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RADIOGRAPHY. VOLUME IV - MAKING A RADIOGRAPH

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Radiography. Vol. IV Making a Radiograph

CR 61215

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INTRODUCTION

The application of radiography in nondestructive testing grows year by year as more and more special procedures and devices are developed. However, there are basic procedures in the science of radiography that do not change. The purpose of this handbook is to provide knowledge of these basic radiographic procedures.

This volume will teach you the basic procedure used in making a radiograph and the effects on the radiograph of all the factors that are involved in producing a radiograph of the desired quality. You will learn to apply the mathematical formulas that are required of the radiographer. You will learn to use the basic charts and graphs that are required. You will learn the procedures to follow in selecting the proper equipment and operating conditions. And, finally, you will learn techniques useful to the radiographer.

This volume is the fourth of a series entitled "Programmed Instruction Handbook - Radiographic Testing" - 5330.14. Prior to reading this volume, the reader should have previously completed the following volumes:

5330.14 (V-I) "Origin and Nature of Radiation"

5330.14 (V-II) "Radiation Safety"

5330.14 (V-III) "Radiographic Equipment"

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.

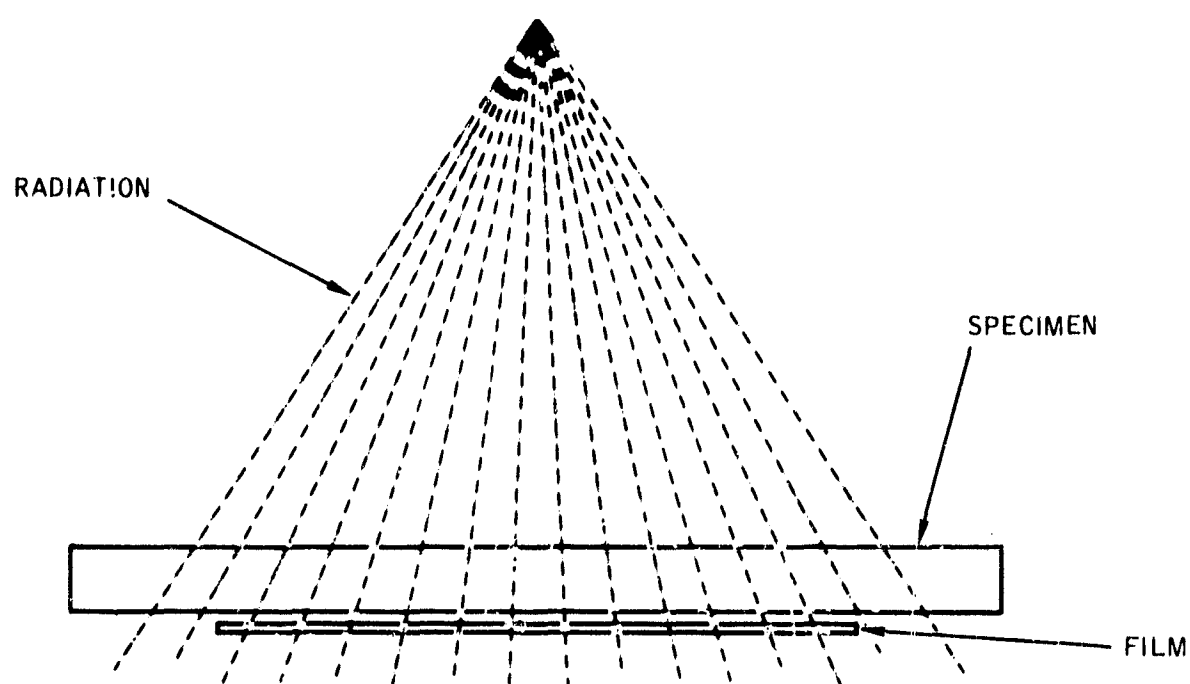
As you will soon see, it's very simple — just follow instructions.

TURN TO THE NEXT PAGE

CHAPTER 1 - RADIOGRAPHIC IMAGE FORMATION

In Volumes I, II and III of the radiographic testing series, we have dealt with background material that is essential to an understanding of radiography. Now we get to the meat of the subject. In this volume you will learn how to make an acceptable radiograph.

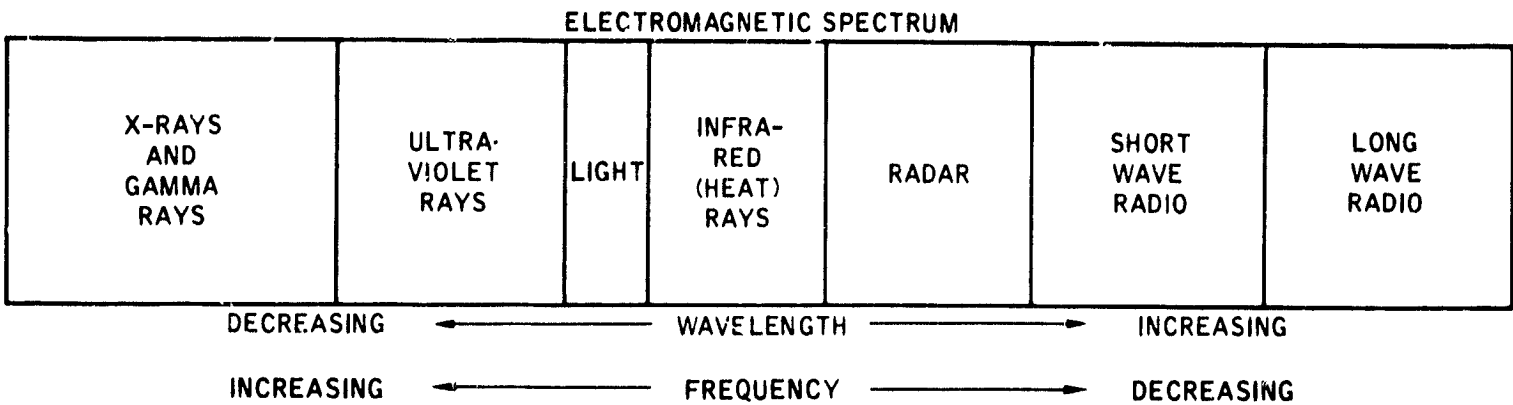
Here is a simplified diagram showing the three basic elements essential to the radiographic process.



In this chapter we are going to discuss these elements, namely: 1) the radiation, 2) the specimen, and 3) the film. These elements will be covered one-at-a-time as we discuss the effect that each has on the radiographic process.

Now turn to page 1-2.

RADIATION - X-rays and gamma rays are of a family of waves that are called electromagnetic waves. This family of electromagnetic waves can be assembled into one group called a spectrum. Here is a chart of the electromagnetic spectrum.

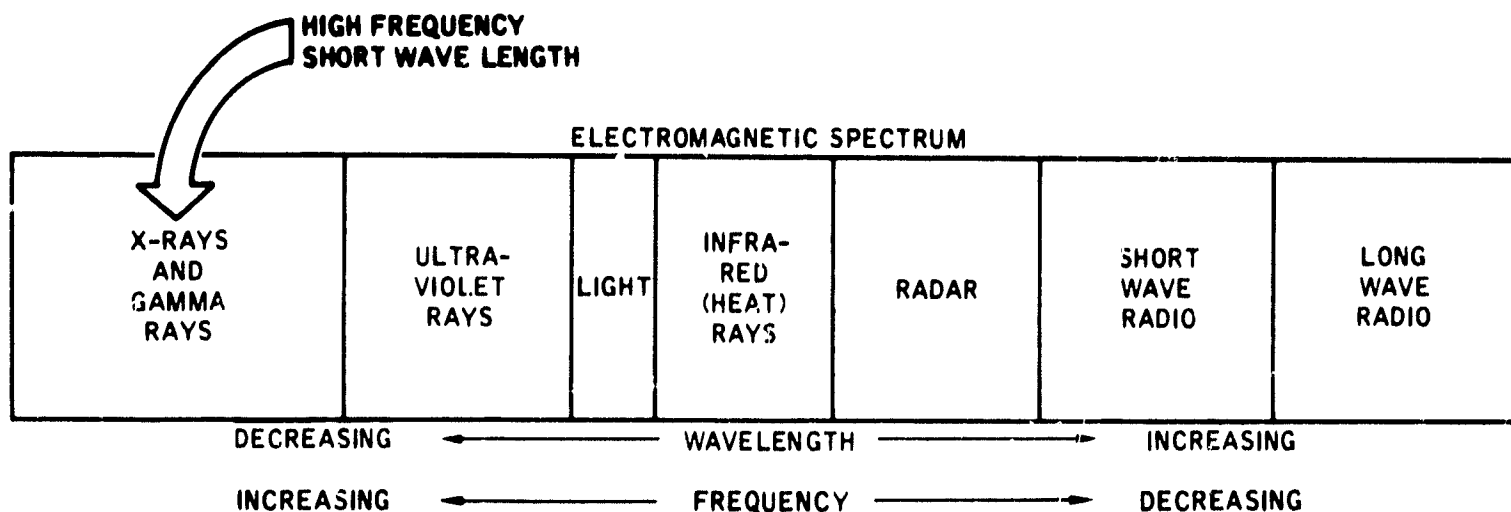


Notice that the spectrum is arranged in order by frequency of the wave. The waves with the lowest frequency are listed at the right end of the chart while the waves with the highest frequency are listed at the left end of the chart.

Looking at the chart would you say that light waves have a higher frequency than X-rays?

- yes Page 1-3
- no Page 1-4

Let's look at that chart again. You seem to have forgotten how it is arranged.



In this chart the electromagnetic wave with the lowest frequency is listed at the right end of the chart. These are the long-wave radio waves. As you move to the left, the frequency of the waves increase so that the waves with the highest frequency are at the left end of the chart. These are the X- and gamma rays. These waves have the highest frequency and the shortest wave length of all the electromagnetic waves.

It is only necessary at this point that you understand the relationship between frequency and wave length. You must understand that X- and gamma rays have a very high frequency and a very short wave length.

Turn to page 1-4.

Good! The electromagnetic spectrum is arranged in order by frequency. X-rays are a higher frequency wave than light waves. X-rays and light rays, since they are both members of the electromagnetic spectrum, have many things in common. As you already know, they both travel at the same speed - 186,000 miles per second. Both also travel in straight lines, neither is affected by magnetic fields, and both will expose photographic film.

We compare X-rays with light in this discussion in order that you will have a visual reference for some of the things that we are going to discuss. X-rays act just like light rays in many way, even though you cannot see X-rays.

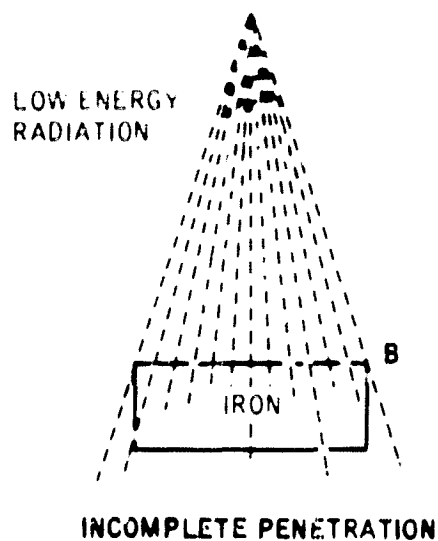
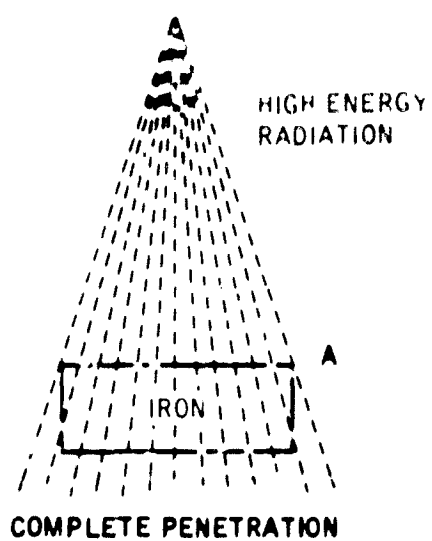
For example - you have seen the visible evidence of the existence of the spectrum in the rainbow that appears after a rain. The raindrops act as prisms to separate the sunlight into its separate frequencies. One edge of the rainbow is red, the other edge is purple. In between, the colors change from one color to another gradually. The different colors are caused by differences in the frequency and wave length of the light waves that make up sunlight. Such a spectrum exists for X- and gamma rays but it is not visible to the unaided eye.

The most important difference to the radiographer between light rays and X-rays is their penetrating ability.

Turn to page 1-5.



Visible light is stopped by opaque substances as you know, but because X-rays have such a high frequency and short wave length they are able to penetrate into, and sometimes through, an opaque object to expose a photographic film placed on the other side of the object. The depth of penetration of the ray depends upon the kind of material in the object and the energy of the ray.

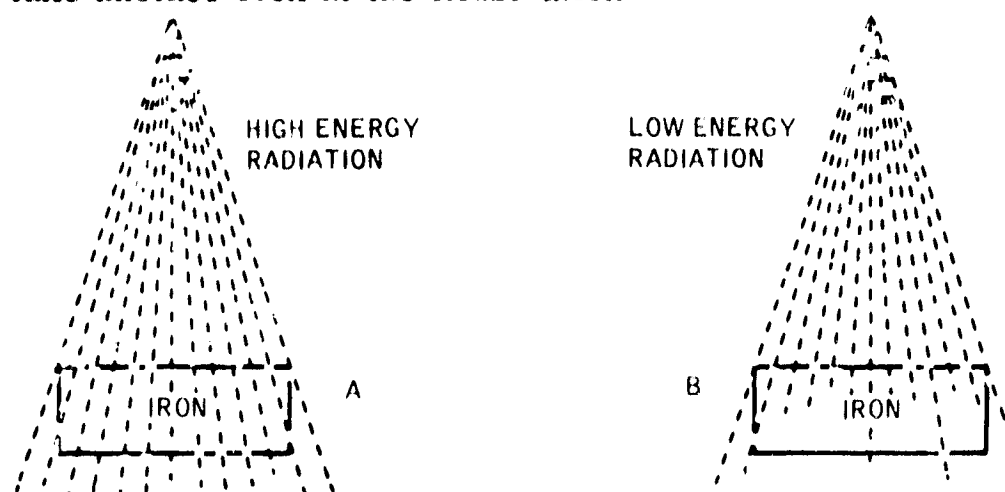


All X-rays penetrate equally well.

True Page 1-6

False Page 1-7

Whoa! Let's take another look at the illustration

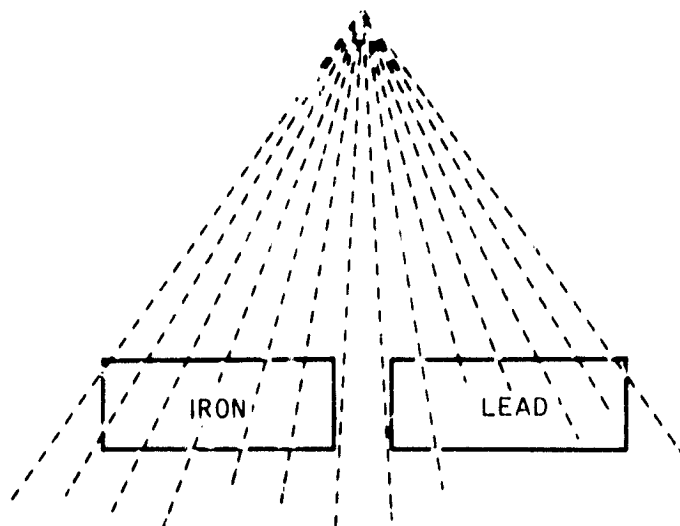


Here we are showing the effect that high energy has on penetration. Example A shows that when X-rays with high energy are used most of the rays pass through the specimen. Example B shows that when X-rays of low energy are used only a few pass through the specimen. This means that the high energy radiation is more penetrating than the low energy radiation.

All X-rays do not penetrate equally well.

Turn to page 1-7.

Good! You got the point that high energy radiation penetrates better than low energy radiation. Now let's change the illustration a little.



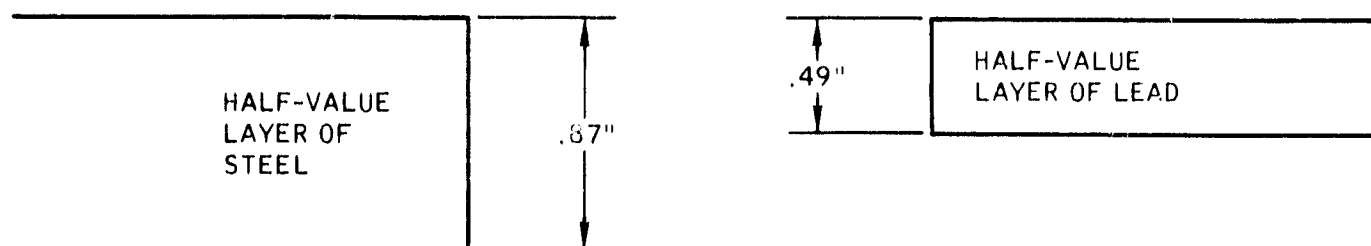
Here we show two different materials under the same X-ray beam.

X-rays penetrate all materials equally well.

True Page 1-8

False Page 1-9

Sorry - X-rays do not penetrate all materials equally well. If you recall from reading Volume II - Radiation Safety - lead sheets are used as shielding because the X-rays have more difficulty penetrating lead. Do you remember the term "half-value layer"? The half-value layer is defined as the thickness of material which will reduce the radiation by half. For example, when using a Cobalt-60 source, the half-value layer for steel is 0.87 inches, while the half-value layer for lead is 0.49 inches.

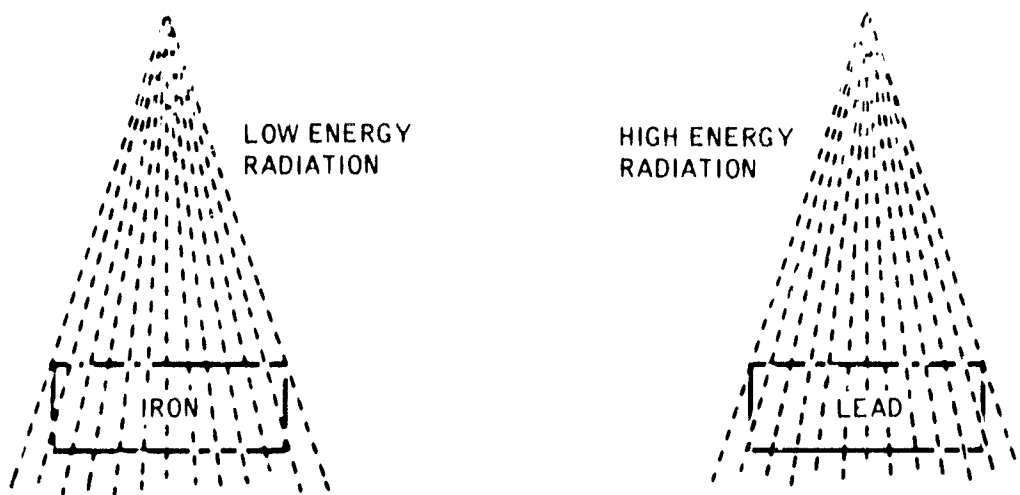


IDENTICAL AMOUNTS OF RADIATION
PASS THROUGH EACH SPECIMEN

This shows us that a given X-ray will penetrate through a greater thickness of steel than lead. So the amount of X-ray penetration depends on the type of material being X-rayed.

Turn to page 1-9

Correct! Notice that we are talking about the amount of rays that actually pass through the material. We have shown that the radiation will penetrate a certain thickness of iron while it will not penetrate the same thickness of lead. Now let's adjust the energy of the radiation.



Here we show low energy radiation penetrating the iron and high energy radiation penetrating the lead.

The high energy radiation penetrates the lead as well as the low energy radiation penetrates the iron.

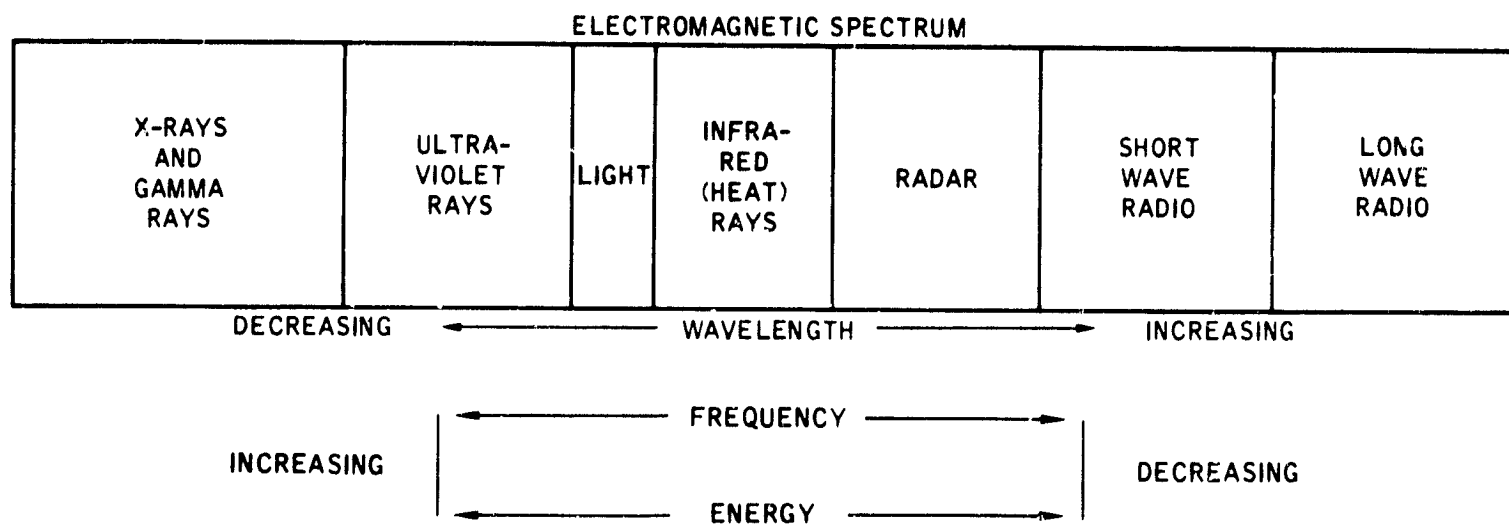
True. Page 1-10

False Page 1-11

Good! The higher energy radiation does penetrate the lead as well as the low energy radiation penetrates the iron. So once again we have shown that the high energy radiation penetrates more regardless of whether we are concerned with different thickness of materials or whether we are concerned with different kinds of materials.

REMEMBER — THE HIGHER THE ENERGY THE GREATER THE PENETRATION.

The next question is - "Where do we get radiation with a higher energy?"



Don't forget the spectrum and how to use it. X-ray energy is dependent on the frequency of the wave - the higher the frequency the higher the energy.

The spectrum tells us that the lower frequency radiation has the highest energy.

True Page 1-12

False Page 1-13

From page 1-9

1-11

Sorry, you've missed the boat. High energy radiation always has greater penetrating power than low energy radiation. And it takes more penetrating power to penetrate the lead than it does to penetrate the iron. But in this case we have chosen a ray that is powerful enough to penetrate the lead so that the penetration through the iron and through the lead are identical.

Turn to page 1-10.

If you are reading this page, you have forgotten some very basic facts that were covered in Volume I. Lower frequency radiation does not have the highest energy.

To increase the energy and penetrating power of a wave, we must increase its frequency. When we increase the frequency of the wave, we decrease the wave length. The shorter wave lengths are more penetrating - have more energy. If you look at the spectrum closely, you will see that it shows the relationship between frequency and energy.

Turn to page 1-13.



You are correct! Lower frequency has lower energy - not higher energy.

We hope you realize that these examples are extremely simplified and are intended only to illustrate a difference in penetration and energy levels of the rays. It is important to you that you keep these basic facts in mind.

The second characteristic of X-rays and gamma rays, in which we are interested, is the characteristic of traveling in a straight line. It is this characteristic that produces the image of a specimen - just as a shadow picture of an object can be produced with a strong light and a screen.

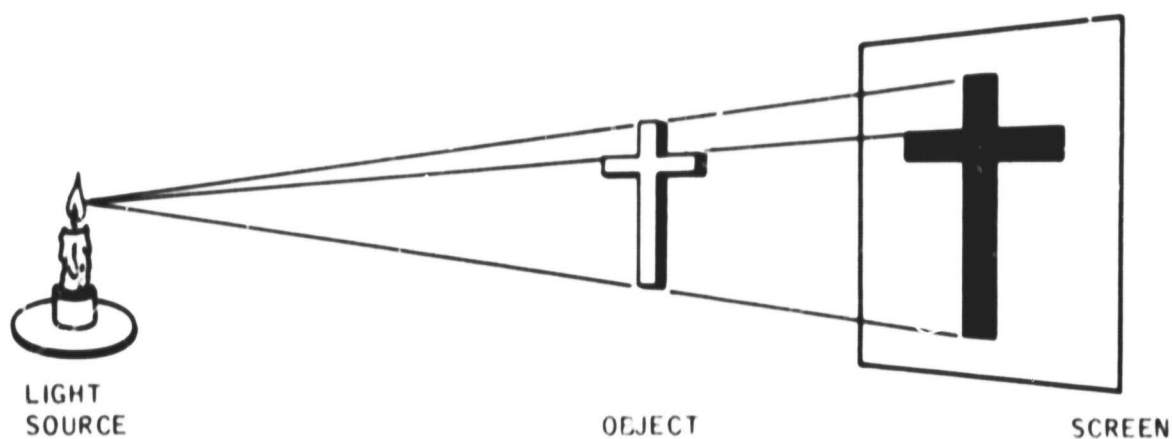
X-rays and gamma rays, like light rays, always travel in straight lines.

False Page 1-14

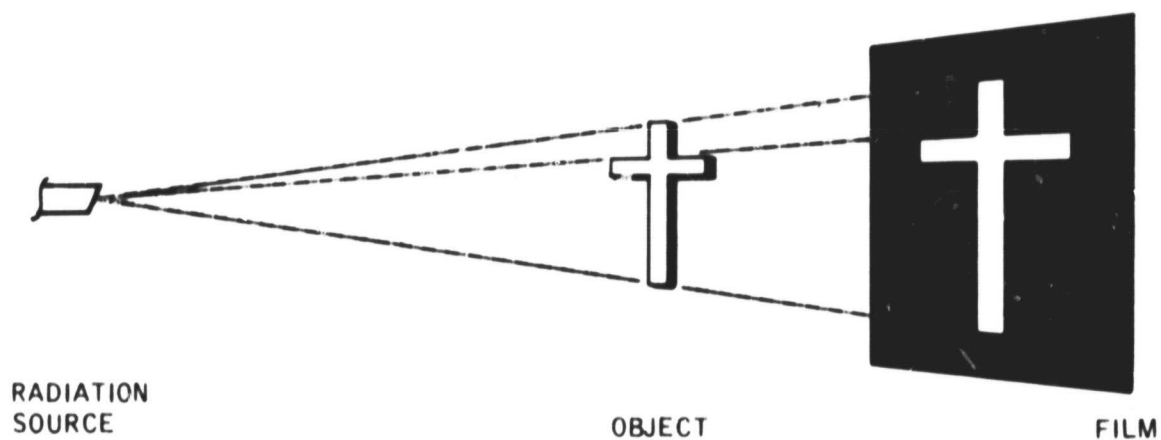
True Page 1-15



You felt that the statement was false - that X-rays and gamma rays did not travel in straight lines like light rays. You are dead wrong. Whenever an object is placed between a strong light and some kind of screen, we get a shadow image of the object on the screen.



Whenever an object is placed between an X-ray source and a film, an image is formed on the film. (The image does not appear until after the film is developed, but nonetheless the image is there even though you cannot see it.)



The fact that the image is reversed (white on black) from the light source image is due to using a film to record the image. We'll get into this a little later.

Since an image is formed, we know that X-rays and gamma rays, like light rays, always travel in straight lines.

Turn to page 1-15.

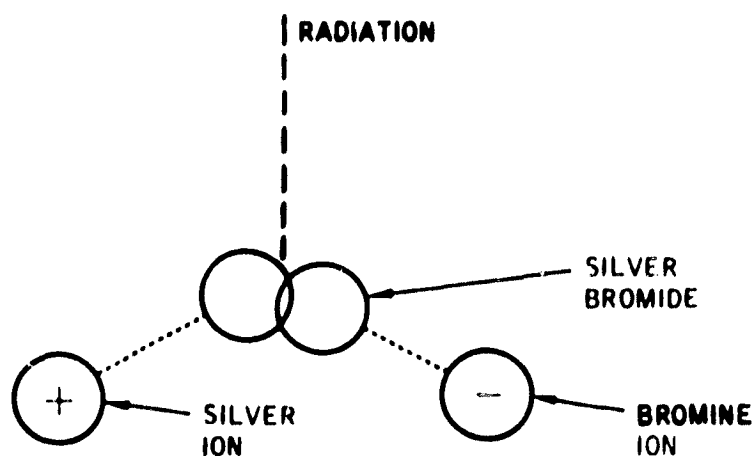
Good! The second characteristic of X-rays and gamma rays that makes the radiograph possible is that they travel in straight lines just like light rays.

Then - to recap a little - the ray penetrates the specimen and travels in a straight line. The third characteristic of X-rays and gamma rays that makes the radiograph possible is the ability of these rays to expose photographic film. Back in Volume I of this series, you learned that this type of radiation has the ability to ionize materials. When the radiation penetrates the film, the film is exposed because of the ability of the rays to ionize the tiny silver bromide grains in the film emulsion. Ionization of the film's emulsion forms a latent image. You will learn more about this latent image in Volume 5.

The ability of the rays to ionize material permits the rays to _____
the film.

penetrate Page 1-16
expose Page 1-17

No, we've confused you. The ability of the ray to ionize the film has nothing to do with permitting the ray to penetrate the film.



Let's take a look at ionization. When the ray passes through the silver bromide layer it breaks the electron bond between the silver and the bromine creating silver ions and bromine ions. The presence of the silver ion in the emulsion is the latent image. Later development removes the bromine ion and adds an electron to the silver leaving metallic silver to darken the film where the ray has passed.

This is the ionizing action going on in the film emulsion that causes the film to be exposed. The emulsion is exposed because the ray causes it to be ionized.

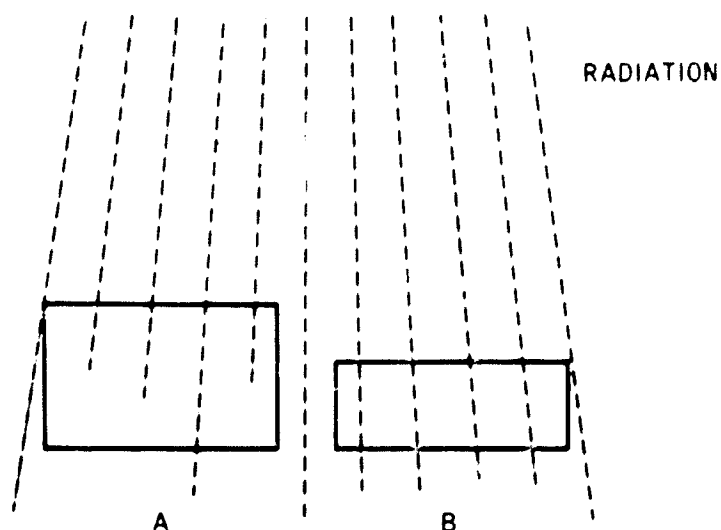
Turn to page 1-17.

Right! The ability of the rays to ionize material permits the rays to expose the film.

So far we have discussed the first element to consider when making a radiograph -- the radiation. Three things about radiation permit us to make a radiograph: 1) the radiation penetrates the specimen (high energy rays are more penetrating than low energy rays); 2) the radiation travels in straight lines; and 3) the radiation exposes the film.

The second element that we must consider in making a radiograph is the specimen itself. In industrial radiography we are very much concerned with producing the best radiographic image possible. To do this we must carefully consider the amount of radiation that is absorbed by the specimen. We must be certain that the specimen is not absorbing so many of the X-rays that too few get through to expose the film emulsion, and conversely we must know that the specimen is not passing too many of the rays and overexposing the film.

"Absorption" is the ability of an element or compound to block or partially block the passage of X-rays through the material. Here we show two specimens made of the same material being exposed to the same ray.



Specimen A being thicker than specimen B has absorbed _____ of the radiation than specimen B.

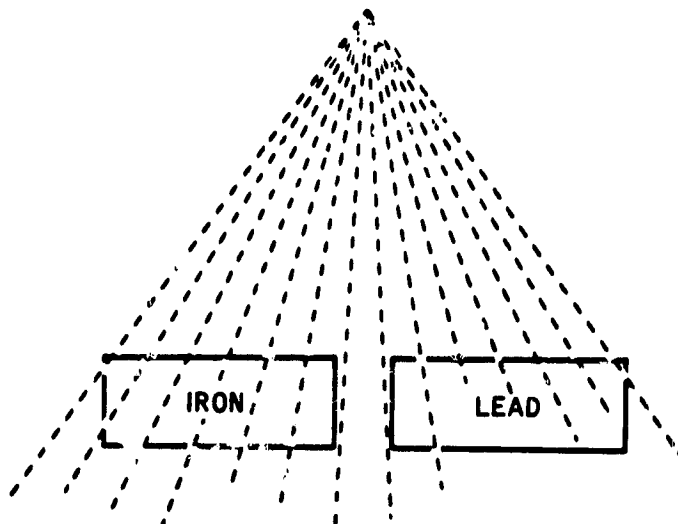
more Page 1-18

less Page 1-19

That's right! Specimen A absorbed more radiation than specimen B.

Absorption by the material and penetration of the ray are inversely related. As the absorption capabilities of the specimen increases, the penetration of the ray decreases. As the penetration ability of the ray increases, the absorption of the ray by the specimen decreases.

Earlier in this chapter we discussed the penetration of the rays through different kinds of materials. Remember this illustration?

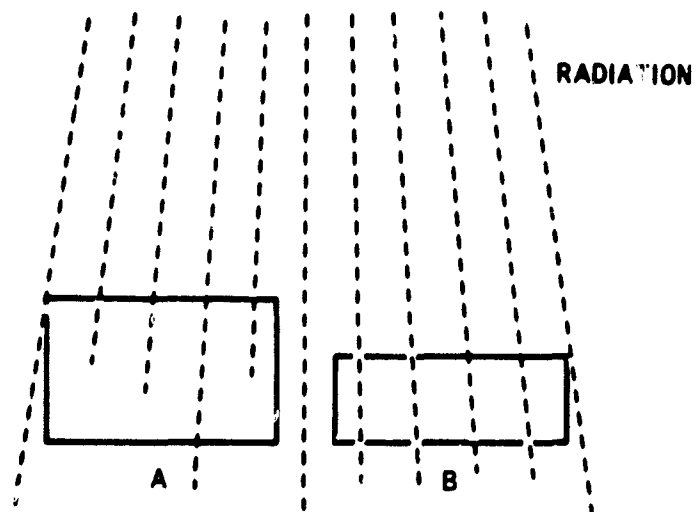


From this illustration we could say that lead has _____ of an absorption capability than iron.

more Page 1-20

less Page 1-21

Sorry. Let's take another look at that illustration.



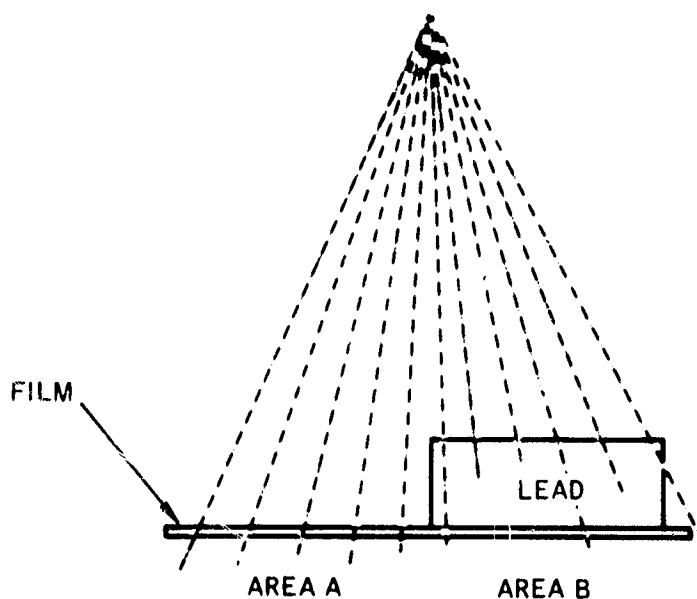
We are trying to show here that the thicker specimen A has absorbed more of the ray than specimen B has. Practically all of the rays that strike specimen B pass through the specimen - practically none are absorbed. But in specimen A some of the rays pass through while others do not. The ones that do not pass through are absorbed by the specimen.

Turn to page 1-18.

Very good. Lead absorbs more rays than iron because it is a denser material than iron. Absorption then depends upon two things - thickness of the material and the density of the material.

To recap then - the second element of the radiograph - the specimen - is capable of absorbing radiation. The amount of absorption depends upon the thickness of the material and the density of the material.

Now we will discuss briefly the third element of radiography - the film.



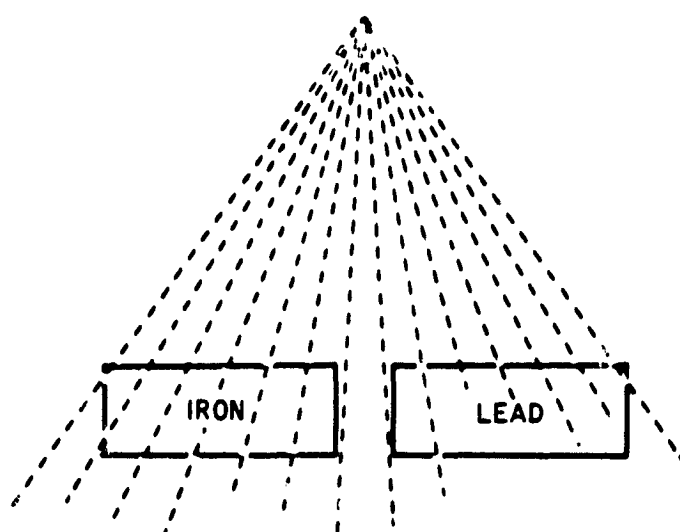
Here we show a simplified diagram of how a radiograph is made. The radiation penetrates the specimen and exposes the film. The formation of the image on the film depends upon the amount of radiation received by different sections of the film. The varying amounts of radiation on different areas of the film causes the film to be exposed by varying amounts depending on the amount of radiation passing through the specimen.

Area A of the film will be _____ than area B.

more exposed Page 1-22

less exposed Page 1-23

Somehow you've got it backwards. Remember, penetration of the ray is just the opposite of absorption by the material. If the ray passes through the material, it is not absorbed by the material. If the ray does not pass through the material, it is absorbed by the material. Now let's look at the illustration again.

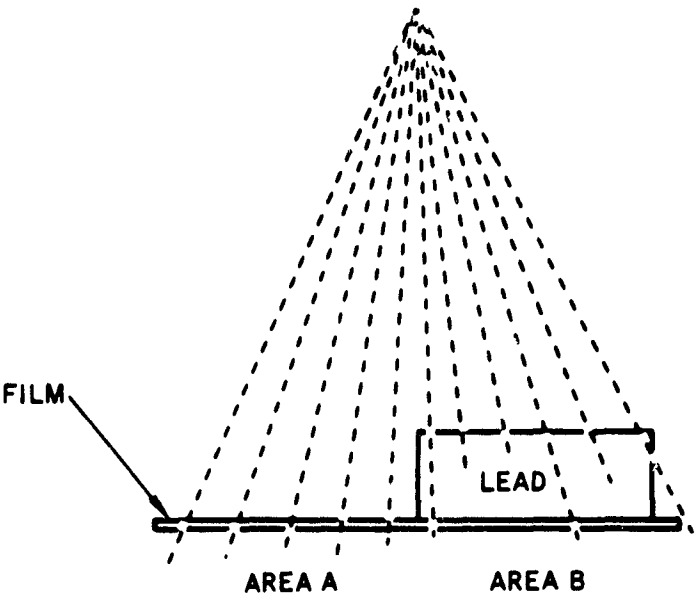


More of the rays pass through the iron than pass through the lead, therefore, the lead has absorbed more rays than the iron. The lead has more of an absorption capability than the iron.

Turn to page 1-20.

Good thinking. Since there is nothing to absorb the rays, area A is fully exposed to the rays. In area B the lead absorbs much of the radiation so the film is not exposed as much.

When the film is developed, the exposed portion turns dark while the unexposed portion will be clear. If the film receives more exposure on one area than another, the area receiving the most exposure becomes darker after development.

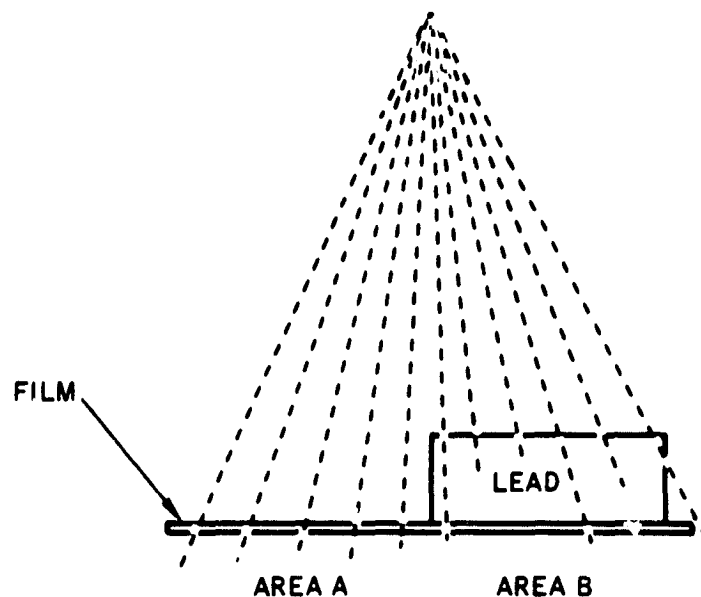


Area A of the film will be _____ than area B after the film is developed.

darker Page 1-24

lighter Page 1-25

Be careful. Since area A is receiving full radiation, it will be heavily exposed.
Since most of the radiation is blocked from area B the film will be lightly exposed.
Look at the figure again.



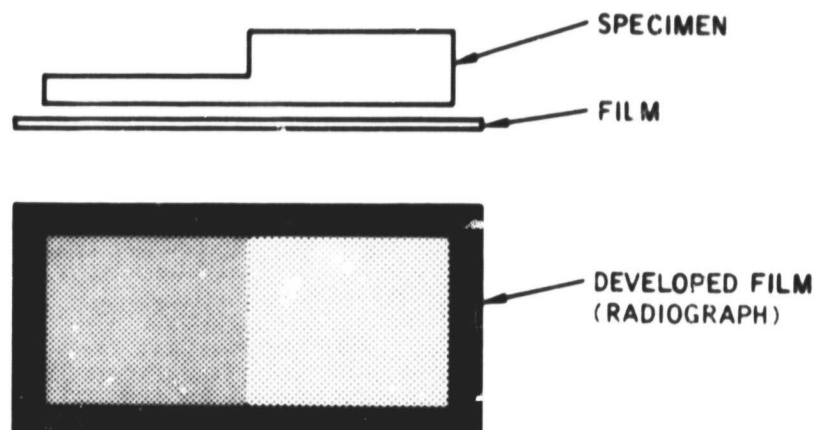
Less radiation at area B of the film - less exposure of the film.

More radiation at area A of the film - more exposure of the film.

Turn to page 1-22.

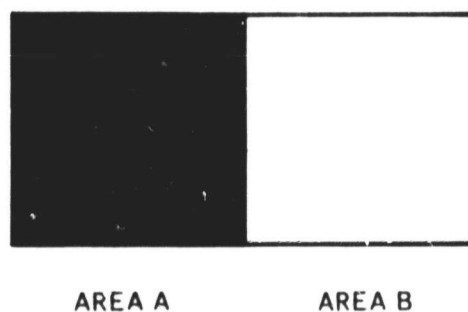
Right! You realize that the area receiving the least rays is the least exposed and therefore lighter.

Now let's look at a radiograph of this specimen.



Note that the area of the film under the thinner section of the specimen appears darker. It is darker because more radiation has penetrated the thinner section exposing the film more.

Now we are ready for another term with which you must become familiar - FILM DENSITY. In radiography the darker portion of the film is said to be more dense and the degree of film darkness is known as the "film density".



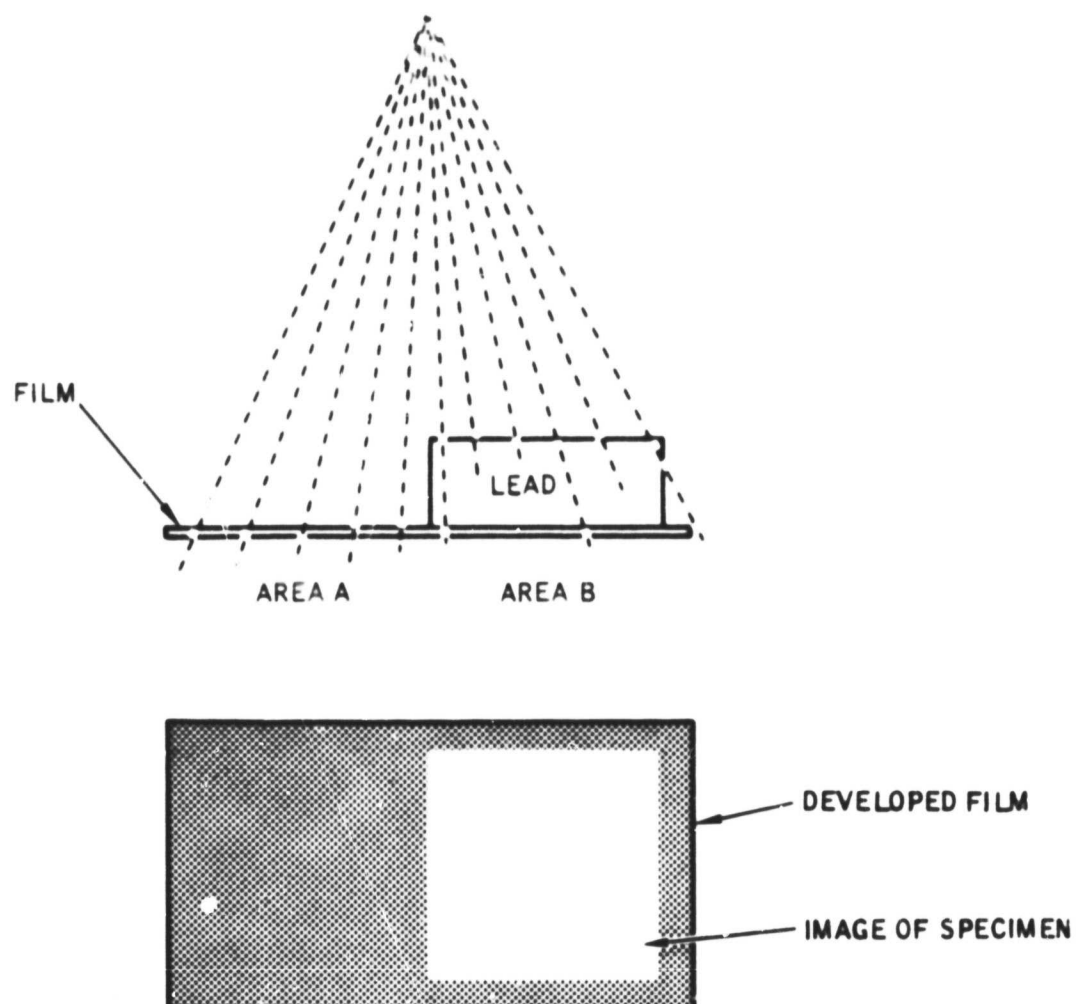
Here we are looking down on a piece of exposed and developed film.

Since area A of the film is darker than area B, area A is said to be _____ than area B.

more dense Page 1-26

less dense Page 1-27

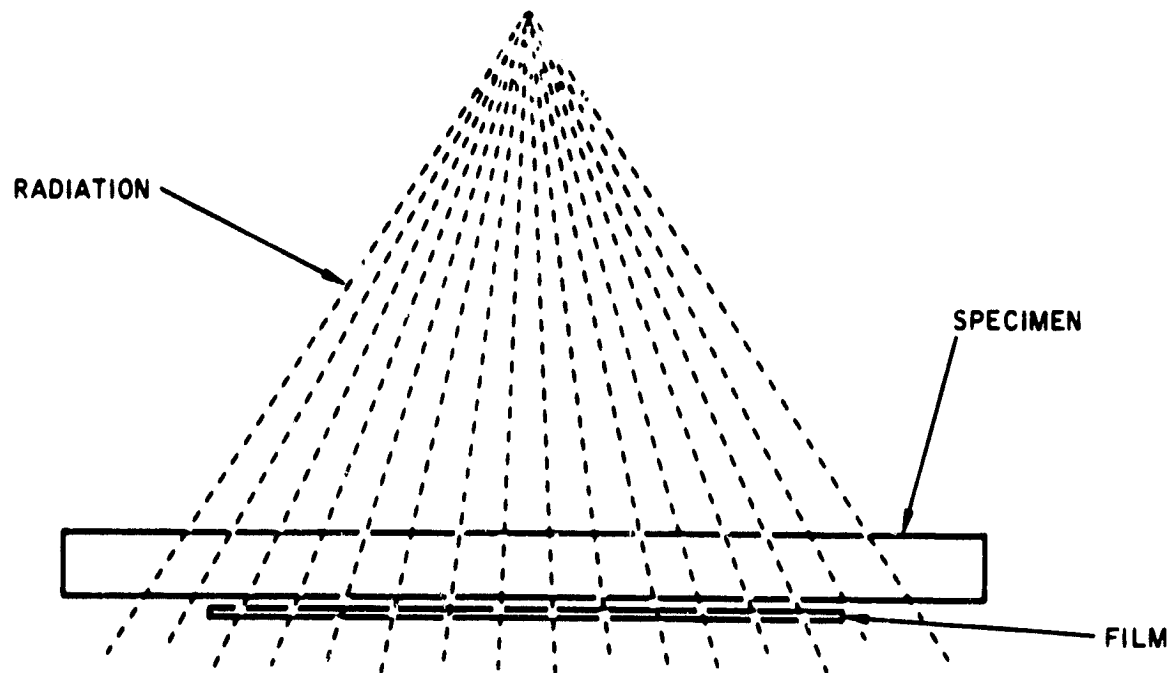
You've got it backwards. Let's look at the illustration again, but this time we have added a view showing what the developed film might look like.



Area A of the film will receive more radiation than area B since much of the radiation is blocked from area B by the lead between the source and the film. Since area A receives more radiation it will be darker than area B when the film is developed. Therefore area A will be darker than area B.

Turn to page 1-24.

Right! The darker the film, the more dense it is. Now let's review a little of what you have learned so far.



- 1) RADIATION - penetrates the specimen (high energy rays penetrate better than low energy rays)
 - travels in straight lines
 - exposes the film
- 2) SPECIMEN - absorbs more or less radiation depending on thickness and density of material
- 3) FILM - is exposed in proportion to amount of radiation reaching film
 - density of developed film increases as exposure increases.

The above is a necessary oversimplification of radiography, but when you completely understand the above factual skeleton, we will hang some more meat on it for you.

Turn to page 1-28.

Wrong! Area A is more dense and area B is less dense.



AREA A

AREA B

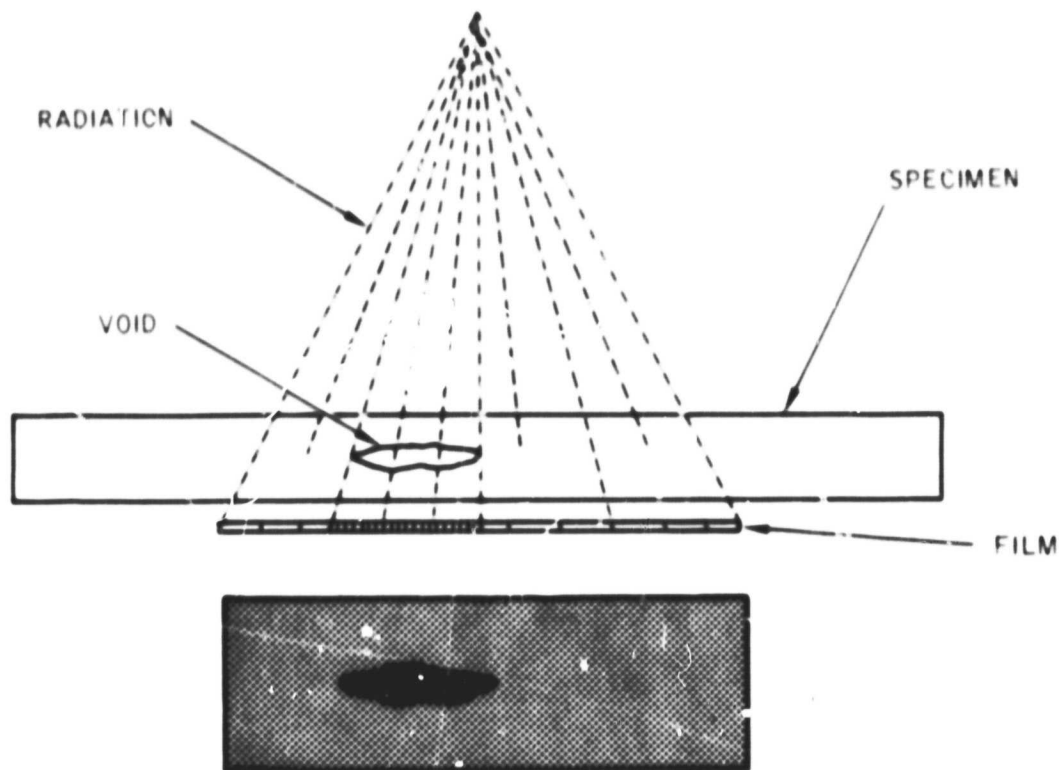
DARKER
MORE DENSE

LIGHTER
LESS DENSE

"Density" is a term you are going to use a lot in your work with radiography. The density, or degree of darkness, of the film is one of the measuring sticks of good radiography.

Turn to page 1-26.

Now that we have discussed the three elements of radiography, let's see how they apply to nondestructive testing.



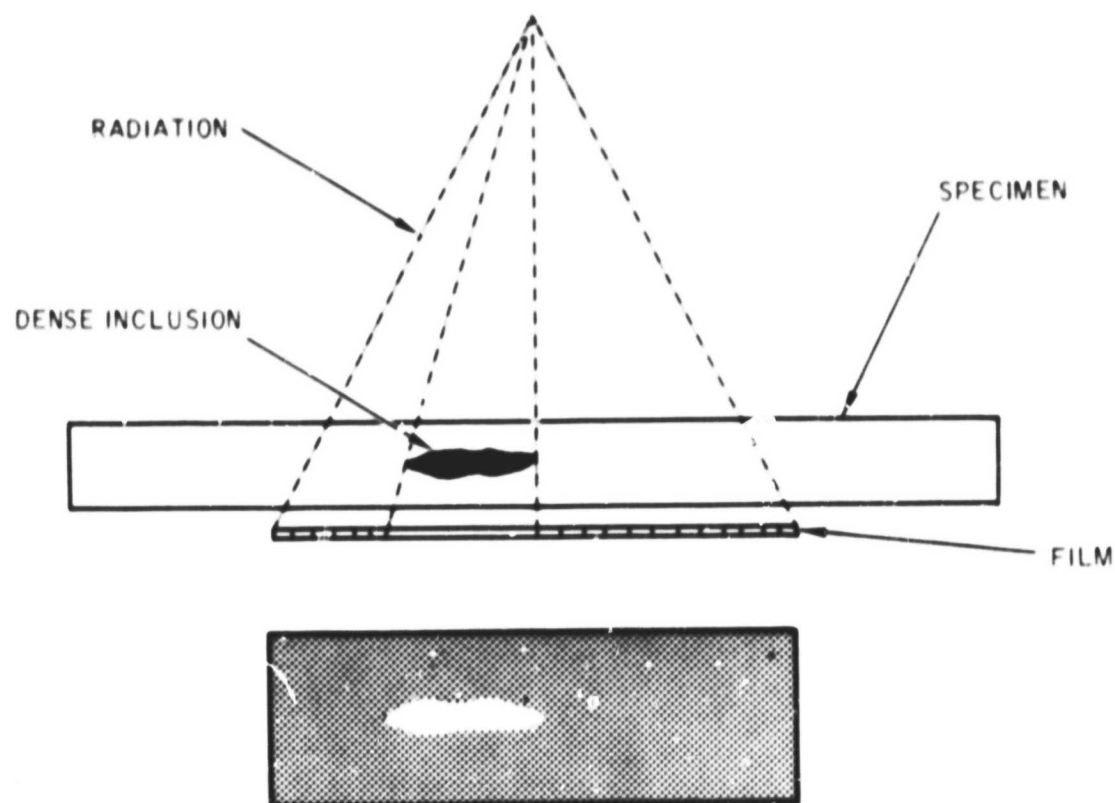
The formation of an image on the film depends upon the amount of radiation received by different sections of the film. The varying amounts of radiation on different areas of the film causes the film to be exposed by varying amounts depending on the amount of radiation passing through the specimen. In short, the radiograph is the photographic record produced by the passage of X-rays or gamma rays through a specimen onto the film. The radiograph becomes an important nondestructive testing tool since a defect such as a void represents a thickness difference in the specimen and will appear as a dark spot on the developed film.

Inclusions more dense than the base material of the specimen will block more of the rays and will therefore appear as _____ spots on the developed film.

dark Page 1-29

light Page 1-30

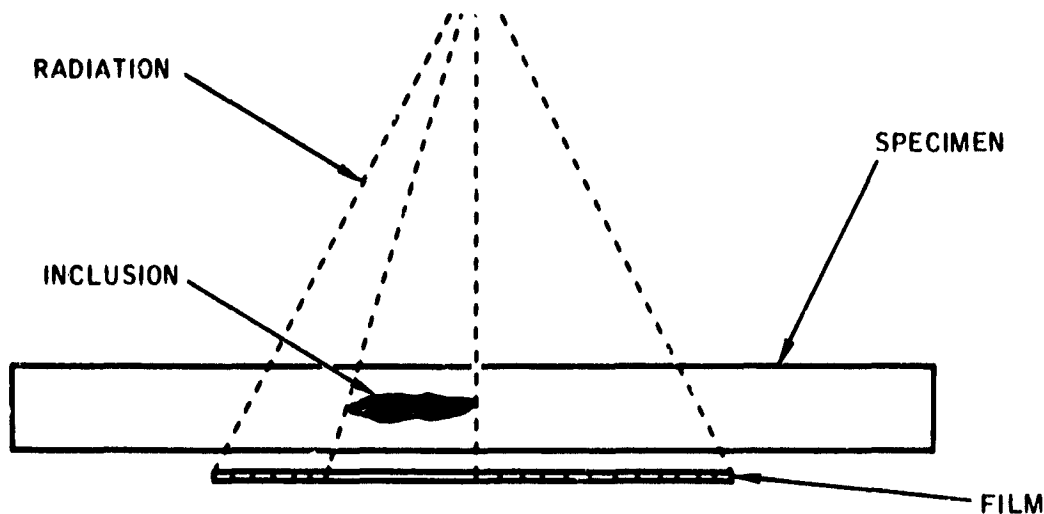
This is a pretty tough question and perhaps we tricked you by asking a question that is reverse to the illustration we showed you. Here is the situation that was covered in the question.



In this case the inclusion is more dense than the specimen material. This means that more of the rays will be blocked by the inclusion. Since more of the radiation is blocked, the film under the inclusion will be exposed less. Less exposure of the film means a light area after the film is developed.

Turn to page 1-30.

Right! Your reasoning was very sound.



Since the inclusion shown above is more dense than the specimen, the film image of the inclusion is lighter. When the inclusion is less dense than the specimen, the image of the inclusion is darker. The formation of the image is a very important part of radiography.

We know that the radiation reaching the film is a function of the penetrating ability of the ray and the absorption ability of the material in the specimen. There will be instances where the amount of radiation that penetrates the specimen will be very small and the energy of the radiation cannot be increased. It is known that when the ray passes through the film only about 1% of its energy is used to expose the film. In order to use more of the available energy of the ray, intensifying screens are used.

Intensifying screens serve the purpose of improving the radiograph by utilizing more of the energy of the ray to secure better exposure of the film in those areas where the ray passes through the specimen.

The intensifying screen intensifies the effect of the ray _____ .
 before it penetrates the specimen Page 1-31
 after it penetrates through the specimen Page 1-32

From page 1-30

1-31

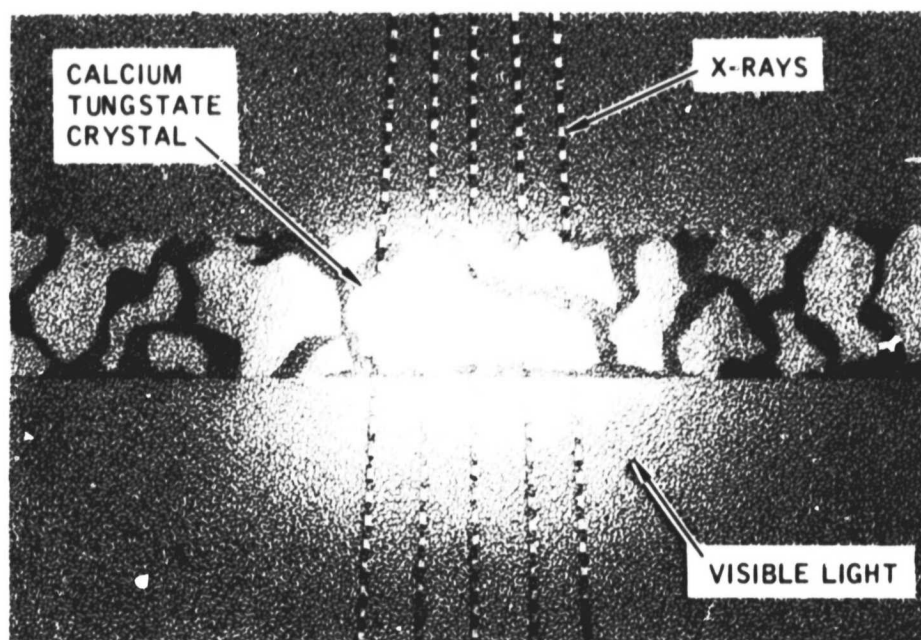
Sorry - we didn't make that point very clear. In using intensifying screens we want only to intensify the effect of those rays that have penetrated through the specimen. We want those rays to have more effect on the film than they ordinarily have.

We want to make absolutely sure that you understand that the intensifying screen does not intensify the ray. It only intensifies the effect of the ray on the film.

Turn to page 1-32.

Good! The intensifying screen intensifies the effect of the ray on the film after it penetrates through the specimen.

There are two types of intensifying screens. The first type we are going to discuss is the fluorescent intensifying screen. Fluorescent screens consist of a thin flexible base coated with a metallic salt that will fluoresce - that is - will glow when energized with X-rays. The light that is emitted by the screen will help expose the photographic film.



When fluorescent intensifying screens are used, the film is exposed by _____
_____.

light rays Page 1-33

both X-rays and light rays Page 1-34

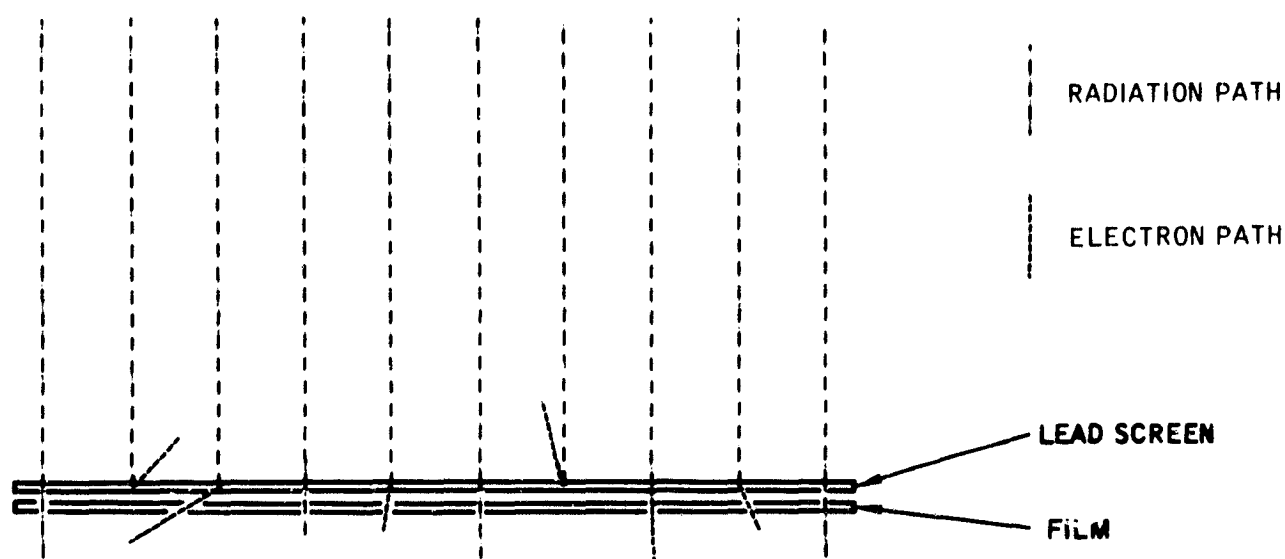
Well, you are almost right. The light rays do help expose the film. In fact, the light rays do most of the exposing. But the X-ray still passes through the film and therefore, still does its job of exposing the film.

When a fluorescent intensifying screen is used, the film is exposed by both X-rays and light rays.

Turn to page 1-34.

Right! Both the X-rays and the light rays do their part in exposing the film. The intensity of light that is emitted by the fluorescent screens depends upon the intensity of the radiation so the screens effectively amplify the effect of the radiation. However, the image obtained through use of fluorescent screens is not as sharp since the light spreads a little through the film.

The second type of intensifying screen used consists of a simple thin sheet of lead. The lead screen acts as an intensifier since X-rays and gamma rays cause electrons to be liberated from the lead. (Remember photoelectric effect and Compton effect from Volume I?) If the lead screen is very close to the film, the electrons expose the film. The effect of the ray is effectively intensified because the electrons have a greater ionizing effect on the film emulsion. Since lead screens also have other functions in radiography, they are covered in a later section.



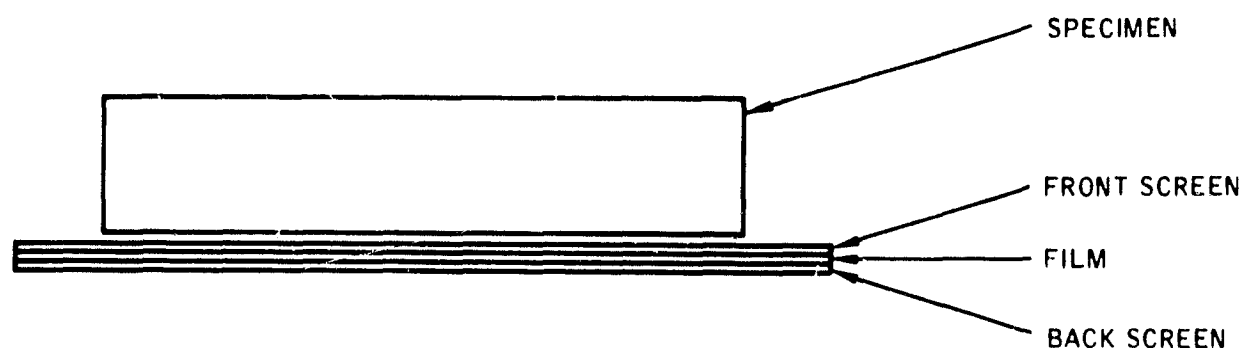
Lead intensifying screens intensify the effect of the ray on the film because of the action of _____,

electrons liberated from the lead screen Page 1-35

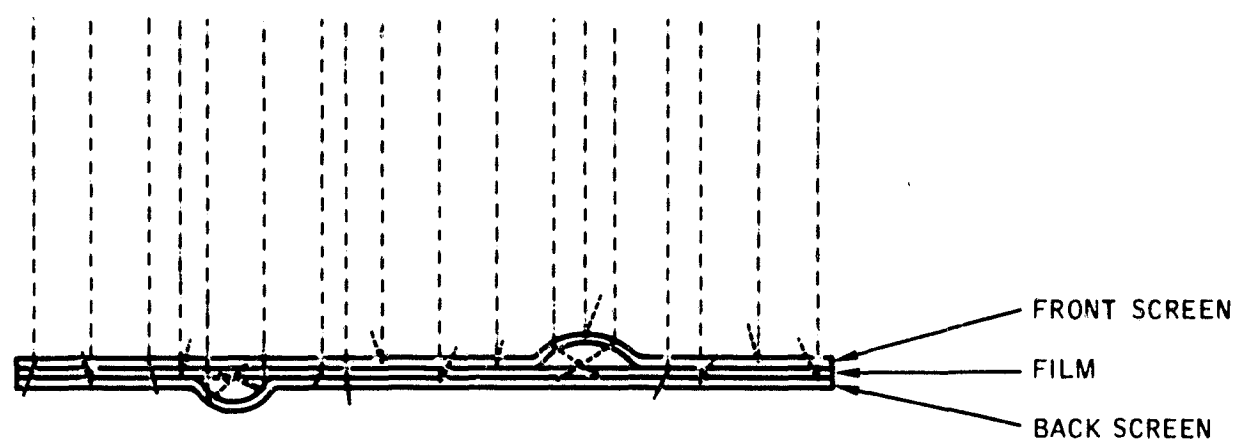
increased radiation from the screen Page 1-36

Very good! The lead intensifying screens intensify the effect of the ray on the film because of the action of the electrons liberated from the screen. The screens do not change the energy of the ray.

Intensifying screens, either fluorescent or lead, are normally placed on both sides of the film. In fluorescent screens the light emitted from the back screen is just as effective as the light emitted from the front screen. In lead screens the back scattered electrons that are emitted from the back screen add appreciably to the formation of the image on the film.



Intensifying screens must be placed in close contact with the film. Any space between the screen and film allows room for the electrons, or light, to spread causing "fuzzy" images.



Turn to page 1-37 for a short review.

By selecting this answer you indicate that you do not fully understand the relationship between the radiation and the screen.

When the radiation passes through the film only about 1% of its energy is used in exposing the film. Without screens we are using very little of the available energy.

When screens are added, they utilize more of the ray's energy in producing light or electrons. They do not increase the radiation.

In turn, the light or electrons have a greater effect on the exposure of the film. Hence, they intensify the effect of the original ray.

Turn to page 1-35.

From page 1-35

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.) Do not 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.



7. penetrates, exposes
(ionizes)

8. The radiation exposes the film by _____ the silver bromide within the film emulsion.

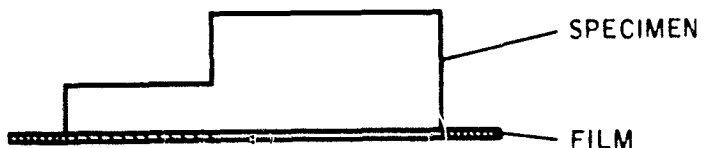


15. electromagnetic

16. The electromagnetic waves that have the highest frequency have the _____ wave length.



23. darker



24. The rays penetrating the thinnest section of the specimen cause the developed film to be _____ dense under the thinner section than under the thicker section.



This is the answer to the blank in Frame number 1.

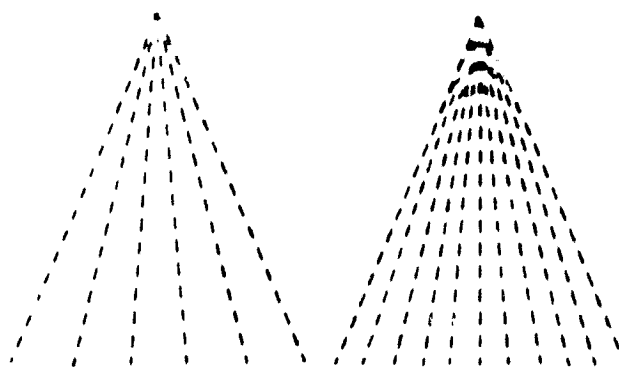
1. four  Frame 2 is next

2. These sections will provide a review of the material you have covered to this point. There will be one or more blanks in each f _____.

Turn to the next page.
Follow the arrow. 

8. ionizing

9. The penetrating power of the radiation depends upon the _____ of the ray

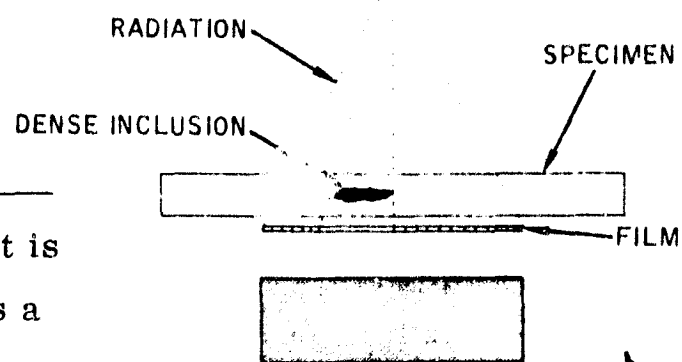


16. shortest

17. The electromagnetic waves that have the shortest wave length have the _____ energy.

24. more

25. A void in the specimen will appear as a _____ spot on the radiograph while an inclusion that is more dense than the specimen will appear as a _____ spot on the radiograph.



2. frame

3. By following the arrows or instructions you will be directed to the section which follows in sequence. Each section presents information and requires the filling in of _____.

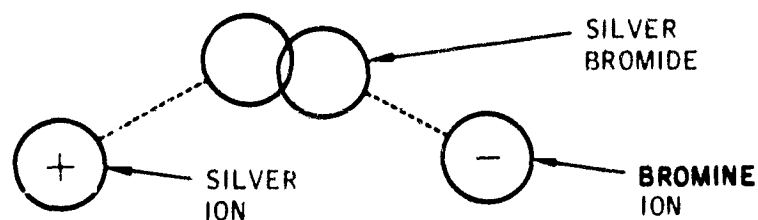


9. energy (wave length)

10. X-rays always travel in a _____ (path).



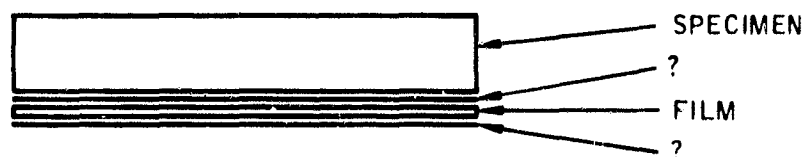
17. most (highest, greatest)



18. When a film is exposed, the silver bromide crystals in the emulsion are _____ by the radiation.



25. dark, light



26. In order to increase the film exposure without increasing the intensity of the radiation we use intensifying _____.

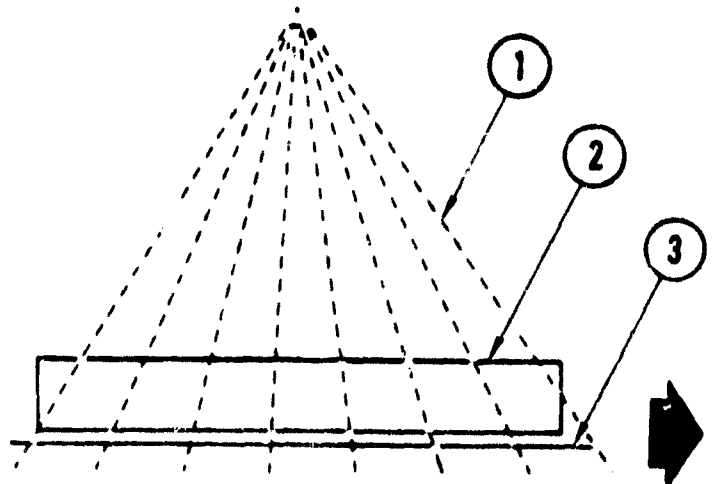


3. blanks (spaces, words)

4. Now for the review. In making a radio-

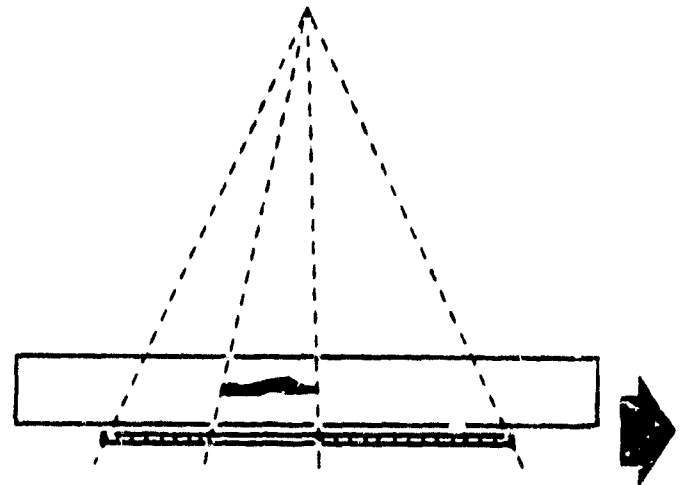
graph we need at least three things:

_____ , and



10. straight line

11. Because radiation, like light, travels
in a straight line we are able to produce
an _____ of the specimen
on the film.



18. ionized

19. When the film is exposed to the rays and then developed, the area of the film
receiving the most _____ is darkest.



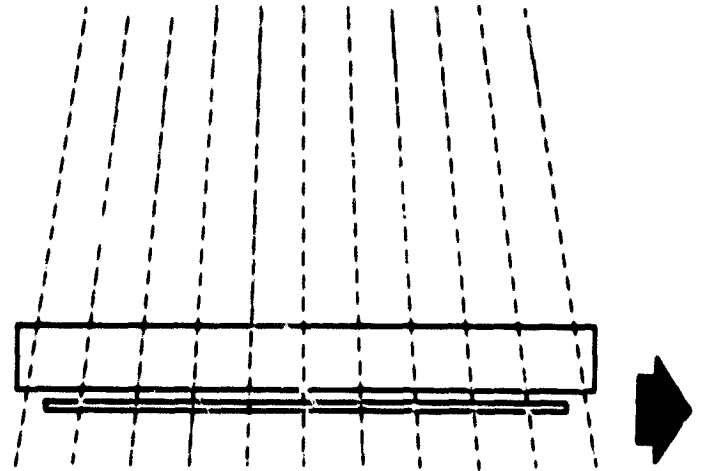
26. screens

27. The fluorescent _____ screen effectively amplifies the effect
of the radiation.



4. radiation, specimen,
film

5. In radiography the radiation provides
the rays that _____ the specimen
expose the film.



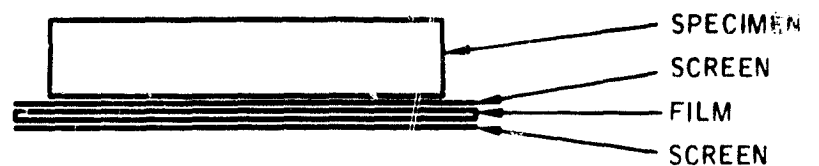
11. image

12. The three most important characteristics of radiation to the radiographer are:
the ability to _____ material, the ability to _____ the film
emulsion, and the ability to follow a _____ path.

19. exposure (rays,
radiation)

20. The darker portion of the developed film is said to be more dense and the
degree of darkness is known as the film _____.

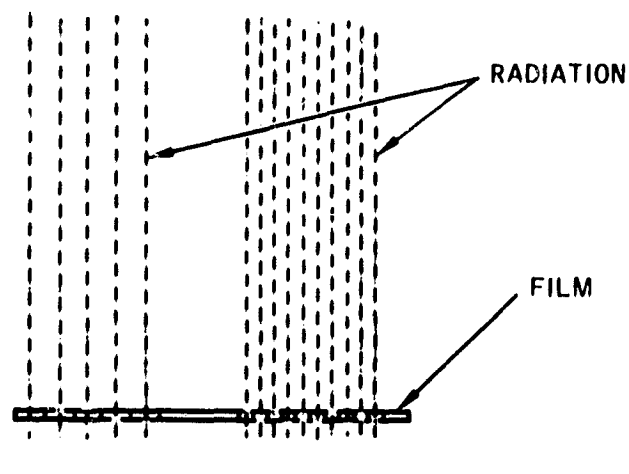
27. intensifying



28. The fluo _____ screens are placed on both sides
of the film when making a radiograph.

5. penetrate (pass through)

6. The radiation _____ the film by ionizing the film emulsion.



12. penetrate, ionize
(expose) straight line

13. The photographic record produced by the passage of X- or gamma rays through a specimen to expose a film is called a _____.

20. density

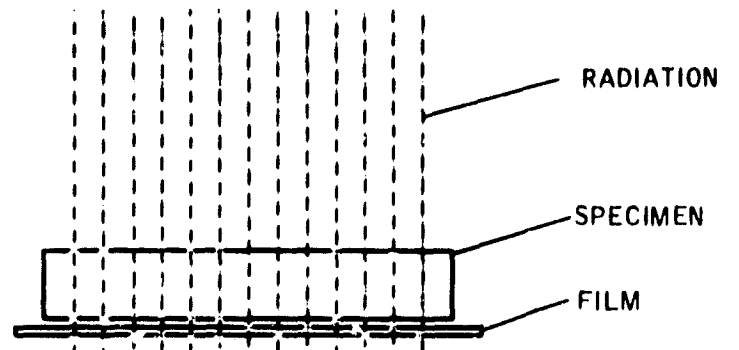
21. In radiographing a specimen of varying thickness, the amount of radiation that reaches the film varies inversely with the thickness of the _____.

28. fluorescent intensifying

29. Lead screens are also used as _____ screens.

6. exposes

7. In radiography, radiation _____
the specimen and _____
the film.



Return to page 1-37,
frame 8, and continue

13. radiograph

14. _____ and _____ rays are electromagnetic waves used
in radiography.

21. specimen (material)

22. The thickest section of any specimen being radiographed will absorb _____
(more, less) of the rays than the thinnest section.

29. intensifying

30. The lead screen acts as an intensifier because _____ are
liberated from the lead by the radiation.

You should not have turned to this page. The instructions were to return to page 1-37, frame 8, and continue the review.



14. X, gamma

15. X-rays and gamma rays are part of a family of waves called _____ waves.



Return to page 1-37,
frame 16, and continue.

22. more

23. Thinner sections of the specimen appear as _____ areas on the developed film.



Return to page 1-37,
frame 24, and continue.

30. electrons

Now turn to the next page.



CHAPTER 2 - RADIOGRAPHIC SENSITIVITY - DEFINITION

So far we have discussed the basic elements of radiation, the specimen, and the film as applied to radiographic image formation and we have discussed the placement of intensifying screens and their effect on the radiograph.

Before a particular radiograph can be of any use as a nondestructive testing tool, we must have some idea, or measure, of how accurate a tool it is. We call this measure of accuracy the "sensitivity" of the radiograph. In general terms, sensitivity is the measure of the smallest discontinuity that can be detected on that particular radiograph. Let's define radiographic sensitivity as:

The measure of the precision of the radiograph.

A radiograph that can detect all discontinuities over 0.01 inch in thickness is more sensitive than a radiograph that can detect all discontinuities over 0.02 inches in thickness.

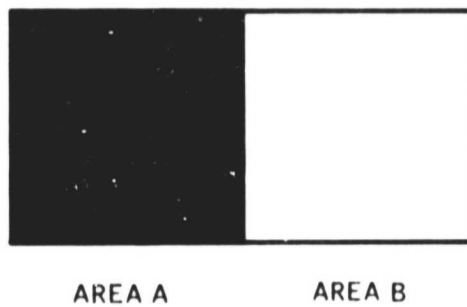
True Page 2-2

False Page 2-3

Right! You seem to understand what is meant by radiographic sensitivity.

Sensitivity in a radiograph is a function of the "contrast" of the radiograph and the "definition" of the radiograph. These terms will be discussed one at a time.

Contrast - contrast is the comparison between film densities for different areas of the radiograph. For example let's compare the density of area A with the density of area B of this example.



The example shows _____ contrast between area A and area B. (Take a guess.)

lots of Page 2-4

very little Page 2-5

From page 2-1

2-3

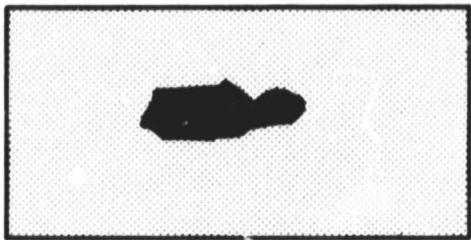
You haven't got the picture.

The ultimate aim of radiography is to reveal any discontinuities that may be hidden in the material of the specimen. The radiograph that can reveal the smallest discontinuity is the best radiograph; it is more precise. The measure of the precision of the radiograph is called "sensitivity". The more sensitive the radiograph, the smaller the discontinuity it will reveal.

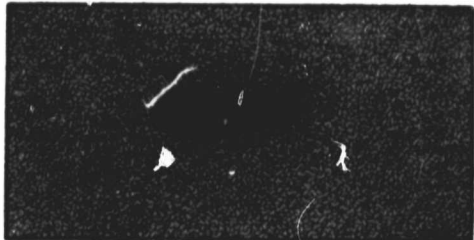
The radiograph that detected all discontinuities over 0.01 inch in thickness is more sensitive than the radiograph that could only detect discontinuities that were over 0.02 inches in thickness.

Turn to page 2-2 and continue.

Right! The example shows a lot of contrast between area A which is dark and area B which is very light. In radiography we are particularly interested in contrast as a comparison of the film density given by the discontinuity as compared to the film density of the specimen. In other words, the image on film of the discontinuity compared to the image on film of the specimen. The human eye can more readily detect an image when it is in "high" contrast with its background.



A



B

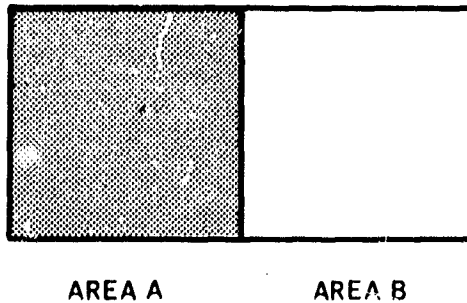
Here are two radiographs showing discontinuities. One has high contrast the other has low contrast.

Radiograph A has _____ contrast.

low Page 2-6

high Page 2-7

Your answer indicates that you felt there was very little contrast between area A and area B in the example.



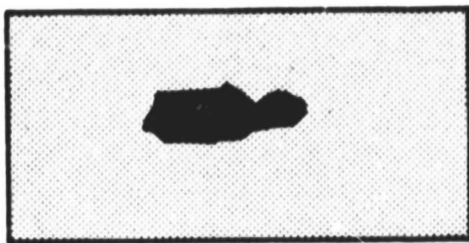
Webster states that contrast means "to exhibit noticeable difference when compared or set side by side". We could speak of contrast in height - meaning one thing was much taller than another. Or we could speak of contrast in size - meaning one thing was much bigger than another. But in a radiograph "contrast" means that one area of the film is much darker than another.

Now look at the figure above. If you agree that one area is much darker than the other, turn to page 2-4.

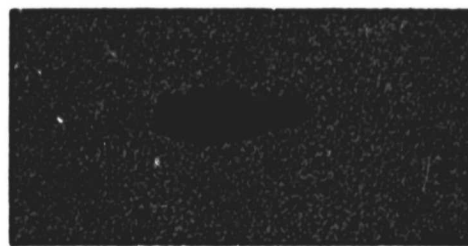
From page 2-4

2-6

I hope you guessed on this one because you guessed wrong. The image of the discontinuity in specimen B is not in very high contrast with the specimen, since it is more difficult to see than the discontinuity in specimen A. The discontinuity in specimen A has high contrast. It is easy to see.



A



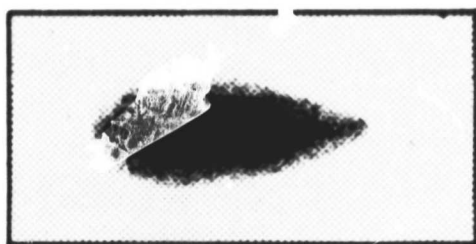
B

High contrast in a radiograph is essential for good viewing.

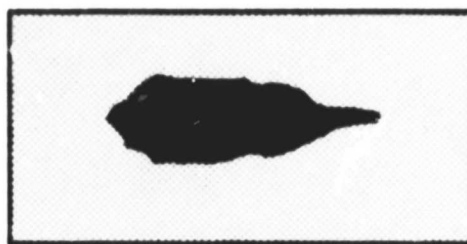
Turn to page 2-7.

Excellent. You seem to understand what we mean by "contrast".

If you recall, we said that the "sensitivity" of a radiograph was made up of two factors - contrast and definition. Since you now know what is meant by contrast let's take a look at what is meant by definition. If the image has "good" definition, the line of demarcation between areas of different densities is clear and sharp. The outline of the specimen is detailed and undistorted. Here are typical examples of what is meant by "good" definition and "poor" definition.



A



B

Which of the two examples shown above would you select as an example of "good" definition?

A Page 2-8

B Page 2-9

From page 2-7

2-8

Example A does not show "good" definition. Here are the examples again.



A



B

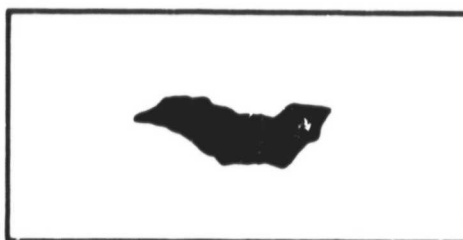
Remember -- in order to have good definition the outline of the image must be clear and sharp. In example A above it is difficult to tell exactly where the discontinuity begins while in example B the outline of the discontinuity is clear and sharp.

Turn to page 2-9.

Very good! You seem to understand what is meant by the term "definition" as it is applied to the radiograph. Here we show the result of low and high contrast and poor and good definition in radiographs.



LOW CONTRAST
POOR DEFINITION



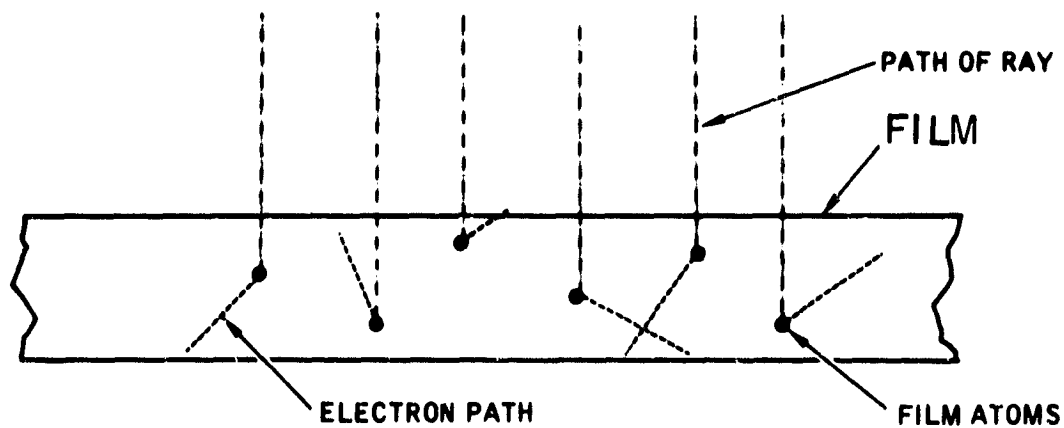
HIGH CONTRAST
GOOD DEFINITION

Now that you understand contrast and definition, let's examine the factors that affect and control each. First - definition. What causes fuzzy subject outlines in the radiograph and what can we do to control them?

Inherent unsharpness. As you learned in previous books of this series, when an X or gamma ray passes through any material, some of the energy is absorbed in the material by ionizing processes known as photoelectric effect and Compton effect. In the photoelectric effect and Compton effect the energy of the ray is absorbed by knocking electrons from atoms in the material. These effects also occur in the film as the X-ray passes through it. Since it cannot be avoided, the generation of free electrons in the film is said to be inherent to the process.

Turn to the next page.

Here we are showing a cross section of the film and a diagram to indicate the spread of electrons through the film.



This scattering of free electrons through the film causes the film to be exposed (ionized) wherever the electrons travel. The scattering, therefore, causes fuzzy edges on the image.

Inherent unsharpness is caused by free electrons that are generated by the radiographic ray as it passes through the _____.

specimen Page 2-11

film Page 2-12

Sorry, you've missed an important point. Inherent unsharpness is caused by the generation of free electrons as the ray passes through the film. It is true that free electrons are also generated in the specimen but, since electrons can travel only very short distances, only those electrons that are emitted from the lower surface of the specimen can affect the film. There are methods we can use to prevent these electrons from reaching the film. You will learn about these later in the program. For the present let's consider only the effect of the ray as it passes through the film.

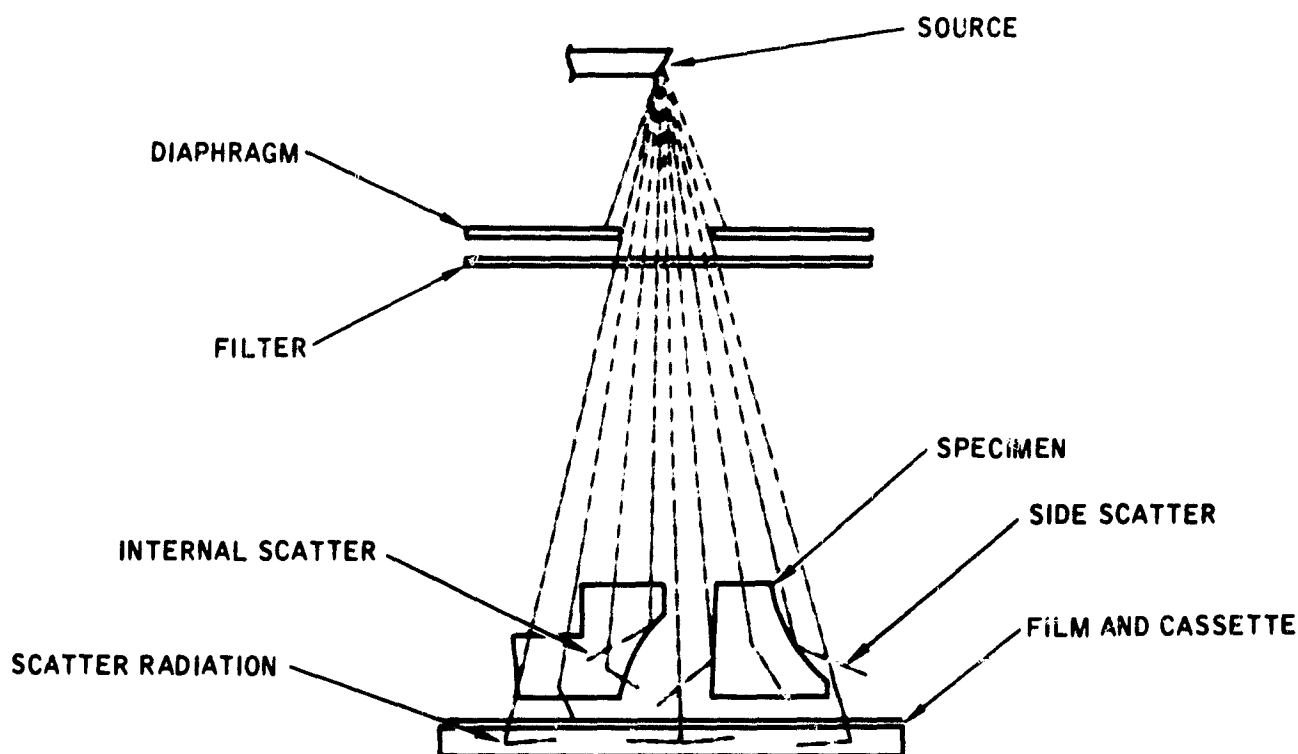
When the ray passes through the film, electrons are separated from the atoms of the film. These free electrons have an effect on the film which is called "Inherent Unsharpness".

Now turn to page 2-12 and continue.

Correct! You must also remember that since the scattering of electrons in the film is inherent to the procedure it is also unavoidable.

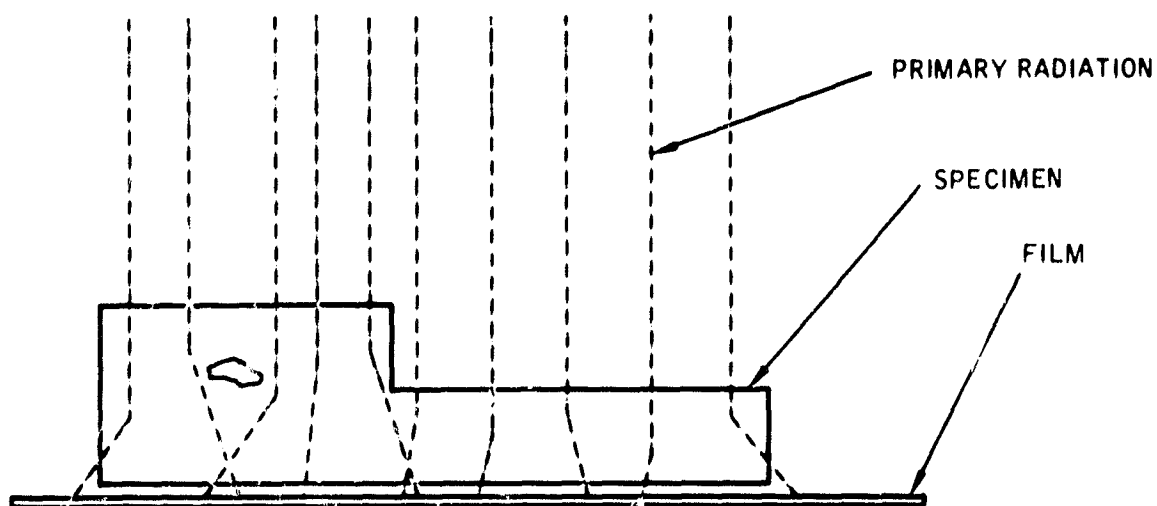
Scatter radiation. Any material, whether specimen, cassette, table top, walls or floor, that is in the path of the primary radiation will generate scattered radiation. You will recall from Volume I that scattered radiation has less energy than the primary radiation and travels in random directions striking the film from many different directions. In the radiography of thick materials the scattered radiation, if not controlled, will form the greater percentage of radiation that reaches the film, adversely affecting both the contrast and the definition of the radiograph. For ease of discussion, scatter is described with reference to its origin. Internal scatter originates within the specimen. Side scatter originates from walls, or any other objects nearby, that are in the path of the primary ray. Back scatter originates from any material, wall, floor, table top, or cassette, that is located in back of the film.

Since we are now discussing those factors that affect the definition of the radiograph we will leave back scatter for the moment and discuss the effect of internal scatter and side scatter on the definition of the radiograph.



Turn to page 2-13.

Internal scatter. The amount of internal scatter is fairly uniform throughout a specimen of uniform thickness, but the amount of scatter increases with the thickness of the material and the density of the material.



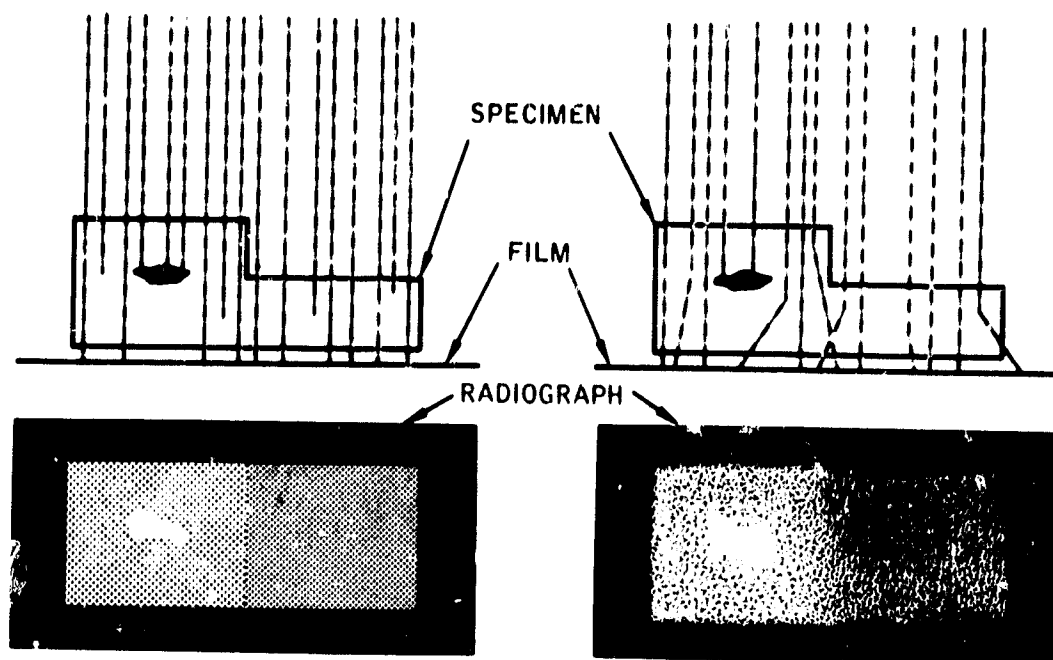
Here we are showing a few rays of internal scatter to illustrate their effect on the definition of the radiograph. Note that they can meet the film at a point outside the area covered by the specimen. Note also that the image of the discontinuity can be diffused because the scatter radiation strikes the film where the image ought to be. Scattered radiation from the thicker part of the specimen can be reaching the film under the thinner sections and vice-versa.

In your opinion, then, internal scatter radiation _____ the definition of the radiograph.

improves Page 2-14

lessens Page 2-15

Sorry - the internal scatter radiation lessens the definition of the radiograph. Let's look at these cross sections and see why.



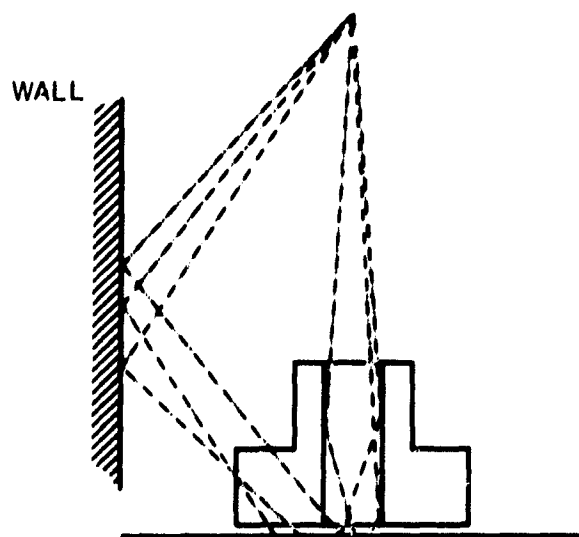
On the left we show the radiograph that would be obtained if there was no internal scatter. On the right we show the effects of internal scatter. Note how the scatter has cut across the change of section to diffuse the sharpness of the image.

Internal scatter lessens the definition of the radiograph.

Turn to page 2-15.

An excellent opinion. The internal scatter will certainly cause the image to become diffused - poor definition.

Side scatter. Side scatter, originating from walls, or any other objects nearby, that are in the path of the primary ray, approaches the specimen and film from the side and causes a blurring of the edge of the image. This effect is called "edge cutting" or "undercutting".



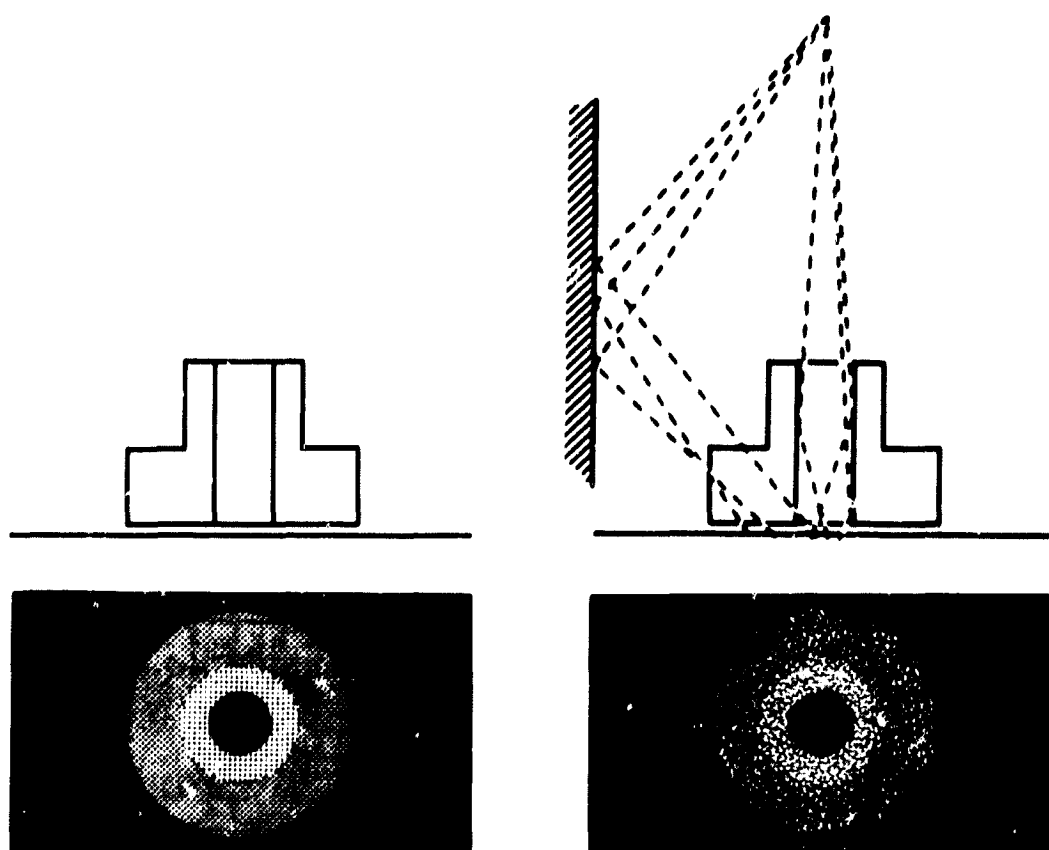
Here we show a few of those side-scattered rays that are undercutting the edge of the image.

Side scattering, then, _____ the definition.

improves Page 2-16

lessens Page 2-17

No — side scatter does not improve the definition of the radiograph. Let's see what effect side scatter has on the radiograph.



On the left we show the radiograph as it would appear if there were no scattered radiation. On the right we show the added effect of side-scattered radiation. Note that the edges of the image are no longer clear and sharp.

Side scatter lessens the definition of the image.

Turn to page 2-17.

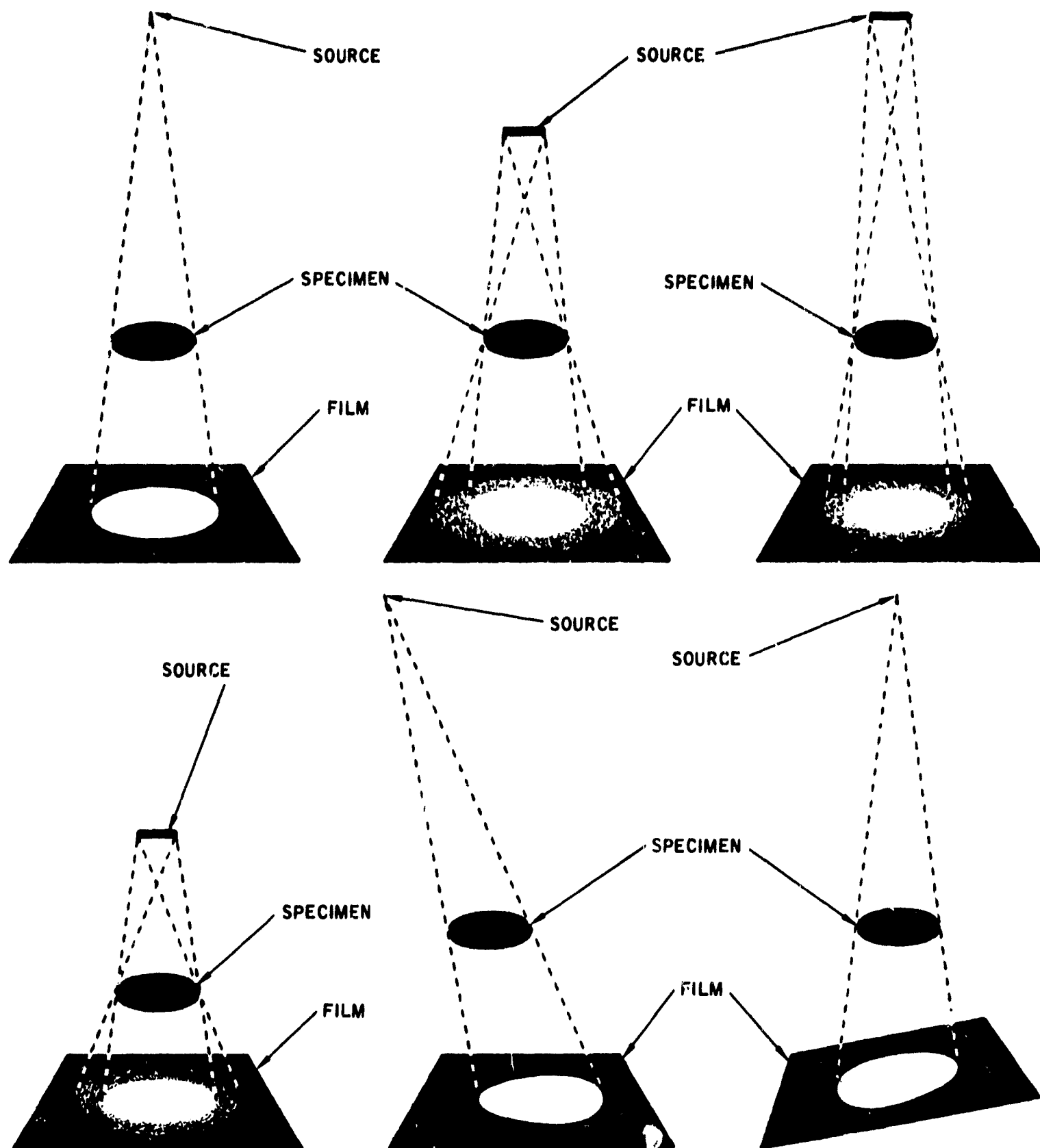
Right. Since side scatter causes the image to become diffused it causes poor definition.

One method of controlling internal scatter and side scatter is to prevent them from reaching the film. This can be accomplished by placing a thin sheet of lead foil between the specimen and the film. The screen absorbs the low energy scattered radiation while allowing the higher energy primary radiation to pass on through. Thus the lead intensifying screen will serve two purposes -- it intensifies the primary image forming rays while blocking the scattered non-image forming rays. Screens will be covered in more detail a little later on in the program.

Geometric unsharpness. Since a radiograph is really a shadow picture, the geometrical rules that govern shadow formation by light also apply to producing radiographic images. If the basic geometric principles of shadow formation are not followed, satisfactory sharpness of outline and freedom from distortion will not be obtained in the radiograph.

Turn to page 2-18.

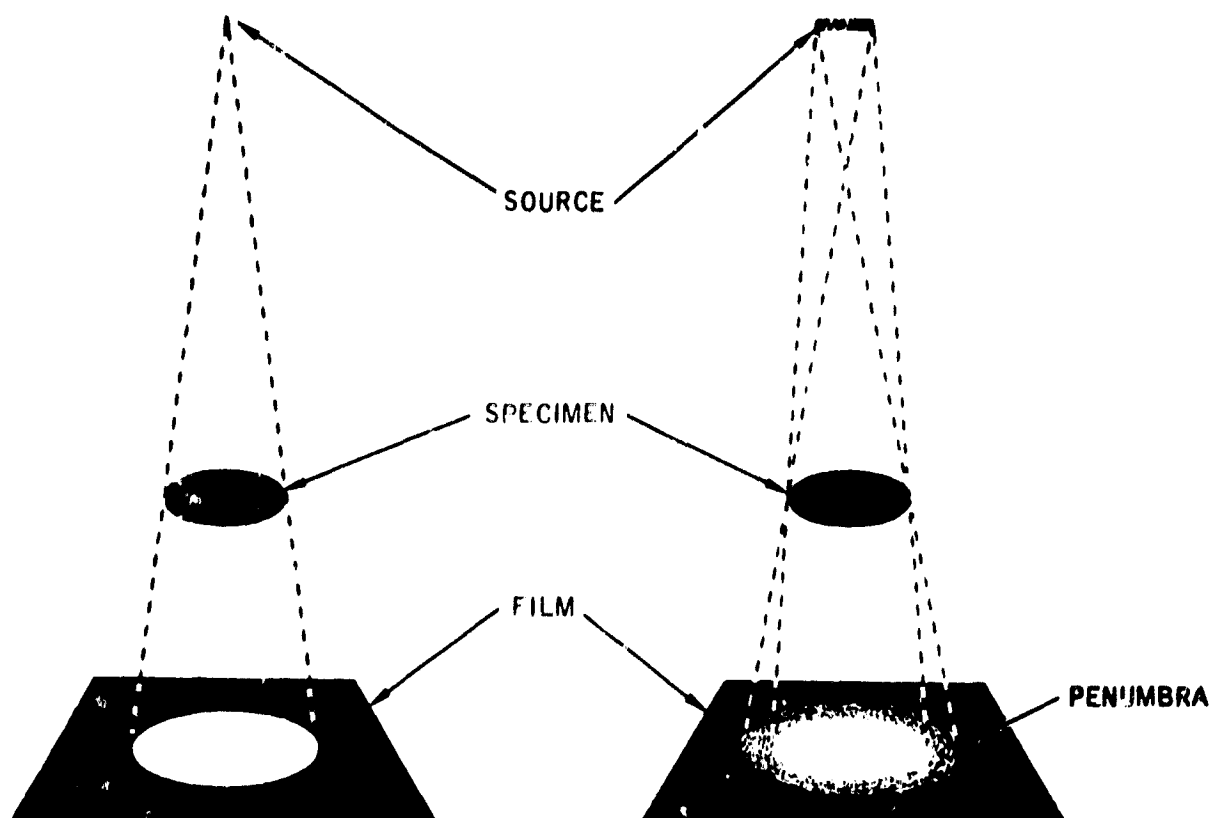
Here is an illustration of the geometric principles that we are talking about.



Here we see the effects of changing the size of the radiation source and of changing the relative positions of source, object, and film. From an examination of these drawings, you will see that certain conditions must be fulfilled to produce the sharpest, truest shadow of the object.

Turn to page 2-19.

Now we are going to compare certain figures that were shown on the previous page and see if we can come up with some rules for preventing geometric unsharpness.



In this illustration we show the effect of the size of the source on the radiograph. On the left we show the effect of a very small source. Note that the image of the specimen has good definition.

On the right we show the effect of a larger source size. Note that the image of the specimen has become fuzzy.

When the source is not a point but a small area, the image cast is not perfectly sharp since each point on the source casts its own shadow of the subject, and all of these shadows are slightly displaced from each other, thereby producing an ill-defined or fuzzy image. The fuzzy edges of the image are called penumbra.

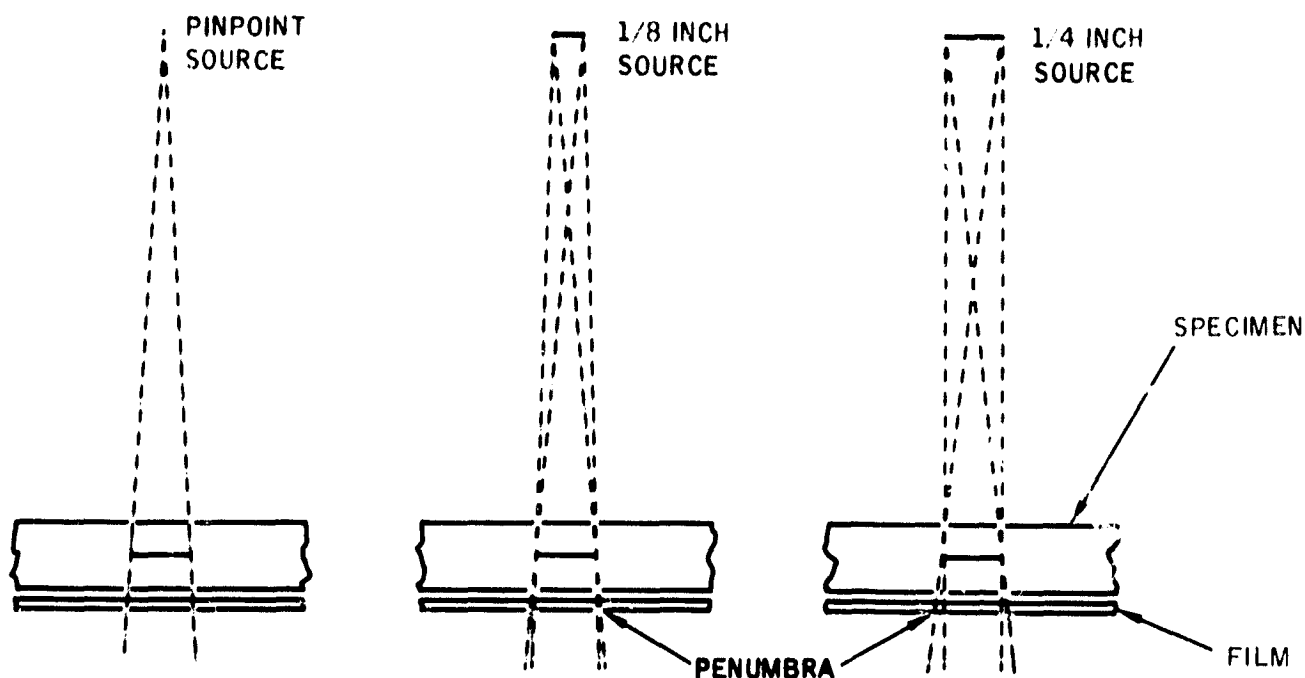
The source should be as small as possible — as nearly a point source as is possible to obtain.

Penumbra is the result of using too small a source.

True Page 2-20

False Page 2-21

Perhaps we've confused you into thinking that penumbra is the result of using a small source. Here we are showing what happens to the image as the source size grows from a pinpoint up to 1/4 inch.



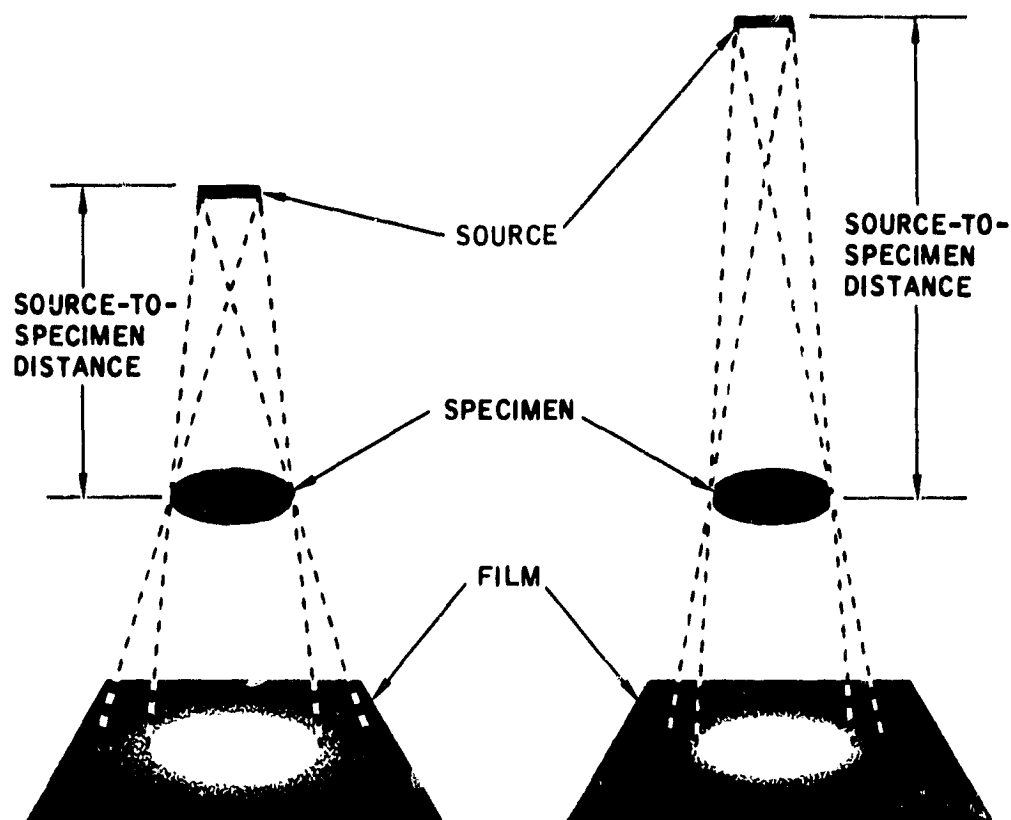
Notice that to form an image we draw a line from each side of the source through a particular point in the specimen. In the figure at the left there is no penumbra because all rays originate at one point. In the figure at the right penumbra exists because the rays coming from the left side of the source form one image and the rays coming from the right side of the source form another image. If we drew lines representing all the rays coming from the source and passing through the same point on the specimen, each line would show where another image is formed. It is no wonder that the edges appear fuzzy.

We hope that you now understand that penumbra can result from using too LARGE a source of radiation. Penumbra cannot be completely eliminated because a point source cannot be obtained. But by reducing the source size the penumbra effect can be reduced to the point where it no longer represents a problem.

Turn to page 2-21.

You are doing fine. Penumbra results from too large a source -- not too small a source. Penumbra cannot be completely eliminated because a point source cannot be obtained. But by using the smallest source size possible the penumbra effect can be reduced to the point where it no longer represents a problem.

Let's compare a couple more possibilities.



In this illustration we show the effect of changing the source-to-specimen distance. Note that as the source moves away from the specimen the penumbra decreases.

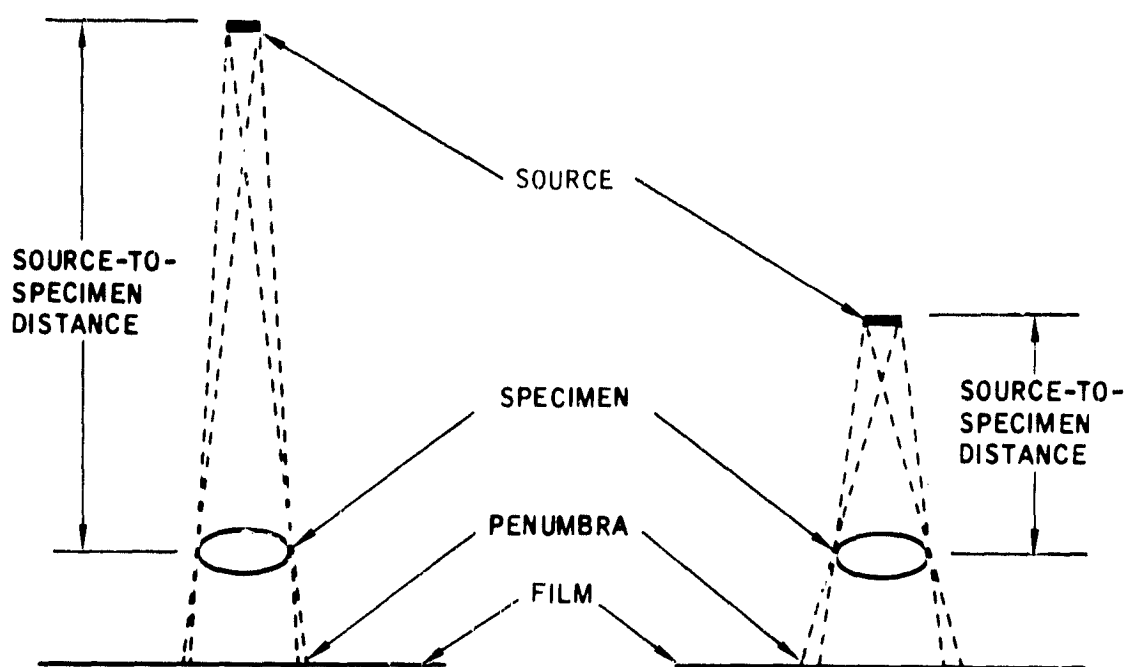
The source should be as far from the specimen as practicable. When the source-to-specimen distance is increased, the effect of the penumbra is reduced.

A short source-to-specimen distance is most desirable to reduce the effect of penumbra.

True Page 2-22

False Page 2-23

Again we hit you with a false statement. The source-to-specimen distance must always be as long as is practical in order to reduce the effect of penumbra. Here, in a side view, we show the straight-line path of the rays that intercept the edges of the specimen. Note the smaller penumbra that results from the longer source-to-specimen distance.

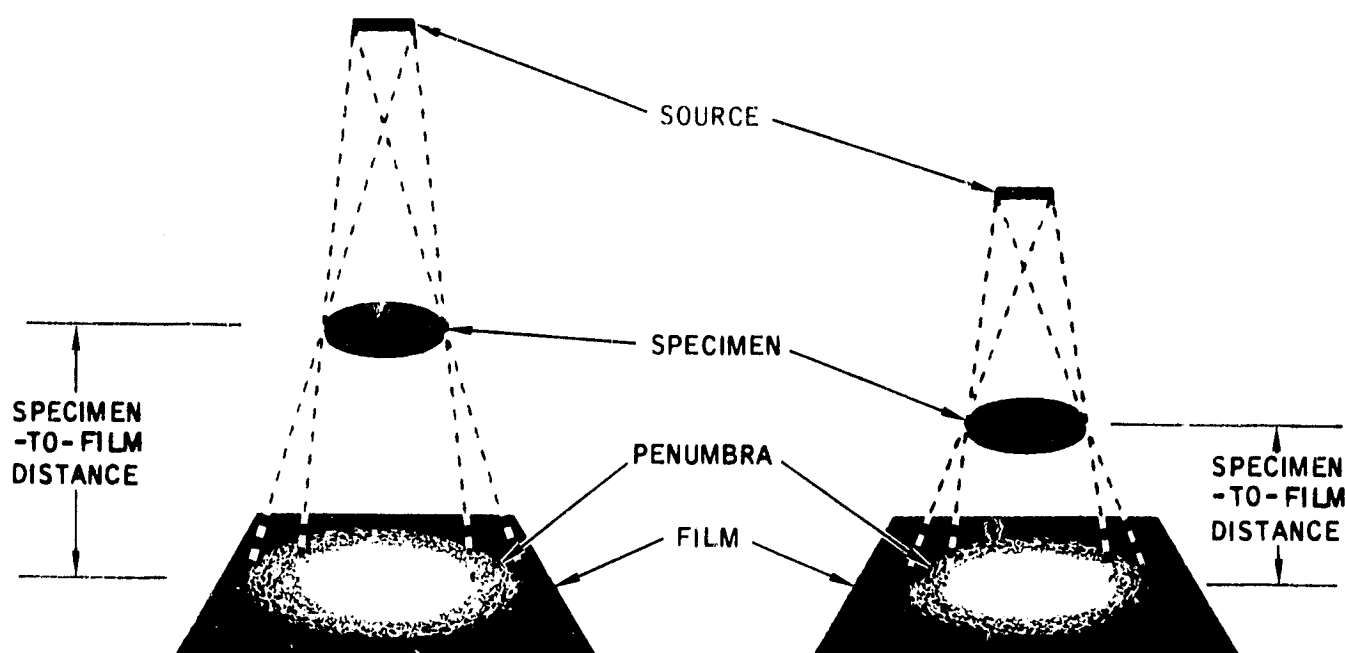


Since our sources are never pinpoint sources we can assume that we will always have some penumbra to contend with. In the figure on the left the penumbra is comparatively small but when we shorten the source-to-specimen distance the penumbra effect becomes larger. Had we increased the source-to-specimen distance the penumbra effect would have become smaller.

Turn to page 2-23.

You are right! The source-to-specimen distance must be as long as other limiting factors will allow in order to reduce unsharpness and improve definition.

Now look at these examples.



In this figure we show the effect of changing the specimen-to-film distance. Note how decreasing the specimen-to-film distance decreases the penumbra.

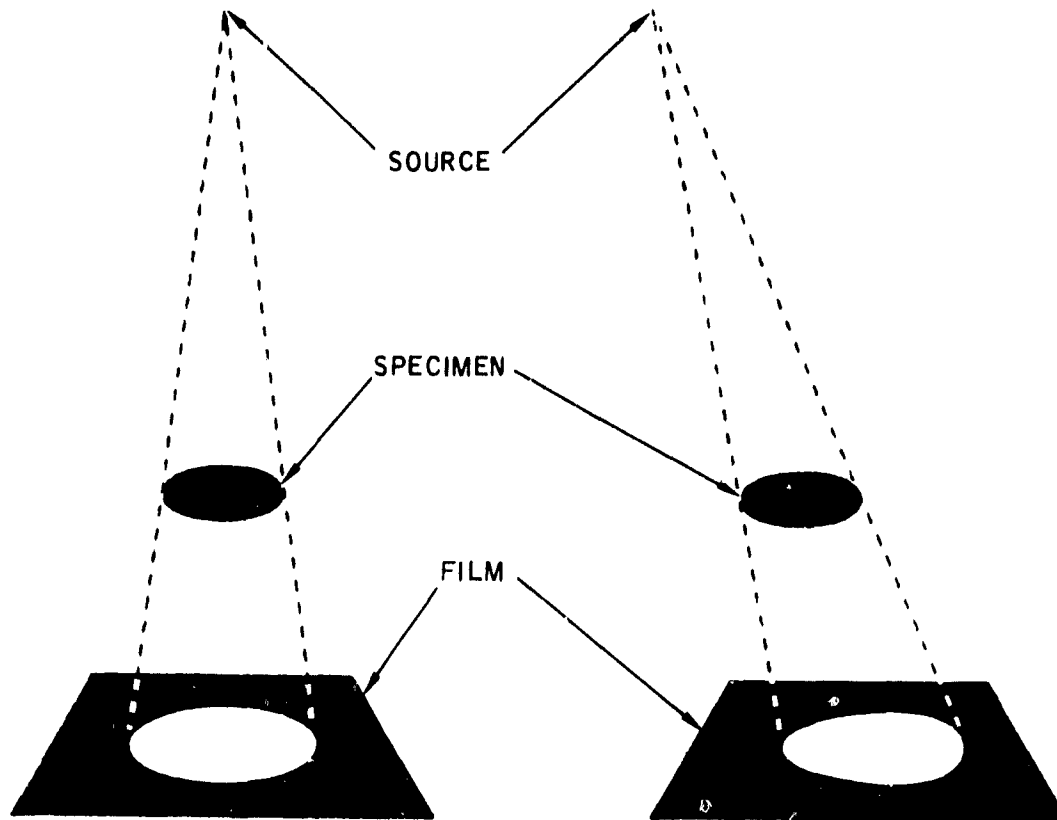
The film should be as close to the specimen as possible. When the specimen-to-film distance is decreased, the effect of penumbra is reduced. An increased specimen-to-film distance also produces an enlargement of the specimen image.

When specimen-to-film distance is kept as small as possible the definition is improved.

True Page 2-24

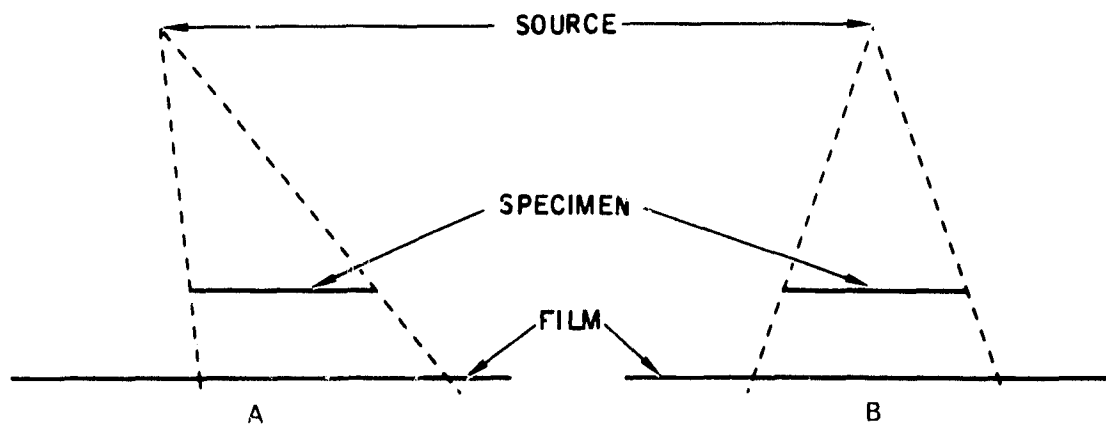
False Page 2-25

Right you are. Reducing the effect of penumbra does improve the definition of a radiograph.



The rays from the source should be directed perpendicularly to the film. When the source is not located on a line that is perpendicular to the film and pointing directly down on the film, the image of the specimen will be distorted. We quite often identify a discontinuity by the shape of the image. If the shape is distorted we will not be sure just what the discontinuity might be.

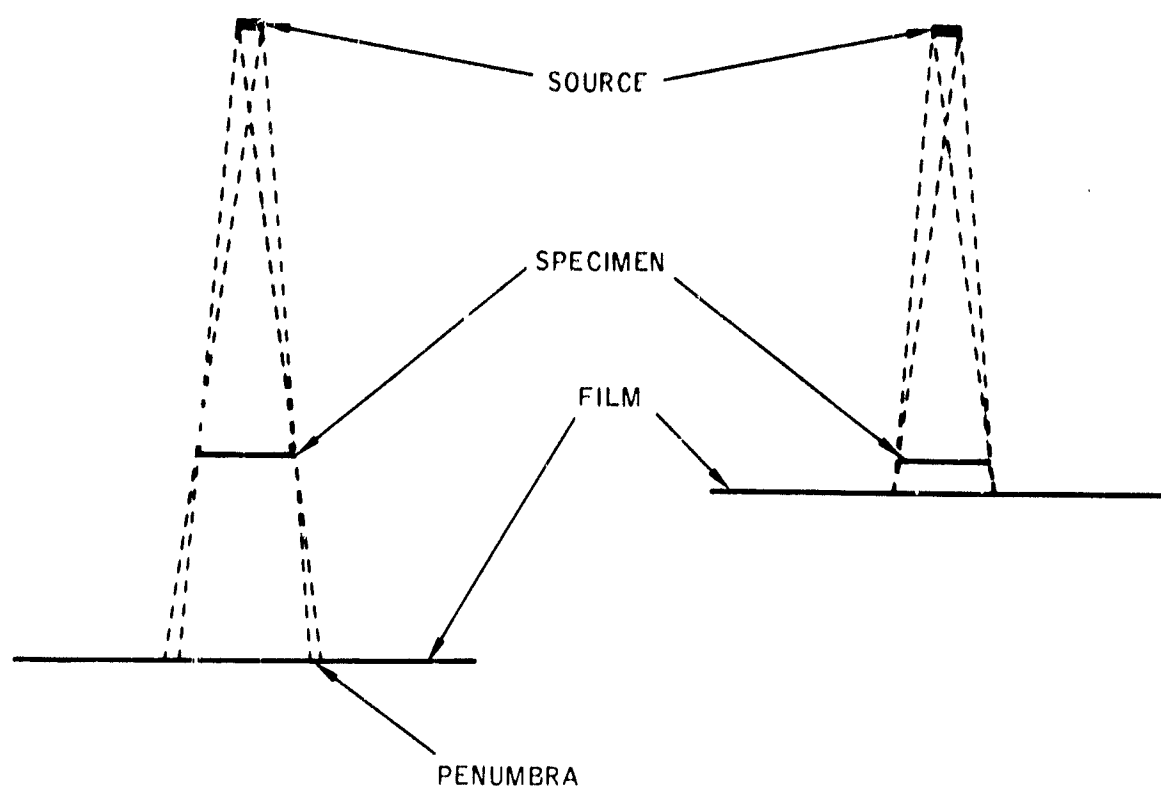
Here we show two rays meeting the film at different angles. Which, in your opinion, will give the least distortion to the radiograph?



A Page 2-26

B Page 2-27

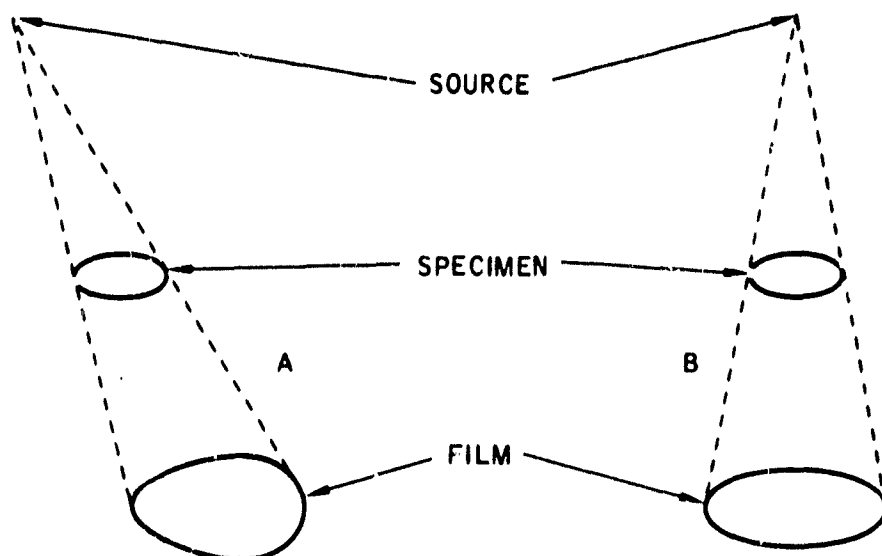
Anything that we do to reduce the effect of penumbra improves the definition of the radiograph.



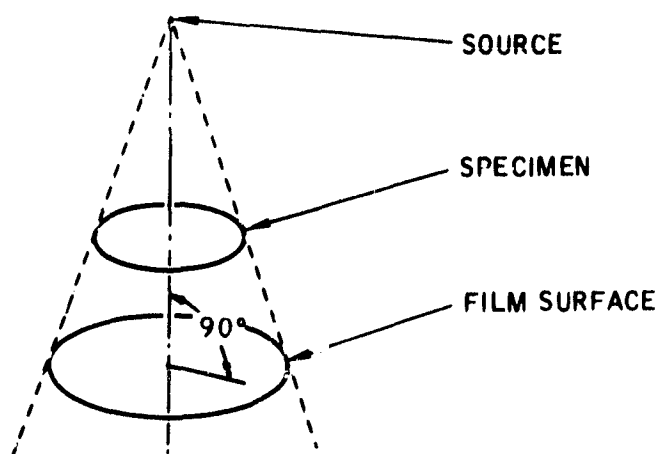
Here, in a side view, we show the effect of decreasing the film-to-specimen distance. Notice that as the distance between the specimen and the film decreases the penumbra decreases. This decrease in penumbra results in better definition in the radiograph.

Turn to page 2-24.

Whoa now! We ask for the ray that would give the least distortion. Here they are again.



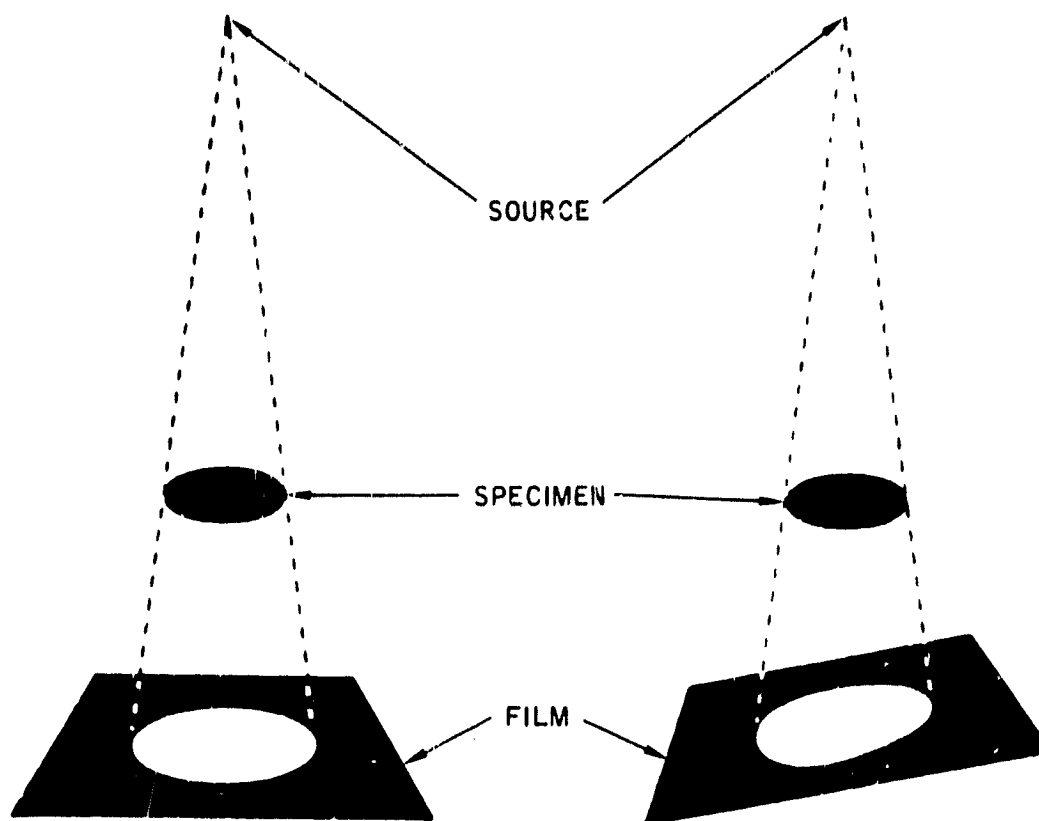
Perhaps you were confused by what is meant by "perpendicular to the film". It is a difficult thing to explain and therefore just as difficult to understand. The rays from a radiation source spread in all directions except where they might be blocked by some means or other. On most radiographic sources some means is provided which directs the radiation in the cone shape shown above. Let's draw an imaginary line through the exact center of the ray.



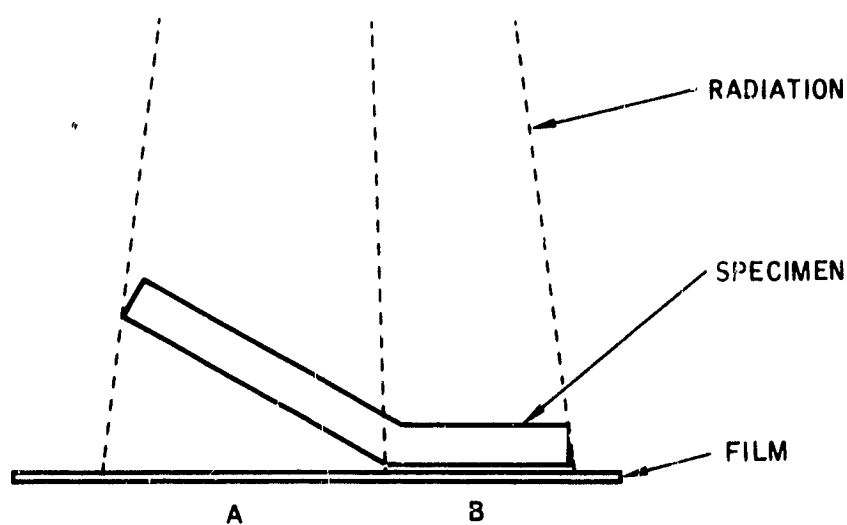
It is this line that should form right angles with the surface of the film. If it forms right angles, then it is perpendicular to the film.

Turn to page 2-27.

Your opinion is a good one. The ray shown in sketch B is perpendicular to the film. The ray in sketch A is not perpendicular to the film.



The above illustration shows that the film should lie in a plane that is parallel to the plane of the specimen. When the film and the specimen are not in parallel planes, distortion of the specimen image results.



Here we show a specimen being radiographed. On which area of the film can we expect a distorted image?

A Page 2-28

B Page 2-29

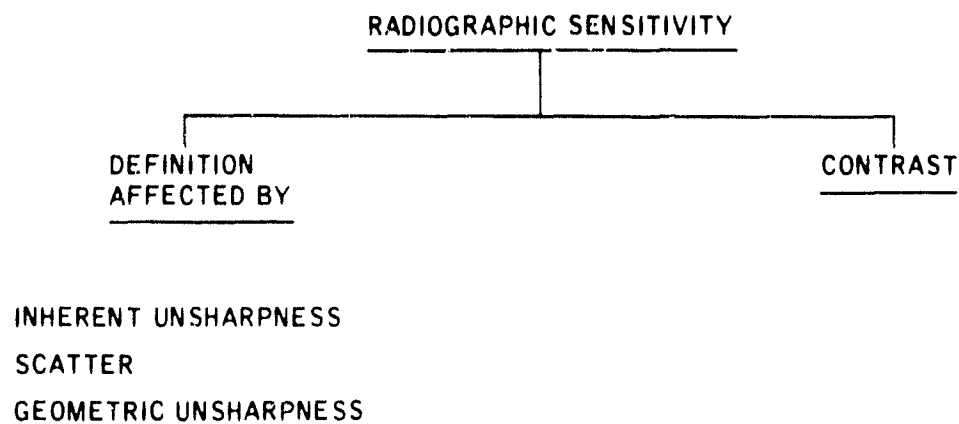


A very good opinion. Making a radiograph is almost like seeing - what you see depends upon the angle from which you view a specimen.

Geometric unsharpness then, can be controlled by following these rules:

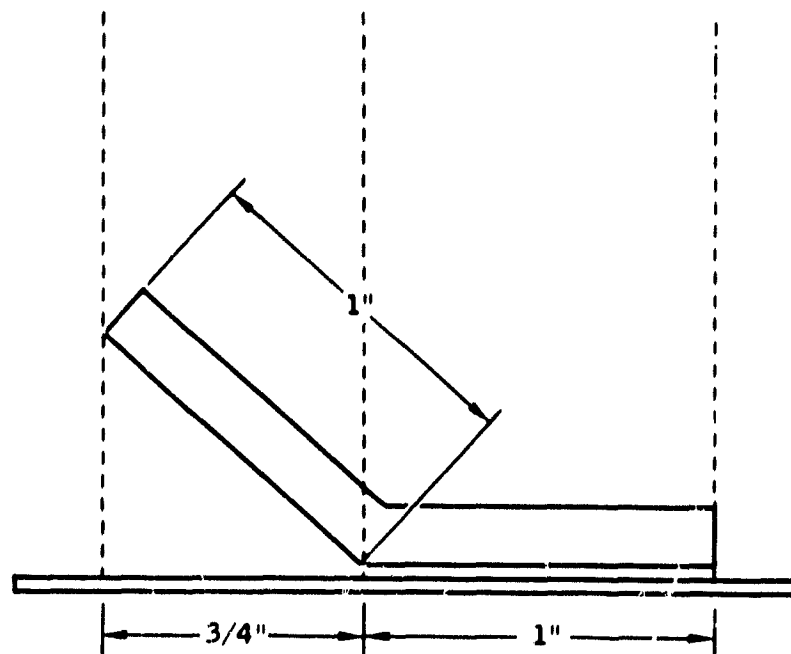
- 1) Source size should be as small as possible.
- 2) The source-to-film distance should be long enough to minimize the effects of penumbra.
- 3) The specimen-to-film distance should be a minimum.
- 4) The source and film locations should be such that the source rays are vertical to the plane of the film.
- 5) The film and specimen locations should be such that the film and specimen lie in parallel planes.

Just to remind you of what we have covered so far -



Turn to page 2-30.

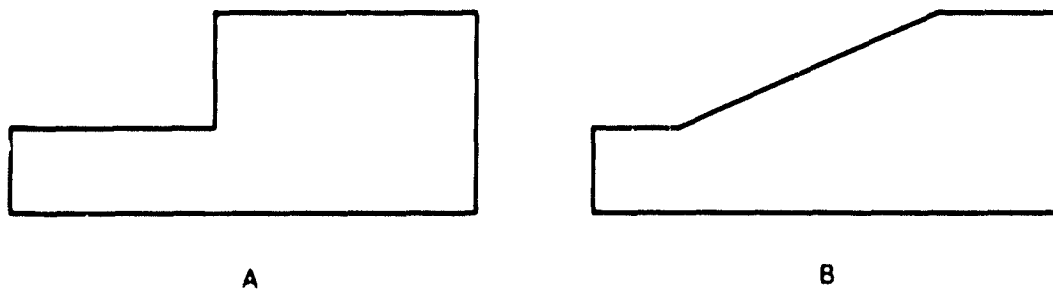
You've missed the boat. Area A will have a distorted image of the specimen while the image shown in area B will be undistorted. Let's look at an enlarged version.



Note how the angled leg of the specimen has been shortened on the radiograph. Since the image is shorter than the specimen we know that the image is distorted.

Turn to page 2-28.

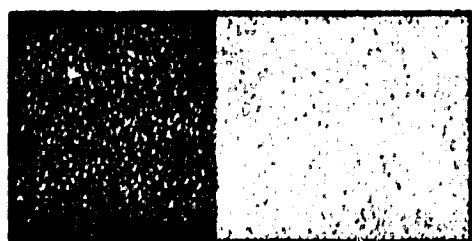
Specimen shape. Another geometrical factor that affects the definition of the radiograph is the abruptness of thickness changes in the specimen. It should be remembered that an abrupt, though small, change in thickness of the specimen may show up well on a radiograph while an inclusion of the same depth with more or less rounded sides may not be visible. The image of the inclusion may well be invisible because of the very gradual change in photographic density caused by the gradual change in specimen thickness.



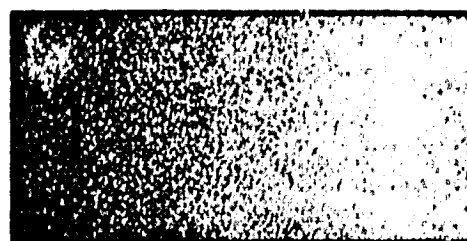
Here we show two specimens whose thickness dimension vary by the same amount. In one, the change from one dimension to the other is abrupt while, in the other, the change is gradual. Which specimen will have the best definition of the thickness change on the radiograph?

- A Page 2-31
 B Page 2-32

Right! The radiograph of specimen A will show an abrupt change in density at the place where the specimen thickness changes while the radiograph of specimen B will show a gradual change in film density between the two areas of maximum and minimum thickness.

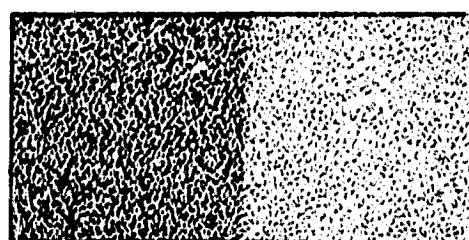


RADIOGRAPH OF
SPECIMEN A



RADIOGRAPH OF
SPECIMEN B

Film graininess. Definition is also influenced by the graininess of the film. Film graininess results from the size of the individual silver grain clumps in the processed film. All films have a certain amount of graininess resulting from exposure and development of the X-ray image. The degree of graininess varies with the type of film. Small grain clumps (fine grain) are desired for good definition. Large (relatively speaking) grain clumps prevent the film from showing a "knife edge" line at a change of section in the specimen.

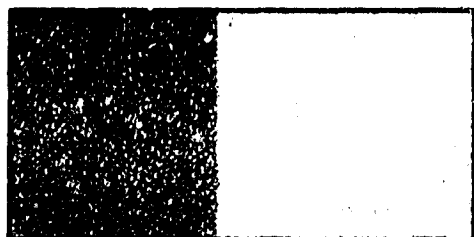


Graininess affects the definition of a radiograph because the large grain clumps make the film more dense.

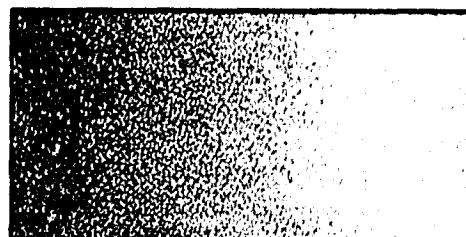
True Page 2-33

False Page 2-34

Sorry--you're wrong. Let's take a look at the radiographs that might be formed by these two specimens.



RADIOGRAPH OF
SPECIMEN A

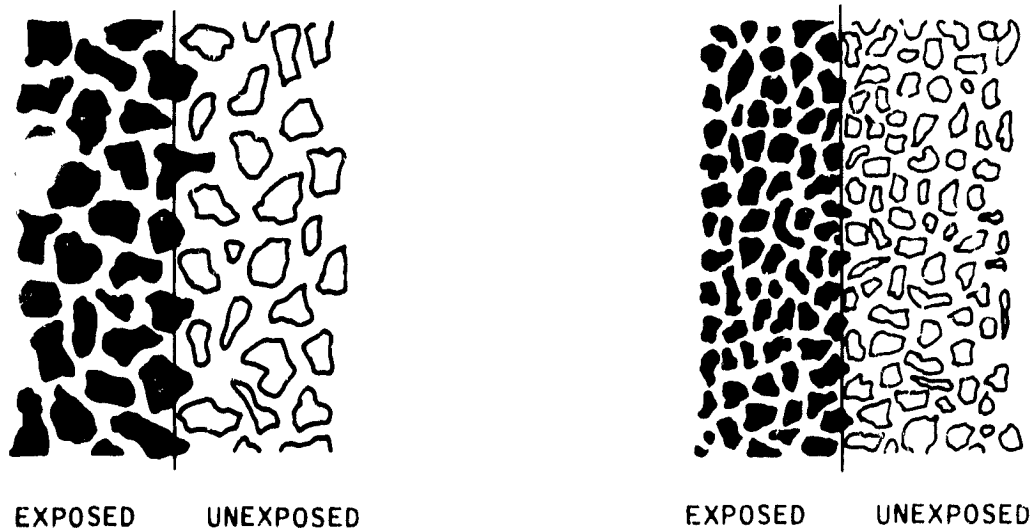


RADIOGRAPH OF
SPECIMEN B

Notice that the change in section is clearly visible in the radiograph of specimen A. But it is very difficult to see exactly where the change starts and stops in the radiograph of specimen B. Keep in mind that here we are showing a rather large change in thickness and are looking for the point where the change begins.

Turn to page 2-31.

The question may have misled you in that, at first, it seems to be a true statement. It is not the blackness (density) of the grain clump that affects the definition so much as it is the size of the clump. When the clump is so large that it covers more area than it should then it can project out into an area where it is not supposed to be. For example:



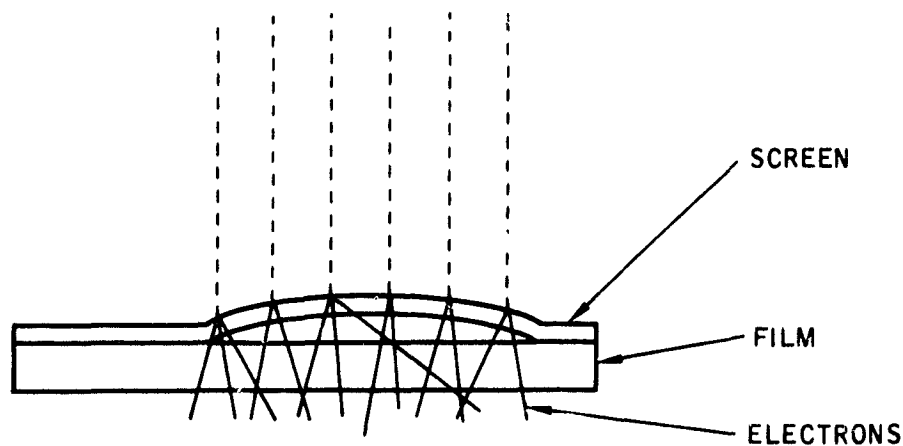
This extremely magnified view represents two films of different graininess. The line across the clumps represents a "knife edge" view that we want to obtain in the radiograph. Notice that, because of their size, the clumps on the left do not have the ability to show the line as clearly as the clumps on the right.

Turn to page 2-34.

Excellent! For any given film, graininess usually increases slightly as kilovoltage increases, but not necessarily at the same rate for all types of films. Because of this, fine grain films are especially useful in the million and multimillion volt ranges.

Fluorescent screens. Fluorescent intensifying screens are another source of unsharpness or lack of definition. While this type of intensifying screen is not often used in radiography, you must remember that, when used, they do lessen the definition. The fuzzyness caused by fluorescent screens increases with increased hardness of the primary radiation. The higher voltage primary rays cause relatively less fluorescence, thus the fluorescence caused by the lower energy scattered radiation becomes relatively more effective. This fact bars the use of fluorescent screens with high kilovoltages and with gamma rays.

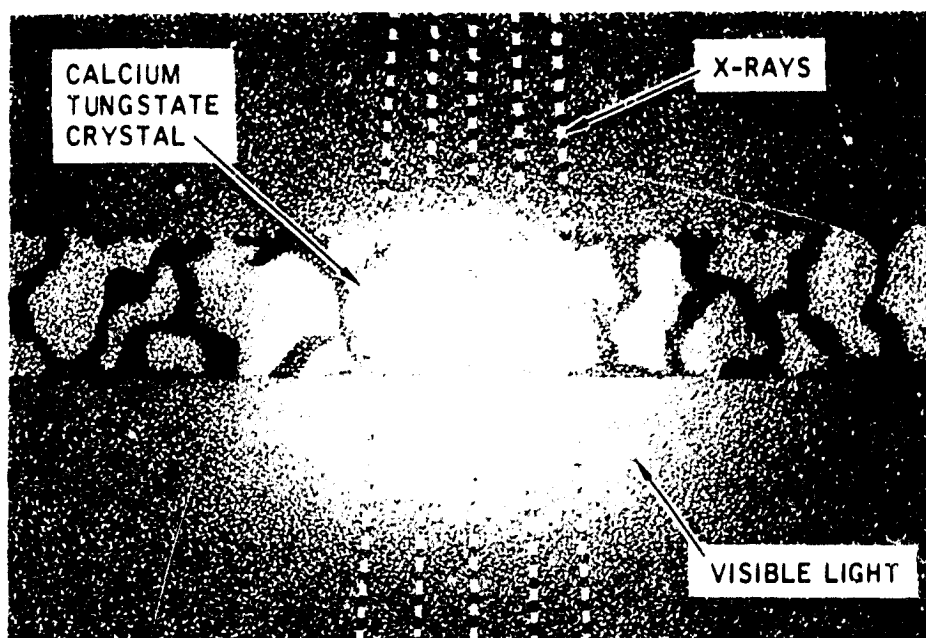
Good contact between the film and the fluorescent screens is imperative. Any space left between the film and the screens allows the light from the screens to spread further resulting in a diffusion of the light through the film and subsequent loss of definition.



When using fluorescent intensifying screens in radiography, you can expect some _____ in definition.

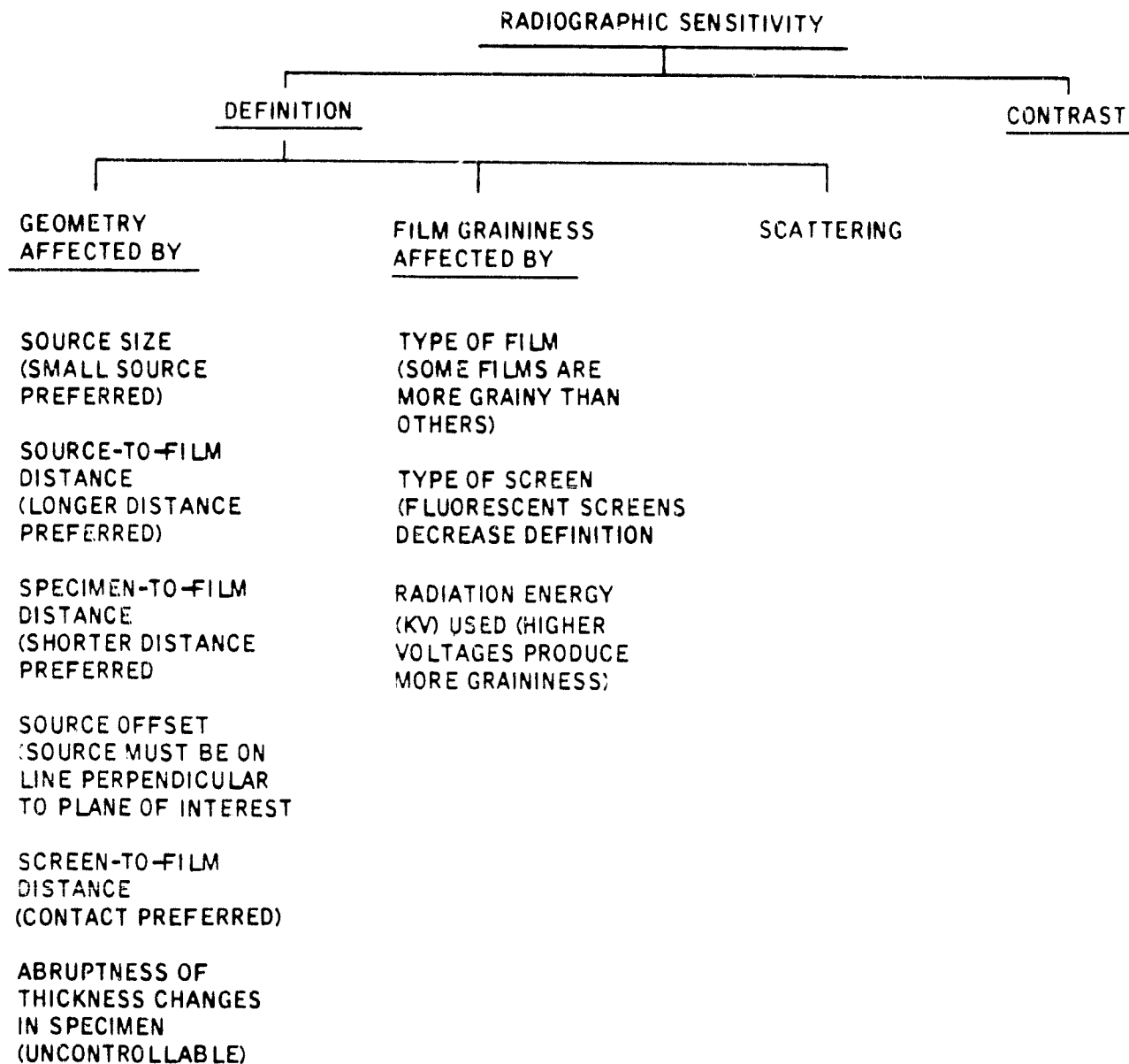
gain Page 2-35
 loss Page 2-36

You have just lost your ticket to the radiographers ball. You have forgotten that the light from the fluorescent material spreads through the film. The film is exposed by this light. Since the light spreads you will get a loss of definition in the final radiograph.

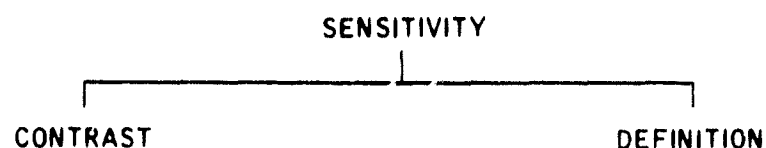


Turn to page 2-36.

Excellent. We have now reached the point where we should have another short review. Here are the factors that affect radiographic sensitivity that we have discussed so far.



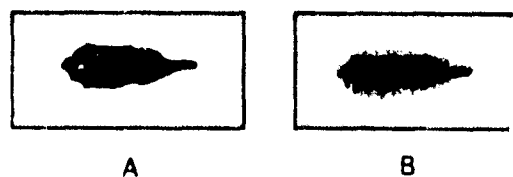
Look these over for a bit then proceed to page 2-37 for a short review.



1. Sensitivity is the measure of the smallest discontinuity that can be detected on the radiograph. It is a function of _____ and _____.



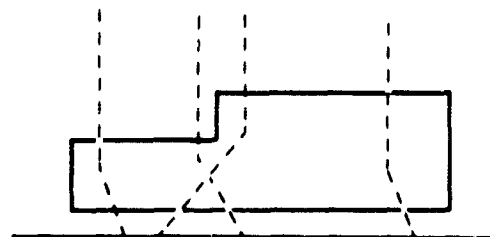
7. definition



8. Example _____ above shows good definition.



14. side scatter

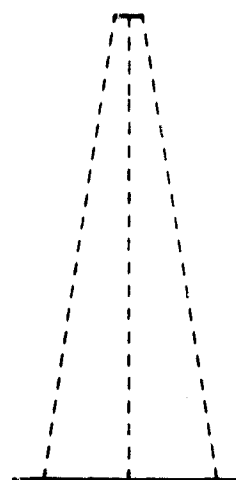


15. Internal scatter is scatter that originates _____ the specimen.



21. minimum

22. The primary beam from the source should be _____ (vertical, horizontal) to the plane of the film to avoid distortion of the image.

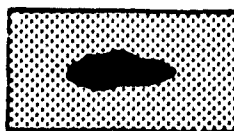


1. contrast, definition

2. The measure of the accuracy of the radiograph is called the sharpness of the radiograph.



8. A



A



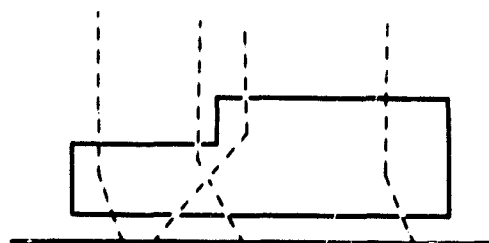
B

9. Example _____ above shows poor definition and low contrast.



15. within (inside)

16. The definition of the radiograph is adversely affected by _____ scatter.



22. vertical



23. An abrupt change in thickness of the specimen results in _____ (good, poor) definition of the change.



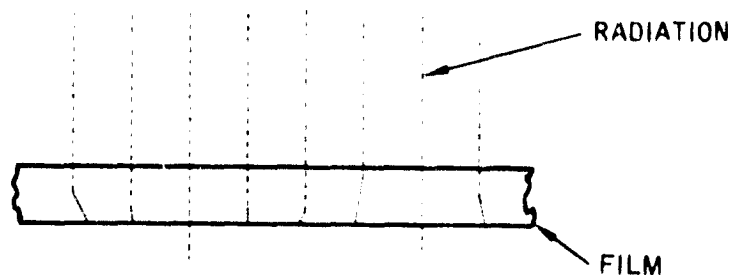
2. sensitivity

3. The measure of the smallest discontinuity that can be detected on a radiograph is a measure of the _____ of the radiograph.



9. B

10. When the radiographic ray strikes the film, _____ are liberated that expose the film. They are the cause of inherent unsharpness.



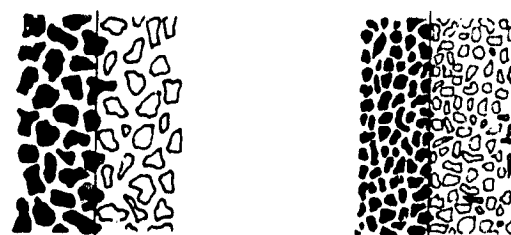
16. internal

17. Internal scatter _____ (improves, lessens) the definition of the radiograph.



23. good

24. Graininess of the film also affects the _____ (definition, contrast) of the radiograph.



3. sensitivity



4. Contrast is a comparison of the _____ between two areas of the radiograph.



10. electrons

11. Inherent unsharpness affects the _____ (definition, contrast) of the radiograph.



17. lessens

18. The geometrical rules that govern shadow formation by light _____ (apply, do not apply) to producing radiographic images.

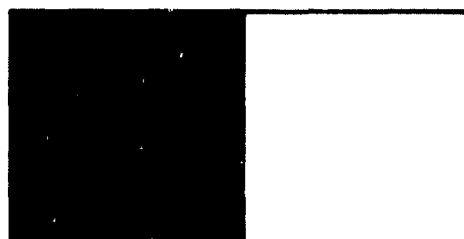


24. definition

25. Fluorescent screens affect the definition of the radiograph since the light _____ through the film.



4. densities



5. The above example shows "high" _____ between areas A and B.



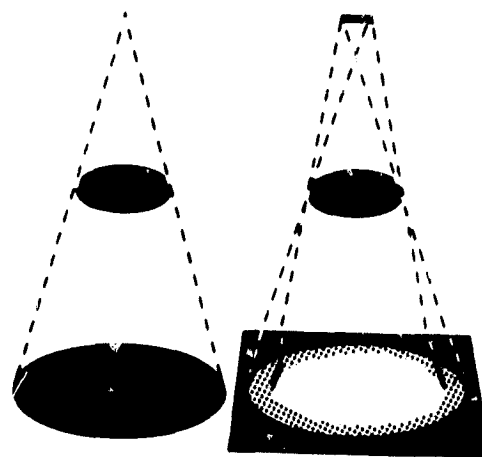
11. definition

12. We can do nothing to prevent inherent unsharpness, the process is uncon_____.



18. apply

19. The figure illustrates that the source size should be as _____ as possible.

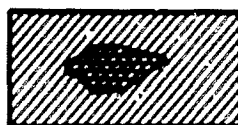


25. spreads

26. Use of fluorescent screens will _____ (increase, decrease) the definition of the radiograph.



5. contrast



GOOD
DEFINITION

6. Definition is the measure of the _____ of the outline of the image.



12. uncontrollable

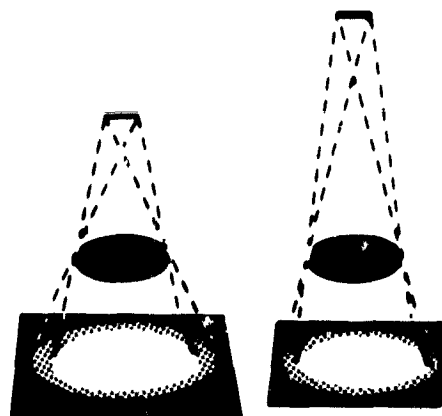


13. Another factor that causes fuzzy images is s _____ s _____.



19. small

20. This figure illustrates that a large source size can be compensated for by _____ the source-to-film distance.



26. decrease

Now turn to the next chapter.



6. sharpness



7. The radiographic image has good _____ if the line of demarcation between areas of different densities is clear and sharp.



Return to page 2-37,
frame 8, and continue.

13. side scatter

14. Fuzzy images can result from undercutting which is caused by _____.



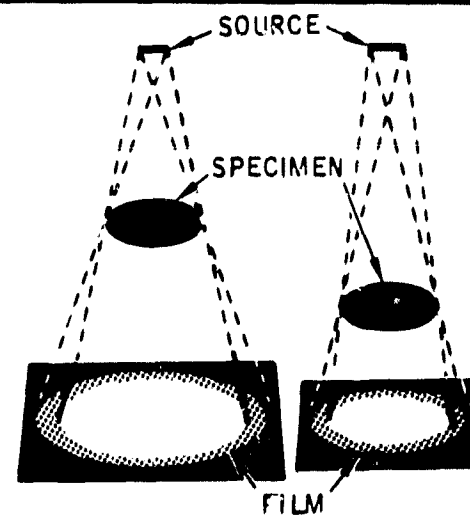
Return to page 2-37,
frame 15, and continue.

20. increasing

21. Geometric unsharpness can be minimized by keeping specimen-to-film distance at a _____ (maximum, minimum).



Return to page 2-37,
frame 22, and continue.

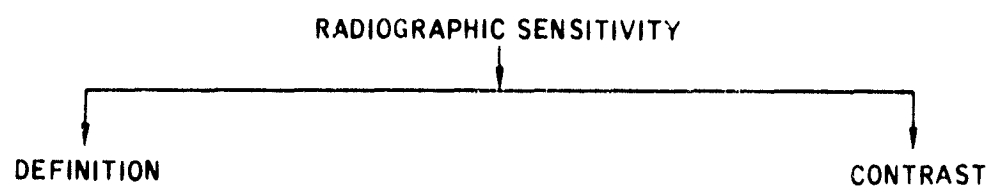


Turn to the next chapter.

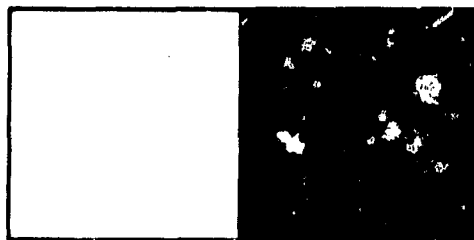


CHAPTER 3 — RADIOGRAPHIC SENSITIVITY - CONTRAST

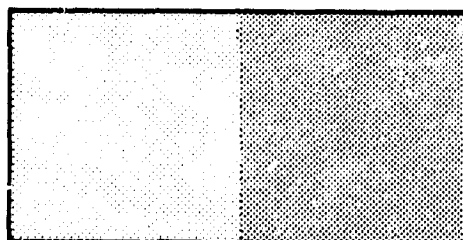
In Chapter 2 we discussed those factors that affect the definition of the radiograph. In this chapter we are going to discuss those factors that affect the contrast of the radiograph.



If you will recall, back in Chapter II we said that contrast was the comparison between film densities for different areas of the radiograph. In those radiographs where the difference in densities was very great we said that the contrast was "high" and when the difference in densities was slight the contrast was "low".



HIGH CONTRAST



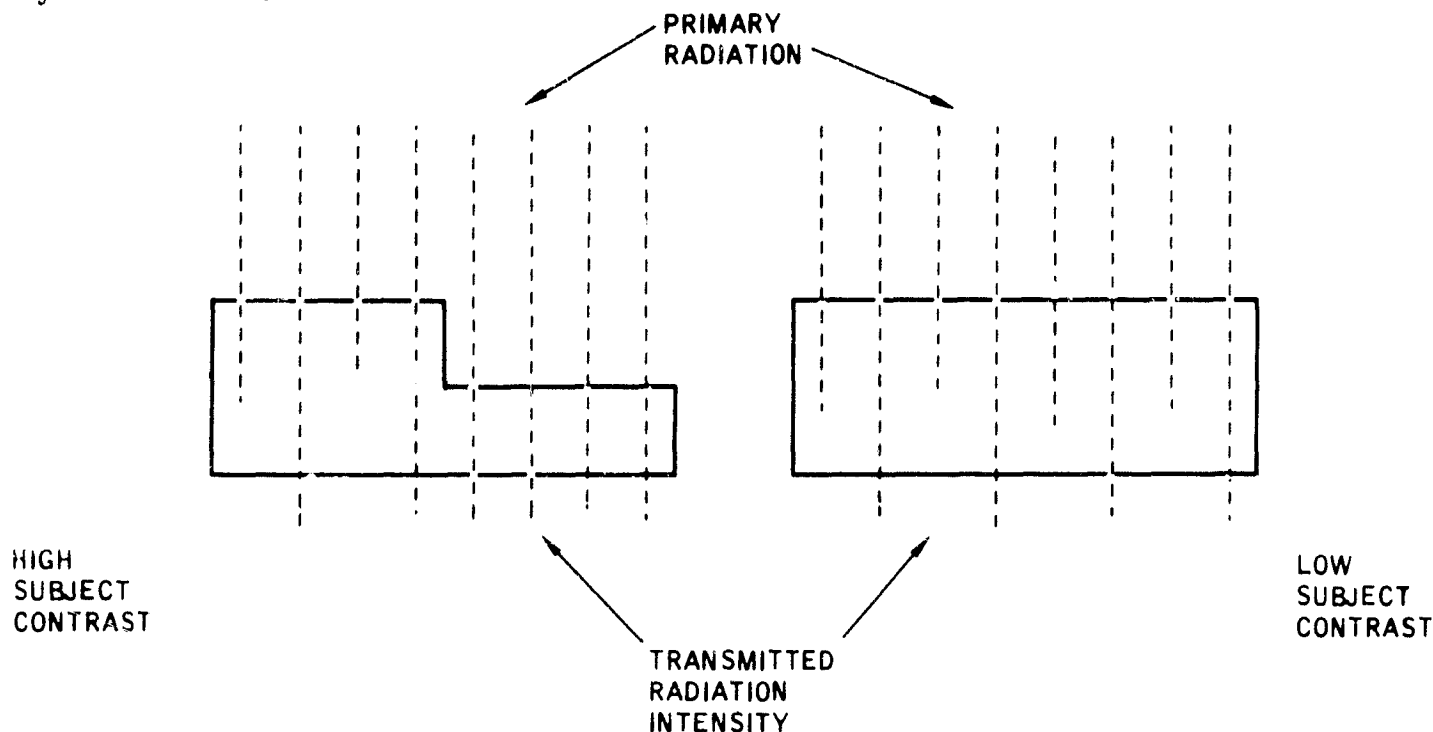
LOW CONTRAST

Now let's take a look at those factors that affect radiographic contrast.

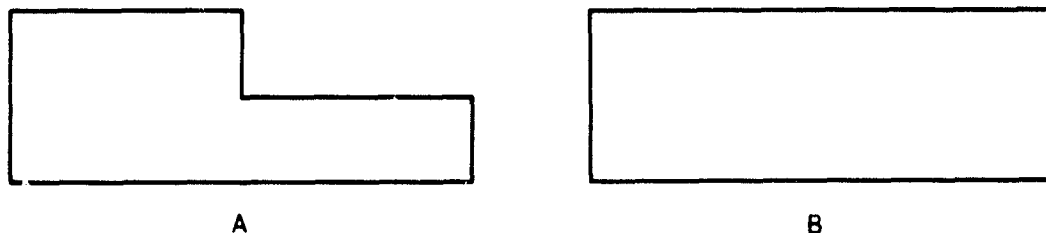
Turn to page 3-2.

First of all it is convenient to think of contrast as being made up of "subject" contrast and "film" contrast. Those factors in the specimen that affect or control the radiographic contrast we refer to as "subject contrast". Those factors in the film that affect or control the radiographic contrast we refer to as "film contrast".

Subject contrast. Subject contrast is best thought of in terms of the transmitted intensities. A radiograph of a specimen of uniform thickness and density has no subject contrast because the radiation passing through the specimen (transmitted) at all points is the same. On the other hand, a specimen that varies in thickness or density transmits different intensities through its various areas thereby giving considerable subject contrast.



Let's settle then for the following formal definition: Subject contrast is the ratio of x-ray or gamma ray intensities transmitted by two selected portions of the specimen.

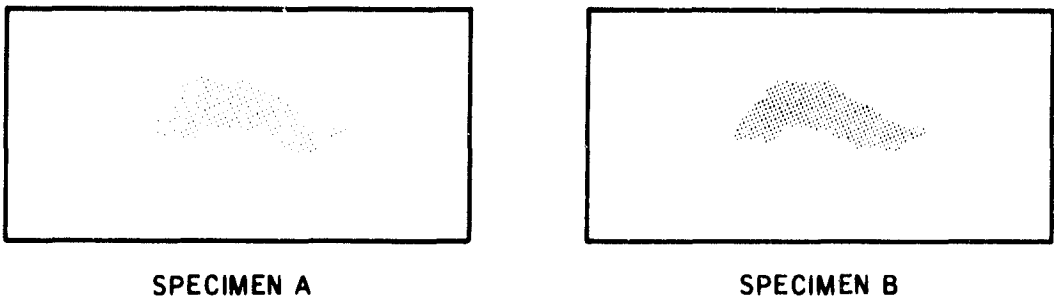


Which of the specimens above has the best subject contrast?

A Page 3-3

B Page 3-4

Very good. Since specimen B has uniform thickness the radiation will pass equally well through all areas of the specimen and there will be no change in contrast in the film that has resulted from anything in the specimen - no subject contrast.

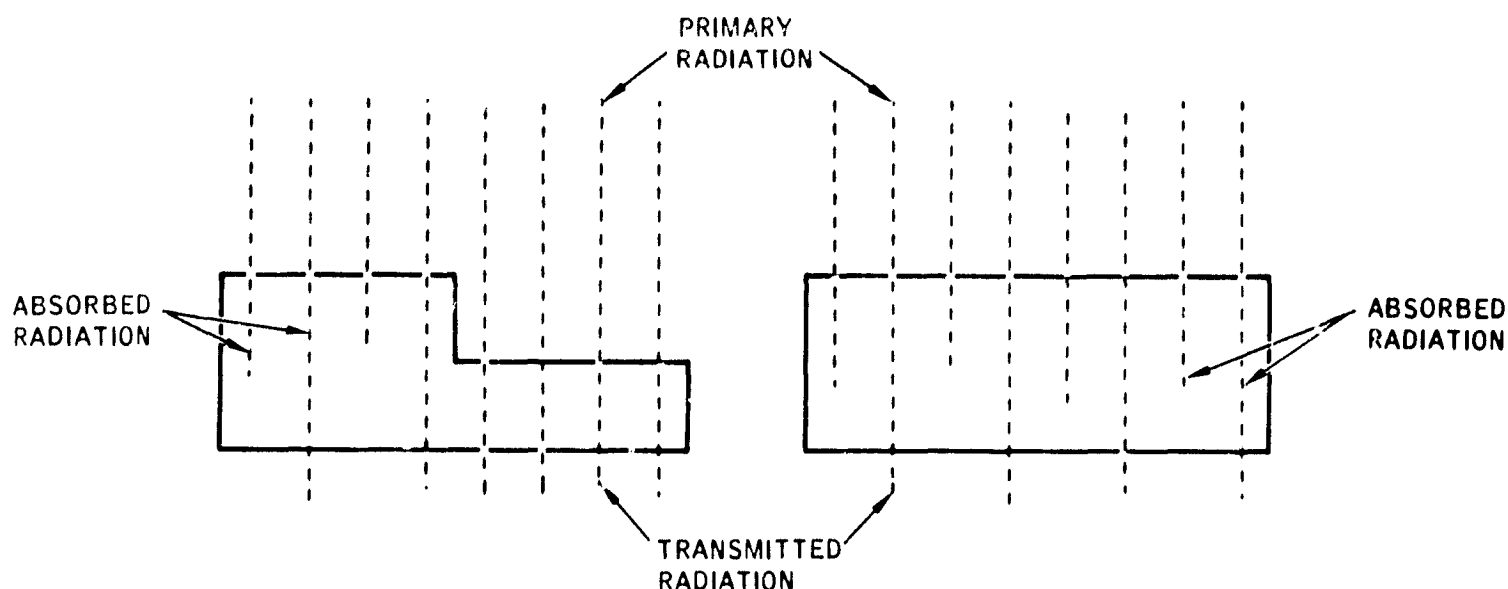


Here we show two specimens - just alike - and inside each specimen we have an inclusion - the inclusions have the same size and shape but inclusion B is more dense than inclusion A. Let us suppose that the base material of the two specimens is more dense than either inclusion.

The subject contrast for inclusion A will be _____ than the subject contrast for inclusion B.

less Page 3-5
greater. Page 3-6

Apparently we've fogged up your think tank with this one.

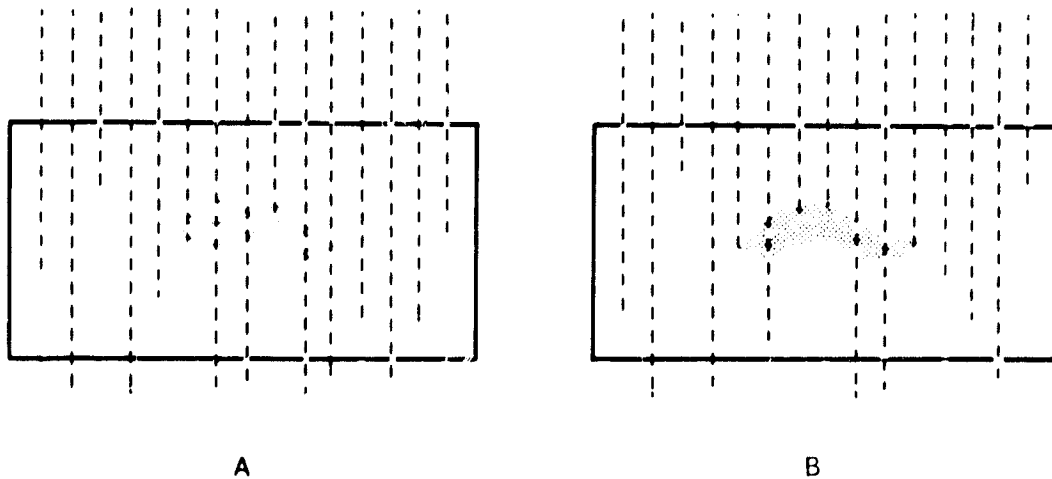


Here we are trying to show what happens to the radiation as it passes through the specimen. In the specimen on the left the thicker section absorbs more of the rays than the thin section. Therefore the thin section transmits more of the rays than the thick section. If we compare the transmitted intensity of the thick section with the transmitted intensity of the thin section we will find that there is a difference. This difference will cause different film densities in the radiograph of this specimen, hence will cause a contrast in the film image that is due to the specimen.

In the specimen on the right there will be no change in the transmitted intensity over the entire specimen since all areas are transmitting the radiation equally well. Hence there will be no density differences on the radiograph of this specimen — no subject contrast.

Turn to page 3-3.

Well, this was a tough one. Let's analyze the problem.



First — remember that the specimens are more dense than either inclusion.

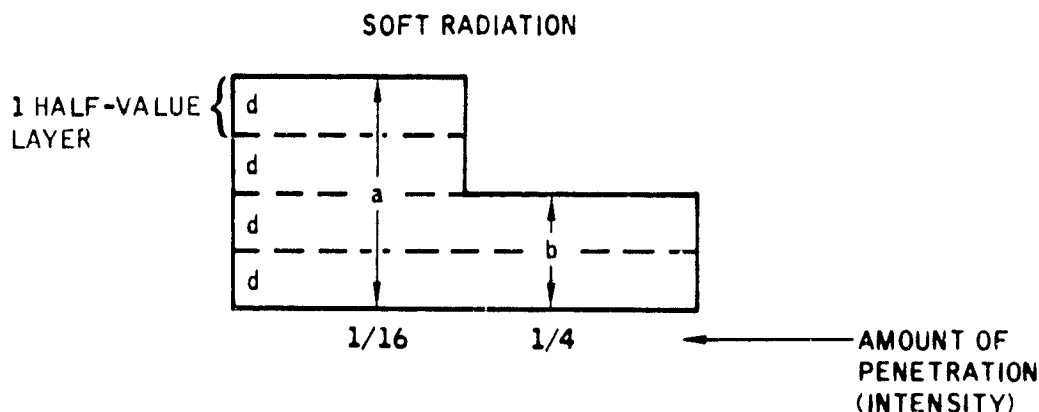
Second — the inclusion is more dense in specimen B than in Specimen A. It follows then, that the change in density between the inclusion and the specimen is greater in specimen A.

The greater change in density means a greater change in transmitted intensity for specimen A.

Turn to page 3-6.

Excellent. You seem to understand the relationship between subject contrast and change in specimen density. A specimen that varies in either thickness or density transmits different intensities through its various areas resulting in contrast on the radiograph.

Radiation energy. Subject contrast is affected by the energy of the radiation. In general, the best possible subject contrast is achieved by utilizing rays produced by the lowest kilovoltage that will penetrate the specimen. In the next few pages we will show you why this is true.



Let us suppose that, for a ray of a given wave length, the half-value layer of this particular specimen is equal to "d". For section thickness "a" the radiation will have to penetrate through 4 half-value layers and will emerge at 1/16 the original value ($1/2 \times 1/2 \times 1/2 \times 1/2 = 1/16$). For section thickness "b" the radiation will have to penetrate through 2 half-value layers and will emerge at 1/4 the original value ($1/2 \times 1/2 = 1/4$).

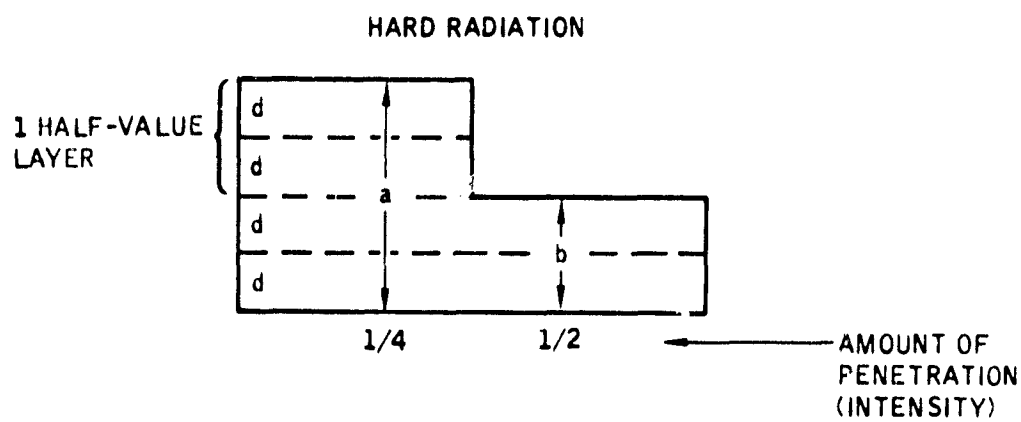
Remembering that subject contrast is the ratio of the transmitted intensities, compare the transmitted intensity of section "a" with the transmitted intensity of section "b".

The subject contrast between the two areas is

4 Page 3-7

16 Page 3-8

Excellent choice. $1/4$ divided by $1/16 = 4$. Now let's use a shorter (harder) wave length. Let's increase the voltage to obtain a wave length that will cause the half-value layer in this material to be " $2d$ ".



At section "a" this ray will now have to penetrate two half-value layers and will emerge at $1/4$ of its original value. At section "b" the ray will have to penetrate one half-value layer and will emerge at $1/2$ of its original value.

Comparing the transmitted intensities of $1/4$ and $1/2$, the ratio of subject contrast is

2 Page 3-9

4 Page 3-10

Perhaps you don't understand just what we mean by "the ratio of transmitted intensities". To take a ratio of two numbers you compare them by dividing the smaller number into the larger number. In this case it works like this: 1/4 (the larger number) divided by 1/16 (the smaller number) equals 4.

$$\frac{1/4}{1/16} = \frac{16}{4} = 4$$

or, if your math is a little rusty, you can think of it this way:

$$1/4 = 4/16; \text{ therefore } 1/4 \text{ is 4 times as big as } 1/16.$$

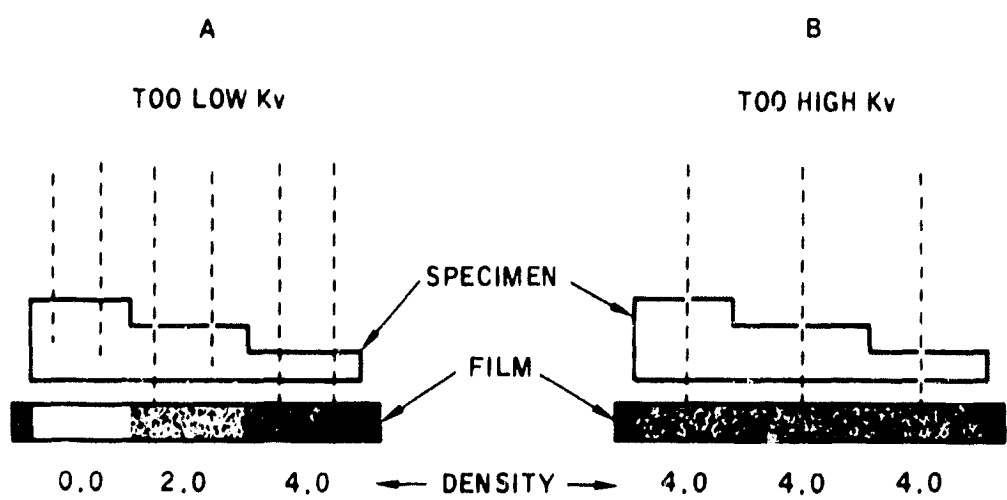
The ratio between 1/4 and 1/16 therefore is 4. The ratio of transmitted intensities is 4.

If the fractions confuse you let's use some real values. Suppose the radiation from the source had a value of 16 roentgens per minute. One fourth of this would be 4 roentgens per minute transmitted intensity. One sixteenth would be 1 roentgen per minute transmitted intensity.

$$\text{Ratio of transmitted intensities} = \frac{4 \text{ roentgens}}{1 \text{ roentgen}} = 4 - \text{contrast}$$

Turn to page 3-7.

Excellent. Referring back to page 3-6, when using the softer radiation, the contrast figured out to be 4. When we increased the energy of the radiation the contrast figures out to be 2. Thus by increasing the penetrating power of the ray we have decreased the contrast from 4 to 2. However, there are limits to how far the kilovoltage can be changed.



As shown in detail "A", a very low kv results in zero penetration of the thickest section of the specimen, while in the thinnest section, penetration is sufficient to give a very high density. This results in very high contrast, but is obviously impractical since discontinuities that might lie in the thickest section could not appear on the image. In detail "B" a kv is selected that is so high that it penetrates all sections almost equally; thus, the result is almost equal density on all sections of the radiograph with no contrast at all.

Contrast, within certain limits determined by specimen thickness, is affected by the energy of the ray.

- True Page 3-11
- False Page 3-12

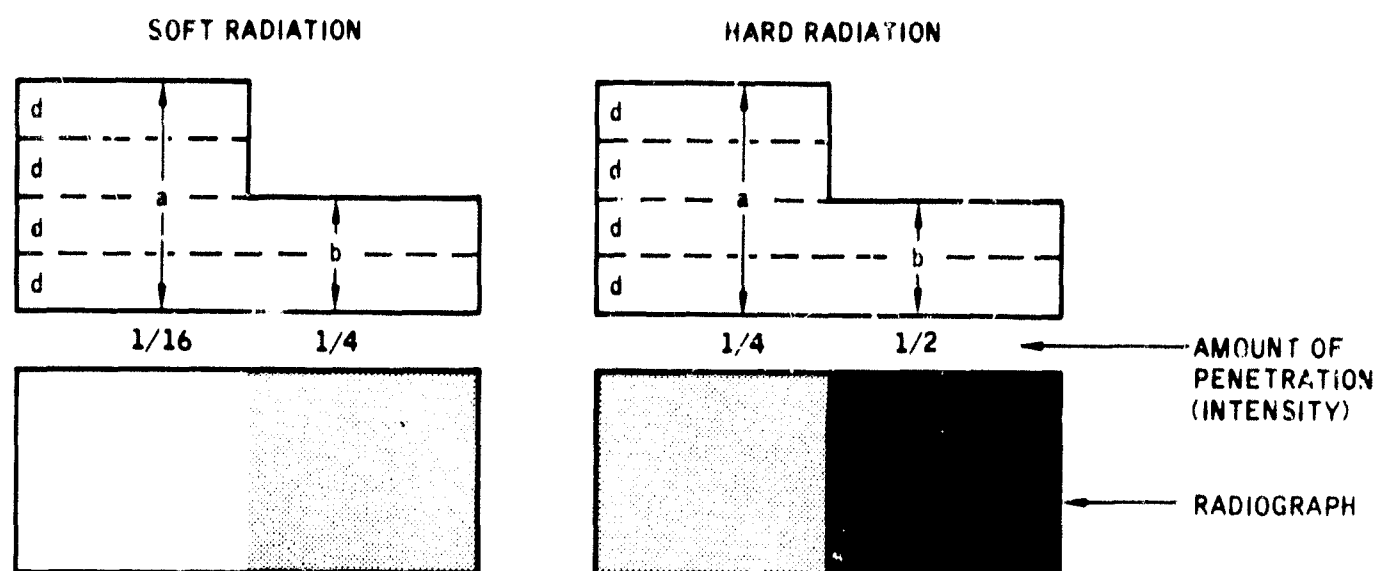
From page 3-7

3-10

Whoa! Since $1/2$ is twice as large as $1/4$ they have a ratio of two. A ratio can always be thought of as the number of times the smaller number will go into the larger number. In this case $1/2$ divided by $1/4$ equals 2; or, if you prefer, $1/2$ is twice as big as $1/4$.

Turn to page 3-9.

Very good! The energy of the ray has a direct effect on the subject contrast. Let's take another look at the effect of increasing the hardness of the ray. On the left we show the penetrating effect of the softer ray that we covered on page 3-6. On the right we show the penetrating effect of the harder ray that we covered on page 3-7. The radiograph of each specimen shows the effective film density that results from the penetration of the rays. The numbers show the comparative amount of penetration.



From a study of the above, which of the following statements is true?

Increasing the energy of the ray increases the subject contrast Page 3-13

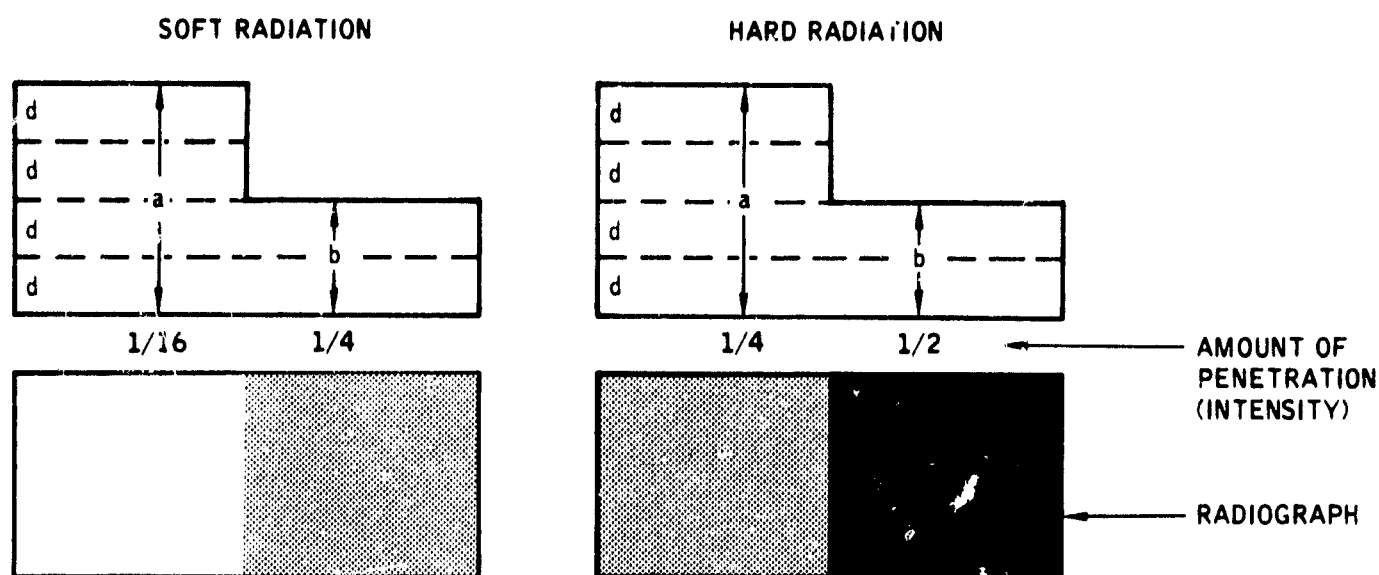
Increasing the energy of the ray decreases the subject contrast Page 3-14

From your answer we assume you feel that contrast is not affected by the energy of the ray. This is not true. Contrast is affected by the energy of the ray. Increasing the kilovoltage across an x-ray tube increases the energy of the ray. As the energy of the ray increases to a high value, the penetrating power of the ray increases so that the rays pass through all thickness of the specimen with almost equal ease. When this occurs there can be no noticeable subject contrast. This is one extreme.

At the other extreme, the energy of the ray is so reduced that it cannot penetrate the thicker parts of the specimen while easily passing through the thinner parts, then we get a high transmitted intensity for the thinner areas but no transmitted intensity for the thicker areas. This results in a great deal of subject contrast.

Turn to page 3-11.

Let's take another look at the illustration.



Note that the radiograph on the left shows a large variation in the density between the two areas. This means that it has high contrast. Note that the radiograph on the right does not show as great a variation in density. This means that it has less contrast.

This change in the degree of contrast between the two film illustrates exactly what we mean when we say increasing the energy of the ray decreases the subject contrast.

Turn to page 3-14 and proceed.

Excellent. This point is difficult but you seem to understand it. Increasing the energy of the ray does decrease subject contrast.

Let's summarize what we know about subject contrast.

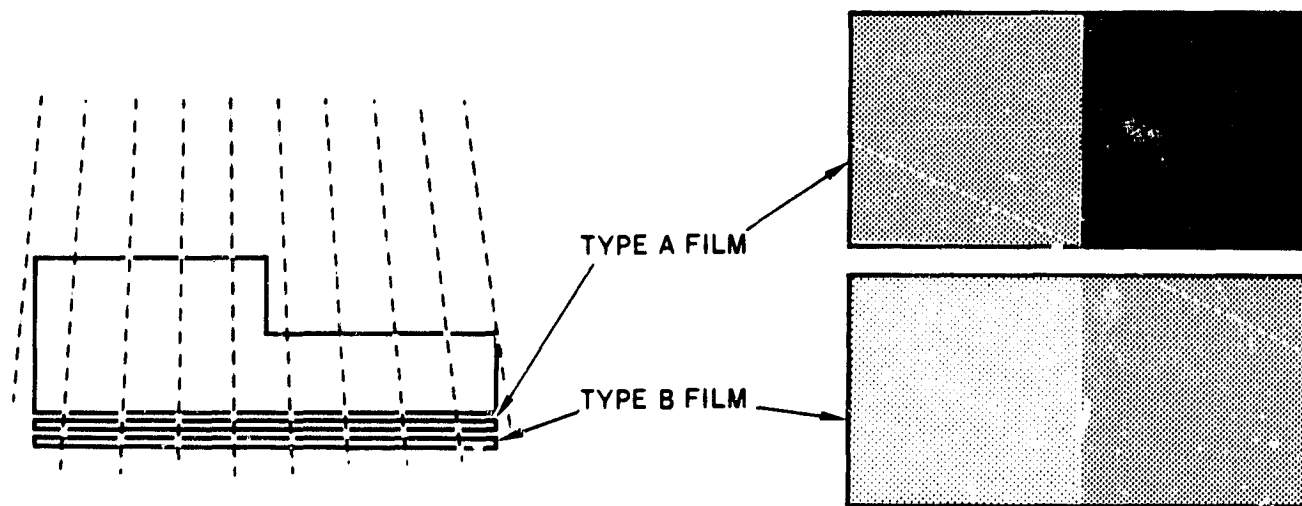
Subject contrast is affected by:

Thickness differences in the specimen.

Density differences in the specimen.

Radiation energy (kev) used.

The next factor that we are going to consider is film contrast. "Film contrast" is defined as the inherent ability of a film to show a density difference for a given change in film exposure (radiation received at the film). The different film manufacturers all produce several different types of films that are used in radiography. Some types have the ability to show more "film contrast" than other types. Assume a given change in exposure from one area of the film to another — the film that shows the greatest density difference has the greatest contrast.



In the illustration above assume that we have exposed these two films together — that is one right beneath the other — so that they both received the same amount of radiation (exposure) transmitted through the specimen.

Which film has more "contrast"?

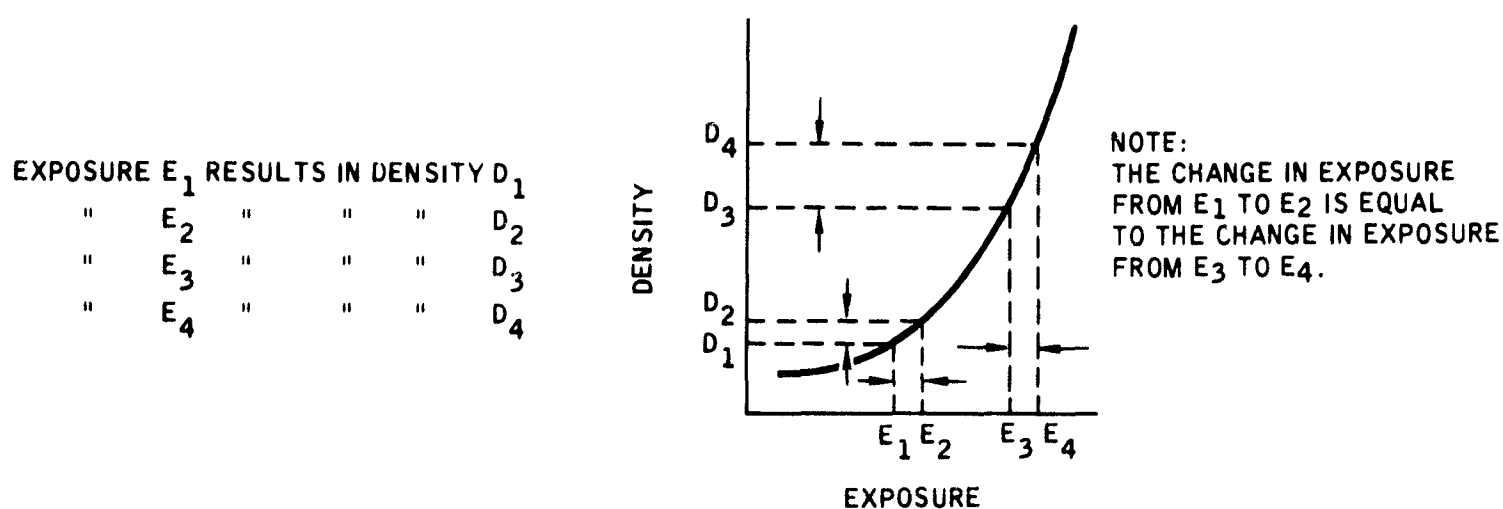
Type A Page 3-15

Type B Page 3-17

Right! Since film A shows a greater change in density for a given change in exposure it shows more contrast.

Films that show high contrast are desired when small defects are sought, since the small change in exposure represented by the change in transmitted radiation caused by a small discontinuity must be shown by a discernible density difference in the film image.

Let's expose several pieces of one type of film with different exposures and then plot the exposure versus the acquired density. When we do this we get a curve that shows the relationship between exposure and density for that type of film. In general such a curve will look like this —

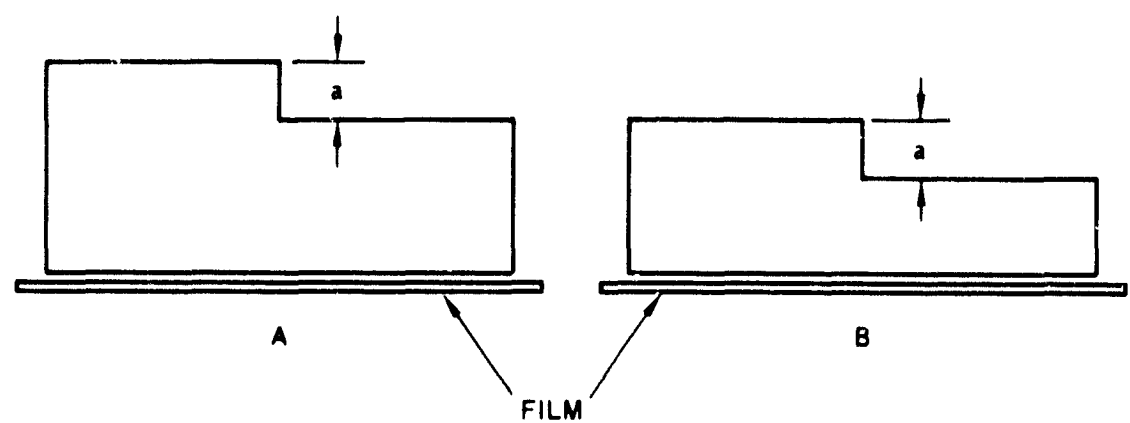


This curve shows that the contrast of the film increases as the film density increases. For example — suppose that the exposure of the film varies from E_1 to E_2 due to a void in the specimen. Note that the resulting contrast is the difference between D_1 and D_2 . Now if we had used a higher exposure so that the void had caused a difference in exposure E_3 to E_4 (equal to $E_1 - E_2$), the difference in density is now D_3 to D_4 . This is considerably greater contrast than D_1 to D_2 .

Thus we can say that film contrast improves with increasing film density. The darker the film the better the contrast. (There are exceptions to this rule which will be discussed in due time).

Turn to the next page.

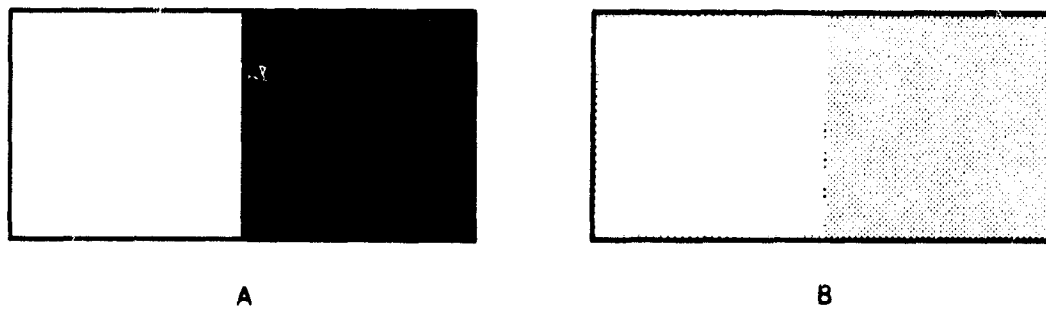
Remember — film contrast improves with film density.



Here we show two similar specimens that differ only in their thickness. Note that the change in thickness (a) of each specimen is the same. Assuming that both specimens receive the same exposure and that the same type of film is used, which radiograph is going to show the most contrast?

- A Page 3-18
- B Page 3-19

You don't seem to understand the term "contrast". Here we are illustrating exactly what is meant by contrast.

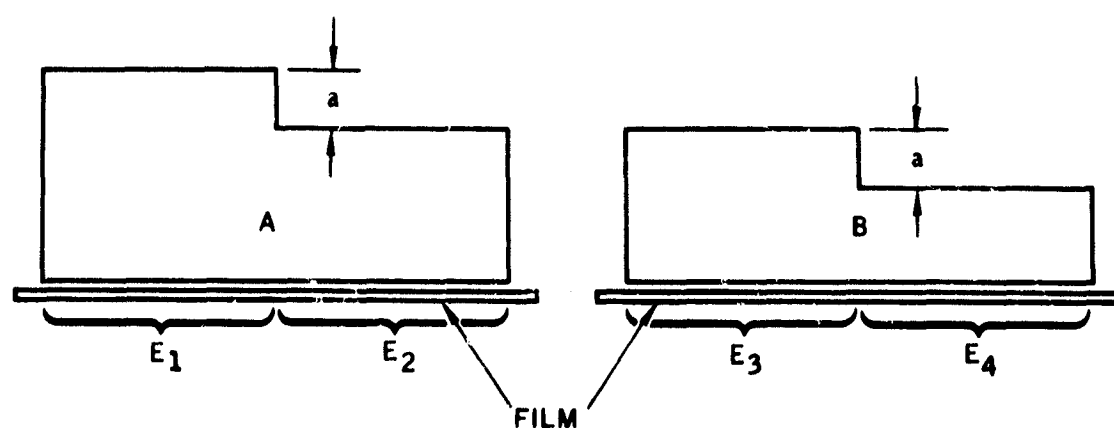


Note that in radiograph A we are showing a very light area next to a very dark area. These two areas of the radiograph show a great deal of difference in darkness (or density). Therefore the radiograph shows a great deal of contrast.

In radiograph B one area of the film is only slightly darker than the other. Since the difference in darkness (or density) is only slight, the radiograph has very little contrast.

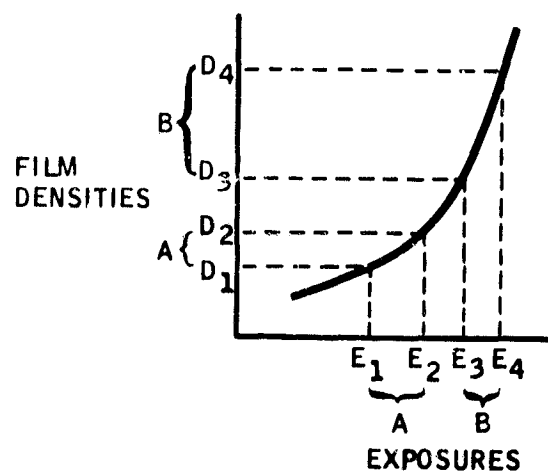
Turn to page 3-14, re-examine the question and select the other answer.

Sorry. Let's analyze the problem.



Specimen A is going to absorb more of the primary rays than specimen B. Therefore, film A is going to receive less radiation than film B. Therefore, film A is going to be less dense than film B. Therefore, film A is going to have less contrast than film B.

Here's what the above situation would be if shown on the film exposure curve.



Although the change in exposure for film A ($E_2 - E_1$) is equal to the change in exposure for film B ($E_4 - E_3$), the change in film density for film A ($D_2 - D_1$) is less than the change in film density for film B ($D_4 - D_3$). Film A will have less contrast than film B.

Turn to page 3-19.

Excellent. That took some reasoning. We hope you realized that specimen B would not absorb as many rays so film B would receive more exposure. We hope you reasoned that since film B received more exposure that it would be darker (more dense) and since it was more dense it would have more contrast.

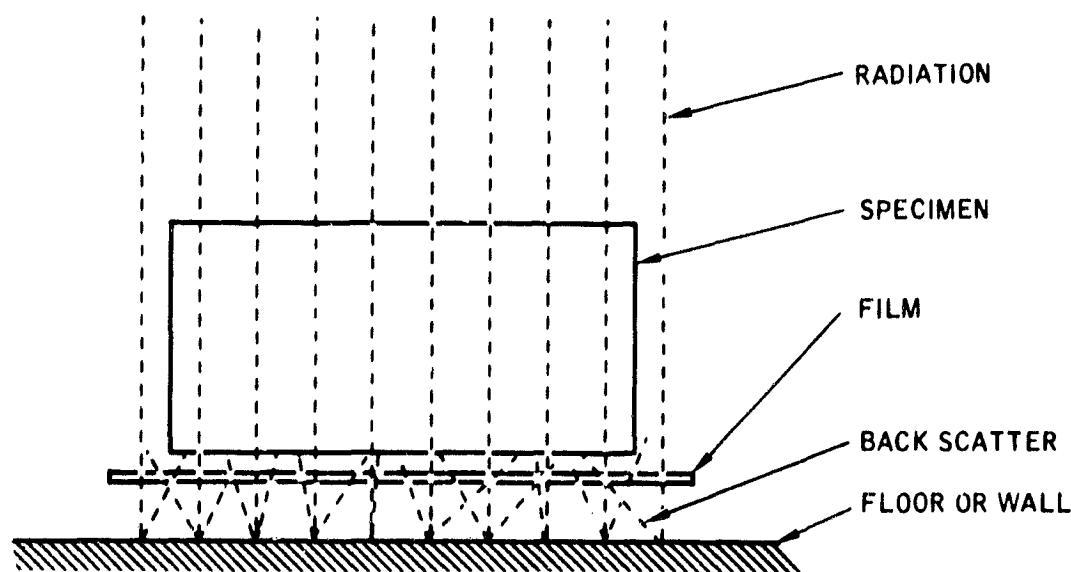
Since contrast is affected by the acquired density, the radiograph should always be exposed to give the highest density which can be viewed and diagnosed with the available viewing equipment.

Now let's take just a moment and sum up what we have learned about contrast.

<u>CONTRAST</u>	
<u>SUBJECT CONTRAST AFFECTED BY</u>	<u>FILM CONTRAST AFFECTED BY</u>
THICKNESS DIFFERENCES IN SPECIMEN (THE GREATER THE CHANGE IN THICKNESS THE GREATER THE CONTRAST)	TYPE OF FILM (SOME FILMS GIVE BETTER CONTRAST THAN OTHERS AT A GIVEN EXPOSURE)
DENSITY DIFFERENCES IN SPECIMEN (THE GREATER THE CHANGE IN DENSITY THE GREATER THE CONTRAST)	DENSITY OF FILM IMAGE (THE DARKER THE FILM THE GREATER THE CONTRAST)
RADIATION ENERGY (KEV) USED (HIGHER ENERGY, LESS CONTRAST, LOWER ENERGY, MORE CONTRAST)	

Review these factors to fix them in your mind for a minute or two — then turn to page 3-20.

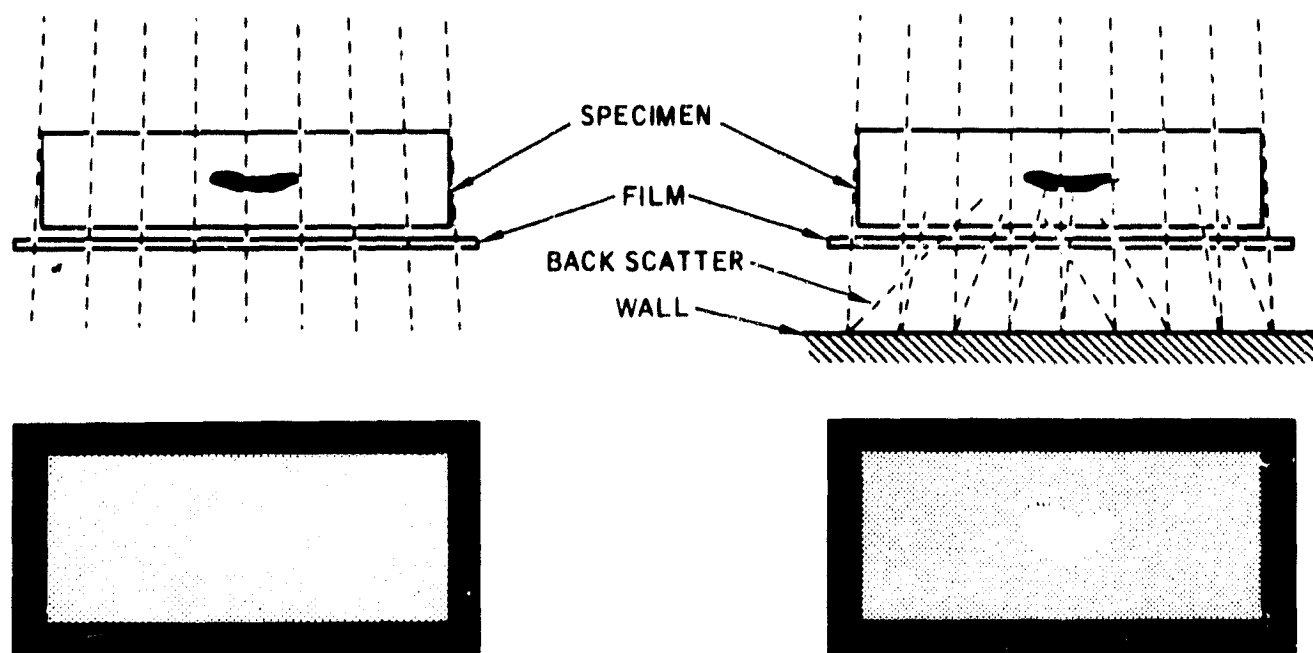
Scatter radiation. In the last chapter we saw how internal scatter and side scatter affected the definition of the radiograph. Contrast is also influenced by scattered radiation from these sources. In addition, back scatter also influences the contrast of the radiograph.



Scatter from all these sources, if allowed to reach the film, would cause a haziness or fog over the whole image, or parts of it, thus reducing contrast.

The contrast of the radiograph is _____ by back scattered radiation.
improved Page 3-21
reduced Page 3-22

By your selection you have indicated that back scattered radiation improves the contrast of the radiograph. This is not correct. Consider the radiograph of a specimen of uniform thickness that contains an inclusion.



In the radiograph on the left (no backscatter) the image of the inclusion is in good contrast with the background image of the specimen. In the radiograph on the right, the image of the inclusion is visible but because the back scatter has intercepted and exposed the film where the image should be, it does not have good contrast with the background image of the specimen.

Turn to page 3-22.

That's right, the contrast of the radiograph will be reduced by back scatter.

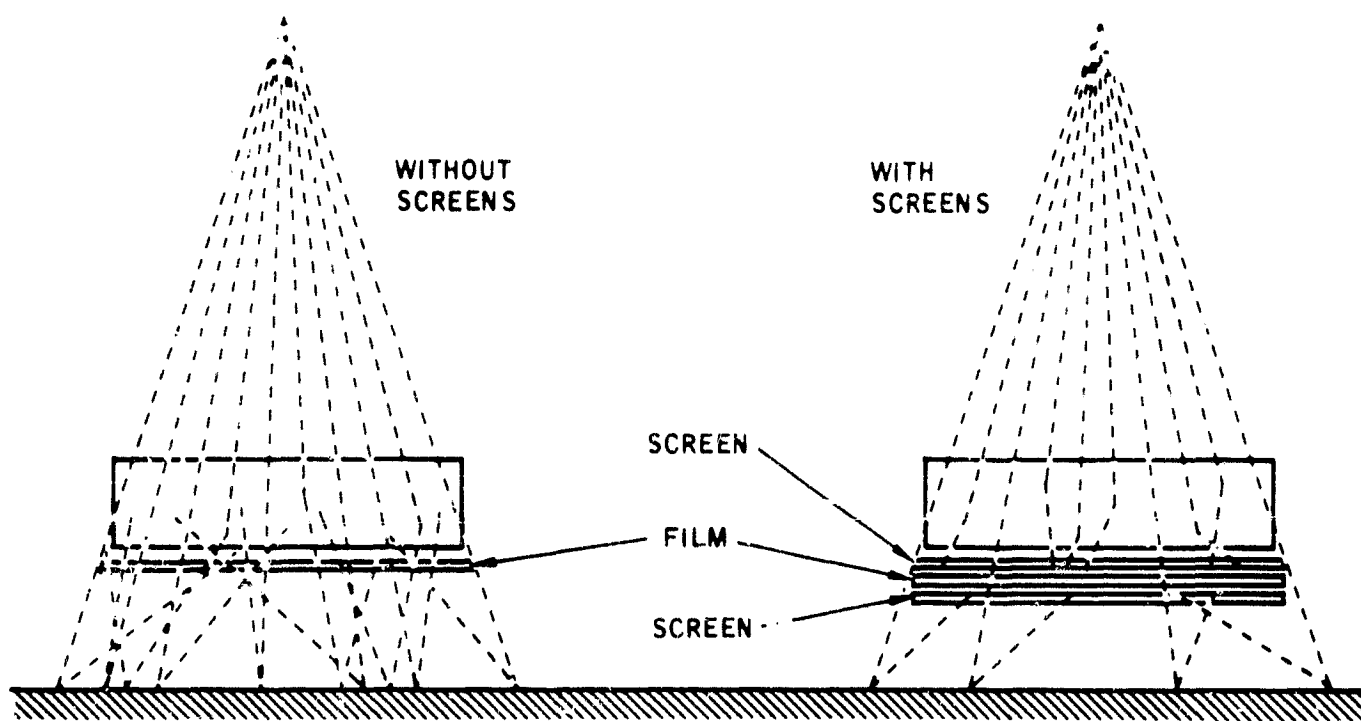
Internal scatter, side scatter, and back scatter all affect the contrast of the radiograph. In Chapter 2 we learned that internal scatter and side scatter also affect the definition of the radiograph. It is apparent then that if all types of scattering are reduced or kept from reaching the film, the quality of the radiograph will be improved.

Scatter control. Since scatter produces an overall fogging, reduces the contrast of the image, and spoils the sharpness of the image, steps should be taken whenever possible to reduce scatter to a minimum. Various techniques are used to control and reduce scatter radiation.

Turn to page 3-23.

Screens. The cheapest, most convenient, and most universal means of controlling the effects of scattered radiation are sheets of lead foil called screens. As you learned earlier in this book, lead screens serve to increase the photographic action on the film largely by reason of the secondary radiation of electrons emitted from the screen.

In addition to intensifying the film image, lead screens serve to filter out (absorb) low energy scattered radiation while being too thin to appreciably absorb the high energy primary rays. Thus, they serve to control scattered radiation and improve the film image quality (definition and contrast).



Scattered radiation is absorbed more than primary radiation by the lead screens because _____.

the scattered radiation has more energy Page 3-24

the primary radiation has more energy Page 3-25

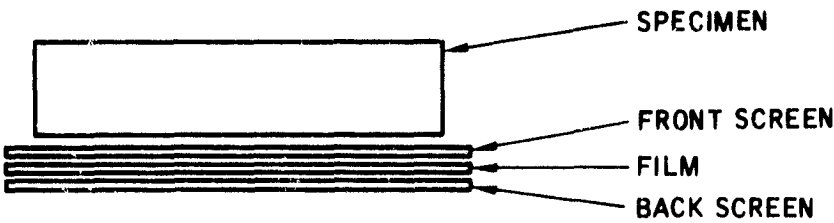
You have forgotten one of the basic facts in radiography. Scattered radiation always has less energy than the primary radiation. Since the scattered radiation has less energy it is more easily absorbed by the lead.

Perhaps you are still confused by the relationship between wave length and energy. If so, you had better learn it fast because you are going to need it. Short wave length — high energy. Long wave length — low energy.

Turn to page 3-25.

Right. The rays with the lower energy are absorbed. Since the scattered rays have lower energy than the primary rays they are absorbed more.

Back screens, because they do not have to permit passage of any rays to create the film image may be of any required thickness. Thus, back screens may be used that are thick enough to absorb essentially all back scattered rays.



Back screens, when thick, are effective in blocking back scattered rays because they absorb _____.

essentially all the back scattered rays of all energies Page 3-26

the lower energy back scattered rays Page 3-27

Good! The back screen serves to absorb essentially all of the back scattered radiation of all energies.

The front screen also has the effect of intensifying the primary radiation more than the scattered radiation. Any scattered radiation that is absorbed by the screen does not have a high enough energy level to cause an appreciable number of electrons to be emitted from the screen. Since the primary rays do have the energy to cause many more electrons to be emitted from the screen, their effect is intensified.

Emission of electrons from front screen to film results mostly in intensification of _____ energy level rays.

high Page 3-28

low Page 3-29

From page 3-25

3-27

Sorry, I'm afraid you do not have the point. Don't forget that the absorption ability of any material depends upon the thickness of the material. Since the back screen is thicker it is capable of absorbing a wider band of ray energies than the thinner front screen. That is to say, the back screen will absorb all of the rays that the thinner screen will absorb plus some more of the higher energy rays.

Turn to page 3-29 and continue.

Right! The lead screen essentially intensifies the high energy level rays and absorbs the low energy level rays. The filtering effect and intensifying effect of the lead screens is dependent upon the energy level of the rays. Above 150 kv the intensifying feature is more effective because the rays have the necessary energy to liberate electrons in the screen. Below 150 kv the shielding effect overcomes the intensifying effect as more of the primary rays will be absorbed.

Proper care and use of screens is very important. Contact between the lead foil and the film is essential to good radiographic quality. As in any intensifying screen, fuzzy images are produced whenever the screen and film are not in close contact. Scratched, buckled, crimped, or gouged screens can show images on the film which may result in rejection of the final radiograph. Grease, lint, dirt, lead chips, etc., because they absorb radiation, will cause a screen to produce their marks on the film. Deep scratches on lead foil screens will result in dark lines on the film. These images may be confused with defect images. Oxidized screens may deposit lead oxide on the film. This oxide will cause streaking or staining of the film upon development.

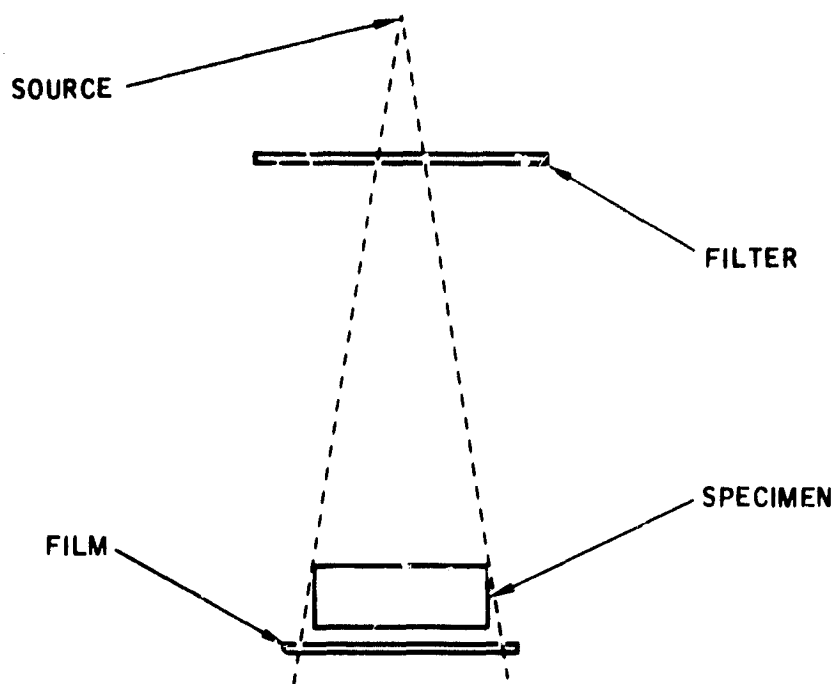
Turn to page 3-30.

You've forgotten some of the basic theory of radiography. High energy rays, because of their abundance of energy, are capable of knocking large numbers of electrons from their orbits in the atom. The lead sheet is a good emitter of electrons when it is placed under the high energy X or gamma radiation. Low energy scattered rays do not cause as many electrons to be emitted from the lead.

Since the primary rays are always of a higher energy than the scattered rays, the screen intensifies the effect of the primary rays more than the effect of the scattered rays.

Turn to page 3-28.

Filters. The scatter effect is also reduced through the use of sheets of copper or lead placed between the source and the specimen. These sheets, usually several millimeters or more thick, are called filters since their purpose is to filter out the lower energy, soft radiation which tends to scatter more.

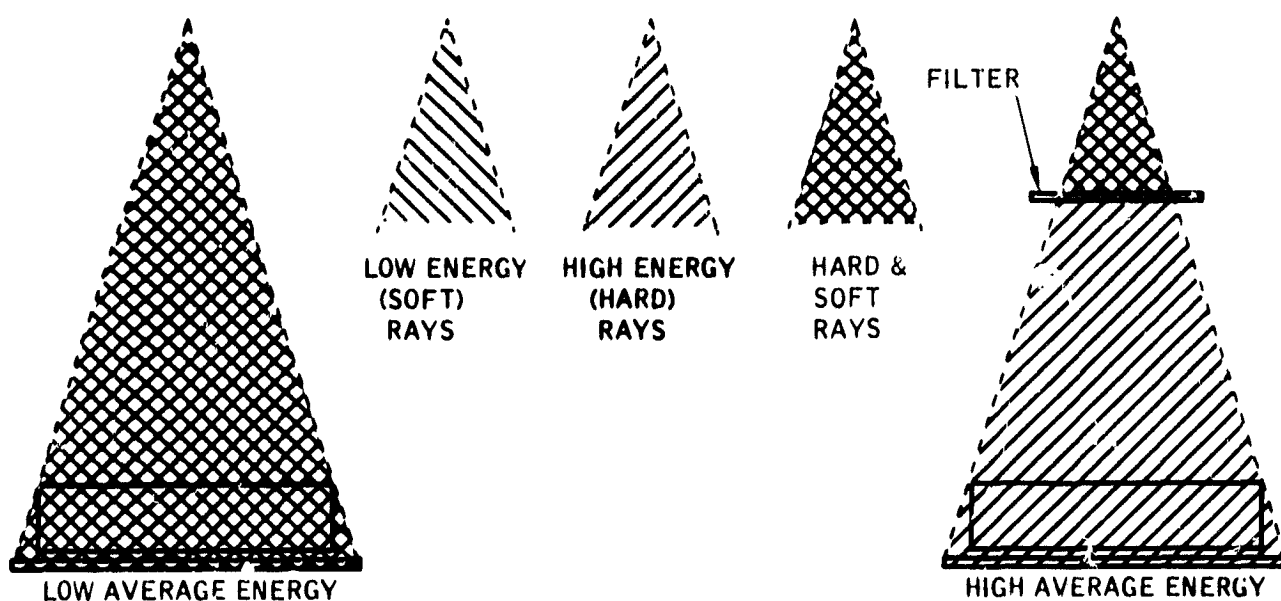


The filter absorbs more of the _____ energy rays from the X-ray beam leaving a higher average energy beam to penetrate the specimen and expose the film.

low Page 3-31

high Page 3-32

Excellent. The low energy rays are filtered from the beam to leave a higher average energy beam.



Here we are showing the effect of a filter. In the view on the left there is no filter. In the view on the right we show the effect of adding a filter.

Since the filtered beam now has a higher average energy there will be less internal scatter from the specimen. Thus filters are another method of controlling scatter.

REMEMBER — HIGH ENERGY RAYS PRODUCE MORE ELECTRONS BUT LESS SCATTERED RADIATION THAN LOW ENERGY RAYS.

Filters are used primarily with X-rays. Gamma rays usually have a limited range of wave lengths and a filter that would eliminate one wave length might eliminate all rays.

The filter is effective in reducing scatter because it reduces the amount of _____ scatter-producing radiation in the beam.

low energy Page 3-33
high energy Page 3-34

No. We are not changing the rules of radiography. Just as the screen absorbed the low energy rays, the filter also absorbs the low energy rays. Remember in any material the low energy rays are absorbed first. If the material is thick enough or dense enough then almost all rays of almost all energies are absorbed.

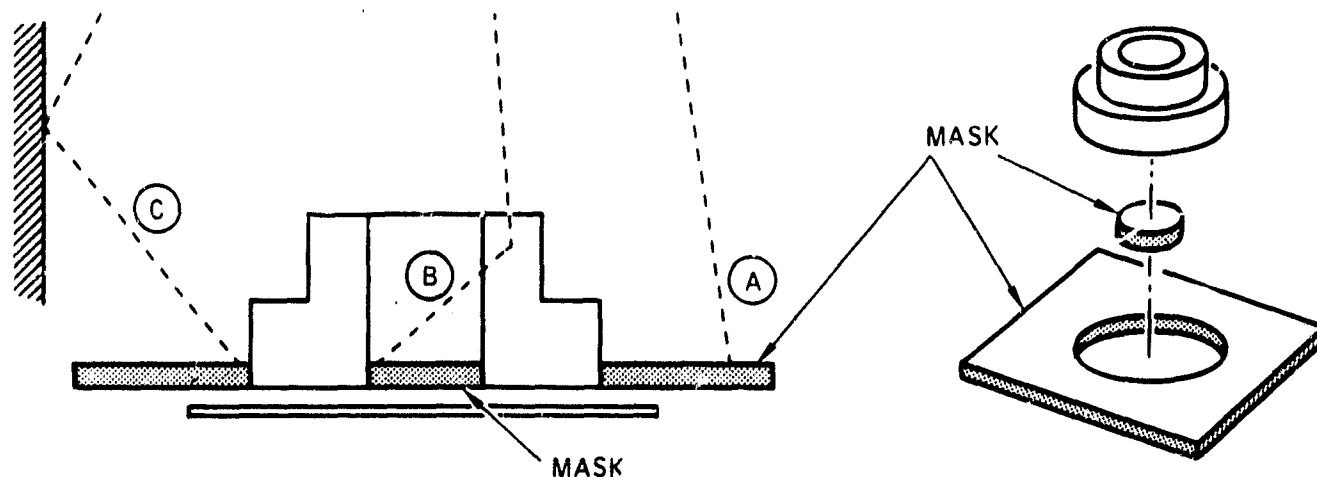
When a filter is placed between the source and the specimen the low energy rays are absorbed by the filter leaving a higher average energy beam to expose the radiograph.

Turn to page 3-31.

Right. The filter reduces the amount of soft, low-energy radiation in the beam. Since the soft radiation tends to scatter more, the filter effectively reduces scatter.

When filters are used it may be necessary to increase the time of exposure to compensate for the radiation absorbed by the filter. Remember, too, that absorption by the filter increases with the density and thickness of the filter material.

Masking. Another technique that is used to reduce the effect of scatter when radiographing castings or other irregularly shaped objects is masking. Masks are prepared by cutting an opening in a lead sheet that will fit around the specimen. Other pieces may be cut to fit internal holes in the specimen.



- (A) Excess primary rays are absorbed, cutting down on number of rays available to cause any scatter from external sources.
- (B) Internal scatter causing edge cutting is reduced.
- (C) Side scatter causing edge cutting is reduced.

The mask is made of radiation absorbing material and is placed _____ the specimen.

on top of Page 3-35

around Page 3-36

We've got you thoroughly confused. Let's see if we can straighten things out for you.

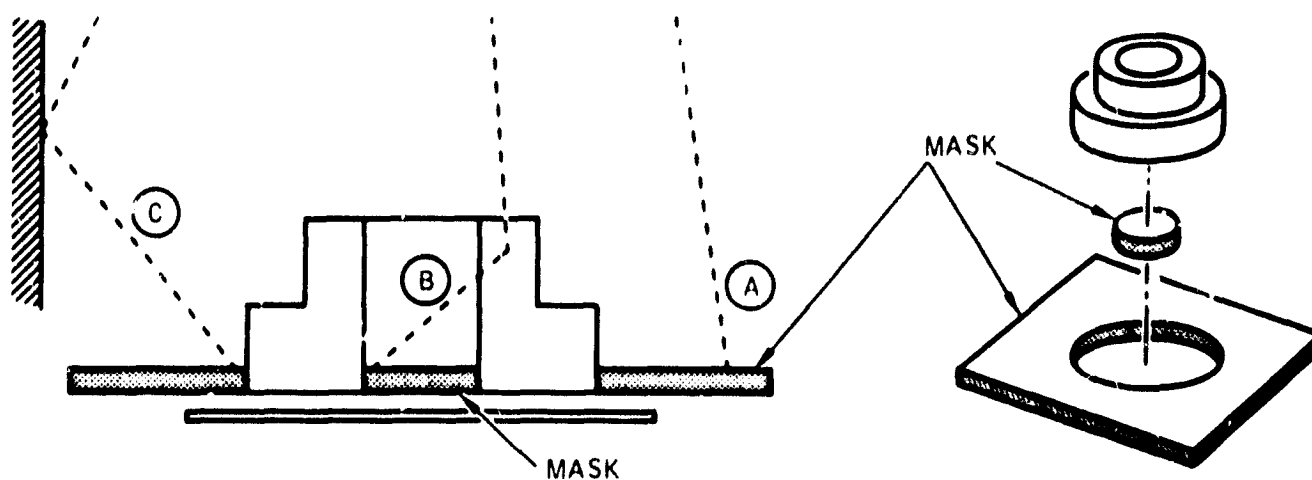
You must remember these facts:

- 1) Soft radiation is low energy radiation, and hard radiation is high energy radiation.
- 2) Soft (low energy) radiation results in more divergent scattering of radiation.
- 3) Filters reduce the amount of soft (low energy) radiation in the beam.
- 4) Therefore — the filter effectively reduces scatter by reducing the amount of low energy radiation in the beam.

Do not confuse scattering of electrons with scattering of radiation. High energy radiation produces more electrons but less scattered radiation than low energy radiation.

Turn to page 3-33 and continue.

Let's take a closer look at the illustration.



The mask is placed around the specimen — not on top of it. In order to reduce edge cutting, the absorbing material must be down around the edges of the specimen to be in position to intercept and absorb the scattered radiation that causes edge cutting (B and C above).

Turn to page 3-36.

Right. The mask is placed around the specimen.

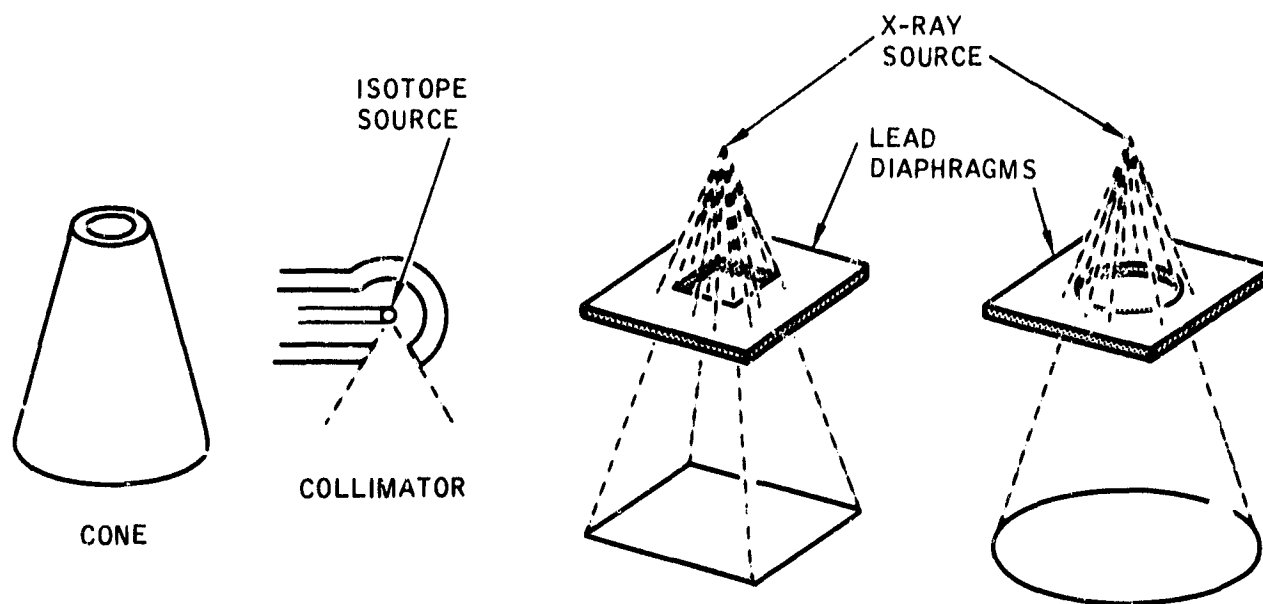
Other types and forms of materials are also used as masking. Metallic shot or powder (lead, copper, or steel) may be placed around the specimen to serve as a mask. Lead and steel wool are also used. Barium and bismuth clay are good radiation absorbers and are easy to mold around irregular objects. Liquid absorbers can also be used.

The material used in masking must have a _____ radiation absorbing ability.

high Page 3-37
low Page 3-38

Very good. The masking material must have the ability to absorb the radiation that it intercepts. It must have a high radiation absorbing ability.

We know that any material that receives primary radiation from the source will generate scatter. It follows then that we can reduce scatter by limiting the radiation beam to the area covered by the specimen. Primary radiation not reaching side walls, etc., cannot add to the scatter problem. In some cases, a lead diaphragm, or lead cone, on the tube head of an X-ray machine, or a collimator on an isotope source, may be a convenient way to limit the area covered by the X-ray beam. Such lead diaphragms and collimators are particularly useful where the desired cross section of the beam is a simple geometrical figure such as a circle, square, or rectangle. In addition, any reduction in the area of radiation is a good safety practice.



Finally, shielding of nearby objects, walls, floors, etc, with lead sheet serves to absorb much of the side and back scatter radiation so that it cannot reach the film.

It is always desirable to limit the amount of material other than the specimen that receives the direct radiation from the source.

True Page 3-39

False Page 3-40

From page 3-36

3-38

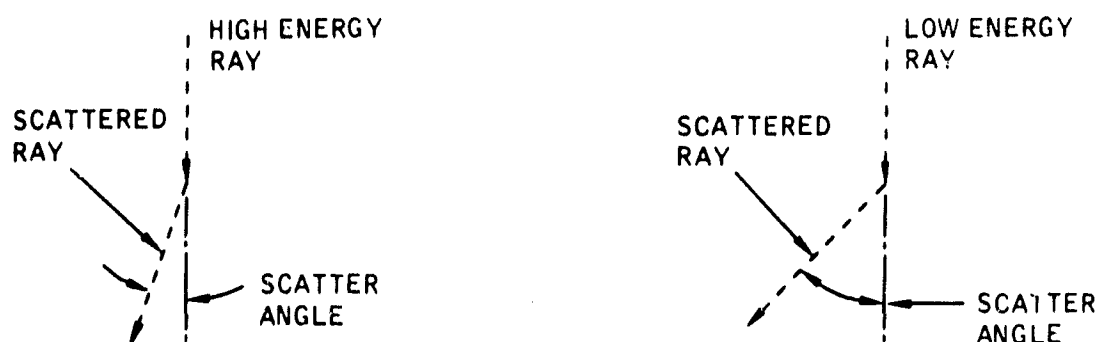
Slow down. You are not thinking. The mask, to be effective, must absorb all the radiation that it intercepts. The mask must have the ability to absorb both the primary radiation and any scattered radiation that strikes it. Therefore it must be a good radiation absorber. It must have a high radiation absorbing ability.

Turn to page 3-37.

Very good. It is always desirable to limit the amount of material that is receiving direct radiation. It is not always possible, but it is always desirable.

Kv and scatter. At the beginning of this chapter we discussed the effect that the energy of the ray had on contrast. You learned that, within limits, the higher kv gave less contrast.

Now we are going to see how kv affects scatter. Back in Volume I you learned that scatter resulting from a high energy primary ray did not have as large a scatter angle as the scatter resulting from a low energy ray.



This essentially tells us that the effect of scatter from low energy rays is worse than the effect of scatter from high energy rays. Scatter from low energy radiation, traveling at a greater angle with respect to the primary radiation, will cause a greater degree of fuzziness in the image. From this we can draw the conclusion that increasing the energy of the ray will reduce the effect of scatter.

In X-radiography we can increase the average energy of the beam by increasing the kilovoltage across the tube.

Increasing kv, then, will _____ the effect of scatter on the radiograph.

decrease Page 3-41

increase Page 3-42

You missed the point. It is always desirable to limit the amount of material that receives the direct radiation from the source. Here's why —

Whenever the primary radiation strikes any material, scatter is created. This scatter is not helpful to the radiograph so any means to reduce scatter is desirable. If, then, we remove all the material we can from the direct beam of radiation and limit the cone of radiation, we are eliminating sources of scatter and thereby reducing scatter.

Turn to page 3-39.

Right! As voltage across the tube is increased we get less scatter to fog the radiograph and to cause fuzzy images, but we also get less contrast in the final image. As voltage across the tube is decreased we get more contrast but we also get more scatter. What is important to you at this point is that you understand the effect that changing the voltage will have on the final image.

Suppose that you had taken a radiograph of some part and found that the edges of the part did not show too well on the radiograph. Keeping everything else the same, what would you expect from the next radiograph if you raised the voltage across the tube?

- a lighter image Page 3-43
- a sharper image Page 3-44

No — you've got it backwards. As the voltage across the tube is increased we can expect less scatter and less contrast. The higher voltage across the tube results in more energy in the wave. The added energy causes the ray to collide with an electron without changing its path very much. The paths of low energy waves are changed considerably when they collide with the electrons of the material in the specimen. Thus low energy waves create more scatter than high energy waves.

The added energy of the high energy ray permits the ray to penetrate all thicknesses of the specimen almost equally well. Since the penetration is almost equal in all areas, the contrast must necessarily be reduced.

Higher voltages — less scatter, less contrast — that's the picture.

Turn to page 3-41 and continue.

From page 3-41

3-43

If you expected a lighter image you are going to be disappointed.

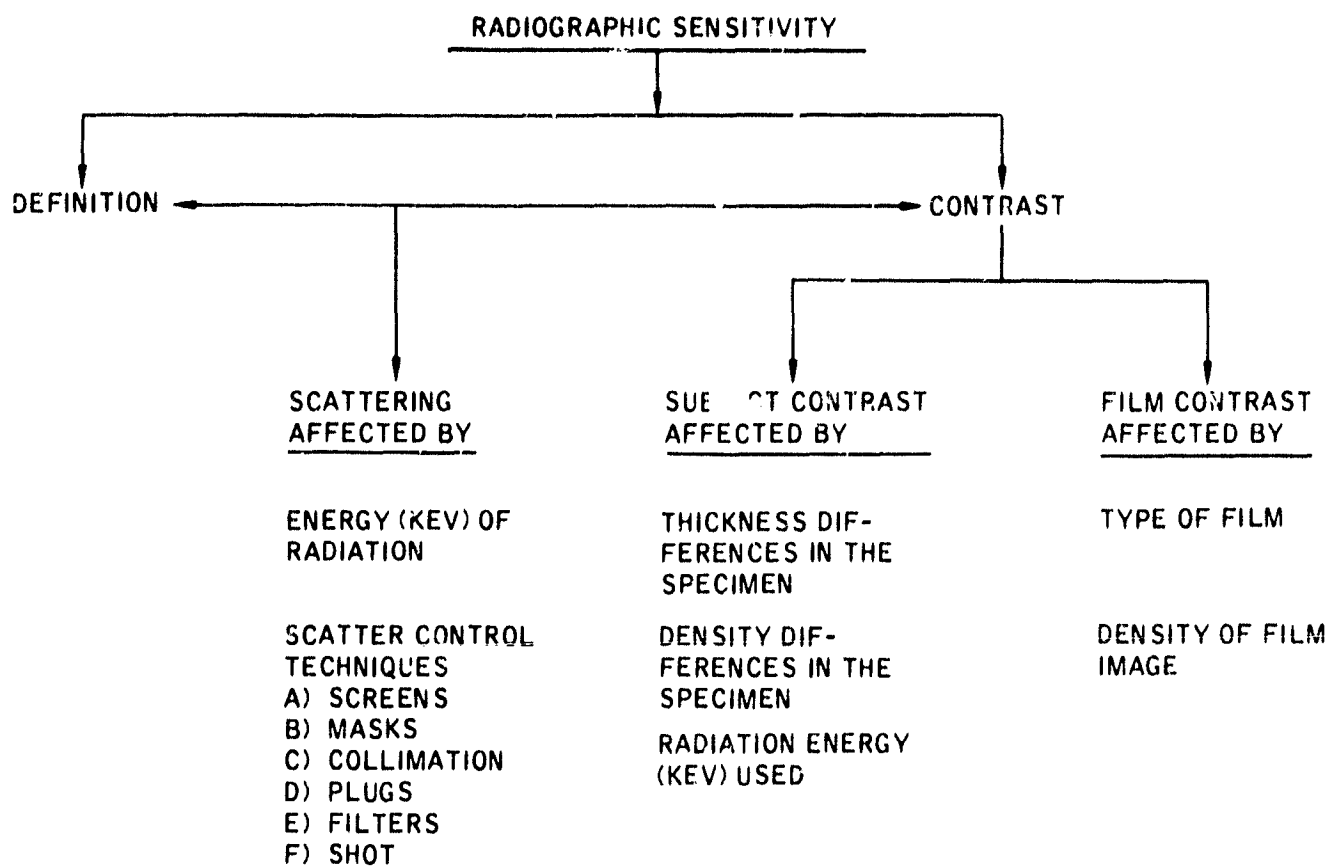
The higher voltage across the tube is going to give you a more penetrating, high-energy ray. The added penetration is going to darken the image.

Turn to page 3-41 and reread the question.

That's right, you could expect a sharper image.

You have probably realized by now that if increasing the voltage reduces the effect of scatter and at the same time reduces contrast there must be some compromise point where the scatter is acceptable and the contrast is adequate. This is true, however, other considerations are more important in the selection of the voltage to use. You will learn about these in the next two chapters.

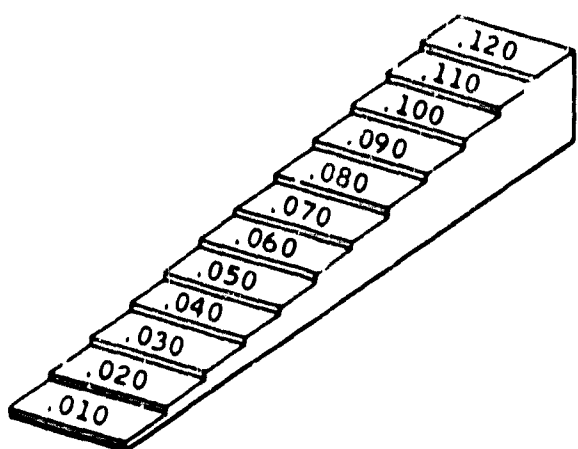
Here's what we've covered so far in this chapter.



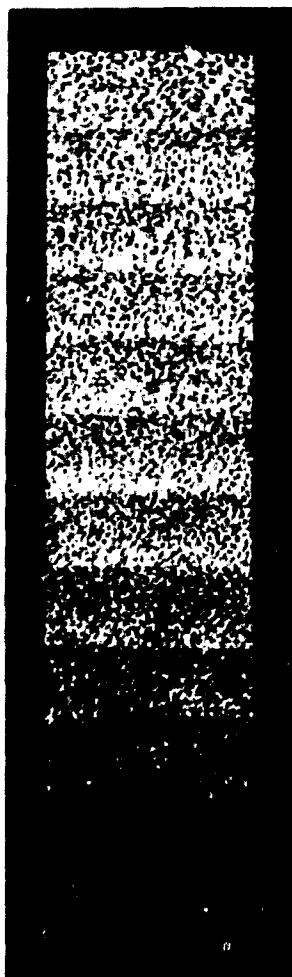
Now that you understand contrast, let's take a look at "latitude".

Turn to page 3-45.

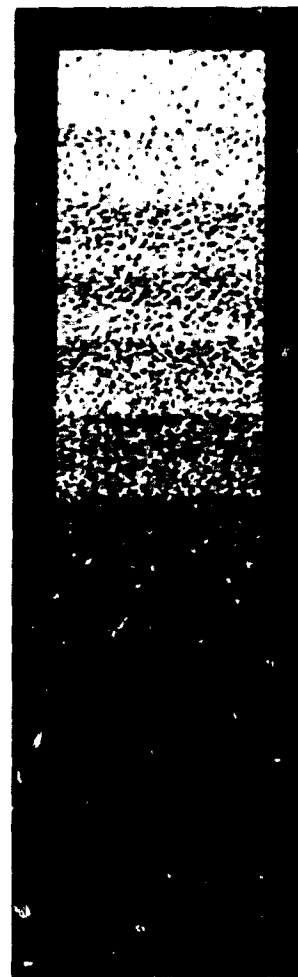
Latitude. Latitude is closely related to contrast, in an opposite sense. Here we show two radiographs of a "step" wedge. Note that in the radiograph on the left all of the steps are visible in the radiograph while in the radiograph on the right the thinner sections cannot be distinguished from each other.



STEP WEDGE



Kv 150



Kv 70

The radiograph on the left has more latitude than the radiograph on the right because more of the thickness variations are visible. The latitude of the radiograph is the range of thickness of material that can be adequately recorded on the radiograph.

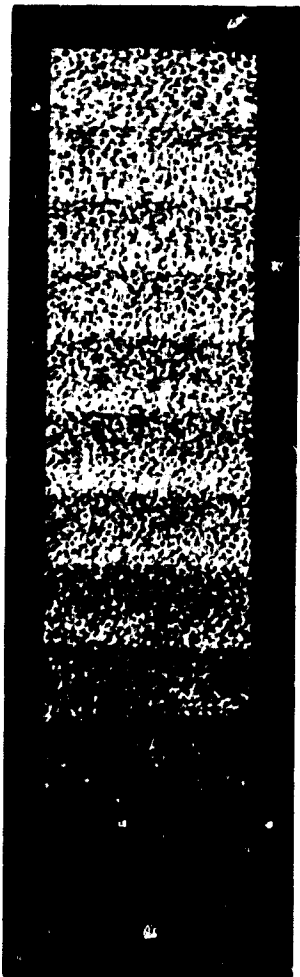
The radiograph on the left has _____ latitude than the radiograph on the right.

more Page 3-46

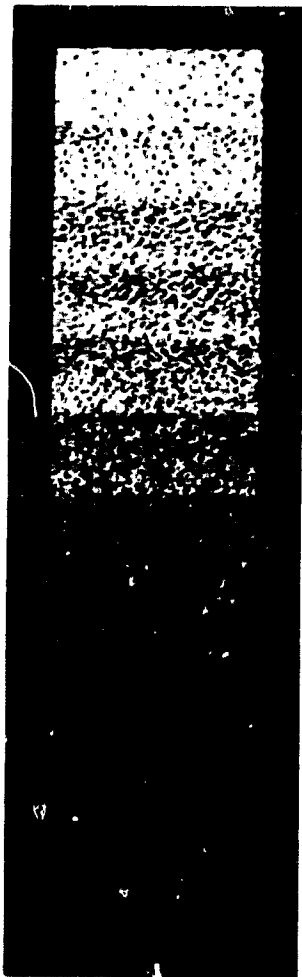
less Page 3-47

Very good. The radiograph showing the most variation in specimen thickness has the best latitude.

Now let's look at those radiographs again.



Kv 150



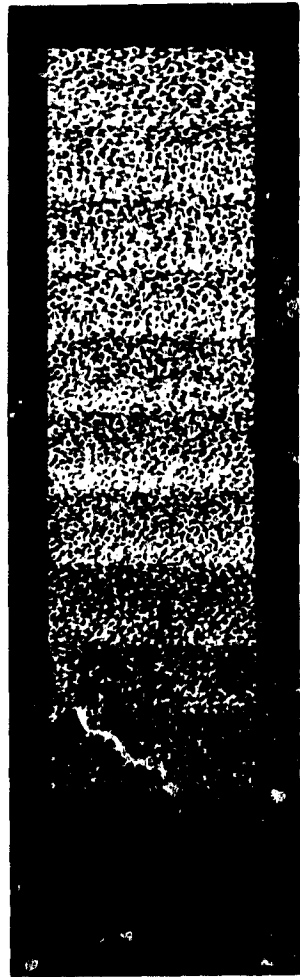
Kv 70

Which of these two radiographs shows the greatest change in film density?

the one on the left Page 3-48

the one on the right. Page 3-49

You felt that the radiograph on the left had less latitude than the radiograph on the right. You haven't quite seen the picture yet. Let's look at those radiographs again.



Kv 150



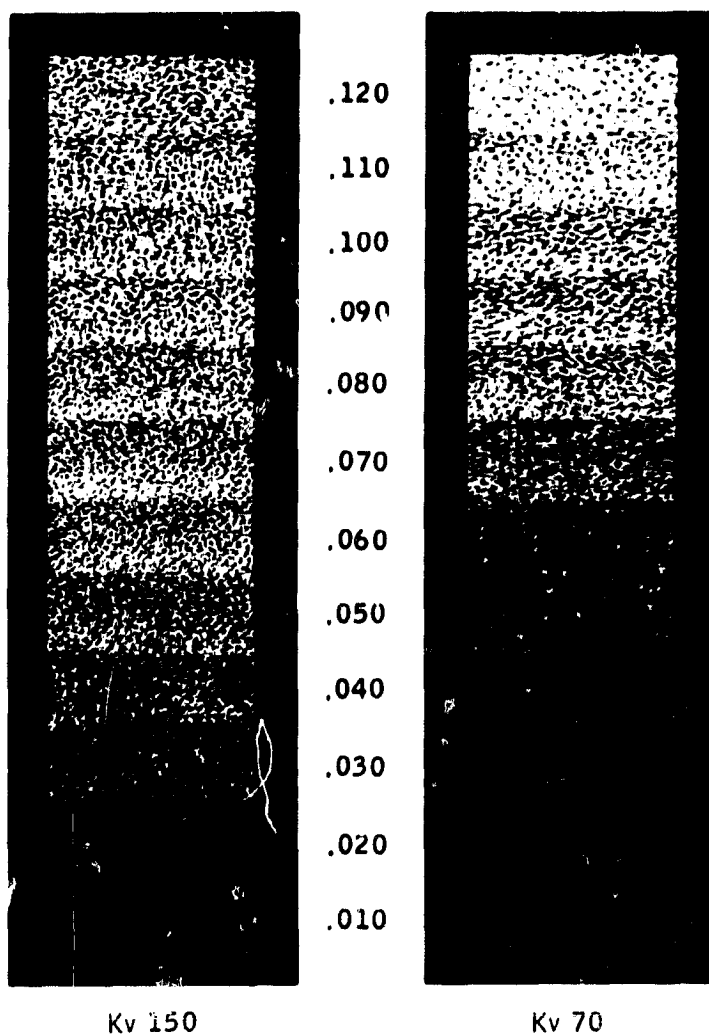
Kv 70

Notice that all the steps of the step wedge are distinctly shown in the left radiograph. In the right radiograph we cannot see the separate steps of the thinner part of the wedge (darkest portion of the radiograph).

This tells us that the left radiograph has more latitude. It shows a wider variation in specimen thicknesses.

Turn to page 3-46.

Whoa! Slow down. We asked which radiograph shows the greatest change in film density.



Compare the film density for step .110 on each radiograph. Note that the one on the right is less dense. Now compare the film density for step .040 in each radiograph. Note that the one on the right is more dense.

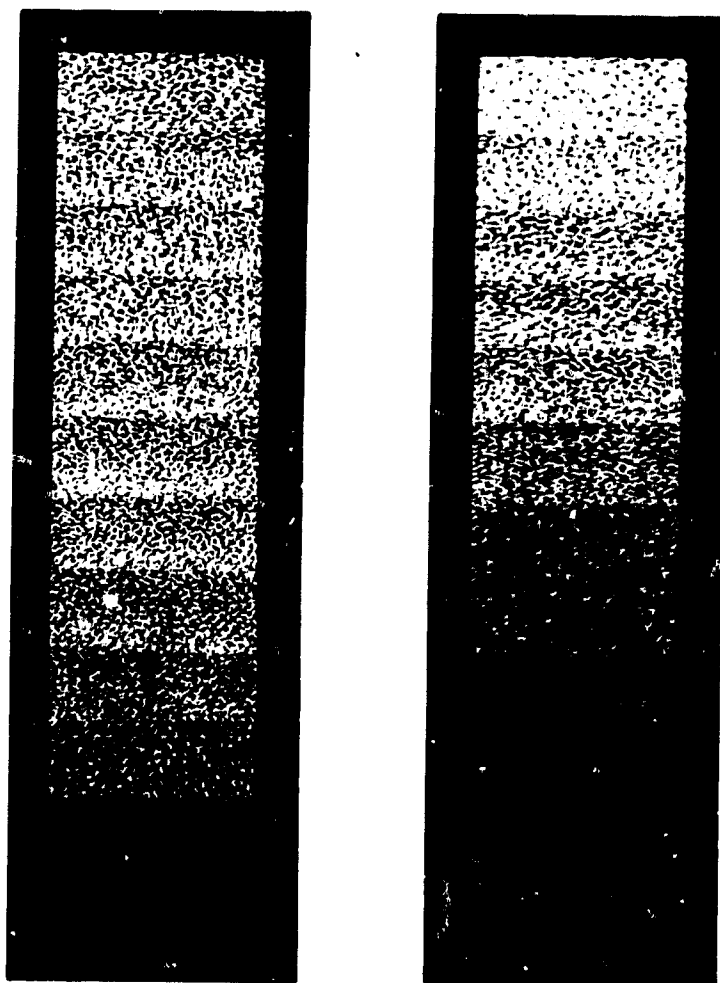
Now since the radiograph on the right shows one area that is less dense and another area that is more dense than corresponding areas on the left radiograph, the right radiograph has more contrast than the left radiograph.

Turn to page 3-49.

Right you are. The radiograph on the right shows more contrast than the radiograph on the left.

But the radiograph on the left has greater latitude.

What we have shown here is that the radiograph having the highest contrast has the least latitude and, vice versa, the radiograph having the lowest contrast has the best latitude.



Kv 150

Kv 70

These radiographs of the step wedge were made at 150 kv and 70 kv. The low voltage radiograph has the best contrast while the high voltage radiograph has the best latitude. This relationship becomes a significant factor in the selection of the proper voltage to use in making a radiograph and will be further discussed in another chapter.

Turn to page 3-45 for a short review.



HIGH CONTRAST



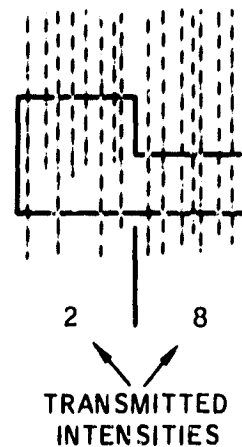
LOW CONTRAST

1. When the difference in density of two areas of a radiograph is very great we have _____ contrast.



10. density

11. What is the ratio of transmitted intensities for the figure at right?
4, 6, or 16



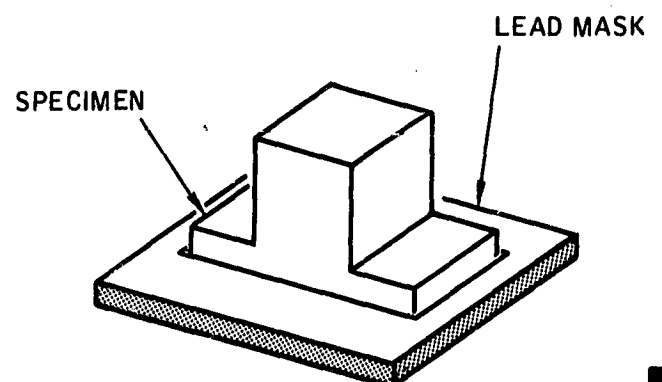
20. back

21. Side scatter also decreases _____.



30. absorbing
(filtering, reducing)

31. Masking is a method used to reduce side scatter and to _____ the amount of scatter producing material in the primary beam.



1. high



2. Here we show an example of a radiograph with low _____.



11. $\frac{8}{2} - 4$



LOW ENERGY
RADIATION



HIGH ENERGY
RADIATION

12. Increasing the energy of the primary radiation reduces the _____ of the radiograph.

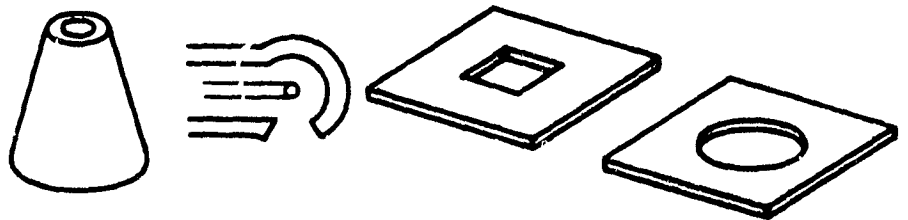


21. contrast

22. Internal scatter _____ contrast.



31. reduce (limit)



32. Lead cones, diaphragms, or collimators are also used to limit the amount of _____ that receives the direct radiation from the source.



2. contrast



SPECIMEN



RADIOGRAPH

3. Radiographic contrast is generally considered to consist of subject and film _____.



12. contrast

13. Greater subject contrast is achieved by utilizing rays with the _____ (lowest, highest) energy that will penetrate the specimen.



22. decreases

23. Scatter radiation reduces subject _____.

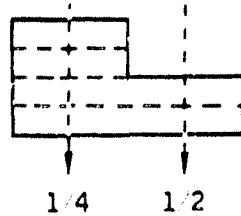


32. material

33. Increasing KV will _____ (increase, decrease) the energy of the primary radiation.



3. contrast, contrast



4. Subject contrast is defined as the ratio of intensities transmitted by two selected areas of the _____.



13. lowest

14. Increasing the applied voltage across the X-ray tube causes the contrast to _____ (increase, decrease).



23. contrast

24. We can improve contrast by preventing scatter from reaching the _____.



33. increase

34. Increasing KV will _____ (increase, decrease) the effect of scatter on the radiograph.



4. specimen



5. A specimen that varies in thickness has _____ (more, less) subject contrast than a specimen of uniform thickness.

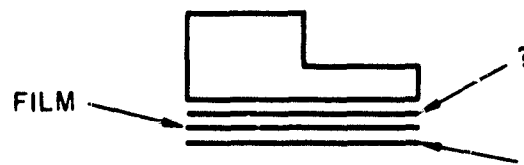


14. decrease

15. Subject contrast is also affected by scattered _____.



24. film



25. The cheapest, and most convenient means of controlling the effects of scattered radiation are sheets of lead foil called _____.



34. decrease

35. Latitude is the range of specimen _____ that can be recorded on the radiograph.

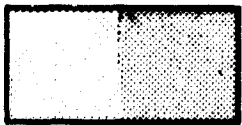


6. Intensity

7. Subject contrast is defined as the _____ of transmitted intensities through different thicknesses of the specimen.



16. exposure



TYPE A

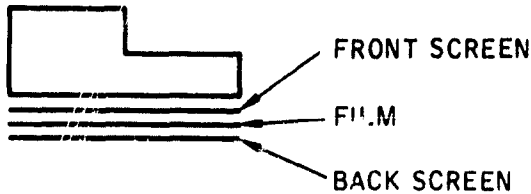


TYPE B

17. These two types of film were exposed together. Which has the greater film contrast?



26. primary



27. A screen placed behind the film functions to absorb _____.



36. poor

37. When a radiograph will adequately record a wide range of specimen thicknesses it has good _____.



7. ratio



A



VOID

B

8. Which of these two specimens has the greatest subject contrast?



17. Type B



18. As the density of the film increases, contrast



27. back scatter

28. Preventing scatter from reaching the film _____ contrast.



37. latitude

38. The low voltage radiograph of a specimen has the best contrast while the high voltage radiograph of the same specimen has the best _____.



8. B



A



B

VOID

9. Specimen B had the greatest subject contrast because the void in specimen B represented a change in specimen _____.



18. increases

19. Film contrast improves as film density _____ (increases, decreases).



28. improves

29. The back screen will absorb a wider band of ray energies because it can be _____ than a front screen.



38. latitude

Turn to page 4-1.



9. density (thickness)

10. Subject contrast varies directly with changes in specimen thickness and with changes in specimen _____.

Return to page 3-50,
frame 11, and continue.

19. increases

20. A wall or floor, or any other material, on the back side of the film can produce _____ scatter.

Return to page 3-50,
frame 21, and continue.

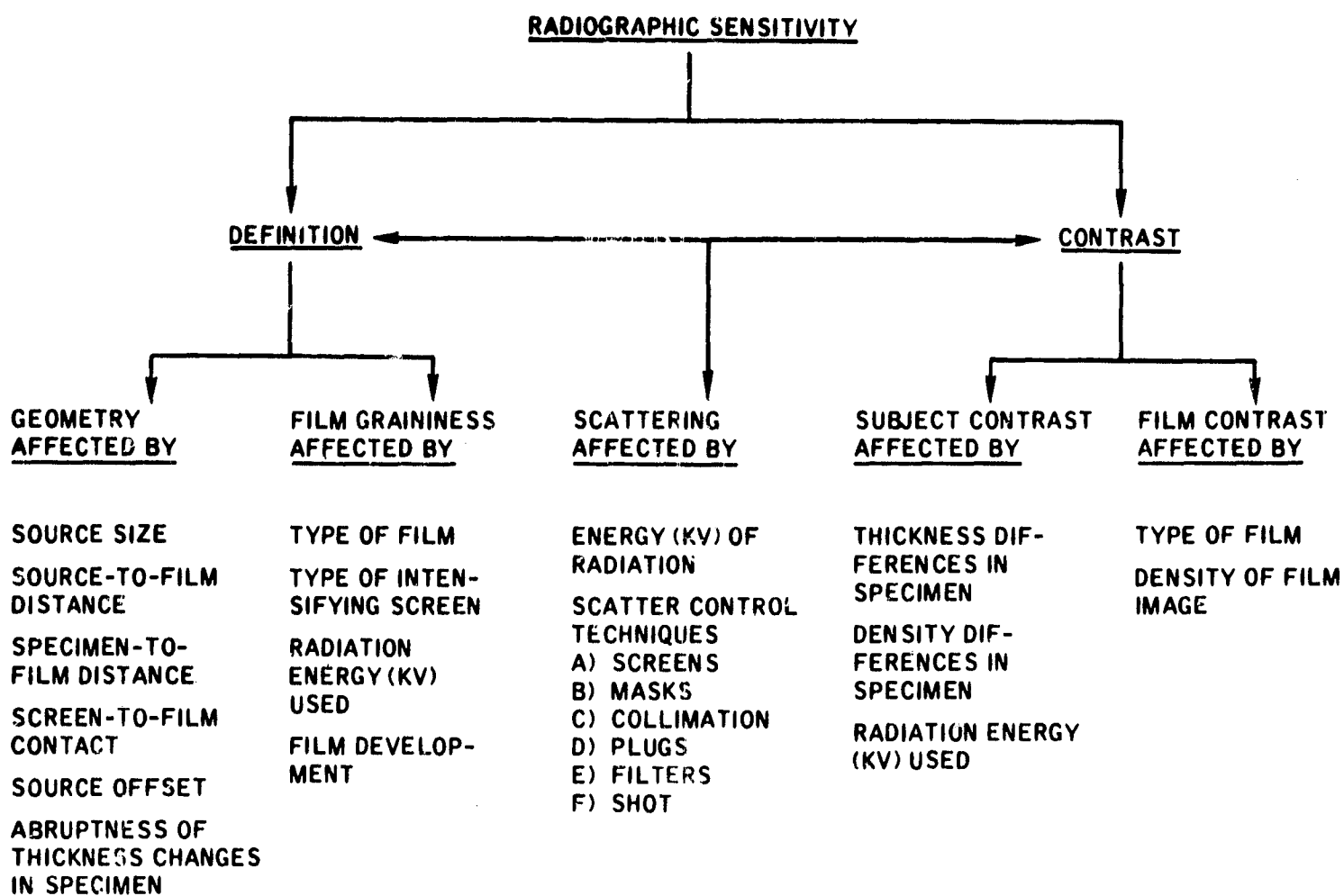
29. thicker

30. A filter, like a screen, functions by _____ the lower energy rays.

Return to page 3-50,
frame 31, and continue.

Turn to page 4-1.

In Chapters 2 and 3 of this book we discussed the factors that determine the quality of the radiograph and, in general, how to control them. Here is a summary of what we covered.



Turn to page 4-2.

In this chapter we are going to discuss the calculations that are necessary to produce the radiograph with the desired quality. The making of a radiograph, like making a photograph, is called an exposure. Those factors that affect the production of the radiograph and are controllable by the operator are called "exposure factors". All of these variable factors in the exposure require some sort of calculation in order to assure some degree of quality in the radiograph. In the following pages we are going to discuss these factors one at a time.

The quality of a radiograph is judged by the variations in density of the image on the film. And, in turn, the density of the image is dependent upon the amount or quantity of radiation that reaches the film. Therefore, the quality of the radiograph is dependent on the quantity of radiation that reaches the film.

What do we mean by a "quantity" of radiation? It is very difficult to imagine a quantity of rays. We can imagine a bucket (or quantity) of water but we can hardly visualize a glassful of rays. But we do know the effect of the rays on film. The longer the rays are allowed to expose the film, the darker the film gets - almost like filling a bucket.

Just as the "gallon" is a measure of a quantity of water, the "roentgen" is a measure of a quantity of radiation.

A film that receives 0.3 roentgens of radiation becomes _____ than a film that receives 0.1 roentgen of radiation.

darker Page 4-3

lighter Page 4-4

Right, the film that receives the highest quantity of radiation becomes darker. The longer the film is exposed to radiation the darker it gets.

Then we can say that the quantity of radiation received by the film is equal to the rate at which the film is receiving radiation multiplied by the time of exposure.

Back in Volume II of this series you learned that the rate of radiation was called the intensity of the radiation. Therefore, at a given distance from the source, the quantity of radiation is equal to the intensity of the radiation multiplied by the time of exposure; or

$$\text{Quantity} = \text{Intensity} \times \text{Time}$$

$$Q = I \times T$$

Q is measured in roentgens, I in roentgens per second, and T in seconds.

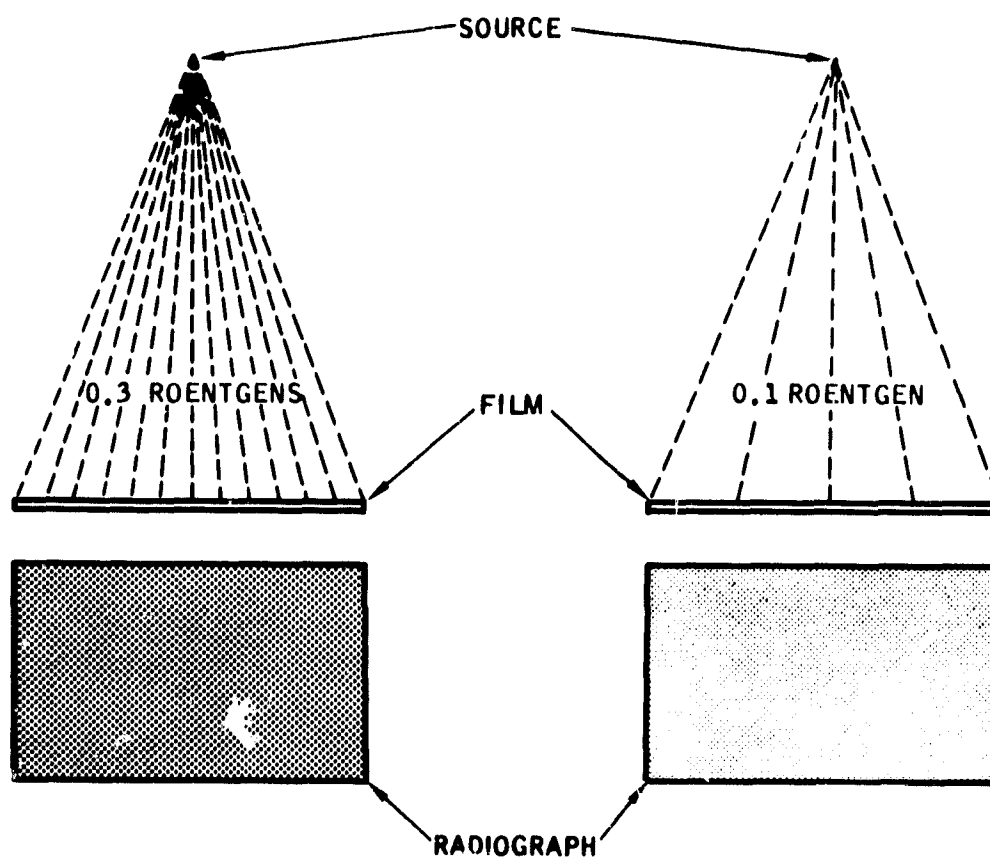
If, at some given point in the radiation beam, we had an intensity of 10 milliroentgens per second from a radiation source and an exposure time of 110 seconds, we would have a total radiation quantity of 1100 milliroentgens.

$$10 \times 110 = 1100$$

In the equation $Q = I \times T$, Q stands for Quantity which is measured in _____ .
 roentgens Page 4-5
 roentgens per second Page 4-6

Be careful - you have stated that the film receiving the most radiation is the lightest. This is not correct. The film that receives the most radiation is the darkest.

Since the roentgen is a measurement of the quantity of radiation, the film receiving 0.3 roentgens receives more radiation than the film receiving 0.1 roentgen; therefore, it gets darker.



Turn to page 4-3.

Very good! Roentgens are the measure of the quantity of radiation. The quantity in roentgens can be computed if the intensity of the ray and the time of exposure are known by using the equation $Q = I \times T$.

The "quantity" and "intensity" of radiation are not easily measured directly so another means of measuring the amount of radiation being produced has been devised.

As you learned in Volume III of this series, the intensity of an X-ray is directly proportional to the current through the X-ray tube. If we decrease the current then the intensity will decrease proportionally. If we increase the current then the intensity will increase proportionally. Or, to put it another way, if we change tube current from M_1 (milliamps for condition 1) to M_2 (milliamps for condition 2) the intensity will change proportionally from I_1 (for condition 1) to I_2 (for condition 2). This is expressed mathematically as:

$$\frac{M_1}{M_2} = \frac{I_1}{I_2}$$

This equation tells us that the change in intensity is _____ to the change in tube current.

directly proportional Page 4-7

inversely proportional Page 4-8

Hold up! Quantity of radiation is not measured in roentgens per second.

Just as gallons per minute measures the rate of flow of water, roentgens per second measures the rate of radiation.

We did not ask for the rate - we asked for the quantity. If water flowed into a bucket at a rate of $1/2$ gallons per minute for 2 minutes you would have 1 gallon of water in the bucket ($1/2 \times 2 = 1$). Similarly, if a radiation source produced radiation at a rate of 10 milliroentgens per second to a film located at some fixed distance from the source, at the end of 2 seconds the film would have received a quantity of 20 milliroentgens ($10 \times 2 = 20$). The quantity of radiation received by the film is measured in roentgens.

Turn to page 4-5.

Excellent. If the current through the tube is increased then the intensity of the beam increases in direct proportion.

$$\frac{M_1}{M_2} = \frac{I_1}{I_2}$$

Let's apply some figures to the above statement to make sure you understand the principle involved here.

Suppose that with a tube current of 5 milliamperes we obtained an intensity of 1.5 roentgens per second at a specified point in the beam. Then let's double the tube current to 10 milliamperes. Since the intensity is directly proportional to the tube current, the intensity at the specified point will double also and we will obtain an intensity of 3.0 roentgens per second.

$$\frac{5}{10} = \frac{1.5}{I_2} \quad I_2 = \frac{10 \times 1.5}{5} = 3.0 \text{ roentgens}$$

Suppose we had increased the current from 5 milliamperes to 15 milliamperes? The intensity would change from 1.5 roentgens per second to _____ roentgens per second.

3.0 Page 4-9

4.5 Page 4-10

Perhaps you do not understand the terms "directly proportional" and "inversely proportional".

When two things are directly proportional - increasing one increases the other by a proportional amount.

When two things are inversely proportional - increasing one decreases the other by a proportional amount.

In this case increasing the tube current will cause a corresponding increase in the intensity, so the two are directly proportional.

Turn to page 4-7.

From page 4-7

4-9

Sorry - 3.0 is not the right answer.

Here's the way the thing works -

We have increased the current from 5 to 15 milliamps. We have tripled the current.

Then the intensity, since it is directly proportional to current, will also be tripled.

$1.5 \times 3 = 4.5$ roentgens per second.

Or, by using the equation $\frac{M_1}{M_2} = \frac{I_1}{I_2}$

$$M_1 = 5 \text{ milliamps}$$

$$M_2 = 15 \text{ milliamps}$$

$$I_1 = 1.5 \text{ roentgens per second}$$

$$I_2 = ?$$

$$\frac{5}{15} = \frac{1.5}{I_2}$$

$$I_2 = \frac{15 \times 1.5}{5} = 4.5 \text{ roentgens per second.}$$

Turn to page 4-10.

From page 4-7

4-10

Very good. $1.5 \times 3 = 4.5$ roentgens per second.

Alright, we now have two equations: $Q = I \times T$ and $\frac{M_1}{M_2} = \frac{I_1}{I_2}$

Since current is proportional to intensity, let's substitute current (M) for intensity (I) in the first equation: $I \times T$ then becomes $M \times T$.

Now since $M \times T$ is no longer the direct measurement of the quantity of radiation, we must call it something else. We call it "exposure" (E).

$$E = M \times T$$

$$\text{milliampere-seconds} = \text{milliamps} \times \text{seconds}$$

This equation tells us that exposure (E) is the product of tube current (M) and time (T).

Since we can easily measure the tube current and the time we will always be able to compute the exposure.

Exposure is measured in _____.

roentgens Page 4-11

milliampere-seconds Page 4-12

From page 4-10

4-11

You are confusing quantity with exposure. Quantity is measured in roentgens while exposure is measured in milliamperes-seconds (ma-sec), or milliamperes-minutes (ma-min).

Quantity and exposure are two very similar terms and, in radiography, mean practically the same thing. The difference between the two is the units in which they are measured.

Exposure is measured in milliamperes-seconds.

Turn to page 4-12.

Right! Exposure is measured in milliamperere-seconds (ma-sec), or perhaps milliamperere-minutes (ma-min).

Now, let's suppose for a moment that we have just made a radiograph where

$$E_1 = M_1 \times T_1$$

and we want to make a second radiograph changing the current and the time but without changing the exposure.

$$E_2 = M_2 \times T_2$$

If $E_1 = E_2$ (exposure doesn't change) then

$$M_1 \times T_1 \text{ must equal } M_2 \times T_2$$

$$M_1 \times T_1 = M_2 \times T_2$$

Do you understand this relationship?

No Page 4-13

Yes Page 4-14

Perhaps the addition of some numbers will help you understand the principle.

Let's make a radiograph using a current of 3 milliamps and a time of 5 seconds.

$$E_1 = M_1 \times T_1$$

$$3 \times 5 = 15$$

The film would receive 15 milliamperes-seconds exposure. Right?

Let's make a second radiograph using a current of 5 milliamps and a time of 3 seconds.

$$E_2 = M_2 \times T_2$$

$$5 \times 3 = 15$$

This film would also receive 15 milliamperes-seconds exposure. Right?

$$E_1 = 3 \times 5 = 15$$

$$E_2 = 5 \times 3 = 15$$

We have just demonstrated how current and time can be changed without changing the exposure. When $E_1 = E_2$; $M_1 \times T_1 = M_2 \times T_2$

Turn to page 4-14.

Fine. When $E_1 = E_2$

$$M_1 \times T_1 = M_2 \times T_2$$

This equation is known as the reciprocity law. It tells us that to maintain a constant exposure, if the current is increased the time must be decreased proportionately.

Here is a sample problem: We have a satisfactory exposure at 5 ma (M_1) exposing for 6 minutes (T_1). We wish to reduce the time to 2 minutes (T_2) by adjusting the tube current. Substituting these figures in the equation we get:

$$M_1 \times T_1 = M_2 \times T_2$$

$$5 \times 6 = M_2 \times 2 \quad (\text{Solve for } M_2)$$

$$\frac{5 \times 6}{2} = M_2 = 15 \text{ milliamperes}$$

In general terms, the reciprocity law states that if the exposure is to remain the same, doubling the exposure time requires that the tube current be _____.

halved Page 4-15

doubled Page 4-16

Good! When applying the reciprocity law, doubling the exposure time requires that the current be halved, or halving the exposure time requires that the current be doubled, to maintain the same exposure.

We many have to lower the tube current because of overheating to protect the tube on a series of shots. This requires adjusting "time" to compensate for changed tube current.

We have been getting a good exposure at 15 ma for a 5 minute shot, but wish to reduce the current to 10 ma.

Which equation would you use?

$$I_1 \times T_1 = I_2 \times T_2 \dots\dots\dots \text{Page 4-17}$$

$$M_1 \times T_1 = M_2 \times T_2 \dots\dots\dots \text{Page 4-18}$$

You've got it reversed. Remember that the exposure is the product of tube current and exposure time ($E = M \times T$). To reduce the current without increasing the time will change the exposure. If you double the exposure time and double the current you will have increased the exposure by a factor of four (2×2). Because we did not want to change the exposure we must reduce the current by half since we doubled the exposure time.

Turn to page 4-15.

You picked the wrong equation. $I \times T$ will give you the quantity of radiation. Remember? Quantity equals intensity multiplied by time. Nowhere in the problem did we say anything about intensity, therefore, you could hardly use an equation calling for intensity.

Since the problem does cover current and time you would use $M \times T$. M stands for current (milliamperes) through the tube and T stands for exposure time.

$M_1 \times T_1 = M_2 \times T_2$ is the correct equation to use in solving this problem.

Turn to page 4-18.



Right! $M_1 \times T_1 = M_2 \times T_2$ is the correct equation to use for this problem.

Now here's the problem again: We have been getting a good exposure at 15 ma (milli-amperes) for a 5 minute shot, but wish to reduce the current to 10 ma. Solve the problem and determine the new exposure time.

$$M_1 = 15 \text{ ma}$$

$$T_1 = 5 \text{ min}$$

$$M_2 = 10 \text{ ma}$$

$$T_2 = ?$$

3.3 minutes Page 4-19

7.5 minutes Page 4-20

Sorry - you didn't work that one right. Compare your work with the following to see where you went wrong. Here's the problem again:

We have been getting a good exposure at 15 ma for a 5 minute shot, but wish to reduce the current to 10 ma. What would be the new exposure time?

$$M_1 \times T_1 = M_2 \times T_2$$

$$M_1 = 15 \text{ ma}$$

$$T_1 = 5 \text{ minutes}$$

$$M_2 = 10 \text{ ma}$$

$$T_2 = ?$$

$$15 \times 5 = 10 \times T_2$$

$$\frac{15 \times 5}{10} = T_2 = 7.5 \text{ minutes}$$

Turn to page 4-20.

Very good! The new exposure time would be 7.5 minutes. Now here is a series of four problems for you to work out. When you have worked out all four problems turn to page 4-21 and check your work.

Problem 1. We have been exposing at 3 milliamperes for 5 minutes. The radiograph is showing evidence of scatter so we want to reduce the time of exposure to 2 minutes. What current should we use to maintain the original film exposure?

$$M_1 = 3, T_1 = 5, M_2 = ?, T_2 = 2$$

Problem 2. We have been exposing at 10 milliamps for 130 seconds. This high current is causing the tube head to heat up so we decide to reduce the current to 8 milliamps. What exposure time should we use so that the film exposure will not change?

Problem 3. What current should we use for a 6 minute exposure if we know that a good radiograph of an identical article is obtainable with 15 milliamps at 4 minutes?

Problem 4. We wish to reduce the current from 20 milliamps to 15 milliamps. We were exposing for 120 seconds. What exposure time should we use with the reduced current in order to maintain the original film exposure?

Turn to page 4-21 and check your answers.

Answer for problem 1. $M_1 \times T_1 = M_2 \times T_2$

$$3 \times 5 = M_2 \times 2$$

$$\frac{3 \times 5}{2} = M_2$$

$$\frac{15}{2} = M_2 = \underline{7.5 \text{ milliamperes}}$$

Answer for problem 2. $M_1 \times T_1 = M_2 \times T_2$

$$10 \times 130 = 8 \times T_2$$

$$\frac{10 \times 130}{8} = T_2$$

$$\frac{1300}{8} = T_2 = \underline{162.5 \text{ seconds}}$$

Answer for problem 3. $M_1 \times T_1 = M_2 \times T_2$

$$15 \times 4 = M_2 \times 6$$

$$\frac{15 \times 4}{6} = M_2$$

$$\frac{60}{6} = M_2 = \underline{10 \text{ milliamps}}$$

Answer for problem 4. $M_1 \times T_1 = M_2 \times T_2$

$$20 \times 120 = 15 \times T_2$$

$$\frac{20 \times 120}{15} = T_2$$

$$\frac{2400}{15} = T_2 = \underline{160 \text{ seconds}}$$

Turn to page 4-22.

Very good. You seem to have the reciprocity law well in hand. The reciprocity law also may be applied to the use of isotopes. When dealing with isotopes in gamma radiography, the activity of the isotope (in curies) is a measure of intensity just as milliamperes are a measure of intensity in X-radiography. Therefore, we can substitute curies (C) for milliamperes (M) in the reciprocity equation.

$$M_1 \times T_1 = M_2 \times T_2 \text{ then becomes } C_1 \times T_1 = C_2 \times T_2$$

To maintain constant exposure conditions when using isotopes in radiography if the activity is increased the exposure time must be decreased proportionally.

This is a restatement of the _____ law.

proportionality Page 4-23

reciprocity Page 4-24

Be careful, you are becoming confused. Although activity and time are increased and decreased proportionally, we do not call it the proportionality law. It is still the reciprocity law. The word reciprocity stems from the word "reciprocal" which means "inversely related" or "opposite in relationship". Since increasing one part is accompanied by decreasing the other, the two are inversely related - hence, they are reciprocals. This is how we arrive at the term reciprocity law.

Turn to page 4-24.

Very good. That is a restatement of the reciprocity law. Now let's see how well you can apply the equation $C_1 \times T_1 = C_2 \times T_2$.

We have been getting a good film exposure using a 40-curie Co-60 source at two minutes. We now have to use another Co-60 source which is rated at 20 curies. What will be the new exposure time if the film exposure is to remain unchanged?

1 minute Page 4-25

4 minutes Page 4-26

We can only suppose that you substituted the wrong values in the equation. Here's the problem again.

We have been getting a good film exposure using a 40-curie Co-60 source at two minutes. We now have to use another Co-60 source which is rated at 20 curies. What will be the new exposure time if the film exposure is to remain unchanged?

$$\text{Then } C_1 = 40 \text{ curies}$$

$$T_1 = 2 \text{ minutes}$$

$$C_2 = 20 \text{ curies}$$

$$T_2 = ?$$

$$\text{Since } C_1 \times T_1 = C_2 \times T_2$$

$$40 \times 2 = 20 \times T_2$$

$$T_2 = \frac{40 \times 2}{20} = \underline{4 \text{ minutes}}$$

Turn to page 4-26.

Excellent! The new exposure time would be 4 minutes.

Now here are four problems which call for the application of the reciprocity law to the use of isotopes. Work through all four problems before turning the page.

Problem 1. We have successfully radiographed a part using an Iridium 192 source of 10 curies with an exposure time of 15 minutes. We now have a 20 curie Ir-192 source. What exposure time should we use with the new source to obtain the same good exposure?

Problem 2. A 15 curie Ir-192 source has been giving satisfactory radiographs of a particular part with an exposure of 25 minutes. We now have more of these parts to inspect so we must cut down the exposure time. What Ir-192 source strength would be required to cut exposure time to 10 minutes per part.

Problem 3. An exposure time of 18 minutes with a Cobalt 60 source of 35 curies has been determined to produce a good radiograph of a part. What would be the correct exposure time to use if the Co-60 source was 100 curies?

Problem 4. Five months ago we radiographed a casting using a 40-curie source of Iridium 192. The activity of this source is now 10 curies. The original exposure produced a satisfactory radiograph with an exposure time of 5 minutes. What exposure time would be required today to obtain a satisfactory radiograph of another identical casting?

Turn to page 4-27 and check your work.

Answer for problem 1. $C_1 \times T_1 = C_2 \times T_2$

$$10 \times 15 = 20 \times T_2$$

$$\frac{10 \times 15}{20} = T_2$$

$$\frac{150}{20} = T_2 = \underline{7.5 \text{ minutes}}$$

Answer for problem 2. $C_1 \times T_1 = C_2 \times T_2$

$$15 \times 25 = C_2 \times 10$$

$$\frac{15 \times 25}{10} = C_2$$

$$\frac{375}{10} = C_2 = \underline{37.5 \text{ curies}}$$

Answer for problem 3. $C_1 \times T_1 = C_2 \times T_2$

$$18 \times 35 = C_2 \times 100$$

$$\frac{18 \times 35}{100} = C_2$$

$$\frac{630}{100} = C_2 = \underline{6.3 \text{ minutes}}$$

Answer for problem 4. $C_1 \times T_1 = C_2 \times T_2$

$$40 \times 5 = 10 \times T_2$$

$$\frac{40 \times 5}{10} = T_2$$

$$\frac{200}{10} = T_2 = \underline{20 \text{ minutes}}$$

Turn to page 4-28 and continue.

Here's a note of caution. The reciprocity law is not accurate when fluorescent intensifying screens are used since the intensity of the light emitted by the screens is not directly proportional to the energy of the ray.

Inverse square law. In Volume II of this series you learned how the inverse square law applied to personnel safety. The same law is applied to radiographic exposure of film. If you recall, the intensity of radiation from a source diminishes as the square of increasing distance. That is to say, the intensity of radiation varies inversely as the square of the distance from the source to the film.

Which of the following equations fits the inverse square law?

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2} \dots\dots\dots \text{Page 4-29}$$

$$\frac{I_1}{I_2} = \frac{M_1}{M_2} \dots\dots\dots \text{Page 4-30}$$

Right! Where I_1 is the intensity at distance D_1 from the source, and I_2 is the intensity at distance D_2 from the source then:

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2} \quad - \text{ the inverse square law}$$

To apply some figures to this equation let's say that we have an intensity of 45 roentgens per hour at a distance of 10 feet from the source. Then what would the intensity be at 30 feet from the source?

$$I_1 = 45 \text{ roentgens per hour}$$

$$I_2 = ?$$

$$D_1 = 10 \text{ feet}$$

$$D_2 = 30 \text{ feet}$$

Substituting in the equation, $\frac{45}{I_2} = \frac{(30)^2}{(10)^2}$

Invert both sides, $\frac{I_2}{45} = \frac{(10)^2}{(30)^2}$

Solve, $I_2 = \frac{(10)^2 \times 45}{(30)^2}$

$$I_2 = \frac{100 \times 45}{900} = 5 \text{ roentgens per hour.}$$

When the distance from the source increases, the intensity of the ray _____.

increases Page 4-31

decreases Page 4-32

You made a poor selection this time. Here are the equations again.

$$(A) \quad \frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

$$(B) \quad \frac{I_1}{I_2} = \frac{M_1}{M_2}$$

Now which of these two equations fits the inverse square law. The clues to the answer are the words "inverse square". Notice in equation (A) D (distance) is squared. Also notice that the subscripts 1 and 2 are inverted from one side of the equation to the other. That is why we call the equation the "inverse square" law.

Turn to page 4-29.

From page 4-29

4-31

You have forgotten the meaning of the word "inverse". If two factors are inversely proportional, one increases as the other decreases. Therefore in the inverse square law - as the distance increases the intensity of the ray decreases.

Turn to page 4-32.



Excellent! In applying the inverse square law the intensity decreases as the distance increases. Now we want to make this point. The inverse square law says that if the distance is doubled the intensity of the ray is reduced to 1/4 of its original value. What does this do to the exposure of the film? Since film exposure is directly related to the intensity, it is obvious that the film exposure would be reduced by 1/4 also.

Therefore, if you wish to maintain the original exposure while doubling the distance, you must increase the exposure by a factor of 4. Reduced to an equation, it looks like this:

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2}$$

Where E_1 is the exposure at distance D_1

and E_2 is the exposure at distance D_2

Now, to apply some figures to this equation let's say we had a good film exposure using 400 ma-seconds for a source-to-film distance of 40 inches. What would be the required exposure for a source-to-film distance of 50 inches to maintain the same film density?

$$E_1 = 400 \text{ ma-seconds}$$

$$D_1 = 40 \text{ inches}$$

$$E_2 = ?$$

$$D_2 = 50 \text{ inches}$$

Then

$$\frac{400}{E_2} = \frac{(40)^2}{(50)^2}$$

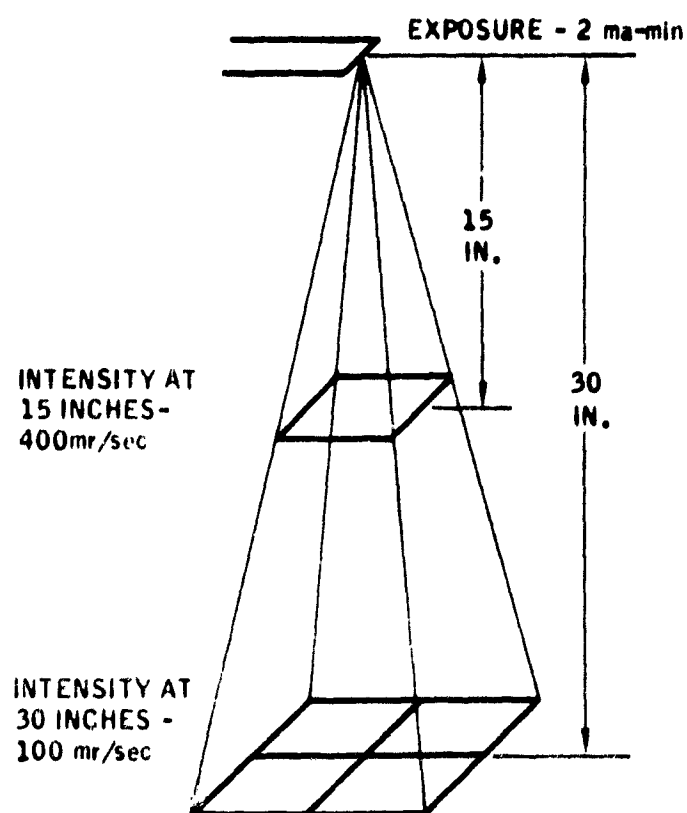
$$E_2 = \frac{(50)^2 \times 400}{(40)^2} = \frac{2500 \times 400}{1600} = 625 \text{ ma-sec.}$$

According to the above example, when we increased the distance from D_1 to D_2 we had to _____ the exposure at the source to maintain the same film density.

reduce Page 4-33

increase Page 4-34

Sorry, you would have to increase the exposure to maintain the same film density if the distance were increased.



Assume that a certain X-ray unit will have an intensity at 15 inches as shown. At 30 inches the intensity will be $1/4$ of this amount as determined by the inverse square law. A film placed at 30 inches will receive $1/4$ the amount of exposure that would be received by a film placed at 15 inches.

Now, in order to have the same intensity (and therefore the same film exposure) at 30 inches as we had at 15 inches we have to increase the exposure at the source by a factor of 4.

$$4 \times 20 \text{ ma-min} = 80 \text{ ma-min}$$

Increased source-to-film distance requires increased exposure to maintain film density.

Turn to page 4-34.

Right! To maintain the same film density when the distance was increased we had to increase the exposure at the source.

Now here are some problems to give you practice in computing distance and exposure.

Problem 1. We have obtained a good film density using an exposure of 20 milliamperere-minutes for a source-to-film distance of 15 inches. We now have to increase the source-to-film distance to 30 inches. What will be the new exposure?

Problem 2. We are increasing our source-to-film distance from 30 inches to 35 inches. We have been exposing at 8 milliamperere-minutes. What exposure is now required to maintain the same film density?

Problem 3. With an exposure of 15 milliamperere-minutes we have obtained a film density of 2.0 for a source-to-film distance of 30 inches. What exposure would be required to maintain the film density at 2.0 if the source-to-film distance was changed to 40 inches?

Problem 4. We have produced a radiograph with good density but it is lacking in definition. To get better definition we decide to increase the source-to-film distance from 25 inches to 40 inches. Our original exposure was 10 milliamperere-minutes. What exposure must we use at 40 inches to maintain the original film density?

Turn to page 4-35 and check your work.

Answer for problem 1

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2} \quad \frac{20}{E_2} = \frac{(15)^2}{(30)^2}$$

$$\frac{E_2}{20} = \frac{(30)^2}{(15)^2}$$

$$E_2 = \frac{(30)^2 \times 20}{(15)^2} = \frac{900 \times 20}{225} = \frac{18000}{225} = \underline{80 \text{ milliampere-minutes}}$$

Answer for problem 2

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2} \quad \frac{8}{E_2} = \frac{(30)^2}{(35)^2}$$

$$\frac{E_2}{8} = \frac{(35)^2}{(30)^2}$$

$$E_2 = \frac{(35)^2 \times 8}{(30)^2} = \frac{1225 \times 8}{900} = \frac{9800}{900} = \underline{10.9 \text{ milliampere-minutes}}$$

Answer for problem 3

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2} \quad \frac{15}{E_2} = \frac{(30)^2}{(40)^2}$$

$$\frac{E_2}{15} = \frac{(40)^2}{(30)^2}$$

$$E_2 = \frac{(40)^2 \times 15}{(30)^2} = \frac{1600 \times 15}{900} = \frac{24000}{900} = \underline{26.7 \text{ milliampere-minutes}}$$

Answer for problem 4

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2} \quad \frac{10}{E_2} = \frac{(25)^2}{(40)^2}$$

$$\frac{E_2}{10} = \frac{(40)^2}{(25)^2}$$

$$E_2 = \frac{(40)^2 \times 10}{(25)^2} = \frac{1600 \times 10}{625} = \frac{16000}{625} = \underline{25.6 \text{ milliampere-minutes}}$$

Turn to page 4-36

Now that you understand how to balance exposures against changes in distances, let's move on.



$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2}$$

This is the equation that says the exposure must be increased as the distance increases.

But $E = M \times T$. Then; by substitution:

$$\frac{M_1 \times T_1}{M_2 \times T_2} = \frac{D_1^2}{D_2^2}$$

Then if you plan to hold tube current at a constant value ($M_1 = M_2$) this equation reduces to:

$$\frac{T_1}{T_2} = \frac{D_1^2}{D_2^2}$$

But if you plan to hold exposure time at a constant value ($T_1 = T_2$) then the equation reduces to:

$$\frac{M_1}{M_2} = \frac{D_1^2}{D_2^2}$$

In using these equations you must always keep carefully in mind exactly which items you are planning to hold at a constant value.

To summarize these equations: if either time or current is held constant then the other must be varied as the square of the distance is varied to maintain the same film exposure.

In order to maintain the same film density without changing the current through the x-ray tube, we must change the _____ as the square of the distance varies.

time of exposure Page 4-37

milliamperes. Page 4-38

Excellent choice. Now here's a sample problem.

We want to increase the source-to-film distance from 30 inches to 50 inches without changing film density or time of exposure. Our original exposure was 5 milliamperes for 6 minutes. What tube current would we use for the new exposure?

$$\frac{M_1}{M_2} = \frac{D_1^2}{D_2^2}, \quad \frac{5}{M_2} = \frac{(30)^2}{(50)^2}, \quad \frac{M_2}{5} = \frac{(50)^2}{(30)^2}, \quad M_2 = \frac{2500 \times 5}{900} = 13.9 \text{ milliamperes}$$

Now here are three examples for you to work on:

Problem 1. We want to change the source-to-film distance from 25 inches to 40 inches without changing film density or exposure time. The first exposure was made with a tube current of 10 milliamperes. What tube current should be used for the second exposure?

$$\frac{M_1}{M_2} = \frac{D_1^2}{D_2^2}$$

Problem 2. We have obtained a good film density with a 10 minute exposure for a source-to-film distance of 45 inches. Now we want to change the source-to-film distance to 35 inches. What exposure time can we use so that neither the film density or the tube current will change?

Problem 3. A film density of 2.0 was obtained with a 15 minute exposure of 4 milliamperes for a source-to-film distance of 22 inches. What exposure time will be required to maintain the same film density and tube current if the source-to-film distance is changed to 34 inches.

Turn to page 4-39 and check your work.

Careful now. You have chosen the answer that says - In order to maintain the same film density without changing the current through the x-ray tube, we must change the milliamperes as the square of the distance varies.

You are forgetting that milliamperes and current through the tube are the same thing. Since we are going to hold the current through the tube (or milliamps) at a fixed value, the only thing we can vary is the time of exposure.

Turn to page 4-37 and continue.

Here we show the answers to the three problems.

Problem 1

$$\frac{M_1}{M_2} = \frac{D_1^2}{D_2^2}$$

$$\frac{10}{M_2} = \frac{(25)^2}{(40)^2}$$

$$\frac{M_2}{10} = \frac{(40)^2}{(25)^2}$$

$$M_2 = \frac{(40)^2 \times 10}{(25)^2} = \frac{16000}{625} = \underline{25.6 \text{ milliamperes.}}$$

Problem 2

$$\frac{T_1}{T_2} = \frac{D_1^2}{D_2^2}$$

$$\frac{10}{T_2} = \frac{(45)^2}{(35)^2}$$

$$\frac{T_2}{10} = \frac{(35)^2}{(45)^2}$$

$$T_2 = \frac{1225 \times 10}{2025} = \underline{6.05 \text{ minutes}}$$

Problem 3

$$\frac{T_1}{T_2} = \frac{D_1^2}{D_2^2}$$

$$\frac{15}{T_2} = \frac{(22)^2}{(34)^2}$$

$$\frac{T_2}{15} = \frac{(34)^2}{(22)^2}$$

$$T_2 = \frac{(34)^2 \times 15}{(22)^2} = \frac{1156 \times 15}{484} = \frac{17340}{484} = 35.8 + \underline{\text{minutes}}$$

Turn to page 4-40.

Now let's consider the effect that a change in source-to-film distance has on gamma radiography.

Remembering that the required exposure varies directly as the square of the source-to-film distance;

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2}$$

and that exposure is equal to source strength multiplied by time;

$$E = C \times T$$

we can substitute $C \times T$ for E and get -

$$\frac{C_1 \times T_1}{C_2 \times T_2} = \frac{D_1^2}{D_2^2}$$

This equation is comparable to the X-ray equation

$$\frac{M_1 \times T_1}{M_2 \times T_2} = \frac{D_1^2}{D_2^2}$$

However in gamma radiography the source strength of a given source is not variable like the current through an X-ray tube. Therefore the only factor that can be varied to compensate for the change in distance is the exposure time. Then if $C_1 = C_2$ the equation reduces to -

$$\frac{T_1}{T_2} = \frac{D_1^2}{D_2^2}$$

This equation, then, can be used for either X-ray sources or gamma ray sources.

Let's assume that we have a good radiograph using a Cobalt-60 source. Our exposure time was 36 minutes for a source-to-film distance of 48 inches. Circumstances force us to make another radiograph of an identical specimen using a source-to-film distance of 60 inches.

Using the same source, the new exposure time will be _____.

56.25 minutes Page 4-41

22.4 minutes Page 4-42

Right. The new exposure time would be 56.25 minutes.

Now here are three problems for you to practice on. Work the problems on a separate piece of paper, then turn to page 4-43 and check your work.

Problem 1. $T_1 = 15$ minutes; $D_1 = 40$ inches; $D_2 = 32$ inches; Solve for T_2 .

Problem 2. Using an Ir-192 source we have obtained a film density of 2 exposing for 12 minutes for a source-to-film distance of 48 inches. We now want to change our source-to-film distance to 36 inches. What exposure time would we use to obtain the same film density?

Problem 3. We have exposure data that tells us that with a 50 Curie, Iridium-192 source, an exposure time of 12 minutes for a source-to-film distance of 48 inches will be satisfactory to radiograph a specimen. We find that we cannot get our source closer than 60 inches. What exposure time must we use to compensate for the increased distance?

Turn to page 4-43.

You have selected the wrong answer. Check your work against the correct solution shown below.

Problem. Let's assume that we have a good radiograph using a Cobalt-60 source. Our exposure time was 36 minutes for a source-to-film distance of 48 inches. Circumstances force us to make another radiograph of an identical specimen using a source-to-film distance of 60 inches. Using the same source, the new exposure time will be _____.

Solution. $T_1 = 36$ minutes; $D_1 = 48$ inches; $D_2 = 60$ inches. Solve for T_2 .

$$\frac{T_1}{T_2} = \frac{D_1^2}{D_2^2}$$

$$T_2 = \frac{D_2^2 \times T_1}{D_1^2} = \frac{(60)^2 \times 36}{(48)^2} = \frac{3600 \times 36}{2304} = 56.25 \text{ minutes}$$

Turn to page 4-41 and continue.

Here are the solutions to the problems given on page 4-41.

Problem 1.

$$T_2 = \frac{D_2^2 \times T_1}{D_1^2}$$

$$T_2 = \frac{(32)^2 \times 15}{(40)^2} = \frac{1024 \times 15}{1600} = \underline{9.6 \text{ minutes.}}$$

Problem 2.

$$T_1 = 12 \text{ minutes; } T_2 = ?; D_1 = 48 \text{ inches; } D_2 = 36 \text{ inches}$$

$$T_2 = \frac{D_2^2 \times T_1}{D_1^2}$$

$$T_2 = \frac{(36)^2 \times 12}{(48)^2} = \frac{1296 \times 12}{2304} = \underline{6.75 \text{ minutes.}}$$

Problem 3.

$$T_1 = 12 \text{ min; } T_2 = ?; D_1 = 48 \text{ in.; } D_2 = 60 \text{ in.}$$

$$T_2 = \frac{D_2^2 \times T_1}{D_1^2}$$

$$T_2 = \frac{(60)^2 \times 12}{(48)^2} = \frac{3600 \times 12}{2304} = \underline{18.75 \text{ minutes}}$$

Turn to page 4-44.

So far in this chapter we've shown you how to change tube current and time of exposure to maintain the same exposure at the film (film density).

$$M_1 \times T_1 = M_2 \times T_2$$

We've shown you how to change exposure time to compensate for a change in isotope source strength to maintain the same exposure at the film (film density).

$$C_1 \times T_1 = C_2 \times T_2$$

We've shown you how to change tube current and exposure time to compensate for a change in source-to-film distance to maintain the same exposure at the film (film density) in X-radiography.

$$\frac{M_1 \times T_1}{M_2 \times T_2} = \frac{D_1^2}{D_2^2}$$

And we've shown you how to change exposure time to compensate for a change in source-to-film distance to maintain the same film density when using gamma ray sources.

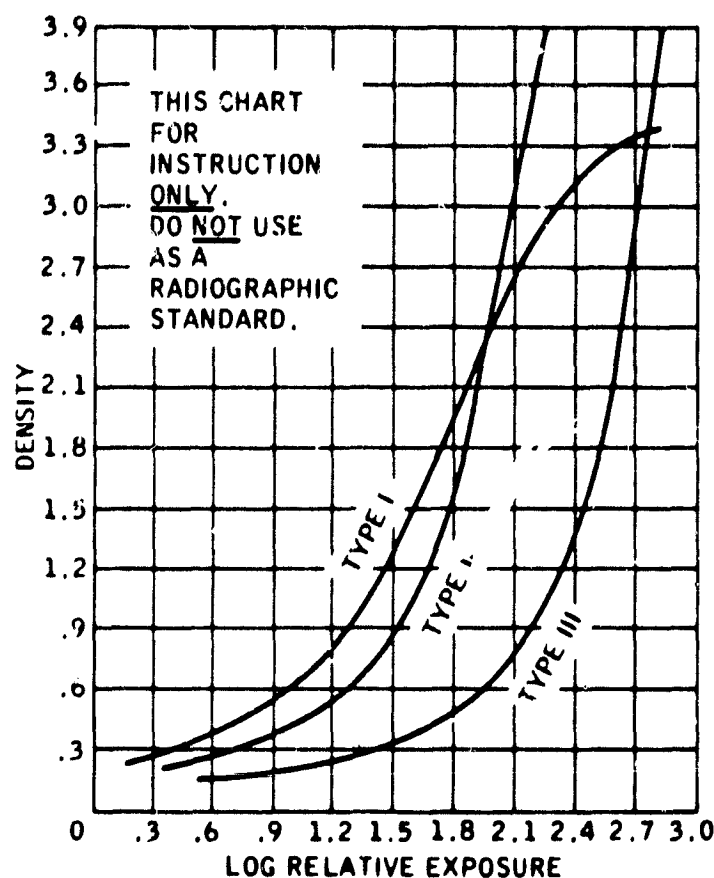
$$\frac{T_1}{T_2} = \frac{D_1^2}{D_2^2}$$

In all of the above situations we kept the exposure at the film (film density) constant. Now suppose that we have a radiograph that is too light or too dark. Is there a method we can use to determine the change in exposure that would be required to give a specific change in film density?

Turn to page 4-45.

Yes, there is. To make this kind of adjustment we make use of special charts, supplied by the film manufacturer, that show the relationship between the exposure applied to a photographic film and the resulting photographic density. These curves are called the film characteristic curves.

Here we show the characteristic curves for three types of X-ray films.



From these curves, if we knew the change in film density that we wanted to achieve, we could find the change in _____ that would be required.

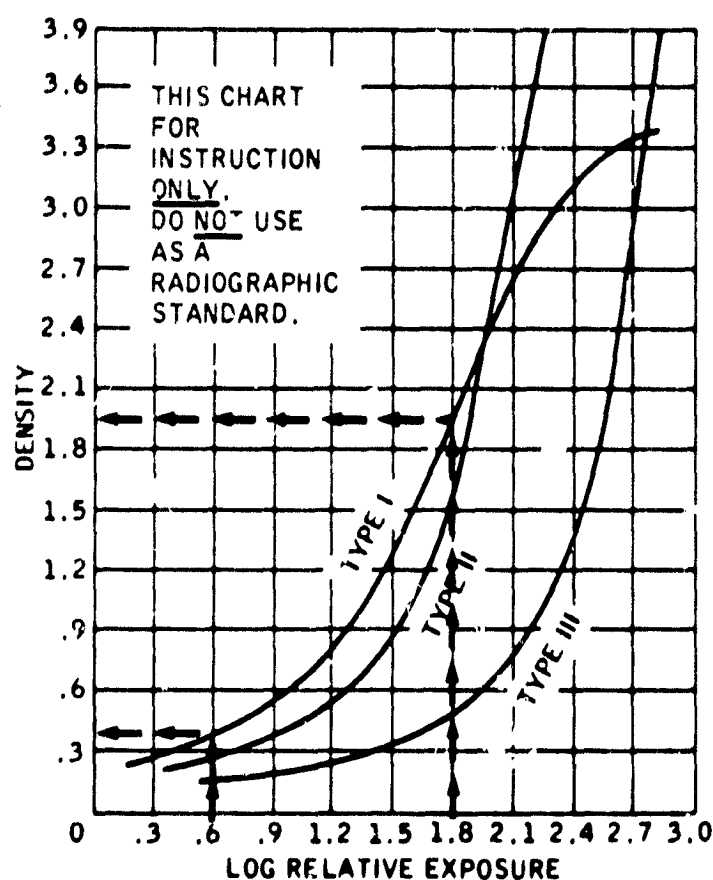
exposure Page 4-46

voltage Page 4-47

Excellent choice. Determining the change in exposure to meet a desired change in density is exactly the purpose of the charts.

These characteristic curves are also known as H & D curves (after the men who developed the curves - Hurter & Driffield), or sensitometric curves. These curves show the relationship between the exposure applied to a photographic film and the resulting photographic density.

For the moment, don't be concerned about the term "log relative exposure." It's a method of comparing exposures that we'll get into a little later. Right now we want to examine the curves to get an idea of what they represent.



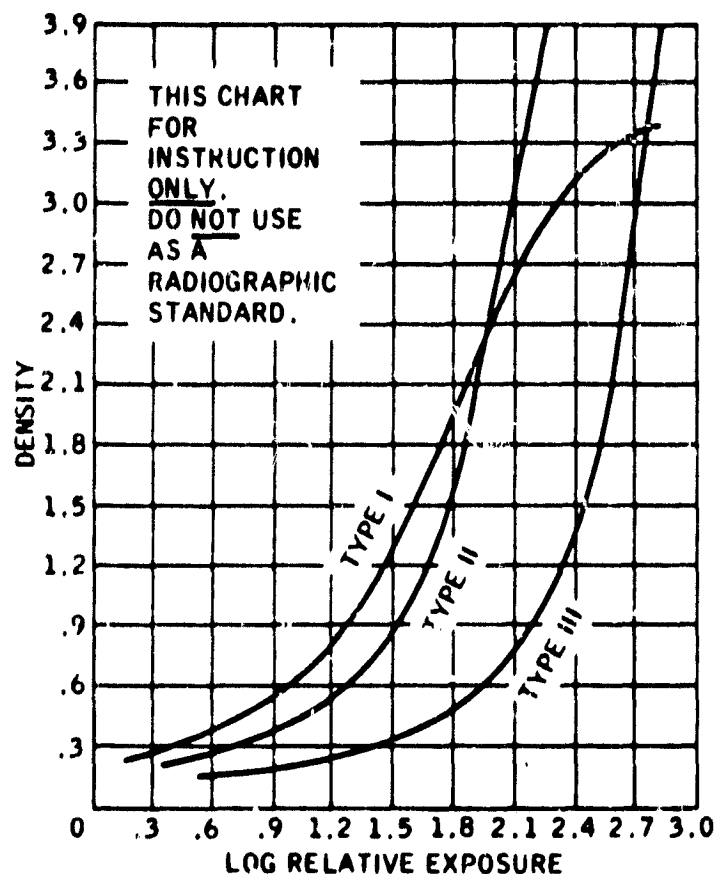
Let's look at type I film in the chart above. With a log relative exposure of 0.6 we get a film density of approximately 0.4. With a log relative exposure of 1.8 we get a film density of approximately 1.95. These two relationships are shown by the dotted lines on the chart.

Using type III film with a log relative exposure of 2.4, the film density would be _____.

3.15 Page 4-48

1.35 Page 4-49

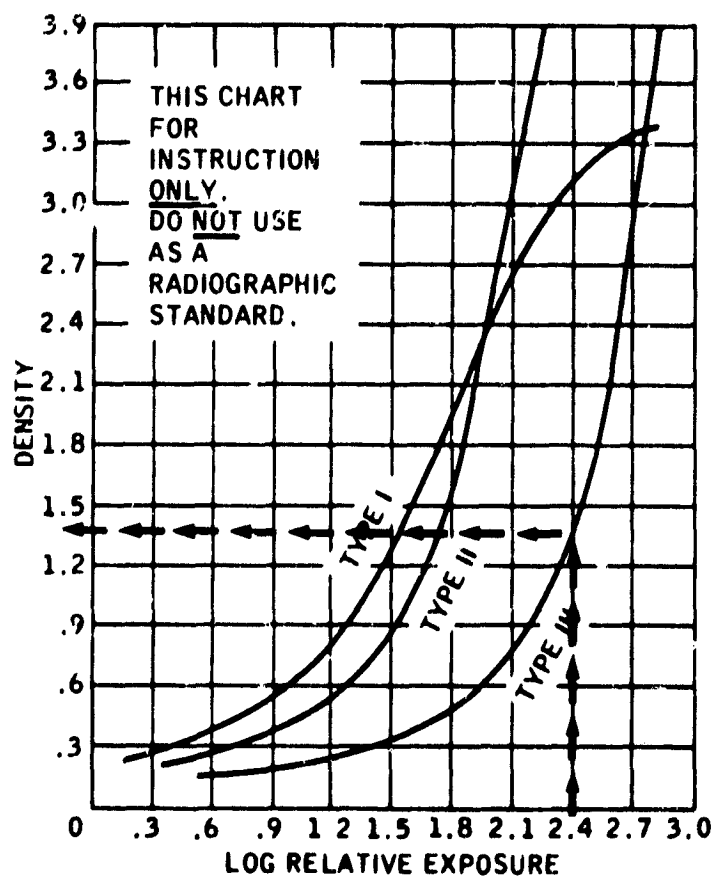
Sorry, we are not playing with voltage charts now. Let's look at these film characteristic curves again.



Note that in these film characteristic charts we are plotting "log relative exposure" on the horizontal axis and "density" on the vertical axis. This means that the plot will show the correct film density for a given relative exposure. Therefore, it follows that if we knew the change in film density that we wanted to achieve we could determine the change in relative exposure that would be required.

Turn to page 4-46 and continue.

Watch out - you are looking at type I film instead of type III film. Here we show the correct way to use the chart for this particular problem.



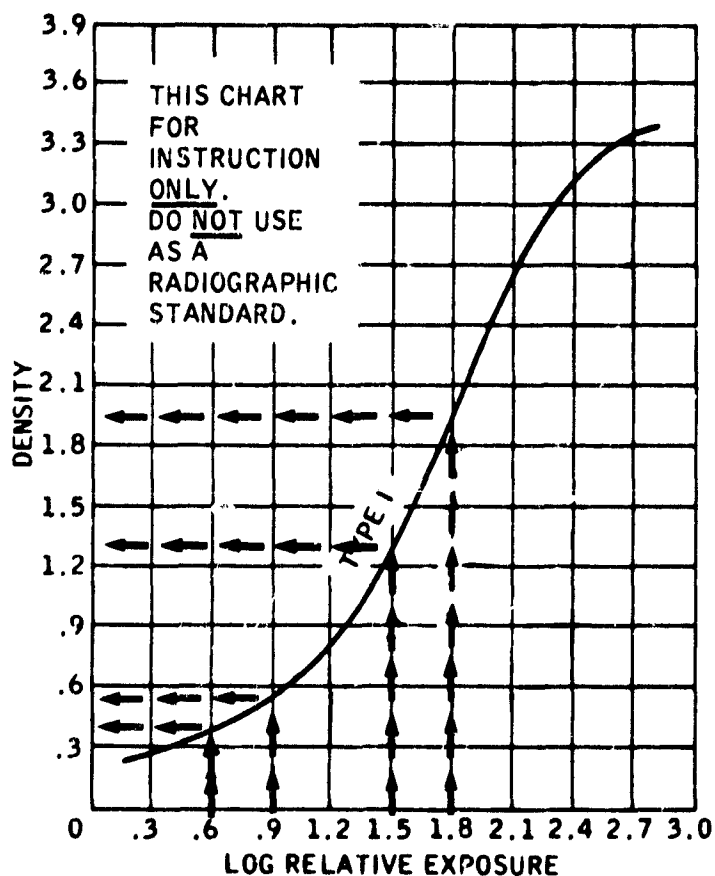
We enter the chart at 2.4 on the horizontal log relative exposure scale, then move vertically (follow dotted line) to the point where we meet the plot for type III film. Then we move horizontally to the left to intersect with the density scale. This gives us a film density of 1.35.

Turn to page 4-49.

Right. The film density for type M film with a log relative exposure of 2.4 would be 1.35.

The H & D curves can give valuable information on all the film characteristics to the radiographer who knows how to use them. For example: the contrast of a film is indicated by the upward slope of the curve at any given point. The steeper the slope, the greater the contrast. The contrast is high wherever the slope is steep because a very small change in exposure at this point will give a large density change. The greater contrast is desirable because then a small change in exposure caused by an inclusion in a specimen would cause a greater variation in the film density.

Let's take a look at type I film in the chart at the right. With a log relative exposure of 0.6 we get a film density of approximately 0.4; with a log relative exposure of 0.9 the film density changes to approximately 0.5. While the log relative exposure changed 0.3 units the film density change 0.1 unit. Now let's move to a steeper part of the curve. At 1.5 log relative exposure the film density is 1.3, and at 1.8 log relative exposure the film density is 1.95. This time the log relative exposure still only changed by 0.3 units but the change in film density is 0.65 units.



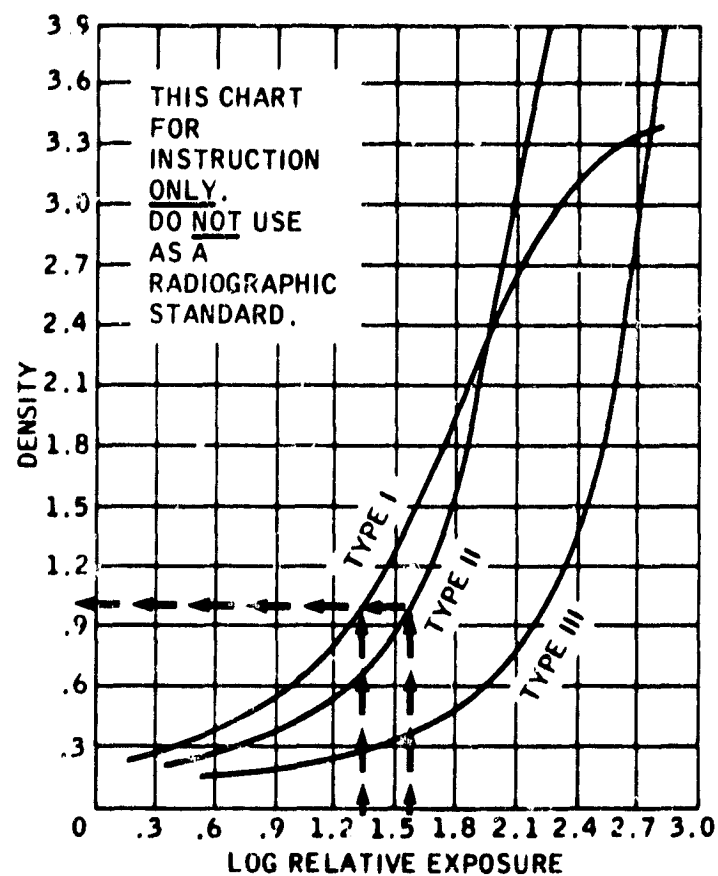
The H & D film curves illustrate that the contrast is _____ when we use exposures that are on the steepest part of the curve.

greatest Page 4-50

least Page 4-51

Very good! The H & D curves show that the contrast is greatest when we use exposures that are on the steepest part of the curve.

The relative speeds of various types of film may also be determined from the characteristic curves.



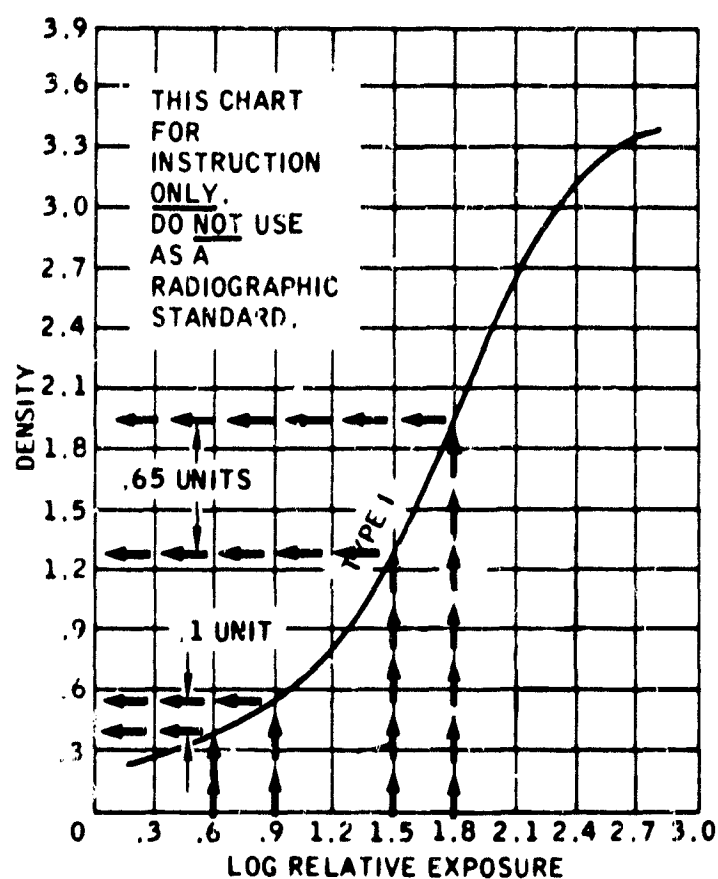
Note that type I film reaches a density of 1 with a log relative exposure of 1.35 while type II film reaches a density of 1 with a log relative exposure of 1.6. Type I film then is faster because it reaches the given density with less exposure. But notice that above a density of 2.4, type II film is faster than type I.

According to the film characteristic chart shown above which of these two films is faster?

type II Page 4-52

type III Page 4-53

Sorry, you made the wrong choice. Let's take another look at the reasons why the characteristic curve will indicate what the contrast is going to be.



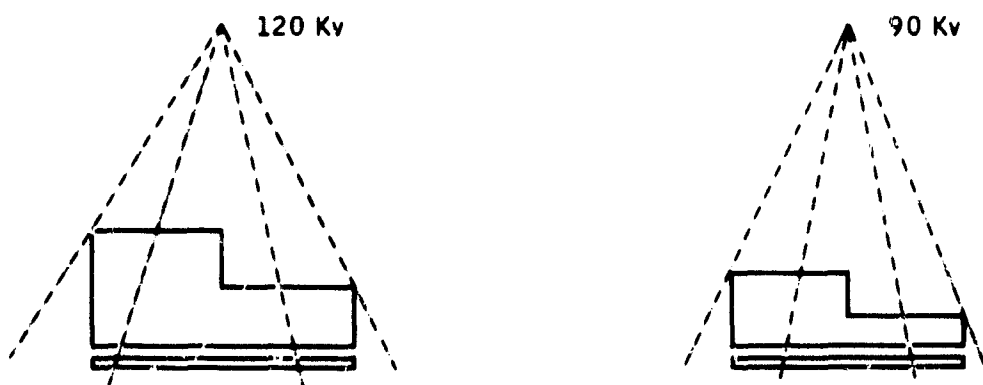
On the lower left end of the curve we show the effect of changing the relative exposure by 0.3 units. On the upper part of the curve we also show the effect of changing the relative exposure by 0.3 units. Note that in each case we have changed the relative exposure by the same amount. Now let's look at the effect this change had on the film density. On the left end of the curve we effected a change in density of 0.1 unit while on the right end we effected a change in density of 0.65 units - 6-1/2 times as much change on the right end as on the left end. Now note that this is caused directly by the steeper slope on the right end of the curve. Therefore, the contrast is greatest when we use an exposure that places us on the steeper part of the curve.

Turn to page 4-50.

Right. Type II film is faster since it reaches a specified density with less exposure than type III film.

The slower films are to the right on the chart while the faster films are to the left.

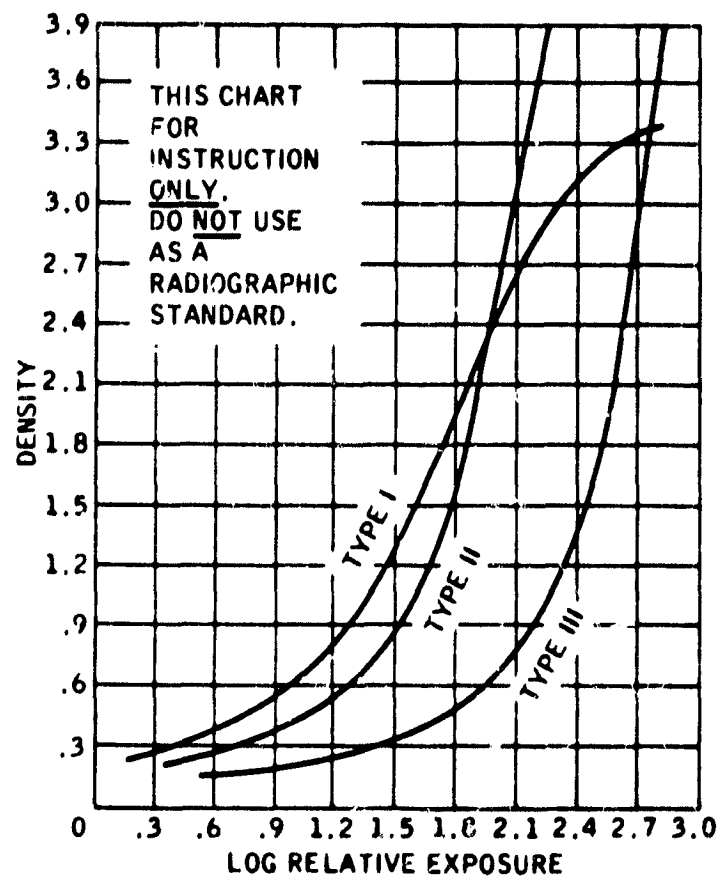
We have noted that the curves plot film density vs the logarithm of relative exposure. "Log relative exposure" is a new term and it looks very complex but don't let it throw you. Let's take it a piece at a time. Relative exposure is used because we do not know what the real exposure is. Remember - the "real" exposure depends upon the exposure factors of kilovoltage used, source-to-film distance, material thickness, type of material, kind of equipment used, etc. - All of those things we have to consider in the exposure for the radiograph. Relative exposure then is the exposure as it appears at the film after it passes through the specimen. That amount of exposure at the film will give you that density, so the exposure is relative only to the film and excludes all other exposure factors.



Here we show two specimens being radiographed separately. We have arranged things so that we have the same amount of exposure at the film regardless of the difference in specimen thickness and any of the other exposure factors. The two films are receiving equal relative exposure.

When we speak of relative exposure, we mean the exposure relative to the _____.
specimen Page 4-54
film Page 4-55

You've got it backwards. Here's the chart again.



Note that type III film is further to the right on the chart than type II. This indicates that type III film is slower. It is slower because it takes a lot more exposure to reach any specified density.

Turn to page 4-52.

No. When we radiograph a specimen we make an exposure. The current and time used in making the exposure are dependent upon many different factors - Kv used, thickness of specimen, film used, source-to-film distance, type of material in the specimen, the type of radiographic equipment we are using, number and kinds of screens used, and filters used. The real exposure is dependent upon all these factors.

But when the radiation reaches the film it has passed through all these conditions and it will expose the film by a certain amount. That much radiation will always give that amount of exposure to the film.

When we speak of relative exposure then, we are talking about the amount of radiation that reaches the film and we thereby eliminate all of the other exposure factors. So when we speak of relative exposure, we are speaking of the exposure relative only to the film.

Turn to page 4-55.

Excellent choice. The exposure relative to the film is what is being plotted on the film characteristic curves.

Now that you understand what is meant by relative exposure, let's take a look at ways in which we can use "relative" exposure. Suppose we had made a $\rho d'$ graph on a particular type of film and we ended up with a density of 1.5. This is too light and we want to increase the density to 2.0. We would look up the relative exposure for each density on the characteristic curve for that film. Suppose we found that the relative exposure required to give a 2.0 density was about 1.3 times the relative exposure required to give a density of 1.5. We would then know that we would have to increase our "real" exposure by the same amount. We would need to increase our real exposure by a factor of 1.3.

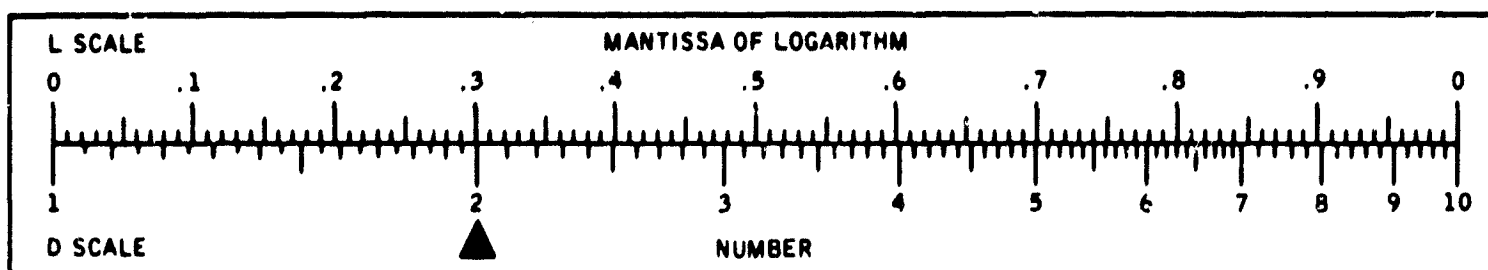
When we find that we need to increase the relative exposure by a certain factor then we know that we need to _____ the real exposure by the same factor.

increase Page 4-56

decrease Page 4-57

Right. An increase in the relative exposure e^2 's for a corresponding increase in the real exposure.

We are now ready to discuss "logarithm of relative exposure". This requires a knowledge of logarithms which we presume you already have. However, because you may be a little rusty and because we don't want to reproduce log tables in this book, we will work through a few sample problems using a scale for finding logarithms just to get everyone in the same groove. If you recall, a logarithm is made up of a "characteristic" and a "mantissa". The mantissa determines the number while the characteristic determines the decimal place. Here is a scale by which the mantissa of a logarithm may be roughly determined.



For example, what is the mantissa of the logarithm of the number 2? First we locate the number 2 on the D (lower) scale. See arrow above. On the upper scale (mantissa of logarithm) we read the mantissa - .301. Now you try one.

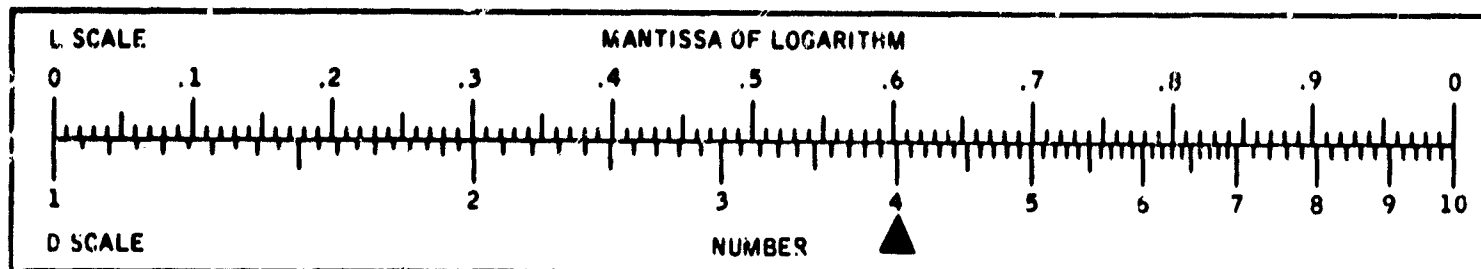
What is the mantissa of the logarithm of the number 4?

Decide what your answer is - then turn to page 4-58 to see if you are correct.

Oops - slow down a bit. The two exposures are directly related. That means - if you find that you should increase the relative exposure by a certain factor, then you must increase the real exposure by the same factor. If you find that the relative exposure must be decreased, then the real exposure must be decreased.

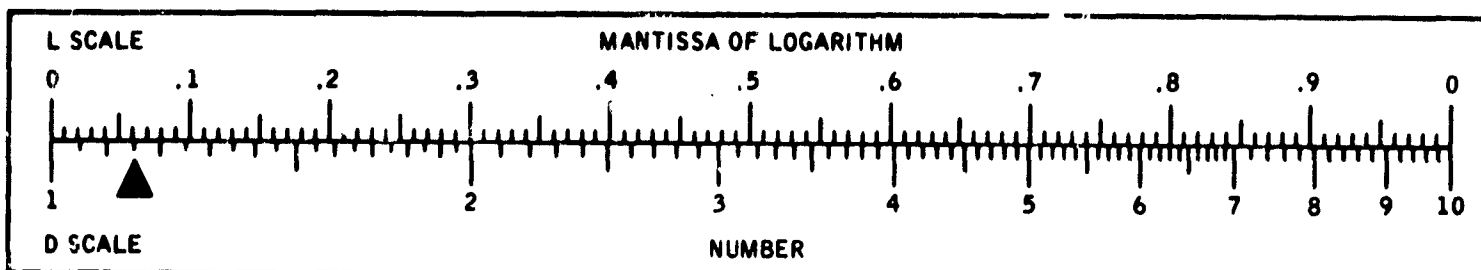
Remember - When we find that we need to increase the relative exposure 1.3 times, then we need to increase the real exposure 1.3 times.

Turn to page 4-56 and continue.



Approximately .602 is correct. You will remember that the mantissa of the logarithm of the number 2 is the same as the mantissa of the logarithm of 20, 200, 2000, etc. The mantissa is the same for all of these numbers.

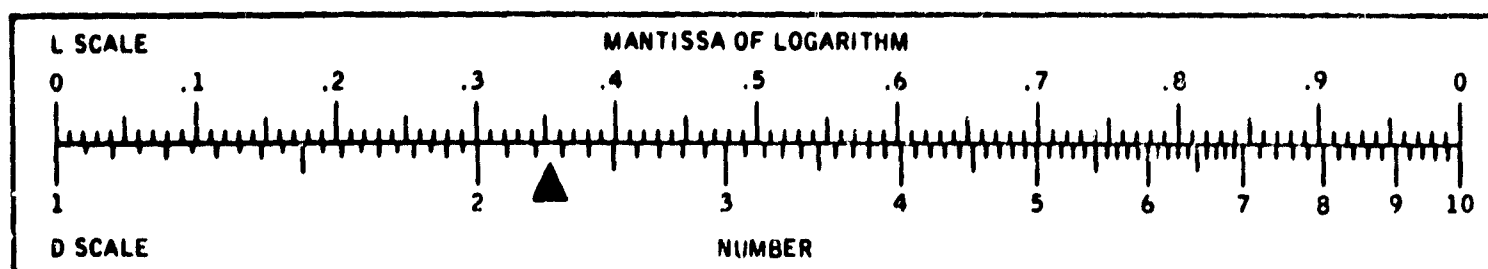
What is the mantissa for the number 115?



The arrow shows where the number 115 is located on the lower scale. The mantissas for the numbers 1.15, 11.5, 115, 1150, 11500 are all the same - .061.

Now you try one. What is the mantissa of the logarithm for the number 22500? As soon as you have determined your answer turn to the next page and see if you are correct.

The correct answer is approximately .352.



Now that you can find the mantissa of the logarithm where do we find the characteristic of the logarithm? This is easily accomplished if you remember the following table:

Log 0 is 0.000	Characteristic
Log 10 is 1.000	
Log 100 is 2.000	
Log 1000 is 3.000	
Log 10000 is 4.000	
etc.	

The number to the left of the decimal point in the logarithm is the characteristic. So from the table, any number from 0 through 9 will have a characteristic of 0. Any number from 10 through 99 will have a characteristic of 1. Any number from 100 through 999 will have a characteristic of 2, etc.

Here are some examples for you to study.

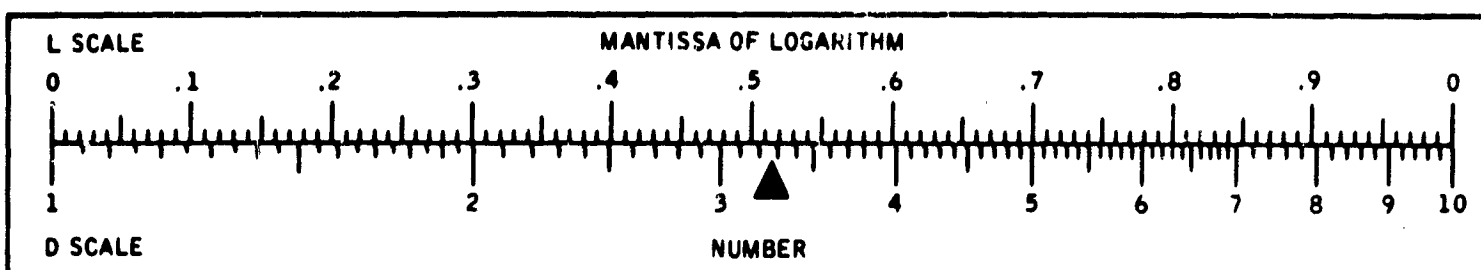
Number	Characteristic of log
12	1.
235	2.
6	0.
1095	3.
104	2.

Now you try some. Check your answers with the answers given on the next page.

Number	Characteristic	Number	Characteristic
1059	_____	20459	_____
938	_____	17	_____
2	_____	225	_____

Number	Characteristic	Number	Characteristic
1059	3.	20459	4.
938	2.	17	1.
2	0.	225	2.

Now that we have reviewed both the characteristic and the mantissa of logarithms let's try putting them together for the complete logarithm.



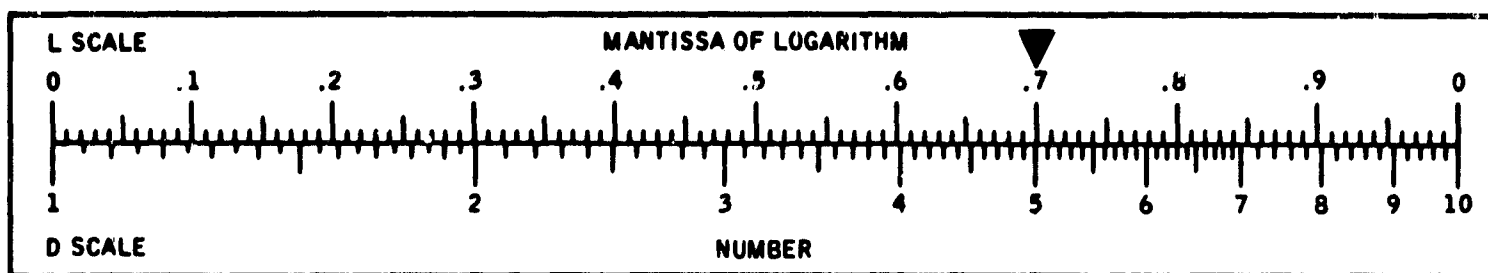
What is the logarithm of 328? First the characteristic - 2, then the mantissa from the scale - .516. The complete logarithm then is 2.516.

What are the logarithms of the following numbers? Check your answers with the answers given on the next page. (Note - In reading the scale approximate answers are close enough.)

Number	Logarithm
15	_____
369	_____
1045	_____
104.5	_____
150	_____
3.69	_____

Number	Logarithm
15	1.176
369	2.567
1045	3.02
104.5	2.02
150	2.176
3.69	0.567

There is one more term we must review just to jog your memory - antilogarithm. Finding the antilogarithm is the reverse of finding the logarithm. You start with the logarithm and work back to the number.



For example - what is the number whose logarithm is 3.700?

First we take the mantissa - .700 and locate it on the L scale as shown (see arrow). This tells us that the antilog of .700 is 5. Now we must locate the decimal point - since the characteristic is 3, we know that the number is between 1000 and 9,999. The number beginning with 5 between 1000 and 9,999 is 5000. Hence the antilog of 3.700 is 5000.

Now you try it - The answers will be found on the next page.

The antilog of 2.740 is_____.

The antilog of 1.080 is_____.

The antilog of 3.935 is_____.

The antilog of 2.740 is 550.

The antilog of 1.080 is 12.

The antilog of 3.935 is 8600.

Now back to radiography and the use of the film characteristic curves.

When we plot the relative exposure on a logarithmic scale we find that the exposures that have the same ratios are always separated by the same interval. For example, here is a set of relative exposures that have a common ratio between them (each successive exposure is twice as big as the last exposure):

Relative exposure - 2, 4, 8, 16, 32, 64, 128, 256

(Note that the ratio between each two successive exposures is = 2; $4/2 = 2$, $8/4 = 2$, $16/8 = 2$, $32/16 = 2$, etc.).

Now let's take the logarithm of each of these exposures and compare them:

Relative exposure -	2,	4,	8,	16,	32,	64,	128,	256
	↓	↓	↓	↓	↓	↓	↓	↓
Log relative exposure -	0.3,	0.6,	0.9,	1.2,	1.5,	1.8,	2.1,	2.4

Now notice the interval between each successive log of relative exposure. The interval is the same for all - 0.3.

0.3	↓	0.6	↓	0.9	↓	1.2	↓	1.5	↓	1.8	↓	2.1	↓	2.4
	↓		↓		↓		↓		↓		↓		↓	
0.3		0.3		0.3		0.3		0.3		0.3		0.3		0.3

Note that we have a ratio between successive exposures of 2 and an interval between logarithms of 0.3. Also - the logarithm of 2 is 0.3. This mathematical characteristic is very handy in making exposure computations.

Turn to page 4-63.

Let's apply this mathematical characteristic to an everyday problem.

Using type I film, let's determine the increase in exposure that would be required to change the density of the film from 1.0 to 2.0. From the chart:

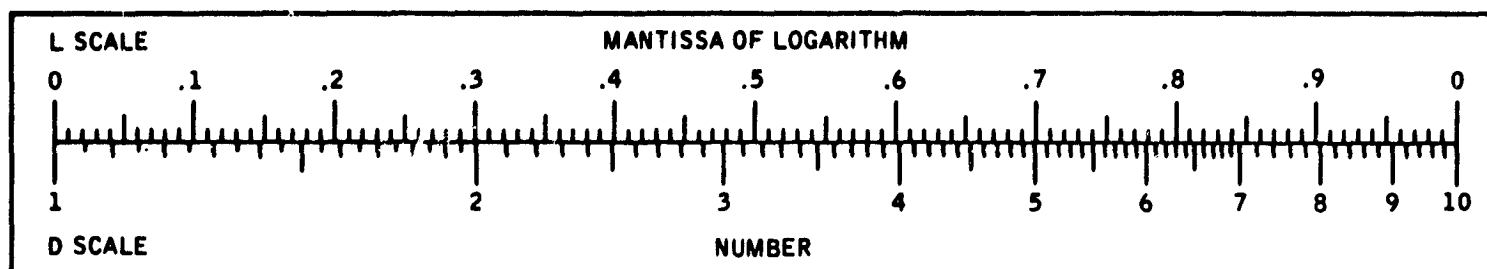
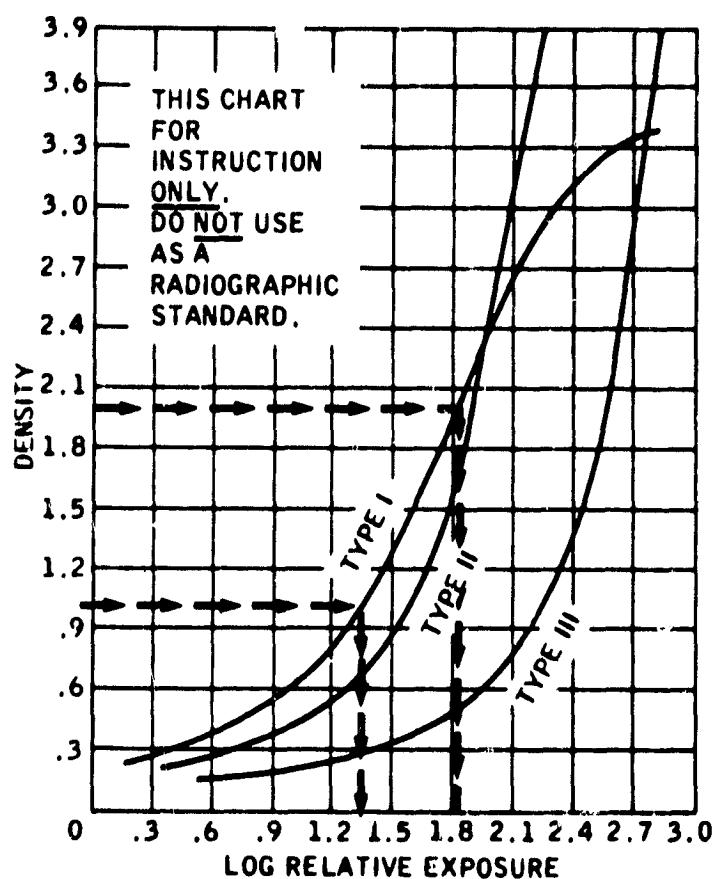
- the log relative exposure for a density of 1.0 is 1.35;
- the log relative exposure for a density of 2.0 is 1.85.

The interval between log relative exposures is: $1.85 - 1.35 = 0.50$. The antilog of 0.50 is approximately 3.18. Therefore, the real exposure must be multiplied by 3.18 to increase the density of the radiograph from 1.0 to 2.0. Note - To increase the density

the exposure had to be increased. Therefore we multiplied by 3.18. If the problem had been such that the exposure was reduced we would have divided by 3.18.

Here is a problem for you to work out. After you have worked the problem, check page 4-64 for the correct answer.

A radiograph made on Type I film with an exposure of 12 milliamperere-minutes has a density of 0.8 in the area of maximum interest. It is desired to increase the density to 2.0 for the sake of increased contrast. What should the new exposure be?



Turn to page 4-64 and check your work.

Note - The information that you take from the chart may not agree exactly with the figures shown below since reading the charts is a matter of the judgment of the individual. Therefore, your answer may not agree exactly with the one given here. You will have to use your own judgment on whether your answer is close enough to be counted as correct. This same reasoning must apply to all problems where data is taken from charts.

Log relative exposure at density of 2.0 = 1.85 (from the chart)

Log relative exposure at density of 0.8 = 1.20 (from the chart)

Interval between log relative exposures = 0.65

Antilogarithm of interval = 4.45

Since the exposure has to be increased to obtain the higher density we multiply the original exposure by 4.45 to obtain the new exposure.

12 milliamperes-minutes X 4.45 = 53.4 milliamperes-minutes

Here are some more practice problems. Using a chart similar to the one given on the next page, work the problems, then check your answers on page 4-66.

Problem 1. A radiograph made on type III film with an exposure of 10 milliamperes-minutes has a density of 1.0. It is desired to increase the density to 2.5. What should the new exposure be?

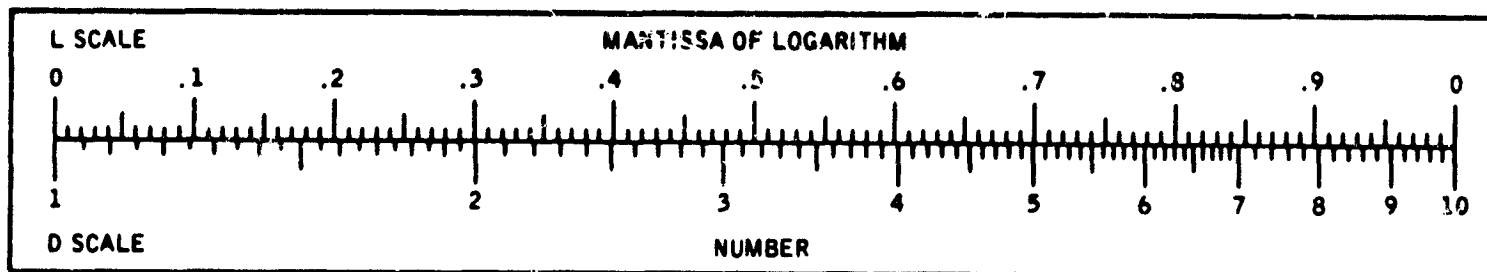
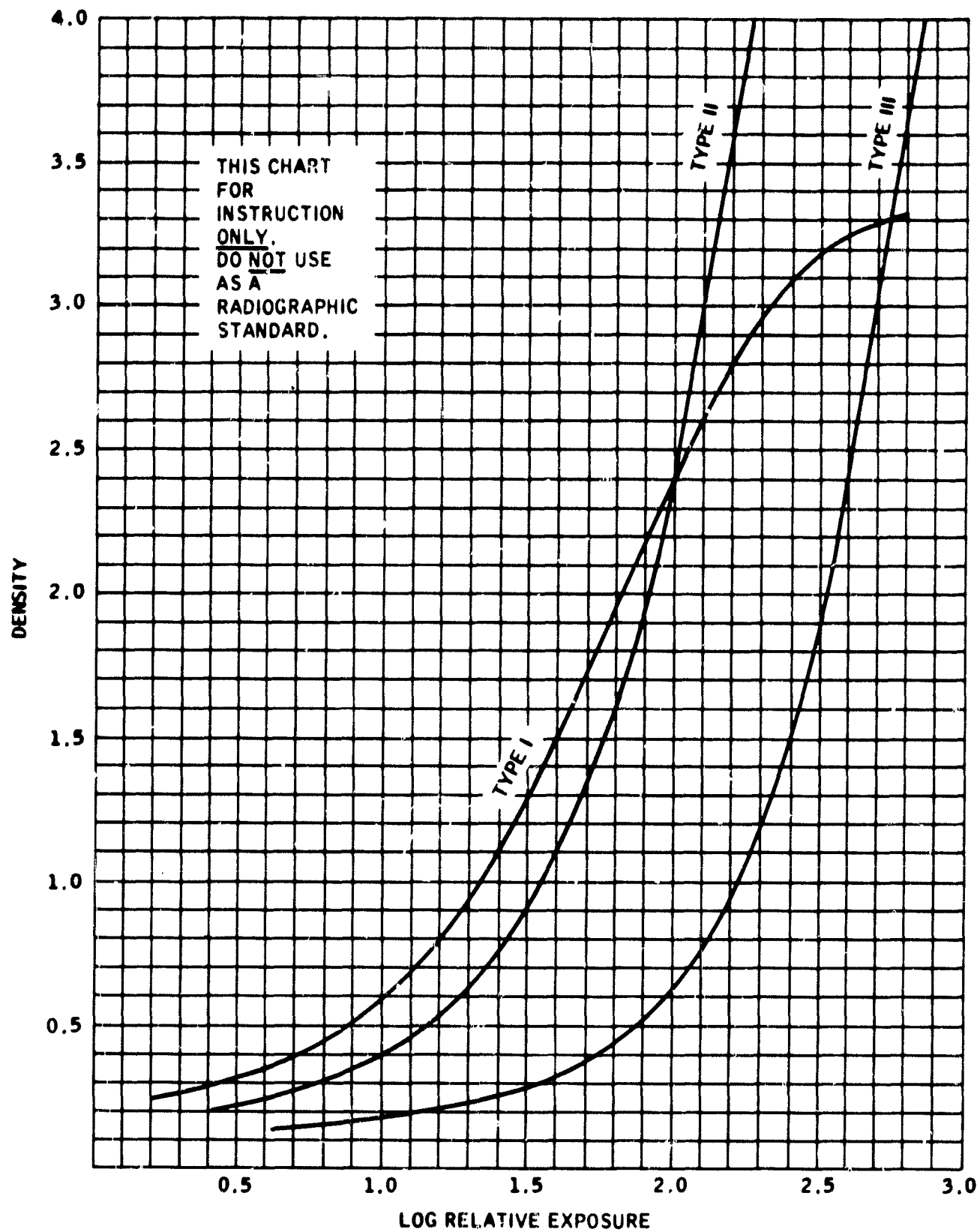
Problem 2. A radiograph made on type II film with an exposure of 8 milliamperes-minutes has a density of 1.3. We want to increase the exposure until we get a density of 3.0. What will be the required exposure?

Problem 3. We have obtained a density of 3.0 on type I film with an exposure of 25 milliamperes-minutes. We wish to reduce the density to 2.5. What is the correct exposure?

Problem 4. We have obtained a density of 3.9 on type II film with an exposure of 20 milliamperes-minutes. We wish to reduce the density to 2.0. What is the correct exposure?



FILM CHARACTERISTICS



Answer for problem 1. Log relative exposure - 2.5 density = 2.62

Log relative exposure - 1.0 density = 2.23

Interval between log relative exposures = 0.39

Antilogarithm 0.39 = 2.45

10 X 2.45 = 24.5 milliamperes-minutes

Answer for problem 2. Log relative exposure - 3.0 density = 2.10

Log relative exposure - 1.3 density = 1.68

Interval between log relative exposures = 0.42

Antilogarithm 0.42 = 2.62

8 X 2.62 = 20.96 milliamperes-minutes

Answer for problem 3. Log relative exposure - 3.0 density = 2.33

Log relative exposure - 2.5 density = 2.05

Interval between log relative exposures = 0.28

Antilog 0.28 = 1.91

$\frac{25}{1.91} = 13.1$ milliamperes-minutes

Note - since we are decreasing the exposure we divide.

Answer for problem 4. Log relative exposure - 3.9 density = 2.25

Log relative exposure - 2.0 density = 1.91

Interval between log relative exposures = 0.34

Antilog 0.34 = 2.19

$\frac{20}{2.19} = 9.1$ milliamperes-minutes

Turn to page 4-67.

The film characteristic charts can also be used to retain the same exposure while changing the type of film being used. Let's try a problem. Suppose we obtained a density of 1.9 using 49 milliamperere-minutes on type I film. What exposure would we use to obtain the same density using type II film?

Log relative exposure at a density of 1.9 for type I film is ... 1.75

Log relative exposure at a density of 1.9 for type II film is ... 1.90

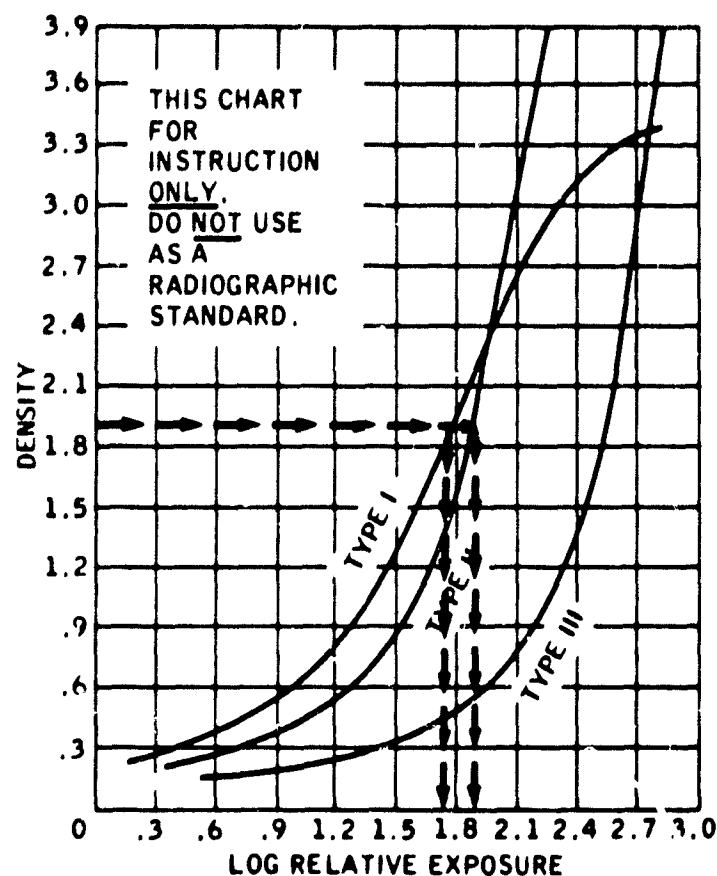
Difference in log relative exposure is ... $1.90 - 1.75 = 0.15$

Antilogarithm of this difference

... Antilog 0.15 = 1.42

49 milliamperere-minutes multiplied by 1.42 is ...

69.6 milliamperere-minutes. So, in switching from type I film to type II film and holding the density at 1.9, we would increase the exposure to 69.6 milliamperere-minutes.



Now you try a problem. Let's take an exposure of 20 milliamperere-minutes on type II film. It gave us a density of 2.0. What would be the proper exposure to maintain the 2.0 density on the slower type III film?

When you have worked the problem check your answer against the solution given on page 4-68. Use characteristic curves and logarithm scale given on page 4-65.

Log relative exposure for type II film at density 2.0 = 1.91

Log relative exposure for type I/I film at density 2.0 = 2.52

Interval between log relative exposures = 0.61

Antilogarithm of interval = 4.08

20 milliamperes minutes multiplied by 4.08 = 81.6 milliamperes-minutes

When you feel that you have mastered the procedure for solving the preceding problem, try these. Use the charts given on page 4-65. The correct solutions will be found on page 4-69.

Problem 1. We have obtained a density of 2.5 on type III film with an exposure of 35 milliamperes-minutes. What would be the required exposure to obtain the same film density on type II film. (Note - in this problem we are going from a slower film to a faster film. The exposure will therefore be reduced.)

Problem 2. We have obtained a density of 2.0 on type III film with an exposure of 18 milliamperes-minutes. What would be the required exposure to obtain the same density on type I film? (Note - type I film is faster than type III film.)

Problem 3. We have obtained a density of 2.8 using type II film with an exposure of 8.2 milliamperes-minutes. We wish to use the slower type III film. What would be the proper exposure to obtain a density of 2.8?

After you have worked the problems, turn to the next page and check your work.

Here are the solutions to the problems given on the previous page.

Problem 1. Log relative exposure - type III film = 2.62

Log relative exposure - type II film = 2.02

Interval between log relative exposures = 0.60

Antilog 0.60 = 3.98

$$\frac{35}{3.98} = 8.8 \text{ milliampere-minutes}$$

Problem 2. Log relative exposure - type III film = 2.52

Log relative exposure - type I film = 1.81

Interval between log relative exposures = 0.71

Antilog 0.71 = 5.12

$$\frac{18}{5.12} = 3.5 \text{ milliampere-minutes}$$

Problem 3. Log relative exposure - type III film = 2.66

Log relative exposure - type II film = 2.07

Interval between log relative exposures = 0.59

Antilog 0.59 = 3.89

$$8.2 \times 3.89 = 32 \text{ milliampere-minutes}$$

Turn to page 4-70.

By way of review, let's work through a problem that requires the application of the mathematical processes we have learned in this chapter.

We have radiographed a 1 1/2-inch steel plate and obtained the following data: Using 240 kv and an exposure of 1600 ma-sec and type III film we obtained a film density of 2.0 at a source-to-film distance of 36 inches.

We now want to radiograph a similar 1 1/2-inch steel plate but we will have to make the following changes: Using film type II and a source-to-film distance of 30 inches, what will be the exposure time required to obtain a film density of 3.0 if the tube current is 8 milliamps?

This problem breaks down into the following steps:

1. Correct the exposure for the change in source-to-film distance (36 inches to 30 inches).
2. Correct the exposure for the change in film and film density (type III film at 2.0 to type II film at 3.0).
3. When the exposure has been corrected for the above factors, determine the exposure time to use with a tube current of 8 milliamperes.

To correct the exposure for the change in source-to-film distance, we will use the equation _____.

$$M_1 \times T_1 = M_2 \times T_2 \dots\dots\dots \text{Page 4-71}$$

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2} \dots\dots\dots \text{Page 4-72}$$

You need a little more review of the equations we have taught you. The equation $M_1 \times T_1 = M_2 \times T_2$ is the equation that is used to determine the X-ray tube current or exposure time. M stands for milliamperes and T stands for time.

To correct the exposure for a change in source-to-film distance we will use the equation -

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2}$$

Where E_1 the original exposure - 1600 ma-sec.

E_2 = the correct exposure - to be computed.

D_1 = the original source-to-film distance - 36 inches.

D_2 = the new source-to-film distance - 30 inches.

It is very important that you remember what each letter in the equation stands for.

Turn to page 4-72.

Right. To correct for the decreased source-to-film distance we use the equation

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2}$$

The distance is to be changed from the original source-to-film distance of 36 inches to the 30 inches specified in the problem. Since the source-to-film distance is being reduced, we know that our exposure must be reduced - the answer will be something under the original exposure of 1600 milliamperere-seconds.

Substitute the correct values in the above equation and solve for the new exposure. When you have reached an answer check your work against the solution given on the next page.

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2}$$

$$\frac{1600}{E_2} = \frac{(36)^2}{(30)^2}$$

$$E_2 = \frac{(30)^2 \times 1600}{(36)^2} = \frac{900 \times 1600}{1296} = 1111 \text{ milliamperes-seconds}$$

We have now made the correction for change of source-to-film distance. We now have to correct the exposure for the change in film type and change in film density. (2.0 density with type III film to 3.0 density with type II film.) These changes can be accomplished simultaneously. Utilizing the data given on the film characteristic chart given on page 4-65, compute the new exposure. When you have reached the solution, check your work against the solution given on the next page.

From the film characteristics chart on page 4-65 we obtain the following:

Log relative exposure - type III film - 2.0 density = 2.52

Log relative exposure - type II film - 3.0 density - 2.1

(Note - the problem conditions require less exposure so our real exposure will be reduced)

Interval between log relative exposures 0.42

Antilog 0.42 = 2.63

$$\frac{1111}{2.63} = 423 \text{ milliamperes-seconds}$$

We have now corrected our exposure for all the necessary factors. It only remains to determine the exposure time required. To do this we apply the equation _____.

$E = M \times T$ Page 4-75

$M_1 \times T_1 = M_2 \times T_2$ Page 4-76

Very good. $E = M \times T$ is the equation to use.

Our corrected exposure is 423 milliampere-seconds and, you will recall, we are going to use a tube current of 8 milliamperes.

Substitute the correct values in the above equation and solve for the exposure time. When you have reached the solution check your work against the solution given on page 4-77.

You made a poor choice. That is not the equation you need at this point.

$M_1 \times T_1 = M_2 \times T_2$ is used only when the exposures for the two conditions are equal
($E_1 = E_2$).

In this problem we know that the exposure (E) is 423 ma-sec. We know that the tube current (M) is 8 milliamperes. We want to determine the exposure time (T). The equation that fits these factors is $E = M \times T$.

Turn back to page 4-75.

$$T = \frac{E}{M}$$

$$T = \frac{423}{8} = 53 \text{ seconds}$$

Now that we have worked a sample problem together, you try one on your own. After you have completed the problem check your work against the solution shown on the next page. Use the same charts, page 4-65, that were used in the previous problem.

Starting with the above data, compute the exposure time that you would use to make a radiograph under the following conditions:

Specimen - 1-inch steel plate.

When you have determined the proper exposure time check your work against the solution found on page 4-78.

From page 4-77

4-78

Correcting for change in source-to-film distance:

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2}$$

$$\frac{E_2}{1400} = \frac{(25)^2}{(36)^2}$$

$$E_2 = \frac{1400 \times 625}{1296} = 675 \text{ milliamperes-seconds}$$

Correcting for film change and density change:

Log relative exposure - type I film - 1.5 density = 1.60

Log relative exposure - type II film - 2.5 density = 2.02

(Exposure increases)

Interval between log relative exposures = 0.42

Antilog 0.42 = 2.63

675 X 2.63 = 1775 ma-sec.

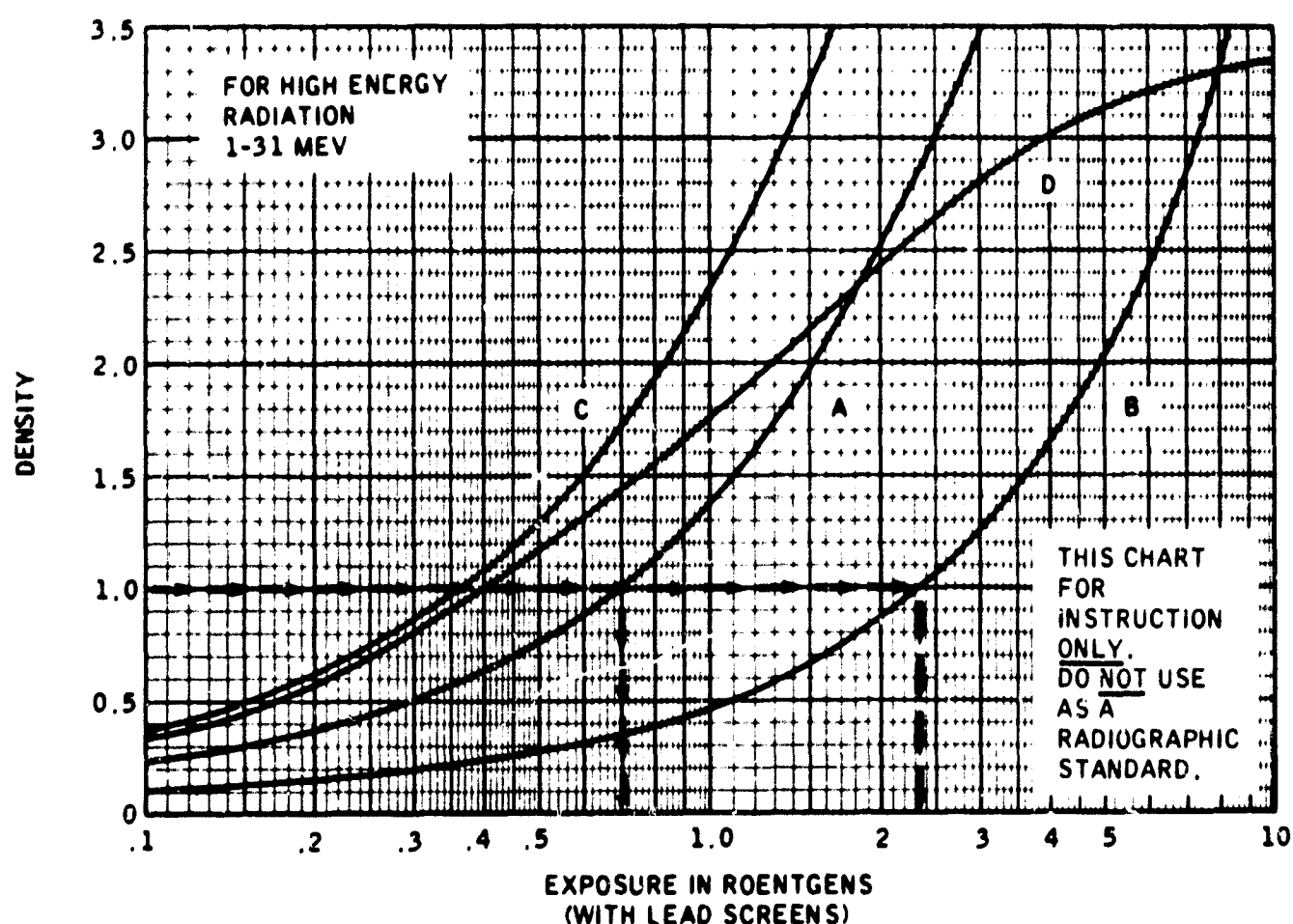
Selecting exposure time:

$$E = M \times T$$

$$T = \frac{E}{M} = \frac{1775}{10} = 177.5 \text{ seconds}$$

Turn to page 4-79.

At this point we are going to introduce a variation of the film characteristic curves. Some film manufacturers publish curves for their films showing the film density plotted against the quantity of radiation in roentgens. Here is a typical chart plotted in this manner.



Note that the horizontal scale (roentgens) is a log scale. You must be careful in reading this type of scale.

In using this type of chart it is not necessary to use logarithms to determine the ratio between exposures. The radiation quantities are read directly from the chart and the ratio is found by dividing one quantity by the other.

For example let's determine the ratio of exposures between film density 1.0 for type A film to film density 1.0 for type B film: From the chart above-

Exposure for density 1.0, type A film = 0.7 roentgens

Exposure for density 1.0, type B film = 2.35 roentgens

Turn to page 4-80.

Then to change from density 1.0 film type A to density 1.0 film type B we would multiply our exposure by $\frac{2.35}{.7} = 3.36$.

If, on the other hand, we wanted to change from density 1.0 film type B to density 1.0 film type A we would multiply our exposure by $\frac{.7}{2.35} = .3$

Let's assume that we have obtained a film density of 1.0 on type A film with an exposure of 300 milliamperes-seconds. We now want to obtain a density of 1.0 on type B film. To do this we would use an exposure of _____.

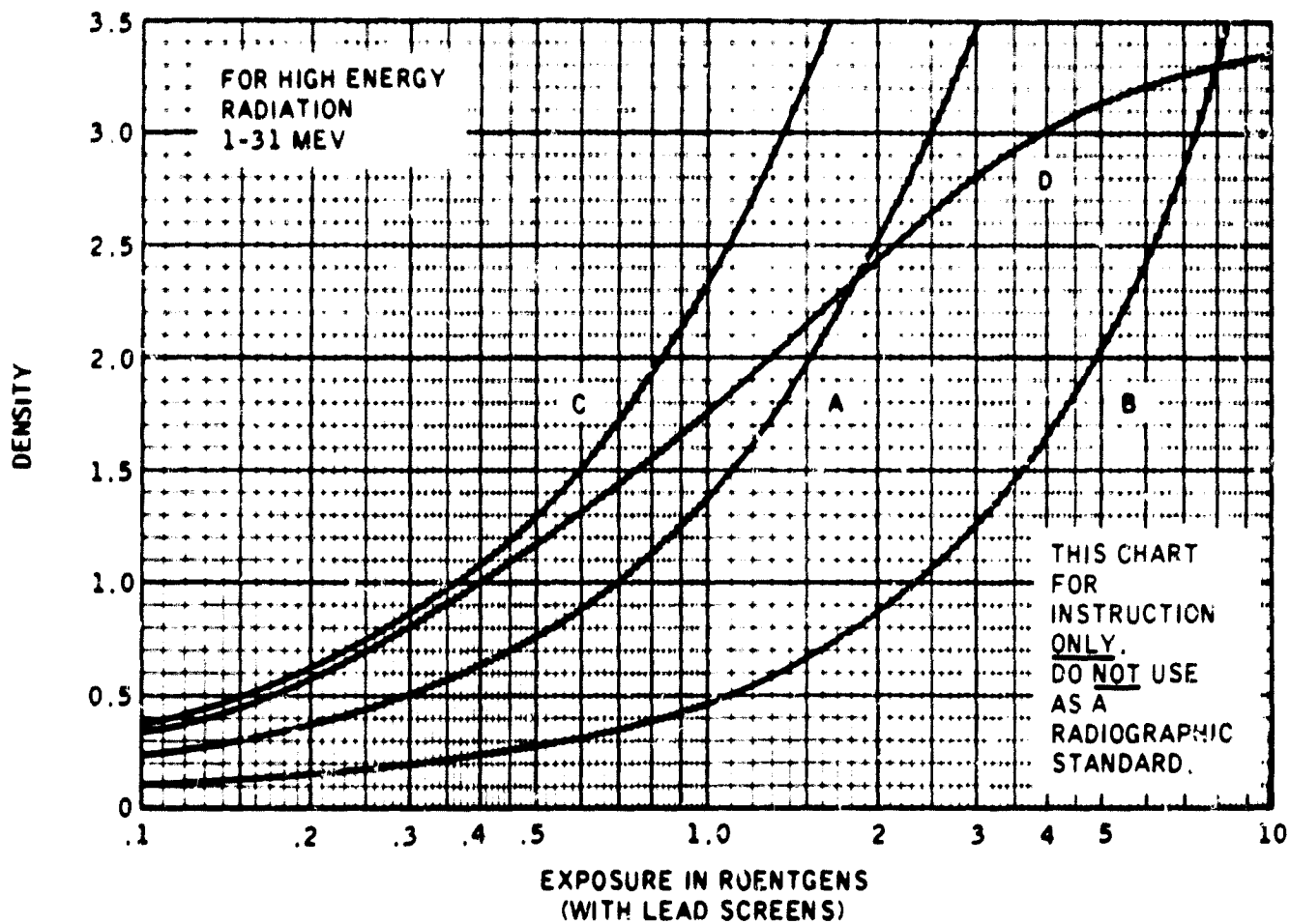
1000 ma-sec Page 4-81

90 ma-sec Page 4-82

From page 4-80

4-81

Very good. 300 X 3.36 1000 (approximately).

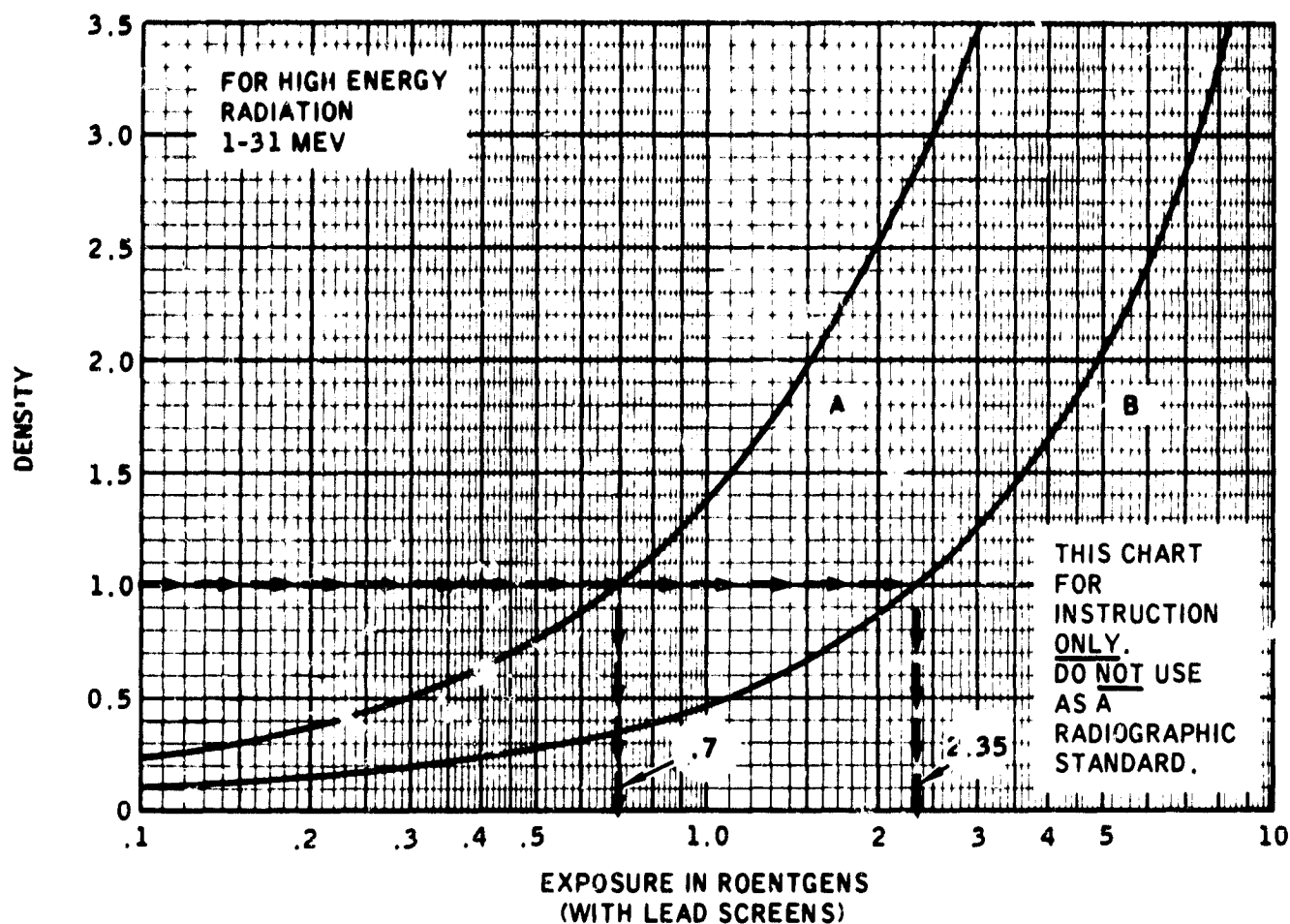


Now let's assume that we have obtained a density of 1.5 on type A film with an exposure of 110 ma-sec. What exposure would we use to obtain a density of 2.5 on type B film?

When you have solved this problem, turn to page 4-83 and check your work.

You have selected a wrong answer. Let's see if we can set you straight.

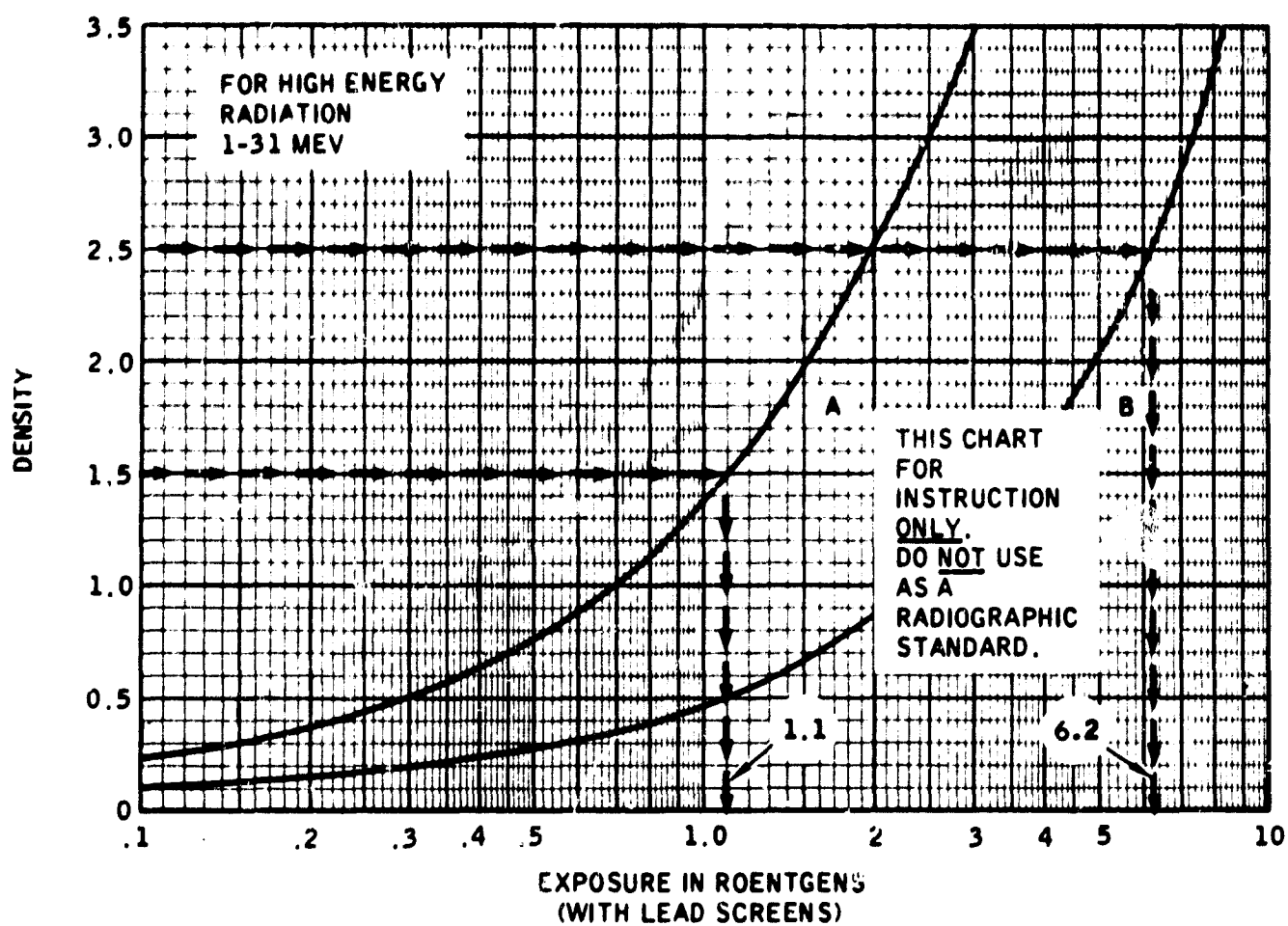
Here's the problem again. We have obtained a film density of 1.0 on type A film with an exposure of 300 ma-sec. We now want to obtain a film density of 1.0 on type B film.



From the chart we obtain the quantity of radiation that was required to give a 1.0 density for both types of film. (See numbers encircled on chart above.) These numbers tell us that in going from type A film to type B film, the radiation quantity increased from .7 roentgens to 2.35 roentgens. The exposure, then, has to increase by a factor of $\frac{2.35}{.7}$ or 3.36. Therefore we have to multiply our original exposure by 3.36.

$$300 \times 3.36 = 1008 \text{ ma-sec (approximately)}$$

Turn to page 4-81 and continue.



From the chart:

Radiation quantity for 1.5 density on type A film = 1.1 roentgens

Radiation quantity for 2.5 density on type B film = 6.2 roentgens

Since the exposure would have to be increased we would multiply our exposure by

$$\frac{6.2}{1.1} = 5.64$$

$$110 \times 5.64 = 620 \text{ ma-sec.}$$

or $110 \times \frac{6.2}{1.1} = 620 \text{ ma-sec.}$

Turn to page 4-84 for a review of this chapter.

1. In the equation $Q = I \times T$, I stands for intensity measured in roentgens per second; T stands for exposure time measured in seconds; and Q stands for radiation quantity measured in _____.

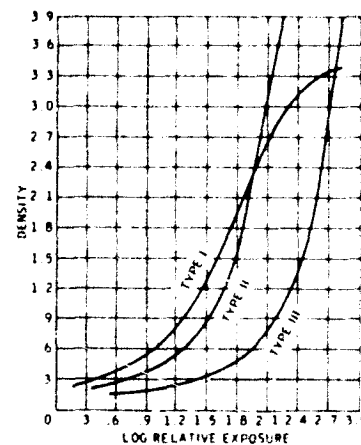
11. time

12. When using X-rays, the exposure is equal to the current through the tube multiplied by the time of exposure. This is represented by the equation _____.

22. distance

23. In a radiographic beam the intensity of the beam decreases as the distance from the source _____.

$$33. \frac{T_1}{T_2} = \frac{D_1^2}{D_2^2}$$



34. In this film characteristic chart, what are the three variables?

1. roentgens

2. In the equation $Q = I \times T$, Q is measured in _____, I is measured in _____ and T is measured in seconds.



12. $E = M \times T$

13. With a tube current of 10 milliamperes and an exposure time of 75 seconds, the exposure will be _____.



23. increases

24. In a radiographic beam the intensity of the beam varies inversely with the square of the distance from the source. If I_1 stands for the intensity at point 1 and I_2 stands for the intensity at point 2; and D_1 stands for the distance from the source to point 1 and D_2 stands for the distance from the source to point 2; then the equation for the inverse square law is _____.



34. Film type, density, and (log relative) exposure

35. The upward slope of the film characteristic curve indicates the amount of density change that results from a change in film exposure. Therefore the slope of the curve is an indication of the film _____.



2. roentgens, roentgens
per second

3. Roentgens is the measure of a _____ of radiation, and roentgens
per second is the measure of the _____ of the radiation.

13. 750 milliampere-
seconds

$$E_1 = M_1 \times T_1$$

$$E_2 = M_2 \times T_2$$

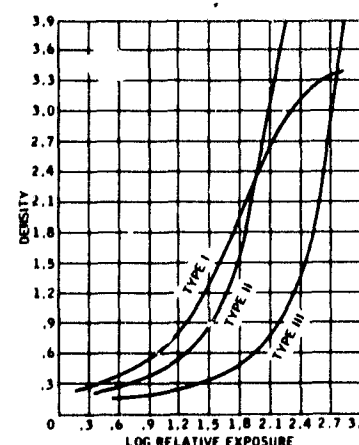
14. From the above equations, if we want to maintain a constant exposure so that
 $E_1 = E_2$, then $M_1 \times T_1$ must equal _____.

24. $\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$

25. The intensity of a beam decreases as the distance from the source increases.
Then the film exposure also decreases as the source-to-film distance
_____.

35. contrast

36. The film characteristics curves also show the relative
speeds of different types of film. The curves lying to
left on the chart are for the _____ (faster, slower)
films.



3. quantity, intensity

Q = Quantity of radiation

I = Intensity of

T = Time of exposure

4. The quantity of radiation in a beam can be determined by multiplying the intensity of the ray by the time of exposure. This is represented by the equation _____.
- 

14. $M_2 \times T_2$

15. $M_1 \times T_1 = M_2 \times T_2$ is the mathematical equation for the reciprocity law. The reciprocity law states that if a constant exposure is to be maintained, increasing the exposure time requires that the tube current be _____.
- 

25. increases

26. In order to compensate for the decreases film exposure that results from an increased source-to-film distance, we _____ (increase, decrease) the exposure at the source.
- 

36. faster

37. "Relative exposure" is a term used to mean exposure relative to the _____.
- 

4. $Q = I \times T$

5. If the intensity of an X-ray beam at a film is 0.015 roentgens per second (15 mr per sec) and the film is exposed to the ray for 100 seconds, how many roentgens does the film receive?



15. decreased

16. An increase in tube current requires that the exposure time be decreased, if the exposure is to remain unchanged. This is a restatement of the _____ law.



26. increase

$$\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2}$$

27. This equation shows that the required exposure at the source varies directly as the square of the source-to-film _____.



37. film

38. "Relative" exposure and "real" exposure are directly related. When the relative exposure is to be increased by a factor of three, the real exposure is to be _____ by a factor of three.



5. $0.015 \times 100 = 1.5$
roentgens

6. The intensity of an X-ray beam is directly proportional to the current through the X-ray tube. Whenever the current through the tube is reduced, the intensity of the beam is _____ (reduced, increased) in the same ratio.



16. reciprocity

17. The mathematical equation for the reciprocity law is _____
_____.



27. distance

28. The required source exposure varies directly as the square of the source-to-film distance. This is expressed mathematically by the equation
_____.



38. increased (multiplied)

2.155

2 - characteristic

155 - mantissa

39. A logarithm has two parts - the mantissa and the characteristic. When converting a logarithm to a number, the mantissa determines the
_____.



6. reduced

$$\frac{I_1}{I_2} = \frac{M_1}{M_2}$$

7. In the above equation, I stands for intensity of the beam and M stands for

_____.



17. $M_1 \times T_1 = M_2 \times T_2$

18. In order to maintain the same exposure if we change the tube current from 10 milliamps to 5 milliamps, we must change the exposure time from 140 seconds to _____ seconds.



28. $\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2}$

29. An exposure of 300 ma-sec has given a satisfactory radiograph of a specimen at a source-to-film distance of 20 inches. What exposure would be required if the source-to-film distance was increased to 40 inches?



39. number

40. When converting a logarithm to a number, the characteristic determines the

_____.



7. current (milliamps)

8. To compute the change in the intensity of a ray that results from a change in the tube current, we use the equation _____.

18. 280

19. In radiography with isotopes, curies are proportional to intensity for a given source just as milliamps are proportional to intensity for a given X-ray machine. If the reciprocity law is expressed mathematically as $M_1 \times T_1 = M_2 \times T_2$ for X-rays it can be expressed mathematically as _____ for gamma rays.

29. 1200 ma-sec

$$\frac{M_1 \times T_1}{M_2 \times T_2} = \frac{D_1^2}{D_2^2}$$

30. This equation tells us that if the current is kept constant ($M_1 = M_2$), the time of exposure will vary _____ (directly, inversely) as the square of the source-to-film distance.

40. decimal place

41. To get from a logarithm to a number we find the antilog of the logarithm. The antilog is the _____ represented by the logarithm.

$$8. \frac{I_1}{I_2} = \frac{M_1}{M_2}$$

9. If the intensity of an X-ray beam is 0.050 roentgens per second at 1 foot from the source when a tube current of 10 milliamps is used, what will be the intensity of the beam at the same point if 20 milliamps are applied across the tube?



$$19. C_1 \times T_1 = C_2 \times T_2$$

20. If $E_1 = E_2$; then $C_1 \times T_1 = C_2 \times T_2$. This indicates that if the activity of a given source decays then the exposure time must be _____ if the same exposure is to be maintained.



30. directly

$$E = C \times T$$

31. In gamma radiography, _____ (source strength, exposure time) cannot be varied to change the exposure.



41. number

42. When the film characteristic curve plots density vs exposure in roentgens, logarithms _____ (are, are not) required to compute changes in exposure.



9. 0.1 roentgens per second

10. In the equation $E = M \times T$, if M is measured in milliamperes, and T is measured in seconds, then E is measured in _____ - _____.

20. increased

21. We had a satisfactory radiograph of a specimen using a 30 curie source of Cobalt-60 with an exposure time of 6 minutes. We now want to radiograph a similar specimen but our source has decayed to 20 curies. What exposure time should we use?

31. source strength

$$E = C \times T$$

32. In gamma radiography, to maintain the same exposure for a given source a change in source-to-film distance requires a change in _____.

42. are not

Now turn to page 5-1.

10. milliamperes-seconds

11. In the equation $E = M \times T$, E stands for exposure, M stands for current (milliamperes), and T stands for _____.



Return to page 4-84,
frame 12, and continue.

21. $\frac{30 \times 6}{20} = \frac{18}{2} = 9 \text{ mins.}$

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

22. This equation is the mathematical way of expressing the inverse square law. The inverse square law tells us that the intensity of the beam decreases as the square of increasing _____.



Return to page 4-84,
frame 23, and continue.

32. exposure time

33. In gamma radiography, the exposure time for a given source varies directly as the square of the source-to-film distance. This is represented by the equation _____.



Return to page 4-84,
frame 34, and continue.

Turn to page 5-1.

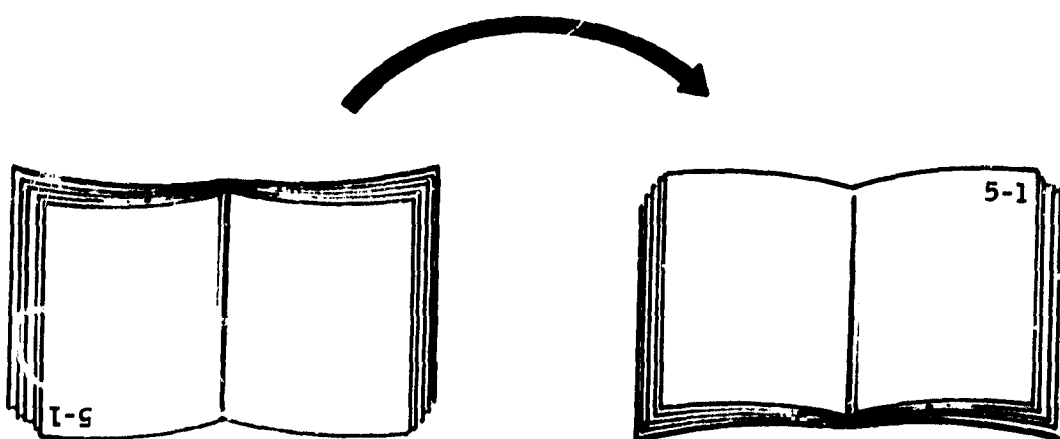


From page 4-94

4-95

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.

In Chapters 1 through 4 of this book we have discussed all of the elements that must be considered when making radiographs. These individual elements have been discussed in some detail giving all of the technical theories as reasons for the practical application. In this chapter we intend to summarize the material so that the practical application is given without discussing the theoretical details for the practice.

The objective that every radiographer has to keep in mind is the production of the best quality radiograph possible under the conditions imposed by the situation. The quality of the radiograph is determined by four factors: distortion, definition, contrast, and density.

The ideal radiograph has a minimum amount of distortion. The image of the specimen and the image of any discontinuity in the specimen must be true so that proper decisions can be made to accept or reject the specimen.

The quality radiograph has a _____ amount of distortion.

minimum Page 5-2

maximum Page 5-3

You are right! Minimum distortion is a deciding factor in selecting the geometry for a radiograph.

The ideal radiograph has sharp definition. Sharp edges on the specimen should appear as sharp edges in the radiograph. Discontinuities are more easily seen in the radiograph if the edges of the image of the discontinuities are sharply defined.

The quality radiograph has the sharpest possible _____.

definition Page 5-4

discontinuities Page 5-5

From page 5-1

5-3

Sorry! Maximum distortion is not a desirable element of a quality radiograph. Perhaps you are confused as to the meaning of distortion.

Anything that is pulled out of its ordinary shape is distorted. In radiography it is very important that the shape of the image is the same as the shape of the specimen. If they are not the same then the image is distorted. A distorted specimen image also means a distorted defect image.

In the quality radiograph we need the least distortion possible - minimum distortion - so that any defects can be properly identified to aid interpretation of the radiograph.

Turn to page 5-2.

SECRET

From page 5-2

5-4

Very good. Sharp definition is a factor that must be considered when making a radiograph.

The ideal radiograph has the highest possible contrast. A marked change in density is required if small discontinuities are to be seen in the radiograph.

The quality radiograph has the _____ possible contrast.

lowest Page 5-6

highest Page 5-7

Perhaps we misled you a little here. It could be said that if there were any discontinuities shown on the radiograph we certainly would want them to be as sharp as possible but this is not the best answer to the question.

The sharpest possible definition is sought so that discontinuities, if any exist, will be better revealed to the radiographer. When making a radiograph, conditions are adjusted to make the definition as sharp as possible.

Turn to page 5-4.

You think that the ideal radiograph has the lowest possible contrast. You have forgotten the meaning of contrast and its effect on the radiograph.

Contrast is a comparison between the film densities of different areas of the radiograph. Two areas of approximately the same density have low contrast while two areas that have extremely different densities have high contrast. The highest possible contrast produces the required change in density to reveal small discontinuities in the specimen. With high contrast, smaller discontinuities are visible.

Turn to page 5-7.

██████████

Right. The highest possible contrast is a factor that must be considered when making a radiograph.

The ideal radiograph must have adequate density. If the radiograph is too dense it will not transmit enough light so that discontinuities can be seen. If it is not dense enough there will not be enough contrast to see any discontinuities.

The quality radiograph must have _____ density.

- maximum Page 5-8
- adequate Page 5-9

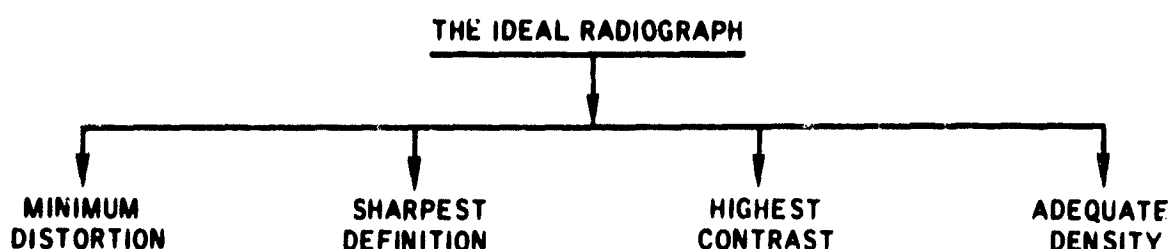
Maximum film density is not a requirement of good radiography. It is true that contrast generally improves with film density but there is a limit. The film can become so dense that no light will shine through it. The practical maximum limit then is established by the film viewing equipment.

The quality radiograph must have a density that establishes the best contrast possible but does not exceed the capabilities of the viewer.

Turn to page 5-9.

Right. Adequate density is another factor that must be considered when making a radiograph. The radiograph must be readable on the viewer.

The following chart sums up the major qualities of the ideal radiograph.



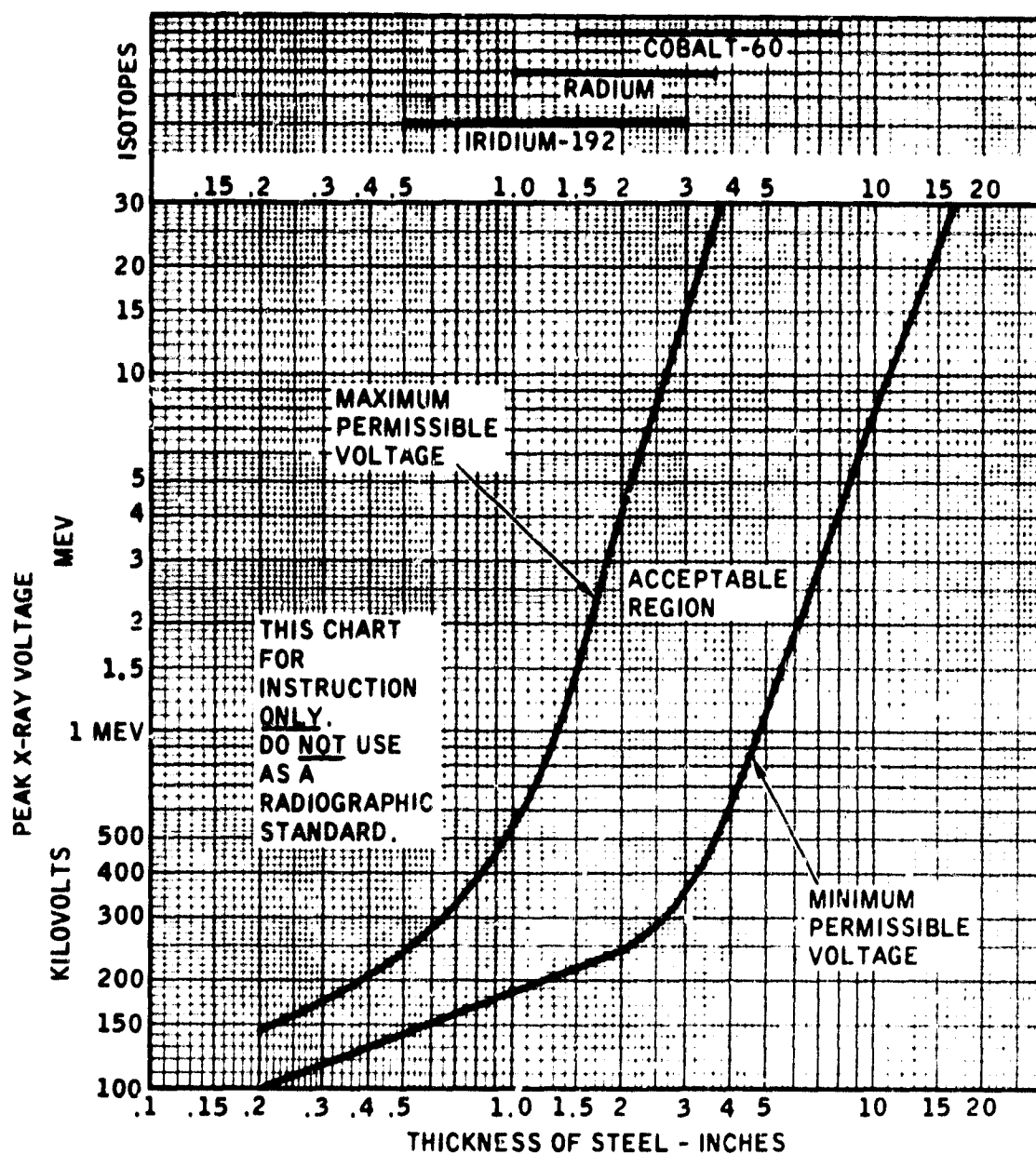
The radiographer must always keep in mind how these qualities are affected by the many radiographic factors with which he will be working. It is on this basis that the decisions are made on how best to utilize all the variables that can be controlled. In the application of radiography to the inspection of a specimen a number of decisions and compromises are made. Some advantages are sacrificed to obtain other advantages. As you will soon see, it is impossible to fix hard and fast rules to cover any and all situations that could arise in the practice of radiography. Such rules are developed for particular machines when used under particular circumstances and fine control can only come from experience with the equipment. The radiographer must use his best judgement in utilizing all of the variables that he can control.

Selection of radiographic sources. Considering that there are a multitude of radiographic sources available for radiography, on what basis does the radiographer select his source?

In actual practice the selection is limited to those sources which are available to him. Other factors that can limit his decision are: size and mobility of equipment and size and mobility of the subjects to be radiographed. However, these decisions are not generally based on the desired quality of the radiograph.

Turn to the next page.

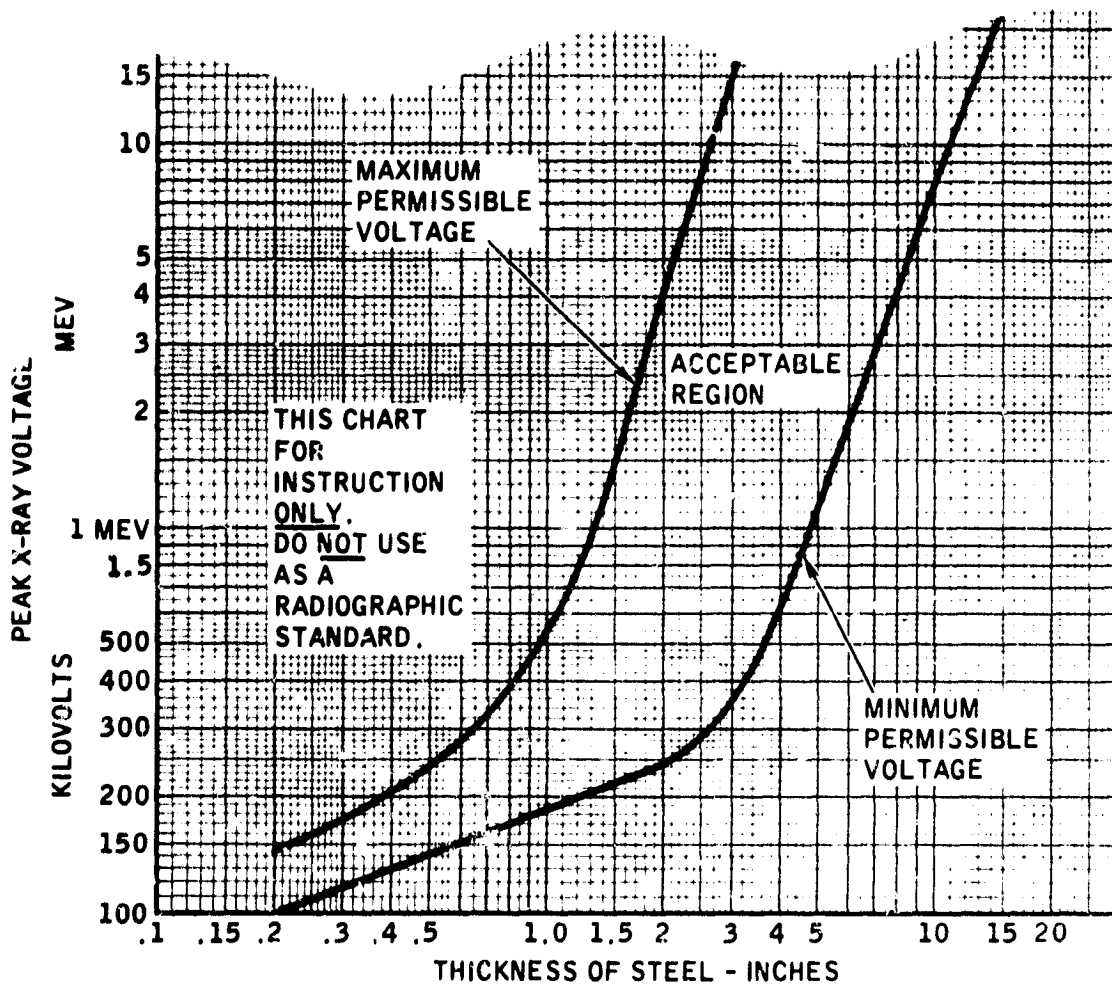
A decision that is based on the desired quality of the radiograph is reached through the use of charts that show the kv or gamma ray energy required to penetrate specified thicknesses of steel. This information is generally presented in the form of a chart similar to the one shown here.



This chart shows the range of voltages, or the gamma ray source, that may be used to radiograph any particular thickness of steel to obtain adequate radiographs in a reasonable length of time. By using this chart the radiographer can identify the thickness limits that are applicable to his equipment.

Turn to page 5-11.

Let's examine that portion of the chart that deals with kv. Note that the chart plots thickness vs voltage.



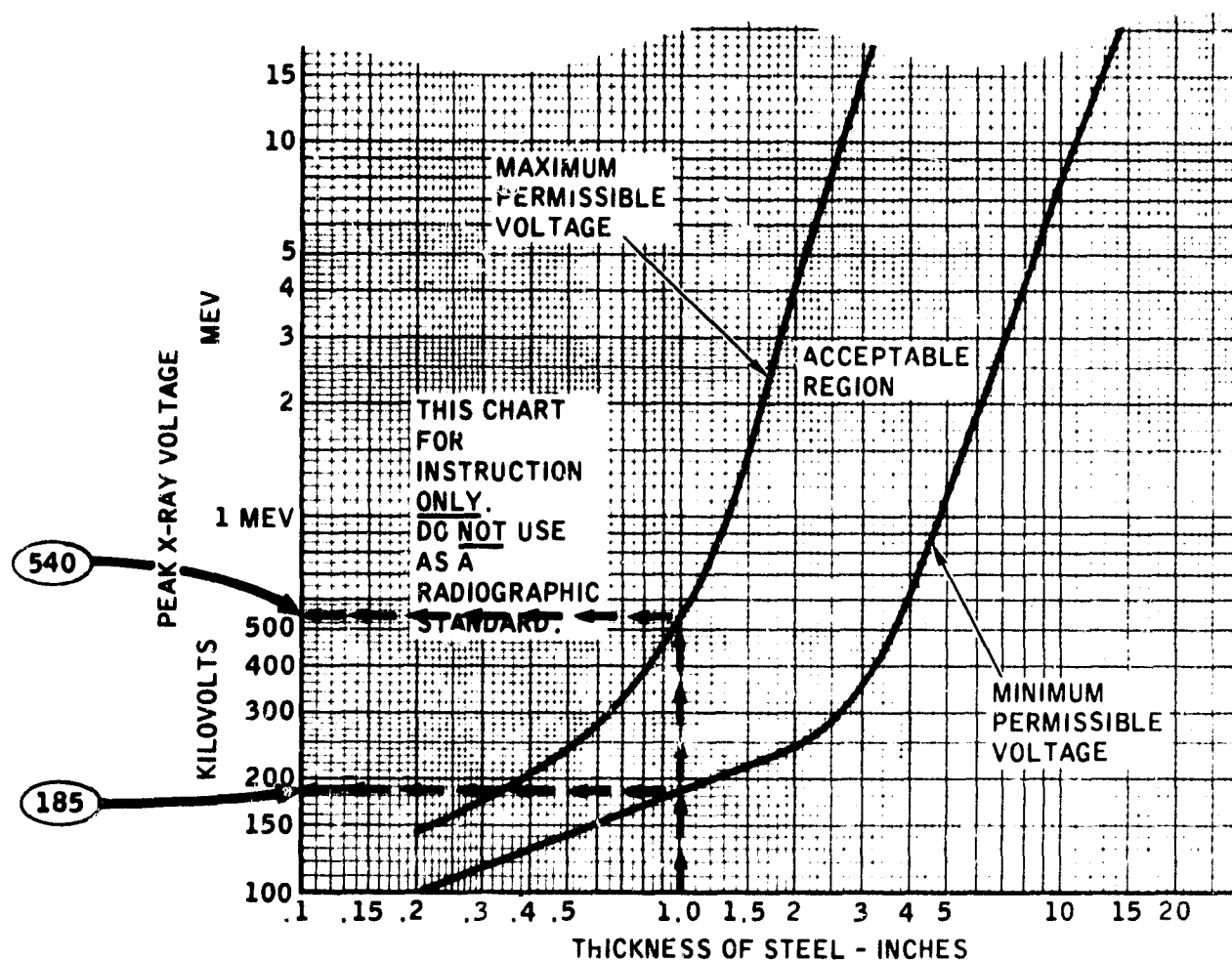
The upper curve indicates the maximum voltage beyond which satisfactory radiographs cannot be obtained. The lower curve indicates the minimum voltage below which adequate radiographs cannot be obtained in a reasonable length of time. Then the area between the lines indicates the "acceptable" region.

According to the chart the limits of the acceptable voltage to use in radiographing 1 inch of steel are _____.

1.4 to 4.8 kvp Page 5-12

185 to 540 kvp Page 5-13

Sorry - you're not reading the chart correctly. Let's take another look at the chart.



Our problem was to find the acceptable voltage limits that could be used to radiograph 1 inch of steel. The dotted line on the chart above shows how we solve this problem. We find "1 inch" on the horizontal axis of the chart. From that point we follow the line vertically until it reaches the first curve. This is the minimum allowable voltage which is read on the vertical axis. (In this example - 185 kvp.) We continue vertically until we reach the second curve. This is the maximum allowable voltage which is also read on the vertical axis. (In this example - 540 kvp.)

Therefore a minimum voltage of 185 kvp and a maximum voltage of 540 kvp are the limits of voltage that can be used to radiograph 1 inch of steel.

Turn to page 5-13.

Very good! Any voltage between 185 kvp and 540 kvp according to this chart is considered adequate to radiograph 1 inch of steel.

This also tells us that the X-ray source must be capable of voltage over 185 kvp or capable of voltages less than 540 kvp to be used as a source to radiograph 1 inch of steel.

According to this chart which of the two machines whose kv ratings are listed below can be used to radiograph 1 inch of steel?

- 50-130 kvp Page 5-14
- 200-750 kvp. Page 5-15

From page 5-13

5-14

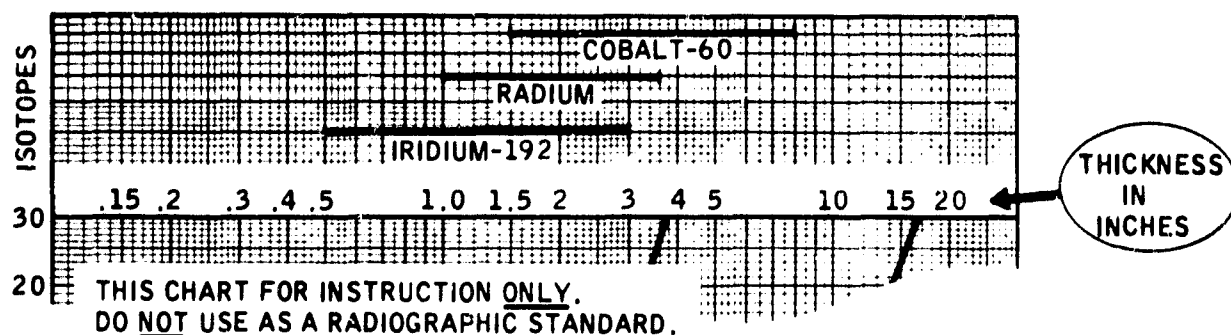
No - No! At least 185 kvp is required. Since the machine rated at only 50 to 130 kvp is not capable of producing 185 kv X-rays, it cannot possibly be used to X-ray 1 inch of steel and produce an adequate radiograph in a reasonable length of time.

Since the other machine is rated at 200 to 750 kvp, its voltage can be adjusted to some point between 200 kv and 550 kv that will produce a satisfactory radiograph.

Turn to page 5-15.

Right. On the basis of the information taken from the chart the 200-750 kv machine would be the one to use.

The upper portion of the chart, reproduced below, indicates the thicknesses of steel that can be satisfactorily radiographed with the more commonly used radiographic isotopes.



The length and position of the line representing the source determines the thickness of steel that can be adequately radiographed with that source.

Iridium-192 can be used to radiograph from _____ to _____ inches of steel.

.5 to 3 Page 5-16

1.5 to 8 Page 5-17

Your answer of .5 to 3 inches is correct. You seem to understand the basic use of this chart which is all we are concerned with at this point. You now know that this type of chart exists and you know how it is to be used.

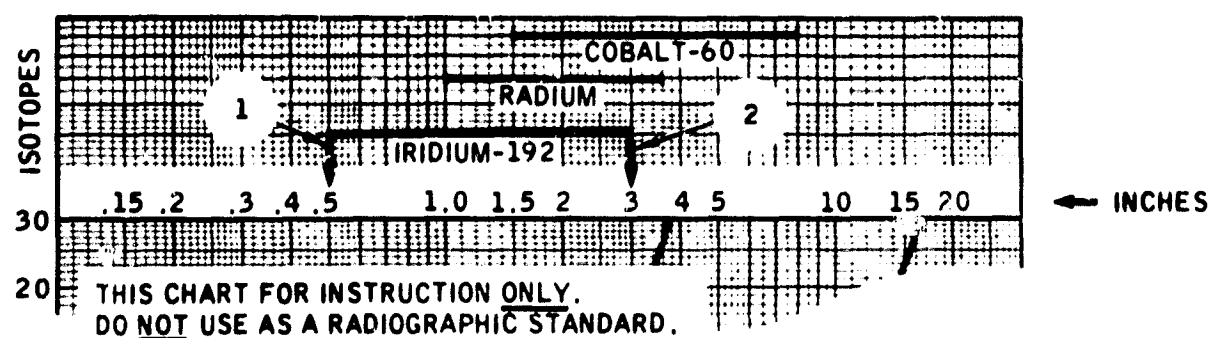
Use of screens. The specification or code under which a component or system is being radiographed will generally specify what screens are to be used and the voltages at which they are to be used. When such is not the case the radiographer must make a selection based on his own knowledge and experience.

The decision to use lead screens is generally a function of the kv (or energy level) used to make the radiograph. Above 120-150 kv the lead screen acts as an intensifier. Below 120-150 kv the screen begins to absorb the primary, image-forming, radiation in addition to absorbing scatter. A general rule to follow is: use lead screens above 120-150 kv; do not use lead screens below 120-150 kv.

According to the general rule, when a specimen is to be radiographed at 2 Mev, lead screens should be used.

True Page 5-18
False Page 5-19

Sorry, we threw that one a little too fast. Here's how the chart works for isotopes.



We are interested right now in Iridium-192 so we draw dotted lines (1) and (2) from the ends of the Iridium-192 line down to the inches scale. This tells us that Iridium-192 can be used to radiograph thicknesses of steel between .5 and 3 inches.

Turn to page 5-16.

Very good. 2 Mev is certainly above 120-150 kv, so lead screens should be used.

As voltages increase, the energy of the scattered radiation also increases. At the higher operating voltages (2000 kv and up) and with gamma sources the thickness of the screen is increased. The best thickness to use is usually determined by experimentation.

Lead screens can be used below 120-150 kv if the screen improves the radiograph and it can improve the radiograph whenever there is excessive scatter. Use of lead screens at these low voltages requires increasing the exposure to compensate for the loss in primary radiation through absorption by the screen.

In any case, lead screens should be used whether they improve the radiograph or not.

True Page 5-20

False Page 5-21

From page 5-16

5-19

You goofed it. Perhaps you didn't read the question closely enough. "2 Mev" is equal to 2000 kv, and 2000 kv is certainly a higher voltage than 120-150 kv.

The general rule was: use lead screens above 120-150 kv; do not use lead screens below 120-150 kv. When a specimen is to be radiographed at 2 Mev, lead screens should be used.

Turn to page 5-15.

From page 5-18

5-20

Sorry - you're wrong. Screens should be used only when they improve the radiograph. If their use does not improve the quality of the radiograph then they should not be used. In almost all cases at voltages above 120-150 kv use of lead screens will improve the radiograph.

Turn to page 5-21.

False is correct. Lead screens should only be used when they improve the quality of the radiograph.

And this brings us to the subject of fluorescent screens. Fluorescent screens permit a great reduction of exposure when compared with the exposure that is necessary using lead screens. Therefore fluorescent screens are used when it is necessary to reduce exposure time. However, due to the spreading of the light emitted from the screen, the definition of the radiograph is not good.

Fluorescent screens should be used only when the exposure without them becomes excessive. When they are used, it is most important that the sensitivity of the radiograph be determined to see that it is within acceptable limits.

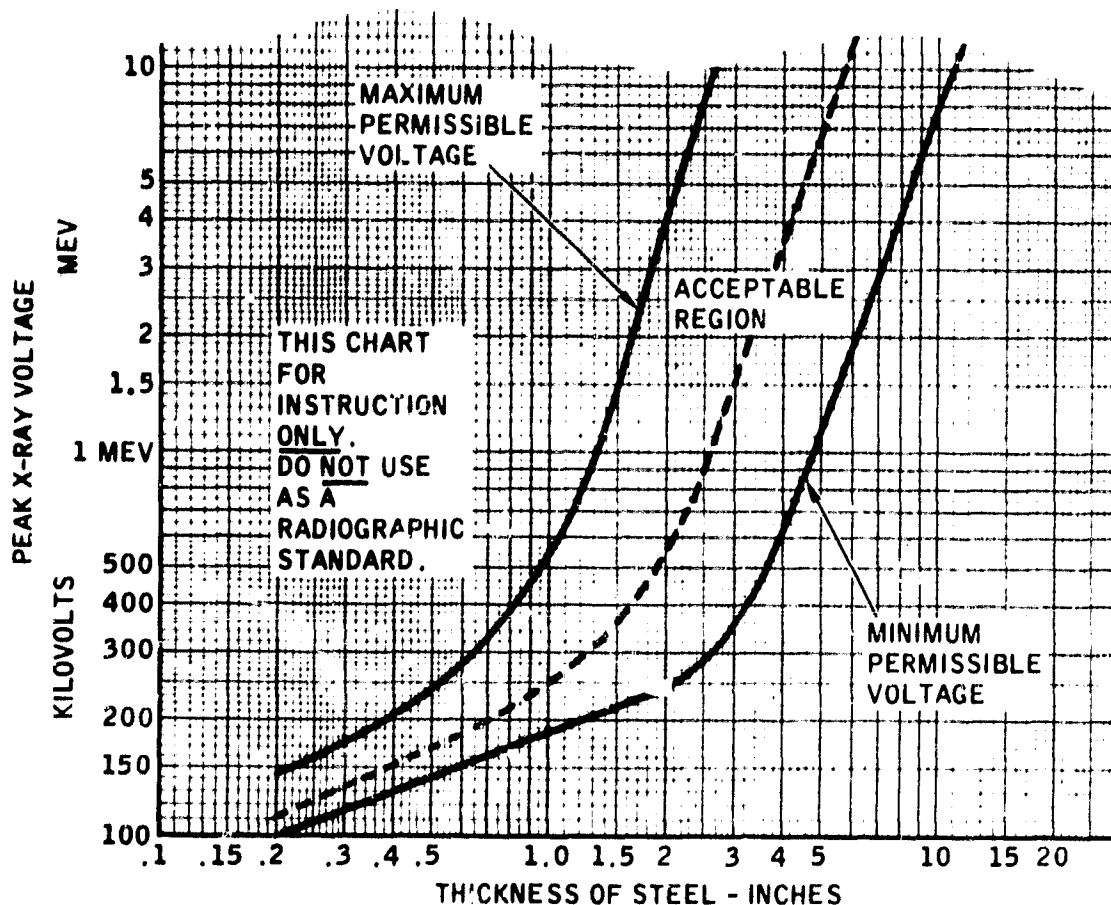
Fluorescent screens are used when a suitable radiograph cannot be obtained in any other way.

True Page 5-22

False Page 5-23

Good thinking. A radiograph made with a fluorescent screen is better than no radiograph at all.

Selection of kilovoltage to use in X-radiography. We can narrow the selection of voltage if you will accept some "conditions". And those conditions are, if you are radiographing articles that do not have much variation in thickness; if you have not radiographed similar articles before; and if you are unfamiliar with the capabilities of your X-ray equipment; a good selection would be a voltage determined by the dotted curve shown on the chart below.



This curve is located about 1/3 the distance between the minimum and maximum voltage curves. This voltage is a practical voltage to use when working in an unfamiliar situation.

Following the above rule of thumb, 2 inches of steel should be radiographed at

_____ kvp.

540 Page 5-24

260 Page 5-25

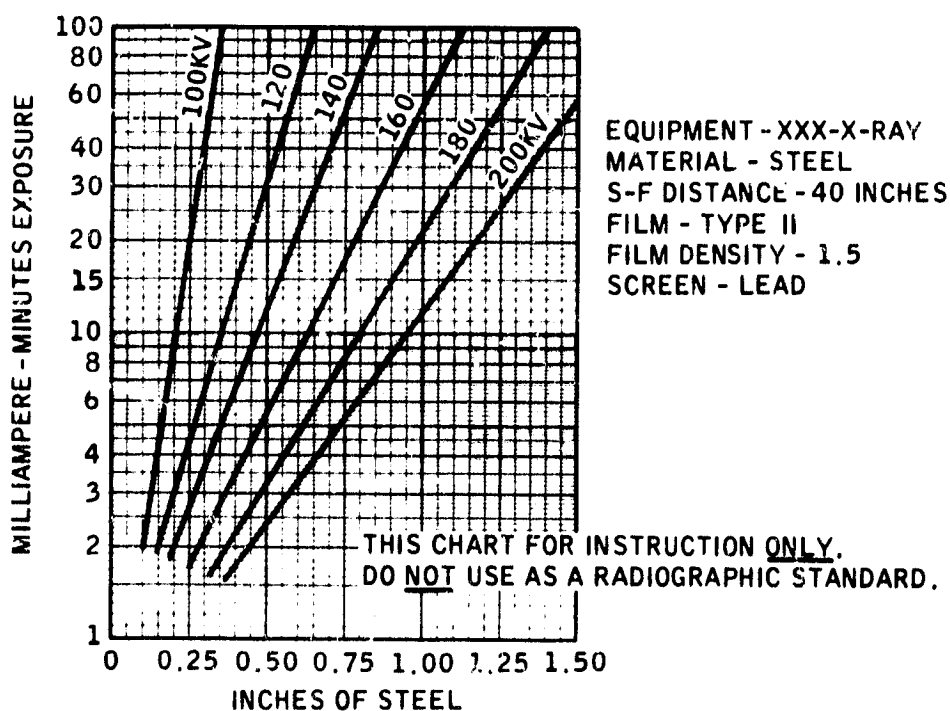
False was not the right answer. You would not use fluorescent screens if there was any other way for you to obtain a good radiograph because of the inherent lack of good definition in a radiograph made with fluorescent screens. The images produced are just naturally fuzzy.

Fluorescent screens are used only when the equipment available will not produce a high enough voltage to allow a reasonable exposure time without fluorescent screens.

Turn to page 5-22.

Right. 540 kvp would be a satisfactory starting point.

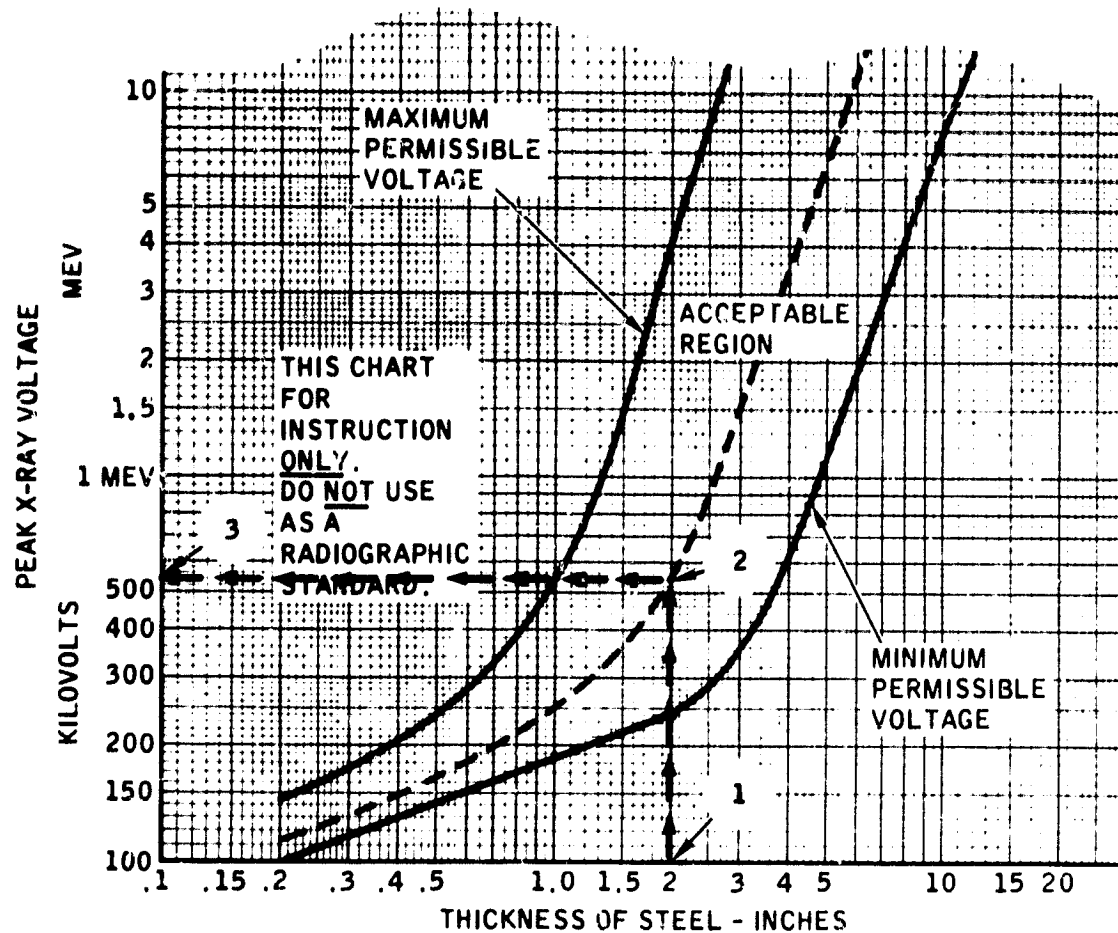
Selection of exposure - X-radiography. Now that you know how to select the proper operating voltage, we will discuss the second step - how to select the necessary exposure. For this we use another type of chart called an "exposure chart". This chart plots the thickness of material vs the exposure required for that material. The exposure chart is usually made up of a family of curves, each curve representing a particular kv.



This chart is based on the use of a particular film, a particular source-to-film distance, a particular film density, a particular specimen material, use of particular X-ray equipment, and the use of lead screens. All of these factors are held constant and the chart will only apply when the exposure is made under these conditions. If you intend to make a radiograph using exposure factors different from those specified on the chart then you must correct the exposure for those changes by calculating a new exposure.

Turn to page 5-26.

You must be looking at the wrong curve. Here's that chart again.

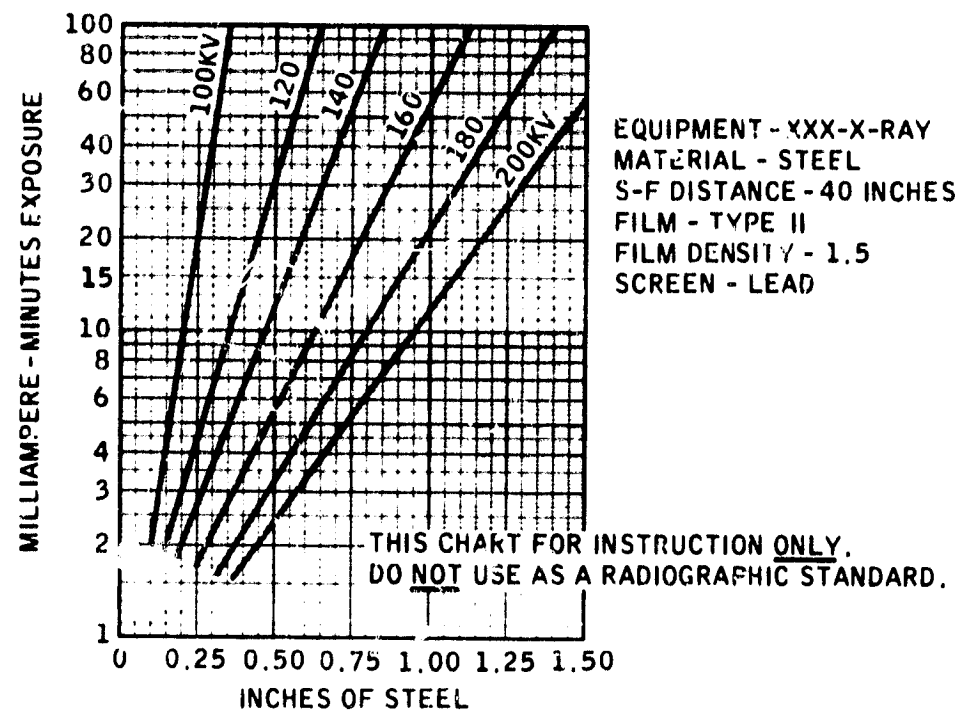


We wanted to determine the voltage required to radiograph 2 inches of steel. The correct solution to the problem is shown by the dashed line on the chart.

We start at the point on the horizontal scale that represents a 2-inch thickness of steel (point ①). We move vertically to the point where the 2-inch line intersects the dashed curve (point ②). From that point we move horizontally to the vertical axis and read the voltage (point ③).

This voltage, 540 kvp, represents a voltage to use that has been determined to be a good starting point when in an unfamiliar situation.

Turn to page 5-24.



Note that the exposure is plotted on a logarithmic scale. This is done to shorten the chart in the vertical direction.

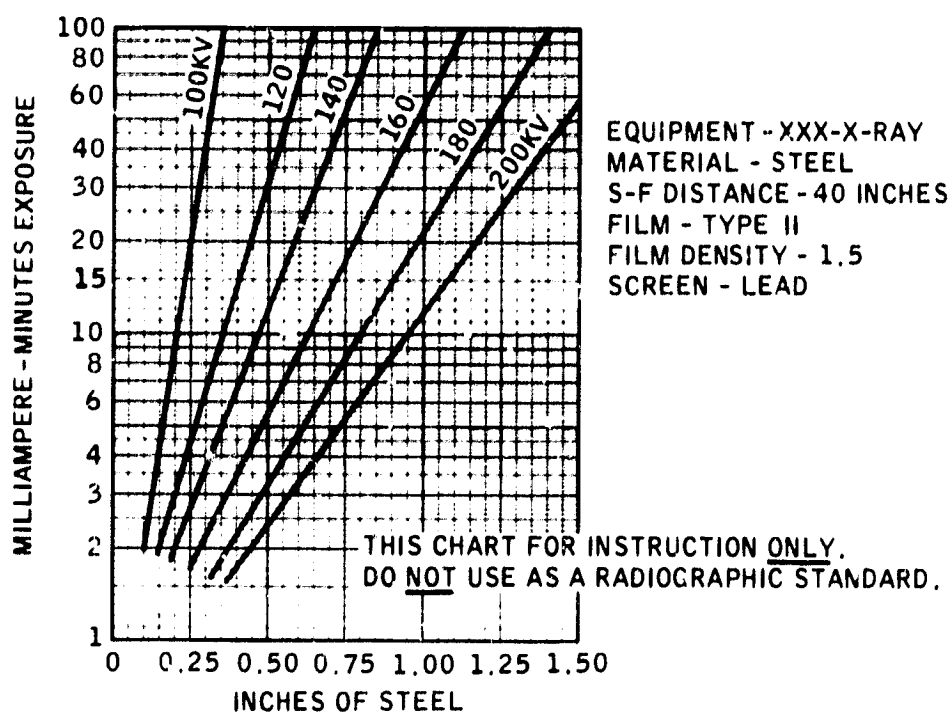
Note that on the left side of the chart the scale shows exposure in ma-min and at the bottom of the chart the scale shows the thickness of the material.

The exposure chart above plots the factors of exposure vs thickness of material for several different _____.

voltages Page 5-27

film types Page 5-28

Excellent! Each dark line on the chart represents a different voltage that could be used.



To use this type of chart you enter the chart at the thickness of the specimen, follow the chart vertically to the kv you have selected, then follow the chart horizontally to the left to find the exposure you should use.

Let's assume that you were going to radiograph 0.75 inches of steel at 200 volts. From the chart above what exposure would be required?

Decide on your answer, then turn to page 5-29.

From page 5-26

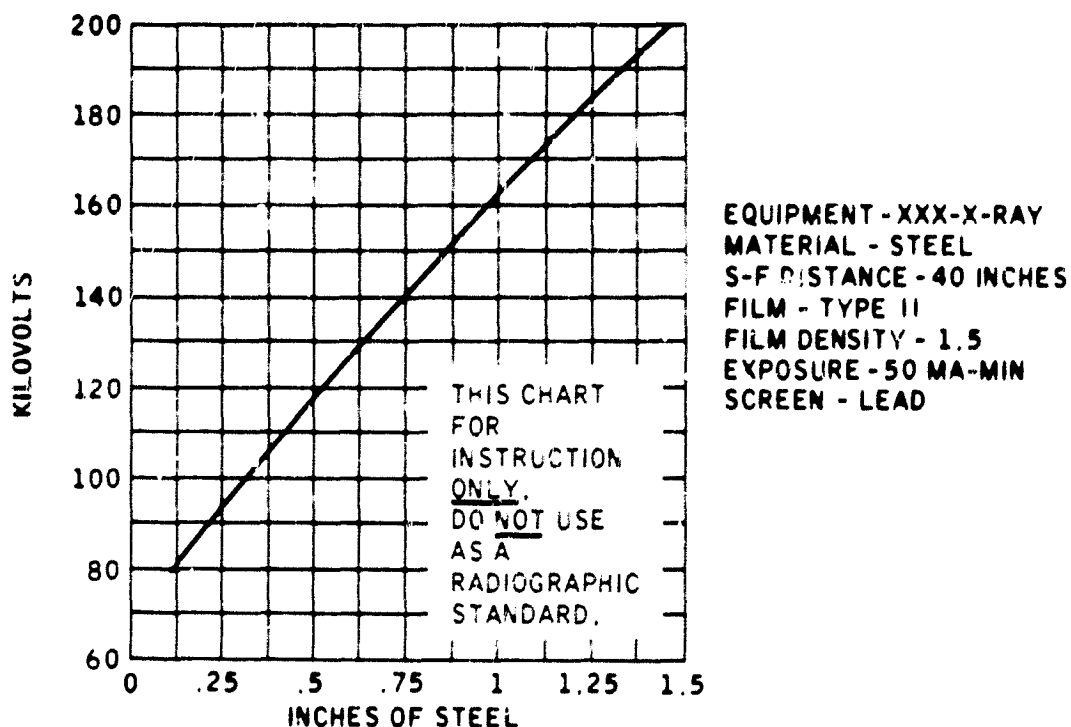
5-28

You just aren't paying very close attention. The chart is prepared for only one type of film - type II. This bit of information is shown in the data listed to the right of the chart. Notice that each one of the dark lines on the chart is identified with the voltage for that plot. This should tell you that we are plotting the factors of exposure vs the thickness of the material for several different voltages.

Go back to page 5-26 and take a closer look at the chart, then select a better answer.

The correct answer - approximately 5.3 milliamperes-minutes. If you were not reasonably close to this answer turn to page 5-30. If you feel that you understand how the chart works, read on.

There is another form of exposure chart you should know about. At first glance this chart would seem to be a voltage selection chart since kv is plotted against thickness.



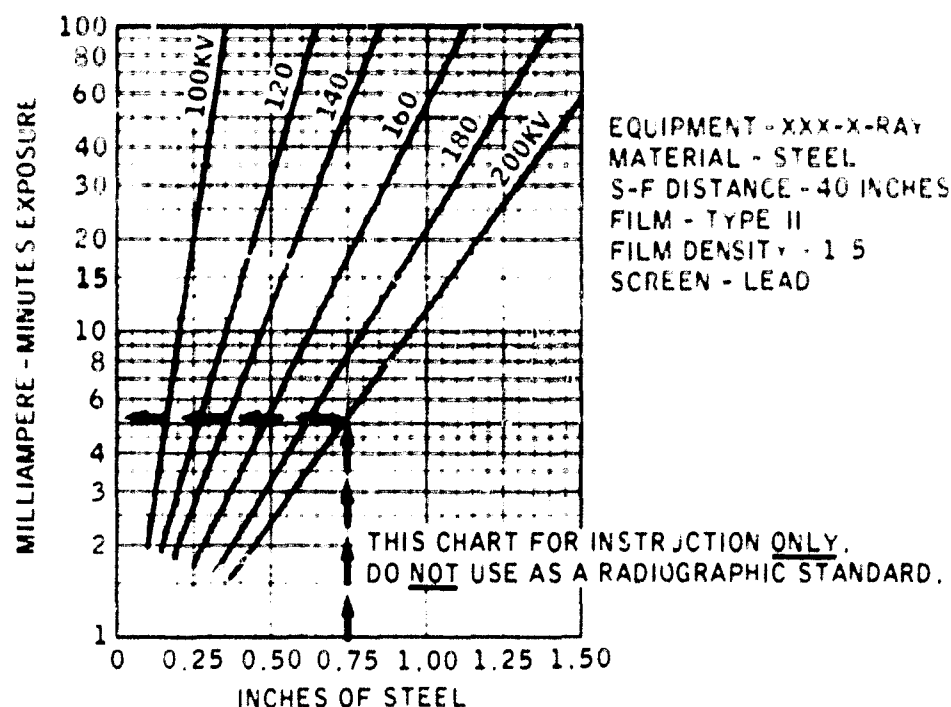
However, this is an exposure chart that has been adapted to a very particular situation. This type of chart is useful only if you have a production run of uniform conditions but varying thicknesses. Note that all the exposure factors, including exposure, are held constant and only kv and specimen thickness are allowed to vary.

When using this chart what exposure would be required to radiograph 0.75 inches of steel?

141 kv Page 5-31

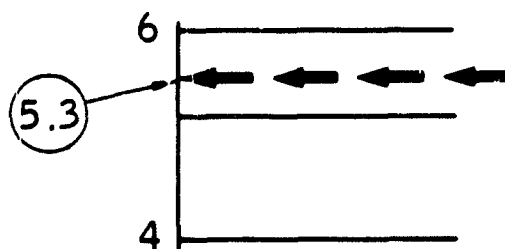
50 ma-min Page 5-32

There are two possible reasons why you didn't get the correct answer - you either worked the chart incorrectly, or you read the chart incorrectly.



The problem was to determine the exposure to use to radiograph 0.75 inches of steel at 200 kv. The dotted line on the chart above shows the solution.

But perhaps you read the exposure incorrectly. The left side of the chart looks like this.



Notice that the divisions between numbers are not equal. This is the result of plotting the chart on a logarithmic scale. But of more immediate importance, notice that the number 5 is not on the scale. This, we assume, may have caused you to misread the chart. You must learn to be very careful when reading charts. This one reads 5.3 not 4.7.

Return to page 5-29 and continue.

From page 5-29

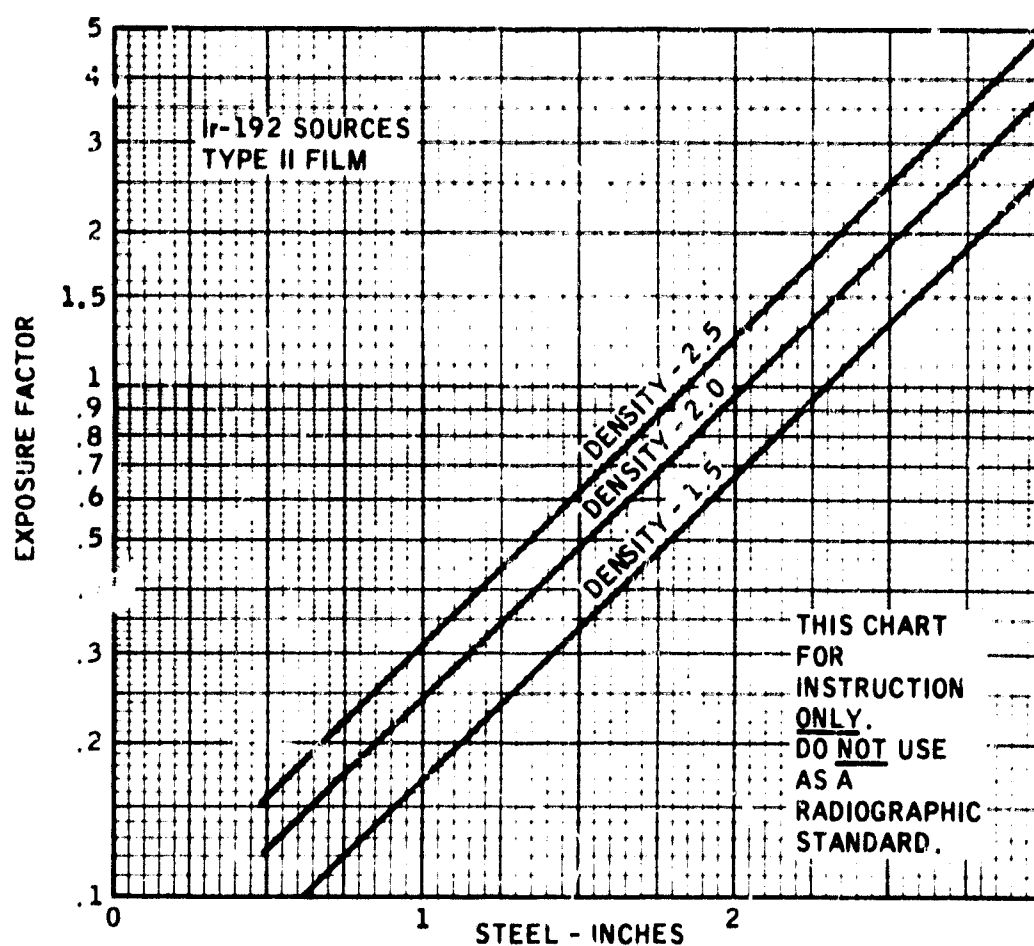
5-31

Sorry - this was a "trick" question but we have a reason. We want to be sure that you realize that the exposure is identified on the chart and does not change. The exposure is fixed at 50 ma-sec. You will find it in the data to the right of the chart.

Turn back to page 5-29 and take a closer look at the exposure data then select the correct answer to the question.

Excellent - the exposure, 50 ma-min, is shown in the exposure data shown to the right of the chart. The chart is good only if this exposure is used.

Selection of exposure - gamma radiography. Exposure charts are also prepared for use with isotope radiography. In these charts the energy of the source is fixed (not variable) which permits the charts to be simpler than the X-ray exposure charts. You will recall that X-ray charts always had to consider the effect of kv (energy) on the exposure.



Here we show a sample gamma ray exposure chart for Ir-192 sources. Note that specimen material, film type, and gamma ray source are standardized. All other exposure factors are variable and can be ascertained from the chart if you know what is meant by "exposure factor".

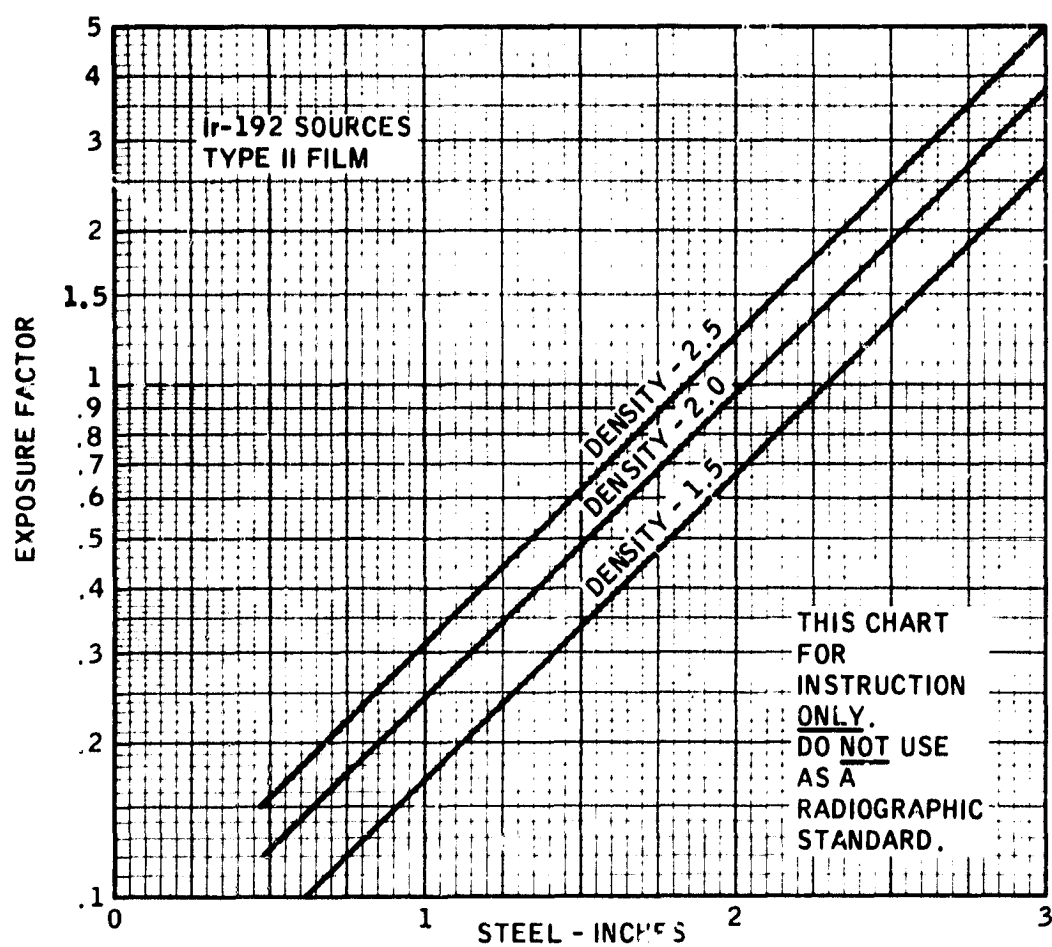
Turn to page 5-33.

Exposure factor for a gamma ray source is defined in terms of the intensity of the source (curies), the time of exposure (minutes), and the square of the source-to-film distance (inches²).

$$\text{Exposure factor} = \frac{I \times T}{D^2} = \frac{\text{curie-minutes}}{\text{inches}^2}$$

Note that the equation follows the reciprocity law in that the exposure factor is directly proportional to the intensity and time. It also follows the inverse square law in that the exposure factor is inversely proportional to the square of the source-to-film distance.

Let's assume that we have a 40 curie source of Ir-192 which we are going to use to radiograph 2 inches of steel with a source-to-film distance of 20 inches. The problem is to determine the correct time of exposure that will give us a film density of 1.5. The first step is to determine from the chart the exposure factor that we will use in the equation.



From the chart, the correct

exposure factor to use to radiograph 2 inches of steel and obtain a film density of 1.5 is _____

.67 Page 5-34

.96 Page 5-35

Very good. The exposure factor we will use in this problem is .67.

$$e. f. = \frac{I \times T}{D^2}$$

The exposure factor from the chart is .67; the intensity is 40 curies; the source-to-film distance is 20 inches; what will be the time of the exposure?

Solving the equation for T we get:

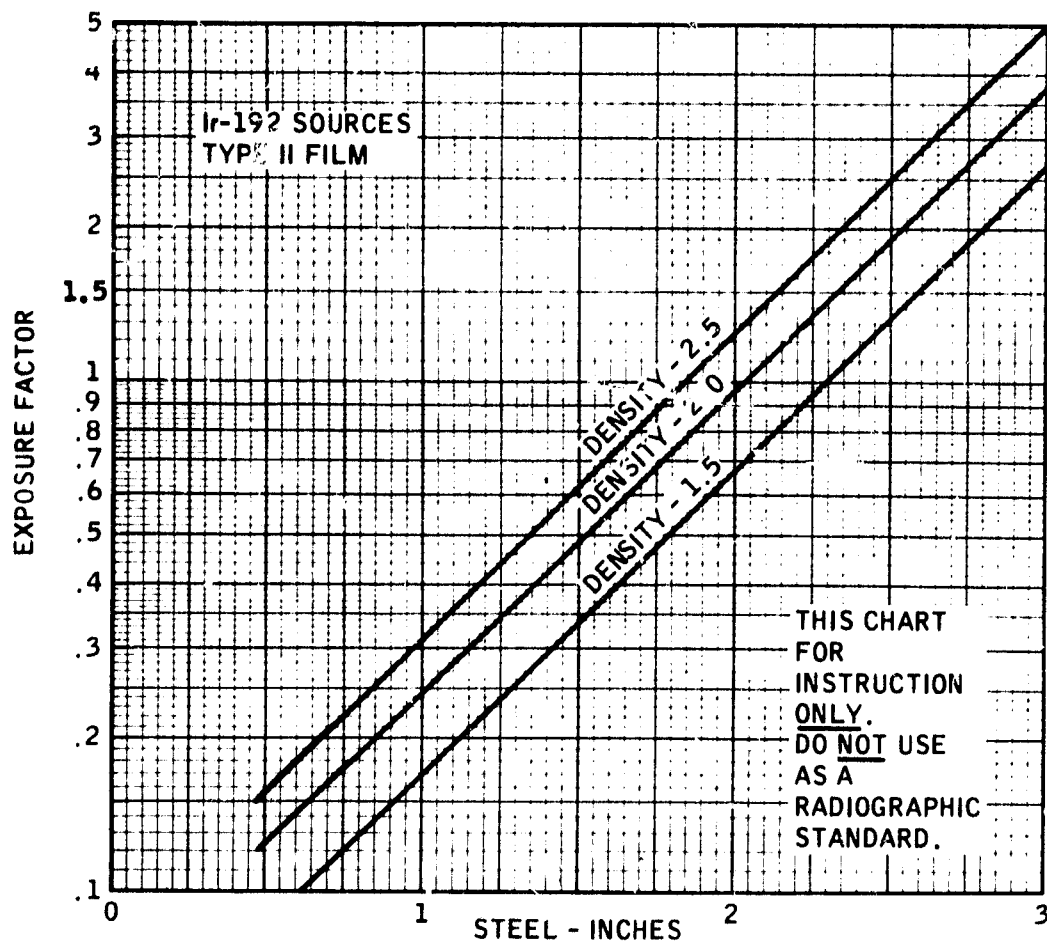
$$T = \frac{e. f. \times D^2}{I}$$

$$T = \frac{.67 \times (20)^2}{40} = \frac{.67 \times 400}{40} = 6.7 \text{ minutes}$$

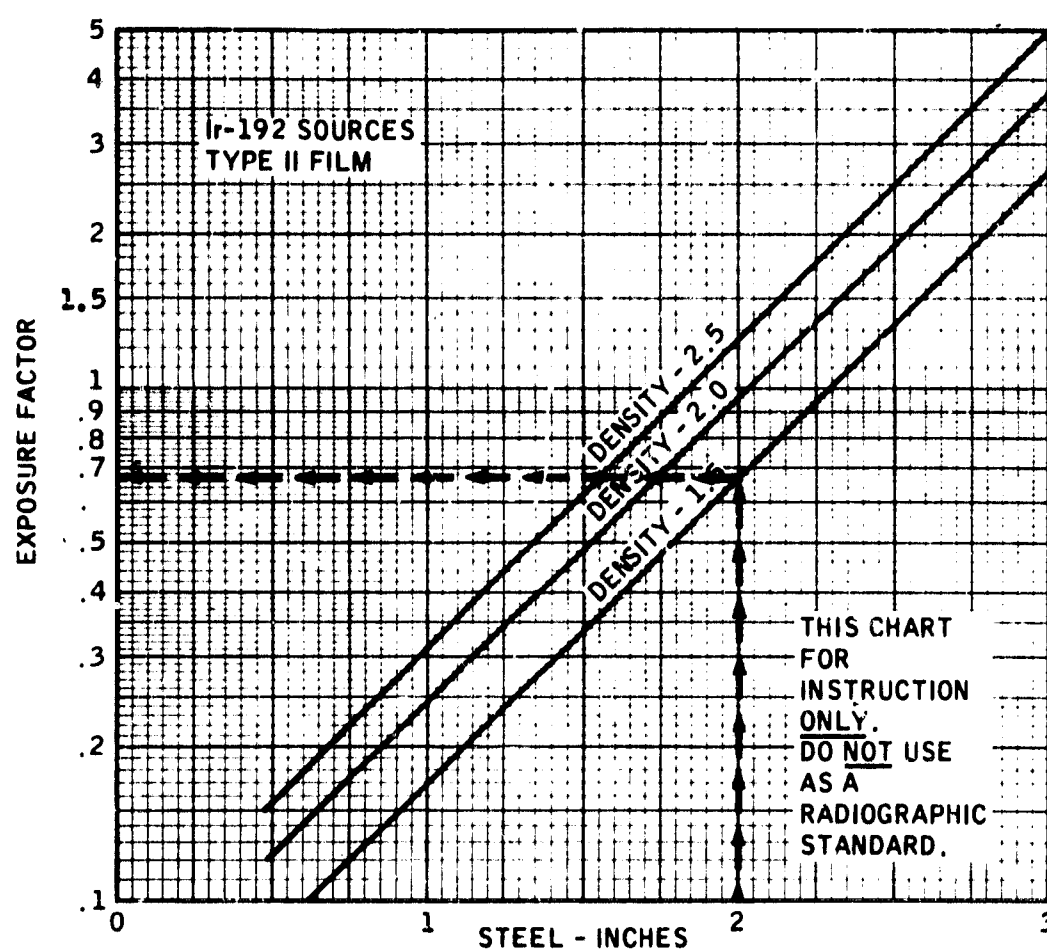
We want to radiograph
2 inches of steel with an
Iridium-192 source of
25 curies. We want to
obtain a density of 2 and
our source-to-film dis-
tance is 15 inches. The
exposure time we will
use is approximately
_____ minutes.

40.8.....Page 5-36

8.6Page 5-37



Be careful. You have selected the wrong density line. Here's the problem again. From the chart, what would be the exposure factor to use in the equation if we were to radiograph 2 inches of steel and obtain a film density of 1.5?



The dotted line on the chart above shows the solution to the problem. First we find 2-inches on the horizontal scale. From this point we move vertically to the plot showing a density of 1.5. At this point we move horizontally to the left to find the exposure factor on the left scale. The approximate exposure factor we would use in this case is .67.

Turn to page 5-34.

Sorry, you goofed it. Here's how your solution should look:

The exposure factor from the chart for 2 inches of steel and a density of 2.0 is .96.

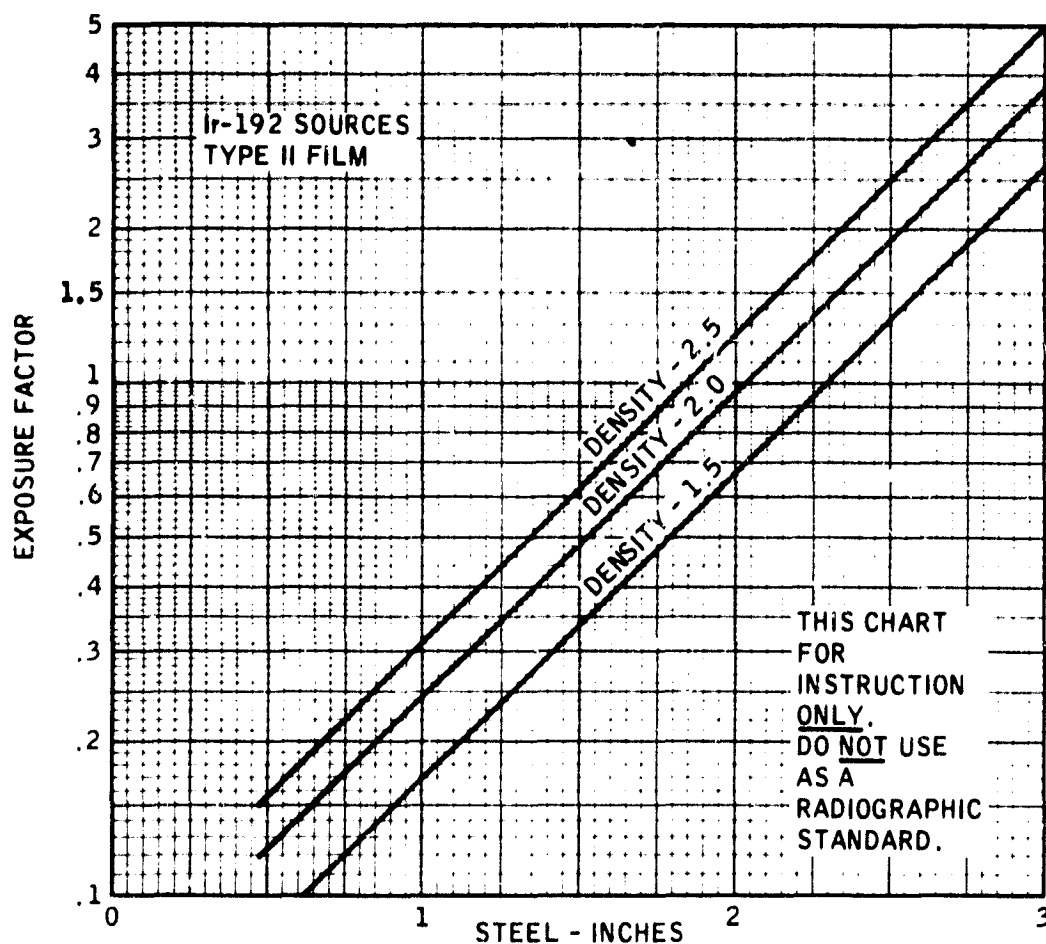
The source-to-film distance is 15 inches and the intensity is 25 curies.

$$T = \frac{e.f. \times D^2}{I}$$

$$T = \frac{0.96 \times (15)^2}{25} = \frac{0.96 \times 225}{25} = 8.6 \text{ minutes}$$

Turn to page 5-35.

Approximately 8.6 minutes - right. Now here's the chart again. After you have worked through the problems below turn to the next page and check your work.



Problem 1. We have a 100 curie source of Ir-192 with which we are going to radiograph a 2.5-inch specimen of steel at a source-to-film distance of 20 inches. What will be the exposure time required to obtain a density of 2.0 on type II film?

Problem 2. What exposure time is required to radiograph 1.5 inches of steel with a 50 curie source of Ir-192 to obtain a film density of 2.5 on type II film when the source-to-film distance is 12 inches?

Problem 3. What is the required exposure time to radiograph 2 1/4 inches of steel to a density of 2.5 on type II film with 75 curies of Ir-192 at a source-to-film distance of 25 inches?

Turn to page 5-38.

Answer to problem 1. Exposure factor from chart - approx. 1.9.

$$T = \frac{e.f. \times D^2}{I}$$

$$T = \frac{1.9 \times 20^2}{100} = \frac{1.9 \times 400}{100} = 7.6 \text{ minutes}$$

Answer to problem 2. Exposure factor from chart - 0.63

$$T = \frac{e.f. \times D^2}{I}$$

$$T = \frac{0.63 \times 12^2}{50} = \frac{0.63 \times 144}{50} = 1.8 \text{ minutes}$$

Answer to problem 3. Exposure factor from chart - 1.75

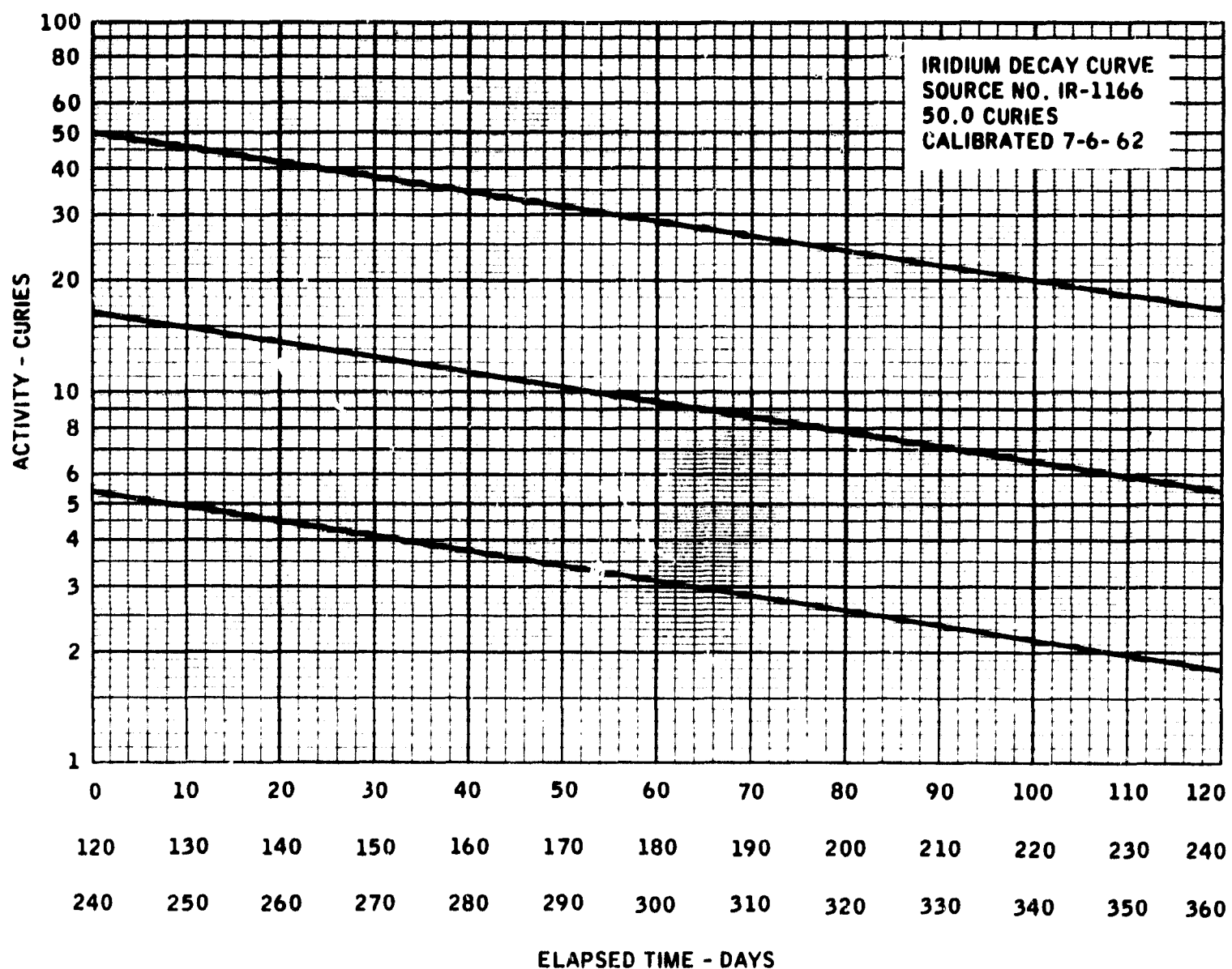
$$T = \frac{e.f. \times D^2}{I}$$

$$T = \frac{1.75 \times (25)^2}{75} = \frac{1.75 \times 625}{75} = 14.6 \text{ minutes}$$

Turn to page 5-39.

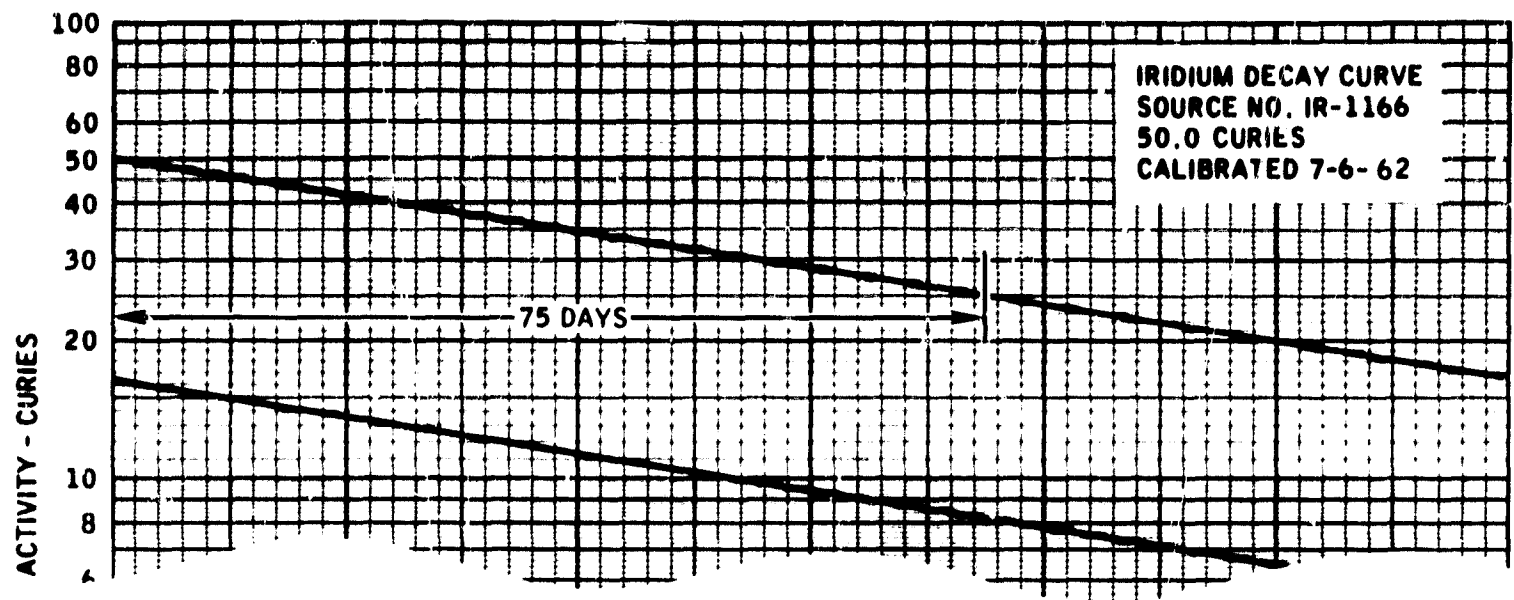
In order to use the gamma ray exposure charts the radiographer must know the activity of the isotope that he is using. The activity of any given isotope on any given day is dependent on the original activity and the half-life of the isotope. The activity of an isotope with a long half-life does not change much from day to day but the activity of an isotope with a short half-life can change by quite a bit.

Since the activity of the isotope decays with the passage of time, the radiographer must have available some way to determine the activity of the isotope at any given time. The simplest way to determine the activity of a given isotope at any time is to consult the decay chart that is provided with the isotope by the manufacturer. Such a chart is shown below.



Turn to page 5-40.

Let's look at a portion of the decay chart. Note the data in the upper right-hand corner.



The isotope for which this chart was constructed is Iridium-192. Note also that the source was given an identification number - IR-1166. This chart is only applicable to the particular source that bears this same identifying number.

The activity of the source (50.0 curies) that is shown is the activity of this source on the date of calibration.

On July 6, 1962, the activity of this source was _____ curies.

1166. Page 5-41

50 Page 5-42

You are confusing the identification number with the activity of the source. Don't forget that the activity of a gamma ray isotope is always measured in curies.

The data in the upper right corner of the chart tells us that Iridium source number IR-1166 had an activity of 50 curies on July 6, 1962.

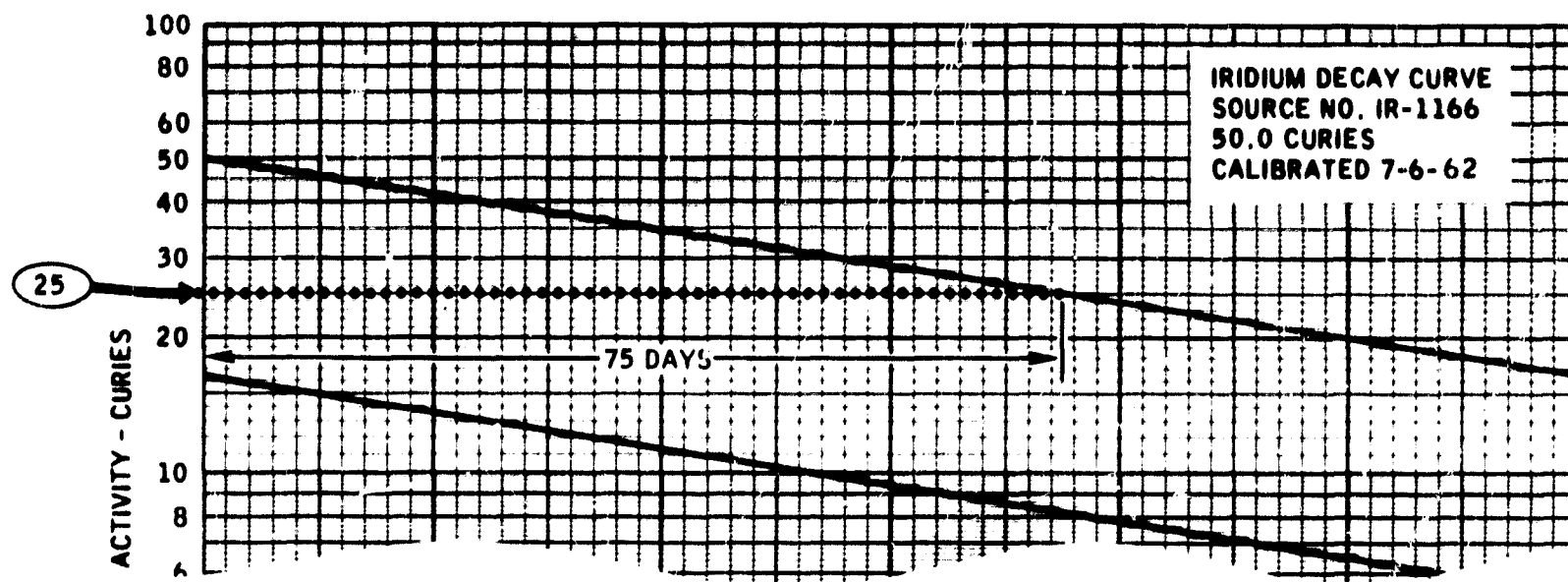


Iridium Decay Curve
Source No. IR-1166
50.0 Curies
Calibrated 7-6-62

Turn to page 5-42.

Right. On July 6, 1962, the activity of Iridium source IR-1166 was 50 curies.

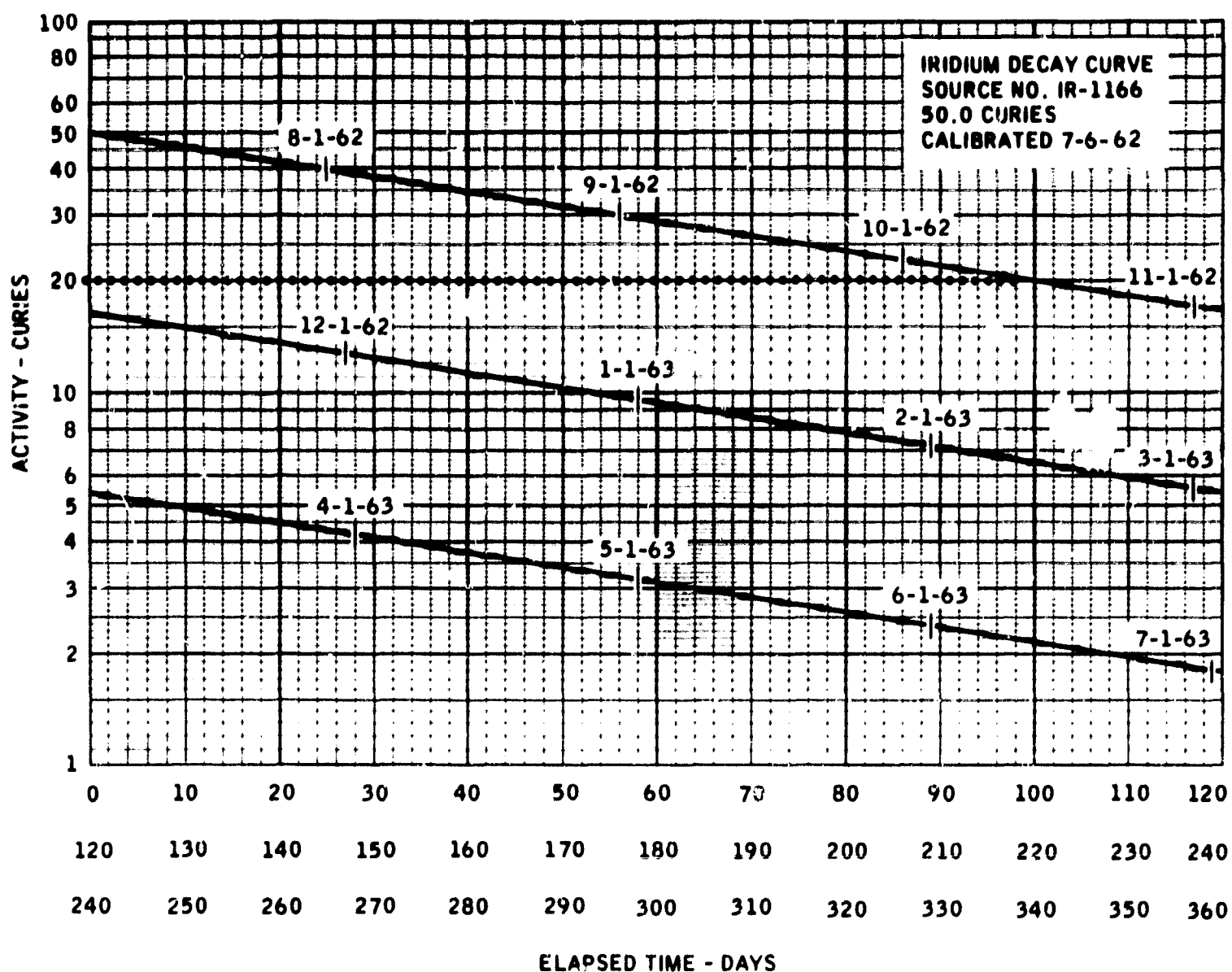
Since Iridium-192 has a half life of 75 days, we know that after 75 days our 50 curies will be reduced to 25 curies. This decay is shown on the chart. (See dotted line.)



Using the chart above (each vertical line represents 2 days) what would be the activity of this source 25 days after the calibration date?

Decide on your answer then turn to the next page.

40 curies is the correct answer. If you were not reasonably close to this answer, return to page 5-42 and try again. If you feel you understand the method, read on.



On this chart we have added the calendar dates to help us determine the activity on any given day.

For example, the activity of IR-1166 on Oct 12, 1962, was 20 curies. (See dotted line above.)

The activity of IR-1166 on Dec. 27, 1962, was _____.

10 curies Page 5-44

20 curies Page 5-45

Right. The activity of this source on Dec. 27 was 10 curies.

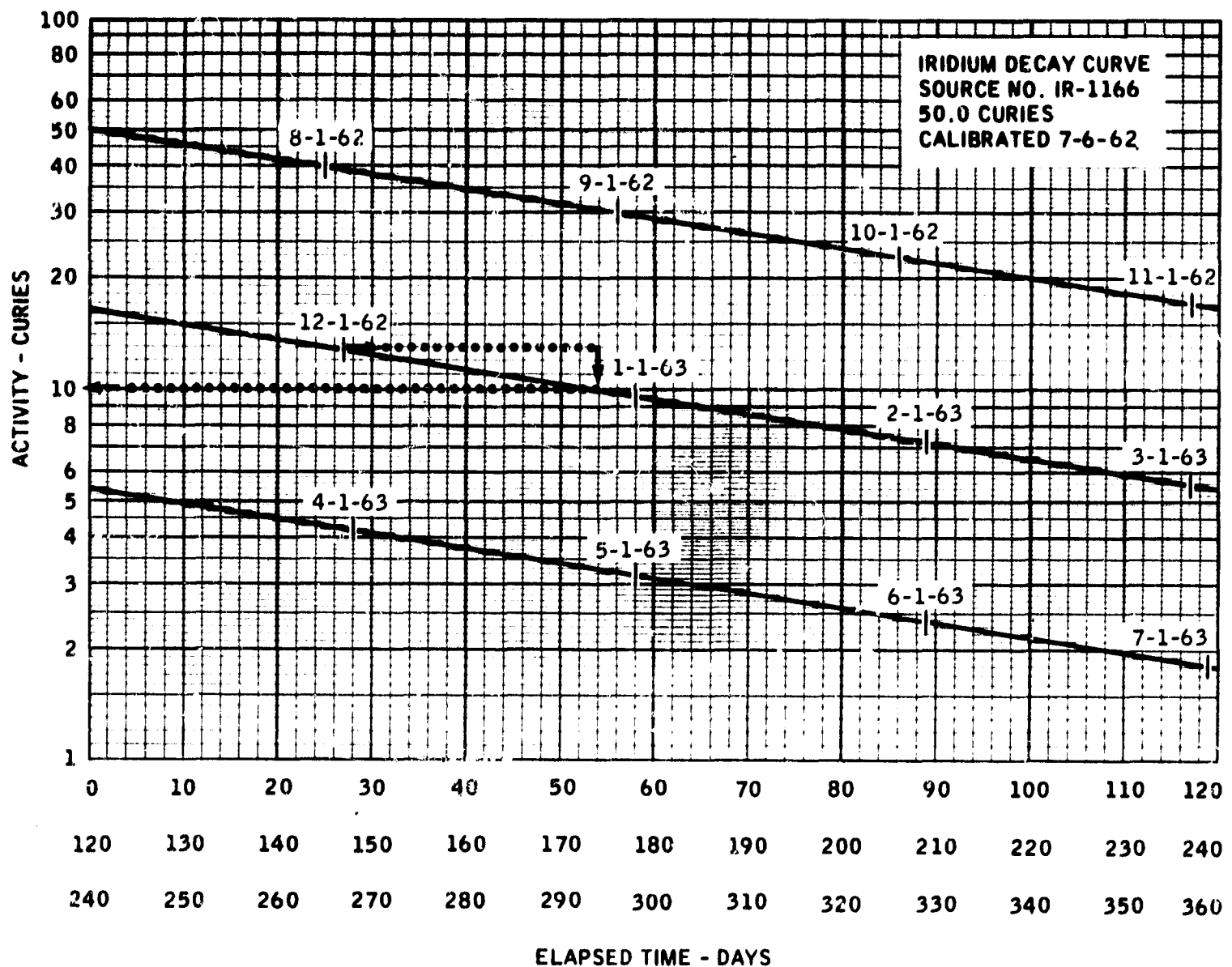
Equivalence charts. In all of the exposure charts we have shown you, the specimen material was steel. Generally exposure charts are made for either aluminum or steel. This can cause problems if the specimen to be radiographed is of some other type of material. However, this type of problem is solved by the use of a radiographic equivalence chart similar to the one shown here.

APPROXIMATE RADIOGRAPHIC EQUIVALENCE FACTORS OF SEVERAL METALS												
	X-RAYS								GAMMA RAYS			
METAL	50 KV.	100 KV.	150 KV.	220 KV.	400 KV.	1000 KV.	2000 KV.	15-24 MEV.	IRIDIUM-192	CESIUM-137	COBALT-60	RADIUM
MAGNESIUM	0.6	0.6	0.05	0.08								
ALUMINUM	1.0	1.0	0.12	0.18					0.35	0.35	0.35	0.40
2024 (ALUMINUM) ALLOY	1.4	1.2	0.13	0.14					0.35	0.35	0.35	
STEEL		12.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
18-8 (STEEL) ALLOY		12	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
COPPER		18.	1.6	1.4	1.4				1.1	1.1	1.1	1.1
ZINC			1.4	1.3	1.3				1.1	1.0	1.0	1.0
BRASS			1.4	1.3	1.3	1.2	1.2		1.1	1.1	1.1	1.1
LEAD			14	12		5.0	2.5		4.0	3.2	2.3	2.0

ALUMINUM IS TAKEN AS THE STANDARD METAL AT 50 KV. AND 100 KV., AND STEEL AT THE HIGHER VOLTAGES AND WITH GAMMA RAYS

Turn to page 5-46.

Don't confuse the example we gave with the problem. The problem was to determine the activity of IR-1166 on Dec. 27, 1962. The correct solution is shown on the chart below.



Since each vertical line represents 2 days, we start at the point marked 12-1-62 and move horizontally to the right 13 1/2 lines ($27 \div 2 = 13 \frac{1}{2}$). In this manner we establish the vertical line that represents Dec. 27. We then move down the line to the point where it intersects with the decay line. From this point we move horizontally to the left hand scale where we read 10.

We now know that on Dec. 27 the activity of IR-1166 is 10 curies.

Turn to page 5-44.

The figures given in the chart are multiplication factors and are used to convert a particular thickness of the selected material to the equivalent thickness of the standard material. In other words, the thickness of the selected material multiplied by the factor given in the chart is the equivalent thickness of the standard material. Note that the standard material for 50 and 100 kv exposures is aluminum (factor 1.0). For higher voltage X-rays and gamma rays, the standard material is steel (factor 1.0).

Let's look at an example: We want to X-ray 0.5 inches of copper at 220 kv. From the chart (partially repeated below) opposite "copper" in the 220 kv column we find the multiplication factor 1.4. Then $0.5 \times 1.4 = .70$

APPROXIMATE RADIOGRAPHIC EQUIVALENCE FACTORS OF SEVERAL METALS											
METAL	X-RAYS								GAMMA RAYS		
	50 KV.	100 KV.	150 KV.	220 KV.	400 KV.	1000 KV.	2000 KV.	15-24 MEV.	IRIDIUM-192	CESIUM-137	COBALT-60 RADIUM
MAGNESIUM		0.6	0.05	0.08		1.0	1.0	1.0			
18-8 (STEEL) ALLOY		12	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
COPPER		18	1.6	1.4	1.1				1.1	1.1	1.1
ZINC			1.4	1.3	1.3				1.1	1.0	1.0
BRASS			1.4	1.3	1.3	1.0					1.1

This tells us that to radiograph 0.50 inches of copper at 220 kv we would use the same exposure as we would normally use for 0.7 inches of steel. One-half inch of copper is equivalent to 0.7 inches of steel.

What is the equivalent in steel of 0.5 inches of copper when being radiographed with Cobalt-60? When you have decided on your answer check it against the correct answer given on the next page.

0.5 X 1.1 = 0.55

One-half inch of copper is equivalent to 0.55 inches of steel when radiographed with Cobalt-60.

APPROXIMATE RADIOGRAPHIC EQUIVALENCE FACTORS OF SEVERAL METALS												
METAL	X-RAYS								GAMMA RAYS			
	50 KV	100 KV	150 KV	220 KV	400 KV	1000 KV	2000 KV	15-24 MEV	IRIDIUM-192	CESIUM-137	COBALT-60	RADIUM
MAGNESIUM	0.6	0.6	0.05	0.08								
ALUMINUM	1.0	1.0	0.12	0.18					0.35	0.35	0.35	0.40
2024 (ALUMINUM) ALLOY	1.4	1.2	0.13	0.14					0.35	0.35	0.35	
STEEL		12.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
18-8 (STEEL) ALLOY		12	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
COPPER		18.	1.6	1.4	1.4				1.1	1.1	1.1	1.1
ZINC			1.4	1.3	1.3				1.1	1.0	1.0	1.0
BRASS			1.4	1.3	1.3	1.2	1.2		1.1	1.1	1.1	1.1
LEAD			14	12		5.0	2.5		4.0	3.2	2.3	2.0

ALUMINUM IS TAKEN AS THE STANDARD METAL AT 50 KV AND 100 KV., AND STEEL AT THE HIGHER VOLTAGES AND WITH GAMMA RAYS

The radiographic equivalent of 3 inches of magnesium when radiographed at 100 kv is _____.

1.8 inches of aluminum Page 5-48

1.8 inches of steel Page 5-49

Very good. The standard metal at 100 kv is aluminum, not steel.

Selection of film. The film to be used is usually specified in the codes or specifications under which the specimen is being radiographed. When the film is not specified the radiographer must be prepared to make his own selection.

Firm rules for the selection of film cannot be drawn. However certain factors must always be considered. These factors are: density, contrast, graininess, and speed.

Density. Film contrast generally increases as the density of the film increases. However, some films are limited to a particular maximum density and, because of this, are useless whenever densities are desired that are above their limits. Essentially, maximum density is limited by the amount of silver in the film emulsion. This limiting factor is indicated on the film characteristics charts by the leveling-off of the curve at the upper density limits. However, for all films the light intensity produced by the film viewer is the real limiting factor. The radiograph must not be so dense that the image will not pass the light from the viewer behind it.

The selection of a film density is more dependent on the light emitted by the film viewer than dependent on the film emulsion.

True Page 5-50

False Page 5-51

1.8 inches of steel is not the correct answer. Let's look at the chart and see why.

APPROXIMATE RADIOGRAPHIC EQUIVALENCE FACTORS OF SEVERAL METALS												
METAL	X-RAYS								GAMMA RAYS			
	50 KV.	100 KV.	150 KV.	220 KV.	400 KV.	1000 KV.	2000 KV.	15-24 MEV.	IRIDIUM-192	CESIUM-137	COBALT-60	RADIUM
MAGNESIUM	0.6	0.6	0.05	0.08								
ALUMINUM	1.0	1.0	0.12	0.18					0.35	0.35	0.35	0.40
2024 (ALUMINUM) ALLOY	1.4	1.2	0.13	0.14					0.35	0.35	0.35	
STEEL		12.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
18-8 (STEEL) ALLOY		12.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
COPPER		18.	1.6	1.4	1.4				1.1	1.1	1.1	1.1
ZINC			1.4	1.3	1.3				1.1	1.0	1.0	1.0
BRASS			1.4	1.3	1.3	1.2	1.2		1.1	1.1	1.1	1.1
LEAD			14	12		5.0	2.5		4.0	3.2	2.3	2.0

ALUMINUM IS TAKEN AS THE STANDARD METAL AT 50 KV AND 100 KV., AND
STEEL AT THE HIGHER VOLTAGES AND WITH GAMMA RAYS

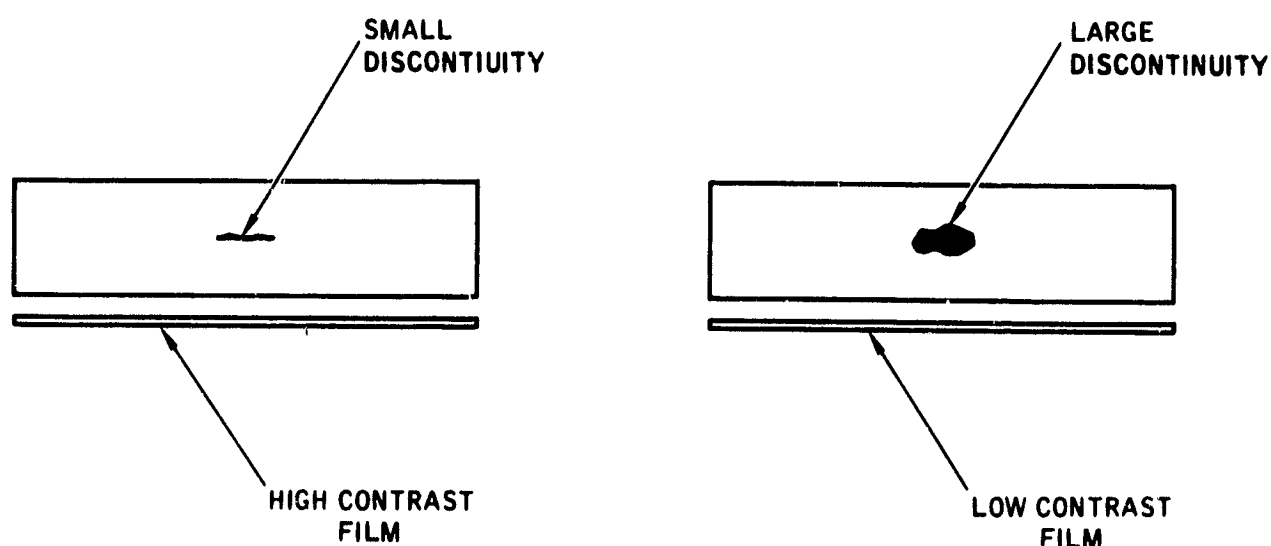
Note the factors that are circled on the chart. Aluminum is the standard metal at 50 and 100 kv. Its factor then is 1 at these voltages. Steel is the standard metal for all the higher voltages and for gamma ray sources. Its factor is 1 at these voltages and energy levels.

Since the question concerned 3 inches of magnesium radiographed at 100 kv., the standard metal is aluminum. $3 \times 0.6 = 1.8$ inches of aluminum.

Turn to page 5-48 and continue.

Right... The film density selected for the radiograph should never be so dark that it cannot be read on available viewing equipment.

Contrast. You will remember that the contrast of a film is determined from the slope of the characteristic curve of the film. The steeper the slope, the more contrast available. Selection of the film on the basis of its contrast is dependent on the type of discontinuities sought. Films that show high contrast are desired when small discontinuities are sought. If the requirements are such that only comparatively large discontinuities are sought, then a film with less contrast may be used.



High contrast films are used in radiography when the discontinuities sought are _____.

large Page 5-52

small Page 5-53

Apparently we haven't made our point very clear.

In radiography, variations in the density of the film indicate changes in the structure of the specimen. The variations in film density are important because they change the amount of light transmitted through the film. It is this variation in the transmitted light that is important to the film interpreter.

Then it follows that the light behind the film has a direct bearing on the amount of light that is transmitted through the film. A dim light cannot shine through a film of high density as well as a bright light. Therefore, the density of the film is selected on the basis of the brightness of the viewer. A high film density can be selected when the viewer is illuminated with a bright light.

Turn to page 5-50.

Your answer indicates that you think high contrast films are required to detect large discontinuity. This is not correct.

Let's look at this in terms of subject contrast. When the thickness of the discontinuity is small in comparison to the specimen thickness, it does not have much effect on the intensity of the radiation passing through it. The small change in intensity of the radiation passing through the discontinuity results in a small variation of the intensity of the radiation as it arrives at the film. The appearance of the image on the film depends upon the ability of the film to respond to the small change in intensity with a marked change in density. Films that are capable of this are said to have high contrast.

High contrast films are used in radiography when small discontinuity are sought.

Turn to page 5-53.

Very good. High contrast films help reveal small discontinuities.

Graininess. Film graininess affects the definition of the radiograph and, you will remember, results from the relative sizes of the individual grain clumps. Graininess is directly related to film speed, the faster films generally having larger grains than slow films. Since fine grain films are invariably slow speed films, exposure times must be increased if the better definition of slower films is desired.

Use of a slower speed film will improve the definition of a radiograph.

True Page 5-54

False Page 5-55

Exactly right. The finer-grained, slow speed films produce sharper images than the ~~coarse-grained~~, fast films.

Film speed. We have just described the effect that film speed has on the definition of the radiograph. The film density is also affected by the speed of the film since faster films reach a given density with less exposure.

As you can see, the choice of film is largely based on the requirements of the radiograph.

The following table was devised for instructional purposes only, but similar tables are provided by all film manufacturers for all of their current films.

FILM CHARACTERISTICS	SPEED	GRAIN	CONTRAST
TYPE I FOR CRITICAL INSPECTION, HIGHER VOLTAGES AND RADIOGRAPHY OF LIGHT METALS AND THEIR ALLOYS.	VERY SLOW	EXTRA FINE	HIGH
TYPE II FOR RADIOGRAPHY OF LIGHT METALS AT LOWER KILOVOLTAGES, AND HEAVIER STEEL PARTS AT 1,000 TO 2,000 KILOVOLTS.	SLOW	FINE	HIGH
TYPE III FOR EXAMINATION OF STEEL OR BRASS ALLOYS WITH MACHINES OF LIMITED KILOVOLTAGES. RECOM- MENDED FOR USE WITH CALCIUM TUNGSTATE SCREENS. WITH LEAD SCREENS MAXIMUM LATITUDE, MEDIUM SPEED AND CONTRAST CAN BE OBTAINED.	MEDIUM	MEDIUM	MEDIUM
TYPE IV HIGHEST AVAILABLE SPEED WITH LEAD SCREENS FOR BOTH X-RAY AND GAMMA WORK. LARGEST GRAIN SIZE	FAST	LARGE	MEDIUM

Turn to page 5-56.

From page 5-53

5-55

You missed. Look at it this way.

Definition is the degree of sharpness of the image.

Small grains in the film will produce a sharper image than large grains.

Small grain films are slower than large grain films.

Therefore slower films, having smaller grains, will have better definition than fast, large-grain films.

Turn to page 5-54.

A table of this type (repeated below) attempts to give a general outline of the film characteristics and the normal use for the films. The table reflects a balance between a high quality radiograph and a relatively short exposure. If a higher quality radiograph is desired, a slower, finer-grained film should be used. On the other hand, if short exposure times are essential and the overall sensitivity is not critical, a faster film should be used.

FILM CHARACTERISTICS	SPEED	GRAIN	CONTRAST
TYPE I FOR CRITICAL INSPECTION, HIGHER VOLTAGES AND RADIOGRAPHY OF LIGHT METALS AND THEIR ALLOYS.	VERY SLOW	EXTRA FINE	HIGH
TYPE II FOR RADIOGRAPHY OF LIGHT METALS AT LOWER KILOVOLTAGES, AND HEAVIER STEEL PARTS AT 1,000 TO 2,000 KILOVOLTS.	SLOW	FINE	HIGH
TYPE III FOR EXAMINATION OF STEEL OR BRASS ALLOYS WITH MACHINES OF LIMITED KILOVOLTAGES. RECOMMENDED FOR USE WITH CALCIUM TUNGSTATE SCREENS. WITH LEAD SCREENS MAXIMUM LATITUDE, MEDIUM SPEED AND CONTRAST CAN BE OBTAINED.	MEDIUM	MEDIUM	MEDIUM
TYPE IV HIGHEST AVAILABLE SPEED WITH LEAD SCREENS FOR BOTH X-RAY AND GAMMA WORK. LARGEST GRAIN SIZE.	FAST	LARGE	MEDIUM

Let's assume that we have made a radiograph using Type III film that has the characteristics shown on the chart above. The definition in the radiograph is not quite satisfactory so we will shoot another radiograph but will use Type_____film.

II Page 5-57

IV Page 5-58

Good thinking. To improve the definition of the radiograph we would use a slower, finer-grained film. In this case - Type II.

Selection of source-to-film distance. The source-to-film distance is often specified in the codes and specifications. When it is not specified, the radiographer must be able to make his own selection.

The selection of the proper source-to-film distance is a primary factor in controlling the unsharpness of a radiograph. The unsharpness can be measured by measuring the width of the penumbra on the radiograph. It has been determined that, for most industrial radiography, an unsharpness of .020 inches will still appear sharp to the unaided human eye. This means that any penumbra measuring .020 inches or less will appear as a sharp image to the unaided eye.

An unsharpness measuring .010 inches will appear sharp to the unaided eye of the film interpreter.

True Page 5-59
False Page 5-60

Poor choice. You have selected a faster, large-grain film. This will not improve the definition of the radiograph.

Here's the chart again.

FILM CHARACTERISTICS	SPEED	GRAIN	CONTRAST
TYPE I FOR CRITICAL INSPECTION, HIGHER VOLTAGES AND RADIOGRAPHY OF LIGHT METALS AND THEIR ALLOYS.	VERY SLOW	EXTRA FINE	HIGH
TYPE II FOR RADIOGRAPHY OF LIGHT METALS AT LOWER KILOVOLTAGES, AND HEAVIER STEEL PARTS AT 1,000 TO 2,000 KILOVOLTS.	SLOW	FINE	HIGH
TYPE III FOR EXAMINATION OF STEEL OR BRASS ALLOYS WITH MACHINES OF LIMITED KILOVOLTAGES. RECOMMENDED FOR USE WITH CALCIUM TUNGSTATE SCREENS. WITH LEAD SCREENS MAXIMUM LATITUDE, MEDIUM SPEED AND CONTRAST CAN BE OBTAINED.	MEDIUM	MEDIUM	MEDIUM
TYPE IV HIGHEST AVAILABLE SPEED WITH LEAD SCREENS FOR BOTH X-RAY AND GAMMA WORK. LARGEST GRAIN SIZE.	FAST	LARGE	MEDIUM

Our original radiograph was made on Type III film. We wanted to improve the definition of the radiograph by using another type of film. In order to improve the definition we would need a finer grained film. Look at the chart and you will see that Type II film has a finer grain than Type III film. Therefore the proper selection is Type II.

Turn to page 5-57 and continue.

Right. Any unsharpness measuring less than .020 inches will appear sharp.

Conversely, we can say that any penumbra measuring over .020 inches will appear unsharp. Thus we can establish a limit for unsharpness that we should try to maintain. Limits of unsharpness can be decreased as the need for finer detail increases. Aerospace requirements often specify that unsharpness be limited to .005 inches.

The amount of unsharpness (U) is controlled by three factors: 1) Source-to-film distance (D); 2) Specimen-to-film distance (t); and 3) Source diameter (d). The unsharpness can be computed by using the following equation.

$$U = \frac{t \times d}{D - t}$$

If we have defined our maximum allowable unsharpness as being .020 inches and we are trying to determine the proper source-to-film distance, we rewrite the equation thus:

$$D = \frac{t \times d}{.020} + t$$

When we substitute values in this equation and solve for D, we arrive at the minimum source-to-film distance required to limit unsharpness to .020 inches. Note - the specimen-to-film distance (t) is the distance from the source side of the specimen to the film (includes the thickness of the specimen).

Let's take a look at an example: The specimen is 2 inches thick, the specimen is placed directly on top of the film, and our source size is .125 inches. We want to maintain an unsharpness at or below .020 inches.

$$D = \frac{t \times d}{.020} + t$$

$$D = \frac{2 \times .125}{.020} + 2 = 14.5 \text{ inches}$$

Now you try one. What is the minimum source-to-film distance required to reduce unsharpness to .005 inches if the 4-inch thick specimen is placed directly on top of the film and the source size is .075 inches?

Solve the problem then check your work on page 5-61.

From page 5-57

5-60

You blew it. Any unsharpness measuring less than .020 inches will appear as a sharp image and .010 inches is certainly less than .020 inches. The image will appear sharp to anyone viewing the film with the unaided eye. Keep in mind that .020 inches is just about the width of a firm pencil line.

Turn to page 5-59.

$$D = \frac{t \times d}{U} + t$$

$$D = \frac{4 \times .075}{.005} + 4 = 60 + 4 = 64 \text{ inches, minimum.}$$

Now try these. When you have worked all three problems turn to page 5-62 and check your work.

Problem 1. The specimen is 5 inches thick and is resting on the film. The source is .2 inches in diameter. What is the minimum source-to-film distance required to obtain an unsharpness of .020 inches?

Problem 2. We are going to radiograph a weld on 1/2" aluminum plate. The plate is resting on the film and the source size is .075 inches. What is the minimum source-to-film distance that can be used if we wish to obtain an unsharpness of .005 inches?

Problem 3. We are radiographing 3-inch steel plate using a .15 inch source of Cesium-137. The film cannot be placed directly on the plate so a gap of 0.25 inches exists between the plate and the film. What is the minimum source-to-film distance if an unsharpness of .020 is to be maintained?

Problem 1. $D = \frac{t \times d}{U} + t$

$$D = \frac{5 \times .20}{.020} + 5 = 50 + 5 = 55 \text{ inches, minimum}$$

Problem 2. $D = \frac{t \times d}{U} + t$

$$D = \frac{.5 \times .075}{.005} + .5 = 7.5 + .5 = 8 \text{ inches, minimum}$$

Problem 3. $D = \frac{t \times d}{U} + t$

Note - specimen-to-film distance is 3.25 inches.

$$D = \frac{3.25 \times .15}{.020} + 3.25 = 24.37 + 3.25 = 27.62 \text{ inches, minimum}$$

In actual practice, the source-to-film distances used are often much greater than the computed minimum distances particularly when source sizes are small and, thinner specimens are being radiographed. In problem 2 above, for example, it is very unlikely that you will have to get within 8 inches of the focal spot of an x-ray tube.

Turn to page 5-63.

On the last few pages we have shown you how to select a minimum source-to-film distance that will give a minimum amount of unsharpness. You will, of course, come upon situations where the minimum distance cannot be obtained. Perhaps adjoining structure will limit the source-to-film distance below the minimum. This means that you will not be able to attain the required limits of unsharpness under these circumstances. Let's see then what effect a shorter distance has upon unsharpness. Let's look at problem 1 again.

The specimen was 5 inches thick; the source was 0.2 inches in diameter. The minimum source-to-film distance worked out as -

$$D = \frac{5 \times .2}{.020} + 5 = 50 + 5 = 55 \text{ inches}$$

Now let's suppose that the allowable unsharpness was .040 instead of .020. The minimum distance would then be reduced to -

$$D = \frac{5 \times .2}{.040} + 5 = 25 + 5 = 30 \text{ inches}$$

We have cut the minimum distance almost in half and our unsharpness is not too excessive. The point we are trying to make here is that when you are forced to accept less than perfect conditions you should be aware of the effect that these conditions will have on the radiograph.

Turn to page 5-64.

Selection of milliamperes. In X-radiography, once the radiographer has determined the proper exposure from exposure charts and has calculated the necessary corrections for changes in film, source-to-specimen distance, and film density, he is ready to select the tube current at which he expects to operate his equipment.

The selection is based on the operating capability of the available X-ray units. The specifications for the equipment will specify the current rating of the tube. These specifications cannot be exceeded without damaging the tube.

An X-ray unit is rated for 300 kv at 10 ma, continuous operation. A milliampere meter on the control panel will indicate from 0 to 20 ma. The maximum current that can be safely put through the tube when operating at 300 kv over long periods of time is _____.

- 10 milliamperes Page 5-65
- 20 milliamperes Page 5-66

Some machines are rated at one amperage for continuous-duty operation and at a higher amperage for a duty-cycle operation. The duty cycle is usually specified - so many minutes "on" followed by so many minutes "off". When using the higher amperage neither the rated current nor the duty cycle should be exceeded.

SUBJECTS

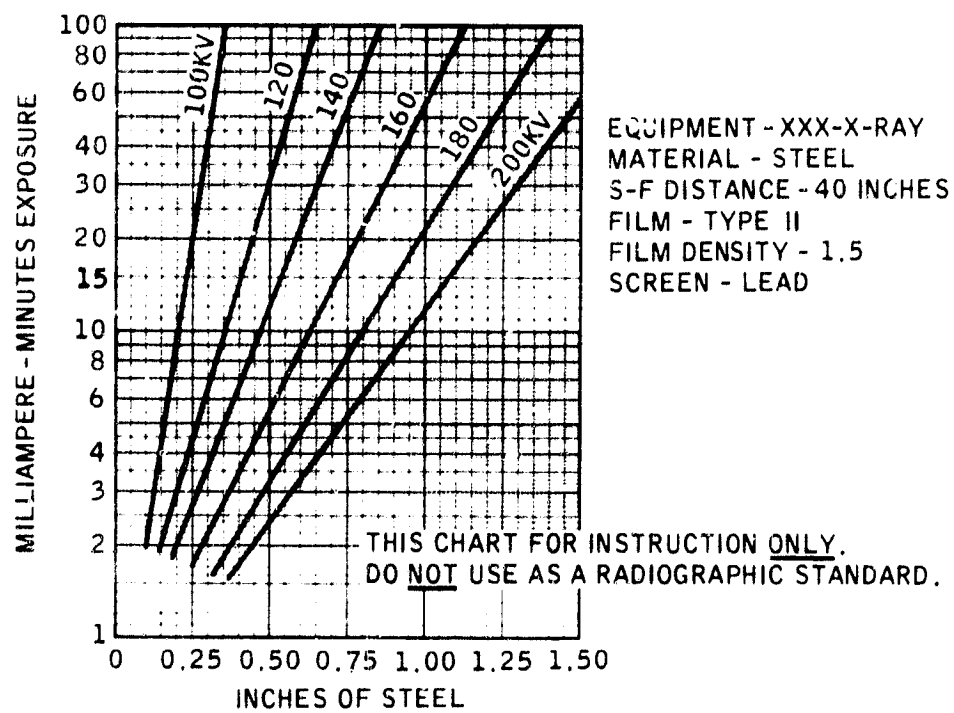
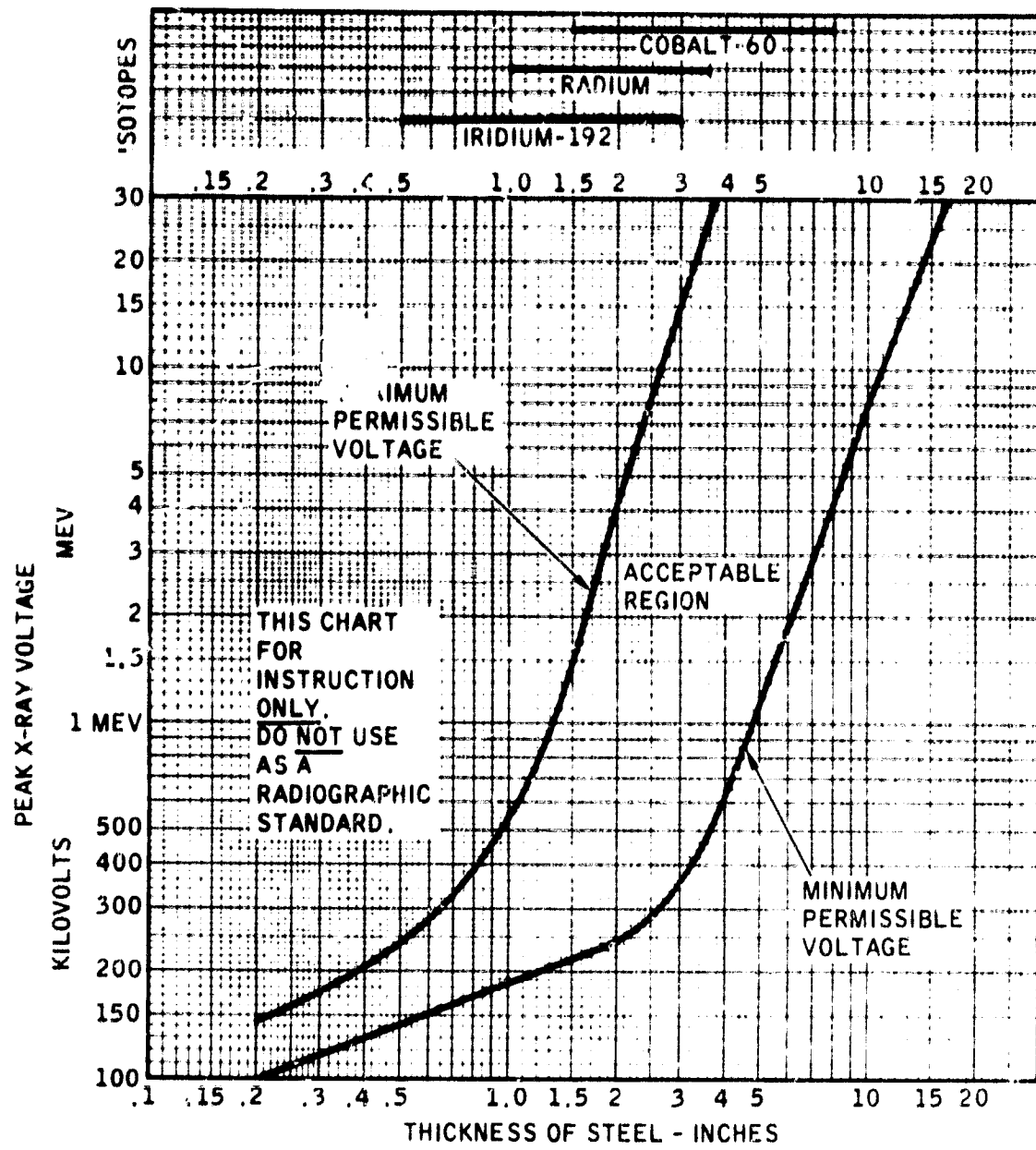
From page 5-64

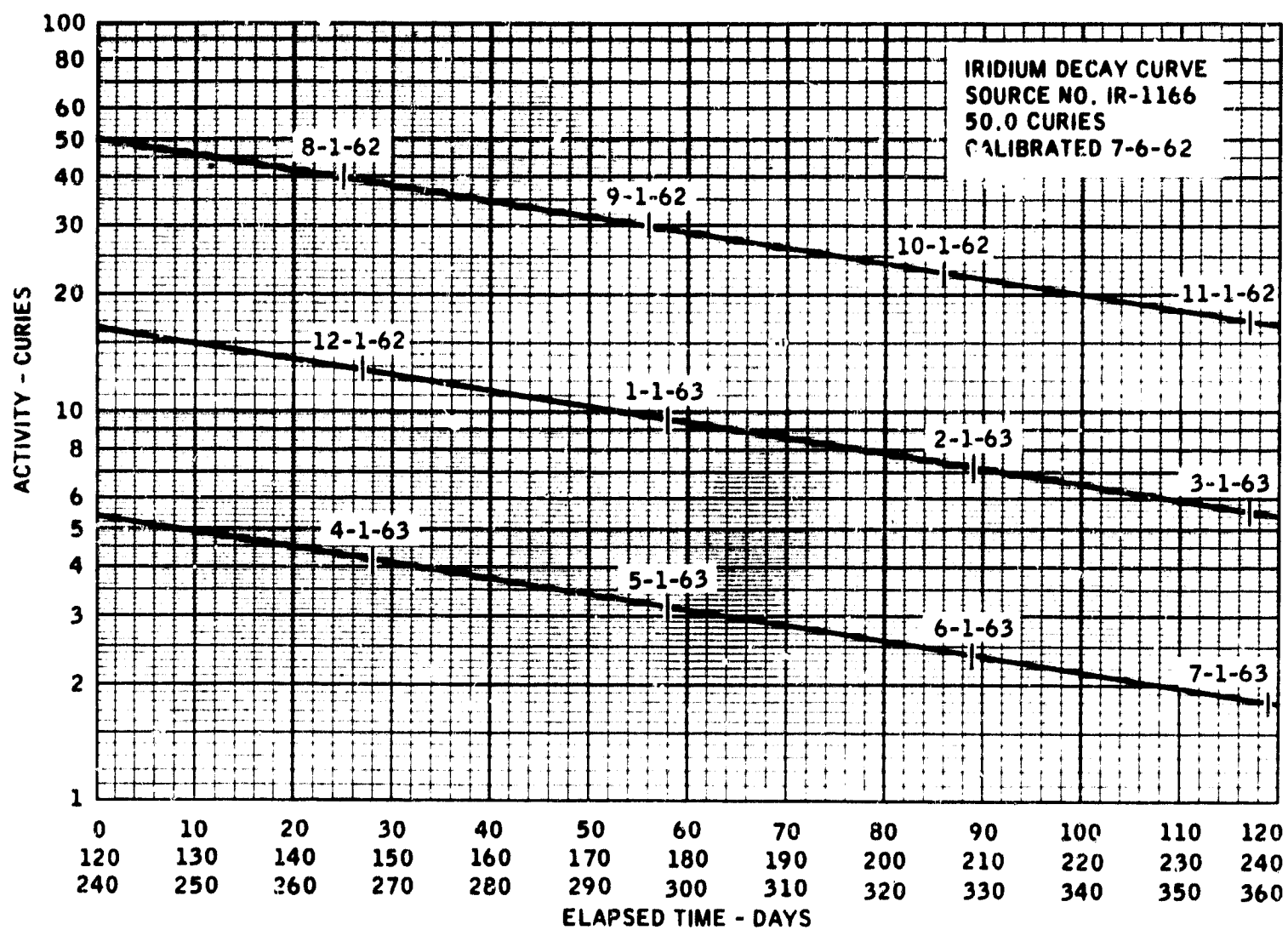
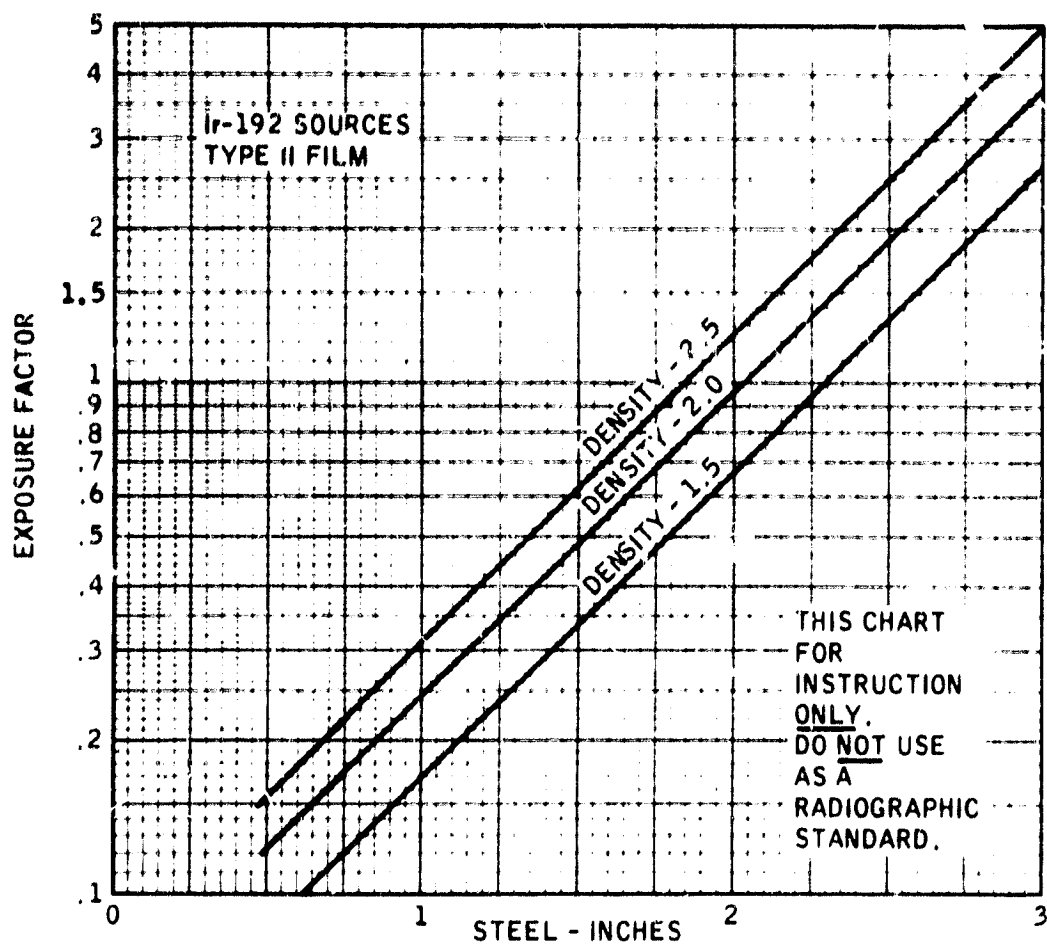
5-66

You just ruined a good X-ray machine. The meter is like a speedometer. It is there to keep you posted on what is going on. It is not there to tell you how fast you should drive.

The maximum current that can be safely used is the rated current. Since this machine was rated at 10 milliamperes, the maximum allowable current is 10 milliamperes.

Turn to page 5-65





APPROXIMATE RADIOGRAPHIC EQUIVALENCE FACTORS OF SEVERAL METALS												
	X-RAYS								GAMMA RAYS			
METAL	50 KV.	100 KV.	150 KV.	220 KV.	400 KV.	1000 KV.	2000 KV.	15-24 MEV.	IRIDIUM-192	CESIUM-137	COBALT-60	RADIUM
MAGNESIUM	0.6	0.6	0.05	0.08								
ALUMINUM	1.0	1.0	0.12	0.18					0.35	0.35	0.35	0.40
2024 (ALUMINUM) ALLOY	1.4	1.2	0.13	0.14					0.35	0.35	0.35	
STEEL		12.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
18-8 (STEEL) ALLOY		12.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
COPPER		18.	1.6	1.4	1.4				1.1	1.1	1.1	1.1
ZINC			1.4	1.3	1.3				1.1	1.0	1.0	1.0
BRASS			1.4	1.3	1.3	1.2	1.2		1.1	1.1	1.1	1.1
LEAD			14	12		5.0	2.5		4.0	3.2	2.3	2.0

ALUMINUM IS TAKEN AS THE STANDARD METAL AT 50 KV. AND 100 KV., AND STEEL AT THE HIGHER VOLTAGES AND WITH GAMMA RAYS

FILM CHARACTERISTICS	SPEED	GRAIN	CONTRAST
TYPE I FOR CRITICAL INSPECTION, HIGHER VOLTAGES AND RADIOGRAPHY OF LIGHT METALS AND THEIR ALLOYS.	VERY SLOW	EXTRA FINE	HIGH
TYPE II FOR RADIOGRAPHY OF LIGHT METALS AT LOWER KILOVOLTAGES, AND HEAVIER STEEL PARTS AT 1,000 TO 2,000 KILOVOLTS.	SLOW	FINE	HIGH
TYPE III FOR EXAMINATION OF STEEL OR BRASS ALLOYS WITH MACHINES OF LIMITED KILOVOLTAGES. RECOMMENDED FOR USE WITH CALCIUM TUNGSTATE SCREENS. WITH LEAD SCREENS MAXIMUM LATITUDE, MEDIUM SPEED AND CONTRAST CAN BE OBTAINED.	MEDIUM	MEDIUM	MEDIUM
TYPE IV HIGHEST AVAILABLE SPEED WITH LEAD SCREENS FOR BOTH X-RAY AND GAMMA WORK. LARGEST GRAIN SIZE.	FAST	LARGE	MEDIUM

	MINIMUM DISTORTION	SHARPEST DEFINITION	HIGHEST CONTRAST	ADEQUATE DENSITY
	1. The qualities shown above describe the ideal _____.			
9. 120 - 150 kv				
10. Lead screens _____ (are, are not) generally used at voltage below 120 - 150 kv.				
18. 1.25	$e.f. = \frac{\text{curie x minutes}}{(\text{inches})^2}$			
19. The exposure factor (e.f.) is represented by the equation — $\frac{I \times T}{D^2}$				
	I stands for the intensity of the source measured in _____.			
27. Type II preferred, Type I possible				
28. The figure .020 inches represents the maximum width of penumbra that will still allow the image to appear _____ to the unaided eye.				

1. Radiograph

THE IDEAL RADIOGRAPH

DISTORTION DEFINITION CONTRAST DENSITY

2. The ideal radiograph has _____ distortion, _____ definition, _____ contrast, and _____ density.

10. are not

11. When fluorescent screens are used the exposure time can be _____ (reduced, increased).

19. curies

20. What exposure time is required to obtain a film density of 2.0 on type II film when radiographing 1.5 inches of steel with 10 curies of Iridium-192 at a source-to-film distance of 15 inches?

28. sharp

29. Since an image having a penumbra measuring .020 inches still appears sharp to an observer we use this measurement to establish the _____ (maximum - minimum) source-to-film distance.

2. minimum, sharpest,
highest, adequate

3. The four qualities that describe the ideal radiograph are: _____
_____, _____, _____,
and _____.



11. reduced

12. _____ screens are used only when the exposure time without
them is excessive.



20. 10.8 minutes

21. The activity of IR-1166 on Nov. 1, 1962, was _____.



29. minimum

30. Penumbra is caused by three geometrical factors. Source-to-film distance,
specimen-to-film distance, and source-size. The minimum source-to-film
distance can be found by using the equation $D = \frac{t \times d}{f} + t$. In this equation, "d"
stands for _____.



3. Minimum distortion, sharpest definition, maximum contrast, adequate density

Use the charts given on pages 5-67, 5-68, and 5-69 to help you answer the questions in this review.

4. An X-ray machine rated at 200 to 750 kvp can be used to radiograph 2 inches of steel. (True - False)



12. Fluorescent

13. If you were going to radiograph 1.5 inches of steel plate with an X-ray machine rated at 200 to 750 kv, what tube voltage would you use?



21. 17 curies

22. When radiographed at 400 kv, 1.6 inches of copper is the equivalent of _____ inches of steel.



30. source diameter

$$D = \frac{t \times d}{U} + t$$

31.and "t" stands for_____.



4. True

5. An X-ray machine rated at 200 to 750 kvp can be used to radiograph 1/4 inch steel plate. (True - False)



13. Any voltage between 210 and 700 kv

[Your answer would have to be considered correct if it lies between these voltages. However it is more nearly correct if it is close to 380 kv.]

14. What exposure would you use to radiograph 1 inch of steel at 180 kv to obtain a film density of 1.5 on type II film with a source-to-film distance of 40 inches and with lead screens?



22. 2.24

23. When radiographed at 100 kv, 0.3 inches of steel is equivalent to _____ inches of aluminum.



31. specimen-to-film distance (specimen thickness only if specimen is on the film)

32. The equation for determining the minimum source-to-film distance is _____.



5. False

6. The maximum voltage that can be used to radiograph 2 inches of steel is approximately _____ kvp.



14. 22 ma-min

15. To radiograph 8 inches of steel using a radiographic isotope you would use _____ (Iridium-192, Cobalt-60).



23. 3.6

24. The selection of the film density is dependent on the quality of the film viewer. The image on the radiograph must never be so dense that it cannot be read on available viewing equipment. (True - False)



32. $D \frac{t \times d}{U} + t$

33. An X-ray unit is rated at 90 kvp and 3 milliamperes. What is the maximum tube current that can be used with this unit?



6. 4000 (4 Mev)

7. The minimum voltage that can be used to radiograph 2 inches of steel is approximately _____ kvp.



15. Cobalt-60

16. We have a 5-curie source of Iridium-192. Should this source be used to radiograph a steel specimen 5 inches thick?



24. True

25. Films that show high contrast are selected when _____ discontinuities are sought.



33. 3 milliamperes

This completes the review of Chapter.

Turn to page 6-1



7. 245

8. Lead screens, when used at voltages above 120-150 kv generally _____
(do, do not) improve the quality of the radiograph.



16. No.

17. We have a 10-curie source of Cobalt-60. Can this source be used to radiograph
1 inch of steel?



25. small

26. Slow speed films produce better definition than high speed films because of
their finer _____.



Turn to page 6-1



8. do

9. Lead screens are generally used at voltages above _____.



Return to page 5-70, frame 10,
and continue.

17. No

$$e.f. = \frac{I \times T}{D^2}$$

18. What is the exposure factor (e.f.) to use in the above equation if you are going to radiograph 2 inches of steel using Iridium-192 if you want to obtain a 2.5 density on type II film?



Return to page 5-70, frame 19,
and continue.

26. grain

27. We have just radiographed a specimen with Type III film and in reading the film have observed what appears to be a discontinuity but the edges seem blurred making identification impossible. We decide that another type of film might aid in identifying the discontinuity. Which film would you recommend?



Return to page 5-70, frame 28,
and continue.

Turn to page 6-1



There are several established techniques and procedures with which all radiographers should be familiar. In this chapter we intend to acquaint you with those procedures.

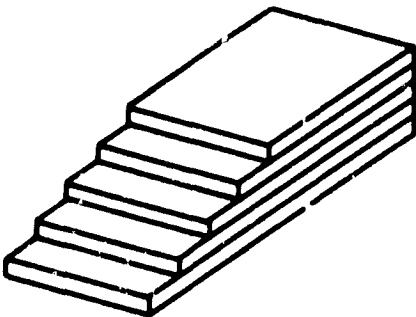
In Chapter 5 we explained how exposure charts are used. We will begin this chapter with the procedure used to prepare the exposure charts that are required with any piece of X-ray equipment you might be using.

Why do we need to prepare exposure charts? Imagine for a moment a radiographer starting out with a brand new X-ray machine. He has no way in the world of knowing exactly how well this machine is going to perform since there are so many uncontrollable variables that make one machine perform differently from another machine even though they may be exactly alike in appearance. He could start shooting blindly hoping to come close to the desired radiograph and make adjustments from that point, but this would be expensive, especially if the specimens he would be radiographing vary a great deal in size and shape.

No, the best way to approach the problem is to perform a systematic analysis of the capabilities of the machine. Many different analysis techniques exist but a systematic procedure relying on a combination of theory and trial exposures is best. Such an analysis technique is the "step wedge" analysis explained on the following pages.

Turn to page 6-2.

The "step wedge" is any object having several distinct, known thicknesses.



Equal thicknesses are not required but the actual thickness of each step must be accurately known. Carefully designed, machine-made step wedges are nice, but equally good results can be obtained with scraps of plate stock. The material used should be the same as the material you expect to be radiographing during production and the overall thickness of the step wedge should exceed the thickness that you could expect to be radiographing.

Random thicknesses of steel, plate stock may be stacked and used to form a step wedge.

- True Page 6-3
- False Page 6-4

Right as rain. The important thing to remember when using random thicknesses for a step wedge is to measure and record the total thickness for each step.

Step wedge analysis. The procedure, now that we have a step wedge, is to make several radiographs of the step wedge keeping the exposure factors under careful control. Each radiograph is made at a different voltage and exposure.

When the radiographs have been developed they are systematically analyzed and the results are plotted on the proper graph paper to form the exposure charts with which you are familiar.

Which of the two statements below do you think describes the correct procedure?

In exposing the radiographs each step of the wedge is exposed at a separate voltage Page 6-5

In exposing the radiographs the entire step wedge is exposed at each separate voltage Page 6-6

From page 6-2

6-4

Sorry - the statement is true.

The only objective of the step wedge is to provide a definite variation in thickness for several "steps". The change in thickness does not have to be exactly the same for each step. Therefore, random thicknesses of plate stock may be used.

Turn to page 6-3 and continue.

It sounds logical - but that is not the correct procedure.

In the step wedge analysis the first step is to radiograph the entire step wedge at one voltage; then radiograph the entire step wedge at a second voltage; and so on.

By doing this we get an accurate picture of the radiographic effect of several different voltages on each step. We then know exactly what will happen when we radiograph a certain thickness with any of the applied voltages.

Turn to page 6-6.

Good thinking! The entire step wedge is radiographed at each of several voltages.

Selection of the voltages to be used is determined by the range of thickness of the step wedge and may be determined from previous experience with other machines or from data supplied by the manufacturer that he has developed through use of similar machines.

The exposure to use at each voltage is determined in the same manner.

Perfect radiographs are not necessary in the step-wedge analysis. It is only necessary that each radiograph show the sharp-edged thicknesses of the step wedge.

Probably the best way to illustrate the "step wedge analysis" procedure is to follow through a typical example. Our step wedge, selected for reasons given on previous pages, consists of 10 pieces of 0.01-inch stainless steel plate. We are using a brand new "XXX" X-ray machine. We select a voltage range of 60 to 120 kv for the radiographs.

It is likely that we based this choice of voltages from -

radiographs of stainless steel made with our new "XXX" unit	Page 6-7
information supplied by the equipment manufacturer	Page 6-8

From page 6-6

6-7

You chose a long and costly procedure to follow. Obtaining any valid data on the operation of the "XXX" machine in this manner would require numerous, costly exposures before any positive conclusions could be reached. The best and most reliable information, assuming lack of experience, is obtained from the equipment manufacturer.

Turn to page 6-8.

Correct. Information supplied by the equipment manufacturer is valid enough for our purposes in step wedge analysis.

From our range of 60 - 120 kv we select several voltages at which we will expose our step wedge. This selection is entirely arbitrary. Any values within the selected range will do. For our example let's use 60 kv at 5 ma-min, 80 kv at 4 ma-min, 100 kv at 3 ma-min, and 120 kv at 3 ma-min.

Note - we repeat that these voltages and exposures are selected from exposure data supplied by the manufacturer of the X-ray equipment.

In our example we could have elected to make 6 radiographs.

True Page 6-9

False Page 6-10

Right!

We could just as easily make 6 radiographs. However, four radiographs are to be made of this step wedge. The voltage and exposure for each radiograph will be carefully recorded on the radiograph.

The preceding steps have established the variable exposure factors of specimen thickness, voltage, and exposure. All other exposure factors must be held constant, and are also carefully recorded on paper.

Film - be sure the same type of film is used for all exposures.

Film development - be sure that there are no deviations from standard, established procedures.

Source-to-film distance - do not allow this distance to vary between shots.

Screens - if screens or filters are used, do not change type or positioning between shots.

Shielding - do not change the method of controlling scatter between shots.

Which exposure factors are recorded?

The voltage and exposure	Page 6-11
All of them	Page 6-12

From page 6-8

6-10

The statement is true. The number of radiographs to make is not pre-determined. .
You may elect to make any number you feel are adequate for your purposes. We could make six exposures if desired.

Turn to page 6-9 and continue.

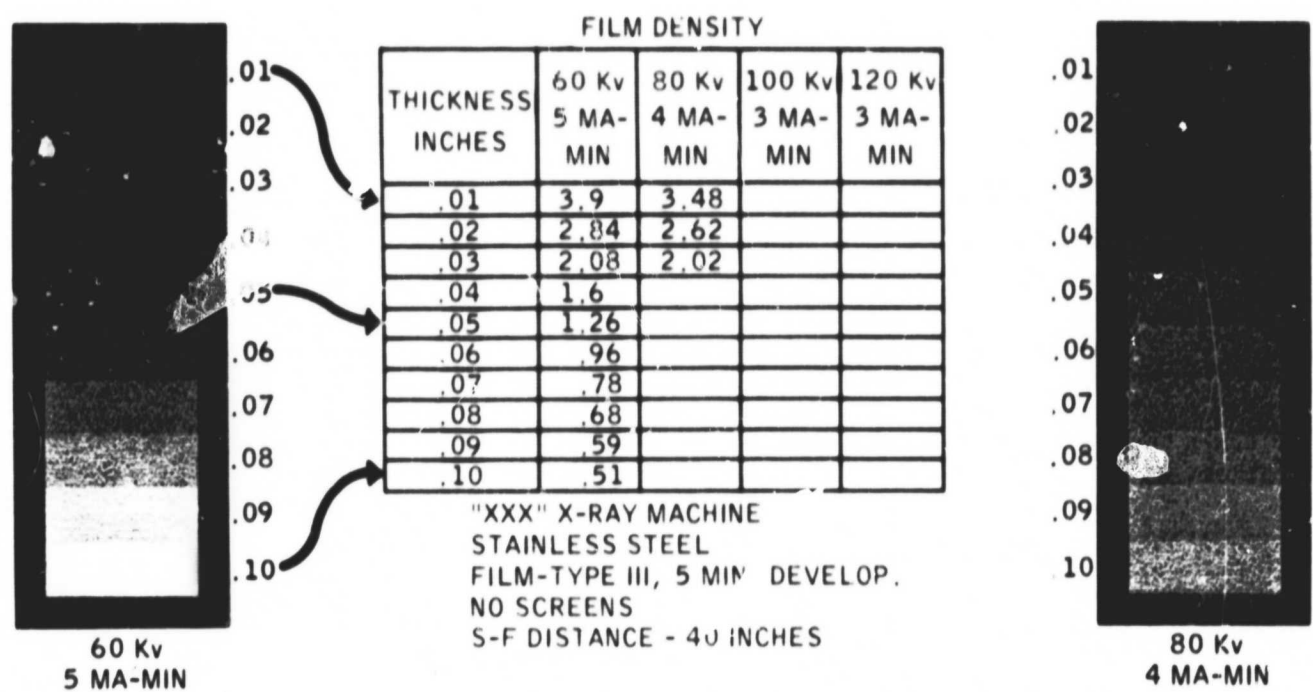
You've missed the boat. All of the exposure factors must be recorded.

For example - if the analysis is made using lead screens, the resulting exposure chart is good only if screens are used. An exposure without screens will result in an entirely different radiograph than one with screens. The exposure factors are ultimately recorded on the exposure chart. This tells the radiographer the conditions under which the exposure chart is accurate. This is why every exposure factor must be recorded.

Turn to page 6-12.

Right! All of the exposure factors are recorded. The voltage and exposure are recorded on the radiograph. The rest are recorded on paper.

Once the set of radiographs are obtained, the analysis phase begins. Each radiograph is examined with a densitometer and the density of the image of each "step" is recorded on a table. A separate column is used for each voltage and exposure.



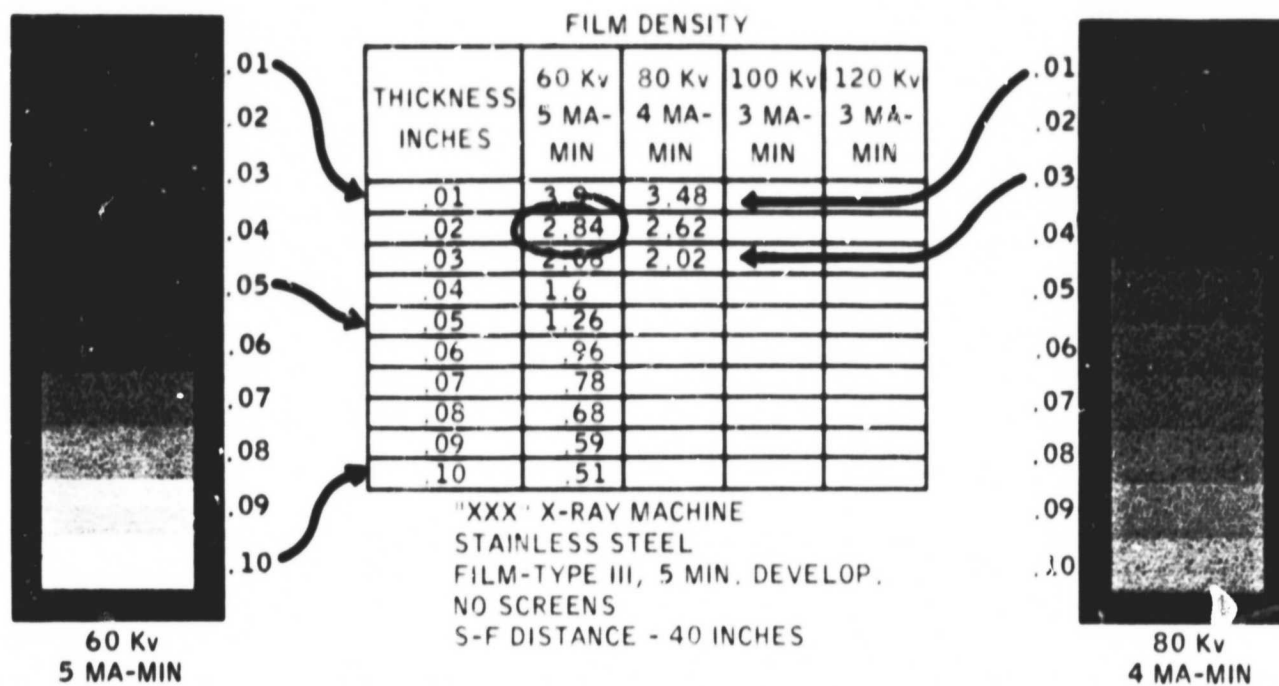
On the left we show a drawing of the typical step-wedge radiograph that might have been obtained with a voltage of 60 kv and an exposure of 5 ma-min. On the right we show the radiograph that might have been obtained with a voltage of 80 kv and an exposure of 4 ma-min. In the center we show a typical table on which we are recording the densities as read from each of the radiographs of the step wedge.

From the table above, the measured film density of the image of the 0.02-inch thickness of stainless steel when radiographed at 60 kv is _____.

3.9 Page 6-13

2.84 Page 6-14

Let's look at that table again.



In the left hand column of the table we have listed the total thickness of each step of the step wedge. As we measure the density of each step on the radiograph, we record it in the appropriate column opposite the correct thickness. The image density, then, of the .02-inch step for 60 kv (circled on the chart above) is 2.84.

Turn to page 6-14.

Right. The density of the image of the 0.02-inch thickness radiographed at 60 kv was recorded opposite .02 in the 60 kv column.

In this same manner the densities of each step on each radiograph was read and recorded. The complete results are shown on the table below.

FILM DENSITY				
THICKNESS INCHES	60 Kv 5 MA-MIN	80 Kv 4 MA-MIN	100 Kv 3 MA-MIN	120 Kv 3 MA-MIN
.01	3.9	3.48	3.24	4.2
.02	2.84	2.62	2.40	3.2
.03	2.08	2.02	1.86	2.56
.04	1.6	1.62	1.52	2.08
.05	1.26	1.32	1.25	1.78
.06	.96	1.09	1.04	1.56
.07	.78	.90	.88	1.34
.08	.68	.78	.77	1.14
.09	.59	.68	.70	1.01
.10	.51	.59	.62	.99

"XXX" X-RAY MACHINE
STAINLESS STEEL
FILM-TYPE III, 5 MIN. DEVELOP.
NO SCREENS
S-F DISTANCE - 40 INCHES

The figure 1.32 in the 80 kv column is the density of the film image of _____ inches of stainless steel radiographed at 80 kv with an exposure of 4 ma-min.

- .04

.

Page 6-15
- .05

.

Page 6-16

Let's look at the table again.

FILM DENSITY				
THICKNESS INCHES	60 Kv 5 MA-MIN	80 Kv 4 MA-MIN	100 Kv 3 MA-MIN	120 Kv 3 MA-MIN
.01	3.9	3.8	3.24	4.2
.02	2.34	2.2	2.40	3.2
.03	2.08	2.02	1.86	2.56
.04	1.6	1.62	1.52	2.08
.05	1.25	1.32	1.25	1.78
.06	.96	1.09	1.04	1.56
.07	.78	.90	.88	1.34
.08	.68	.78	.77	1.14
.09	.59	.68	.70	1.01
.10	.51	.59	.62	.99

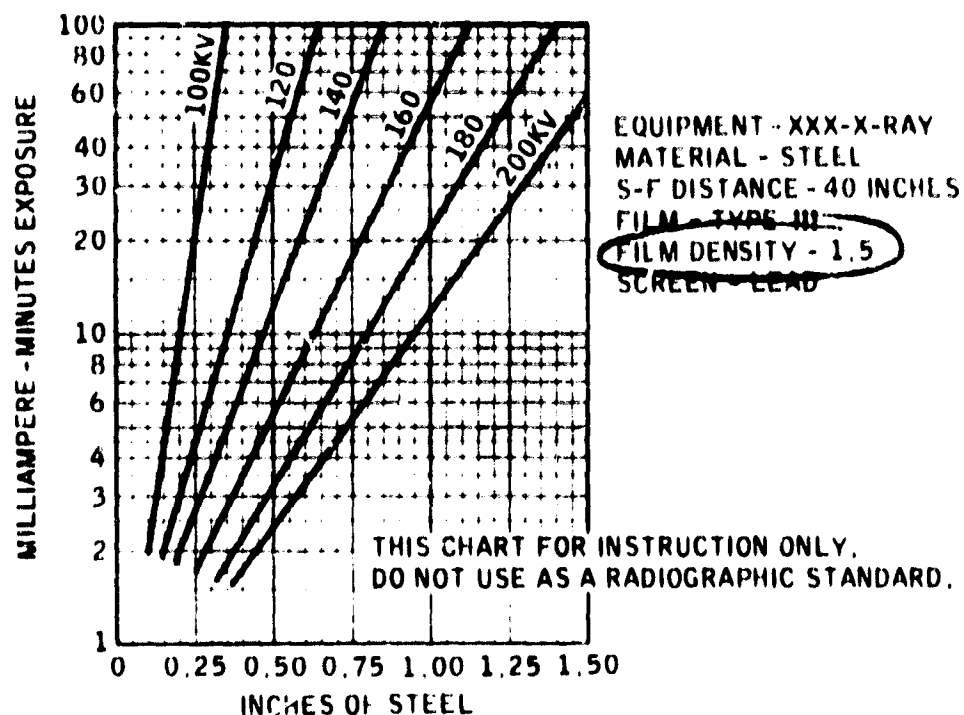
"XXX" X-RAY MACHINE
STAINLESS STEEL
FILM-TYPE III, 5 MIN. DEVELOP.
NO SCREENS
S-F DISTANCE - 40 INCHES

Note that the figure 1.32 in the 80 kv column is opposite the .05-inch thickness. This tells us that the film density of the .05-inch step in the 80 kv radiograph is 1.32.

Turn to page 6-16.

Very good. You seem to understand how the measured densities have been recorded on the chart.

Now let's take a quick look at a typical exposure chart to see where we are going.



Note that the exposure chart specifies one density. (In this chart a density of 1.5 was selected as the standard density.)

The table we have just completed contains exposure data that covers a wide range of densities. It is now necessary to adjust all of our data to a standard density so that we can construct a chart like the one above. The density we choose as a standard depends on the available viewing equipment. For purposes of our example, let's select a density of 2.5 as a good mid-range density.

The next step in the step wedge analysis is to -

adjust our recorded data to obtain a standard density of 2.5 Page 6-17

compare our recorded data with the exposure chart shown on this page . . Page 6-18

Good thinking. The next step is to convert the exposure for each and every density shown on our chart to an exposure that will result in a standard density of 2.5.

For example: from our chart (partially repeated below) we know that an exposure of .01 inches of steel at 60 kv at 5 ma-min (E_1) results in a film density of 3.9. From this data we want to determine the exposure (E_2) that would be required to give a film density of 2.5 for the same thickness of material and at the same voltage.

FILM DENSITY

THICKNESS INCHES	60 Kv 5 MA-MIN	80 Kv 4 MA-MIN	100 Kv 3 MA-MIN	120 Kv 3 MA-MIN
.01	3.9	3.48	3.24	4.2
.02	2.84	2.62	2.40	3.2
.03	2.08	2.02	1.86	2.56
.04	1.6	1.62	1.52	2.08
.05	1.26	1.32	1.25	1.78
.06		1.09	1.04	1.54

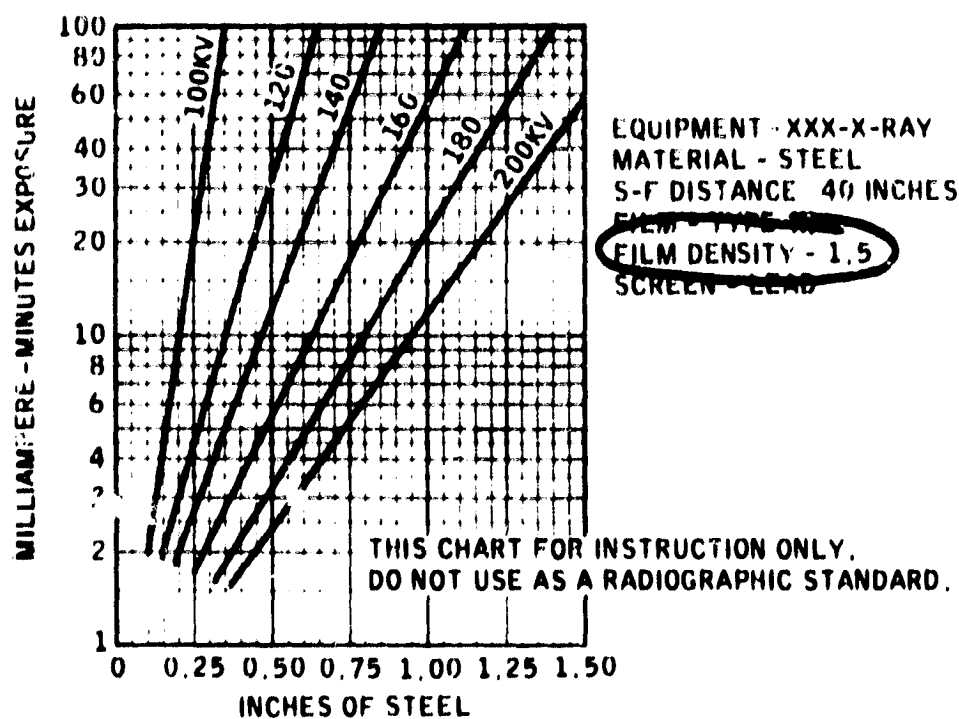
E_1 →

Do you recall the mathematical process of computing the change in exposure required to give a particular change in film density?

We would use the inverse square law Page 6-19

We would use the film characteristic curves Page 6-20

We were afraid that we would confuse you by putting that exposure chart in there. We only wanted to point out that the exposure chart was constructed to give one film density.



If you will recall, in using this exposure chart any data taken correctly from the chart and applied to making a radiograph will result in the radiograph having a density of 1.5.

We have selected a density of 2.5 for our exposure chart. When our exposure chart is completed, use of the data should result in a radiographic density of 2.5.

For this reason our next step is to adjust our recorded data to the selected standard density of 2.5.

Turn to page 6-17 and continue.

The inverse square law deals with the change in exposure that goes with a change in source-to-film distance. The source-to-film distance is one exposure factor that we are being careful not to change, so the inverse square law is not applicable here.

We are changing film densities. We have exposed a certain thickness of steel and obtained a certain density. We now want to determine from this exposure (E_1) the exposure (E_2) that would be required to obtain a density of 2.5. To accomplish this we make use of the film characteristic curves.

Turn to page 6-20.

Correct. We would use the film characteristic curves to compute the change in exposure required to change the density to 2.5 .

Let's continue with our example and convert the exposure for .01 inches at 60 kv with 5 milliampere-minutes exposure.

THICKNESS INCHES	FILM DENSITY			
	60 Kv 5 MA-MIN	80 Kv 4 MA-MIN	100 Kv 3 MA-MIN	120 Kv 3 MA-MIN
.01	3.9	3.48	3.24	4.2
.02	2.84	2.62	2.40	3.2
.03	2.08	2.02	1.86	2.56
.04	1.6	1.62	1.52	2.08
.05	1.26	1.32	1.25	1.78
.06		1.09	1.04	

Using the film characteristic chart we find

Log relative exposure (E_1) for 3.9 density, Type III film - 2.851

Log relative exposure (E_2) for 2.5 density, Type III film - 2.630

Interval between log relative exposures - 0.221

Antilog of interval 1.66

The exposure must decrease, therefore: $E_2 = \frac{5 \text{ ma-min}}{1.66} = 3.0 \text{ ma-min}$

Then, the exposure required to obtain a film density of 2.5 using Type III film when radiographing .01 inches of steel at 60 kv is _____.

3 milliampere-minutes Page 6-21

5 milliampere-minutes Page 6-22

Very good. Our computed exposure is 3.0 milliampere-minutes.

We now proceed, in the same manner, to compute a new exposure for each and every entry in our original density table. A second table is prepared for listing of the computed data.

E₂

THICKNESS INCHES	60 Kv	80 Kv	100 Kv	120 Kv
.01	3.0	2.75	2.2	-
.02	4.35	3.80	3.15	2.25
.03	6.0	4.90	4.05	2.95
.04	7.9	6.2	5.0	3.60
.05	10.3	7.60	6.0	4.25
.06	12.7	9.2	7.1	4.9
.07	15.8	11.0	8.4	5.6
.08	19.0	13.0	9.8	6.5
.09	22.5	15.3	11.5	7.0
.10	27.0	18.0	12.8	7.6

EQUIPMENT - "XXX" X-RAY
MATERIAL - STAINLESS STEEL
S-F DISTANCE 40 INCHES
FILM-TYPE III, 5 MIN. DEVELOP.
DENSITY - 2.5
SCREENS - NONE

NOTE

Here we show the completed exposure table. Note that the exposure factors are also listed on this table and that the 2.5 density is specified. Each exposure on this table will result in a film density of 2.5 for the thickness of material if applied at the indicated voltage.

From the table above, the exposure required to obtain a film density of 2.5 when radiographing .05 inches of stainless steel at a voltage of 80 kv on the "XXX" X-ray unit with a source-to-film distance of 40 inches without screens on Type III film is_____.

- 7.6 milliamp-minutes Page 6-23
- 2.75 milliamp-minutes Page 6-24

Somehow we lost you on that last turn; so let's turn back a ways.

In the first step we made radiographs of the step wedge at 4 different voltages and exposures.

In the next step we read and recorded the film density of each step on the radiographs. In this way we recorded the film density that resulted from an exposure at a given voltage.

We are now converting that exposure and density to a new exposure at a selected standard density.

Our original exposure of 5 milliamperce-minutes at 60 kv resulted in a density of 3.90 for .01 inches of stainless steel.

We are now computing the exposure required under the same conditions to give us a film density of 2.5.

The answer must be something other than the original exposure (5 milliamperce-minutes). Turn back to page 6-20 and see if you can determine where the correct answer (3 milliamperce-minutes) is found.

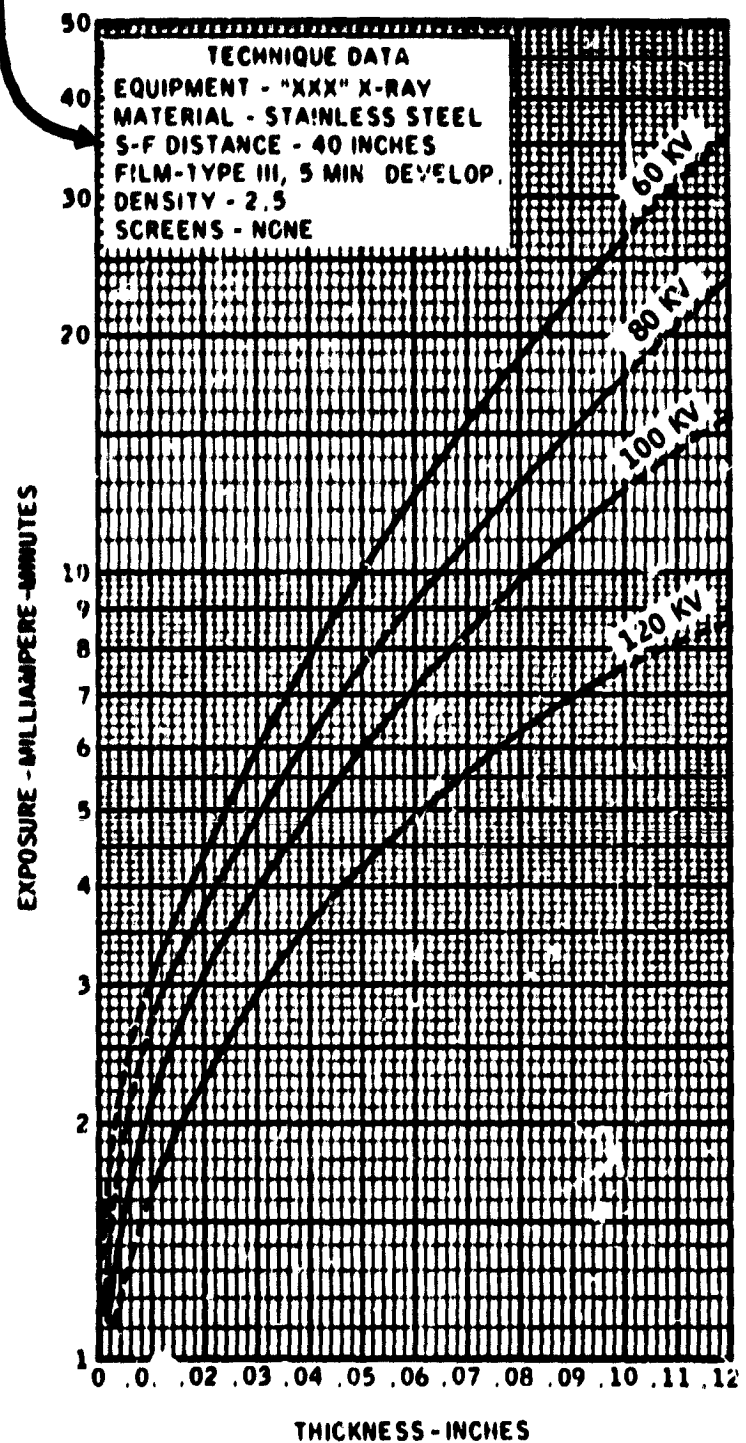
Right! The exposure, under conditions established for the table, required for 0.05 inches at 80 kv is 7.6 milliamperere-minutes.

The final step in the step wedge analysis procedure is to transfer the data from the exposure table to the more usable exposure chart. The data is plotted on a semilog graph paper and curves connecting those points are drawn. The completed chart is shown below.

The horizontal axis of the chart shows the thickness of the material, while the vertical axis (on a log scale) shows the exposure. It is essential to add the supporting data on the chart. There should be enough exposure information on the chart to allow complete identification of the chart without referring to other information.

Turn to page 6-25.

SUPPORTING DATA



Let's have another look at that chart.

EXPOSURE (MILLIAMPERE-MINUTES)				
THICKNESS INCHES	60 Kv	80 Kv	100 Kv	120 Kv
.01	3.0	2.75	2.2	-
.02	4.35	3.80	3.15	2.25
.03	6.0	4.90	4.05	2.95
.04	7.9	6.2	5.0	3.60
.05	10.3	<u>7.60</u>	6.0	4.25
.06	12.7	9.2	7.1	4.9
.07	15.8	11.0	8.4	5.6
.08	19.0	13.0	9.8	6.5
.09	22.5	15.3	11.5	7.0
.10	27.0	18.0	12.8	7.6

EQUIPMENT - "XXX" X-RAY
 MATERIAL - STAINLESS STEEL
 S-F DISTANCE - 40 INCHES
 FILM - TYPE III, 5 MIN. DEVELOP.
 DENSITY - 2.5
 SCREENS - NONE

And we'll repeat the question. The exposure required to obtain a film density of 2.5 when radiographing .05 inches of steel at a voltage of 80 kv on the "XXX" X-ray unit with a source-to-film distance of 40 inches without screens on Type III film is

_____ .

If you compare the exposure factors called for in the question with the exposure factors specified on the chart you will find that they agree with the exception of those underlined. Before using any chart like this you must always be sure that the exposure factors agree.

Those factors that are underlined give us the clue to enable us to find the correct answer. Opposite the .05-inch thickness under the 80 kv column we find 7.6 (shown circled on the chart). This is the required exposure in milliamperes-minutes.

Turn to page 6-23.

The step wedge analysis we have used as an example is the simplest we could devise. The material used was comparatively thin and the steps were of very small thicknesses. This was done to assure that all of the steps of the wedge would appear on each radiograph at each voltage. You will find that a wider variation in material thickness will require more than one radiograph at each voltage. You may find that the thicker part of the wedge will require one exposure and the thinner part of the wedge will require another exposure. However, whatever the case, the analysis of the data taken from each radiograph is handled in the manner we have just shown you.

Latitude analysis. Another technique that results in data that is useful to the radiographer is the latitude analysis. Quite often it is necessary to know beforehand whether or not the radiograph is going to show adequately all the thicknesses of the specimen.

The latitude analysis procedure is fairly simple once we have constructed the exposure chart. The first step is to decide on an acceptable film density range. What is the maximum acceptable density and what is the minimum acceptable density?

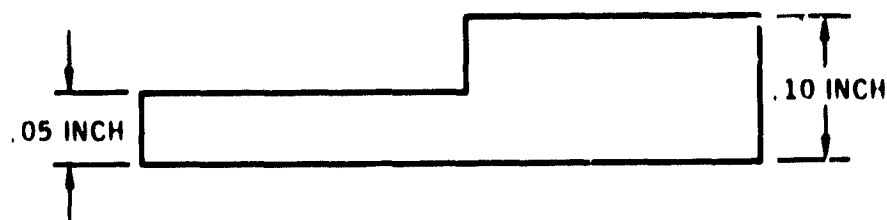
For the following example we have selected a density range of 2.0 to 3.0. (If you recall, the exposure chart that we just completed was calculated to give a film density of 2.5.)

Our selection of a density range of 2.0 to 3.0 is the first step in the

construction of an exposure chart Page 6-26
latitude analysis. Page 6-27

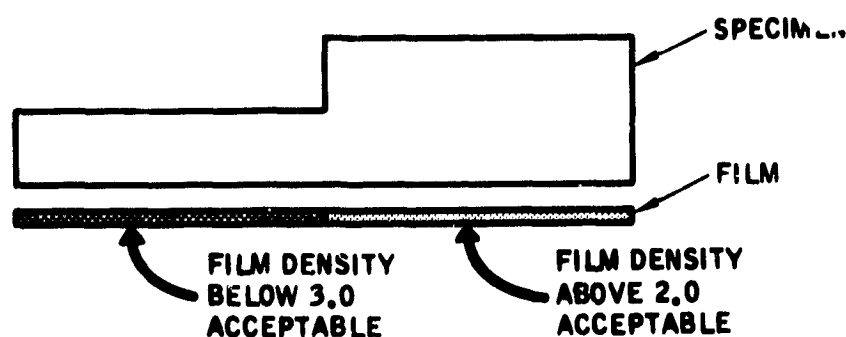
It is true that the latitude analysis starts with an exposure chart but the selection of an acceptable density range is the first step taken in the latitude analysis.

Here is why the radiographer needs a latitude analysis.



Suppose we were to radiograph the specimen above using the exposure chart we have just constructed. Would you expose for the .10-inch thickness or for the .05-inch thickness; or for some thickness in between? That, of course, is a difficult question to decide with the data we now have. If we expose for one thickness, the density of the other thickness may not be adequate. We need to analyze the situation further.

The first step then is to decide what film densities will be acceptable. In our example we have decided that a minimum density of 2.0 under the thickest section of the specimen will be acceptable and that a maximum density of 3.0 under the thinnest section will be acceptable.



Turn to page 6-27.

Right. We begin our latitude analysis by selecting the acceptable density range of 2.0 to 3.0.

The next step in the latitude analysis procedure is to change the curves we obtained in the exposure chart from a density of 2.5 to densities of 2.0 and 3.0. This is accomplished as follows:

From the H & D curves we take the following information -

Log relative exposure, Type III film, density 3.0 = 2.70

Log relative exposure, Type III film, density 2.5 = 2.63

Log relative exposure, Type III film, density 2.0 = 2.53

Compute the change in log relative exposures -

Change in LRE (2.5 to 3.0) = 2.70 - 2.63 = .07

Change in LRE (2.5 to 2.0) = 2.63 - 2.53 = .10

Find the change ratios -

Antilog .07 = 1.18

Antilog .10 = 1.26

We now know that if we multiply any 2.5 exposure by 1.18 we will have a 3.0 exposure. If we divide any 2.5 exposure by 1.26 we will have a 2.0 exposure.

Now we want you to let us know your feelings at this moment.

I understand what we are doing and am ready to go on Page 6-28

I don't understand and think you ought to give a clearer explanation . . . Page 6-29

Fine! Let's get on with it.

The next step is to take several convenient exposures from the 2.5 exposure chart and list them in a table.

60 Kv			
STEEL THICKNESS	(2.5) EXPOSURE	(3.0) EXPOSURE	(2.0) EXPOSURE
.01	3.0		
.04	7.9		
.06	12.7		
.10	27.0		

Here we show a table constructed for the 60 kv curve. Similar tables would also be constructed for the 80, 100, and 120 kv curves.

We now compute the data to fill the 3.0 exposure column by multiplying the 2.5 exposure figure by the factor 1.18 ($3.0 \times 1.18 = 3.5$). In this manner we compute the values to completely fill out the 3.0 exposure column.

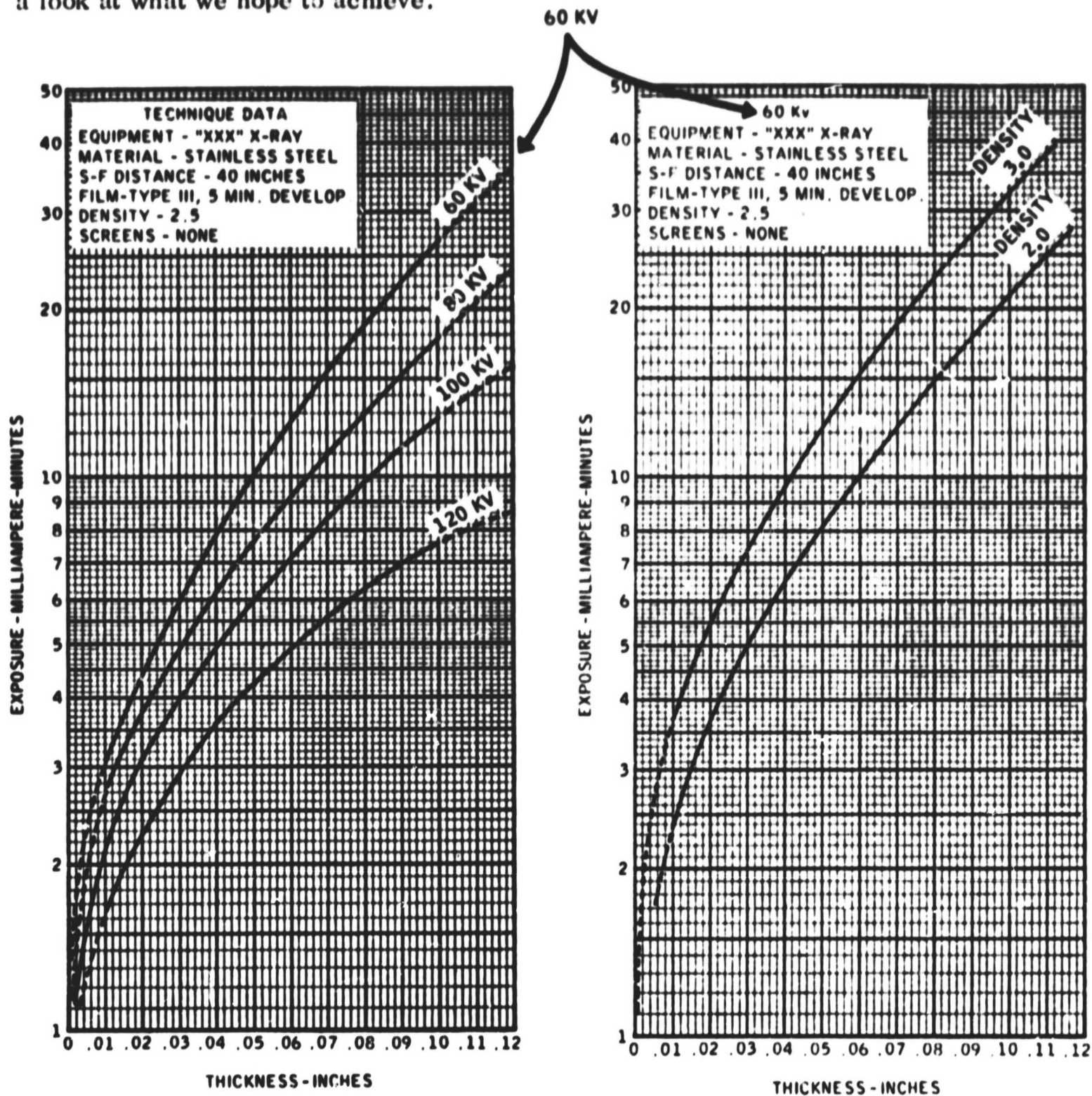
60 Kv			
STEEL THICKNESS	(2.5) EXPOSURE	(3.0) EXPOSURE	(2.0) EXPOSURE
.01	3.0	3.5	
.04	7.9	9.4	
.06	12.7	15.0	
.10	27.0	31.9	

The factor 1.18 is used to compute all of the exposures shown in the 3.0 column.

True Page 6-31

False Page 6-32

Very well. Perhaps it will help you understand what we are trying to do if we take a look at what we hope to achieve.



On the left we show our 2.5 density exposure chart. On the right we show the latitude analysis chart. We are interested right now in pointing out the differences between the 60 kv curves on each chart. The latitude analysis chart is very similar to the exposure chart. The difference is that instead of showing curves for several different voltages at one density we are showing curves for two different densities at one voltage. Turn to the next page.

All that we are doing is converting the single 60 kv curve to two curves. Instead of a single density, we are showing two densities. Any point between the two curves will be between the maximum allowable density of 3.0 and the minimum allowable density of 2.0. Any point that is not between the two curves will not be within the acceptable density range.

To convert the single 2.5 density curve to a 3.0 curve we determine the change in log relative exposure that is required to go from a 2.5 density to a 3.0 density. If you will recall from an earlier chapter, this is accomplished by use of the film characteristic (H & D) curves. Refer back to page 4-63 if you feel you need to review the procedure. Then return to this page.

We also convert the 2.5 density curve to a 2.0 density curve in the same manner. This is all that we are trying to do at this point.

Turn back to page 6-28 and continue.

Right. We multiply all of the exposures in the 2.5 column by the factor 1.18 to obtain the exposures listed in the 3.0 column.

We next compute the data to fill the 2.0 exposure column by dividing the 2.5 exposure figure by 1.26 ($3.0 \div 1.26 = 2.4$). In this manner we compute the values to completely fill out the 2.0 exposure column.

60 Kv			
STEEL THICKNESS	(2.5) EXPOSURE	(3.0) EXPOSURE	(2.0) EXPOSURE
.01	3.0	3.5	2.4
.04	7.9	9.4	6.3
.06	12.7	15.0	10.1
.10	27.0	31.9	21.4

In this step we divided by the factor 1.26 because we knew that the exposure should be _____.

increased Page 6-33

decreased Page 6-34

Sorry - the statement is true. But let's see if we can explain why the factor 1.18 is used to compute all the 3.0 exposures.

If you will recall from an earlier chapter, for any specific film the film density of the radiograph is dependent only on the relative exposure. In order to obtain a film density of 3.0 we must have a specific amount of radiation at the film. This specific amount of radiation will always result in a 3.0 density. It is also true that to obtain a 2.5 density a specific amount of radiation is required and that amount of radiation at the film will always give a 2.5 density. Thus the exposure required to obtain a 3.0 density and the exposure required to obtain a 2.5 density are directly related to each other, and this relationship has a constant value. It never changes. For Type III film, the amount of radiation required to give a 3.0 density is always 1.18 times the amount of radiation required to give a 2.5 density.

Turn to page 6-31.

No. The exposure should be decreased. This is an important point because it is the only way you can determine whether to divide by the factor or multiply by the factor.

Since we started with a 2.5 density and want a 2.0 density, we are decreasing the density. To get less density, we need less exposure. Therefore, we divide the exposure that gave us a 2.5 density by the factor 1.26 to get the exposure that results in a 2.0 density.

Turn to page 6-34.

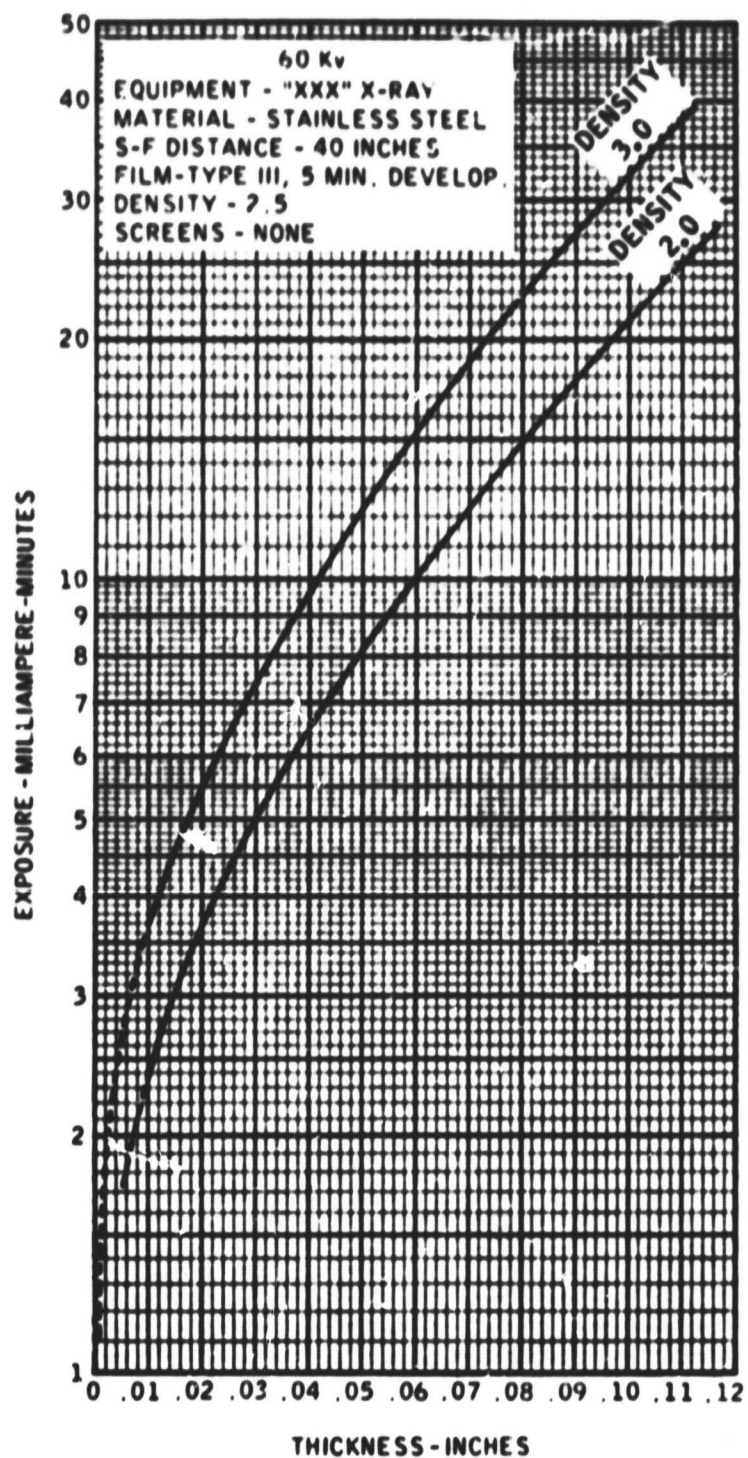
Very good. We decreased the film density from 2.5 to 2.0 by decreasing the exposure.

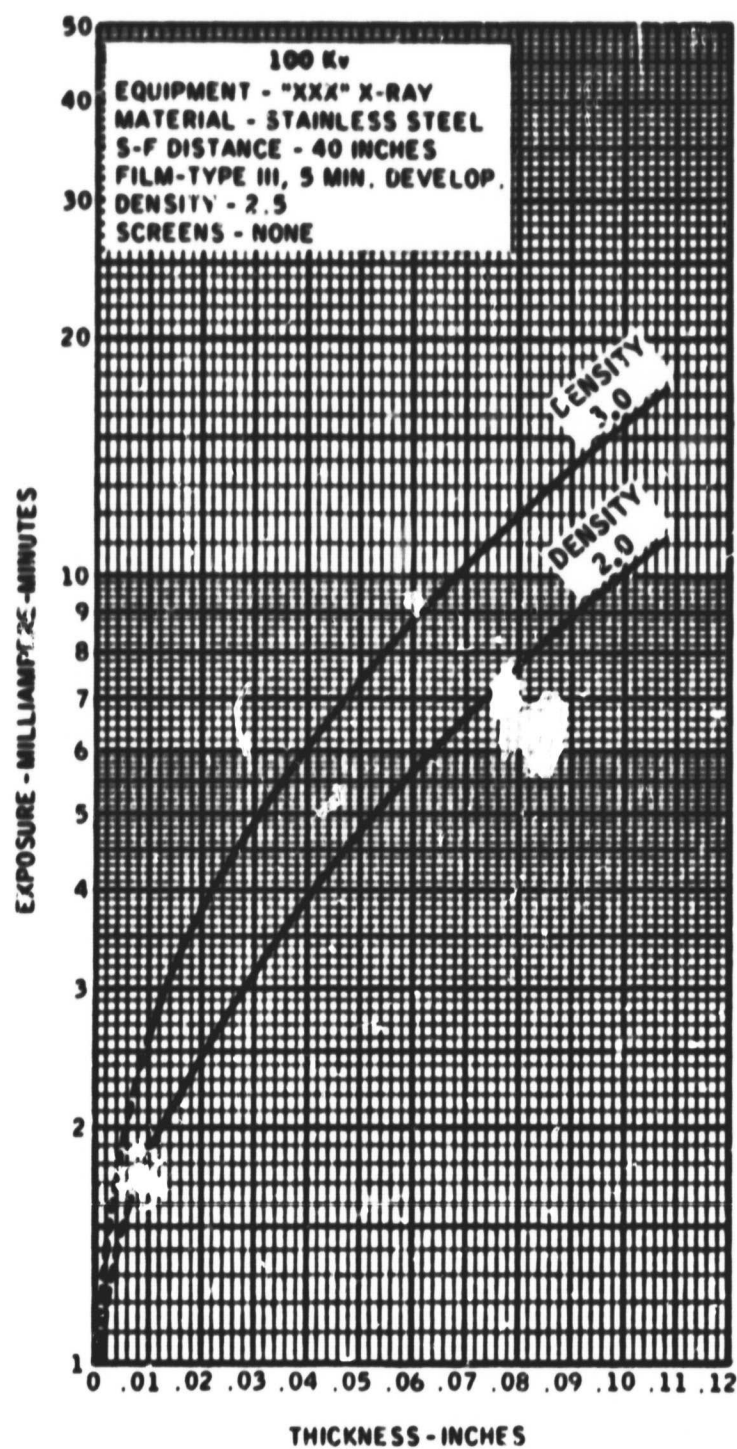
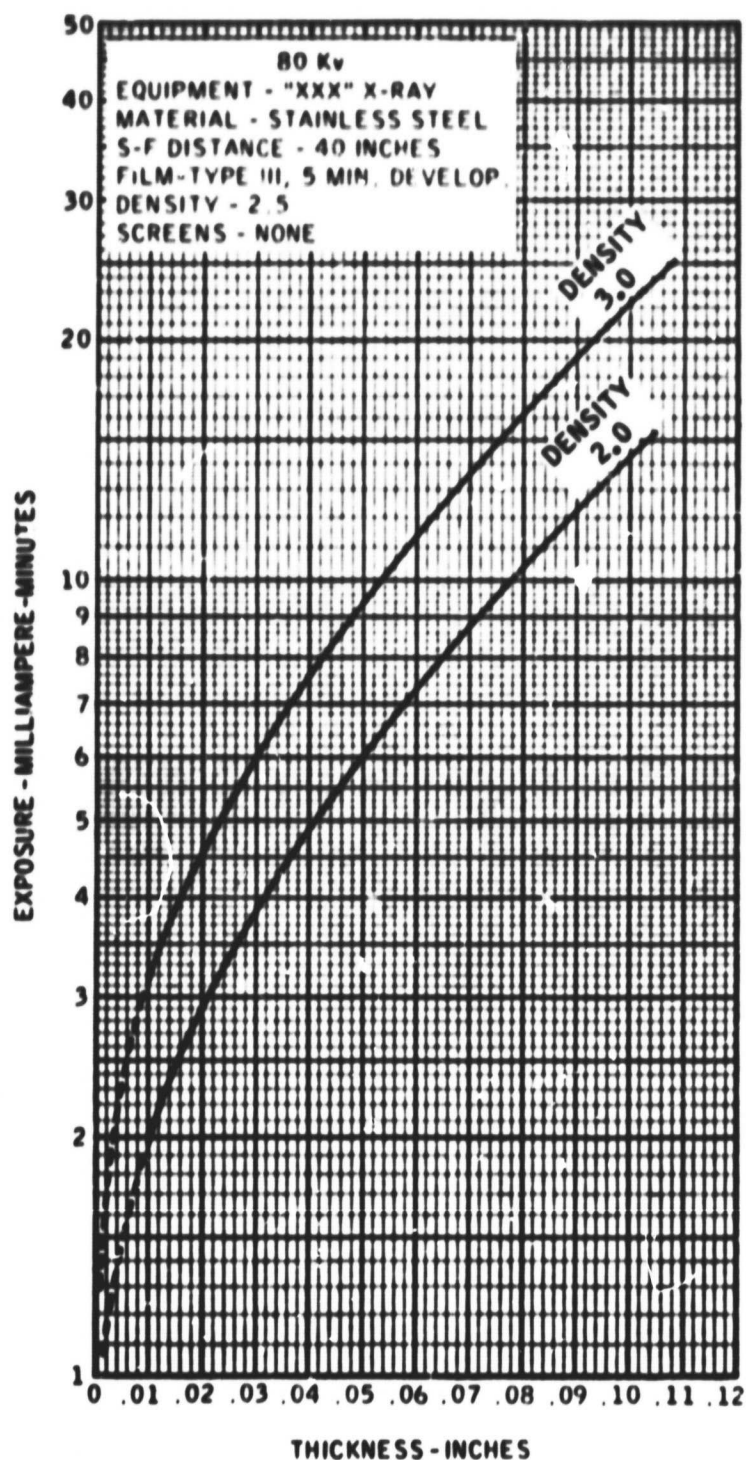
We have shown you how to construct the exposure table for 60 kv. The next step is to plot the data from the table on semilog graph paper in the same way we plotted the exposure charts. The 60 kv curves are shown below.

Note that there are separate curves for 3.0 density and 2.0 density.

This completes the latitude analysis for the 60 kv exposures. We can make the latitude analysis for the 80, 100, and 120 kv exposures in the same manner. The results are shown on pages 6-35 and 6-36.

Turn to page 6-35.





Here we can compare the latitude analysis of the 80 kv exposure with the latitude analysis of the 100 kv exposure. Note the similarity of the curves and how they are displaced from each other.

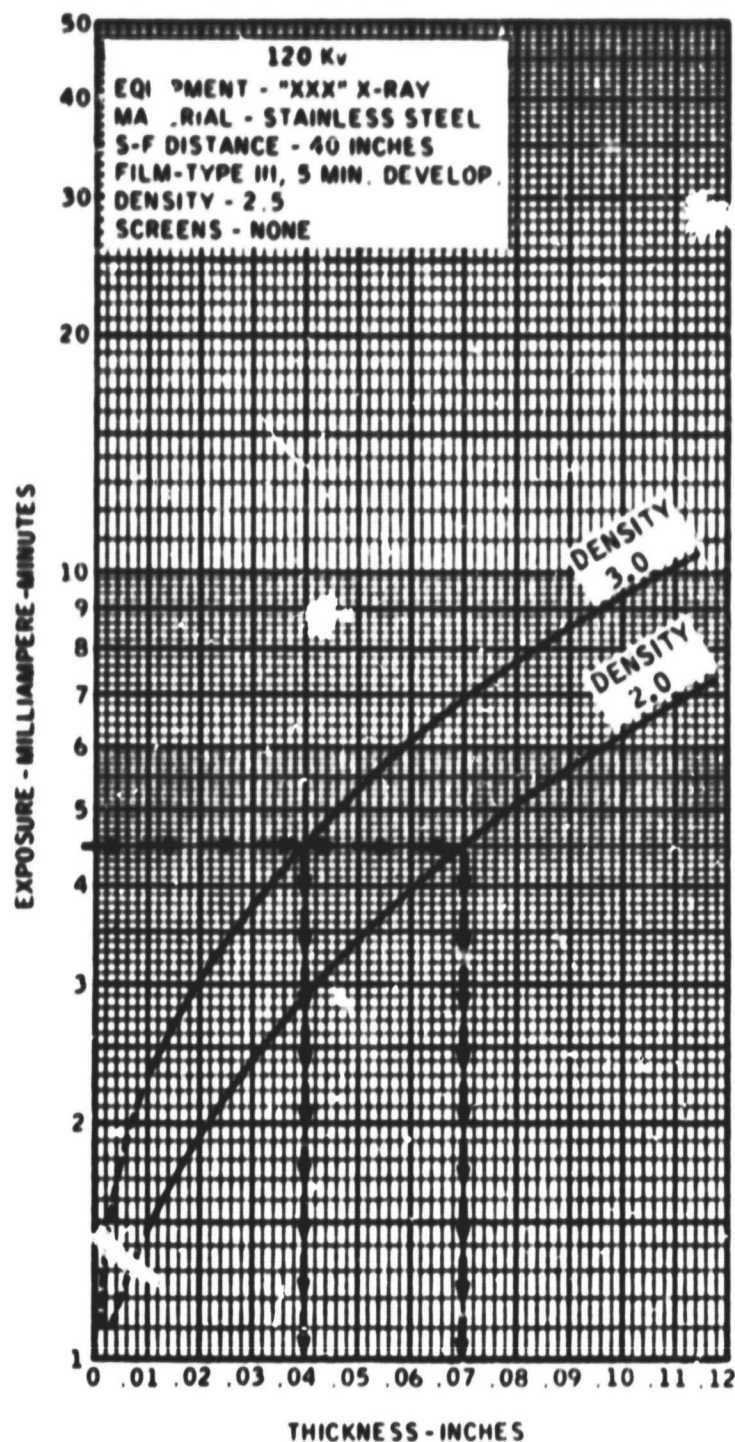
Turn to page 6-36.

The 120 kv curves shown here completes the analysis phase. Remember that the curves represent the extremes of allowable film density. Therefore, any point between the two curves will be of acceptable density and the horizontal distance between the two curves is an indication of the greatest change in specimen section that can be radiographed with any given voltage and exposure.

For example (see the dotted lines on the chart) with an exposure of 4.5 ma-min at 120 kv we can radiograph a specimen that varies in thickness from .04 inches to .07 inches and know that the film densities will not be outside the established limits.

Now you try one. Decide on your answer and then turn to the next page to see if you are correct. Approximate thickness will be close enough.

What are the thickness limits of stainless steel that we can radiograph using a 6.2 ma-min exposure at 120 kv assuming all other exposure factors are as specified on the chart?



The correct answer is .06 inches to .10 inches. If you did not get the correct answer turn back to page 6-36 and study the example again.

Now let's take a look at a more practical problem. Suppose that we expect to radiograph a part whose thickness dimensions vary between a maximum of .1 inch and a minimum of .065 inches. The maximum allowable density is 3.0 and the minimum allowable density is 2.0. Can we get one radiograph that will satisfy all of the requirements?

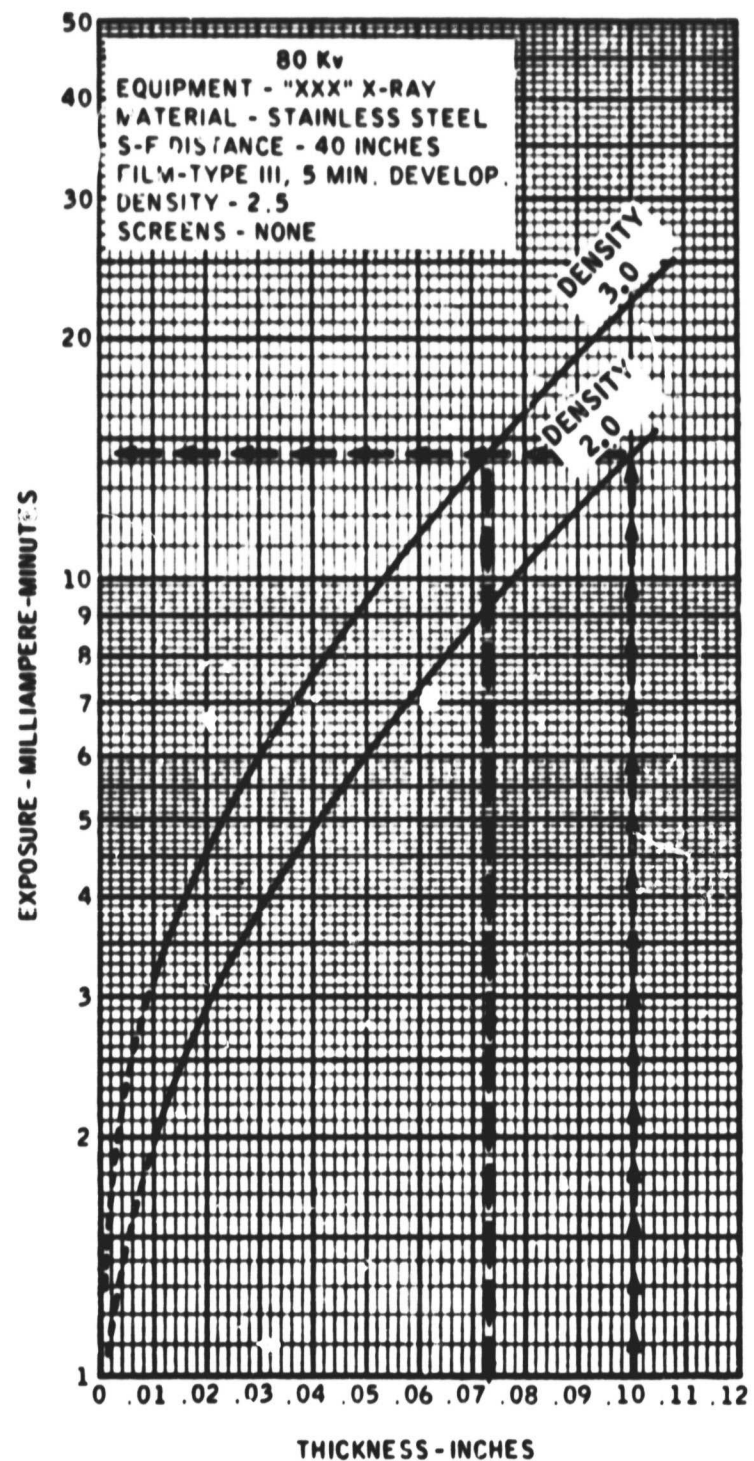
Let's look first at the 80 kv curves. On the horizontal axis we locate the maximum thickness (.10 inch) then move vertically up the chart to the point of intersection with the 2.0 density curve. The horizontal line from that point establishes the exposure. Of interest to us at this time is the point of intersection of the exposure line and the 3.0 density curve. A vertical line from this point to the horizontal axis establishes the minimum specimen thickness that can be radiographed and still maintain a 3.0, or less, density.

In your opinion can we radiograph our .065 to .10-inch specimen with

80 kv and get a radiograph that is within acceptable density limits of 3.0 and 2.0?

Yes Page 6-38

No Page 6-39

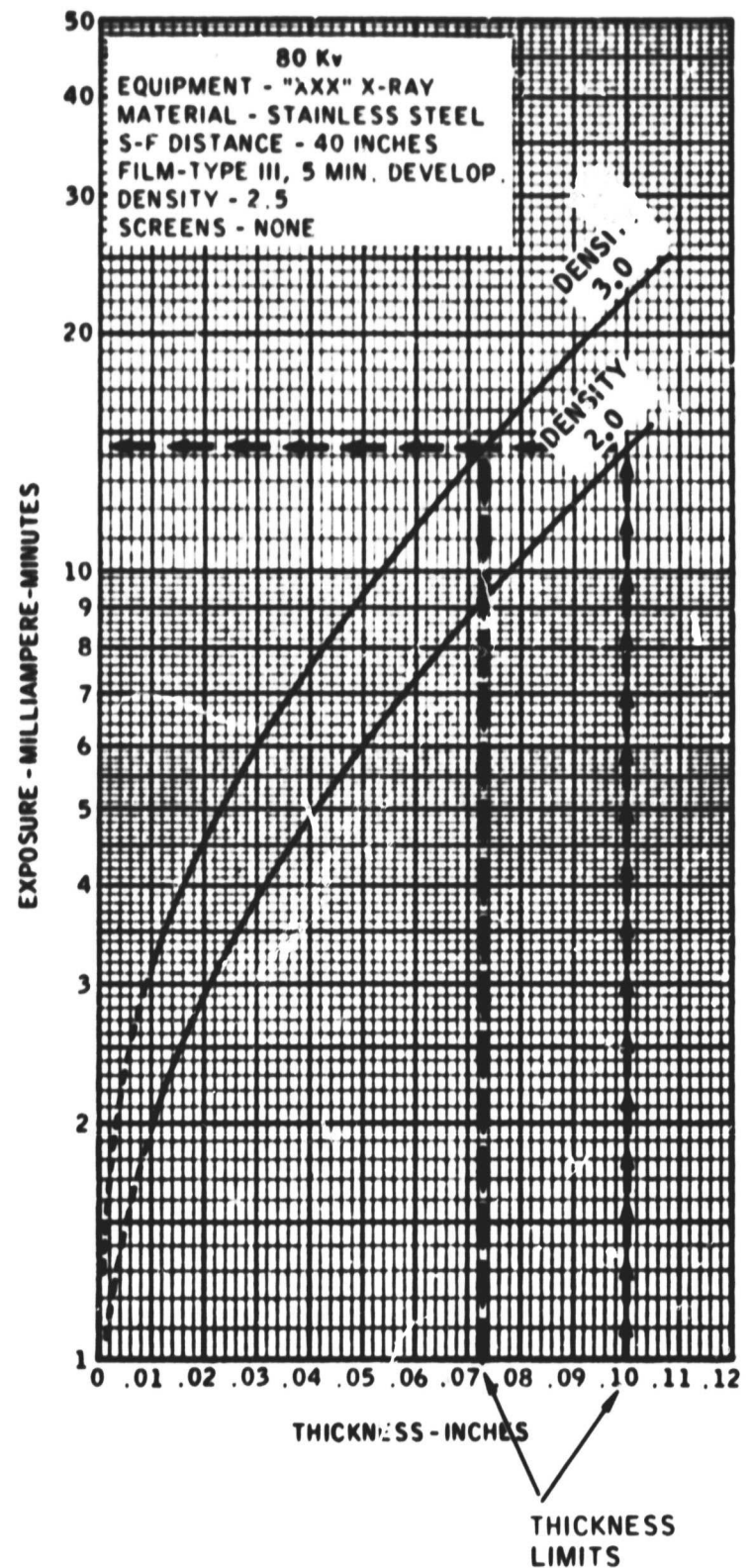


Sorry - you cannot radiograph that particular specimen with 80 kv and have the film density of the radiograph within the acceptable limits.

Let's look at that 80 kv chart again.

Note where the two vertical dashed lines intersect the horizontal scale. These two points establish the maximum and minimum thickness that can be radiographed with the exposure identified by the horizontal dashed line. The maximum thickness is .10 inch but the minimum thickness is .073 inches. Our problem required a minimum thickness of .065 inches.

Turn to page 6-39.



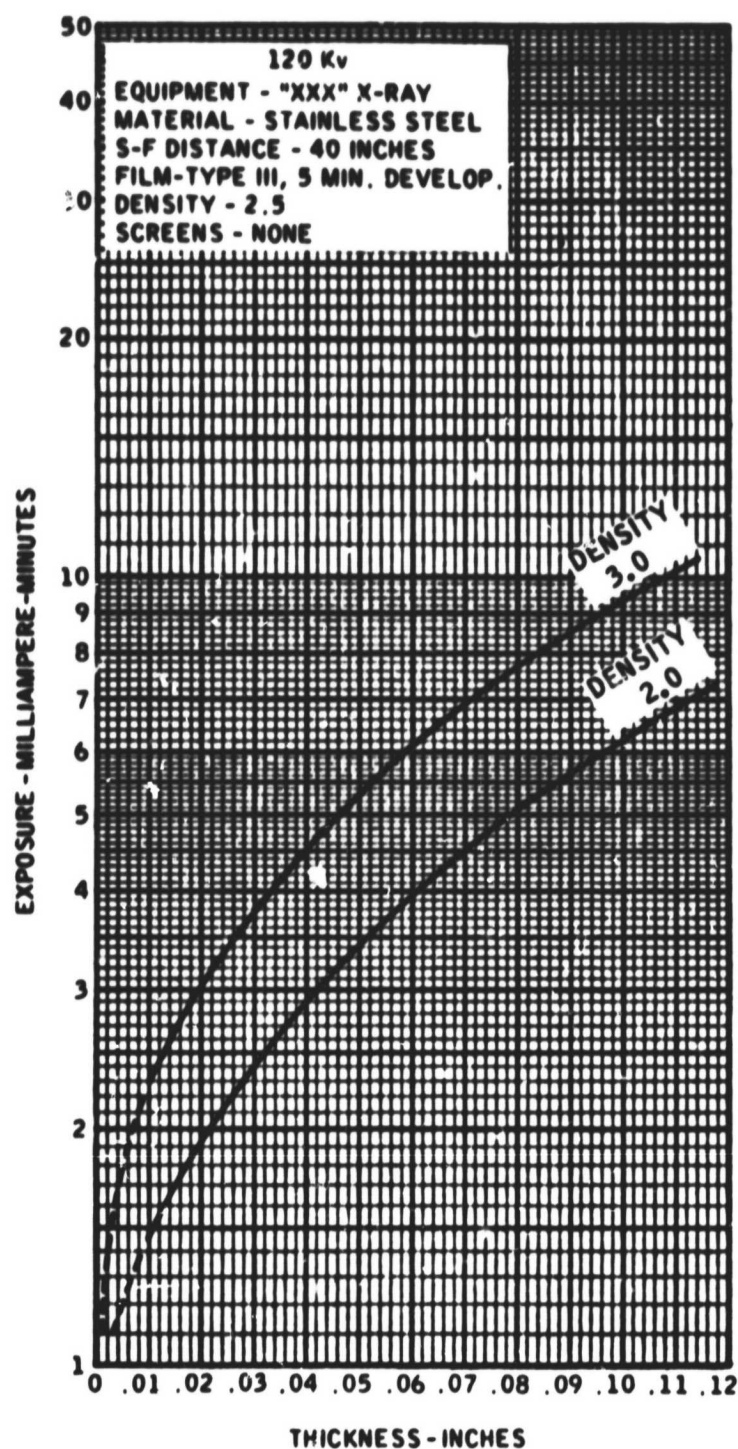
Right - we cannot radiograph this specimen with 80 kv and get a radiograph with acceptable density limits.

Now let's apply the 120 kv chart to the same problem.

Our specimen measured .065 to .10 inches in thickness. Will a radiograph made at 120 kv be within the acceptable density limits?

Yes Page 6-40

No Page 6-41



Excellent. We have discovered that a specimen we cannot successfully radiograph at 80 kv can be radiographed at 120 kv.

Note that the thickness range at 80 kv was from .072 to .10 inches. The thickness range at 120 kv was from .062 to .10 inches. Once again we have demonstrated that increasing the kilovoltage increases the latitude of the radiograph.

We have shown you only a sampling of the complete step wedge analysis and latitude analysis. A similar analysis should be made for all available films under different exposure conditions.

It is apparent from the latitude analysis that it is not always possible to satisfactorily radiograph a specimen of widely varying thicknesses with one exposure. One way to overcome this problem is to make two or more shots of the same specimen.

When making more than one exposure because of varying thicknesses of the specimen it is important that the exposure remain exactly the same for each shot.

True Page 6-42

False Page 6-43

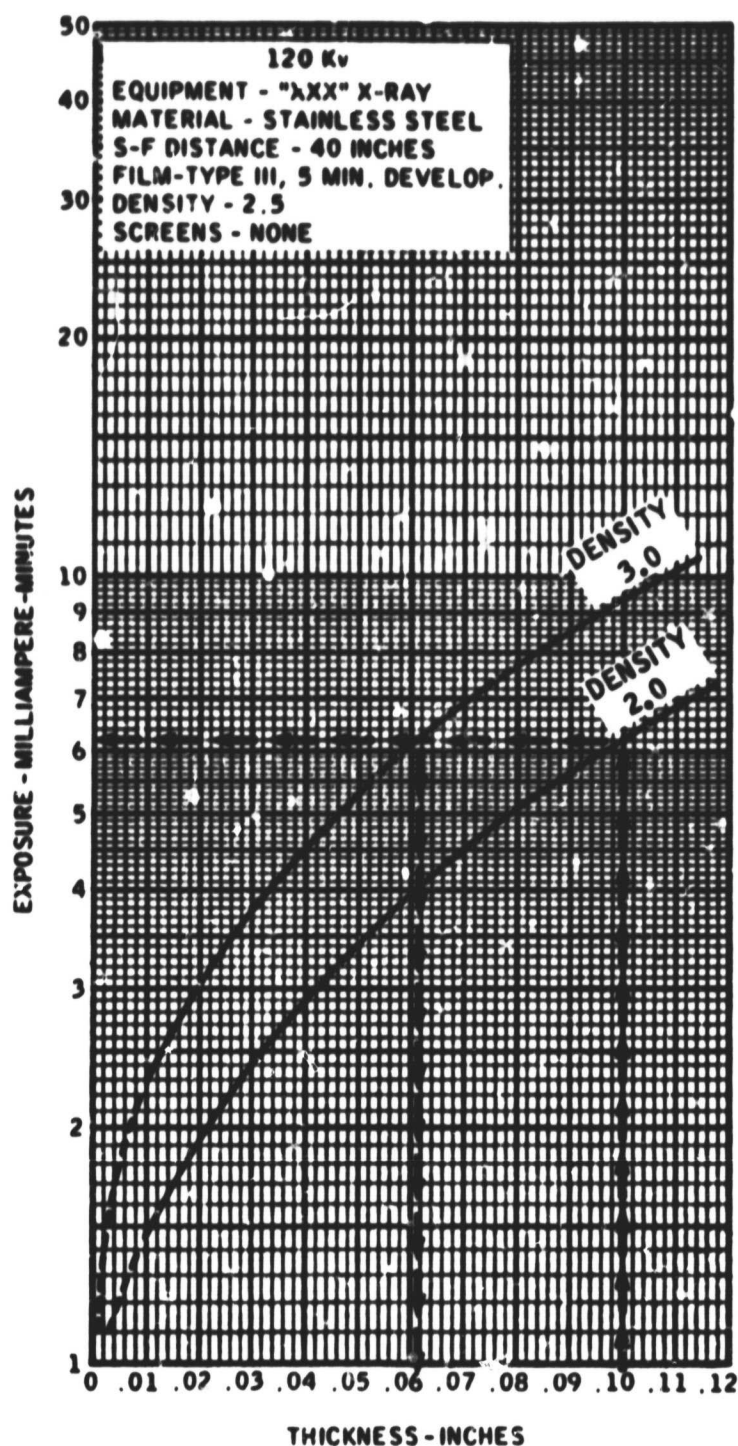


The specimen can be radiographed at 120 kv within acceptable film density limits. Let's see how we can arrive at this answer.

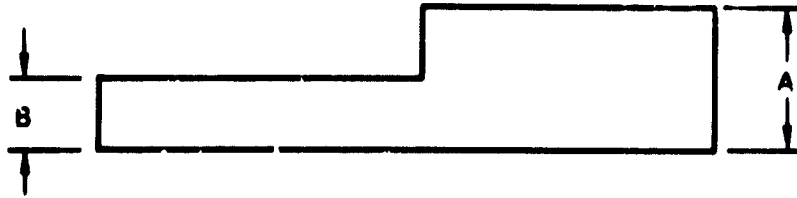
We enter the chart at .10 inches on the horizontal scale. From this point we draw a line vertically to the intersection of the 2.0 density curve. We then draw a line horizontally to the vertical axis. This establishes the proper exposure. From the point of intersection of the horizontal exposure line and the 3.0 density curve, we drop a line vertically to the horizontal axis. This vertical line meets the axis at .062 inches and establishes the minimum thickness.

Since the minimum thickness stated in our problem (.065 inches) is greater than the minimum thickness established by the chart (.062), we know that we can radiograph this specimen with 120 kv and still be within acceptable density limits.

Turn to page 6-40.



The statement is false. Let's take a look at a sample specimen to see why the statement is false.



We have determined that it is impossible to radiograph this specimen with one exposure and obtain a radiograph that is within acceptable film density limits, so we decide to make two separate radiographs.

For the first radiograph we will select an exposure that will be satisfactory for thickness A. For the second radiograph we will select an exposure that will be satisfactory for thickness B. Because of the difference in thicknesses, the two exposures must be different.

Turn to page 6-43.

Right! Since the thicknesses are different they require different exposures.

There is a way to produce satisfactory radiographs of this specimen with only one exposure.

"Two-Film" technique. The two-film technique is the process of loading two, or more, films in the same cassette. The presence of one film has very little radiographic effect on the others and all the films in the cassette will be exposed at the same time.

Satisfactory radiographs of varied thickness specimens can be obtained by loading the cassette with two films of different speeds. The faster film provides an acceptable image of the thicker areas while the slower film provides an acceptable image of the thinner areas. The choice of films to use is determined by means of data presented in the step wedge analysis and the latitude analysis.

When viewing radiographs made by the two-film method you can expect -
all areas of the specimen to be adequately shown

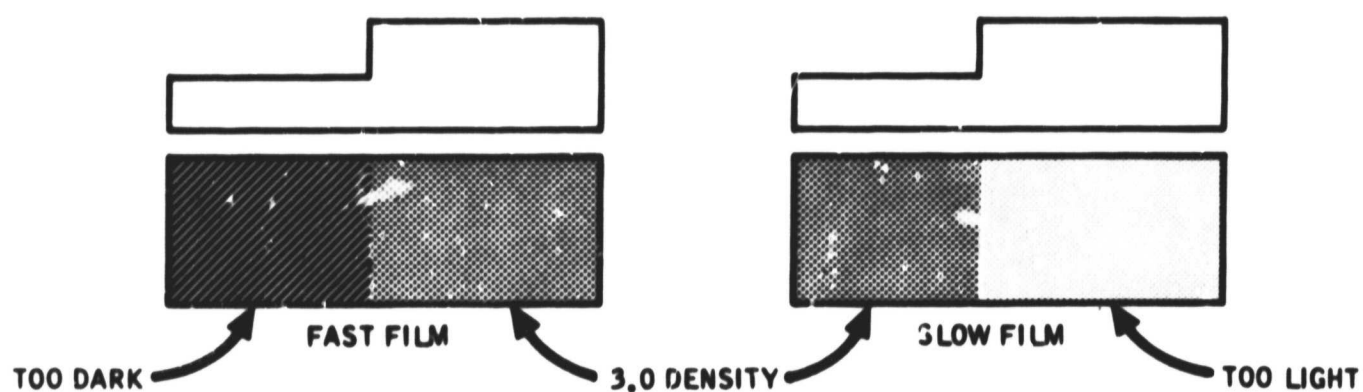
on either radiograph Page 6-44

thicker areas of the specimen to be adequately shown on one radiograph and thinner
areas of the specimen to be adequately shown

on the other radiograph Page 6-45

You will be disappointed if you expect that either radiograph will show images of all areas of the specimen within acceptable limits. Let's see why.

In selecting the film to use in our two-film process, we selected a fast film to provide an acceptable image of the thicker section of the specimen with a particular exposure. By "acceptable image" we mean one that does not exceed our acceptable density range. The image of the thinner sections of the specimen will be overexposed beyond acceptable limits with the fast film.



We selected a slow film to provide an acceptable image of the thinner section of the specimen with the same exposure. The image of the thicker section of the specimen will be underexposed on the slower film.

Then too, remember that if we could get acceptable images of all thicknesses of the specimen on one radiograph there would be no need for using the two-film method.

The two-film method results in two radiographs. One will show the thicker areas of the specimen within acceptable density ranges and the other will show the thinner sections within acceptable density limits.

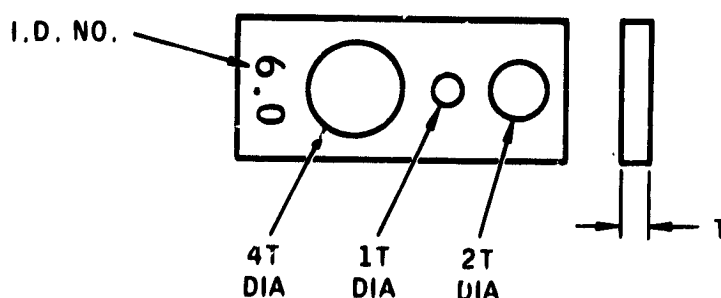
Turn to page 6-45.

Right. The thicker sections of the specimen are viewed on one radiograph and the thinner sections are viewed on the other radiograph.

We have covered a lot of basic groundwork on the theory of radiography. We have covered very thoroughly the nature of radiation and how it is used in making a radiograph, but we still haven't answered the question "How do we determine that we have a good radiograph?" How do we know that the radiograph will show any discontinuities if they are present?

Penetrameters. The answer is a very practical one. We add to the specimen a known discontinuity. Then if this discontinuity appears in the radiograph we know that any discontinuity that is at least as large as the added discontinuity will also appear on the radiograph. The added discontinuity is called a penetrameter (often referred to as a "penny").

There are several different kinds of penetrameters that are used in special cases but the theory is the same for all and you will be able to recognize their usefulness if we describe the standard penetrameter.



The standard penetrameter is a rectangle of metal of a specified thickness with three holes of set diameter drilled through it. It is identified (I. D. No.) by raised lead numbers which indicate the minimum thickness of material in inches for which the penetrameter is normally used.

The penetrameter shown above is normally used on material _____ .
 with an inside diameter of six inches Page 6-46
 with a thickness of six inches Page 6-47

I.D. means "identification" not "inside diameter" in this case.

The identification, or I.D. number tells us the minimum thickness of the material on which the penetrometer is normally used. Thus a penetrometer with an I.D. No. of 1.0 will be used with 1-inch thick material; I.D. No. 2.5 is used with 2.5-inch thick material; etc.

The penetrometer we showed had an I.D. No. of 6.0; therefore it is normally used on material with a thickness of six inches.

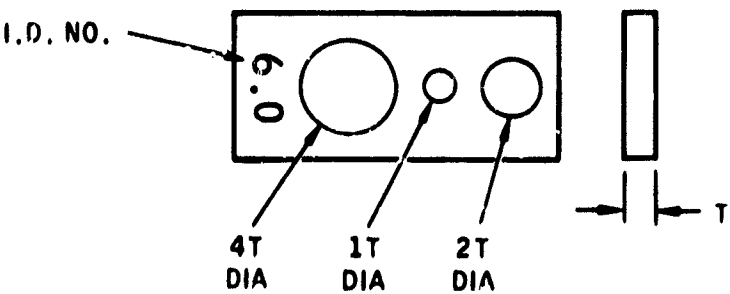
Turn to page 6-47 and continue.

Right. The 6.0 penetrameter is used with 6-inch thick material.

The penetrameter I. D. number for materials over 1 inch in thickness is simply the thickness of the material in inches as we have just shown you. However, below 1 inch another method of identification is used. This method is shown in the table below:

<u>I. D. number</u>	<u>Material thickness</u>
25	0.250 inches (1/4")
37	0.375 inches (3/8")
50	0.500 inches (1/2")
62	0.625 inches (5/8")
75	0.750 inches (3/4")
87	0.875 inches (7/8")

The thickness of the penetrameter is also significant.

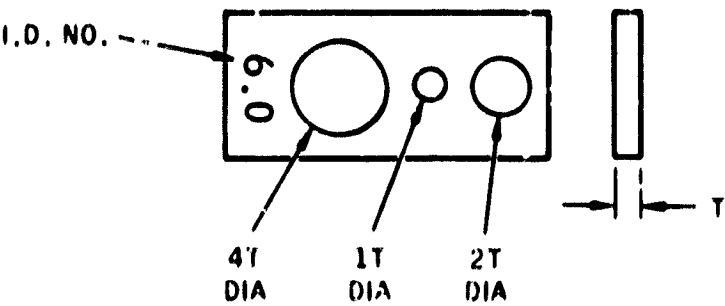


The thickness (T) of the standard penetrameter is 2% of the thickness for which the penetrameter is used. (In this case 2% of 6 inches is 0.12 inches; the penetrameter in our example should be 0.12 inches thick.)

The thickness of the standard 1.0 penetrameter is

- 0.02 inches Page 6-48
- 0.12 inches Page 6-49

Good thinking. .02 x 1.0 0.02 inches.



The size of the three holes drilled through the penetrameter are based on the thickness of the penetrameter. The diameter of each hole is a multiple of the penetrameter thickness as shown on the drawing above.

The "2T" hole has a diameter that is _____

2 tenths of an inch Page 6-50

twice the thickness of the penetrameter Page 6-51

You are confusing the thickness of the standard 1.0 penetrameter with the thickness of our example which was a 6.0 penetrameter.

We can compute the thickness of the standard 1.0 penetrameter as follows:

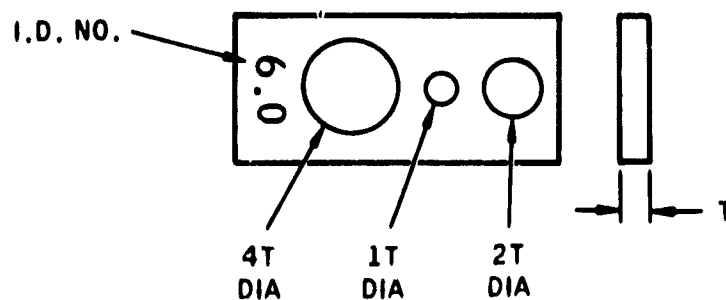
2% of 1.0 = 0.02 inches;

or $.02 \times 1.0 = 0.02$ inches

Turn to page 6-48.

Two-tenths of an inch is a good guess but it is not the correct answer.

In the standard penetrometer the thickness of the penetrometer determines the diameter of the holes.



The "1T" hole has a diameter that is equal to the thickness of the penetrometer; the "2T" hole has a diameter that is equal to twice the thickness of the penetrometer; and the "4T" hole has a diameter that is equal to 4 times the thickness of the penetrometer.

Turn to page 6-51.

Right. The "2T" hole has a diameter that is twice the thickness of the penetrameter.

But, as usual, there are exceptions to the rule. In the following table we have listed the hole sizes for penetrameters 50 and thinner. Note that the hole sizes for these penetrameters do not follow the rule.

I.D. NO.	T	1T HOLE DIA	2T HOLE DIA	4T HOLE DIA
50	.010	.010	.020	.040
37	.005	.010	.020	.040
25	.005	.010	.020	.040

This is a practical approach. In the present state of the art (except for special applications) a .010-inch hole is an acceptable limit.

In a 25 penetrameter the 1T hole has a diameter of _____ inches and the thickness is .005 inches.

.005	Page 6-52
.010	Page 6-53

You are confused. Let's see if we can straighten this out for you.

I.D. NO.	T	1T HOLE DIA	2T HOLE DIA	4T HOLE DIA
50	.010	.010	.020	.040
37	.008	.010	.020	.040
25	.005	.010	.020	.040

In the penetrameters for material thinner than 1/2 inch the hole sizes no longer follow the rules. All penetrameters thinner than the 50 penetrameter have holes of the same size. However, the thickness of the penetrameter still follows the rule. Therefore the 25 penetrameter has a thickness that is 2% of 1/4 inch or .005 inches ($.02 \times .25 = .005$) while the 1T hole is actually .010 inches in diameter. See chart above.

Turn to page 6-53.

Right. The thickness of the 25 penetrometer is 2% of 1/4 inch or .005 inches, and the diameter of the 1T hole is .010 inches.

There is one other important fact that you must know about penetrameters. You may have already guessed - the penetrometer should be made from the same material as the specimen being radiographed. If you are radiographing steel, steel penetrameters must be used. If you are radiographing aluminum, aluminum penetrameters must be used.

Radiography of most of the common materials does not present a problem in selecting a penetrometer but there will be occasions where some special alloy is to be radiographed and penetrameters made from this alloy are not available. In such a case, a penetrometer of radiographically similar material may be used.

It is beyond the scope of this book to discuss all the factors of radiographic similarity. Let's just say that radiographic similarity will be established by specifications or directives. In short - if you are faced with this problem, get help from the experts.

In radiographing articles made from special alloys a penetrometer made from standard materials may be used if it is _____ similar to the alloy.

radiographically Page 6-54

chemically Page 6-55

You are absolutely right. The penetrameter should be radiographically similar to the alloy that we are radiographing.

Now that you know what a penetrameter is, let's take a look at its use.

As previously mentioned, the penetrameter is placed on the specimen to add a known discontinuity to the specimen. In the analysis of the radiograph the image of the penetrameter serves as a check on the contrast of the radiograph while the outline of the holes serves as a check on the definition of the radiograph.

In determining that a radiograph has adequate contrast we examine _____ .

the image of the penetrameter	Page 6-56
the outline of the penetrameter	Page 6-57

You are not reading very carefully. Nowhere did we say anything about chemical similarity. A penetrometer made from standard materials may be used in the radiography of special alloys only if the standard material is radiographically similar to the alloy.

This means that the X- or gamma ray absorption rates of the two materials must be similar.

Turn to page 6-54 and continue.

Good thinking. We examine the image of the penetrameter to determine that the radiograph has adequate contrast. If the penetrameter has caused enough of a density change so that the image is visible, the contrast of the radiograph is acceptable even though the outline of the penetrameter is difficult to distinguish.

In determining that the radiograph has adequate definition we examine _____

_____ .

the outline of the penetrameter Page 6-58

the outline of the penetrameter holes Page 6-59

The outline of the penetrometer does not give an indication of adequate contrast.

There is a possibility that the outline of the penetrometer could be very indefinite yet the change in film density caused by the penetrometer is enough to show adequate contrast.

Turn to page 6-56.

It is true that the outline of the penetrameter will give an indication of the definition of the radiograph. However, it is not the best means of judging the quality of definition.

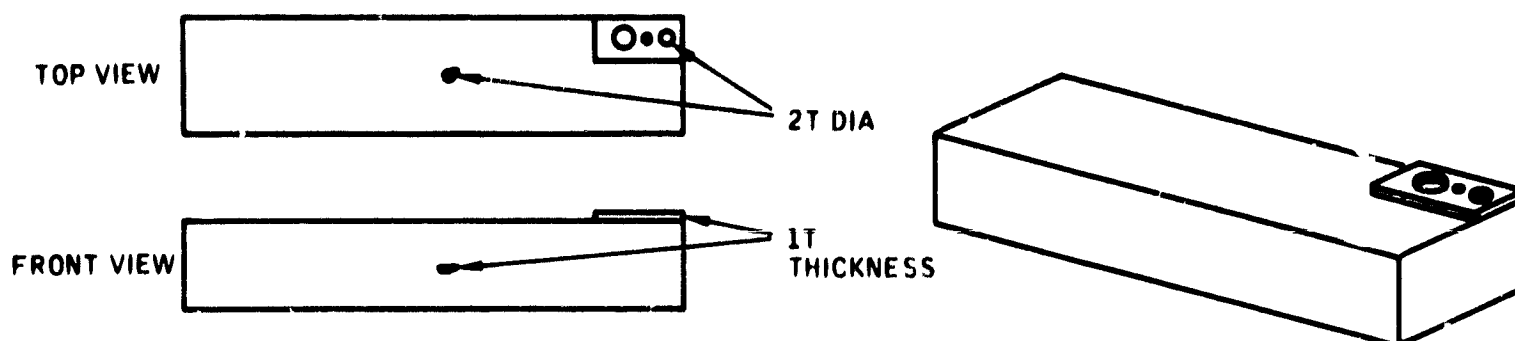
When examining the outline of the image of the penetrameter, it is difficult to measure the amount of unsharpness. The accurately drilled holes however do present a means of judging the amount of unsharpness. When the image of the "2T" hole is not visible, we know that the unsharpness measures at least the width (or diameter) of the hole.

Turn to page 6-59.

Right. We examine the outline of the penetrameter holes to determine that the radiograph has adequate definition.

Sensitivity standard. The penetrameter is added to the specimen, then, to serve as a gage by which we can be assured that the radiograph is of, or better than, a specified quality.

Suppose, for example, that specifications require that the radiograph have a sensitivity of 2%. This means that the thickness of the penetrameter must be less than 2% of the thinnest section of area of interest being radiographed. In the analysis of the radiograph the image of the penetrameter must be clearly visible and the 2T hole must also be visible. If the image of the penetrameter and the image of the hole are clearly visible you can reasonably conclude that the radiograph reveals all voids, inclusions, or cracks whose dimensions measured on a plane parallel to the film are as large as the diameter of the hole, and whose dimensions measured on a plane perpendicular to the film are as large as the thickness of the penetrameter.



From the above you can also conclude that discontinuities with thicknesses measuring less than the thickness of the penetrameter will not be revealed.

True Page 6-60

False Page 6-61

This is not a reasonable conclusion. Discontinuities measuring less than the thickness of the penetrameter may also be revealed

Remember that the penetrameter assures us that we have a particular quality level, or better.

Turn to page 6-61.

Very good. We may have better sensitivity but never less sensitivity than the penetrameter indicates.

Sometimes specifications require special quality levels other than 2%. If so, we can use the standard penetrameters to indicate different degrees of sensitivity. The following table is used to determine the proper penetrameter dimensions that are required to attain a specified sensitivity.

SENSITIVITY	PENNY T AS % OF T_m	PERCEPTIBLE HOLE DIA
0.7%	1%	1T
1.0%	1%	2T
1.4%	2%	1T
2.0%	2%	2T
2.8%	2%	4T
4.0%	4%	2T

T = THICKNESS

T_m = THICKNESS OF MATERIAL

Column 1 specifies the % of sensitivity to be achieved.

Column 2 specifies the thickness of the penetrameter as a percentage of the thickness of the specimen material.

Column 3 specifies the penetrameter hole that must be visible in the radiograph.

To attain a 2% sensitivity, the chart indicates that we use a penetrameter whose thickness is 2% of the thickness of the material being radiographed and the _____ hole must be visible in the radiograph.

- 1T Page 6-62
- 2T Page 6-63

You have misread the chart. Let's look at the chart again.

SENSITIVITY	PENNY T AS % OF T_m	PERCEPTIBLE HOLE DIA
0.7%	1%	1T
1.0%	1%	2T
1.4%	2%	1T
2.0%	2%	2T
2.8%	2%	4T
4.0%	4%	2T

T = THICKNESS T_m = THICKNESS OF MATERIAL

We wanted to determine which hole in the penetrometer would have to be visible to assure us that we had obtained a 2% sensitivity in the radiograph.

We determine this from the chart by following across the 2% sensitivity line (shown circled on the chart above).

To attain a 2% sensitivity, then, we use a penetrometer whose thickness is 2% of the thickness of the material being radiographed and the 2T hole of that penetrometer must be visible in the radiograph.

Turn to page 6-63.

Right. The 2T hole must be visible in the radiograph before we are assured of a 2% sensitivity.

SENSITIVITY	PENNY T AS % OF T _m	PERCEPTIBLE HOLE DIA
0.7%	1%	1T
1.0%	1%	2T
1.4%	2%	1T
2.0%	2%	2T
2.8%	2%	4T
4.0%	4%	2T

T = THICKNESS

T_m = THICKNESS OF MATERIAL

Now let's assume that we are going to radiograph a specimen made of 3-inch steel and we only need a sensitivity of 4%. If you will check the chart, you will find that to assure that we have attained a 4% sensitivity we must use a penetrameter whose thickness is 4% of the thickness of the material and the 2T hole must be visible.

The first step is to determine the thickness of the penny that we will use.

We will need a penetrameter that is_____.

.12 inches thick.Page 6-64

.04 inches thick.Page 6-65

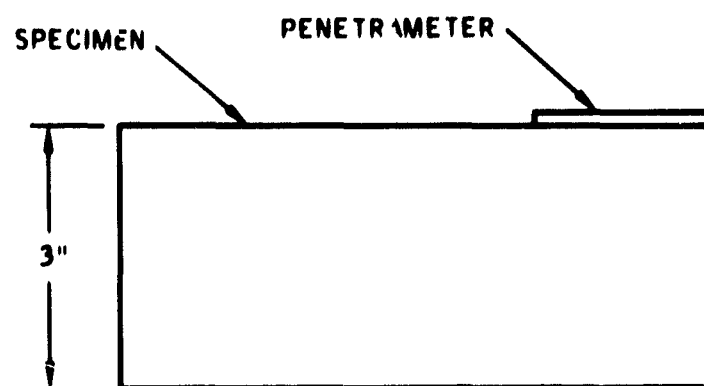
Correct. 4% of 3 inches is .12 inches.

Now the picture gets a little confusing so you must be careful. The standard penetrometer for 3-inch material (3.0 penny) will only be .06 inches thick (2% of 3 inches) and we need a penny that is .12 inches thick. Therefore we will need a penny that is twice as thick as the standard 3.0 penny.

Therefore, to assure that we have attained a 4% sensitivity when radiographing 3 inches of steel we would use a _____ penny.

- 3.0 penny Page 6-66
- 6.0 penny Page 6-67

Wrong choice. Let's see if we can clear it up for you.



The problem is to determine the thickness of the penny required to assure a 4% sensitivity. From the sensitivity table we have determined that the thickness of the penetrator should be 4% of the thickness of the specimen. Our specimen is 3 inches thick.

The rest is arithmetic:

4% of 3 inches is .12 inches

or, $.04 \times 3 = .12$

Turn to page 6-64.

It is very easy to slip up on this operation and you have slipped.

Let's look at it in a way that may be easier to understand.

Use of the standard 3.0 penny for 3-inch material will result in assurance of a 2% sensitivity. Since we want to be assured of 4% sensitivity we will use a penny that is twice as thick as the standard. We will use a 6.0 penny.

Turn to page 6-67.

Right. To assure that a 4% sensitivity has been attained when radiographing 3 inches of steel we would use a penetrameter that is twice as thick as the standard (2%) penny - in this case a 6.0 penny.

SENSITIVITY	PENNY T AS % OF T_m	PERCEPTIBLE HOLE DIA
0.7%	1%	1T
1.0%	1%	2T
1.4%	2%	1T
2.0%	2%	2T
2.8%	2%	4T
4.0%	4%	2T

T = THICKNESS

T_m = THICKNESS OF MATERIAL

We want to radiograph a 1-inch steel specimen and obtain a 1% sensitivity. What size penny should we use?

1.0 Page 6-68

50 Page 6-69

Slow down a bit. The 1.0 penetrometer will give a 2% sensitivity for the 1-inch specimen.

You must not forget that the I. D. number of the standard penetrometer identifies it in relationship to the thickness of material and 2% sensitivity.

A 1.0 penetrometer assures 2% sensitivity for 1-inch material

A 2.0 penetrometer assures 2% sensitivity for 2-inch material

A 3.0 penetrometer assures 2% sensitivity for 3-inch material

etc.

In our problem we specified a sensitivity of 1% for the 1-inch material. This indicates that we are reducing the allowable sensitivity by half. Therefore we should reduce the thickness of the standard penetrometer by half. For 1-inch material, then, we would use the .50 penetrometer to attain a sensitivity of 1%.

Turn to page 6-69.



Excellent. You seem to have the idea well in hand.

Naturally we are not always able to exactly match the penetrometer to the specimen thickness. Few specimens measure exactly 1-inch, 2-inches, 1/4 inch, or what have you.

For specimen thicknesses that are between penny sizes, we must _____
_____.

- use the next larger penny size Page 6-70
- use the next smaller penny size Page 6-71

This is not the course to take and here is why.

For any one specimen thickness, increasing the penny size decreases the proven sensitivity. The sensitivity may be in the radiograph, but it could not be proved if the next larger size penny were used.

It is best to take the next smaller penny. This would prove a sensitivity a little better than that required.

Turn to page 6-71.

Good thinking. We use the next smallest penny size so as to maintain our proof of sensitivity below 2%.

Let's suppose that you are going to radiograph an aluminum forging. This forging is 2 1/8 inches thick. You have aluminum penetrameters for 2-inch material and for 2 1/4-inch material.

To assure that you have a 2% sensitivity in the radiograph you would use the _____ penetrameter.

- 2 1/4-inch Page 6-72
- 2-inch Page 6-73

We've managed to confuse you.

A penetrometer designed to show a 2% sensitivity on 2 1/4-inch material will be thick enough and its holes large enough to show a good indication on the final radiograph. This would lead you to think you had achieved the 2% sensitivity when you may not have really achieved it.

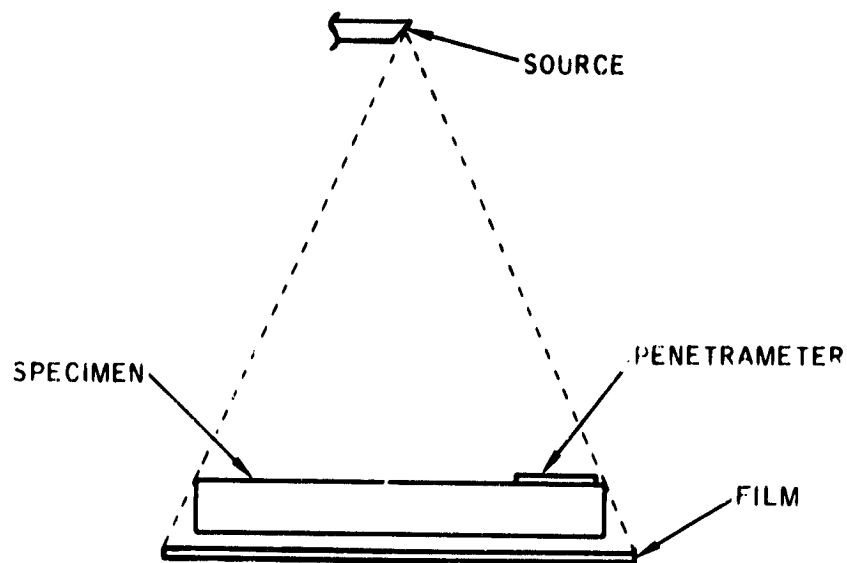
Think of it this way - the thinner the penetrometer the better the sensitivity. This is the fact that leads to the rule:

USE THE NEXT SMALLEST PENNY SIZE IF YOU DO NOT HAVE ONE OF
THE CORRECT SIZE.

Turn to page 6-73.

Right. The "2-inch" penetrameter is the next smallest and therefore is the one you should use in this situation.

Placement of penetrameters. As we stated earlier, the penetrameter is a discontinuity of known size and shape that is added to the specimen to serve as a sensitivity gage. However, the shape of the penetrameter and its holes is more regular than the defects commonly encountered and its edges are sharper making it more easily detected. To compensate for this advantage, the penetrameter is placed in the most disadvantageous position; i.e., on top of the specimen.



If the details of the penetrameter image can be seen in spite of its unfavorable location, the radiographer can be sure that his radiograph is satisfactory.

Under normal conditions the penetrameter is placed _____.

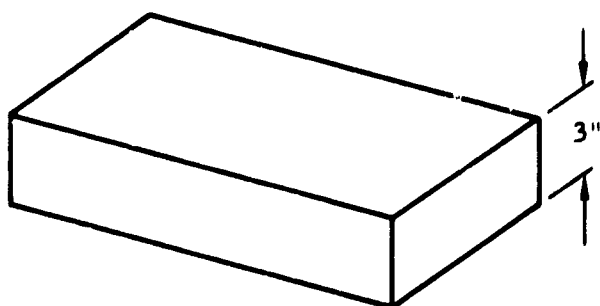
between the specimen and the source Page 6-74

between the specimen and the film Page 6-75

Right. "On top of the specimen" means that the penetrameter is placed on the source side of the specimen.

The penetrameter must not be placed over the area of interest of the specimen since it may hide discontinuities that lie under it. In some cases the entire specimen and not just a portion of it is the point of interest. The penetrameter in these cases cannot be placed on the specimen.

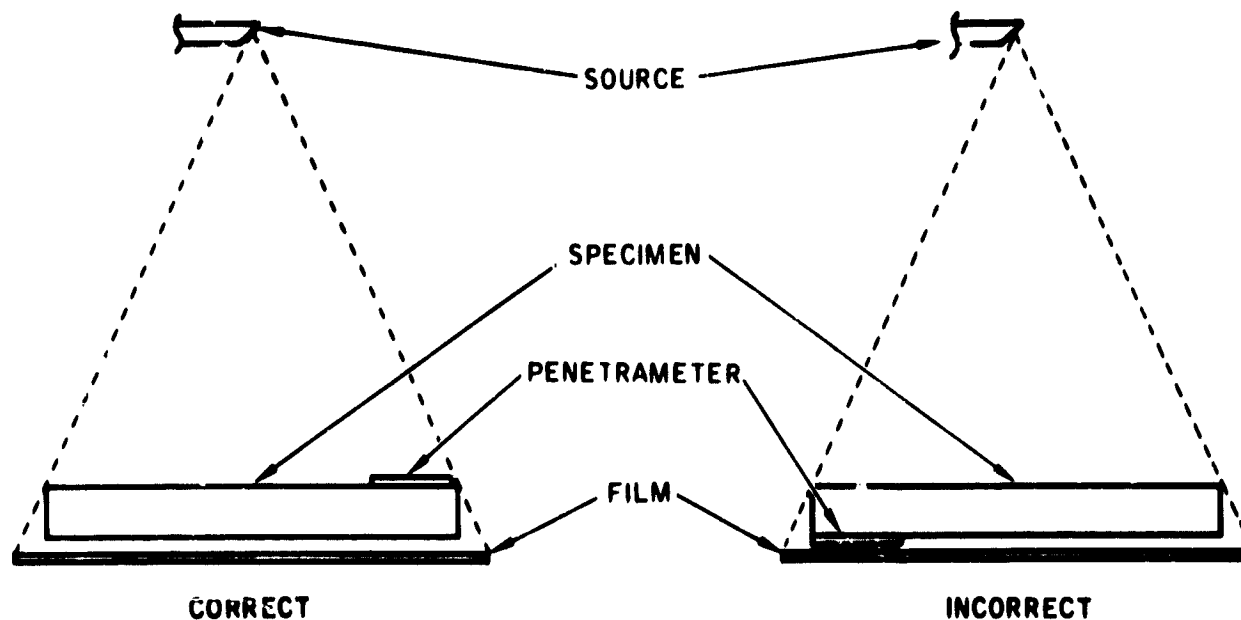
If it is impractical to place the penetrameter on the specimen it may be placed on a separate block of the same material provided the block is the same thickness as the specimen.



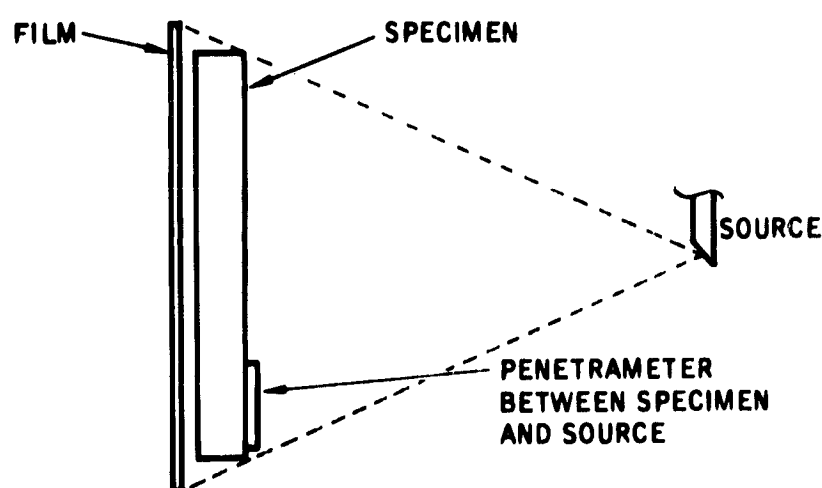
Here we show a piece of aluminum bar stock which we want to radiograph prior to some machining operations. We want to be assured that the entire bar is free of any discontinuities that would exceed 2% of its thickness. The penetrameter is to be placed on a separate block of material. The total thickness of block and penetrameter is

- 3.02 inches Page 6-76
- 3.06 inches Page 6-77

Sorry, we haven't clarified what we mean by "on top of the specimen".

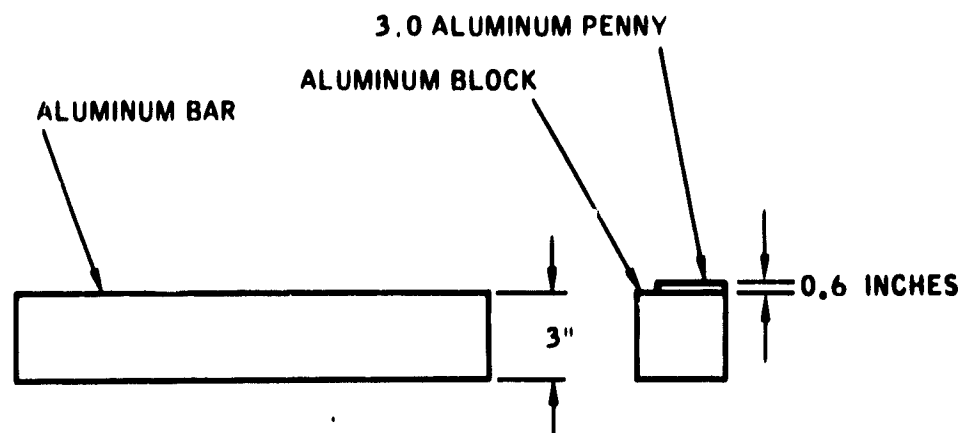


When the penetrometer is "on top" of the specimen it is placed on the source side of the specimen. Thus it is between the specimen and the source. We make this distinction because the set-up is not always in the vertical direction.



Turn to page 6-74.

Hold it. Let's look at a picture.

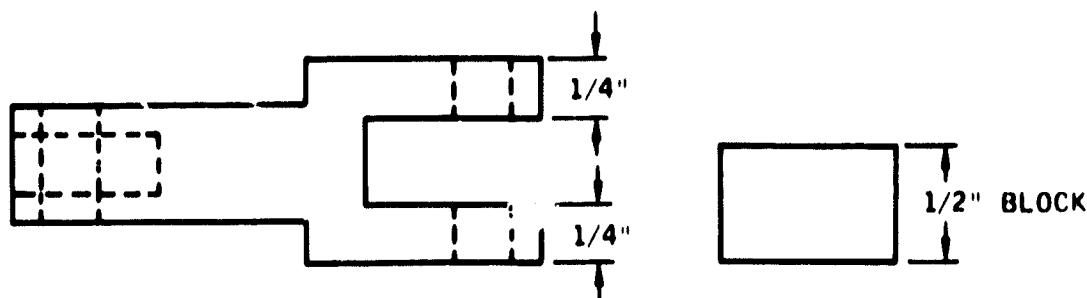


Since the aluminum block has to be the same thickness as the bar, it must be 3 inches thick. The penetrameter must be 2% of 3 inches or .06 inches thick. Therefore the total thickness of block and penny is 3.06 inches.

Turn to page 6-77.

Right. The total thickness of the block and penny is 3.06 inches.

The separate block technique is not always the best way. Some attention must be given to the geometry of the part. For example let's look at a fitting shaped like this:



A half-inch block will not have the same effect on the image of the penetrometer as the two 1/4-inch thicknesses of the fork since the specimen-to-film distance is changed.

A variation in the block technique can be used in this situation. In this variation the penetrometer is placed on another identical part to determine that proper sensitivity has been achieved.

If another identical part is not available a "two shot" method may be used. In the "two shot" method the penetrometer is placed on the part and a radiograph made to determine the sensitivity. Then the penetrometer is removed from the part and a second radiograph is made without changing any of the exposure factors.

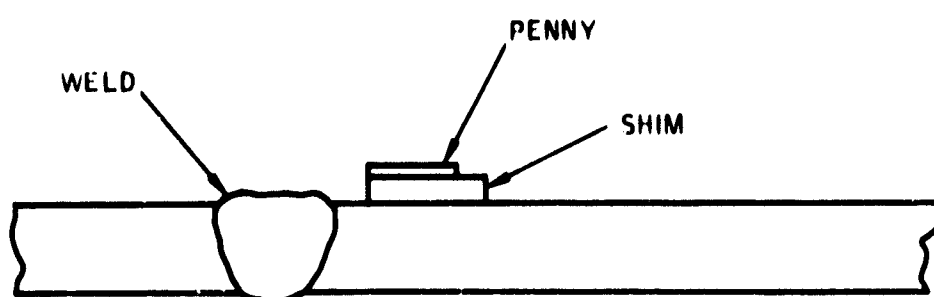
Either the "identical part" method or the "two shot" method is used when _____

it is impractical to put the penetrometer on the specimen Page 6-78

the specimen geometry is complex Page 6-79

Right! The "identical part" or "two shot" methods are only used when it is impractical to place the penetrameter on the part.

Placing a penetrameter so that it indicates what it is supposed to indicate calls for some ingenious thinking on the part of the radiographer. It is always important that the amount of material under the penetrameter is equal in thickness to the thickness of the material being radiographed.



Here we show a cross section of a weld. We are going to radiograph this weld and it is impractical to place the penetrameter on top of the weld. We can place the penetrameter on a shim whose thickness is equal to the difference in thickness between the material and the weld.

The shim is used to _____

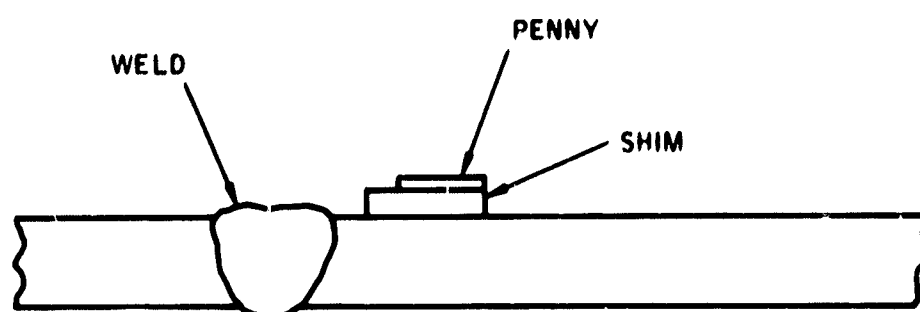
position the penetrameter so that the source-to-specimen distance of
the penetrameter is the same as that of the weld Page 6-80
obtain a thickness of material under the penetrameter equal to the
thickness of the weld Page 6-81

Sorry - complex geometry is not the reason for using the "identical part" or "two shot" methods. The part may be very complex and still the penetrameters are placed on the part. We could have put a penetrameter on that forked fitting if it didn't interfere with the area we were examining. The penetrameter should always be put on the part if it does not interfere with the area of interest.

If we are interested in seeing if any discontinuities exist in all areas of a complex specimen, then it is impractical to put the penetrameter on the specimen since it may hide discontinuities. Under this situation we can use the "identical part" or "two shot" method.

Turn to page 6-78.

That is not why the penetrameter is placed on a shim. If you look at the drawing closely you will realize that the penetrameter is actually above the weld.



The penetrameter is placed on the shim so that the material beneath the penetrameter is exactly equal to the thickness of the weld. The weld projects above and below the material being welded so the thickness of the shim is determined by subtracting the thickness of the material from the thickness of the weld.

Turn to page 6-81.

Exactly - the shim is added to provide a thickness of material under the penetrameter equal to the thickness of the weld.

When a specimen has a wide variation in thicknesses the radiographer needs to know that the image of each thickness has the proper sensitivity. This can be accomplished by placing a penetrameter on each thickness, however, usually a penetrameter placed on the thickest section and another penetrameter placed on the thinnest section will demonstrate whether or not the technique has produced the necessary latitude to provide adequate sensitivity in all sections of the specimen.

The "separate block" method cannot be used to gage the sensitivity of a radiograph of a multi-thickness specimen.

- True Page 6-82
- False Page 6-83



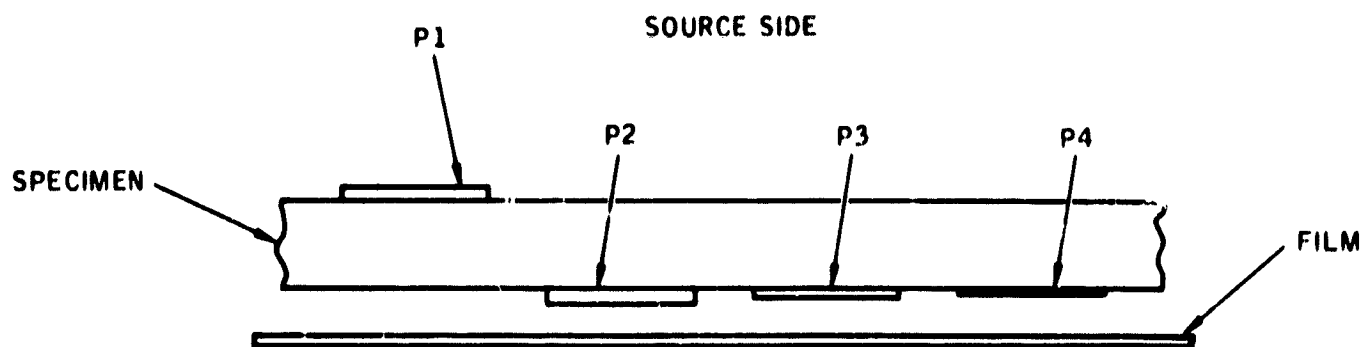
Perhaps you felt that the statement was true because one block would not cover all thicknesses of the specimen. This is true, however, there is nothing to prevent us from using more than one block in the "separate block" method. We can use one block that is equal in thickness to the thickest section of the specimen and another block that is equal in thickness to the thinnest section of the specimen. Keep in mind that the blocks should be made of the same material as the specimen.

The "identical part" or "two shot" method could also be used. The penetrometer should be placed on the specimen if possible. If it is not possible, then one of the other methods may be used.

Turn to page 6-83.

Excellent thinking. The "separate block" method can be used - one block for the thickest section; another block for the thinnest section.

There are unique cases where the penetrameter cannot be placed on the source-side of the specimen (pipes, tubing, or ducting whose inside is inaccessible for example). When this situation occurs a "film side equivalent" technique is used.



A specimen of similar size and material is obtained and the proper size penetrameter (P1) is placed on the source side. Three penetrameters (P2, P3, and P4) of varying sizes are placed on the film side. A radiograph is then taken which must show the correct quality as evidenced by the image of P1. From this radiograph we can select the penetrameter image (P2, P3, or P4) that will serve as the "film side equivalent" sensitivity of P1.

The final objective of the above procedure is to _____.

choose three penetrameters which will be the equivalent of the source

side penetrameter Page 6-84

select the correct size penetrameter to place on the film side of the

specimen Page 6-85

Somehow you don't have the picture.

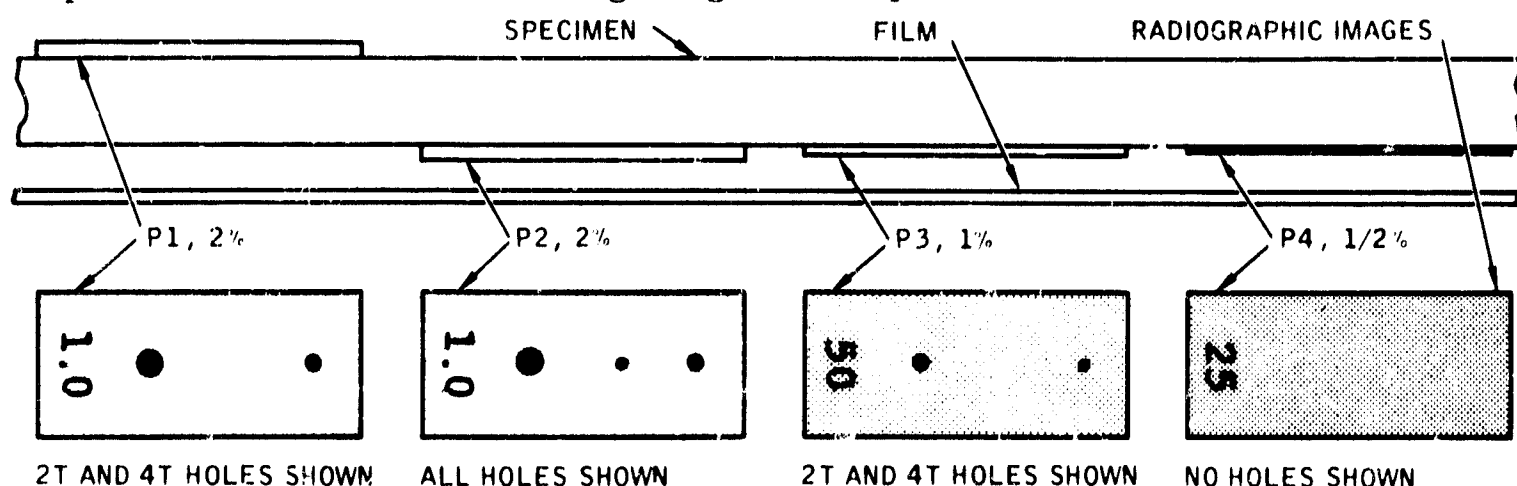
The idea behind the "source-side equivalent" procedure is to find the right size penetrometer that can be placed on the film side of the specimen and still give us the same sensitivity reading as the correct "source-side" penetrometer.

Return to page 6-83 and reread that page keeping the above idea in mind.

XXXXXXXXXX

Right. We are trying to select one penetrameter we can place on the film side of the specimen that will show the equivalent sensitivity of the penetrameter placed on the source side.

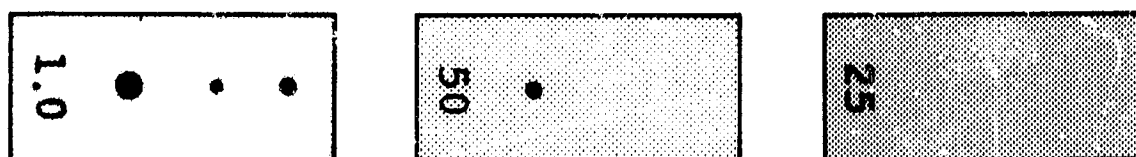
Now let's look at an example. Here we show the set-up again with values assigned to the penetrameters and the resulting images of the penetrameters.



P1 is the standard 2% penetrameter required to show 2% sensitivity. If this penetrameter does not show 2% sensitivity the exposure must be changed. P2 is identical to P1 (a penetrameter thicker than P1 is never required). P3 is half the thickness of P2. P4 is half the thickness of P3. The penetrameters are selected in this manner so that the hole sizes are in direct ratio of 2:1.

In selecting the "film side equivalent" penetrameter we look for the smallest hole shown in the thinnest penny. In this case we would select the 50 penny as our film-side penetrameter and look for the 2T hole on the radiograph as evidence of 2% sensitivity.

Let's presume for a moment that our film-side penetrameter images looked like this:



Which penetrameter would we select as our film side penny, and which hole would we look for?

1.0, 1T Page 6-86

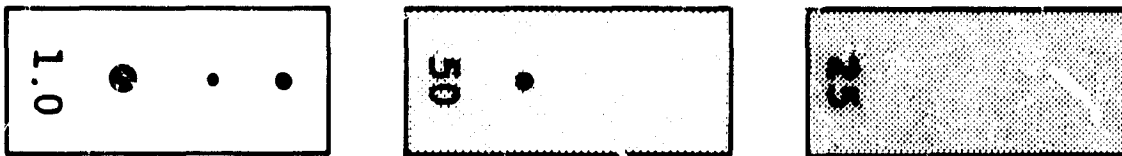
50, 4T Page 6-87

Right. The 1T hole on the 1.0 penetrameter is the smallest hole. Since no other penetrameter shows a smaller hole we would use the 1.0 penetrameter as the film-side penetrameter and look for the 1T hole.

This covers the basic procedures to be followed in the proper placement of penetrameters.

Now turn to page 6-88 for the review of this chapter.

A reasonable choice but not the correct answer. In selecting the "film side equivalent" penetrameter we first look for the smallest visible hole. The penetrameter showing the smallest hole is the one selected. When the smallest visible hole appears in two penetrameters we select the thinnest penetrameter of the two as our "film side" equivalent.

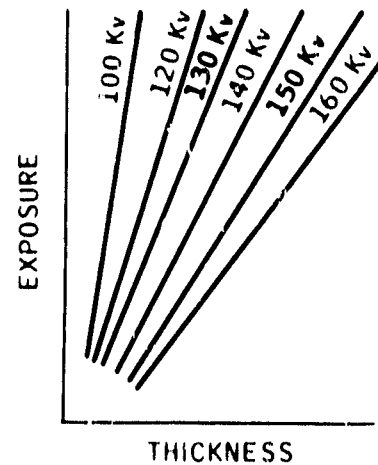


In the present case the 1.0 penetrameter shows the smallest hole. Therefore, it is selected in spite of the fact that the 50 penetrameter is thinner.

Turn to page 6-86.

From page 6-87

1. Exposure charts are used by the radiographer to determine the proper _____ that is required to radiograph a certain thickness of material at a specified voltage.

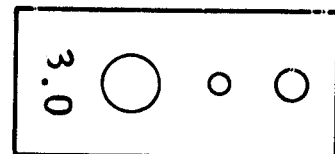


9. characteristic curves

10. The final step in the step wedge analysis procedure is to plot the data on graph paper to form an _____ chart.

18. 6

19. The thickness of this standard penetrameter is _____ inches.



27. 4.0

28. What is the I.D. No. of the standard penetrameter required to measure a 0.7% sensitivity when radiographing 2 inches of steel?

SENSITIVITY	PENNY T AS % OF T_m	PERCEPTIBLE HOLE DIA
0.7%	1%	1T
1.0%	1%	2T
1.4%	2%	1T
2.0%	2%	2T
2.8%	2%	4T
4.0%	4%	2T

T = THICKNESS

T_m = THICKNESS OF MATERIAL

1. exposure

2. The exposure chart can be prepared by means of a systematic analysis technique utilizing radiographs of an object of several distinct, known thicknesses called a

_____ .



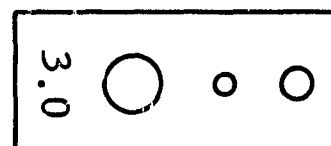
10. exposure

11. The first step in the latitude analysis is to select the maximum and minimum acceptable film _____ .



19. $.02 \times 3 = .06$

20. The diameter of the largest hole in this standard penetrameter is _____ .



28. 1.0

29. When radiographing a specimen whose thickness does not match any of the available penny sizes we use the next _____ (smaller, larger) penny size.



2. step wedge

3. In the step wedge analysis procedure several radiographs of a step wedge are made using different _____ and voltages.



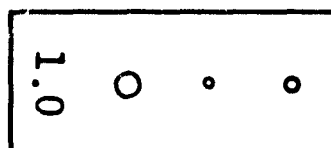
11. density

12. The data from the step wedge analysis exposure chart is converted to the _____ and _____ densities selected.



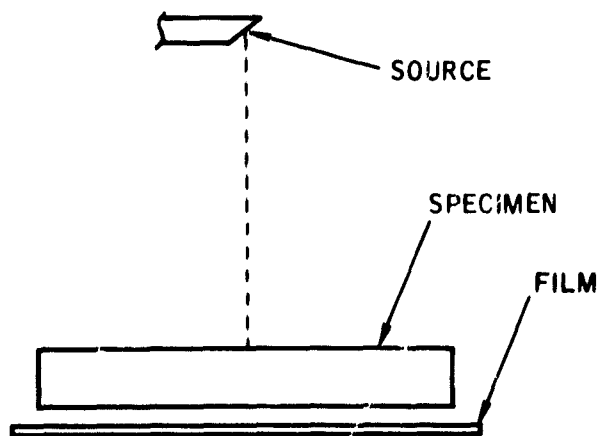
20. .24 inches
(4 x .06)

21. The diameter of the smallest hole in this standard penetrameter is _____.



29. smaller

30. Under normal conditions the penetrameter is placed on the _____ of the specimen.



3. exposures

4. In the step wedge analysis an accurate account must be kept of the _____ factors such as voltage, exposure, film type, source-to-film distance, and use of screens.



12. maximum, minimum

13. On the latitude analysis chart the horizontal distance between the two curves represents the greatest change in specimen _____ that can be radiographed with one voltage and exposure.



21. .02 inches

22. The thickness of this standard penetrameter is _____.



30. source side

31. In the "separate block" technique, the penetrameter is placed on a separate block whose thickness is equal to the _____ of the specimen.



4. exposure

5. Each radiograph of the step wedge is examined with a densitometer and the _____ of each step of each radiograph is recorded in a table.



13. thickness

14. The latitude analysis demonstrates that increasing the voltage _____ (increases, decreases) the latitude of the radiograph.



22. .01 inches
(.02 x .5)

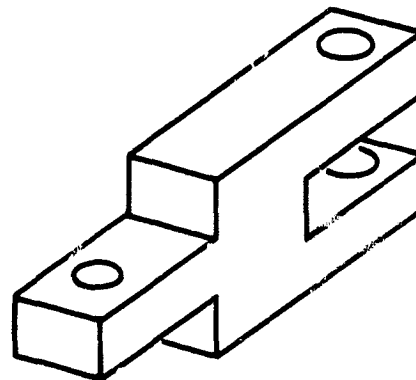
23. The smallest hole in the thinnest penetrameter is _____ inches in diameter.



31. thickness

32. In radiographing this specimen it is impractical to place the penetrameter on the specimen. What technique would you use to assure the proper sensitivity?

_____ or _____.



5. density

THICKNESS INCHES	120 Kv 3 MA-MIN	130 Kv 3 MA-MIN	140 Kv 4.5 MA-MIN	160 Kv 6 MA-MIN
.01	2.47	2.84	4.35	-
.02	1.80	2.12	3.50	4.6
.03	1.32	1.66	2.78	4.5
.04	.96	1.32	2.27	3.94
.05	.75	1.08	1.96	3.43
.06	.61	.84	1.61	3.05
.07	.50	.69	1.33	2.65

6. From this step wedge density table the density of the film image of .03 inches of stainless steel radiographed at 130 kv for 3 ma-min is _____.

14. increases

15. The _____ - _____ technique is the process of loading two films in the same cassette.

23. .010

24. When radiographing steel a penetrameter made of _____ should be used.

32. identical part, or
two shot

33. In radiographing welds, shims are added under the penetrameter so that the amount of material under the penny is equal to the thickness of the _____.

6. 1.66

7. An exposure chart specifies the film density for which the chart is constructed. In the step wedge analysis we select a standard _____ to which we will construct an exposure chart.



15. two-film (multiple film)

16. When the cassette is loaded with a fast film and a slow film, the _____ film can be expected to show adequately the thicker sections of the specimen.



24. steel

25. The image of the penetrameter in the radiograph serves as a check on the _____ (sensitivity, contrast, definition) of the radiograph.



33. weld

34. In the "film side equivalent" technique the object is to determine the correct size penetrameter to place on the film side of the specimen that will be the equivalent of the proper _____ penetrameter.



7. density

8. The step wedge density table shows the resulting film density of each thickness of the step wedge for several different exposures. We convert this data to show a constant _____ and the resulting exposure for each thickness of the step wedge.



16. fast

17. The sensitivity of a radiograph can be determined by adding a discontinuity of known size and shape to the specimen when making the radiograph. This known discontinuity is called a _____.



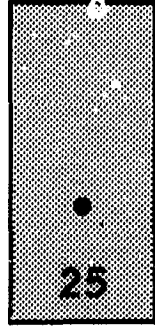
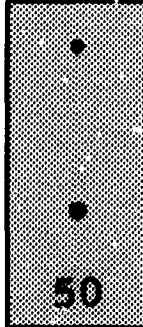
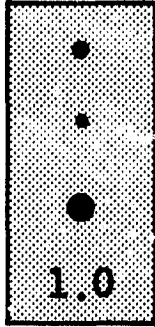
25. contrast

26. The outline of the holes in the penetrameter serves as a check on the _____ of the radiograph.



34. source side

35. In selecting the "film side equivalent" penetrameter to use we look for the smallest hole shown in the image of the _____ penny.



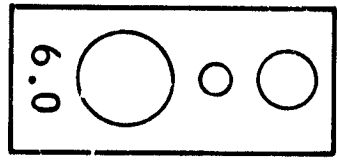
8. density

9. In converting the step wedge density data into exposure chart form, we make use of the film _____ .

Return to page 6-88, frame 10.

17. penetrameter

18. This penetrameter is to be used on material that is _____ inches thick.



Return to page 6-88, frame 19.

26. definition

27. What is the I.D. No. of the standard penetrameter required to measure a 4% sensitivity when radiographing 2 inches of steel?

SENSITIVITY	PENNY T AS % OF T_m	PERCEPTIBLE HOLE DIA
0.7%	1%	1T
1.0%	1%	2T
1.4%	2%	1T
2.0%	2%	2T
2.8%	2%	4T
4.0%	4%	2T

T = THICKNESS T_m = THICKNESS OF MATERIAL

Return to page 6-88, frame 28.

35. thinnest

You have completed the review of Chapter 6. Now turn to the next page.



You have just completed the fourth volume of the programmed instruction course on Radiography.

Now you may want to evaluate your knowledge of the material presented in this handbook. A set of self-test questions are included at the back of the book. The answers can be found at the end of the test.

We want to emphasize that the test is for your own evaluation of your knowledge of the subject. If you elect to take the test, be honest with yourself - don't refer to the answers until you have finished. Then you will have a meaningful measure of your knowledge.

Since it is a self evaluation, there is no grade - no passing score. If you find that you have trouble in some part of the test, it is up to you to review the material until you are satisfied that you know it.

Now turn the book around and flip to page T-1 at the back of the book.

RADIOGRAPHIC TESTING - VOLUME IV - MAKING A RADIOGRAPH

Self-Test

1. A photographic record produced by the passage of X- or gamma rays through a specimen to expose a film is called a _____.
2. The ability of an X-ray to ionize material is the reason the ray _____.
 - a) penetrates the specimen
 - b) forms penumbra
 - c) exposes the film
 - d) travels in a straight line
3. X-rays and gamma rays are part of a family of waves called _____ waves.
 - a) electromagnetic
 - b) visible
 - c) light
 - d) radio
4. The electromagnetic spectrum indicates that X-rays have a _____ wave length than light rays.
5. The degree of darkness of photographic film is called film _____.
6. X-rays and gamma rays always travel in _____.
7. The thickest section of any specimen being radiographed will absorb _____ (more, less) of the rays than the thinnest section.
8. After film has been exposed by radiation and then developed, the area of the film receiving the most radiation is _____ (darkest, lightest).
9. In a radiograph the thinnest section of a specimen appears _____ (darkest, lightest) on the film.
10. An inclusion that is more dense than the specimen will appear as a _____ (light, dark) spot, or line, on the radiograph.
11. In radiography an image of the specimen is formed on the film because _____.
 - a) X-rays travel in a straight line
 - b) the emulsion is 0.01 inches thick
 - c) X-rays travel at the speed of light
 - d) the specimen generates scatter

12. The ability of a material to block or partially block the passage of X-rays is known as _____.

a) absorption	c) absorption
b) penetration	d) scatter
13. The depth of penetration of an X-ray into a material depends upon the _____ of the ray.
14. "Hard" rays are of _____ wave length than "soft" rays.
15. Two types of radiographic intensifying screens are _____ and _____.
16. The intensity of the light emitted by the fluorescent screen depends upon the intensity of the _____.

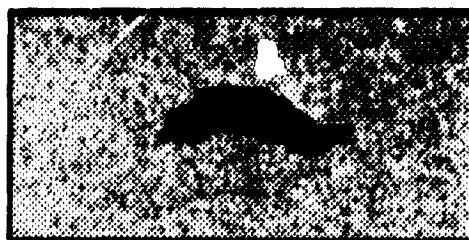
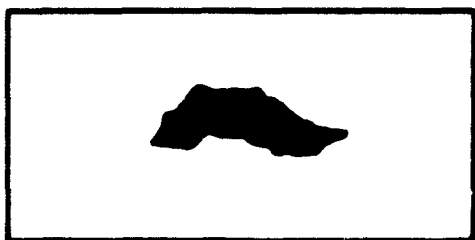
a) radiograph	c) contrast
b) definition	d) radiation
17. The lead screen acts as an intensifier because _____ are liberated from the lead by the radiation.
18. The measure of the accuracy of the radiograph as a nondestructive testing tool is called the _____ of the radiograph.

a) density	c) sensitivity
b) intensity	d) exposure
19. The measure of the smallest discontinuity that can be detected on a radiograph is a measure of the _____ of the radiograph.

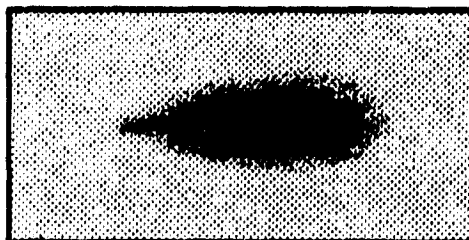
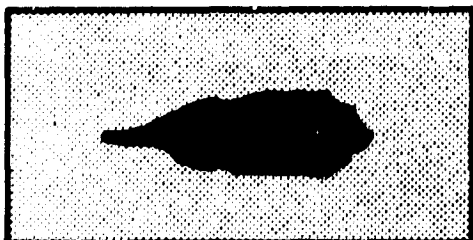
a) density	c) sensitivity
b) intensity	d) exposure
20. Contrast and definition are the two factors that determine the _____ of the radiograph.

a) density	c) sensitivity
b) intensity	d) graininess
21. "Contrast" is defined as the comparison between _____ for different areas of the radiograph.
22. "Definition" is the measure of the _____ of the outline of the image in the radiograph.

23. Here we show the difference between good and poor _____.



24. Here we show the difference between good and poor _____.



25. Inherent unsharpness is caused by free electrons that are generated by the radiographic ray as it passes through _____.

- | | |
|-----------------|-----------------|
| a) the air | c) the film |
| b) the specimen | d) the cassette |

26. Inherent unsharpness _____ (is, is not) controllable.

27. Side scatter _____ (is, is not) controllable.

28. Undercutting is caused by _____.

- | | |
|------------------|-------------------|
| a) side scatter | c) lead screens |
| b) poor geometry | d) free electrons |

29. In each pair of items below underline the item that will give the best radiographic geometry.

larger source size - smaller source size

larger source-to-specimen distance - smaller source-to-specimen distance

larger specimen-to-film distance - smaller specimen-to-film distance

30. The source should be located directly above the area of interest and on a line that is _____ to the plane of the film.

- | | |
|------------------|-------------|
| a) perpendicular | b) parallel |
|------------------|-------------|

T-4

31. The plane of interest in the specimen should be _____ to the plane of the film.

- a) perpendicular b) parallel

32. Which of the two inclusions shown in this cross-section will have the best definition in the radiograph?



33. Fluorescent intensifying screens _____ (decrease, increase) the definition of the radiograph.

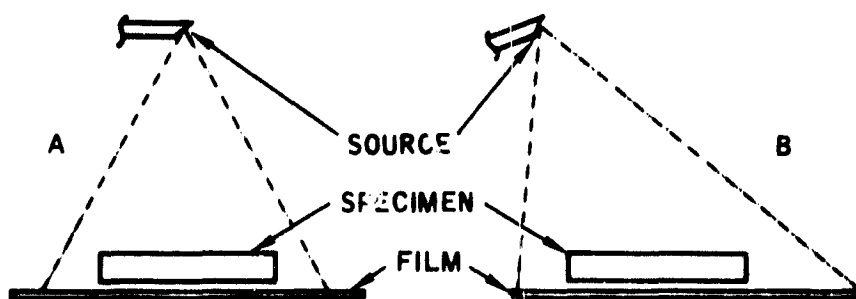
34. Fine grain films give _____ (better, poorer) definition when used in radiography.

35. Graininess for any given film usually _____ (increases, decreases) slightly as kilovoltage increases.

36. Three of the following factors will affect the definition of a radiograph. They are: _____, _____, and _____.

- a) scattering d) exposure time
b) geometry e) tube current
c) film density f) film graininess

37. Which of the two rays shown will give the least distortion to the image of the specimen?



38. Side scatter will affect both the _____ and _____ of a radiograph.

- a) definition c) contrast
b) distortion d) graininess

39. A large source size can be compensated for by _____.

- a) increasing source-to-specimen distance c) increasing specimen-to-film distance
b) addition of lead screens d) increasing penumbra

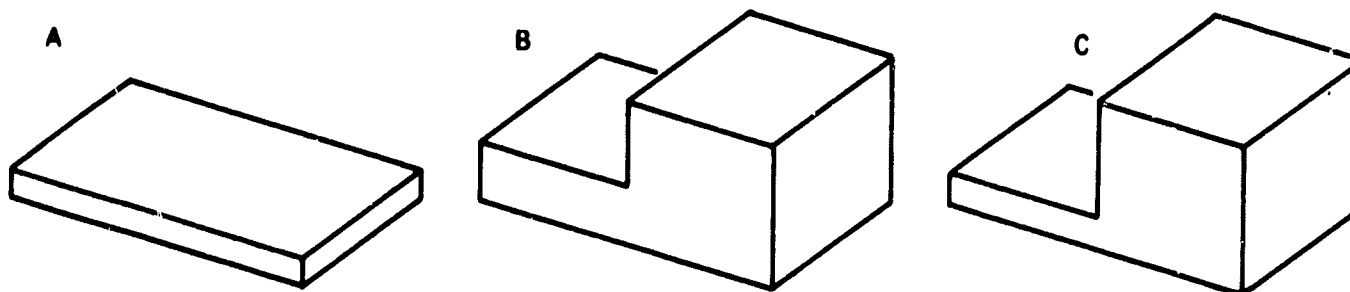
40. Internal scatter increases as the _____ and _____ of the specimen material increases.

- a) thickness
- b) density
- c) length
- d) width

41. Subject contrast and film contrast are the two factors that comprise radiographic _____.

- a) density
- b) sensitivity
- c) definition
- d) contrast

42. Which of these specimens will provide the greatest subject contrast? _____.



43. Greater subject contrast is achieved by utilizing rays with the _____ (lowest, highest) energy that will penetrate the specimen.

44. Scatter _____ radiographic contrast.

- a) reduces
- b) increases
- c) does not affect

45. Any material on the film side of the specimen that receives primary radiation may cause scatter called

- a) internal scatter
- b) side scatter
- c) back scatter
- d) forward scatter

46. "Film contrast" is the inherent ability of a film to show _____ for a given change in film exposure.

- a) no appreciable change in density
- b) graininess
- c) a difference in density
- d) no graininess

47. Film contrast improves as film density _____ (increases, decreases).

T-6

48. The cheapest and most convenient way of controlling scatter radiation is to use _____.
- a) screens
 - b) cassettes
 - c) densitometers
 - d) shielding
49. Lead foil in direct contact with the film in a cassette absorbs _____.
- a) all radiation to protect the film from exposure
 - b) light rays that might otherwise expose the film
 - c) long wave length radiation more than short wave length
 - d) short wave length radiation more than long wave length
50. A lead foil screen acts as an intensifying screen because of the _____.
- a) short wave length radiation absorbed by the screen
 - b) elimination of back scatter generated by the floor
 - c) decreased photographic action on the film
 - d) electrons emitted from film side of the screen
51. Lead screens improve both the _____ and the _____ of the final radiograph.
- a) density
 - b) contrast
 - c) exposure
 - d) definition
52. Lead foil is placed behind the film to _____.
- a) absorb as much side scatter as possible
 - b) reduce non image-forming backscatter
 - c) reduce the quality of image-forming primary rays
 - d) limit the amount of light striking the film
53. A lead screen will _____ and _____ the effect of radiation from the source.
- a) filter
 - b) expose
 - c) intensify
 - d) reverse
54. A fluorescent screen will _____ the effect of radiation from the source.
- a) filter
 - b) expose
 - c) intensify
 - d) reverse

55. A filter will reduce the amount of _____ in the primary radiation beam.

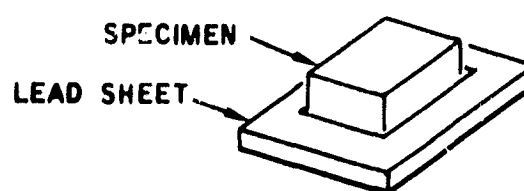
- a) scatter
- b) electrons
- c) high energy radiation
- d) low energy radiation

56. A filter is placed _____.

- a) between the source and the specimen
- b) between the specimen and the film
- c) around the specimen
- d) behind the film

57. The use of additional radiation absorbing material around the specimen to help control scatter as shown is known as _____.

- a) collimation
- b) shielding
- c) masking
- d) filtering



58. Covering the walls, floors, or any other object which may receive any of the primary radiation, with lead is a method of controlling scatter called _____.

- a) collimation
- b) shielding
- c) masking
- d) filtering

59. Increasing kv will _____ (increase, decrease) the effect of scatter on the radiograph.

60. Low energy rays cause _____ (more, less) scatter than high energy rays.

61. The range of specimen thicknesses that can be adequately recorded on the radiograph is known as the _____ of the radiograph.

- a) sensitivity
- b) latitude
- c) accuracy
- d) intensity

62. The intensity of an X-ray is directly proportional to _____.
- a) the kilovoltage across the tube c) the backscatter
b) the penumbra of the radiograph d) the current through the tube
63. The tube current in milliamperes multiplied by the time in seconds equals _____.
- a) density c) exposure
b) intensity d) kilovoltage
64. We have a satisfactory exposure at 5 ma exposing for 6 minutes. We want to reduce the exposure time to 2 minutes. What current would we have to use? (Show your calculations.)
65. When using a radioactive isotope in making a radiograph, we can express the equation for exposure as $C \times T$. In this equation, C stands for _____.
- a) current through the tube c) degree of contrast
b) intensity in curies d) coarseness of the film
66. We have a satisfactory radiograph using a 10 curie source of Co-60 with an exposure of 2 minutes. What exposure time would we use to obtain a satisfactory radiograph of the same specimen using another Co-60 source that is rated at 20 curies? (Show your calculations.)
67. $M_1 \times T_1 = M_2 \times T_2$ and $C_1 \times T_1 = C_2 \times T_2$ are equations for the _____.
- a) intensity law c) reciprocity law
b) density law d) inverse square law
68. $\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$ is the _____ equation.
- a) intensity law c) reciprocity law
b) density law d) inverse square law

69. To compute the change in exposure that is required by a change in source-to-film distance we would use the equation _____.

a) $M_1 \times T_1 = M_2 \times T_2$ c) $\frac{E_1}{E_2} = \frac{D_1^2}{D_2^2}$

b) $\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$ d) $\frac{E_1}{E_2} = \frac{D_2^2}{D_1^2}$

70. If we are to maintain the same exposure but must decrease the source-to-film distance, we must _____ the time of exposure.

- a) increase b) decrease

Many of the questions between this point and question number 90 will require use of the charts that have been supplied with this book. We remind you that these charts have been prepared for instructional purposes only. They are not to be used as radiographic standards. In preparing your answers you are demonstrating your ability to recognize and use the charts. The answers are not to be taken as radiographically correct. In reading the charts, approximate values will be satisfactory for the purpose of this self-test.

71. At a film density of 2.0, type A film is _____ than type D film.

- a) faster b) slower

72. Type A film has _____ (more, less) contrast at a density of 0.6 than at a density of 1.5.

73. We have exposure data for a particular X-ray machine as follows:

Specimen - 4-inch steel

Film - type D

Voltage - 1.5 mev

Film density - 2.0

Current - 10 ma

Source-to-film distance - 40 inches

Exposure time - 2.4 minutes

If voltage and current do not change, what exposure time will be required to obtain a film density of 3.0 on type A film with a source-to-film distance of 30 inches for the same specimen?

74. We have obtained a film density of 3.0 on type II film of a specimen using an exposure of 500 ma-sec. We decide to use the slower type III film to radiograph this specimen. What exposure will be required to obtain a film density of 2.5 for this radiograph?
75. List the four major qualities of the ideal radiograph.

76. The approximate limits of the acceptable voltage that can be used to radiograph 2 inches of steel are _____ to _____.
77. Can an X-ray machine that is rated at 200-750 kvp be used to radiograph 3 inches of steel? _____.
78. The maximum thickness of steel that can be radiographed with a Cobalt-60 source is _____ inches.
79. The thickness limits of steel that can be radiographed with a Radium source are _____ inches to _____ inches.
80. Lead screens act as intensifiers at voltage above _____.

a) 1000 kv	c) 325 kv
b) 150 kv	d) 2000 kv
81. A lead intensifying screen should be used at 100 kv _____.

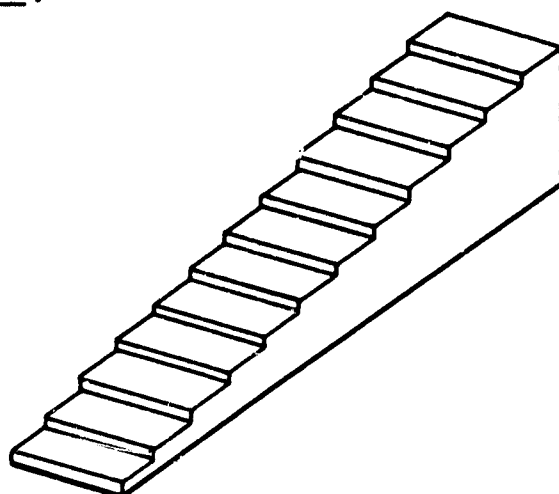
a) to protect the operator	c) if it improves the radiograph
b) to emit electrons	d) to help generate scatter
82. Fluorescent screens are used _____.

a) whenever possible
b) to improve the definition of the radiograph
c) to prevent scattered radiation from reaching the film
d) only when the exposure without them is excessive

83. The final selection of the voltage to use to radiograph any specimen depends on _____.
- the current through the machine
 - the type of film used
 - the thickness of the specimen
 - the density of the film multiplied by the distance from source to film
84. What is a practical voltage to use to radiograph 1.5 inches of steel in an unfamiliar situation? _____.
85. What exposure would you use to radiograph 3/4-inch steel plate to obtain a film density of 1.5 on type II film with a source-to-film distance of 40 inches using an "XXX" X-ray machine at 180 kv and lead screens? _____.
86. What exposure factor would you use in radiographing 1.5 inches of steel with Iridium-192 to obtain a film density of 2.0 on type II film? _____.
87. The exposure factor equation is _____.
- $$\text{e.f.} = \frac{I \times T}{D^2}$$
 - $$\text{e.f.} = M_1 \times T_1$$
 - $$\text{e.f.} = \frac{t \times d}{.020} + t$$
 - $$\text{e.f.} = \frac{C_1 \times T_1}{C_2 \times T_2}$$
88. We want to radiograph 2 inches of steel with an Iridium-192 source of 25 curies. We want to obtain a film density of 2.0 on type II film. If our source-to-film distance is 15 inches, how long should the exposure be? (Show your calculations.)
89. What was the activity of Iridium-192 source IR-1166 on 9-20-62? _____.
90. Two inches of copper is radiographically equivalent to _____ inches of steel when radiographed at 400 kv.
91. The maximum film density to which the radiograph should be exposed is dependent upon _____.
- the quality of the film viewer
 - the variation in thickness of the specimen
 - the speed of the film
 - the graininess of the film

92. High contrast films are used when _____.
- a) the voltage is relatively high
 - b) the subject contrast is high
 - c) the viewing equipment is poor
 - d) relatively small discontinuities are sought
93. Use of a slower speed film improves the definition of the radiograph because the slower film _____.
- a) requires more exposure
 - b) is more sensitive to X-rays
 - c) requires less voltage
 - d) has finer grain
94. The selection of the proper source-to-film distance is a primary factor in controlling _____.
- a) contrast
 - b) unsharpness
 - c) graininess
 - d) scatter
95. When the penumbra on a radiograph measures less than .020 inches the image will appear _____ to the unaided eye of the film interpreter.
- a) fuzzy
 - b) sharp
 - c) distorted
 - d) dark
96. Source-to-film distance, specimen-to-film distance, and source size are the three factors that control the _____ of the radiograph.
- a) density
 - b) exposure
 - c) film size
 - d) unsharpness
97. The minimum source-to-film distance required to reduce penumbra to satisfactory limits can be determined by using the equation $D =$ _____.
- a) Pr^2
 - b) $\frac{t \times d}{U} + t$
 - c) $U + d$
 - d) $\frac{U}{t \times d} - t$
98. An X-ray unit is rated for 300 kv at 10 ma, continuous operation. A milli-ampere meter on the control panel will indicate from 0 to 20 milliamperes. The maximum current that can be safely put through the tube when operating continuously at 300 kv is _____.

99. To a radiographer the device illustrated is known as a _____.



100. In the radiographic analysis procedure that is used to prepare an exposure chart the first step is to _____.
- a) make several radiographs of a step wedge
 - b) radiograph several objects of known thicknesses
 - c) convert the densities read from the radiographs to a standard density
 - d) plot the exposures on a graph
101. In selecting the voltages and exposures to use in the step wedge analysis we use data supplied by _____.
- a) past experience with the machine
 - b) experience with other machines
 - c) the equipment manufacturer
 - d) the film manufacturer
102. Which exposure factors are recorded in the process of making a step wedge analysis? _____.
- a) voltage and exposure
 - b) source-to-film distance and film type
 - c) film density and material
 - d) all of them
103. In the step wedge analysis process it is sometimes necessary to vary the source-to-film distance. (True - False) _____.
104. After the step wedge radiographs have been made, the _____ of the image of each step is recorded on a chart.
- a) sharpness
 - b) contrast
 - c) density
 - d) length
105. The chart that results from a step wedge analysis is normally based on a selected film density. (True - False) _____.

106. The final step of the step wedge analysis is to plot the data on a graph to form _____.
- a) a film characteristic curve c) an exposure chart
b) a decay curve d) an equivalence chart
107. The latitude analysis chart is useful in determining the range of specimen _____ that can be radiographed with one exposure.
- a) thicknesses c) densities
b) materials d) types
108. In changing an exposure chart into a latitude analysis chart the first step in the procedure is to select _____.
- a) the required voltage c) the proper source-to-film distance.
b) an acceptable film density range d) the proper X-ray equipment
109. The "two exposure" technique may be used when one radiograph does not have enough _____ to produce a satisfactory radiograph of a specimen.
- a) latitude c) graininess
b) definition d) activity
110. The process of loading more than one film into a cassette is known as the _____ technique.
111. When a fast film and a slow film are loaded in the same cassette, the slow film can be expected to show adequately the _____ (thinner, thicker) sections of the specimen.
112. What is the thickness of the standard 1.5 penetrameter? _____.
113. On what thickness of material would you use the standard 1.5 penetrameter to obtain a 2% sensitivity? _____.
114. The diameter of the largest hole in a standard 2.0 penetrameter is _____ inches.
115. The diameter of the 2T hole in a standard 3.0 penetrameter is _____ inches.
116. The diameter of the smallest hole in a standard 25 penetrameter is _____ inches.

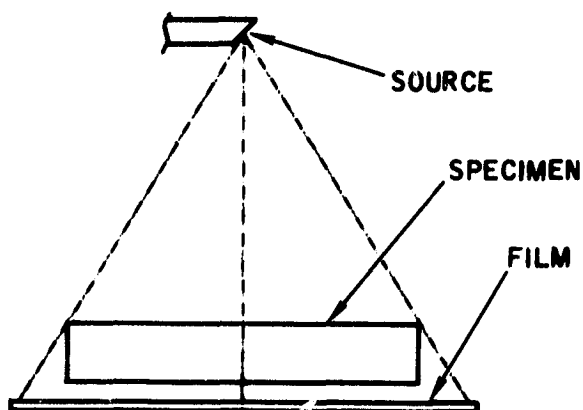
117. The penetrameter is a tool used to check the _____ of a radiograph.
- a) contrast c) sensitivity
b) definition d) emulsion
118. The image of the penetrameter on the radiograph is proof that the radiograph has the proper _____.
- a) contrast c) sensitivity
b) definition d) emulsion
119. The image of the penetrameter holes on the radiograph is proof that the radiograph has proper _____.
- a) contrast c) sensitivity
b) definition d) density
120. Using the chart below, what size penetrameter (give I. D. No.) would be used to obtain an 0.7% sensitivity when radiographing 2 inches of steel ? _____

SENSITIVITY	PENNY T AS % OF T _m	PERCEPTIBLE HOLE DIA
0.7%	1%	1T
1.0%	1%	2T
1.4%	2%	1T
2.0%	2%	2T
2.8%	2%	4T
4.0%	4%	2T

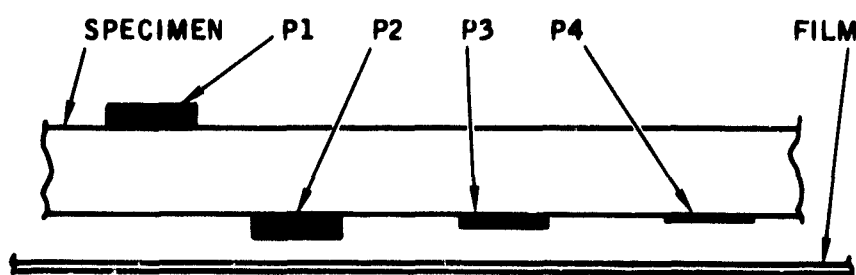
T = THICKNESS

T_m = THICKNESS OF MATERIAL

121. Using the chart from the preceding question, which penetrameter hole would have to be visible on the radiograph to assure the 0.7% sensitivity? _____.
122. In the figure below, draw in a penetrameter where you think it should be placed.



123. When it is impractical to place a penetrameter on a specimen, it may be placed on a separate block of material provided the specimen and the block are the same _____ and _____.
124. When the article to be radiographed is so complex that a separate block technique cannot be used and the penetrameter cannot be placed on the article, either of two methods can be used. These two methods are called _____ and _____.
125. When radiographing welds, shims are added under the penetrameter so that the amount of material under the penny is equal to _____.
126. In the "film side equivalent" technique shown below, P2 cannot be _____ (thicker, thinner) than P1.



127. Referring to the illustration in the preceding question, P3 should be _____ as thick as P2.
128. In selecting the "film side equivalent" penetrameter to use, we look for the smallest hole shown in the image of the _____ penetrameter.

ANSWERS FOR SELF-TEST

	Page No. <u>Ref.</u>		Page No. <u>Ref.</u>
1. radiograph	1-1	27. is	2-17
2. c	1-15	28. a	2-15
3. a	1-2	29. <u>smaller source size</u>	2-18
4. shorter	1-2	<u>larger source-to-specimen</u>	
5. density	1-24	<u>distance</u>	
6. straight lines	1-13	<u>smaller specimen-to-film</u>	
7. more	1-17	<u>distance</u>	
8. darkest	1-22	30. a	2-24
9. darkest	1-22	31. b	2-27
10. light	1-29	32. b	2-30
11. a	1-13	33. decrease	2-34
12. c	1-17	34. better	2-31
13. energy (voltage, wave length)	1-5	35. increases	2-34
14. shorter	Volume I	36. a, b, f	2-36
15. lead, fluorescent	1-32	37. a	2-24
16. d	1-34	38. a, c	2-12
17. electrons	1-34	39. a	2-21
18. c	2-1	40. a, b	2-13
19. c	2-1	41. d	3-2
20. c	2-2	42. c	3-2
21. densities	2-2	43. lowest	3-6
22. sharpness	2-7	44. a	2-12
23. contrast	2-4	45. c	2-12
24. definition	2-7	46. c	3-14
25. c	2-9	47. increases	3-14
26. is not	2-9	48. a	3-23
		49. c	3-23

	Page No. Ref.		Page No. Ref.
50. d	3-26	71. slower	4-50
51. b, d	3-23	72. less	4-49
52. b	3-25		
53. a, c	3-26	73. $\frac{T_1}{T_2} = \frac{D_1^2}{D_2^2}$ or $T_2 = \frac{T_1 \times D_2^2}{D_1^2}$	
54. c	2-34		
55. d	3-30	$T_2 = \frac{2.4 \times (30)^2}{(40)^2} = 1.35 \text{ min.}$	
56. a	3-30		
57. c	3-33	From film characteristic curves -	
58. b	3-37	Exp. type D film, 2.0 density - 1.28	
59. decrease	3-39	Exp. type A film, 3.0 density - 2.5 (exposure increases)	
60. more	3-39	$\frac{1.35 \times 2.5}{1.28} = 2.64 \text{ min.}$ Chapter 4	
61. b	3-45		
62. d	4-5	74. Log rel exp 3.0 type II - 2.10	
63. c	4-10	Log rel exp 2.5 type III - 2.62	
64. $M_1 \times T_1 = M_2 \times T_2$	4-12	Interval 0.52	
$M_2 \times 2 = 5 \times 6$		Antilog of interval - 3.31	
$M_2 = \frac{30}{2} = 15 \text{ ma}$		500 X 3.31 = 1655 ma-sec Chapter 4	
65. b	4-22	75. maximum contrast	
66. $C_1 \times T_1 = C_2 \times T_2$	4-24	maximum definition	
$20 \times T = 40 \times 2$		minimum distortion	
$T = \frac{40 \times 2}{20} = 4 \text{ min}$		adequate density 5-1	
67. c	4-14	76. 260 kv to 4.2 Mev (approx.) 5-10	
68. d	4-28	77. Yes 5-10	
69. c	4-28	78. 8 inches 5-15	
70. decrease	4-32	79. 1.0 to 3.7 (approx.) 5-15	
		80. b 5-16	
		81. c 5-18	

	Page No. Ref.		Page No. Ref.
82. d	5-21	106. c	6-16
83. c	5-22	107. a	6-25
84. 380 kv (approx.)	5-22	108. b	6-25
85. 8.5 ma-min	5-24	109. a	6-40
86. .5 (approx.)	5-32	110. two film	6-43
87. a	5-33	111. thinner	6-44
88.		112. 0.030 inches	6-47
$e.f. = \frac{I \times T}{D^2} \quad T = \frac{e.f. \times D^2}{I}$		113. 1.5 inches	6-45
$T = \frac{.98 \times (15)^2}{25} = \frac{.98 \times 225}{25} = 8.64$		114. 0.16 inches	6-48
8.64 minutes (approx.)	5-34	115. 0.12 inches	6-48
89. 25 curies	5-39	116. 0.010 inches	6-51
90. 2.8	5-44	117. c	6-59
91. a	5-48	118. a	6-54
92. d	5-50	119. b	6-54
93. d	5-53	120. 1.0	6-67
94. b	5-57	121. 1T	6-61
95. b	5-57	122.	6-73
96. d	5-59		
97. b	5-59		
98. 10 ma	5-64		
99. step wedge	6-2		
100. a	6-3		
101. c	6-6	123. material, thickness	6-74
102. d	6-9	124. identical part, two shot	6-77
103. false	6-9	125. the thickness of the weld	6-78
104. c	6-12	126. thicker	6-85
105. true	6-16	127. one half	6-85
		128. thinnest	6-85

