SECTION V INTERPRETATION OF RADIOGRAPHIC INSPECTION

6.5 RADIOGRAPHIC INTERPRETATION.

6.5.1 General. The recording of an X-ray image pattern on a film is called radiography. This film, when processed, is called a radiograph. Its interpretation is called radiographic inspection. To obtain the greatest value from this procedure, characteristics of the radiograph must be understood and properly applied. It is possible to make erroneous deductions based on radiography that could result in improper disposition of the material. It is the duty of the radiographer to continually guard against this possibility. The interpretation and correlation of this information is affected by a number of characteristics in the process that ultimately are reflected in the radiograph. The characteristics of the radiograph are reviewed and discussed in the following paragraphs.

6.5.2 Radiographic Image Quality. Radiographic interpretation cannot be performed without knowledge of the image quality. Knowledge of the image quality tells the film reader the minimum size of discontinuities they can expect to visualize.

6.5.3 Sensitivity. Radiographic sensitivity is defined as the differential in thickness, in terms of percentage of total thickness recorded by radiography. This sensitivity is a result of X-ray image contrast, film contrast, image sharpness, image distortion, and image density obtained in the radiograph. In normal radiographic practice no attempt is made to record the ultimate radiographic sensitivity in each radiograph. However, it is required that a certain quality of radiography be attained to assure satisfactory inspection. To assure this quality of inspection by radiography, penetrameters (image quality indicators) are used. The application of penetrameters is discussed in an earlier section.

6.5.3.1 Examination of the penetrameter image on the radiograph will indicate the sensitivity. Correct radiographic procedure will show the image details of the penetrameter sharply defined. However, the penetrameter sensitivity is a gauge of a certain standard of sensitivity. It cannot actually measure the sensitivity in percent. This idea of penetrameter sensitivity has several limitations that SHOULD be kept in mind:

- The eye is limited in resolution.
- Discontinuities are detectable only in the direction of primary radiation.
- Variations in material density are not considered.
- Definition or sharpness of transition between densities is not considered.
- Actual defects are usually irregular in shape while penetrameters have a definite size and shape.

6.5.4 Definition or Detail. Definition or detail in radiography is the sharpness of the image outline reproduced on the film. The size of the focal spot, the physical condition of exposure, and the film resolution determine the definition. If a screen is used, then the screen resolution will also affect the definition. In addition to the focal spot size, the object-to-film distance is an important factor in the sharpness of shadow picture (Figure 6-47). The resolution of the film is a function of grain size.

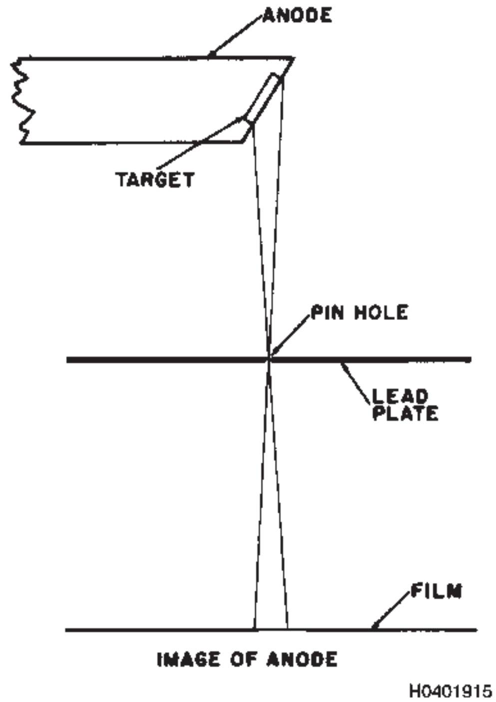

Figure 6-47. Pinhole Picture of Focal Spot

6.5.4.1 Since the radiograph is a shadow picture, the geometric interrelationship between the elements of the radiographic system is important. Ideal X-ray focal spots and radioisotope sources SHOULD be pinpoints. With such sources, we would obtain sharp images under all conditions. All our radiation sources have finite size since X-ray tube focal spots must be large enough to withstand the energy dissipated as heat to prevent melting and target destruction. The radioactive activity of an isotope is proportional to the source strength in curies, so the smaller the size, the lower the intensity.

6.5.4.1.1 To better understand geometrical relationship, (Figure 6-48) illustrates various conditions true to X-ray and light shadow formations. Diagram “A” in (Figure 6-48) shows the size of the shadow is to the size of the object as the distance of the light to the card is to the distance of the light to object. This image is a true projection. If the source has finite size, the shadows cast will not be perfect projections, but will have surrounding areas out of register, producing a gray cast of unsharpness, which is called penumbra. Diagrams “B” through “D” in (Figure 6-48) show the effect of changing source size, altering the relative position of source, object, and recording surface. From these examples, it will be seen that the following conditions are desirable to produce sharp shadow images:

- The X-ray source SHOULD be as small as possible.
- The X-ray source SHOULD be as far from the object as possible.
- The recording surface SHOULD be as close to the object as possible.

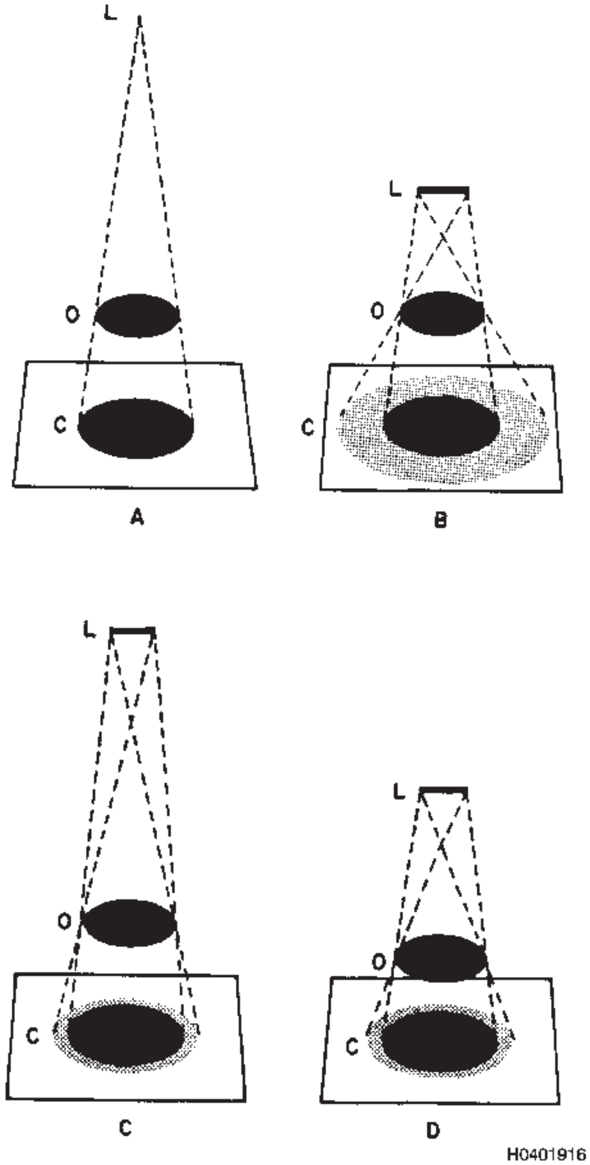

Figure 6-48. Geometrical Factors

6.5.4.1.2 There are other factors affecting detail. They include motion, screens, film, and scatter. If the source, object, or film move independently of each other or are not in phase, blurring will result. Rigid supports for all three elements must be used to prevent this blurring. Since characteristics and conditions of film, screens, and scatter are also related to film contrast and density, they will be discussed later in subsequent paragraphs.

6.5.5 Density. Radiographic density is the blackening or darkening produced on the radiograph resulting from the metallic silver deposits remaining on the film after exposure and processing. Density is measured in terms of visible light transmission. The accepted scale of density measurement is the logarithm of the ratio of incident light to transmitted light as given by the following equation: (paragraph 6.7.6.)

$$D = \log \frac{I_0}{I_t}$$

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Where:

D = density

I_o = intensity of incident light

I_t = intensity of transmitted light

6.5.5.1 Measurement of radiographic density SHALL be done with electronic direct-reading type densitometers capable of measuring the light transmitted through a radiograph with a film density up to 4.0 with a density unit resolution of 0.02 (paragraph 6.3.12.1). The electronic direct-reading type densitometer is more accurate than the visual type. The densitometer SHALL be calibrated with a reference density strip, traceable to the National Institute of Standards and Technology (NIST), prior to determining the density of a radiograph (paragraph 6.3.12.1.1). These calibrated density strips SHALL be replaced whenever they are physically damaged (e.g., scratched, crimped, or become wet by any fluid) to such an extent it might influence their effectiveness. The carbon, dot printed, etc. density strips SHALL NOT be used even though they MAY be NIST traceable. These strips are not able to correlate the densitometer directly to Air Force radiographic needs. Each type of calibrated reference density strip will calibrate the densitometer to a different standard level. The restrictive use of only the photographic or radiographic calibration reference density strip will better enable the standardization of all densitometers to a single calibration value establishing a common (H and D units) density for a given radiographic inspection. The aperture of the densitometer SHALL be black in color. If it is not, it MAY be darkened with a black magic marker or other indelible ink.

6.5.5.1.1 While performing the densitometer calibration procedure, the following SHALL apply:

a. Follow manufacturer's instructions, substituting the calibration strip supplied with the instrument with the NIST traceable radiographic calibration reference density strip.

b. The calibration reference density strip SHALL be removed from its protective cover during the calibration procedure, and maintained in its protective cover when not in use.

c. The calibration reference density strip SHALL NOT be pulled or slid when it is between the aperture and stage diffuser. The aperture SHALL be raised so it is not in contact with the density strip when the strip is being repositioned or removed from the densitometer.

d. Calibrated reference density strip measurements SHALL be determined from the center of the steps used for the calibration procedure.

6.5.5.1.2 The density of a radiograph is important. Densities less than 0.5 show very little of the object due to three factors: (1) the density of the emulsion base, (2) the basic “fog” of the film, and (3) the lack of uniform response of the film at low radiation exposures. Special illuminators are required to view radiographs with a density of 3 to 4. Radiographs with a density over 4 are extremely difficult to “read.” A density of 2 to 3 is recommended for all radiographs.

6.5.6 Contrast. Maximum contrast is achieved in radiography when the maximum X-ray image contrast is coupled with the maximum available film contrast. High-density radiographs viewed with high intensity illuminators provide the best radiographic contrast. As one of the factors that affect sensitivity, contrast SHOULD be high. Some of the general rules regarding contrast are as follows:

- Contrast increases as kVp decreases.
- Contrast increases as film development increases.
- Contrast increases as film speed decreases.
- Contrast decreases as kVp increases.
- Contrast decreases as film development decreases.
- Contrast decreases as film speed increases.

6.5.7 Fog. Fog is the darkening of radiographic emulsion caused by humidity, heat, cosmic radiation, certain chemicals, out of control development chemicals, scatter radiation, and bad development practices. It is defined as the darkening of the film emulsion by an inadvertent cause. The fog level of film brings no useful information to the film and merely creates a high background that reduces contrast and image visibility. The faster the speed of the film, the more susceptible it will be to fogging.

6.5.8 Distortion and Magnification. Some of the factors that cause distortion and magnification are discussed in other areas of this manual. However, distortion can also be caused by improper alignment of the X-ray machine and/or film in relation to the object. If distortion is so excessive areas are obscured, it may be necessary to radiograph the object at a different angle. The total distortion or magnification tolerated on a radiograph will depend upon the desired sensitivity and the geometry of the object itself.

6.5.9 Kilovoltage and Processing. Any attempt to evaluate a radiograph must take into consideration the conditions under which the radiograph was made. The effects of different kilovoltages and processing techniques cause a variation in contrast and latitude.

6.5.10 Viewing Radiographs. Viewing the radiograph is the final step in the radiographic inspection procedure. The radiographer must be aware of the various factors that can influence his decision. Some factors are density of the film, artifacts on films as a result of handling and processing, level of illumination for viewing radiographs, response of human eye to differences in light intensity, and the acuity of vision.

6.5.10.1 Viewing Conditions. Reading large numbers of radiographs is a strain on the eyes and fatiguing to the film interpreter. The environment of a film reading area SHOULD be pleasant and SHALL be free of objectionable background light, which MAY cause reflection on the radiographic film. Two and one-half foot-candles of ambient light measured at the viewer is optimum for viewing. This light level will aid the film interpreter by accommodating the eye so they are more sensitive to light. When attempting film interpretation, the radiographer SHOULD wait at least three (3) minutes before reading film, when coming into the viewing room from ordinary artificial room light. When coming from full sunlight, the interpreter SHOULD allow 5-minutes for dark adaptation before viewing. If the eyes are subject to the full brightness of the illuminator during changes of the radiographs, at least 30-seconds re-adaptation is necessary (Figure 6-49). The film reading illuminator or illuminators SHOULD transmit at least 2-foot-candles of light through the film at the viewing surface of the film. This quantity of light is sufficient to view radiographs with a density of 3-H and D units. There SHOULD also be a high intensity illuminator with a variable light intensity capable of transmitting the required light through densities in the order of 4 to 4.5-H and D units for interpreting these high densities. All film viewers SHALL be of the type that provides a uniform level of illumination over the entire viewing surface.

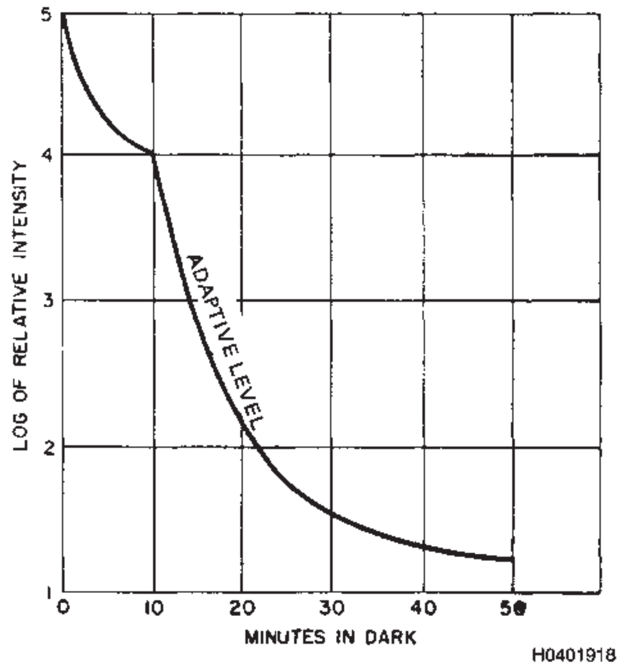

Figure 6-49. Dark Adaptation Diagram

6.5.10.2 Limitations of Eye. The eye is the evaluation medium in radiography. Visual accuracy varies considerably from one individual to another. Oddly enough, a perfect eye does not necessarily mean a perfect visual system. Certain “defects” can be present. Vision must not only record shapes and sizes, but also the variation of light intensities. In this area the eye is especially unreliable. The relative brightness of two light sources, for example, can be gauged only approximately. And even such approximate evaluation is possible only when the light sources are close to the same order of brightness. For example, a bright object or area appears brighter when viewed against a dark field. Conversely, the object will appear darker than it really is when the surrounding area is comparatively brighter.

6.5.10.3 Visual Size. In any task requiring critical examination, we are usually more conscious of size than anything else. The minimum size of an object seen under a given set of conditions is called the threshold size. This varies greatly depending on brightness-contrast between the immediate background and the detail being examined. It also varies with the level of brightness. The physical size of an object can easily be measured, but it is difficult for most individuals to interpret physical size into visual size. The type in which this is printed has a definite physical size measured in points, a point being about 1/72 of an inch. The visual size, however, depends on the distance from the page to the eye. The visual size of the letters at two feet is only one-half that obtained for a page-to-eye distance of one foot. The visual size is the angle subtended at the eye by an object at a distance. The threshold size of a critical detail (such as this black print on a white background) is about one-minute (1/60 of one degree) for persons of normal vision. An individual with sub-normal vision will be able to pick up an object of just about twice the visual size required for normal vision. The relation of a visual size of one-minute of a degree to physical size for different viewing distances is given in (Table 6-20).

Table 6-20. Visual Size Versus Physical Size

Viewing Distance (inches)	Physical Size (inches)
10	0.0029
12	0.0035
15	0.0044
20	0.0058
24	0.0070

6.5.10.3.1 For a given viewing distance the visual size is the maximum when the line of sight is perpendicular to the plane in which the object lies. Referring again to this printed page, this means a line from the eye perpendicular to the page. As the page is inclined (to decrease the angle between the line of sight and the page), the visual size of the print is decreased until at 45° the type size is only 70-percent of what it was at 90°. For a 45° angle, assuming an object of fixed physical size and fixed viewing distance, visibility equal to 90° can be had only by increasing the illumination level by 2-1/2 times. An aid in reading radiographic film is the pocket comparator with graduated reticules having linear and circular scales. They are able to measure the size of discontinuities and/or defects depicted on this film.

6.5.10.4 Visual Contrast. A certain level of contrast is desirable between small detail and its immediate surroundings. However, a high degree of contrast between those immediate surroundings and any large area outside the field in which the detail lies is unfavorable. The contrast between this print and the page is favorable, but a high contrast between the page and the desk on which it lies is detrimental to good vision. For each contrast there is a threshold size, and, conversely, for each threshold size there is a minimum contrast if the object is to be just visible. If the eye is to detect a difference as the brightness level decreases, the difference in brightness levels must be greater and greater. It is evident the eye must have considerable time to adjust to low levels of light intensity.

6.5.10.5 Speed of Sight. Sight is not instantaneous, it takes time to see. We do not see when the eyes are in motion. In reading this line, the eyes focus on a point called the point of fixation. This point of fixation is then moved along the line in a series of jumps. The eyes come to a dead stop several times, about three times usually in reading a line of this print. What we do is read a portion of the line during each fixation period. The time of one of the fixation periods varies between 0.07 and 0.3-second. Hence, these times become the limiting periods in seeing. As a visual task increases in difficulty, these fixation periods become longer. Involved, too, is the problem of reaction time, that is, the time that elapses between seeing and acting. Any task involving sight becomes a series of complex time intervals. The time for seeing is naturally greatly influenced by experience, mental reaction time, brightness level, contrast-brightness, and visual size. The rapidity with which any visual examination can be carried out is a relation between these factors and the necessary accuracy or exactness of the examination.

6.5.10.6 Illuminators/Viewers. The illuminator must provide sufficient light to transmit adequate light for the observer to distinguish areas easily. Since the human eye has greater visual acuity and contrast visualization at given levels of light, the illuminator must provide control of light levels to adjust for optimum visual response of observer. The accepted differential of density detectable by the average individual is 0.02. Thus, a 2-percent change in thickness must result in density change of 0.02 or more. The contrast sensitivity of the human eye is greatest when light reaching the eye comes from one source. Therefore radiographs SHOULD be read in areas of subdued light to avoid reflection and glare. The eye responds best if all the light reaching it is approximately the same brightness.

6.5.10.6.1 Opaque masks to suit the size of radiographs being viewed and to isolate areas of interest SHALL be used to avoid brightness around edges of film, excess light from low density areas of no interest and reduce light intensity from the illuminator when changing radiographs. This prevents the eye from continually adjusting itself to the changing light levels that cause fatigue. At normal light levels, the eye can see the differences in light brightness of 2-percent. As light reaching the eye decreases, the percentage increases.

NOTE

Radiographs having great ranges of density and complicated image patterns SHOULD be viewed on high intensity, 14 x 17 illuminators having adjustable diaphragms and variable light intensity to assure best eye response.

6.5.11 Reading (Interpreting) Radiographs. Interpretation of radiographic images cannot be translated into mathematical formulas or routine procedures. The wide variety of test objects and the various fabrication processes by which they have been made makes radiographic interpretation a complex subject. Radiographic inspection is conducted to assure a material or part has the required integrity to reliably perform the function for which it was designed. This does not mean perfection. All parts, materials, and processes are imperfect. Therefore, the purpose of radiography is to determine the degree of imperfection. The effects of discontinuities or manufacturing deviations must be correlated with the function of the part. Specifications are usually used to spell out the discontinuities that could be considered detrimental to the function of the part and the acceptable magnitudes of the discontinuities. It is the duty of the film interpreter to recognize the various discontinuities, their magnitudes, and be capable of relating them to the particular specification required. The responsibility and capability of the radiographic interpreter cannot be over emphasized. Often, many human lives and investments of millions of dollars are depending on the judgment of the radiographic interpreter. Any information that can be of assistance in making a judgment of discontinuities SHOULD be fully utilized. Interpretation of the shadow images visible in the radiograph is an acquired skill, and there is no substitute for experience. Experience aids the film reader in recognizing discontinuities and in identifying where they can be expected to occur in a particular part or structure. The mistakes in radiographic interpretation most often are a result of misreading film artifacts. There are a number of density patterns that resemble welding and casting defects that are often unjustified causes for rejects. A good check is to look at the surface of the film by reflected light to observe any unusual patterns.

6.5.11.1 The inspector reading the radiographs SHOULD be acquainted with the exposure technique used, material radiographed, conditions of processing, and the geometry of the exposure setup. In this way they can judge more accurately the radiographs produced and interpret the discontinuities more accurately. To determine if the part is rejectable or acceptable they will generally consult with the structural or design engineer unless standards have been established.

6.5.12 Typical Use of Radiography. The radiographic inspection method is expensive when compared to other nondestructive inspection methods, and SHOULD be used for evaluation of internal discontinuities that cannot be evaluated by more economical methods. Therefore surface discontinuities considered detrimental to the function of the part SHOULD be evaluated by visual inspection or other NDI methods more economical than radiography. The major use of radiography is to reveal internal discontinuities. We will now discuss some of the various ways radiography is used to locate discontinuities in castings, welds, and during in-service inspections.

6.5.13 Castings. The process of forming various shapes of metal by pouring molten metals into molds accounts for a considerable share of the critical components of an aircraft. These castings are made by melting ferrous and nonferrous alloys and casting them into useable shapes. The majority of castings encountered requiring X-ray inspections are made of light alloys; that is, aluminum and magnesium alloys. There are a number of inherent difficulties in this manufacturing technique which plague the foundry. Since the molten metal occupies a larger space than the same material after it freezes or cools, precautions SHALL be taken to prevent the metal from shrinking too rapidly and forming voids which are called shrinkage or from rupturing the metal to cause hot cracks. The molten metal also traps considerable gases from the air. These can result in tiny regular shaped bubbles in the solid metal casting. Some metals, such as aluminum, accumulate gas on the surface of the molten metal. This may be trapped in the casting if adequate precautions are not taken to prevent pouring the gas into the mold. In addition, sand can wash from the walls of the mold into the casting forming inclusions that reduce the strength of the castings.

6.5.13.1 It is necessary to control the quality of the casting process to assure reliability of the castings. Radiographic inspection is a satisfactory quality control since the conditions likely to make the casting unacceptable are readily detected by this inspection. For the purpose of inspection, airframe castings can be divided into classes based on their function and on their margins of safety for design loading conditions. These classes are defined in SAE-AMS 2175A *"Castings, Classification and Inspection Of"* and are basically as follows:

- Class 1. A casting, which the single failure of, would cause significant danger to operating personnel or would result in a significant operational penalty. In the case of missiles, aircraft, and other vehicles, this includes loss of major components, loss of control, unintentional release or inability to release armament stores, or failure of weapon installation components. Class 1 castings SHALL be further classified under Class 1A and Class 1B below.

    - Class 1A. A Class 1 casting, which the single failure of, would result in the loss of a missile, aircraft, or other vehicle. These castings receive 100-percent radiographic inspection.
    - Class 1B. Class 1 casting, which are not included in Class 1A. Radiographic inspection is accomplished in accordance with sampling Table 1 of SAE-AMS 2175A.

- Class 2. All castings not classified, as Class 1. Class 2 castings SHALL be further classified under Class 2A and Class 2B below.
    - Class 2A. Castings have a margin of safety of 200-percent or less. Radiographic inspection is accomplished in accordance with Table 11 of SAE-AMS 2175A.
    - Class 2B. Castings have a margin of safety greater than 200-percent, or for which no stress analysis is required. All target drone castings and aerospace ground support equipment fall in this category, except for such critical parts, the failure of which would make the equipment unsatisfactory and cause the vehicles which they are intended to support, to become inoperable. Radiographic inspection is not required.

6.5.13.1.1 Radiographic examination is ideally suited to the inspection of castings because the most common casting discontinuities are three-dimensional and are, therefore, almost independent of angle of inspection. Exceptions in some cases include fine cracks, cold shuts, unfused chills, and chaplets. To reveal these, the radiation must be at or near the same parallel plane as the discontinuity. Hairline surface cracks such as those produced by grinding are seldom, if ever, revealed by radiography.

6.5.13.1.2 In most cases, it is possible to identify radiographic images with the common types of discontinuities, which are inherent in the casting process. This information is valuable to the foundry in procedure development work that may be necessary to meet a standard of quality. Although the discontinuities commonly encountered in aluminum and magnesium castings are similar to those in ferrous metals, a group of irregularities called “dispersed defects” may frequently be present. These “defects,” prevalent in light alloy castings, consist of tiny voids scattered throughout part or all of a casting. Gas porosity and shrinkage porosity in aluminum alloys are examples of dispersed defects. On radiographs of sections more than one-half inch thick, it is difficult to distinguish images corresponding to the individual voids. Instead, dispersed defects may appear on film deceptively as mottling, dark streaks, or other irregularities.

6.5.13.1.3 Radiographic studies of new casting produced by the foundry reveal the type and location of internal discontinuities. This aids the foundry to change the casting technique by altering the gating, relocating chills, changing the pouring temperatures, repositioning, increasing or decreasing the risers or altering the size, correcting a faulty sand condition, or increasing the venting in the mold. After developing an acceptable casting procedure the casting can be duplicated with assurance of a quality part.

6.5.13.1.4 In general, castings are irregular in shape and can vary considerably in cross section thickness from area to area. Therefore, it is important to utilize equipment of adequate capacity to penetrate the section thickness and kind of material under consideration with a technique giving inherent wide latitude with adequate sensitivity. In some instances, even when radiographing light alloys castings, lead filter screens MAY be employed.

6.5.13.1.5 Correct radiographic procedure requires the selection of the lowest voltage that will do the job in a reasonable exposure time. Where many castings are examined, a convenient technique is to establish a reasonable exposure time and select the voltage required for the thickness of the particular section being radiographed. Good practice normally requires exposures be longer than 1-minute. When castings with great differences in thickness must be radiographed in one exposure, an increase in voltage will provide wider latitude, as well as shorter exposure time; however, contrast is reduced. If other factors remain constant, the most desirable combinations of voltage and exposure time for a specific part being examined may be governed largely by the acceptable radiographic sensitivity.

6.5.14 Casting Defects.

6.5.14.1 Shrinkage. Shrinkage is a form of discontinuity that appears as dark spots on the radiograph. Shrinkage assumes various forms but in all cases it occurs because molten metal shrinks as it solidifies, in all portions of the final casting. Shrinkage is avoided by making sure that the volume of the casting is adequately fed by risers which sacrificially retain the shrinkage. Shrinkage can be recognized in a number of characteristic by varying appearances on radiographs. There are at least four types: (1) cavity; (2) dendritic; (3) filamentary; and (4) sponge types. Some documents designate these types by numbers, without actual names, to avoid possible misunderstanding.

6.5.14.2 Cavity Shrinkage. Cavity shrinkage appears as areas with distinct jagged boundaries. It may be produced when metal solidifies between two original streams of melt coming from opposite directions to join a common front; cavity shrinkage usually occurs at a time when the melt has almost reached solidification temperature and there is no source of supplementary liquid to feed possible cavities.

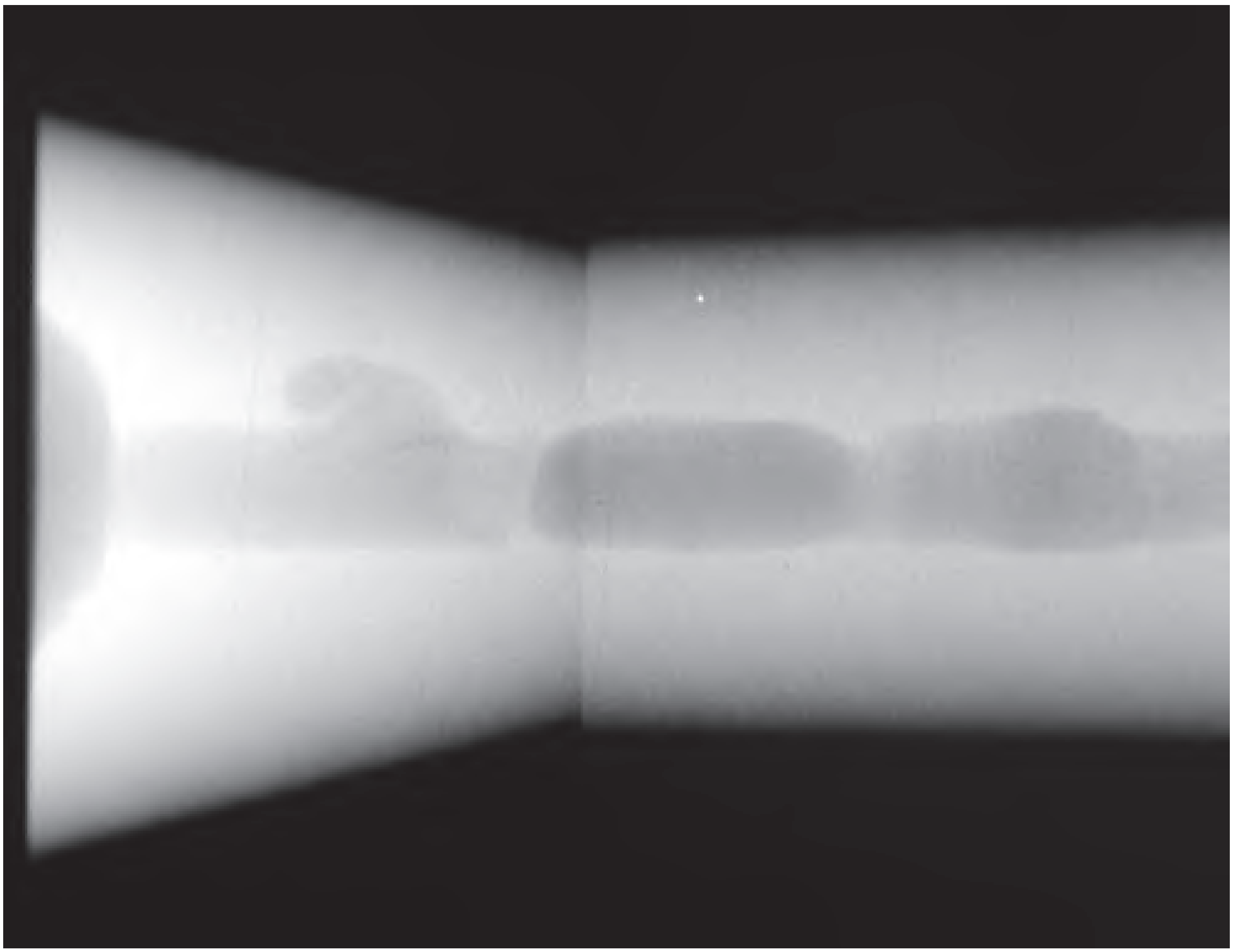

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Figure 6-50. Cavity Shrinkage

6.5.14.3 Dendritic Shrinkage. Dendritic shrinkage is a distribution of very fine lines or small elongated cavities that may vary in density and are usually unconnected.

6.5.14.4 Filamentary Shrinkage. Filamentary shrinkage usually occurs as a continuous structure of connected lines or branches of variable length, width and density, or occasionally as a network.

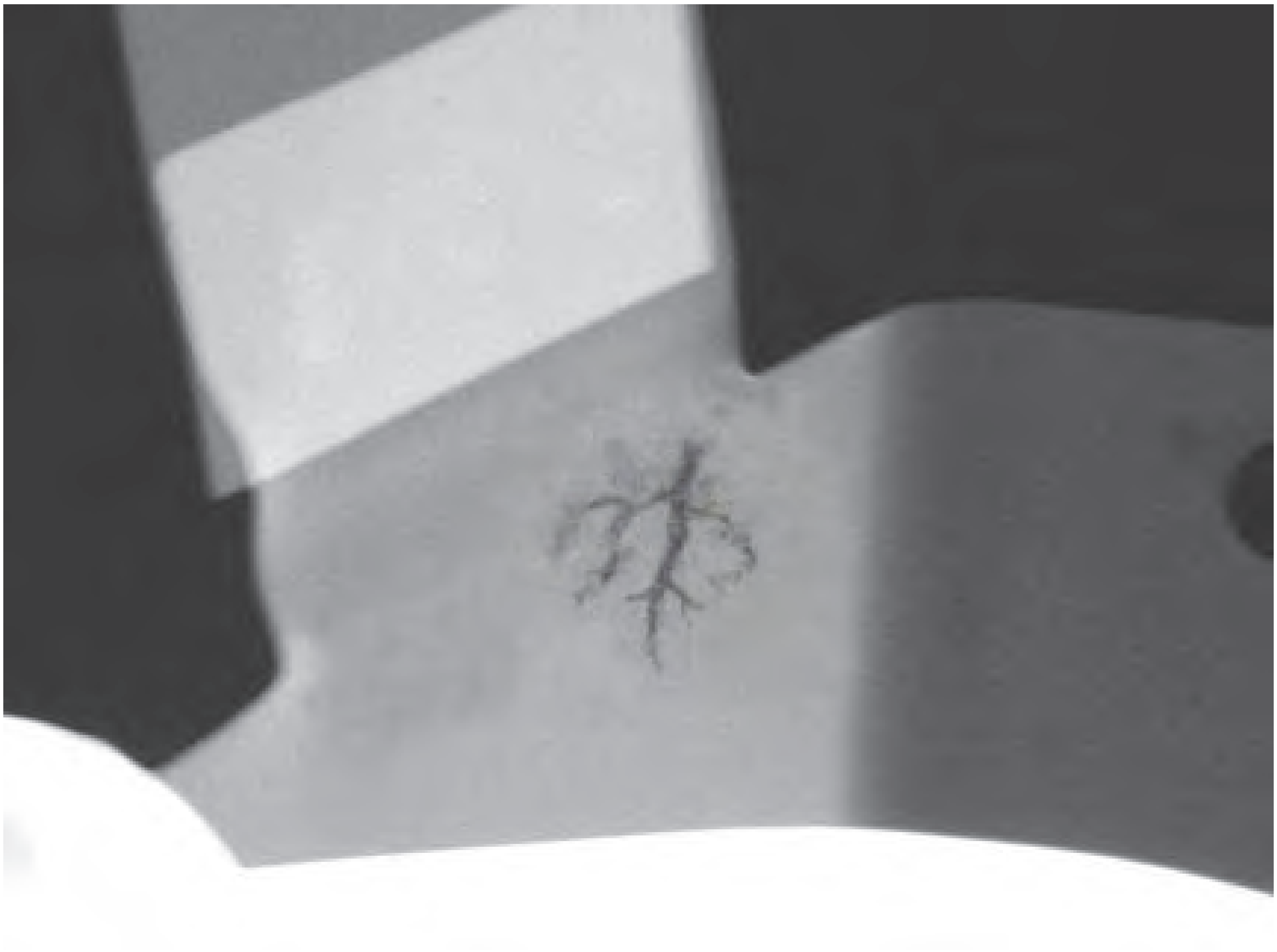

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Figure 6-51. Filamentary Shrinkage

6.5.14.5 Sponge Shrinkage. Sponge shrinkage shows itself as areas of lacy texture with diffuse outlines, generally toward the mid-thickness of heavier casting sections. Sponge shrinkage may be dendritic or filamentary shrinkage; filamentary sponge shrinkage appears more blurred because it is projected through the relatively thick coating between the discontinuities and the film surface.

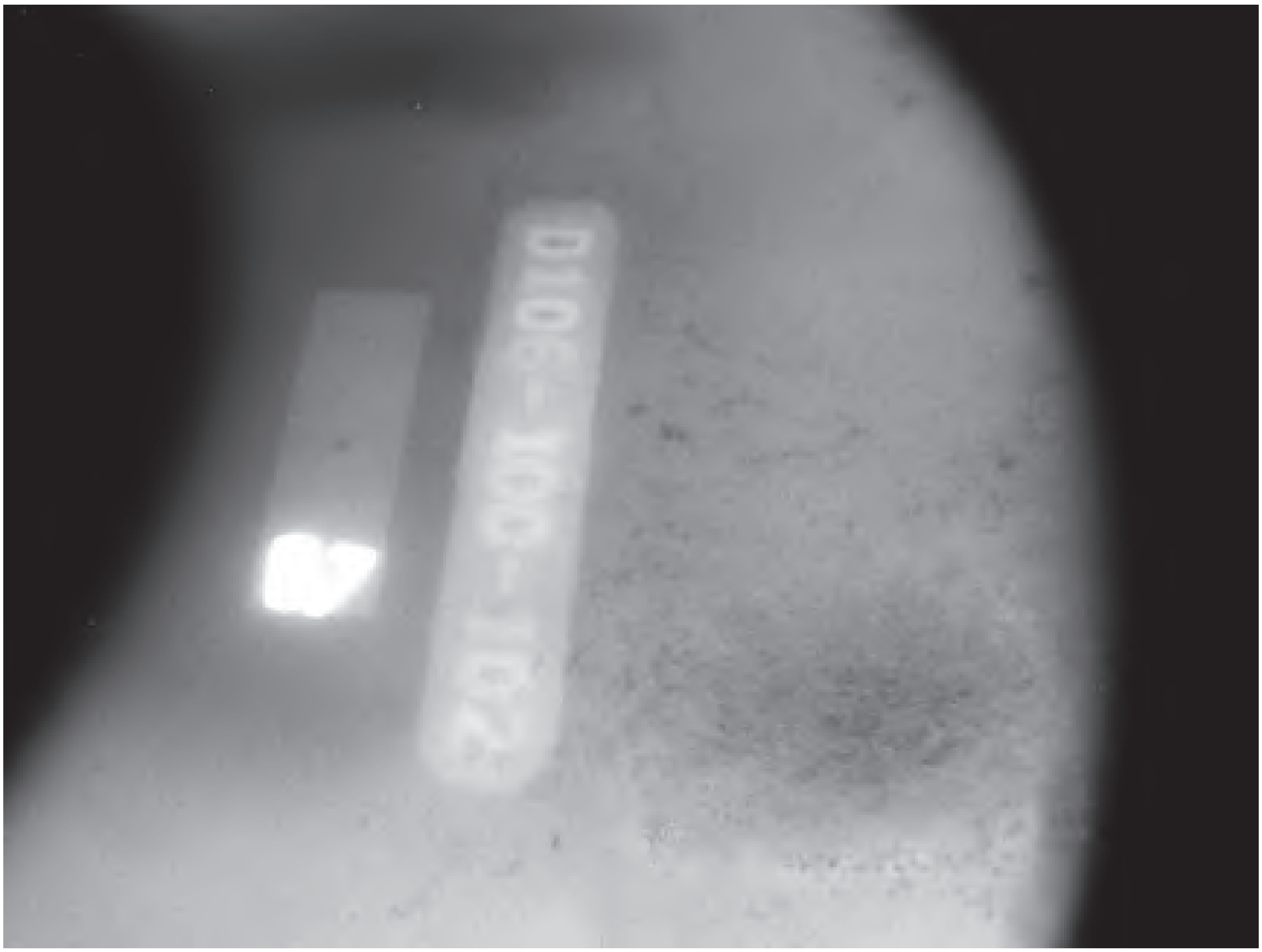

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Figure 6-52. Sponge Shrinkage

6.5.14.6 Gas Porosity or Blow Holes. Gas porosity or blow holes are caused by accumulated gas or air which is trapped by the metal. These discontinuities are usually smooth-walled rounded cavities of a spherical, elongated or flattened shape. If the sprue is not high enough to provide the necessary heat transfer needed to force the gas or air out of the mold, the gas or air will be trapped as the molten metal begins to solidify. Blows can also be caused by sand that is too fine, too wet, or by sand that has a low permeability so that gas can't escape. Too high a moisture content in the sand makes it difficult to carry the excessive volumes of water vapor away from the casting. Another cause of blows can be attributed to using green ladles, rusty or damp chills and chaplets.

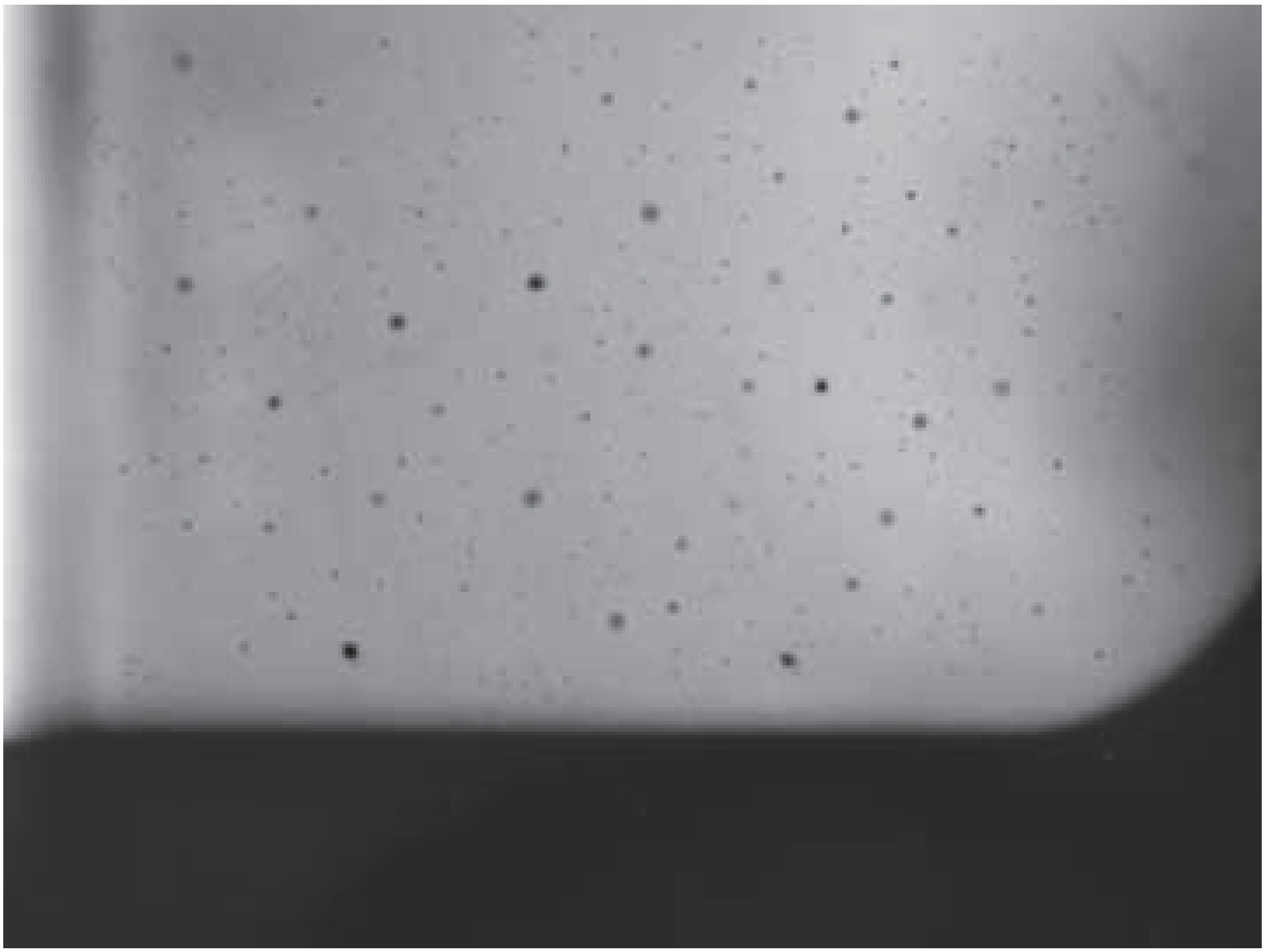
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Figure 6-53. Gas Porosity

6.5.14.7 Inclusions. Inclusions are nonmetallic materials in a supposedly solid metallic matrix. They may be less or more dense than the matrix alloy and will appear on the radiograph, respectively, as darker or lighter indications. The latter type is more common in light metal castings.

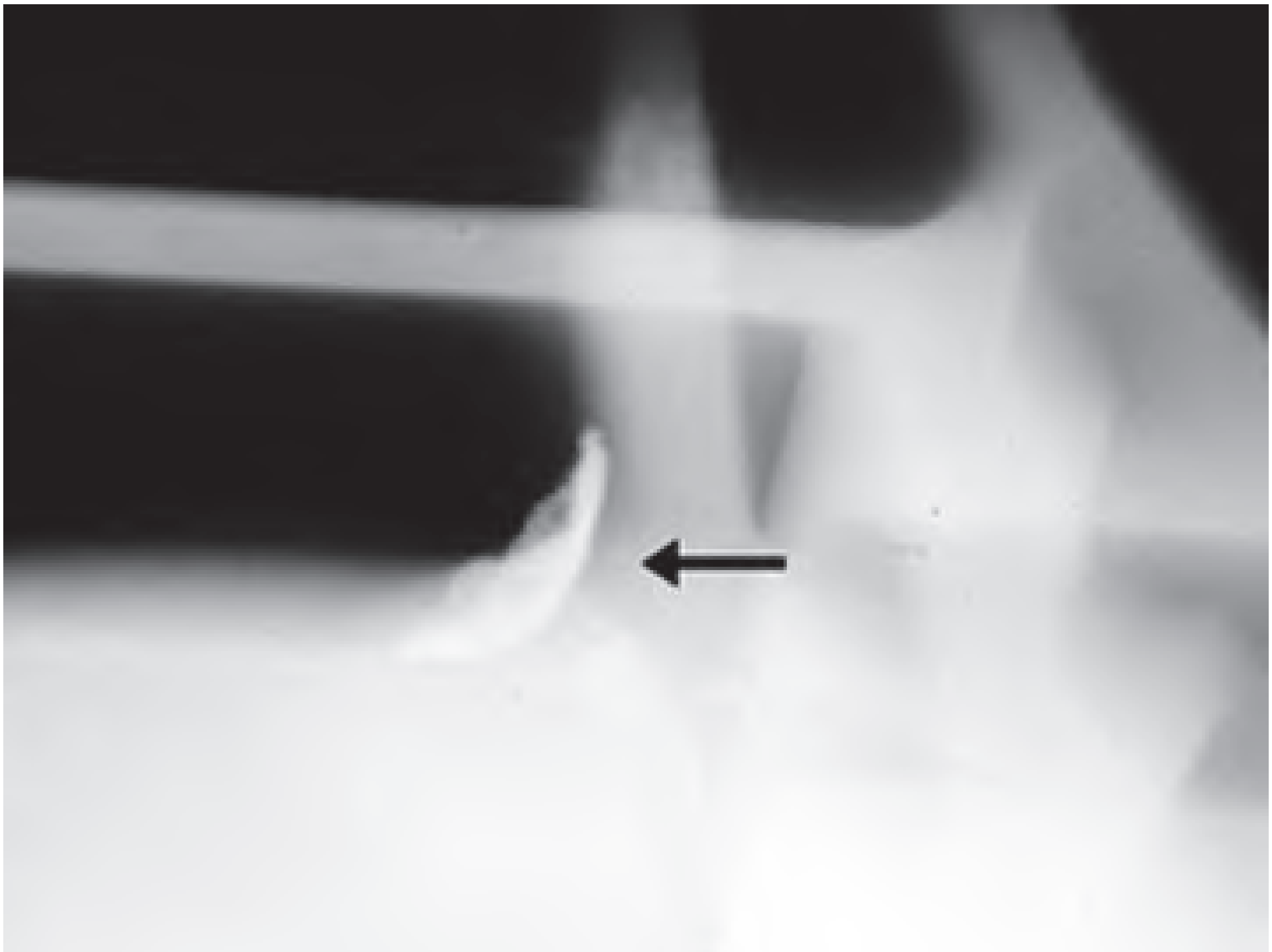

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Figure 6-54. Inclusions

6.5.14.8 Sand Inclusions and Doss. Sand inclusions and doss are nonmetallic oxides, appearing on the radiograph as irregular, dark blotches. These come from disintegrated portions of mold or core walls and/or from oxides (formed in the melt) which have not been skimmed off prior to introduction of the metal into the mold gates. Careful control of the melt, proper holding time in the ladle and skimming of the melt during pouring will minimize or obviate this source of trouble.

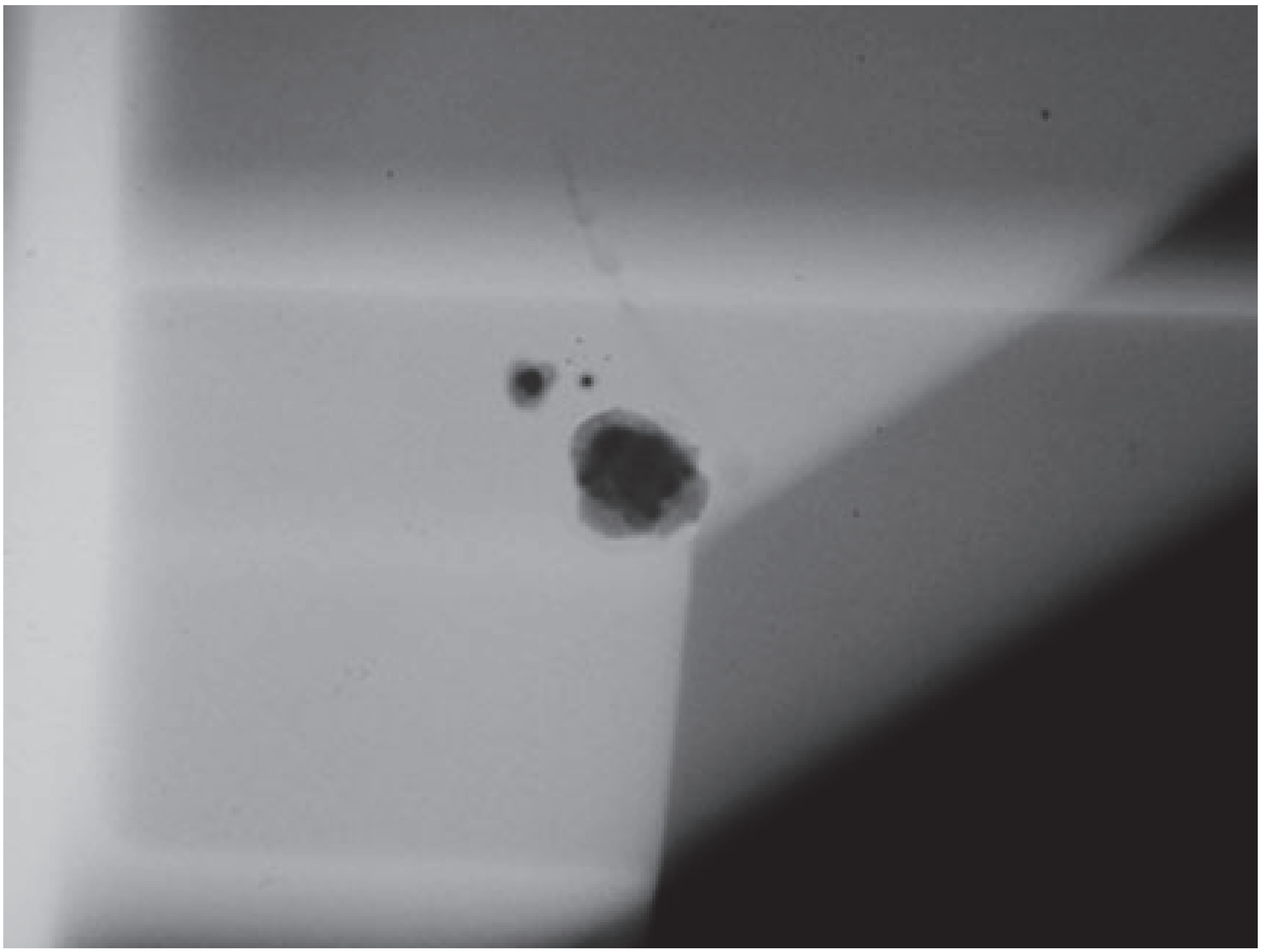

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Figure 6-55. Sand Inclusions

6.5.14.9 Cracks. Cracks are thin (straight or jagged) linearly disposed discontinuities that occur after the melt has solidified. They generally appear singly and originate at casting surfaces.

6.5.14.10 Cold Shuts. Cold shuts generally appear on or near a surface of cast metal as a result of two streams of liquid meeting and failing to unite. They may appear on a radiograph as cracks or seams with smooth or rounded edges.

6.5.14.11 Core Shift. Core shift may be detected when it is possible to angle the radiation or rotate the piece in a manner that would make it possible to measure the deviation of a specified wall thickness. Core shifts may be caused by jarring the mold, insecure anchorage, or omission of chaplets.

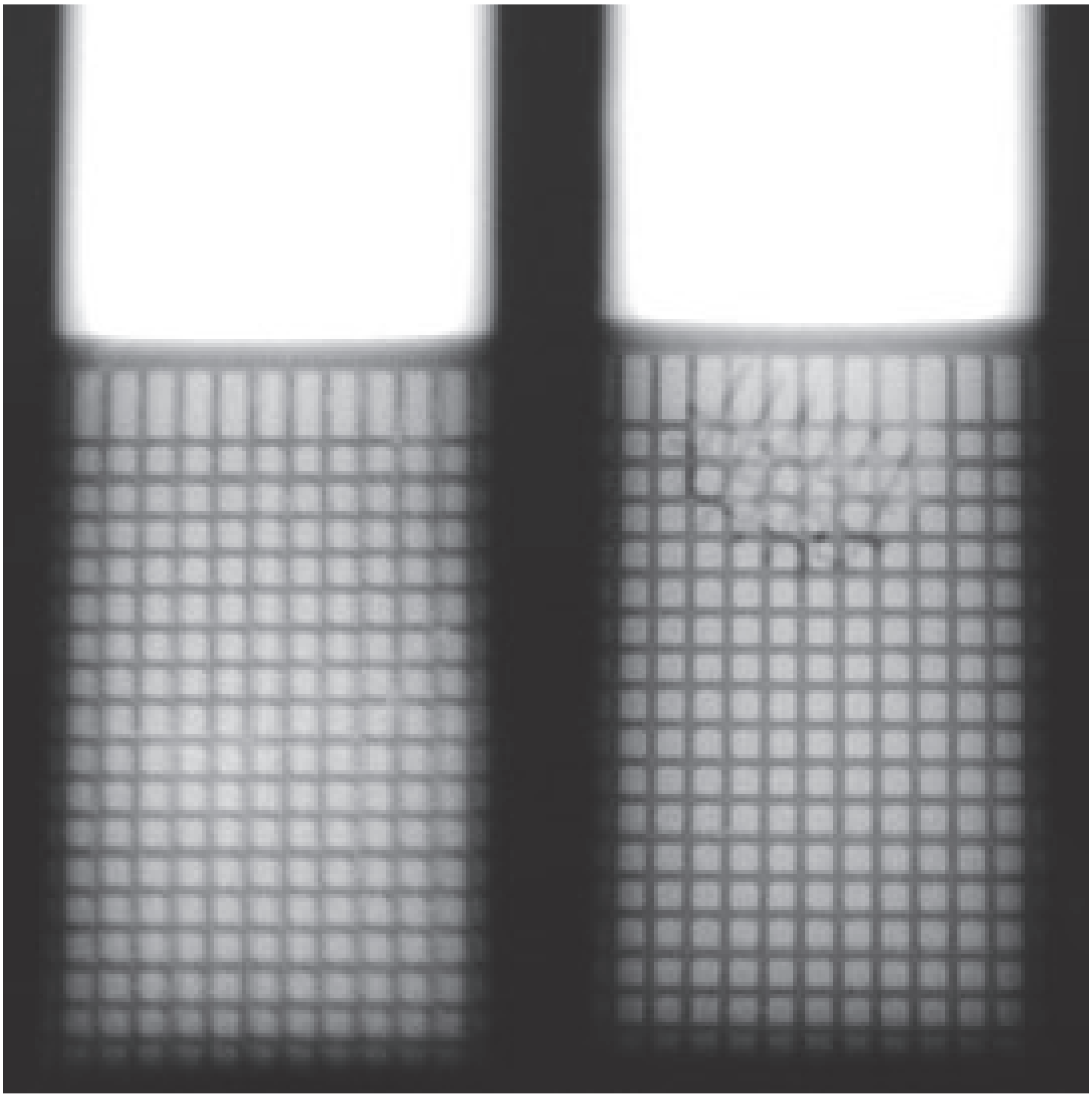

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Figure 6-56. Core Shifts

6.5.14.12 Hot Tears. Hot tears are linearly disposed indications that represent fractures formed in a metal during solidification because of hindered contraction. The latter may occur due to overly hard (completely unyielding) mold or core walls. The effect of hot tears, as a stress concentration, is similar to that of an ordinary crack; how tears are usually systematic flaws. If flaws are identified as hot tears in larger runs of a casting type, they may call for explicit improvements in technique.

6.5.14.13 Misruns. Misruns appear on the radiograph as prominent dense areas of variable dimensions with a definite smooth outline. They are mostly random in occurrence and not readily eliminated by specific remedial actions in the process.

6.5.14.14 Mottling. Mottling is a radiographic indication that appears as an indistinct area of more or less dense images. The condition is a diffraction effect that occurs on relatively vague, thin-section radiographs, most often with austenitic stainless steel. Mottling is caused by interaction of the object's grain boundary material with low-energy X-rays (300 kV or lower). Inexperienced interpreters may incorrectly consider mottling as indications of unacceptable casting flaws. Even experienced interpreters often have to check the condition by re-radiography from slightly different source-film angles. Shifts in mottling are then very pronounced, while true casting discontinuities change only slightly in appearance.

6.5.15 Welds. Metal may be joined together by welding to form many shapes and structures required in aircraft. This fabrication procedure, when carefully controlled, will provide a joint equal in strength to the parent materials. There must be just enough heat to produce fusion and adequate penetration, but not too much, which would cause porosity, cracks, or undercutting.

6.5.15.1 Most weld discontinuities can be readily detected by radiographic inspection since they consist of a change in material homogeneity. Cracks in welds are often detectable since they will usually occur in the direction of the thickness of the plate and will be parallel to the X-ray beam. Stresses created in the metal by welding and not accompanied by a physical separation of material will not be detected by radiography, and cracks not properly oriented may also be missed. Oxides created by the molten metal may become trapped in the weld and result in reduced strength.

6.5.15.1.1 In tungsten inert gas (TIG) welding, tungsten electrode inclusions can occur. These appear as nearly clear specks in a radiograph due to the very high absorption of the radiation by tungsten. These inclusions usually appear in clusters of two or more. A single tungsten inclusion is unusual.

6.5.15.1.2 Foreign material whose density is approximately the same as the weld metal may not be detected. In the inspection of weldments, radiography is an indispensable tool for the location of internal discontinuities. It is the oldest and best known nondestructive means for this purpose. It is used to establish welding procedures, to qualify welders, to inspect welded fabrications, and for quality control of welded parts. For routine inspection, test welds made periodically in process on production welding MAY be inspected by X-ray to supplement destructive tests where results are in doubt. When quality has been established, an occasional X-ray exposure can be made on routine work. All X-ray shadow images are geometric projections of the actual size of conditions in or on the weld. There may be some slight distortion depending on angle of X-ray beam and distance of the weld from the film. Density, in general, is some indication of the depth magnitude of the weld discontinuity.

6.5.16 Welding Defects and Conditions.

6.5.16.1 Inadequate Weld Reinforcement. Inadequate weld reinforcement is an area of a weld where the thickness of weld metal deposited is less than the thickness of the base material. It is very easy to determine by radiograph if the weld has inadequate reinforcement, because the image density in the area of suspected inadequacy will be more (darker) than the image density of the surrounding base material.

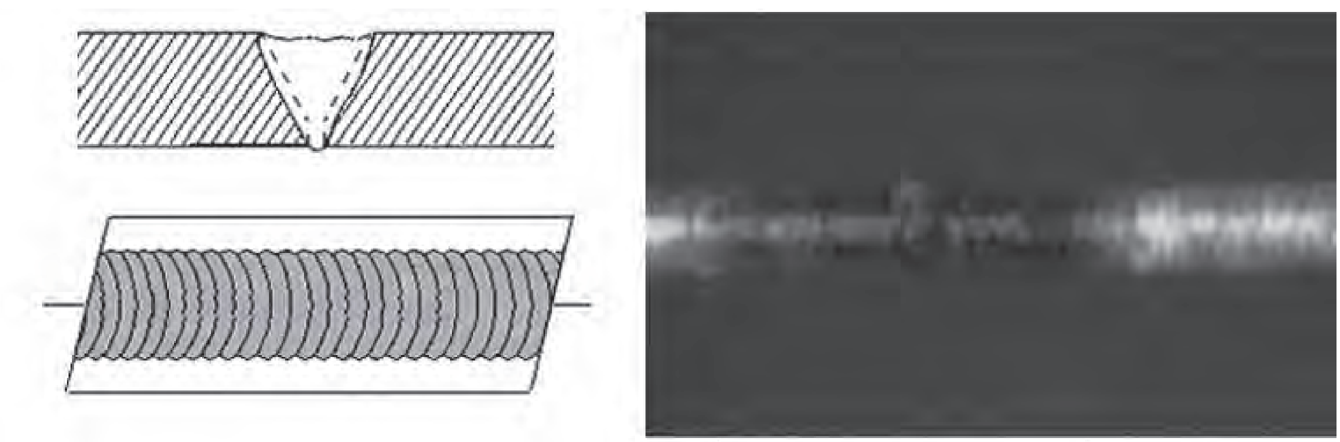

Figure 6-57. Inadequate Weld Reinforcement

6.5.16.2 Offset. Offset or mismatch are terms associated with a condition where two pieces being welded together are not properly aligned. The radiographic image is a noticeable difference in density between the two pieces. The difference in density is caused by the difference in material thickness. The dark, straight line is caused by failure of the weld metal to fuse with the land area.

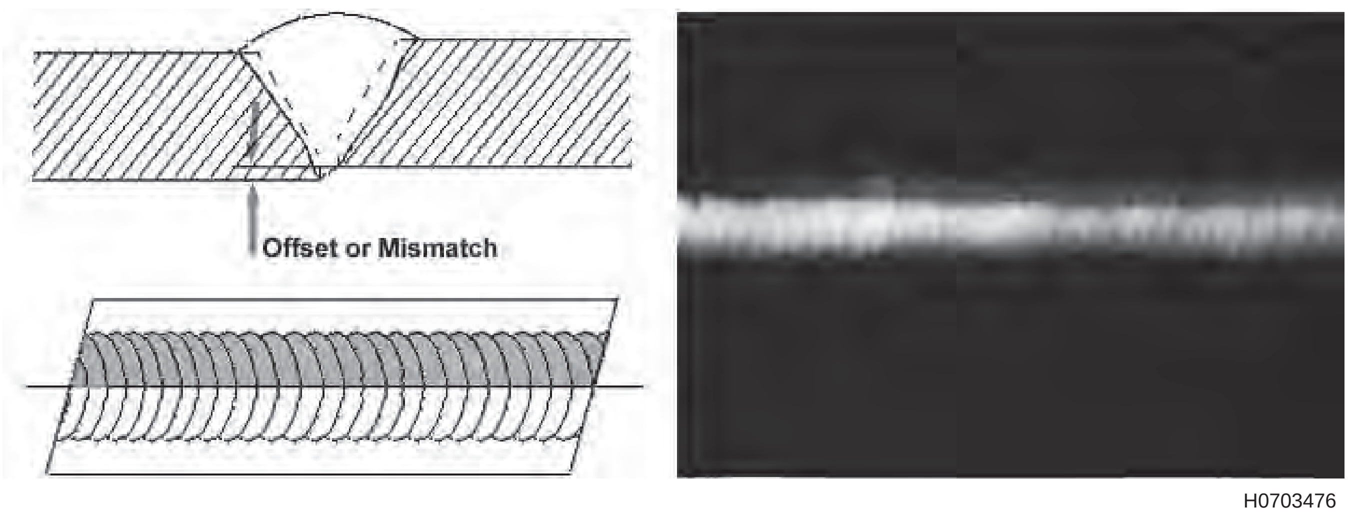

Figure 6-58. Offset

6.5.16.3 Excessive Reinforcement. Excess weld reinforcement is an area of a weld that has weld metal added in excess of that specified by engineering drawings and codes. The appearance on a radiograph is a localized, lighter area in the weld. A visual inspection will easily determine if the weld reinforcement is in excess of that specified by the engineering requirements.

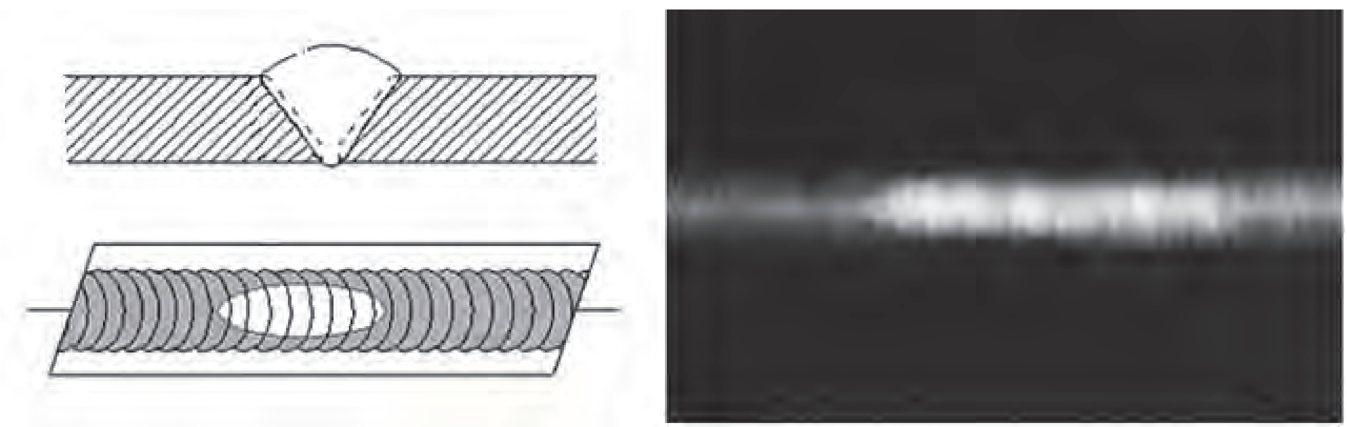

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Figure 6-59. Excessive Reinforcement

6.5.16.4 Undercutting. Internal or root undercut is an erosion of the base metal next to the root of the weld. In the radiographic image it appears as a dark irregular line offset from the centerline of the weldment. Undercutting is not as straight edged as lack of penetration because it does not follow a ground edge.

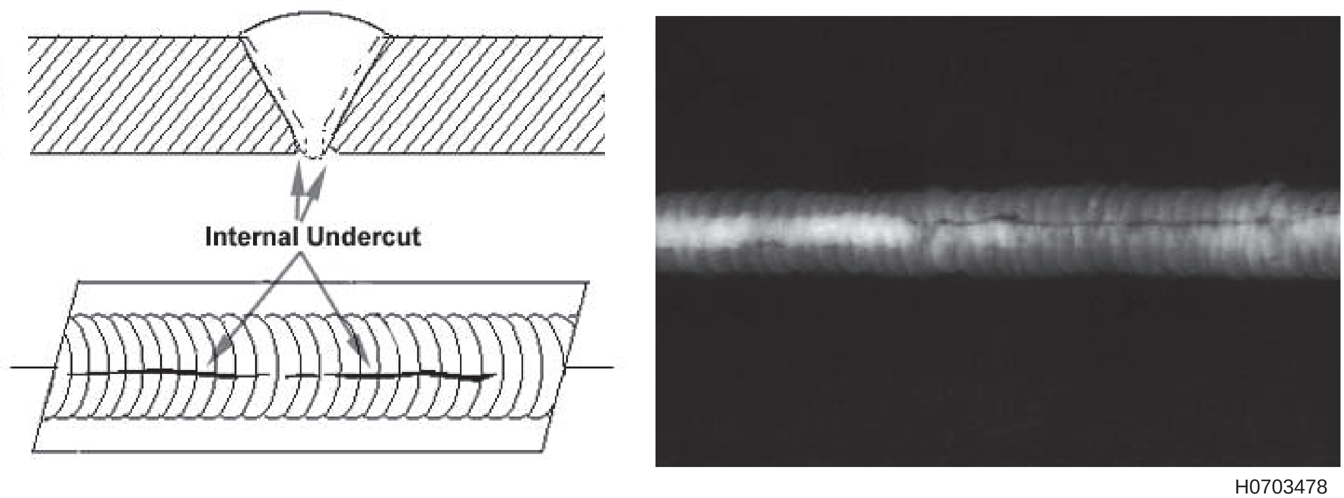

Figure 6-60. Internal Undercutting

6.5.16.5 External Undercut. External or crown undercut is an erosion of the base metal next to the crown of the weld. In the radiograph, it appears as a dark irregular line along the outside edge of the weld area.

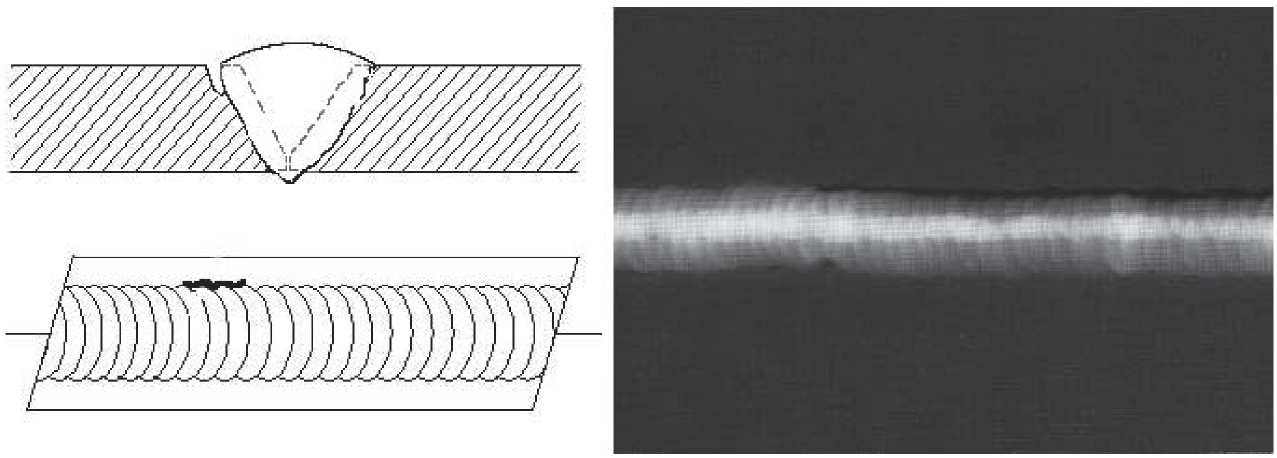

Figure 6-61. External Undercutting

6.5.16.6 Suck Back. Internal concavity or suck back is condition where the weld metal has contracted as it cools and has been drawn up into the root of the weld. On a radiograph it looks similar to lack of penetration but the line has irregular edges and it is often quite wide in the center of the weld image.

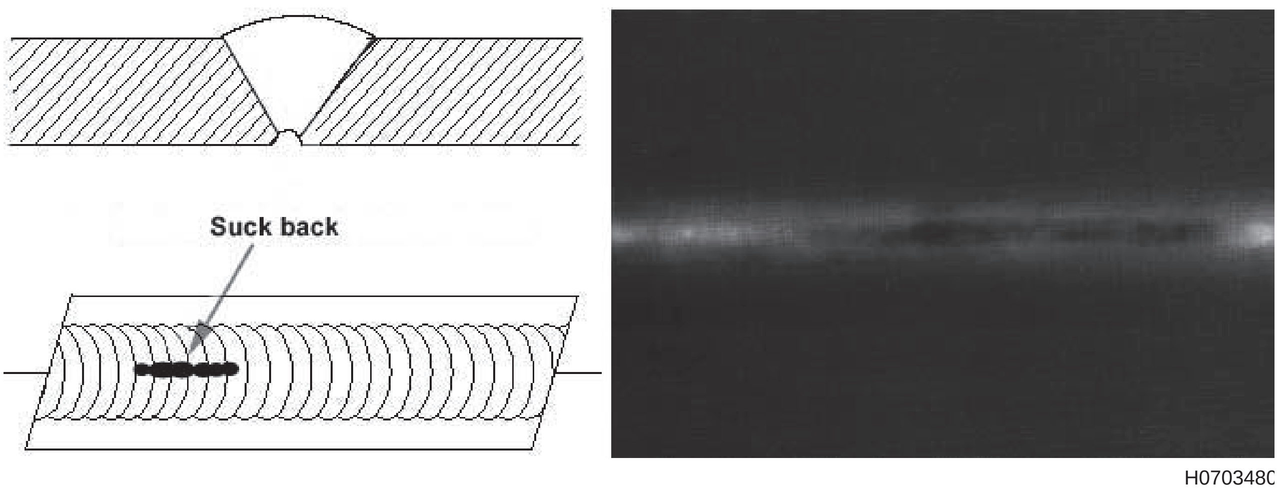

Figure 6-62. Suck Back

6.5.16.7 Slag. Slag inclusions are nonmetallic solid material entrapped in weld metal or between weld and base metal. In a radiograph, dark, jagged asymmetrical shapes within the weld or along the weld joint areas are indicative of slag inclusions.

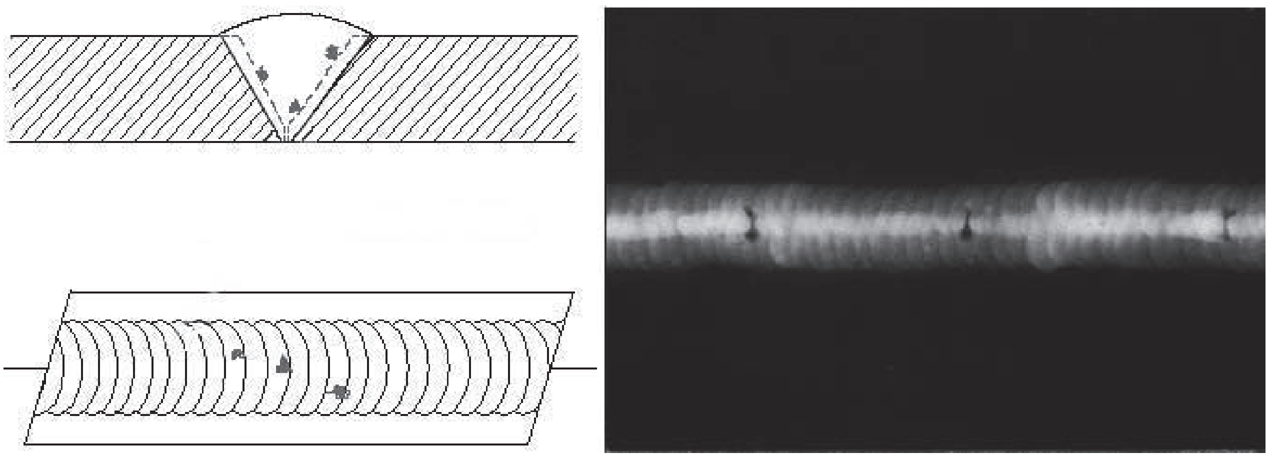

Figure 6-63. Slag Inclusions

6.5.16.8 Porosity. Porosity is the result of gas entrapment in the solidifying metal. Porosity can take many shapes on a radiograph but often appears as dark round or irregular spots or specks appearing singularly, in clusters or rows. Sometimes porosity is elongated and may have the appearance of having a tail This is the result of gas attempting to escape while the metal is still in a liquid state and is called wormhole porosity. All porosity is a void in the material, so it will have a radiographic density more than the surrounding area.

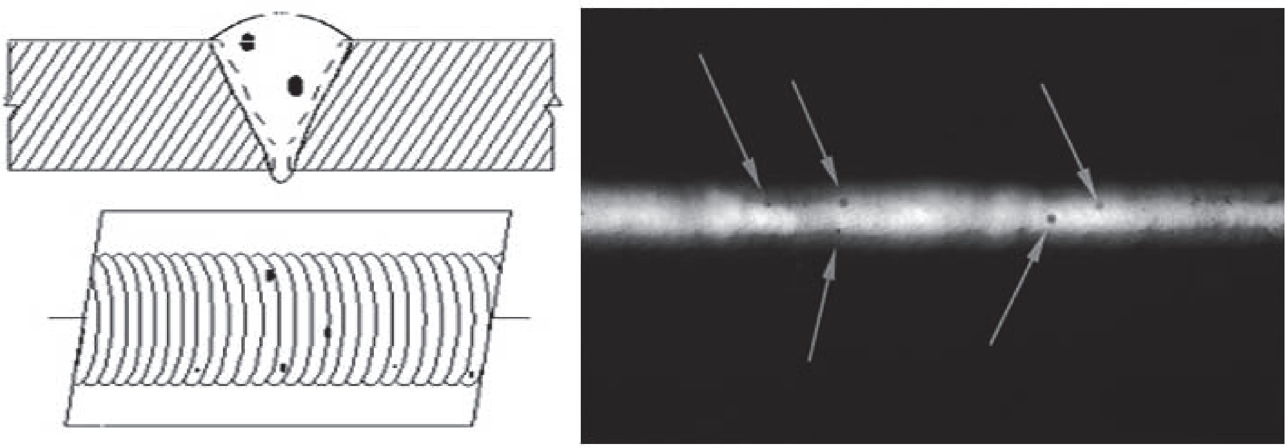

Figure 6-64. Porosity

6.5.16.9 Cluster Porosity. Cluster porosity is caused when flux coated electrodes are contaminated with moisture. The moisture turns into gases when heated and becomes trapped in the weld during the welding process. Cluster porosity appear just like regular porosity in the radiograph but the indications will be grouped close together.

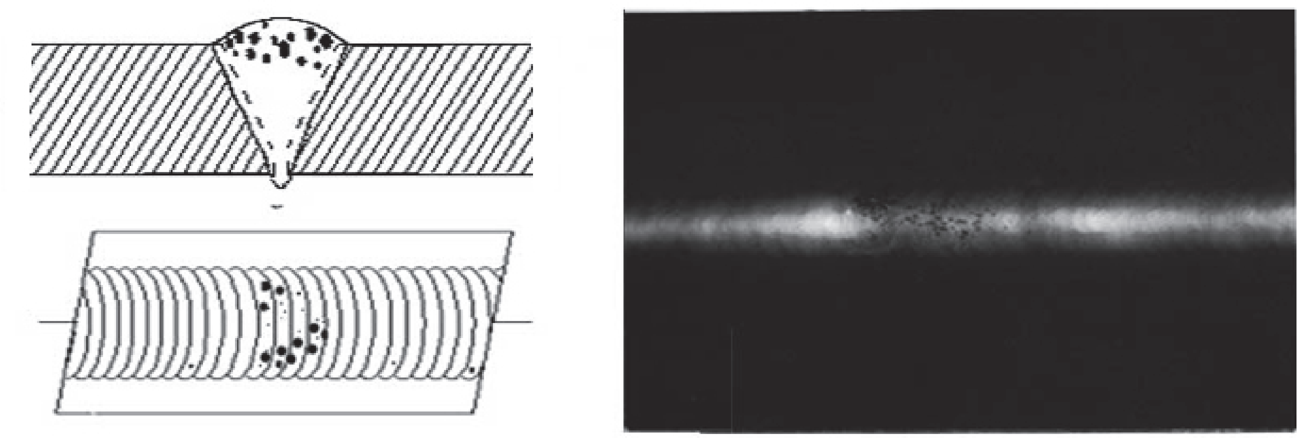

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Figure 6-65. Cluster Porosity

6.5.16.10 Cracks. Cracks can be detected in a radiograph only when they are propagating in a direction that produces a change in thickness that is parallel to the X-ray beam. Cracks will appear as jagged and often very faint irregular lines. Cracks can sometimes appear as “tails” on inclusions or porosity.

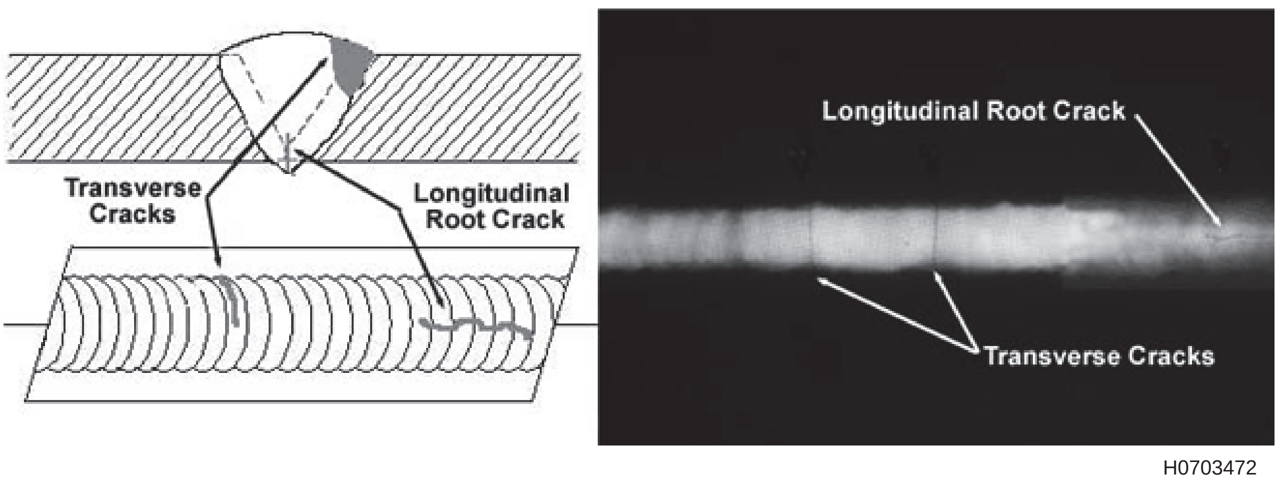

Figure 6-66. Cracks

6.5.16.11 Incomplete Penetration. Incomplete penetration may occur in a fillet weld. This will show on a radiograph as dark lines along one side of weld image.

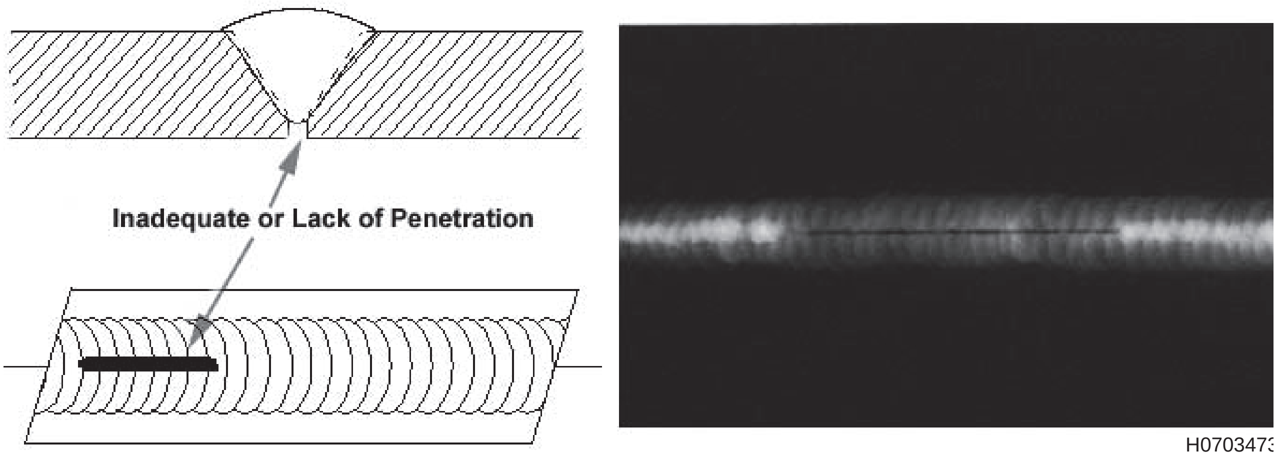

Figure 6-67. Incomplete Penetration

6.5.16.12 Lack of Fusion. Incomplete fusion is a condition where the weld filler metal does not properly fuse with the base metal. Appearance on radiograph: usually appears as a dark line or lines oriented in the direction of the weld seam along the weld preparation or joining area.

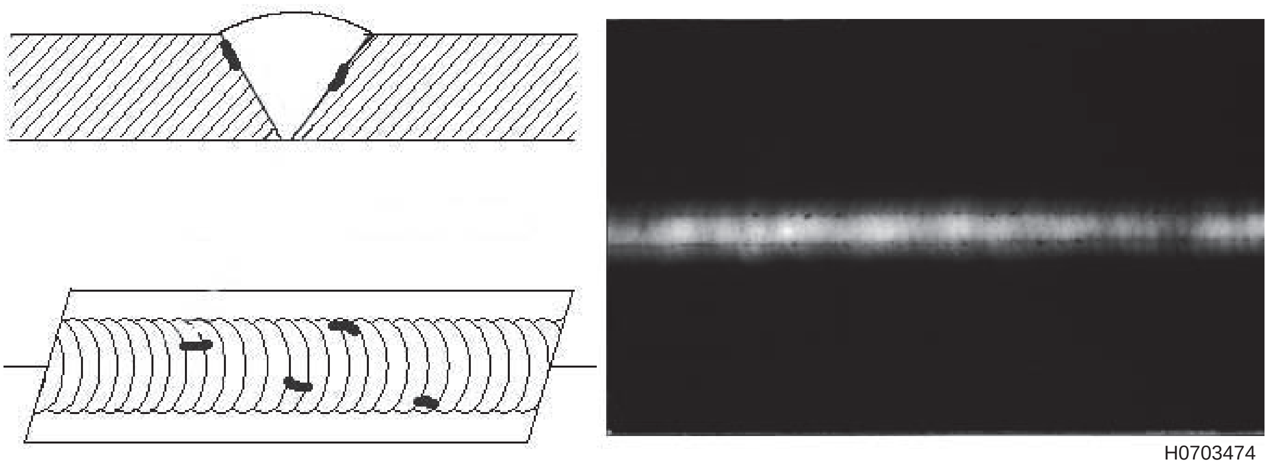

Figure 6-68. Lack of Fusion

6.5.16.13 Cold Lap. Cold Lap is a condition where the weld filler metal does not properly fuse with the base metal or the previous weld pass material (interpass cold lap). The arc does not melt the base metal sufficiently and causes the slightly molten puddle to flow into base material without bonding.

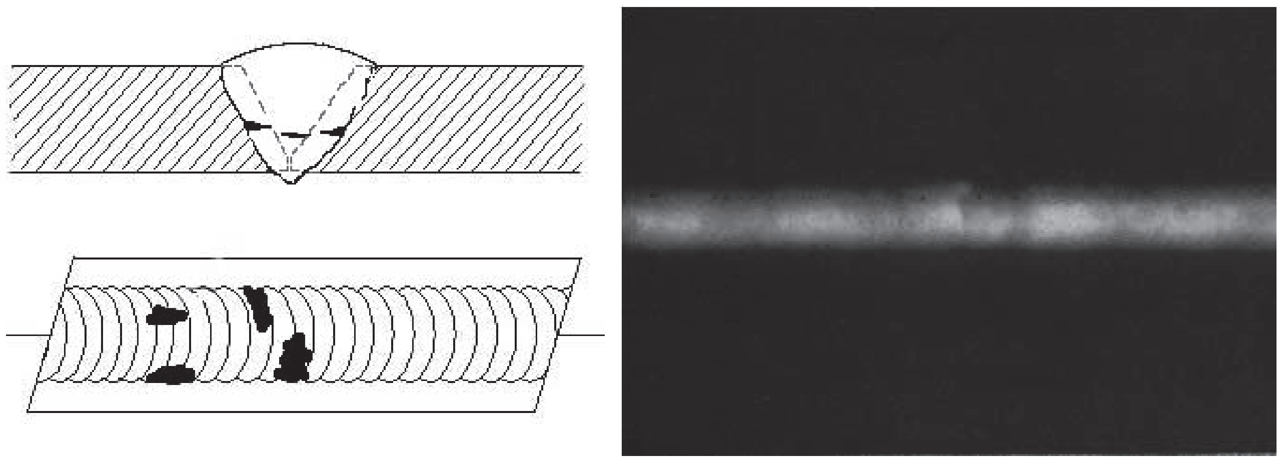

Figure 6-69. Cold Lap

6.5.16.14 TIG Weld Discontinuities. The following discontinuities are peculiar to the TIG welding process. These discontinuities occur in most metals welded by the process including aluminum and stainless steels. The TIG method of welding produces a clean homogeneous weld which when radiographed is easily interpreted.

6.5.16.15 Tungsten Inclusions. Tungsten is a brittle and inherently dense material used in the electrode in tungsten inert gas welding. If improper welding procedures are used, tungsten may be entrapped in the weld. Radiographically, tungsten is more dense than aluminum or steel; therefore, it shows as a lighter area with a distinct outline on the radiograph.

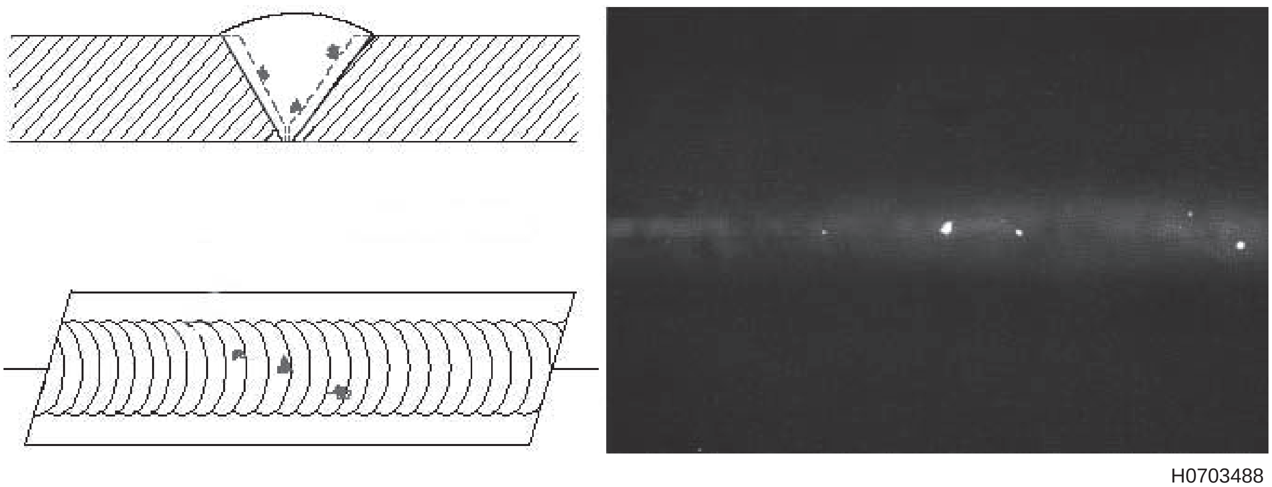

Figure 6-70. Tungsten Inclusions

6.5.16.16 Oxide Inclusions. Oxide inclusions are usually visible on the surface of material being welded (especially aluminum). Oxide inclusions are less dense than the surrounding materials and, therefore, appear as dark irregularly shaped discontinuities in the radiograph.

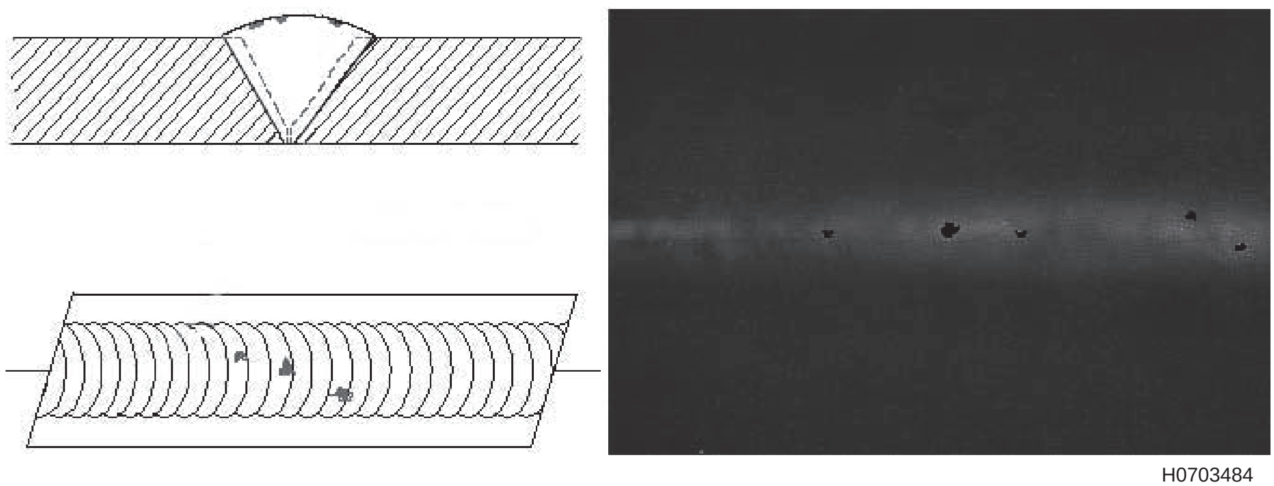

Figure 6-71. Oxide Inclusions

6.5.16.17 Discontinuities in Gas Metal Arc Welds (GMAW). The following discontinuities are most commonly found in GMAW welds.

6.5.16.17.1 Whiskers. Whiskers are short lengths of weld electrode wire, visible on the top or bottom surface of the weld or contained within the weld. On a radiograph they appear as light, “wire like” indications.

6.5.16.17.2 Burn-Through. Burn-through results when too much heat causes excessive weld metal to penetrate the weld zone. Often lumps of metal sag through the weld creating a thick globular condition on the back of the weld. These globs of metal are referred to as icicles. On a radiograph, burn through appears as dark spots which are often surrounded by light globular areas (icicles).

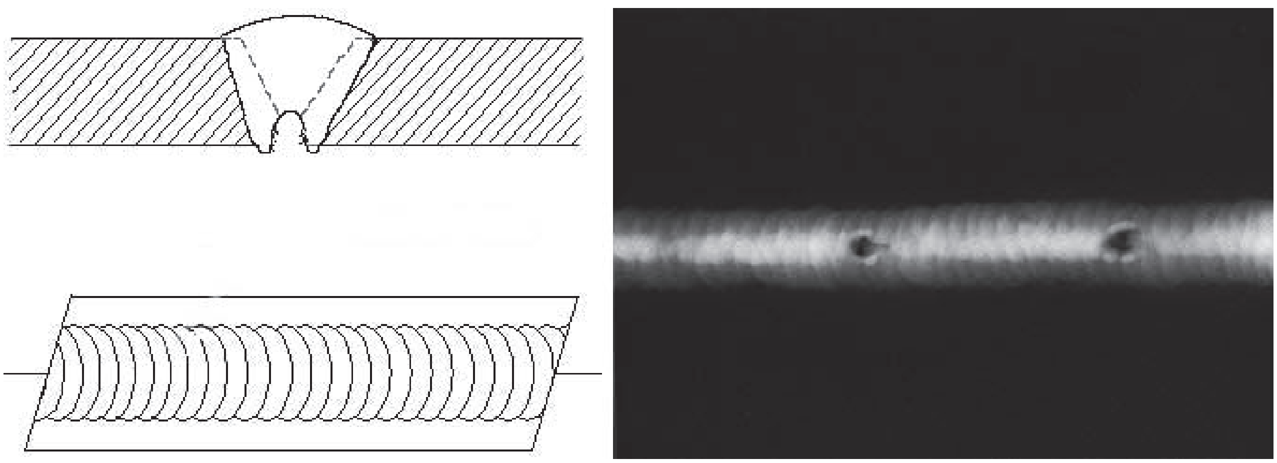

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Figure 6-72. Burn-Through

6.5.16.18 Aluminum and Magnesium Welds. Radiographic technique and equipment for examining welds in aluminum and magnesium alloys are no different than methods used for steel welds. The discontinuities produced by fusion welding of aluminum and revealed on film by radiography include:

- Entrapped gas, ranging from fine gas porosity to large gas holes. The porosity may be in line or at random.
- Inclusions of tungsten particles, foreign materials, flux, and oxide. Since the density of oxide films is nearly the same as aluminum, they will not produce a detailed indication on a radiograph unless present in large quantities.
- Inadequate penetration.
- Incomplete fusion.
- Cracks.
- Surface irregularities.

6.5.16.19 Spot Welds. A special exposure technique is necessary for the inspection of spot welds. The welded areas are X-rayed with a low-voltage, high-intensity, beryllium-window X-ray tube on extremely fine grained films. Spot welds and seam welds produce X-ray images of aluminum and its alloys entirely different from those of any other welding technique. Because of the rather large percentage of radiographically dense alloying constituents that produce informative patterns, some of the high strength aluminum alloys are well suited for spot weld radiography. The images show positive indications of the following:

- Variations in weld nugget shape (oversize, undersize, absence, misshapen, doughnut, and crescent shaped).
- Extrusion and expulsion of metal from nugget.
- Cracks.
- Foreign materials (for example, tip pickup).
- Porosity.
- Segregation of the alloying elements.
- Electrode impressions.

6.5.16.19.1 Flash Welds. Produce heat by creating an arc between the pieces to be joined and pressure welding, done by applying pressure to suitably prepared surfaces at temperatures lower than the melting point of the parts. Flash welds are seldom radiographically inspected. When performed, the inspection is usually made to detect cracks produced in welding procedure.

6.5.16.19.2 Incomplete Fusion. Incomplete fusion at the interfaces between weld and parent metal has certain factors in common with a crack. However, the plane of incomplete fusion is rarely normal to the plate surface, and for this reason is not always revealed. Where such a discontinuity is suspected, additional exposures at various angles may reveal the lack of fusion.

6.5.17 In-Service Inspections. When materials are utilized fully as required in the design of modern aircraft, there is occasional failure due to fatigue. These failures are results of over-stress of the material due to unusual operating conditions or deterioration of the material, such as wear, corrosion, cracks, or crack like discontinuities, water in honeycomb, foreign objects, and assembly issues. This type of material change may be the most difficult to detect due to the very nature of the changes and the inaccessibility of the areas in which these changes are most likely to occur in an aircraft. Radiography has been used to detect these conditions when they occur in inaccessible areas and are not available for visual inspection.

6.5.17.1 Wear. Rivets and bolts may wear the skin, spar, and frame holes so there is not a correct fit in the holes for adequate strength in joints or attachments of a wing section. This can occur due to continued flexing of components from use or because of severe stress due to unusual operating conditions in turbulent weather or an adverse landing. This condition may also result in radial cracks from bolt holes. This type of failure is extremely difficult to detect by radiography. Any angle of exposure results in superimposition of bolt or nut over crack. Loose bolts and rivets have been detected satisfactorily when occurring in a position to be located. Elongation of rivet holes caused by bearing failure or sheared rivets SHOULD NOT be confused with elongation of holes from drilling. If fatigue is suspected in a riveted joint, the half moon indications SHOULD all be on the same side of the rivet and the rivets in the joint SHOULD show similar indications of failure. Intermittent indications would normally be considered fabrication tolerance.

6.5.17.2 Corrosion. Corrosion may occur in aircraft materials, which reduces its strength and expedites the possible failure. This deterioration of the metal may be due to electrolytic action, moisture, chemicals, or gases which attack the metals, intergranular action due to improper heat treatment at the time of manufacture, or other factors. This condition usually occurs on internal surfaces of such components as tubular supports or housings. Since corrosion represents a change of material and occurs in all directions it is easily detected by a proper radiographic exposure. If corrosion has proceeded to this point, the support is appreciably reduced in strength and may experience failure.

6.5.17.3 Cracks and Crack-Like Discontinuities. Cracks and other crack-like discontinuities are found in numerous parts and structures. This is particularly true where structures are subjected to vibration or fatigue loading, due to propagation of these crack-like discontinuities. Cracks are very dangerous discontinuities and are the most difficult service type failure to detect by radiography, since these crack separations are usually not associated with other detectable conditions that give a clue to their presence. Crack-like discontinuities will appear in a radiograph as very straight and sharply outlined dark or black lines. Cracks may also appear as diffused jagged lines; in some cases they have a tree-like pattern. Scatter radiation from the sides of a crack can act as an amplifier of the crack image in a radiograph. Crack-like discontinuities oriented at any angle other than 90-degrees to the X-ray film and not parallel with the X-ray beam produce very little change to the radiation transmission and may not be visible in the radiographic image. Radiography can only be depended on to reveal crack-like discontinuities that are aligned within approximately 7-degrees of the X-ray beam. This depends on the thickness and width of the crack. Normally cracks that are easily detectable by X-ray are visible to the naked eye. Radiography MAY be used to determine extent of cracks or other conditions detected visually, or by magnetic particle or penetrant methods of inspection.

6.5.17.3.1 In castings, crack-like discontinuities can be due to shrinkage, hot tears, cold shuts, or other sources typical of the casting process. The forging process can introduce cracks, laps, and seams that appear crack-like in radiographic images. In weldments, longitudinal or transverse cracks may be found. Lack of weld penetration produces a crack-like discontinuity.

6.5.17.4 Water in Honeycomb. A typical condition that occurs in honeycomb structures is the formation of water in the cores. Entrapped water causes corrosion of both face sheet and core material. This entrapped water will also freeze and expand at high altitudes. This expansion distorts the cells and can break the bonds between core and facing sheets. When this condition exists, vibration of the face sheet can occur, causing failure of adjacent bonds and propagation of bond failure. Radiographic inspection is conducted to evaluate core damage and water content as a maintenance inspection. Entrapped water in honeycomb cells usually appears as a smooth, consistent, light density area that does not have a grainy or porous appearance. The lightest area (more dense substance) indicates greater amounts of water.

6.5.17.4.1 Epoxy in honeycomb cells appears grainy, non-homogeneous. If the cell is not spotty and completely filled, the epoxy will be located around the periphery of each cell.

6.5.17.4.2 Radiographic inspection for moisture detection can be made with the honeycomb core cell walls in either the vertical or horizontal plane. The preferred method is with the core cell walls in the horizontal plane because core cells which are partially filled with moisture are more readily identifiable (less easily confused with solid adhesive).

6.5.17.4.3 If practical, confirmation of partially filled cells with water can be made by repeating the radiographic procedure with the honeycomb cell walls in the opposite plane.

6.5.17.4.4 Radiographic exposures indicating filled core cells are not always conclusive for moisture detection and SHOULD be confirmed by other means if possible.

6.5.17.5 Foreign Objects. Radiography is an excellent method to locate and evaluate foreign objects. Foreign objects MAY be free rivets, bolts, or other objects that could be detrimental to the function of the part or assembly.

6.5.17.6 Workmanship. Radiographic inspections, after completion of repair, assure quality of workmanship. On occasion components are misassembled. In some areas it is not possible to check dimension by physical or visual means. Radiography MAY be used if precautions are taken to assure proper geometrical relation to determine dimension of internal spacing.

6.5.18 Assemblies. Radiography has found wide use in the revaluation of various assemblies to determine status or condition. If the use of the assembly produces changes in it, which are recordable by an X-ray beam, then radiography may be useful in supplying confirming evidence of the suspected condition. Radiographic inspection of oil coolers has resulted in an inspection method that can detect foreign material in the cooler.

6.5.19 Radiographic Standards. It is inherent to good practice, in many cases, that castings or weldments are thicker in cross section than required for the necessary strength of the part. For this reason, some flaws in the casting can be tolerated with no detrimental effect to the aircraft. In order to determine what castings or weldments are acceptable for use in an aircraft, standards of acceptability are prepared as a guide to the radiographer. There are two general types of standards prepared; the specific standard applicable to only one particular part and the general standard.

6.5.19.1 A specific standard for a part is prepared by X-raying the part and then destructively testing the part by applying force of the same type and direction as would be expected in actual service. If the yielding force is greater than the design load, the X-ray film of the part MAY be used as a standard. These types of standards are normally used by foundries and copies of these standards are limited in supply since the part is destroyed by testing and additional retakes cannot be made.

6.5.19.1.1 General standards are prepared by an engineering society, company, or government agency as a guide in determining if the casting and weldments are sound. These standards are based on experience and engineering judgment to provide a casting and weldment generally acceptable for normal use. Radiographic standards prepared by the American Society for Testing and Materials (ASTM) International, 100 Barr Harbor Dr., P.O. Box C700, West Conshohocken, PA 19428-2959 are approved for use.

6.5.19.1.2 Paints, sealants, and adhesives used in fabricating structures often build up to thicknesses readily observed on radiographs. Radiographic indications of these materials can result in obliterating the area of concern and/or cause misinterpretation of the radiograph. The method of application and the built up thickness causes a very rough surface of widely varying thicknesses. The radiographic indication often appears similar to a radiograph of a weld bead. The materials in the liquid or gel state can entrap foreign particles, such as metal chips or gas bubbles. These cause radiographic indications similar to inclusions or porosity. During curing, drying, or service, the organic material can form crack patterns. Radiographic indications of the cracks can appear as dry mud cracks, dendrites (tree branches), or one or two very wide cracks. The indications are difficult to interpret and require substantial experience to evaluate. Cracks in coating materials are normally recognized by the crack pattern and the fact that the crack will exceed normal or usual metal crack width. The best method of confirming these indications is to remove the paint, sealant, or adhesive and to X-ray again. Unfortunately, limited access does not always permit coating removal. Triangulation can be used to define the location of the indication as being on top of the structure.

6.5.20 Digital Radiographic Image Analysis.

NOTE

Digital radiographic image processing scanning index SHALL be 100 microns or less.

6.5.20.1 Processing and Analysis. Image processing and analysis or enhancing can help determine the quality of an existing digital image, and provide hints as to correct problems in the image. Additionally, enhancement and processing make digital images easier to interpret than traditional film-only based radiographic methods.

6.5.20.1.1 Group Processing Techniques. Group processing of pixels is a mathematical process that changes a pixel's value based on the values of neighboring pixels. This mathematical process is known as a convolution, and the application of the process on an image is called applying a convolution filter to the image. Some examples of convolution filters are noise filtering, image sharpening, image blurring, and edge enhancement. There are many more filters used in digital imaging, but these are the most commonly accepted in digital radiography.

6.5.20.1.1.1 Noise Filtering. Random patterns of noise in an image can be removed to some degree by applying a noise removing convolution filter. The most common of these in use for digital radiography is known as a "median filter." The median filter works by examining the pixels surrounding a given pixel, and sorting them in order of magnitude. The median value is then used to replace the pixel being examined. This tends to remove small noise spikes in an image while leaving the information containing portion of an image relatively untouched.

6.5.20.1.1.2 Image Sharpening. Image sharpening improves the sharpness of an image and is usually executed by the means of a high pass or related convolution filter. The high pass filter accentuates high spatial frequency changes in an image making the image sharper. This filter type is used frequently in digital radiography because it enhances areas of high contrast change making indication more easily seen and measured.

6.5.20.1.1.3 Image Blurring. Image blurring can help the viewing of noisy images by blending the noise into the background image when a median filter either introduces too many artifacts, or just unable to eliminate the type of noise in the image. Frequently, a blurred image is processed again by a sharpening filter to help create an "edge enhancement" effect. Blurring is most frequently executed through the use of a low pass filter which attenuates areas of high contrast change.

6.5.20.1.1.4 Edge Enhancement. Edge enhancement convolution filters help define the edges of contrast change within an image, making them easier to see. Edge enhancement filters can frequently change the size of an indication (usually making it appear slightly larger than it actually is) so caution SHALL be exercised in it use.

6.5.20.1.2 Frame Processing Techniques. Frame processing techniques manipulate the image by changing the locations of pixels within an image. "Image rotation" and "image scaling" are common frame processing techniques.

6.5.20.1.2.1 Image Rotation. Sometimes a digital image is not in the orientation we would like to view it, so the image MAY be rotated to adjust it. Rotation of digital images SHOULD be performed only in 90° increments to avoid having to produce interpolated or extrapolated pixel values for areas of the image that do not fall exactly on a pixel boundary.

6.5.20.1.2.2 Image Scaling. Image scaling is the magnification or reduction of apparent image size on a monitor or printing device. In digital radiography it is common to not use interpolation or extrapolation methods that alter the actual pixels of the image except to make them either smaller or larger. Other scaling methods try to guess at what a pixel value SHOULD be based on the pixels surrounding it during magnification routines.

6.5.20.1.2.3 Other Frame Processing Techniques. Other frame processing techniques include transforms, which map image data into another space or domain and operate on it there, frequently with a convolution filter or another frame processing technique. Examples include Fourier transforms and YCC photo CD color space conversions. Some compression algorithms rely on domain transforms as well.

6.5.20.2 Compression. Image compression techniques for digital images fall into two main categories, "lossless" and "lossy" compression.

6.5.20.2.1 Lossless Compression. Lossless compression techniques are the only compression styles universally accepted by the industrial digital radiography community. In a lossless compression algorithm, the original raw data can always be reconstructed exactly as it was before compression. There is no loss of the original information; it is just coded in a way that is smaller for storage.

6.5.20.2.2 Lossy Compression. Lossy compression techniques sacrifice some of the image data to create even smaller file sizes while trying to maintain the overall quality of an image. The amount of loss can vary in most techniques, and is determined by the quality factor used in the compression algorithm. Lossy compression techniques degrade an image over each subsequent compression from a decompressed image in a manner similar to making a noisy copy of an analog cassette tape, then making a copy of a copy, using the same equipment. The original raw data is lost and irretrievable in a lossy compression technique. Examples of lossy compression include: "Discrete Cosine transform" compression, standard "JPEG" compression, and "wavelet" compression methods. Of these, wavelet compression tends to produce the highest quality copy with a high compression ratio and low image loss.

NOTE

Lossy compression is not recommended for anything but copies of digital radiographs.

SECTION VI PROCESS CONTROL OF RADIOGRAPHIC INSPECTION

6.6 RADIOGRAPHIC PROCESS CONTROL.

6.6.1 Scope and Purpose. Process control of radiography or any of the other NDI methods means variables involving materials, equipment, personnel, and documentation are well defined and maintained. This means that the features which are significant in terms of process reliability be identified so controls can be put in place.

6.6.2 Radiographic Process Control Requirements. Although the entire X-ray process must be closely controlled to produce the expected results, this requirement centers on film processing. The novice might think X-ray is a cure all, but to the informed it is a very costly and sometimes inaccurate NDI method. X-ray procedures SHOULD be followed precisely. Proper beam alignment, the correct film, source focal spot size, and correct exposure parameters are critical. This radiographic process has many factors that affect the quality of the final product.

6.6.2.1 During radiographic inspection/exposure parameters requiring control include: variations in the radiation source, voltage, current, heat removal, geometry factors (i.e., focal spot size, shape, and location), beam collimation and direction, source-to-object, source to film/detector distances, and object to film detector distances.

6.6.2.2 Variables to be controlled during radiographic film storage include: handling and processing the film, screens, cassettes, and chemicals. For the most part, process control of these variables is dependent on the radiographer and the care the inspector uses in setting up all these features. Good record keeping of the entire process is important in maintaining reliability.

6.6.3 Process Control in the Darkroom. Darkroom design is discussed in (paragraph 6.4.5), but the design is critical toward controlling the radiographic process. The darkroom SHALL be completely protected against radiation and visible light. For efficiency and reducing the possibility of damaging radiographic film, two distinct areas SHOULD be established within the darkroom. One area SHOULD be designated the “dry area” and the other the “wet area.” The dry area is where film is unloaded and placed on hangers, prepared to be loaded in the automatic film processor, loaded in cassettes, or cut to support special inspections. Liquids or materials that could damage unprotected film SHOULD NOT be allowed in this area. The wet area is where development chemicals are mixed and hand development is accomplished. Wet hangers and other wet equipment SHOULD NOT be permitted out of this area of the darkroom. These two areas SHOULD be physically separated to prevent the wet chemicals from being accidentally transferred to the film loading areas, causing spots or other artifacts on the film.

6.6.3.1 If possible, the dark room SHOULD adjoin the X-ray room or radiographic work area. A film-transfer cabinet SHOULD be installed in the separating wall, particularly if a large volume of work is done. Film can then be handled efficiently without interfering with darkroom processing. The film-transfer cabinet SHALL be lead lined if it adjoins the X-ray room.

6.6.3.2 Ventilation. Proper ventilation of the darkroom SHALL be determined by Bioenvironmental. The circulation of clean fresh air will reduce fatigue and provide a healthier atmosphere for personnel. Light-tight ventilators SHALL be installed and the number will depend on the size of the darkroom. Ventilators SHOULD keep the air moving from the dry side to the wet side of the room and out of the building.

6.6.3.3 Safelights. To minimize the fogging of undeveloped radiographic film by the safelights in the darkroom, the following provisions apply:

- General illumination SHALL be indirect.
- Safelights SHOULD be suspended from the ceiling and SHALL be at least four feet from undeveloped/exposed film.
- Only the minimum level of safelights needed to perform darkroom operations SHALL be allowed.
- Only safelight filters (6B or equivalent) designated for use with industrial radiographic film SHALL be allowed.
- The manufacturer’s recommended bulb wattage SHALL NOT be exceeded
- The darkroom walls SHOULD be painted a light color, which best reflects light from the safelight. The darkroom SHOULD have an antechamber type entrance that makes an efficient light trap
- During the development and preparation of uncovered, undeveloped radiographic film, ambient light SHALL NOT exist in the darkroom.

6.6.3.3.1 Why Test Safelights. The level of safelight present in the darkroom SHALL be the minimum required to perform undeveloped film preparation/development operations. Safelights for darkroom operation contribute to unwanted densities (fog) on radiographic film. To overcome this problem, the length of time undeveloped industrial radiographic film can safely be exposed to the level of safelight within a specific darkroom SHALL be understood. This time period is much shorter for exposed film than for unexposed film. The reason for this time difference is exposed film is approximately five times more susceptible to fog caused by safelights than unexposed film.

6.6.3.3.1.1 The safelight fog evaluation procedure consists of two tests: the individual safelight test and the periodic collective safelight test. These tests have a requirement to be performed separately or jointly depending upon the circumstances. Both of these tests SHALL be performed during initial safelight evaluation for a new or in-use darkroom facility whenever the periodic collective safelight test results are unacceptable. Procedures for performing the safelight fog test are published in TO 33B-1-2 WP 106 00.

6.6.3.3.2 Individual Safelight Testing. Circumstances when this test SHALL be performed are:

- Initial test on newly installed safelights
- Changes are made to existing lights such as replacing entire units, bulbs, filters, or changing the position (e.g. reflecting versus direct lighting)
- Filters are suspected of fading or being adversely affect by damage like crazing, scratches, and cracks
- Collective safelight test results are unsatisfactory
- A safelight is suspect of producing excessive safelight fog.

NOTE

The maximum time undeveloped film can be exposed to safelight shall be posted in the darkroom in an area clearly visible to all radiographers.

6.6.3.3.3 Periodic Collective Safelight Testing. Periodic collective safelight filters deteriorate during use. This rate of deterioration is dependent on their age, amount of use, and amount of heat generated by the bulb. Therefore, a periodic schedule SHALL be established to collectively test safelights to prevent film fog, dependent upon their use. Circumstances, which determine when this test SHALL be performed, are 1) during the periodic test cycle, which SHALL NOT exceed one-year, and 2) repositioning safelights, 3) when reestablishing an undeveloped film handling area, and 4) when installing additional safelights. The collective safelight test film SHALL be maintained on file for one year or replaced when the test is performed again.

6.6.3.3.4 Troubleshooting if Failure to Meet Standards. If maximum allowable time undeveloped film can be exposed to safelights is 4-minutes and 45-seconds or less, or not suitable for operational needs, one or more of the following actions SHALL be taken:

1. Replace safelight filters that are faded, cracked, are not designated for industrial radiographic film, crazed, do not fit properly, or scratched.

2. Replace safelight bulbs exceeding the wattage recommended by the safelight manufacturer.

3. Replace unserviceable safelights, such as those still emitting ambient light after filter and bulb problems have been corrected.

4. Eliminate or reconfigure uncontrollable ambient light sources such as doorways, ventilating and heating ducts/vents, faulty film pass through box, building structural cracks, and holes around pipes and electrical wiring.

5. In the event the individual safelight tests are all within an acceptable tolerance, but the collective safelight test is unacceptable, investigate, the validity of the individual safelight test and when, in fact, the results of these tests are correct, reduce the number of safelights in the darkroom.

6.6.4 Controlling the Development Process.

6.6.4.1 Control Strip. A major variable in the radiographic process is the processing of the film. The chemical concentrations, contaminants, and temperature are important variables which affect the process. A method of monitoring changes during film processing involves periodically processing many control-exposed films to detect changes in film density and/or contrast. Procedure is located in TO 33B-1-2 WP 106 00. The last strip in the control exposure SHOULD be processed with the control film of the new batch to maintain continued control from month to month. In cases where films from one manufacturer are processed in another film manufacturer's recommended solutions, the period between control tests may need to be shortened.

6.6.4.1.1 The radiographic inspector SHALL use the control strip to detect changes in the radiographic process. If the inspector ensures the equipment is properly maintained, takes care to use the equipment in a repeatable manner, maintains good records, and maintains the repeatability of film processing, then the radiographic inspection process will remain in good control.

6.6.4.2 Manual Processing Chemicals. Although the shape of the characteristic curve is relatively insensitive to changes in x-ray or gamma-ray quality, it is affected by changes in degree of development. Degree in development depends on the type of developer, temperature, degree of activity, and the time of development. Within certain limits, increased degree of development increases the speed and contrast of an x-ray film. However, if development is carried to far, the speed of the film may cease to increase and may even decrease. The result is the fog increases and contrast may decrease.

6.6.4.2.1 Testing Developer Activity. The success of this method of compensating for the gradual decrease of developer activity will depend upon the use of an adequate system for testing this activity. Since there is no simple direct physical or chemical test of developer activity, the easiest way of making the test is to process, at frequent intervals, film strips exposed in some standard manner, and to compare the densities obtained with an identical film strip processed in the fresh solution. The standard strips are cut from a sheet film, 8x10 inches or larger, which has been exposed to direct X-rays through a test object. The most suitable form of test object is a stepped wedge made up of a number of sheets of any convenient metal. The wedge SHOULD have about 15 steps and be large enough to cover completely the largest cassette or film holder used. When given the proper exposure this SHOULD produce series of densities extending over the density range used in practice. It is essential all strips used in testing a batch of developer receive identical exposures. For this reason, no screens of any kind are used and all the sheets of film required SHOULD be exposed simultaneously in the same cassette. For instance, at 80 kilovolts, using an aluminum step tablet, three sheets MAY be exposed in the same cassette without introducing significant differences in the densities of the top and bottom films. At 180 kilovolts, using a steel tablet, five sheets MAY be exposed at once. At 1000 kilovolts, a steel tablet having steps 1/4- to 1/2- inches high can be used, and five sheets of film exposed at once. When this penetrating radiation is used, two extra films are included, and the top and bottom films are discarded after exposure. The exposed films SHOULD be stored in a cool/dry place (ideally, at 70°F and 50-percent relative humidity, or below). When manually processing test strips, they SHOULD be developed dark end down on regular film-processing hangers in the center of the tank and be given the same development time and agitation used in practice.

6.6.4.2.2 Stop Bath Acidity. The stop bath acidity is not as critical as developer activity, but a check can be made with litmus paper to assure the bath is acidic and capable of neutralizing the alkaline developer.

6.6.4.2.3 Fixer Bath Activity. The diminished activity of the fixer solution with use in manual processing can be readily noted by the extended time required for clearing of the film emulsion. Fixer time can be increased to compensate for deterioration of the chemicals or chemicals MAY be replenished by addition of the chemical constituents of the fixer.

6.6.4.3 Automatic Processing Chemicals. Automatic processors and their chemicals are designed to give the optimum degree of development. All the variables that affect the degree of development are controlled and kept constant by the processor. The responsibilities of the operator are to keep the machine clean and to make sure that temperatures and replenishment rates are maintained at proper levels.

6.6.4.3.1 Control of Processing Solutions. It is rare when chemicals manufactured under exactly the same conditions possess precisely the same properties. In actuality, differences exist. Accordingly, it is unavoidable, X-ray films processed in automatic processors show some degree of variation in quality. Radiographic quality is affected by the following factors, making it necessary to minimize such variations in the control of processing solutions.

6.6.4.3.2 Developer Control. The activity level of the developer solution used in automatic processing is kept constant by the addition of replenisher. The degree of exhaustion of the active components may differ from case-to-case depending on the type of processor, the average density of the radiographs, and the water quality, even if the quantities of film processed remain constant. Process the film lengthwise to avoid losing the film in the rollers. When a new batch of developer is put into use, one or more strips are processed and preserved as the standard for comparison throughout the useful life of the developer. Thereafter, a strip SHOULD be processed after every 50, 14x17-inch films or equivalent processed or 5-gallons of developer. If the densities of the test strip are less than those of the strip processed in the fresh solution, the rate of addition of replenisher SHOULD be increased. On the other hand, if the densities of the test strips are too high, the rate of addition of replenisher SHOULD be decreased.

6.6.4.3.2.1 Even when the same replenishment rates are used in different facilities, the activity of the developer solutions differs over time from one situation to another. The developer solution SHOULD therefore be controlled in a manner suited to the specific conditions of the particular facility. Developer solution is controlled in several ways, but in radiography the “sensitometric” and “densitometric” methods are in general use as control procedures.

6.6.4.3.2.1.1 Sensitometric Method. This method provides the highest control accuracy. A control strip which is exposed to visible light or X-rays in step fashion is developed under predetermined conditions and a characteristic curve is derived from this control strip. The characteristic values (of speed, contrast, and fog) obtained from the characteristic curve are graphically represented. If the characteristics of the control strip deviate from normal, corrective action is taken to bring the developer solution into control. In practice, the characteristics obtained from fresh developer are used as the standard and a control strip is processed after processing a certain number of films or at the beginning of each work shift (at the time processing conditions are stabilized following processor preparation).

6.6.4.3.2.1.2 Densitometric Method. The densitometric method also uses control strips. The density of a specific step of relatively high density is used to plot a control chart. The control film is processed at the same specified time as indicated for the sensitometric control method.

6.6.4.3.3 Fixer Control. An exhausted fixer solution will produce adverse effects relative to the permanency of radiographs. It is necessary to check the fixer solution for exhaustion once per month, or when regular processor maintenance is performed. Fresh chemicals are metered into the processor as film is processed and it is this replenishment that keeps the solution active. The normal replenishment rates for auto-fixer are 170 to 190 ml per 14x17 film processed. Fixer process control checks SHALL be performed in accordance with Operating/Maintenance Manual recommendations.

SECTION VII RADIOGRAPHIC INSPECTION EQUATIONS

6.7 RADIOGRAPHIC EQUATIONS.

6.7.1 General. The following are a list of equations normally used to perform radiographic inspections.

6.7.2 Exposure Factor. A quantity that combines milliamperage with time and distance. Techniques are often provided in terms of kilovoltage and exposure factor. In such cases, it is necessary to determine the time from the milliampere-minutes or milliampere-seconds.

6.7.2.1 mAM. To obtain the exposure time from mAM, divide mAM by the mA used. This will give the time in minutes. Multiply the 10 hundredths of a minute by 60 to get the answer in minutes/seconds format. For example:

100 kV, 17 mAM
If 4 mA is used:
17 / 4 = 4.25 minutes
.25 (= 25 hundredths of a minute) X 60 = 15
Time would be 4 minutes, 15 seconds

6.7.2.2 mAS. To obtain the exposure time from mAS, divide mAS by the mA used. This will give the time in seconds. Divide by 60 to obtain the time in minutes. Then divide the 10 hundredths of the minute by 60 to get exact seconds. For example:

100 kV, 525 mAS
If 4 mA is used:
525 / 4 = 131.25 seconds
131.25 / 60 = 2.19
.19 (= 19 hundredths of a minute) X 60 = 11
Time would be 2 minutes, 11 seconds

6.7.3 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).

6.7.3.1 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 16-square-inches, an area four-times as great as that 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:

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

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

6.7.4 Source-to-Film Distance (SFD). The sharpest image would be formed by having a SFD so great 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. Consequently, 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 following formula 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.

The formula is: $$\frac{T_2}{(D_2)^2} = \frac{T_1}{(D_1)^2} \qquad T_2 = T_1\left(\frac{D_2}{D_1}\right)^2 \text{ or } \frac{T_1(D_2)^2}{(D_1)^2}$$

H0000353

Where:

T_1 = Original Exposure (MAS).

T_2 = New Exposure (MAS).

D_1 = Original Distance (SFD).

D_2 = New Distance (SFD).

For example, if a technique calls for exposing a part at 36-inches using 300 MAS, but the tube head must be moved to make a 48-inch SFD, what would the new exposure be?

Substituting:

Cross multiplying gives $(T_2) * (1296) = (300) * (2304)$ or $T_2 = (300 * 2304)/1296$.

Solving, T_2 = 533 MAS, which would be our new exposure.

6.7.5 Film Density. In photographic terms, density is a measure of the degree of blackening or darkening produced on the radiograph, caused by exposure to radiation and resulting from the metallic silver deposits remaining on the film after exposure and processing. Density is measured in terms of visible light transmission with test strips. The accepted scale of film density measurement is the logarithm of the reciprocal of the fraction of incident light to transmitted light as given by the following equation:

$$D = \log \frac{I_0}{I_t}$$

H0401920

Where:

D = film image density.

I_0 = original light intensity falling upon one surface of film.

I_t = light intensity transmitted through the film.

For example, an increase in the amount of blackening from one area of a particular film to another, reduces the proportion of the incident light transmitted from 50 to 25-percent would cause the film density to change from 0.3 to 0.6.

6.7.5.1 More examples of typical relationships between light transmission and density are in (Table 6-3). A typical density used in practical radiography is 2.0 and represents 1-percent transmittance. Density is measured with densitometers and test strips (paragraph 6.5.5.1).

6.7.6 Logarithms for Density and Exposure Calculations. Logarithms are used extensively in X-ray exposure calculations and in the measurement of X-ray film density. Radiographers SHALL be sufficiently familiar with logarithms so they can perform some simple calculations. A brief review of logarithms and their use is therefore included here. More detail can be found in various handbooks and intermediate mathematics texts. Logarithms are used because they provide a convenient method of handling very large ranges of numbers, and they reduce calculations involving multiplication and division to addition and subtraction. The logarithm is the power (or exponent) to which the base must be raised to give the original number. Logarithms MAY be taken from any base; however, most calculations in radiography involve either the base 10 or the base e (2.718). Logarithms to the base 10 are indicated by “log x,” and logarithms to the base e are denoted by “ln x.” For the moment, let us consider logarithms to the base 10: log 100 = 2, because $10^2 = 100$. Similarly, the logarithm of 1,000 is 3 or: log 1,000 = 3, since $10^3 = 1{,}000$. The logarithms of all numbers that are integer powers of 10 (e.g., 10, 100, 1,000, etc.) are whole numbers (1, 2, 3, etc.). Logarithms of other numbers are decimal numbers and are found in tables of logarithms or calculated on some hand calculators. A table of four-place logarithms to the base 10 is given in (Table 6-22). The logarithm is made up of two basic parts, the “characteristic,” which is the number before the decimal point and the “mantissa,” which is the number after the decimal point. The characteristic indicates the order of magnitude of the number x; for example, numbers 10 through 99 have a characteristic of 1. Characteristics for other ranges are given in (Table 6-21). The digits of the number determine the mantissa. In (Table 6-22), the mantissa of 328, for example, find by going to the number 32 along the left hand side and looking across that row under the column marked “8.” We see in the table the mantissa of 328 is given as 5159. What is the logarithm of 328? It can be seen the characteristic of 328 would be 2 (Table 6-21). Therefore, log 328 is equal to 2.5159.

Table 6-21. Characteristics of Logarithms

Number	Characteristic
1	0
10	1
100	2
1,000	3
10,000	4

NOTE

The value of the characteristic is one less than the number of digits in the number.

Table 6-22. Four-Place Logarithms to the Base 10

N	0	1	2	3	4	5	6	7	8	9		0	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
16	2041	2048	2095	2122	2148	2175	2201	2227	2253	2279	61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
41	6128	6138	6140	6160	6170	6180	6191	6201	6212	6222	86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
43	6335	6345	6355	6365	6375	6484	6493	6503	6513	6522	89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
50	6990	6908	7007	7016	7024	7033	7042	7050	7059	7067	95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996
N	0	1	2	3	4	5	6	7	8	9	N	0	1	2	3	4	5	6	7	8	9

*Interpolation in this section of the table is inaccurate.

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Table 6-23. Antilogarithms

	0	1	2	3	4	5	6	7	8	9
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476
.17	1479	1483	1486	1489	1493	1496	1600	1503	1507	1510
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858
.27	1862	1866	1871	1875	1879	1884	1888	1892	1807	1901
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812
.45	2818	2825	2831	2838	2844	2851	2858	2804	2871	2877
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944
.47	2951	2958	2965	2972	2979	2985	2992	2993	3006	3013
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155
	0	1	2	3	4	5	6	7	8	9

	0	1	2	3	4	5	6	7	8	9
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793
.58	3802	3811	3819	3828	3837	3936	3945	3954	3963	3972
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610
.75	5623	5630	5649	5662	5675	5689	5702	5715	5728	5741
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977
	0	1	2	3	4	5	6	7	8	9

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Table 6-24. Effect of Relative Exposure on Film Sensitivity

Change in Relative Exposure	Change in Density
0.5 to 1.0	0.3 to 0.7
1.0 to 1.5	0.7 to 1.5
1.5 to 2.0	1.5 to 3.0

6.7.6.1 Logarithms provide a convenient method of multiplying and dividing. To multiply two numbers, you take the logarithms of both numbers and add them to get the logarithm of the product. To obtain the product, you then take the antilogarithm of this sum. The antilog is the inverse function of the log. In other words, the antilog of x is equal to 10^x. The antilogs for mantissas of 0.000 to 0.999 are listed in (Table 6-23). The value of x is then obtained by properly placing the decimal point according to the characteristic of the sum of the logarithms.

Example: Multiply 20 times 8 using logarithms.

(1) Take the log of 20: log 20 = 1.3010

(2) Take the log of 8: log 8 = 0.9031

(3) Take the sum of these logarithms: 1.301 + 0.9031 = 2.2041

(4): Take the antilog of the sum:

The antilog of 0.2041 = 1600

The characteristic of 2 indicates a number between 100 and 999.

Therefore the answer is 160.

In this example, the regular mathematical calculation is simple, however, with very large numbers, the use of logarithms significantly simplifies calculation.

6.7.6.1.1 Division is accomplished by taking the difference between the logs of the two numbers.

Example: 6/73 = antilog (log 6 - log 73).

6.7.6.2 In radiography, logarithms find particular use in the preparation of exposure charts and in film characteristic curves which plot film density against relative exposure. Logarithms to the base 10 MAY be converted to natural logarithms by the equation ln x = 2.3 log x.

6.7.7 Material Contrast Factor. In consideration to radiation absorption, the most important variable that can be controlled by the radiographer in industrial X-ray inspection is the kilovoltage. The amount of radiation absorbed by the part being inspected depends on the atomic number, density, and thickness of the material. The radiographer cannot change these factors, but can change the energy of radiation in the attenuation equation:

In $(-\mu x) = I_T/I_0$,

we see the linear attenuation coefficient (μ) can be changed by changing radiation energy. This in turn will change the ratio I_T/I_0, or the percent radiation transmitted through a part of thickness, x. In industrial radiographic applications, the difference in thickness (often due to discontinuities) is the actual parameter from which interpretation is made. Therefore, the greater the change in the radiation transmitted due to a particular change in material thickness, the more obvious is the thickness change revealed in the final image. This radiation difference due to material thickness change is called the material contrast. The material contrast is a function of the absorption characteristics of the part being inspected and the radiation energy level. When measurements have been made and a numerical value has been established, it is called the material contrast factor.

6.7.8 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:

where: $$U_g = Ft/d$$

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F = maximum dimension of the focal spot

$_t$ = distance from the source side of the test object to the film

d = distance from the source to object

6.7.8.1 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.

6.7.8.2 Suppose a specimen having a maximum thickness of 1.5-inchs (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).

6.7.9 Heel Effect. For simplicity's sake, most literature states the intensity of radiation of the primary beam is constant, this is not quite correct. There is a variation in intensity due to the angle at which X-rays are emitted from the focal spot. This variation in intensity is called the heel effect (Figure 6-12).

6.7.9.1 The intensity of the beam diminishes rapidly from the central ray toward the anode side and increases slightly toward the cathode side. In general practice the heel effect is not evident, provided the maximum lateral dimension of the object to be radiographed is less than half the source-to-film distance (SFD). In other words, coverage of a 14 x 17-inch film requires an SFD of approximately 36-inches to provide a field intensity of plus or minus 12-percent over the entire film. This is based upon using part of the radiation field within a cone having a 30-degree included angle. Remember, the source for an X-ray tube is the focal spot. For a single exposure of larger areas requiring multiple films, the SFD must be increased. For example, to determine the SFD to cover an area that fits within a circle, which has a diameter of 56-inches, do the following calculation:

$$SFD = \frac{R}{Tan\theta}$$

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θ equals the half-angle of the cone = 15-degrees

Tan 15 = 0.268

R = one-half the diameter = 28-inches

$$\text{Therefore, SFD} = \frac{28}{0.268} = 104.5\text{-inches}$$

If the SFD is limited, the radius of beam coverage can be calculated by rearranging the formula:

R = Tanθ X SFD

Using the same cone half-angle of 15-degrees, Tanθ = 0.268

Assume the SFD is limited to 60-inches

R = 0.286 X 60 = 17-inches

If the radiographer must radiograph an area larger than a 34-inch diameter circle, more than one setup must be used.

SECTION VIII AIR FORCE RADIOGRAPHIC INSPECTION SAFETY

6.8 SCOPE AND PURPOSE OF RADIATION PROTECTION.

6.8.1 General.

NOTE

Each branch of service has specific requirements governing radiation safety. Navy and Marine Corp radiographic operations are governed by NAVSEA S0420-AA-RAD-010. Air Force radiographic operations are governed by paragraphs 6.8.2 - 6.8.8.4.9. Army radiographic operations are governed by paragraphs 6.9.1- 6.9.9.10.

a. This section is intended to serve as a guide to the safe use of X-ray and sealed gamma-ray sources for industrial radiographic purposes. It provides guidance to persons who use these sources and to others who may have a responsibility for their use. It recommends operational procedures, personnel controls, and radiation protection practices to eliminate needless exposure of personnel to ionizing radiation. In addition, it provides criteria for the guidance of qualified personnel for the design or modification of industrial radiographic X-ray and sealed gamma-ray installations.

b. The word "SHALL" identifies requirements necessary to meet the standards of protection of this section. The word "SHOULD" indicates advisory recommendations to be applied when practical.

c. The provisions of this section incorporate provisions of Title 10, Code of Federal Regulations, Parts 19-21, and 34, Air Force Instructions (AFI) 21-101, 48-148, 91-203, AFMAN 48-125, and miscellaneous policy statements. Although the provisions incorporated herein are correct at the time of issuance, users SHOULD review these federal, Air Force regulations periodically to assure compliance with current regulations. This section is based in part on recommendations contained in National Institute of Standards and Technology (NIST) (formerly National Bureau of Standards) Handbook 114, *General Safety Standard for Installations Using Non-Medical X-ray and Sealed Gamma Source, Energies up to 10 MeV*, and in National Council on Radiation Protection and Measurement (NCRP) Report No. 116, *Limitation of Exposure to Ionizing Radiation, and NCRP Report No. 51, Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities.* Exposure limits specified herein are derived from those specified in federal regulations, particularly Title 10, Code of Federal Regulations, (10 CFR) Part 20. In the event of conflict, the more restrictive limits apply.

6.8.2 Responsibilities.

6.8.2.1 Installation Radiation Safety Officer (RSO).

a. The Installation RSO is responsible for initiation, supervision, and execution of the Installation Radiation Protection Program. This program provides for routine health physics surveillance of all operations involving the use of ionizing radiation to ensure safe practices. Consultant services of qualified individuals are available at USAFSAM/OEC, 2510 Fifth St, Area B-Building 840, Wright-Patterson AFB OH 45433, DSN 798-3764, Commercial 937-938-3764 and ESOH Service Center 888-232-3764 to assist the Installation RSO with the radiation protection program.

b. The Installation RSO annually performs a comprehensive assessment of all aspects of the Radiation Safety Program and operational procedures. The RSO will determine the need for additional surveys, safety precautions, administrative or physical controls. The RSO will document findings, recommendations, and restrictions and forward copies to the Unit Commander and the radiography supervisor.

c. The Installation RSO provides As Low as Reasonably Achievable (ALARA) training in accordance with 10 CFR 19 and 29 CFR 1910 to assist radiography supervisors.

d. The Installation RSO surveys exposures in controlled and uncontrolled areas as required by paragraph 6.8.4.6.

e. The Installation RSO assists in any investigations of overexposures, abnormal exposures, or incidents involving radiation exposures resulting from NDI operations.

f. The Installation RSO ensures contract radiography services are conducted in accordance with applicable state and federal regulations, and the requirement of this technical order.

g. The Installation RSO establishes appropriate action levels for personnel dosimetry results, such that, if this level is exceeded an investigation will result to assess the cause and minimize future occurrences.

h. The Installation RSO assists deploying radiographers with determining whether a comprehensive Radiation Safety Program exists at the deployed location and what steps, if any, need to be taken prior to deployment. The RSO will assist NDI Laboratory Supervisor in contacting the appropriate offices to perform scatter surveys or annual assessments if required. The Installation RSO in the AOR (or COCOM/MAJCOM BEE affiliated with AOR) will have AF radiation safety oversight for the AOR.

6.8.2.2 Unit Commander. The Unit Commander ensures that the Nondestructive Inspection Laboratory, its facilities, and the radiation protection program fulfill the requirements of AFI 21-101, AFI 48-148, AFMAN 48-125, and this document.

6.8.2.3 NDI Laboratory Supervisor. The NDI Laboratory Supervisor will normally be delegated the responsibility for administering all industrial radiography operations and ensuring compliance with all aspects of the Radiation Safety Program. Normally, this individual is appointed by the Unit Commander as the Unit Radiation Safety Officer (RSO). This person SHALL:

6.8.2.3.1 Determine and periodically check the competency of industrial radiographers.

6.8.2.3.2 Maintain control of all industrial radiographic equipment.

6.8.2.3.3 Ensure newly assigned workers are provided initial radiation safety training (ALARA training) and thereafter, receive annual refresher training.

6.8.2.3.4 Develop and maintain current radiological safety operating procedures. These procedures and instructions should describe the actions or steps necessary to safely conduct a particular task, and shall be maintained with the radiation producing equipment. These procedures and instructions SHALL be clearly written and will be annually reviewed to ensure they are kept current.

6.8.2.3.5 Develop and maintain current emergency procedures. These emergency procedures should not be imbedded within a document, but rather should be stand-alone and easily located. They SHALL describe the actions required to be followed in the event of a mishap or emergency and SHALL specify, but not be limited to, the following:

a. Individuals to contact in the event of a suspected overexposure. As a minimum, list the NDI Laboratory supervisor, Unit RSO, Installation RSO, and the Unit Safety Officer/NCO.

b. Forms to be completed (e.g., AF 190, AFTO 125 or equivalent).

c. Where to take the individual for treatment/observation, including the physical address of the facility.

d. How to approximate the degree of exposure.

e. What to do with direct reading dosimeters/TLDs.

6.8.2.3.6 Maintain, as a minimum, two separate utilization log books; one for shielded areas and the other for unshielded areas (if areas not utilized, a book is not required). The unshielded log SHALL be subdivided to clearly identify each unshielded area and include its own set of utilization forms for each individual area (AFTO Form 115 and AFTO Form 125 or approved equivalent). All Utilization log books SHALL contain as a minimum:

a. Current radiation protection survey.

b. Operating procedures approved by the Installation RSO.

c. Emergency procedures approved by Installation RSO.

d. AFTO forms 125, 125A, and 115.

e. Other applicable information for the local job site.

6.8.2.3.7 Procure and maintain adequate radiation survey instruments and personnel monitoring devices. Establishes robust radiation survey instrument and personnel monitoring device calibration programs, which including a staggered calibration schedule.

6.8.2.3.8 Maintain exposure devices, radiography facilities, and associated equipment.

6.8.2.3.9 Ensure personnel are entered into the personnel monitoring program and promote proper wear and use of devices.

6.8.2.3.10 Assume control and institute corrective actions in emergency situations.

6.8.2.3.11 Investigate, in coordination with the Installation RSO, the cause of incidents that result in suspected overexposures and unnecessary radiation exposures and determine necessary action to prevent recurrence and maintain all radiation exposures "As Low As Reasonably Achievable" (ALARA).

6.8.2.3.12 Ensure compliance with the requirements of 10 CFR 34 when conducting or overseeing contract operations involving sealed sources.

6.8.2.3.13 Ensure personnel comply with all mandatory operating procedures as established in this TO and all locally generated safety operating instructions.

6.8.2.3.14 Determines whether a comprehensive Radiation Safety Program exists at deployed locations and what steps, if any, need to be taken prior to deployment. With assistance from the home-station Installation RSO, contacts the appropriate offices to perform scatter surveys or annual assessments if required.

6.8.2.4 <u>Radiographer in Charge</u>. The radiographer in charge (RIC) is a qualified radiographer and SHALL be identified prior to performing the inspection. This person is normally senior in grade and will ensure all radiation safety monitors and radiation safety monitor assistants understand their duties while performing the inspection. RIC duties include:

a. Supervision of radiation safety monitors and assistants to ensure a safe inspection.

b. Following all mandatory operating procedures as established in this TO and all locally generated safety operating instructions.

c. Ensuring compliance with the Radiation Protection Survey and all approved operating procedures.

d. Ensuring utilization logs are correctly filled out.

6.8.2.5 <u>Radiation Safety Monitors</u>. Radiation safety monitors are qualified radiographers who work under the direct supervision of the radiographer in charge. Duties include:

a. Operating radiation survey meters.

b. Establishing location of radiation barriers.

c. Setting up personnel barriers.

d. Preventing unauthorized personnel from entering a radiation area.

e. Recording radiation intensity reading at barriers.

f. Recording doses from direct reading dosimeters.

g. Utilizing dosimetry devices as specified by the Radiation Safety Officer.

h. Performing other duties as directed by the radiographer in charge.

6.8.2.5.1 <u>Radiation Safety Monitors Assistants</u>. Radiation Safety Monitor Assistants are those persons who assist the radiographer and/or the Radiation Safety Monitor in preventing unauthorized access into radiographic inspection areas. Safety assistants SHALL NOT be authorized inside the radiation area during irradiation. Assistants will be stationed outside the radiation area, but in such a location as to allow them to monitor the barrier and prevent barrier penetration. Assistants SHOULD always be in direct vision or contact with the safety monitor or radiographers to effect radiation termination if required. If this is not possible, adequate means of communication SHALL be specified by the Installation RSO during a survey of the radiographic inspection area and operation. Adequate means of communication MAY include, but not limited to two-way radios, whistles, electronic/propellant activated noise alarms, or ultrasonic/infrared intrusion barriers. Assistants will receive their instructions directly from the Radiographer in Charge or the Radiation Safety Monitor, but not from the other assistant. Training requirements are located in paragraph 6.8.2.5.1.1. Duties include:

a. Operating radiation survey meters.

b. Assisting with setting up personnel barriers.

c. Preventing unauthorized personnel from entering a radiation area.

d. Wearing a TLD and/or EPD if specified by the Installation Radiation Safety Officer.

6.8.2.5.1.1 Training for Radiation Safety Monitor Assistants. Assistants SHALL receive, as a minimum, radiation safety training covering the following items: properties of X-ray and gamma radiation, hazards of excessive exposure to radiation, methods of measuring radiation, radiation protection, and operation of specific measurement devices that will be used. This training SHALL be conducted by a qualified radiographer, Bioenvironmental Engineer or Radiation Safety Officer and documented in the individual's training record or the Maintenance Management Information Control System (MMICS). Refresher training SHALL be conducted annually.

6.8.3 Qualifications and Training of Industrial Radiographers.

6.8.3.1 Qualifications of Civilian Industrial Radiographers. See Appendix A for information regarding qualification and certification of Air Force civilian personnel.

6.8.3.2 Industrial Radiographic Safety Training.

6.8.3.2.1 Initial Training. All industrial radiographers SHALL complete an approved course of instruction in the use of industrial X-ray equipment, which includes radiation hazards control, and demonstrate an understanding of acceptable practice. As a minimum, each radiographer SHALL be instructed in those portions of the following subjects, which applies to industrial radiographic operations and demonstrate understanding thereof:

a. Fundamentals of Radiation Safety

(1) Characteristics of X-ray and Gamma Radiation.

(a) Electromagnetic Spectrum.

(b) Properties of X-ray and Gamma Radiation.

(2) Interaction of Radiation with Matter.

(a) Ionization.

(b) Photoelectric Effect.

(c) Compton Effect.

(d) Pair Production.

(3) Attenuation of Radiation.

(a) Exponential Function.

(b) Half-Value Layer (HVL) and Tenth-Value Layer (TVL).

(c) Filtration.

(d) Shielding.

(4) Inverse Square Law.

(5) Radiation Scattering.

(a) Secondary.

(b) Sky Shine.

(6) Units of Radiation Measurement.

(a) Roentgen.

(b) Radiation Absorbed Dose (rad), Roentgen Equivalent Man (rem).

(c) Gray (Gy), 1 Gy = 100 rad; Sievert (Sv), 1 Sv = 100 rem.

(d) Exposure Rate and Dose Rate.

(7) Quantity of Radiation.

(a) Curie, Becquerel; 1 Curie (Ci) = 3.7×10^{10} Becquerel (Bq).

b. Hazards of Exposure to Radiation.

(1) Naturally Occurring Radiation.

(2) Biological Effects.

(a) Mechanism of Tissue Damage.

(b) Variables Influencing Radiation Doses.

(c) Somatic and Genetic Effects.

(d) Occupational Dose Limits.

(e) Non-Occupational/Public Exposure Limits.

c. Radiation Exposure Records.

(1) Prior Exposure History.

(2) Reports of Radiation Exposures.

d. Radiation Measurement.

(1) Principles of Radiation Measurement.

(a) Energy Dependence.

(b) Response Time.

(c) Ionization Chamber Instruments.

(d) Geiger-Mueller Instruments.

(2) Direct Reading Dosimetry.

(a) Use of TLD (or film) Badges.

(b) Pocket Ion Chambers (Pocket Dosimeters).

(c) Electronic Dosimeters (Indications and Alarms).

(3) Survey Meters.

(a) Meter Differences.

(b) Meter Operation and Calibration.

(c) Meter Capabilities and Limitations.

(d) Survey Techniques.

e. Radiation Protection.

(1) Control of Radiation Dose.

(a) Dose Rate Factors (X-ray and/or Gamma Radiation).

(b) Time, distance, and shielding.

(c) ALARA principle.

(2) Safety Equipment for Unshielded Operations.

(3) Safety Equipment for Shielded Operations.

f. Practical Application Requirements.

(1) Choosing Radiographic Equipment to Use.

(2) Radiation Exposure in Shielded Operations.

(a) Accidental Exposure.

(b) Beam Orientation.

(c) Location of Operating Controls.

(d) Checkout of Safety Devices.

(3) Radiation Exposure in Unshielded Operations.

(a) High (and very high) Radiation Areas.

(b) Placement of Barriers.

(c) Measurement of Exposure Rates.

g. Inspection and Maintenance Performed by Radiographers.

(1) Interlocks.

(2) Warning Devices.

(3) Radiography Equipment/Facilities.

h. Emergency Procedures.

i. Case Histories of Radiography Accidents.

j. Regulations.

(1) Applicable Military Service.

(2) Federal.

(3) State.

(4) Local.

6.8.3.2.2 Annual/Refresher Training. Annual/refresher radiation safety training SHALL include the items identified below and be annotated on AF Form 55, or approved equivalent documentation method.

a. Deficiencies identified during periodic quality audits of the radiation protection program and unit training inspections.

b. Review of accidents and unusual events.

c. Review of dosimetry results (emphasizing dose reduction and ALARA).

d. Review of basic radiation safety principles, operations, emergency procedures, new safety regulations, license requirements, and other pertinent information.

6.8.3.2.3 Training for Users of Radiographic Source Materials. These additional requirements SHALL be completed when using gamma emitting radiographic sources.

NOTE

If personnel do not use, possess, or provide direct contract oversight of gamma emitting radiographic sources, 10 CFR training requirements are not required.

a. If a radiographer or a radiographer's assistant has not participated in a radiographic operation for more than three months since the last training inspection, that individual's performance SHALL be observed and recorded the next time the individual participates in a radiographic operation.

b. Retain the training inspection records of the performance of radiographers and radiographer's assistants (for RSO compliance inspection purposes) for 3 years.

c. Topics specified in 10 CFR 19.12 (e.g., proper storage, transfer, and use of radiation sources, public health problems associated with use of the radiation sources, precautions, or procedures to minimize radiation exposure and the purposes and functions of protective devices employed, the responsibility to promptly report any condition which may lead to unnecessary radiation exposure, actions to take in the event of malfunction of protective devices or other emergency conditions, and exposure reports which workers may request).

6.8.4 Radiation Protection.

6.8.4.1 As Low As Reasonably Achievable (ALARA). All exposures SHALL be kept "As Low As Reasonably Achievable." Exposure to radiation, even at very low dose rates, is permissible only when the benefit derived from such exposure exceeds the risk incurred. Each individual SHALL strive at all times to maintain all radiation exposures "As Low As Reasonably Achievable." Individuals SHALL NOT ever knowingly expose themselves, or cause others to be unnecessarily exposed to radiation.

6.8.4.2 Radiation Dose Limits.

6.8.4.2.1 Occupational Dose Limits.

6.8.4.2.1.1 Dose Limits for Occupationally Exposed Adults. The annual peacetime ionizing radiation dose received by occupationally exposed adults SHALL NOT exceed the following:

a. An annual limit, which is the more limiting of:

(1) The total effective dose equivalent (TEDE) of 5 rem (50 mSv); or

(2) The sum of the deep dose equivalent from external sources and the committed dose equivalent to any individual organ or tissue, other than the lens of the eye, of 50 rem (500 mSv).

b. The annual limits to the lens of the eye, to the skin, and to the extremities, which include:

(1) An eye-lens dose equivalent of 15 rem (150 mSv); and

(2) Shallow-dose equivalent to the skin or to any extremity of 50 rem (500 mSv).

6.8.4.2.1.2 Dose Limit for Minors. The annual occupational dose limits for minors (less than 18-years of age) are 10% of the annual occupational dose limits specified for adults.

6.8.4.2.1.3 Dose Limits for Pregnant Females (Embryo/Fetus). The radiation dose to the embryo/fetus of an occupationally exposed pregnant female SHALL NOT exceed 0.5 rem (5 mSv) for the entire pregnancy. Additionally, efforts SHOULD be made to maintain the exposures ALARA and relatively uniform, that is, free of substantial dose rate variations above monthly exposure rates. Refer to AFMAN 48-125 for details.

6.8.4.2.2 Dose Limits for Individual Members of the Public. The total effective dose equivalent to members of the public SHALL NOT exceed 100 mrem (1 mSv) in a year, above background, from all radiation sources under control of the installation activity commander. Additionally, the dose in any unrestricted area from external radiation sources such as industrial X-rays SHALL NOT exceed 2 mrem (0.02 mSv) in any 1 hour.

6.8.4.2.3 Multiple Sources of Radiation. When any individual is likely to be exposed to radiation from more than one source simultaneously, or at different times, the protection associated with each source SHALL be increased so the total dose received by any one person from all sources SHALL NOT exceed applicable exposure limits. Additionally, the TEDE limits, the sum of external and internal radiation exposure, requires special consideration be given to ensure the combination of internal and external exposure does not exceed limits.

CAUTION

Occupationally exposed personnel SHALL NOT wear their dosimetry devices while undergoing medical or dental X-ray procedures.

6.8.4.2.4 Medical, Dental Diagnostic, or Therapeutic, and Naturally Occurring Radiation. Radiation exposures resulting from necessary medical, dental diagnostic, or therapeutic radiation procedures SHALL NOT be included in the determination of the radiation exposure status of the individual concerned. Similarly, exposures resulting from naturally occurring sources or from sources in consumer products, SHALL NOT be included in determining an individual’s dose.

6.8.4.3 Personnel Radiation Monitoring Requirements.

NOTE

A monthly wearing period SHALL be implemented for thermoluminescent dosimeters (TLD) issued to minors and to pregnant women. Criteria requiring individual dosimetry are defined in: Title 10, Code of Federal Regulation, Parts 20 and 34; and AFMAN 48-125. See paragraph 6.3.10.2 for more detailed information regarding TLDs and EPDs.

6.8.4.3.1 Criteria. Use of personnel monitoring devices is mandatory for each individual who MAY be exposed to ionizing radiation during the normal course of their duties or occupation according to the following criteria.

6.8.4.3.1.1 TLDs are the primary dosimetry device as the legal record of radiation exposure in the Air Force. For more information, see paragraph 6.3.10.2.1.

6.8.4.3.1.2 Occupationally exposed adults who may reasonably be expected to receive an annual dose in excess of 100 mrem (1 mSv).

6.8.4.3.1.3 Occupationally exposed adults entering any high or very high radiation area (regardless of the anticipated magnitude of exposure).

6.8.4.3.1.4 Declared pregnant women, are to be monitored for the entire period of pregnancy IAW AFMAN 48-125.

6.8.4.3.1.5 All minors who may reasonably be expected to receive an annual radiation dose in excess of 50 mrem (.5 mSv) total effective dose equivalent (TEDE) to the whole body.

6.8.4.3.1.6 Other individuals as necessary for the effective management of the ALARA program, such as radiation safety monitors supporting unshielded radiography operations who do not otherwise require dosimetry devices, will be provided with dosimetry devices to include TLDs if their radiation dose would reasonably be expected to exceed the general public exposure limit of 100 mrem (1 mSv) TEDE per year or 2 mrem in one hour, above background.

6.8.4.3.1.7 Individuals not meeting any of the criteria contained herein should not be enrolled in, or be needlessly continued in the dosimetry program except on a case-by-case basis. If in doubt, Installation RSOs SHOULD enroll individuals in the dosimetry program for a limited duration, and base continued use of dosimetry on actual exposures received.

6.8.4.3.2 Wear of Whole-Body Dosimeters. TLD badges, used to provide a permanent record of the cumulative exposure to the whole body, SHALL be worn on the trunk (below the shoulders and above the hips) outside of clothing, on the portion or area of the body nearest the radiation source. The dosimeter window SHALL face out from the body.

6.8.4.3.3 Wearing Additional Dosimeters. If radiation exposure to the eyes, extremities, or skin is likely to be significantly different from whole body exposure, additional TLDs (collar, wrist, ring, etc.) SHALL be worn to document the actual exposure received by these areas. (Note: If eye protection providing at least 700 milligram per square centimeter thickness is used, the Installation RSO SHALL annotate this fact on the dosimetry issue listing beside the individual's name so the correct eye exposure can be noted.)

6.8.4.3.4 Storage of Monitoring Devices. TLD badges and dosimeters SHALL be centrally stored, located in a low background radiation area, in an environment free from excessive temperature and humidity. The TLD badges and pocket dosimeters SHALL be returned to the rack at the end of each work period.

6.8.4.3.5 Recording Readings of Direct Reading Dosimeters. Direct reading dosimeters SHALL be read and doses recorded daily in the utilization log. Record of these exposures SHALL be maintained as required by AFRIMS. Air Force units will document dosimeter readings on AFTO Form 115. USAFSAM will host the WebREMS program, an Internet-based application which will issue and read all electronic personal dosimeters. All doses will be stored in a central database at USAFSAM for correlation to corresponding TLD doses and dose reporting. WebREMS may be used in lieu of the AFTO Form 115 Utilization Log.

6.8.4.4 Dose Reporting and Recording Procedures.

6.8.4.4.1 Dose Record Custodian.

a. Commanders SHALL designate in writing an individual to serve as the dose record custodian to be responsible for preparing and maintaining the records of occupational exposure to ionizing radiation.

b. This individual MAY be the medical/health records custodian, Installation RSO, or another individual who prepares the dosimetry report and controls dosimeter issuance and recovery.

6.8.4.5 Emergency Situations and Suspected Exposures Above Limits.

6.8.4.5.1 Emergency Situations. An exposure above occupational limits shall be suspected, and an emergency situation shall be considered to exist, when:

a. A direct reading dosimeter (EPD) registers 500 mrem (5 mSv) or more (10 CFR 34.47) or any individuals' direct reading dosimeter exceeds maximum scale.

b. The radiography supervisor, regardless of dosimeter readings, believes an overexposure has occurred, either to another radiographer or any person(s) not directly involved in the radiographic operation.

NOTE

Dosimeters determined to exceed maximum scale reading, or drift, prior to the first actual X-ray production of the shift, SHALL be considered defective. These dosimeters SHALL be withdrawn from service and turned into the servicing TMDE or PMEL calibration facility for evaluation.

6.8.4.5.2 Actions for Emergency Situations and Suspected Exposures Above Limits. If an exposure above occupational limits is suspected, an emergency situation SHALL be considered to exist. The following actions SHALL be taken:

NOTE

In those instances where the Installation Bioenvironmental Engineering services cannot be notified, or is not locally available, the control TLD and the TLD of the suspected overexposed individual SHOULD be sent via AIR MAIL; from overseas or FIRST CLASS from CONUS to: USAFSAM/OEA, 2510 Fifth Street, Area-B, Bldg. 840, Wright-Patterson AFB, OH 45433, DSN 798-3764.

a. Immediately cease all radiography operations and report the incident to the Immediate Supervisor.

b. Obtain the name, social security number, and organization of all personnel suspected of overexposure.

c. Notify the Installation RSO or Bioenvironmental Engineering Services of the suspected overexposure. Prepare to turn in the affected individual's TLD badge and the control badge for immediate processing, as directed. The occupational health physician in consultation with the RSO, will determine the need for medical treatment.

d. Read and record direct reading dosimeters.

e. Determine and record exact position and duration of exposure.

f. Update the Industrial Utilization Log as needed. Make sure the detailed sketch of the area includes the positions of personnel suspected of being overexposed. Record all other pertinent data about the incident (x-ray apparatus position, kV, mA, and direction of primary beam).

g. Obtain a signed statement from the exposed individual(s) of actions resulting in (or contributing to) the exposure.

h. After completion of the above phase of the investigation and in the case of non-monitored personnel being exposed, the following procedure can be used by the RSO or radiographers to quantify personnel exposure:

(1) Re-establish the exact position(s) of all objects at the time of the accident.

(2) Place suitable dosimetry devices at the position of the exposed individuals.

WARNING

Survey meters SHALL NOT be used, unless they have an integrate mode, or remote cameras are available to observe the instruments, since personnel using them will be unnecessarily exposed to radiation.

(3) Expose the dosimeters, operating the gamma-ray or X-ray apparatus at the same technique as occurred during the incident, with the time of the exposure equal to the time personnel indicated they were present in the area or enclosure.

NOTE

If personnel were moving within the enclosure during the accident exposure, the dosimeters SHALL be placed at the position closest to the X-ray apparatus and at various points of his travel.

i. A complete report of the incident SHALL be prepared by the Unit RSO and NDI Laboratory Supervisor (if not the Unit RSO, with signed statements from all operators and personnel exposed indicating their concurrence with the report. A copy of this report SHALL be provided to the Installation Radiation Safety Officer for review and filing in the industrial workplace case file. Additionally, copies will be forwarded to Air Force NDI Office, AFLCMC/EZPT-NDIO, aflcmc-ezpt-ndio@us.af.mil; DSN 339-4931, and to USAFSAM/OEA, 2510 Fifth Street, Area-B, Bldg. 840, Wright- Patterson AFB, OH 45433, DSN: 798-3764.

j. Assure a new control badge is obtained, and designated as a replacement for the control badge submitted for analysis.

6.8.4.5.3 Administrative Assessment of Dose. If a dosimeter is lost, damaged, or if the occupationally-exposed individual's TEDE or CEDE cannot otherwise be determined, the Installation RSO SHALL determine and assign an administrative dose pursuant with AFI 48-148 and AFMAN 48-125, and report the assigned dose to USAFSAM/OEA for inclusion in the individual's permanent dosimetry file.

6.8.4.6 Radiation Protection Surveys.

NOTE

Radiation Protection Surveys (Scatter Surveys) of all Shielded and Unshielded x-ray installations SHALL be performed by a fully qualified Health Physicist, Bioenvironmental Engineer, Nuclear Medicine Science Officer, and/or qualified Radiological Health Technician before the installation is placed into routine operation. A survey SHALL be re-accomplished whenever equipment (e.g. type of tubehead, interlock, etc.), or administrative controls (e.g. building modifications, locations of monitors, etc.) have changed.

6.8.4.6.1 Definition. As used in this section, radiation protection survey means an evaluation of potential radiation hazards associated with the use of industrial X-ray and gamma equipment, under specified conditions, when used in shielded and/or unshielded installations. When appropriate, such evaluation includes inspection of equipment, examination of its location with reference to controlled and uncontrolled areas in the immediate environment, and measurements of exposure levels.

6.8.4.6.2 Consultant Assistance. Consultant services of qualified health physicists are available to assist Installation RSOs. See paragraph 6.8.2.1. (a).

6.8.4.6.3 Local RSO Involvement. An assessment of shielded installations SHALL be made by, or under the direction of the local Installation RSO initially before use. Assessments shall also be used before changes are made in shielding, operation, workload, equipment ratings or occupancy of adjacent areas when these changes, in the opinion of the RSO, can adversely affect radiation protection. If supplementary shielding is installed as a result of the radiation protection survey or re-evaluation, another survey SHALL be made to confirm the adequacy of the shielding after the modification.

6.8.4.6.4 Survey Conditions. In evaluating the results of the survey, consideration SHALL be given to actual operating conditions, including workload, use factor, occupancy factor, and attenuation of the useful beam provided by objects permanently in the path of the useful beam.

6.8.4.6.5 Identification of Radiation Hazards. Radiation hazards found in the course of a survey of any type installation SHALL be eliminated before the installation is used routinely. If the design and/or approved use of a shielded installation depend upon restrictions on the use factor of any primary barrier, it must be verified these restrictions are actually observed.

6.8.4.6.6 Inspection of Safety and Warning Devices.

WARNING

All interlock, "ON/OFF" beam control mechanisms, safety and warning devices, remote monitoring systems, etc., SHALL be inspected for proper operation PRIOR to initial operation, on each shift, when X-ray equipment will be used. A log initialed by the person making these inspections SHALL be maintained with the utilization log. For units who do not use their facilities on a regular basis, Interlocks SHALL be subjected to detailed operational testing at intervals not to exceed six-months. Any malfunctioning devices SHALL be appropriately serviced prior to use and reinspected to verify proper operation.

6.8.4.6.7 Compliance in Uncontrolled Areas. Whenever, in the opinion of the RSO or the radiographer, there is a reasonable probability a person in an uncontrolled area, adjacent to any type of radiation installation, may receive more than 2 mrem (0.02 mSv) in any one hour, or 100 mrem (1 mSv) in any calendar year, above background, then one or more of the following courses of action as determined by the RSO SHALL be taken to ensure no person will receive exposure in excess of the basic radiation protection standard:

a. Use personnel or area monitoring devices to estimate the exposure received by occupants of the area, applying appropriate occupancy factors for each assessed location (coordinate with USAFSAM/OEA, 2510 Fifth Street, Area-B, Bldg. 840, Wright-Patterson AFB, OH 45433, DSN: 798-3764).

b. Add supplementary shielding to the protective barriers to ensure conformity with protective barrier recommendations contained in this publication.

c. Restrict use of the equipment (workload (on-time), kVp, or use factor).

d. Restrict occupancy of the area.

6.8.4.6.8 Shielded Installation. A radiation protection survey SHALL be made before the installation is placed into routine operation. The installation SHALL be inspected to verify adequacy of shielding, radiation protective devices and operational procedures.

WARNING

- The use of engineering design controls, such as additional shielding, SHALL take precedence over operational (administrative) controls.
- Surveys SHALL be performed while the x-ray apparatus is operating at the maximum kilovoltage and milliamperage required for the Tube Warm-up Procedure.

6.8.4.6.8.1 When surveying shielded installations, the radiation exposure measurements SHALL be made in all adjacent areas accessible to personnel. The measurements SHALL be made under facility design conditions of operation that will result in the greatest exposure at the point of interest. X-ray apparatus SHALL be operated at the maximum kilovoltage (kVp) specified in the design criteria for the facility and at its maximum milliamperage (mA) for continuous operation at that voltage. High energy equipment (e.g., linear accelerators, betatrons, etc.) SHOULD be operated at maximum output.

6.8.4.6.9 Unshielded Installations. A radiation protection survey SHALL be conducted before the installation is placed into operation. Additionally, unshielded installations SHALL be actively surveyed by radiographers during each subsequent operation. Initial surveys SHALL include radiation exposure measurements to establish, or verify safe operating conditions as established by the applicable standard operating procedures.

6.8.4.6.9.1 Pulsed X-ray.

CAUTION

The electronic personal dosimeters (EPD), personal alarming dosimeter (PAD) and Digital Alarming Dosimeter (DAD) DO NOT accurately measure radiation in short-pulsed (60-nanosecond) X-ray environments.

a. For designation of all areas, where pulsed X-ray operations will be performed, a detailed radiation protection survey SHALL be conducted by a fully qualified Health Physicist, Bioenvironmental Engineer, Nuclear Medicine Science Officer or qualified radiological health technician.

b. The RSO or their representative SHALL evaluate each area to ensure that the restricted area is setup IAW paragraph 6.8.6.2.3.2.1.

c. Additionally, all workers, working in close proximity to pulsed X-ray operations SHALL be briefed on safety procedures and SHALL NOT enter the established restricted area.

6.8.4.6.10 Report of Radiation Protection Survey.

CAUTION

Existing installations SHALL NOT be assumed to conform to the provisions of this publication, unless a valid radiation protection survey has been made by a qualified expert and a report has been placed on file at the installation.

6.8.4.6.10.1 Distribution and Retention of Survey Reports.

6.8.4.6.10.1.1 Survey Report Distribution. The written survey report (with attachments) SHALL be forwarded by the individual conducting the survey to the organization surveyed with an information copy to the USAFSAM/OEC, 2510 Fifth Street, Area-B, Bldg. 840, Wright-Patterson AFB, OH 45433. If the survey is performed by an organization other than the USAFSAM/OEC, a copy of the survey report SHALL be submitted for review. A statement of corrective action(s) taken, if required, SHOULD be submitted by the Laboratory supervisor, to the organization that performed the survey with information copies to the Installation Bioenvironmental Engineering office and USAFSAM/OEC. The report SHALL include recommendations for any corrective measures and SHOULD indication if a further survey is necessary after corrections have been made.

6.8.4.6.10.1.2 Report Retention Requirements. Reports of all radiation protection surveys SHALL be retained by the local Bioenvironmental Engineering Services and the Laboratory supervisor together, with a record of the actions taken, with respect to the recommendations the survey contains.

6.8.4.6.10.2 Survey Report Contents.

6.8.4.6.10.2.1 Identification of the radiation source(s), and location of each by suitable means, e.g., serial number, room number, and building number or name.

6.8.4.6.10.2.2 The radiation output (kV/mA) of the radiographic device (the radiation output of the device will be the level specified by the manufacturer or obtained from remote survey readings. Unnecessary radiation exposure SHALL NOT be incurred to obtain such information.)

a. X-ray source -- in roentgens per minute (R/min), at one-meter, at maximum kV and mA, (under shielding conditions indicative of normal operation). The potential and current at which the X-ray tube was operated during the test will be specified if less than the system operating limits.

b. Gamma-ray source -- in roentgens per minute (R/min) at one meter or specific activity remaining (curies or Becquerel) and calibration date.

6.8.4.6.10.2.3 Identification of the radiation survey instruments used, including its serial number and the date calibrated.

6.8.4.6.10.2.4 The location of the source, and the orientation of the useful beam in relation to each exposure measurement.

6.8.4.6.10.2.5 Exposure rates in all adjacent areas accessible to personnel. The location of exposure rate measurements SHALL be in accordance with applicable criteria and SHALL be suitably identified by drawings when appropriate.

6.8.4.6.10.2.6 An assessment of whether the measured exposure rates will result in uncontrolled areas having a total exposure of greater than 2 mrem (0.02 mSv) in any one - hour, or greater than 100 mrem (1 mSv) in a year, above background, using the expected workloads, use factors and occupancy factors for the facility. The occupancy factor SHALL NOT be used to determine compliance with the 2 mrem (0.02 mSv) in any one-hour limit.

6.8.4.6.10.2.7 A description of the existing mechanical and electrical limiting devices and safety devices that restrict the orientation of the useful beam and position of the source or otherwise support radiation protection efforts.

6.8.4.6.10.2.8 A statement indicating the appropriate classification of the installation (paragraph 6.8.6) and the radiological design criteria for which it was designed, if available.

6.8.4.6.10.2.9 A statement of what controls are required, if exposures are estimated to exceed 100 mR in a year or 2 mR in any one- hour in uncontrolled areas. Engineering controls (e.g., additional shielding, physical barriers, etc.), SHALL always take precedence over administrative controls (e.g., restrictions on workload).

6.8.4.6.10.2.10 Identification of the individual conducting the survey, to include parent organization and the date the survey was accomplished.

6.8.4.6.10.2.11 A statement of facility compliance/non-compliance with the following directives.

a. If an installation does not comply with this publication, it SHALL be stated what action must be taken to ensure compliance.

b. If a resurvey is required, it SHALL be so stated. The time frame as to when the resurvey is required, and whether or not operations are permitted prior to the resurvey SHALL be included.

6.8.4.7 Annual Radiation Assessment.

NOTE

While a radiation assessment must be conducted annually, a radiation protection survey (scatter survey) may not be required to be performed as often. See paragraph 6.8.4.6 for information on when to perform radiation protection surveys.

6.8.4.7.1 A radiation assessment SHALL be conducted by the Installation RSO or his/her representative, as an integral part of the annual quality assurance audit of the Radiation Protection Program. Assessments SHALL verify the adequacy of operating procedures, the presence and proper use of radiation warning signs and signals, and other necessary equipment. Annual ALARA training and assessment of worker dose to radiation SHALL also be verified and conducted IAW AFI 48-148 and AFMAN 48-125. A formal report SHALL be generated to document the assessment findings and revalidate operating procedures, emergency procedures, and protection survey results and restrictions.

6.8.4.7.1.1 Annual assessment SHALL document the following:

a. Review all radiation exposure records and surveys.

b. Evaluate the content and effectiveness of the ALARA training program.

c. Review existing facility designs for compliance with this document and other applicable instructions.

d. Verify proper location and operation of interlocks, warning signs, and beacons/lights.

e. Evaluate new X-ray equipment.

f. Assess impact of new facility modifications if any.

g. Verify all required forms are correctly completed.

h. Generate a formal report of assessment findings and deliver it to the Unit Commander and Laboratory supervisor.

6.8.4.8 Industrial Radiographer's Radiation Protection Checks. The following checks are required as specified to ensure operations are consistent with the principles of ALARA.

a. The radiographer-in-charge SHALL ensure a comprehensive radiation protection check is performed before an X-ray operation begins.

b. All radiographers SHALL ensure each exposure is adequately controlled IAW installation RSO survey and assessment parameters.

c. Personnel SHALL physically hand-carry a survey meter into a radiation area to check radiation levels with a survey meter prior to re-entry into the area to ensure the radiation source has successfully terminated.

6.8.4.8.1 Measuring Exposure Rates Using Survey Meters (Ionization Chamber). For specific information on the operating principles, characteristics, and recommended survey meters for use, see paragraph 6.3.10.3.

6.8.4.8.1.1 Calibration of Radiation Survey Instruments. Radiation survey meters used for industrial radiography SHALL be calibrated as follows:

NOTE

If a battery indicator is located on the survey meter, it SHALL be checked each time the instrument is turned on.

6.8.4.8.1.1.1 User Operational Check. The survey meter SHALL be checked by the user with a radiation check source prior to the first monitoring operation of the day, and at two week intervals, or as specified IAW manufacturer's instructions for instruments not in regular use. Battery condition and source check reading information SHALL be annotated on an AFTO Form 140.

6.8.4.8.1.1.2 Test Measurement and Diagnostic Equipment (TMDE) Calibration Requirements. Radiation survey meters SHALL be calibrated at intervals determined by AFMETCAL and/or as listed in TO 33K-1-100-WA-1.

6.8.4.8.2 Handling and Use of Radiation Survey Instruments.

6.8.4.8.2.1 Handling Survey Meters. Survey meters are delicate instruments, therefore, they SHALL be handled with care. Most survey instruments are not waterproof and SHALL be protected from wet weather conditions. If it rains when working outdoors, a clear, plastic bag will have no appreciable effect on radiation monitoring capability and will not hamper the operating of the control switches. If the components of the survey meter become wet, the instrument MAY have to be serviced and recalibrated. When survey meters are transported in vehicles, they SHOULD be placed in the driver's compartment with adequate support and restraint to prevent damage during transit.

6.8.4.8.2.2 Guidelines for Use.

NOTE

The zero will continually shift on some survey meters; personnel using these meters SHALL continually recheck the zero control and adjust the meter as necessary.

a. Whenever radiographic operations are performed, at least one calibrated and operable radiation survey instrument SHALL be available at shielded installations, and at least two calibrated and operable radiation survey instruments SHALL be available at unshielded installations. The instrument(s) SHALL be turned ON and used as specified or demonstrated in the current, RSO-approved Radiation Protection Survey and operating procedures during all radiographic operations. The instrument(s) SHALL have an adequate instrument response for the range of radiation energies encountered. When entering the area after deactivation of the radiation source, radiographers SHALL use a suitable, calibrated survey meter to assure the source has returned to its “off” position and that X-rays are no longer being produced.

b. Due to the response time of electrical components, survey meters will not instantly indicate the maximum exposure rate. Typically, survey meters have a response time ranging from 2 to 15-seconds, with longer response times being required for lower dose rates. Therefore, prior to use, turn survey meters on for several minutes, and allow to stabilize. (The Victoreen/Inovision 450, 450B, 450P, 451B, 450-CHP, and 451P Models’ response time is required to reach 90% of true value ranges from 3 to 8-seconds and from 3 to 5-seconds respectively.) Thus, in order to accurately measure the actual dose rate present, the operator must hold the survey meter in a set position for a period of time longer than the specified response time. Survey meter response times are published in the instrument instruction manual.

6.8.5 Industrial Radiographic Operations.

6.8.5.1 System Types. There are two primary types of industrial radiographic systems; a sealed gamma emitting radioactive source, typically referred to as a gamma camera, and machine generated X-ray devices. Air Force radiographic operations use machine generated X-ray systems. No gamma emitting sources are currently used or are in the Air Force inventory.

6.8.5.1.1 Sealed Gamma Ray Sources.

WARNING

Sealed sources used in radiography, usually contain multi-curie quantities of gamma emitting radioactive material and are extremely hazardous if not used properly. Therefore, each radiographer and radiographer's assistant must meet minimum training and experience requirements. A thorough understanding of the hazards and proper procedures for safe handling and use of radiography sources is a fundamental requirement for any individual who is to assume the duties and responsibilities of a radiographer.

6.8.5.1.1.1 Use of Sealed Gamma Ray Sources.

a. Activities SHALL NOT obtain, possess, or use radioactive material sources (gamma cameras), without a USAF Radioactive Material Permit, in accordance with AFI 40-201, *Managing Radioactive Materials in the USAF*. Application for this permit SHOULD be made through the Installation RSO to AFMSA/SG3PB IAW AFI 40-201.

b. Approval by the Installation RSO is required before contractor personnel are permitted to use radioactive materials on any Air Force installations. The Installation RSO SHALL be consulted for current procedures to obtain that approval. Additionally, in cases where contractor requests assistance in performing gamma radiation inspections under this license, the NDI lab supervisor, or assistant in his/her absence, SHALL contact the Installation RSO to ensure proper authorization has been granted and proper procedures are followed.

6.8.6 Industrial Radiographic Installation Classifications.

NOTE

The Air Force classifies two types of installations shielded and unshielded. A shielded installation is described as any enclosed radiographic facility designed to limit exposures on the outside of the facility. An unshielded installation is an area where fixed shielding cannot be used (e.g., flight line, open hangars make-shift buildings, etc.).

6.8.6.1 SHIELDED INSTALLATIONS. The Air Force describes a shielded installation as any enclosed radiographic facility designed to limit exposures on the outside of the facility to less than 2 mrem (0.02 mSv) in any one-hour and less than 100 mrem (1 mSv) in a year, above background. The shielding design incorporates the energy of the X- or gamma ray source to be used, as well as the expected workload, use factors, and occupancy factors of installation. Occupancy factor SHALL be considered only for the 100 mrem (1 mSv) in a year limit.

6.8.6.1.1 Requirements for Shielded Facilities. An installation SHALL be classified as "shielded" when it conforms to all of the following mandatory requirements: Each of the following SHALL be provided (except where specifically noted) without regard to the size and/or configuration of the enclosure.

6.8.6.1.1.1 Shielding requirements will limit radiation exposure as identified in paragraph 6.8.8.4.1.

6.8.6.1.1.2 No person, either within the controlled area or in the environs of a "Shielded" installation, SHALL receive radiation exposures exceeding the total effective dose equivalent limits for members of the public.

6.8.6.1.1.3 The radiation source and all objects to be exposed are within a permanent enclosure, and no person is permitted to remain within during irradiation.

6.8.6.1.1.4 Each entrance used for personnel access to the enclosure/high-radiation area SHALL have both visible and audible warning signals. These signals include: warning signs, beacons, and audible alarms, the latter two are tied to and discussed under "interlock system."

a. Warning Signs.

(1) IAW 10 CFR 20.1902, the interior of the exposure room SHALL be posted with "Caution, High Radiation Area" or "Danger, High Radiation Area" or "Grave Danger, Very High Radiation Area" signs so they are visible from any location within the room. The interior of a cabinet installation SHALL be posted with an identical sign that SHALL be visible with the access door open.

(2) The entrance to the exposure room, or cabinet for cabinet type installations, housing X-ray equipment SHALL be posted with radiation marking signs, either "Caution, Radiation Area," "Danger, High Radiation Area" or "Grave Danger, Very High Radiation Area," as applicable. In addition, gamma radiography sources and cabinet type installations containing a radioactive source SHALL have a "Caution, Radioactive Materials" sign attached to the outside.

(3) A label or sign "Caution, Produces X-rays when energized" (or equivalent) SHALL be affixed to the X- ray tube head.

b. Interlock System. The visible and audible warning beacons/signals SHALL be tied to an interlock system. The interlock system SHALL be placed on each door to interrupt power to the control box/tube head, stopping the irradiation process, when unauthorized access is attempted. In the event of a warning beacon/signal malfunction (i.e. bulb burns out), the interlock SHALL terminate power to the x-ray tube. A time delay/interlock MAY be locally fabricated or purchased in order to meet this requirement. The wiring harnesses are similar to the harnesses used with X-ray Interlock Assembly. All time delay interlock systems installed SHALL be compatible with all X-ray units commonly available. The pre-start switch, pre-exposure alarm, and warning beacons SHALL all be tied to the interlock system and are discussed further in the following paragraphs.

c. Pre-Start Switch. The switch SHALL be located inside the enclosure, so if irradiation is interrupted by opening a safety interlock, resumption of operation can only be accomplished after the pre-start switch has been reactivated. This ensures a thorough search for personnel working within the enclosure is performed prior to activating the source. A pre-start switch SHALL NOT be required if:

(1) The tube head is de-energized (or gamma shutter is closed) when an interlock is tripped.

(2) The X-ray tube (or gamma shutter) cannot be re-energized by merely closing the interlock. To re-energize the X-ray tube, the entire time delay interlock system must be re-initiated at the X-ray machine control panel.

d. Pre-exposure Audible Alarm. A pre-exposure audible alarm, SHALL be used within the enclosure and must be actuated at least 20-seconds before irradiation starts. Audible alarms SHALL cease when radiation is started, but the visible warning signal (see paragraph 6.8.6.1.1.4, step e) SHALL remain actuated during irradiation. The audible signal SHALL be of a frequency, or capable of producing a sound pressure level, so it can be heard over background noise that may be present. Audible alarms are not required if the enclosure is so small it cannot be entered by an individual. An example of such an enclosure is a cabinet X-ray system that has a small opening into which the part to be radiographed is placed, but into which an individual could not gain entry without difficulty.

NOTE

The interlock system with a rotating Amber light operating during the audible alarm and separate Red light operating during the radiation process is authorized for use in the shielded facility.

e. Warning Beacons. Rotating or flashing strobe-type visible warning beacons SHALL be used at all entrances to the enclosure. These must be activated at least 20-seconds before irradiation starts (simultaneously with audible alarm). These beacons SHALL be located so they are visible to an individual entering, or already inside of the facility, and will be operational when X-rays are being produced. An adequate sign SHALL be clearly displayed near the lights to explain their function. Red warning beacons SHALL be located within the enclosure, and red beacons SHALL be used outside all entrances to the enclosure. Low intensity, flashing warning lights SHALL NOT be used unless special circumstances occur. The Installation RSO SHALL be the only approval authority for these special circumstances.

f. Entrance/Exit. A suitable means of exit SHALL be provided so any person, who accidentally may be shut inside, can leave the enclosure without delay. This door SHALL be tied to the interlock, so if it is accidentally opened during exposure, it will automatically turn the exposure off.

g. Emergency Shut-off Switch. Emergency shut-off switch(s) SHALL be provided within the facility, and labeled with a sign stating "EMERGENCY SHUT-OFF" in red letters on a white background. Sufficient number of signs and switches SHALL be placed where they are visible and readily activated from any portion of the interior of the shielded/protective installation. The emergency shut-off switch SHALL NOT be obstructed. The area directly in front of and two feet on either side of the emergency shut-off shall remain clear at all times. An emergency shut-off switch SHALL NOT be required if the enclosure is so small that it cannot be entered by an individual. An example of such an enclosure is a cabinet X-ray system.

6.8.6.1.1.5 The shielded facility SHALL NOT be used for excessive storage. All radiation warning signs and shut-off switches SHALL be at eye level (approximately 5 feet from ground), visible from all directions, with no obstructions. Excessive clutter may interfere with accurate survey measurements and cause an unsafe condition should an emergency shut-off and egress from the facility become necessary.

6.8.6.1.2 MANDATORY OPERATING PROCEDURES – Shielded Installation.

6.8.6.1.2.1 Operating Procedures. The following are mandatory operating procedures that SHALL be adhered to in "shielded" installations:

a. Facilities for shielded operations are designed to limit the exposure at the exterior surface of facilities to 2 mrem (0.02 mSv) in one-hour and 100 mrem (1 mSv) in a year, above background. Since such designs incorporate expected workloads, use factors, and occupancy factors, these "design" parameters serve as administrative limits for the operations of shielded installations. When the operating conditions have changed such that there is a probability that the exposure of any person may be increased, a radiation protection resurvey or evaluation SHALL be conducted. If in doubt, a health physicist or nuclear medicine science officer SHALL be consulted.

b. A thorough search for personnel working within the enclosure SHALL be conducted prior to activating the source.

c. The installation SHALL be inspected by the radiographers each day the facility is to be used to verify the proper operation of audible and visible warning signals, interlock, delay switches, and other exercises that have a bearing on radiation protection. A general purpose or AFTO Form 135 initialed by the individual making the inspection SHALL be maintained.

NOTE

For units who do not use their facilities on a regular basis, Interlocks SHALL be subjected to detailed operational testing at intervals not to exceed six-months. A general purpose or AFTO Form 135 initialed by the individual performing the inspection SHALL be maintained.

d. A qualified radiographer SHALL be present at the control panel during all radiographic exposures and will be the only person authorized to operate radiographic equipment. At least one operational, calibrated survey instruments SHALL be available for immediate use by the radiographer during all radiographic operations.

e. All radiographers participating in radiographic operations SHALL correctly wear a TLD and properly calibrated EPD.

f. Except when making verification of safety interlock operation or in emergencies, door interlocks SHALL NOT be used as a means of terminating the exposure. The exposure SHALL be terminated at the control panel.

g. When a radiographic exposure has been completed, the safety-switch key SHALL be removed from the control panel. The radiographer in charge SHALL retain positive control of the safety-key switch at all times during radiographic operations, and the safety-switch key SHALL not be left unattended in the control panel between individual exposures.

h. The radiation producing equipment and power safety-switch key SHALL be placed in secure areas separate from one another. Only radiographers specifically authorized by the Commander SHALL have access to the storage areas.

i. When entering the exposure room after deactivation of the radiation source, radiographers SHALL use a calibrated survey meter to ensure the source has returned to its "off" position (to ensure X-rays are no longer being produced).

j. All information required on the AFTO Form 125, *Industrial Radiography Utilization Log* SHALL be recorded by the radiographer in charge (paragraph 6.8.7.1).The completed form will be maintained on file for three years. If a suspected overexposure occurs, any generated during the subsequent investigation SHALL be filed w Unit Radiation

k. Dosimeter readings SHALL be correctly documented on AFTO Form 115, *Digital Alarm Dosimeter Results Log* or approved equivalent log. See paragraph 6.8.4.3.5 for more detailed information about recording dosimeter readings.

6.8.6.2 UNSHIELDED INSTALLATIONS. An installation SHALL be classified as "unshielded," if due to operational requirements it cannot be provided with the inherent degree of protection specified for Air Force shielded installations. Such installations include fenced or "roped-off" areas located either in the open, or inside buildings such as hangar bays.

6.8.6.2.1 Establishment of Restricted Area. Radiographic operations in unshielded facilities require an initial evaluation of the exposure area to determine the bounds of the area to be restricted during exposure.

a. A restricted area means: "any area to which access is controlled by the individual in charge of radiation protection for the purpose of protection of individuals from exposure to radiation and radioactive materials." This implies a restricted area is one that requires control of access, occupancy, and working conditions for radiation protection purposes.

b. The dose limit in any unrestricted area from external radiation sources SHALL NOT exceed 2 mrem (0.02 mSv) in any one-hour. In addition, operations SHALL be conducted so radiation exposure to individual members of the public SHALL NOT exceed 100 mrem (1 mSv) in a year, above background. It SHALL be noted the definition does not limit the radiation exposure to a particular rate (such as 4 mR/hr), but permits higher exposure rates PROVIDING that the total quantity of radiation in any unrestricted area during any one-hour does not exceed 2 mrem (0.02 mSv) and during any calendar year considering occupancy factors, does not exceed 100 mrem (1 mSv) to any single individual. Occupancy factor SHOULD be considered for determining compliance with the annual limit.

c. Special consideration SHALL be given to ensure restricted areas are of sufficient size to preclude adverse impact on adjacent operations. When in doubt, ensure qualified experts are consulted prior to initiation of operations.

d. Summary data, comparing the measured exposure rate with the maximum allowable on-time (in minutes per hour) of the radiation source so the total dose in any one hour does not exceed 2 mrem is provided (see Table 6-25).

Table 6-25. Maximum Permissible Dose Rate Versus Hourly Duty Cycle

Measured Exposure Rate (mrem/hr)	Total Time X-ray is Operated During a One-Hour Period (minutes)
30	4
24	5
20	6
17	7
15	8
13	9
12	10
8	15
6	20
5	24
4	30
2	60

6.8.6.2.2 Requirements for Unshielded Facilities. Unshielded installations SHALL conform to all of the following requirements:

NOTE

High Radiation Area boundaries SHALL be calculated only. Surveys SHALL NOT be performed unless such surveys can be accomplished (using devices such as those, which integrate dose) without additional, unnecessary exposure to personnel.

6.8.6.2.2.1 Compliance with radiation dose limits applicable to the general public and to occasionally exposed individuals requires that access to areas in which radiation doses could exceed 2 mrem (0.02 mSv) in any one-hour or 100 mrem (1 mSv) in a year, above background, SHALL be restricted. "Radiation Area" postings SHALL be extended out from the X-ray tube such as to encompass such areas, or alternative arrangements made to restrict access to this area.

6.8.6.2.2.2 If the beam orientation or technique factors change between exposures, the radiation area boundaries SHALL be reestablished and the boundaries of radiation areas reverified.

6.8.6.2.2.3 Red, rotating, or flashing strobe-type visible warning beacons SHALL be used and positioned at the X-ray source (low-Intensity flashing warning lights SHALL NOT be used). The beacon positioned at the source SHALL be rotating/flashing ONLY when the source is energized.

NOTE

The interlock system with a rotating Amber light operating during the audible alarm and separate Red light operating during the radiation process is authorized for use in the unshielded installation.

6.8.6.2.2.4 An X-ray interlock or gamma shutter, as applicable, SHALL be installed between the control unit and the rotating/flashing strobe-type X-ray (or gamma) "on" beacon. The interlock assembly enables electrical power to the "X-ray On" power circuits only after the rotating/flashing strobe type "X-ray On" warning beacon is attached. Interlock Bypass Plugs SHALL NOT be used.

6.8.6.2.2.5 Bioenvironmental radiation surveys for unshielded locations SHALL be used for set-up instructions and manning requirements. Deviations from set-up procedures or location and number of radiographers, safety monitors, or safety monitor assistants SHALL be approved by the RSO prior to X-ray operations. If the perimeter is of such a size or is so arranged that the operator cannot readily determine whether the radiation area is unoccupied, a sufficient number of radiographers and/or radiation safety monitors and/or safety monitor assistants SHALL be strategically located to provide adequate visual surveillance over the entire area. These personnel SHALL have in their possession an adequate and properly calibrated, operable survey meter. The requirement for additional monitors MAY not be necessary if: the radiographic procedures are to be accomplished in a fenced-in, or in a locked area to which access is controlled by the radiographer. In addition, there SHALL NOT be less than one radiation safety monitor. X-ray and gamma ray controls SHOULD be placed so all monitors, for the entire perimeter of the barrier, can be seen and heard by the radiographer-in-charge. If this is not possible, a hand held battery powered communication device SHALL be used.

6.8.6.2.2.6 The radiation source and equipment, essential to the use of the source, SHALL be made inaccessible to unauthorized use, tampering or removal while not in use. This SHALL be accomplished by such means as a locked enclosure.

6.8.6.2.2.7 Two qualified radiographers, and as many radiation safety monitor assistants as needed, SHOULD be used. If two qualified radiographers are not available, at least one qualified radiographer and as many radiation safety monitor assistants (see paragraph 6.8.2.5.1) as required to prevent radiation barrier penetration SHALL be present for radiographic operations. Training for radiation safety monitor assistants SHALL be conducted IAW (see 6.8.2.5.1.1). This applies to constant potential in

6.8.6.2.2.8 If the unshielded installation is in a remote area, and if entry into the enclosed area can be absolutely prevented during irradiation, the source and all objects exposed SHALL be within a conspicuously posted perimeter that limits the area in which the exposure can exceed 100 mR/hr (1 mSv/hr) in an hour provided:

a. The perimeter is posted with a sufficient number of "Caution, Radiation Area" signs so as to be clearly visible from any direction of approach.

b. The boundary of the restricted area can be determined where applicable.

c. The requirements of this (see paragraph 6.8.6.2) can be met.

6.8.6.2.2.9 Personnel SHALL NOT be exposed to more than the dose limits prescribed in paragraph 6.8.4.2.

6.8.6.2.2.10 When entering the area after deactivation of the radiation source, radiographers SHALL use a suitable calibrated survey meter to assure the source has returned to its “off” position and that X-rays are no longer being produced.

6.8.6.2.3 MANDATORY OPERATING PROCEDURES – Unshielded Installation.

6.8.6.2.3.1 Operating Procedures. The following are mandatory operating procedures that SHALL be adhered to when performing radiographic inspection operations in "unshielded" installations:

CAUTION

Industrial X-ray or sealed gamma-ray sources will be used in unshielded areas by only qualified radiographers and with written approval of the Radiation Safety Officer.

6.8.6.2.3.1.1 Required Equipment. In addition to the radiation producing equipment, the following equipment SHALL be used at the site selected for radiographic purposes.

a. At least two serviceable, properly calibrated, radiation survey meters, authorized for use with X-ray or gamma radiography operations. One instrument SHALL be placed near the operator’s console, and the other utilized for surveys of the perimeter as appropriate.

b. TLD for each radiographer. For more information (see paragraph 6.3.10.2.1). Each radiographer SHALL wear one TLD during all radiographic operations.

c. EPD for each radiographer. Each radiographer SHALL wear one EPD or direct reading dosimeter (in constant potential radiation environment) See paragraph 6.8.6.2.3.2 for requirements specific to pulsed radiation

NOTE

The EPDs do not accurately measure radiation in the pulsed radiation environment.

d. An interlock assembly designed to prevent irradiation unless a properly functioning warning light is connected in the circuit.

e. At least two, 250-foot coils of rope with sufficient supporting stands (recommended).

f. Radiation warning signs: sufficient quantity of each required type, e.g., "Caution, Radiation Area" and "Caution or Danger, High Radiation Area."

g. For X-ray equipment, at least 75-feet of power cable and coolant hose; or as recommended by radiation protection survey.

h. A red, rotating/flashing strobe-type beacon (low intensity, blinking, warning lights SHALL NOT be used) and in some situations, as specified by the Installation RSO, a radiation warning sign stating "X-ray ON" (or "SHUTTER OPEN" for gamma radiography), when the light is lit. The rotating/flashing strobe-type red beacon SHALL be as close to the radiation source as possible, and still be visible from all angles of approach, and SHALL be connected to the control circuit in such a manner the light will be ON when the radiation source is activated. An "X-ray ON" light is typically used at entrance locations to an unshielded facility and is lit during irradiation.

i. For night radiographic operations, sufficient lighting equipment to illuminate the area.

j. A minimum of 500-feet (150-meters) of commercially available barrier material, which states "CAUTION RADIATION AREA" (bright yellow background with magenta letters and radiation symbol) (Figure 6-73) and self-supporting stands MAY be used to cordon off the affected area.

6.8.6.2.3.1.2 Operations.

a. Once the restricted area is identified, it SHALL be adequately posted to ensure against inadvertent entry. In some buildings, it may be feasible to lock appropriate doors, or limit access to very large work areas as a simple means of radiation area control. In other locations it MAY be necessary to establish boundaries by roping off, or barricading passageways at appropriate locations. In any event, sufficient control in the form of posting, use of safety monitors, and use of access limiting devices SHALL be in place to guarantee no individual can enter the area inadvertently.

b. In general, when radiographic operations are conducted without benefit of shielding it is often necessary to erect a rope barrier around X-ray tube head at a distance of 230 feet (70 meters) or more for vertical beam orientation. For exposures requiring near horizontal or horizontal beams, the barrier MAY have to be extended in the direction of the beam for more than a hundred meters to achieve exposure rates at the barrier less than or equal to the maximum limits. (Fixed or portable shielding SHOULD be used whenever practicable to reduce the size of area which must be controlled.) All entrances into the isolated area SHALL be secured and posted, and any uncontrolled area must not contain exposure rates that would allow personnel to receive in excess of 2 mrem (0.02 mSv) in any one-hour. All positions around the barrier SHALL be in view of one of the radiographers or radiation monitors during exposures.

c. Place radiation warning signs along the barrier so at least one can be seen from any direction of approach.

d. Extend the power cable from the tube head to the controls so the operator is located as far as possible from the radiation source, usually at least 75-feet (23-meters). Place the controls so all monitors, or the entire perimeter of the barrier, can be seen by the radiographer. If this is not possible, either a consultant health physicist, Nuclear Medicine Science Officer, or other qualified individual SHALL specify adequate means of communication during a survey of the unshielded operation. Adequate means of communications MAY include two-way radios, whistles, electronic/propellant-activated noise alarms or ultrasonic infrared intrusion barriers, but need not be limited to these methods.

e. Place the red, rotating/flashing strobe-type (X-ray warning) beacon near the X-ray tube and connect to the X-ray interlock circuit.

f. Illuminate the area for night operation.

g. Ensure no one is inside, on top, or below the object being radiographed.

h. Prior to making an exposure, the area SHALL be surveyed by the radiographers to establish patterns of any radiation fields that could be present and to determine the adequacy of rope barrier placement.

i. Upon completion of the survey and modification of the barrier, if needed, put the film in place and proceed with the radiographic exposure.

j. If the barrier is penetrated by anyone during the exposure, the radiation source SHALL be immediately turned off, detain the individual, secure the area, and the incident reported to the radiography supervisor. Begin emergency procedures.

k. The radiographic apparatus SHALL NOT be left unattended when operating and unauthorized personnel SHALL NOT operate it. This equipment SHALL always be stored in a secure area. A key lock SHALL be installed on all radiographic unit consoles. While in storage or unattended by an authorized radiographer, the power safety-switch key SHALL be removed from the console and securely maintained separate from the apparatus. Only radiographers authorized by the Unit Commander SHALL have access to the industrial radiographic unit power safety-switch key storage areas.

l. In the case of multiple exposures in an open area in which the beam direction, intensity (kVp, mA) or attenuating materials are significantly altered, the barrier perimeter SHALL be re-established as necessary.

WARNING

Bioenvironmental engineering will approve all Laser pointers prior to use and personnel will be trained in accordance with AFI 48-139, *Laser and optical Radiation Protection Program.* The Lorad Class 3R Laser Pointer SHALL NOT be directed above the horizon near the flight line, as this may be dangerous to flight operations. The laser will have a warning affixed to it, and it SHALL only be in the on position when aligning film and off at all other times. The laser will be treated as a dangerous tool and SHALL not be pointed at any individual.

m. All information required on the AFTO Form 125, *Industrial Radiography Utilization Log* SHALL be recorded by the radiographer in charge (paragraph 6.8.7.1).The completed form will be maintained on file for three years. If a suspected overexposure occurs, any generated during the subsequent investigation SHALL be filed w Unit Radiation

n. Dosimeter readings SHALL be correctly documented on AFTO Form 115, *Digital Alarm Dosimeter Results Log* or approved equivalent log. See paragraph 6.8.4.3.5. for more detailed information about recording dosimeter readings.

6.8.6.2.3.2 Unshielded (Pulsed X-ray).

6.8.6.2.3.2.1 Establishment of Restricted Area for Pulsed X-ray. The radiation scatter and primary beam footprint for pulsed X- ray operations is minimal. Additionally, low energy pulsed X-ray scatter radiation is difficult to accurately measure. Therefore, restricted area requirements are defined below to ensure compliance with the general public exposure limits identified in paragraph 6.8.4.2.2. Assumptions used for this determination included a total workload of 30,000 images per year, 27 pulses per image and up to 40 images per hour. An occupancy factor of 0.5 was used for determining compliance with the yearly limit. These restrictions are guidelines as each area authorized for radiation operations must have an initial radiation protection survey accomplished and documented by the Installation RSO.

a. For vertical image projections, a 16-foot radius around the tube head is required. Additionally, the primary beam SHALL be controlled to 28-feet. For the occasional horizontal image projections, a 16-foot area SHALL be controlled to the sides and back of the tube head. On the target end of the tube head a 28-foot area must be controlled. The unit has a radiation cone angle of approximately 40-degrees.

b. Trained NDI personnel SHALL always maintain a minimum distance of 12-feet from the tube head, and stay out of the primary X-ray beam to ensure radiation dose is ALARA.

6.8.6.2.3.2.2 Unshielded Pulsed X-ray Operating Procedures. The following are minimum mandatory requirements that SHALL be adhered to when performing pulsed radiographic operations in "unshielded" areas. Requirements are based on the current pulsed X-ray systems used, approved operations and techniques, and a study completed by USAFSAM/OEHHD. If new pulsed X-ray systems are acquired with an X-ray tube head output greater than 3.5 mR/pulse at one foot from the tube head and/or a tube current rating greater than 0.5 mA, contact USAFSAM/OEC (see paragraph 6.8.2.1, step a(1)) for additional guidance.

6.8.6.2.3.2.3 General. Industrial X-ray operations involving pulsed X-rays will only be accomplished by qualified radiographers and upon completion of radiation protection survey by the Installation RSO.

6.8.6.2.3.2.4 Required Pulsed X-ray Equipment. In addition to the radiation producing equipment, the following equipment SHALL be readily available for use at the site selected for radiographic purposes.

a. A minimum of one TLD badge for each radiographer involved in the radiography operations.

b. Two pocket ion chambers dosimeters per radiographer are required.

NOTE

The electronic personal dosimeters (EPD), personal alarming dosimeter (PAD) and Digital Alarming Dosimeter (DAD) do not accurately measure radiation in short-pulsed (60-nanosecond) X-ray environments.

c. At least 75-feet of rope with sufficient supporting stands (recommended).

d. Radiation warning signs: sufficient quantity (minimum of least two) stating "Caution, Radiation Area."

e. For X-ray equipment, at least 12-feet X-ray tube head activation cord or as recommend by the radiation protection survey.

f. The tube-head SHALL provide visual and audible indication of tube activation and require key activation.

g. For night radiographic operations, sufficient lighting equipment to illuminate the area.

h. A minimum of 75-feet of commercially available barrier material which states "CAUTION RADIATION AREA" (bright yellow background with magenta letters and radiation symbol) and self-supporting stands MAY be used to cordon off the affected area.

6.8.6.2.3.2.5 Pulsed X-ray Operations.

a. Once the restricted area is identified, it SHALL be adequately posted to assure against inadvertent entry. In some buildings, it MAY be prudent to lock appropriate doors or limit access to work areas as a simple means of radiation area control. In other locations it MAY be necessary to establish boundaries by roping off or barricading passageways at appropriate locations. In any event, sufficient control in the form of posting, use of safety monitors and use of access limiting devices SHALL be in place to guarantee no individual can enter the area inadvertently.

b. All positions around the barrier SHALL be in view of at least one of the radiographers or radiation monitors during exposures.

c. Place radiation warning signs along the barrier so at least one can be seen from any direction of approach.

d. Place the controls so the entire perimeter of the barrier can be seen by the radiographer. If this is not possible, either a consultant health physicist or Nuclear Medicine Science Officer or other qualified individual SHALL specify adequate means of communication during a survey of the unshielded operation. Adequate means of communications MAY include two-way radios, whistles, electronic/propellant-activated noise alarms, or ultrasonic infrared intrusion barriers, but need not be limited to these methods.

e. Illuminate the area for night operation.

f. Ensure no one is inside or on top of the object being radiographed.

g. Educate personnel who may be in close proximity to radiation on safety procedures. The controlled area SHALL NOT be entered during X-ray procedures.

h. If the barrier is penetrated by anyone during the exposure, the radiation source SHALL be turned off immediately and the incident reported to the radiography supervisor.

i. In the case of multiple exposures in an open area in which the beam direction, number of X-ray pulses, or attenuating materials are significantly altered, the barrier perimeter SHALL be re-established as necessary.

j. All information required on the AFTO Form 125, *Industrial Radiography Utilization Log* SHALL be recorded by the radiographer in charge (paragraph 6.8.7.1).The completed form will be maintained on file for 3 years. If a suspected overexposure occurs, any generated during the subsequent investigation SHALL be filed with Unit Radiation.

k. Dosimeter readings SHALL be correctly documented on AFTO Form 115, Digital Alarm Dosimeter Results Log or approved equivalent log. See paragraph 6.8.4.3.5 for more detailed information about recording dosimeter readings.

6.8.7 Utilization Log.

6.8.7.1 Utilization Log. The Industrial Radiography Utilization Log, AFTO Form 125, SHALL be completed for all shielded, unshielded inspections and suspected overexposures of personnel. The completed form SHALL be maintained on file for 3 years. If a suspected overexposure occurs, any other documents generated during the subsequent investigation SHALL be filed with the respective utilization log. When a log is completed, the radiography supervisor (lab chief) will sign the log.

6.8.7.1.1 The following information SHALL be recorded:

a. Facility Location: Identify building number, street address, and room number if applicable.

b. Organization: Enter maintenance organization radiographers are assigned to.

c. Aircraft: Identify model number of aircraft that part or component is attached to or removed from.

d. Part/Component: Identify part nomenclature to be radiographed. Similar part/components may be grouped as a series as long as the general X-ray beam orientation does not change.

e. Date: Enter date of inspection.

f. Supervisor: Enter the name and rank of radiographer-in charge. A new entry is required if the radiographer-in-charge changes.

g. Shift: Enter the duty shift of the operation. A new entry is required if the operation covers multiple shifts.

h. Number of Exposures: Enter the number of exposures performed to complete a specific radiographic inspection. Multiple exposures are only authorized if the exposure series parameters do not change e.g., wing inspections will have multiple exposures with the same beam direction.

i. kVp : Enter highest kVp used to radiograph the part/component.

j. mA : Enter highest mA used to radiograph the part/component.

k. Time: Enter individual exposure time used to radiograph the part/component. (On series shots, enter the time of the longest single exposure.)

l. Radiation Level: Enter highest recorded survey meter reading from predetermined points around the barrier. One monitor can observe survey meter readings from various locations. Refer to sketch drawing to determine where the readings will be observed and recorded. Each number on the radiation level block used in the operation SHOULD correlate with a number in the sketch.

m. Sketch of Restricted Area: Prepare a detailed sketch in accordance with the Installation RSO’s survey and assessment determinations to identify the following:

(1) Aircraft/part orientation or position.

(2) Tubehead location, position, and beam direction.

(3) Control console position. (SHALL also be radiographer-in-charge position and correlates with the number one position in the radiation level block.)

(4) Barrier position.

(5) Exposure rates in mr/hr at predetermined radiation survey points on the barrier.

(6) Locations of monitors and assistants during the exposure.

6.8.8 Radiation Areas and Facilities.

6.8.8.1 High Radiation Areas. Each of the types of installations specified herein involves the creation of "High Radiation Areas." Access to all high radiation areas created by radiographic operations with sealed sources SHALL be controlled in accordance with 10 CFR 20.1601. 10 CFR 20.1601 also states controls WILL NOT prevent an individual from leaving a high radiation area. To ensure high levels of safety, these rules will also be applied to radiographic operations performed with X-ray sources. Requirements include one or more of the following features:

a. Control devices that, upon entry into the area, cause the level of radiation to be reduced (below that level at which an individual might receive a deep-dose equivalent of 100 mrem (1 mSv) in 1 hour at 30-centimeters from the source (or from any surface that the radiation penetrates).

b. Control devices that energize a conspicuous visible or audible alarm such the individual entering the area, and the supervisor of the activity, are made aware of the entry.

c. Entries that are locked, except during periods when access to the areas is required, with positive control over each entry.

d. Continuous direct or electronic surveillance capable of preventing unauthorized entry.

6.8.8.2 Very High Radiation Areas. A "Very High Radiation Area" is an area in which radiation levels could be encountered at 500 rads (5 gray) per hour at one-meter from a radiation source or from any surface that the radiation penetrates (10 CFR 20.1602). Additional measures SHALL be instituted to ensure that an individual is not able to gain unauthorized or inadvertent entry into a "Very High Radiation Area." The requirements of 10 CFR 20.1602 SHALL be implemented for all radiation sources, including X-ray machines, which create very high radiation areas.

6.8.8.3 New Facilities. New radiation facilities SHALL be constructed to meet the requirements of one of these classes of installations. The classes differ in the relative dependence on the "inherent shielding," "operating restrictions," and "supervision" necessary to secure the required degree of protection. In addition, each class has certain advantages and limitations. The above referenced paragraphs contain details of the respective installation classes.

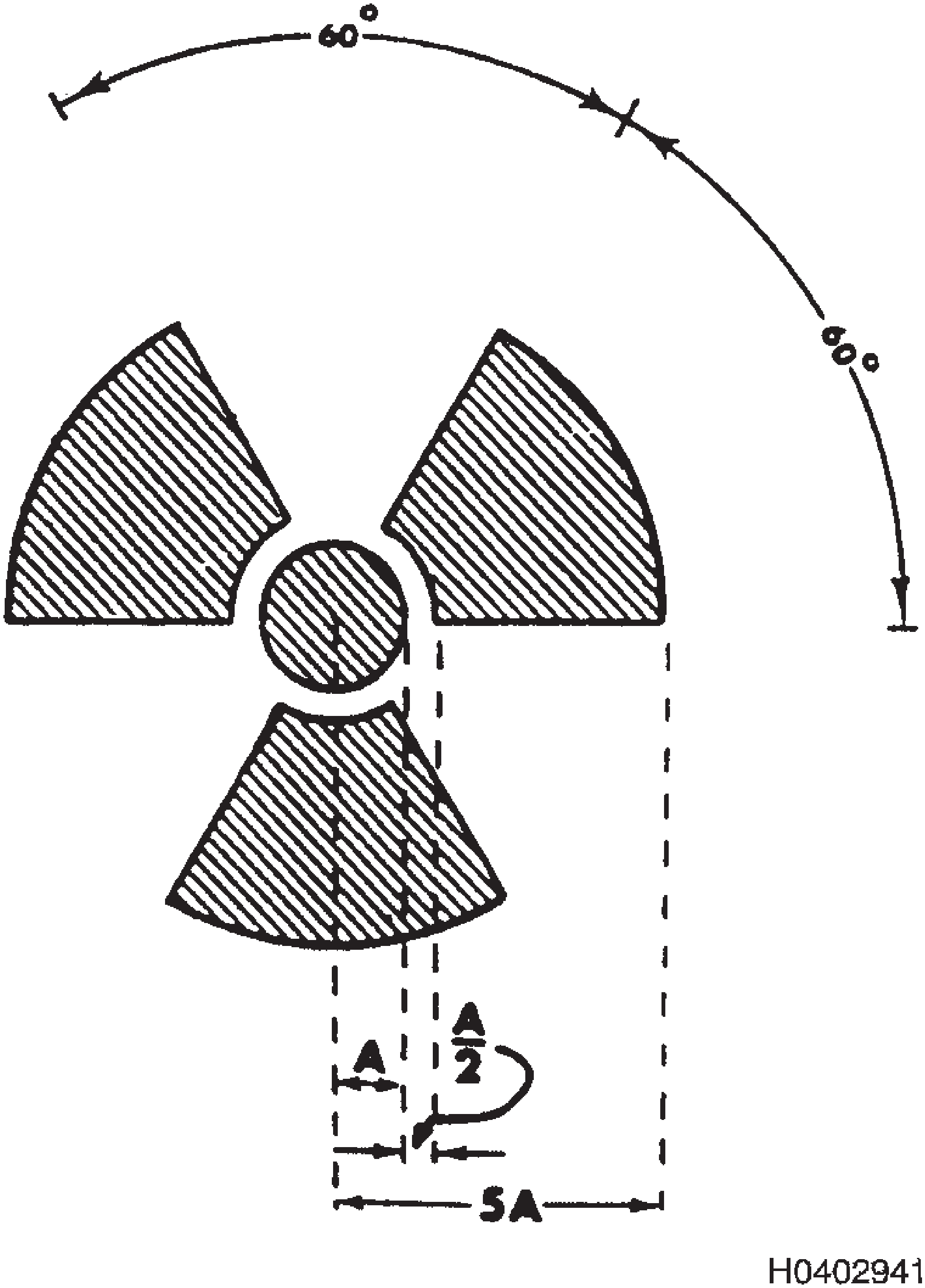

Figure 6-73. Radiation Symbol

6.8.8.4 NDI Facility Design and Modification.

6.8.8.4.1 Determining Shielding Requirements. The structural shielding requirements of any new installation or of an existing one in which changes are contemplated, MAY be decided by a Health Physicist, Radiological Physicist, Nuclear Medicine Science Officer, or a qualified Bioenvironmental Engineer, provided it is approved by the appropriate MAJCOM Headquarters. To adequately determine shielding requirements, the following data concerning the source of radiation SHALL be provided:

a. Type of radiation source (e.g., X- or gamma-ray).

b. Maximum and average tube potential (kilovoltage) or the energy of the radiation source.

c. Maximum and average tube current (milliamperage) or the source output in roentgens (R) per minute at one meter (R/min) from the source.

d. The expected workload in milliampere minutes (mA-min) per week.

e. The use factors for each wall, floor, and ceiling as appropriate. This is the fraction of the workload during which the useful beam is pointed in the direction under consideration (see Table 6-26).

f. The type of occupancy of all areas which might be affected by the installation (see Table 6-27).

g. The structural details of the building. This will include a dimensioned drawing of the facility, with notation of the typical distances from the X-ray source to each barrier of the facility, as well as the expected construction materials for the facility.

Table 6-26. Use Factors (U)*

Installation Use	Shielded	
	Collimated Sources	Open Sources
Floors	1	1
Walls	1/4	1
Ceilings	1/16	1
* For use as a guide in planning shielding when compete data are not available.		

Table 6-27. Occupancy Factors (T)

Full Occupancy (T = 1)	X-ray control space and waiting space, darkrooms, film reading areas, workrooms, shops, offices, and corridors large enough to hold desks, living quarters, children's play areas, occupied space in adjoining buildings.
Partial Worker Occupancy (T = 1/4)	Worker restrooms, occupational use corridors too narrow for desks.
Partial Occupancy (T = 1/8)	Public corridors too narrow for desks, utility rooms, and employee lounges.
Occasional Public Occupancy (T = 1/20)	Rest rooms or bathrooms, storage rooms, vending areas, outdoor areas with seating.
Rare Occupancy (T = 1/40)	Outside areas used only for pedestrians or vehicular traffic, unattended parking lots, attics or crawl spaces, stairways, unattended elevators, janitors closets.
* For use as a guide in planning shielding where adequate occupancy data are not available.	

6.8.8.4.2 Direction of Useful Beam.

a. Although the cost of shielding MAY be reduced significantly by arranging the installation so the useful beam is not directed toward occupied areas, the cost of shielding SHALL NOT override potential safety concerns. However, since weapon system requirements can change during the useful life of a facility, shielding SHALL be adequate enough for any potential future requirements.

b. Devices that permanently restrict the direction and cross section of the useful beam MAY reduce the area requiring primary barriers.

6.8.8.4.3 Radiation Energy, Output, and Workload. The shielding for each occupied area SHALL be determined on the basis of the expected maximum use kilovoltage or energy, mA or R/min, workload, use factor, and occupancy factor affecting it. Consideration SHOULD be given to the possibility the values of these parameters MAY increase in the future. It MAY be more economical to provide a higher degree of protection initially than to add to it later.

6.8.8.4.4 Structural Details of Protective Barriers. Shielding for radiographic installations is normally provided by installation of sheet lead or concrete. Facilities where high workloads and gamma-ray sources are used MAY use a combination of these materials, or use concrete loaded with high iron content aggregate to improve shielding efficiency. The half-value layers of lead and concrete (the thickness of each material necessary to reduce the exposure intensity by a factor of two) for various energy X-rays and gamma rays are shown in Table 6-28.

Table 6-28. Peak Voltage (kVp)

HALF-VALUE AND TENTH-VALUE LAYERS						
Attenuation Material						
Peak Voltage	Lead (mm)		Concrete (cm)		Steel (cm)	
kVp	HVL	TVL	HVL	TVL	HVL	TVL
70	0.17	0.52	0.84	2.8		
100	0.27	0.88	1.6	5.3		
125	0.28	0.93	20.	6.6		
150	0.30	0.99	2.24	7.4		
200	0.52	1.7	2.5	8.4		
250	0.88	2.9	2.8	9.4		
300	1.47	4.8	3.1	10.4		
400	2.5	8.3	3.3	10.6		
500	3.6	11.9	3.6	11.7		
1000	7.9	26	4.4	14.7		
2000	12.5	42	6.4	21		
3000	14.5	48.5	7.4	24.5		
4000	16	53	8.8	29.2	2.7	9.1
6000	16.9	56	10.4	34.5	3.0	9.9
Cesium-137	6.5	21.6	4.8	15.7	1.6	5.3
Cobalt-60	12	40	6.2	20.6	2.1	6.9

6.8.8.4.5 Quality of Protective Material. All shielding materials SHALL be of assured quality, uniformity, and permanency.

6.8.8.4.6 Lead Barriers. Lead barriers SHALL be mounted in such a manner they will not cold-flow because of their own weight and SHALL be protected against mechanical damage. Additionally, lead sheets at joints SHOULD be in contact with a lap of at least one-half inch, or twice the thickness of the sheet, whichever is greater. Welded or burned lead seams are permissible provided the lead equivalent of the seams is not less than the minimum requirement.

6.8.8.4.7 Joints Between Different Materials or Structures. Joints between different kinds of protective materials SHALL be constructed so the overall protection of the barrier is not impaired. Additionally, joints at the floor and ceiling SHALL be constructed so the overall protection is not impaired.

6.8.8.4.8 Shielding of Openings in Protective Barriers. In the planning of an installation, careful consideration SHOULD be given to reducing the number and size of all perforations of protective barriers and openings into the protected areas. Protection for all such openings SHALL be provided by means of suitable protective baffles.

a. Perforations. Provision SHALL be made to ensure nails, rivets, or screws which perforate lead barriers are covered and give protection equivalent to the imperforated barrier.

b. Openings for Pipes, Ducts, Conduits, Louvers, etc. Holes in barriers for pipes, ducts, conduits, louvers, etc., SHALL be provided with baffles to ensure the overall protection afforded by the barrier is not impaired. These holes SHOULD be located outside the range of possible orientations of the useful beam.

c. Doors and Observation Windows. The lead equivalent of doors and observation windows of exposure rooms, cubicles, and cabinets SHALL NOT be less than required for the walls or barrier in which they are located.

6.8.8.4.9 General Requirements for Doors.

a. Location of Doors. Where practical, doors into exposure rooms SHOULD be located so the operator has control of access to the room.

b. Interlock Switches for Doors. All door(s) and panel(s) opening into an X-ray exposure room or cabinet (except those opened or removed only with tools) SHALL be provided with single interlocking switches preventing irradiation unless the door or panel is closed. Double doors SHALL have interlock switches that operate independently of each other.

c. Resumption of Operation. If the opening of a door or panel to a "Shielded" Installation has interrupted the operation of any radiation source, it SHALL NOT be possible to resume operation by merely closing the door or panel in question. To resume operation, it SHALL be necessary to re-energize the source at the console, and this procedure SHALL cause the time delay interlock system to be re-initiated. It SHALL NOT be possible to resume operation by merely re-engaging the interlock.

d. Escape or Interruption of Irradiation from Inside Exposure Room. The exposure room SHALL include at least one means of exit that MAY be rapidly opened from the inside. A suitable means SHALL be provided to quickly interrupt irradiation from inside the room. The means of accomplishing this SHALL be explained to all personnel and a sign explaining its use SHALL be conspicuously posted inside the exposure room. Preferably, the beam SHOULD NOT be directed toward the door or interrupting device.

e. Threshold Baffle for Door Sill. A door baffle or threshold will generally be required for radiography sources and for installations operating above 125 kVp, if the discontinuity can be struck by the useful beam.

f. Lap of Doorjamb. The protective lead covering of any door leading to an exposure room or cabinet SHALL overlap the doorjamb and lintel so as to reduce the radiation passing through clearance spaces to the allowable limit for the door itself.