SECTION IV APPLICATION OF RADIOGRAPHIC INSPECTION

6.4 EFFECTIVE RADIOGRAPHIC INSPECTIONS.

6.4.1 Introduction. This section describes the factors that determine whether or not a particular radiographic inspection is sufficiently sensitive to detect small defects. Sensitive radiography requires maximum subject contrast resulting from correct kilovoltage; alignment of the beam with the plane of the likely flaw; a sharp image, due to good geometry and secondary radiation; and finally, optimum density to give good film contrast. Each of these factors is described in turn and a description is given of quantitative transformations to allow exposure and density changes with a minimum of experimentation.

6.4.2 Factors Affecting Image Quality.

6.4.2.1 Radiation Energy. The radiation energy chosen must be compatible with absorption rate of the subject. For low-absorbing subjects, low-energy radiation produces radiographic images with good contrast. Conversely, for inspection of thick, highly absorbing subjects, the radiation must be capable of sufficient penetration to produce an image within a reasonable period of time. To achieve a high-contrast, 96 to 99-percent of the incident radiation SHOULD be absorbed by the subject. Increasing kilovoltage reduces contrast because the quantity of radiation at any given energy increases and, perhaps more importantly, the proportion of radiation with a short wavelength (high energy) increases disproportionately. These two relationships are in Figure 6-21). High energy radiation can penetrate the subject more easily, thus, reduces subject contrast. The effect on the final image of low or high contrast is shown (Figure 6-22). The right diagram in (Figure 6-22) shows for a given subject, a doubling of kilovoltage increases transmitted radiation 15 to 30 times. This example shows the disproportionate effect a small kilovoltage change can have upon a particular inspection.

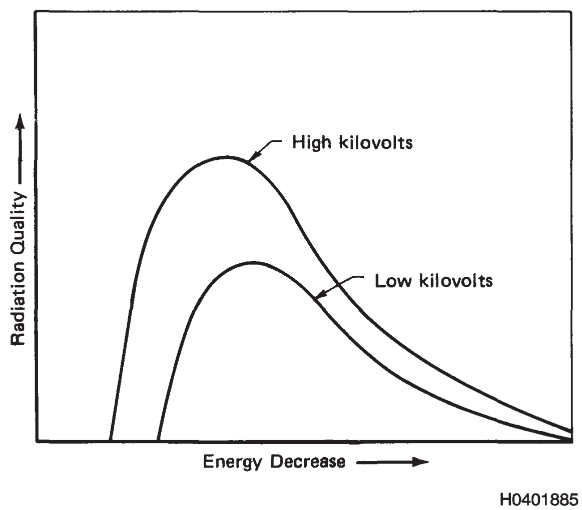


Figure 6-21. Effect of Kilovoltage on Transmitted Radiation Output

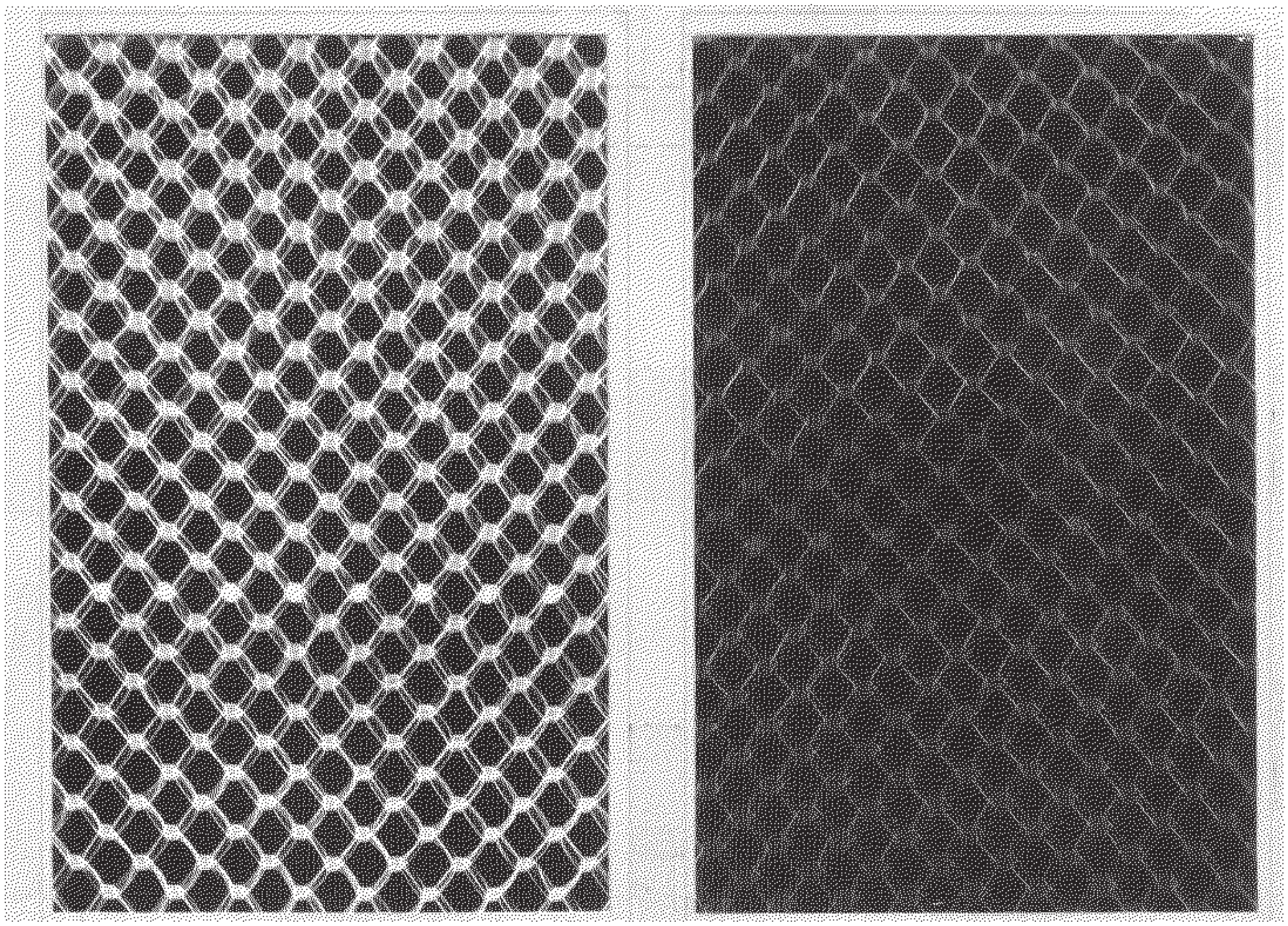


Figure 6-22. Radiographs of Honeycomb Showing Effect of Kilovoltage on Contrast

6.4.2.1.1 If industrial radiographic applications were to use monochromatic radiation, and if there was no scattering to be considered, the radiation absorption could be mathematically calculated with high precision using the classical attenuation equation, however, in normal applications, it is not possible to calculate the right kilovoltage to be used for a particular inspection because this optimum condition does not exist. The best initial approach is to use past experience. Approximate radiation energies compatible with various subjects is indicated in (Table 6-10).

Table 6-10. Approximate Radiation Energies Compatible With Various Absorbers

Radiation Source, kVp	Aluminum or Other Light Metals	Steel
2-25	0.001-0.11 in.	0.001-0.01
25-50	0.1-0.75 in.	0.01-0.125
50-150	0.5-3 in.	0.125-0.75
100-250	2-8	0.125-1.75
150-400	3-12	0.375-3 in.
Ir ÿ 192		0.625-4 in.
Cs ÿ 137		0.75-4 in.
1 mev		1.5-5
Co ÿ 60		1.5-7
8-12 mev		3.12
24 mev		3.18

6.4.2.1.2 It SHOULD be noted, as radiation energy increases, the differences between absorbing materials become less pronounced than at lower energies. Due to photoelectric absorption, the atomic number of an absorber has a large effect upon radiation absorption at energies of 100 kV or less. At high energies, in the 1 MeV range, the material density becomes the major controlling factor in determining radiation absorption. A 10-percent change in radiation energy has a very definite effect at low energies. In MeV energy ranges, this same percent change in energy can hardly be detected in transmission characteristics

6.4.2.2 Radiation Quantity. An alteration in the filament current (mA) produces a direct change in the quantity of radiation emitted, but has no effect upon the radiation energy. Additionally, filament current (mA) and time are usually interchangeable. That is, the product of milliamperage and time is constant for the same photographic effect. This is known as the “reciprocity law.” This law is valid for X- and gamma ray exposures, with or without lead screens, and over the range of radiation intensities and exposure times used in industrial radiography. There is one exception, which is the use of fluorescent screens, discussed in (paragraph 6.3.8.9). For very low or high intensities, the reciprocity law fails because of changes in the efficiency of the response of the film emulsion to unit radiation. If high production radiography is required, a source with a high radiation output would be economical. Usually, the high-output equipment requires a source with a comparatively large focal spot therefore, rate of radiation output is often directly related to focal spot size. The resulting unsharpness due to geometry can become detrimental to image quality.

6.4.2.3 Exposure Geometry. The geometrical setup used to produce a radiographic image is an important factor that contributes to final image quality. Geometrical relationships affect the image sharpness and help control image distortion.

6.4.2.4 Image Distortion. For the best radiograph, the source beam SHOULD be aligned perpendicular to the part and the film SHOULD be located on the same plane as the part. This positioning projects the image of the part upon the film in the true shape of the object with minimal distortion. Any deviation from these relative positions of source, object, and film will produce an image with some degree of distortion. This alignment is particularly critical for crack detection. Since discontinuities revealed in radiographic images are usually identified by their shape, images free of distortion are very important in interpretation. Where complex structures are encountered in aircraft inspection, it is often impossible to locate the various parts in the most desirable positions, and sometimes an inspection MAY be facilitated by planned distortions. Interpretation of distorted images is not impossible, but the film reader must mentally visualize the geometry of the object under evaluation, and how the exposure would project the distorted image onto the film. This ability requires practice and experience.

6.4.2.5 Image Unsharpness. This is the term applied recognizing there will always be unsharpness of the image to some degree, and perfect image sharpness is unattainable. The amount of geometric image unsharpness is due to size of the source of radiation and relative distances as shown in (Figure 6-23). The distance on the film over which an edge is spread is known as the penumbral shadow or the geometrical unsharpness, U_g. The value of U_g does not enter into other computations; it sets the upper limit for Ft/d. The value must be determined experimentally. The equation to determine unsharpness is located in (paragraph 6.7.8).

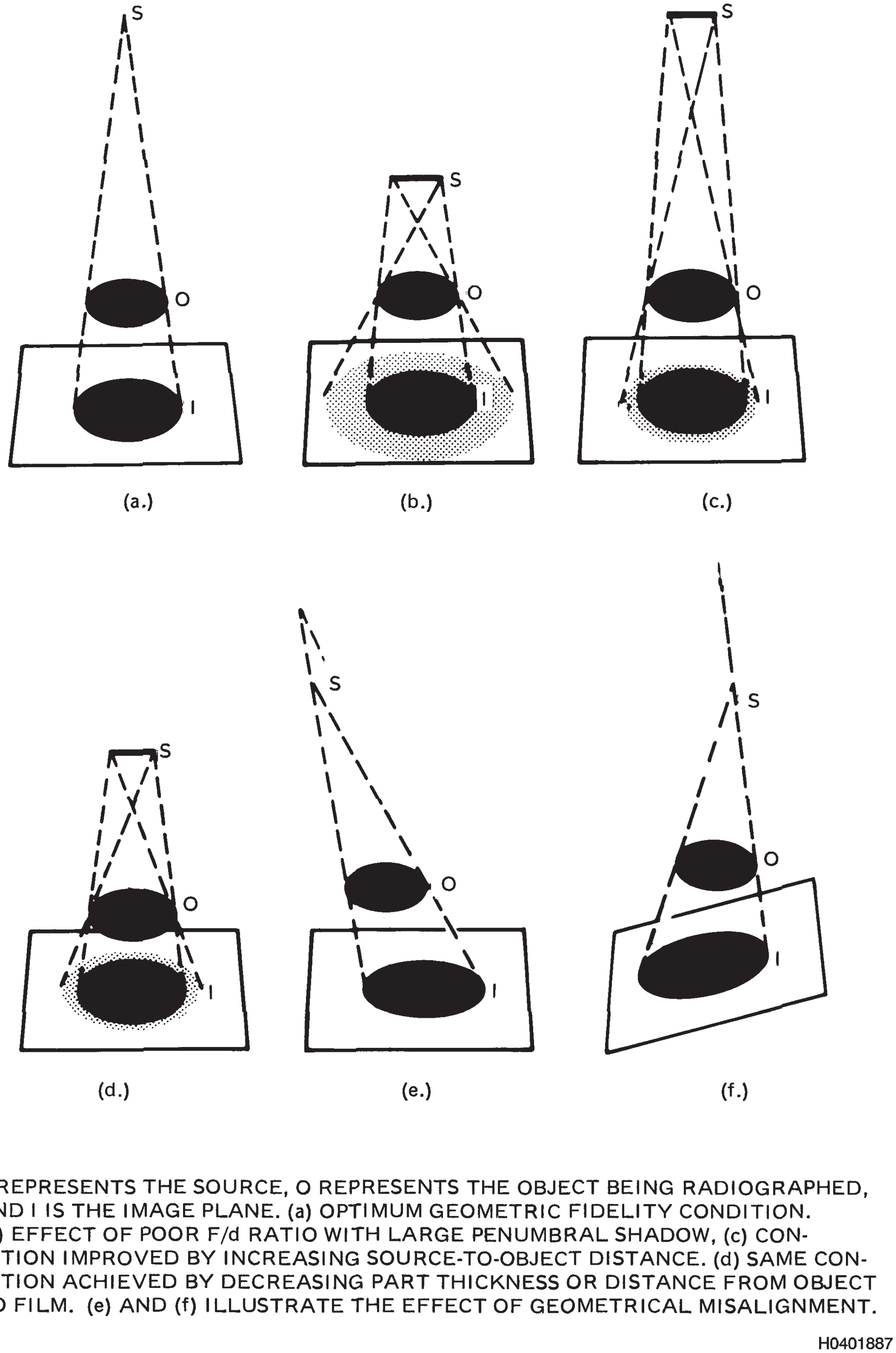


Figure 6-23. Possible Geometric Distortions

6.4.2.5.1 In considering geometrical unsharpness, recognize the value of new microfocus X-ray sources and the potential for geometric magnification. A nomogram is used to assist in solving this equation for various geometrical conditions (Figure 6-24). Note that 3 out of 4 terms in the equation must be known before it can be used.

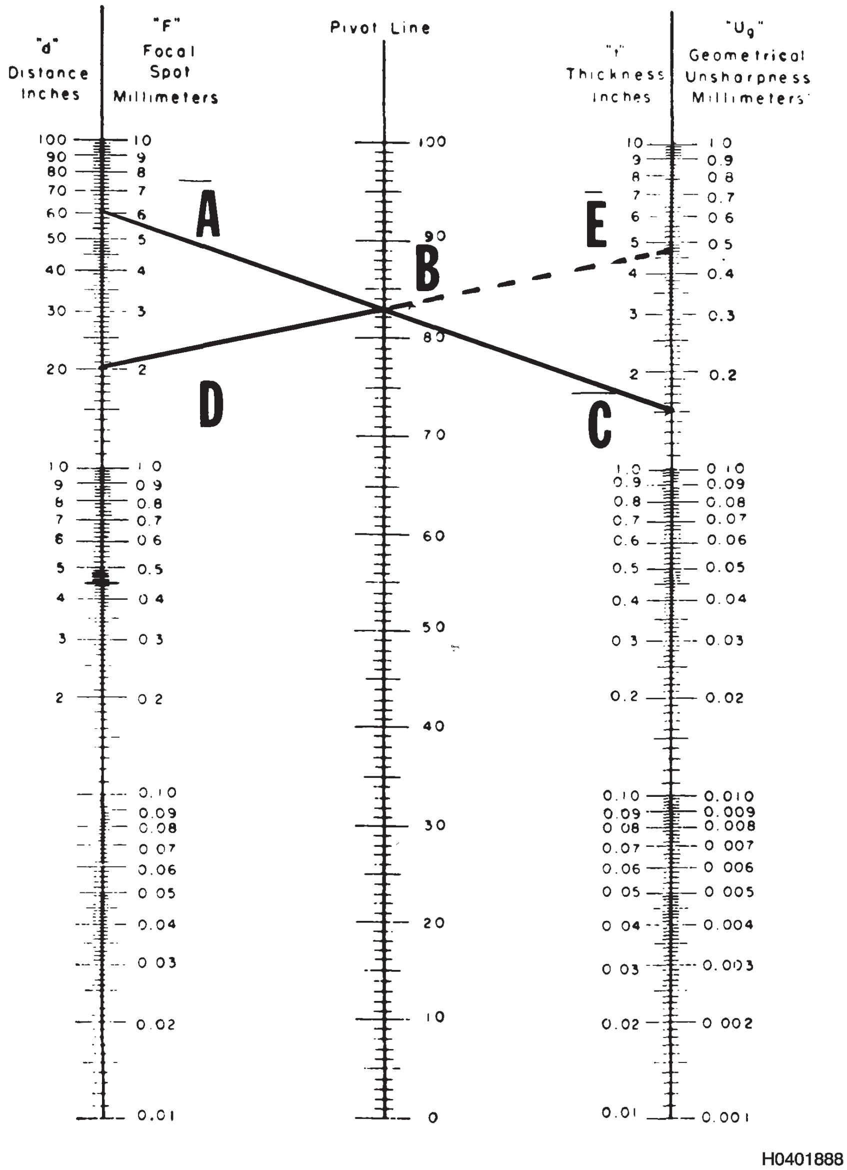


Figure 6-24. Nomogram to Assist in Solving Equation $U_g = Ft/d$

6.4.2.5.2 Suppose a specimen having a maximum thickness of 1.5-inches (t) is to be radiographed at 20-inch source-to-film distance (SFD) (d) using a source of effective focal size 6mm. The need is to establish an approximate value for U_g. The steps in using the nomogram are:

a. Plot the points A and C that represent the known value of F and t. The pivot line is intersected at B.

b. Plot a line joining point D (the value of d) and B. The extension of this line at E gives the value of U_g (0.47mm).

6.4.2.5.3 Remember unsharpness of the radiographic image is also affected by the characteristics of the X-ray film. Therefore, the total image sharpness MAY be controlled by either “geometrical unsharpness” or “film unsharpness.” The greater of these two values will control the total unsharpness of the image. In any given situation, the geometric unsharpness, which can be tolerated most, will set the lower limit for the adjustable parameter. Additional demands on image sharpness are paid for in intensity of the image. Image unsharpness is inversely proportional to the source-to-object distance, whereas the intensity is inversely proportional to the square of this distance. Therefore, the trade-off of intensity for sharpness is not an equitable one. In many cases, this uneven exchange is necessary because it is very important to achieve good geometric definition. The basic principles of shadow formation SHALL be given primary consideration to ensure satisfactory sharpness and low distortion of radiographic images. Distortion cannot be entirely eliminated since some of the test object may be further away from the film than other parts, and radiation from all sources cannot be made ideally parallel; images will always be less than perfect. In summary, five general rules can be stated which promote quality assurance from geometric considerations.

a. Use as small a focal spot as possible, as the considerations will allow.

b. The distance between the source and the object SHOULD be as great as practical.

c. The film SHOULD be as close as possible to the object being radiographed.

d. Central beam SHOULD be as near to perpendicular with the film as possible.

e. As far as the shape will allow, planes within the specimen plane of interest SHOULD be parallel with the film.

6.4.2.6 Film Placement. After the film and film holder have been chosen, consideration SHALL be given to the position of the film in relation to the part. In radiography of small parts, this could be a simple matter of laying the part on the film. With complex structures involved, film positioning is not quite as simple. A few rules can be of assistance in such inspection situations:

a. Always position the film as close as possible to the area of interest.

b. Attempt to locate the film so the plane of the area of interest and the film are perpendicular to the radiation beam. This is to prevent distortion in the final image.

6.4.2.6.1 When positioning the film, care SHALL be used to prevent sharp bends in the film or applying pressures to the film holder that can produce pressure marks or crimp marks (artifacts) on the final image. In radiography of curved surfaces, the source and film SHOULD be positioned, if possible, to take the best advantage of the inverse square law and to prevent as much distortion as possible. Flexible film holders SHOULD be used in order to place the film as near as possible to the surface of the test object. It may be noted in (Figure 6-25) the distance from source to the entire surface of the film is nearly constant and the thickness of the test object is also a constant to the path of radiation. This preferred positioning is not always possible, but it SHOULD be used when practical.

NOTE

The part undergoing inspection will always be between the source and the film.

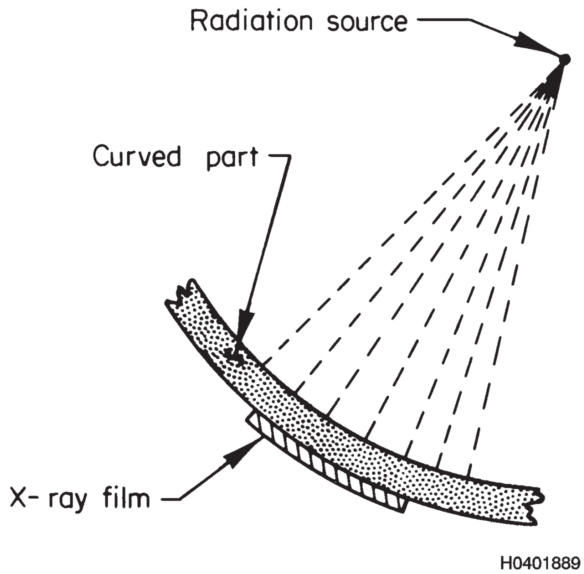


Figure 6-25. Preferred Geometry for Radiography of Curved Surfaces

6.4.2.7 Focal Spot Size. The ideal focal spot would have a pinpoint source of radiation. Though microfocus tubes approach this ideal, in actual practice this is impossible. Radiation sources have finite dimensions. The actual focal spot size in an X-ray tube is the projected area being bombarded by electrons from the heated filament; in gamma radiography, it is the radioactive pellet. To reduce the apparent size, the X-ray target is positioned at a small angle, and from the position of the X-ray film, this area appears as the projection of this focal spot on the film plane. This projection is referred to as the effective focal spot. Focal spot sizes must increase with increasing kilovoltage rating to prevent melting of the target material. Radiation is being emitted from the entire area of the effective focal spot. This radiation is projected at different angles through the test object and spreads the image of a sharp edge over a finite distance on the film. Examples of the formation of shadow projections are shown (Figure 6-23). What has been said about focal spot size in X-ray tubes also applies to gamma radiography where the pellet of radioactive material functions as the focal spot. The relatively large size of the pellets accounts for the inferior definition obtained with gamma radiographs.

6.4.2.8 Source-to-Film Distance (SFD). The sharpest image would be formed by having a SFD so great that the radiation would be parallel at the film plane (Figure 6-23). However, since radiation intensity or quantity is diminished in relationship to the inverse square of the distance, the radiation quantity available to expose the film would be very small, and exposure times would become impractical. Due to this, economics and practicability must be considered when producing a radiographic image. It is recommended the longest practical SFD be used for critical exposures to improve image sharpness. If the source-to-film distance is changed, the formula (paragraph 6.7.4) can be used to correct the exposure. Because an increase in distance causes a decrease in beam intensity, only the intensity is changed. The kilovoltage SHALL NOT be changed when correcting for SFD changes.

6.4.2.9 Inverse Square Law. When the X-ray tube output is held constant, or when a particular radioactive source is used, the radiation intensity reaching the specimen is governed by the distance between the tube (source) and the specimen, varying inversely with the square of this distance. The explanation below is in terms of X-rays and visible light, but applies with equal force to gamma rays as well. Since X-rays conform to the laws of light, they diverge when they are emitted from the anode and cover an increasing larger area with lessened intensity as they travel from their source. This principle is illustrated by Figure 6-26).

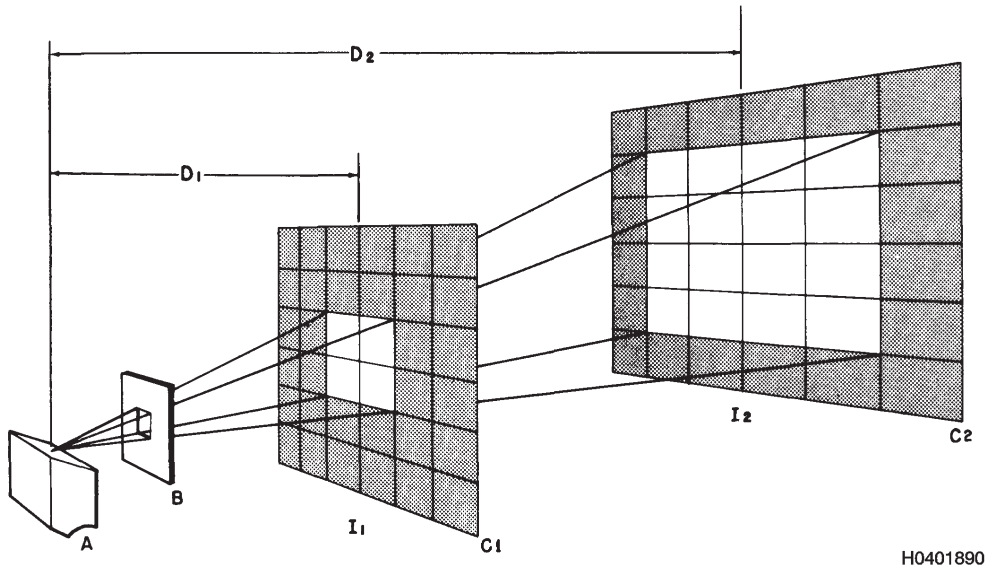


Figure 6-26. Inverse Square Law Diagram

6.4.2.9.1 In this example, it is assumed the intensity of the X-rays emitted at the anode (A) remains constant, and the X-rays passing through the aperture (B), cover a 4-square-inch area upon reaching and recording surface (C1), which is 12-inches (D_1) from (A). If the recording surface (C1) is moved 12-inches farther from the anode to (C2), so the distance between (A) and (C2) is 24-inches (D_2) or twice the distance between (A) and (C1); the X-rays will cover l6-square-inches, an area four-times as great as at (C1). Therefore, the radiation-per-square-inch on the surface at (C2) is only one-quarter that at (C1). Thus the exposure that would be adequate at (C1) must be increased four-times in order to produce a radiograph at (C2) of equal density. In practice, this is done by increasing either the time, or milliamperage. Mathematically the inverse square law is expressed as follows: (paragraph 6.7.3).

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

where I_1 and I_2 are the intensities at distances D_1 and D_2 respectively.

Example: An intensity of 2 mR/hr was measured at 40-inches from the source. What would be the intensity reading at 30-inches, and at 20-inches? Do not forget to take the square of the predetermined value for D_2 when determining unknown distances.

6.4.2.10 Source/Defect Orientation. Radiography can be used quite reliably to detect cracks, provided certain stringent criterion is met. It is very easy to produce an apparently high quality radiograph that does not show an existing crack, or with a crack indication so faint it can barely be seen. The resolution of a crack depends upon total density change, and film/subject contrast. The human eye can detect density changes of 0.02 H & D units, however, to detect cracks, a density change of 0.05 H & D units is more reasonable. There are several factors that produce density changes on X-ray film. The primary factor in the case of crack detection is a change in thickness or mass between the crack and part being inspected. A general rule is the crack must be at least 2-percent of the parts thickness if it is to produce a readable indication. This rule has variables that influence film density changes, and in some cases a change of as little as a 1-percent thickness will produce a visible indication. In other instances, a crack exceeding 5-percent of the part thickness MAY NOT produce a readable change in density. Regardless of total density change across an indication, if the contrast is not high, crack indications can be missed.

Example: A change in density of 0.05 H & D units can be easily seen if it is an abrupt change. Conversely, a change or 0.25 H & D units (5 times 0.05) is difficult to see if it is a gradual change over an area (e.g., a gradual increase over 1/2-inch width as opposed to a 1/8-inch width).

6.4.2.10.1 When an X-ray tube focal spot is centered directly over a crack with a depth parallel to the beam (X-ray beam and crack plane coincide), the film density change will be a function of the ratio of crack depth to metal thickness. Indications of narrow cracks with parallel sides will appear as fine dark lines with high contrast. Wide cracks with sloping sides will result in broader indications of lower contrast. A sketch illustrating the film density changes between two different width cracks when the X-ray tube is centered over the crack origin is shown in (Figure 6-27). The stress on a part will affect crack width. Example: compressive stress in the lower wing surface of an aircraft on the ground tends to reduce crack width. This compressive stress is due to the weight of the structure, engines, ordnance pylons, etc. Jacking the aircraft, to place the lower surface in neutral stress or in tension is frequently done to enhance detection of small cracks. One general characteristic of a crack and its indication, is the tendency for it to curve or deviate from a straight line. An apparent exception is a very short crack or a crack between two adjacent fasteners, but even here, when the indication is examined under magnification, there will be some edge jaggedness or change in edge appearance.

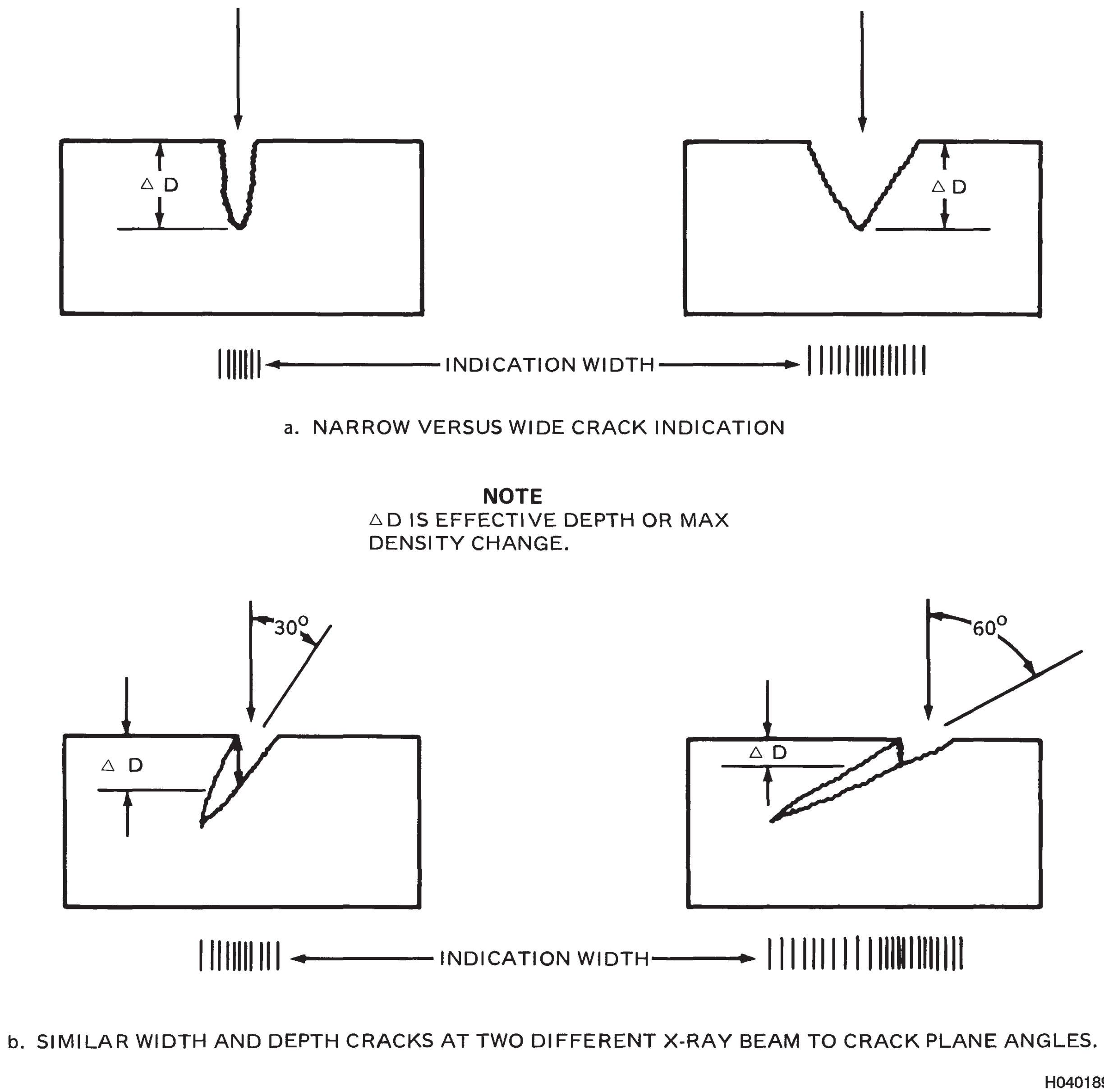


Figure 6-27. Density Changes Due to Varying Crack Widths and Intersection Angles

6.4.2.10.2 Obtaining parallelism between the X-ray beam and the crack plane is difficult to achieve. Cracks do not always initiate at the expected origin, and often are not perpendicular to the part surface. When the X-ray beam passes through a crack at any angle other than directly along the crack plane, both the width of the crack and the intersect angle determine the density change and indication contrast. Two cracks, of approximately the same width and depth, but with differing angles to the X-ray beam and the crack plane intersection are shown in Figure 6-27. As the angle between the X-ray beam and crack plane increases, both film density change and contrast decreases. The film indication becomes broad and more diffuse until it blends into the background and is no longer discernible.

6.4.2.10.3 Detection of cracks depends upon crack width, depth, total metal thickness, and angle of intersection. When only the intersection angle varies, it becomes a matter of statistics or probability. The probability of detecting a crack at various intersect angles is reflected in Table 6-11. This table indicates the probability of detecting a crack with an intersect angle of 9° is 75-percent. Conversely, the chances of missing a crack with a 9° intersect angle is 25-percent or 1 out of 4. When developing X-ray procedures to detect cracks, the maximum angle of intersection is 5°, which corresponds to an 85-percent probability of detection. The preferred limit is 2 1/2° corresponding to 90-percent detection probability.

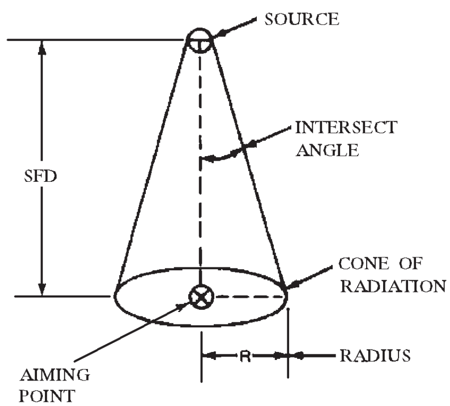
Table 6-11. Correlation Between Beam Divergence and Crack Detectability

Beam to Crack Angle (Degree)	Probability of Crack Detection (Percent)
0	96
3	89
6	82
9	75
15	48
21	30
27	23
45	4

6.4.2.10.4 An X-ray beam with a 2 1/2° or 5° intersect angle will not project over the surface of a 14-inch by 17-inch piece of film at normal focal-spot-to-film distances (FFDs). The entire film will be exposed, but only a small cone of radiation will be within the desired intersect angle limits. The radiation cone coverages at various intersect angles and FFDs is reflected in (Table 6-12). This table can be used to determine the necessary FFD when developing procedures. Example: A 12-inch long splice plate must be inspected for cracks. A 72-inch FFD is required Table 6-11), to be within the 5° intersect angle limit, (6.3-inches on either side of the aiming point). Cracks occurring farther than 6.3-inches from the aiming point will produce indications with reduced film contrast and density change, meaning there is a greater chance of not detecting them. This emphasizes the need for information on probable crack location and orientation before developing an X-ray procedure. It also demonstrates the requirement for accurate tube head alignment during equipment setup.

Table 6-12. Radiation Cone Radii at Various Intersect Angles and SFDs

	RADIUS of CONE (inches)				
SFD	2 1/2°	5°	7 1/2°	10°	Intersect Angle
36”	1.57	3.15	4.74	6.35	
48”	2.10	4.2	6.32	8.46	
60”	2.62	5.25	7.9	10.58	
72”	3.14	6.3	9.48	12.7	
84”	3.67	7.35	11.06	14.8	



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6.4.2.11 Scatter Radiation. Whenever X-rays interact with material, one or more of the following will occur; absorption, scattering, or penetration. In industrial radiography, scatter radiation (paragraph 6.2.8) can present a problem since it has the ability to expose the X-ray film without contributing to image information. Exposure of the film from scatter radiation is referred to as fog, and substantially reduces image contrast. Scatter radiation can have three different sources; reflected scatter, back scatter, and forward scatter (Figure 6-28). Reflected scatter comes from the area around any objects that might be in the radiation beam (e.g., the part under test, tube head stand or a wall). Back scatter is scatter radiation, which comes from objects behind the film (e.g., the floor). Forward scatter is the third source of scatter radiation, and is caused by the test object itself. This scatter can obliterate an object’s edges on the film, referred to as “undercutting.” The amount of scatter radiation is affected by the radiation energy and the atomic number of the element causing the scatter. The lower the atomic number of a material, the greater the degree of scatter radiation. Materials with a high atomic number will cause less scatter.

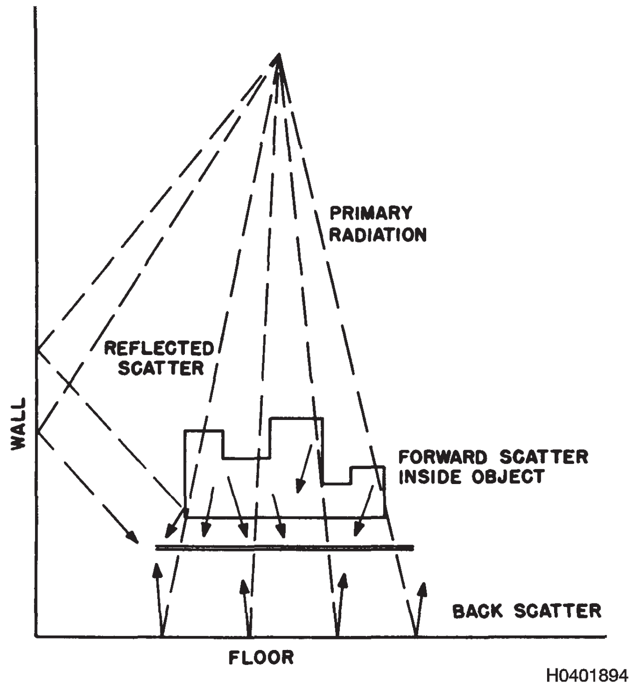

Figure 6-28. Sources of Scatter Radiation

6.4.2.11.1 Several techniques can be used to reduce scatter radiation. Radiographic cones or masks made of lead or other high absorbing materials will reduce the radiation area to only the area necessary for exposure. Lead in many different forms can be placed behind the X-ray film and test object to reduce excessive backscatter. Lead foil MAY be placed between the test object and the X-ray film to absorb some of the scatter radiation before the film is exposed. The lead foil acts as scatter filters since it permits the higher energy image forming radiation to be transmitted to the film, and at the same time absorbs the lower energy scattered radiation. A note of caution; filters in this position will reduce subject contrast. In some cases, the scatter problem can be of such a magnitude special techniques must be applied. Masking the part is often required because of large variations in part thickness, thus differences in absorption will lead to scatter from excessive amounts of radiation being transmitted through thin sections. Look at (Figure 6-29) to understand how a lead sheet could be used for masking. In this case, the object is a steel hub. Without the lead sheet (1/8 inch thick) definition would be poor due to internal scatter.

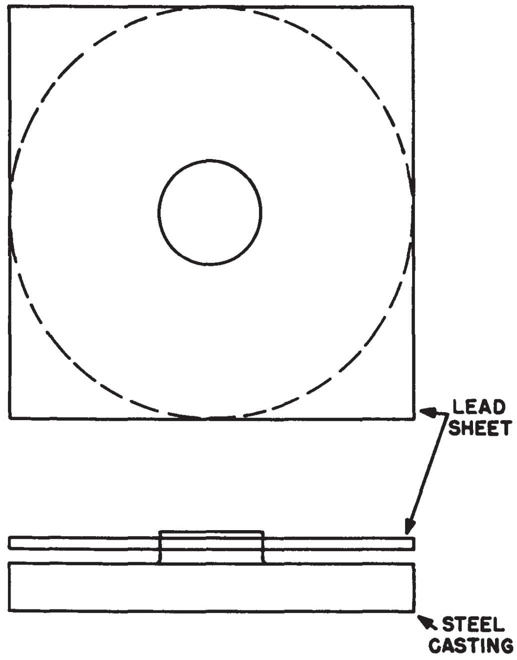

Figure 6-29. Masking to Avoid Scatter

6.4.2.11.2 Controlling scatter radiation requires common sense and ingenuity. A concrete, wood, or composition floor will generate enough back-scattered radiation to fog a film. Film holders SHOULD always be laid on, or backed with a sheet of 1/8-inch lead. The backing SHOULD be as large as possible to match the primary radiation field. This thickness of lead is enough for radiation generated up to 300 kVp, except when fluorescent screens are in use, in which case a 1/4-inch sheet SHOULD be used. The "Potter-Bucky Grid" is a device constructed to specifically absorb object-scatter-radiation. This grid is made somewhat like a Venetian blind; it consists of strips of material, comparatively transparent to radiation, and strips of lead. The strips of lead absorb object scatter radiation at angles other than the direct beam. To prevent the lead strips from being revealed in the image, the grid is moved during exposure so the image of the lead strips is actually distributed over the entire image, but will not show detail. These grids are usually used in industry for radiography of low atomic materials where scatter is a problem of considerable proportions, especially in the medical field.

6.4.2.12 Effects of Processing. Processing variables, especially development time, also affect density and film contrast through their effect upon the slope of the characteristic curve. Tests with a typical industrial film showed as development time was reduced, the effect was to produce a family of characteristic curves displaced to the right. This means, the log relative exposure needed to produce a standard density, increased as development time decreased. There were other effects too. Optimum development time maximized the slope of the characteristic curve (and thus film contrast) at only slight cost in fogging Figure 6-30).

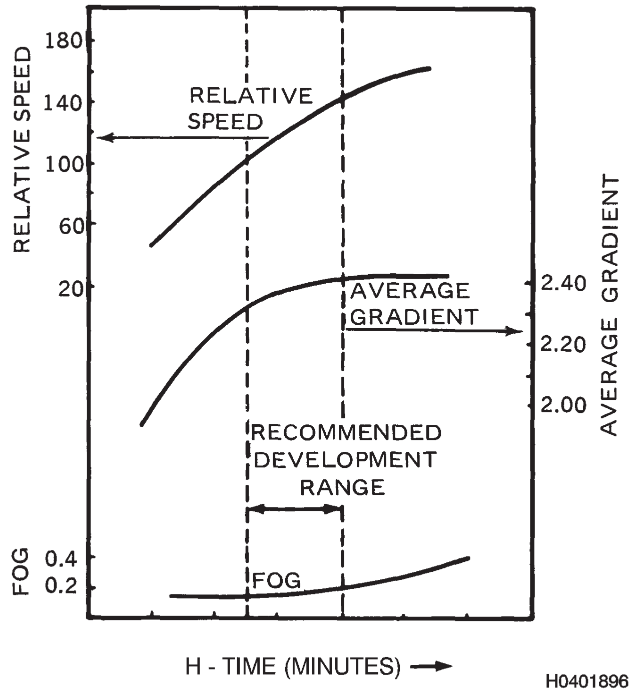

Figure 6-30. Effect of Development Time Upon Film Speed, Contrast, and Fogging

6.4.3 Radiographic Sensitivity. The following affects radiographic sensitivity:

6.4.3.1 Exposure Factor. The exposure factor is a quantity that combines milliamperage (X-ray) or source strength (gamma rays) with time and distance. Radiographic techniques are sometimes given in terms of kilovoltage and exposure factor, or radioactive isotope and exposure factor. In such cases, it is necessary to multiply the exposure factor by the square of the distance to be used to find, for example, the milliampere-minutes or millicurie hours required.

6.4.3.2 Radiographic Contrast. Contrast in a radiograph is the difference in the resultant density, produced for a given change of X-ray or gamma ray absorption. It is affected by many factors, some of which must be compromised, thus, operator judgment becomes important. The choice of X-ray equipment is one of the most important considerations. The shorter the effective wavelength of X-rays, the greater the penetrating power. Also consider the higher the kilovoltage used, the shorter the effective wavelength of the generated radiation. As a result, the higher the x-ray tube voltage, the greater the penetrating power of X-rays generated. This is true for steel, with X-rays generated below 8 to 10 MeV, for aluminum, up to 20 to 22 MeV, and for lead, up to only 2 to 3 MeV (Table 6-13).

Table 6-13. Relative Absorption of Materials Material Kilovoltage Exposure

Material	Kilovoltage	Exposure Time	Thickness
Lead	200 kVp	1 min	1/16 inch
Copper	200 kVp	1 min	1/2 inch
Steel	200 kVp	1 min	3/4 inch
Titanium	200 kVp	1 min	1 inch
Aluminum	200 kVp	1 min	4 inches
Magnesium	200 kVp	1 min	5 inches

6.4.3.2.1 If the penetrating power of the radiation is great, each increment of thickness in the object will absorb less of the total than it would if the penetrating power of the radiation is lower. Conversely, if low kilovoltage is utilized, less of the total radiation will be transmitted through the object. Each small change in absorption due to thickness of material will then cause a relatively large change in transmission, thus, the lower the voltage used, the greater the radiographic contrast. Therefore, kilovoltage MAY be lowered to perform an inspection, but SHALL NOT be increased above the level prescribed in the specific inspection instructions without approval from the responsible engineering authority.

6.4.3.3 Subject Contrast. Subject or object contrast SHALL also be considered by the radiographer. At X-ray voltages from 30 kVp to 5 MeV, aluminum has a lower absorption rate per unit thickness than steel. Therefore, it takes a greater thickness change of aluminum to cause the same given change you would notice with steel. Hence, aluminum has less object contrast than steel. The change in thickness versus the change in transmitted radiation is graphically shown (Figure 6-31). During the radiographic process, the differences in object contrast are, however, partially compensated for because lower energy radiation (longer wavelength) can be used to examine a given thickness of aluminum compared to the same thickness of steel (e.g., a 1-percent thickness change will produce sufficient density change on film to be visible when viewed on most metal subjects, but with magnesium and lighter metals, it is difficult to record 2-percent thickness change). Object contrast is a somewhat limiting factor in light metals and material with both low density and atomic number. The relations between X-ray absorption of steel, aluminum, and magnesium are shown in (Figure 6-32).

NOTE

It is recommended on light materials, the radiographer SHOULD use lower kilovoltage, and consequently, longer exposure time than on heavier materials.

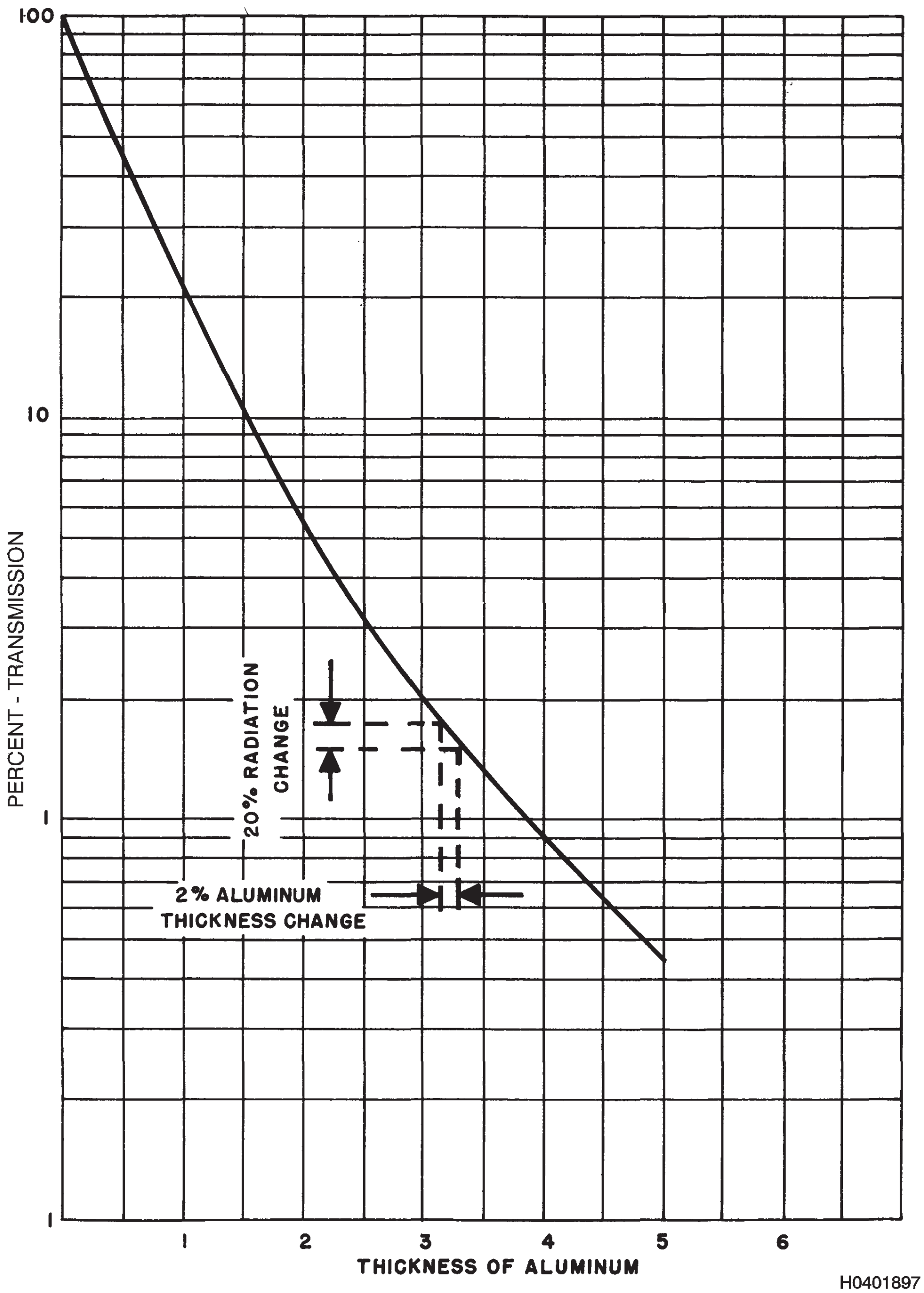

Figure 6-31. Radiation Transmission Versus Thickness of Aluminum at 150 kVp

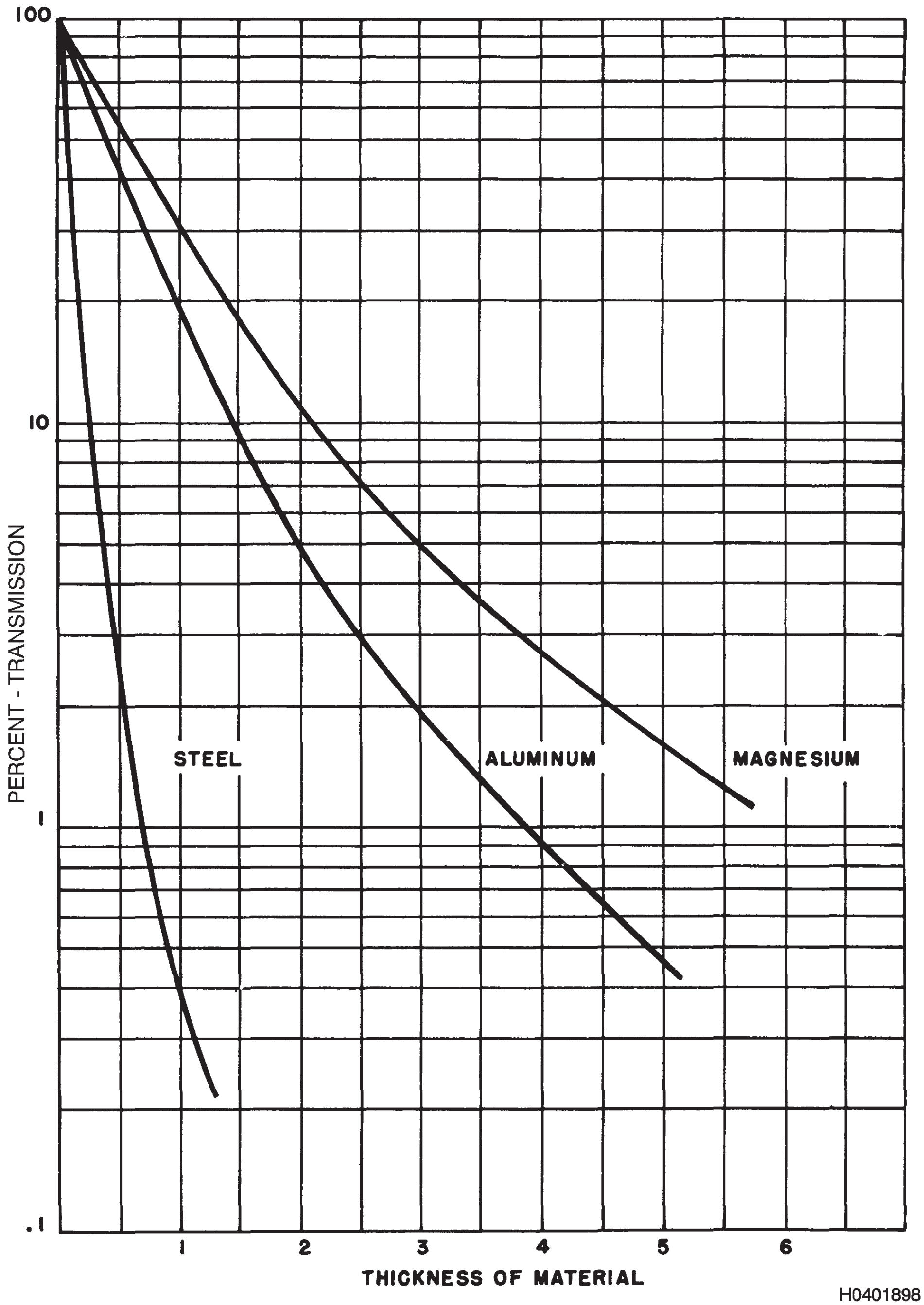

Figure 6-32. Radiation Transmission Versus Thickness for Various Densities at 150 kVp

6.4.3.3.1 For materials of approximate uniform thickness, where the range of transmitted X-ray intensities is small, the technique producing high contrast will show all portions of the area of interest with an increased radiographic sensitivity; however, if the part radiographed transmits a wide range of X-ray intensities, a technique producing lower contrast will be necessary to record the detail in all portions of the radiograph, probably with some decrease in radiographic sensitivity. In cases where an extreme range of intensities is transmitted, high radiographic contrast MAY be obtained by double-loading the film holder with two high-contrast films of different speeds. The kilovoltage and exposure are so chosen that the thick portions of the object be satisfactorily recorded on the faster film and the thin portions on the slower film.

6.4.3.4 Film Contrast. Film of the no-screen type generally give higher contrast with or without lead screens than screen type films with or without lead screens. Screen type films with calcium tungstate screens, however, produce maximum contrast with sacrifice of detail due to the grain size of the screens. The contrast of a film can be seen from the slope of the characteristic curves.

6.4.3.5 Film Latitude. The film characteristic reverse of contrast is film latitude; the higher the film contrast, the smaller the film latitude; and the lower the film contrast, the greater the film latitude. Film latitude is the range of radiation intensities a film is capable of recording.

6.4.4 Improving Radiographic Sensitivity.

6.4.4.1 Using Quality Indicators. Earlier, we discussed the equipment (paragraph 6.3.9). Now we will discuss their use.

6.4.4.1.1 Contrast Sensitivity. The penetrameter material thickness is added to the thickness of the test object. This increase in thickness causes more radiation to be absorbed, and the penetrameter outline is seen on the final image as a less dense area. This change in film density due to the additional radiation absorption is a measure of the image contrast. The human eye is normally used as a detector in reading radiographic images, and the eye responds to differences in the quantity of light being transmitted through the film due to the density differences. It is assumed under practical industrial film inspection conditions, the human eye is capable of just detecting density differences of LD = 0.02, which corresponds to a light transmission difference of 4.72-percent. Since density differences of 0.02 are considered just barely discernible, good practice is to strive for a density difference of 0.08 to assure good visualization of discontinuities.

CAUTION

Penetrameters SHALL always be removed from the specimen after inspection on aircraft.

6.4.4.1.2 Detail Sensitivity. Detail sensitivity of the radiographic image is revealed by the capability of visualizing the penetrameter holes. When the 2-percent penetrameter is used on the test object, it is usually required the 2T penetrameter hole is visible on the radiograph. If the 2T hole can be seen, the image is said to have 2-percent radiographic sensitivity. The film reader can then assume the capability of seeing any discontinuity that represents a 2-percent dimensional change of the object total thickness. The 1T hole, DOES NOT represent 1-percent image sensitivity because the thickness of the penetrameter has not been reduced to 1-percent of the test object thickness. Calculations reveal visualization of the 1T hole in a 2-percent penetrameter actually reveals 1.4-percent image sensitivity. Resolution of the holes in the penetrameter is a combined measure of image sharpness and contrast, and is thus a measure of the image quality, but note the regular and expected outline of the holes is more readily seen than a crack line. The penetrameter SHALL NOT be placed over an area of interest, since the penetrameter or the lead identification numbers could hide discontinuities. In some cases, the penetrameter cannot be placed on the actual test specimen. In these instances, it is acceptable to place the penetrameter on a separate block of the same material and of the same thickness as the specimen. Remember, when placing an IQI, the purpose of the penetrameter is to reveal image quality to the film reader, therefore, place it in the least disruptive position. Also remember, when placing the IQI, the density SHOULD NOT vary more than +30 or -15-percent from the area of interest. Plaque penetrameters suffer from a number of disadvantages, the most serious of which is the minimum thickness of 0.005 inches. ASTM E1742 provides additional information on the use of penetrameters. The preceding actions have shown effective radiographic inspection requires techniques that have optimum geometry, film choice, contrast, and density. Subsequent paragraphs explain how characteristic curves and technique charts can provide quantitative data to permit precise adjustments.

6.4.4.2 Screens. The radiation reaching the film may be, in part, caused by the use of intensifying screens to reduce the exposure time. The intensification factor for lead or calcium tungstate screens depends on the energy converted to either electrons or light to which the screen is sensitive. This factor varies with kilovoltage and type of film. The film SHALL be selected to achieve the highest efficiency of energy conversion from the screens used. The use of screens is covered more thoroughly in (paragraph 6.3.8.9).

6.4.4.3 Technique Charts. The characteristics of X-ray equipment SHALL be known to properly operate the unit and obtain maximum results. The utilization of X-ray equipment with the least amount of lost time requires a set of technique charts, which show the exposure times required for various thicknesses of material under stated conditions. These charts are generally available from the manufacturers of X-ray machines (Figure 6-33). Due to the differences between individual equipment, it MAY be necessary or desirable to prepare additional technique charts for the specific purposes and conditions for which the equipment will be applied. If published technique charts are available, they can be used as a guide in preparing the detailed charts.

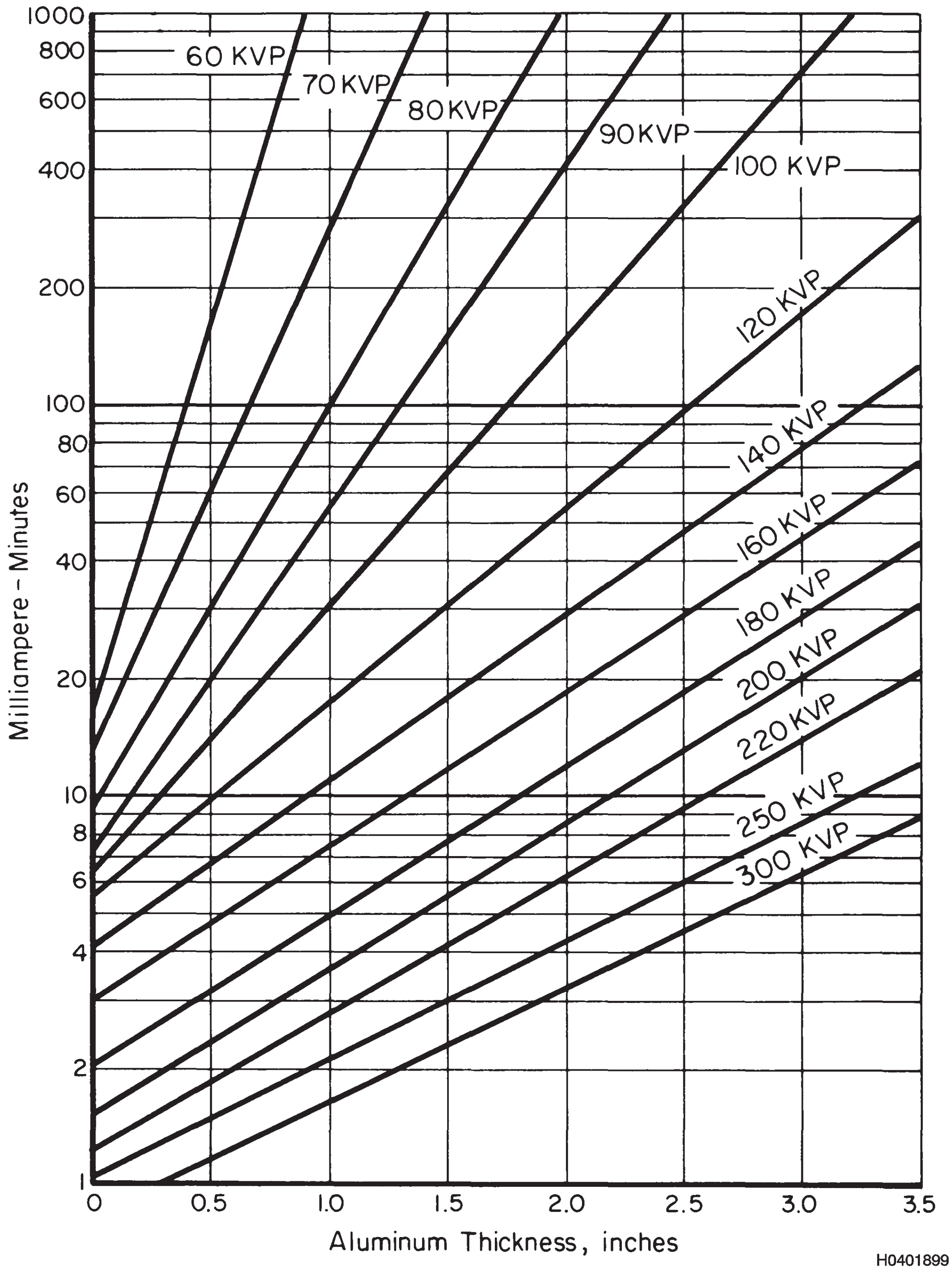

Figure 6-33. A Typical X-ray Exposure Technique Chart

6.4.4.3.1 Identification of Technique Charts. The following items must be recorded to adequately identify technique charts:

- Type of unit.
- Material (type and thickness).
- Film type.
- Quality Enhancers (screens).
- Kilovoltage.
- Current and exposure time.
- Source-to-film distance.
- Film processing factors (temperature, method, etc.).
- Density of radiograph desired.

6.4.4.4 Step Wedge Radiographs. A step wedge MAY either be a solid block, or made up from plates of the same material used as the object being radiographed (Figure 6-34). A radiograph of the step wedge will give a symmetrical shadow picture of varying densities corresponding to the steps on the wedge. Make a series of radiographs of the step wedge at different exposures while keeping other radiographic factors constant (including subsequent processing). Preparation of the technique chart requires the following steps:

a. Select an estimated exposure for the thinnest section of the step wedge, based on exposures for similar material in the middle of the voltage range, or a trial exposure on this material. In planning the exposures, pick out a series in an approximate geometrical progression. For example, a series of 120 MAS, 220 MAS, 320 MAS and so on might be chosen.

b. Expose the step wedge under the conditions previously selected, at the times calculated for the mid-voltage point.

c. Process the radiographs using fresh solutions, mixed according to manufacturer’s directions.

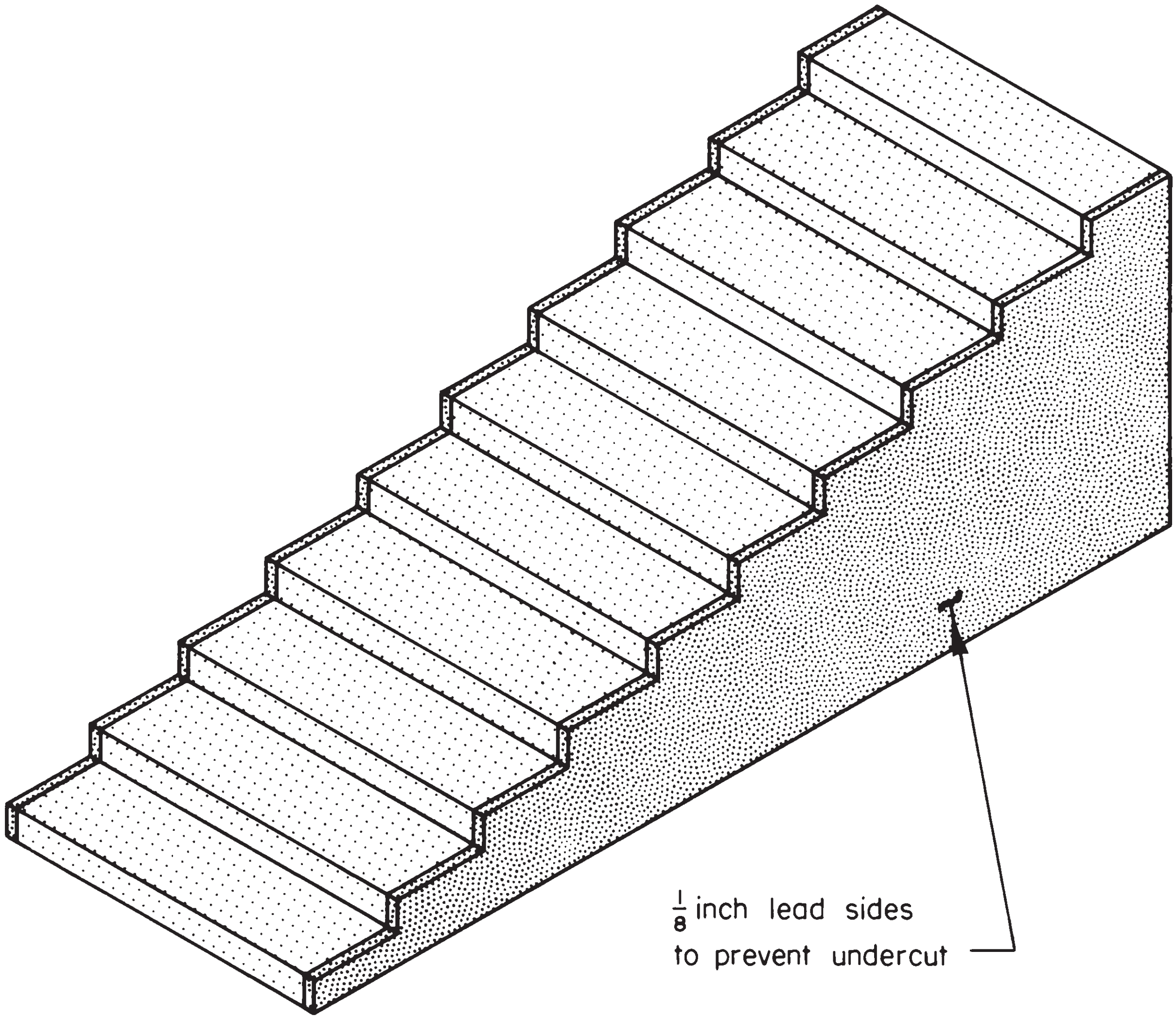

Figure 6-34. Sketch of Desirable Stepped Block for Radiation Measurements

6.4.4.5 Plotting the Data.

NOTE

The “Constant Exposure Chart” is used to plot data for a single kilovoltage setting. Additional curves for other kilovoltages can be made by repeating the procedure at any desired kilovoltage.

6.4.4.5.1 Constant Exposure Chart. Make density measurements of each step on each of the radiographs with a densitometer and record this data in a table. The final table SHOULD show a density for each step thickness at each exposure. Now plot this data on semi-logarithmic graph paper with density and object thickness as the coordinates. This will give a set of curves, one for each exposure. This is a Constant-exposure chart and is only one type of technique chart.

6.4.4.5.2 Constant Density Chart. It is more common to plot technique charts in the form shown in Figure 6-35). This is a constant-density chart for three different kilovoltages. To prepare this type of technique chart, it is necessary only to plot points taken from the graph prepared in (paragraph 6.4.4.3). Record and plot the points for each thickness at the intersection of the selected density and exposure curves. This will result in a single curve on the constant density chart for one kilovoltage.

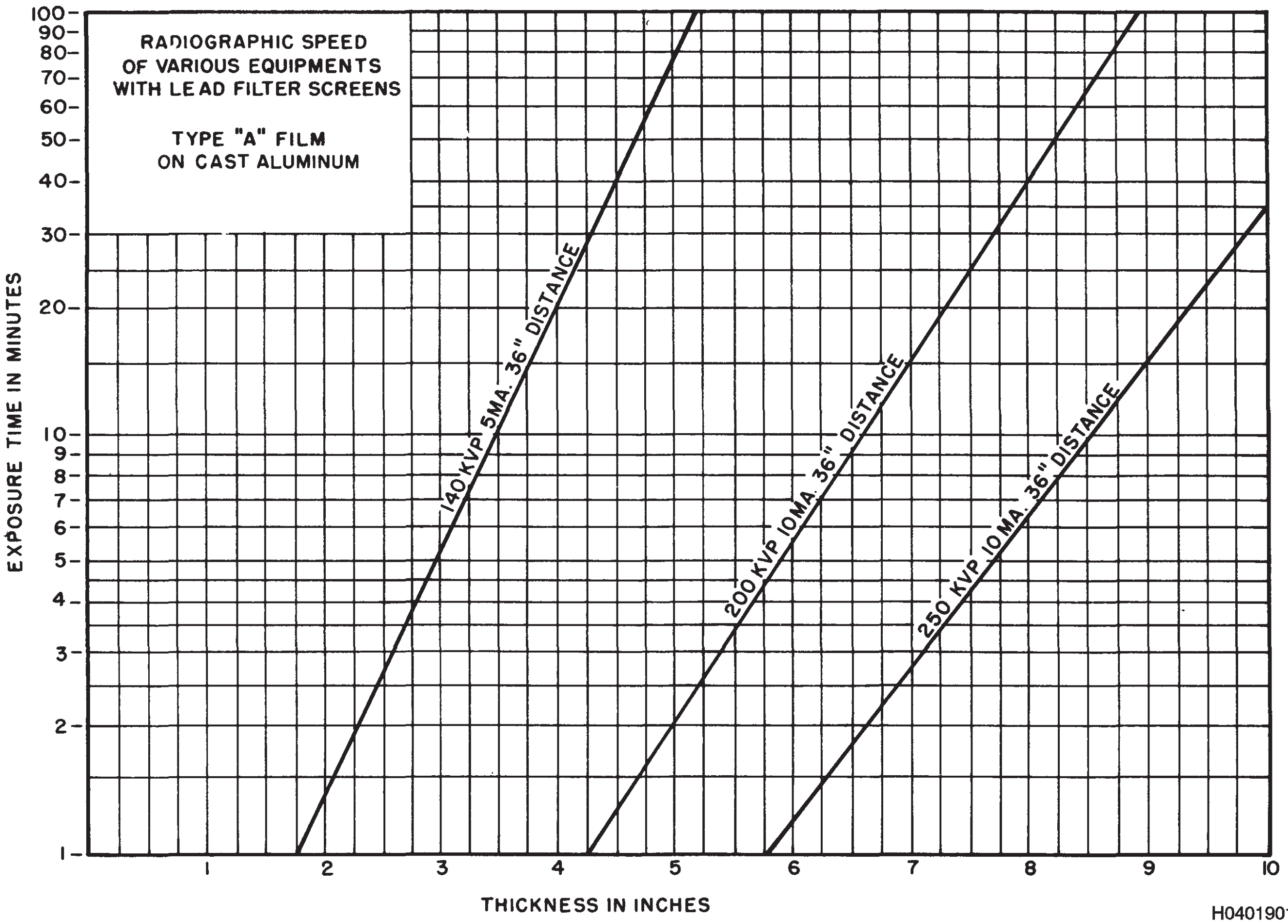

Figure 6-35. Typical Technique Constant-Density Chart

6.4.4.5.2.1 Constant-density charts MAY also be prepared directly from the radiographs if a set of constant exposure charts is not desired. To do this, proceed as follows:

a. Select the exposure and thickness of the step wedge that will produce the desired density.

b. Plot this exposure of time versus the thickness of material on a sheet of semi-logarithmic graph paper, and label this line with the kVp used for this series of exposures.

c. Repeat the above procedure for a series of voltages through the voltage range of the equipment.

6.4.4.6 Logarithms (log). The use of logarithms is discussed further (paragraph 6.7.6).

6.4.4.6.1 Since logarithms are used a great deal in the interpretation of radiographs, a brief discussion of them is included here. A more detailed treatment will be found in (paragraph 6.7.6) and some handbooks and intermediate algebra texts. Before discussing logarithms, it will be necessary to define the term "power." The "power of a number" is the product obtained when it is multiplied by itself a given number of times, thus 10^3 = 10 X 10 X 10 = 1,000 and 5^2 = 5 X 5 = 25. In the first example, 1,000 is the third power of 10; in the second, 25 is the second power of 5, or 5 raised to the second power. The figure ^{2} is known as the exponent. Fractional exponents are used to denote roots.

6.4.4.6.2 Negative exponents indicate reciprocals of powers, thus the base 10 logarithm of a number is the exponent, or the power to which ten must be raised to give the number in question. For example, the log of 100 is 2. The log of 316 = 2.50; the log of 1,000 is 3. It is also said that 1,000 is the antilogarithm (antilog) of 3. Logarithms consist of two parts: a decimal, which is always positive, called the mantissa; and an integer, which MAY be positive or negative, called the characteristic. In the case of log 316 = 2.50, “0.50 is the mantissa” and “2 is the characteristic.” No matter what the location of the decimal point might be, the logarithms of all numbers having the same figures in the same order have the same mantissa.

6.4.5 Darkroom Design. A dark room is required to process exposed film. Dark rooms provide a space to open exposed radiographs under safe conditions. Darkroom space SHOULD be determined by work volume, but in general, a high efficiency operation can be achieved when the space allows two to three persons to work together at the same time. The darkroom SHALL be completely protected against radiation and visible light. The walls of the darkroom SHALL be painted a light color which best reflects light from the safelight. A ventilator SHOULD be used to keep the air moving from the dry side to the wet side of the room and out. The darkroom SHOULD have an antechamber type entrance that makes an efficient light trap.

6.4.5.1 Preferably there SHOULD be a film loading darkroom and a processing darkroom. If film loading, unloading, and processing are to be carried out in the same darkroom, the wet area SHALL be in a position opposite the dry area. The following precautions SHALL be observed when the darkroom area is large enough for a loading darkroom and a processing darkroom.

6.4.5.1.1 Darkroom Loading (Dry Area). The loading darkroom is to be provided with film containers, cassette and film holder storage, and a loading bench. The loading darkroom SHALL always be kept clean, and free of water and chemicals.

6.4.5.1.2 Darkroom Processing (Wet Area). The processing tanks, washing tanks, hangar racks, and work benches SHALL be arranged to facilitate film processing. Since the air is readily contaminated in a hot and humid processing darkroom, forced ventilation SHALL be used. An air conditioner MAY also be necessary to keep the air dry.

6.4.5.1.2.1 A dark room, which is used for other types of film processing, MAY be used for processing radiographs unless the various activities interfere with each other.

6.4.5.1.3 Arrangement for Manual Processing. Suggested arrangement of manual processing tanks is shown in (Figure 6-36). The chemicals SHOULD be arranged as shown in the sketch in sequential steps of the process and traversing from left to right. This arrangement is used with the assumption most people are right-handed.

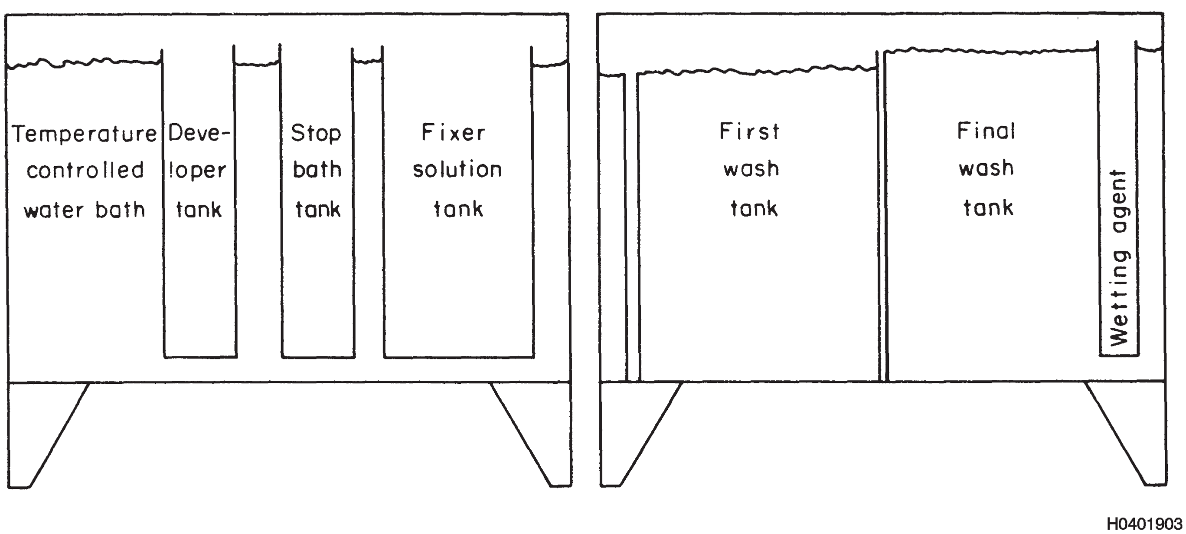

Figure 6-36. Suggested Arrangement of Manual Film Processing Tank

6.4.5.1.3.1 Assuming a developing time of 5-minutes, a single 5-gallon tank will develop 30 films an hour. The stop bath tank SHOULD have a capacity equal to the developing tank. The capacity of the fixing bath tank SHOULD be double the developing tank. The wash tank SHOULD hold from 20 to 25 gallons. Install the wash tank so films are placed in the tank at the outlet end. If dark room volume requirements must be greater, use the above relationships to plan the additional facilities. The finish of the benches, walls, and floor adjacent to the tanks SHOULD be adequate to protect against the action of chemical solutions and water that might be spilled on them.

6.4.5.1.3.2 Film bins are desirable since they are light-tight and close automatically. The boxes of film can be stored here in perfect safety and are readily available. For the mixing of chemicals, enamel pails, several funnels and stirring rods must be provided. Where films must be dried rapidly, film drying cabinets are necessary. These dryers SHOULD have a filtered air intake, film racks, exhaust fan, and heating element. It is best to wire the fan and heating elements on the same circuit so the heating element cannot be turned on without the fan.

CAUTION

There might be a time when film jams within the processor. In this situation, the processor lid MAY need to be removed, exposing any undeveloped film to light. Care SHALL be taken to prevent exposure to undeveloped film by working under safelight.

6.4.5.1.4 Arrangement for Automatic Processing. The general arrangement of a darkroom, where an automatic processor is used, is illustrated in Figure 6-37. The loading end of the processor is located in the dry area of the darkroom and is under safelight illumination. The output end of the processor is generally located on the outside of the darkroom wall under ambient illumination. When processing film in the automatic processor, the film is unloaded from the cassette film holder as in manual processing. However, it is then immediately fed into the loading end of the processor. After processing is completed, the film exits the other end of the processor. At this point, the film is ready for interpretation and filing as required. Cleanliness in automatic processing is essential. Lint and other contaminants, if they are allowed to enter the processor, can cause many spots as they collect on rollers and affect subsequent films.

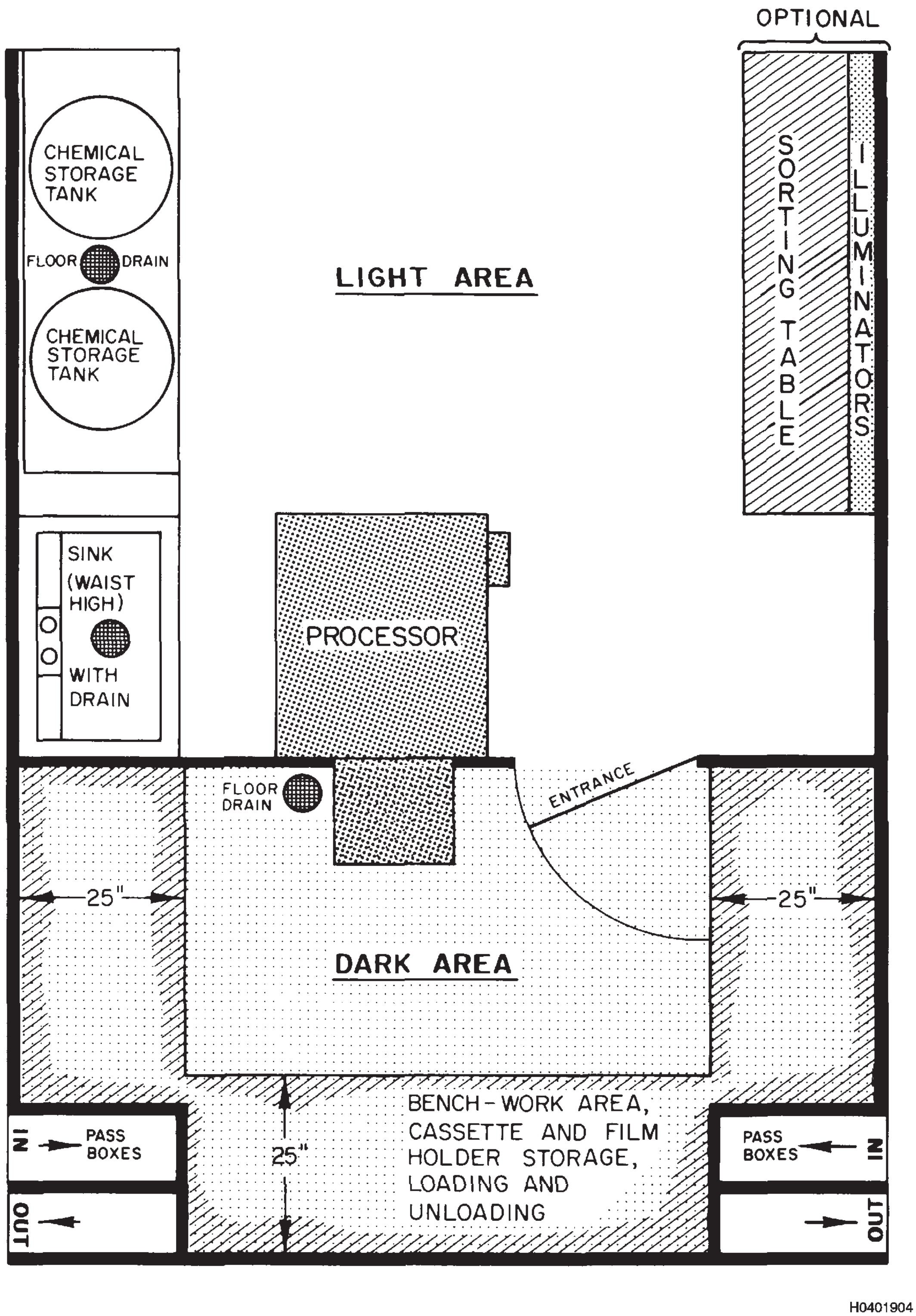

Figure 6-37. Typical Arrangement of Through-the-Wall Automatic Processing Darkroom

6.4.5.2 Safelight.

CAUTION

Keep exposed film a minimum of 1-meter away from the direct light of the safelight; exposed films are more sensitive to illumination from safelights than are unexposed films. Screen-type films are more sensitive to fogging than non-screen film. In addition, emulsions are less sensitive when wet, so they can be exposed to safelights for longer periods after immersion in the developing solution.

Light having spectral qualities outside the region in which sensitive materials are affected is to be used for safelight illumination. A safelight filter, colored dark reddish orange or equivalent is recommended for use in the darkroom. Industrial X-ray films SHALL be handled at a distance of at least 4 feet from a safelight. The safelight MAY be turned on under normal conditions for 10 to 15-minutes without any detrimental effect on X-ray film. Safelights require process control which is located in (paragraph 6.6.3.3).

6.4.5.3 Processing Tanks. Processing solutions are either alkaline or acidic, therefore, the processing tanks must be alkali or acid resistant. Suitable materials include: stainless steel, plastics, and enamelware.

6.4.5.3.1 Plastics have such low thermal conductivity, that plastic containers are suitable for keeping processing solutions warm, but the contents of such containers cannot be rapidly heated or cooled from the outside. Stainless steel which provides adequate protection against corrosion and provides easy temperature control is widely used.

6.4.5.4 Dark Room Cleanliness.

NOTE

If spilled chemicals settle on film and evaporate, they may cause spotting.

Due to the sensitivity of X-ray film, cleanliness is very important. Work areas and any accessories (e.g., film hangers, funnels, stirring rods, and thermometer) SHALL be washed thoroughly after use to avoid contaminating film. Processing tanks SHALL be scrubbed clean before filling with fresh solution. It is advisable to sterilize the tanks periodically with a 5-percent solution of sodium hypochlorite (bleach). Allow the sterilizing solution to remain in the tank overnight and then drain and rinse thoroughly. If any solution is spilled, wipe it up immediately.

6.4.6 Radiographic Film.

6.4.6.1 Film Comparisons. Manufacturer's literature generally provides speed, contrast, and processing data pertinent only to the films and chemicals they produce. Presentation of the data differs greatly from one manufacturer to another, as do their methods for developing this data. Historically, when faced with the necessity to substitute one manufacturer's film with another manufacturer's film, the radiographer would compare manufacturer's literature and then perform trial exposures with the new film. Using the first radiograph as a basis, the radiographer would modify the exposure parameters and try again. Often this procedure would have to be repeated several times, depending on the experience of the radiographer and difficulty of subject, before an acceptable radiograph was produced. We even find the process used by manufacturers to make the film varies to such an extent that the different film emulsions will have different effects on different processing techniques and chemicals. This iterative process involves considerable expenditure of time and significant cost in supplies. When evaluating a new film, the radiographer SHOULD contact the responsible engineering authority for that weapon system and request current information on how each manufacturer's film works for that specific application.

6.4.6.2 Care of Radiographs. The final radiograph represents a considerable investment of time and money; great care SHOULD be taken to preserve the final image. Unexposed X-ray films are highly sensitive to, and adversely affected by, chemicals, heat, moisture, mechanical pressure, visible light, and radiation such as X- and gamma rays. Utmost care therefore SHOULD be taken in the handling of such films and in the selection of storage locations.

6.4.6.3 Handling of Radiographs. The radiographs SHOULD NOT be handled with bare hands, and always handle the film at the extreme edges. The emulsion layer is scratched when strongly rubbed, so black streaks appear in the processed radiograph. A low density shadow, looking like a crescent mark or “flare,” is seen in the radiograph when the film is folded or flexed. Generally, the crease made in a film before exposure has a lower density than one made after exposure. Mechanical pressure also influences the film likewise. The film SHOULD NOT be crimped or sharply bent. Soft, white, cotton gloves SHOULD be used to handle all radiographs between the time they are processed and the time they are disposed of. Thin, soft, cotton gloves SHOULD be worn to avoid marks resulting from contact with fingers contaminated with body oil, lotion, or processing chemicals. The use of gloves made of synthetic fibers or gloves of synthetic fibers blended with cotton SHOULD be avoided, since they could cause static marks. Foreign substances such as water, coffee, or other materials SHOULD NOT be allowed to contact the emulsion surfaces. The films SHOULD always be picked up carefully, never sliding them across surfaces that could be dirty or have some gritty substances that can introduce scratches on the emulsion surfaces. If the film is interleaved the interleaving paper SHOULD be left on the film when it is placed on the work bench before exposure, as it protects the film from dirt, iron powder, moisture, chemicals, and other undesirable matter. When attempting to interpret high-density film areas with high-intensity illuminators, care SHOULD be used to prevent overheating of the radiograph. White cotton gloves can be ordered through the supply system.

6.4.6.3.1 Good uniform contact between the screens and the film is very important. If they are in poor contact, the image sharpness will be adversely affected. Particular care SHOULD be used to obtain good contact between the screens and the film when the cassettes are of the flexible type. When removing the film from a film holder, remove the film by opening the screens, therefore avoiding friction between screens and film.

6.4.7 Film Handling Problems.

6.4.7.1 Problems Associated with Storage.

6.4.7.1.1 Fogging from Light.

Phenomenon:
The radiograph is fogged in the same pattern as the interleaving paper texture.

Problem Cause:
The film has been exposed to light while yet covered with interleaving paper.

Corrective Action:
1. Check the darkroom for light leaks.
2. Check the X-ray film storage box for light leaks.
3. Before turning on the normal room lights, make it a rule to ensure no film is on the work bench.
4. Be sure to seal the X-ray film case after use.

6.4.7.1.2 Fogging from Radiation.

Phenomenon:
The shadow of an unexpected object or the head foil as embedded in the X-ray film case appears in the radiograph.

Problem Cause:
The film has been exposed to X- or gamma rays during storage.

Corrective Action:

Keep X-ray films in a lead foil coated X-ray film storage box and store in a radiation free environment.

6.4.7.2 Problems Associated with the Safelight.

6.4.7.2.1 Fogging from Safelight.

Phenomenon:

The radiograph has a fog on one side or shows letter form shadows.

Problem Cause:

1. White light is leaking from a slit in the safelight box.
2. The film has been allowed to stand under safelight illumination for too long a time or placed too near the safelight.
3. A lamp having a higher capacity than standard rating is used as the safelight source.

Corrective Action:

1. Check the safelight filter periodically (every six months to once a year) and replace it if faded.
2. Observe safelight requirements, such as the prescribed lamp wattage and safelight-to-film distance, and complete work under safelight illumination as quickly as possible.
3. Periodically check to ensure the safelight is functioning under normal prescribed conditions.

6.4.7.3 Problems Associated with Handling Before Development.

6.4.7.3.1 Dirt Deposits or Stains on the Screen.

Phenomenon:

The radiograph has irregular shaped light spots.

Problem Cause:

There are dirt deposits or stains on the intensifying screens.

Corrective Action:

1. Keep the surfaces of intensifying screens clean and dry at all times.
2. Wipe the surfaces of intensifying screens with cleaner from time-to-time.

6.4.7.3.2 Spots on the Radiograph.

Phenomenon 1:

The radiograph has dark spots of a relatively low density.

Problem Cause:

Water was splattered on the film.

Phenomenon 2:
The radiograph has dark spots of high density

Problem Cause:
Developer solution was splattered on the film.

Phenomenon 3:
The radiograph has light and dark spots of a relatively low density.

Problem Cause:
Stop bath solution was splattered on the film.

Phenomenon 4:
The radiograph has light spots which are barely developed.

Problem Cause:
Fixer solution was splattered on the film.

Corrective Action:
Handle the films at such a distance from the processing area that water and processing solutions cannot affect them.

6.4.7.4 Problems Associated with Loading and Unloading.

6.4.7.4.1 Film Adhesion.

Phenomenon:
The radiograph has irregular shaped spot-like marks.

Problem Cause:
The film loaded in the cassette adhered to the intensifying screen.

Corrective Action:

1. Do not leave film in a cassette for a long period of time during hot, wet seasons or in a hot place.
2. When the cassette is wet, leave it to dry in the shade choosing a place where there is a good draft.

6.4.7.4.2 Static Marks.

Phenomenon:

The radiograph has tree-like or branching marks.

Problem Cause:

Static marks result from the contact, peeling, or friction of foreign matter caused by static electricity. They are apt to occur when the air is dry.

Corrective Action:

1. Keep the darkroom air at the proper humidity levels (60 to 70-percent RH).
2. Any materials of rubber or synthetic fibers, which are easily charged with static electricity, SHOULD not be used near the film.
3. Handle the film gently.
4. Ground the darkroom workbench.

6.4.7.4.3 Kink Marks.

Phenomenon:

The radiograph has light or dark marks which are crescent shaped or irregular.

Problem Cause:

The film was broken locally or sharply bent during handling. Dark marks appear when the film is sharply bent before exposure while sharp bending of an exposed area may become the cause of light marks.

Corrective Action:

1. Carefully hold the edge of the film and avoid bending it.

6.4.7.5 Problems Associated with Post-Development Processing.

6.4.7.5.1 Uneven Fixing.

Phenomenon:

The radiograph has light, irregular shaped marks, or streaks.

Problem Cause:

Fixing proceeded locally.

Corrective Action:
1. Agitate the film in the fixer solution at frequent intervals, especially in the early course of fixing.
2. Replace the fixer solution with a fresh one before it is exhausted beyond use.

6.4.7.5.2 Uneven Drying.

Phenomenon:
The radiograph has light, blurred lines, or irregular shaped marks of film surface luster.

Problem Cause:
Draining was incomplete and uneven so the drying speed differed from one area to the other.

Corrective Action:
1. Use a wetting agent to drain the film evenly.
2. When hot air is used, gradually heat the air that is blown over the film.

6.4.8 Preparation for Manual Processing.

a. To place the film on the film hanger, grasp one upper corner between the thumb and index finger and fasten it to the hanger with one of the bottom hanger clips.

b. Fasten the other bottom clip and finally the two top clips.

c. The film SHOULD be flat and taut with the punched number (if any) at the bottom of the hanger to prevent streaking due to developer flow through the holes when processing. If it is not, repeat the procedure.

6.4.9 Storage of Radiographs. Industrial film SHOULD NOT be stored near a radiation source. Precautions SHALL be taken to ensure unexposed radiographic film is protected from exposure to radiation by storing film in a lead lined container or in a room removed from x-ray operations. If an exposure is suspected, perform a fog test on a sample film processed with all safelights off. Background density shall not exceed 0.30 density units total. If the film fails the fog test it SHALL be used for training or clearing only.

6.4.9.1 Industrial X-ray films are quite sensitive to heat and moisture, therefore, a cool dry place SHOULD be chosen for storage. Storage temperatures SHOULD be maintained in the 40 to 75°F (5 to 23°C) range. Once film is removed from the envelope, the emulsion will absorb moisture until it attains equilibrium with the moisture content of the surrounding air. On the other hand, excessive dryness is not suitable to the storage of industrial X-ray films, because in such locations films might change with static electricity, resulting in plus-density marks on the radiographs. When X-ray film is not allowed to stabilize at room temperature moisture may condense on the film when it is removed from it’s protective envelope.

6.4.9.2 Industrial X-ray films could develop fog when exposed to polished metal surfaces, painted surfaces, hydrogen peroxide, coal gas, hydrogen sulfide, ammonia gas, mercury vapor, formalin, engine exhaust gases, acetylene, and terpene. Provisions SHALL be made to prevent this kind of fog, which is referred to as a false sensitometric effect

6.4.9.3 The final radiographs SHOULD be placed in film filing envelopes for final storage. These envelopes are constructed of heavy paper to protect the films. The envelope SHOULD be identified as to the radiographs it contains and filed in a systematic manner to facilitate retrieval if and when necessary. Envelopes SHOULD be marked prior to insertion of the film to prevent pressure marks. Films SHOULD NOT be stored in high humidity areas. Film filing cabinets are available for film storage. Ordinary filing cabinets are not sufficiently strong to withstand the heavy loads of filed film. X-ray films present no greater fire hazard in storage than an equal quantity of paper records. There is no necessity for expensive vaults equipped with elaborate fire protection devices. The storage area must be kept clean.

6.4.9.4 The disposition for industrial radiographs is referenced in AFMAN 33-363, AFI 33-364, and AFRIMS through the AF Portal. Specific inspection instructions and TO 00-20-1 SHALL be consulted to determine which inspection radiographs SHALL become part of official aircraft/support equipment records. All radiographs SHALL be disposed of according to AFMAN 23-110.

6.4.10 Processing Chemicals.

CAUTION

Manufacturers material data sheet SHALL always be followed when using their chemicals.

Liquid and powdered chemistry in concentrate form are available for manual and automatic processing. When mixed with appropriate quantities of water, these solutions are then ready for the processing sequence of industrial X-ray films.

6.4.10.1 Chemicals for Manual Processing.

6.4.10.1.1 Developer. When radiographic film is exposed to ionizing radiation, an invisible image (called a latent image) is formed in the emulsion layer of the film. The process of converting the latent image to a visible image is called development, and a developer solution is used in this process.

6.4.10.1.1.1 Developer Composition. Chemically, “development” refers to the reducing action of a chemical. It is necessary to reduce only the silver compound deposited in the latent image of exposed film during exposure to metallic silver to form a visible image. The chemical which is chosen to reduce the exposed silver compound to metallic silver is called a developing agent. The developing agent is not used alone, but in combination with other ingredients which perform special functions. They include the accelerator which activates the developing agent, the preservative which reduces the aerial oxidation of the developer, the restrainer which prevents development fog by restraining the action of the developer on the unexposed silver compound, and other additives used to harden the gelatin and soften the water among other things.

6.4.10.1.1.2 Many developers are kept alkaline by the accelerator. The more alkaline the developer or the greater the quantity of accelerator added to the developer, the stronger the action of the developer. The developer for X-ray film contains more ingredients than the developers for conventional black-and-white films because a larger quantity of silver halide is used in X-ray film.

6.4.10.1.2 Stop Bath. The silver image becomes too dense to serve the intended purpose unless the action of the developer is stopped at a proper time. If, in the case of manual processing, the film is directly transferred from the developer to the fixer, uneven fixation could occur. To stop the action of the developer and prevent uneven fixation, a 3-percent solution of acetic acid is used. If the stop bath is not used, the developer carried over with the film not only increases the exhaustion of the fixer, but it might cause reduced processing uniformity or stain formation in the radiograph.

6.4.10.1.3 Fixer. After development and stop bath neutralization, the emulsion still contains unreduced non-image forming silver halide, which is detrimental, especially to the radiograph as viewed by transmitted light. The fixer is used to remove the unreduced silver halide.

6.4.10.1.3.1 The most common fixing baths are solutions of sodium thiosulfate. Ammonium thiosulfate is also used when quick fixation is required. These chemicals possess activity that converts silver halides to soluble compounds. The emulsion which is softened by the developer is hardened by the fixer. Almost all fixers in use today are of this acid hardening type.

6.4.10.1.4 Wash Accelerator or Quick Washing Agent. Film removed from the fixing bath retains not only the fixer ingredients, but also other compounds that were formed in dissolving the silver halides. To remove these, the film is washed in running water for 20-minutes or more. Some manufacturers offer an agent to reduce the washing time to one-third or one-fifth the time required without its use.

6.4.10.1.5 Wetting Agent. After the wash step, water adheres to the film in streaks and drops. If the film is dried in this condition, not only will the drying time be extended, but water marks will be left on the surface of the radiograph.

6.4.10.1.6 Other Processing Chemicals. In addition to the chemicals discussed above, certain chemicals MAY also be used on finished radiographs to alter densities. When the density of the silver image is too high, a chemical solution called a reducer is used to reduce it. When the density of the silver is too low, a chemical called an intensifier is used to increase it.

6.4.10.2 Chemicals for Automatic Processing.

CAUTION

Medical automatic processing chemicals are formulated to function at high temperatures, but are not capable of producing acceptable industrial radiographic results. Only development chemicals formulated to be used to develop industrial radiographic film SHALL be used in industrial radiographic film processors.

The composition of chemicals formulated for use in automatic processors differs somewhat from chemicals used in hand processing. The most pronounced difference is automatic processing chemicals protect the film against mechanical pressure and roller stains. The developing solution contains a hardener, in addition to its constituents, to inhibit excessive softening of the emulsion. Softening of the emulsion interferes with the transport of the film through the processor. Automatic processing chemicals are specially designed for use at high temperatures. Chemicals for use in automatic processor are supplied in concentrated liquid form, and a starter system is adopted for ease of use.

6.4.10.2.1 Automatic Processing Chemical Requirements. Here are the major requirements that automatic processor chemicals must meet.

6.4.10.2.1.1 Rapid Reaction and Activity Recovery. In automatic processing, development and fixing must each be completed within the time frame of 1 to 2.5 minutes. To give constant results, processing solutions must provide for quick recovery of working strength, when replenished at rates proportional to the quantity of film processed.

6.4.10.2.1.2 Suitability for High Temperature Processing. As processing solutions are maintained at high temperatures, they must be formulated so performance will not be adversely affected by elevated temperatures.

6.4.10.2.1.3 Extended Performance Maintenance. Processing solutions are generally used in automatic processors over a long period of time without being replaced. Throughout this period, the processing solutions must show constant performance, without harming the tanks, racks, and films.

6.4.10.2.2 Automatic Processing Developer. In the roller transport type automatic processors for industrial X-ray films, processing solutions are used at higher temperatures (e.g., 86°F or (30°C)) than in manual processing in order to speed the process. Many transport rollers are used to squeegee the film and remove the exhausted solutions from the surfaces. Developers used in automatic processors are specifically formulated to be suitable for processing at high temperatures and include special chemicals which adjust the contrast and fog. A hardener is included to harden the emulsion, thus, providing sufficient resistance to the forced roller squeegee effect.

6.4.10.2.3 Automatic Processing Fixer. The fixer used in roller transport type automatic processors is especially formulated to produce a greater emulsion-hardening effect than with the fixer used in manual processing. Developer tank transport rollers reduce the amount of developer carryover to the fixer. This extends the life of the fixer, although the primary function of the rollers is to move the film through the processor.

6.4.10.2.4 Chemicals NOT Required in Automatic Processing.

6.4.10.2.4.1 Stop Bath – The stop bath is not used in roller transport type automatic processors, because the rollers adequately remove developer solution from the surfaces of the film. This prolongs the life of the fixer to a far greater extent than in manual processing.

6.4.10.2.4.2 Wash Accelerator – In roller transport type automatic processors, the fixer tank rollers efficiently remove fixer from the film surfaces and wash tank rollers provide for continual turnover of fresh water on the film surface; therefore, the necessity of a wash accelerator is not required.

6.4.10.2.4.3 Wetting Agent – In roller transport type automatic processors, the rollers effectively remove the wash water clinging to the surfaces of the film so a wetting agent is not needed.

6.4.10.3 Mixing Radiographic Chemicals. All mixing vessels SHALL be made of either polypropylene, enamelware, stainless steel, glass, hard rubber, or glazed earthenware. Metal containers such as aluminum, iron, and zinc will contaminate the solutions and result in fogging on the developed radiograph and therefore, SHALL NOT be used. Chemicals SHALL be mixed thoroughly in accordance with the manufacturer's instructions.

6.4.11 Processing Radiographic Film. This section will deal with manual processing first and automatic processing second.

6.4.11.1 Manual Film Processing.

6.4.11.1.1 Developer.

CAUTION

Developer solution SHALL NOT be allowed to drain back into the developer solution tank. The developer solution that is draining becomes oxidized and reduces the useful life of the working bath.

6.4.11.1.1.1 Developer Solution. Manufacturers make developers in standard powder and liquid forms. These developers commonly use three reducing agents, metol, phenodone, and hydroquinone. A combination of these ingredients produces all of the steps of grays and jet black, bringing out the best possible results.

6.4.11.1.1.1.1 Metol or phenodone and hydroquinone will not develop when used alone. To produce any density on the film also requires an alkaline solution. The alkali in effect "opens the door" and permits the developing agents to enter the pores of the emulsion. The speed with which the "door opens" is determined by the amount and potency of the alkali. If too much alkali is present, the developer will tend to produce chemical fog. But, if too little is used, developing will be retarded. Within these limits, the stronger the alkali, the more rapidly development will be completed. Some of the alkalis used in developing solutions are sodium hydroxide, potassium hydroxide, sodium carbonate, potassium carbonate, and borax.

6.4.11.1.1.1.2 Developing solutions containing only the developing agents and alkali would rapidly be exhausted by oxidation from the air. The life of all developing agents is limited by: 1) the reduction of silver bromide to metallic silver, and 2) the amount of oxygen absorbed by the developing agents from the air. There is, however, a chemical whose inclusion in developing solutions extends its useful life. This chemical, sodium sulfite, along with oxygen, have a natural attraction for each other. The affinity is so great when added to a developing solution, sodium sulfite actually prevents oxidation by air of the other components for limited periods of time. To assist in reducing oxidation of developing and fixing solutions the following SHALL apply:

- Use a replenishment tank with a floating lid, which matches the general configuration of the container. The floating lid SHALL be manufactured from a material that will not react with the processing chemistry. It SHOULD also have a specific gravity less than the chemistry so it will float naturally. One material that has these characteristics is "polypropylene." The floating lid SHALL be used in conjunction with the dust cover lid that fits over the top opening of the container.
- Only enough chemical that WILL be consumed within a one-week period SHALL be mixed.
- Developing solutions which are not mixed for use or replenishment SHOULD be maintained in their sealed, original manufacturer's containers.
- Developing solutions SHALL NOT be used two-years past the date of their manufacture.

6.4.11.1.1.1.3 As stated earlier, all developing agents have a tendency to deposit silver in the unexposed parts of the film emulsion after a certain period of time. This tendency may be retarded or restrained if bromide is added to the solution, in-other-words, this may slow development. The proportion of bromide in an X-ray developer SHOULD be just enough to prevent chemical fog without materially reducing the activity of the solution. Remember, bromide is removed from the film emulsion during development; therefore, since bromide is a restrainer, it SHOULD be evident as each piece of film is developed, more restrainer is being added to the solution. Additionally, developing agents gradually lose potency as they age and/or are used. Consequently, as each piece of film is processed, developing time for the next film must be theoretically increased. The most important characteristic of any developing formula is its ability to produce and reproduce a certain degree of film blackening for a particular quantity of absorbed X-ray energy. Consistency and stability can only be secured by maintaining constant developer activity. To achieve the stability required, the developing solution SHALL be tested and replenished per process control requirements and manufacturer's instructions.

NOTE

Whenever process control requirements and manufacturer's instructions are in conflict, the process control requirements within this technical manual SHALL take precedence.

NOTE

For consistent results, the various parameters of development must be kept constant.

6.4.11.1.1.2 Developer Temperature. The image density and contrast of a radiograph are influenced by development temperature and time. It is necessary to keep the developer at a specified temperature (normally 68°F/(20°C) for manual processing) and carry out development during a specified time. When the temperature of the developer is higher than normal, the sensitivity, resolution, and contrast of the developed film will be reduced similar to the results obtained by extending the development time, and vice versa. With the reduction of these preferred qualities, latitude and fog level will increase, decreasing the usefulness of inspection results. In any case, it is important the temperature of the developer be kept within a range from 64.4° to 73.4°F (18° to 23°C). Because development time varies with each brand of developer, the instructions given by the manufacturer SHALL be followed.

6.4.11.1.1.3 Development Time. The sensitometric properties of X-ray film change when the development time is changed while maintaining constant levels for other conditions, such as temperature and agitation. X-ray film speed and contrast increase to a certain extent with increasing development time, but contrast could fail due to fog or other causes. The graininess might become coarser when development time needs to be extended to increase speed and contrast. A maximum limit of 8-minutes SHOULD NOT be exceeded at a developer temperature of 68°F/(20°C) (Figure 6-38). Film SHALL NOT be left in the developer solution any longer than the prescribed time for its specific temperature (Table 6-14). Uncontrolled time and temperature during film development will cause under or over development, which reduces or eliminates useful information from being discernible on the radiograph. Developing solutions, which pass their useful life, SHALL be disposed of properly. Check state and local regulations to determine proper method of disposal.

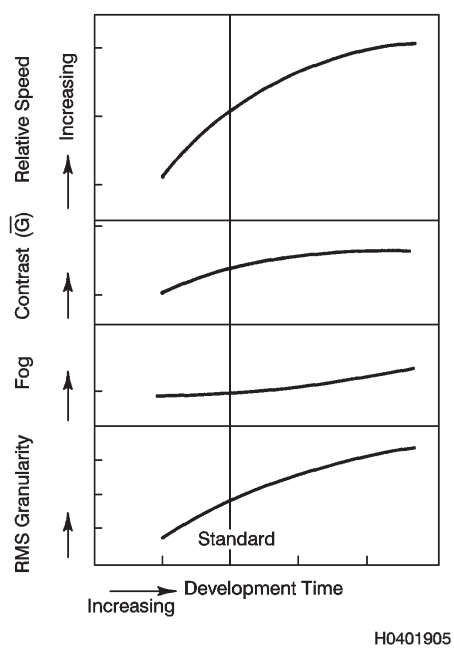

Figure 6-38. Development Time Related Photographic Properties of X-ray Film

Table 6-14. Developing Time Versus Temperature

Time (Minutes)		
Normal	Maximum	Temperature
3-1/4	6-1/4	80
3-3/4	6-3/4	76
4	7	72
4-1/2	7-1/2	70
5	8	68 (Recommended)
5-1/2	8-1/2	65
6	9	63

6.4.11.1.1.4 Developer Agitation. During development, the developer solution or the hanger loaded with exposed film is agitated at frequent intervals in order to keep the emulsion in contact with fresh solutions at all times, thus accomplishing even development. If films are allowed to develop without any movement, there is a tendency for each area of the film to affect the development of the areas immediately below it. This is because the products of development have a higher specific gravity than the developer. The greater the film density from which the reaction products flow, the greater is the restraining action upon the development of lower portions of the film. The solution in contact with high density areas of the film will be locally exhausted so development of those areas stops, while the solution in contact with low density areas is exhausted to a lesser extent so development proceeds. As a result, such a radiograph will show low contrast. Thorough and even agitation of the film during development is very important. When tray processing is used, care SHALL be taken to assure radiographs do not cling to one another, and the tray SHALL be rocked to provide continual mixing and redistribution of the solution.

6.4.11.1.1.5 Developer Exhaustion and Replenishment. If the water volume is not accurately measured in the preparation of developer solutions, the resulting properties will vary from the original specifications and fog could result. Accurate measurement of water volume is therefore important, however, it SHOULD be remembered the development capacity of even an accurately prepared developer solution decreases as it is used. It is necessary to check the developer solution for exhaustion by maintaining records of the sizes and quantities of X-ray films processed and the number of days the developer has been used.

6.4.11.1.1.5.1 To obtain uniform radiographic results over a period of time, it is necessary to check the activity of the developer solution and add developer replenisher in proportion to quantity of film processed or at regular intervals. The extent to which the developer replenisher influences the sensitometric properties of X-ray film is demonstrated in (Figure 6-39). The rate of replenishment varies with the size and quantity of films and their average density. The developing power of the developer decreases with increasing density or film size, and vice versa. The relative areas of various size films as determined by assigning the value 1 to the reference size 10 x 12 inches (25.4 x 30.5 cm) are shown Table 6-15).

NOTE

In order to reduce variations in developer solution activity and achieve uniform radiographic results, replenisher SHALL be added in small quantities and at frequent intervals.

Table 6-15. Film Size Versus Relative Area

Film Size	Relative Area
35.6 x 43.2 cm (14 x 17 in.)	2
25.4 x 30.5 cm (10 x 12 in.)	1
11.4 x 43.2 cm (4-1/2 x 17 in.)	0.6
8.5 x 30.5 cm (3-1/3 x 12 in.)	0.3

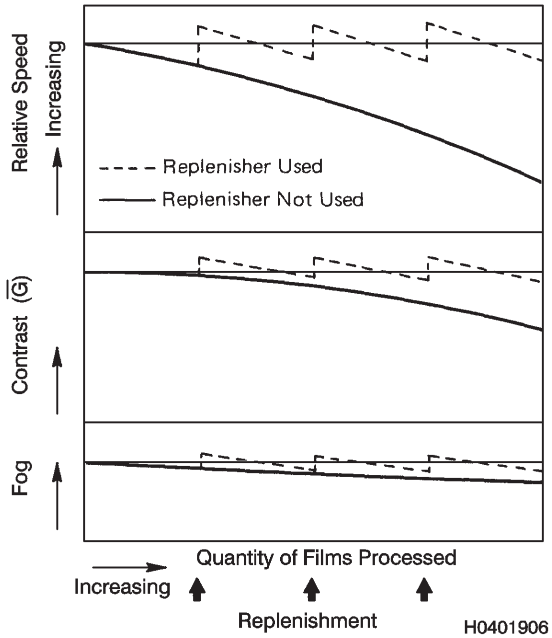

Figure 6-39. Effects of the Developer Replenisher on the Properties of X-ray Films

NOTE

It is recommended radiographic inspection facilities use the replenishment method while performing the manual film development process.

6.4.11.1.1.6 Developer Aging. As films are developed without replenishment, the developing solution becomes exhausted chemically until no developing action can take place. For a given quality of developer, without considering the effects of oxidation, levels of bromide, hardener, and contamination, the development time must be increased for successive films to fully develop them. It is estimated a five-gallon tank of developer will develop 140 films, size 14 x 17 inches, satisfactorily without excessive increase in development time. It is convenient to divide the total number of films that can be developed by 5-gallons of developer into seven groups of 20 films each. As each group of 20 films, 14 x 17 inches, or equivalent film area is developed, the development time must be increased 1/4-minute, assuming a normal time of 5-minutes at 68°F (20°C). Even when drained, each film carries about 1-1/2-ounces of developer with it, so developer must be added to keep the tank at the 5-gallon level. When the specified number of films has been developed, discard the solution. This method is known as the exhaustion method of developing.

6.4.11.1.1.6.1 Another method of processing is the replenisher method. By adding replenisher solution periodically, the activity of the developer is kept at the same level. In this method, films must be removed from the tank quickly without allowing the excess developer to drain off the film back into the tank. Approximately 1-gallon of replenisher SHOULD be added for every 40 films, 14 x 17 inches, or equivalent film area (based on 5-gallons of developer). If this amount of developer cannot be added at the specified time, too much developer is draining back into the tank. In this case, enough developer must be drained from the tank so the replenisher can be added. For dense radiographs it MAY be necessary to increase the quality of replenisher added. In this case, it is also desirable to add replenisher at shorter intervals to keep the level of developer activity more nearly constant.

NOTE

The developer solution SHALL be discarded when the replenisher used equals four times the original quantity of developer solution, when it fails the process control requirements or at each two month period, whichever occurs first.

6.4.11.1.1.6.2 Fresh developer is referred to as “wild” and will often result in excessive contrast on the first few films. This is apparently due to the lack of equilibrium between the developer and the reaction products. It is sometimes recommended a small quantity of old developer be mixed with the fresh developer to temper the solution.

6.4.11.1.2 Stop Bath.

WARNING

Glacial acetic acid SHALL be handled with adequate ventilation, and great care SHALL be used to avoid injury to the skin or clothing. Glacial acetic acid SHALL always be slowly added to water, while stirring constantly. Water SHALL NOT be added to the acid, since this may cause boiling, splattering acid, causing burns to the hands or face.

6.4.11.1.2.1 Stop Bath Solution. The stop-bath consists of a mild glacial acetic acid solution, designed to neutralize the alkali of the developer. Developer solution will contaminate the stop-bath, but much of this contamination can be eliminated by allowing the radiograph to drain for one or two seconds prior to placing it in the stop-bath.

NOTE

Stop-bath SHOULD be used during hand developing radiographic film, when allowed by the operational environment.

6.4.11.1.2.2 Stop Bath Function. The function of the stop bath is to nullify the action of the developer through the use of acetic acid. It stops development in the shortest period of time to prevent uneven development and subsequent streaking on the film. Therefore, it is important to assure the action of the developer is terminated over the entire surface of the film. The stop-bath also protects the fixing solution, which is slightly acidic, from the alkalis of the developer, thereby extending its useful life.

6.4.11.1.2.3 Stop Bath Temperature. Care SHALL be exercised to prevent a rapid change in the extent of swelling in the emulsion layer. To meet these requirements, the stop bath SHALL be maintained at a constant temperature close to that of the developer solution. If the temperature of the developing solution is 68°F (20°C), the temperature of the stop bath SHALL be maintained within the range of 59° to 68°F/(15° to 20°C). If sodium carbonate is used to formulate the stop-bath, it SHALL be used between 65°F (18°C) and 70°F (21°C); otherwise, it will cause carbon dioxide blisters to form in the film’s emulsion.

6.4.11.1.2.4 Stop Bath Agitation. After the film is placed in the stop bath, it SHALL be continuously agitated for about 15-seconds to prevent uneven development. Ensure films do not cling to one another, and immerse films in the stop bath for 1- 2 minutes, agitating about every 30-seconds.

6.4.11.1.2.5 Stop Bath Exhaustion and Replenishment. The stop bath is checked for exhaustion with a pH meter or litmus paper. When the pH of the stop bath exceeds 6.0, its neutralizing power has decreased to such an extent it no longer is able to perform its proper function. Make it a rule to replace the stop bath when its pH value is close to the critical level of 5.5. If a stop bath cannot be prepared for one reason or another, a fresh running water rinse MAY be used in place of the acetic acid stop bath.

6.4.11.1.3 Fixer.

6.4.11.1.3.1 Fixer Solution. There are only two chemicals in common use that will act as clearing agents by dissolving the undeveloped silver bromide in thin film emulsion. These are 1) sodium thiosulfate (hypo) and 2) ammonium thiosulfate. Weight-for-weight, ammonium thiosulfate has approximately three-times the fixing power of sodium thiosulfate. It is the clearing agent in liquid high-speed fixing concentrates, while hypo is used in regular-speed formulas.

6.4.11.1.3.1.1 When a solution of ammonium thiosulfate in used as a fast action fixer, not only is the film cleared in a shorter time, but twice the fixing capacity of ordinary fixer solutions is made available. The fixing capacity limit is likely to be exceeded more easily with fast acting fixer solutions because the time to clear is short, even when twice the fixing time needed by a fresh solution is required. Fast acting type fixers are not recommended for general use because they could cause discoloration or image fading. Clearing times and fixing capacities for ordinary and fast-acting fixers are compared in (Figure 6-40).

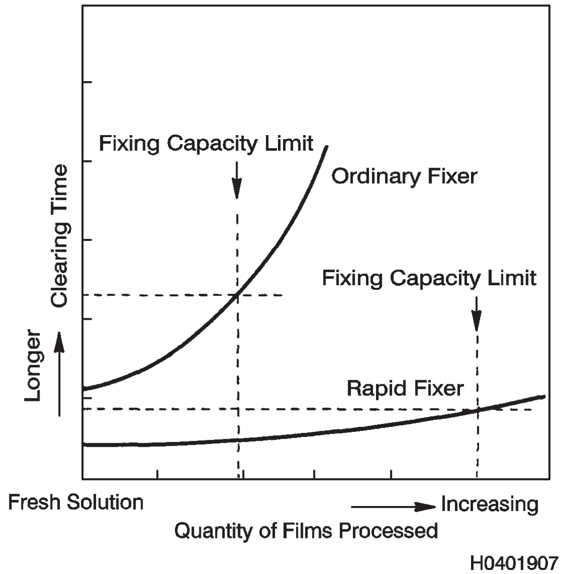

Figure 6-40. Clearing Time and Fixing Capacity of Fixers

6.4.11.1.3.1.2 It is essential the fixing solution neutralize the alkaline developer adhering to the film. In other words, development must stop before fixing can begin. The neutralizer is an acid; the most suitable of which are acetic and sulfuric acid in weak concentration. If a fixing bath is to be used for a long period of time, a large quantity of acid is necessary to neutralize the alkalinity of the developer. Fixing is accomplished by means of the thiosulfate only.

6.4.11.1.3.2 Fixer Function. After development, the emulsion contains all of the unexposed and undeveloped grains of silver. A permanent image cannot be retained in the exposed and developed X-ray film unless it is treated with the fixer. The undeveloped silver must be removed from the emulsion if the image is to be permanent. Fixing conditions greatly influence the degree of radiographic permanency. Therefore, control of these conditions, as described below, needs to be addressed.

6.4.11.1.3.3 Fixer Temperature and Fixer Time. The fixer temperature does not influence the fixing speed to the same extent the developer temperature affects development time, but generally, fixing time decreases with an increase in fixer temperature. The relationship between the fixer temperature and the fixing time is shown in (Figure 6-41). The fixer temperature SHALL be adjusted to be in close range of the developer temperature to avoid related detrimental effects on the emulsion.

6.4.11.1.3.3.1 As a general rule, fixing requires twice the time that elapses from the moment the film is immersed in the fixer solution to the time the milky emulsion becomes completely transparent. If the fixing time is inadequate, the film retains some insoluble salts (complex silver thiosulfate compounds). If they are allowed to remain, they will react with the environment and degrade the image, causing it to discolor and fade. Even if the fixing exceeds twice the clearing time, the quality of the processed radiographs will not be adversely affected. On the other hand, if the film is allowed to remain in the fixer solution for too long a time, the density of the image will decrease and the film will acquire a brown color. Granularity might also be affected depending on the circumstances. Films SHALL NOT be left in the fixing bath for an excessive period of time.

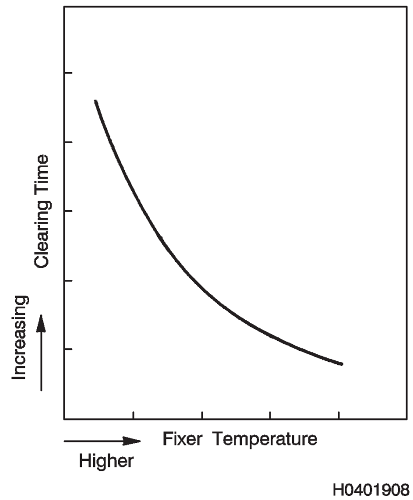

Figure 6-41. Fixer Temperature-Time Curve

6.4.11.1.3.4 Fixer Agitation. When the film is first transferred from the stop bath into the fixing bath, it SHALL be agitated continuously for 10-seconds and thereafter occasional agitation is to be employed. Ensure films do not cling to one another. If the stop bath is unavoidably skipped (the skipping of the stop bath SHALL be avoided to prevent uneven development), and the film is directly transferred from the developer solution into the fixing bath, or if the film is rinsed after development and transferred into the fixing bath, it SHALL be agitated vigorously in the fixer for about 30-seconds. If agitation is not vigorous enough, uneven fixation may result and dichroic fog and stains may occur when the fixer solution is exhausted. Dichroic fog is likely to start from the presence of traces of developer in the fixing bath. When viewed by transmitted light, film with dichoric fog has yellowish to brownish stains. These stains are of a bluish, greenish, or yellowish metallic luster when viewed by reflected light.

6.4.11.1.3.5 Fixer Capacity. In general practice, the fixer solution is not replenished and is used until fully exhausted. As it is used, its fixing capacity decreases to a point at which the time required for the film to clear is increased by twice the time required with fresh fixer solution. When this critical state has been reached, the fixer solution SHALL be replaced. If this limit is exceeded, proper fixation will not be accomplished even if the film remains in the fixer solution longer than twice the clearing time. Such practice will further result in image discoloration of fading.

6.4.11.1.3.5.1 During use, films carry the processing solution into the fixing bath. The amount of processing solution carried on the film has a significant effect on the strength of the fixer solution exhausting it over time. The smaller the carry-over, the less the fixer solution will be degraded. If film is to be drained thoroughly, it must be held out of solution for a long period of time, and such exposure to air brings with it the risk of discoloration. Films, wet with any of the processing solutions, SHALL NOT be allowed to remain in contact with the air for longer than 10-seconds.

6.4.11.1.3.5.2 When films are repeatedly transferred directly from the developer solution into the fixing bath, or rinsed and transferred into the fixing bath without using the stop bath, the hardening capacity of the fixer solution decreases rapidly so films are easily scratched or longer than normal drying times are required after washing. Furthermore, under these conditions, development MAY proceed even in the fixing bath, thus leading to dichroic fog and uneven fixation. In such cases, it is necessary to replace the fixer solution even before complete exhaustion has taken place.

6.4.11.1.3.6 Hardening. Because X-ray film is handled frequently and is subject to more abuse than photographic negatives, it is customary to use a hardening agent. This hardening agent, or “hardener”, tans and toughens the emulsion. Some of the common hardeners are “alum” and “aluminum and chloride” for high-speed fixers. One distinct advantage of the hardener used in high-speed fixers is the production of a hardened film, which will not melt in water as hot as 175°F (79.4 °C) after the film is dried.

6.4.11.1.3.7 Clearing Action. When a film is removed from the developing solution, the undeveloped areas are swollen and yellow in appearance. Sometime after immersion in the fixer, this yellow becomes transparent; this change MAY be observed and recorded. The time required for this change is known as the "clearing time." To adequately fix a film, it SHALL be immersed in the fixer at least twice as long as it took to clear. This period SHALL NOT exceed fifteen minutes. For example, if the clearing time is two-minutes then the fixing time is four-minutes. The fixing solution will become deficient with each use. This deficiency is insidious, and MAY be overcome by adjusting the fixing time up to the maximum fifteen-minute time period. The cause of the fixer degradation may be due to one or more of the following:

6.4.11.1.3.7.1 The accumulation of soluble silver salts will gradually prevent the fixer from dissolving unexposed silver halide from the film emulsion, therefore, making the fixer incapable of properly clearing the radiographic film.

6.4.11.1.3.7.2 The loss of chemical activity is evident when long periods of time are required to clear a radiograph. This situation will cause colored stains on the radiograph, swelling of the emulsion that inhibits hardening and results in long drying times, and reticulation or sloughing during drying.

6.4.11.1.3.7.3 Reduction of activity caused by dilution of the fixer solution when stop bath, rinse water, and developer solution are carried over by the film being processed. The effects of this dilution/contamination are reduced by allowing the radiograph to drain into the stop bath prior to being put in the fixer. Care SHALL be taken to not contaminate the developer solution.

6.4.11.1.4 Washing. Thorough washing is necessary to remove the processing solutions and complex silver salts (complex silver thiosulfate compounds). If such salts are allowed to remain after washing, they will gradually decompose and cause the image to discolor or fade. Because hardeners are used in X-ray fixing solutions, it is difficult to remove small quantities of the fixer retained by the gelatin.

6.4.11.1.4.1 Wash Water Flow Rate and Temperature. The faster the flow of water in contact with the emulsion, the faster the undesired compounds are removed and the shorter the washing time becomes. The wash water temperature SHOULD preferably be slightly lower than the fixer temperature to avoid adverse conditions in emulsion. In practice, however, considerable capacity is required to maintain adequate control of wash water temperature. Ideally, the developer temperature SHOULD be 68°F/(20°C) and the wash water temperature varies greatly with the season. If such variations are present, there is no alternative but to make slight changes in the stop bath and fixer temperatures in favor of the wash water temperature, as shown in Table 6-16).

Table 6-16. Examples of Temperature Adjustments for Processing Solutions

	Developer	Stop Bath	Fixer	Wash Water
Summer	20°C (68°F)	22 to 25°C (71.6 to 77.0°F)	25 to 28°C (77.0 to 82.4°F)	30°C (86°F)
Winter	20°C (68°F)	18 to 15°C (64.4 to 59.0°F)	16 to 13°C (60.5 to 55.4°F)	10°C (50°F)

6.4.11.1.4.2 Wash Time. The speed of washing is determined by the speed with which the clearing agent diffuses out of the film into the water. The quantity of clearing agent remaining in the gelatin is continually halved in the same period of time as washing continues. For example, if a film gives up one-half its clearing agent in 1-minute, then after 2-minutes one-quarter remains, after 3-minutes one-eighth, in 4-minutes one-sixteenth, and so on, provided the film is continually exposed to fresh water. Washing will never remove all traces of fixer. The object of washing is to remove enough fixer so the film MAY be maintained without fading for any given period of time. The processed film SHOULD be washed in running water at 68°F (20°C) for 50 minutes or more. For most practical purposes, X-ray film will be washed sufficiently in 30-minutes if the water changes at the rate of four to eight-times per hour (Table 6-17). The wash water temperature SHOULD be between 65°F and 80°F. Regardless of the type of fixer used, if the film is allowed to fix twice the required time, three times a normal washing time is required.

Table 6-17. Manual Washing of Radiographic Film

Manual Approximate Film-Washing Times at 68°F		
Class of Film	**Rate of Water Change**	**Washing Time**
I	4 times per hour	35 minutes
I	8 times per hour.	20 minutes
II	4 times per hour	35 minutes
II	8 times per hour	20 minutes
III	4 times per hour	35 minutes
III	8 times per hour	20 minutes
IV	4 times per hr.	35 minutes
IV	8 times per hour	20 minutes

6.4.11.1.4.2.1 If the temperature of the wash water falls below 50°F, it is not possible to adequately remove the fixer from the emulsion in the above length of time. Washing takes three-times as long when the temperature is between 50 to 60°F as it does at 70 to 75°F. Thus, the rule for washing time for X-ray film is true only when the wash water is relatively warm. If the film has been over fixed, and then washed at 50°F, there is no practical way to remove enough fixer to prevent fading of the image. In addition, if the temperature difference between fixer and wash water exceeds 15°F, there is a possibility of unequal swelling of the emulsion known as reticulation.

6.4.11.1.4.3 Wetting Agent Action. The use of a wetting agent between the washing and drying operations is highly recommended. When the film is removed from the wash tank, small drops of water will cling to the emulsion. Areas under these drops will dry more slowly and cause distortion of the gelatin, changing the density of the silver. These are frequently visible and can be troublesome in film interpretation. Most water also contains large amounts of solid material in the form of calcium and other chemicals, which will remain on the film as a white residue after the water drops have evaporated. Such “water-spots” can be prevented by immersing the washed film in a wetting agent for one to two-minutes before transfer into the drying cabinet. Various detergents or commercial wetting agents can be used.

6.4.11.1.5 Drying. The final step in processing is drying of the X-ray film. Film SHALL be dried immediately after washing. Water streaks and drops adhere to film surfaces and if they are not removed prior to drying, the areas lying underneath will dry more slowly than the surrounding areas thus, changing the density of the silver image and resulting in spots. Such uneven drying can be prevented by gently wiping the film with a sponge or accelerated if the film is immersed in a wetting agent solution following washing. In addition to speeding drying time, this technique also prevents the formation of watermarks or streaking on the emulsion. Hang up the films in a dry rack where the film hangers can be suspended. Where a large number of films must be handled, special equipment may be necessary. The forced air dryer SHOULD have a filter over the air inlet with the unit providing 104 to 122°F (40 to 50°C) hot air movement over the film.

6.4.12 Manual Film Processing Procedure.

6.4.12.1 Preparation.

a. Be sure all films are placed on hangers properly.

b. Check the temperature of all processing solutions using a bimetallic thermometer (Table 6-17).

c. Agitate the developing chemicals and make sure they are at the proper level; replenish if necessary.

d. Be sure wash water flow is adequate.

6.4.12.2 Step-by-Step Manual Processing Procedure (Figure 6-42).

CAUTION

Films SHALL NOT be allowed to remain out of solutions for more than 10 seconds since this will cause uneven development.

NOTE

Drain the films and hangers for several seconds between operations to prevent carryover of chemicals from one tank to another.

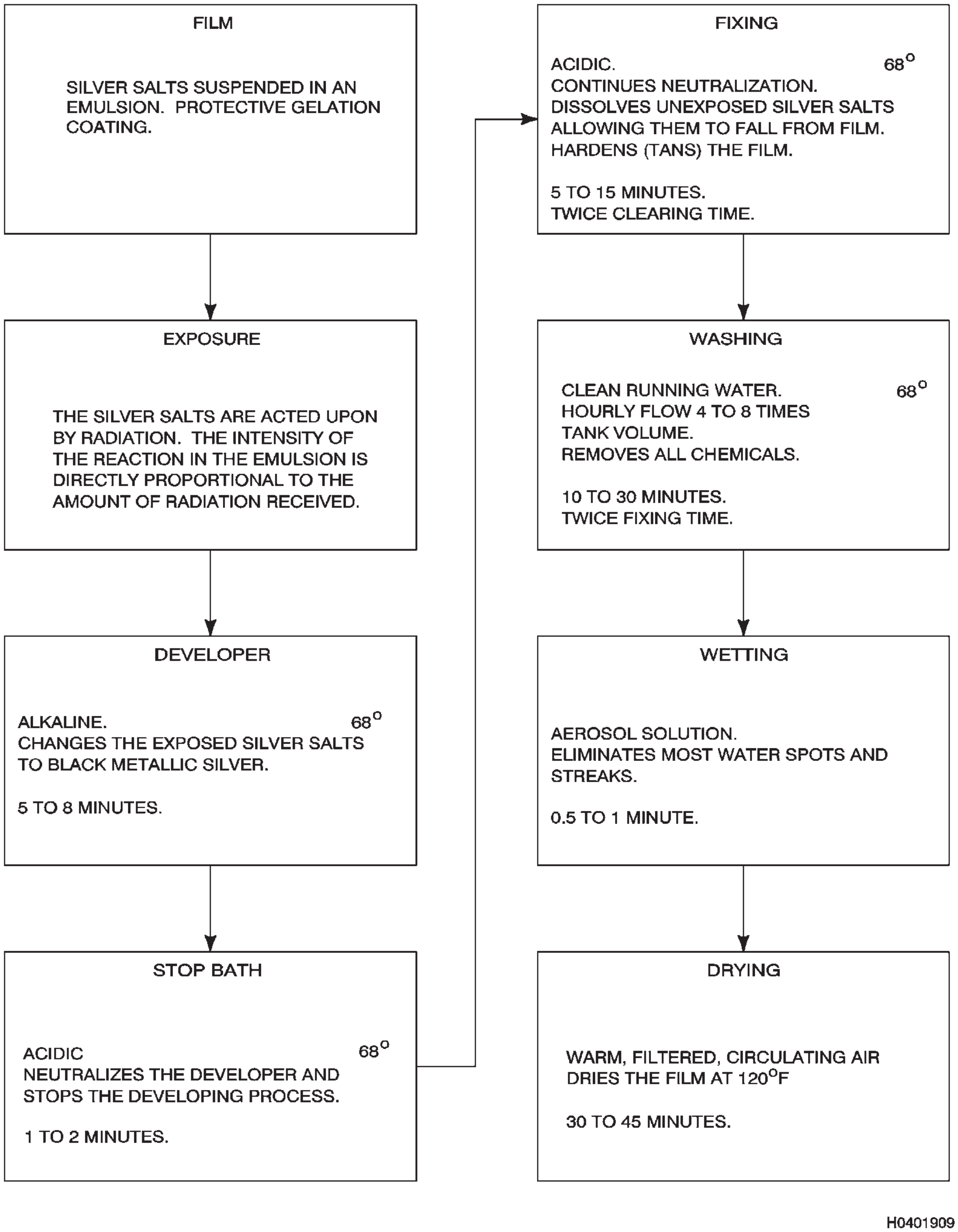

Figure 6-42. Manual Film Processing

a. Immerse the films (and hanger) in the developing solution. Agitate the hangers by hand at 30-second intervals. This SHALL be done during the entire developing time.

b. Remove the films from the developer and immerse in stop bath for approximately 1 - 2 minutes.

c. Remove the films from the stop bath solution and immerse in the fixing solution. The total "clearing time" SHALL be determined according to (paragraph 6.4.11.1.3.7).

d. Remove the films from the fixing bath and immerse in the wash water for the recommended period.

e. Dry the films.

f. Remove the films from the film hangers.

6.4.13 Automatic Film Processing. A system of rollers is generally employed as the transport mechanism in automatic processors, as shown in one manufacturer's sectional view Figure 6-43). Automatic processors decrease dry-to-dry processing time from approximately one-hour, in a manual hand tank system, down to 5 to 13-minutes (Table 6-18). Furthermore, the automatic processor reduces variations in radiographic quality. However, the processor alone cannot produce these effects unless combined with suitable film and processing chemicals.

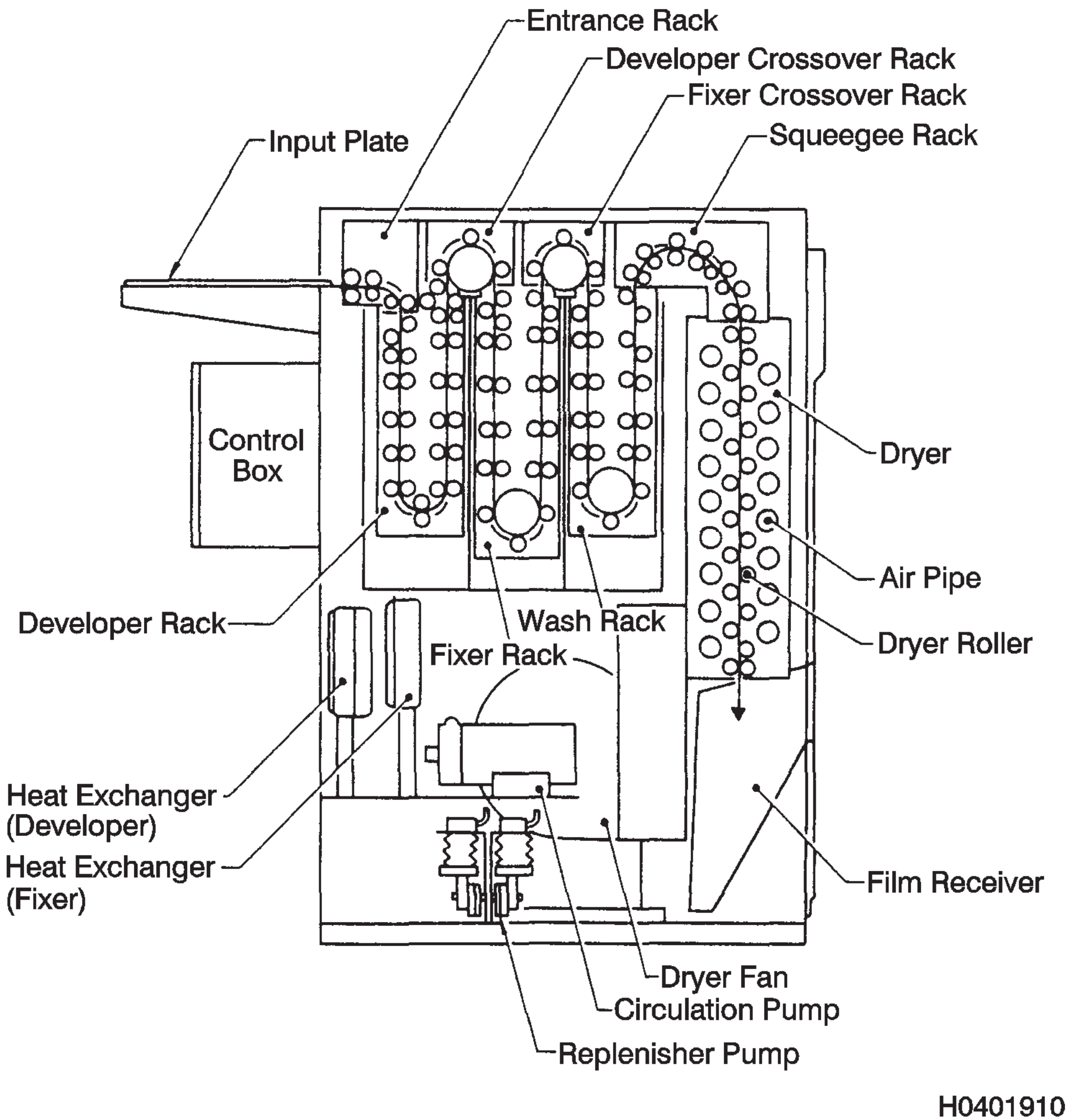

Figure 6-43. Sectional View of Fuji FIP 4000 Processor

Table 6-18. Conditions for Manual and Automatic Processing

	Development	Stop Bath	Fixing	Washing	Finishing Bath	Drying	Total
Manual	20°C/68°F	20°C/68°F	20°C/68°F	20°C/68°F	20°C/68°F	40°C/104°F	
Processing	5 min.	30 sec.	5 min.	50 min.	30 sec.	30 min.	91 min.
Fuji Fip 4000	30°C/86°F	–	31°C/88°F	31°C/88°F	–	About 45°C/113°F	
Processor	1 min. 35 sec.	–	1 min. 30 sec.	1 min. 30 sec.	–	50 sec.	5 min. 25 sec.

6.4.13.1 Advantages of Automatic Film Processing. In addition to eliminating the variations in radiographic quality, and reducing processing time by 3/4, automatic film processors also take up less space within the darkroom, help to keep the room cleaner and are easily installed. Automatic processing is particularly advantageous when large volumes of film need to be processed. Automatic processing also provides for greater uniformity of development, thus providing more consistent results. The quality level of these results is determined by chemical and equipment condition, and conscientiousness of the operator. However, because the cycle is faster and the chemical temperatures are higher in automatic processing than they are with manual processing, the use of automatic processing will produce a more narrow (high) latitude radiograph and has a noticeable effect on the radiographic technique. Therefore, apparent film characteristics will be significantly altered by the use of automatic processing. As a result, film quality, when automatic processing is used, is generally lower than that which is obtainable with manual processing. However, the advantages of speed of processing, lower manpower requirements, and consistency of development generally are felt to be more important in the decision to use automatic processing.

6.4.13.2 Rapid Access to Finished Radiographs. The following methods are employed in automatic processing to gain rapid access to finished radiographs.

6.4.13.2.1 Raising Processing Solution Temperatures. The chemical reactions are facilitated by applying relatively high temperatures in processing solutions.

6.4.13.2.2 Reinforcing Chemical Solution Supply to Film Surfaces. A fine spray or processing jet is continuously applied to the film surfaces, as solutions are forced to circulate in the processing tanks, keeping them well mixed and maintaining them in agitated contact with the film surfaces. Such methods facilitate chemical reactions between the emulsion and the processing chemicals.

6.4.13.2.3 Increasing Chemical and Film Interaction through Transport Roller Pressure. The film is brought into direct contact with the transport rollers so the rollers not only squeegee the film, but force processing solutions against the film surfaces, thus facilitating chemical reactions.

6.4.13.3 Care in Automatic Processing. In automatic processing, it is very important certain processing conditions be kept constant as indicated in (Table 6-18). Processing control SHALL be rigidly practiced by making periodic measurements to avoid variations in solution temperatures, replenishment rates, and wash water flow rates.

6.4.13.4 X-ray Film Requirements for Automatic Processing. Industrial X-ray films designed for automatic processing SHALL meet the following requirements.

6.4.13.4.1 Increased Adaptability to Rapid Processing. In spite of satisfactory development, the radiographic image could discolor and fade with time if fixing, washing, and/or drying are not adequate. Film processed with an automatic processor SHALL meet special requirements not required by film processed by manual systems. For instance, the emulsion layer must be thinner and the emulsion must react with processing chemicals more rapidly.

6.4.13.4.2 Increased Strength of the Emulsion Layer. Rapid processing will serve no purpose if the resulting quality is inferior to hand processing. When solution temperatures are increased, softening and swelling of the emulsion layer is also increased subjecting the film to severe physical conditions and roller pressure. For automatic processing, the emulsion layer of industrial X-ray film must therefore be strong enough to withstand such severe processing conditions.

6.4.13.4.3 Adoption to a Polyester Based Film. It has been many years since flammable cellulose nitrate film base was replaced first with inflammable cellulose acetate then with polyester base materials. Polyester base materials are advantageous because they provide flatness and great strength. Little expansion and contraction take place and the material is not hygroscopic. These advances in a polyester film base are indispensable to rapid film transport in automatic processors.

6.4.13.4.4 Adoption to Chemicals Used in Automatic Processing. The composition of chemicals formulated for use in automatic processors differs somewhat from that of chemicals used in hand processing. For details on chemicals used in automatic processors (paragraph 6.4.10.2).

6.4.14 Silver Recovery. The value and scarcity of silver makes recovery of it economically feasible. Approximately 80-percent of the silver in the film emulsion is transferred to the fixer solution; the remaining 20-percent forms the radiographic image. Here we will discuss methods used to recover the silver from both the fixer and the film.

6.4.14.1 Recovering Silver from Fixer. The unexposed and undeveloped silver halides in the film emulsion are removed by the fixer solution. Therefore, the exhausted fixer becomes rich in silver content. There are three basic methods of silver recovery from the fixer solution. These are by electrolysis, metallic replacement, and chemical precipitation.

6.4.14.1.1 Electrolysis Recovery Method. When electric current is passed between two electrodes immersed in the silver-bearing fixer, the silver is electronically deposited upon the cathode. This silver can be stripped from the cathode and refined. This method permits re-use of the fixer.

6.4.14.1.2 Metallic Replacement. This method consists of replacing the metallic silver with a less valuable base metal such as iron, zinc, or copper. As an example, if steel wool is inserted into the exhausted fixer solution, the silver in solution is replaced by the iron, and the silver accumulates on the bottom of the container in the form of sludge. The sludge is removed and refined to reclaim the silver. The fixer SHALL be discarded after silver recovery by this method.

6.4.14.1.3 Chemical Precipitation. Silver can be reclaimed from fixer by the addition of certain chemicals to the exhausted fixer. The silver is precipitated out of the solution in the form of a sludge that can be recovered and refined. The chemical reaction generates obnoxious fumes and odors, and separate facilities are recommended for this method of silver recovery. The fixer SHALL be discarded after silver recovery by this method.

6.4.14.2 Recovering Silver from Film. There are two methods used to recover silver from obsolete films: stripping or burning. It is usually more economical to simply market used or obsolete film than to attempt silver reclamation from film on a small scale. Detailed information on silver recovery is provided in AFMAN 23-110 Vol 6.

6.4.14.2.1 Stripping. A chemical or mechanical means is used in this method to strip the silver bearing emulsion from the film base. The emulsion is then refined to reclaim the silver.

6.4.14.3 Burning. The second method is burning the film in an incinerator that controls the burning process and the fly ash. The residual ashes are then processed to obtain the silver content.

6.4.15 Film Reproduction Technique. Often duplicate radiographs are required. If it is known in advance that duplicate films are required, it is quicker and more economical to expose two films simultaneously in the original exposure. If lead screen techniques are being used, slight increases in exposure will be required.

6.4.15.1 If multiple copies of an existing radiograph are required, they can be reproduced by contact printing techniques. The duplicate radiograph can be made on a direct-positive film that produces a duplicate-tone facsimile of the original. The film gradient of the duplicating film is -1.0, which means density differences in the original image are faithfully reproduced in the duplicate image. Duplicating film cannot reproduce radiographic density ranges equivalent to originals. But by varying exposure, the density differences can be recorded accurately.

6.4.15.1.1 If duplicating film is not available, it is possible to use medical film designed for use with fluorescent screens. These duplicates are also produced by the direct printing method. However, these films have a special property. While not a positive film, they do undergo reversal with large exposures. That is, they increase in density up to a saturation point after which time they decrease in density with exposure, and thus reverse. It is necessary to expose these films such that reversals occur, and the original image is duplicated. If the original radiograph has a high density, exposures of as much as two-minutes to a photoflood lamp MAY be required. These exposure requirements must be generated for each specific situation; generalization here is not practical.

6.4.16 Film Artifacts. An artifact is the product of human error and in the case of film is usually due to mishandling the film in some step in the radiographic process. Here we will discuss some typical artifacts you may run across.

6.4.16.1 Processing Artifacts. Chemical spots can occur if any chemicals are splashed, contacted, or transferred by wet fingers to the undeveloped film. Dark spots indicate either water or developer on the film before processing. Light or undeveloped spots indicate the stop bath or fixer has been allowed to contact the film before processing. Stains caused by chemical reactions, over development, or underdevelopment are processing artifacts. Streaks from contaminated hangers are quite common as well as streaks from lack of agitation during the development period.

6.4.16.2 Handling Artifacts. Many artifacts are introduced by film handling. Crowfoot static marks can be caused by sliding the film over surfaces, creating an electrical discharge of static electricity, particularly under very dry atmospheric conditions. Half-moon-shaped marks (either dark or light) can be caused by crimping the film, particularly with the thumb, these are often referred to as thumb crimps, handle X-ray film as if it were a piece of wet paper. Scratching of the emulsion when the film is wet and the emulsion is soft is a common artifact.

6.4.16.3 Exposure Artifacts. The most common exposure artifacts are caused by excessive pressure applied to the film before, during, or after exposure. Either heavy parts or excessive bending of the film can apply sufficient pressures to the film emulsion as to render it insensitive to exposure. These artifacts usually appear as unexposed areas on the film.

6.4.16.4 Manufacturing Artifacts. Artifacts due to the manufacturing process are comparatively rare. On occasion exposed spots or other manufacturing artifacts, such as roller marks or foreign material may occur on the emulsion surface. Artifacts which are commonly encountered, their cause, and any remedial action which SHOULD be taken are shown (Table 6-19).

Table 6-19. Description of Film Artifacts

Condition	Cause	Remedy
1. White or dark areas as results of pressure on emulsion.	Pressure Marks	Handle film carefully; avoid bending when placing in cassette. Do not place heavy objects on exposure holder.
2. Usually dark areas on film of shadow pattern.	Exposure to light	Light leaks in corners of exposure holders. Test film by developing without exposure to X-rays.
3. Black, sharp chicken-track type pattern.	Static Patterns; The result of rapid removal of film from paper cover of film box.	Handle film properly.
4. Mottled effect over complete area on film.	Paper pattern	Remove paper from film when exposing with screens.
5. Spots on Radiograph	Moisture on screen; fixer comes in contact with film prior to development process	Do not allow film to remain in lead screen exposure holders overnight in humid atmosphere; exercise care of film around processing chemicals.
6. Processing streaks	Chemicals not adequately removed from hanger clips; film placed in water without being placed in stop bath; insufficient agitation during development	Follow proper processing procedures
7. Film Scratches	Abrasive material, fingernails and rough handling during loading or unloading	Use care when handling film
8. Crimp Marks	Bending the film abruptly, when loading or unloading in holder; could be from positioning films in tight areas	Use care when handling film

Table 6-19. Description of Film Artifacts - Continued

Condition	Cause	Remedy
9. Screen Marks	Blemishes on lead screens may become intensified and can create significant indications on film; Dirt on fluorescent screens interferes with light transmission.	Screens should be inspected to ensure they are absolutely clean, smooth and free of any imperfections or foreign matter.
10. Delay Streaks	Delay in feeding successive film may result in chemicals drying on automatic processor rollers.	Clean exposed rollers with damp cloth.
11. Developer Scum	Surface on top of developer tank clings to surface of film	Mix solutions thoroughly before processing film
12. White dots on film	Unclean screens	Clean lead screens with steel wool and soap periodically
13. Fuzzy image	Lack of screen contact with film	Ensure screen and film are in full contact with each other.
14. Grainy image	Could be grain pattern of some high temperature alloys	Certain high temperatures are associated with grain patterns at voltage range of 150 to 250 kVp. This condition is eliminated at higher voltages
15. Surface of film is discolored when viewed by reflected light	Dichroic (chemical) fog.	Change developer and short-stop since this condition is usually the result of exhausted solutions.
16. Spots on illuminator appear as dark areas on radiograph.	Dirt on the illuminator	Wipe illuminators periodically with damp cloth
17. Unexplained shadowed area on film	Non-uniform light pattern from illuminator.	Change lamps to correct filament pattern or select fluorescent lamps to match in light response.
18. Foggy film	Use of film beyond expiration or inadvertent exposure to radiation	Protect films from radiation by lead-lined film chest. Use film before expiration. If questionable, check film by processing before exposure.
19. Unexplained pattern of hinges	Back scatter pattern of cassettes.	Back up cassette with lead blocking to prevent scatter from cassette or other surfaces.
20. Puckered or net-like linkages	Reticulation, Film processed through extreme temperature changes.	Maintain all processing solutions and was water at approximately same temperature.
21. Blisters	Reaction between alkaline developer and acid fixing bath	Maintain correct solutions by following manufacturer's directions.
22. White blotches on film	Water on screens	Dry screens. Do not use for 24 hours
23. Water sports	Results of splashing water on films after they are dried	Handle film in dry area of darkroom. Completely remove from processing section. Do not remove film from hangers until dry under clips.

6.4.17 Special Radiographic Techniques.

6.4.17.1 Introduction. The previous sections of this chapter have primarily been concerned with conventional film radiography. While film radiography offers a versatile tool for the detection and identification of material discontinuities, there are a variety of special radiographic techniques that MAY be employed to extend the capabilities of conventional radiography. Special radiographic techniques are placed into two broad categories.

6.4.17.1.1 Special Purpose Techniques. This category relates to radiographic techniques which require the capabilities of an inspection method to extend beyond normal parameters for a specific objective. This category includes such techniques as "multi-thickness," "multiple film," "triangulation," "thickness measurement," "stereo (three-dimensional)," and "geometric magnification."

6.4.17.1.2 Special Imaging Methods. This second category relates to special methods, such as: "radioscopy," "image intensifiers," "X-ray vidicon," "stereo radioscopy," "photo-radiography," "Polaroid radiography," "photothermographic film," "computed tomography (CT)," and "neutron radiography." Special radiographic methods not included in authorized inspection manuals, SHALL NOT be used without written approval of the appropriate depot engineering activity.

6.4.17.2 Special Purpose Techniques.

6.4.17.2.1 Multi Thickness Techniques. Many situations require radiography of parts with varying thicknesses, and sometimes these may be made of two or more materials. If concentration on one area with a nearly constant thickness is all that is required, optimization of image density is straightforward. However, it may be necessary to obtain an acceptable exposure for two or more varying thicknesses using the same radiographic image. For example, small thickness variations of 0.8 to 0.6 inches can lead to large variations in density ranging from 1.2 to 1.7 respectively. The goal is to ensure all areas of interest have densities not so low as to lose film contrast, and not so high they cannot be evaluated. An acceptable range of densities is 1.0 to 3.5. The procedure recommended during technique development is to identify the thickest area of interest, and then, from exposure charts and trial-and-error, determine the exposure and kilovoltage that provides a density of 1.0. A trial exposure will then show the density of the image of the thinnest area of interest. There are three possible courses of action an inspector can take:

6.4.17.2.1.1 If the density of the thinnest section of the image is approximately 3.5, and the image can be satisfactorily interpreted, the technique is optimized.

6.4.17.2.1.2 If this density is too low, the exposure SHOULD be increased to raise the average density of thick and thin areas.

6.4.17.2.1.3 If the density of the thinnest section is too high, the range of thicknesses is too great for satisfactory imaging. One possible solution is to raise the kilovoltage substantially, as this reduces contrast of thin areas. A better (and more common) solution is to load the cassette with two films of different speed and expose them simultaneously. This technique is commonly known as "multi-film or double-loading." In the latter case, care is required to ensure that an acceptable image density is obtained for all areas of interest.

6.4.17.2.2 Multiple Film Techniques. Multiple film techniques (commonly known as double-loading) permit the inspection of parts with multiple thicknesses using a single radiographic exposure. Since a major expense associated with radiographic inspection can be attributed to setup, it may be desirable to expose a multi-thickness component in a single exposure, rather than set up an exposure for each cross section of the component. Using multiple film techniques allow this to be achieved.

6.4.17.2.2.1 An example of this technique is to load a cassette with both a Class 1 and a Class 3 film to provide wide latitude. The faster Class 3 film provides a readable density film for the thicker sections of the component, while the slower Class 1 film provides the appropriate film density for the thinner sections of the component. Thus, in a single radiographic exposure, two images with varying density will be generated covering the required latitude for the inspection of a multi-thickness component.

6.4.17.2.2.1.1 If a part has even more complexities than what was described in the previous paragraph, it is possible to use three classes of films and cover even wider latitudes.

6.4.17.2.2.2 Technique Parameters. Several parameters must be considered when choosing a multiple film technique. In addition to the exposure parameters always of concern in radiographic inspection, the radiographer must be concerned with the choice of film to be used and the combination of these films with various screens.

6.4.17.2.2.2.1 Film Choice. The film combination selected is based on the range of thicknesses that must be covered in a single exposure. The simplest multiple film techniques employ two different films, such as a Class 1 and a Class 2 film, to cover the range of densities for the inspection of an object. An exposure must then determine which best provides the combination of contrast and sensitivity in the two films.

6.4.17.2.2.2.2 Film Positioning. When film is double-loaded, realize the film nearest the X-ray source acts as an absorber and the film furthest from the source will receive less exposure. This absorption effect is of considerable magnitude at low kilovoltages and decreases with increased radiation energies. The choice of film position will affect the range of material thickness that can be visualized in a single exposure. Typically, the slowest film is placed nearest to the source, while the faster film would be placed farthest from the source. Pre-packaged double-loaded film will normally be marked “source-side” by the manufacturer to make positioning easier. Once a technique has been established, care SHALL be taken to assure the same film is always placed in the same position for the exposure. If the positions of the films are inadvertently switched, the resulting densities in the final images will be different than expected.

6.4.17.2.2.2.3 Multiple Film Techniques with Lead Screens. Lead screens have a definite effect on the quality of a radiographic image. Lead screens are very dense, and preferentially absorb the lower energy scattered radiation. This reduces the fog on the final image and allows a higher contrast, higher quality image. Also, at energies above 125 kVp, lead screens provide a definite intensification. This intensification is due to the efficient conversion of X-ray photons into electrons in lead foils. These electrons in turn expose the X-ray film and thus provide intensification in the final image. These properties of lead screens MAY be useful in developing a multiple film technique.

6.4.17.2.2.2.3.1 As discussed earlier, combinations of films can be used for radiography of multi-thickness materials, but the optimum image quality MAY NOT be achieved. Therefore, the use of lead screens MAY be introduced to help regulate the relative speeds of the films used. As an example, assume the combination of a Class 1 and a Class 2 film could not provide the required latitude for a given component. Lead screens can be used to increase the latitude of the total exposure.

6.4.17.2.2.2.3.2 Most lead screens consist of thin lead foils backed on one side by cardboard, rubber, or vinyl. With this configuration, lead screens have a filtration effect on the films beneath them and an intensification effect on films facing the foil-coated side. If a combination of a Class 1 and a Class 2 film is used and insufficient latitude is provided, the latitude MAY be increased by placing the faster Class 2 film nearest the source with a backed 0.005-inch lead screen between the two films with the lead screen in contact with the Class 2 film. This increases the latitude through two effects. First, the lead foil intensifies the near Class 2 film, and second, the lead acts as a filter, slowing the response of the Class 1 film. Thus, over all the latitude of the exposure is increased.

6.4.17.2.2.2.3.3 On the other hand, if the latitude was excessive with the two films using no screens, the opposite effect can be achieved by placing the slower film nearest the source and the faster film farthest the source, with lead screens in between facing the slower film. This combination speeds up the slower film by intensification and slows down the faster film by filtration. Thus, the total latitude is reduced.

6.4.17.2.2.2.3.4 When only a slight increase in latitude is required, two sheets of the same film class may be employed, and lead screens MAY be used as described above to achieve a relative speed difference between the two films.

6.4.17.2.2.2.3.5 There is no end to the combinations that may be employed in multiple film radiography. Using the principles outlined above, any capable radiographer SHOULD be able to accommodate a wide variety of complex components with a multiple film exposure. Experience provides the required proficiency.

6.4.17.2.3 Triangulation Technique. In some cases, it is desirable to know the location of a given discontinuity relative to one of the plane surfaces of the object. If repairs are to be made, it is desirable to know from which surface the repair SHOULD be started. A single radiograph MAY NOT reveal this information. This information can be obtained by making a double exposure with suitable markers placed on the object. These markers are placed on both the source side and on the film side. Either two exposures can be made on one film where discontinuity is very prominent; or two separate films can be used and later be superimposed. These radiographs can be used for measurement purposes to obtain the desired information (Figure 6-44).

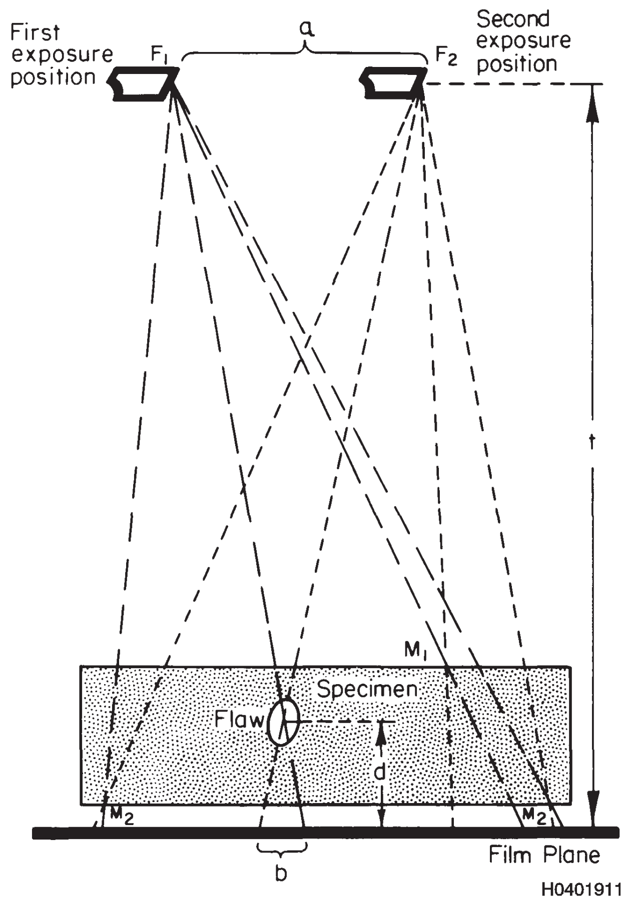

Figure 6-44. Triangulation Technique Used to Determine Flaw Depth in an Object

6.4.17.2.3.1 In this technique, small lead markers, usually in the form of triangles, are attached to the two surfaces of the object, one set of three or four markers on the source side and one set on the film side. If two separate exposures are to be made, each film SHALL be carefully aligned with the object so both films occupy the same position. After the markers are positioned, one exposure is made with the normal source, object, and film position. A second exposure is made with all conditions the same between the object and film with the exception that the source is shifted 10° to 45° from the initial position. The greater this shift, the greater the accuracy of determining the position of a given discontinuity from one of the object's surfaces.

6.4.17.2.3.2 If the discontinuity is sufficiently prominent, both exposures MAY be made on the same film. In either case, the distance of the discontinuity above the film is given by the following expression:

$$d = \frac{bt}{a + b}$$

H0401912

Where:

d = distance of discontinuity above film plane

a = distance of the source shift

b = change in position of discontinuity image on radiographs

t = source film distance

6.4.17.2.3.3 It is good to know which of the two surfaces of the object is nearest to the discontinuity. In this case, the shift of the discontinuity and marker images is measured. If the shift of the discontinuity image is less than one-half the shift of the markers on the source side of the object, then the discontinuity is nearer to the film. If the shift is greater than one-half, the discontinuity is nearer the markers on the source side of the object.

6.4.17.2.4 Thickness Measurement. Sometimes it is impossible to determine the thickness of an object using conventional mechanical measurement techniques. In these instances, a special radiographic technique for the measurement of material thickness MAY be employed. Although the mathematical development of a relationship between film density and the thickness of an absorber is too complex for practical use, an empirical method of thickness measurement has proven useful. By exposing the object of interest and a step wedge of the same material on a single film, it is possible to obtain a good estimate of the thickness of the material section. It is imperative the composition and structure of the step wedge be the same as the material being measured if any accuracy is to be achieved. Thickness is determined by measuring the resultant film density and finding the step on the wedge is that nearest to the same density. For best results, the section of interest and the step wedge SHOULD be placed as close to one another as possible to avoid variations in the uniformity of the radiation beam. This technique MAY also be employed to measure void dimensions (parallel to the beam direction).

6.4.17.2.5 Stereo (Three Dimensional). Normally, objects appear in their true perspective and correct spatial relationship because of a property of the eyes, called stereoscopic vision. That is, each eye receives a slightly different view and the two images are combined by interpretation to give the impression of three-dimensions. A single radiographic image does not possess this perspective; therefore it does not give the impression of depth. However, some estimate of depth can be judged from detail observed by an experienced radiographer. The mechanics of stereoradiography are relatively simple. Two radiographs are made from two positions of the X-ray tube. These positions can be thought of as the “left eye” and the “right eye.” As a matter of fact, the two positions represent the distance between the eyes. A so-called stereoscope is used to view the images (Figure 6-45). Each eye sees only one image but the brain blends these two images into one.

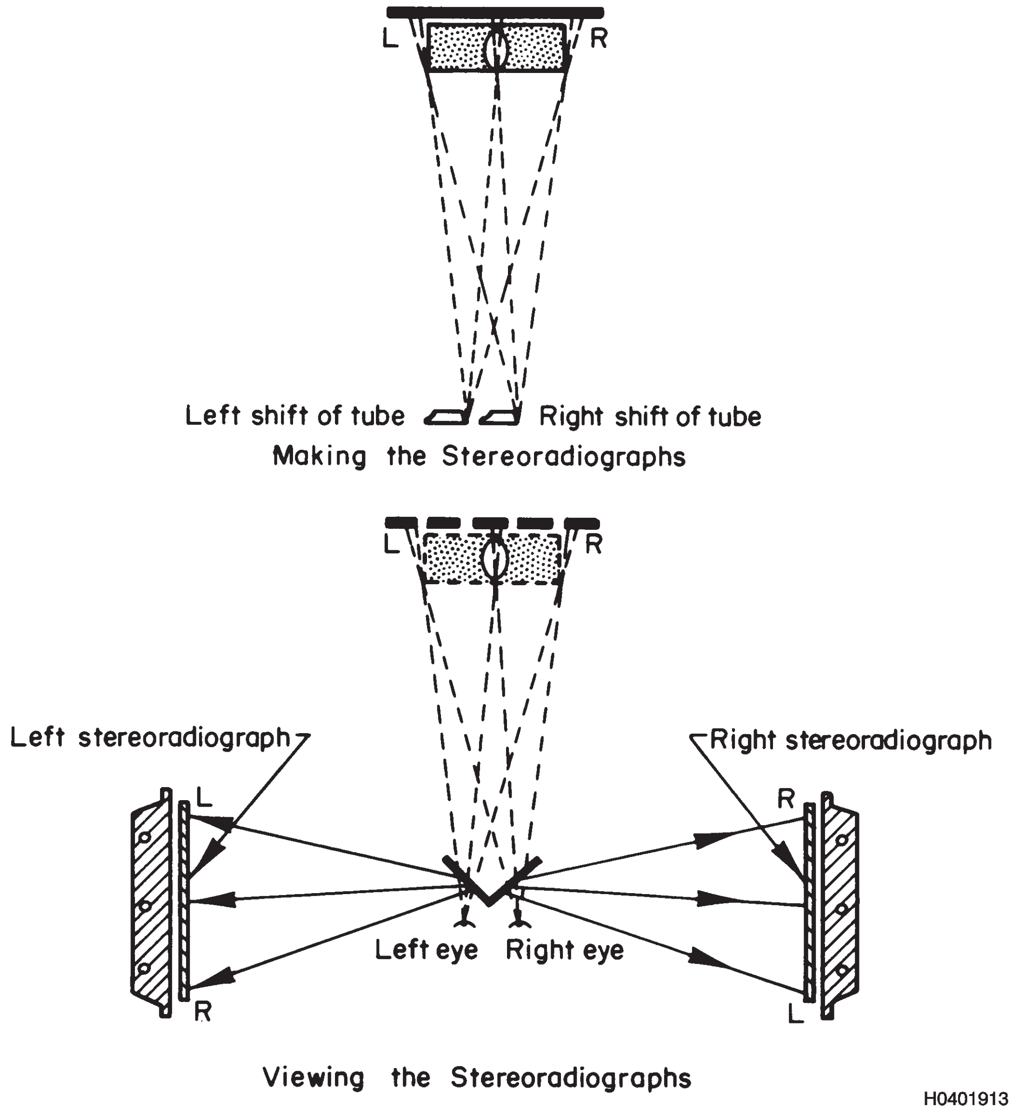

Figure 6-45. Sketch Showing Procedure for Making and Viewing Stereo Radiographs

6.4.17.2.5.1 Remember the radiographic image produced does not define the surfaces of the object as in a photo or by direct vision. This is because no radiation is reflected from the surface as under normal optical means. Therefore, in order to obtain apparent depth, it is usually necessary to define the surfaces of an industrial object by means of an X-ray attenuating marker such as a very coarse, high-absorption mesh or grid. These grids can be easily constructed by using 1/16-inch solid lead solder. Such grids, especially on objects with plane surfaces, SHOULD be placed on both the source and the film side.

6.4.17.2.5.2 It is important when taking the radiographs for the distance of shift of the source to be approximately one-tenth the focal film distance. Also, in viewing the resultant radiographs, each film must be positioned so as to duplicate the exact conditions of exposure. That is, the eyes of the viewer SHOULD be in the same relative position as the focal spot of the X-ray tube or source. This positioning is facilitated by placing a different lead marker on each of the two films. The eyes will then see a true representation of the part just as the X-ray tube saw the actual part.

6.4.17.2.5.3 Stereoradioscopic methods can also be used to present stereo images when using realtime radiography.

6.4.17.2.6 Geometric Magnification. For some applications, it is desirable to magnify the radiographic image. This can be done optically after the radiograph has been taken, or it can be done during the radiographic process by using geometric magnification. This is particularly effective when X-ray sources with small focal spots are used (e.g., the mini-focus and micro-focus sources) as described in (paragraph 6.3.3.2.3). Geometric enlargement can be realized by moving the radiographic object away from the detector, toward the radiation source. Moving their inspection object halfway between the X-ray source and detector produces a magnification factor of two. If the object is closer to the X-ray source (say 1/10th of the source-detector distance) then the magnification is ten times. Useful radiographic images have been produced with small micro-focus sources with geometric magnifications of 10X or more. Although this discussion has covered geometric magnification using only a film detector, this special method can be used with any imaging detector, including radioscopic detectors. Recognize as magnification increases the inspected volume of the object decreases. Therefore, more radiographic views MAY be needed for a complete inspection.

6.4.17.3 Special Imaging Methods. Conventional film radiography has its own capabilities and its own limitations. The capabilities of film radiography have been covered thoroughly in the previous sections. Consider some of the limitations of film radiography. Film takes a long time to process, and the results of the inspection cannot be known until the film is processed. Therefore, in some situations, a need exists to provide a more rapid means of imaging. There are many alternatives to the use of conventional film for recording radiographic images. These include the use of “radioscopy,” “image intensifiers,” “X-ray vidicon,” “stereo radioscopy,” “photo-radiography,” “Polaroid radiography,” “photothermographic film,” “computed tomography,” “neutron radiography,” and computed “digital” radiography. The following paragraphs discuss the advantages and capabilities of these imaging systems. Most provide for more rapid imaging than is available using conventional film radiography. However, each of these methods also has its own limitations. Special imaging methods not included in authorized inspection manuals SHALL NOT be used without written approval of the appropriate depot engineering authority.

6.4.17.3.1 Radioscopy. The oldest non-film imaging method involves the use of fluorescent screens to produce a visible image. These phosphor screens fluoresce (emit visible light) in proportion to the amount of radiation striking them. Thus, an instantaneous visible image is produced, and the results may be instantly read using a now outdated method called fluoroscopy. Modern, prompt-view, or real-time radioscopic systems make use of closed-circuit television systems to bring these images out to a safe viewing location, where a bright television image can be viewed. Radioscopy is defined in ASTM standards as “the electronic production of a radiological image that follows very closely the changes with time of the object being imaged.”

6.4.17.3.2 Fluorescent Screens. The light-emitting fluorescent screen can be viewed directly to see the prompt X-ray image. However, this method is rarely used now because closed-circuit television methods can provide a safer, more efficient environment to view the low-light level signal from the fluorescent screen. The fluorescent screen light signal can be detected by sensitive television cameras, such as the image orthicon. In some systems, the weak light signal from the fluorescent screen is amplified by using a light-image intensifier tube between the fluorescent screen and the television camera.

6.4.17.3.3 Image Intensifiers. Image intensifiers are specially designed, evacuated electronic tubes, which intensify the image on fluorescent screens with very fine grains. The input signal, fine grain screens used in image intensifiers, do not produce sufficient light to be viewed and employed for direct fluoroscopy. Therefore, an image intensification system is employed as shown in (Figure 6-46). The fluorescent screen is backed by a photo-emissive layer that produces electrons in proportion to the number of visible light photons emitted by the fluorescent screen. A series of focusing and accelerating electrodes propel these electrons toward a second and much smaller fluorescent screen, which has very high detail resolution. This screen is typically viewed by a light-sensitive vidicon or other television camera and displayed on a television monitor. The image intensifier provides the immediate imaging capability of the fluorescent screen while providing higher brightness and detail resolution in a safe area remote from the radiation. However, resolution is still less than obtained with Class 4 radiographic films. There is also no permanent record provided unless a photograph or video tape is made. The X-ray image intensifier is widely used as part of a radioscopic X-ray inspection system.

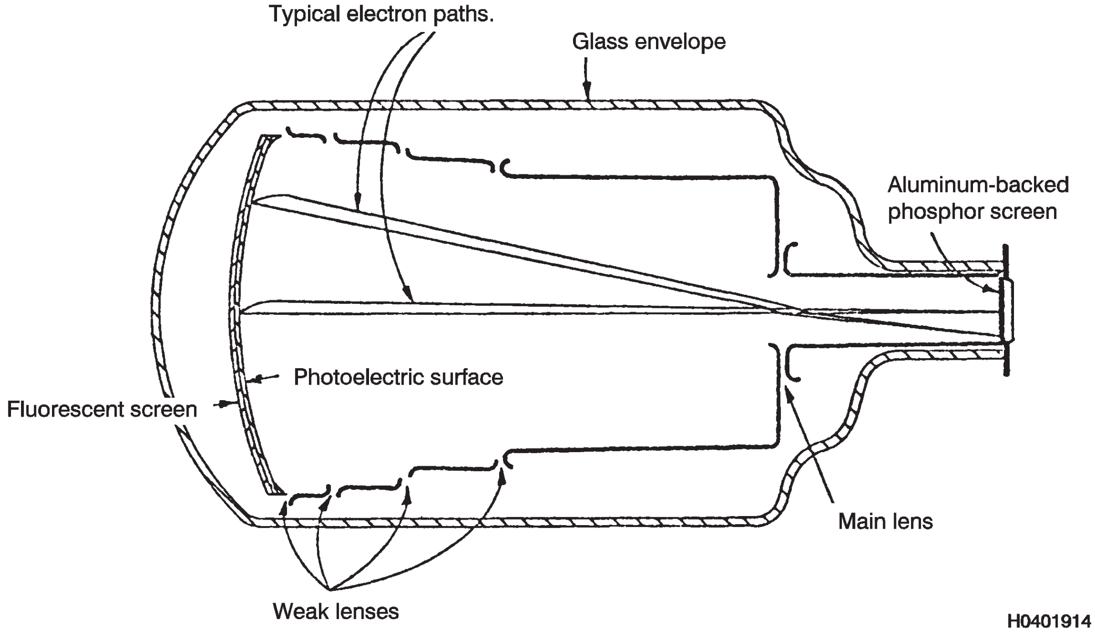

Figure 6-46. Typical Image Intensifier Tube

6.4.17.3.4 X-ray Vidicon. The X-ray vidicon system consists of a specially designed television camera directly sensitive to X-rays. It has a specially coated face capable of imaging X-radiation, because its electrical resistance changes with radiation, a phenomenon called photoconductivity. This small area coating provides very fine resolution. The results of this type of inspection are displayed on a television monitor. The sensitive area of the television vidicon tube is generally very small, on the order of 3/8 by l/2-inch. When this small area is viewed on a 17-inch television monitor, a magnification of 30 times results, thus, very high detail resolution is accomplished. These systems are used primarily for the inspection of very fine detail, such as in the inspection of microelectronic circuits. This system is capable of resolving wires as small as 0.001 inch in diameter.

6.4.17.3.5 Stereoradioscopy. Stereo imaging can be done in real-time, using microfocus X-ray sources, geometric magnification, and radioscopic systems. The stereo pair images can be obtained using only minimal movement of the microfocus X-ray source when geometric magnification is used. This stereo pair imaging can be done by magnetic movement of the X-ray tube electron beam. The two stereo views, obtained at TV field rates (1/60 second), can be combined electronically into a stereo pair image for 30-frames/second viewing. An observer, wearing special polarizing glass and looking at the television stereo image through a 1/60 second changing polarizing filter, will see a stereo, radioscopic image.

6.4.17.3.6 Photoradiography. Photo radiography is a combination of radioscopy and photography. In this method, the image of a fluoroscopic or image intensifier output screen is photographed by a conventional camera on small or miniature-type film rather than by direct contact. This method has the advantage over fluoroscopy in the film has the property to integrate and react to the total light emitted by the screen during the time of exposure, whereas the integration time of the eye is relatively short. Furthermore, the resultant film can be viewed with transmitted light and the photographic process can be used to enhance the contrast of the fluorescent image. This method has been used to limited extent for the examination of propellant grains, die and precision castings, and similar parts and assemblies when a large number of parts of the same configuration and size are inspected. Airframes have been inspected for component shift and material changes by using photoradiography. The system has limitations since all fluorescent screens commonly used are grainy. In addition, there is loss of definition through the lens of the camera. The main advantage of the system is that it is less expensive because of the use of smaller sized film. The image can be enlarged for viewing by a magnifying system or by projection. In general, this system permits radiographic sensitivity of about four to five-percent. The photoradiography accessory is available as an assembly and usually consists of a light-tight hood, a fluorescent screen or image intensifier assembly, and the camera. Various type cameras are available, some, of which employ sheet film and others using 70-mm roll film.

6.4.17.3.7 Polaroid Radiograph. If a convenient, permanent image is needed and the time required for conventional film radiography is prohibitive, an alternate MAY be radiography with other film. An example of this is Polaroid radiography. Just as Polaroid photography facilitates very rapid development of photographic images, there are available Polaroid X-ray films which provide the same advantages. These require the special Polaroid film holders and a film processor if the larger sizes are used. In some cases the typical Polaroid 4 by 5-inch adapter can be used. Polaroid radiographic films are used just as regular films are used in conventional film radiography. They have their own characteristic curves and an appropriate exposure technique SHOULD be used. However, after the exposure has been made, rather than process the films by conventional techniques, they are dry developed as a Polaroid photograph, and results are available after about one minute. Currently, available Polaroid films provide for either viewing by reflected or transmitted light. Polaroid radiographs provide nearly instant interpretation and a permanent image. However, Polaroid radiographs are low in contrast and detail resolution compared to conventional film. Polaroid radiographs can be made to establish the geometrical alignment of the X-ray beam with the part before a typical film radiograph is exposed. This technique is useful in those cases where critical alignment is required.

6.4.17.3.8 Photothermographic Film. The photothermographic process uses a special “dry silver” film which is heat processed, eliminating the need for chemical processing. The film is sensitive to visible green light. Therefore, to produce the image, phosphor intensifying screens are placed in intimate contact with the film. When struck by X-rays, the screens fluoresce, forming an image on the film. Because film itself is insensitive to X-rays, care SHALL be taken to assure the coated side of the film is in direct contact with the coated side of the screen during the exposure. Since this film is dependent upon the screens for forming the latent image, only screens approved by the film’s manufacturer SHALL be used. To aid in maintaining the necessary contact, vacuum cassettes SHALL be used for holding the film and screens, unless an approved procedure states otherwise. Photothermographic film is less sensitive than Class 4 films; therefore, it is not suitable for most critical applications and SHALL NOT be used for critical crack detection. Photothermographic film is processed by exposing the film to heat in a special thermal processor. The heat causes the latent image in the silver halide grains to form in the reducible silver salts. This process is very fast; typically requiring 20-seconds to process a 14 by 17-inch film. During this process the radiograph is also stabilized, requiring no additional processing. The image produced SHOULD remain stable for years under normal storage conditions. However, exposure of the film to bright light for several days could cause some discoloration of the white background.

6.4.17.3.9 Computed Tomography (CT). Computed Tomography (CT) is a radiation inspection method that can provide quantitative density and geometric images of thin cross sections of an inspection object. The method, adapted for nondestructive testing after extensive use in medical radiology, employs a computer to reconstruct an image of a cross-sectional plane through the object. CT inspection of a tree, for example, would look very much like the surface of a tree stump, showing the varying density of the winter and summer wood rings and an accurate representation of the tree growth rings. CT information is derived from a large number of observations of radiation intensity over many different viewing angles. Using CT, one can, in effect, slice open the test object, examine its internal features, perform dimensional inspections and identify any material or structural anomalies that may exist. As compared to conventional radiography, a major advantage of CT inspection is internal structures are not hidden or shadowed by other structures that might be in the beam path. Also CT inspection can provide quantitative information about density variations and spatial locations within the inspected material. An obvious disadvantage is that currently used CT image reconstruction methods require full access to the inspected part; full 180-degrees of data must be collected by the scanner. Also, the inspection object must be small enough to fit in the CT handling and scanning system. Systems large enough to handle missiles up to 9-feet in diameter are in use.

6.4.17.3.10 Neutron Radiography.

6.4.17.3.10.1 Description. Neutrons are useful for radiography because the attenuation of thermal neutrons is very different from that of X-rays. In general terms, the attenuation pattern is reversed, as many light materials (e.g., hydrogen, lithium, boron) have high attenuation of thermal neutrons while many heavy materials (e.g., bismuth, lead) are relatively transparent. Therefore, in this sense, neutron radiography can serve as a complementary inspection technique to X radiography. The advantages of thermal neutron radiography include excellent sensitivity to materials containing low atomic number elements (particularly hydrogen, lithium, and boron), some additional high attenuation materials (examples include silver, cadmium, indium, and gold), and rare earth elements (particularly samarium, gadolinium, and dysprosium).

6.4.17.3.10.2 Applications. Sensitivity to low atomic number materials opens up neutron inspection to a variety of applications involving water, explosives, fluids, rubber, plastics, and corrosion products (usually a hydroxide). An example of this type of inspection is neutron radiography of small explosive devices in metal cases to assure the presence of the explosives. Lead-covered explosive lines represent such an example. Inspection applications involving materials like cadmium have been demonstrated in the nuclear industry for cadmium reactor control materials. Cadmium plating inspection can also be considered. A major application involving rare earth materials is the inspection of investment-cast turbine blades to detect residual ceramic core left in cooling passages after leaching.

6.4.17.3.10.3 Disadvantages. Disadvantages of neutron radiography include the relatively high cost and additional radiation safety problems. Where high volume applications exist, for example turbine blade inspection, cost need not be a prohibitive factor. The additional radiation safety issues arise mainly from the generation of radioactivity in the inspection sample. These problems are rare and where they exist they are usually easily handled by shielding and/or short waiting-time periods for the radioactivity in the sample to decay.

6.4.18 Digital Radiographic Techniques.

6.4.18.1 Transition from Film to Filmless. Making the transition from film to filmless is a simple process, usually requiring only a few test exposures to optimize the technique. Phosphor plate systems have such a wide dynamic range that over-exposure and under-exposure situations are rare. Direct capture systems like amorphous silicon or amorphous selenium also increase the dynamic range. The time lag from exposure to seeing the result for all of these systems is so short that developing a technique is much easier and faster than with traditional film based inspection methods.

6.4.18.2 Phosphor Plate Imaging. The dynamic range of a phosphor imaging plate is approximately five times that of radiographic film. This means a single exposure using a phosphor system is similar to a triple load (or greater) film technique. The result of this phenomenon is the ability to successfully image parts with a wide range of subject contrast. Thick and thin sections, previously not viewable with film, can now be captured without multi-film or multi-exposure techniques. This also allows for more flexibility in the time/ma combination, which allows for drastic reductions in time of exposure. Some applications have dropped exposure times by as much as 95-percent, which greatly improves productivity, reduces personnel exposure to radiation, and increases X-ray tube life. Further refinements in software allow for the use of a battery operated, pulse X-ray source, rather than a traditional X-ray tube.

6.4.18.2.1 Phosphor plate imaging can be used from 20 kV up to 15 MeV with excellent results. Since the response of the phosphor is different than from film, kV can also be adjusted favorably. Typical kV reductions for X-ray are approximately 15-percent. The lower kV will increase image quality while again lowering personnel exposure and increase tube life.

6.4.18.2.2 The sensitivity of the phosphor plate leads to another effect. Since the phosphor can produce an image with less radiation, the radiographer now has the flexibility to choose an X-ray tube with a smaller focal spot, which again increases definition and sharpness. Micro-focus X-ray tubes are smaller, lighter, and easier to handle making radiography simpler and safer.

6.4.18.2.3 As in all X-ray systems, image quality is affected by signal-to-noise ratio. This means longer exposure times will increase image quality. Lower exposure times can be used when inspecting for foreign objects, water, core damage, and foam adhesion. This is due to the relatively low image requirements of these inspections. The contrast sensitivity of the phosphor systems makes water intrusion detection better than with film. For crack detection, longer exposure times will be required, but will still be less than for film. Fatigue cracks and stress-corrosion cracks can be imaged using phosphor plate systems, however, evaluations are still being conducted to determine the size detection capabilities of these systems. All of these applications still require the use of a procedure to standardize the inspections and to assure reliable results.

6.4.18.3 Phosphor Plate Handling. Another drastic change from a film system to a phosphor system is the handling of the phosphor media. The plates are flexible and can be used in a conventional film cassette. They are positioned and exposed in a similar fashion to film. With proper handling and care, the plates are capable of many thousands of re-use before replacement.

6.4.18.4 Direct Capture Systems. Amorphous silicon and amorphous selenium systems have the capability of producing filmless images in a very short time, with no mechanical moving parts. The image acquisition time is usually fixed at 5 to 10-seconds, leaving the dose to be controlled by adjusting the ma. The optimum kV will be 5 to 10-percent less than film.

6.4.18.4.1 These systems are excellent choices for factory and laboratory environments where handling of the panel is kept to a minimum in an X-ray cabinet or vault. Positioning these devices on aircraft is difficult and cumbersome. The risk of damage to the panel is high, making these devices impractical for field use. Exposure to temperature and humidity extremes further deters their use on the flight line. Portable versions of these devices have been used on aircraft, but their small field of view and low resolution make them unreliable for crack detection.