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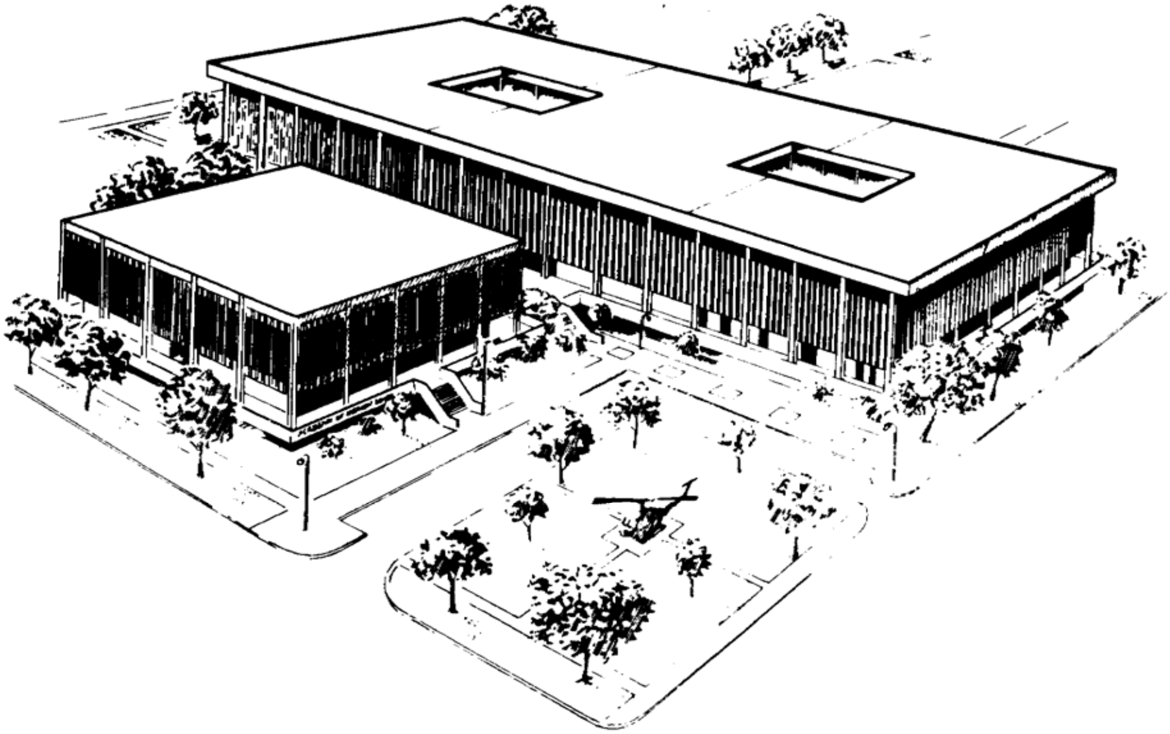

PRINCIPLES OF RADIOGRAPHIC EXPOSURE

SUBCOURSE MD0952 **EDITION 200**

DEVELOPMENT

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CORRESPONDENCE COURSE OF

THE U.S. ARMY MEDICAL DEPARTMENT CENTER AND SCHOOL

SUBCOURSE MD0952

PRINCIPLES OF RADIOGRAPHIC EXPOSURE

INTRODUCTION

In Subcourse MD0950, "Fundamentals of X-Ray Physics," the fundamentals of atomic structure, energy, electricity, magnets, circuits, x-ray circuits, and tubes, as well as x-ray safety, were discussed. That subcourse should provide you with an adequate background for this course in radiographic exposure.

Much improvement in radiographic equipment and materials has been made since diagnostic radiography made its entrance on the medical scene at the close of the nineteenth century. Effort is continually being made to standardize procedures and techniques, yet a great deal of both art and judgment are still needed.

This subcourse discusses the many factors and principles involved in projecting a latent image onto the x-ray film which, when developed, will have maximum diagnostic value.

Subcourse Components:

The subcourse instructional material consists of the following:

Lesson 1, Principles of Radiographic Exposure I
Lesson 2, Principles of Radiographic Exposure II

Study Suggestions:

Here are some suggestions that may be helpful to you in completing this subcourse:

--Read and study each lesson carefully.
--Complete the subcourse lesson by lesson. After completing each lesson, work the exercises at the end of the lesson, marking your answers in this booklet.

--After completing each set of lesson exercises, compare your answers with those on the solution sheet that follows the exercises. If you have answered an exercise incorrectly, check the reference cited after the answer on the solution sheet to determine why your response was not the correct one.

Credit Awarded:

To receive credit hours, you must be officially enrolled and complete an examination furnished by the Nonresident Instruction Branch at Fort Sam Houston, Texas. Upon successful completion of the examination for this subcourse, you will be awarded 9 credit hours.

You can enroll by going to the web site http://atrrs.army.mil and enrolling under "Self Development" (School Code 555).

A listing of correspondence courses and subcourses available through the Nonresident Instruction Section is found in Chapter 4 of DA Pamphlet 350-59, Army Correspondence Course Program Catalog. The DA PAM is available at the following website: http://www.usapa.army.mil/pdffiles/p350-59.pdf.

LESSON ASSIGNMENT

LESSON 1	Principles of Radiographic Exposure I
TEXT ASSIGNMENT	Paragraphs 1-1 through 1-46.
LESSON OBJECTIVES	After completing this lesson, you should be able to:
	1-1. Identify the correct characteristics of both primary and remnant radiation beams.
	1-2. Identify the correct relationship between machine factors (kVp, mA, sec, and FFO) and the characteristic of the x-ray beam and film exposure, (density, contrast, and fog).
	1-3. Identify additional factors (focal spot, size, grids, object to film distance, coning devices and patient) and their proper relationships to film (density, contrast, and fog).
SUGGESTION	After completing the assignment, complete the exercises at the end of this lesson. These exercises will help you to achieve the lesson objectives.

LESSON 1

PRINCIPLES OF RADIOGRAPHIC EXPOSURE

Section I. INTRODUCTION

1-1. GENERAL

a. The purpose of an x-ray examination is to assist in the solution of a medical or surgical problem, that is, to obtain diagnostic information. The radiograph constitutes the record, and it must satisfy one prime requisite--that of depicting all anatomical details of the body part being examined in such a way as to facilitate diagnosis. Making a radiograph is essentially a photographic procedure. The exposure and processing of the x-ray film involves complex physical and chemical changes that result in the formation of the silver image. Fortunately, standardization of the several operations in the production of the image greatly simplifies the procedure (figure1-1).

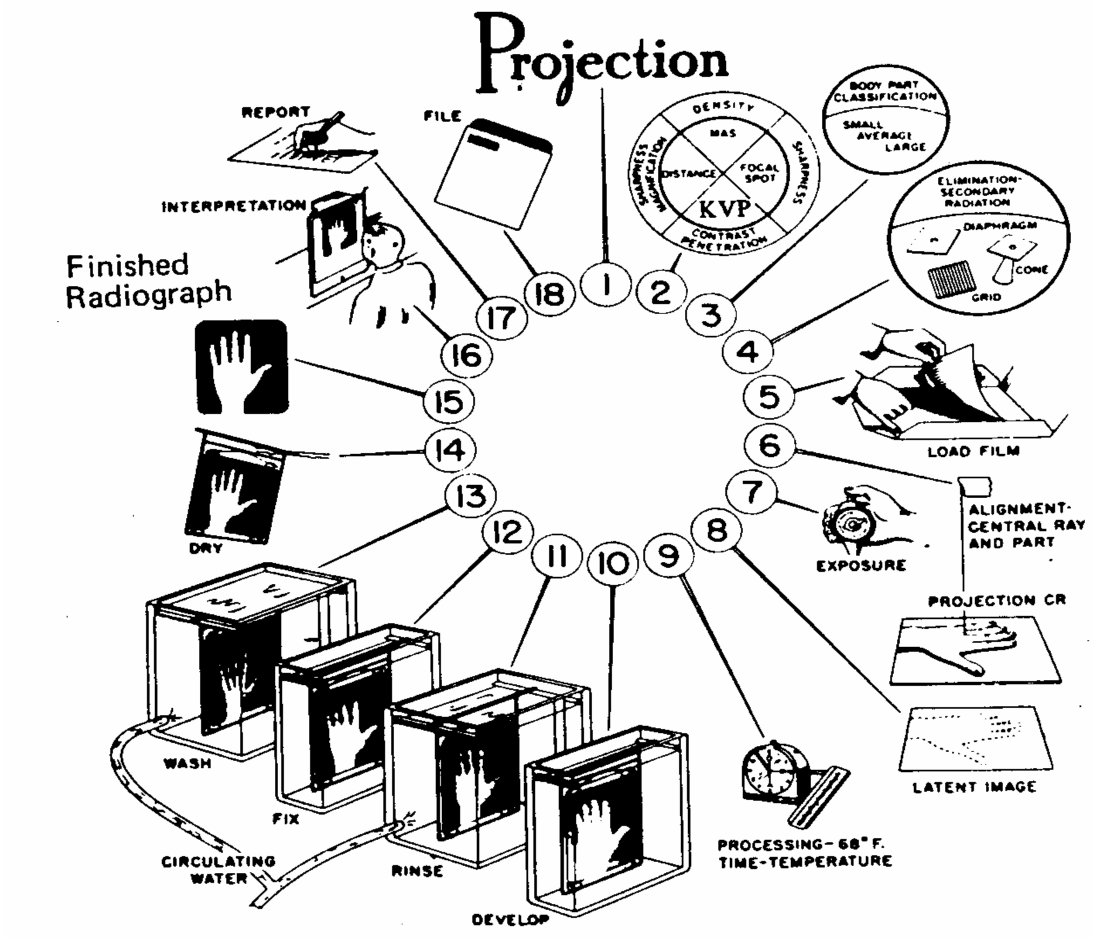


Figure 1-1. Steps in the production of a radiograph.

b. Radiologic technology entails the use of standardized apparatus and technique so that all operations will consume a minimum of time and yield radiographs of the best quality. The training of x-ray specialists should include comprehensive instruction in the fundamentals of radiographic exposure so that satisfactory radiographs can be produced irrespective of military assignment. The purpose of this subcourse, therefore, is to present the principles of radiographic exposure.

1-2. THE X-RAY BEAM

a. **Primary Radiation.** Primary radiation (PR) (figure 1-2) is confined to the portion of the x-ray beam emitted from the focal spot (FS) of the x-ray tube. Because of the inverse square law, its intensity is reduced as the distance from the focal spot increases. The average wavelength is shortened by absorption of much of the longer wavelength radiation by the glass envelope around the tube and also by aluminum filtration. This reduces unnecessary patient irradiation.

b. **Remnant Radiation.** Remnant radiation (RR) is that portion of the primary radiation that passes through the tissues to expose the x-ray film and record the radiographic image. It is the image-forming radiation. Remnant radiation is intermingled with secondary and scatter radiation (SR) from the tissues, the amount depending upon its wavelength and the manner in which it is controlled, as well as the type and thickness of the tissue.

c. **The Central Ray.** The central ray (CR) is the center of the x-ray beam. The term is employed in describing the direction of the x-rays in a given projection. The course of the central ray extends from the focal spot in the x-ray tube (perpendicularly from the tube housing) to the x-ray film.

(1) The entire distance traversed by the central ray is known as the Source-to-Image Distance *(SID).*

(2) The distance from the object or body part to the x-ray film measured along the course of the central ray is known as the *object-film distance (OFD).*

d. **Secondary Radiation** is radiation emitted by atoms that have absorbed x-rays (for example, characteristic radiation). It has longer wavelengths than the primary radiation that causes it. *Scatter radiation* refers to those x-ray photons that have undergone a change in direction after interacting with atoms. It may also have been modified by an increase in wavelength. In this subcourse, secondary and scatter radiation are normally considered together and abbreviated SR. Since SR is unfocussed and may come from any direction, its action on the radiograph may cover the entire image with a veil of fog unless it is controlled by certain accessories.

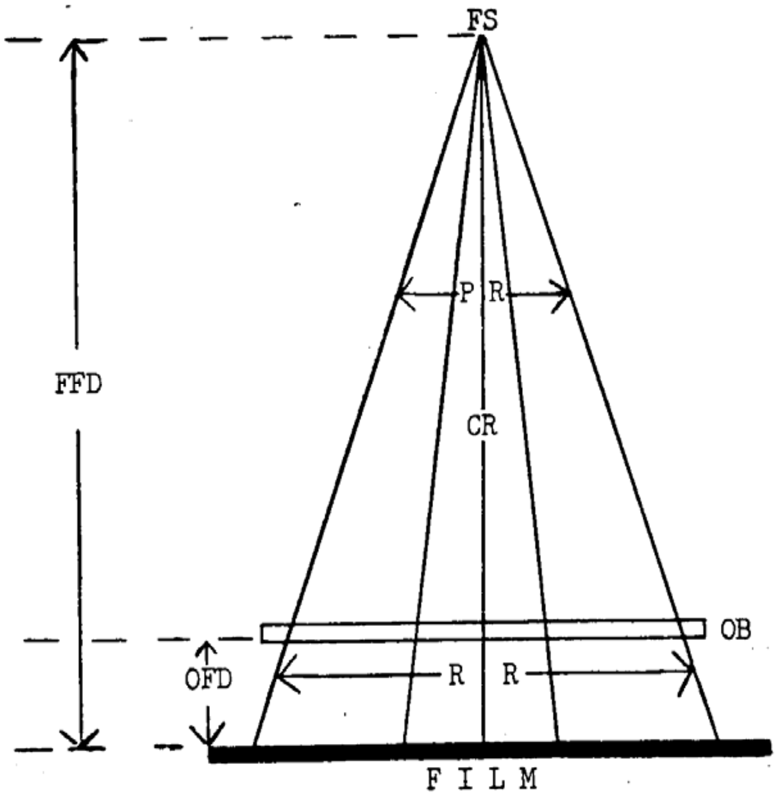


Figure 1-2. The various components of an x-ray beam with relation to an object and an x-ray film.

1-3. X-RAY EXPOSURE TERMS

a. The nomenclature of x-ray exposure comprises various terms, which have come to be called *radiographic factors.* Following is a list of these radiographic factors and their related symbols. These should be memorized, as each of them influences the character of the radiographic image.

(1) AP--anterior-posterior position.

(2) CR--central ray.

(3) FS--focal spot.

(4) SID--source-to-image distance.

(5) kVp--kilovolts peak.

(6) mA--milliamperes.

(7) mAs--milliampere-seconds.

(8) OFD--object-film distance.

(9) PA--posterior-anterior position.

(10) PR--primary radiation.

(11) RR--remnant radiation.

(12) SR--secondary and scatter radiation.

(13) (sec)--time of exposure in seconds

b. Several items of apparatus, when used, have a definite influence on the radiographic image. These accessories, which will be discussed in detail later in this subcourse, include the following:

(1) X-ray intensifying screens in cassettes, used to augment the exposure effect of the x-rays.

(2) The beam-restricting device, which limits the size of the x-ray beam irradiating the body parts.

(3) The stationary grid, which reduces the SR reaching the x-ray film.

(4) The Potter-Bucky (P-B) diaphragm, similar to the stationary grid, but mechanized to move during the exposure.

Section II. THE SILVER IMAGE

1-4. IMAGE CHARACTERISTICS

The film base of x-ray film has spread over it an emulsion of gelatin and silver bromide. Exposure to x-rays or light produces an atomic (electrical) change in the silver bromide crystals in which negative electrostatic fields are set up around specks on the exposed crystals. When the film is put in the developer solution, the silver (positively charged) separates from the bromine parts of the crystals and gravitates to the specks, neutralizing the negative field. This forms deposits of metallic silver that conform in density to the degree of exposure to x-rays and light. Thus, the radiographic image is composed of many deposits of black metallic silver on both surfaces of the radiograph. These deposits blend into an image to represent the anatomical structures examined. The image has two major characteristics, density and contrast, which directly influence the diagnostic quality of the radiograph.

1-5. RADIOGRAPHIC DENSITY

Radiographic density is the resultant deposit of black metallic silver on an x-ray film after exposure and processing. Details of the tissue elements examined are rendered as densities of varying concentration. During passage through a body part, the x-rays are absorbed by tissue components in different amounts. This results in various degrees of silver concentration on the radiograph. The degree of silver concentration determines the brightness or tone value of the densities when viewed on an x-ray illuminator. The tonal relationship between one density and another enables image details to become visible. The greater the number of tones present (correct tone rendition), the greater the number of structural details that can be visualized in the image. The range of tones in an image is photographically known as the "gray scale." Thus, diagnostic value is enhanced by many shades of gray in the image.

1-6. RADIOGRAPHIC CONTRAST

Radiographic contrast exists when two or more radiographic densities are present. It provides differentiation among various translucent radiographic densities to reveal all possible anatomical details when viewed on an x-ray illuminator. In figure 1-3 (left), contrast does not exist--there is only one radiographic density; in figure 1-3 (right), contrast does exist--the image has numerous densities with different tone values.

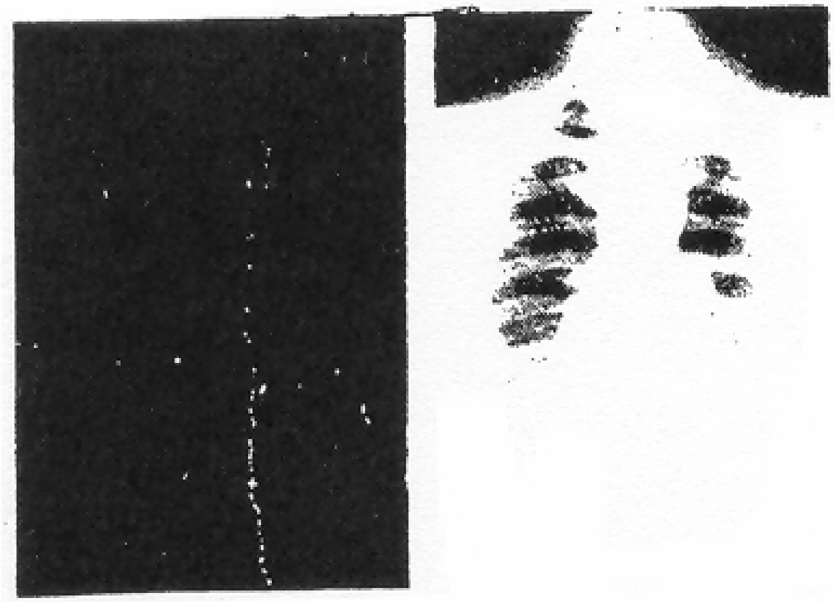


Figure 1-3. Two radiographs show a difference in density. Left, a single radiographic density; right, many Radiographic densities. The right exhibits adiographic contrast; the left does not.

a. **Factors Influencing Contrast.** The scale of densities determining contrast and visibility of details is influenced by x-ray wavelength that, in turn, is regulated by kilovolt peak (kVp). The exposure factor of kVp can be used as the active variable in altering radiographic contrast. Generally, visualization of details depends upon the degree of contrast and/or sharpness rendered. The contrast inherent to the x-ray developer, the type of film, the x-ray intensifying screens, and the type of tissue contribute to the sum total of radiographic contrast.

b. **Contrast Scale**. The scale of contrast in a radiographic image is determined by the number and tone value of the various densities. Radiographic contrast may vary widely or within some acceptable range depending upon the part being examined. A good radiograph possesses correct density balance over the entire contrast scale--clear differentiation between tissue details of diagnostic interest without loss of detail in other areas of the image.

(1) <u>Short-scale contrast</u>. In this type of contrast, the range of image densities is short and small in number, each density exhibiting a large tonal difference from its neighbor. In A, figure 1-4, long wavelength radiation is directed toward the step-wedge. It easily penetrates steps 1 and 2; the silver emulsion largely absorbs remnant radiation and an opaque density is produced. The radiation is greatly absorbed by step 3, and more by step 4, resulting in remnant radiation of such low intensity that a translucent density with a gray tone is produced in the former and a light gray tone in the latter. The radiation passing to steps 5 and 6 is totally absorbed, and the film is not exposed because there is no emergent radiation. A representative image of the entire wedge was not recorded because of inadequate penetration. The differences between densities are wide, and the number of densities is insufficient to portray a complete image of the subject. This diagram illustrates that radiographic details of an object cannot be seen in an image unless there are discernible differences in tone value between densities, and that there must be a silver deposit on the film if a detail within the object is to be demonstrated.

(2) <u>Long-scale contrast</u>. In this type of contrast, the range of image densities is wide and great in number, each density exhibiting only a small tonal difference from its neighbor. In B, figure 1-4, short wavelength radiation is directed toward the step-wedge. The radiation penetrates all portions of the wedge, and the selective degree of absorption by each step permits remnant radiation to emerge with different intensities producing separate translucent densities of varying tone value. The transition between tones is gradual, each tone is distinctive, and the image is completely informative. Desirable long-scale contrast is produced when the kVp is adjusted to delineate all normal structures satisfactorily. In the case of human radiography, when the scale of densities representing a departure from the normal occurs, the image is open to suspicion from a diagnostic standpoint. The criterion of good radiographic contrast is whether one sees all one expects to see.

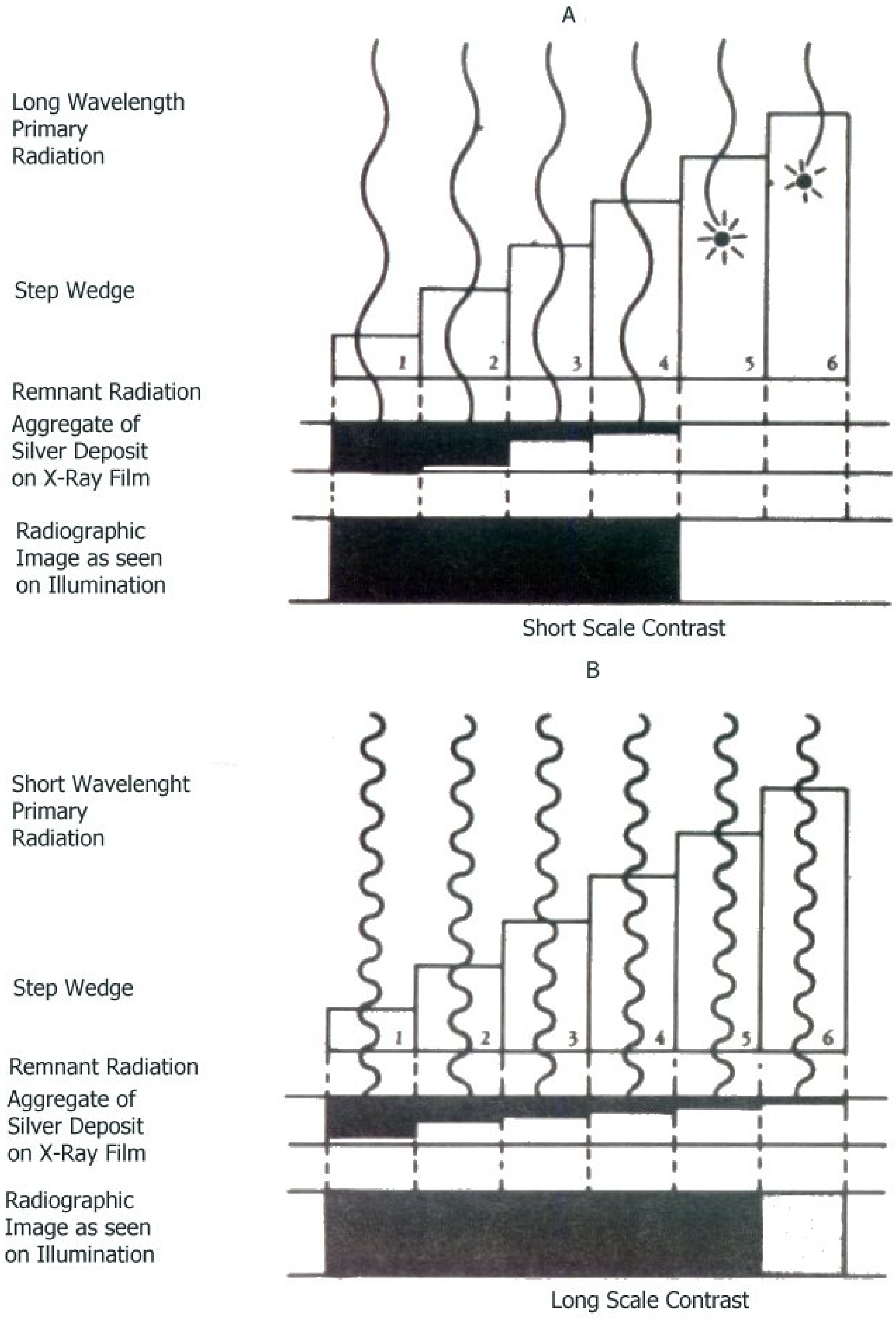


Figure 1-4. Short and long scale contrasts.

1-7. SHORT-SCALE VERSUS LONG-SCALE CONTRAST

a. The entire image exhibiting short-scale contrast is invariably incomplete, for details representing the thinner and thicker portions of the body part are not always shown. Only those details in the image produced by exposure factors optimum for the area are rendered with maximum visibility. Short-scale contrast is useful only as a special procedure for more adequately visualizing details of small tissue areas or in differentiating between various soft tissues that have similar absorptive powers. Typical examples of short-scale contrast are shown in figure 1-5.

b. Long-scale contrast makes possible the visualization of small variations of image density. To obtain the maximum diagnostic information in the survey film, a compromise must be made between the radiograph with short-scale contrast and that exhibiting the longer scale contrast. Typical examples of long-scale contrast are shown in figure 1-6. Although long-scale contrast generally occupies one end of the contrast range and short-scale contrast the other, there is no definite point that separates the two scales. In other words, contrast is a relative measure of the differences in radiographic densities. Radiograph A may exhibit long-scale contrast when compared with radiograph B. However, if A were compared with radiograph C (with a longer contrast scale), then radiograph A would exhibit short-scale contrast.

1-8. X-RAY PENETRATION

X-rays vary widely in penetrating human tissues. Each type of tissue absorbs radiation according to its own composition and thickness. Only a very small fraction of the original primary radiation is effectively utilized in an exposure because the greater part of the radiation is either absorbed by the tissues or converted into SR. The greater the tissue absorption, the less intense the emergent (remnant) radiation that can expose a film and record the image. To obtain a correct radiographic exposure, the x-radiation must be qualitatively and quantitatively adequate.

1-9. FACTOR OF X-RAY WAVELENGTH

Satisfactory image densities result only when radiation penetrates the entire part. The degree of penetration is controlled by kVp. Attempts to penetrate the part by using high milliampere-seconds (mAs) and low kVp (relatively longer wavelength radiation) result in long exposures that seldom yield satisfactory images. When these long, impractical exposures are employed, the shorter wavelengths still create most of the image since the longer wavelengths are largely absorbed. Objections to such an exposure procedure include: lack of complete penetration; the patient reaches the maximum permissible dose sooner; the patient may move during the exposure; and the latitude of exposure allows no margin for error. When the wavelength is shortened by increasing kVp, the absorption properties of flesh and bone are brought closer together because of a more uniform penetration of the tissues.

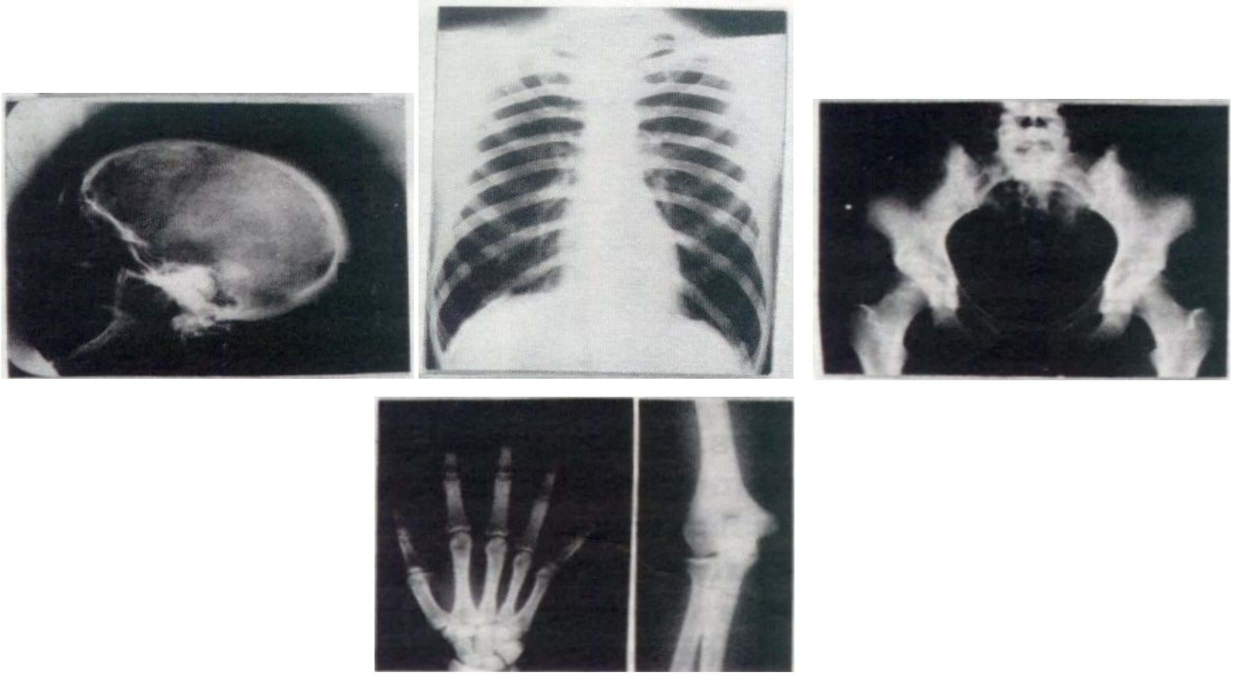


Figure 1-5. Typical radiographs exhibiting various degrees of short-scale contrast.

Figure 1-6. Typical radiographs exhibiting various degrees of long-scale contrast.

1-10. ABSORPTION BY BODY PARTS

When long wavelength radiation is used, bone absorbs most of the radiation that strikes it so that few osseous details may be shown in a radiograph. On the other hand, soft tissue details would be visible. The difference in absorption properties between these two tissues using long wavelength radiation are quite wide, and details of both kinds of tissue cannot be shown in a single image. A single radiograph recording both classes of tissue cannot be shown in a single image. A single radiograph recording both classes of tissue is preferable. The type of body part being examined has a decided bearing upon detail visualization, and the wide range of available kVp makes possible detailed representation of any part of the body.

a. When x-rays pass through human tissue, each type of tissue absorbs its proportion of radiation according to its own composition and thickness. For example, as x-rays pass through one thickness of flesh, then through a thickness of bone, and finally through another thickness of flesh or fat, the total absorption is the sum of the various degrees of absorption occurring in the different tissues (figure 1-7).

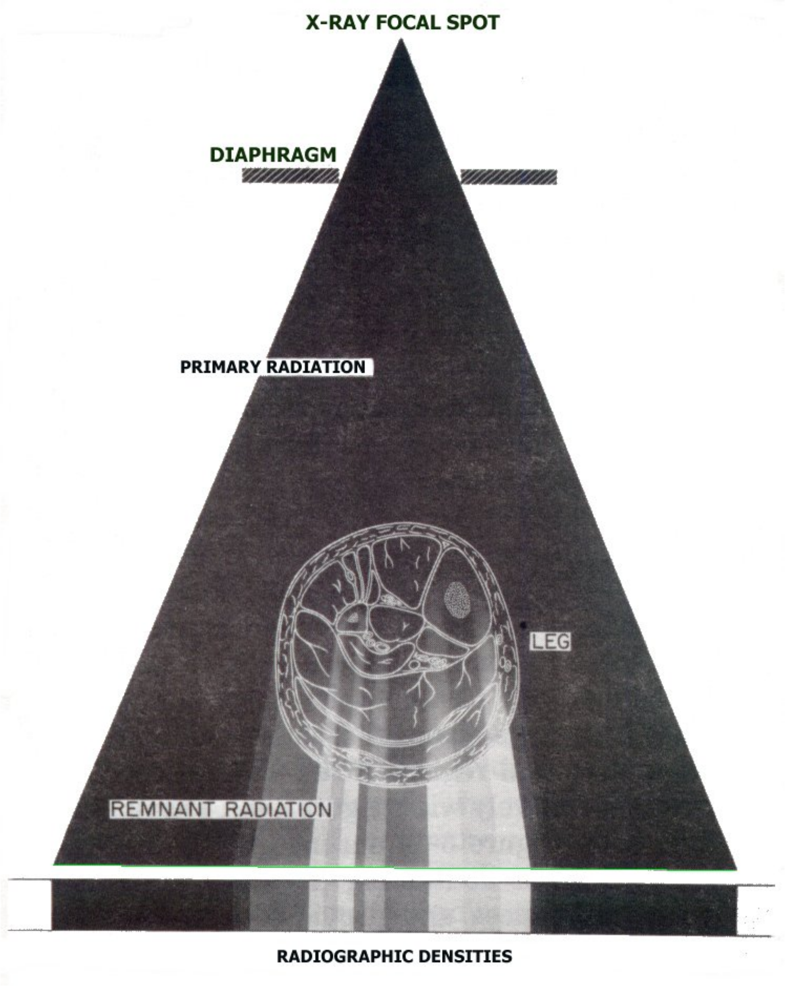


Figure 1-7. Penetrating and absorption of an x-ray beam Transversing a body part (leg).

b. Tissue contrast represents the relative differences in the tissue components of an anatomical part with respect to its x-ray absorption. The greater the absorption difference of a tissue with relation to adjacent tissue densities, the greater the contrast; the lower the absorption difference, the lower the contrast.

1-11. ABSORPTION VARIABLES

In radiography, there are a number of unpredictable absorption variables in body tissues that are influenced by physiologic or pathologic changes, but they may be disregarded, in some measure, if the exposure system provides enough latitude. Generally, small deviations from the normal in tissue absorption or thickness can be ignored. Recognizably abnormal conditions may be easily compensated by adjustment of the variable exposure factors selected, especially mAs.

a. **Large Absorption Differences**. When structural tissue details are widely different, we also find wide differences in absorbing power. Consequently, wide differences in tone value will exist in the radiograph. Where a body part contains thick, heavy bone surrounded by a large quantity of muscle and fat, as in the lumbar vertebral region, x-ray absorption differences become relatively wide (figure 1-8). The image of a calcified body (figure 1-9) outlined by the darker adjacent densities of its containing tissues also exhibits great tonal differences and provides easy visibility. Such parts present little difficulty in recording even though large errors in exposure may be made.

b. **Small Absorption Differences**. At times, absorption differences between some tissues may be very small, and in such cases, differentiation becomes difficult. The kidney, gallbladder, and liver areas are typical examples in which the x-ray absorbing power of the tissues is almost the same (figure1-10). The tonal differentiation of a small portion of lymphatic tissue within its surrounding tissues also cannot be a distinctive against its background density, as could a calculus because of the small tissue absorption differences. A shorter scale of contrast in the image would, therefore, be helpful and perhaps necessary.

1-12. RADIOGRAPHIC EXPOSURE

Radiographic exposure factors relating to image characteristics have two important aspects: photographic and geometric. The *photographic* aspect is related to quantity and *distribution* of silver deposited on the film and the *geometric* aspect is related to the *form and sharpness of* the image definition. Radiographic exposure sensitizes the silver bromide crystals within the film emulsion. This action is based upon the combined effects of (1) the intensity of the x-rays reaching the film from a given SID; (2) the time that the x-rays act on the emulsion; and (3) the wavelength of the x-rays. If the x-rays do not penetrate the object or body part and reach the film, there is no exposure; hence, no emulsion response.

Figure 1-8. Anteroposterior radiograph of the lumbar vertebrae, showing wide absorption differences.

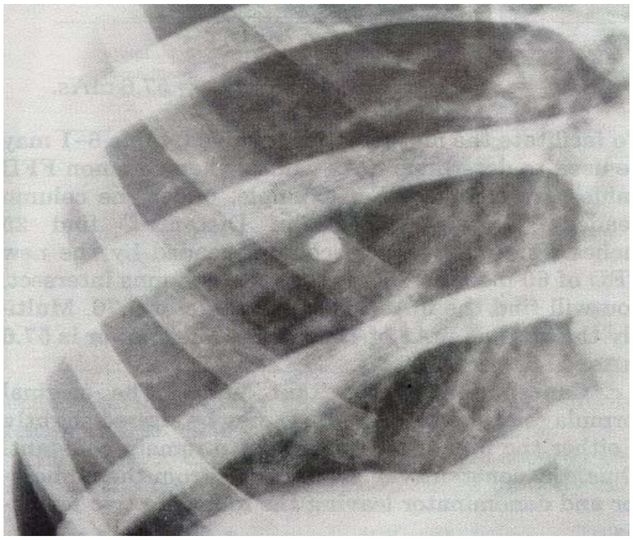


Figure 1-9. Portion of chest radiograph showing a calcification of high contrast against a low contrast background group of densities representing small differences in absorption by pulmonary tissues.

Figure 1-10. Radiograph of the kidney region that exhibits small differences in density because the tissues penetrated are almost comparable in tissue density.

1-13. VALUE OF CONSTANTS

To understand the many factors influencing the radiographic image, the function of each factor in the exposure system must be appreciated. The role of any factor must be determined by the use of the factor as a variable, while all other factors remain constant. The influence of development on the radiographic image must also be known in establishing the whole processing procedure as a constant; any variations in radiographic quality may then be attributed to exposure variations rather than to development. For example, to experimentally determine the radiographic influence of kVp in the exposure system, it should be employed as the variable and all other exposure and processing factors should be constant. The establishment of an exposure system should be based upon the employment as constants of those factors that have the greatest influence on the quality of the image and selection of one factor that possesses only a single radiographic function as the variable.

Section III. THE EFFECT OF SOURCE-TO-IMAGE DISTANCE ON DENSITY

1-14. SOURCE-TO-IMAGE DISTANCE

Source-to-image distance (SID) influences the density of the radiograph, the size and shape of the image of the part being examined, and the sharpness with which image details are rendered. Since intensity directly influences radiographic density, any change in distance will cause a change in density when other factors are constant.

1-15. APPLICATION OF INVERSE SQUARE LAW

Since x-rays diverge as they are emitted from the focal spot and proceed in straight paths, they cover an increasingly larger area with lessened intensity as they travel from their source. This principle is illustrated in figure 1-11. It is assumed that the intensity of the x-rays emitted at the focal spot remains the same and that x-rays cover an area of 4 square inches at the horizontal plane (C), 12 inches from FS. When the SID is increased to 24 inches to plane D or twice the distance between focal spot and C, the x-rays will cover 16 square inches an area four times as great as that at C. The intensity of the radiation per square inch on the plane at D is only one-quarter than at the level C. Thus, an adequate exposure at D must be increased four times in order to produce at D an equal radiographic density. (See the formula and example given in the following paragraph.) Table 1-1 may be used for determining the correct mAs multiplying factor when the SID is changed.

Original focus-film distance	New Source-to-Image Distance							
	20"	25"	30"	36"	40"	48”	60"	72"
20"	1.00	1.56	2.25	3.22	4.00	5.76	9.00	12.96
25"	.64	1.00	1.44	2.07	2.56	3.68	5.76	8.29
30"	.44	.69	1.00	1.44	1.77	2.56	4.00	5.76
36"	.31	.48	.69	1.00	1.23	1.77	2.77	4.00
40"	.25	.39	.56	.81	1.00	1.44	2.25	3.24
48"	.17	.27	.39	.59	.69	1.00	1.56	2.25
60"	.11	.17	.25	.36	.44	.64	1.00	1.44
72"	.08	.12	.17	.25	.31	.44	.69	1.00

Table 1-1. mAs conversion factors for changes in SID.

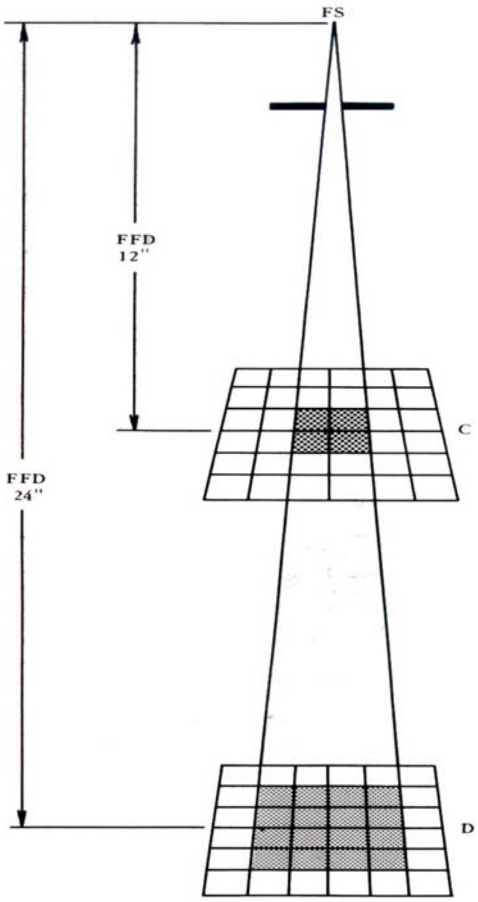


Figure 1-11. Change in distance influences radiographic density.

1-16. ARITHMETICAL RELATION OF mAs AND SID

a. **Rule**. The mAs required to produce a given radiographic density is directly proportional to the square of the film focal distance when the remaining factors are constant:

$$\frac{\text{Original mAs}}{\text{New mAs}} = \frac{\text{Original SID}^2}{\text{New SID}^2}$$

or:

$$\frac{mAs_l}{mAs_2} = \frac{SID_1^2}{SID_2^2}$$

b. **Example.** If an exposure of 10 mAs (mAsl) at an SID of 25 inches (SID1) is used and the SID is increased to 60 inches (SID2), what mAs (mAs2) must be used to maintain the same radiographic density? mAsl, SID1, and SID2 are known; mAs2 is unknown and must be solved for.

$$\text{mAs2} = \frac{\text{mAs}_1 \text{ x } \text{SID}_2^2}{\text{SID}_1^2} = \frac{10 \text{ x } 60^2}{25^2} = \frac{36{,}000}{625} = 57.6 \text{ mAs.}$$

NOTE: To facilitate the mathematics involved, table 1-1 may be used to determine mAs values when common SID values are changed. For example, under the column headed "Original Source-to-Image Distance," find 25 inches. Find the vertical column headed by the new SID of 60 inches. Where these two columns intersect will be found the mAs multiplying factor 5.76. Multiply the original mAs of 10 by 5.76. The answer is 57.6 mAs.

c. **Cancellation of Constant Value**. The original formula relating mAs and SID may be altered slightly if either the mA or the time (sec) is to remain constant. Thus the constant value will cancel from the numerator and denominator leaving the following two formulas:

Constant sec: $$\frac{\text{ma}_1 \text{ x sec}_1}{\text{mA}_2 \text{ x sec}_2} = \frac{\text{SID}_1^2}{\text{SID}_2^2} \text{ or}$$

$$\frac{\text{mA}_1}{\text{mA}_2} = \frac{\text{SID}_1^2}{\text{SID}_2^2}$$

Constant mA: $$\frac{\text{mA}_1 \quad \text{x} \quad \text{sec}_1}{\text{mA}_2 \quad \text{x} \quad \text{sec}_2} = \frac{\text{SID}_1^2}{\text{SID}_2^2} \quad \text{or}$$

$$\frac{\text{sec}_l}{\text{sec}_2} = \frac{\text{SID}_1^2}{\text{SID}_2^2}$$

Section IV. FUNCTION OF KILOVOLTAGE

1-17. INTRODUCTION

a. Of all the exposure factors, kVp has the greatest effect on the radiographic image when all other factors remain constant. Because kVp is the factor that gives the rays their penetrating quality, it directly influences the quality of radiation reaching the film. This, in turn, determines the radiographic contrast and density. Kilovoltage is a major agent in the production of SR that must be controlled to prevent fogging on the film. Use of low kVp may result in images deficient in details; injudicious use of high kVp may result in fogged or high-density images in which details are obscured by excessive silver deposits and a degradation of contrast.

b. kVp also has a limited effect on quantity of radiation. Because changing kVp varies the speed of the electrons, and therefore, the wavelength of radiation, an increase of kVp gives a corresponding increase in the number of diagnostic photons. Even though the major attribute of kVp is the variation in penetrating power kVp does affect, to a smaller degree, the quantity.

1-18. GREATER EXPOSURE EFFICIENCY BY USE OF HIGHER KILOVOLTAGE

Exposure efficiency is improved by the high-kilovoltage technique for the following reasons:

a. Anatomical details in all tissue thicknesses are rendered as translucent densities.

b. Greater image sharpness is obtained because shorter exposures may be used with a smaller focal spot.

c. The radiation dose to patients is reduced because the body absorbs less radiation than at the lower kVp; therefore, more radiation can reach the film to expose it and exposures can be reduced.

d. Heat production in the x-ray tube is reduced because smaller energy loads can be used, thereby increasing the efficiency and life of the x-ray tube.

e. Greater exposure latitude may be secured because of the narrowed absorption range of the body tissues.

f. The use of many radiographic techniques is possible.

g. More satisfactory radiography is possible when the source of electric power is variable or in state of constant flux.

1-19. RELATION OF kVp-mAs-SID-DENSITY

Radiographic density is not only influenced by kVp but it also varies with the mAs and SID used. In medical radiography, there is no simple mathematical method for determining kVp-mAs density ratios. Such factors as the thickness and density of the body tissues to be examined, the characteristics of the x-ray apparatus, and if the film is used with or without intensifying screens exert pertinent influences. Fairly close approximations between kVp and other exposure factors have been of necessity established by experience--by trial and error. There are two procedures that may be followed: one is used in determining the approximate change in mAs required to compensate for a change in kVp, the other in determining the change in kVp required for a given mAs change. Changing the kVp or mAs and keeping the density constant requires complex mathematical manipulations.

1-20. OVEREXPOSURE

When greater than necessary kVp is used, the overall density appears high with SR fog (figure 1-12). The contrast scale is degraded and detail is obscured. Usually, a reduction of 10 to 20 kVp will correct the appearance (figure 1-13). It may be necessary to adjust the mAs factor slightly. To avoid overexposure due to kVp, the optimum kVp for routine projections listed in Table 1-2 should be adhered to.

1-21. UNDEREXPOSURE

Use of inadequate kVp is characterized by blank, transparent areas without silver deposit and other areas having high densities--few intermediate tones of density are present (figure 1-14). An increase of 15 to 20 kVp will usually produce sufficient penetrating radiation to obtain the necessary detail, provided the mAs is also adjusted.

1-22. KILOVOLTAGE AND CONTRAST

Since the visualization of detail is dependent upon radiographic contrast kVp is an important factor. Radiographic details cannot become visible unless the radiation is able to penetrate the part being examined. When the radiation is optimum for a given part, numerous details become visible because of the large number of small density differences (figure 1-15).

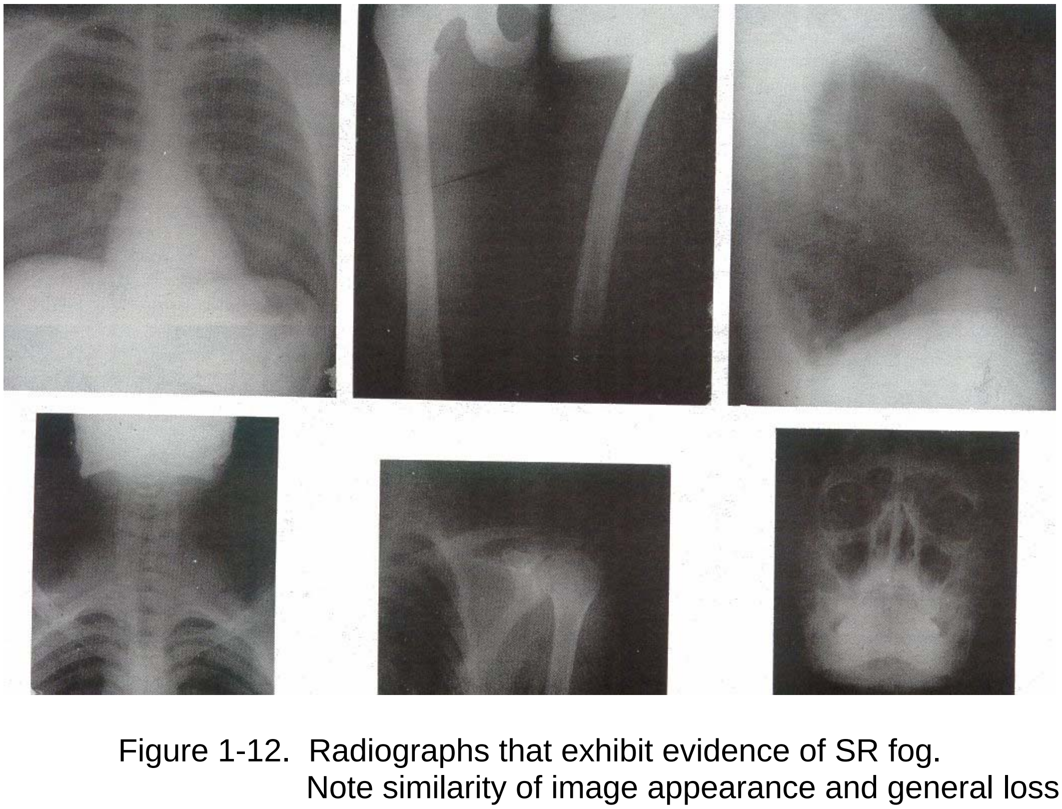


Figure 1-12. Radiographs that exhibit evidence of SR fog.
Note similarity of image appearance and general loss in satisfactory contrast.

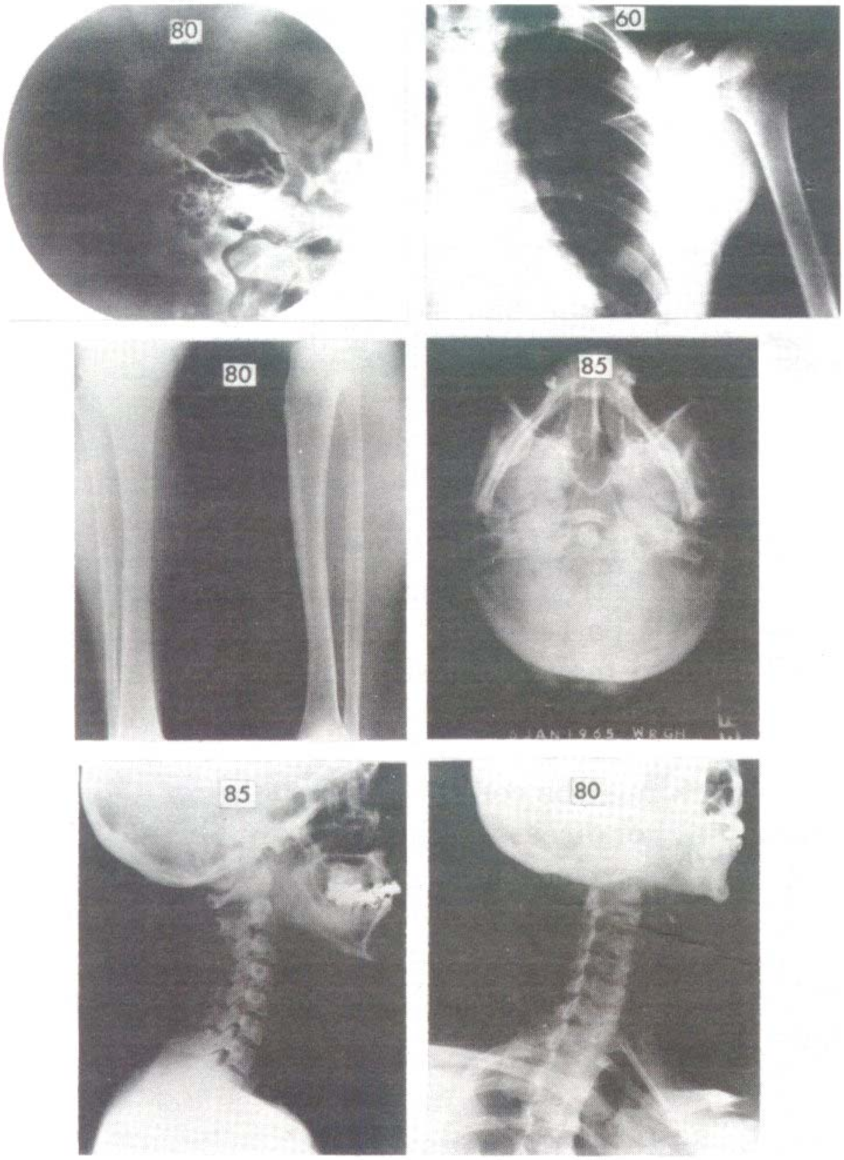


Figure 1-13. Radiographic examples that exhibit an abundance of details made possible by the use of optimum kVp for the part. (kVp is shown on each image.)

KVp	Regions
50	Thumb, fingers, toes Hand Wrist
60	Forearm, elbow, arm Foot, ankle
65	Leg, knee Cervical vertebrae (PA)
70	Lumbar vertebrae (PA) Pelvis Mandible
75	Thigh, hip
80	Shoulder, clavicle Chest (thin)
85	Cervical vertebrae (Lateral) Thoracic vertebrae Skull Sinuses Chest (average thickness)
90	Chest (thick)

Table 1-2. Standard kVp settings for various anatomical parts of average thickness.

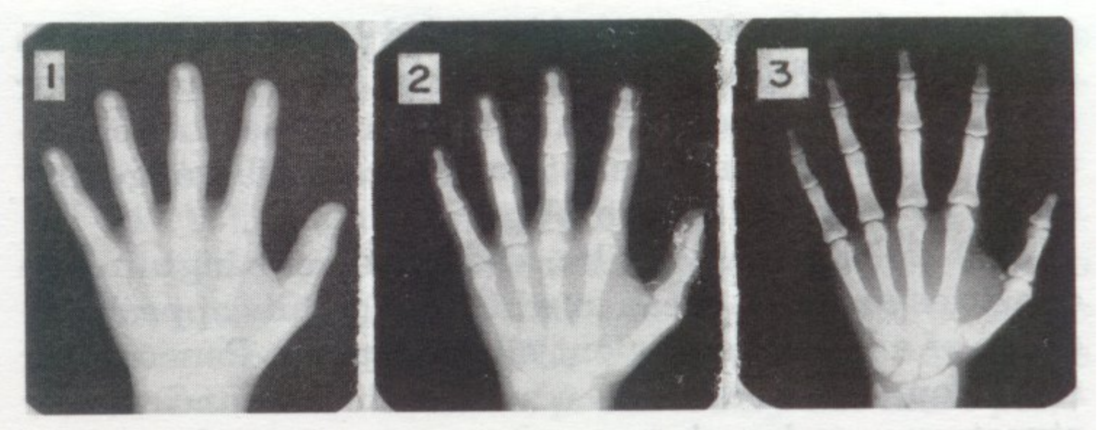


Figure 1-14. Radiographs of the hand made with insufficient kVp. Numerals indicate exposure sequence. Exposure 1,120 mAs; 2,240 mAs; 3,480 mAs; all at kVp 30.

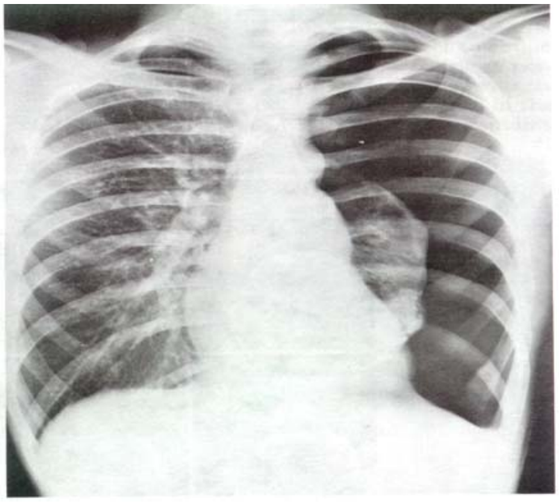


Figure 1-15. Radiograph of the chest demonstrating the wide range of radiographic densities required for diagnostic purposes. This radiograph exhibits long-scale contrast.

1-23. CONTRAST WITHOUT FOG

Figure 1-16 consists of a series of radiographs of a dried skull and illustrates the influence of kVp on contrast. The absence of fluids in the specimen eliminates in large measure the influence of SR on the image. The images, therefore, may be considered free of SR fog. The radiographs were exposed in 5-kVp increments from 45 to 100 kVp. The density effect of each kVp adjustment was offset by compensating mAs. As a guide in mAs compensation, a step-wedge was recorded in each radiograph--the density of its third step being used as a "control." This density was maintained constant for all kVp. The procedure made it possible to demonstrate the constant characteristics of each skull image produced by each advance in kVp.

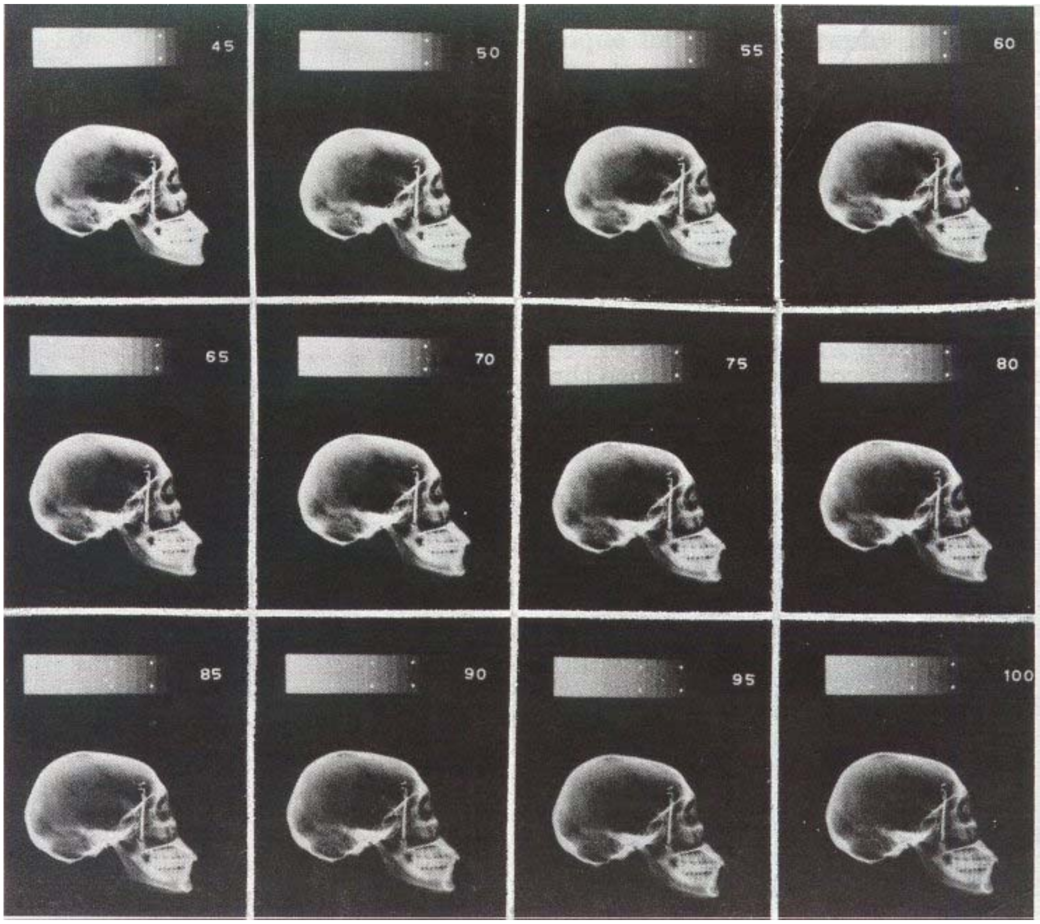


Figure 1-16. Radiographs of a dried skull demonstrating the influence of kVp on contrast and its relation of detail (kVp is shown on each image).

a. In the 45-kVp film, there are very high image densities and also areas in which no details appear because of a lack of sufficient silver deposit. Penetrating radiation was needed to traverse the thicker and denser structures, such as the jaws, pars petrosae, and superior portions of the vault. With an increase in kVp, some details in these latter structures appear. At 90 and 100 kVp, all structures were thoroughly penetrated and all radiographic details are visible. In comparing the 45-kVp and 100-kVp radiographs, a difference in "brightness" of the images is manifest. The lower-kvp film attracts the eye at once because of its brilliance; short-scale contrast exists. The eye ignores the absence of a large number of details representative of the anatomy. The few details adequately recorded are composed of rather heavy silver deposits and a rapid fall-off in image density occurs in areas representing the thicker or denser anatomical structures. Also, the distribution in densities is unequal. At 100 kVp, there is a uniform distribution of translucent densities over the entire image. This radiograph has a lower level of "brightness," but the image contains an abundance of details, which are necessary for diagnostic purposes; long-scale contrast exists. The contrast scale lengthens as the kVp rises. Examples of long-scale contrast radiographs are shown in figure 1-13.

b. This does not mean that low kVp always produces radiographs of inferior quality. Some soft-tissue examinations, for example mammography (radiography of the female breast), *require* low kVp for differentiation of tissues.

1-24. KILOVOLTAGE AND EXPOSURE LATITUDE

Exposure latitude varies with the kVp applied and is the range between minimum and maximum kVp that will produce a diagnostically acceptable scale of translucent densities. Exposure latitude is an important element in any standardized exposure system. Since "correct exposure" may be any one within a fairly wide range if the kVp is adequate for thorough penetration, use of an optimum kVp is more likely to produce greater uniformity of radiographic results than would the use of relatively low variable kVp. A general rule is the longer the scale of radiographic contrast, the greater is the exposure latitude.

1-25. WIDE EXPOSURE LATITUDE

a. When optimum kVp values are used, the exposure latitude is wide because long-scale contrast is produced in the image that can compensate at times for wide errors in mAs. The large number of densities with small tonal differences produced by the more penetrating radiation serves to retain image details in the thin and thick portions of the part.

b. Figure 1-17 depicts a series of anterior-posterior (AP) direct exposure radiographs of the elbow in which the optimum kVp was 60, the SID of 30 inches, and the mAs varied in steps of 15 mAs from 30 to 165. The exposure latitude may be considered to range between 60 and 150 mAs because visualization of all required details was attained in the images, although they possessed varying degrees of density. The extremes in density shown in this range, however, are not recommended for routine radiography. Selection of the optimum density may be made by choosing three adjacent radiographs in the series that approach most nearly the required density--75, 90, and 105 mAs. A desirable density may be considered as produced by about 90 mAs.

1-26. NARROW EXPOSURE LATITUDE

a. Exposure latitude is usually narrow when short-scale contrast prevails, as produced by the lower kVp. The small number of usable densities present requires that exposure be more nearly correct in order to produce a useful radiograph. The scale of contrast, however, is seldom such that all desired tissues are shown in the same image, particularly if a subject contains widely different densities to be recorded. Also, narrow exposure latitude (low kVp) often requires a high impractical mAs setting.

b. Figure 1-18 shows a series of three screen-grid lateral radiographs of a skull, made with 55 kVp, 36-inch SID, and 50, 100, and 150 mAs. The 50 mAs image is underexposed; the 100-mAs radiograph shows the facial bones with excessive silver deposits, but some parts are underexposed; and the 150-mAs image shows opaque silver deposits in the facial area, with some other parts well shown, but some parts still not recorded. This illustrates how the extremes of short-scale contrast produce images, which are not fully informative.

Figure 1-17. Direct exposure radiographs of the elbow demonstrating exposure latitude (mAs value is shown on each image).

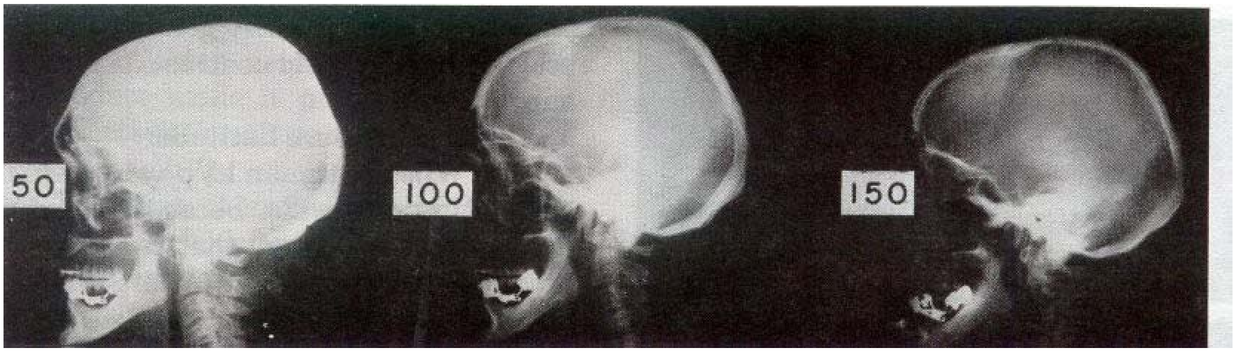


Figure 1-18. Lateral screen grid radiographs of the skull at 55 kVp (mAs value is shown on each image).

Section V. FACTORS INFLUENCING SECONDARY RADIATION FOG

1-27. INTRODUCTION

Secondary radiation fog, a *supplemental* density, is a fairly uniform veil of silver overlying the image. It is produced by stray radiation, both that produced in the tissues (secondary radiation) and also that diverted from its straight path as it passes through the tissue (scatter radiation). If it occurs with any great density, it prevents the visualization of detail and badly affects the general quality of the image. By controlling the amount of SR reaching the film, the detail and general quality of the image can be protected. Figure 1-12 consists of radiographs that exhibit SR fog, The images have a dull gray appearance and lack important details.

1-28. INFLUENCE OF TISSUES

a. The quantity of SR emitted by human body tissue depends upon:

(1) Tissue thickness. The radiation emerging from a tissue thickness of 6 inches may assume a ratio of SR to remnant radiation of 5 to 1; and, with greater thicknesses, it may rise as high as 10 to 1. Relatively little SR fog will appear on radiographs of thin parts of the body (such as the hand, wrist, elbow, foot, and ankle).

(2) Tissue density. The greater the fluid content (hydration) of a tissue, the larger the amount of SR emitted.

b. Since the structural composition and thickness of a normal body part are relatively constant, the amount of SR emitted by a particular part are relatively constant, the amount of SR emitted by a particular part may be considered a constant for a given kVp. When there are tissue abnormalities, however, these must be taken into consideration. For example, an injured knee joint containing excess fluid may produce a much larger quantity of SR than a normal knee. Exposure factors must be altered and various fog controlling accessories employed.

1-29. INFLUENCE OF KILOVOLTAGE

The characteristics of primary radiation can be changed by kVp, with control of SR fog and favorable image quality. With the increase of kVp, the quantity of fog produced reaches a point where it exceeds many times the density produced by remnant radiation. This means that the desired image may be almost completely hidden because of the fog. The more the image is veiled by fog, the less detail is affected by factors that would normally alter it.

a. In figure 1-19, a series of chest radiographs illustrate that as kVp advances, radiographic density and fog increase. These radiographs were exposed with a range of 50 to 100 kVp in increments of 10 kVp; the mass and al other factors were constant. SR in this case comes, of course, from the human thorax. In the 50-and 60-kVp radiographs, no perceptible fog is shown on the images. In the 80-kVp radiograph, the overall density is increased, and the fog density can be visually separated from the density produced by remnant radiation. The combined densities rapidly gain in silver concentration as kVp advances. The fog density is obvious in the 90- and 100-kVp radiographs.

b. To balance densities and secure a satisfactory image, mass must be changed to offset the density influence of increased kVp, along with measures to diminish the amount of SR. Figure1-20 shows a series of posteroanterior (PA) radiographs of the chest, with a range of 40 to 100 kVp in increments of 5. The overall density effect of kVp was compensated by changing mass values. All the radiographs are relatively free from fog and the images more nearly in accordance with their true tissue-absorption pattern. Since the 90- and 100-kVp radiographs (K and M, figure 1-20) show a small amount of fog, 80 kVp (1, figure 1-20) seems to be the optimum value to use in PA (posterior-anterior) chest radiography.

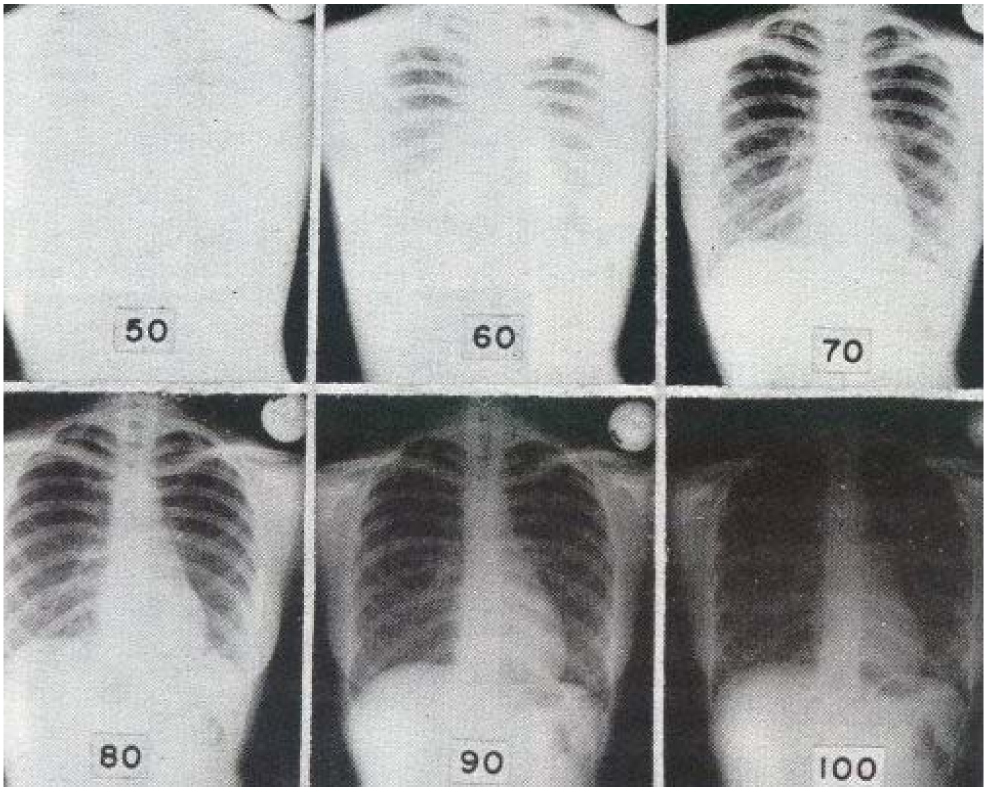


Figure 1-19. Series of chest radiographs demonstrating that at the kVp advances and all other factors are constant, radiograph density increases (kVp is shown on each image).

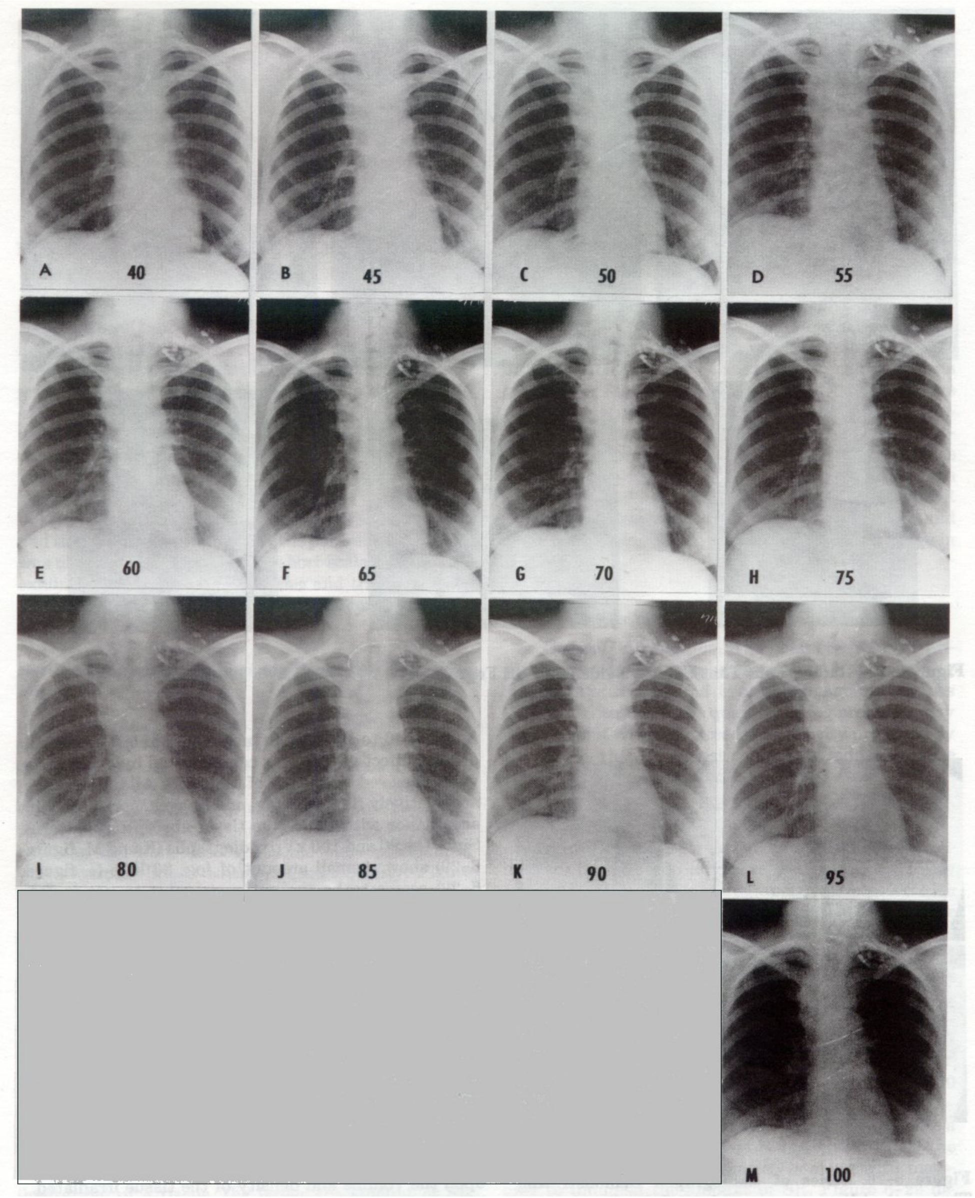


Figure 1-20. Series of screen radiographs of the chest in which mass was decreased in compensation for increasing kVp density effect. (kVp is shown on each image.) mass factors: A, 70; B, 40; C, 20; D, 10; E, 8.3; F, 6.3; G, 5; H, 4.12; I, 3.3; J, 2.5; K, 2; L, 1.6; M, 1.6.

Section VI. METHODS OF CONTROLLING FOG

1-30. KILOVOLTAGE

When reducing the kVp as a means of reducing fog, image details distant from the film may still be fogged. Given correct exposure, structures nearer the film are usually rendered satisfactorily. Use of lower kVp helps to increase contrast of nearer structures, but often results in insufficient penetrating radiation. Use of higher kVp brings with it more SR, depending upon the volume and density of the tissue. Therefore, for a given projection, there are lower and upper limits for kVp settings. Between these limits is an optimum setting, which assures penetration with an acceptable fog level. An acceptable image may require various other means of SR control.

1-31. EFFECTS OF HIGHER KILOVOLTAGES

Radiographs made with a high kVp often exhibit excessive densities. It may be difficult to determine whether the densities are due to overexposure by remnant radiation (RR) or by SR. The best and easiest first step would be to cut mass in half. This should produce either a correct exposure or one from which the correct setting can be judged, and the excessive fog will have been greatly reduced. By using this rule-of-thumb method of halving the mass when overexposure occurs or doubling it when underexposure exists, an image of the desired density can be obtained. If not, an additional small mass adjustment should correct the image. The kVp need not necessarily be reduced.

1-32. EFFECTS OF LOWER KILOVOLTAGES

When overexposure occurs with a low kVp (50 kVp, for example), it is generally not complicated by excessive SR fog. Halving the mass should produce an approximately correct density. The kVp should not be lowered further. Figure 1-21 depicts two PA radiographs of a hand made with 50 kVp and 100 mass (A, figure 1-21) and 50 mass (B, figure 1-21). The image in A, figure 1-21, shows low fog level with high density. By halving the mass, a satisfactory image was obtained (B figure 1-21).

1-33. GRIDS

Secondary radiation is produced both by the beam passing through the patient's body and also by its passage through the table. Numerous centers of SR are set up through the irradiated part (figure 1-22). The radiation thus produced tends to fog the film and cover the image. This often makes the use of grids necessary.

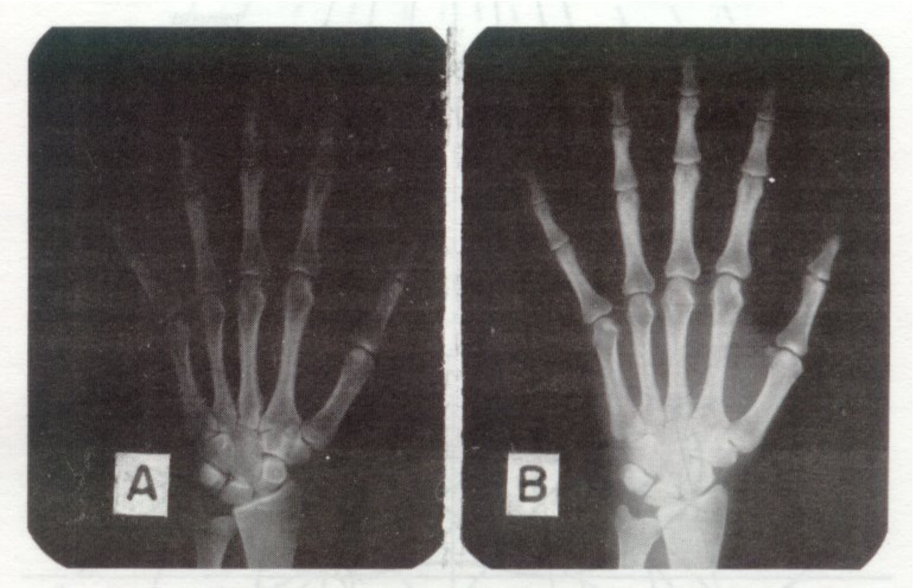


Figure 1-21. Two PA radiographs of the hand using 50 kVp. mass factors: A, 100; B, 50.

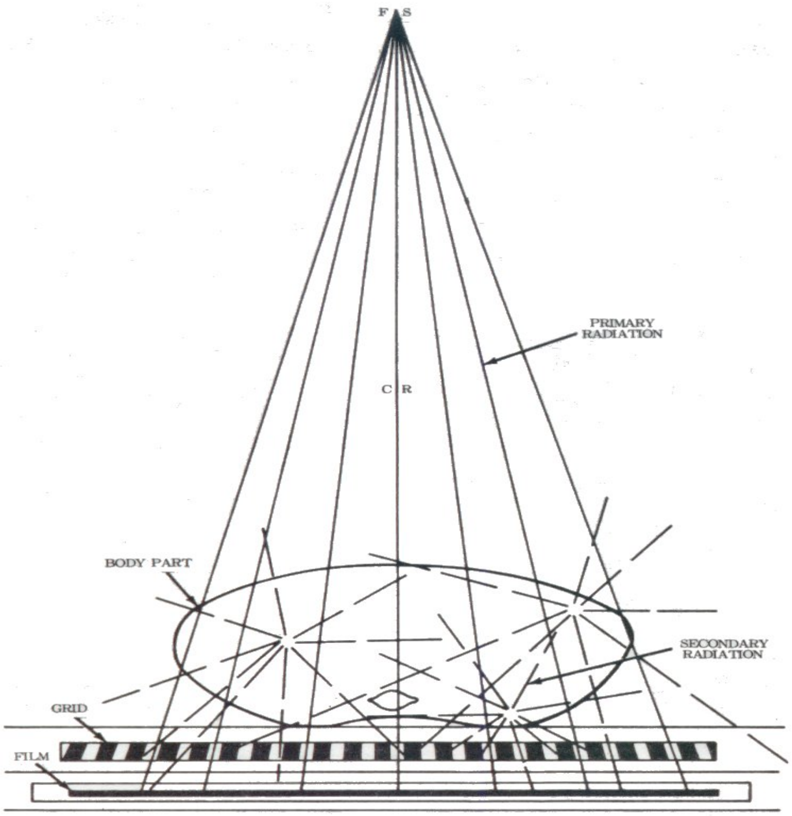


Figure 1-22. Absorption of secondary radiation by lead strips in the grid.

1-34. FUNCTION OF GRIDS

The function of a grid is to absorb SR before it reaches the film. Although all SR cannot be absorbed by the grid, it can be greatly reduced. The two grid types most commonly used are the stationary wafer grid and the Potter-Bucky grid diaphragm; the basic principle and structure are the same.

1-35. THE STATIONARY WAFER GRID

The stationary wafer grid is composed of alternate strips of lead and a radio-translucent (x-ray transparent) substance, such as wood, aluminum, or a synthetic material. The strips are placed parallel to each other and form a very thin, rectangular sheet the same size as the x-ray film. The grid is inserted between the patient and the film so that the strips are lined up vertically beneath the patient's body. The primary radiation emitted from the focal spot of the tube passes between the lead strips to reach the film. Since the SR is unfocused and is traveling in all directions, most of it strikes the lead strips at large angles and is absorbed, thus having little effect upon the film (figure 1-23). As much as 90 percent of the SR can be absorbed by the stationary wafer grid.

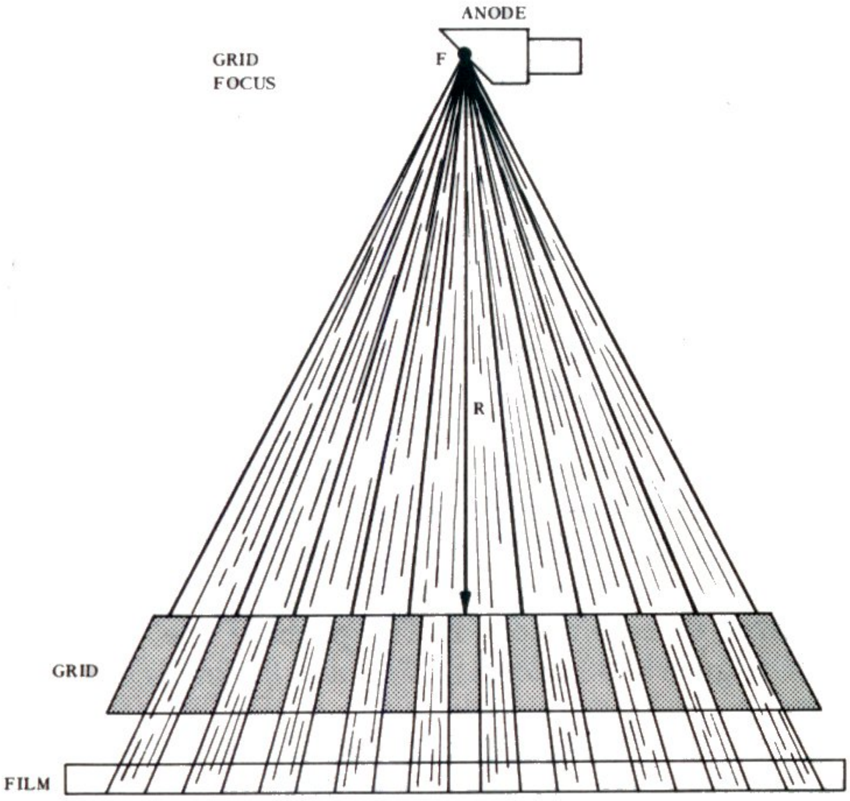


Figure 1-23. The Potter-Bucky focused diaphragm. Extension of the directions of the tilted lead strips are indicated by broken lines which intersect at the imaginary point called the *grid focus.*

a. The use of such a grid, therefore, greatly increases the diagnostic value of the radiograph, because it greatly improves the quality of the image. Even though an image of the lead strips in the grid appears on the radiograph as evenly spaced thin white lines, they are not a disadvantage from the diagnostic standpoint. At the normal viewing distance of about 30 inches, the lines can seldom be seen.

b. Normally, wafer grids are focused--that is, the lead strips are not parallel. Special care must be exercised in the use of this type of grid. If it is used at too short or too long SID, the outside edges of the radiograph will be underexposed because the outer rays will be absorbed by the lead strips. The beam must also be exactly perpendicular to the center of the grid, because tilting the beam across the lead strips will lead to uneven absorption.

1-36. NECESSITY FOR INCREASING EXPOSURE

When a grid is used, the lead strips absorb a considerable amount of energy. Because of this, the exposure must be increased by adding kVp or mass in order to maintain image density. Since the grid is very thin, there is little increase in the object-to-film distance (OFD) and, therefore, only minor distortion of the radiographic image.

1-37. GRID RATIO

The effectiveness of a grid in absorbing SR is determined by the grid ratio. The grid ratio is that of lead strip depth to radiolucent spaces width. For instance, a grid with 0.25-mm translucent spaces and 2-mm deep lead strips would have a grid ratio of 2 0.25, or B. Such a grid would be called an 8:1 grid, a common ratio. The efficiency of grids increases with increased grid ratio. This means that an 8:1 grid is more efficient than a 5:1 grid. With the lower grid ratios, less fog is eliminated, but more latitude is allowed in positioning and in SID selection.

1-38. USE WITH CASSETTES

Grids are available in varying sizes and are used according to the size of the cassette to be covered. However, grids larger than cassettes may be used if carefully supported by a wooden frame. Without this support, the thin grid would be bent. There is one advantage to the lightness of the grids, in that they are fairly easy to use with portable equipment and for radiography of thick body parts in an upright position. Intensifying screens are normally used with grids to counteract the absorption of rays, but sometimes a screen is not used, particularly in exposures of ribs, shoulders, and knees. While this may produce good radiographic results, the patient is likely to receive a large dosage of radiation. Grid cassettes containing built-in grids and screens are frequently used.

1-39. THE POTTER-BUCKY DIAPHRAGM

The Potter-Bucky (P-B) diaphragm is a grid that moves across the film during the exposure. It is placed between the patient and the cassette. The strips of lead and radiotranslucent material may be thicker than those of stationary grids because the movement of the grid during the exposure keeps the shadows of the lead strips from appearing on the radiograph.

1-40. THE FOCUSED BUCKY

The P-B diaphragm in general use is a focused grid: The lead strips are inclined so that, if extended, they would meet a focal point. Ideally, the x-ray tube should be placed exactly at this point (figure 1-23). The vertical distance between the grid focus and the center of the grid is called the grid radius (R, figure 1-23). An 8:1 grid, however, will be efficient if the SID is not changed by more than plus or minus 25 percent of the grid radius; SID longer or shorter than this will produce a decrease in density near the edges of the radiograph (figure 1-24). The beam must not be tilted across the lead strips for the same reason. However, tilting the beam parallel to the lead strips does not cause a variation of density. Since the Bucky is positioned under the top of the radiographic table with the lead strips parallel to the long axis of the table, the beam may be tilted along the table's long axis, but not tilted across the table. To obtain the highest degree of grid efficiency, care must be taken to direct the tube toward the center of the grid. The decrease in efficiency caused by an off-center position of the tube is the same as when angling the tube (figure 1-25).

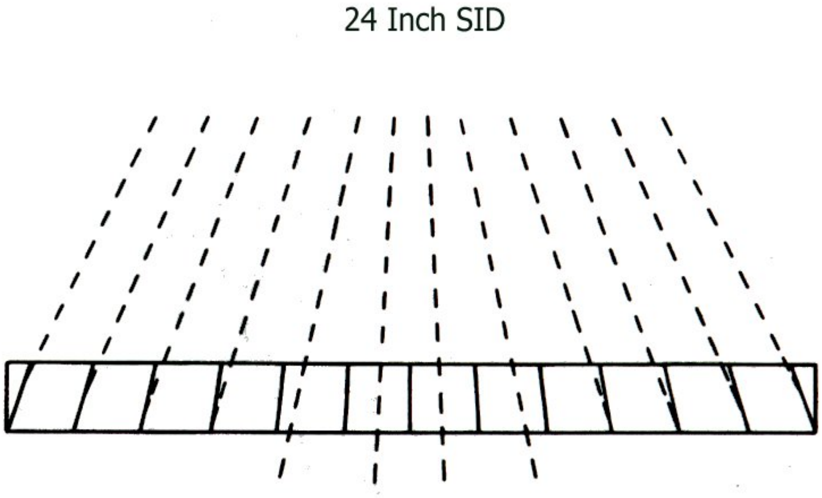


Figure 1-24. Effect of SID of less than 25 percent of the grid radius. Note increase in absorption of rays by the lead strips toward the edge of the film.

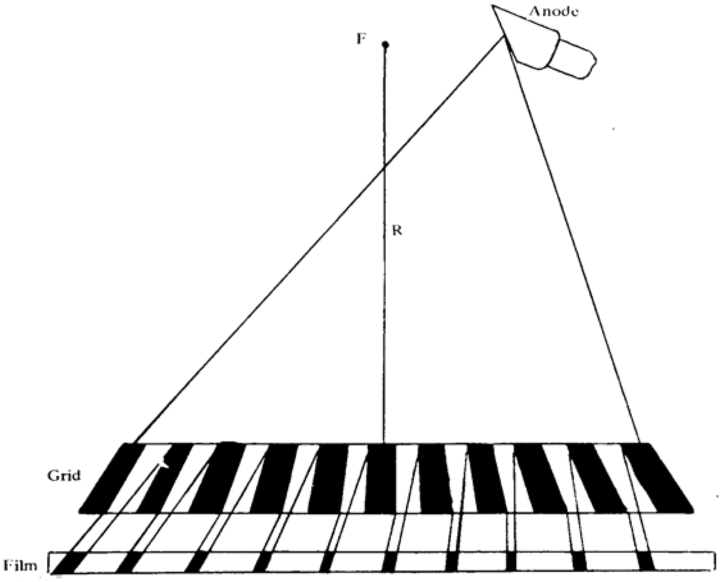


Figure 1-25. Effect of angled or off-center ray

a. It is important that a focused grid, which has a "film side" and a "tube side", be placed correctly, with the film side toward the film. The edges of the radiograph will be virtually unexposed if the grid is inverted.

b. The most commonly used grid ratios in P-B diaphragms are 8:1 and 12:1. When changing from grid to nongrid, nongrid to grid, or from one grid to another, appropriate changes in the technique must be made.

(1) One conversion system is outlined below:

Ratio	Nongrid to Grid	Grid to Nongrid
5:1	+15 kVp or 2.5 x mAs	-15 kVp
6:1	+15 kVp or 2.5 x mAs	-15 kVp
8:1	+20 kVp or 3.5 x mAs	-20 kVp
12:1	+25 kVp or 4.5 x mAs	-25 kVp
16:1	+30 kVp or 5.5 x mAs	-30 kVp

(2) Another conversion system is as follows:

Ratio	Nongrid to Grid	Grid to Nongrid
5:1	+10% of kVp	-10% of kVp
8:1	+15% of kVp	-15% of kVp
12:1	+20% of kVp	-20% of kVp
16:1	+25% of kVp	-25% of kVp

(3) The different conversion systems given above represent different schools of thought. In the first, the nonlinear aspects of kVp are not considered important; in the second, they are taken into account by using percentages. Both systems are expected to produce adequate results.

1-41. POTTER-BUCKY MECHANISMS

The movement of the P-B diaphragm during the x-ray exposure is accomplished by a mechanism, which moves the grid between the patient and the film. Two types of P-B diaphragms have been used.

a. The manual cock-type utilized a spring for this movement. The motion is in one direction and for a limited distance. Each time the grid is used, the spring must be stretched by a cocking device and the grid held in place by a releasable catch. A hydraulic timing device is used to control the speed of the grid motion. The grid should move slightly longer than the exposure time to ensure motion of the grid during the whole exposure. The difference should not be too great, because if the grid moves too slowly, the film may show grid lines-as a result. The grid is released just prior to exposure by either a manual or an electrical remote control switch. A bell rings upon completion of the grid motion. A manual cock-type Bucky is not used for exposures shorter than 3/4 sec. Potter-Bucky diaphragms are seldom seen in modern x-ray equipment.

b. The reciprocating grid is generally preferred, and utilizes an electric motor to move the grid back and forth above the film. The device that moves the grid be so designed that the time during which the grid stops at each end of its sweep is as short as possible. Grid motion is automatic with the exposure. Ordinarily, reciprocating grids may be used for exposures as short as 1/20 sec. However, some high-speed grids may be used for exposures of even shorter duration.

1-42. GRID LINES ON FILM

The appearance of grid lines on the film when the Potter-Bucky is utilized is usually caused by the following errors:

a. The exposure is started before the grid is travelling at full speed.

b. The exposure is prolonged after the grid has stopped moving or the movement has slowed down.

c. There is irregularity in the movement of the grid (which may occur if anything rubs against the grid, restraining its motion).

d. The tube target is not aligned with the center of the diaphragm.

e. There is improper synchronism between the movement of the grid strips and pulsations in the tube current. If the speed of the grid is such that succeeding lead strips are always above a given point on the film at the instant when the pulsations of the current produce penetrating rays (at kVp), images of the grid will appear on the film.

1-43. MODIFICATION OF THE PRIMARY BEAM

Besides avoiding excessive kVp and controlling SR with grids, modifying the primary beam is also a way of avoiding excessive SR. If the volume of irradiated tissue is kept as small as possible, the quantity of SR will be reduced in proportion. For this reason, the size of the field of entry of the x-ray beam must be limited to the smallest possible area that will cover the area of diagnostic interest. There is no reason, for instance, for irradiating an area much larger than the film being used. The size of the field of entry is restricted by using such devices as cones, cylinders, diaphragms, or collimators in the path of the primary beam. Figure 1-26 shows a cone, a cylinder, and a diaphragm.

1-44. CONES, CYLINDERS, DIAPHRAGMS, AND COLLIMATORS

Besides reducing the amount of SR produced (figure 1-27) and thereby improving the quality of the radiography, these devices also reduce radiation damage to the patient. Placed close to the x-ray tube, they absorb the wide-angle radiation that would not form a **useful image. They do not focus or bend the x-ray beam, but rather absorb the unwanted part of the beam.**

a. **Cones**. A cone-shaped metal tube that absorbs unwanted divergent rays (A, figure 1-26) is known as a cone. The purpose of the cone is to produce a limited beam of radiation so that a specific size film is completely covered.

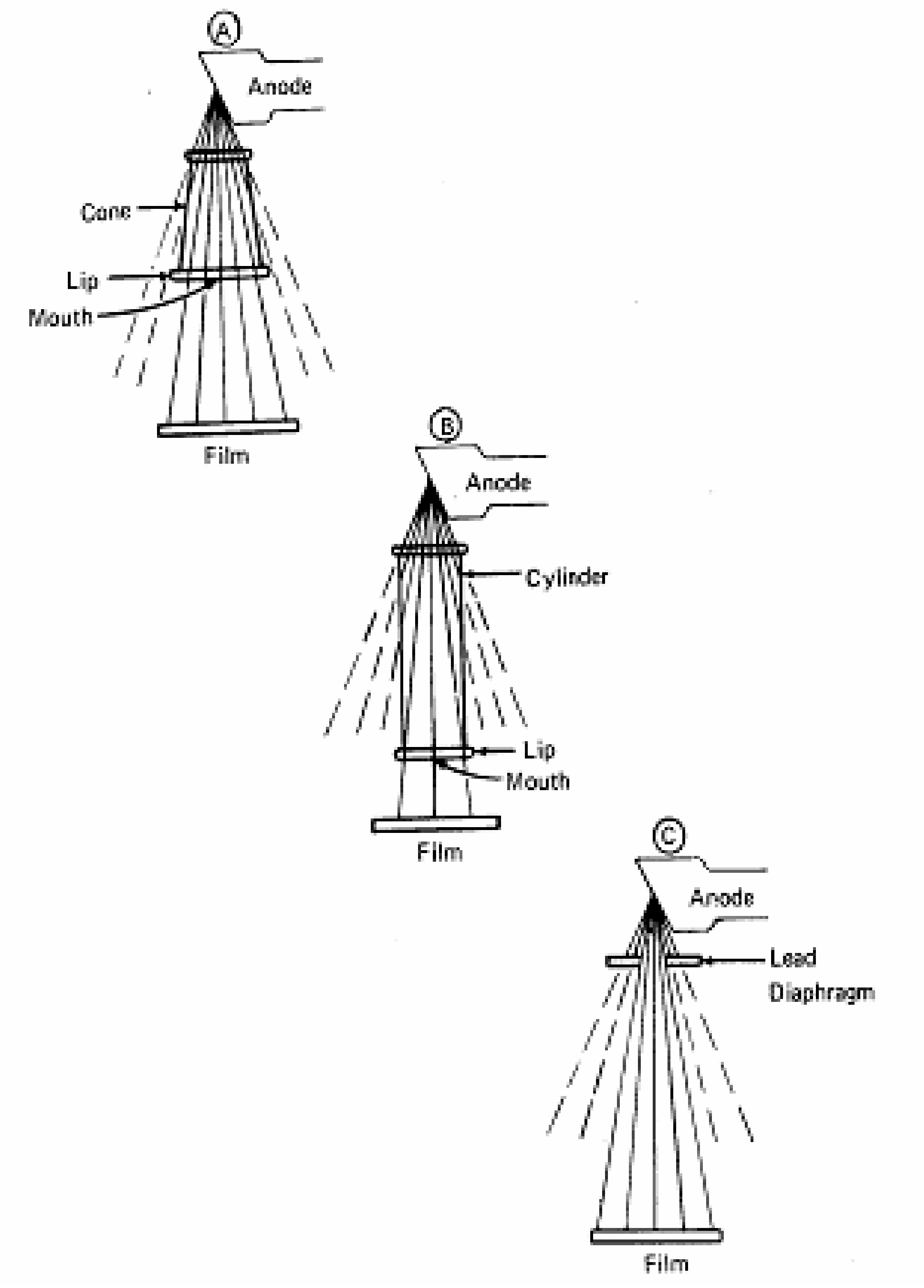


Figure 1-26. Cone, cylinder, and diaphragm.

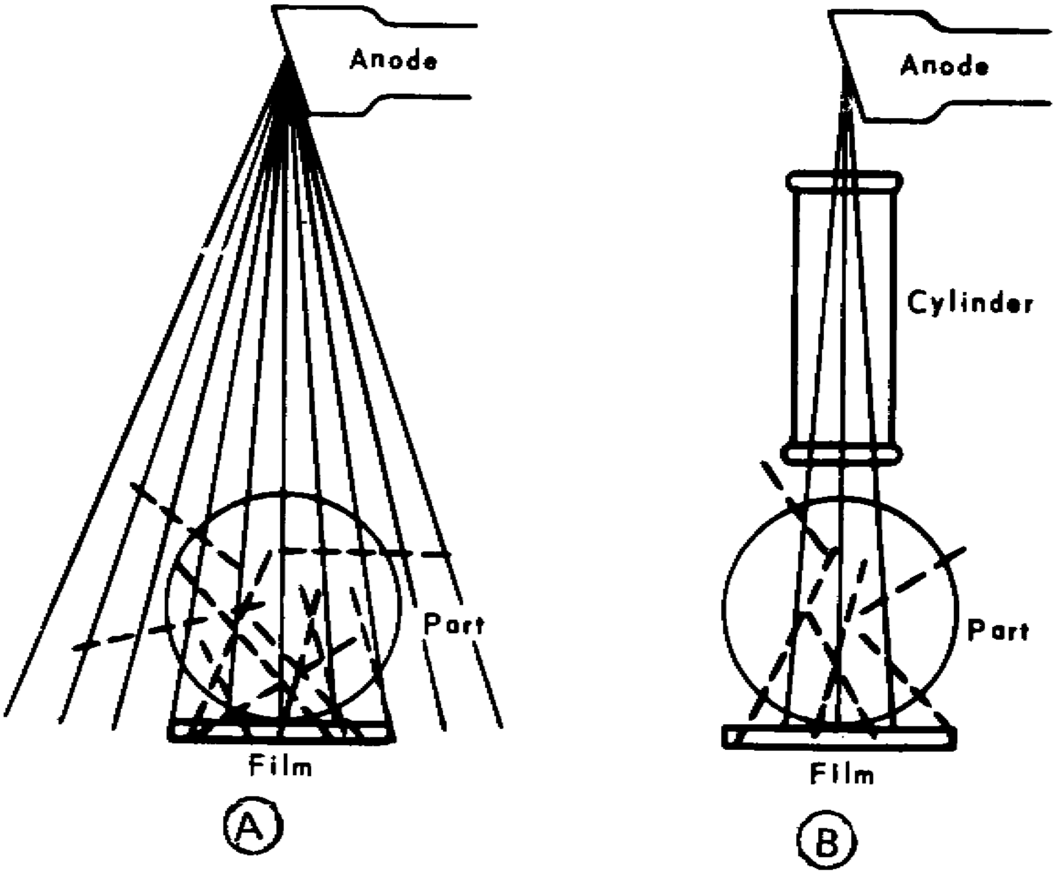


Figure 1-27. Effect of cylinder on secondary radiation formation.

b. **Cylinders**. A cylindrically shaped metal tube that absorbs the unwanted part of the beam (B, figure 1-26) is called a cylinder. The cylinder differs from the cone in that the cylinder is used to project a small beam of radiation to the center of the film. Most cylinders are extension cylinders that can be extended in length. As the cylinder is lengthened, the cone field becomes smaller; as it is shortened, the cone field becomes larger.

c. **Diaphragms**. A diaphragm consists of a piece of lead with a small hole cut into it (C, figure 1-26). Unwanted radiation is absorbed by the lead while useful radiation passes through the hole to the film. The diaphragm usually is used only when cones or cylinders are not available, but it may be made to produce almost any size cone field desired.

d. **Collimators**. The best all around device for restricting the primary beam is the collimator. It has a series of adjustable shutters, which provide a variety of square and rectangular x-ray fields. In addition, the collimator projects a light, which indicates the actual x-ray field.

(1) Collimators should be checked periodically to make sure the light field coincides with the radiation field. Simply mark the boundaries of the light field on a cassette with an opaque marker, and make an exposure. Any discrepancies discovered should be corrected according to the manufacturer's brochure.

(2) Some collimators are automatic; that is, they automatically adjust to the film size when the Becky is used.

1-45. GEOMETRY OF FILM COVERAGE

a. Using the principle of similar triangles, the size of the cone field can be found for cones, cylinders, or diaphragms. The factors, which determine the diameter of the cone field (DCF), are: (1) SID, (2) distance from the anode to the lip or bottom of the cone (ALD), and (3) the diameter of the mouth of the cone (DC) (figure 1-28).

b. Mathematically, the relationship may be expressed as:

$$\frac{\text{SID}}{\text{ALD}} = \frac{\text{DCF}}{\text{DC}}$$

c. When used with cones, the unknown factor is the DCF, in which case the Source-to-Image Distance (SID), anode-lip distance (ALD), and the diameter of the cone (DC) are dictated by the situation. When a cylinder is used, the SID, DC, and desired DCF are always known, the unknown factor being ALD (degree of extension of the cylinder). In this case, the ALD must be adjusted to produce the desired DCF. In making a diaphragm, the ALD is determined by the position of the filter slot in the tube head where the diaphragm is to be placed. If the SID is fixed, a hole has to be cut that will produce the specific-sized cone field. The size of the hole needed can be found by solving for DC.

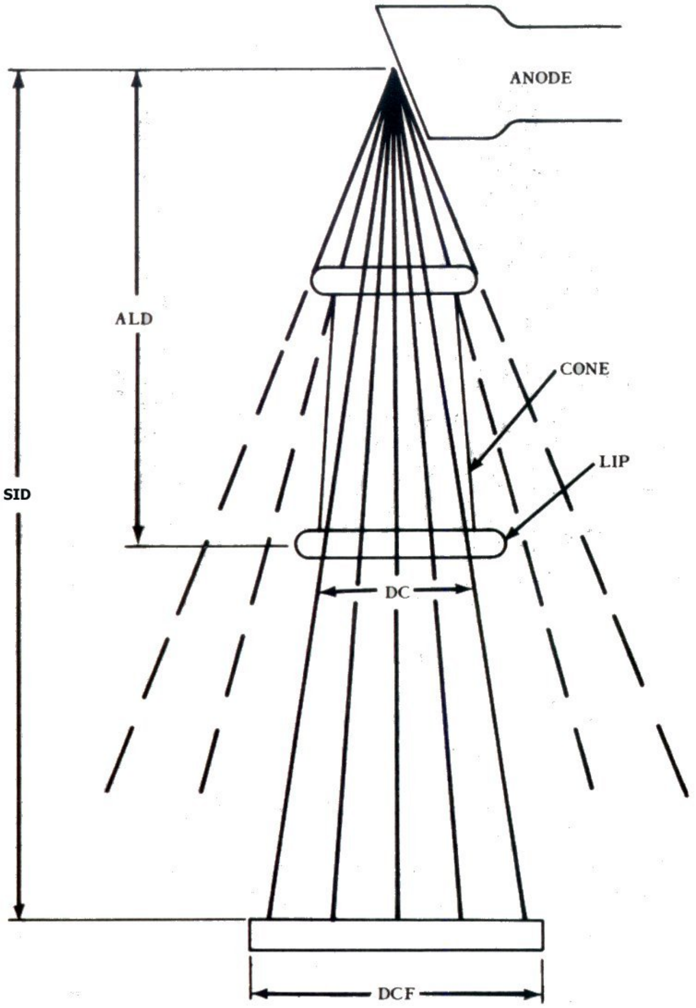
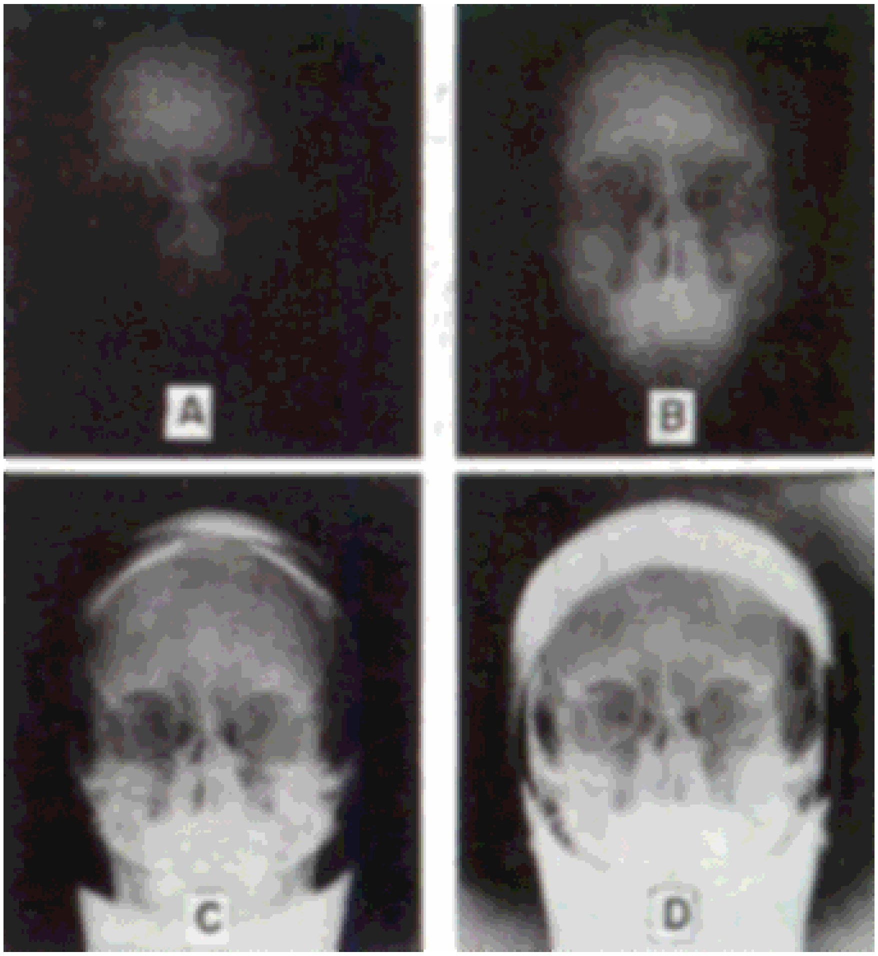


Figure 1-28. Determination of film coverage using a cone.

1-46. RATIO OF SECONDARY RADIATION TO REMNANT RADIATION

The ratio of SR to RR emitted by thin parts is small, irrespective of the size of the field. However, thicker and denser structures will produce a very disadvantageous ratio unless great care is taken with all factors. One such part is illustrated in figure 1-29. In this figure, the radiographs of frontal sinuses were all exposed using the same factors. A was made without a cone, and shows a high density mainly because of fog. B was made with a large cone, and the fog is slightly reduced. C was made with a smaller cone, and the fog has been greatly reduced. D was made with a cone of the correct size, and shows all anatomic details clearly and with a minimum of fog. When a collimator is used and the entire film area is to be exposed, the beam should be limited to the film size. When using a cone, cylinder, or diaphragm, the diameter of the cone field should be no larger than the film diagonal.



A - Without a cone
B - With a large cone
C – With a small cone
D – With a cone of correct size

Figure 1-29. Screen radiographs of the frontal sinuses which were all exposed with the same factors.

Continue with Exercises

EXERCISES, LESSON 1

INSTRUCTIONS. Answer the following exercises by marking the lettered response that best answers the question or best completes the incomplete statement or by writing the answer in the space provided.

After you have completed all of these exercises, turn to "Solutions to Exercises" at the end of the lesson and check your answers. For each exercise answered incorrectly, reread the material referenced with the solution.

1. What is the name of the radiation, which emerges from the body to expose the x-ray film?

   a. Filtered.

   b. Remnant.

   c. Stray.

   d. Intensifying.

2. What is SR?

   a. Both scatter radiation and secondary radiation.

   b. Unused remnant radiation.

   c. X-rays absorbed by the filter.

   d. Stray radiation from the tube head.

3. In order for a radiograph to have maximum diagnostic value, it should have:

   a. Uniform silver deposits.

   b. Uniform tone value.

   c. Numerous shades of gray.

   d. Numerous highlights.

4. Contrast scale is affected by which of these technique factors?

   a. Distance.

   b. Time.

   c. mA.

   d. kVp.

5. Which of the primary factors controls the penetrating quality of the x-ray beam?

   a. mA.

   b. kVp.

   c. Seconds.

   d. SID.

6. Which of the following kinds of tissue will absorb the most radiation during an exposure?

   a. Viscera.

   b. Fat.

   c. Muscle.

   d. Bone.

7. Which of these exposure factors usually should be used to compensate for body tissues that show signs of pathologic changes?

   a. SID.

   b. mAs.

   c. Filters.

   d. kVp.

8. If you increase SID and want to maintain contrast and density at a fairly constant level, the:

   a. mAs must be increased.

   b. mAs must be decreased.

   c. kVp must be decreased.

   d. kVp must be increased.

9. Suppose a technique requires an exposure of 25 mAs and an SID of 30 inches. If the SID is increased to 72 inches, what will be the new mAs?

   a. 50.

   b. 72.

   c. 122.

   d. 144.

10. To change the density on the film without changing the amount of heat formed in the tube, you would change the:

    a. mA.

    b. kVp.

    c. SID.

    d. Seconds.

11. Density is affected by which primary factors?

    a. kVp, mAs, SID, focal spot size.

    b. mAs, focal spot size.

    c. kVp, mAs, SID.

    d. SID, OFD, focal spot size.

12. Increasing kVp would:

    a. Decrease density and increase contrast.

    b. Decrease density and lower contrast.

    c. Increase density and lower contrast.

    d. Increase density and increase contrast.

13. Grids and cones should be used by the specialist when he needs to:

    a. Increase the mAs value.

    b. Compensate for SID.

    c. Radiograph thin body parts.

    d. Control secondary radiation.

14. What is the effect on a radiograph when a focused grid with the notation "tube side" on one edge is used with the wrong SID?

    a. None of the secondary radiation is absorbed.

    b. All of the remnant radiation is lost.

    c. The film shows loss of detail.

    d. The outer edges of the film are underexposed.

15. The grid or Bucky is placed between the:

    a. Patient and film.

    b. Patient and x-ray tube.

    c. Patient and filter.

    d. Focal spot and filter.

16. A 16:1 grid would be more efficient than an 8:1 grid because:

    a. It absorbs more secondary radiation.

    b. Handling of SID and tube centering is less critical.

    c. Less secondary radiation is produced.

    d. A sharper image is produced.

17. Which of these describes the type of Bucky mechanism that is preferred for radiography?

    a. Manual cock-type.

    b. Oil piston.

    c. Reciprocating.

    d. Coiled spring.

18. Appearance of uniform grid lines on the film even though the grid is moving may be caused by:

    a. Excessive travel time.

    b. Use of low range kVp.

    c. Cassette off center in the Bucky tray.

    d. Poor synchronization.

19. Cones, cylinders, diaphragms, and collimators control the size of the primary beam by:

    a. Absorbing the unwanted x-rays.

    b. Filtering out the unused x-rays.

    c. Focusing the x-rays to the film.

    d. Spreading the x-rays over a large area.

20. What is the diameter of a cone field (DCF) in inches if SID = 36 inches, ALD = 15 inches, and DC = 5 inches?

a. 9.

b. 12.

c. 15.

d. 18.

Check Your Answers on Next Page

SOLUTIONS TO EXERCISES, LESSON I

1. b (Para 1-2b)

2. a (Para 1-2d)

3. c (Para 1-5; 2-35)

4. d (Para 1-6a)

5. b (Para 1-9)

6. d (Para 1-10)

7. b (Para 1-11)

8. a (Para 1-15; 1-16)

9. d (Para 1-15; 1-16)

$$\frac{mAs_l}{mAs_2} = \frac{SID_1^2}{SID_2^2} \qquad 900x = 25 \text{ x } 5184$$

$$x = \frac{25 \text{ x } 5184}{900}$$

$$\frac{25}{x} = \frac{30^2}{72^2} \qquad x = \frac{129{,}600}{900}$$

$$\frac{25}{x} = \frac{900}{5184} \quad x = 144$$

10. c (Para 1-15; 1-19)

11. c (Para 1-19)

12. c (Para 1-20)

13. d (Para 1-34, 1-44)

14. d (Para 1-35;1-40a)

15. a (Para 1-35, 1-39)

16. a (Para 1-37)

17. c (Para 1-41b)

18. d (Para 1-42e)

19. a (Para 1-44)

20. b (para 1-45)

$$\frac{SID}{ALD} = \frac{DCF}{DC} \qquad 15\ DCF = 5 \times 36$$

$$15\ DCF = 180$$

$$DCF = 12$$

$$\frac{36}{15} = \frac{DCF}{5}$$

End of Lesson 1

LESSON ASSIGNMENT

LESSON 2	Principles of Radiographic Exposure II
TEXT ASSIGNMENT	Paragraphs 2-1 through 2-53.
LESSON OBJECTIVES	When you have completed this lesson, you should be able to: 2-1. Identify factors affecting the geometry of image formation, definition and distortion, and to select the correct intensifying screen for a particular purpose in the radiographic exposure room. 2-2. You should also be able to identify the advantages of optimum kilo-voltage techniques, according to technique direction charts in the radiograph exposure room.
SUGGESTION	After completing the assignment, complete the exercises of this lesson. These exercises will help you to achieve the lesson objectives.

LESSON 2

PRINCIPLES OF RADIOGRAPHIC EXPOSURE II

Section I. FUNCTION OF MILLIAMPERE-SECONDS

2-1. INTRODUCTION

The mAs (mA x sec) directly influences radiographic density when all other factors are constant. This is because it controls the amount of radiation. Either the mA or sec may be changed to conform to required radiographic exposures as long as their product--mAs--remains the same. This holds true on all direct x-ray exposures. Exposures using intensifying screens may show some loss of density when exposure is extremely long and mA quite small. Actually, the mA is seldom changed for a given projection and may be considered as a constant; the sec can readily be changed and should constitute the variable in the mAs. For ease in computation, the mAs, rather In its separate components, may be employed for a given projection.

2-2. RULE-OF-THUMB FOR DENSITY CHANGES

It requires at least a 20 percent increase in mAs to produce any noticeable increase in density. The usually applied rule-of-thumb is to alter density by either doubling or halving the initial mAs. If further alteration is needed, intermediate adjustments can be made.

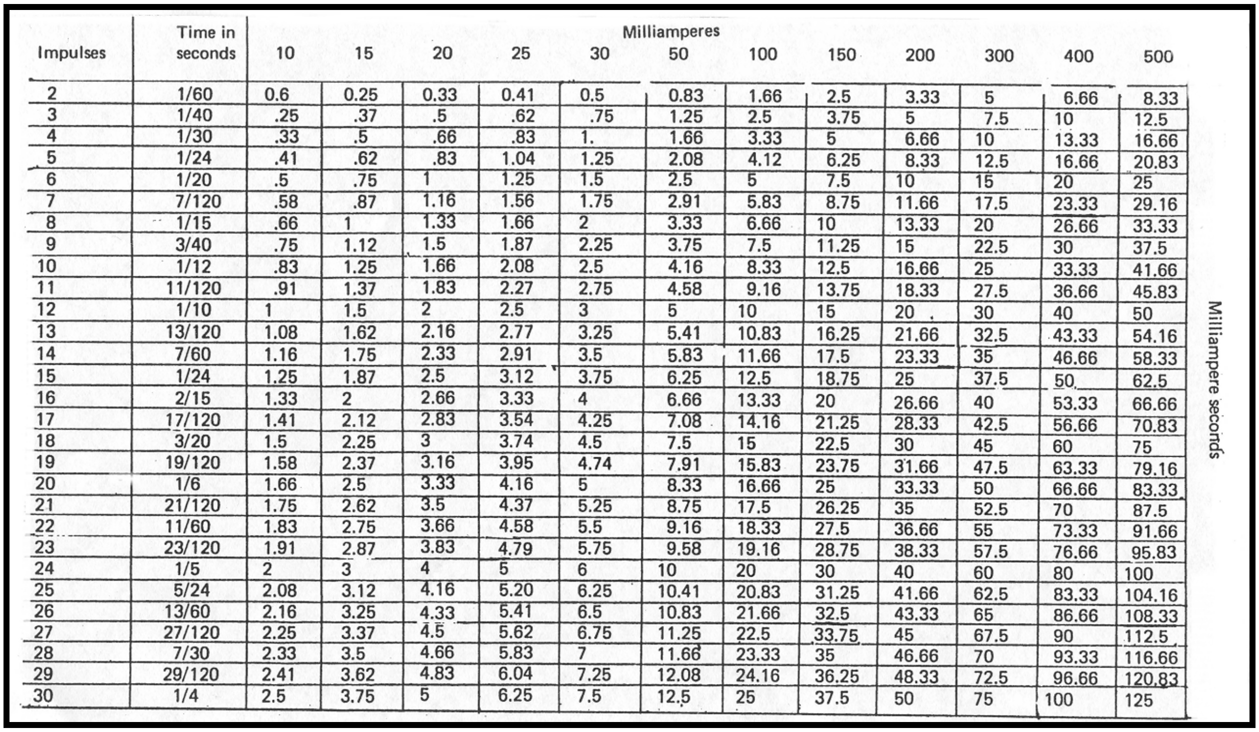
2-3. RECIPROCITY LAW

An important photographic law formulated in 1875 states that the reaction of a photographic emulsion to light is equal to the product of the intensity of the light and the duration of exposure (emulsion reaction = time light intensity). This rule applies in radiography when direct exposures are made. When intensifying screens are used, the law does not strictly hold true, because exposure of the film under these circumstances is chiefly caused by fluorescent light from the screens, and very little by the direct action of x-rays. Failure of this law may be observed when the radiographic density is greater upon short exposure with a large quantity of fluorescent light than that produced by a long exposure and a small amount of fluorescent light, even though the mAs remains the same. It is not necessary to be concerned about this effect in routine work. Normally, the mAs value may be considered reliable for use as an exposure factor. For example, about the same radiographic density will be obtained whether 50 mA is used for 1/10 sec 10 mA for 5/10 sec--both conditions give 5 mAs.

2-4. TABLES OF MILLIAMPER-SECOND VALUES

a. Tables 2-1 and 2-2 make possible rapid determination of mAs values I the sec and the mA are known. Table 2-1 lists the common fractional exposures and the number of impulses employed for short exposures. Table 2-2 lists exposure times of longer duration. To use the tables, find the exposure to be used in the left-hand vertical column; then in the horizontal at the bottom of the table, find the mA value to be used. The required mAs value is found at the point where these two columns intersect.

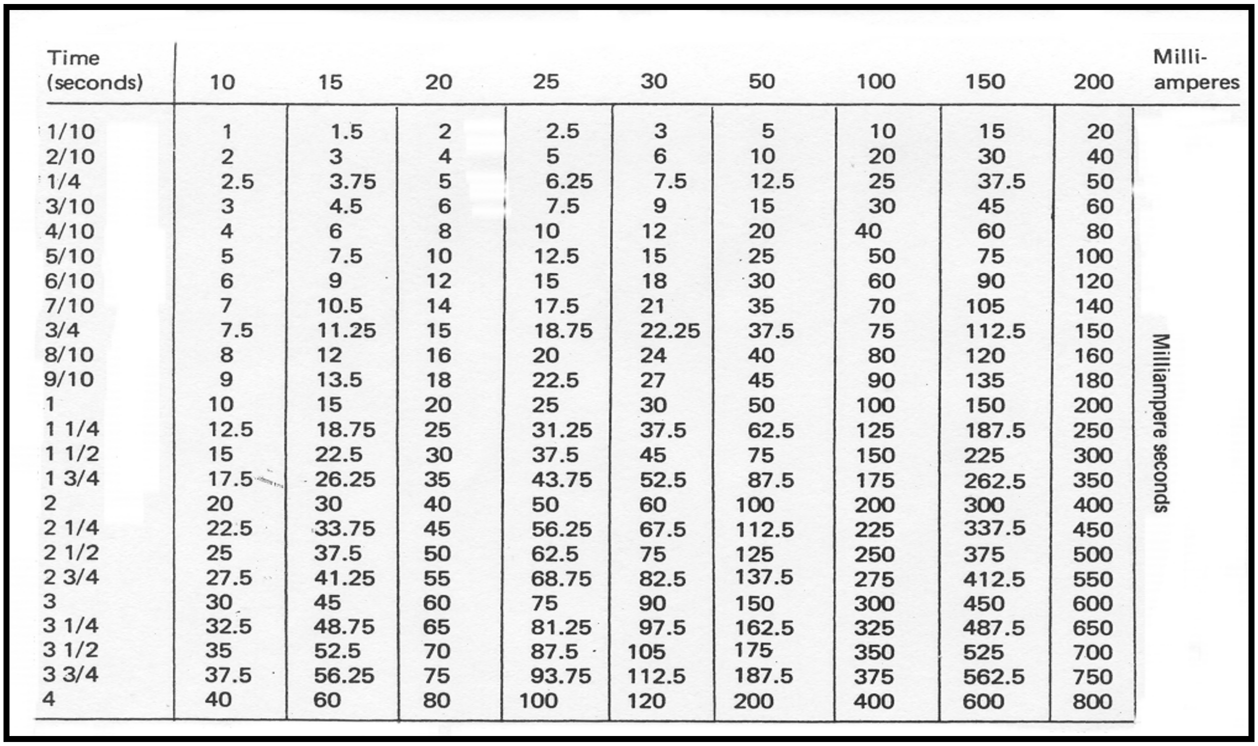
b. In computing mAs values, it is often convenient to use the decimal equivalent of the exposure-time fraction. Table 2-3 lists decimal equivalents of commonly employed exposure fractions. The numerators of fractions are listed horizontally at the top of the table, and the denominators are listed vertically in the columns to the left and the right. The body of the table contains the decimal equivalents of various combinations of numerators and denominators.



	Time in	Milliamperes											
Impulses	seconds	10	15	20	25	30	50	100	150	200	300	400	500
2	1/60	0.6	0.25	0.33	0.41	0.5	0.83	1.66	2.5	3.33	5	6.66	8.33
3	1/40	.25	.37	.5	.62	.75	1.25	2.5	3.75	5	7.5	10	12.5
4	1/30	.33	.5	.66	.83	1.	1.66	3.33	5	6.66	10	13.33	16.66
5	1/24	.41	.62	.83	1.04	1.25	2.08	4.12	6.25	8.33	12.5	16.66	20.83
6	1/20	.5	.75	1	1.25	1.5	2.5	5	7.5	10	15	20	25
7	7/120	.58	.87	1.16	1.56	1.75	2.91	5.83	8.75	11.66	17.5	23.33	29.16
8	1/15	.66	1	1.33	1.66	2	3.33	6.66	10	13.33	20	26.66	33.33
9	3/40	.75	1.12	1.5	1.87	2.25	3.75	7.5	11.25	15	22.5	30	37.5
10	1/12	.83	1.25	1.66	2.08	2.5	4.16	8.33	12.5	16.66	25	33.33	41.66
11	11/120	.91	1.37	1.83	2.27	2.75	4.58	9.16	13.75	18.33	27.5	36.66	45.83
12	1/10	1	1.5	2	2.5	3	5	10	15	20	30	40	50
13	13/120	1.08	1.62	2.16	2.77	3.25	5.41	10.83	16.25	21.66	32.5	43.33	54.16
14	7/60	1.16	1.75	2.33	2.91	3.5	5.83	11.66	17.5	23.33	35	46.66	58.33
15	1/24	1.25	1.87	2.5	3.12	3.75	6.25	12.5	18.75	25	37.5	50	62.5
16	2/15	1.33	2	2.66	3.33	4	6.66	13.33	20	26.66	40	53.33	66.66
17	17/120	1.41	2.12	2.83	3.54	4.25	7.08	14.16	21.25	28.33	42.5	56.66	70.83
18	3/20	1.5	2.25	3	3.74	4.5	7.5	15	22.5	30	45	60	75
19	19/120	1.58	2.37	3.16	3.95	4.74	7.91	15.83	23.75	31.66	47.5	63.33	79.16
20	1/6	1.66	2.5	3.33	4.16	5	8.33	16.66	25	33.33	50	66.66	83.33
21	21/120	1.75	2.62	3.5	4.37	5.25	8.75	17.5	26.25	35	52.5	70	87.5
22	11/60	1.83	2.75	3.66	4.58	5.5	9.16	18.33	27.5	36.66	55	73.33	91.66
23	23/120	1.91	2.87	3.83	4.79	5.75	9.58	19.16	28.75	38.33	57.5	76.66	95.83
24	1/5	2	3	4	5	6	10	20	30	40	60	80	100
25	5/24	2.08	3.12	4.16	5.20	6.25	10.41	20.83	31.25	41.66	62.5	83.33	104.16
26	13/60	2.16	3.25	4.33	5.41	6.5	10.83	21.66	32.5	43.33	65	86.66	108.33
27	27/120	2.25	3.37	4.5	5.62	6.75	11.25	22.5	33.75	45	67.5	90	112.5
28	7/30	2.33	3.5	4.66	5.83	7	11.66	23.33	35	46.66	70	93.33	116.66
29	29/120	2.41	3.62	4.83	6.04	7.25	12.08	24.16	36.25	48.33	72.5	96.66	120.83
30	1/4	2.5	3.75	5	6.25	7.5	12.5	25	37.5	50	75	100	125

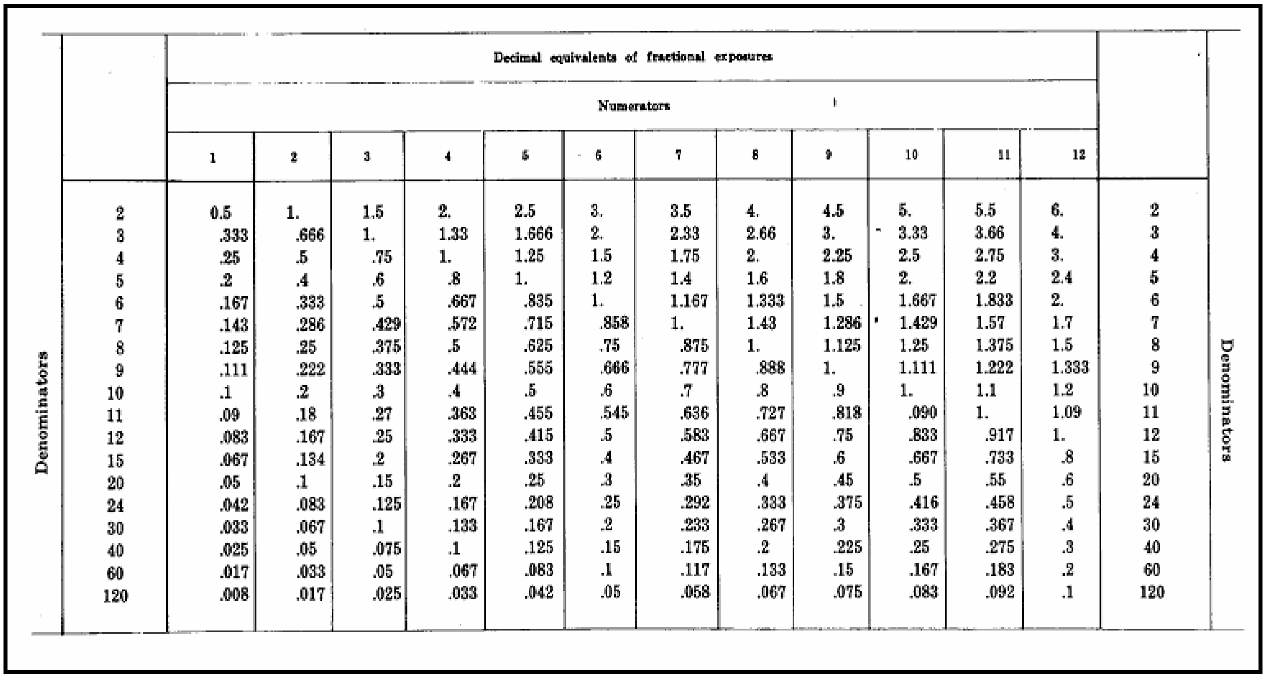
Milliampere seconds

Table 2-1. Table of mAs values derived by multiplying specific mAs and time values. (Time values are shown as impulses (1/20 sec.) and as time fractions.)



Time (seconds)	10	15	20	25	30	50	100	150	200	Milli-amperes
1/10	1	1.5	2	2.5	3	5	10	15	20	Milliampere seconds
2/10	2	3	4	5	6	10	20	30	40	
1/4	2.5	3.75	5	6.25	7.5	12.5	25	37.5	50	
3/10	3	4.5	6	7.5	9	15	30	45	60	
4/10	4	6	8	10	12	20	40	60	80	
5/10	5	7.5	10	12.5	15	25	50	75	100	
6/10	6	9	12	15	18	30	60	90	120	
7/10	7	10.5	14	17.5	21	35	70	105	140	
3/4	7.5	11.25	15	18.75	22.25	37.5	75	112.5	150	
8/10	8	12	16	20	24	40	80	120	160	
9/10	9	13.5	18	22.5	27	45	90	135	180	
1	10	15	20	25	30	50	100	150	200	
1 1/4	12.5	18.75	25	31.25	37.5	62.5	125	187.5	250	
1 1/2	15	22.5	30	37.5	45	75	150	225	300	
1 3/4	17.5	26.25	35	43.75	52.5	87.5	175	262.5	350	
2	20	30	40	50	60	100	200	300	400	
2 1/4	22.5	33.75	45	56.25	67.5	112.5	225	337.5	450	
2 1/2	25	37.5	50	62.5	75	125	250	375	500	
2 3/4	27.5	41.25	55	68.75	82.5	137.5	275	412.5	550	
3	30	45	60	75	90	150	300	450	600	
3 1/4	32.5	48.75	65	81.25	97.5	162.5	325	487.5	650	
3 1/2	35	52.5	70	87.5	105	175	350	525	700	
3 3/4	37.5	56.25	75	93.75	112.5	187.5	375	562.5	750	
4	40	60	80	100	120	200	400	600	800	

Table 2-2. Table of mAs values derived by multiplying specific mA and time values from 1/10 to 4 seconds.



Denominators	Decimal equivalents of fractional exposures												Denominators
	Numerators												
	1	2	3	4	5	6	7	8	9	10	11	12	
2	0.5	1.	1.5	2.	2.5	3.	3.5	4.	4.5	5.	5.5	6.	2
3	.333	.666	1.	1.33	1.666	2.	2.33	2.66	3.	3.33	3.66	4.	3
4	.25	.5	.75	1.	1.25	1.5	1.75	2.	2.25	2.5	2.75	3.	4
5	.2	.4	.6	.8	1.	1.2	1.4	1.6	1.8	2.	2.2	2.4	5
6	.167	.333	.5	.667	.835	1.	1.167	1.333	1.5	1.667	1.833	2.	6
7	.143	.286	.429	.572	.715	.858	1.	1.43	1.286	1.429	1.57	1.7	7
8	.125	.25	.375	.5	.625	.75	.875	1.	1.125	1.25	1.375	1.5	8
9	.111	.222	.333	.444	.555	.666	.777	.888	1.	1.111	1.222	1.333	9
10	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.	1.1	1.2	10
11	.09	.18	.27	.363	.455	.545	.636	.727	.818	.090	1.	1.09	11
12	.083	.167	.25	.333	.415	.5	.583	.667	.75	.833	.917	1.	12
15	.067	.134	.2	.267	.333	.4	.467	.533	.6	.667	.733	.8	15
20	.05	.1	.15	.2	.25	.3	.35	.4	.45	.5	.55	.6	20
24	.042	.083	.125	.167	.208	.25	.292	.333	.375	.416	.458	.5	24
30	.033	.067	.1	.133	.167	.2	.233	.267	.3	.333	.367	.4	30
40	.025	.05	.075	.1	.125	.15	.175	.2	.225	.25	.275	.3	40
60	.017	.033	.05	.067	.083	.1	.117	.133	.15	.167	.183	.2	60
120	.008	.017	.025	.033	.042	.05	.058	.067	.075	.083	.092	.1	120

Table 2-3. Table for determination of decimal equivalents of fractional exposure times.

2-5. MILLIAMPERE AND TIME RELATION

a. **Rule**. The mA required for a given radiographic density is tersely proportional to the time of exposure when the mAs is to remain constant. This rule may be expressed by the following formula:

$$mA_1 \times sec_1 = mA_2 \times sec_2$$

mA_1 = original mA
sec_1 = original sec
mA_2 = new mA
sec_2 = new sec

b. **Sample Problem**. If 10 mA (mA_1) and an exposure time (sec_1) 0.5 sec are employed in making a radiograph and it is desired to decrease the exposure time (sec_2) to 0.05 sec, what mA (mA_2) would be needed to assure comparable radiographic densities?

c. **Solution**. mA_1, sec_1, and sec_2 are known; mA_2 is unknown.

$$mA_2 = \frac{mA_1 \times sec_1}{sec_2} \quad mA_2 = \frac{10 \times 0.5}{0.05} = \frac{5}{0.05} = 100 \text{ mA. Answer.}$$

2-6. TIME-DENSITY RELATION

When all other factors but time are constant, the total mAs, and thus the total quantity of x-radiation emitted by the x-ray tube, increases in direct proportion to the time of exposure. Thus, the quantity of x-rays applied in 1 second is doubled when the exposure time is 2 seconds. Since radiographic density is influenced by this action, increasing the time increases the density and vice versa.

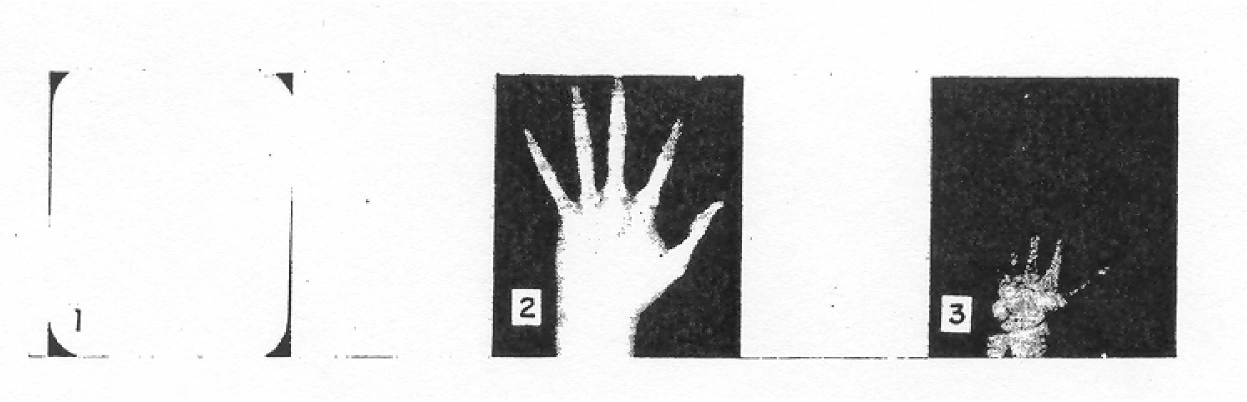
2-7. EXPERIMENT: MILLIAMPERE-TIME DENSITY RELATION

a. **Purpose**. The purpose of this experiment is to demonstrate the interrelation of mA and exposure time with respect to radiographic density when all other factors are constant.

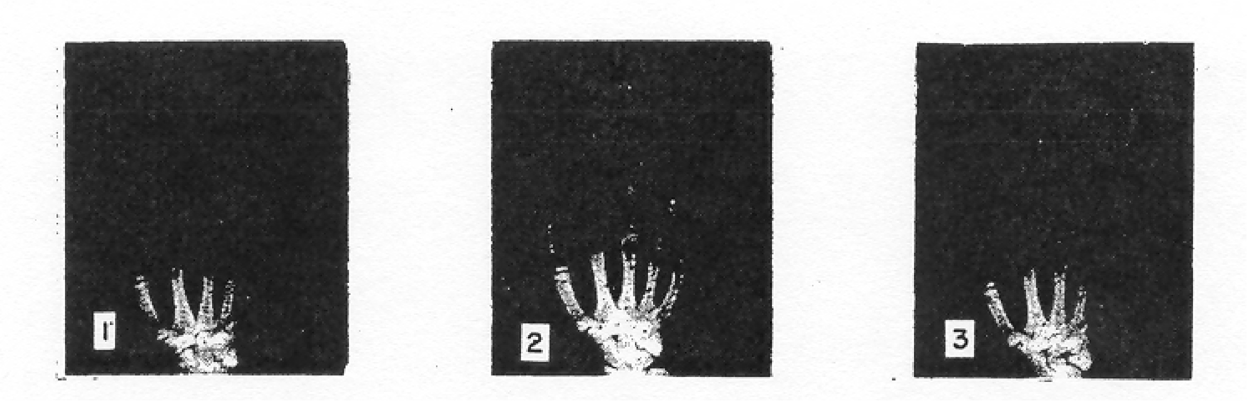
b. **Theory**. The mA required for a given radiographic density is inversely proportional to the exposure time when all other factors are constant.

c. **Procedure**. The mAs-density relation is demonstrated by six posterior-anterior (PA) radiographs of the hand.

d. **Comment**. The radiographs (figure 2-1) demonstrate that as the mA increased and all other factors but time are constant, time may be reduced equalize radiographic densities. In B 1, 2, and 3 the mA is progressively increased, but density has been held constant by compensating sec. Since mA and time directly influence density, in actual practice the mA is usually established as a constant and the exposure time as a variable. Modern apparatus usually calibrated with preset mA stations, and it is difficult to convert to manual control operation and accurately select all mA readings from the meters.



A. Influence of sec on radiographic density (with absorber, hand). Exposure times for radiographs 2 and 3, respectively, were 5 and 10 times that of radiograph 1.



B. Effect of mA and time on radiographic density when all other factors are constant (with absorber, hand); exposure sequence is indicated by numerals in lower left corner of images.

Figure 2-1. Influence of sec on radiographic density

Section II. GEOMETRY OF IMAGE FORMATION

2-8. GENERAL

The formation of the radiographic image is dependent upon geometric conditions associated with its projection. Actually, the image is composed of various details that are renditions of the anatomical structures through which the x-ray beam has passed. These details are defined by various degrees of sharpness and shape, depending upon the geometric conditions. “Definition” is the word used to describe the sharpness with which the detail is recorded. Radiographic details are never points in the image but are minute areas of black metallic silver.

2-9. SHADOWS AND X-RAY IMAGES

A shadow is a mass of darkness or shade produced on a surface by an object that intercepts a beam of light--it is a silhouette. An x-ray image is also a shadow, but it contains abundant details. Except for the physical laws for the formation of a shadow by light and those that make an x-ray image, there is no similarity between a shadow and an x-ray image. The shadow caused light and the images produced by x-rays are very dissimilar in appearance. There is some resemblance between an image produced by a lens and that produced by an x-ray beam, but the means of production are entirely dissimilar. The laws governing the formation of a light shadow, such as size and shape of light source and its distance from the object and recording surface, have a definite influence on the size, shape, and peripheral sharpness of the shadow. This situation is comparable to the production of an x-ray image using such factors as FS, SID, OFD, et cetera.

2-10. SHADOW FORMATION BY LIGHT

When a slightly enlarged though sharp shadow of an object is to be produced by means of light :

a. The source of the light must be small.

b. The source of the light should be at a practical distance to avoid objectionable enlargement.

c. The recording card should be as close to the object as possible so to avoid a great degree of enlargement.

d. The light should be directed perpendicularly to the recording card.

e. The plane of the object and the plane of the recording card should parallel.

2-11. ILLUSTRATION

To demonstrate shadow formation by light, a source of light (LS), an opaque object (OB) to be projected by the light, and a recording card (RC) are needed. The plane of the object should be parallel to the plane of the recording card.

a. **Point Light Source**. Assume that light from a tiny point shines on the recording card (A, figure 2-2), and the object is interposed between the light source and the recording card. A shadow (S) of the object will be formed, the edges of which are sharply defined. The shadow naturally is larger than the object. The degree of enlargement will vary according to the distance of the object from recording card and light source. When the object moved nearer the light source, the margins of the shadow are still sharply defined, but the shadow is greatly enlarged (B, figure 2-2). When the object placed at the same distance from the recording card, as shown in diagram but the distance from the light source is increased, the shadow is somewhat reduced (C, figure 2-2). In all these examples, the periphery of the shadow is sharply delineated because a point source of light was used; the size of the shadow varied with the distance between the object and the recording card, as well as between the object and the light source.

b. **Area Light Source**. Assume another situation in which the light source is a small area (D, figure 2-2) instead of a point. The relation of the object to the recording card is the same as shown in diagram B. Light emanates from many points in this source, and many light beams strike the object; each, in turn, produces its shadow of the object on the recording card. The result of these combined shadows is diffused margins of the image so that it is not sharply defined. The shadows produced in diagrams A, B, and C is umbra's and their margins are sharply defined. In diagram D, an a penumbra is present, but its margins are not sharp. The area of unsharpness is penumbra (P). Some improvement in definition may be secured if the object placed nearer to the recording card or if the light source is moved farther away.

2-12. IMAGE CHARACTERISTICS

Every radiographic image is a projection on a two-dimensional surface of a three-dimensional body. Just as a map is a distorted image of terrain, a radiograph is a distorted image of the body part it represents. It becomes very important, then, to understand the mechanics of distortion so as keep it at a minimum. The source of the x-ray beam is at the target in the x-ray tube, and it cannot be a point--it must be a small area. The size the area varies with the capacity of the tube. The radiographic image cannot ever be geometrically sharp, both because the beam source is an area and also, because of the fact that the image itself is made up of many minute specks of silver on both sides of the film base. In spite of all the geometric factors that distort the image, a useful radiograph can be produced proper precautions are taken.

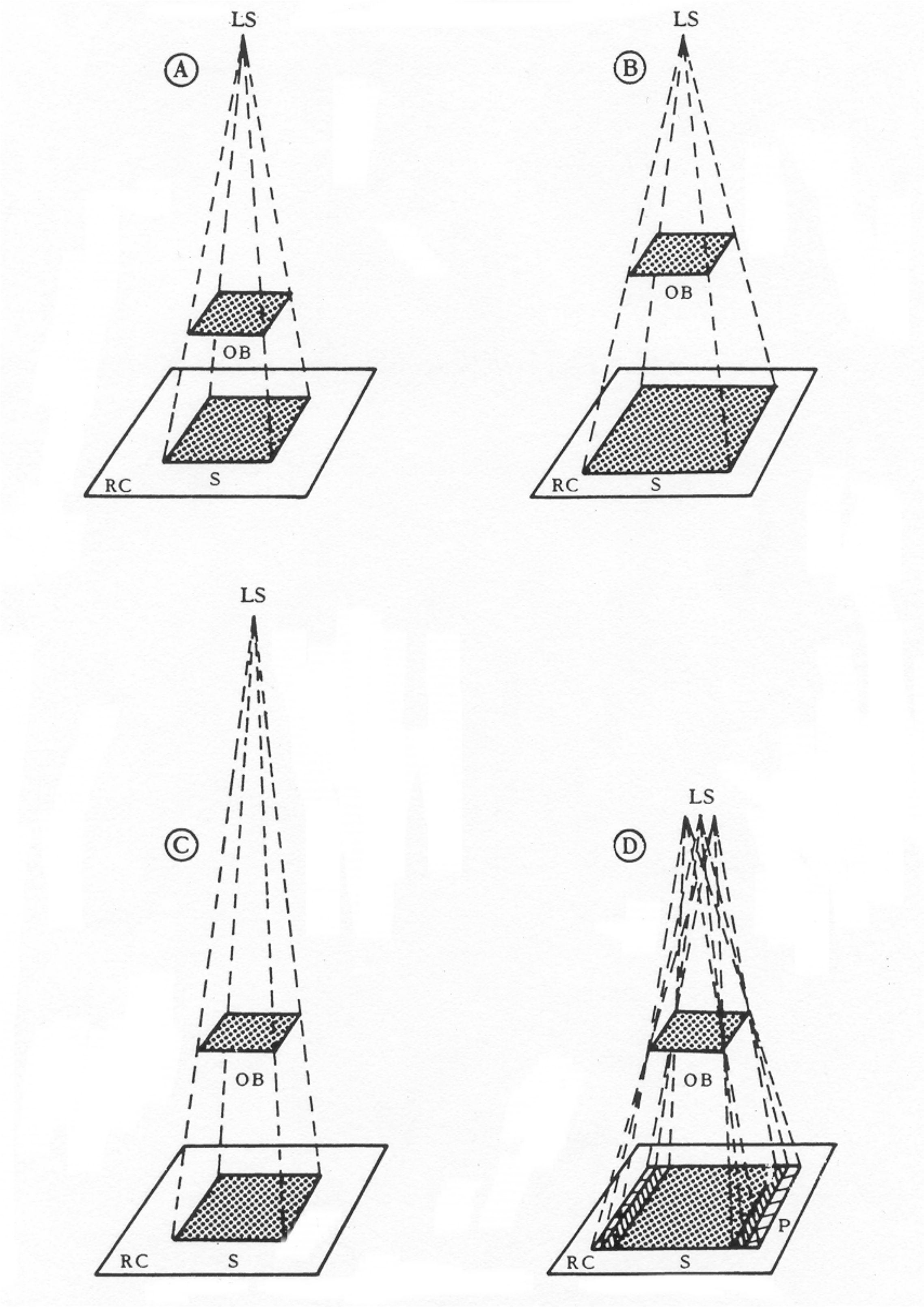


Figure 2-2. Diagrams illustrating shadow formation by light. (description in text)

2-13. REDUCTION OF UNSHARPNESS

a. **Measures**. Measures to reduce detail unsharpness to a minimum are:

(1) As small a focal spot as possible should be used, consistent h the safety limits of the electrical load on the x-ray tube.

(2) The source-to-image distance should be as long as possible, within practical working limits.

(3) The object-film distance should be minimal.

(4) The central ray should pass through the center of the part perpendicular to its major planes and that of the film.

b. **Influence of Factor Change**. The effects of the above changes illustrated in figure 2-3. In diagram A. an object was placed so that object-film distance was long; a large focal spot was used. The penumbra projected on the film was wide, indicating excessive image unsharpness that was also influenced by the relatively short source-to-image distance. The situation represents the worst sort of geometric relationship between image and object. In diagram B, the same conditions prevailed as in A, except that smaller focal spot was used. The narrower penumbra indicates that less unsharpness was produced. In diagram C. a long source-to-image distance was used with other conditions remaining as in A. The increased source-to-image distance narrowed the penumbra, but not to the same extent as in B, where a smaller focal spot was used. In diagram D, the same conditions prevailed as in C except that a small focal spot was used. The very narrow penumbra indicates a decrease in unsharpness due to the use of a smaller focal spot. This condition should prevail when an appreciable object-film distance exists. Diagram E shows the object close to the film; an average source-to-image distance and a large focal spot were used. A fair degree of sharpness was achieved, although a smaller focal spot, as shown in diagram F, slightly improved the sharpness. Diagrams E and F illustrate that when the object is close to the film, the size of the focal spot is, in a measure, immaterial when the thickness of the object is within average limits. A large focal spot at a long source-to-image distance with the object close to the film as shown diagram G produced a very narrow penumbra. By using a smaller focal spot the same conditions as in G, the maximum sharpness was obtained as shown in diagram H. Of all the situations depicted in diagrams A through H, the image sharpness is at its maximum in H.

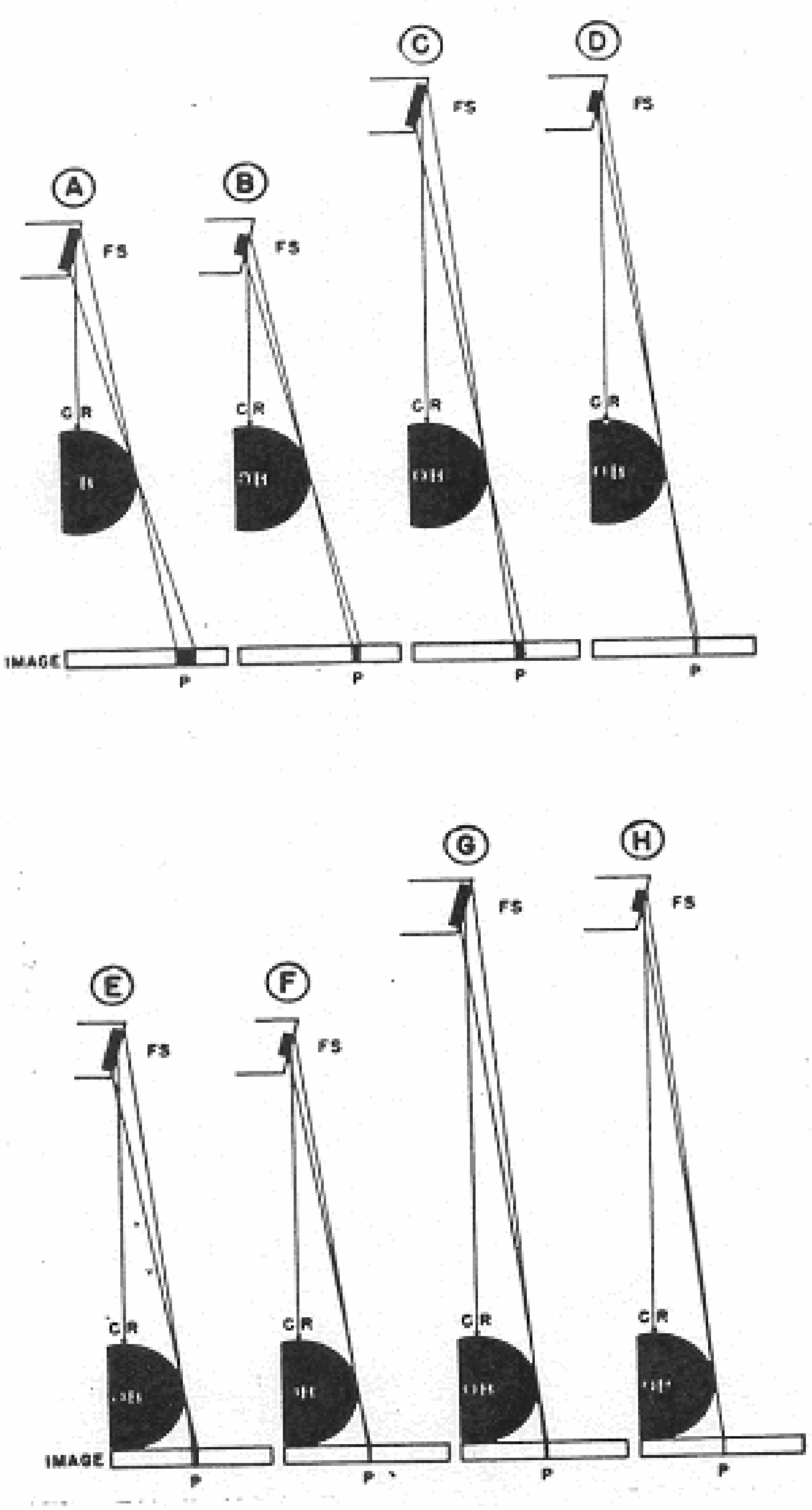


Figure 2-3. Situations affecting image sharpness.

2-14. TYPES OF DEFINITION

Definitions may be divided into three types: (1) geometrical unsharpness, which is influenced by focal spot, object-film distance, and Source-to-Image Distance; (2) motion unsharpness, which may be voluntary or involuntary on the part of the patient, or caused by vibration of the apparatus; and (3) screen unsharpness, which is influenced by the character of the screens and screen-film contact. All of these factors contribute to the total unsharpness. Correction of some factors may involve increased unsharpness from some other factor. For example, if a radiograph were made without screens to ensure image sharpness, patient movement might cause blurring because a long exposure time had become necessary.

2-15. GEOMETRICAL UNSHARPNESS: INFLUENCE OF FOCAL SPOT

a. Geometrical unsharpness is influenced by all factors of projection that alter the size, shape, and location of images of structures traversed by x-rays. The FS of the x-ray tube is comparable to the light source used shadow formation and, therefore, influences image sharpness. Other factors being constant, the smaller the FS, the sharper the definition. A large FS means more efficient tube cooling, but it also means poor image definition. A long Source-to-Image Distance may moderate this effect to some extent, but in general a small FS is advantageous. Of course the unsharpness produced by a large FS is not as pronounced as that resulting from the object being too far from the film.

b. The site of the projected focal spot varies with the angle at which it is projected from the target (figure 2-4). When the projected FS is nearly perpendicular to the face of the target, it is large (D, figure 2-4) becoming smaller as the angle decreases toward the central ray. The focal spot as projected at the central ray (B, figure 2-4) is characteristic of the rated or effective focus of the tube. As the projected focal spot moves anode-wise from the central ray, it becomes smaller (A, figure 2-4) until it reaches the limits of the anode side of the beam. At routine Source-to-Image Distance, these differences in sharpness of definition are minimal and difficult to determine visually.

2-16. GEOMETRICAL UNSHARPNESS: INFLUENCE OF OBJECT-FILM DISTANCE

When the object is at some distance from the film as shown in diagram B, figure 2-3 the sharpness is not as great as it is in F figure 2-3, wherein the object is shown next to the film. The larger the object-film distance (OFD) the greater the unsharpness. The use of grids requires an increase in OFD, but the gain in contrast offsets the small amount of image unsharpness introduced. The effect of OFD is illustrated in figure 2-5. A series of four posterior-anterior (AP) radiographs of a hand was made in which all factors were constant except the OFD. Radiograph A was made with the hand on the film; for B the OFD was 2 inches; for C, 6 inches: and for D, 8 inches. As the OFD was increased the size of the hand increased.

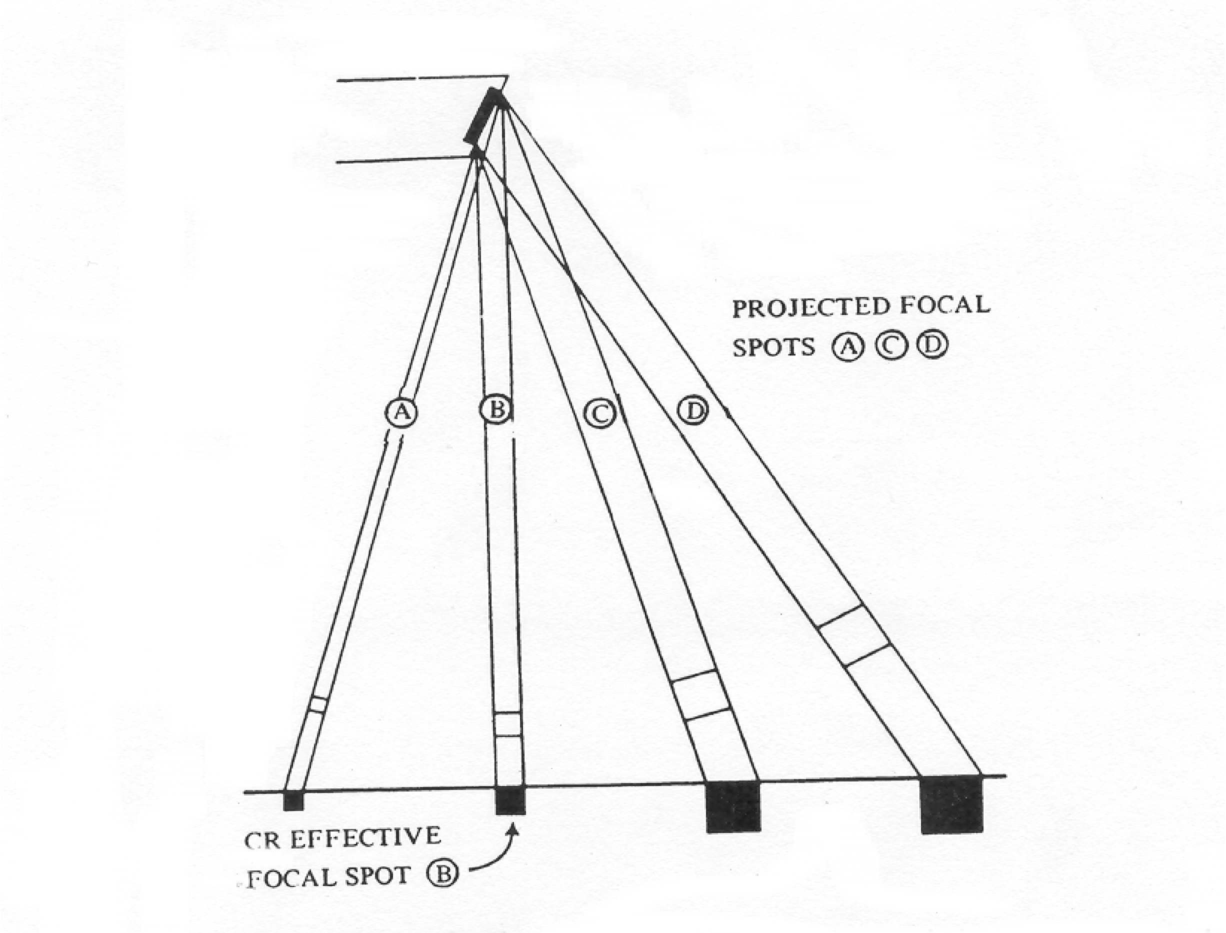


Figure 2-4. The size of the focal spot varies with the angle at which it is projected from the target.

2-17. GEOMETRICAL UNSHARPNESS: INFLUENCE OF SOURCE-TO-IMAGE DISTANCE

When a body part is placed on a film, image unsharpness is minimal, and its degree is directly related to the projected FS and the SID. When a short SID is used, the unsharpness increases. The image of the plane of the body part next to the film is always sharper than the image of the plane farthest away. At maximum SID definition is improved and the image is also more nearly the actual size of the body part. In most ways sharpness is improved as the SID is increased. However, there are practical limits to SID extension. Also, the greater the SID, the greater the probability of introducing motion unsharpness, because of the need for longer exposures. When a body part cannot be placed close to the film, the SID should be increased beyond that normally used. Try doubling the SID as a start.

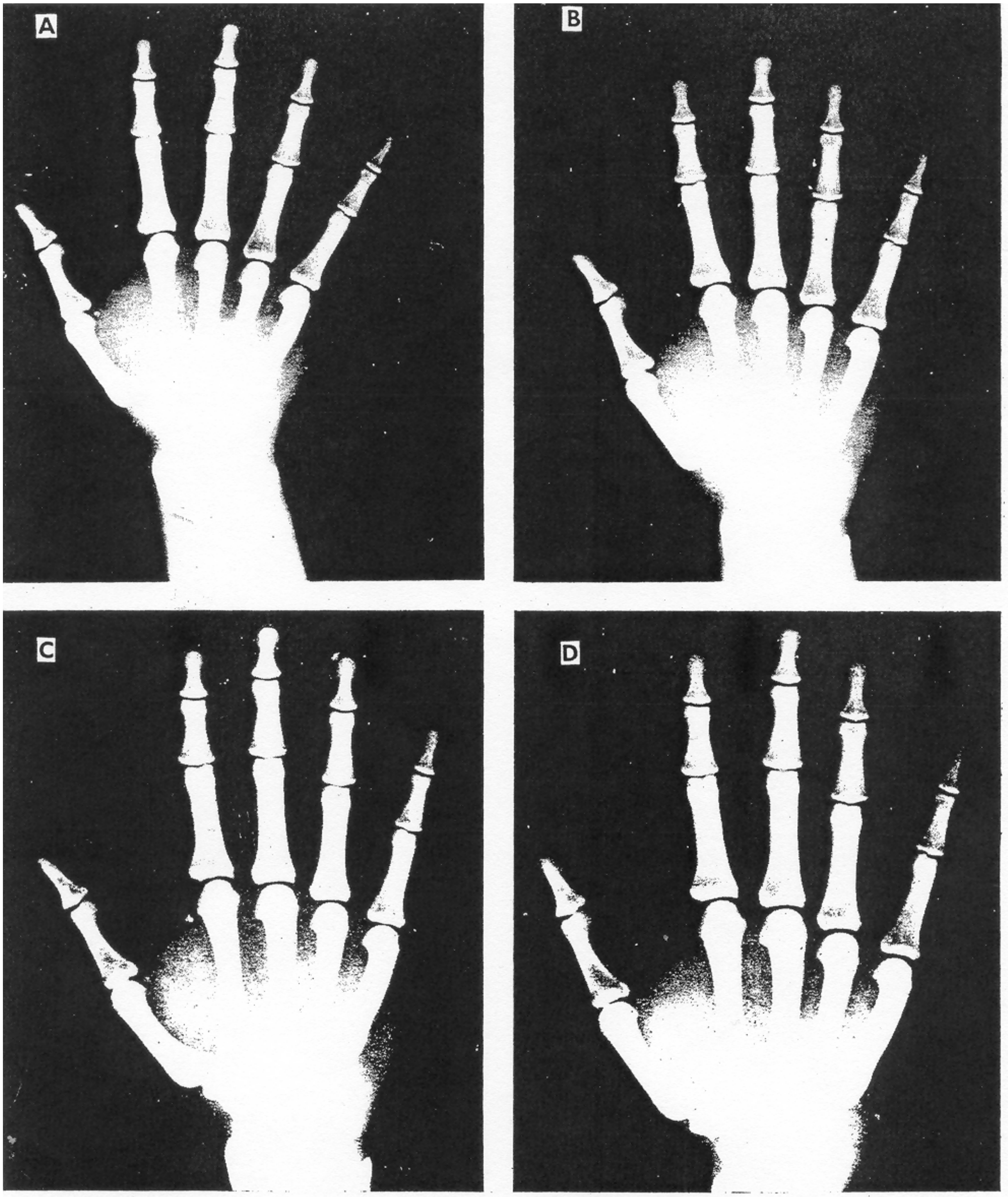


Figure 2-5. Radiographs of the hand made without cones where in the OFD has been varied. A, no OFD; B, 2 inches; C, 6 inches; D, 8 inches

2-18. MOTION UNSHARPNESS

Motion of a body part being examined directly influences sharpness of image definition. The only means for controlling the effects of motion are (1) patient cooperation, (2) immobilization of the part being examined, and (3) short exposures.

a. **Voluntary Motion**. Voluntary motion may take several forms. The uncooperative child may need to be restrained. The patient who does not understand and is fearful may need his confidence restored. Immobilization of the part and use of short exposures may help.

b. **Involuntary Motion**. Involuntary motion is normally associated with the physiological activity of the body tissues. Respiration produces movement of the thorax and its contents so that short exposures are mandatory. The normal adult respiratory rate is 16 to 18 per minute; in some pulmonary or cardiac lesions, the rate may be greater; in the newborn, it may be 30 to 40 per minute. Respiration also influences, in some degree, the viscera adjacent to the diaphragm. Movement of the heart and great vessels is an important radiographic factor. Functional activity of other abdominal viscera tends to produce motion.

c. **Effect of Motion on Image**. The influence of motion in producing image unsharpness is shown in figure 2-6, the object moved during the exposure resulting in unsharpness in the margins of the image.

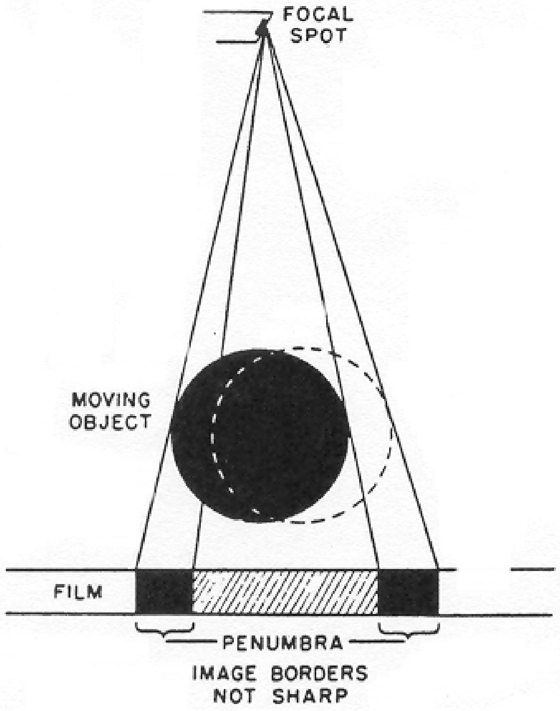


Figure 2-6. The influence of motion in producing image unsharpness.

2-19. IMMOBILIZATION

Immobilization is imperative in radiography, for differential diagnoses depend upon the visualization of sharp, undistorted images. Movement should be eliminated during the exposure to avoid blurring of details in the image.

a. **Composing the Patient**. The x-ray technologist is responsible for keeping the body part immobile. Frequently, the patient may be nervous and afraid; some may tremble. A few words of assurance will often help put the patient at ease.

b. **Immobilization Needed**. Much of the success in obtaining a good radiograph is dependent upon the closeness and firmness with which the part is placed against the cassette and the method of immobilization used. Even with short exposures, immobilization is necessary. Proper immobilization assures comparison of symmetrical parts, for it also serves to prevent involuntary rotation of the part. The tube carriage should always be locked in position because its vibration is a common cause of blurred radiographs.

c. **Immobilization Methods**. There are a number of good methods for immobilizing the body part, such as sandbags, compression bands, cones, and special clamps. Many of these devices for immobilization are found in the modern laboratory. An important aspect of immobilization is compression of tissues, particularly in the abdomen. By displacing some of the tissues, less SR is produced and better definition attained because of the improvement in contrast.

d. **An Advantage of Motion**. Tissues in motion can in some instances serve diagnostic purposes, because their movement can be made to blur out undesirable details of superimposed structures. This can be effectively used in lateral radiography of the thoracic vertebrae and sternum.

2-20. SCREEN UNSHARPNESS

The introduction of unsharpness when x-ray intensifying screens are used is discussed in the next section of this lesson.

2-21. DISTORTION: INTRODUCTION

Body parts are not always symmetrical since the body is an irregularly shaped object. Because of this, the image of a body part is sometimes misshapen, and the relationship of various parts to one another may be incorrectly shown. This untrue portrayal of the shape or size of a body part in a radiograph is called distortion. Every radiograph will show a certain amount of distortion, as explained earlier. There are two kinds of distortion: (1) magnified distortion, in which the image is larger than the object; and (2) true distortion, in which the image shape is different from the shape of the object.

2-22. MAGNIFIED DISTORTION

Magnification, or magnified distortion, is a normal occurrence in radiography, as already has been explained. The degree of enlargement is a function of SID and OFD. When the object is close to the film, enlargement is minimal. As the object is placed farther and farther from the film, magnification becomes more and more pronounced. Therefore, the film should always be placed as near the object as possible, even though some true distortion of the image may result.

a. **Effects of Magnified Distortion**. Figure 2-7 illustrates the effects of magnified distortion. Two series of lateral radiographs of a dried skull were made in which the SID varied. Radiographs A-D: A, 72 inches; B, 40 inches; C, 30 inches; and D, 20 inches. As the SID was decreased, the images became larger. Radiographs E-H: SID for E-H are the same as in A-D, but OFD was increased to 4 inches. Note the tremendous increase in enlargement as the SID was decreased. The least enlargement is shown in each group at an SID of 72 inches.

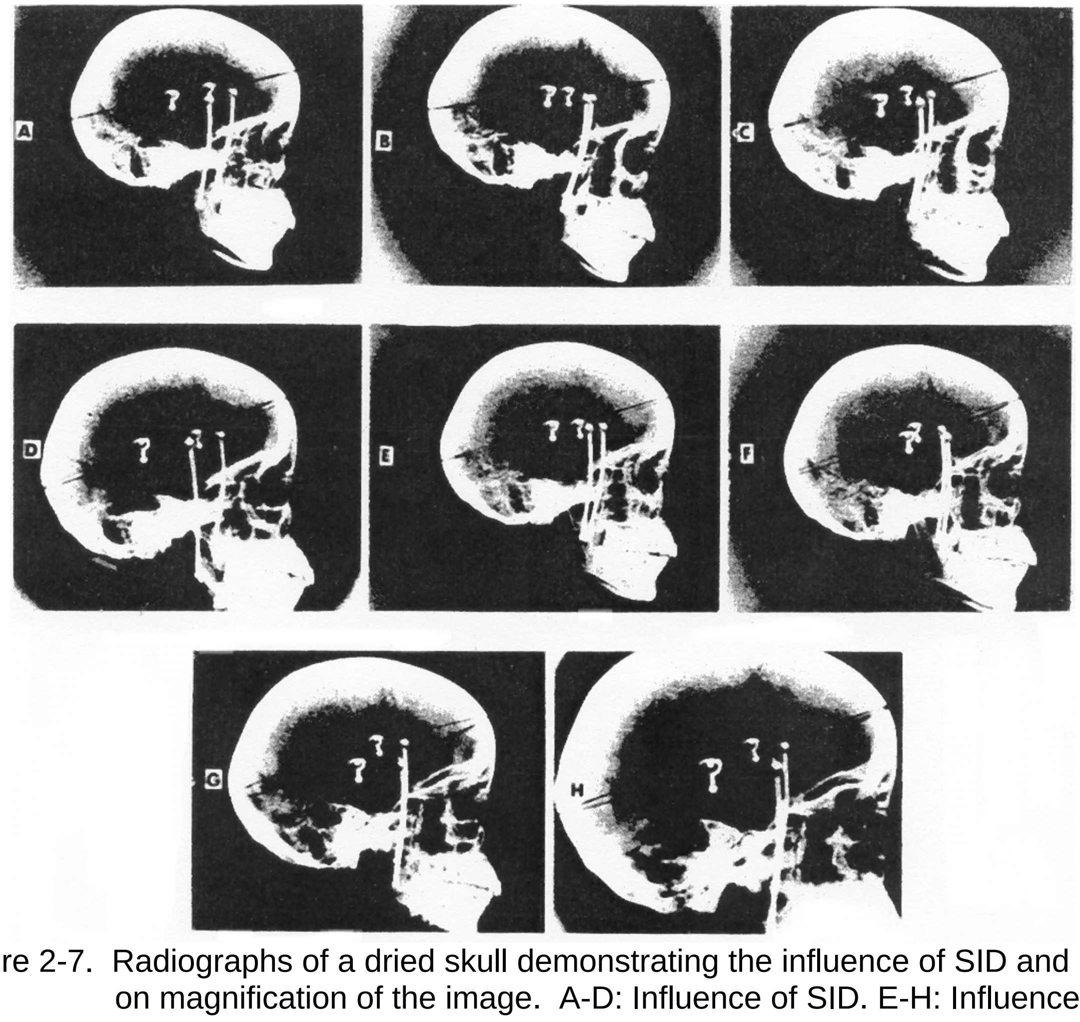


Figure 2-7. Radiographs of a dried skull demonstrating the influence of SID and OFD on magnification of the image. A-D: Influence of SID. E-H: Influence of OFD and SID.

b. **Opaque Object** . Occasionally an opaque object in the tissues may have a diameter less than that of the tube FS. If sufficient magnification is achieved by a reasonable OFD and a short SID, the object may be visualized as a diffuse gray area, but without much detail.

2-23. TRUE DISTORTION

Because the body is an irregularly shaped object, all body parts cannot be over the center of the film; nor can all tissues planes be parallel with the film. Some portions will be projected obliquely and their details distorted more than those in the center of the film. True distortion in a radiographic image is a variation from the true size and shape of the body part. It is most important that the size and shape of the image of various anatomical structures be comparable to the original. In the main, therefore, the central y should be perpendicular to the plane of the film and the major planes of the object. However, there are occasions in which body parts are deliberately distorted to obtain certain diagnostic information, as in posterior-anterior (PA) radiography of the sinuses.

2-24. ILLUSTRATION OF TRUE DISTORTION

Figure 2-8, a series of radiographs of apertures made in a lead plate, illustrates the effects of true distortion. From left to right, the holes were numbered 1, 2, and 3. In diagrams A, C, and E, the SID was 60 inches and in diagrams B, D, and F the SID was 25 inches. An OFD of 2 inches was used. In all diagrams, the central ray passed through the center of hole #1, and divergent portions of the x-ray beam passed through holes number two and number three. Diagrams of the various positions assumed by the aperture plate with respect to the FS and film are shown. Below the diagrams are the radiographic images that were obtained under each set of conditions.

a. **Diagram A.** All radiographic images exhibit magnified distortion because the 60-inch SID permits projection of approximately parallel x-rays.

b. **Diagram B.** Since the SID was shortened to 25 inches, magnified distortion of the images is greater than that shown in diagram A. Some oblique radiation partially altered the shape of the number three image.

c. **Diagram C.** The aperture plate was tipped so that the right-hand edge rested on the film. The center of hole number 1 was supported 2 inches from the film; the SID was 60 inches. Besides magnification of all images, the horizontal image axis is foreshortened and true distortion of the original shape occurs.

d. **Diagram D.** When the SID is reduced to 25 inches, greater magnification and distortion are shown. Image number 1 in diagrams C and D shows less distortion, because it is produced by the central portion of the beam.

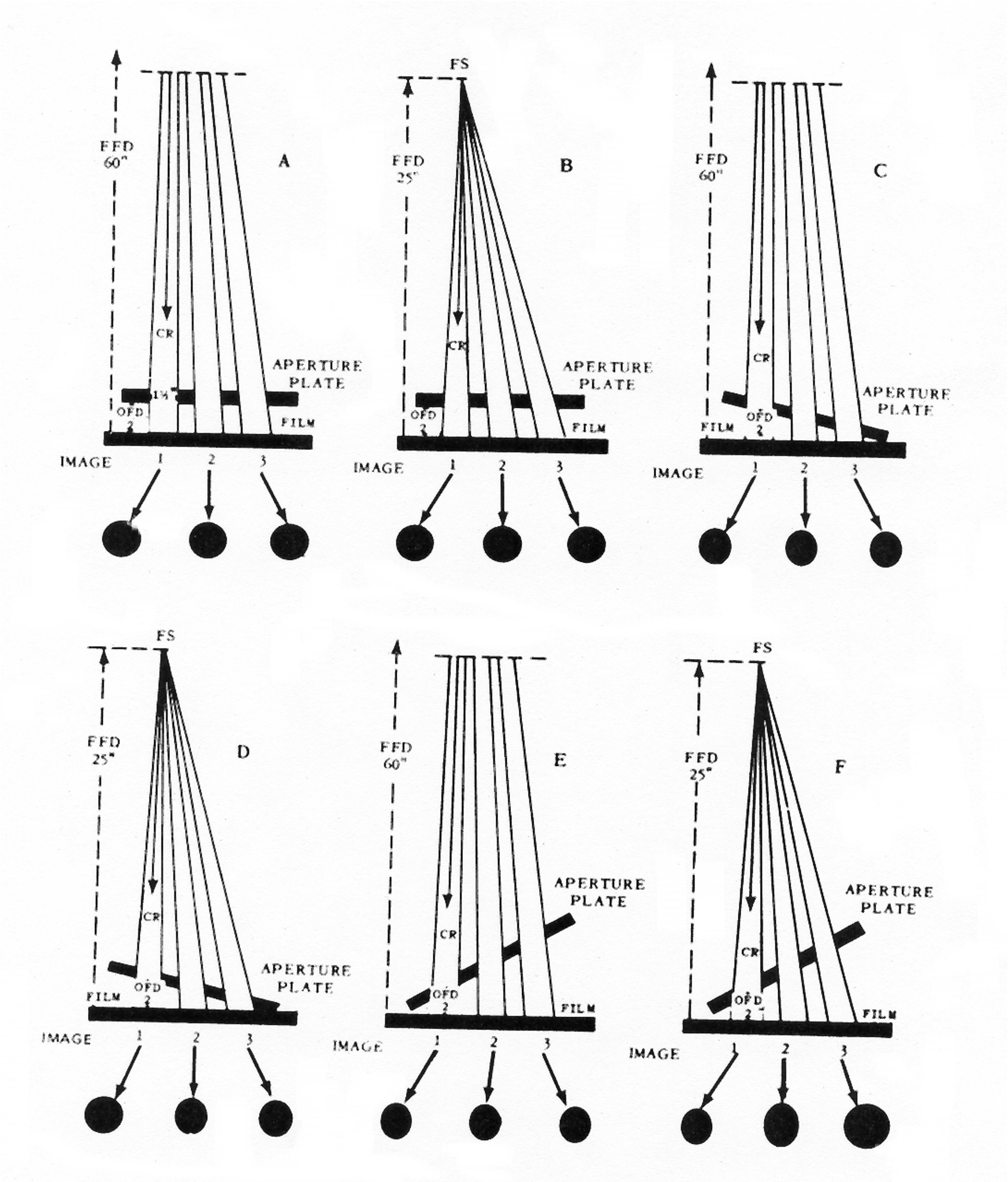


Figure 2-8. Radiographs of apertures in a lead plate, illustrating effects of distortion.

e. **Diagram E.** The aperture plate was inclined in a reverse direction to that shown in diagram D, and at a greater angle to the film plane. The center of hole number one is supported 2 inches above the film. An SID of 60 inches was used. Magnification of the images in their vertical axes is shown in number one to number three, but foreshortening of the horizontal image axes occurs, thereby producing true distortion.

f. **Diagram F.** The SID was reduced to 25 inches in this diagram, and the size and shape of image number one is about the same as that shown in diagram E. However, because of the great angle at which holes number two and number three are inclined, considerable true distortion and magnification occurs in image number two; number three image assumes a more spherical form although greatly magnified.

Section III. X-RAY INTENSIFYING SCREENS

2-25. INTRODUCTION

X-ray intensifying screens are radiographically indispensable. Although they introduce some measure of detail unsharpness in the image, their value in radically shortening exposures and reducing motion unsharpness is of prime importance. Less than 1 percent of the x-rays produced by the x-ray tube are absorbed by the emulsion and the latent image. A means for fully utilizing this small percentage of energy, without complicating the technical procedure, is the use of x-ray intensifying screens that serve to increase the effect of the x-radiation on the sensitized emulsion by means of fluorescence, thereby reducing the exposure. Fluorescence is that property of certain chemicals which enables them to absorb x-rays and instantaneously emit light.

2-26. FILM EXPOSURE HOLDERS

Holders for x-ray film must have two characteristics. They must (1) protect the film from light, and (2) allow the film to be exposed to x-rays.

a. **Cardboard Holder**. The direct-exposure film holder (cardboard holder) meets both of these requirements. These holders are made to fit the various film sizes. They have lightproof envelopes in which the film is placed before being taken from the darkroom. The front of the holder must face the x-ray tube during an exposure, since there is a lead foil lining in the back. This lining helps prevent fogging from backscatter radiation.

b. **Cassette**. A cassette is a film holder about 1/2-inch thick with a metal frame (either aluminum or stainless steel), a front of Bakelite, and a hinged lid with flat springs. It is used with two intensifying screens, one on either side of the film (figure 2-9). One screen is mounted on the inside of the lid and the other on the inside of the Bakelite front of the cassette. The lead foil backing in a cassette helps prevent fogging as it does in the cardboard holder. The cassette must also be loaded in the darkroom.

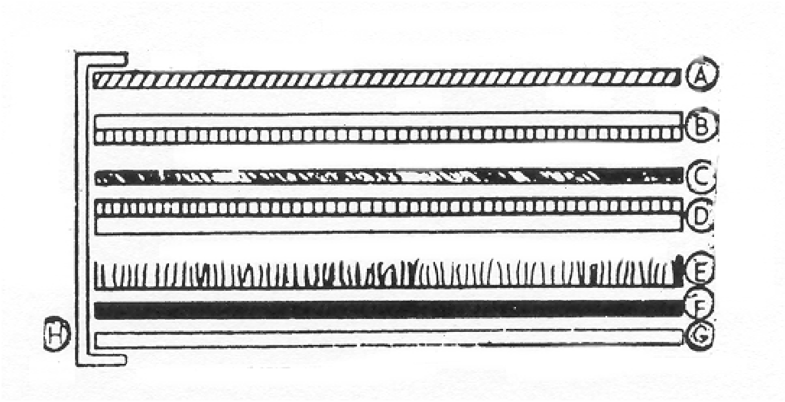


Figure 2-9. Cassette with the film in place between the built-in intensifying screens. (cross-section) (A), Bakelite plastic front faces tube; (B), front intensifying screen with crystals facing film;(C), x-ray; (D), back intensifying screen with crystals facing film;(E), felt cushion; (F), lead foil backing; (G), hinged metal back; (H) metal frame for support.

2-27. INTENSIFYING SCREENS

Intensifying screens are made by incorporating fine fluorescent crystals in a binding substance that is spread on one side of a piece of special cardboard.

a. Each of the numberless fine crystals on the intensifying screen emits light in every direction. When uniformly radiated, the intensifying screen appears to be uniformly bright. The film emulsion is sensitive to the blue light emitted by the fluorescent crystals. More than 90 percent of the density recorded on an x-ray film when intensifying screens are used is caused by the light emitted by the screens; the direct x-rays cause less than ten percent of the density. Because these screens increase the effect of the x-rays on the film, less x-ray exposure is required to attain the desired density. Intensifying screens have made possible the use of grid diaphragms, without which high-quality radiographs of large anatomic areas could not be obtained.

b. The action of the intensifying screens is as follows: The x-rays pass through the Bakelite front of the cassette and strike the first intensifying screen. As the rays strike it, the screen emits light that affects the emulsion on the side of the film facing it. The x-rays themselves penetrate and act on the film to a small degree. They strike the second intensifying screen, which reacts and exposes the emulsion on the backside of the film. It is for this reason that an x-ray film has a coat of sensitive emulsion on both sides. For maximum effectiveness, intensifying screens should not continue to emit light after the x-rays stop. This condition, known as phosphorescence or screen lag, is undesirable.

2-28. SPEED

An intensifying screen is considered to be “high speed” or “fast” when only a short x-ray exposure is needed to produce the required darkening of the film (density), and “slow” if a slightly longer x-ray exposure is necessary.

a. **Intensifying (Speed) Factor.** The speed factor of a set of intensifying screens may be defined as the ratio of the exposure required without the use of the screens to the exposure required with the use of the screens to the exposure required with the use of the screens. Expressed as a ratio:

$$\text{intensifying (speed) factor} = \frac{\text{exposure without intensifying screens}}{\text{exposure with intensifying screens}}$$

Since the numerator is always greater than the denominator, the intensifying factor of screens is always greater than one. Exposure with intensifying screens will always be for a shorter time to produce the desired density in the radiographic image than without them.

b. **Crystal Size.** The size of fluorescent crystals or grains used to coat an intensifying screen affects the speed of the screen and the sharpness of definition in the radiographic image. The larger the crystal size, the faster the speed of the screen. The light emitted grows broader as the size of the crystals increases. Therefore, a screen coated with the larger-sized crystals is a faster screen, but the detail and sharpness of definition of the radiograph are decreased. The smaller the size of the crystals, the slower the screen; but sharpness of detail is increased. There will be some decrease in the sharpness of the image no matter how small the crystals of the screen may be. This is true because the light emitted by a crystal is scattered by the adjacent crystals.

c. **Types of Screens**. Intensifying screens commonly used are the slow speed (high detail), medium or par speed (medium detail), and fast or high speed (low detail). The effect of the crystal size on screen speed and on detail (definition) of the radiographic image is shown in figures 2-10.

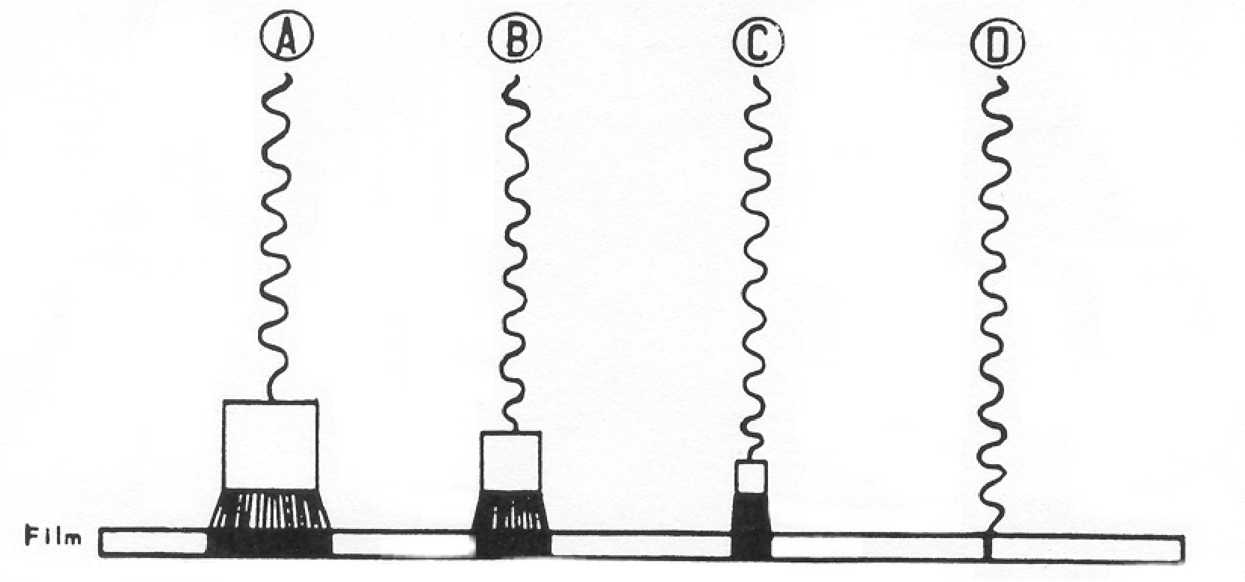


Figure 2-10. Effect of crystal size on speed of intensifying screen and on detail of radiographic image. A, large crystal size--more light is produced by the crystal and a high-speed screen results. B, medium sized crystals, a medium amount of light is emitted, and a medium or par-speed screen results. C, small crystals--less light is emitted, and a slow-speed but high-definition screen results. D, direct action of x-rays no crystals are used, and-only x-rays exposed the film. There is drastic reduction in speed but definition .is greatly improved.

d. **Screen Conversion Factors**. Manufacturers of intensifying screens usually publish particulars for changing the technique from one screen to another.

(1) Dupont recommends the following for their Cronex (Registered trademark of E. I. Dupont DeNemours & Co., Inc.) screens.

mAs Factor	Type of Screen
25	Medical film without screens
4	Detail
2	Fast detail Fast detail
1	Par speed
0.5	Hi-plus

(2) For example, if 100 mAs were used with par speed screens and it was necessary to change to hi-plus screens, the new mAs would be 50 (100 x .5 = 50). There are many manufactures of intensifying screens and individual manufactures should be consulted for appropriate technique conversions for their screens.

2-29. SCREEN CONTACT

Perfect contact between the x-ray film and the two screens is required. The double-coated x-ray film must be evenly placed between the active faces of the two screens and must be in full contact with both. Any space between the film and the screen allows the rays emitted from the screen at that point to spread and produce blurring of the image at that location on the film. (figure 2-11) Evenness of contact between the film and the two screens can be tested in the following way. A radiograph of a piece of wire screen is made. The screen is placed over the front of the cassette, and a film exposure is made using 50 kVp, 1.5 mAs, and 40-inch SID. The image of the wire mesh will appear in sharp detail over the entire surface of the film if the contact is good. Wherever there is an area of poor contact, the image will be blurred.

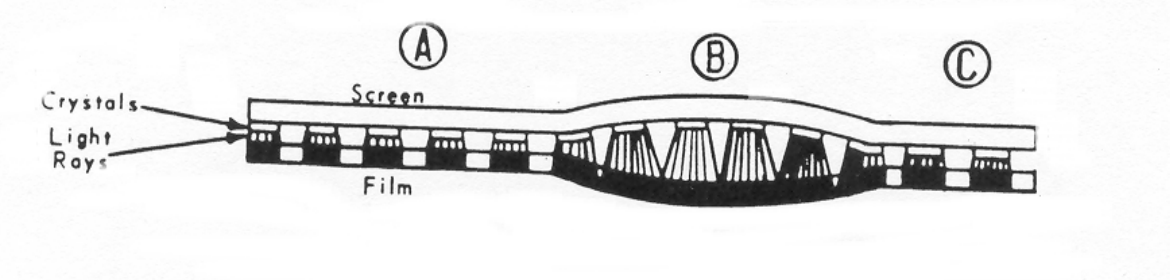


Figure 2-11. Poor screen contact produces a blurred radiographic image. Inareas A and C the film and screen are in good contact. In area B, light rays from one crystal cross those of others, and the resultant image of each crystal blurs into those of the adjacent crystals.

2-30. PROPER CARE OF SCREENS

Because the intensifying screens influence the quality of the radiograph, it is very important that they be kept in good condition. Except when it is being loaded or unloaded, the cassette should be kept closed so as to keep the screen surfaces free of dust and protected from scratches.

a. **Mounting**. Only rubber cement or special adhesive tape should be used to mount intensifying screens. Do not use water-soluble paste. In older type screens, one of the pair is thicker than the other; the thicker one is mounted on the lid of the cassette, and the thinner one in the front.

b. **Cleaning**. Any foreign matter on a screen will absorb light during the exposure and cause white shadows to appear on the radiograph. For washable screens, follow the recommended directions of a manufacturer's solution. In the absence of a commercial cleaner, use damp cotton and a mild soap rinse with wet cotton and dry with dry cotton. Since the cardboard backing will absorb water and warp, do not use any more water than is absolutely necessary. Stand the cassette on its side, leaving it half open to dry in a room free from dust. There is one type of screen that may be cleaned with pure grain alcohol swabbed on with cotton (see manufacturer's instructions); do not allow the alcohol to touch the letters appearing on the side of the screen as the printing may run and stain the surface of the screen. Whenever possible, commercially produced, antistatic cleaning solutions should be used.

c. **Handling**. Intensifying screens are very easily scratched, chipped, or nicked. They must be handled with care to keep them free of marks that will mar the radiographic image. Even the corner of a film brushing across the screen can scratch its surface. The x-ray specialist must be very careful not to scratch the screen with his fingernails in removing the film from the cassette.

2-31. FLUOROSCOPIC SCREEN

Use of the fluoroscopic screen is based upon the same physical principles as the intensifying screen. However, the fluoroscopic screen not only fluoresces, but also phosphoresces. Although phosphorescence is undesirable for intensifying screens, it is a necessary factor for fluoroscopic screens. The fluorescent material generally used to coat the active surface of a fluoroscopic screen is cadmium zinc sulfide. The fluoroscopic screen has a lead glass backing to protect the fluoroscopist.

Section IV. STANDARDIZATION OF EXPOSURE

2-32. RADIOGRAPHIC QUALITY

Uniform radiographic quality can only be achieved through complete control and standardization of exposure and processing procedures. The apparatus, x-ray tube, x-ray film, and processing chemicals have been scientifically designed to facilitate standardization. Sound judgment must be used when selecting the exposure factors and processing the exposed x-ray film. Also, a balance should exist in compromise between the exposure factors used, the clinical situation presented to the x-ray specialist and the objective of the examination--the diagnosis. Radiographic quality should be evaluated along realistic lines. If the quality is not what the radiologist should reasonably expect, the practical reasons for failure should be investigated.

2-33. DIAGNOSTIC USEFULNESS

Knowledge of the normal appearance of anatomic structures in the image and visual acuity in noting deviations from the normal are the tools that the radiologist uses in making his interpretations. Because an essential point in the radiographic diagnosis often appears in an inconspicuous portion of the image, a systematic analysis and evaluation of the entire image is necessary. This requires the entire image to be diagnostically informative and to have translucent silver deposits representative of the anatomic structures. The radiographic images must represent the true anatomic situation, and their appearance should always be fairly consistent. Standardized projections of an anatomic part always portray the structures in the same manner.

2-34. CRITERIA FOR RADIOGRAPHIC QUALITY

a. All image densities should be translucent when viewed before a conventional x-ray illuminator.

b. All portions of the image should have some silver deposit. Areas devoid of silver deposit and those with excessive silver deposits are diagnostically useless.

c. The part examined should be fully penetrated.

d. The basic mAs factor should be selected so as to provide the best overall radiographic density for the patient whose measurement is within the average thickness range.

e. Contrast should be such that differentiation between densities or details can be readily made.

f. Image details should not be obscured by SR or chemical fog.

g. Maximum sharpness and true shape of the image should be consistent with the clinical needs of the examination.

2-35. CONTRAST EXTREMES

To satisfy diagnostic requirements, there should be a good balance of densities. The extremes of the contrast scale--opaque areas and transparent areas--cannot reveal the details of an object. Images that merely depict size, shape, or outline of the object are not satisfactory; there must be a multitude of gray tones to differentiate detail. There is however, a limit to the number of useful tones because differentiation between densities is difficult when the contrast scale is unduly lengthened. Through recognition of the value of long-scale contrast for a given projection, errors in the application of exposure factors can be corrected.

2-36. CONTRAST AND SHARPNESS

Image contrast and sharpness are the basic factors in detail visibility. It is desirable to record with sufficient contrast slight variations in radiographic density of all details within the part examined and to show small differences over a wide range of tissue thickness in the same exposure. If all radiographic densities are translucent, there is image representation of all tissue details because all elements within the part have been penetrated. The scale of contrast should not be shortened beyond the point where essential detail, when viewed before an x-ray illuminator, begins to be lost to the eye in the higher and lower densities of the radiograph. It is preferable to stop short of this limit so as to have sufficient latitude to allow for unavoidable density deviations that may occur because of unusual or unpredictable tissue absorption. As a rule, improvements in detail visibility of some body parts can be effected by increasing the contrast within limits. However, certain restrictions as to overall detail visibility are imposed. On occasion, small areas of image detail are rendered brightly visible because the exposure factors may be optimum for the region. However, adjacent areas may be devoid of sufficient silver to produce a satisfactory overall image because the radiation did not penetrate all the tissues. Except for special cases, it is best to be satisfied with lower contrast (long-scale contrast) and be assured of penetration that will reveal details in all parts of the image. The greater number of densities provided by long-scale contrast makes possible the visualization of a larger number of tissue components.

2-37. VALUE OF TOTAL IMPRESSION

The evaluation of an x-ray image is dependent upon the distinctness of all the recognizable detail and not on contrast or sharpness alone. In judging the usefulness of radiographs, these two Qualities must be carefully evaluated. Generally, it is easier to correct unsatisfactory image sharpness by greater contrast, rather than the opposite. Figure 2-12 depicts a wide difference in contrast of two PA screen radiographs of the chest. Radiograph A was made with 80 kVp and 3.3 mAs; B, with 50 kVp and 20 mAs; both at a 72- inch SID. Owing to the shorter exposure time for A, it is sharper than Band possesses a wide range of densities; however, the high contrast of B may create the impression of greater sharpness because of the exaggerated density values.

2-38. STANDARDIZED EXPOSURE SYSTEM

Most modern radiography is “production-line” effort. A standardized system for selecting and applying exposure factors must produce consistently good radiographic quality. In formulating a standardized exposure system, the ideal should establish all factors as constants with the exception of one as a variable. With kVp as the factor of penetration and radiographic contrast, mAs as the factor of radiographic density, and SID and OFD as geometric factors influencing image sharpness, shape, and size, standardization of radiography becomes a four-phase operation.

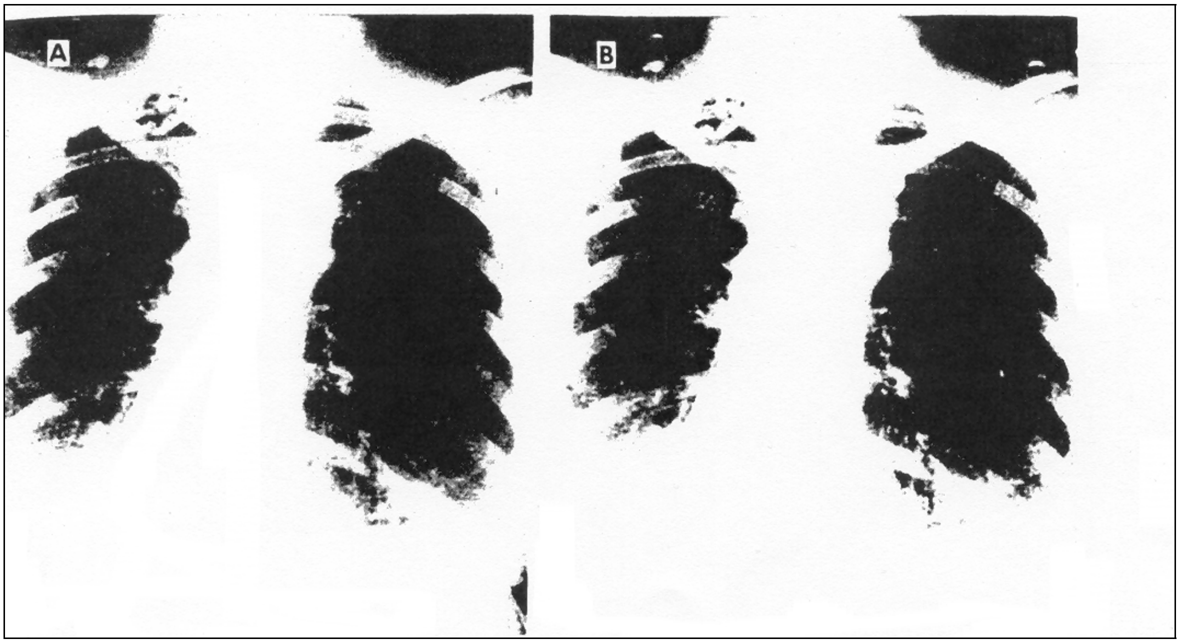


Figure 2-12. Postero-anterior screen radiographs of the chest depicting wide differences in contrast: A, 80 kVp; B, 50 kVp. Factors: A, 3.3 mAs, 72-inch SID; B, 20 mAs, 72-inch SID.

a. **Standardization of Exposure Factors.** All exposure factors for a given exposure are reduced to constants with the exception of one variable (sec).

b. **Standardization of Exposure Techniques.** For purposes of standardization, exposure techniques are divided into three major classes: direct, screen, and screen grid.

c. **Standardization of Projections.** Routine methods have been established for positioning the patient and projecting the central ray for each given projection.

d. **Standardization of Processing Procedure.** Time and temperature values are reduced to constants so that changes in radiographic density can be more properly attributed to exposure.

2-39. OPTIMUM KILOVOLTAGE TECHNIQUE

The optimum kVp technique is based upon standardization of the processing procedure and the reduction of exposure factors to constants with the exception of one variable (mAs). In working out an optimum kVp technique, each projection must be considered individually.

a. By trial, a fixed or optimum kVp is established for an average tissue thickness of a particular body part; the x-ray wavelength used to penetrate the tissues must be adequate. The amount and kind of tissue, the relation of bone to soft tissue, and its penetrability by x-radiation must be evaluated. Measurement of the part must be made along the course traversed through the tissues by the central ray, and the average range of measurements verified by checking many individuals. The kVp that thoroughly penetrates the part, irrespective of size, and produces satisfactory contrast is established as a constant. (Using kVp as a constant to establish contrast places the burden of providing sufficient silver in the image upon the mAs) The kVp should not be changed unless the conditions under which it was established are changed (Table 2-4). Average thickness ranges are also guides for establishing basic mAs values for various projections since approximately 80 percent of all patients fall within these ranges. Average thickness range and a reliable optimum kVp have been established for a number of projections (Table 2-4). Using the principles advocated, the kVp for some other projection may be easily found.

b. With the kVp fixed, a basic mAs or density value must be established for the average thickness range of the part. In deriving mAs values for thicknesses outside the average range or for variations in the physiologic or pathologic state for the tissues, the rule-of-thumb for density changes is used.

c. The FFO need seldom be changed, and in most instances may be considered a constant. All other factors, including processing, are constants.

2-40. ADVANTAGES

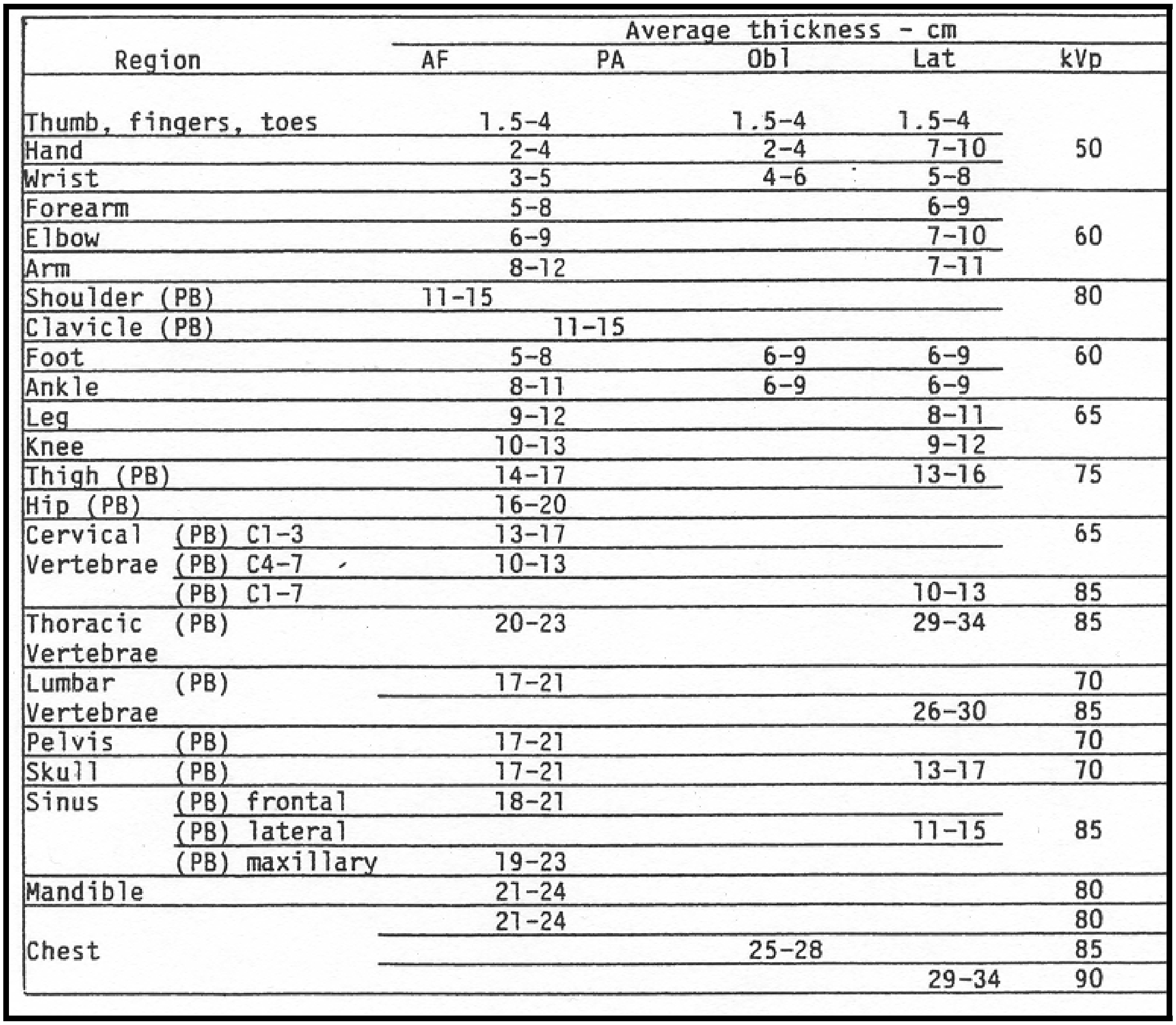
There are several important advantages in using this method:

a. Less mAs permits more radiographs in a given projection before the radiation safety limit is reached. When the wavelength is optimum, a lower mAs value is usually more adequate for the exposure than that used for the same purpose with lower kVp.

b. The overall radiographic density is uniform from case to case. Any differences from the normal density may be attributed to abnormal tissue changes.

c. Duplication of results is easy to attain in follow-up cases.

d. The technique may be used with any type of apparatus. Whatever the type of generator, the only variable to adjust is the mAs.



Region	Average thickness - cm AF	PA	Obl	Lat	kVp
Thumb, fingers, toes		1.5-4	1.5-4	1.5-4	50
Hand		2-4	2-4	7-10	
Wrist		3-5	4-6	5-8	
Forearm		5-8		6-9	60
Elbow		6-9		7-10	
Arm		8-12		7-11	
Shoulder (PB)	11-15				80
Clavicle (PB)		11-15			
Foot		5-8	6-9	6-9	60
Ankle		8-11	6-9	6-9	
Leg		9-12		8-11	65
Knee		10-13		9-12	
Thigh (PB)		14-17		13-16	75
Hip (PB)		16-20			
Cervical (PB) C1-3		13-17			65
Vertebrae (PB) C4-7		10-13			
(PB) C1-7				10-13	85
Thoracic (PB) Vertebrae		20-23		29-34	85
Lumbar (PB)		17-21			70
Vertebrae				26-30	85
Pelvis (PB)		17-21			70
Skull (PB)		17-21		13-17	70
Sinus (PB) frontal		18-21			85
(PB) lateral				11-15	
(PB) maxillary		19-23			
Mandible		21-24			80
Chest		21-24			80
			25-28		85
				29-34	90

Table 2-4. Exposure factors. Average thickness ranges and appropriate optimum kilovoltages for various projections with which basic mAs may be used for making nongrid or grid (P-B) exposures.

2-41. RULES FOR APPLICATION

When all other exposure factors remain constant, the factors listed below function as described. Successful operation of the optimum kVp technique is dependent upon rigid acceptance and application of these data

a. Source-to-image distance influences radiographic density, image sharpness, and magnification.

b. Kilovoltage regulates radiation wavelength and the scale of radiographic contrast; determines the degree of tissue penetration and exposure latitude and influences radiographic density and the production of SR fog.

c. Milliampere-seconds are the factor that regulates the quantity of x-radiation emitted by the x-ray and radiographic density. It may be recalled from paragraph 1-17 that kVp also affects radiation quantity. Since kVp is mainly noted for its effect on radiation QUALITY, kVp is usually NOT altered if only the radiation quantity to be adjusted.

2-42. SELECTION OF FACTORS

The selection of factors that influence the image should be based upon consideration of all aspects that might have an eventual effect on radiographic quality.

a. **Focal Spot.** The FS should always be selected so that the maximum image sharpness is obtained, assuming that the exposure factors to be used conform to the rated capacity of the x-ray tube.

b. **Collimation.** Collimation in some form should be used for all projections. The size of the field should be such as to exactly cover the size of film used at a given SID. There are occasions when the field size should conform to the size of the anatomical area being examined. For example, a particular beam-restricting device may cover an 8 x 10 film, but be inadequate for delineating a very small area, such as the mastoid process. A smaller device (cylinder) would be needed.

c. **Grids.** Stationary or moving grids are used in examining the heavier tissue parts. The x-ray specialist should be familiar with grid ratios as well as the SID used with the various grids. The higher the grid ratio, the greater the care in selecting the SID and in centering the tube to the grid and part to avoid “grid cutoff.” For best results, conventional moving grids of 8:1 or 12:1 ratio should be used with optimum kVp. The stationary grid of the Lysholm type is a very useful accessory when a moving grid is impractical.

d. **Source-to-Image Distance.** The SID should be chosen to produce the most realistic geometric image pattern with satisfactory sharpness of definition. Once the SID is selected for a specific projection, it should be established as a constant. If the distance must be changed for a given projection, the mAs can be adjusted to maintain density by applying the formula governing mAs-SID relationship.

e. **Kilovoltage.** The variety of effects that may be produced on the radiographic image by kVp makes it an important and influential exposure factor. Consequently, it should be closely controlled and established as a constant for a given projection. When a kVp provides an acceptable contrast scale in a given projection of a normal part, that kVp should be fixed. Thereafter, all images produced by a given projection will present the same scale of contrast.

f. **Basic mAs.** Since it controls the amount of radiation, the mAs factor is the one most reliable for regulating the amount of silver (density) in the image. There should be a satisfactory range of densities for interpretations of all portions of the image. A basic mAs value can be established for any average thickness range of a part for a normal person.

2-43. THICKNESS ONLY A GUIDE

a. The thickness of any part serves only as a guide who the specialist can use to expose the normal part and to determine what mAs will compensate for abnormal tissue changes. Knowledge of the structural makeup of the area is necessary. The part should also be judged from a physiologic and pathologic standpoint as to whether it is reasonably normal. If a question arises as to whether the patient is “average” or “in-range,” a measurement of the part should be made. The following shows compensations required of the “above” or “below-range” part.

Below range		In range	Above range	
3-5 cm	1-2 cm	Basic set	1-2 cm	3-5 cm
1/2 x sec	2/3 x sec		1 1/2 x sec	2 x set

b. Since the mA will remain constant, a change in sec will give a corresponding change in mAs. By means of these modifications, the radiographic density obtained will be approximately correct--a “repeat” is seldom required.

2-44. ESTABLISHING A BASIC mAs

First, select the correct quality of radiation (kVp) for a given projection. Then, determine the quantity of radiation (mAs) by making three initial radiographs of a part, thickness of which is approximately at the middle of the average thickness range. In determining exposure factors for a given projection, make the first radiograph with the optimum kVp for the part (table 2-4), and with a mAs value estimated to be correct. For the second radiogram, double the mAs value (2 x). Make the third radiograph with one-half the original mAs value (1/2 x). All other factors are constant. The three radiographs are viewed on the illuminator, and the density appropriate for the part is chosen.

a. When using the above method, sometimes none of the densities will be exactly correct; however, one of the radiographs perhaps shows a density close to the one desired, so that another radiograph made with an appropriate change in the mAs will provide the required radiographic density and a more nearly correct basic mAs value. The final mAs value is then used on several patients whose measurements fall within the average thickness range. If the density level is satisfactory for measurements at the center and at the extremes of the range, the mAs should be established as basic and used for all patients measuring in the average range.

b. Once the correct mAs is determined, it becomes the basic value to be used for all thicknesses in the average range established for the given projection. Departures from the basic mAs value should be made only when the influence of disease or trauma alters the absorption characteristics of the part or when the speed characteristics of the film or screens change.

c. The method explained herein for changing density can be used for all projections as long as it is used in a systematic manner. Only one exposure factor should be changed at a time when any exposure technique is to be altered. Changing two factors at a time introduces too many variables that are difficult to control.

2-45. EXAMPLE

a. In PA screen radiography of the adult chest, the average thickness range is 21 to 24 centimeters (approximately 70 percent of patients). A basic mAs may be used when an optimum kVp of 80 is used at an SID of 72 inches and with average-speed screens. In this projection the basic mAs should be established for a normal healthy adult measuring 22 to 23 centimeters (the middle thickness in the range). Projections that have little variation from the average thickness range, such as a PA of the chest, require refinement in application of the mAs values to those thicknesses slightly in excess of or less than the average. A typical example of a standardized PA chest technique is shown in figure 2-13. The physical characteristics of the patients whose radiographs are shown in figure 2-13 as follows:

Radiograph	Thickness (cm)	Sex	Age (yrs)	Height (in)	Weight (lbs)
A	17	F	20	65	105
B	18	F	24	63	110
C	19	F	29	60	101
D	20	F	22	63	107
E	21	M	61	67	135
F	22	F	21	58	132
G	23	F	24	60	123
H	24	M	60	68	165
I	25	M	34	63	130
J	26	M	60	67	173
K	27	M	55	67	199
L	28	M	36	70	206
M	29	M	60	69	193

Constant Factors

kVp	80	Cone	To cover area
mA	100		
FFD	72"	Film	Screen-type
Screens	Average speed	Developer	Rapid
Filtration	Alum., 1 mm	Development	5 min. at 68° F.

Variable Factors

Thickness Ranges	A* time	B* time
—17 cm.	1/40 sec.	1/60 sec.
18-19 cm.	1/30 sec.	1/40 sec.
20-25 cm.	1/20 sec.	1/30 sec.
26-27 cm.	1/15 sec.	1/20 sec.
28- cm.	1/10 sec.	1/15 sec.

*To compensate differences in efficiency of X-ray output in various X-ray generators, it is necessary to establish by trial the time category (A or B) that will produce the desired radiographic density. In making the test radiographs, a subject with a 22-23 cm. chest should be radio-graphed employing an exposure of 1/20 sec. (column A) If the density is too great, then 1/30 sec (column B) may be used. The density of this second radiograph will usually be satisfactory; on this basis the time values for the other thickness groups will be found in column B. The chest radiographs reproduced on this spread were made with the time values listed under Column A

Figure 2-13. A typical example of standardized posteroanterior chest technique

b. Radiation that completely penetrates the part and produces a consistently uniform density and contrast is most important in applying a standardized technique as illustrated in figure 2-13. The characteristics of height, weight, or sex cannot, per se, be used to determine the x-ray absorbing properties of the tissues being exposed.

2-46. THICKNESS GREATER THAN AVERAGE

When a chest measurement is slightly greater than average (average is 21 to 24 cm for an adult), the only change needed is in the mAs factor. The increased thickness of the 25- to 26-cm chest requires more radiation of the same quality produced by 80 kVp on chests within the average range. The kVp is held constant since it has been predetermined that 80 kVp provides the necessary quality of radiation to penetrate any size adult chest within a reasonable range in the PA direction. When a basic mAs is given to a 25- to 26-cm chest, the radiographic density may be too low. When the mAs is doubled, the density may be too great, with excess fog. Consequently, a value should be used which is found by adding one-half of the basic value to the basic value. The density should then be comparable to that produced by the basic value on a 23-cm chest. Original contrast is maintained, and SR fog is not a problem. Chests with a thickness of 27, 28, 29, or 30 cm can be exposed with double the mAs, probably without any increase in kVp. Chests exceeding 30 cm in thickness require an increase in both mAs and kVp. The higher kVp causes an increase of SR fog that would be eliminated by the use of a stationary parallel-grid. The kVp, therefore, should be raised to 100 to increase penetration and to compensate for the grid. Consequently, a new group of conditions must be set up and a new basic mAs established to assure proper density. The same SID and screens should be used.

2-47. SMALLER THICKNESSES

If the basic mAs are used for a 17- or 18-cm chest, the density will be excessive. A satisfactory result can be obtained, however, by exposing with one-half of the basic mAs. To balance the densities for the 19- and 20-cm chests, two-thirds the basic mAs may be used and for 13 to 16 cm, one-third the basic mAs. For infants (less than 13 cm) one-half of the basic mAs may be used, but the kVp should also be reduced from 80 to 70 to provide increase in contrast.

2-48. OVEREXPOSURE

Modern x-ray film, in combination with intensifying screens, is exceedingly fast and requires only relatively short exposures to produce radiographs of good Quality. An overexposed film lacks proper radiographic density and contrast. To the trained eye, the overexposed radiograph is easily identifiable.

a. One type of overexposure exhibits an overall grayness with low contrast. This appearance is caused by shortened development of the film, a procedure often followed in an attempt to correct the error made in the exposure time or to compensate for excessive kVp. In another case, full development is employed and obliterates the image of all the thinner parts.

b. If the kVp is correct, overexposure due to the mAs factor may usually be corrected by making another radiograph with one-half the original mAs (i/2 x). Frequently, the density of this second radiograph is satisfactory or is so near in quality that if a third radiograph is made, only a minor adjustment of mAs is needed to secure the most desirable quality. Halving mAs when the image is too dense (and doubling mAs when it is not dense enough) is called the “rule-of-thumb” method.

2-49. EXAMPLE OF CORRECTING OVEREXPOSURE

To illustrate the procedure in altering density by the rule-of-thumb method when determining a basic mAs value or correcting a faulty one, a series of AP screen-grid radiographs of the lumbar vertebrae (figure 2-14) was made with 70 kVp and a 36-inch SID. The first radiograph (A) was made with a trial exposure of 200 mAs. The density was excessive. Applying the rule-of-thumb for density, the second radiograph (8) was made with 100 mAs. The density was reduced, but it was still somewhat excessive. The mAs was halved again for the third radiograph (C), but the density became insufficient. A fourth radiograph (D) was made using 75 mAs, a value midway between 100 and 50, which yielded a satisfactory image density. Once the basic value is established, the need for correcting overexposure or underexposure seldom exists when an optimum kVp is used. The experienced x-ray specialist soon recognizes the degree of overexposure and can make short cuts; for instance, the second radiograph (8) can be eliminated by quartering the original mAs and securing a working density that can be easily adjusted if necessary.

Figure 2-14. A series of AP screen-grid radiographs of the lumbar vertebrae. Factors: 70 kVp and 36-inch SID. For A, 200 mAs; B, 100 mAs; C, 50 mAs; and D, 15 mAs.

2-50. UNDEREXPOSURE

A radiograph is underexposed when important details are lacking because of inadequate radiographic density. Details of thin structure may be visible, but those representing the heavier parts are absent. When the kVp is of a value to secure proper penetration of the part but mAs is insufficient for proper density, the radiograph will reveal very faint detail in image areas corresponding to the greater tissue densities--the kVp is satisfactory for the part, but detail may be better visualized if more silver were deposited on the film. Usually the density will be satisfactory when the mAs is doubled; however, a further small adjustment may be necessary to provide a satisfactory' image.

2-51. EXAMPLE OF CORRECTING UNDEREXPOSURE

A series of PA screen-exposure radiographs of the chest (figure 2-15) was made using 80 kVp and 72-inch SID. The first radiograph (A) was made with 3.3 mAs and resulted in an underexposure. The second radiograph (8) was made with 6.6 mAs and the resulting density was excessive. The third radiograph (C) was made with five mAs, approximately midway between the previous mAs values, and a correct exposure was obtained.

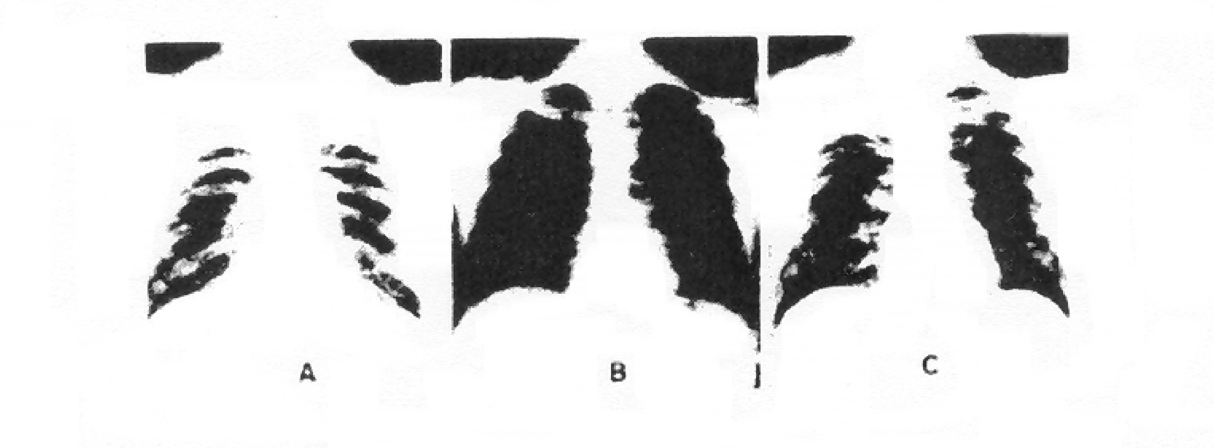


Figure 2-15. A series of PA screen-exposure radiographs of the chest.
A Factors used: 80 kVp and 72-inch SID. For A,
3.3 mAs; B. 6.6 mAs; and C, 5 mAs.

2-52. PHOTOTIMING

The use of optimum kVp in radiographic photo-timing eliminates many problems in the choice of appropriate factors. SID is constant for given projections, and the burden of regulating the mAs is on the photo timer. When calibrated and operated properly, it will provide the desired radiographic density on each film.

2-53. SUMMARY

Knowledge of the function of each exposure factor makes it possible for the x-ray specialist to predict the quality of any radiograph exposed with a given group of factors. Also, if an error has been made in applying a factor, analysis of the image should readily reveal the exposure factor at fault. Correction can then be made.

Continue with Exercises

EXERCISES, LESSON 2

INSTRUCTIONS. Answer the following exercises by marking the lettered response that best answers the question or best completes the incomplete statement or by writing the answer in the space provided.

After you have completed all of these exercises, turn to "Solutions to Exercises" at the end of the lesson and check your answers. For each exercise answered incorrectly, reread the material referenced with the solution.

1. Which of the following combinations would produce 30 mAs?

Seconds	mA
a. 1/60.	500
b. 3/20.	200
c. 5/20.	200
d. 4/10.	200

2. To effect a moderate increase in the density of a radiograph, with the kVp and processing remaining constant, you should normally use:

   a. A longer SID.

   b. Faster intensifying screens.

   c. A larger focal spot.

   d. A doubled mAs.

3. Which of the following most accurately states the reciprocity law?

   a. Change in density = 0.35 x milliamperage.

   b. Emulsion reaction = time x light intensity.

   c. Milliamperes x time = time x milliamperes.

   d. 1/2 milliamperes x time = milliamperes x 1/2 exposure time.

4. Suppose a technique of 50 mA and an exposure time of 0.0 second is used for a radiograph. For a second exposure, the sec is decreased to 0.2 second. What mA should be used to keep the same film density?

    a. 120 mA.

    b. 150 mA.

    c. 175 mA.

    d. 200 mA.

5. Increasing exposure time would cause, primarily:

    a. More contrast.

    b. A decrease in fog.

    c. An improvement in detail.

    d. An increase in density.

6. Which of these factors has most to do with determining the size and shape of an image on a radiograph?

    a. Source-to-image distance.

    b. Focal-spot size.

    c. Object-film distance.

    d. Crystal size of screens.

7. The most noticeable difference between a radiograph and a shadow is the:

    a. Outline of the image.

    b. Silhouette effect.

    c. Length of exposure time.

    d. Presence of detail.

8. Focal spot size affects:

    a. Density.

    b. Distortion.

    c. Contrast.

    d. Definition.

9. The advantage of using a compression band when radiographing the abdomen is that it permits:

    a. No involuntary motion.

    b. Reduction of exposure time.

    c. Improvement of contrast.

    d. The patient to continue breathing during exposure.

10. When it is permissible to use movement in tissues as a diagnostic aid.

    a. When desiring to blur out details.

    b. When the body part cannot be immobilized.

    c. When movement is due to equipment vibration.

    d. When the patient is in traction.

11. One reason it is impossible to remove all distortion from a radiograph is that the:

    a. Body tissues have varying densities.

    b. Body is irregularly shaped.

    c. Focal spot is not a point source.

    d. Use of a filter diffuses the primary beam.

12. Proper use of which of the following sets of variables will best serve to minimize magnified distortion?

    a. Focus-film and object-film distance.

    b. Source-to-image distance and focal-spot size.

    c. Focal-spot and screen crystal sizes.

    d. Focal-spot size and object-film distance.

13. The advantage of using intensifying screens in radiography lies in:

    a. Increased film detail.

    b. Increased body part penetration.

    c. Shorter exposure time.

    d. No change needed in technique factors

14. What protective measure built into a cardboard holder or cassette prevents fogging of the x-ray film by secondary radiation?

    a. Aluminum sheet.

    b. Bakelite strip.

    c. X-ray absorbing film envelope.

    d. Lead foil backing.

15. Intensifying screens aid in the exposing of an x-ray film by:

    a. Changing the x-rays to photons

    b. Emitting blue light, increasing the photographic effect

    c. Converting x-rays to corpuscular rays

    d. Increasing the sensitivity of the film emulsion.

16. What type of intensifying screens produces the best detail?

    a. Slow speed

    b. High speed

    c. Medium speed

    d. Optimum speed

17. What happens when the intensifying screens and film are not in good contact?

    a. Pressure points destroy the image.

    b. The x-ray image is blurred.

    c. Image is too light.

    d. The x-ray image is uneven.

18. Which, if any, of the following named preparations is recommended for use in cleaning washable intensifying screens?

    a. Manufacturer's solution.

    b. Pure grain alcohol.

    c. Barium platinocyanide.

    d. Soap and water.

19. When standardizing a radiographic technique for a given body part, which factor should remain as the variably.

    a. SID

    b. kVp

    c. Screen speed

    d. mAs.

20. You are viewing a radiograph and notice an overall grayness with low contrast. This may be caused by:

    a. Overexposure and short development.

    b. Short exposure time.

    c. Using the low kVp range.

    d. Improper mA setting.

Check Your Answers on Next Page

SOLUTIONS TO EXERCISES, LESSON 2

1. b (para 2-1)

2. d (para 2-2)

3. b (para 2-3)

4. b (para 2-5a)
   mA x sec1 = mA2 x sec2
   50 x 0.6 = mA2 x 0.2
   mA2 = 150

5. d (para 2-6)

6. c (paras 2-10c, 2-11a)

7. d (para 2-9)

8. d (para 2-15a)

9. c (para 2-19c)

10. a (para 2-19d)

11. b (para 2-21)

12. a (para 2-22)

13. c (para 2-25)

14. d (2-26a & d)

15. b (para 2-27a)

16. a (para 2-28)

17. b (para 2-29)

18. a (para 2-30b)

19. d (para 2-40f)

20. a (para 2-45)

End of Lesson 2