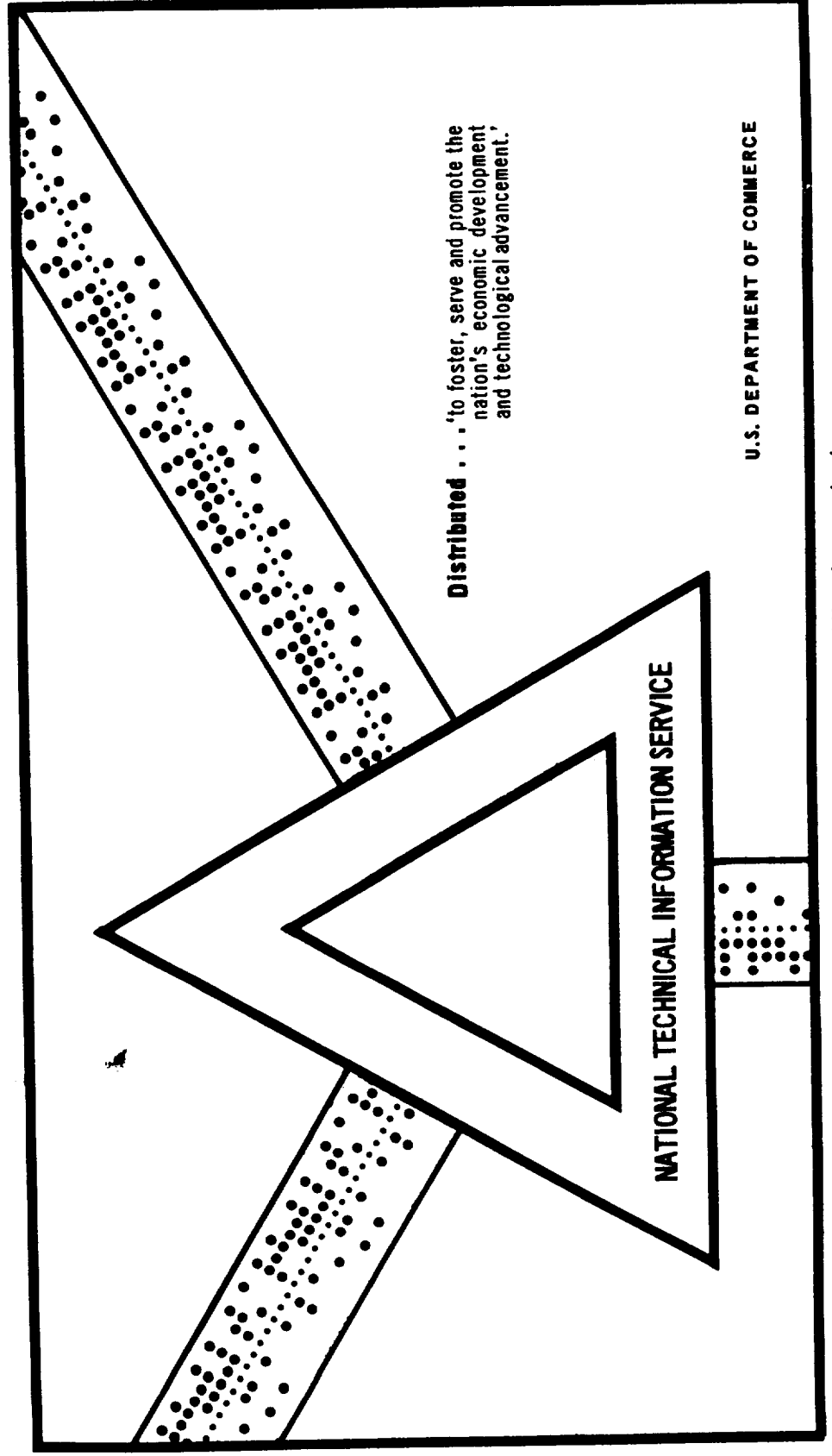


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RADIOGRAPHY. VOLUME II - RADIATION SAFETY

Convair Division
General Dynamics Corporation
San Diego, California

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Radiography. Vol. II - Radiation Safety

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INTRODUCTION

The use of high-energy radiation, specifically gamma and X-radiation, has served to benefit mankind in many ways since its discovery. At the same time, the extensive use of radiation has created an ever-increasing hazard to health. Since it is possible for radiation to damage the body, it is essential that anyone working with radiation be aware of the harmful effects and the steps which can be taken to provide protection.

As its title implies, the purpose of this handbook is to provide the radiation worker with the knowledge necessary to work safely with gamma rays and X-rays in radiography. This volume will instruct you in the ways that radiation can cause damage; the units of measurement; permissible limits of radiation exposure; radiation measurement devices; and, most important, the means of providing protection for yourself and others.

This volume is the second of a series entitled "Programmed Instruction Handbook - Radiographic Testing" - 5330.14. The understanding of the material covered in this volume depends upon the reader having previously completed the first volume of the series, 5330.14 (V-1), "Origin and Nature of Radiation."

INSTRUCTIONS

The pages in this book should not be read consecutively as in a conventional book. You will be guided through the book as you read. For example, after reading page 3-12, you may find an instruction similar to one of the following at the bottom of the page -

- Turn to the next page
- Turn to page 3-15
- Return to page 3-10

On many pages you will be faced with a choice. For instance, you may find a statement or question at the bottom of the page together with two or more possible answers. Each answer will indicate a page number. You should choose the answer you think is correct and turn to the indicated page. That page will contain further instructions.

As you progress through the book, ignore the back of each page. THEY ARE PRINTED UPSIDE DOWN. You will be instructed when to turn the book around and read the upside-down printed pages.

As you will soon see, it's very simple - just follow instructions.

TURN TO THE NEXT PAGE

D

It was soon after the discovery of X-rays and radioactive materials that it became apparent that ionizing radiation presents a hazard to human health. As one who works in the field of radiography, it is important that you know the answers to many questions about ionizing radiation and its effects on humans.

You must be able to control radiation exposure. And when we speak of radiation, we mean high-energy, ionizing rays such as those emitted from X-ray machines and radioactive materials. But this does not mean that these are the only sources of radiation. There is "natural" radiation in our environment.

It is a scientific fact that radiation from space reaches our planet. This is known as "cosmic radiation." Science also knows that more cosmic radiation is present at high elevations on earth. For instance, there is more cosmic radiation present at the top of Pike's Peak than at sea level. But, regardless of the amount, there is some cosmic radiation everywhere.

Turn to the next page.

From page 1-1

1-2

There are other natural radiation sources on earth besides cosmic radiation. Radioactive materials such as radium exist below the surface. Most water in the world contains radioactive materials.

Do you think it is possible for humans to avoid all radiation? (Select an answer and turn to the page indicated.)

Yes Page 1-3

No Page 1-4

From page 1-2

1-3

You believe it is possible for humans to avoid all radiation. That is not the answer we were looking for.

The point that should be established here is that if there is radiation in our environment, we are exposed to it. It is scientific fact that there is cosmic radiation on earth as well as radioactive minerals inside the earth.

Now look at the question again. Do you think it is possible for humans to avoid all radiation?

No Page 1-4

That's right. Radiation is present in our natural environment and we can't avoid it. Humans have been exposed to natural radiation since the beginning of their lives on earth. We are not continuously aware of it because we can't detect it with our senses; but it is there.

There are other radiation sources besides natural radiation. X-ray generating equipment and radioactive isotopes are used for many jobs within our society. They are used for medical and dental purposes. They are essential to your field of interest, nondestructive testing. In all these applications, radiation makes a valuable contribution to mankind. Still, there is one fact you must remember. That is the purpose of this book. Simply stated:

IONIZING RADIATION HAS THE ABILITY TO DAMAGE HUMAN BODY TISSUE.

Yet we know that we have been living with natural radiation for centuries and the general population does not appear to be suffering any ill effects caused by radiation. This should lead you to believe that...

...damage to human tissue becomes a problem when ionizing radiation exceeds a certain level Page 1-5
only certain types of ionizing radiation can damage human tissue Page 1-6

Good analysis. Since we live in a radiation environment with no apparent ill effects, it must take a certain amount of radiation to create a problem. That's exactly the case.

We will discuss acceptable and unacceptable radiation exposure (dose) later in the book. However, a couple of points to keep in mind from this point on are:

- > Acceptable limits of radiation exposure have been established to protect radiation workers.
- You can perform all your duties and stay within these acceptable limits.

Now, remembering that when we talk of radiation hazards we mean radiation received that exceeds acceptable limits, turn to page 1-7.

Although your choice may seem like a logical assumption, you made the wrong guess.

Up to this point we have made no distinction between the types of radiation with respect to effects on the human body.

In fact, there is no need to distinguish one radiation from another. Any type of ionizing radiation, if received in sufficient quantity, can damage human body tissue. The types of radiation that exist in our environment are not important here. The fact that the small amount of natural radiation we do receive does not harm us is important.

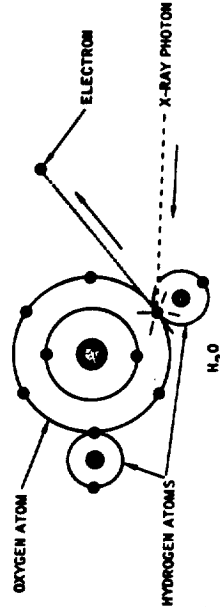
Just assume that the exposure we receive from everyday living includes some of all the radiation types and return to page 1-4 and select the other answer.

RADIATION HAZARD

We have said that excessive ionizing radiation can damage human tissue. This creates a potential hazard to anyone exposed to excessive radiation doses. To better understand how this happens, a simplified look at the structure of human tissue and how it may be affected by ionization is in order.

The basic building block of all living tissue is the "cell." The cell is a unit containing minerals, liquids, proteins, and sugars held together in a watery combination by a thin membrane. Cells are capable of splitting or dividing and creating new cells. This is a natural means of cell reproduction. Most cells have a limited life span and, as they die, are replaced by new cells created by cell-division.

Now let's see how radiation can affect the human cell. Like all matter, the smallest unit of a human cell is the atom. Since the cell contains a lot of water, we'll look at the atoms of a water molecule in a cell being penetrated by ionizing radiation.



Note in the above illustration that the photon knocked an electron out of orbit (thereby creating an ion pair). This is the main process by which damage to tissue occurs. It is known as:

Cell division Page 1-8

Ionization Page 1-9

No. The process by which an electron is knocked out of orbit is not cell division. We did mention cell division as a means by which cells naturally divide to create new cells. But ionizing an atom or molecule within a cell with radiation would not necessarily cause cell division. It would cause one of several types of damage to the cell. If you will recall from Volume I of this series, X-rays or gamma rays create ions in matter they pass through and their energy is absorbed in the process. An atom in which an electron is knocked out of orbit by radiation becomes an ion and the displaced electron becomes an ion. The combination of the two is called an ion pair.

As we also learned in Volume I, the process by which ion pairs are created is called...

...ionization Page 1-9

Right. Ionization is the process by which an electron is knocked out of the orbit of its parent atom.

Almost all the tissue damage done by radiation is caused by ionization. Radiation damage to tissue can occur when enough electrons are knocked out of enough atoms. This results in breaking down the structure of cells to the point that they may die; they may lose their ability to reproduce; or they may reproduce in an abnormal manner.

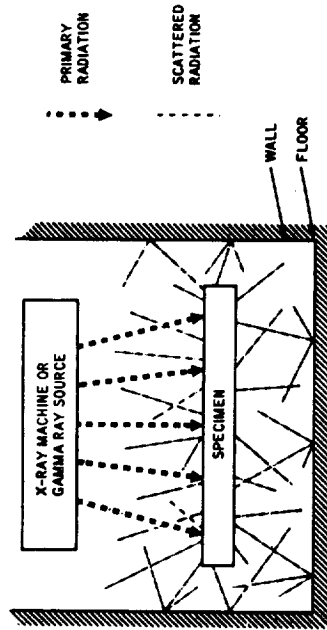
We can see that if cell damage in body tissue is extensive enough, the tissue itself will be damaged. There will be more on the effects of tissue damage later in the book. But, now, let's see what types of radiation you may encounter as a radiographer.

The radiation that you will use is X-radiation and gamma radiation. Most of the discussion will only concern gamma and X-radiation. Other types will be mentioned but these two are the main ones.

Limiting our discussion mainly to X-rays and gamma rays simplifies it considerably. Essentially, the only difference between the two is their origin. X-rays are produced in a high voltage electron tube in an X-ray machine. Gamma rays are produced or emitted from a radioactive isotope contained in an isotope "camera" or "projector." Otherwise, we can consider them the same, especially when discussing radiation hazards. All radiation beams from either source, when received in sufficient quantity, have the power to damage human tissue.

Turn to the next page.

Shown below is a simplified drawing of the way radiation acts when it is projected onto a radiographic test specimen. Just assume that the exposure is being made in a room from which no radiation can escape.



As you learned in Volume I, a portion of the primary radiation "scatters" when it strikes an object.

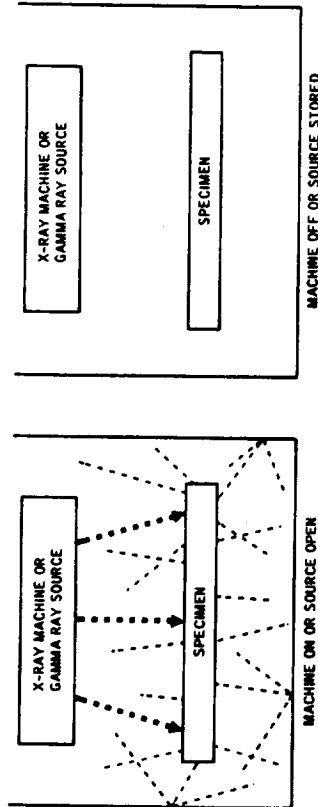
Choose the correct statement.

Radiation hazard exists in both the primary and scattered radiation shown in the above illustration Page 1-11

Radiation hazard exists only in the primary radiation shown above Page 1-12

Correct. Radiation hazard exists in both primary and scattered radiation. If the human body received either in sufficient quantity, damage to tissue could occur.

Now, to generalize a bit, an X-ray machine sends out X-rays only when electrical power is "on" the machine. A radioactive isotope (source) emits radiation at all times but there is also a way of turning it off and on. The small source that produces the radiation can be "stored" (placed by remote control) in a lead shielded storage container within the unit to "shut off" the radiation exposure.



Comparing the two illustrations above, which of the following do you agree with?

Primary and scattered radiation are present only when the X-ray machine is on or gamma ray source is open Page 1-13

Although there is no radiation shown in the "equipment-off" picture, it would probably take hours for all the radiation to clear away if the machine or source had just been used Page 1-14

Your answer shows that you believe that a radiation hazard can exist only from the primary radiation of a gamma or X-ray source. That is not correct.

When the primary gamma ray or X-ray strikes an object, atoms of the object are ionized and a portion of the primary radiation is scattered. This scattered radiation also has the ability to ionize other objects it hits.

Return to page 1-10, read the material again, and select the correct answer.

Exactly. If the X-ray machine is off or the gamma ray source is stored, radiation is "turned off." This is not to say that flicking a switch on an X-ray machine or "thinking" that a source is stored assures you of safety. It should also be noted that isotope sources will always "leak" a small amount of radiation. But, effectively, the source is considered to be off when it is stored.

All safety devices must be checked and you should always be certain that equipment is "off" before you assume that radiation is not present. But, once the cause of the radiation is turned off (or stored), radiation should no longer be present. In the case of our room, illustrated on the other pages, you could enter it as soon as you were sure that the X-ray equipment was off or the isotope was safely stored.

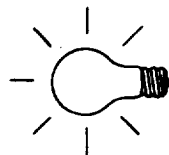
What do you think happened to the test specimen when it was exposed to X-radiation?

It is possible for it to become a radioactive isotope capable of emitting ionizing radiation Page 1-15

When the radiation producer (X-ray machine or gamma ray source) is turned off, the specimen ceases to be affected by radiation Page 1-16

Your choice is wrong. It does not take hours for radiation to clear away. When using radiographic equipment, radiation is present only when the equipment is "on."

You may consider the operation of X-ray and gamma ray equipment similar to turning an electric light on and off.



WHEN THE X-RAY MACHINE IS ON OR THE GAMMA SOURCE IS OPEN, RADIATION IS PRESENT.



WHEN THE X-RAY MACHINE IS OFF OR THE GAMMA SOURCE IS STORED, RADIATION IS OFF.

In view of this, we could say that...

...primary and secondary radiation is present only when the X-ray machine is on or the gamma ray source is open Page 1-13

No. That's not right. Exposing the test specimen to the ionizing radiation used in radiography would not make it radioactive. It would not turn it into an isotope capable of giving off ionizing radiation.

Remember that we said you could enter the room where X-ray or gamma ray tests had been made as soon as the equipment was off. This means that the room would contain no ionizing radiation with the equipment off. If the test specimen had been made radioactive, this would not have been the case, would it?

So...

...when the radiation producer (X-ray machine or gamma ray source) is turned off, the specimen ceases to be affected by radiation Page 1-16

Right. The specimen is not affected by the radiation after the radiation is "turned off." Exposure of materials to the gamma or X-radiation used in radiography does not cause them to become radioactive. Nor can a person exposed to radiation become radioactive. Because of the complex nature of tissue and the cell reproduction process, excessive radiation can damage the human body. But this damage does not cause the body to become radioactive and emit radiation.

This may be explained by remembering what was said about the structure of the atom and effect of radiation on human cells. Ionizing radiation may penetrate matter and strike an electron, knocking it out of orbit. However, as you learned in Volume I of this series, to make something radioactive (or create an artificial isotope) you must penetrate the nucleus of an atom (as would be done by bombardment with neutrons).

Gamma rays and X-rays used in radiography do not significantly affect the nucleus of an atom.

Do you think a person who had suffered radiation damage could spread radiation damage to other humans?

Yes Page 1-17

No Page 1-18

You believe that a person who had received radiation damage could spread radiation damage to other humans. That is not so.

When a human is exposed to radiation, a chemical change may take place if enough electrons are knocked out of orbit in enough atoms. But the human tissue has not been made radioactive. If a material is not radioactive it cannot cause radiation damage.

There is a condition known as "contamination" that can be spread; but we will talk about that later.

Return to page 1-16 and take another look at the material.

Very good. You realize that a person who has received radiation damage cannot spread radiation damage to others. Human tissue does not become "radioactive" because of exposure to gamma or X-radiation. Nor does any other material when exposed to the radiation used in radiography. If radiation exposure to a material is sufficient to knock out a substantial number of electrons, there may be a chemical change in the material. But, the material has not been made radioactive. It cannot "spread" radiation to other materials.

There is a separate hazard in working with radiation producing materials by which the materials themselves could be spread about. This hazard is called "radioactive contamination." Radioactive contamination is the uncontrolled release of radioactive materials. Since no radioactive materials are associated with X-ray machines, contamination is not a problem in the use of X-rays. But let us consider it in the use of isotopes.

It is not intended that you learn all about contamination. Nearly any hazards that you will encounter from isotopes are caused by radiation from a controlled source. This means that the isotope is contained in a unit which does not allow any radioactive material to escape. Hence, contamination is not a major safety hazard in radiographic work. Still, we should look at an example in which a controlled source could be changed into an uncontrolled source. For illustration purposes, assume that the isotope (source) is removed from an isotope camera and placed on a drop hammer. It is pounded a few times until the source is reduced to small bits. The bits are blown around the area by a fan. Is there a hazard from the scattered bits of radioactive material?

Yes Page 1-19

No Page 1-20

Of course. There is a potential hazard from any radioactive material. Although the isotope has been reduced to small bits, the smaller pieces still emit radiation.

Since the radioactive material in our example is uncontrolled and may be spread about freely, the area around which the isotope pieces are scattered has become contaminated. And, any object which might pick up the pieces would also be contaminated.

This leads us to believe that anyone working in a contaminated area.

. . . would be exposed to radiation hazards but could not spread radioactive contamination to other persons Page 1-21

. . . would be exposed to radiation hazards and could spread radioactive contamination to other persons Page 1-22

Well, we will admit that this is a pretty unrealistic example. But, your answer is a little unrealistic too. You said that there would be no hazard from scattered bits of radioactive material. That just isn't true.

Even though the radioactive isotope is reduced from a solid chunk to small bits, it is still the same material.

Because it is the same material, it is still radioactive and will continue to give off radiation. So your answer should have been...

...yes Page 1-19

You believe that anyone working in a contaminated area would be exposed to radiation hazards but could not spread radioactive contamination to other persons. No, that's not the answer. It is true that there is a hazard from radiation. But, let's look at the other part of the answer.

Consider the fact that the particles of radioactive material in a contaminated area are uncontrolled. They are just like bits of dirt. They could be scattered about by people walking through the area and picking up particles on their shoes. Or pieces could be swept throughout the area by a janitor.

Assume that you touched the contaminated floor with your hand; then you dialed a number on the telephone. You could leave particles on every digit of the phone number you dialed. The people who used the phone after you would certainly pick up some of the radioactive material.

So, you see, it is possible to spread radioactive contamination to other persons.

Right?

Right Page 1-22

That's a good analysis. Anyone entering a contaminated area could accidentally pick up pieces of radioactive material and possibly spread it to other people. Contamination should not be a great problem in radiography operations as long as safety rules are followed. In event of an accident which could result in contamination, the main consideration is to keep people at a safe distance from the area until an authorized cleanup crew has removed the hazard.

Now, let's summarize the major topics covered so far.

- Natural radiation in our environment causes all people to be exposed to ionizing radiation.
- Ionizing radiation has the ability to damage human tissue.
- Damage to human tissue from radiation becomes a problem when radiation exposure exceeds a certain level.
- Industrial radiography can be performed safely and efficiently by using all the safety rules and staying within radiation exposure limits.
- Ionization is the process by which damage to tissue occurs.
- Radiation hazard exists from both primary and scattered radiation.
- The difference between X-rays and gamma rays is their origin.
- When an X-ray machine or gamma ray source is "off," radiation in the surrounding area is "off."
- Exposure to gamma or X-radiation does not make material (be it a metal test specimen or human tissue) radioactive.
- A person who has suffered radiation damage cannot spread radiation damage to other persons.
- A person who is contaminated can spread radioactive contamination.

Turn to the next page.

INTERNAL AND EXTERNAL RADIATION EXPOSURE

A look at the ways that radiation can enter the human body is timely at this point in our discussion. In working with radiation you will hear the terms "internal exposure" and "external exposure." We will discuss both of these. However, the main hazard in radiography comes from external exposure to ionizing rays. Still, so you can recognize the hazards in event of an accident involving an isotope, knowing about internal radiation exposure is also important.

External Radiation Hazard

External radiation exposure, as the name implies, comes from radiation sources outside the body. It exposes the body to ionizing rays which enter the body and can damage tissue in the way we discussed earlier in this chapter.

The sources are usually (but not always) at some distance from the body. An example of this type of external hazard is radiographic exposure equipment (X-ray machines or gamma source cameras).

Do you think that radioactive contamination on your clothing or skin would be an external radiation hazard?

Yes

Page 1-24

No

Page 1-25

Well, I didn't really give you much information on which to make your choice. Radio-active contamination on your skin or clothing would be an external radiation problem. Earlier in the chapter we discussed the fact that contamination is a hazard because it can emit ionizing radiation. If it were on your clothing or skin it would be outside the body. Therefore, it would be an external hazard. Right?

Right..... Page 1-24

Sure it would. If you had radioactive contamination on your skin it would be an external radiation hazard. It would emit radiation from outside the body that could penetrate the skin and ionize atoms of the tissue.

Some types of radiation are more "penetrating" than others and, because of this, present a greater external radiation hazard. The most penetrating type of radiation from isotopes is gamma radiation. The fact that gamma rays are so penetrating is what makes them so useful in radiography.

Two other types of radiation that are emitted from radioactive material are beta and alpha radiation. While both of these are less penetrating than gamma rays, alpha radiation is the least penetrating of all and can be stopped by a sheet of paper.

Which of the following combinations of radiation would present the greatest external radiation hazard?

Alpha and beta radiation Page 1-26

Gamma and beta radiation Page 1-27

No, alpha and beta radiation do not present as great an external radiation hazard as gamma and beta rays.

When considering the potential external radiation hazard of various rays, the penetrating ability of the rays is the prime factor. The greater the ability of a ray to penetrate, the greater is the possibility that it will enter the body and damage tissue.

Alpha and beta radiation are both less penetrating than gamma rays. And, alpha rays are the least penetrating of all. Listed in order of their penetrating power they are:

1. Gamma - most penetrating
2. Beta - less penetrating
3. Alpha - least penetrating.

The combination of these which would be the most penetrating is...

...gamma and beta Page 1-27

Certainly. Gamma and beta rays both present a greater external hazard than alpha radiation. In fact, alpha radiation presents practically no external hazard as it cannot penetrate the dead outer layer of skin. External radiation must penetrate into the body to damage the tissue. But remember that gamma radiation, the type with which you will be most concerned, is the most penetrating of all.

Internal Radiation Hazard

Internal radiation exposure results when radioactive material (or contamination) gets inside the body. The most common ways that contamination can enter the body are by breathing, swallowing, or through breaks in the skin.

In radiography, the possibility of internal radiation hazard is somewhat remote. However, as was pointed out earlier in our discussion of contamination, it might be possible for a source to be crushed and release radioactive materials.

Any accident involving radioactive isotope equipment is a potential hazard (both internal and external). It could be possible that the isotope container itself might be broken in an accident. It could then leak radioactive material which could be taken into the body by breathing or swallowing.

Would you assume that any time radioactive contamination is present there is a potential internal radiation hazard?

Yes Page 1-28

No Page 1-29

Right. Any time you are in a contaminated area, you are exposed to a potential internal radiation hazard.

Since you can't detect radiation with any of the senses (sight, touch, smell, etc.), you should remember conditions under which you could encounter contamination. To be on the safe side, any gamma ray source that has received physical damage may be suspected of leaking radioactive material. Of course there are ways of checking to see if an isotope in a source camera is leaking contamination. But stay on the safe side and don't take chances before the checks are made.

Once inside the body, radioactive materials emit the various types of rays (alpha, beta, or gamma) dependent upon the type of source involved. Several factors determine the amount of damage that can be done by radioactive materials inside the body. The amount of material absorbed, the length of time the material is in the body, and the type of isotope all have an effect on the damage that may be caused.

Do you think the half-life of radioactive material inside the body would also be a factor in the amount of damage caused?

Yes

Page 1-30

No

Page 1-31

You don't believe that any time contamination is present there is a potential internal radiation hazard? Your answer is wrong.

Let's look again at the most common ways that contamination can enter the body. They are:

- Breathing
- Swallowing
- Breaks in the Skin

These three give fairly good access to the inside of the body. If there is uncontrolled radioactive material around, it could be pretty easy to take some into the body by one of these methods.

Therefore, we would say that if contamination is present, it creates a potential internal hazard.

Turn to page 1-28

Correct. The half-life of radioactive material inside the body is a factor in the amount of damage caused. If the half-life is extremely short, the radiation is not present to cause damage over an extended period.

The half-life we are talking about here can better be called the "radioactive" or "physical" half-life. This will distinguish it from a couple of other types of half-life we want to discuss. Some radioactive materials, once inside the body, accumulate in various body organs and are retained there to emit radiation until they decay. If the radioactive (physical) half-life is short, the decay is faster. As a measure of the harm which may be done by the material inside the body, health physicists have adapted another term - "effective half-life."

Effective half-life is the combined effect of radioactive half-life and another factor known as "biological half-life." Biological half-life is the time it takes one-half of the radioactive material to be passed from the body as waste. Many types of contamination are disposed of by the body's normal waste disposal functions.

Which of the following do you think is true?

The longer the radioactive half-life and the biological half-life, the shorter the effective half-life and the less the exposure Page 1-32

The longer the radioactive half-life and the biological half-life, the longer the effective half-life and the greater the exposure Page 1-33

You don't believe the half-life of radioactive material inside the body could affect the amount of damage done? That was a bad guess. The half-life is a factor in determining damage from internal radiation.

Just to review a bit, half-life (or radioactive half-life) is the time it takes one-half of the atoms of a radioactive isotope to disintegrate. If a material inside the body had a very short half-life, say about one-minute, the radioactivity would dissipate rapidly. It would be dangerous only for a short time. It would not emit radiation over a long period. But, if the half-life of the material was five years, it would remain active and emit radiation over an extended period of time.

So the half-life of material causing internal radiation does affect the amount of damage done Page 1-30

Your answer is wrong. Your choice shows that you believe long radioactive and biological half-lives result in a relatively short effective half-life and less exposure to radiation.

Let's review the definitions.

Radioactive half-life. The time it takes one-half of the atoms of a radioactive isotope to disintegrate.

Biological half-life. The time it takes one-half of the radioactive material to be passed from the body as waste.

Effective half-life. A combination of the other two. It is the time needed to lose one-half of the radioactive threat by a combination of biological elimination and radioactive decay.

There are two points to be made here:

1. A long effective half-life of material inside the body results in higher exposure to radiation.
2. If there is a long radioactive half-life and a long biological half-life, the effective half-life is longer.

Turn to page 1-33

You believe that the longer the radioactive and biological half-lives, the longer the effective half-life and the greater the exposure to radiation. You are right. Effective half-life is the time needed to dissipate one-half of the radioactive threat by a combination of biological elimination and radioactive decay. And if the other two take a long time, effective half-life is long.

Now let's take another look at the definitions of the types of half-life we are discussing.

The time it takes one-half of a radioactive material to be passed from the body by the waste disposal functions of the body is...

...biological half-life..... Page 1-34

...radioactive half-life..... Page 1-35

Correct. Biological half-life is the time it takes one-half of a radioactive material to be passed from the body as body waste.

The biological action of the body's waste disposal functions will eliminate some radioactive materials rapidly. These materials do not stay in the body long enough to do much damage. Other materials are not easily eliminated biologically. These are the ones which do the most damage over a long period of time. But remember, biological half-life is a function of the biological processes of the human body.

Try another definition. The time it takes to rid the body of one-half of a radioactive material by a combination of biological elimination and radioactive decay is...

...radioactive half-life..... Page 1-36

...effective half-life..... Page 1-37

Nope. That's the wrong answer. Radioactive half-life is not the time it takes one-half of a radioactive material to be passed from the body as body waste.

Radioactive half-life is concerned with radioactive decay. It is the time it takes one-half of the atoms of a radioactive isotope to disintegrate. Or, another way to say it, radioactive half-life is the time it takes an isotope to lose one-half of its radioactivity.

The answer you were looking for concerns the biological processes of the body. Consider that the body's waste disposal functions are biological processes. The time it takes one-half of a radioactive material to be passed from the body as waste material is...

...biological half life..... Page 1-34

Wrong selection. The time it takes to rid the body of one-half of a radioactive material by a combination of biological elimination and radioactive decay is not radioactive half-life.

Radioactive half-life is concerned with radioactive decay. It is the time it takes one-half of the atoms of a radioisotope to disintegrate. Or, another way to say it, radioactive half-life is the time an isotope needs to lose one-half of its radioactivity.

The answer you wanted concerns radioactive decay. But that's just part of the story. It also concerns biological elimination. Biological elimination and radioactive decay occur simultaneously to rid the body of the radioactive threat. When the combination of these two reduces the radioactive threat to one-half its original value, you have...

...effective half-life Page 1-37

Exactly. Effective half-life is the time it takes to rid the body of one-half of a radioactive material by a combination of biological elimination and radioactive decay.

Before we proceed, let's take a final look at the definitions of the three types of half-life.

Radioactive half-life. The time it takes one-half of the atoms of a radioactive isotope to disintegrate.

Biological half-life. The time it takes one-half of a radioactive material to be passed from the body as waste.

Effective half-life. A combination of the other two. It is the time needed to lose one-half of the radioactive threat by a combination of biological elimination and radioactive decay.

The really important thing to be learned here is that damage continues to be caused as long as radioactive material is in the body. Internal radiation can be very serious and there isn't much that can be done about it once radioactive material is inside the body. But it can be avoided by avoiding contamination.

The considerations in this chapter were intended to introduce you to the subject of radiation safety. We will elaborate on many of the concepts later. But, before we continue, turn to the next page for a quick review of the points we have covered thus far.

From Page 1-37	<p>1. The next few pages are different from the ones which you have been reading. There are _____ arrows on this entire page. (Write in the correct number of arrows.) <u>Do not</u> read the frames below. FOLLOW THE ARROW and turn to the TOP of the next page. There you will find the correct word for the blank line above.</p>	<p>This is the answer to the blank in Frame number 1.</p> <p>1. four Frame 2 is next</p>
8. acceptable	<p>9. exceeding</p>	<p>9. exceeding</p>
<p>9. The real hazard in radiography comes from _____ the acceptable limits.</p>	<p>10. Tissue cells attacked by _____ radiation may die or lose their ability to reproduce.</p>	<p>10. Tissue cells attacked by _____ radiation may die or lose their ability to reproduce.</p>
16. scattered, X-, gamma	<p>17. When using an X-ray machine or a gamma ray source, _____ and _____ radiation are present only when the machine is on or the source is open.</p>	<p>17. primary, scattered</p>
24. external	<p>25. Alpha and beta radiation are _____ (more, less) penetrating than gamma rays or X-rays.</p>	<p>18. This means that when an X-ray machine or gamma ray source is "off," radiation in the surrounding area is "_____."</p>
26. less	<p>28. Contamination taken inside the body presents an _____ radiation hazard.</p>	<p>15. less</p>

3. blanks (or spaces or words)	
4. Now for the review: Natural radiation in our environment causes all people to be exposed to ionizing _____.	
11. atom	
12. The process by which an electron is knocked out of the orbit of its parent atom is _____.	
19. radioactive	
20. A person who has received an overexposure of gamma or X-radiation cannot spread it _____ d _____ to other humans.	
27. radioactive	
28. The time it takes one-half of a radioactive material to be passed from the body as waste material is called _____ half-life.	

2. frame	
3. By following the arrows or instructions you will be directed to the page which follows in sequence. Each section presents information and requires the filling in of _____.	
10. ionizing	
11. Tissue cell damage is caused when an electron is knocked out of the orbit of its parent _____.	
18. "off"	
19. When a test specimen is exposed to X-rays or gamma rays it does not become _____.	
26. internal	
27. The _____ half-life is the time it takes one-half of the atoms of an isotope to disintegrate.	

4. radiation (rays)		
5. Radiation has the ability to damage human body _____		
12. ionization		
13. The basic difference between gamma rays and _____ rays is their origin.		
20. radiation damage		
21. It is possible to spread r _____ c _____		
28. biological		
29. The time needed to lose one-half of internal radioactivity by a combination of biological elimination (biological half-life) and radioactive decay (radioactive half-life) is known as _____ half-life.		

5. tissue		
6. The process by which radiation can damage human body tissue is _____		
13. X-		
14. _____ rays and _____ rays have the power to damage human tissue.		
21. radioactive contamination		
22. The main hazard in radiography comes from e _____ radiation.		
29. effective		
30. Long _____ half-life and long _____ half-life of radioactive material in the body result in long effective half-life.		

We saw in Chapter 1 that radiation can damage human tissue. It is, therefore, important that there be some means for detecting and measuring radiation. We will discuss detection and measurement instruments in a later chapter. But, before you can measure anything there must be some unit for expressing the measurement. When distance is measured, feet, yards, or miles may be used to express the measurement. When weight is measured, pounds or ounces serve as the units of measurement.

The same holds true for radiation. Before it can be measured, there must be meaningful units to express the measurement.

ROENTGEN

The basic unit used to express exposure to gamma or X-radiation is the "roentgen." Measurement is made in air to find the number of roentgens. Actually, "radiation" is not being directly measured. Instead, the same process by which radiation damages human tissue is put to work in the measurement of radiation. It may be said that the roentgen (r) is a unit which expresses radiation exposure...

...absorbed by human tissue Page 2-2

...based on the ionizing effect of radiation Page 2-3

From page 2-1

2-2

Your choice is wrong. The roentgen is not a direct measure of radiation quantity absorbed by human tissue. The roentgen is a measure of radiation exposure in air.

In Chapter 1, we saw what happens in human tissue as it is penetrated by ionizing radiation. The process by which the cells are damaged was called ionization.

The same thing that happens in cells also occurs in the air as radiation penetrates it. Ionization occurs and is put to work in measuring radiation quantity in the air it passes through.

We would say, then, that the roentgen is a unit which expresses radiation exposure...

...based on the ionizing effect of radiation Page 2-3

6. ionization	
7. Since we live with natural radiation in our environment, we can say that radiation must exceed a certain level before it causes _____ to tissue.	
14. X-rays, gamma	
15. Radiation hazard exists from both _____ and scattered radiation.	
22. external	
23. The most penetrating type of external radiation from isotopes is _____ radiation.	
30. radioactive, biological	
31. _____ radiation is a greater hazard in radiography than internal radiation.	

7. damage	
8. All the duties of radiography can be performed within a _____ limits of exposure.	 Return to page 1-38, frame 9.
15. primary	
16. Primary and _____ radiation are both present when using an _____ ray machine or a _____ ray source.	 Return to page 1-38, frame 17.
23. gamma	
24. In radiography, gamma rays and X-rays present an _____ radiation hazard.	 Return to page 1-38, frame 25.
31. External	
This is the end of review of Chapter 1. Turn to page 2-1.	

Exactly. The roentgen (r) is a unit which expresses gamma and X-radiation exposure based on the ionizing effect of radiation. It is not a direct measure of radiation in tissue. Of course, if a certain amount of radiation is present in the air, human tissue in the same air would be exposed to that radiation. It can be said that the roentgen is a unit of measure of the exposure a person could receive in a radiation area.

There are several ways to technically define the roentgen. In your work in radiography you may hear it explained as one of the following:

1. One roentgen is the quantity of ionizing radiation that produces 2,083 million ion pairs in one cubic centimeter (cc) of air. This definition relates closely to our explanation that the roentgen unit is based on the ionizing effect of radiation since we know that radiation creates ion pairs by ionization.

2. One roentgen is the quantity of ionizing radiation that will transfer 83 ergs of energy (the equivalent of 1610 billion ion pairs) as it passes through one gram of air.

There are other technical definitions which are basically other ways of saying the same thing. The technical definitions are not particularly important in your work. The definition you should remember is one of those below. Which one do you think is correct?

The roentgen is the basic unit of measure of gamma or X-radiation in air based on the ionizing effects of radiation Page 2-4

The roentgen is the basic unit of measure of any type of radiation in air based on the ionizing effect of radiation Page 2-5

Right. The roentgen is a unit of gamma or X-radiation in air based on the ionizing effects of radiation.

The way the roentgen is measured can be seen by considering the ionization process. When an atom is ionized, ion pairs are created. An ion pair consists of a negatively charged particle and a positively charged particle. The number of ion pairs can be measured by the amount of electric current they produce. As we said on the preceding page, one roentgen is the quantity of radiation that produces 2,083 million ion pairs in one cc of air.

In reality, the roentgen unit is a comparatively large quantity of radiation. So, while we are discussing measurement units, let's discuss one which reduces the roentgen to a smaller unit used in measurement of personnel exposure. That unit is the "milliroentgen." It is abbreviated "mr" ("m" for milli; "r" for roentgen).

Do you know what the term stands for?

The milliroentgen (mr) is 1/1,000,000 (one one-millionth) of a roentgen . . . Page 2-6

The milliroentgen (mr) is 1/1,000 (one one-thousandth) of a roentgen Page 2-7

From page 2-3

2-5

Your selection is not the definition of the roentgen. Your answer shows that you believe the roentgen is a measure of any type of radiation. That is not so.

The roentgen is a unit of measure only of X-rays and gamma rays. It is, as your answer stated, a measure of these rays in air and it is based on the ionizing effect of radiation.

Turn to page 2-4.

From page 2-4

2-6

Your answer shows that you believe that a milliroentgen is $1/1,000,000$ of a roentgen. That is incorrect.

A milliroentgen is $1/1000$ of a roentgen. When a term is preceded by the word "milli" it means that the unit is divided by 1,000. Other examples are milliamperes, and millivolts.

You may also see a milliroentgen written as ".001 roentgen." That's the same thing - one thousandth of a roentgen. It would take 1,000 milliroentgens to make one roentgen.

Turn to page 2-7.

That's right. The rad is a measure of absorption and the roentgen is a measure of exposure. The relationship may be thought of as a cause and effect situation. The exposure in roentgens is the cause. The absorption in rads is the effect.

The rad can be related to any type of radiation. If human body tissue absorbed a quantity of alpha radiation, the absorbed dose would be measured in rads. Medical people have means of measuring the absorbed dose. The measurement might include measuring the temperature rise of the tissue along with other techniques. The measurement would be expressed in rads.

So, it's easy to see that the rad stands for...

....roentgen absorbed dose..... Page 2-10

....radiation absorbed dose..... Page 2-11

Correct. One mr is 1/1,000 roentgen (also expressed as .001 roentgen).

We have seen that the roentgen expresses gamma and X-radiation measured in air. Since we are interested in damage to the body from radiation, we must go further to see how radiation absorption in tissue and biological effects can be stated in measurement units.

RAD, RBE, AND REM

The rad, RBE, and rem are units that permit us to relate radiation to the biological effects it can cause in human tissue. These terms also allow us to relate and compare the relative effects of the different types of radiation.

Taking first things first, the "rad" stands for radiation absorbed dose. The rad is the unit for expressing the amount (absorbed dose) of energy given off by ionizing radiation in material. Technically, it is defined as the quantity of radiation that results in material absorbing 100 ergs of energy in each gram of the material.

The rad applies to all types of radiation. It is a unit of absorbed dose in material (such as human tissue) of alpha, beta, gamma, and X-radiation. In comparison with the roentgen, it could be said that...

...the rad is a measure of absorption and the roentgen is a measure of exposure..... Page 2-8

...the rad and the roentgen are both measures of exposure..... Page 2-9

From page 2-7

2-9

No, that's not right. The rad and the roentgen are not both measures of exposure.

The rad, spelled out, stands for radiation absorbed dose. It means just that. It is the unit of measure of absorbed radiation dose in human tissue. Of course, you must have exposure to radiation before you can have absorption. But once you have exposure, the unit for expressing absorption is "rad."

Return to page 2-7 and review the material.

From page 2-8

2-10

Well, you may have heard the rad called "roentgen absorbed dose" at some time or other. But that is not the name we are looking for here.

Just to keep us all in step, we will say "rad" stands for "radiation absorbed dose."

That's easy enough when you think about the rad as being an absorbed dose of radiation. Besides, roentgens apply only to X-rays and gamma rays. The rad is a measure of absorbed radiation dose for any type of radiation.

Turn to page 2-11.

Correct. There may be other names for it, but for our purpose we will say the rad means "radiation absorbed dose."

Since the rad is not a measure of exposure (like the roentgen) there is no way to measure rads in the air. The meters used to detect gamma rays and X-rays do not measure rads. They measure roentgens.

Before we get too far off first base, let's look again at the use of the rad in relating radiation to biological effects in humans. To assess biological effects of the different types of radiation, it must be known how much of the radiation is absorbed by tissue. That's where the rad comes in. It expresses the absorbed dose. But, for simplification, let's put some limits on the use of the rad.

We know that the roentgen is a measure of X-rays and gamma rays in air. We also know that the rad is a unit of absorbed dose in human tissue for all types of radiation. But get this: for practical purposes, an exposure of one roentgen of gamma ray or X-ray gives an absorbed dose in tissue equal to one rad.

Does this mean that the exposure stated in roentgens may be substituted for rads as a measure of gamma ray or X-ray absorption in tissue?

Yes

Page 2-12

No

Page 2-13

That's exactly what it means. Well, maybe not exactly, scientifically, and technically. But, for our purpose, the exposure in roentgens may be substituted for rads as a measure of gamma ray and X-ray absorption in tissue. This is so because, for practical application, one roentgen of exposure is about equal to one rad of absorption in tissue.

The above comparison can be made since the amount of ionization in human tissue caused by one roentgen of exposure is about the same as the ionization which occurs in air for the same exposure. Now, to check the relationship of roentgens and rads.

- The roentgen may be used for exposure and absorption for X-rays and gamma rays.
- The rad must be used to express absorption of other types of radiation in tissue.

Turn to page 2-14

Nope. You missed. But don't feel too bad about missing. We are speaking in general terms and haven't yet covered the end result of our efforts. When we finally get to the point of how radiation is related to biological effects for measurement purposes, it will be a little clearer.

We did say before that the roentgen is a measure of exposure in air, not in human tissue. This is true. But the absorbed dose in rads of X-rays and gamma rays closely approximates the exposure in roentgens.

So, for right now, let's say that when radiation doses and biological effects are measured...

...the exposure stated in roentgens may be used as a measure of gamma ray or X-ray absorption in human tissue Page 2-12

The next factor we will consider, in relating radiation to its biological effects on humans, is the "RBE." This term brings us closer to the measurement of radiation effects on human tissue. R stands for Relative Biological Effectiveness.

The RBE is not technically a unit of radiation measurement. It is a factor needed for computing the effects of radiation. Scientists have worked out RBE factors for the different types of radiation. For instance, one roentgen (or one rad) of gamma or X-radiation has an RBE of one. One rad of alpha radiation has an RBE of 20. We could say that the RBE is a factor that compares the biological effectiveness of the different types of radiation and that the...

...biological effectiveness of alpha radiation is higher than that of gamma radiation..... Page 2-15

...biological effectiveness of alpha radiation is lower than that of gamma radiation..... Page 2-16

Exactly. The biological effectiveness of alpha radiation is higher than gamma radiation. This means that 1 rad of alpha radiation can do more damage to tissue than 1 rad of gamma rays. Of course it is not likely that radiography will involve any alpha radiation hazard. But in any instance where it might occur, alpha can be very damaging if it does reach the tissue. Here are RBE values for different types of radiation:

<u>Radiation Type</u>	<u>RBE</u>
X and Gamma	1
Beta	1
Alpha	20
Neutrons (fast)	10

The exact values of all the RBE's do not need to be memorized. However, you should remember that RBE stands for Relative Biological Effectiveness and...

...is a measured unit which compares the biological equivalent of the different types of radiation..... Page 2-17

...is a unit determined by experiment which compares the biological effectiveness of the different types of radiation Page 2-18

No, the truth is the opposite of your answer. You said that the biological effectiveness of alpha radiation is lower than gamma radiation. It is the other way around.

You may be confused because we said earlier that alpha radiation is the least penetrating of the radiations. We also said that gamma rays and X-rays are the ones which most concern us in radiography. These statements are true. But they have nothing to do with RBE.

RBE factor was established to compare biological effectiveness of the different types of radiation after the radiation reached the body tissue. In such an instance, alpha radiation can be highly effective in causing damage.

Here are the two RBE values again:

X-rays and Gamma rays - RBE = 1
Alpha rays - RBE = 20

From this, you can see that...

... biological effectiveness of alpha radiation is higher than gamma radiation Page 2-15

Wrong choice. The RBE is not a measured unit and it does not compare the biological equivalent of the types of radiation. Instead it is an experimentally determined unit which compares the Relative Biological Effectiveness of the different types of radiation.

In the study of radiation, scientists realized that all radiation was not the same. Human tissue reacts differently to the different types of radiation. Because of this, the RBE was determined in experiments. It is now used to relate radiation to the effects it causes on the human body. However, it is just a factor to be used in determining effects. It cannot be measured.

The definition again:

RBE (Relative Biological Effectiveness) is a unit determined by experiment which compares the biological effectiveness of the different types of radiation Page 2-18

Correct. You recognize that the RBE is an experimentally determined unit which compares the biological effectiveness of the different types of radiation. Now let's see how the RBE is used.

We learned that the rad is the unit of measure of the absorbed dose in body tissue. And we know that the RBE gives us a factor for the biological effectiveness of a radiation type. These two - the magnitude of the dose and its biological effectiveness - give us the necessary elements to find the "biological dose." And that's what we've been leading up to - a way to relate radiation exposure to the effects it can cause in human tissue.

The unit to express the biological dose is the "rem." Rem stands for "roentgen equivalent man." It is a unit which expresses the biological effect produced in humans by any type of radiation. The rem is not measured directly like the roentgen but is a computed unit. The biological dose for any type of radiation may be obtained by multiplying the absorbed dose by the relative biological effectiveness. Which one of the following formulas would find the biological dose for any type of radiation?

$r \times RBE = rem$ Page 2-19

$rad \times RBE = rem$ Page 2-20

The formula you chose is wrong. Let's identify the elements to see where the trouble is. Remember, you want the biological dose for any type of radiation. Here is your selection:

$$r \times \text{RBE} = \text{rem.}$$

rem - roentgen equivalent man. This unit is the biological dose. It is the element we want to find.

r - roentgen. This unit is a measured exposure in air of X-rays or gamma rays only.

RBE - Relative Biological Effectiveness. This unit is used to relate the biological effectiveness of the different types of radiation.

What we were after was the following:

$$\text{absorbed dose} \times \text{RBE} = \text{biological dose in rems.}$$

Two of the elements in the formula you chose were correct:

$$\text{---} \times \text{RBE} = \text{rem.}$$

The third element, r or roentgen, would have been correct if you wanted to find the biological dose of X-ray or gamma ray. This goes back to our statement that $1 r = 1 \text{ rad}$. But, in the question we asked, we were talking about any type of radiation. This could include alpha, beta, or neutron. And these radiations are not measured in roentgens. So, instead of using "r" in the formula, we must use the symbol for the absorbed dose or "rad."

Here is the one you should have chosen:

$$\text{rad (radiation absorbed dose)} \times \text{RBE} = \text{rem.} \dots\dots\dots \text{Page 2-20}$$

Very good. The formula you selected is correct if you want the biological dose for any type of radiation. Here it is again:

$$\text{rad} \times \text{RBE} = \text{rem}$$

As we learned previously, the rad is the absorbed dose in tissue for any type of radiation. But we also learned that in certain types of radiation, the roentgen may be substituted for the rad as an expression of absorbed dose. This means that...

$$\dots \text{the formula,} \quad r \times \text{RBE} = \text{rem,}$$

may be used to compute the biological dose for alpha, gamma, and

X-radiation. $\dots\dots\dots$ Page 2-21

$$\dots \text{the formula,}$$

$$r \times \text{RBE} = \text{rem,}$$

may be used to compute the biological dose for gamma and X-radiation,

$$\dots \text{but the formula}$$

$$\text{rad} \times \text{RBE} = \text{rem,}$$

must be used to compute alpha radiation. $\dots\dots\dots$ Page 2-22

No, that's not right. The formula,

$$r \times RBE = \text{rem},$$

can only be used to compute the biological dose for X-rays and gamma rays. It cannot be used when discussing alpha radiation.

The "r" in the formula you selected stands for roentgen. We learned earlier that the roentgen is a unit of measure for gamma and X-radiation only. We also saw that it could be used as an approximation of gamma ray and X-ray absorption in tissue.

Alpha radiation is not measured in roentgens. The best measure of alpha is in the energy it gives off in tissue. That unit is the rad. So we have to use a different formula in computing the biological dose in rems of alpha radiation.

Return to page 2-20, review the material, and select the other answer.

Right. The formula,

$$r \times RBE = \text{rem},$$

may be used to get biological dose in rems for gamma or X-radiation. But it cannot be used for the other types of radiation. The formula for the other types must use rads instead of roentgens to get the biological dose in rems.

The rem, or roentgen equivalent man, is used to express the biological dose for any radiation. This simply means that when you convert exposure or absorption of the different types of radiation to rems, you may add them together and get a dose total that is meaningful. The dose is used to keep score on radiation workers. Limits are established that are expressed in rems. More on these limits later. But now let's look at the way the types of radiation may be added to determine the biological dose.

Assume that a person working in a radiation area received a mixed dose of radiation consisting of gamma, beta, and alpha radiation. To evaluate the dose and apply it to the permanent records, all radiation must be converted to rems.

<u>Radiation Type</u>	<u>Exposure/Absorbed Dose</u>	<u>RBE</u>	<u>Dose in Rems</u>
Gamma	0.3 r (or rad)	X 1	= 0.3
Beta	0.1 rad	X 1	= 0.1
Alpha	.02 rad	X 20	= 0.4
Total			0.8 rem

Turn to the next page.

From page 2-26

Exactly. The expression "rems per hour" is the biological dose rate. The rem dose is always the biological dose and the rate at which it is received is the biological dose rate.

Another rate in which you will be interested is the exposure rate. Which of the following would be an expression of the exposure rate of X-rays and gamma rays?

RBE per hour (RBE/hr)..... Page 2-31
 roentgens per hour (r/hr) Page 2-32

From page 2-26

You are only half right. Which means you selected the wrong answer.

In our question we asked about biological dose rate. Of the two expressions of time rates on page 2-26, only one has anything to do with biological dose rate.

Return to page 2-26 and see if you can select the right answer.

From page 2-22	2-23
The total, 0.8 rem, is the biological dose which relates the different types of radiation to their biological effects on human tissue. Note the line for gamma ray exposure in the example on page 2-22.	
From this we can see that...	
...1 r of gamma radiation = 1 rem.....	Page 2-24
...1 r of gamma radiation = 0.3 rem.....	Page 2-25
From page 2-23	2-24
Right. One r (roentgen) of gamma radiation = 1 rem. And the same thing is true for X-rays since the RBE for X-rays is the same as for gamma rays. Stated in summary:	
The biological dose in rems for X-ray and gamma ray is equal to the exposure in roentgens.	
Assume that you were required to record your biological dose in rems on a form after completing a job in a radiation area. By reading the proper instrument you determined that your gamma ray exposure during the job was 2 mr.	
You could enter the 2 mr reading directly on the form and show it as 2 millirems.....	Page 2-26
You could enter the 2 mr reading on the form after converting it to 2 rems by use of the formula.....	Page 2-27

From page 2-22	2-23
The total, 0.8 rem, is the biological dose which relates the different types of radiation to their biological effects on human tissue. Note the line for gamma ray exposure in the example on page 2-22.	
From this we can see that...	
...1 r of gamma radiation = 1 rem.....	Page 2-24
...1 r of gamma radiation = 0.3 rem.....	Page 2-25
From page 2-23	2-24
Right. One r (roentgen) of gamma radiation = 1 rem. And the same thing is true for X-rays since the RBE for X-rays is the same as for gamma rays. Stated in summary:	
The biological dose in rems for X-ray and gamma ray is equal to the exposure in roentgens.	
Assume that you were required to record your biological dose in rems on a form after completing a job in a radiation area. By reading the proper instrument you determined that your gamma ray exposure during the job was 2 mr.	
You could enter the 2 mr reading directly on the form and show it as 2 millirems.....	Page 2-26
You could enter the 2 mr reading on the form after converting it to 2 rems by use of the formula.....	Page 2-27

Good thinking. A 2 mr reading on an instrument could be entered directly on a record form as 2 millirems (mrems). No need to use a formula or other mental gymnastics.

That brings us to the end result we were looking for. The units for expressing radiation measurement. The rem is the standard unit for record keeping of the radiation worker's biological dose. It relates all radiations to their biological effects and permits establishment of standardized dose limits. For gamma and X-radiation, the roentgen (r) is the equivalent of the rem. And these are the two types of radiation with which you will be most concerned.

DOSE AND DOSE RATE

We have explained the definition of absorbed dose and biological dose. And we can see that a dose is the radiation absorbed in the body. Another term which we will use is the "dose rate." Dose rate is the time rate at which a radiation dose is received. It is the dose per unit of time. Which of the following do you think expresses biological dose rate?

- .02 rads per hour Page 2-28
- .02 rems per hour Page 2-29
- Both of the above Page 2-30

Wrong. One roentgen (r) of gamma radiation does not equal 0.3 rem. Let's look at the problem again:

<u>Radiation Type</u>	<u>Exposure/Absorbed Dose</u>	<u>RBE</u>	<u>Dose in Rems</u>
Gamma	0.3 r (or rad)	x 1	= 0.3 rem

The RBE factor of gamma radiation is one. In the formula for gamma ray biological dose, $r \times RBE = \text{rem}$, you can substitute 1 for the RBE factor:

$$r \times 1 = \text{rem}.$$

This means that the dose in rems is always equal to the gamma ray exposure in roentgens. Here are a couple of examples:

A radiation worker received 2 r of gamma ray exposure. What is the biological dose in rems?

Solution:

$$\begin{aligned} r \times RBE &= \text{rems} \\ 2 \times 1 &= 2 \text{ rems} \end{aligned}$$

A worker received 1 r of gamma ray exposure. What is the biological dose?

Solution:

$$\begin{aligned} r \times RBE &= \text{rems} \\ 1 \times 1 &= 1 \text{ rem} \end{aligned}$$

So we can now see that an exposure of 1 r of gamma radiation = 1 rem. Right?

Right Page 2-24

From page 2-29

2-31

No. RBE per hour is not an expression of exposure rate. RBE, since it is not actually a measurement unit, would not be stated in conjunction with a unit of time. It is simply an experimental unit which compares the biological effectiveness of the different types of radiation.

The unit of exposure to gamma and X-radiation is the roentgen. And the rate at which exposure is received is...

...roentgens per hour (r/hr) Page 2-32

From page 2-29

2-33

Right. Roentgens per hour is an expression of radiation exposure rate. An exposure of .02 roentgens of X-rays or gamma rays in one hour would be stated as ".02 r/hr" or "20 mr/hr."

Dose rate is the dose per unit of time and the exposure rate is the exposure per unit of time.

Of course, with respect to X-rays and gamma rays, the exposure rate in roentgens per hour is the same as dose rate in rems. That's the reason that you will hear gamma and X-radiation exposure expressed as a dose rate and stated in roentgens per hour.

Turn to the next page.

Now let's summarize the definitions of measurement units.

Roentgen. The roentgen is the basic unit of measurement of gamma or X-radiation in air based on the ionizing effects of radiation. One roentgen is equal to one rem.

Radiation Absorbed Dose - rad. The rad is the unit for expressing the absorbed dose of ionizing radiation in material such as human tissue. The rad can be related to any type of radiation. For gamma rays or x-rays, one rad is equal to one roentgen.

Relative Biological Effectiveness - RBE. RBE is an experimentally determined unit which compares the biological effectiveness of the different types of radiation.

Roentgen Equivalent Man - rem. The rem is a unit which expresses the biological effect or biological dose in humans for any type of radiation. The biological dose in rems for X-rays or gamma rays is equal to the exposure in roentgens ($1r = 1 \text{ rem}$).

Dose rate. The dose rate is the time rate at which a radiation dose is received.

Turn to the next page.

Now, for a quick drill, match the definitions to the correct unit by writing the unit in the space corresponding to the correct definition.

rad	_____	A unit for expressing the absorbed dose of ionizing radiation in material such as human tissue.
rem	_____	The time rate at which a radiation dose is received.
dose rate	_____	An experimentally determined unit which compares the biological effectiveness of the different types of radiation.
roentgen	_____	A unit which expresses the biological dose in humans for any type of radiation.
RBE	_____	The basic unit of measurement of gamma and X-radiation in air based on the ionizing effect of radiation.

Turn to the next page and check your answers.

Here is the way your answers should have looked:

rad A unit for expressing the absorbed dose of ionizing radiation in material such as human tissue.

dose rate The time rate at which a radiation dose is received.

RBE An experimentally determined unit which compares the biological effectiveness of the different types of radiation.

rem A unit which expresses the biological dose in humans for any type of radiation.

roentgen The basic unit of measurement of gamma and X-radiation in air based on the ionizing effect of radiation.

If you missed any of the selections, return to page 2-33 for another look at the definitions. Otherwise, this completes our discussion of the measurement units. Turn to the next page for a review of the chapter.

From page 2-35

1. The abbreviation "r" stands for _____ and "mr" for _____.

8. all (any)

9. For practical purposes, one roentgen of gamma ray or X-ray exposure is equal to _____ rad of absorption.

16. rem

17. Rem stands for _____ equivalent man.

24. roentgens (r)

25. An exposure of 2 mr of gamma radiation is equal to _____ mrem.

1. roentgen, milliroentgen	2. X-, gamma, air
2. The roentgen is a measure of _____ rays and _____ rays in _____.	3. Measurement of the roentgen is based on the _____ effect of radiation in air.
9. 1	10. rad
10. The _____ must be used to express absorption of alpha radiation in tissue.	11. The factor that expresses the biological effectiveness of the different types of radiation is _____.
17. roentgen	18. biological dose
18. The rem expresses the _____ for any type of radiation.	19. The biological dose in rems for X-ray or gamma ray is computed by multiplying _____ by the _____ factor.
25. 2	26. rem
26. The standard unit for keeping records of radiation worker's biological dose for all types of radiation is the _____.	27. The standard unit for measuring exposure to gamma and X-radiation is the _____.

3. Ionizing		
4. One mr is _____ roentgen.		
11. RBE		
12. The RBE is not a measured value but was determined by _____.		
19. r (or rad), RBE		
20. To obtain the biological dose for alpha radiation, use the formula $\text{rem} = \text{_____} \times \text{_____}$		
27. roentgen		
28. The unit of absorbed dose is the _____.		

4. 1/1,000 (.001)		
5. While the roentgen measures _____ and _____ in _____, the _____ is a measure of absorbed dose in tissue.		
12. experiment		
13. RBE stands for _____.		
20. rad, RBE		
21. An exposure of 1 r of gamma ray of X-ray equals _____ rem.		
28. rad		
29. The time rate at which a radiation dose is received is called _____.		

<p>5. X-rays, gamma rays, air, rad</p>	<p>6. Rad stands for _____.</p>	<p>6. radiation absorbed dose</p>	<p>7. The rad is a measure of _____ while the roentgen is a measure of _____.</p>
<p>13. relative biological effectiveness</p>	<p>14. The RBE of gamma rays or X-rays is _____.</p>	<p>14. one</p>	<p>15. The RBE of alpha radiation is (higher, lower) _____ than that of gamma radiation.</p>
<p>21. one</p>	<p>22. One mrem equals _____ rem.</p>	<p>23. 1/1000 (.001)</p>	<p>23. The combined dose for all types of radiation may be totaled after converting all exposures to _____ equivalent _____.</p>
<p>29. dose rate</p>	<p>30. The biological dose rate is expressed in _____ per hour.</p>	<p>30. rems</p>	<p>31. .02 mr per hour is an expression of _____.</p>

7. absorption, exposure

8. The rad is a unit of absorbed dose in tissue of _____ types of radiation.

Return to page 2-36,
frame 9.

13. higher

16. The unit which expresses the biological dose is the _____.

Return to page 2-36,
frame 17.

23. roentgen(s), man

24. The biological dose in rems for X-rays or gamma rays is equal to the exposure in _____.

Return to page 2-36,
frame 25.

31. exposure rate

This completes the review of Chapter 2. Turn to page 3-1.

The problem of radiation hazard to radiography workers is an important one. We have seen the way radiation can damage human tissue. This makes it necessary to establish dose limits for radiation workers and make sure the limits are observed.

The conditions and limits of radiation exposure are established by various federal and state agencies. The primary agency is the United States Atomic Energy Commission (AEC). But all the agencies combined cannot assure radiation safety. It is the job of the workers themselves to use the exposure rules for their own protection. The fact that limits are established does not assure protection against carelessness or disregard for rules. Any time radiation exposure is received unnecessarily, the exposure is considered to be excessive whether or not it exceeds the allowable limits.

We have said before that radiography can be performed safely. Indeed, it must be performed safely. It becomes unsafe only when excessive radiation is received.

Turn to the next page.

Do you believe it is desirable, if possible, to limit your radiation biological dose to less than the regulatory limit established by the AEC?

- No..... Page 3-3
- Yes..... Page 3-4

You do not think it would be desirable to limit your biological dose to less than the regulatory limit established by AEC? It was the other answer that we wanted you to select.

When you work in radiography you will receive a certain amount of radiation exposure.

The idea is to keep the exposure to the minimum required and still do the job satisfactorily.

Your biological dose is a cumulative thing. Each dose is added to those received in the past to form a sort of permanent score sheet. Any unnecessary exposure is not available to be used as a buffer or to be used in performing your job. So...

...it is desirable, if possible, to limit your biological dose to less than the regulatory limit established by AEC..... Page 3-4

Sure. If possible, limit your biological dose to less than the regulatory limit established by the AEC. The "if possible" in this statement may need a little explanation. It means that if it is possible to perform your job satisfactorily and stay well below the limits, do so. Any unnecessary radiation should be avoided.

Up to this point we have mentioned the radiation limits for radiography workers several times. It is time to take a closer look at these limits and assign some numbers to them.

The AEC, as the primary controlling agency, has specified that any organization with a license to possess and use radioactive materials must make certain that individuals are not exposed to radiation in excess of regulatory limits. While there are exceptions which we will discuss a little later, the basic requirements are that radiation workers will not receive an occupational dose in excess of the following:

Area of Body Exposed	Rems Per Calendar Quarter
Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	1-1/4
Hands and forearms; feet and ankles	18-3/4
Skin of whole body	7-1/2

Turn to the next page.

Notice that on the previous page we called these limits as "occupational" dose. This is the standard terminology for the radiation limits received while employed in a job which requires the use of radiation. Another point to remember is that, in radiography, most of the radiation received is to the whole body.

By studying the limits on the preceding page we can see that the lowest allowable dose is to the:

Whole body Page 3-6

Feet and ankles Page 3-7

The limits are stated in "rems per calendar quarter." I would like to know what a calendar quarter is before I continue. Page 3-8

From page 3-5

Not so. We were asking you to identify the limitation which specified the lowest allowable dose. "Feet and ankles" was not the correct answer. You probably didn't read the figures closely enough. Here are the limits for the parts of the body in the question:

Whole body.....1-1/4 rems per calendar quarter

Feet and ankles...18-3/4 rems per calendar quarter

From this you can see that the most restrictive limit is imposed on whole body exposure.

Return to page 3-5 and select another answer.

From page 3-5

Right. The most restrictive limit for radiation workers is for exposure to the whole body. Whereas the limit for the feet and ankles is 18-3/4 rems per calendar quarter, the whole body dose limit is only 1-1/4 rems per calendar quarter. This can be interpreted to mean that 1-1/4 rems of whole body exposure is as damaging as 18-3/4 rems exposure to the feet and ankles. From this analysis you can see that radiation damage varies with the amount of the body exposed.

The limits you saw on the other page also showed the head and trunk, active blood-forming organs, lens of the eyes, and gonads limited to 1-1/4 rems per calendar quarter. The hands and forearms are limited to 18-3/4 rems per calendar quarter. This establishes still another point. Not only does radiation damage vary with the amount of the body exposed, it...

...is less for the hands and forearms than it is for the feet and ankles for a given amount of radiation Page 3-9
varies with the part of the body exposed Page 3-10

From page 3-5

3-8

Good for you. If you don't know what a calendar quarter is, you at least don't mind asking.

A calendar quarter is approximately 1/4 year and determined by either of the following subdivisions:

a. January 1 through March 31; April 1 through June 30; July 1 through September 30; October 1 through December 31.

b. Four periods in a calendar year of 13 complete consecutive weeks each.

The AEC regulations provide some alternatives for splitting the year into quarters. But for our talking purposes, these definitions are adequate.

Return to page 3-5 and continue.

From page 3-6

3-9

No. For a given amount of radiation, approximately the same damage will be caused to the hands and forearms as to the feet and ankles. The exposure limits are 18-3/4 rems per calendar quarter for each of these sets of extremities. This tells us something about the damage which is caused to each by a given amount of radiation.

The important point we wanted to make here is that different parts of the body are damaged more by radiation than others. This can be seen by noting the limits assigned to the parts. e.g.:

lens of the eye, gonads - limited to 1-1/4 rem/calendar quarter
hands and forearms - limited to 18-3/4 rem/calendar quarter.

So the real point to be made here is:

Not only does radiation damage vary with the amount of the body exposed, it also varies with the part of the body exposedPage 3-10

Sure. Not only does radiation damage vary with the amount of the body exposed, it also varies with the part of the body exposed.

One other factor can be detected by looking at the exposure limits. Note that they are all given in rems per calendar quarter - 1-1/4 rems/calendar quarter for the whole body; 18-3/4 rems/calendar quarter for the hands and forearms. In each case a rate of exposure is established - so many rems over a certain period of time. In each quarter, for an extended period, a person is permitted a specified dose.

Which of the following statements do you believe is correct?

The physical effects received by a radiation dose vary with the time span over which the dose is received Page 3-11

A given radiation dose will cause less damage if it is received over a very short period of time than if it is received over a long period of time Page 3-12

Both of the above Page 3-13

Good. You recognize that the physical effects received by a radiation dose vary with the time span over which the dose is received. And the relationship is as follows:

A radiation dose of a given amount will have less effect if it is received over a long period of time. The same dose may cause permanent damage if received all at once.

The reasons for this is that the tissue of the body is capable of repairing radiation damage if it is given adequate time to do so. Tissue repair is accomplished by the undamaged tissue cells creating new cells to replace the dead or damaged cells.

When a given exposure is over a long period of time, considerable tissue repair will be accomplished during the period of exposure. Or, if exposure is intermittent, repair occurs between exposures. But when the same exposure is received all at one time, the maximum effects are felt, and tissue repair becomes more difficult.

We should make a point here. There is considered to be no biological necessity to restrict exposure in any period of time less than a calendar quarter where the doses do not exceed those specified by the regulatory limits. In other words, the entire 1 1/4 rems could be absorbed at one time with no adverse effect. In practice, however, many employers limit exposure to smaller increments for shorter periods of time simply to spread the allowable dose more evenly thus making work schedules more predictable. For example, 0.1 rem per week is a commonly used limit.

Now let's list the three variables we have covered so far which influence radiation effects. Effects vary with:

- The amount of the body exposed
- The part of the body exposed
- The time span over which a radiation dose is administered.

Turn to page 3-14.

From page 3-10

3-12

Hold on now. You're off on the wrong foot. You say that a radiation dose causes less damage if it is received over a short period of time. It doesn't work that way.

The physical effects of radiation vary with the time span over which the dose is received. But the relationship isn't the one you picked. It is possible for a person to be exposed to relatively high radiation doses over a long period of time without suffering III effects. But the same dose received all at one time could produce a violent reaction.

Turn to page 3-11 and we will take a look at the reasons for this.

From page 3-10

3-13

Well you are half right. Unfortunately that means you are half wrong too.

Speaking first of the wrong portion, radiation received over a short period of time does not cause less damage. This is more damaging than if the same radiation were received over a lengthy period.

The selection you wanted was: "The physical effects received by a radiation dose vary with the time span over which the dose is received."

We actually jumped a little ahead of ourselves with this question but if you will turn to page 3-11 we will try to show you why this happens.

Another variable which affects the amount of damage radiation can do is the age of the person exposed. Science has discovered that body cells which are most active in dividing and reproducing themselves and those which are least mature are more vulnerable to radiation.

A young child two or three years old is an example of a person whose cells are active in reproducing. As a child grows, cells must divide and multiply to promote the growth. The growing child also has a large number of immature cells because of this reproduction.

Which of the following would be subject to greater radiation damage from a given exposure?

A person who is 25 years old Page 3-15

A person who is 13 years old Page 3-16

You believe that a person who is 25 years old would be subject to greater damage from a given radiation exposure than a 13 year old. That's wrong.

We discussed the way body cells are damaged by ionizing radiation. The cells which are most vulnerable to ionizing rays are the cells of someone whose body is growing. Such is the case of a 13 year old person whose body cells are in a process of multiplying to build the body to full growth.

Because so many cells are dividing in the growing body, there are also many immature cells. The immature cells, those which have not grown to their full size or strength, can be considered to be weak. It is for this reason that they are more easily damaged by radiation. From this we can see how the age of the person is a variable in the amount of damage that radiation can do.

Turn to page 3-16.

From page 3-14

3-16

Sure. A 13 year old person is more vulnerable to radiation damage than a 25 year old person. The active reproduction of the cells and the number of immature cells account for this.

Because of the possible damage which can be caused in persons who are not fully grown, federal regulations have established a minimum age for radiation workers.

The minimum age is 18 years.

This means that...

...a person under age 18 cannot receive more than 1-1/4 rems per calendar

quarter Page 3-17

...no person under 18 years old can work in an area where radiographic inspections are being performed Page 3-18

From page 3-16

3-17

No. That is wrong. A person under 18 years old cannot receive up to 1-1/4 rems per calendar quarter.

The point we are trying to get across is this:

A person under 18 years old cannot receive any occupational exposure.

In order to provide protection for younger people who may still be growing, the AEC has set a minimum age for radiation workers. This age is 18 years. It means that...

...no person under 18 years old can work in an area where radiographic inspections are being performed..... Page 3-18

Exactly. No person under 18 years old can work in an area where radiographic operations are being performed. Actually, the AEC limit states that a company or agency using radiation must assure that no one under age 18 receives radiation exposure in excess of 10% of the limits for radiation workers.

We have now covered four variables which influence the effect radiation can have on individuals. They are:

- The amount of the body exposed
- The part of the body exposed
- The time span over which a radiation dose is administered
- The age of the individual exposed

One final variable in the effects radiation can have on the human body is the biological difference among individuals. We know that people differ in the way they are put together biologically.

Do you believe that an overdose of radiation of a given amount can be fatal to one person and not to another?

No Page 3-19

Yes Page 3-20

You do not believe that an overdose of radiation could be fatal to one person and not to another. Sorry. It's the other way around.

We said that people differ in the way they are put together biologically. For example, some people have frequent head colds. Others very rarely have them. Some people are diseased. Others are not.

It's true that all people receive radiation damage when exposed to ionizing rays. But they do not all react the same way to a given radiation dose. There are biological differences which cause some people to react differently to radiation than others.

Because of this biological difference among people, it is possible that a radiation overdose could kill one person and not another Page 3-20

Yes is right. An overdose of radiation of a given amount can kill one person and not another. That is what is meant by a biological difference among individuals. Some people are affected differently than others by a radiation dose.

We have now covered five variables in the way radiation doses affect individuals. Just to review them briefly, identify the list which contains all of them.

The five are: the amount of the body exposed; the biological difference among individuals under 18 years of age; the part of the body exposed; the time span over which a dose is received; and the age of the individual exposed Page 3-21

The five are: the amount of the body exposed; the time span over which a dose is received; the age of the individual exposed; the part of the body exposed; the biological difference among individuals Page 3-22

You missed the boat. Let's compare the lists side by side.

YOUR CHOICE	CORRECT ANSWER
• The amount of the body exposed.	• The amount of the body exposed.
• The biological difference among individuals under 18 years of age.	• The time span over which a dose is received.
• The part of the body exposed.	• The age of the individual exposed.
• The time span over which a dose is received.	• The part of the body exposed.
• The age of the individual exposed.	• The biological difference among individuals.

Comparing the two you can see that the variation between the two lists is in the item on biological difference among individuals. Your choice states that the biological difference among individuals is prevalent only if the individuals are under 18 years old. That is not so. The biological difference concerns all individuals regardless of age.

You were probably thinking about the fact that age does play an important role in radiation effects and that a person under 18 years old cannot work in a radiation area. This point can be confusing since the harmful effects of radiation exposure on individuals under age 18 is also a result of biological differences. But these are two distinct points, both affecting radiation damage caused by a given dose. Review the correct list above, then turn to page 3-22.

That's the right list. The five variables which influence the effect radiation doses have on an individual are:

- The amount of the body exposed
- The part of the body exposed
- The time span over which a radiation dose is administered
- The age of the individual exposed
- The biological difference among individuals

Turn to the next page.

The radiation limits we previously discussed in this chapter are those which have been established for radiation exposure to people in "restricted" areas. A restricted area is one that no one but authorized people may enter and is controlled by the persons performing radiographic inspections in that area. The limits for exposure in restricted areas are higher than those prescribed for the general population. Why do you think this is possible?

People working in restricted areas build up an "immunity" to radiation and less physical damage is caused by a given biological dose. Page 3-24

It is possible to keep accurate records of radiation exposure and maintain control over the biological dose of workers in a restricted area. Page 3-25

Correct. There is no way to monitor exposure to the general public. Therefore, radiation in all areas except restricted areas must be kept to an acceptable minimum. In a restricted area, the exact exposure status is known for all workers at all times and the limits are higher. Remember that there is no way to build up immunity to radiation as the other answer implied.

Actually, there is another reason for allowing higher exposure limits inside a restricted area. It is policy in our country that the general public should not be expected to accept the same radiation exposures as persons who earn their living working with radiation.

Now let's take a look at the method of keeping track of occupational doses of people in restricted areas. Employers using radiation equipment are required to keep up-to-date records on all employees in areas where radiation exceeds a certain level. On the following page is a form for recording radiation doses similar to the one recommended by the AEC for keeping the current records. The record keeping system may use this form, a similar form, or another system which has approval of the controlling state and federal agencies.

Turn to the next page.

You believe that people working in a restricted area can build up an immunity to radiation. This may sound like a logical answer but it is wrong. A person cannot build up an immunity to radiation.

We have seen the way that ionizing radiation damages body tissue cells. When a photon knocks an electron out of orbit in an atom, cell damage is caused. There is no immunity against this process.

If an area of living tissue is exposed to X-rays or gamma rays daily for a few minutes, more and more damage is caused. Each time the tissue is penetrated by radiation some cells are damaged. Cells do not build up a resistance or immunity to radiation.

The exposure to the general population is kept lower than that for radiation workers in controlled areas for another reason. Radiation monitoring procedures and controls are not available for the general public. In order to allow radiation workers to receive higher amounts of exposure, certain requirements must be met. Their exposure can be higher because...

...it is possible to keep accurate records of radiation exposure and to maintain control over the biological dose of workers in a restricted area Page 3-25

IDENTIFICATION			
1. NAME (Print—Last, first, and middle)		2. SOCIAL SECURITY NO.	
3. DATE OF BIRTH (Month, day, year)		4. AGE IN FULL YEARS (N)	
5. METHOD OF MONITORING (N, S, P, R, or C) N—Neutron; S—Shallow; P—Penetrating; R—Residual; C—Combined			
6. PERIOD OF EXPOSURE (From—To)			
7. METHOD OF MONITORING (N, S, P, R, or C) N—Neutron; S—Shallow; P—Penetrating; R—Residual; C—Combined			
8. PERMISSIBLE DOSE AT BEGINNING OF PERIOD COVERED BY THIS SHEET			
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88. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
89. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
90. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
91. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
92. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
93. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
94. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
95. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
96. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
97. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
98. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
99. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			
100. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET			

The form shows four main items to be completed. They are identification, occupational exposure, dose for the period, and lifetime accumulated dose. Many of the information items of the form are self-explanatory. While it is not necessary that you memorize all the information on the form, you will need to learn about some of the terms and computations.

Starting with Item 5 on the form we can see that it requests information on the part of the body exposed. Now to review briefly a point we made before, which of the following is true?

Nearly all of the radiation exposure in radiography is to the whole body . . . Page 3-27
Most of the radiation exposure in radiography is to the hands and forearms . . . Page 3-28

Good memory. You recall that we said most of the radiation exposure in radiography is to the whole body. So most of the doses recorded in Item 5 of the form will be whole body radiation.

Here is the next item on the form, Item 6:

OCCUPATIONAL EXPOSURE	
6. PERMISSIBLE DOSE AT BEGINNING OF PERIOD COVERED BY THIS SHEET	7. PERMISSIBLE DOSE AT END OF PERIOD COVERED BY THIS SHEET

The permissible dose to be entered here is obtained from Item 18 of the last previously completed form. We will discuss this entry when we get to Item 18.

Note that the entry for Item 6 requires permissible dose "at beginning of period covered by this sheet." This implies that one of these forms must be completed on a radiation worker at the end of some specific period of time. The dose limits we discussed in this chapter also covered a specific time span. The frequency with which the form must be completed is the same time period for which the limits are established. The form must be completed at least every . . .

...calendar year . . . Page 3-29
...calendar quarter . . . Page 3-30

From page 3-26

3-28

Wrong guess. The point we made previously was that most of the radiation you will receive in radiography will not be to the hands and forearms. It will be to the whole body.

The reason for this is that radiographic workers do not handle radioactive materials with their hands and will be some distance from an X-ray machine or a gamma ray source when using them. Radiation will not be directed in a beam onto the hands or forearms. It will fill the surrounding area.

So...

...most of the radiation exposure in radiography is to the whole body Page 3-27

From page 3-27

3-29

You believe the form must be completed at least each calendar year. That's not so.

The dose limits for people in restricted areas are established for a certain time period. The limit for whole-body exposure is 1-1/4 rems per calendar quarter.

The dose records for radiation workers are required to be completed at least every...

...calendar quarter Page 3-30

The next item on the form, Item 17, is an important one for you to understand. Let's take a look at it.

LIFETIME ACCUMULATED DOSE	
17. PERM. ACC. DOSE	18.
19. (17 - 18) =	20.

The permissible accumulated dose (abbreviated "PERM. ACC. DOSE" on the form) is more commonly called "maximum permissible dose" or "MPD." The "MPD" terminology does not imply that the permissible dose is accumulated. But it is. For this reason, let's use the terminology on the form - permissible accumulated dose - for our discussion here.

The permissible accumulated dose is the occupational dose a person could have been permitted in relation to his correct age. We can say that permissible accumulated dose.....

....when compared with total accumulated dose, tells a person his status with respect to the allowable dose limits Page 3-32
...shows the total occupational radiation dose a person has received during his lifetime up to the current date Page 3-33

Precisely. The doses entered on the form must be for time periods not exceeding a calendar quarter. This means that the current exposure chart must be tabulated at the end of each calendar quarter and a new one started for the next quarter.

The next entry on the form, Item 7, requires the methods of monitoring the radiation dose. We will discuss the methods later in the book.

Items 8 through 13 shown below are self-explanatory. It should be noted that the dose is recorded in rem.

8. PERIOD OF EXPOSURE (month-yr)	DOSE FOR THE PERIOD (rem)				11. RUNNING TOTAL FOR QUARTER (rem)
	9. GAMMA	10. BETA	11. NEUTRON	12. TOTAL	

Items 14, 15, and 16 are devoted to entering and totaling previous and new radiation doses.

LIFETIME ACCUMULATED DOSE			
14. PREVIOUS TOTAL	15. TOTAL DOSE RECORDED ON THIS SHEET	16. TOTAL ACCUMULATED DOSE	17. REM

Item 14 is obtained from the last preceding form. Item 15 is the total dose recorded in Item 13 on the current form. Item 16 is the sum of the other two and is the total amount of occupational radiation dose received during a person's lifetime to date.

Turn to the next page.

Right. Permissible accumulated dose, when compared with total accumulated dose, tells a person his status with respect to the allowable dose limits. In other words, depending upon your age, you can accumulate a certain dose and not exceed the AEC limits. Here is Item 17 again.

ALLOWED DOSE	
5	17. PERM. ACC. DOSE
1	$(N - 18) =$
	rem

Let's pull the simple formula out of the block for a closer look.

$$5 (N-18) = \text{Permissible Accumulated Dose in rems}$$

Here is the meaning of the elements in the formula.

5 = average yearly allowable whole-body dose (in rems) based on the limit of 1-1/4 rems per calendar quarter.

N = age in years of the person for whom the form is being completed.

18 = 18 years of age

So...

N-18 = the number of years the person is under 18 Page 3-34

N-18 = the number of years the person is above 18 Page 3-35

You believe that permissible accumulated dose shows the total occupational radiation dose received during a person's lifetime to date. That's wrong.

It looks as though you have confused "permissible accumulated dose" with "total accumulated dose." Let's look at a part of the form again.

LIFETIME ACCUMULATED DOSE	
14. PREVIOUS TOTAL	15. TOTAL DOSE RECORDED ON THIS SHEET
rem	rem
	17. PERM. ACC. DOSE
	$(N - 18) =$
	rem

Items 14 and 15 added together give the total accumulated dose to be entered in Item 16. This shows the total occupational dose a person has received in the past. It is the status up to the current date.

Item 17 is something else. It is an entry showing the permissible accumulated dose a person could have been permitted in relation to his current age. It does not reflect any amount of radiation he has received. Only that which he could have been permitted to receive. We will elaborate on this on the next page. But remember this:

Permissible accumulated dose, when compared with total accumulated dose, tells a person his status with respect to the allowable dose limits Page 3-32

From page 3-32

3-34

From page 3-33

3-35

Nope. "N-18" does not represent the number of years under 18.

Say that a person is 25 years old. Then:

$$N = 25$$

$$25 - 18 = 7$$

7 = the number of years the person is above age 18 Page 3-35

Sure. N-18 equals the numbers of years the person is above age 18. We saw earlier that a person must be 18 years old to work in a radiation area. The objective of the formula, then, is to establish the permissible accumulated dose in rems for the total number of years above age 18.

Let's see if you can set up the formula and find the permissible accumulated dose for a person who is 33 years old. Work the problem on a separate sheet of paper.

Your answer should be:

147 rems Page 3-36

75 rems Page 3-37

57 rems Page 3-38

O.K., we didn't make the point very clear so let's explain it further.
To start with, permissible dose is not obtained by adding total accumulated dose to permissible accumulated dose.
Let's review three definitions.

LIFETIME ACCUMULATED DOSE			
N. TOTAL ACCUMULATED DOSE		M. PERMISSIBLE DOSE	
rem	rem	rem	rem
S(N - M) =			

16. Total accumulated dose is the total amount of occupational radiation dose received during a person's lifetime up to a certain date.
17. Permissible accumulated dose is the dose a person could have received and remain within the allowable dose limits.
18. Permissible dose is the portion of permissible accumulated dose remaining at the end of the period covered by the current exposure time.

To find how much permissible dose you have remaining you need to find the difference between what you are allowed (permissible accumulated dose) and what you have already used (total accumulated dose). Or....

...subtract item 16 of the form from item 17 Page 3-40

No. The answer is not 57 rems. We don't believe you set up the formula correctly. Here it is again:

5(N-18) = permissible accumulated dose in rems
5 = yearly allowable dose (in rems) based on the limit of 1-1/4 rems per calendar quarter

N = age in years of the person for whom the form is being completed.
18 = 18 years of age.

Let's go through the steps of solving for permissible accumulated dose for a person who is 47 years old.

$$\begin{aligned} N &= 47 \\ 5(N-18) &= \text{rems} \\ 5(47-18) &= \text{rems} \\ 5 \times 29 &= 145 \text{ rems} \end{aligned}$$

The person's age is 29 years above 18. He is allowed 5 rems per year on an average basis. Therefore, his permissible accumulated dose is 145 rems.

Return to page 3-35 and solve for the correct answer to the problem on that page.

Uh huh. That's it. To find permissible dose you subtract the total accumulated dose from the permissible accumulated dose. Here is an example:

LIFETIME ACCUMULATED DOSE			
16. TOTAL ACCUMULATED DOSE	17. PERM. ACC. DOSE	18. PERMISSIBLE DOSE	
78 mrem	75 mrem	?	mrem

What do you think about the form entries now?

Permissible dose is -3 rems and indicates that the person has accumulated more than the permissible dose of radiation..... Page 3-41
Since the value for Item 16 is larger than Item 17, it cannot be subtracted from Item 17 Page 3-42

That's the ticket. When total accumulated dose = 78 rems and permissible accumulated dose = 75 rems, permissible dose is -3 rems. This indicates that at a specific point in that person's lifetime he has been exposed to more than the allowable radiation dose.

Now let's go back and consider the dose limits for the whole body again. Remember we said that there are exceptions to the whole-body limit of 1-1/4 rems per calendar quarter.

The exception to the rule states that a person may receive up to 3 rems per calendar quarter (or 12 rems per year) if his total accumulated dose does not exceed 5(N-18) rems. This means a person may receive up to 3 rems per calendar quarter provided that.....

... the formula for computing permissible accumulated dose is changed to 12(N-18) and a plus figure is shown in the permissible dose block on his exposure record Page 3-43

... his average exposure for each year he is past 18 years old does not exceed 5 rems/year Page 3-44

From page 3-40

3-43

Well, Rem 16 is larger than Rem 17. But technically you can subtract a larger number from a smaller one. In doing so you go "in the hole" or in debt.

Algebraically, if you subtract a larger number from a smaller number you get a minus value. Like this:

$$\begin{array}{r} 75 \\ -78 \\ \hline -3 \end{array}$$

Return to page 3-40 to get back on the track.

From page 3-41

3-43

Gee Whiz, that sure sounded impressive. But it is the wrong answer.

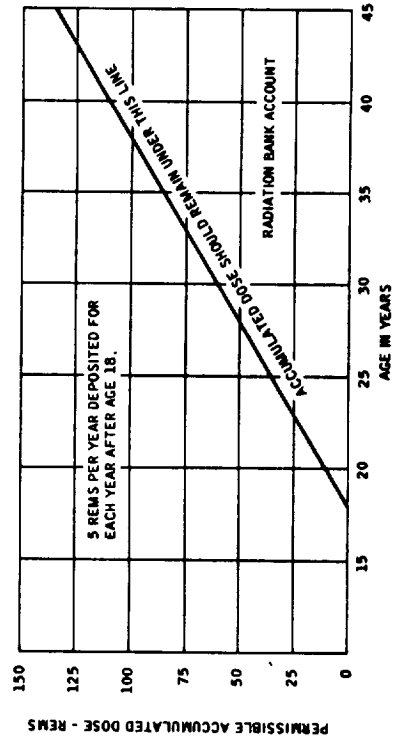
For whole-body dose, the formula $5(N-18)$ rems gives a fixed relationship to the average dose of a person past 18 years old. It would not be changed to $12(N-18)$ for any reason.

If the formula were changed from 5 to 12 rems this would mean that a person could average 12 rems per year for each year he was past 18. That's not right.

Return to page 3-41 for a review, then continue.

Yep. That's right. A person may receive up to 3 rems per calendar quarter (or 12 rems per year) provided that he does not average more than 5 rems/year for each year he is past age 18-5(N-18).

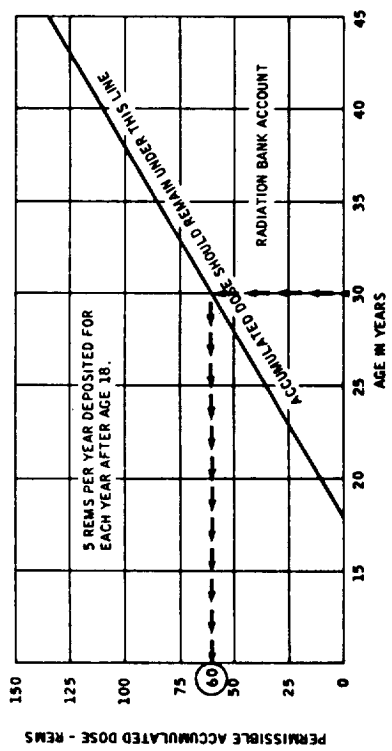
This can be demonstrated by the radiation banking concept. Just consider that an individual has a radiation bank account. For each year after he is 18 years old, 5 rems are deposited in his account. Here is how this would look:



If a person started in radiation work on his 30th birthday, he would have a radiation bank account of ...

- ... 50 rems ... Page 3-45
- ... 60 rems ... Page 3-46

No. The 30 year old radiation worker would have more than 60 rems in the bank. Here is the chart again.



Read upward from the age 30 point at the bottom of the chart to the diagonal line representing the bank account. Then read horizontally to the scale on the left side of the chart. The indication is that the person has 60 rems in his account.

The chart is used to illustrate the manner in which the radiation bank account is increased by 5 rems per year after age 18. There is another way to find the balance in the account. You can use the formula $5(N-18) = \text{permissible dose in rems}$:

$$5(30-18) = 60 \text{ rems}$$

Right?

Right. The bank account shows a balance of 60 rems for a 30 year old person just beginning to work in radiation.

Let's see if you remember a point we made earlier.

A person, age 30, starting to work as a radiographer is allowed, in his first year, a dose of...

... 12 rems Page 3-47
... 5 rems Page 3-48

Exactly. A dose of 12 rems is permissible in one year for a person who is age 30 and is just starting to work as a radiographer. The reason, of course, is that he has a bank account of 60 rems. As long as he does not exceed 5(N-18) rems permissible accumulated dose he can continue to use 12 rems per year.

Assume that a person is 21 years old when he starts to work as a radiographer. He has 15 rems in his bank account. (5 rems per year x 3 years past age 18 = 15 rems.) Here is his balance sheet:

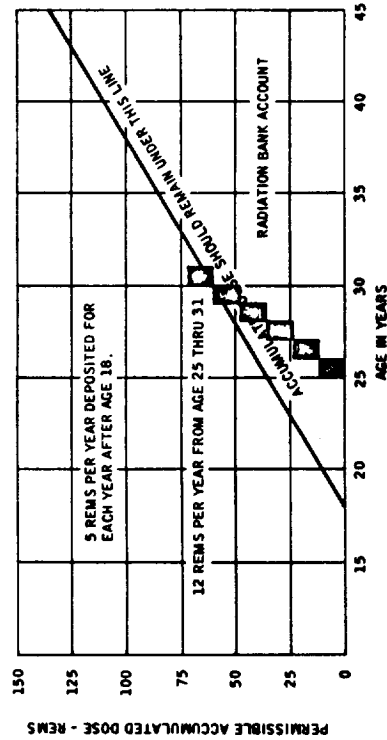
AGE	REM DOSE PER YEAR	DEPOSITS	BALANCE
21	12	5	15
22	4	5	8
23	5	5	9
24	12	5	9
25	7	5	2
			?

The balance on his 26th birthday is:

0 rems Page 3-49
-5 rems Page 3-50

Sure. In our example, the radiographer would have a balance of zero (0) rems on his 26th birthday.

Let's look at one other example. A person who is 25 years old starts work as a radiographer. As shown below, he received 12 rems per year until his 31st birthday.



What do you believe from looking at the chart?

The radiographer is allowed 5 rems between his 31st and 32nd birthdays since he has not exceeded 5(N - 18) rems Page 3-51
Between his 30th and 31st birthdays, the radiographer exceeded his permissible accumulated dose Page 3-52

Bad guess. The age 30 person would be allowed more than 5 rems in his first year as a radiographer.

The limits of 1-1/4 rems per calendar quarter and 5 rems per year are average values. A person cannot average more than 5 rems per year for each year he is above age 18.

We stated the maximum limit as follows:

A person may receive up to 3 rems per calendar quarter or 12 rems per year if he doesn't exceed 5(N-18) rems.

A person who is 30 years old and has never been employed as a radiation worker has 60 rems in his radiation bank account. He certainly would not exceed 5(N-18) rems if he used the maximum in his first year of work. So let's allow him the full . . .

. . . 12 rems Page 3-47

You believe the radiographer's balance on his 26th birthday is -5 rems. That's wrong. Here is the balance sheet again.

AGE	DOSE PER YEAR	DEPOSITS	BALANCE
21	12	Balance on 21st birthday	15
22	4	5	8
23	5	5	9
24	12	5	9
25	7	5	2
			?

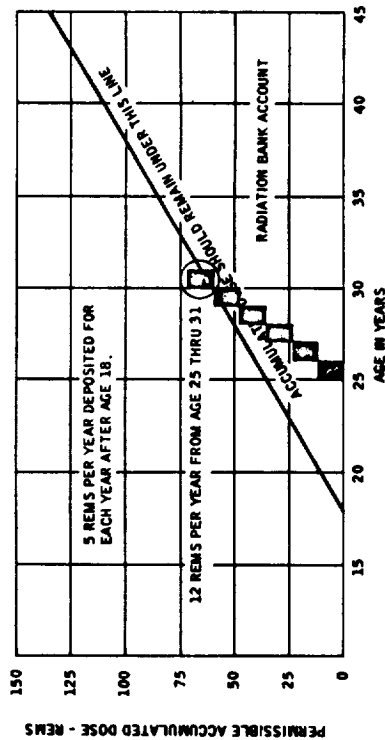
Notice that the man in question started with 15 rems in the bank. Between his 21st and 22nd birthdays he used 12 rems, deposited 5 rems, and retained a balance of 8 rems.

Between his 24th and 25th birthdays he used 12 rems deposited 5 rems, and had a balance of 2 rems on his 25th birthday.

Between his 25th and 26th birthdays he used 7 rems and deposited 5 rems. So we can see:

He started with a balance of 2 rems
He deposited 5 rems
For a total of 7 rems
He used, during the year 7 rems
For a balance of 0 rems

Careful now. You can be arrested for robbing the bank. And that is what you would be doing if you allowed the radiographer in our example to receive 12 rems between his 31st and 32nd birthdays. That's because he would be accumulating more than $5(N-18)$ rems. Here is the banking chart again:



Notice that between the worker's 30th and 31st birthdays the block showing the 12 rem dose for that year exceeds the balance in the bank. In other words, the radiographer "overdraws" his account. This means that he has exceeded $5(N-18)$ rems. Computing the permissible accumulated dose for a worker on his 31st birthday we have:

$$5(31 - 18) = 65 \text{ rems}$$

Looking at the chart we can see that the accumulated dose on the worker's 31st birthday is 72 rems. He is overdrawn by 7 rems.

Return to page 3-49, review the material, then proceed.

Right. The radiographer exceeded his permissible accumulated dose between his 30th and 31st birthdays.

In our discussion so far we have probably left the impression that when a worker's total accumulated dose exceeds 5(N-18) rems, he must not be exposed to any additional occupational radiation until he had replenished his bank account.

Actually, AEC regulations will permit this worker to continue to receive up to 1 1/4 rems per quarter, but, IN NO CASE, can he knowingly receive more. This will protect the worker's employability and at the low dose levels involved does not create a health problem.

The radiation dose limits we have discussed here are those which are currently accepted by the AEC and other regulatory agencies. For convenience, the permissible dose is sometimes converted to weekly or monthly limits by some employers. But regardless of the breakdown of the limits, they always relate back to what is acceptable to the AEC.

Another point to remember is that the limits may be subject to change as more is learned about the effects of ionizing radiation. You should always refer to applicable documents for the latest information.

Turn to the next page for a review of the material in Chapter 3.

From page 3-52

1. If possible, it is good to limit your radiation dose to _____ than the regulatory limit.

7. amount, part (part, amount)

8. A third variable in the extent of damage to the body is the _____ over which a radiation dose is received.

14. fatal

15. It is _____ (possible, not possible) for a person to build up an immunity to radiation.

21. 5, 18

22. An area in which radiography is being performed that no one but authorized people may enter is known as a _____ area.

1. less	
2. Most of the radiation received in radiography is to the _____ body.	
8. time-span	
9. The _____ of the individual exposed is another variable.	
15. not possible.	
16. Records of radiation workers must be brought up to date at least every _____.	
22. restricted	
23. The limits of exposure for radiography workers working in a restricted area are _____ (higher, lower) than those prescribed for the general population.	

2. whole	
3. Whole-body dose must be limited to an average dose of _____ rems/calendar quarter.	
9. age	
10. The final variable is the _____ difference among individuals.	
16. calendar quarter	
17. The total occupational dose received during a person's lifetime up to the current date is the total _____ dose.	
23. higher	
24. Persons working in a restricted area may receive up to _____ rems per calendar quarter or _____ rems per year provided that their permissible accumulated dose does not exceed 5 (N-18).	

3. $1\frac{1}{4}$		
4. A dose of $1\frac{1}{4}$ rems per calendar quarter equals a dose of _____ rems per year.		
10. biological		
11. A person who is age _____ (20 or 10) is subject to greater radiation damage from a given exposure than a person who is age _____ (20 or 10).		
17. accumulated		
18. The occupational dose a person could have been permitted to receive in relation to his current age is the p _____ accumulated dose.		
24. 3, 12		
25. A person who exceeds his _____ accumulated dose must not accumulate additional occupational exposure at a rate greater than $1\frac{1}{4}$ rems per calendar quarter.		

4. 5		
5. The most restrictive dose limit ($1\frac{1}{4}$ rems per calendar quarter) is for radiation doses to the _____.		
11. 10, 20		
12. A radiation dose of a given amount has less effect if it is received over a _____ period of time.		
16. permissible		
19. The formula for finding a person's permissible accumulated dose is _____.		
25. permissible		
26. Find the permissible accumulated dose for a person who is 27 years old.		

5. whole body	
6. There are _____ (how many?) variables in the way radiation doses influence damage to the body.	
12. long	
13. A person must be _____ years old to work in a radiation area.	
19. 5 (N-18)	
20. In the formula 5 (N-18), N = the person's _____.	
26. 45	
27. A person who is 18 years old and working as a radiographer is allowed to receive _____ rems in his first year of work.	

6. five	
7. Two of the variables are the _____ of the body exposed and the _____ of the body exposed.	 Return to page 3-53, frame 8
13. 18	
14. An overdose of radiation of a given amount can be f _____ to one person and not to another	 Return to page 3-53, frame 15
20. age	
21. A radiation worker "banks" _____ rems for each year he is above age _____.	 Return to page 3-53, frame 22
27. five	
This is end of review for Chapter 3. Turn to page 4-1.	

Certainly. Body cells with high radiosensitivity are more easily damaged by ionizing radiation. Just to give you an idea of which body cells are more sensitive, here is a partial list of the cells listed in the order of decreasing radiosensitivity.

1. White blood cells
2. Immature red blood cells
3. Cells lining the gastro-intestinal canal
4. Cells of the reproductive organs
5. Skin cells
6. Cells of the blood vessels
7. Cells of the tissue, bone, muscle, and nerves.

From the above, you can see that one of the first indications of radiation damage is ...

... deterioration of the cells of the tissue and nerves Page 4-5
 ... a change in the cells of the blood Page 4-6

You believe that body cells with high radiosensitivity are less easily damaged by ionizing radiation. That's not true.

When something is sensitive to the effects of radiant energy it is radiosensitive. This means that it "feels" the radiant energy, or radiation, and is affected by it in some way. And the relationship is not the same as your answer. The more sensitive an item is to radiation, the higher the sensitivity.

Certain body cells are more sensitive to radiation than others. This means that ...

... body cells with high radiosensitivity are more easily damaged by ionizing radiation Page 4-3

From page 4-3

4-5

Nope. Deterioration of the cells of the tissue and nerves is not one of the first indications of radiation damage.

The list of cells on the other page was shown in an order of decreasing radiosensitivity. This simply means that the farther down the list an item appears, the less the radiosensitivity of that item.

We already know that the more radiosensitive a cell is, the easier it is damaged by radiation.

Return to page 4-3 and select the other answer.

From page 4-3

4-6

That's right. One of the first indications of radiation damage is a change in the cells of the blood. These are the most radiosensitive cells in the body.

Periodic blood tests were once performed on radiation workers but have generally been discontinued. The tests are not nearly sensitive enough to detect exposures at or near regulatory limits. Such tests may be useful following radiation disasters.

Here is another look at the partial list of radiosensitive cells:

1. White blood cells
2. Immature red blood cells
3. Cells lining the gastro-intestinal canal
4. Cells of the reproductive organs
5. Skin cells
6. Cells of the blood vessels
7. Cells of the tissue, bone, muscle, and nerves.

In each case, the list identifies the cell as the element damaged. But the cells are a part of the tissue and various organs which are in turn damaged. It isn't necessary to remember all the items on the list. But they give you some idea of the radiosensitivity of the different parts of the body.

Turn to the next page.

The biological effects caused by an overdose of radiation can be divided into two types. They are:

SOMATIC EFFECTS

GENETIC EFFECTS

Somatic effects are the physical effects on the body of the individual who receives radiation.

Genetic effects are those which can be passed to the next generation or to later descendants as hereditary characteristics.

Which of the following is a somatic effect of radiation?

A reduction in the number of white blood cells as a direct result of exposure to ionizing radiation. Page 4-8

An abnormality in the offspring of a person who had received ionizing radiation Page 4-9

Very good. A reduction in the number of white blood cells as a direct result of exposure to ionizing radiation is an example of the somatic effects of radiation. It is a physical symptom in the person directly exposed to ionizing rays.

Much more is known about the somatic effects of radiation than about the genetic effects. Most of the data collected to date on radiation damage have concerned somatic effects. Nearly all the data on genetic effects are from animal experiments. According to the experts, the data that are available on humans are not conclusive enough to establish any positive trends of genetic effects.

Since genetic effects are the traits which are passed to future generations as hereditary characteristics, which of the following do you believe?

It may take several generations of offspring to conclusively determine genetic effects caused by bombing of the Japanese during World War II Page 4-10

It is not reasonable to assume that radiation causes genetic effects in man simply because it causes genetic effects in other animals Page 4-11

No. An abnormality in the offspring of a person who had received ionizing radiation is not a somatic effect of radiation.

Somatic effects are the physical effects on the body of the person who receives radiation. An abnormality in an offspring would not fall into this category.

We will define these more clearly a bit later. But for now remember that an example of a somatic effect of radiation is

... a reduction in the number of white blood cells as a direct result of exposure to ionizing radiation Page 4-8

Right. In determining the genetic effects of radiation, it may take several generations of offspring to permit conclusive observation. We have lived in the atomic age a relatively short period of time. And the bombing of Japan occurred in the very recent past. By scientific observation of the Japanese who received heavy radiation doses, science can learn much more about genetic effects in the next several generations than is known at present.

The same analysis could be applied to the somatic effects of radiation. Because of the relatively short time we have studied and observed radiation, there is also much to be learned about somatic effects.

But one fact we established in the last chapter should be recalled here. The most severe radiation effects may be expected from a large dose . . .

... over a long period of time Page 4-12

... over a short period of time Page 4-13

From page 4-8

4-11

You do not feel it is reasonable to assume that radiation causes genetic effects in man simply because it causes genetic effects in other animals. You are a little off the track in your concept.

Medical research has long been performed on animals lower than man. This research has included immunization methods, disease contagiousness, cancer research, and many others. The treatment of a particular human disease may be preceded by several years of research on lower animals.

This same concept may be applied to research on radiation effects. Indeed, it has been applied. The main test subjects have been mice and fruit flies. In these animals conclusive signs of genetic effects of radiation have been observed. The hereditary characteristics of the offspring have been abnormal in some respects when large overdoses of radiation were experienced by the adults. By this type of experimentation, it is possible to predict genetic effects on humans. However, the exact nature of the effects cannot be conclusively established until much more scientific knowledge is obtained.

Return to page 4-8.

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Return to page 4-8.

Wrong choice. But maybe we didn't state it too clearly. The most severe radiation effects are not from a large dose over a long period of time. They are from a large dose over a short period of time.

For instance, a person could conceivably accumulate 200 rems over a 40-year working life in radiography. This would not exceed the allowable dose limits.

~~If~~ a person received a dose of 200 rems over a 24 hour period it could be very serious.

Turn to page 4-13 and we will see how serious it could be.

Right. The most severe radiation effects are caused by a large dose over a short period of time. And, with this in mind, we will now look at the effects normally associated with certain levels of radiation dose received over a relatively short period of time.

The time element in this case is 24 hours. That is, with whole-body doses as shown within a 24-hour period, the following effects will result.

WHOLE BODY DOSE 24-HOUR PERIOD	EFFECTS
0 TO 25 REMS	NO DETECTABLE EFFECT
25 TO 50 REMS	SLIGHT TEMPORARY BLOOD CHANGES
100 REMS	NAUSEA, FATIGUE
200 TO 250 REMS	FIRST DEATH
500 REMS	HALF DIE (MEDIAN LETHAL DOSE)

Before proceeding, study the doses and the effects on the table for a few seconds.

The effects in the table are:

Genetic	Page 4-14
Somatic	Page 4-15

1. The effects described in the table are not genetic effects. They are not concerned with hereditary characteristics which can be passed on to later descendants. It's review the definitions of genetic and somatic effects again.

Somatic Effects - The physical effects on the body of the individual who receives the dose of radiation.

Genetic Effects - Those which can be passed to the next generation or to later descendants as hereditary characteristics.

Some of the effects in the table were blood changes; nausea and fatigue; and death. You can see that these are physical effects on the body of the individual irradiated. They are ...

ou forgot a point we made earlier. That point is that the effects of radiation vary
ecause of biological differences among individuals. So the effects listed in the table
annot very well be exact for all individuals.

or example, one person who received 350 rems of gamma or X-radiation over a
hort period of time might possibly die. But another person, although he would
ecome quite ill, could recover from such an overdose.

'e will elaborate further on this point. Turn to page 4-17.

You say the effects in the table are somatic effects. And you are right. They are the
physical effects on the body of the person irradiated. Here is the table again:

WHOLE BODY DOSE 24-HOUR PERIOD	EFFECTS
0 TO 25 REMS	NO DETECTABLE EFFECT
25 TO 50 REMS	SLIGHT TEMPORARY BLOOD CHANGES
100 REMS	NAUSEA, FATIGUE
200 TO 250 REMS	FIRST DEATH
500 REMS	HALF DIE (MEDIAN LETHAL DOSE)

Do you believe the effects in the table can be considered exact for all individuals?

Yes Page 4-16

No. Page 4-17

Correct. The effects in the table cannot be considered exact for all individuals. There is a biological difference among individuals that results in a variation in the effects caused by a given dose of radiation. This can be seen by considering the last figure on the table:

500 rems - Half die

If all individuals reacted the same to a given dose of radiation, you could reasonably assume that if 500 rems is lethal to one person, it would be lethal to all. This is not true. A 500-rem dose is one which will be fatal to about one-half the humans exposed. The point to remember here is that radiation effects are not exact. Even the 500-rem figure is not exact. It is only an approximation as are all the figures on the table. Whereas 50% of one group could be killed by a dose of 450 rems in a 24-hour period, it might take 525 rems to reach 50% deaths in another group.

The point we are discussing, that at which 50% of the people die from a given radiation dose, had another name assigned to it in the table. Do you remember what it was?

Median Lethal Dose Page 4-18

Lethal Dose. Page 4-19

Yep. The point at which 50% of the people die from a radiation dose is called 'median lethal dose.' It is abbreviated "MLD."

Although the MLD is not an exact figure because of the differences among individuals, the table showed that it was ...

... 500 rems Page 4-20

... 250 rems Page 4-21

Close, but no cigar. The dose at which 50% of the people die is not called "lethal dose." However, it is certainly lethal to part of the people. We are just trying to get the name correct because it is one which you will hear in nearly any discussion on radiation safety. Take another look at the table.

WHOLE BODY DOSE 24-HOUR PERIOD	EFFECTS
0 TO 25 REMS	NO DETECTABLE EFFECT
25 TO 50 REMS	SLIGHT TEMPORARY BLOOD CHANGES
100 REMS	NAUSEA, FATIGUE
200 TO 250 REMS	FIRST DEATH
500 REMS	HALF DIE (MEDIAN LETHAL DOSE)

You can see that the point at which one-half the people die is called "median lethal dose." The term "median" means in the middle. In this instance, the middle or median point is that at which one-half of the people die and one-half recover from a radiation dose of a given amount.

So the point at which 50% deaths occur is called...

... median lethal dose Page 4-18

Right. The median lethal dose (MLD) is about 500 rems. Of those exposed to this amount of radiation, about one-half will die.

Injury and disability are certain for the one-half which survives such an overdose. This could include drastic abnormalities in the blood, cataracts on the eyes, skin damage, and possible cancer.

But remember that these effects are from the very large overdose of 500 rems. Compare this dose with the permissible accumulated dose for radiation workers, 5(N-18). You can see that none of the symptoms on the table should ever be experienced by anyone receiving normal amounts of radiation in radiography.

Let's ask you to recall one other factor from the table of effects.

It is possible to receive a dose of up to _____ rems in a 24-hour period or less without showing detectable effects.

50 Page 4-22

25 Page 4-23

Wrong. The median lethal dose, or MLD, is not 250 rems. Let's review the table of doses versus effects.

WHOLE BODY DOSE 24-HOUR PERIOD	EFFECTS
0 TO 25 REMS	NO DETECTABLE EFFECT
25 TO 50 REMS	SLIGHT TEMPORARY BLOOD CHANGES
100 REMS	NAUSEA, FATIGUE
200 TO 250 REMS	FIRST DEATH
500 REMS	HALF DIE (MEDIAN LETHAL DOSE)

Between 200 and 250 rems the first death occurs. But that isn't the MLD. As you can see, the median lethal dose is about ...

... 500 rems Page 4-20

Your figure is too high. A dose of 50 rems in a short period of time would almost certainly be detectable in the blood. Review the table.

WHOLE BODY DOSE 24-HOUR PERIOD	EFFECTS
0 TO 25 REMS	NO DETECTABLE EFFECT
25 TO 50 REMS	SLIGHT TEMPORARY BLOOD CHANGES
100 REMS	NAUSEA, FATIGUE
200 TO 250 REMS	FIRST DEATH
500 REMS	HALF DIE (MEDIAN LETHAL DOSE)

You can see that it is possible to receive a dose of up to 25 rems without showing detectable effects Page 4-23

From page 4-20

4-23

Exactly. It is possible to receive a dose of up to 25 rems in a short period of time without showing detectable effects. As can be seen, a dose of up to 50 rems would be detectable in the blood.

WHOLE BODY DOSE 24-HOUR PERIOD	EFFECTS
0 TO 25 REMS	NO DETECTABLE EFFECT
25 TO 50 REMS	SLIGHT TEMPORARY BLOOD CHANGES
100 REMS	NAUSEA, FATIGUE
200 TO 250 REMS	FIRST DEATH
500 REMS	HALF DIE (MEDIAN LETHAL DOSE)

The effects of an overdose of radiation are not necessarily detectable immediately after exposure. Most of them appear in the body after some delay. The period between exposure and the appearance of the symptoms is called the "latent period." For instance, for an overdose of around 200 rems, a latent period of about a week may pass. Then symptoms such as loss of hair, diarrhea, sore throat, and loss of appetite will appear.

The effects we have discussed will give you a general idea of how serious radiation overdose can be. It can, in fact, be deadly. But in radiography, there is no reason for receiving an overdose of radiation. Simply by keeping dosage within the prescribed limits and following good safety practices you can perform all radiography jobs safely.

Turn to the next page for a review.

From page 4-23

1. Anything that is sensitive to the effects of radiant energy is said to be _____

4. 25

5. Biological effects on the human body caused by radiation overdose may be classified as either _____ effects or _____ effects.

8. somatic, genetic

9. The most severe radiation effects are caused by a large dose of radiation over a _____ period of time.

12. 50, die (live)

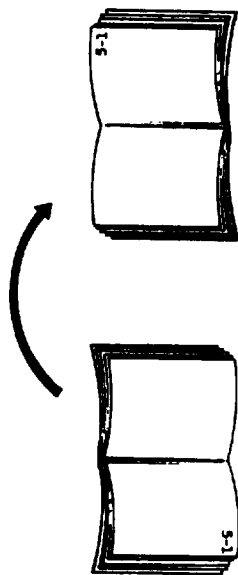
13. A dose of up to _____ rems may not show detectable effects.

1. radiosensitive	
2. One of the most radiosensitive parts of the human body is the _____	
5. somatic, genetic	
6. _____ effects are those which can be passed to descendants as hereditary characteristics.	
9. short	
10. MLD stands for _____.	
13. 25	
14. A dose of between 25 rems and _____ rems in a 24 hour period will produce detectable blood changes.	

2. blood (blood cells)	
3. One of the first detectable indications of radiation damage is a change in the blood _____	
6. Genetic	
7. _____ effects are the physical effects on the body of the individual receiving the radiation overdose.	
10. median lethal dose	
11. The median lethal dose (MLD) for humans is about _____ rems received over a short period of time.	
15. 50	
End of review. Turn to page 4-28.	

3. cells	
4. Radiation doses of up to _____ rems can escape detection by blood test.	Return to page 4-24, frame 5.
7. Somatic	
8. Much more scientific knowledge has been determined on _____ (genetic or somatic) effects than on _____ (genetic or somatic) effects.	Return to page 4-24, frame 9.
11. 500	
12. Approximately _____ % of the people exposed to 500 rems over a short period of time will _____	Return to page 4-24, frame 13.

Now you are ready to start back through the book and read those upside-down pages.
TURN OR ROTATE THE BOOK 180° — LIKE THIS



READ PAGE 5-1 AND CONTINUE AS BEFORE.

CHAPTER 5 - RADIATION MEASURING DEVICES

5-1

The detection and measurement of radiation exposure received by radiation workers is obviously highly important. Since man cannot detect radiation with his senses, devices must be used to detect and measure radiation in the air surrounding a radiation area. The devices we are primarily concerned with here, as classified for use, are survey meters and personnel monitoring devices commonly used in the field of radiography. In this chapter, we will look at the principles of operation and the uses of these two types.

Survey meters are portable instruments used to monitor radiation areas. As a normal procedure they are always used around X-ray and gamma ray radiographic operations. They are designed to give radiation exposure rate.

Personnel monitoring devices are, as the name implies, attached to the clothing of people working in radiographic areas. They do not give an indication of exposure rates but give cumulative readings of exposure.

Either type of device measures gamma or X-radiation exposure in...

... rads Page 5-2

... roentgens Page 5-3

... rems Page 5-4

From page 5-1

5-2

No. Radiation exposure is not measured in rads. The rad stands for radiation absorbed dose and is a unit of absorption. It expresses the amount (absorbed dose) of energy given off by ionizing radiation in material.

The radiation measuring devices (survey meters and personnel monitoring devices) detect and measure radiation in the air surrounding a radiation area. Only one of the units on the previous page does that.

Return to page 5-1 and select the correct answer.

Exactly. Either of the types of radiation measuring device radiation exposure in roentgens.

Both types of devices depend upon a principle we discussed earlier. or solid matter is irradiated, electrons are knocked free from their atoms. free electrons have a negative charge and the particles from which they have a positive charge. They become negative and positive ions. Which statement do you believe?

Because of the creation of ion pairs, both survey meters and personnel monitoring devices are able to measure radiation exposure rate. Page 5-5
The operation of both survey meters and personnel monitoring devices depends upon the principle of ionization Page 5-6

on page 5-1

5-4

ing choice. The devices we are speaking of do not measure radiation exposure in roentgens. The rem does not express radiation exposure. It is a computed value that assesses the biological dose in human tissue. There is no way to directly measure rem.

radiation measuring devices (survey meters and personnel monitoring devices) detect and measure radiation in the air surrounding a radiation area. Only one of the devices on the previous page does that.

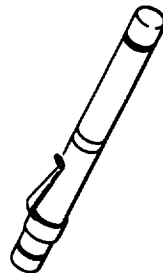
turn to page 5-1 and select the correct answer.

That's exactly the point. The operation of both survey meters and personnel monitoring devices depends upon the principle of ionization. They do not both measure radiation exposure rate.

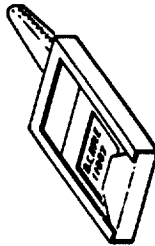
Now let's elaborate on the personnel devices.

PERSONNEL MONITORING DEVICES

For the purpose of our discussion we will cover two types of personnel monitoring devices. They are:



POCKET DOSIMETER



FILM BADGE

The pocket dosimeter and the film badge are called personnel monitoring devices because they are worn on the clothing of personnel working in a radiation area. And, as we said before, they both work on the principle of ionization and both provide...

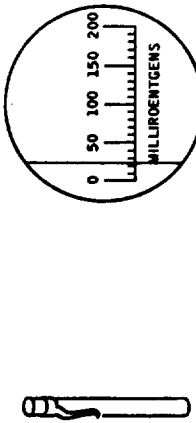
...cumulative readings of radiation exposure Page 5-7

...readings of exposure rate Page 5-8

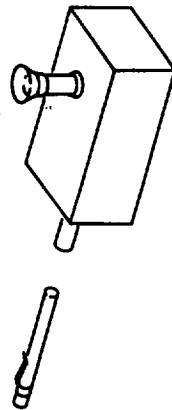
You say that pocket dosimeters and film badges both work on the principle of ionization and both provide cumulative readings of exposure. Good work. You are right. But one of these works on the principle of ionization in air and the other on the ionizing effect of radiation on solid matter. Let's read further to see which one does what.

Pocket Dosimeter

The pocket dosimeter is an instrument about the size of a large fountain pen that may be clipped to the clothing or in the pocket of the user. There are basically two types of pocket dosimeters both of which are similar in appearance and operation. One is a direct-reading device, meaning that the indication may be read directly from the dosimeter itself. The other is non-direct reading (also called "pocket chamber") and must be read by use of a reading device.



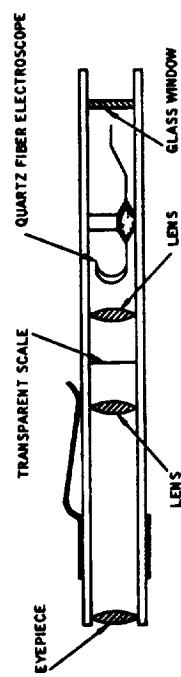
DIRECT-READING POCKET DOSIMETER AND TYPICAL SCALE



NON-DIRECT-READING POCKET DOSIMETER AND READING DEVICE

Turn to page 5-9

The type of pocket dosimeter we are primarily concerned with here is the direct-reading type. Here is a cutaway drawing of the direct-reading dosimeter.



TYPICAL DIRECT-READING POCKET DOSIMETER

The dosimeter is read by looking through the eyepiece, the lenses, and the transparent scale at an indication provided by the quartz fiber electroscope. The indication itself is produced in an ionization chamber of which the electroscope is a part. An ionization chamber is a gas-filled (in this case, air-filled) enclosure for collecting ions formed by high energy radiation.

We will elaborate on the electroscope and the ionization chamber further. But first, let's check something.

The pocket dosimeter which does not require a separate reading device is the...

...non-direct-reading type Page 5-10

...direct-reading type Page 5-11

No, personnel monitoring devices do not give readings of exposure rate. We only mentioned this point briefly before so let's review it a little.

We are discussing two types of radiation detection and measurement equipment. They are:

SURVEY METERS
PERSONNEL MONITORING DEVICES

Of these two, the first type, survey meters, gives a reading of exposure rate.

The second type, personnel monitoring devices also can be divided into two types - pocket dosimeters and film badges. These devices both give cumulative readings of exposure. This simply means that as the devices are irradiated with ionizing radiation, they record the total exposure received. And, assuming that radiation exposure is intermittent, they continue to record the exposure as a part of the total. They add new exposure to that previously received.

This will be easier to see after we look at the way pocket dosimeters and film badges operate.

Turn to page 5-7.

Bad guess. The pocket dosimeter which does not require a separate reading device is not the non-direct-reading type.

As the name implies, the non-direct-reading dosimeter cannot be read directly. This means that by looking at the instrument itself you cannot read the exposure. You must use another device to read the indication. That would be a reading device. By inserting the non-direct-reading dosimeter into the reading device, an optical system presents a scale similar to that of the direct-reading dosimeter.

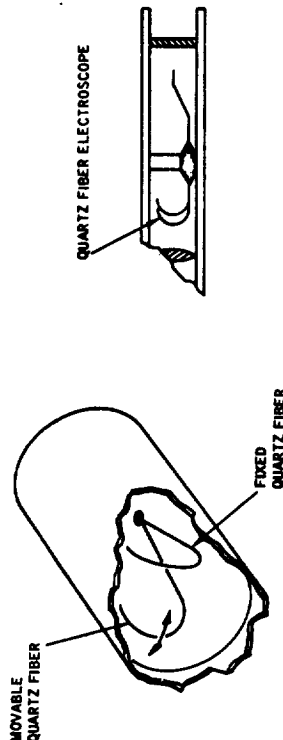
Which brings us back to the point we wanted to make:

The pocket dosimeter which does not require a separate reading device is the...

...direct reading type Page 5-11

Right. The direct-reading pocket dosimeter does not require a separate reading device. It has the optical system and the indication built in. Let's take a closer look at how this works.

The quartz fiber electroscopes operate on the principle that like electrical charges repel each other and unlike charges attract each other. The electrode consists of two quartz fibers, one fixed and one movable.



Each time before the dosimeter is used, it is placed in a charging device which places a like electrical charge on each quartz fiber. What do you think happens?

The movable fiber is attracted to and moves toward the fixed fiber Page 5-12

The movable fiber separates from the fixed fiber Page 5-13

From page 5-11

5-12

That's the wrong answer. Let's review the facts we have to work with.

- The electroscope operates on the principle that like charges repel.
- The electrode of the electroscope consists of two quartz fibers, one movable and the other fixed.
- A like electrical charge is placed on each fiber prior to using the dosimeter.

When a like electrical charge is placed upon each fiber, they tend to repel each other. The movable fiber is forced away from the fixed fiber. Here is how it would look:



QUARTZ FIBERS
WITHOUT CHARGE



QUARTZ FIBERS AFTER
LIKE CHARGE IS APPLIED

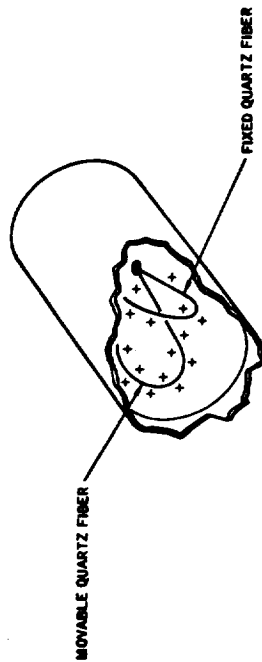
So now we can see that...

...the movable fiber separates from the fixed fiber..... Page 5-13

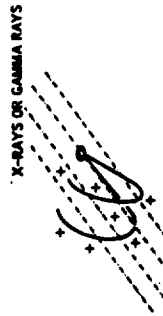
From page 5-11

5-13

Exactly. The hinged movable fiber separates from the fixed fiber because both are charged with a like electrical charge. Here are the fibers separated and with plus signs added to show that a positive charge has been applied which is strong enough to fully deflect the movable fiber.



The electrode is so designed that as long as the plus charge is on the fibers they will stay separated. Now let's see what happens when gamma rays or X-rays pass through the ionization chamber.



We know that the passage of radiation through air (or gas) causes ionization. And that's exactly what happens when the rays enter the ionization chamber. Ion pairs are created with some positive and some negative particles.

Turn to the next page.

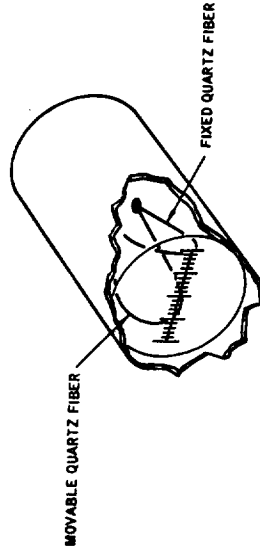
When ionization occurs in the chamber, air in the chamber becomes a conductor of electricity. When this occurs, an electron flow is created. The negative particles are then attracted to the positive charge of the quartz fibers. When the negative ions reach the fibers, they give up their charge and neutralize an amount of the charge on the fibers. In other words, they reduce the amount of positive charge on the fibers.

With the positive charge reduced, ...

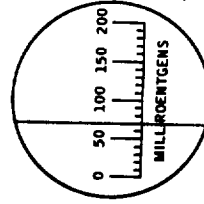
...the movable fiber would move toward the fixed fiber Page 5-15

...the movable fiber would tend to separate further from the fixed fiber Page 5-16

Correct. If the charge on the quartz fibers is reduced, the movable fiber moves toward the fixed fiber. That's what makes the pocket ionization chamber work. It is able to measure ionization (hence radiation) by means of the electrostatic fiber movement and a properly calibrated scale. Here is the scale superimposed over the electrostatic.



Now assume that the fixed fiber is not visible and that the scale and viewing area encompass only the movable fiber. This is the view you have when you look down the barrel of the dosimeter after exposure to gamma or X-radiation.



The indication above tells you that ionization in the instrument has caused the movable fiber of the electrostatic to move to a position that indicates, ...

...an exposure rate of 70 mr Page 5-17

...an exposure of 70 mr Page 5-18

From page 5-14

5-18

No. Reducing the positive charge on the quartz fibers does not cause the movable fiber to tend to separate further from the fixed fiber. Let's see the fibers before and after the electrical charge is applied.



BEFORE CHARGE

AFTER CHARGE

Note that the fibers are not separated before the electrical charge is applied. When a like electrical charge of, say, 150 volts is applied, the fibers separate. When ionization occurs in the chamber, negative ions are created. These are attracted to the positive charge of the fibers. When they reach the fibers, they give up their charge and neutralize a part of the positive charge on the fibers. Assume that the charge on the fibers was reduced from the original 150 volts to 100 volts. The force holding the fibers apart is reduced and look like this:

X-RAYS OR GAMMA RAYS



So with the positive charge reduced...

...the movable fiber would move toward the fixed fiber

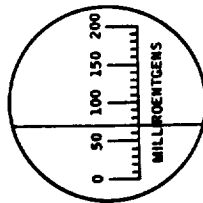
From page 5-15

5-17

Nope. That's wrong. The pocket dosimeter does not indicate exposure rate. Let's review briefly.

The two types of detection and measurement devices we are primarily concerned with are survey meters and personnel monitoring devices. The ones we are talking about now are personnel monitoring devices. These consist of the pocket dosimeter and the film badge. The survey meter is a device which measures rate. Personnel monitoring devices provide cumulative readings of exposure.

The dosimeter reading we were talking about had nothing to do with exposure rate. When you see this reading on a dosimeter it means exposure - not exposure rate.



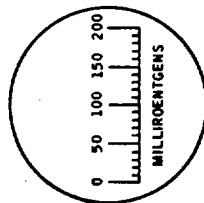
The reading shows an exposure of 70 mr

Page 5-18

From page 5-18	5-19
Very good. The range of the dosimeter we showed you was 0 to 200 mr. And that is the normal range of most pocket dosimeters. You should always know the limits of radiation measurement equipment you may use.	
The normal operating accuracy of the dosimeter is about plus or minus 10%. While this may sound like a wide variation, it is not considered significant. One reason for this is that the dosimeter should always be worn in conjunction with the other personnel monitoring device we mentioned. This gives the wearer a double check on his status. The other personnel monitoring device is the...	
...survey meter	Page 5-21
...film badge	Page 5-22

From page 5-15	5-18
Good thinking. The dosimeter reading indicates an exposure of 70 mr. It is the cumulative exposure received by the instrument since it was last charged.	
In an on-the-job situation, the pocket dosimeter must be used by radiographic personnel at all times when radiation exposure is possible. The dosimeter is stored in a non-radiation area when it is not in use. Before use, the dosimeter should be recharged to zero. This permits the wearer to get an instantaneous reading at any time during the day on the amount of radiation he has received. The instantaneous reading is an important advantage of the dosimeter.	
Now see if you can recall the range on the dosimeter scale we showed you. It reads from...	
...0 to 200 mr	Page 5-19
...50 to 150 mr	Page 5-20

Wrong choice. The range of the dosimeter scale we showed you previously was not 50 to 150 mr. Here it is again.



It is desirable to know the ranges of the instruments used in radiation measurement. By knowing them you will know the limits within which you can work and expect to have an indication of your exposure. And on the dosimeter we were talking about the limits are....

...0 to 200 mr Page 5-19

ou say the survey meter falls into the category of a personnel monitoring device. That's wrong. The survey meter is not considered a personnel device. It is used to monitor radiation areas.

he two types of personnel devices are worn on the clothing of personnel in radiation areas. They give cumulative readings of radiation exposure. The one we have covered so far is the pocket dosimeter. The other is the...

...film badge Page 5-22

From page 5-19

5-22

Sure. The second type of personnel monitoring device is the film badge. And that's our next subject.

Film Badge

The film badge (sometimes called a "photographic dosimeter") measures ionizing radiation by use of special photographic film. When radiation strikes the film, ionization within the film emulsion darkens or "exposes" the film much the same as does light. The darkening of the film is proportional to the amount of radiation exposure received by the film.

After the film badge has been worn for a period of time (such as a week or two), the film is removed and developed. A comparison is then made between the film from the film badge and the characteristics of a similar film (called a control film) which has been exposed to a known amount of similar radiation. The comparison reveals the amount of X-ray or gamma ray exposure (in roentgens) received by the film which...

...cannot be related directly to the exposure of the wearer of the badge... Page 5-23

...can be related directly to the exposure of the wearer of the badge... Page 5-24

From page 5-22

5-23

You say the amount of X-ray or gamma ray exposure (in roentgens) received by the film cannot be related directly to the exposure of the wearer of the badge. That's the wrong answer.

Remember, we said earlier that the film badge is worn on the clothing of radiographic personnel. It receives only the exposure that is also received by the wearer while working in a radiation area. If the exposure dose in roentgens received by the badge can be determined, the dose can be related directly to the exposure of the wearer of the badge... Page 5-24

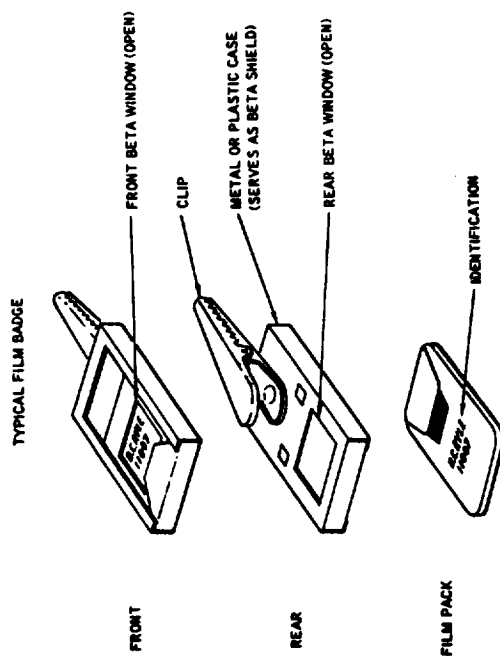
Right. The X-ray or gamma ray exposure (in roentgens) received by the film can be related directly to the exposure of the wearer of the badge. In other words, if a film badge received 200 mr during one week, the wearer is presumed to have received 200 mr in the same period.

Interpreting the dose on the film is a critical operation and is performed by specialists in that field rather than by radiographic workers. The interpretation is performed by using a "densitometer." The densitometer measures the density of the developed film to determine the amount of radiation the film has received.

After the densitometer reading is obtained, it is compared to a "characteristic curve." This curve portrays the density versus dose for a control film of the same type which was exposed to similar radiation of known energy and dose.

In its simplest form, the film badge consists of the case, the film enclosed in a light-proof paper wrapping inside the case, and a clip for attaching the case to the wearer's clothing. The badge is illustrated on the next page.

Turn to the next page.



We have spoken of the film badge in connection with its use in measuring X-rays and gamma rays. Indeed, these are the types of radiation we are most concerned with here. However, the film badge also has an open window which permits the entry of higher energy beta radiation as well as X-rays and gamma rays. The case will shield all the beta radiation from the film that it covers (which is all except the window) and readings from those areas will indicate only gamma and X-radiation. You would expect alpha radiation...

...to register only on the film area which beta radiation exposes..... Page 5-26

...to not register on any part of the film Page 5-27

From page 5-25

5-26

No, that's wrong. Alpha radiation will not register on the film area which beta radiation exposes. Nor will it register on any other part of the film.

Alpha radiation is not a penetrating radiation. It will not penetrate a sheet of paper. And what is the film wrapped in? Light-proof paper. So we can see that alpha radiation will not show up on the film of the film badge. Since alpha radiation is not an external radiation hazard, there is no need for it to be monitored with a film badge.

Return to page 5-25 for a quick review, then proceed.

From page 5-26

5-27

Exactly. Alpha radiation will not expose the film in a film badge. Since alpha radiation is not an external radiation hazard, there is no need to monitor it with a film badge.

The film badge is an important device in monitoring radiation received by radiography personnel. As we said before, it and the dosimeter should be worn together as a double check. When compared to the pocket dosimeter, the film badge...

...does not provide an immediate indication of the amount of exposure Page 5-28

...also provides an immediate indication of the amount of exposure Page 5-29

Uh huh - that's right. When compared to the pocket dosimeter, the film badge does not provide an immediate indication of exposure. The film must be processed and interpreted before a reading is obtained.

The film badge does have one distinct advantage that the pocket dosimeter does not have. See if you can recognize it.

The film badge is not as sensitive to light as the pocket dosimeter because it is sealed in a light-proof wrapper and therefore will give a more accurate reading. . . Page 5-30

Once it is processed, the film serves as a positive, permanent record of a radiation worker's exposure Page 5-31

Nope. That's not the choice you wanted. When compared with the pocket dosimeter, the film badge doesn't provide an immediate indication of the amount of exposure.

The dosimeter reading is always readily available. You either pull it from your pocket and read it or slip it into a reading device and read it.

But the film badge is not that simple. It is worn for a while, then sent in for developing. Then it is inspected with a densitometer to check the density. Finally the density is compared with the characteristics of a control film. Now you finally have the reading.

So, when compared with the dosimeter, the film badge does not provide an immediate indication of the amount of exposure Page 5-28

Well, that was another of those impressive sounding answers that was wrong.

With proper handling and processing, the film badge may be more accurate than the pocket dosimeter. But it is not because one is sealed in light-proof paper and the other is not.

The film in the film badge is wrapped because light will expose the film as readily as radiation. The film must be wrapped if it is to work as a radiation measurement device. A normal amount of light will have no effect on the pocket dosimeter. So this is not a factor in considering the accuracy of the two devices.

Return to page 5-28 and select the other answer.

Good thinking. An advantage of the film badge is that it provides a permanent record of the wearer's exposure. Once the film has been developed, it can be filed and retained for an indefinite period.

In using the film badge and pocket dosimeter as a double check on exposure, records must be kept for each type of device. Normally a daily dosimeter reading log or record is kept for all dosimeter users. This record can be compared with the film badge reading after the film is processed. There will be some variation in the readings of the two and the film badge is generally considered the most reliable. For this reason, the film badge reading is the one which is normally recorded on the current occupational external radiation exposure form which we discussed earlier. Here is that form again:

Current Occupational External Radiation Exposure					
1. NAME (Print—last, first, and middle)		2. SOCIAL SECURITY NO.			
3. DATE OF BIRTH (Month, day, year)		4. AGE IN FULL YEARS (yr)			
5. DOSE RECORDING FOR (Specify: Whole body; site of of whole body; or hands and forearms, head and neck)					
6. PERMISSIBLE DOSE AT BEGINNING OF PERIOD COVERED BY THIS SHEET		7. METHOD OF MONITORING (e.g., film badge; etc.)			
8. PERIOD OF EXPOSURE (From—To)		9. GAMMA		10. NEUTRON	
		11. TOTAL		12. EXPOSURE TOTAL FOR PERIOD (mrem)	
		13. REMARKS			

Which of the following is applicable for form completion?

The film badge reading can be entered in Item 9 of the form only after it is converted from roentgens to rems Page 5-32

The film badge reading can be entered directly in Item 9 of the form Page 5-33

You say that the film badge reading can be entered in the exposure form only after it is converted from roentgens to rems. That's not exactly the right answer.

We will admit that the form asks for the dose in rems. Also the film badge gives exposure in roentgens. But we learned something earlier that should be recalled here.

Item 9 on the form asks for gamma ray dose. And what did we learn about gamma ray exposure in roentgens versus the gamma ray dose in rems? They are the same. When talking about gamma rays and X-rays, one roentgen equals one rem. So this means that the film badge reading can be entered directly in Item 9 of the form.

Right? Page 5-33

Right. When measuring gamma rays or X-rays, the film badge reading can be entered directly on the exposure form. There is no need to convert from roentgens to rems since they are equal.

Now, before we go to the next topic, let's review the major points covered on personnel monitoring devices.

- The two types of personnel monitoring devices we discussed were the pocket dosimeter and the film badge.
- Both the pocket dosimeter and the film badge work on the principle of ionization and provide cumulative readings of radiation exposure.
- There are two types of pocket dosimeters - the direct-reading and the non-direct reading.
- The direct-reading pocket dosimeter has a quartz fiber electroscope in the ionization chamber of the instrument.
- The quartz fiber electroscope operates on the principle that like charges repel and unlike charges attract.
- The quartz fiber electroscope discharges when negative ions caused by ionizing radiation strike the fiber.
- The range of the typical dosimeter is 0 to 200 mr.
- The film badge measures radiation by use of photographic film which is "exposed" by the ionizing effect of the radiation.
- The film from a film badge is checked with a densitometer to determine the density or blackening of the film caused by ionizing rays.
- The amount of exposure received by the film can be directly related to the exposure of the wearer of the badge.

Turn to the next page.

- The film badge, in its simplest form, consists of the case, the film enclosed in a light-proof paper, and an attaching clip.
- The film badge, as it is used in radiography is primarily for measurement of X-rays and gamma rays. It will also detect beta radiation but will not detect alpha radiation.
- The pocket dosimeter provides an immediate indication of exposure whereas the film badge does not.
- The film badge provides a permanent record of radiation exposure whereas the dosimeter does not.
- Both the film badge and the pocket dosimeter should be worn during all work around radiation. This practice gives a double check on the exposure a person receives and gives a back-up check should one of the devices fail to work properly.

As a final thought, the film badge and pocket dosimeter are not safety devices, as is sometimes stated. They are recording devices which indicate whether or not a radiation control program is working.

Turn to the next page.

SURVEY METERS

Survey meters are carried by radiographic personnel during any radiographic operation. The meters are designed to give a rapid reading of the radiation intensity in an area.

For example, when using a gamma source camera, a survey meter will give an instantaneous reading, in roentgens or milliroentgens per hour, of the amount of radiation at any distance from the source. A survey meter held near a source camera provides a positive check on whether or not the source is closed.

The use and operation of survey meters differs from that of personnel monitoring devices. One distinct operational difference is that survey meters...

...measure radiation rate Page 5-36

...measure total exposure instead of radiation rate Page 5-37

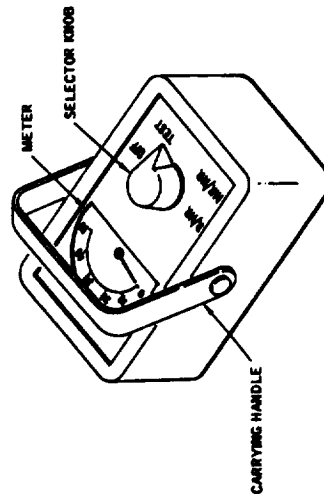
From page 5-35

5-36

Yep. Survey meters differ from personnel monitoring devices in that they measure radiation rate. They are dose-rate instruments. We will discuss briefly two types of survey meters - ionization chamber meters and Geiger-Mueller counters.

Ionization Chamber Survey Meter

Like the pocket dosimeter, the ionization chamber survey meter uses a chamber to collect the ion pairs produced by ionizing rays of gamma and X-radiation. There are, however, distinct differences between this type of meter and the pocket dosimeter. Here is an illustration of a typical ion chamber survey meter.



Turn to page 5-38.

From page 5-36

5-37

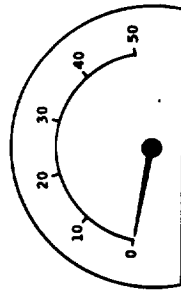
Nope. You have it backwards. We are discussing a difference between survey meters and personnel monitoring devices. And it is the personnel devices which measure total exposure instead of radiation rate.

We said that survey meters measure roentgens or milliroentgens per hour. And that means rate. So many roentgens per unit time equals radiation rate.

Return to page 5-3, review briefly, then continue.

The ion chamber in the meter consists of two electrodes which are insulated from each other and have opposite charges. The electrodes are connected to a battery. When ionizing radiation enters the chamber, ion pairs are created. The positive ions flow to the negative electrode and the negative ions to the positive electrode. When the ions reach the electrodes, a current flow is created through the circuit. This current is measured by a meter which gives radiation rate in roentgens (or milliroentgens) per hour.

The desired range of the meter may be selected by a selector knob. The typical meter we showed you on the preceding page was capable of reading either roentgens per hour or milliroentgens per hour depending upon the setting of the selector knob.

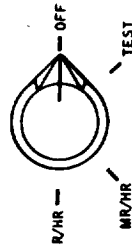
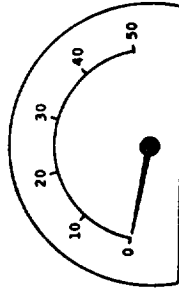


What is the maximum reading that could be obtained from this meter by properly positioning the selector knob?

50 mr/hr Page 5-39

50 r/hr Page 5-40

No. The maximum reading of the meter is not 50 mr/hr. Let's look at the selector knob and the meter again.



The maximum deflection on the meter scale is 50. So we don't have a problem with that. But to get the maximum reading from the scale, the selector knob must be properly positioned to read the highest value. There are two possibilities - mr/hr and r/hr. We already know that the roentgen is a larger unit than the milliroentgen. (It takes 1,000 milliroentgens to make one roentgen.)

To get the maximum reading, the selector knob should be placed to r/hr. Then the maximum reading which could be registered on the meter would be....

...50 r/hr Page 5-40

From page 5-38

5-40

Exactly. The maximum reading that could be obtained from our typical meter is 50 r/hr. The two ranges on the selector knob, mr/hr and r/hr, permit reading two ranges on the same scale. The ranges are 0 to 50 mr/hr and 0 to 50 r/hr.

Most survey meters of this type have a capability similar to the typical one we showed you. They usually read up to a maximum of 25 r or 50 r per hour. However, some such meters are available with readings up to 500 r/hr.

Before we proceed, let's check one thing. The type of meter we are discussing at this point is the...

...Geiger-Mueller counter Page 5-41

...ionization chamber survey meter Page 5-42

From page 5-40

5-41

You believe the name of the meter we have been discussing is the Geiger-Mueller counter. That's wrong. We haven't discussed that one yet.

The names of the meters are important to the extent that the characteristics of the two types are different. And in the on-the-job situation you should know what you are doing when you select a meter.

So remember that a meter which is capable of reading up to 500 r/hr is an...

...ionization chamber survey meter Page 5-42

That's the name. The meter we have been discussing is an ionization chamber survey meter. And this type of meter is the most useful for radiographic field survey work. Its construction is simple, it is rugged, and it has a relatively wide range. Now let's turn to the other type to explore its capabilities.

Geiger-Mueller Counters

Geiger-Mueller (G-M) counters (often shortened to "Geiger Counters") are survey meters used to measure relatively low levels of radiation. They operate on the same principle of ionization as the ion chamber survey meter. But, unlike the ion chamber survey meter, the G-M counter uses a "Geiger-Mueller tube" instead of an ionization chamber.

The Geiger-Mueller tube is similar in operating principle to the ion chamber. However, it is designed to amplify or multiply the effects of ionizing rays. This is done by accelerating the primary ions caused by ionizing radiation entering the tube. This acceleration causes the primary ions to become ionizing particles themselves which are capable of causing many secondary ionizations. By means of this multiplying effect, full ionization of the gas in the tube can occur when even a single photon enters. Thus, a large electrical pulse is formed which may easily be read on a meter. This means that...

....it would be difficult to measure low levels of radiation Page 5-43

....the G-M counter is capable of measuring relatively low levels of radiation Page 5-44

No, that's wrong. It is not difficult to measure low levels of radiation with the Geiger-Mueller counter. The fact is that the G-M counter is very effective in measuring low levels of radiation. That is its main function in radiography.

The G-M tube uses a multiplying effect to get its reading. When ionization occurs in the tube, the primary ions are accelerated by means of high voltage. Once accelerated, the ions cause secondary ionization of other molecules. This action is somewhat like an avalanche. One rock is started rolling down a hill; it starts other rocks which in turn start others. In the amplification of the ions, an avalanche is created which flows to an electrode to produce a current for measurement.

If one photon enters the G-M tube, its ionizing effect is amplified to the point where it may be measured. So we can agree that...

....the G-M counter is capable of measuring relatively low levels of

radiation Page 5-44

From page 5-44	5-45
Very good. The range of the Geiger-Mueller counter is less than the range of ionization chamber survey meters. So much less, in fact, that the G-M counter is not suitable for use as a survey meter in many radiographic situations.	
But the G-M counter does have an advantage over the ionization chamber survey meter. Can you recognize it?	
The G-M counter is not as sensitive to beta rays and, therefore, can measure X-rays and gamma rays better	Page 5-47
The G-M counter is more accurate for measuring low levels of radiation	Page 5-48

From page 5-42	5-44
Exactly. The G-M counter is capable of measuring relatively low levels of radiation. The greater the ionization, the easier it is to measure radiation. And the secondary ionization caused by the G-M tube amplifies the ionization to the point that low radiation levels may be read. That is a distinct advantage it enjoys over the ionization chamber survey meter.	
The normal range for G-M counters is from 0 mr up to about 50 mr/hr. This range is...	
...less than the range for ionization chamber survey meters	Page 5-45
...greater than the range for ionization chamber survey meters	Page 5-46

From page 5-44

5-46

You have it backwards. The range of the G-M counter is not greater than the range of the ionization chamber survey meter. Conversely, it is much less. While there is considerable variation among meters of the same type, we could say that the values below are pretty typical of the average meter:

<u>G-M Counter</u>	<u>Ionization Chamber Meter</u>
Minimum - 0 mr/hr	Minimum - 0 mr/hr
Maximum - 50 mr/hr	Maximum - 50 r/hr

So, while the G-M counter only reads up to about 50 mr/hr, the ionization chamber meter reads up to 50 r/hr (and much higher in some cases).

Therefore, the range of the G-M counter is less than the range of the ionization chamber survey meter

Page 5-45

From page 5-45

5-47

Nope. You are wrong. The answer you selected shows that you suspect that the G-M counter is not as sensitive to beta rays and, therefore, can measure X-rays and gamma rays better. That's not so.

We haven't really discussed the characteristics of either type of meter as they relate to the various kinds of radiation. In reality, the G-M counter will measure low levels of beta particles better than the ionization chamber meter. But this is not really an important factor in our discussion here.

The real point we wanted to make is that the G-M counter has one advantage over the ionization chamber survey meter.

Return to page 5-45 and review briefly.

From page 5-45 5-48

Correct. The G-M counter is more accurate when measuring low levels of radiation than is the ionization chamber survey meter.

However, there is one important disadvantage of Geiger-Mueller counters. If the counter is turned on while the probe is in a very high field of radiation, the needle may not react in a normal manner. The needle could be expected to swing to the extreme right, however, in many cases it may not move at all or it may indicate an erroneous on-scale reading. This behavior is sometimes called "flooding" or "jamming" and is not predictable. The only way to protect against it is to turn on the G.-M. counter well away from the radiation area and observe it closely for rise when approaching the source.

There are many different makes and models of Geiger-Mueller counters and ionization chamber survey meters. The examples we have discussed here do not begin to scratch the surface on this subject. However, the best way to learn to use a device such as a meter is by actually using one. You will have plenty of opportunity for that when you actually are in an on-the-job situation. So let's just briefly review the data we have covered in this chapter and then proceed with new subject matter.

Turn to the next page.

From page 5-48	1. Radiation measuring devices fall into two general categories. They are _____ and p _____.
9. electroscopes	10. The electroscope consists of two _____ fibers - one _____ and one _____.
18. control film	19. The film badge is capable of detecting beta, gamma, and X-radiation but will not detect _____ particles.
27. 2	28. The electrodes have _____ (like, unlike) charges.

1. survey meters, personnel monitoring devices	
2. Survey meters measure radiation exposure in _____.	
10. quartz, fixed, movable	
11. When the dosimeter is charged, the movable quartz fiber _____ from the fixed fiber.	
19. alpha	
20. An advantage of the film badge is that it provides a permanent _____ of exposure.	
28. unlike	
29. When ionizing radiation enters the ionization chamber the resulting current flow is read on the _____.	

2. rate	
3. Personnel monitoring devices give c _____ readings of exposure.	
11. separates (or moves away from	
12. The principle that causes the fiber to separate states that like charges _____ and unlike charges _____.	
20. record	
21. The film of a film badge is checked with a _____ to determine the density resulting from ionizing rays.	
29. meter	
30. The Geiger-Mueller counter uses a Geiger-Mueller _____ instead of an ionization chamber.	

3. cumulative	
4. Either type of device measures gamma or X-radiation exposure in _____.	
12. repel, attract	
13. When ionization occurs in the ionization chamber of the dosimeter, negative particles flow to the _____ charge of the quartz fibers.	
21. densitometer	
22. An advantage of the pocket dosimeter is that it provides an _____ indication of exposure.	
30. tube	
31. The G-M tube _____ the effect of ionizing radiation.	

4. roentgens	
5. All the radiation measuring devices use the principle of _____ in detecting radiation.	
13. positive	
14. Ionization in the chamber causes the movable electroscopes fiber to move _____ (toward) (away from) the fixed fiber.	
22. immediate	
23. When wearing both a pocket dosimeter and a film badge, the reading of the _____ is usually considered the more reliable.	
31. multiplies (amplifies)	
32. The multiplying effect of the Geiger-Mueller tube allows the G-M counter to read relatively _____ levels of radiation.	

5. ionization	
6. We discussed two types of personnel monitoring devices. They are p _____ and _____.	
14. toward	
15. The typical dosimeter scale reads from 0 to _____.	
23. film badge	
24. A meter used to give a quick reading of radiation intensity in an area is a _____.	
32. low	
33. The G-M counter is better than the ionization chamber survey meter at detecting _____ levels of radiation.	

6. pocket dosimeters, film badges	
7. The pocket dosimeter and the film badge both provide _____ readings of exposure.	
15. 200 mr	
16. The pocket dosimeter should always be worn at the same time the _____ is worn.	
24. survey meter	
25. Survey meters measure r _____.	
33. low	
34. The normal operating range of the _____ is from 0 to about 50 mr/hr.	

8. chamber	
9. The indication in the ionization chamber of the pocket dosimeter is provided by a quartz fiber _____.	Return to page 5-39, frame 10.
17. ionization (radiation)	
18. The exposed film from the film badge is compared to the characteristics of a _____.	Return to page 5-39, frame 19.
26. ionization chamber, Geiger-Mueller	
27. The ionization chamber survey meter has _____ (a number) electrodes.	Return to page 5-19, frame 28.
35. less	
This completes review of Chapter 5. Turn to page 6-1.	

7. cumulative	
8. The reading of a pocket dosimeter is produced in an ionization _____.	
16. film badge	
17. The film badge operates on the principle that _____ darkens or exposes film.	
25. radiation rate	
26. Two types of survey meters are _____ survey meters and _____ counters.	
34. G-M counter	
35. The operating range of the G-M counter is _____ (more) (less) than the range of the ionization chamber.	

Thus far we have covered radiation doses and their effects on the human body; radiation measurement units; and the devices for measuring the amount of radiation a person receives. We have firmly established the fact that radiation can damage the human body.

In this chapter, we will look at the ways of providing protection for the human body. The protective measures against radiation are primarily designed to hold exposure to or below the allowable limits. This is necessary because there is no way to undo or retract radiation damage after it has occurred. There are no radiation damage pills that will cause the symptoms to disappear and there is no vaccination against radiation.

But before we get into the protective measures let's lay a little groundwork. We need to discuss the intensity or dose rates of various radiation sources.

Turn to the next page.

DOSE RATE CALCULATIONS

The discussion here will primarily concern gamma-source radioisotopes. Most of the same considerations apply to X-ray machines but there are more factors to consider when using isotopes.

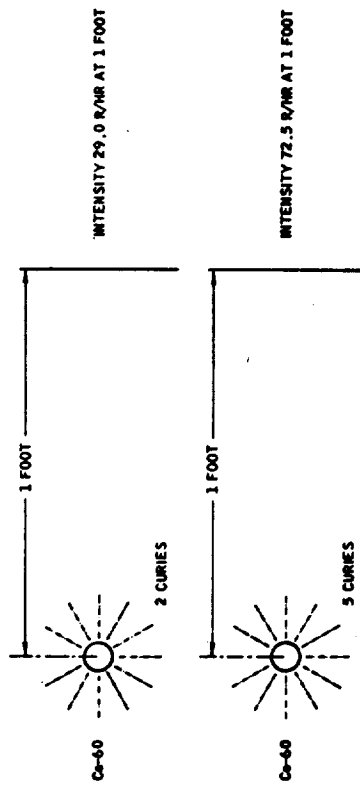
For each curie of activity of an isotope, there is a predetermined dose rate. And the dose rate for each isotope for a given activity is different. By dose rate, in this instance, we are talking about the intensity of the rays as measured in roentgens. The standard dose rate of various isotopes is expressed in roentgens per hour per curie and is given for an exact distance of one foot (or, in some instances, a distance of one meter).

Now, reading the above carefully, you can see that we could abbreviate the standard dose rate as...

....r/hr/curie at 1 foot (roentgens per hour, etc.) Page 6-3

....r/hr/curie/foot (roentgens per hour, etc.) Page 6-4

Very good. Standard dose rates for various isotopes are expressed as $r/hr/curie$ at 1 foot. Or - roentgens per hour per curie at one foot. Let's look at an example using two Cobalt-60 isotopes of different activities.



We have shown two Co-60 sources above, one with an activity of 2 curies and the other with an activity of 5 curies.

We learned in Volume 1 that radiation intensity or dose rate of an isotope varies directly with the activity of the source. For that reason the intensities shown above are different.

From an examination of the two diagrams above can you tell what the dose rate or intensity at one foot would be if you had a 1 curie source of Co-60?

Yes. It would be 14.5 $r/hr/curie$ at 1 foot Page 6-5

No. I would need more information Page 6-6

You believe the standard dose rate for an isotope could be expressed as " $r/hr/curie/foot$." That's the wrong answer.

Your selection says standard dose rate is expressed as roentgens per hour per curie per foot. The standard dose rate is expressed as roentgens per hour per curie. But it is not expressed "per foot." This would mean that an isotope would have a standard relationship to each foot of distance from the isotope. Distance is a prime factor in determining radiation exposure. But in trying to establish a standard for the different isotopes they are all checked for a radiation amount at one foot. Their standard dose rates are expressed in roentgens per hour per curie at a distance of one foot. Or...

... $r/hr/curie$ at 1 foot Page 6-3

From page 6-3

6-5

Absolutely. One curie of Co-60 always has a gamma intensity or dose rate of 14.5 roentgens per hour at a distance of one foot from the source. This is characteristic of Co-60. In the two diagrams shown, the intensities are multiples of 14.5 r/hr/curie at 1 foot:

$29.0 \text{ r/hr at 1 foot} \div 2 \text{ curies} = 14.5 \text{ r/hr/curie at 1 foot}$

$72.5 \text{ r/hr at 1 foot} \div 5 \text{ curies} = 14.5 \text{ r/hr/curie at 1 foot}$

From the information given so far, do you think you could give the r/hr/curie value at 1 foot for Ir-192?

Yes. It would be 14.5 r/hr/curie at 1 foot. Page 6-7

No. I would need more information Page 6-8

From page 6-3

6-6

You feel that you would need more information to determine the dose rate or intensity for 1 curie of Co-60 at one foot.

Actually, you have all the information that would be needed to determine the gamma radiation dose rate at a distance of 1 foot from 1 curie of Co-60.

Remember we said that the radiation intensity for a given isotope varies directly with the activity of the source.

Return to page 6-3 and try dividing the roentgen per hour values by the number of curies in each source. This will give you the roentgens per hour at 1 foot for 1 curie of Co-60 in each case.

You are right. You do not have enough information to find the dose rate at one foot for 1 curie of Ir-192.

Although one curie of Ir-192 gives the same number of disintegrations per second as Co-60, they do not emit the same number of gamma rays and their photon energies are different. The dose rate at one foot for one curie of Ir-192 is 5.9 r/hr. One curie of Ir-192 always has a dose rate of 5.9 roentgens per hour at a distance of 1 foot. This value is characteristic of Ir-192.

What would be the intensity of an Ir-192 source with an activity of 4 curies?

5.9 r/hr at 1 foot..... Page 6-9

23.6 r/hr at 1 foot..... Page 6-10

Wrong. The dose rate for 1 curie of Ir-192 is not 14.5 r/hr/curie at 1 foot.

The dose rate for 1 curie of Ir-192 cannot be computed from the information given so far. It is not the same as Co-60.

As we said at the beginning of this chapter, each radioactive isotope has its own peculiar dose rate for each curie of activity.

One curie of Co-60 and one curie of Ir-192 have the same number of disintegrations per second, but remember from Volume 1 that each has a different number of gamma rays that result from these disintegrations and each one emits photons of different energies.

This means that the dose rate of their gamma radiations will be different and that...

...you need more information Page 6-8

Nope. I must have led you astray somewhere. The intensity of an Ir-192 source with an activity of four curies would not be 5.9 r/hr at one foot.

As we stated, one curie of Ir-192 has a dose rate of 5.9 r/hr at 1 foot. The only point we are trying to make here is that four curies of an isotope have four times the intensity at a given distance as one curie of that isotope. So...

$$5.9 \text{ r/hr at 1 foot} \times 4 \text{ curies} = 23.6 \text{ r/hr at 1 foot.}$$

Turn to page 6-10.

hrr. The dose rate of a four curie Ir-192 source is 23.6 r/hr at 1 foot since the dose rate for one curie at one foot is 5.9 r/hr.

Let's look at a table showing several isotopes commonly used in radiography.

RADIOISOTOPE	R/HR/CURIE AT 1 FOOT
COBALT-60 (Co-60)	14.5
IRIDIUM-192 (Ir-192)	5.9
CESIUM-137 (Cs-137)	4.2
THULIUM-170 (Tm-170)	.03

These values are available from a number of sources but it is advantageous if you memorize them. They are the starting point for most computations in gamma radiography.

The dose rates given in r/hr/curie at 1 foot for each of the isotopes in the table are fixed values that never vary. The photon energies emitted by each radioisotope are always the same. On the other hand, X-ray machines produce a wide range of photon energies depending on the voltage of the machine.

From a practical standpoint, there is no need for standard dose rate values for X-ray equipment. The manufacturers of the equipment furnish charts that bypass this step in making calculations for X-radiography.

Turn to the next page.

No. That's not the correct choice. Time and distance are certainly important factors. So, we suppose, would type of radiation source be in some instances and if you could control this. But this time we were looking for three protective measures that will provide protection against radiation regardless of the type of source used. Let's list them again. Protection is provided by:

- Controlling the length of time a person is exposed to a radiation source.
- Controlling the distance between personnel and a radiation source.
- Placing absorbing materials between personnel and the radiation source.

When summarized, we say that radiation protection is provided by...

...time, distance, and shielding Page 6-13

Dose rate calculations are important since they are used in computing the requirements for personnel protection. We have said that the protective measures are primarily designed to hold radiation exposure to or below the allowable limits.

There are three basic means of providing protection from radiation. The three means are:

- Controlling the length of time a person is exposed to a radiation source.
- Controlling the distance between personnel and a radiation source.
- Placing absorbing materials between personnel and the radiation source.

The three means may be used separately or in combination with one another. To shorten the protective measures to simple terms that can be easily remembered, we could say that radiation protection is provided by...

...time, distance, and type of radiation source Page 6-12

...time, distance, and shielding Page 6-13

Yep. That's right. The three factors of personnel protection are time, distance, and shielding. These are the factors which you will always have to remember when working in radiography if you are to be sure of protecting yourself and others. We will discuss the three individually, but remember they are most effective when used in combination with each other.

TIME

The relationship of time to radiation exposure is a simple one. The longer you stay in a radiation area, the more radiation exposure you receive. Exposure increases in direct proportion to the time spent in ionizing radiation. Assume that a person receives 1 mr in one minute from a radiation source.



If a person spent 5 minutes at the same distance from the same source he would receive...

...1 mr Page 6-14
 ...5 mr Page 6-15

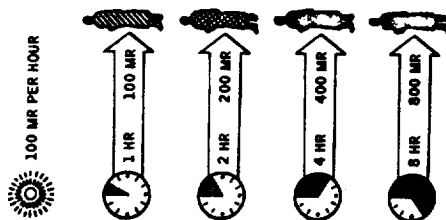
Bad guess. A person spending 5 minutes at a certain distance from a source would not receive the same exposure as a person spending 1 minute at the same distance from the same source.

The longer you stay in a radiation area, the more radiation exposure you receive. And the relationship is directly proportional.

A person who stays 1 minute in a radiation area and receives 1 mr of exposure is actually experiencing a dose rate of 1 mr/minute. If the person stayed 5 minutes at the same distance from the same source, he would receive 5 x 1 milliroentgens, or 5 mr Page 6-15

Sure. The person would receive 5 mr in 5 minutes.

We have said the relationship of time to exposure is directly proportional. As the time of exposure increases, exposure increases at the same rate.



When work is to be performed in a radiation area, all operations should be carefully planned in advance. This will assure that a minimum amount of time is spent where radiation is strongest.

Turn to the next page.

DISTANCE

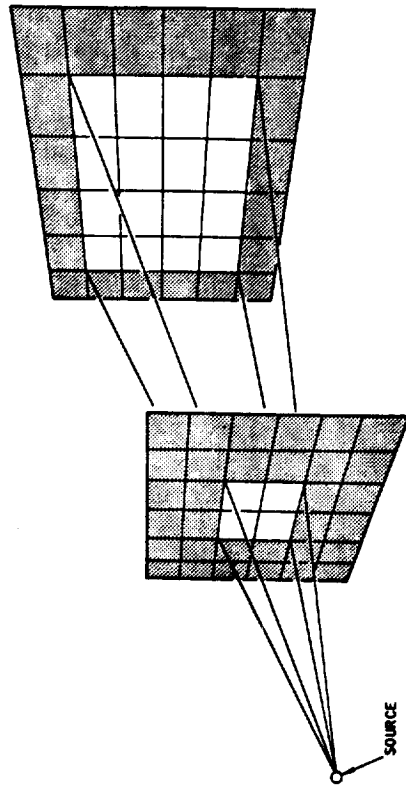
Distance from a radiation source is a very important and very effective means of protecting personnel. The fact that makes distance so effective is that radiation exposure decreases drastically as distance from the source increases.

A mathematical law known as the "inverse square law" states the relationship of distance to varying radiation intensity. This law states that radiation intensity varies inversely as the square of the distance from the source. The law is valid when the radiation comes from a "point" source and we will consider all our X-ray machines and gamma ray sources as point sources.

To further define the inverse square relationship, let's say that you are standing at a certain distance from a source and are receiving a certain amount of radiation. If you double that distance, you will receive only $1/4$ the amount of radiation.

Turn to the next page and we will illustrate our point.

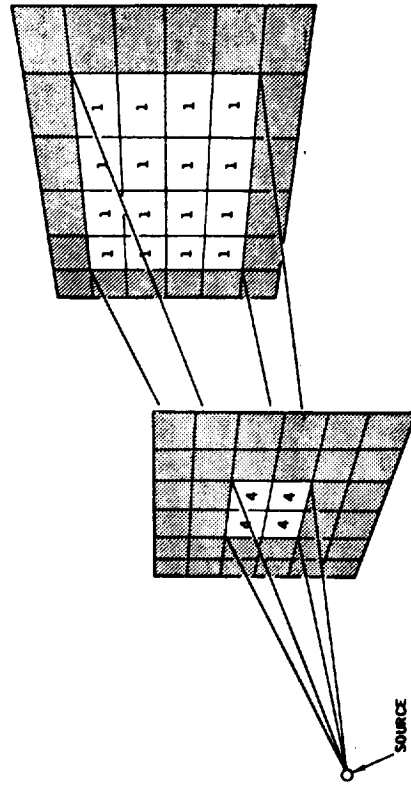
Shown below is a point source of radiation. Of course, if this were an isotope, radiation would be emitted in all directions. But let's just use a segment of the beam that consists of a fixed radiation intensity. And assume that each of the squares in the two series of squares is the same size.



Notice that when the beam strikes the first series of squares (the series closest to the source), all the radiation is concentrated on four squares. Now assume that the second series of squares is twice the distance from the source as the first series. The same radiation is spread over 16 squares. This means that each of the 16 squares in the second series is...

...receiving the same amount of radiation as each of the four squares in the first series Page 6-18
 ...receiving one-fourth of the amount of radiation as each of the four squares in the first series Page 6-19

That's not correct. Each square in the second series of squares is not receiving the same amount of radiation as each of the four squares in the first series. Here is the illustration again with some mr/hr values assigned to the squares.



Our assumptions again:

- Each of the squares in the two series is the same size.
- The second series of squares is twice the distance from the source as the first series.

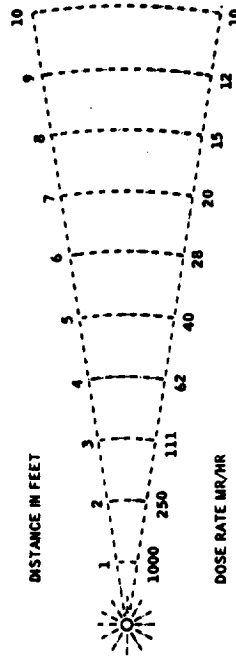
At the point where the beam strikes the first series, there is a total of 16 mr/hr - or 4 mr/hr on each square. When the beam reaches the second series, it is distributed over a much wider area. Such a wide area, in fact, that the intensity on each square is reduced to 1 mr/hr.

Radiation intensity has been reduced as the square of the distance from the source. Or, stated in another way, if the distance from the source is doubled, each square in the second series...

...receives one-fourth the radiation of each of the squares in the first series Page 6-19

Correct. Each of the squares in the second series receives one-fourth the radiation received by each of the squares in the first series. And if a man were substituted for one of the squares in each series, that man would receive one-fourth the radiation at the point where the distance was doubled.

To further illustrate the effect of distance on safety, here is a source with intensities at various distances from the source.



At a distance of 1 foot from the source, a dose rate of 1,000 mr/hour is experienced. Merely moving one additional foot away from the source reduces dose rate to 250 mr/hour (double the distance, reduce radiation to one-fourth). But by moving on out to a distance of 10 feet from the source, the dose rate is only 10 mr/hour or 1/100 the radiation at 1 foot.

The same considerations apply if you are getting nearer the source instead of farther away. The dose rate increases drastically as you approach the source. This relationship of varying intensity as the distance from the source changes is computed by using the inverse square law which states that radiation intensity...

...decreases inversely as the square of the distance from the source..... Page 6-20

...varies inversely as the square of the distance from the source Page 6-21

Well, your answer is not wrong, but it is incomplete.

Your choice shows that you believe the inverse square law states that radiation intensity decreases inversely as the square of the distance from the source. And this is a true statement if the distance is increasing. But it is also true that radiation intensity increases as the square of the distance from the source if the distance is decreasing.

The point to note here is that the inverse square rule applies both ways - increasing or decreasing distance. In other words, increasing or decreasing distance causes radiation intensity (or dose rate) to vary.

So, while you were not wrong, the other choice would have been a better answer. It said...

...radiation intensity varies inversely as the square of the distance from the source Page 6-21

From page 6-21

No, it's the other way around. In the formula,

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

I_1 = Intensity at D_1 and I_2 = Intensity at D_2 .

There are two distances and two intensities in the formula - D_1 , D_2 , I_1 , and I_2 .

Just remember that the subscript numbers match each other - one to one and two to two.

$$I \text{ (1)} = \text{Intensity at } D \text{ (1)}$$

$$I \text{ (2)} = \text{Intensity at } D \text{ (2)}$$

Turn to page 6-23.

From page 6-19

Sure. The inverse square law states that radiation intensity varies inversely as the square of the distance from the source. With increasing distance, radiation intensity decreases. With decreasing distance, radiation intensity increases.

There is a simple formula used in radiography to determine radiation intensity or dose rate at varying distances from a gamma ray source or an X-ray machine. The inverse square law formula for determining dose rate is shown below:

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

To begin with let's state that this formula must be memorized. But to help in learning it, let's identify the elements:

I = Intensity and D = Distance

I_1 = The known intensity at a known distance (D_1).

D_1 = The distance from a source where intensity is known (I_1). D_1 is always squared in the formula.

I_2 = The unknown intensity at a second known distance (D_2).

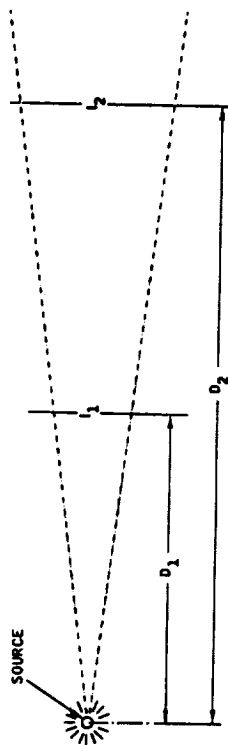
D_2 = The distance from a source at which you want to find the unknown intensity (I_2). D_2 is always squared in the formula.

By studying the above, you can see that...

... I_1 = Intensity at D_2 and I_2 = Intensity at D_1 Page 6-22

... I_1 = Intensity at D_1 and I_2 = Intensity at D_2 Page 6-23

Exactly. In the inverse square formula, $I_1 = \text{Intensity at } D_1$ and $I_2 = \text{Intensity at } D_2$. Let's illustrate the elements of the formula as it would be if you wanted to find intensity at an increasing distance.



Learning the formula will be simple enough after we have worked a few problems. But, just for drill, can you put the elements together? The inverse square formula is stated as:

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2} \dots\dots\dots \text{Page 6-24}$$

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2} \dots\dots\dots \text{Page 6-25}$$

You forgot something. Here is the answer you picked:

$$\frac{I_1}{I_2} = \frac{D_2}{D_1}$$

The arrangement of the symbols (I_1 , I_2 , D_1 , and D_2) in your choice is correct. But something is left off.

The formula is for the inverse square law. This law states that radiation intensity varies as the square of the distance from the source. To achieve this relationship mathematically, the distances must be squared in the formula. This will become more apparent after you see a couple of problems. But, for right now, let's say the formula is...

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2} \dots\dots\dots \text{Page 6-25}$$

Very good. The formula is:

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

Let's see how it is applied in an actual situation. At 2 feet from a radiation source, radiation intensity is 600 r/hr. What would the intensity be at 10 feet from this source?

$$\begin{aligned} I_1 &= 600 \text{ r/hr} \\ D_1 &= 2 \text{ feet} \\ I_2 &= \text{Unknown} \\ D_2 &= 10 \text{ feet} \end{aligned}$$

Substituting into the formula we have:

$$\frac{600}{I_2} = \frac{10^2}{2^2} = \frac{100}{4}$$

$$I_2 = \frac{600 \times 4}{100} = \frac{2400}{100} = 24 \text{ r/hr}$$

Thus the intensity at a distance of 10 feet is 24 r/hr

Now, using the same steps, it's your turn to work one. (Use a separate sheet of paper for your solution.)

At 3 feet from a radiation source, intensity is 75 r/hr. What is the intensity at 10 feet?

22.5 r/hr Page 6-26

6.75 r/hr Page 6-27

Your answer, 22.5 r/hr, is wrong. Let's state the problem again.

At 3 feet from a radiation source, intensity is 75 r/hr.

What is the intensity at 10 feet?

There are numerous ways that this problem could have been solved in error. But, to get your answer, there is one mistake that probably occurred. You forgot to square the distances D_1 and D_2 . The formula requires this. Let's go through the problem.

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

$$I_1 = 75 \text{ r/hr}$$

$$D_1 = 3 \text{ feet}$$

$$I_2 = \text{Unknown}$$

$$D_2 = 10 \text{ feet}$$

Substituting into the formula we get:

$$\frac{75}{I_2} = \frac{10^2}{3^2} = \frac{100}{9}$$

$$\text{Then, } I_2 = \frac{75 \times 9}{100} = \frac{675}{100} = \dots$$

6.75 r/hr Page 6-27

Good. The intensity at I_1 is 59 r/hr since the 10 curie source in question has an intensity of 5.9 r/hr/curie at 1 foot. Here is the problem again:
A radiographic inspection is to be performed in an open area using a 10-curie source of Ir-192. What would the radiation intensity be at 20 feet from the source?

Now, on a separate sheet of paper, substitute the values of the problem into the inverse square formula. Your problem should look like one of these.

$$\frac{59}{I_2} = \frac{20^2}{1^2} \dots\dots\dots \text{Page 6-30}$$

$$\frac{59}{I_2} = \frac{1^2}{20^2} \dots\dots\dots \text{Page 6-31}$$

From page 6-25
Right. Intensity at $I_2 = 6.75$ r/hr. Now let's try a problem of the same type but with one additional step. First, here is the table showing standard dose rates for one curie of the common isotopes in roentgens per hour at one foot.

RADIOISOTOPE	R/HR/CURIE AT 1 FOOT
COBALT-60 (Co-60)	14.5
IRIDIUM-192 (Ir-192)	5.9
CESIUM-137 (Cs-137)	4.2
THULIUM-170 (Tm-170)	.03

A radiographic inspection is to be performed in an open area using a 10-curie source of Ir-192. What would be the radiation intensity at 20 feet from the source.

In this problem, I_1 would equal...

...59 r/hr ... Page 6-28

...5.9 r/hr... Page 6-29

In the problem we stated, you believe that I_1 would equal 5.9 r/hr. That's the wrong choice. Here is the table again.

RADIOISOTOPE	R/HR/CURIE AT 1 FOOT
COBALT-60 (Co-60)	14.5
IRIDIUM-192 (Ir-192)	5.9
CESIUM-137 (Cs-137)	4.2
THULIUM-170 (Tm-170)	.03

The standard dose rate for Ir-192 is 5.9 r/hr/curie at one foot. This means that each curie of Ir-192 has an intensity or dose rate of 5.9 r/hr at one foot. Now here is the problem again:

A radiographic inspection is to be performed in an open area using a 10-curie source of Ir-192. What would the radiation intensity be at 20 feet from the source.

Note that the source is 10 curies. If each curie has an intensity of 5.9 r/hr at one foot, 10 curies has an intensity of $10 \times 5.9 = \dots$

...59 roentgens per hour. Page 6-28

That's correct. The problem becomes:

$$\frac{59r}{I_2} = \frac{20^2}{1^2}$$

Now you have all the elements you need to find the radiation intensity at 20 feet from a 10 curie source of Ir-192. Solve the problem showing your work in the space below.

The intensity at 20 feet is:

148 mr/hr Page 6-32

6.95 r/hr Page 6-33

You made an error in the way you set up the problem. Here is another look at it.

A radiographic inspection is to be performed in an open area using a 10-curie source of Ir-192. What would the radiation intensity be at 20 feet from the source?

Here is the basic formula with the relationships of the intensities and distances noted with arrows:

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

We already know that I_1 is 59 r/hr (Ir-192 has an intensity of 5.9 r/hr/curie at one foot and the source in question is 10 curies).

Now let's find D_1 . It is the distance at which the intensity of I_1 is known. In this case, it is one foot because we started with the Ir-192 dose rate at 1 foot.

This leaves D_2 which is the distance at which we want to find the intensity I_2 . In this problem, it is 20 feet. So:

$$\begin{aligned} I_1 &= 59 \text{ r/hr} \\ D_1 &= 1 \text{ foot} \\ I_2 &= \text{Unknown} \\ D_2 &= 20 \end{aligned}$$

In your solution, you had D_1 and D_2 transposed. The formula should have been:

$$\frac{59r}{I_2} = \frac{20^2}{1^2} \dots\dots\dots \text{Page 6-30}$$

Very good. The answer is 148 mR/hr. This method can be used for any of the isotopes as long as you have a known intensity at a known distance.

The same formula may be used to find the intensity or dose rate when moving closer to an isotope. All you need is a known intensity at a known distance. Here is an example.

At 2 feet from an isotope, the intensity is 600 r/hr. What is the intensity at 1 foot? Substituting in the formula you would have:

$$\frac{600}{I_2} = \frac{1^2}{2^2} \dots\dots\dots \text{Page 6-34}$$

$$\frac{600}{I_2} = \frac{2^2}{1^2} \dots\dots\dots \text{Page 6-35}$$

From page 6-30

6-33

You made an error in your calculations. 6.95 r/hr is not the correct answer. Here is the problem again remembering that $I_1 = 59$ r/hr.

$$\frac{59}{I_2} = \frac{20^2}{I_1^2}$$

The first step is to square D_2 and D_1 . So we have:

$$\frac{59}{I_2} = \frac{400}{1}$$

The next step is to cross-multiply 59×1 and $I_2 \times 400$. This gives us:

$$400 I_2 = 59 \times 1 \quad \text{or} \quad I_2 = \frac{59}{400}$$

It is on the above step of the solution that you probably made your error. To get your answer, you transposed the numerator and the denominator in the fraction $\frac{59}{400}$.

<u>Wrong</u>	<u>Right</u>
$\frac{400}{59}$	$\frac{59}{400}$

In the correct solution, you have:

$$I_2 = \frac{59}{400} = .1475 \text{ r/hr} = 148 \text{ mr/hr} \dots \dots \dots \text{Page 6-32}$$

From page 6-32

6-34

Correct. The problem of finding intensity at 1 foot from an isotope with an intensity of 600 r/hr at 2 feet may be substituted into the formula thusly:

$$\frac{600}{I_2} = \frac{1^2}{2^2}$$

Now, complete the problem. Your answer should be:

150 r/hr $\dots \dots \dots$ Page 6-36

2400 r/hr $\dots \dots \dots$ Page 6-37

Bad guess. Intensity is not 150 r/hr. There is no possible way that this answer could be correct. Here is why.

In the problem, we asked for the intensity at 1 foot from an isotope that has an intensity of 600 r/hr at 2 feet. We know that radiation intensity increases when we move closer to the source. Therefore, intensity cannot drop from 600 r/hr to 150 r/hr when moving closer to the isotope. The intensity must increase.

Here is the solution:

$$\frac{600}{I_2} = \frac{1^2}{2^2} = \frac{1}{4}$$

$$I_2 = \frac{4 \times 600}{1} = 2400 \text{ r/hr} \dots\dots\dots \text{Page 6-37}$$

Your choice, $\frac{600}{I_2} = \frac{2^2}{1^2}$, is wrong. You have the distances reversed. Here is the problem again:

At 2 feet from an isotope, the intensity is 600 r/hr.
What is the intensity at 1 foot?

Assigning the values we have:

- $I_1 = 600 \text{ r/hr}$
- $D_1 = 2 \text{ feet (the distance for the known intensity, } I_1)$
- $I_2 = \text{Unknown}$
- $D_2 = 1 \text{ foot (the distance for the unknown intensity, } I_2)$

Now for the basic formula:

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2} \quad \text{(Don't forget the relationships of } I_1 \text{ to } D_1 \text{ and } I_2 \text{ to } D_2 \text{ as shown by the arrows.)}$$

So, substituting, you should have:

$$\frac{600}{I_2} = \frac{1^2}{2^2} \dots\dots\dots \text{Page 6-34}$$

Exactly. In the problem of moving from 2 feet to 1 foot from an isotope, intensity becomes 4 times as high. This is the same concept we stated when we started our discussion on distance as a protective measure. If you move twice the distance away from a radiation source, dose rate or intensity will be reduced to $1/4$ the original amount. If you reduce the distance from a source by $1/2$, the intensity increases 4 times.

There is one other example of the inverse square law application that we should cover. That is solving for an unknown distance at which a desired intensity will be achieved. Here is the way such a problem would be stated.

Intensity at 3 feet is 320 r/hr. At what distance would the intensity be reduced to 20 r/hr? Substituting into the inverse square formula, your problem would be which one of the following?

$$\frac{320}{20} = \frac{3^2}{D_2^2} \dots\dots\dots \text{Page 6-38}$$

$$\frac{320}{20} = \frac{D_2^2}{3^2} \dots\dots\dots \text{Page 6-39}$$

Here is the way you set up your problem:

$$\frac{320}{20} = \frac{3^2}{D_2^2}$$

Your method is wrong. We are still using the basic inverse square formula even though the distance D_2 is the unknown quantity in this problem. The basic formula is:

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

By comparing the formula with the way you set up the problem, we can determine that the factor D_2^2 is misplaced. Just for practice let's restate the problem and substitute into the formula.

Intensity at 3 feet is 320 r/hr. At what distance would the intensity be reduced to 20 r/hr?

$$\begin{aligned} I_1 &= 320 \text{ r/hr} \\ D_1 &= 3 \text{ feet} \\ I_2 &= 20 \text{ r/hr} \\ D_2 &= \text{Unknown} \end{aligned}$$

Then, substituting, we have:

$$\frac{320}{20} = \frac{D_2^2}{3^2} \dots\dots\dots \text{Page 6-39}$$

That's right. If radiation intensity at 3 feet is 320 r/hr and you want to find the distance at which intensity is reduced to 20 r/hr, the problem will look like this:

$$\frac{320}{20} = \frac{D_2^2}{3^2}$$

And here is the solution:

$$D_2^2 = \frac{320 \times 9}{20} = \frac{2880}{20} = 144$$

$$\text{then, } D_2 = \sqrt{144} = 12 \text{ feet.}$$

So, to reduce radiation intensity from 320 r/hr to 20 r/hr, you would move from 3 feet to a distance of 12 feet.

Turn to the next page.

Now it's your turn to solve a problem similar to the one on the preceding page.

If radiation intensity is 240 r/hr at 5 feet, find the distance at which intensity is 15 r/hr. (Use the space below for your work.)

Your answer should be:

400 feet Page 6-41

20 feet Page 6-42

Your answer, 400 feet, is wrong. It looks like you didn't finish the problem. Here it is again.

If radiation intensity is 240 r/hr at 5 feet, find the distance at which intensity is 15 r/hr. Now let's review the entire problem.

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2} \quad \text{Where, } \begin{array}{l} I_1 = 240 \text{ r/hr} \\ D_1 = 5 \text{ feet} \\ I_2 = 15 \text{ r/hr} \\ D_2 = \text{Unknown} \end{array}$$

$$\text{Then, } \frac{240}{15} = \frac{D_2^2}{5^2}$$

$$D_2^2 = \frac{240 \times 25}{15} = \frac{6000}{15} = 400$$

Now, since the answer you selected was 400 feet, this is probably as far as you took the solution. But let's look again:

$$D_2^2 = 400$$

At this point we do not know what D_2 is. Instead, we have the square of D_2 . So, to complete the problem we would...

$$D_2 = \sqrt{400} = 20 \text{ feet} \dots\dots\dots \text{Page 6-42}$$

Yep. Your answer, 20 feet, is correct.

The methods for applying the inverse square law to radiation intensities shown here may be used in many practical situations. When you are in an on-the-job situation, the uses of the inverse square concept will become readily apparent.

The law applies only to radiation sources that are not shielded. For example, an isotope may emit a certain amount of radiation at one foot. But, if there is a concrete wall between you and the one-foot distance from the source, a calculation using the intensity at one foot would not be valid. The law is valid only for radiation in an open area.

Another important limitation in actual situations is the effect of scattered, or reflected, radiation. The inverse square law assumes that all x-ray and gamma radiation will travel in a straight line, but this assumption is not always true. In many cases scattered radiation can make significant addition to the radiation traveling directly from the source.

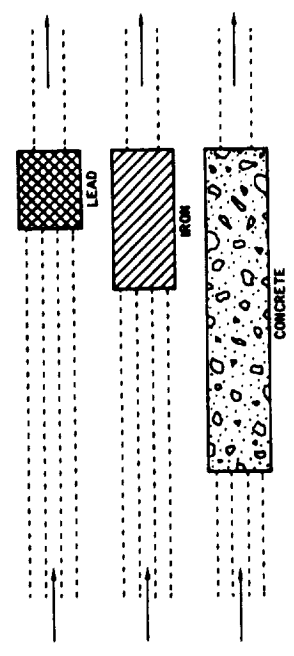
Therefore, an inverse square law calculation must never be used to decide if a particular location may be occupied by personnel unless the calculated radiation intensity is verified with a survey instrument measurement.

We have covered two of the three primary means of personnel protection - TIME and DISTANCE. Turn to the next page for a look at the third concept - SHIELDING.

From page 6-43

Very good. Lead provides a better shield against radiation than water. The higher number of electrons in lead increases the odds that photons will be stopped as they penetrate lead. In short, lead is a more dense material. And, the more dense the material, the better it shields against radiation.

There are several commonly used shielding materials. The ones you will encounter most frequently are lead, concrete, and iron. Because of the differing physical properties of these materials, different thicknesses of each are required to accomplish the same reduction of a given amount of electromagnetic radiation. Let's take an isotope which is producing an equal intensity on samples of the three shielding materials.



Which list below shows the materials in order of their efficiency in absorbing electromagnetic radiation?

Concrete, iron, and lead..... Page 6-46

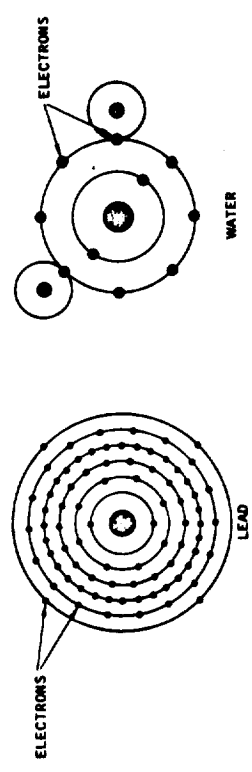
Lead, iron, and concrete..... Page 6-47

From page 6-42

SHIELDING

The third means of providing personnel safety is by shielding. This simply means that some absorbing material is placed between the radiation source and personnel in the area. For our discussions on shielding, we will be concerned only with X-ray and gamma ray shielding.

The point was made earlier that the damaging effects of radiation come from the fact that radiation knocks electrons in atoms in the body out of orbit. This same principle allows us to use solid materials as shields against radiation. Shielding materials absorb the radiation energy when X-rays or gamma rays collide with electrons in the material. Because photons are absorbed by the shielding material, less radiation is present on the other side of the material and persons on the shielded side receive less exposure. Some materials provide greater protection for a given thickness than others. Here are a couple of atoms from materials which could be used for shielding.



Now, to review from Volume I, which of these materials would provide the greatest protection for a given thickness?

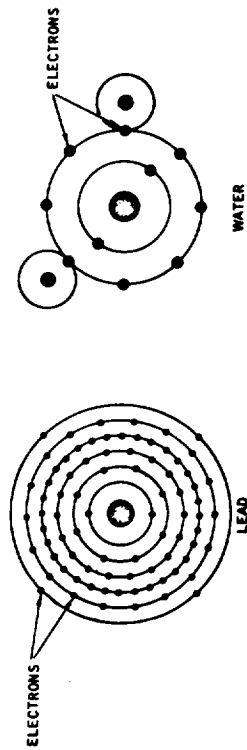
Lead..... Page 6-44

Water..... Page 6-45

From page 6-43

6-45

Wrong on this point. Water does not provide a better shield for a given thickness than does lead. Let's study the atoms again.



Remember that a material absorbs radiation by having electrons knocked out of orbit in the atoms of the material. It follows, then, that a material having a large number of electrons would make the better shield against radiation.

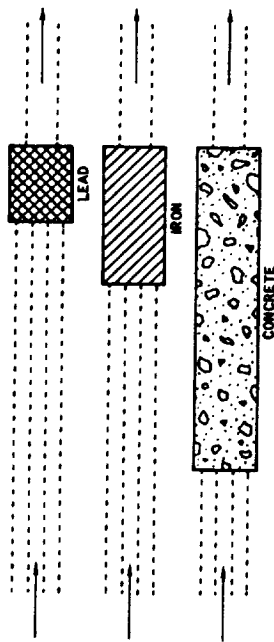
Notice above that the lead atom has a much higher number of electrons than the water atom. This greatly increases the chances that a photon will collide with an electron in the lead atom. Therefore, for a given thickness, lead will absorb more radiation than water.

Turn to page 6-44

From page 6-43

6-46

That's the wrong order. Your choice shows that you believe concrete is more efficient in absorbing electromagnetic radiation than iron or lead. That's not the way it works. Here are the materials again.



Notice that the radiation entering each material is reduced to one-half by passing through the materials. But it takes a lot less lead to reduce the rays to one-half their value than it takes for concrete to effect the same reduction. The reason for this is that lead is more dense than concrete and can absorb radiation more efficiently.

So, listed in order of shielding efficiency, we have...

...lead, iron, and concrete..... Page 6-47

Correct. Lead is the best absorber of the three; then comes iron followed by concrete.

In practical application, the two most common shielding materials are lead and concrete (and combinations of the two). For radiographic operations in confined areas, special rooms are constructed for making gamma ray and X-ray exposures. These rooms are planned with the intent of keeping radiation outside the rooms at an acceptable level. The walls of the rooms (as well as floors and ceilings if required) may be of concrete construction and have the additional protection of sheets of lead attached to the walls. Remote controls permit operation of radiographic equipment from outside the rooms.

When radiographic operations are performed outside the shielded rooms, portable screens are used to provide a certain amount of shielding.

In either type of operation, it is not practical to use enough shielding to completely stop all electromagnetic rays. The objective is to limit the radiation that passes through the shielding to a permissible level. It is, therefore, necessary to have a means of calculating the amount of shielding required to reduce radiation to a known level. This calculation is made by using a concept discussed in Volume I. This concept states that there is a certain thickness of material that will reduce radiation passing through that material to one-half the original intensity. This thickness is known as...

...half-life Page 6-48

...half-value layer Page 6-49

No. Half-life is not the correct name for a thickness of material that will reduce radiation passing through that material to one-half the original intensity.

Half-life (or radioactive half-life) is the time it takes a radioactive isotope to lose one-half of its radioactivity. This is something quite different from "half-value layer."

Half-value layer (or H. V. L.) is a thickness of material (such as lead, iron or concrete). This thickness will stop one-half of the radiation entering the material.

Turn to page 6-49.

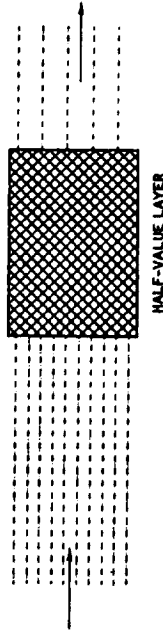
Sure. Half-value layer (H. V. L.) is a thickness of a material that will reduce radiation to one-half the original intensity.

For each radioisotope or each X-ray of a given energy, there is a characteristic half-value layer of any material. These are standard values and are available in tables or charts to be used in computing the reductions in radiation.

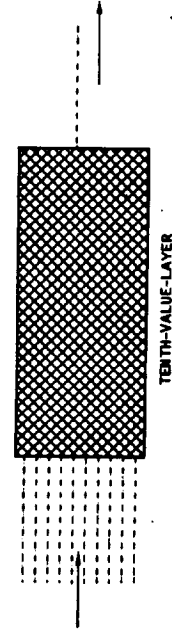
There is another standard that has been established to show the reduction of radiation by various shielding materials. This is known as a "tenth-value layer." It is the thickness of a material that will reduce radiation passing through that material to one-tenth the original intensity.

Which would be thicker?

Half-value layer. Page 6-50
Tenth-value layer. Page 6-51



Tenth-value layer is the thickness of a material that reduces radiation passing through that material to one-tenth the original value.



We can see from the definitions that a greater thickness of material is required to reduce radiation to one-tenth than is needed to reduce radiation to one-half.

Turn to page 6-51

Yep. A tenth-value layer is thicker than a half-value layer. But we have to qualify this statement. When making such a comparison, the analysis is true only when we are speaking of a particular isotope and a particular shielding material. Because, as you can see from the table below, half- and tenth-value layers vary in thickness depending upon the type of isotope and the type of shielding material.

SHIELDING MATERIAL	RADIOISOTOPE SOURCE					
	COBALT-60		IRIDIUM-192		CESIUM-137	
	1/10	1/2	1/10	1/2	1/10	1/2
LEAD	1.62	0.49	0.64	0.19	0.84	0.25
CONCRETE	8.6	2.6	6.2	1.9	7.1	2.1

NOTE: THICKNESSES GIVEN IN INCHES.

This table shows only three isotopes and the two most common shielding materials, lead and concrete. But there are tables showing standard half- and tenth-value layers for the other isotopes and other shielding materials.

Just for a little practice in using the table, how many half-value layers for Co-60 are there in 13 inches of concrete?

5 H. V. L. Page 6-52

26.5 H. V. L. Page 6-53

That's right. Five half-value layers of concrete for Co-60 would total 13 inches. Now let's look at another problem.

Radiation intensity at a certain point is 81 r/hr. How many H. V. L. are required to reduce the intensity to less than 3 r/hr?

5 H. V. L. Page 6-54

6 H. V. L. Page 6-55

I don't fully understand the method for solving the problem and would like to have it demonstrated Page 6-56

That's the wrong figure. It would not take 26.5 H.V.L. for Co-60 to total 13 inches of concrete. Look at the table again.

SHIELDING MATERIAL	RADIOISOTOPE SOURCE					
	COBALT-60		IRIDIUM-192		CESIUM-137	
	1/10	1/2	1/10	1/2	1/10	1/2
LEAD	1.62	0.49	0.64	0.19	0.84	0.25
CONCRETE	8.6	2.6	6.2	1.9	7.1	2.1

NOTE: THICKNESSES GIVEN IN INCHES.

Notice that the half-value layer of concrete for Co-60 is 2.6 inches. In your solution, you used 0.49 inches which is the half-value layer of lead for Co-60. To find the number of H.V.L. of concrete it would take to total 13 inches, divide 2.6 into 13 and get...

5 H.V.L. Page 6-52

Exactly. It takes 5 H.V.L. to reduce 81 r/hr to below 3 r/hr. The 5 H.V.L. result in a reduction to approximately 2.5 r/hr.

For the next problem, the table of half- and tenth-value layers for the different isotopes is needed.

SHIELDING MATERIAL	RADIOISOTOPE SOURCE					
	COBALT-60		IRIDIUM-192		CESIUM-137	
	1/10	1/2	1/10	1/2	1/10	1/2
LEAD	1.62	0.49	0.64	0.19	0.84	0.25
CONCRETE	8.6	2.6	6.2	1.9	7.1	2.1

NOTE: THICKNESSES GIVEN IN INCHES.

Now try this problem:

At a certain distance from a Co-60 source, the radiation intensity is 900 mr/hr. Using the half-value layer concept, find the thickness of lead that would be required at that distance to reduce radiation to below 30 mr/hr.

8.1 inches Page 6-57

2.45 inches Page 6-58

The problem cannot be solved without knowing the distance from the Co-60 source Page 6-59

No, the answer is not 6 H. V. L. That was not even an expert guess. But, rather than to go into a long discussion here, let's assume that you do not fully understand the method for solving the problem.

Turn to page 6-56 for a demonstration of the methods for finding the number of half-value layers needed to reduce intensity to a certain level.

is choice. The H. V. L. concept is an important one and you should learn all about it you can.

first place, we know that each H. V. L. placed in a radiation beam reduces radiation one-half its original intensity. With this thought in mind, let's look at the beam again.

Radiation intensity at a certain point is 81 r/hr. How many half-value layers are required to reduce the intensity to less than 3 r/hr?

is more than one way to solve the problem. Here is one method showing step-by-step the effect of each H. V. L.

Initial intensity = 81 r/hr

- 1 H. V. L. reduces 81 r/hr to 40.5 r/hr
- 2 H. V. L. reduces 40.5 r/hr to 20.25 r/hr
- 3 H. V. L. reduces 20.25 r/hr to 10.13 r/hr
- 4 H. V. L. reduces 10.13 r/hr to 5.06 r/hr
- 5 H. V. L. reduces 5.06 r/hr to 2.53 r/hr

the original objective was to reduce intensity to a point below 3 r/hr, we must use all of 5 half-value layers.

to page 6-54.

Your answer of 8.1 inches of lead is wrong. Let's restate the problem:

At a certain distance from a Co-60 source, the radiation intensity is 900 mr/hr.

Using the half-value layer concept, find the thickness of lead that would be required at that distance to reduce radiation to below 30 mr/hr.

Did you compute the radiation reduction in half-value layers and find that you need 5 H. V. L. to reduce radiation intensity to below 30 mr/hr? If you did not, turn to page 6-59 for a review of the entire problem.

If you did determine that 5 H. V. L. would be required to reduce radiation intensity to 30 mr/hr, you probably then used the tenth-value thickness from the table instead of the half-value thickness.

SHIELDING MATERIAL	RADIOISOTOPE SOURCE					
	COBALT-60		IRIDIUM-192		CESIUM-137	
	1/10	1/2	1/10	1/2	1/10	1/2
LEAD	1.62	0.49	0.64	0.19	0.84	0.25
CONCRETE	8.6	2.6	6.2	1.9	7.1	2.1

NOTE: THICKNESSES GIVEN IN INCHES.

Five half-value layers are required to reduce radiation intensity to 30 mr/hr. The half-value thickness of lead for Co-60 is 0.49 inches. Therefore we have:

$$5 \text{ H. V. L.} \times 0.49 \text{ inches} = \underline{2.45 \text{ inches of lead}}$$

Turn to page 6-58.

Excellent. In the problem, it would take 2.45 inches of lead to accomplish the desired reduction in radiation intensity.

Now let's try a slightly different problem - one which also requires the half- and tenth-value layer table.

SHIELDING MATERIAL	RADIOISOTOPE SOURCE					
	COBALT-60		IRIDIUM-192		CESIUM-137	
	1/10	1/2	1/10	1/2	1/10	1/2
LEAD	1.62	0.49	0.64	0.19	0.84	0.25
CONCRETE	8.6	2.6	6.2	1.9	7.1	2.1

NOTE: THICKNESSES GIVEN IN INCHES.

You have a radiation source of Cs-137. The source produces a radiation intensity of 50 r/hr on the source side of a 1-inch layer of lead. How many half-value layers does the shield consist of?

3 H. V. L. Page 6-60

4 H. V. L. Page 6-61

No. You do not need to know the distance from the source to solve this problem.

Let's work through all the steps of the solution.

At a certain distance from a Co-60 source, the radiation intensity is 900 mr/hr. What is the thickness of lead that would be required at that distance to reduce radiation to below 30 mr/hr?

The first step is to find the number of half-value layers required to reduce 900 mr/hr to 30 mr/hr. Here is that solution:

- 1 H. V. L. reduces 900 mr/hr to 450 mr/hr
- 2 H. V. L. reduces 450 mr/hr to 225 mr/hr
- 3 H. V. L. reduces 225 mr/hr to 112.5 mr/hr
- 4 H. V. L. reduces 112.5 mr/hr to 56.3 mr/hr
- 5 H. V. L. reduces 56.3 mr/hr to 28 mr/hr

Thus it takes 5 H. V. L. of lead to reduce radiation intensity from 900 mr/hr to below 30 mr/hr, or 28 mr/hr. The half-value layer of lead for Co-60 is obtained from the table.

SHIELDING MATERIAL	RADIOISOTOPE SOURCE					
	COBALT-60		IRIDIUM-192		CESIUM-137	
	1/10	1/2	1/10	1/2	1/10	1/2
LEAD	1.62	0.49	0.64	0.19	0.84	0.25
CONCRETE	8.6	2.6	6.2	1.9	7.1	2.1

NOTE: THICKNESSES GIVEN IN INCHES.

H. V. L. of lead for Co-60 = 0.49 inches

Then: 5 H. V. L. x 0.49 inches = 2.45 inches of lead to reduce 900 mr/hr to below 30 mr/hr.

Turn to page 6-58.

You say 3 H. V. L. That's not right. Here is the problem:

You have a radiation source of Cs-137. The source produces a radiation intensity of 50 r/hr on the source side of a 1 inch layer of lead. How many half-value layers of lead are shielding the source?

The first step is to find the half-value thickness of lead for Cs-137.

SHIELDING MATERIAL	RADIOISOTOPE SOURCE					
	COBALT-60		IRIDIUM-192		CESIUM-137	
	1/10	1/2	1/10	1/2	1/10	1/2
LEAD	1.62	0.49	0.64	0.19	0.84	0.25
CONCRETE	8.6	2.6	6.2	1.9	7.1	2.1

NOTE: THICKNESSES GIVEN IN INCHES.

Using the table we find that thickness to be 0.25 inch. Thus:

- 1 H. V. L. = 0.25 inch
- 2 H. V. L. = 0.5 inch
- 3 H. V. L. = 0.75 inch
- 4 H. V. L. = 1.00 inch

So, 1 inch of lead shielding provides 4 H. V. L. for Cs-137 Page 6-61

From page 6-58

6-61

Yes, in the problem, 1 inch of lead is 4 H.V.L. for Cs-137. Let's continue with the same problem.

The Cs-137 source is producing an intensity of 50 r/hr on the source side of a 1-inch layer of lead. What is the intensity on the opposite side of the lead shielding?

25 r/hr. Page 6-62

3.125 r/hr Page 6-63

From page 6-61

6-62

That's not a very good guess. When talking about 4 half-value layers reducing a radiation intensity of 50 r/hr, the answer has to be lower than 25 r/hr. Let's go through it step by step.

1 H.V.L. reduces 50 r/hr to 25 r/hr

2 H.V.L. reduce 25 r/hr to 12.5 r/hr

3 H.V.L. reduce 12.5 r/hr to 6.25 r/hr

4 H.V.L. reduce 6.25 r/hr to 3.125 r/hr

So, 4 H.V.L. reduce 50 r/hr to:

3.125 r/hr Page 6-63

Sure enough. Four half-value layers of lead will reduce a Cs-137 intensity of 50 r/hr to 3.125 r/hr.

Before we leave the subject, here's another point. The effect of radiation scattering must be considered in applying shielding. Half-value layer calculations, such as we have done on the preceding pages, will provide walls that are adequate for protection of personnel in the next room from X- or gamma radiation traveling directly from the radiation source to them.

However, if the ceiling is thin and inadequately shielded, the radiation could pass through the ceiling, scatter off the air above, and produce an increased radiation intensity in adjacent rooms. To prevent this situation, consider all sides, including the top and bottom of a radiation source for shielding and always verify the radiation intensity in surrounding areas with a survey meter.

We have now seen how the three protective measures - TIME, DISTANCE, and SHIELDING - provide radiation safety. All three have a drastic effect on radiation intensity. Individually or in combination with each other they will keep radiation doses to an acceptable level. But, like any other tools, they are only as effective as the person who uses them. Use them properly and you should never exceed your radiation dose limits.

Turn to the next page for a review of this chapter.

From page 6-63.

1. Standard dose rates for the various isotopes are expressed in _____ at a distance of _____ foot.

7. 25

3. The mathematical law that is applied to the relationship of distance to varying radiation intensity is the _____ law.

14. D_1, D_2

15. At 3 feet from a radiation source, radiation intensity is 200 r/hr. You want to know the intensity at 8 feet from the source. Substitute the values in the formula and you have _____ = _____.

21. More

22. List concrete, lead, and iron in order of their ability to shield against radiation. 1. _____ 2. _____ 3. _____

1. r/hr/curie, one

2. At a distance of 1 foot from a 10 curie Ir-192 source, the radiation intensity is 59 r/hr. The standard dose rate at 1 foot for Ir-192 is _____.

8. inverse square

9. The inverse square law states that radiation intensity varies _____ as the _____ of the _____ from the source.

$$15. \frac{200r}{I_2} = \frac{8^2}{3^2}$$

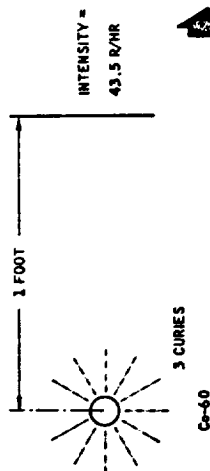
16. Now solve the problem. Intensity at 8 feet is _____.

22. 1. lead, 2. iron,
3. concrete

23. The two most common shielding materials are _____ and _____.

2. 5.9 r/hr/curie

3. What is the dose rate of 1 curie of Co-60 at one foot?



9. inversely, square, distance

10. If you are standing a certain distance from a radiation source, then move twice as far from the source, you will receive only _____ the amount of radiation.

16. 28.1 r/hr

17. The dose rate of Co-60 is 14.5 r/hr/curie at one foot. When using a 5 curie source of Co-60 intensity at 15 feet from the source is _____.

23. lead, concrete

24. The thickness of a material that reduces radiation passing through that material to one-half the original intensity is called a _____.

3. 14.5 r/hr	
4. Co-60 always has a _____ of 14.5 r/hr/curie at _____ foot.	
10. $1/4$	
11. The law by which this is expressed (inverse square law) states that radiation intensity varies _____.	
17. .32 r/hr.	
18. At 5 feet from an isotope, radiation intensity is 80 mr/hr. The intensity at 1 foot would be _____.	
24. half-value layer	
25. The _____ is a thickness of _____ a material that reduces radiation to one-tenth the original intensity.	

4. dose rate, one	
5. The three basic means of providing personnel protection are _____, _____, and _____.	
11. Inversely as the square of the distance from the source.	
12. When distance from a source increases, radiation exposure _____.	
18. 2000 mr/hr (or 2 r/hr)	
19. Radiation intensity at 2 feet is 675 r/hr. At what distance would the intensity be reduced to 3 r/hr. _____.	
25. tenth-value layer	
26. Radiation intensity at a certain point is 12 r/hr. How many H. V. L. are required to reduce the intensity to 1 r/hr? _____.	

5. time, distance, shielding

6. The longer you remain in a radiation area the _____ (more, less) exposure you receive.

12. decreases

13. The inverse square law formula is: _____.

30 feet

20. In addition to time and distance, _____ also provides personnel protection.

26-4 H.V.L.

_____ value layer of lead for Co-60 is .49 inch. At a certain distance from a _____, radiation intensity is 450 mr/hr. What is the thickness of lead _____ to reduce intensity to below 30 mr/hr? _____.

6. more

7. If you receive 5 mr of radiation in 1 minute, you would receive _____ mr in 5 minutes at the same distance from the same source.

$$13. \frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

14. In the formula, I_1 is the intensity at distance _____ and I_2 is the intensity at distance _____.

20. shielding

21. _____ (More, Less) dense materials provide the best shielding from ionizing radiation.

27. 1.96 inches

This ends review of Chapter 6. Turn to page 7-1.

CHAPTER 7 - RADIATION SAFETY REGULATIONS

7-1

The use of radioisotopes in industry must be carefully controlled because of the potential danger to humans. We have said before that the primary controlling agency is the Atomic Energy Commission (AEC). The regulations established by this agency are designed to protect radiation workers and the general public.

The AEC regulations governing radiography are contained in Title 10 of the "Code of Federal Regulations." Certain parts apply to safety in radiography. They are:

- Part 20 - "Standards for Protection Against Radiation"
- Part 30 - "Licensing of Byproduct Material"
- Part 31 - "Radiation Safety Requirements for Radiographic Operations."

There are many other useful documents available (such as the "AEC Licensing Guide - Industrial Radiography"). However, the above three parts of the federal code establish the framework for all radiographic safety requirements. Anyone working in radiography should be thoroughly familiar with Parts 20, 30, and 31.

Turn to the next page.

From page 7-1

7-2

In order to establish control over the use of isotopes, a licensing arrangement is used. Any organization that wants to use isotopes must be granted a license to do so. Before such a license is granted, the prospective licensee must prove that he has satisfied all the safety requirements of the AEC regulations. The following list will familiarize you with some of the requirements an organization must satisfy to receive a license to use radioactive isotopes. All items on the list must be submitted by the licensee for approval of the controlling agency.

- Description of radiography facilities.
- Detailed data on survey instruments including make, model number, sensitivity range, calibration information, etc.
- Detailed data on film badges and pocket dosimeters.
- Complete operating and emergency procedures including step-by-step details on the use of all equipment and facilities.
- Training program for all radiographic personnel covering the safety requirements of the regulations.
- Organization and management of the radiography program.

The above listed items are only a sampling but should give you a good idea of the AEC requirements. And remember, the licensee must be able to prove that he has met all the requirements.

Turn to the next page.

From page 7-3

7-3

There are other agencies besides the AEC that are involved in the control of radioactive materials. The AEC is allowed to enter into agreements with any state for that state to assume some of the AEC's regulatory authority for control of radioisotopes. Once a state is approved as an "Agreement State," it issues and controls the licenses for radiography operations. Such states must have regulations or laws that are compatible with AEC requirements.

Once a state has been licensed as an agreement state, do you think the state could revise the dose limits to a higher value?

Yes Page 7-4

No Page 7-5

From page 7-3

7-4

Nope. An agreement state is not allowed to raise the dose limits.

An agreement state's regulations are subject to approval of the AEC. This means that the limits of the agreement state must be at least as strict as those of the AEC.

In effect, an agreement state simply assumes the responsibility of enforcing the AEC requirements.

Turn to page 7-5.

Correct. An agreement state could not raise the dose limits established by the AEC. The state is, in effect, enforcing the federal regulations.

There are other federal agencies that have important responsibilities in the control of radioactive materials. Some of these agencies and their responsibilities are:

- Interstate Commerce Commission (ICC). The ICC regulates all transportation of radioactive materials in interstate commerce by rail, water, or public highway (except in the U. S. mail).
- Civil Aeronautics Board (CAB). The CAB has authority over transportation of radioactive materials by air.
- U. S. Postal Service. The Postal Service has regulatory authority over radioactive materials carried in the mails.
- U. S. Coast Guard. Handling and storage of radioactive material aboard ships are the responsibility of the Coast Guard.

Which of the following agencies can issue a license to use radioisotopes in radiography?

- AEC, any state, ICC Page 7-6
- AEC, agreement states Page 7-7

Wrong on two counts. The AEC can issue licenses to use radioisotopes in radiography. But neither any state nor the ICC can issue licenses.

The AEC is the primary controlling agency for licensing organizations to use isotopes. They are empowered to enter into agreements with states which allow the states to control the licensing function. However, a state must meet all the AEC requirements before they are allowed such authority. So just "any" state cannot grant licenses.

The function of the ICC is to control transportation of radioactive material. They have no control over the issuance of licenses for radiography.

From this we can see that the agencies which can issue a license for radiography are . . .

- . . . AEC, agreement states Page 7-7

Exactly. The AEC and agreement states are the ones authorized to issue licenses for radiography operations.

We have already discussed some of the AEC safety requirements. To mention a few, we covered the keeping of radiation exposure records, exposure limits, and permissible accumulated dose concept.

There are many other details covered in Parts 20, 30, and 31 of Title 10 in the "Code of Federal Regulations" that the competent radiographer must be familiar with. The same applies to the handling and shipping requirements of the other agencies - states, ICC, CAB, Postal Service, and Coast Guard.

It is impractical to cover all the details contained in the state and federal regulations in this handbook. Many of the detailed requirements are items to which you will need to refer on rare occasions. Others you will need almost daily. The important thing is that you be aware of published safety requirements and use them when you need detailed information.

But remember, all the rules, procedures, and training you can obtain will not assure you of safety in radiography operations. It is your own personal ability to apply the rules along with a liberal amount of common sense that will make your radiographic work safe.

Now turn the book around and flip to page T-1 at the end of the book for a self-test of the material covered in this book.

RADIOGRAPHIC TESTING - VOLUME II - RADIATION SAFETY

Self-Test

1. Gamma and X-radiation damage human body tissue by a process known as _____.
2. When a body tissue cell is damaged by radiation,
 - a) The cell may lose its ability to reproduce.
 - b) The cell may die.
 - c) Damage is caused by knocking an electron out of the orbit of its parent atom.
 - d) All of the above.
3. The basic difference between X-rays and gamma rays is
 - a) Their RBE.
 - b) Their origin.
 - c) Their ability to damage cells of human tissue.
 - d) That gamma rays are electromagnetic radiation.
4. Radiation hazard to humans exists from
 - a) Natural radiation.
 - b) Primary and scattered radiation.
 - c) Primary beams only.
 - d) All types of radiation except electromagnetic radiation.
5. Materials exposed to gamma rays and X-rays become radioactive and dangerous to handle.

True () False ()
6. A person who becomes contaminated with radioactive material can spread contamination to other persons.

True () False ()
7. The primary hazard in radiography comes from
 - a) Internal radiation.
 - b) Gamma rays and alpha particles
 - c) Beta particles.
 - d) External radiation.

8. _____ radiation hazard exists when radioactive materials get inside the body.
True () False ()
9. An X-ray machine presents an internal radiation hazard.
True () False ()
10. The most penetrating radiation from radioisotopes is
a) Beta particles. c) Gamma rays.
b) Alpha particles. d) X-rays.
11. Radioactive (or physical) half-life is
a) The time it takes one-half of the atoms of a radioisotope to disintegrate.
b) The time it takes one-half of a radioactive material to be passed from the body as waste material.
c) The time needed to rid the body of one-half of a radioactive material by a combination of biological elimination and radioactive decay.
12. Biological half-life is
a) The time it takes one-half of the atoms of a radioisotope to disintegrate.
b) The time it takes one-half of a radioactive material to be passed from the body as waste material.
c) The time needed to rid the body of one-half of a radioactive material by a combination of biological elimination and radioactive decay.
13. Effective half-life is
a) The time it takes one-half of the atoms of a radioisotope to disintegrate.
b) The time it takes one-half of a radioactive material to be passed from the body as waste material.
c) The time needed to rid the body of one-half of a radioactive material by a combination of biological elimination and radioactive decay.
14. The basic unit of measure used to express gamma or X-radiation exposure is the
a) rem c) roentgen
b) rad d) RBE
15. The abbreviation "r" stands for _____.
16. The abbreviation "mr" stands for _____.
17. The term "rad" stands for _____.
18. The term "rem" stands for _____.

ESRO 14 (7-62)

19. The term "RBE" stands for _____.
20. The roentgen is a measure of
a) Alpha radiation. c) Radiation damage to human cells.
b) X-rays and gamma rays. d) All of the above.
21. The unit which is a measure of absorbed dose in tissue is the
a) rem c) roentgen
b) rad d) RBE
22. An exposure of one roentgen of gamma radiation equals an absorbed dose of one rad.
True () False ()
23. The unit that compares the biological effectiveness of the different types of radiation is the
a) rem c) roentgen
b) rad d) RBE
24. The unit that expresses the biological dose produced in humans by any type of radiation is the
a) rem c) roentgen
b) rad d) RBE
25. An exposure of 5r of gamma or X-radiation equals _____ rem.
26. The time rate at which a radiation dose is received is called _____.
27. The whole-body radiation dose must normally be limited to a dose of
a) 1 1/4 rems per calendar quarter. c) 7 1/2 rems per calendar quarter.
b) 18 3/4 rems per calendar quarter. d) 5 rems per calendar quarter.
28. A given radiation dose will cause less damage if it is received over a very short period of time than if it is received over a long period of time.
True () False ()
29. The most serious radiation exposure is to the
a) Whole body. c) Skin.
b) Feet and ankles. d) Hands and forearms.

30. A person who is 10 years old would be subject to greater radiation damage from a given exposure than a person age 27.

True () False ()

31. A person must be _____ years old to be allowed to work in a radiation area.

32. There are five variables which influence the effect that radiation doses have on individuals. List three of these variables.

a) _____
b) _____
c) _____

33. Permissible accumulated dose is

- a) The occupational dose received by a person in any calendar quarter.
b) The occupational dose a person could have been permitted in relation to his current age.
c) The radiation dose recorded on his records for any reporting period.
d) The total radiation dose a person has received during his lifetime.

34. The formula for finding permissible accumulated dose is

- a) $12(N-18)$ c) $5(N-18)$
b) $18(5+N)$ d) $12(N+18)$

35. The permissible accumulated dose for a person who is 35 years old is _____.

36. If a person does not exceed his permissible accumulated dose, he is allowed to receive a whole-body dose of _____.

- a) 5 rems per year. c) 12 rems per year.
b) $18 \frac{3}{4}$ rems per year. d) Any balance that he has in his radiation bank account.

37. For each year a person is past age 18, how many rems are deposited in his radiation bank account for whole-body exposure?

- a) $18 \frac{3}{4}$ rems c) $1 \frac{1}{4}$ rems
b) 12 rems d) 5 rems

38. Some body cells are more radiosensitive than others.

True () False ()

39. The earliest indications of radiation damage may be detected in the

- a) Nerve cells. c) Bone cells.
b) Skin cells. d) Blood cells.

40. The physical effects of radiation on the body of an individual receiving the radiation are called

- a) Somatic effects. c) Genetic effects.
b) Latent effects. d) Radiosensitive effects.

41. The radiation effects which can be passed on to the offspring or to a later generation of a person receiving radiation are called

- a) Future effects. c) Somatic effects.
b) Genetic effects. d) Radiosensitive effects.

42. It is possible to receive a dose considerably above the regulatory limits without showing detectable radiation effects.

True () False ()

43. In relation to radiation effects, MLD stands for _____.

44. The MLD for humans is the radiation dose

- a) That causes the first death.
b) That causes slight, temporary blood changes.
c) That is considered lethal to all persons exposed.
d) That causes 50% of those exposed to die.

45. The MLD for humans is _____ rems (fill in from below) whole body exposure within a 24 hour period.

- a) 250 c) 750
b) 500 d) 1,000

46. Portable instruments used to monitor radiation areas are called

- a) Film badges. c) Personnel monitoring devices.
b) Survey meters. d) Area meters.

47. Devices attached to the clothing of people working in radiation areas for measurement of radiation are called

- a) Survey instruments. c) Personnel monitoring devices.
b) G-M counters. d) Portable rate meters.

48. Radiation measuring devices operate on the principle of ionization.

True () False ()

49. Two types of personnel monitoring devices are _____ and _____.

50. Two types of survey meters are _____ and _____.

51. Personnel monitoring devices provide cumulative readings of radiation exposure.

True () False ()

52. Survey meters provide

- a) Cumulative readings of radiation exposure.
- b) Radiation exposure rate readings.
- c) Readings which must be checked on a separate reading device.
- d) Only readings of gamma radiation.

53. Pocket dosimeters depend upon a _____ (Fill in from below) for their indication.

- a) G-M tube.
- b) Battery to provide electrical power.
- c) Quartz fiber electroscope.
- d) Theory that like charges attract and unlike charges repel.

54. The normal operating range of a pocket dosimeter is

- a) 0 to 200 mr.
- b) 50 to 500 mr.
- c) 0 to 75 r/hr.
- d) 25 to 250 r.

55. The film badge operates on the principle that _____ (fill in from below) exposes film.

- a) Light.
- b) Heat.
- c) Ionizing radiation.
- d) Alpha particles.

56. Which statement about the film badge is true?

- a) It has the advantage of providing an immediate indication of radiation exposure.
- b) It is easily exposed by alpha particles.
- c) It has the advantage of providing a permanent record.
- d) All of the above.

57. The pocket dosimeter has the advantage of

- a) Being more accurate than the film badge.
- b) Providing a permanent record of radiation exposure.
- c) Providing an immediate indication of radiation exposure.
- d) All of the above.

58. When wearing a pocket dosimeter, there is no need to wear a film badge at the same time.

True () False ()

59. How many electrodes does the ionization chamber survey meter have?

- a) 2
- b) 3
- c) 4
- d) 6

60. When ionizing radiation enters the ion chamber of an ionization chamber survey meter, positive ions flow to the negative electrode(s) and negative ions flow to the positive electrode(s).

True () False ()

61. The Geiger-Mueller counter uses the G-M tube to

- a) Slow down the ion flow to make detection easier.
- b) Provide electrical power for operation of the meter.
- c) To amplify the effects of the radiation entering the tube.
- d) To read extremely high levels of radiation.

62. When reading low levels of radiation, the _____ (G-M counter or ion chamber meter) is more effective.

63. In most radiographic operations, the ionization chamber survey meter is more desirable than the G-M counter.

True () False ()

64. The standard dose rate of a radioisotope is expressed in

- a) Roentgens per hour per curie at any standardized distance not exceeding 75 feet.
- b) Roentgens per hour per curie per foot.
- c) Roentgens per hour per curie at a distance of one foot.
- d) None of the above.

65. The intensity at 1 foot from a 10 curie source of Ir-192 is 59 r/hr. The standard dose rate for one curie at 1 foot for Ir-192 is _____

- a) 590 r/hr/curie.
- b) 5.9 r/hr/curie.
- c) .59 r/hr/curie.
- d) 59 r/hr/curie.

66. The standard dose rate at 1 foot for Co-60 is 14.5 r/hr/curie. What is the intensity at 1 foot for a 7 curie source of Co-60?

- a) 14.5 r/hr
- b) 75 r/hr
- c) 145 r/hr
- d) 101.5 r/hr

67. The three basic means of providing personnel protection from radiation are _____, _____, and _____.

68. A person receives 3 mr/hr at a certain distance from a radiation source. What would be his exposure if he remained at the same distance for 3 hours? _____

69. The inverse square law as applied to radiation protection states that _____

- a) Radiation intensity varies inversely as the square of the time spent near the source.
- b) Radiation intensity varies proportionally with distance from the source.
- c) Radiation intensity varies inversely as the square of the distance from the source.

70. The formula for the inverse square law is _____

$$a) \frac{I_2}{I_1} = \frac{D_1^2}{D_2^2}$$

$$b) \frac{I_1^2}{I_2^2} = \frac{D_2^2}{D_1^2}$$

$$c) \frac{I_1}{I_2} = \frac{D_2}{D_1}$$

$$d) \frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

71. At 2 feet from a radiation source, radiation intensity is 300 r/hr. What is the intensity at 8 feet from the source? _____

72. At 10 feet from an isotope, radiation intensity is 150 mr/hr. The intensity at 1 foot would be _____.

73. Radiation intensity at 6 feet from an isotope is 40 r/hr. At what distance would the intensity be reduced to 10 r/hr? _____

74. Materials used in shielding radiation are most effective when they _____

- a) Have a small number of electrons in their atoms.
- b) Are dense materials.
- c) When thickness of their half-value layer is a high number.
- d) All of the above.

75. List concrete, lead, and steel in order of their effectiveness in providing shielding against radiation. _____

(1) _____ (2) _____ (3) _____

76. The two most commonly used shielding materials are _____ and _____.
77. The thickness of a material which stops one-half the radiation penetrating it is called _____.
78. The thickness of a material which stops nine-tenths of the radiation penetrating it is called _____.
79. Radiation intensity at a certain point is 20 r/hr. How many H. V. L. are required to reduce the intensity to 5 r/hr? _____.
80. The H. V. L. of lead for Co-60 is 0.49 inch. At a certain distance from a Co-60 source, radiation intensity is 600 mr/hr. What thickness of lead is required to reduce intensity to 75 mr/hr? _____.

Turn to the next page for answers to the self-test.

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