, smoking, wounds

- - - - - - -

13. The process by which a radioactive atom gets rid of excess energy and becomes more stable by emitting radiation is known as radioactive _____. By allowing some decay time and, if no new radioactive atoms are produced, the number of radioactive atoms in a radiation source and, consequently, the radiation intensity due to the source will (increase, decrease). (Section II-6, Frames 71 through 78.) — control

- - - - - - -

14. We should review the meaning of the term "radioactive contamination". Radioactive contamination is radioactive material which results in a state of impurity (or the condition which results from the presence of a radioactive impurity). The impurity may be mixed with the material which it contaminates or may be only on the surface. — decay, decrease

- - - - - - -

15. In other words, radioactive contamination is radioactive material which has been deposited in any place where it is not desired and particularly, any place where its presence may be (desirable, harmful, of no consequence).

- - - - - - -

16. Radioactive material is not radiation; it is a source of radiation. So, radioactive contamination is a _____ of _____.

harmful

- - - - - - -

7.2 Radioactive Contamination (Solid, Liquid, and Gaseous)

source, radiation

17. Radioactive material may be in the form of a solid, liquid, or gas; therefore, radioactive contamination may be in the form of a _____, _____, _____.

- - - - - - -

18. Examples of radioactive contamination in the solid form are radioactive dust, metallic chips or filings, or very small solid particles. Radioactive contamination in the solid form may be so small in size that it cannot be seen with the naked eye. Larger objects could also be considered as being radioactive _____ in the _____ form.

solid, liquid, gas

- - - - - - -

19. However, when a solid piece of radioactive material is large enough that you can locate it fairly easily and shield it or dispose of it, it is usually not thought of as "contamination". But, it will still be a source of _____.

contamination, solid

- - - - - - -

20. So, you see we cannot use size alone to separate radiation sources and radioactive contamination in the solid form. Usually, contamination in the solid form is thought of as radioactive particles that cannot be seen with the naked eye and can be found only with radiation-detection instruments. radiation

- - - - - - -

21. Solid particulate radioactive contamination is usually found by one of two methods. The first is to hold the probe of a detection instrument very near the surface to be checked and move it slowly over the surface while watching the meter for a sign of radiation. The other is to rub a small piece of filter paper (about 2 in. diam) over a small area (about 4 in. by 4 in.) of the surface and then use a detection instrument to see if radioactive material has been transferred to the filter paper. This last technique is called making a "smear" test.

- - - - - - -

22. The smear technique will indicate that the radioactive contamination is (transferable, nontransferable).

- - - - - - -

23. If the radioactive contamination is nontransferable, the probe technique (will, will not) be more effective than the smear technique. transferable

- - - - - - -

24. If an area is smeared and the filter papers show no radioactive contamination, this (is, is not) proof that the area has no radioactive contamination. will

- - - - - - -

25. Radioactive contamination in the liquid form may be considered as small radioactive particles (atoms) in chemical solutions, cleaning solutions, water, etc. To give you an idea of contamination (nonradioactive) in the liquid form, let us suppose someone poured a little water into your automobile's gasoline tank. Then you would consider your gasoline to be contaminated with water. On the other hand, if someone poured a little gasoline into your automobile's radiator, you would consider your radiator water to be contaminated with gasoline. is not

- - - - - - -

26. A liquid that is contaminated with radioactive material (water samples in test tubes) is easier to check for (alpha, beta) radiation because _____ particles would probably have a shorter range than the thickness of the test tube.

- - - - - - -

27. Gaseous contamination may be thought of as radioactive material which is floating in the air--not solid or liquid. To give you an idea of gaseous contamination, think of yourself as having walked into a room where ammonia has accidentally been released. You can smell it; and, if the concentration is high enough, you can see a foggy vapor. The ammonia is gaseous in form, and it has _____ the fresh air in the room. Unfortunately, you cannot smell or see radioactive material or contamination. The only way you can tell radioactive material or contamination is present is to detect the radiation from it with a radiation-detection instrument. (For very large radiation doses, you would feel the after effects; but these usually occur hours, days, or weeks after the exposure. A dose large enough for the effects to be felt immediately is usually fatal. beta, alpha

- - - - - - -

28. The special containment features of buildings containing nuclear reactors are designed to keep _____ radioactivity from spreading.

contaminated

- - - - - - -

29. The very nature of a nuclear reactor facility makes it necessary for operators to be constantly on the alert for radioactive contamination in all three forms: _____, _____, and _____.

gaseous

- - - - - - -

30. As you recall, the principal hazard associated with transferable radioactive contamination is that it can easily enter the body, and the damage it can cause is much greater when it is in the body than when it is outside the body.

solid, liquid, gaseous

- - - - - - -

31. Thus, the greatest efforts should be directed toward keeping radioactive contamination of any kind from coming in contact with the body and especially from _____ the body.

- - - - - - -

32. While nontransferable radioactive contamination is less hazardous than transferable, it is still a source of _____ and, as such, it is a hazard.

entering

- - - - - - -

33. Also, under certain conditions, nontransferable radioactive contamination may become _____ if the conditions of its containment change.

radiation

- - - - - - -

transferable

## 7.3 Contamination, Surface and Airborne

34. However, as long as the radioactive contamination is of the nontransferable type, it is no great hazard. For this reason we shall concern ourselves, hereafter, with the transferable type; and we shall identify it as either surface or airborne contamination.

– – – – – – –

35. Surface contamination is simply contamination which is on the surface of objects such as on table tops, floors, tools, walls, or human bodies. Surface contamination may be in either solid or _____ form.

– – – – – – –

36. Contamination which is in the air is not _____ contamination, but it is _____ contamination. liquid

– – – – – – –

37. Airborne contamination may be in a gaseous form or it may be in the form of very small solids (particles) which are floating in the air. Radiation from this small solid-particle form of airborne contamination is often referred to as "particulate activity". surface, airborne

– – – – – – –

38. If a surface is contaminated by a very fine powder which is radioactive, air currents (caused by fans or by sweeping with a broom) will cause some of the surface contamination to become _____ _____ .

– – – – – – –

39. Whenever a certain amount of this contamination gets on the surface of an object, measures must be taken to prevent it from being (spread, radioactive).

airborne contamination

- - - - - - -

40. This action may include marking off the area (with signs and ropes) and controlling entrance into (and exit from) the area. It will certainly include starting a decontamination (clean-up) program. These things are done to minimize the hazard to personnel by preventing the contamination from being _____ to uncontrolled areas and so that everyone will know that the area is _____.

spread

- - - - - - -

41. The signs, ropes, decontamination procedures, etc., serve two purposes. They minimize the hazard to all personnel by letting them know that the area is _____, and they also prevent the contamination from being _____ to uncontrolled areas.

spread, contaminated

- - - - - - -

## 7.4 Contamination Zones

contaminated, spread

42. When a surface becomes contaminated above a specified amount, signs and ropes are put up to inform everyone that the area is contaminated and that precautions must be taken to prevent the contamination from being spread. An area which is marked off by signs and ropes because of contamination is called a _____ zone.

- - - - - - -

43. A "contamination zone" is defined as an area where control measures are established to prevent contamination from being spread to other areas. A person entering a contamination zone must take precautions to prevent the _____ material from getting either on or inside his body.

contamination

- - - - - - -

44. Earlier we discussed a number of ways that radioactive material could get inside your body. If you consider the ways again, it is obvious why _____, _____, or _____ are forbidden in a contamination zone.

radioactive

- - - - - - -

45. Table II-11 lists the surface contamination levels at which contamination zones are to be established.

eating, drinking, smoking

- - - - - - -

Table II-11. Guide for Establishment of Contamination Zones

| Type of Radiation | Direct Reading (Probe) Surface Contamination | Transferable (Smear) Surface Contamination |
|---|---|---|
| Alpha | 300 d/m per 100 $cm^2$ | 30 d/m per 100 $cm^2$ |
| Beta-gamma | 0.25 mrad/hr | 1000 d/m per 100 $cm^2$ |

- - - - - - -

46. A contamination zone is established if the alpha surface contamination by _____ test is 30 d/m per 100 $cm^2$.

- - - - - - -

47. Roughly, 100 $cm^2$ is an area about one-fourth the size of this sheet of paper. — smear

- - - - - - -

48. The d/m per 100 $cm^2$ necessary to establish a contamination zone is much (smaller, larger) for alpha than it is for beta-gamma.

- - - - - - -

49. One reason beta and gamma radiation can be evaluated together is that the RBE of each is (1, 2.5, 5, 10). — smaller

- - - - - - -

50. If a surface is checked by probe for beta-gamma contamination and the instrument reads about _____ mrad/hr, a contamination zone must be set up. — 1

- - - - - - -

51. If a smear is taken of a table top in an experiment room and the smear reads 2000 d/m beta-gamma and 20 d/m alpha, it (is, is not) necessary to set up a contamination zone. — 0.25

- - - - - - -

52. A G-M survey meter will respond only to (alpha, beta-gamma, fast neutrons, thermal neutrons). — is

- - - - - - -

53. We mentioned earlier that one method of determining the transferable surface contamination level is by wiping a smear pad (piece of filter paper) over an area 4 in. x 4 in. (100 $cm^2$) and then determining the number of atoms on that smear paper which disintegrate (decay) per minute. — beta-gamma

- - - - - - -

54. Do not be confused by the units used for allowable levels for contamination involving alpha radiation. Even though both the levels determined by direct readings and by smear techniques are stated in d/m per 100 $cm^2$, there is no simple, direct reason why they differ by a factor of 10. (Among other things, different detection instruments are used; smears will pick up only a part of the transferable contamination on the 100 $cm^2$; and nontransferable contamination may contribute to the direct reading.)

- - - - - - -

55. Note that for transferable alpha contamination, a contamination zone is established when the level is 30 _____ in one minute over an area of 100 $cm^2$.

- - - - - - -

56. A contamination zone is established for alpha contamination at a lower level than for beta (or gamma) contamination because (alpha, beta) is more damaging if it is ingested. — disintegrations

- - - - - - -

57. If you should approach a contamination zone and the signs indicate that transferable beta and/or gamma contamination is in the zone, then you should know that the surface contamination level may be at least _____ disintegrations/min per 100 $cm^2$. — alpha

- - - - - - -

1000

## 7.5 Contamination Clothing

58. When work must be done in a contamination zone, two things are important to keep in mind.
    1. Dress so that your body is protected both externally and internally from the contamination.
    2. Take every precaution to see that the contamination is not spread outside the zone.

- - - - - - - -

59. If work has to be performed in a contamination zone, it may be necessary to remove your unmarked coveralls or street clothing and put on a clean pair of coveralls labeled with the word CONTAMINATION. You must wear contamination clothing when you enter (and as long as you are in) a _____ _____, or whenever you are working with contaminated material.

- - - - - - - -

60. Contamination coveralls are worn in a contamination zone for two reasons. First, they are worn to prevent the wearer's skin from becoming contaminated; and second, they are worn for better control of the clothing in order to restrict the spread of contamination. (For example, contamination clothing will, most likely, not be laundered with other clothing.)

contamination zone

- - - - - - - -

61. The primary reason for wearing contamination clothing is to prevent the wearer's (coveralls, skin) from becoming _____.

- - - - - - - -

62. It is true that street clothes and ordinary coveralls may offer as much protection as contamination coveralls. However, street clothes, unknowingly contaminated, could be worn to plant cafeterias or homes; ordinary coveralls, unknowingly contaminated, could be worn outside the controlled areas into offices and lunch rooms. This would spread radioactive contamination into these places.

skin, contaminated

- - - - - - -

63. Other contamination zone clothing which may be required, depending on the type of radiation and the job to be done, may include rubber boots, plastic booties, rubber (or cotton) gloves, caps, canvas hoods, and face masks.

- - - - - - -

A list of required contamination clothing for general work should be posted at the entrance to each contamination zone.

- - - - - - -

64. Since contamination coveralls are plainly marked, it is easier to prevent the _____ of _____ by controlling the handling of this special clothing.

- - - - - - -

65. So when there is work to be done which involves contamination, street clothes or unmarked coveralls should be replaced with _____ coveralls.

spread, contamination

- - - - - - -

66. Two pairs of coveralls should be worn in a contamination zone where the contamination level may be high or where alpha-emitting contamination is difficult to detect once it is embedded in the cloth.) The outer pair of coveralls is removed immediately upon leaving the contamination zone to prevent _____ the contamination. — contamination

- - - - - - -

67. All persons exiting from, and equipment being removed from, any contamination zone must always be checked for contamination with a radiation-detection instrument. This helps prevent the spread of radioactive material to areas outside the _____. — spreading

- - - - - - -

68. Similarly, equipment transferred between supposedly clean areas is also checked (by Health Physics personnel) and given a green tag which indicates that the equipment is not _____. — zone or contamination zone

- - - - - - -

69. When work in a contamination zone is finished, the contamination coveralls should be left in laundry bags either in the _____ zone or in a controlled area. — contaminated

- - - - - - -

contamination

## 7.6 Regulated Zones

70. The controlled area we have been talking about is generally referred to as a "regulated zone". A regulated zone (see Figure II-24) is an area where operations are restricted for the purpose of (destroying, controlling, producing) radioactive contamination.

— — — — — — —

71. Regulated zones are established for the convenience of controlling employees whose work requires them to enter contamination zones frequently; these zones make frequent and inconvenient clothing changes unnecessary.

— — — — — — —

72. A regulated zone may contain radiation zones, contamination zones, or both; it may range in size from a very small area to a large area encompassing several buildings. (Figure II-24 should give you a better idea of the difference between the regulated, radiation, and contamination zones.)

— — — — — — —

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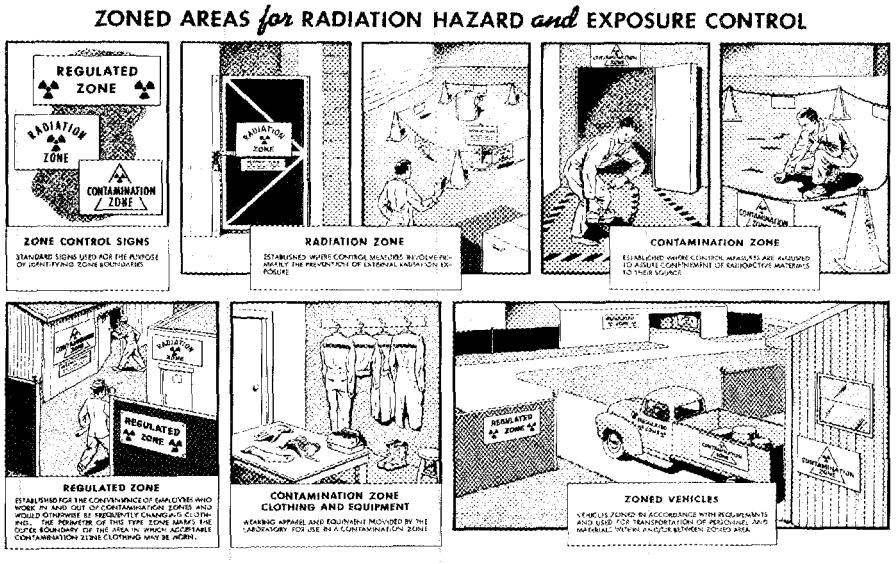


Fig. II-24.

73. Contamination-zone clothing may be worn only in a contamination zone or a regulated zone. Also, a person cannot leave a contamination zone wearing contamination clothing (to go into the surrounding or adjacent regulated zone) until his contamination clothing has been checked and shown to be free of transferable contamination. This rule is to prevent the possible _____ of contamination to other areas.

spread

- - - - - - -

74. If a person's skin has become contaminated, he should check with his supervisor and with a Health Physics representative as to the proper action to be taken. If the contamination is not too severe or extensive, probably a shower or general washing may be adequate. However, if (after reasonable decontamination efforts have been taken with the assistance of a Health Physics representative) the remaining level of contamination on a person's body exceeds the permissible limits, the individual may have to be referred to the Health Division (where additional decontamination efforts can be performed under medical supervision).

- - - - - - -

75. If, after working in a contamination zone, you find that some radioactive contamination has reached your skin, the first thing to do is to _____ the area thoroughly.

wash or bathe

- - - - - - -

76. If washing does not reduce the contamination to a permissible level, a _____ _____ representative should be contacted and his advice taken.

- - - - - - -

77. Surface contamination may not be too difficult to contain and clean up; however, it may be very difficult to contain and clean up airborne contamination.

Health Physics

- - - - - - -

78. If you are in an area where there is airborne contamination, your entire body is surrounded by the contamination and every square inch of body is exposed to the radiation. More serious than that, however, is the fact that every time you take a breath, you breathe in _____ _____.

- - - - - - -

79. If the level of airborne contamination is greater than a certain value, assault masks (gas masks of the full-face, canister type) should be worn to filter the air that is breathed.

radioactive material or radioactive contamination or airborne contamination

- - - - - - -

80. A supply of assault masks should be kept (ready for use) in areas where there is a possibility of a high level of _____ contamination.

- - - - - - -

81. The use of this type mask would result in the radioactive material being filtered out by the (mask, lungs). Consequently, (more, less) internal exposure would result.

airborne

- - - - - - -

82. A gas mask will filter out particulate contamination, but the noble gases (xenon, krypton, etc.) are difficult to handle because they seldom react with other materials. With such gases, the canister type gas mask (is very effective, has little effect).

mask, less

---

83. While the noble gases (can, cannot) be filtered out, they are exhaled from the lungs rather quickly. Thus, the amount of tissue damage is determined by the time spent in the contaminated area.

has little effect

---

Noble gases do not react chemically (except in very unusual circumstances) with other gases or metals, etc. Argon is a good example because air contains about 0.94% argon-40. When argon-40 is exposed to neutrons, it is converted to argon-41 (which decays with a half life of 1.82 hr, by emitting beta and gamma radiation). In the vicinity of a reactor, airborne argon-41 contamination can be a problem.

cannot

---

84. Radioactive iodine vapor (a hazardous type of airborne contamination often found in gaseous waste from reactors and experiments) is filtered out by special filter cartridges which contain activated charcoal.

---

85. In areas where there is a possibility of radioactive iodine vapor, a gas mask is used which has special filter cartridges of activated _____.

---

charcoal

## 7.7 Continuous Air Monitors

86. To help determine the presence of airborne contamination, instruments called continuous air monitors (abbreviated CAM) are placed at strategic positions in a room. A stream of air is continuously drawn past a probe which detects _____ in the air.

- - - - - - -

87. Airborne contamination is detected by a _____. radioactivity or radioactive contamination

- - - - - - -

88. The CAM also draws air through a filter paper which collects particulate matter (and a limited amount of other airborne contamination). Radiation from the radioactive material on the filter paper is measured by a detector located near the paper. (Any other airborne contamination in the air around the detector also contributes to the measured radiation level.) Thus, both gaseous and particulate radioactivity in the _____ is detected by a CAM. Figure II-25 shows one type of continuous air monitor. CAM

- - - - - - -

89. When a person ingests radioactive material, gaseous or particulate, some will remain in the body. Once the material is in the body, it can be lost in only two ways--radioactive <u>decay</u> and <u>excretion</u> from the body. air

- - - - - - -

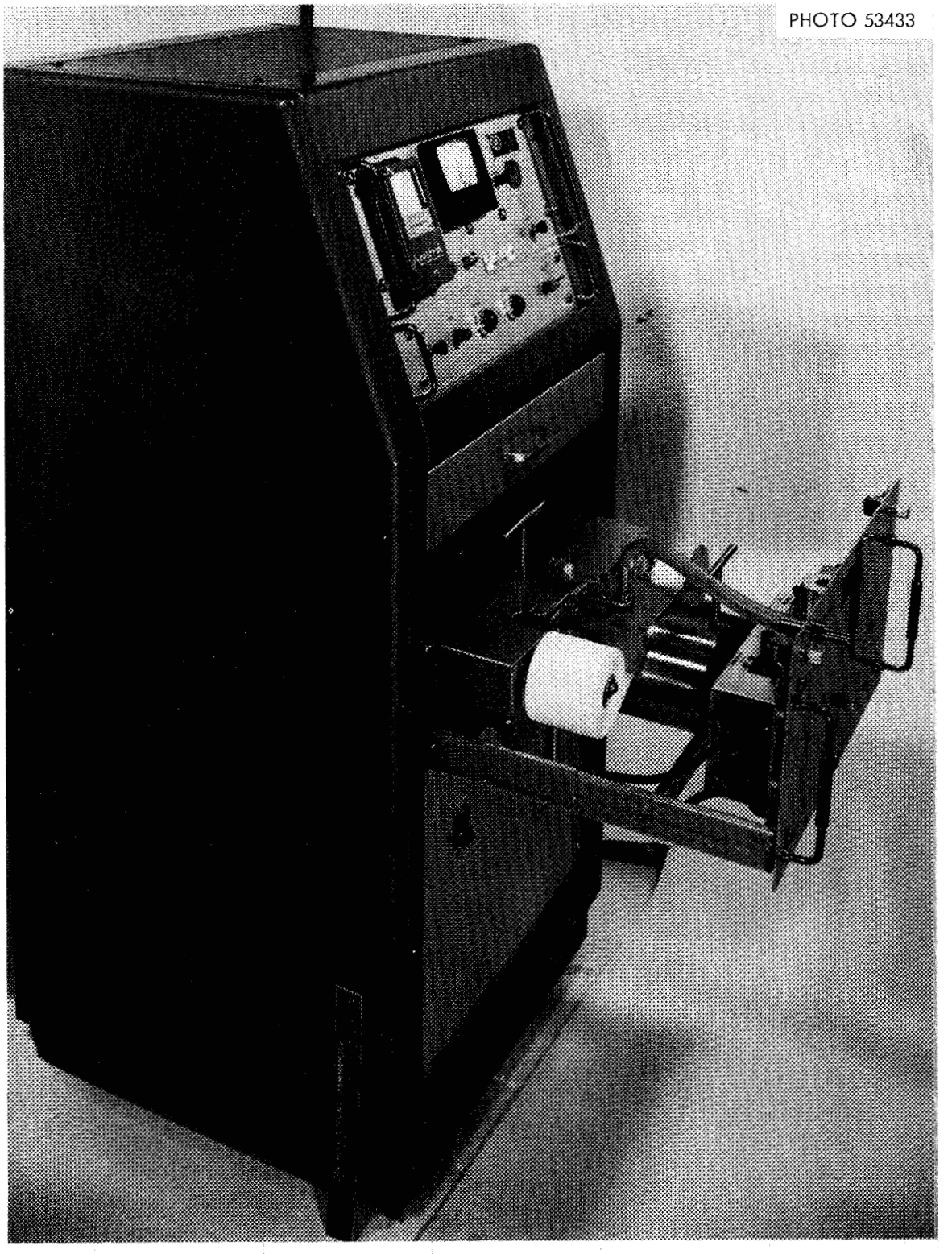


Fig. II-25. Air Monitor (continuous, beta-gamma)

90. If a person continues to ingest radioactive contamination, the amount in the body will increase until it reaches a level such that the intake is just balanced by the loss through _____ and radioactive _____.

- - - - - - -

91. The amount of radioactive material in the body remains constant when the amount going into the body equals the amount lost by radioactive _____ and by _____.

excretion, decay

- - - - - - -

## 7.8 Maximum Permissible Body Burden

decay, excretion

92. The amount of radioactive material in the body at this constant, equilibrium level is called the "body burden". This amount may or may not be harmful, since it depends upon the level of concentration of each isotope. (That is, for the same isotope, being exposed to different concentrations would result in different equilibrium body burdens.) A quantity called the "maximum permissible body burden" can be calculated for each isotope, which tells the maximum quantity which can be allowed in an average adult human without exceeding the various yearly and quarterly dose limits.

- - - - - - -

93. The total amount of an isotope in a person's body at any time is his _____ _____.

- - - - - - -

94. Assuming a continuous intake (at work) of some radioisotope at some concentration, you would eventually have an equilibrium _____ _____ of that isotope. This occurs because you eventually lose as much as you take in on a daily basis. This loss occurs because of _____ _____ and _____.

body burden

- - - - - - -

95. If your body burden exceeds the _____ _____ _____ _____ for a particular radioactive _____, you will exceed the maximum allowable quarterly dose.

body burden, radioactive decay, excretion

- - - - - - -

The maximum allowable quarterly dose used in the calculation is the dose to that organ in which damage by the radiation would cause the most damage to the body.

maximum permissible body burden, isotope

- - - - - - -

96. Since it is difficult to measure precisely the body burden of all the individuals at ORNL continuously, most of the effort is concentrated on minimizing surface, airborne, and waterborne contamination.

- - - - - - -

97. An uncontaminated drinking-water system is insured by keeping potable water and process water in completely separate systems. The potable water system is (never, seldom) connected to any system which contains (or could accidentally contain) radioactive liquid waste.

- - - - - - -

98. Active enforcement of contamination zone rules aids in keeping everyone's body burden low by helping to reduce the amount of radioactive material taken _____ the body. never

- - - - - - -

99. Radiation detectors such as continuous air monitors warn us of _____ contamination. Sources of this type of contamination are isolated from personnel. The containment system (which isolates these sources) is usually connected to an approved airborne-waste disposal system. into

- - - - - - -

100. The CAM indications (readings) and alarm points are quite often misunderstood because it is so difficult to state precisely what a number such as the alarm point really means. The concept is fairly straightforward; therefore, let us look at the concept and not worry about the exact numbers. airborne

- - - - - - -

101. Let us assume that your job requires that you breathe slghtly contaminated air 8 hours a day for 5 days a week. If this continues until the amount of radioactive material taken into your body would equal that lost by _____ and _____, your body will have reached the equilibrium _____ _____ (for the assumed concentration of contamination).

- - - - - - -

102. But while you are working, how can you tell if the air is contaminated enough to eventually cause you to exceed the maximum "_____ body burden"? (True, we could wear gas masks all day or breathe clean air from tanks or bottles containing compressed air, but the use of this equipment is uncomfortable.)

decay, excretion, body burden

- - - - - - -

103. You are right; we should monitor the contamination level in the air and determine whether continuing to breathe this air 40 hours a week would eventually cause us to exceed the maximum permissible _____ _____. The CAM is therefore set to alarm whenever the airborne contamination reaches a level high enough to eventually cause a person's body burden to exceed the maximum permissible body burden. (This would give a person adequate warning in time to take protective measures and to prevent his inhaling enough airborne contamination to increase his body burden--of radioisotopes--past the permissible point.)

permissible

- - - - - - -

## 7.9 Maximum Permissible Concentration

body burden

104. It is very clumsy to keep repeating "that concentration of radioactive material in air which (if breathed for 40 hours each week) would result in the maximum permissible body burden", so we use a unit called the Maximum Permissible Concentration (MPC) to take its place. If we continue to breathe air which has the MPC of a certain isotope in it; then eventually we will accumulate the maximum permissible body burden.

- - - - - - -

The MPC values are usually stated in μc/cc ($10^{-6}$ curie per cubic centimeter).

- - - - - - -

105. We should discuss how, in the ideal case, the CAM is made to warn us (by an alarm) that the air contains the MPC of a radioactive isotope. We know that the instrument indication is in counts/sec and that when the counting rate reaches a certain number of counts/sec, the alarm is sounded.

- - - - - - -

106. We also know that the counts/sec (as measured by the detector) is due to radioactive material collected on the filter which is near the detector. The alarm point (in counts/sec) of most CAM's is set to be equivalent to the counts/sec which would be measured if the filter contained the amount of radioactive material which would be collected in 30 minutes from air which contained the MPC of an isotope.

- - - - - - -

107. The CAM filter efficiency is chosen to be similar to the filtering efficiency of human lungs; the CAM airflow rate is similar to the human breathing rate. The unit in which MPC is measured is _____.

- - - - - - -

108. In the ideal case, therefore, a CAM is set to alarm at a level which would result from a _____ collection of air containing the _____ of any radioisotope. μc/cc

- - - - - - -

109. Unfortunately, the airborne contamination is usually made up of a mixture of different isotopes and it is not possible to determine a value to use for mixtures which may be different each time. Around reactors, normally, the MPC value used is that for the most hazardous beta-gamma emitter which might be expected to be encountered. (Generally, the alarm set point is about 100 times the indication from the natural radioactivity in the air.)

30-minute, MPC

- - - - - - -

110. If a CAM is set to alarm when the most hazardous beta-gamma emitter reaches its _____ in the air, any other isotope causing the alarm will be below its own MPC.

- - - - - - -

Radiation from sources other than the material collected on the filter also causes the actual operation of the CAM to differ from the ideal. We have already mentioned the contribution due to radiation from gaseous and other airborne contamination (surrounding, but not on, the filter). Radiation from sources outside of the CAM can also contribute to the instrument indication even though the detector and filter are inside a shield. Sometimes radiation from a very radioactive piece of material can, by itself, cause a CAM to alarm.

MPC

- - - - - - -

111. When a CAM reading is increasing, its rate of increase is a better indication of the airborne contamination than the reading itself, since the level indicated is normally that from the material which has already been collected on the filter. A rapid rate of rise would indicate a (high, low) concentration of radioactive airborne material.

- - - - - - -

112. Table II-12 is a list of a few radioactive isotopes and their maximum permissible concentrations in air (based on 40 hr/week exposures). This list is far from complete, but it is included just as an illustration. high

– – – – – – –

Table II-12. A Sample List of Some Maximum Permissible Concentrations*

| Substance | MPC $_{air}$ ($\mu$c/cc) (for 40-hr/week exposure) | Critical Organ(s) (on which MPC is based) |
|---|---|---|
| $^{239}Pu$ | $2 \times 10^{-12}$ | Bone |
| $^{241}Am$ | $6 \times 10^{-12}$ | Bone and kidney |
| Natural U | $6 \times 10^{-11}$ | Lung |
| $^{242}Cm$ | $1 \times 10^{-10}$ | Liver |
| $^{90}Sr$ | $3 \times 10^{-10}$ | Bone |
| $^{131}I$ | $9 \times 10^{-9}$ | Thyroid |
| $^{45}Ca$ | $3 \times 10^{-8}$ | Bone |
| $^{59}Fe$ | $5 \times 10^{-8}$ | Lung |

*National Bureau of Standards Handbook 69

– – – – – – –

## 7.10 Self Test

113. A radioactive impurity or the condition that exists from the presence of the impurity is called _____ _____. (If you made an incorrect response, repeat Frames 14 and 15.)

– – – – – – –

114. The energy released from an unstable atom as it changes to a more stable form is called _____. (If you made an incorrect response, repeat Frames 14 through 16.)

radioactive contamination

- - - - - - -

115. The three forms or states of radioactive contamination are _____, _____, and _____. (If you made an incorrect response, repeat Frame 17.)

radiation

- - - - - - -

116. Some examples of radioactive contamination in the solid form are dust, metallic chips, metallic filings, and particles. When the solid form of contamination is large enough to locate and shield it or dispose of it, it is usually no longer considered as contamination; but it is still a _____ of _____. (If you made an incorrect response, repeat Frames 18 through 20.)

solid, liquid, gaseous

- - - - - - -

117. If, in spite of our efforts, we get radioactive material in some drinking water, this is an example of the _____ form of _____. (If you made an incorrect response, repeat Frame 25.)

source, radiation

- - - - - - -

118. If, near the reactor, argon-41 is released, it will _____ the air. This form of contamination is _____. (If you made an incorrect response, repeat Frame 27.)

liquid, contamination

- - - - - - -

119. Contamination which has been confined by some method is referred to as _____ contamination. Contamination which is easily spread is referred to as _____ contamination. Both types of contamination are sources of _____, but the major hazard is presented by the _____ contamination. (If you made an incorrect response, repeat Frames 30 through 32.)

contaminate, gaseous

- - - - - - -

120. The hazard of any transferable radioactive contamination is due to the fact that it may _____ _____ _____ _____. (If you made an incorrect response, repeat Frames 25 through 33.)

nontransferable transferable, radiation, transferable

- - - - - - -

121. Transferable radioactive contamination which is floating in air may be either gaseous or dust; it is all called _____ contamination. (If you made an incorrect response, repeat Frames 32 through 37.)

get inside your body

- - - - - - -

122. List three actions which can be taken to prevent surface contamination from spreading. (If you made an incorrect response, repeat Frames 38 through 41.)

airborne

- - - - - - -

Answers to Frame 122
Putting up ropes and signs, controlling entrance, controlling exit, decontamination.

- - - - - - -

123. A contamination zone is a contaminated area marked off by _____ and/or _____ where _____ measures are taken to prevent the _____ of contamination. (If you made an incorrect response, repeat Frame 41.)

- - - - - - -

124. A contamination zone is established when the transferable surface contamination level (as measured by the smear technique) is _____ d/m per 100 $cm^2$ due to alpha radiation or _____ d/m per 100 $cm^2$ due to beta-gamma radiation. (If you made an incorrect response, repeat Frames 44 through 54.)

signs, ropes, control or protective, spread

- - - - - - -

125. Why are contamination zones established at a lower level due to alpha contamination than for beta-gamma contamination? (If you made an incorrect response, repeat Frame 55.)

30, 1000

- - - - - - -

Answer to Frame 125
If it gets inside your body, more internal damage will result from alpha-emitting material than from an equal amount (in curies) of beta- or gamma-emitting material.

- - - - - - -

126. Prior to entering a contamination zone, you should put on some type of _____ _____. This will protect your skin from _____ and will help restrict the spread of contamination because of special _____ measures for this type clothing. (If you made an incorrect response, repeat Frames 57 through 64.)

- - - - - - -

127. Two pairs of contamination coveralls should be worn when performing work in an area where the contamination level is very high or where _____-emitting contamination is present. (If you made an incorrect response, repeat Frame 65.)

contamination clothing, contamination, control

- - - - - - -

128. All personnel and equipment leaving any contamination zone must be _____ for _____ with a radiation-detection instrument. (If you made an incorrect response, repeat Frames 66 through 68.)

alpha

- - - - - - -

129. A regulated zone may contain _____ zones, _____ zones, or both. (If you made an incorrect response, repeat Frame 69.)

checked, contamination

- - - - - - -

130. A person wearing contamination clothing cannot leave a contamination zone to go into the surrounding or adjacent regulated zone until his contamination clothing has been checked and found to be _____. (If you made an incorrect response, repeat Frame 70.)

radiation, contamination

- - - - - - -

131. Radioactive gases and floating particles are examples of _____ contamination. (If you made an incorrect response, repeat Frames 74 and 75.)

uncontaminated or free of contamination

- - - - - - -

132. One of the protective measures which may be used following a release of airborne contamination would be to have all the personnel _____ the building until the contaminated air has been removed by some approved disposal (ventilation) system. (If you made an incorrect response, repeat Frames 76 through 80.)

airborne

- - - - - - -

133. If the level of airborne contamination is greater than a certain value, _____ _____ should be worn to filter the air that is breathed. (If you made an incorrect response, repeat Frames 80 through 84.)

evacuate or leave

- - - - - - -

134. To help us determine if there is airborne contamination present, instruments such as a _____ _____ _____ are used. This instrument is generally referred to as a _____. (If you made an incorrect response, repeat Frames 86 through 88.)

assault masks or gas masks

- - - - - - -

135. The amount of radioactive material which may get inside your body will be reduced by two methods--radioactive _____ and _____. (If you made an incorrect response, repeat Frames 89 and 90.)

continuous air monitor, CAM

- - - - - - -

136. The total amount of an isotope in a person's body at any time is his _____ _____. When the amount of radioactive material being taken into the body equals that being lost by radioactive decay and excretion, we could say that the "equilibrium" _____ _____ has been reached. (If you made an incorrect response, repeat Frames 77 through 81.)

decay, excretion

- - - - - - -

137. You would exceed the maximum allowable quarterly dose if the _____ _____ _____ _____ is exceeded. (If you made an incorrect response, repeat Frame 92.)

body burden, body burden

- - - - - - -

138. The CAM warms us of (surface, liquid, airborne) contamination. (If you made an incorrect response, repeat Frame 96.)

maximum permissible body burden

- - - - - - -

139. The CAM is set to alarm whenever the airborne contamination reaches a level high enough that, if it were breathed continuously for _____ _____ each week, the _____ _____ body burden would be exceeded. (If you made an incorrect response, repeat Frames 97 through 102.)

airborne

- - - - - - -

140. MPC is an abbreviation for _____ _____ _____. The MPC is that concentration of radioactive material in air which, if breathed for 40 hours each week, would result in the maximum _____ _____ burden being reached. (If you made an incorrect response, repeat Frame 104.)

40 hours, maximum permissible

- - - - - - -

141. A rapid rate of increase on a _____ would indicate a release of airborne contamination has occurred. A 30-minute collection of air containing the _____ of a certain isotope would, in the ideal case, actuate the _____ on this instrument. (If you made an incorrect response, repeat Frames 104 through 108.)

maximum permissible concentration, permissible, body

- - - - - - -

142. The important properties of radioactive contamination are as follows:

a. It is not radiation; it is a _____ of radiation.

b. It may be _____ in an unpredictable manner.

c. If it gets into the body, radiation exposure will continue for _____ hours each day for as long as the material stays in the body or remains _____.

d. Some materials tend to _____ in specific organs of the body and are, therefore, very hazardous.

CAM, MPC, alarm

- - - - - - -

source, spread, 24, internal, accumulate or concentrate

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