Standard Guide for Radiographic Examination[1]

This standard is issued under the fixed designation E94; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This guide[2] covers satisfactory X-ray and gamma-ray radiographic examination as applied to industrial radiographic film recording. It includes statements about preferred practice without discussing the technical background which justifies the preference. A bibliography of several textbooks and standard documents of other societies is included for additional information on the subject.

1.2 This guide covers types of materials to be examined; radiographic examination techniques and production methods; radiographic film selection, processing, viewing, and storage; maintenance of inspection records; and a list of available reference radiograph documents.

NOTE 1—Further information is contained in Guide E999, Practice E1025, Test Methods E1030, and E1032.

1.3 *Interpretation and Acceptance Standards*—Interpretation and acceptance standards are not covered by this guide, beyond listing the available reference radiograph documents for castings and welds. Designation of accept - reject standards is recognized to be within the cognizance of product specifications and generally a matter of contractual agreement between producer and purchaser.

1.4 *Safety Practices*—Problems of personnel protection against X rays and gamma rays are not covered by this document. For information on this important aspect of radiography, reference should be made to the current document of the National Committee on Radiation Protection and Measurement, Federal Register, U.S. Energy Research and Development Administration, National Bureau of Standards, and to state and local regulations, if such exist. For specific radiation safety information refer to NIST Handbook ANSI 43.3, 21 CFR 1020.40, and 29 CFR 1910.1096 or state regulations for agreement states.

1.5 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (See 1.4.)

1.6 If an NDT agency is used, the agency shall be qualified in accordance with Practice E543.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E543 Specification for Agencies Performing Nondestructive Testing

E746 Practice for Determining Relative Image Quality Response of Industrial Radiographic Imaging Systems

E747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E801 Practice for Controlling Quality of Radiological Examination of Electronic Devices

E999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E1030 Test Method for Radiographic Examination of Metallic Castings

E1032 Test Method for Radiographic Examination of Weldments

E1079 Practice for Calibration of Transmission Densitometers

E1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films

E1316 Terminology for Nondestructive Examinations

E1390 Specification for Illuminators Used for Viewing Industrial Radiographs

E1735 Test Method for Determining Relative Image Quality of Industrial Radiographic Film Exposed to X-Radiation from 4 to 25 MeV

---

[1] This guide is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.01 on Radiology (X and Gamma) Method.

Current edition approved June 1, 2010. Published November 2010. Originally approved in 1952. Last previous edition approved in 2004 as E94 - 04. DOI: 10.1520/E0094-04R10.

[2] For ASME Boiler and Pressure Vessel Code applications see related Guide SE-94 in Section V of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E1742 Practice for Radiographic Examination
E1815 Test Method for Classification of Film Systems for Industrial Radiography
2.2 *ANSI Standards:*
PH1.41 Specifications for Photographic Film for Archival Records, Silver-Gelatin Type, on Polyester Base[4]
PH2.22 Methods for Determining Safety Times of Photographic Darkroom Illumination[4]
PH4.8 Methylene Blue Method for Measuring Thiosulfate and Silver Densitometric Method for Measuring Residual Chemicals in Films, Plates, and Papers[4]
T9.1 Imaging Media (Film)—Silver-Gelatin Type Specifications for Stability[4]
T9.2 Imaging Media—Photographic Process Film Plate and Paper Filing Enclosures and Storage Containers[4]
2.3 *Federal Standards:*
Title 21, Code of Federal Regulations (CFR) 1020.40, Safety Requirements of Cabinet X-Ray Systems[5]
Title 29, Code of Federal Regulations (CFR) 1910.96, Ionizing Radiation (X-Rays, RF, etc.)[5]
2.4 *Other Document:*
NBS Handbook ANSI N43.3 General Radiation Safety Installations Using NonMedical X-Ray and Sealed Gamma Sources up to 10 MeV[6]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminology E1316.

4. Significance and Use

4.1 Within the present state of the radiographic art, this guide is generally applicable to available materials, processes, and techniques where industrial radiographic films are used as the recording media.

4.2 *Limitations*—This guide does not take into consideration special benefits and limitations resulting from the use of nonfilm recording media or readouts such as paper, tapes, xeroradiography, fluoroscopy, and electronic image intensification devices. Although reference is made to documents that may be used in the identification and grading, where applicable, of representative discontinuities in common metal castings and welds, no attempt has been made to set standards of acceptance for any material or production process. Radiography will be consistent in sensitivity and resolution only if the effect of all details of techniques, such as geometry, film, filtration, viewing, etc., is obtained and maintained.

5. Quality of Radiographs

5.1 To obtain quality radiographs, it is necessary to consider as a minimum the following list of items. Detailed information on each item is further described in this guide.
5.1.1 Radiation source (X-ray or gamma),
5.1.2 Voltage selection (X-ray),
5.1.3 Source size (X-ray or gamma),
5.1.4 Ways and means to eliminate scattered radiation,
5.1.5 Film system class,
5.1.6 Source to film distance,
5.1.7 Image quality indicators (IQI's),
5.1.8 Screens and filters,
5.1.9 Geometry of part or component configuration,
5.1.10 Identification and location markers, and
5.1.11 Radiographic quality level.

6. Radiographic Quality Level

6.1 Information on the design and manufacture of image quality indicators (IQI's) can be found in Practices E747, E801, E1025, and E1742.

6.2 The quality level usually required for radiography is 2 % (2-2T when using hole type IQI) unless a higher or lower quality is agreed upon between the purchaser and the supplier. At the 2 % subject contrast level, three quality levels of inspection, 2-1T, 2-2T, and 2-4T, are available through the design and application of the IQI (Practice E1025, Table 1). Other levels of inspection are available in Practice E1025 Table 1. The level of inspection specified should be based on the service requirements of the product. Great care should be taken in specifying quality levels 2-1T, 1-1T, and 1-2T by first determining that these quality levels can be maintained in production radiography.

NOTE 2—The first number of the quality level designation refers to IQI thickness expressed as a percentage of specimen thickness; the second number refers to the diameter of the IQI hole that must be visible on the radiograph, expressed as a multiple of penetrameter thickness, *T*.

6.3 If IQI's of material radiographically similar to that being examined are not available, IQI's of the required dimensions but of a lower-absorption material may be used.

6.4 The quality level required using wire IQI's shall be equivalent to the 2-2T level of Practice E1025 unless a higher or lower quality level is agreed upon between purchaser and supplier. Table 4 of Practice E747 gives a list of various hole-type IQI's and the diameter of the wires of corresponding EPS with the applicable 1T, 2T, and 4T holes in the plaque IQI. Appendix X1 of Practice E747 gives the equation for calculating other equivalencies, if needed.

7. Energy Selection

7.1 X-ray energy affects image quality. In general, the lower the energy of the source utilized the higher the achievable radiographic contrast, however, other variables such as geometry and scatter conditions may override the potential advantage of higher contrast. For a particular energy, a range of thicknesses which are a multiple of the half value layer, may be radiographed to an acceptable quality level utilizing a particular X-ray machine or gamma ray source. In all cases the specified IQI (penetrameter) quality level must be shown on the radiograph. In general, satisfactory results can normally be obtained for X-ray energies between 100 kV to 500 kV in a range between 2.5 to 10 half value layers (HVL) of material thickness (see Table 1). This range may be extended by as

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.
[5] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401.
[6] Available from National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

TABLE 1 Typical Steel HVL Thickness in Inches (mm) for Common Energies

Energy	Thickness, Inches (mm)
120 kV	0.10 (2.5)
150 kV	0.14 (3.6)
200 kV	0.20 (5.1)
250 kV	0.25 (6.4)
400 kV (Ir 192)	0.35 (8.9)
1 MV	0.57 (14.5)
2 MV (Co 60)	0.80 (20.3)
4 MV	1.00 (25.4)
6 MV	1.15 (29.2)
10 MV	1.25 (31.8)
16 MV and higher	1.30 (33.0)

much as a factor of 2 in some situations for X-ray energies in the 1 to 25 MV range primarily because of reduced scatter.

8. Radiographic Equivalence Factors

8.1 The radiographic equivalence factor of a material is that factor by which the thickness of the material must be multiplied to give the thickness of a "standard" material (often steel) which has the same absorption. Radiographic equivalence factors of several of the more common metals are given in Table 2, with steel arbitrarily assigned a factor of 1.0. The factors may be used:

8.1.1 To determine the practical thickness limits for radiation sources for materials other than steel, and

8.1.2 To determine exposure factors for one metal from exposure techniques for other metals.

9. Film

9.1 Various industrial radiographic film are available to meet the needs of production radiographic work. However, definite rules on the selection of film are difficult to formulate because the choice depends on individual user requirements. Some user requirements are as follows: radiographic quality levels, exposure times, and various cost factors. Several methods are available for assessing image quality levels (see Test Method E746, and Practices E747 and E801). Information about specific products can be obtained from the manufacturers.

9.2 Various industrial radiographic films are manufactured to meet quality level and production needs. Test Method E1815 provides a method for film manufacturer classification of film systems. A film system consist of the film and associated film processing system. Users may obtain a classification table from the film manufacturer for the film system used in production radiography. A choice of film class can be made as provided in Test Method E1815. Additional specific details regarding classification of film systems is provided in Test Method E1815. ANSI Standards PH1.41, PH4.8, T9.1, and T9.2 provide specific details and requirements for film manufacturing.

10. Filters

10.1 *Definition*—Filters are uniform layers of material placed between the radiation source and the film.

10.2 *Purpose*—The purpose of filters is to absorb the softer components of the primary radiation, thus resulting in one or several of the following practical advantages:

10.2.1 Decreasing scattered radiation, thus increasing contrast.

10.2.2 Decreasing undercutting, thus increasing contrast.

10.2.3 Decreasing contrast of parts of varying thickness.

10.3 *Location*—Usually the filter will be placed in one of the following two locations:

10.3.1 As close as possible to the radiation source, which minimizes the size of the filter and also the contribution of the filter itself to scattered radiation to the film.

10.3.2 Between the specimen and the film in order to absorb preferentially the scattered radiation from the specimen. It should be noted that lead foil and other metallic screens (see 13.1) fulfill this function.

10.4 *Thickness and Filter Material*— The thickness and material of the filter will vary depending upon the following:

10.4.1 The material radiographed.

10.4.2 Thickness of the material radiographed.

10.4.3 Variation of thickness of the material radiographed.

10.4.4 Energy spectrum of the radiation used.

10.4.5 The improvement desired (increasing or decreasing contrast). Filter thickness and material can be calculated or determined empirically.

TABLE 2 Approximate Radiographic Equivalence Factors for Several Metals (Relative to Steel)

Metal	Energy Level									
	100 kV	150 kV	220 kV	250 kV	400 kV	1 MV	2 MV	4 to 25 MV	^{192}Ir	^{60}Co
Magnesium	0.05	0.05	0.08							
Aluminum	0.08	0.12	0.18						0.35	0.35
Aluminum alloy	0.10	0.14	0.18						0.35	0.35
Titanium		0.54	0.54		0.71	0.9	0.9	0.9	0.9	0.9
Iron/all steels	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Copper	1.5	1.6	1.4	1.4	1.4	1.1	1.1	1.2	1.1	1.1
Zinc		1.4	1.3		1.3			1.2	1.1	1.0
Brass		1.4	1.3		1.3	1.2	1.1	1.0	1.1	1.0
Inconel X		1.4	1.3		1.3	1.3	1.3	1.3	1.3	1.3
Monel	1.7		1.2							
Zirconium	2.4	2.3	2.0	1.7	1.5	1.0	1.0	1.0	1.2	1.0
Lead	14.0	14.0	12.0			5.0	2.5	2.7	4.0	2.3
Hafnium			14.0	12.0	9.0	3.0				
Uranium			20.0	16.0	12.0	4.0		3.9	12.6	3.4

11. Masking

11.1 Masking or blocking (surrounding specimens or covering thin sections with an absorptive material) is helpful in reducing scattered radiation. Such a material can also be used to equalize the absorption of different sections, but the loss of detail may be high in the thinner sections.

12. Back-Scatter Protection

12.1 Effects of back-scattered radiation can be reduced by confining the radiation beam to the smallest practical cross section and by placing lead behind the film. In some cases either or both the back lead screen and the lead contained in the back of the cassette or film holder will furnish adequate protection against back-scattered radiation. In other instances, this must be supplemented by additional lead shielding behind the cassette or film holder.

12.2 If there is any question about the adequacy of protection from back-scattered radiation, a characteristic symbol (frequently a ⅛-in. (3.2-mm) thick letter *B*) should be attached to the back of the cassette or film holder, and a radiograph made in the normal manner. If the image of this symbol appears on the radiograph as a lighter density than background, it is an indication that protection against back-scattered radiation is insufficient and that additional precautions must be taken.

13. Screens

13.1 *Metallic Foil Screens:*

13.1.1 Lead foil screens are commonly used in direct contact with the films, and, depending upon their thickness, and composition of the specimen material, will exhibit an intensifying action at as low as 90 kV. In addition, any screen used in front of the film acts as a filter (Section 10) to preferentially absorb scattered radiation arising from the specimen, thus improving radiographic quality. The selection of lead screen thickness, or for that matter, any metallic screen thickness, is subject to the same considerations as outlined in 10.4. Lead screens lessen the scatter reaching the film regardless of whether the screens permit a decrease or necessitate an increase in the radiographic exposure. To avoid image unsharpness due to screens, there should be intimate contact between the lead screen and the film during exposure.

13.1.2 Lead foil screens of appropriate thickness should be used whenever they improve radiographic quality or penetrameter sensitivity or both. The thickness of the front lead screens should be selected with care to avoid excessive filtration in the radiography of thin or light alloy materials, particularly at the lower kilovoltages. In general, there is no exposure advantage to the use of 0.005 in. in front and back lead screens below 125 kV in the radiography of ¼-in. (6.35-mm) or lesser thickness steel. As the kilovoltage is increased to penetrate thicker sections of steel, however, there is a significant exposure advantage. In addition to intensifying action, the back lead screens are used as protection against back-scattered radiation (see Section 12) and their thickness is only important for this function. As exposure energy is increased to penetrate greater thicknesses of a given subject material, it is customary to increase lead screen thickness. For radiography using radioactive sources, the minimum thickness of the front lead screen should be 0.005 in. (0.13 mm) for iridium-192, and 0.010 in. (0.25 mm) for cobalt-60.

13.2 *Other Metallic Screen Materials:*

13.2.1 Lead oxide screens perform in a similar manner to lead foil screens except that their equivalence in lead foil thickness approximates 0.0005 in. (0.013 mm).

13.2.2 Copper screens have somewhat less absorption and intensification than lead screens, but may provide somewhat better radiographic sensitivity with higher energy above 1 MV.

13.2.3 Gold, tantalum, or other heavy metal screens may be used in cases where lead cannot be used.

13.3 *Fluorescent Screens*—Fluorescent screens may be used as required providing the required image quality is achieved. Proper selection of the fluorescent screen is required to minimize image unsharpness. Technical information about specific fluorescent screen products can be obtained from the manufacturers. Good film-screen contact and screen cleanliness are required for successful use of fluorescent screens. Additional information on the use of fluorescent screens is provided in Appendix X1.

13.4 *Screen Care*—All screens should be handled carefully to avoid dents and scratches, dirt, or grease on active surfaces. Grease and lint may be removed from lead screens with a solvent. Fluorescent screens should be cleaned in accordance with the recommendations of the manufacturer. Screens showing evidence of physical damage should be discarded.

14. Radiographic Image Quality

14.1 *Radiographic image quality* is a qualitative term used to describe the capability of a radiograph to show flaws in the area under examination. There are three fundamental components of radiographic image quality as shown in Fig. 1. Each component is an important attribute when considering a specific radiographic technique or application and will be briefly discussed below.

14.2 *Radiographic contrast* between two areas of a radiograph is the difference between the film densities of those areas. The degree of radiographic contrast is dependent upon both subject contrast and film contrast as illustrated in Fig. 1.

14.2.1 *Subject contrast* is the ratio of X-ray or gamma-ray intensities transmitted by two selected portions of a specimen. Subject contrast is dependent upon the nature of the specimen (material type and thickness), the energy (spectral composition, hardness or wavelengths) of the radiation used and the intensity and distribution of scattered radiation. It is independent of time, milliamperage or source strength (curies), source distance and the characteristics of the film system.

14.2.2 *Film contrast* refers to the slope (steepness) of the film system characteristic curve. Film contrast is dependent upon the type of film, the processing it receives and the amount of film density. It also depends upon whether the film was exposed with lead screens (or without) or with fluorescent screens. Film contrast is independent, for most practical purposes, of the wavelength and distribution of the radiation reaching the film and, hence is independent of subject contrast. For further information, consult Test Method E1815.

Radiographic Image Quality				
Radiographic Contrast		Film System Granularity	Radiographic Definition	
Subject Contrast	Film Contrast		Inherent Unsharpness	Geometric Unsharpness
Affected by: • Absorption differences in specimen (thickness, composition, density) • Radiation wavelength • Scattered radiation Reduced or enhanced by: • Masks and diaphragms • Filters • Lead screens • Potter-Bucky diaphragms	Affected by: • Type of film • Degree of development (type of developer, time, temperature and activity of developer, degree of agitation) • Film density • Type of screens (that is, fluorescent, lead or none)	• Grain size and distribution within the film emulsion • Processing conditions (type and activity of developer, temperature of developer, etc.) • Type of screens (that is, fluorescent, lead or none) • Radiation quality (that is, energy level, filtration, etc. • Exposure quanta (that is, intensity, dose, etc.)	Affected by: • Degree of screen-film contact • Total film thickness • Single or double emulsion coatings • Radiation quality • Type and thickness of screens (fluorescent, lead or none)	Affected by: • Focal spot or source physical size • Source-to-film distance • Specimen-to-film distance • Abruptness of thickness changes in specimen • Motion of specimen or radiation source

FIG. 1 Variables of Radiographic Image Quality

14.3 *Film system granularity* is the objective measurement of the local density variations that produce the sensation of graininess on the radiographic film (for example, measured with a densitometer with a small aperture of ≤ 0.0039 in. (0.1 mm)). Graininess is the subjective perception of a mottled random pattern apparent to a viewer who sees small local density variations in an area of overall uniform density (that is, the visual impression of irregularity of silver deposit in a processed radiograph). The degree of granularity will not affect the overall spatial radiographic resolution (expressed in line pairs per mm, etc.) of the resultant image and is usually independent of exposure geometry arrangements. Granularity is affected by the applied screens, screen-film contact and film processing conditions. For further information on detailed perceptibility, consult Test Method E1815.

14.4 *Radiographic definition* refers to the sharpness of the image (both the image outline as well as image detail). Radiographic definition is dependent upon the inherent unsharpness of the film system and the geometry of the radiographic exposure arrangement (geometric unsharpness) as illustrated in Fig. 1.

14.4.1 *Inherent unsharpness* (U_i) is the degree of visible detail resulting from geometrical aspects within the film-screen system, that is, screen-film contact, screen thickness, total thickness of the film emulsions, whether single or double-coated emulsions, quality of radiation used (wavelengths, etc.) and the type of screen. Inherent unsharpness is independent of exposure geometry arrangements.

14.4.2 *Geometric unsharpness* (U_g) determines the degree of visible detail resultant from an "in-focus" exposure arrangement consisting of the source-to-film-distance, object-to-film-distance and focal spot size. Fig. 2(a) illustrates these conditions. Geometric unsharpness is given by the equation:

$$U_g = Ft/d_o \quad (1)$$

where:

U_g = geometric unsharpness,
F = maximum projected dimension of radiation source,
t = distance from source side of specimen to film, and
d_o = source-object distance.

NOTE 3—d_o and t must be in the same units of measure; the units of U_g will be in the same units as F.

NOTE 4—A nomogram for the determination of U_g is given in Fig. 3 (inch-pound units). Fig. 4 represents a nomogram in metric units.
Example:
Given:
Source-object distance (d_o) = 40 in.,
Source size (F) = 500 mils, and
Source side of specimen to film distance (t) = 1.5 in.
Draw a straight line (dashed in Fig. 3) between 500 mils on the F scale and 1.5 in. on the t scale. Note the point on intersection (P) of this line with the pivot line. Draw a straight line (solid in Fig. 3) from 40 in. on the d_o scale through point P and extend to the U_g scale. Intersection of this line with the U_g scale gives geometrical unsharpness in mils, which in the example is 19 mils.

Inasmuch as the source size, F, is usually fixed for a given radiation source, the value of U_g is essentially controlled by the simple d_o/t ratio.

Geometric unsharpness (U_g) can have a significant effect on the quality of the radiograph; therefore source-to-film-distance (SFD) selection is important. The geometric unsharpness (U_g) equation, Eq 1, is for information and guidance and provides a means for determining geometric unsharpness values. The

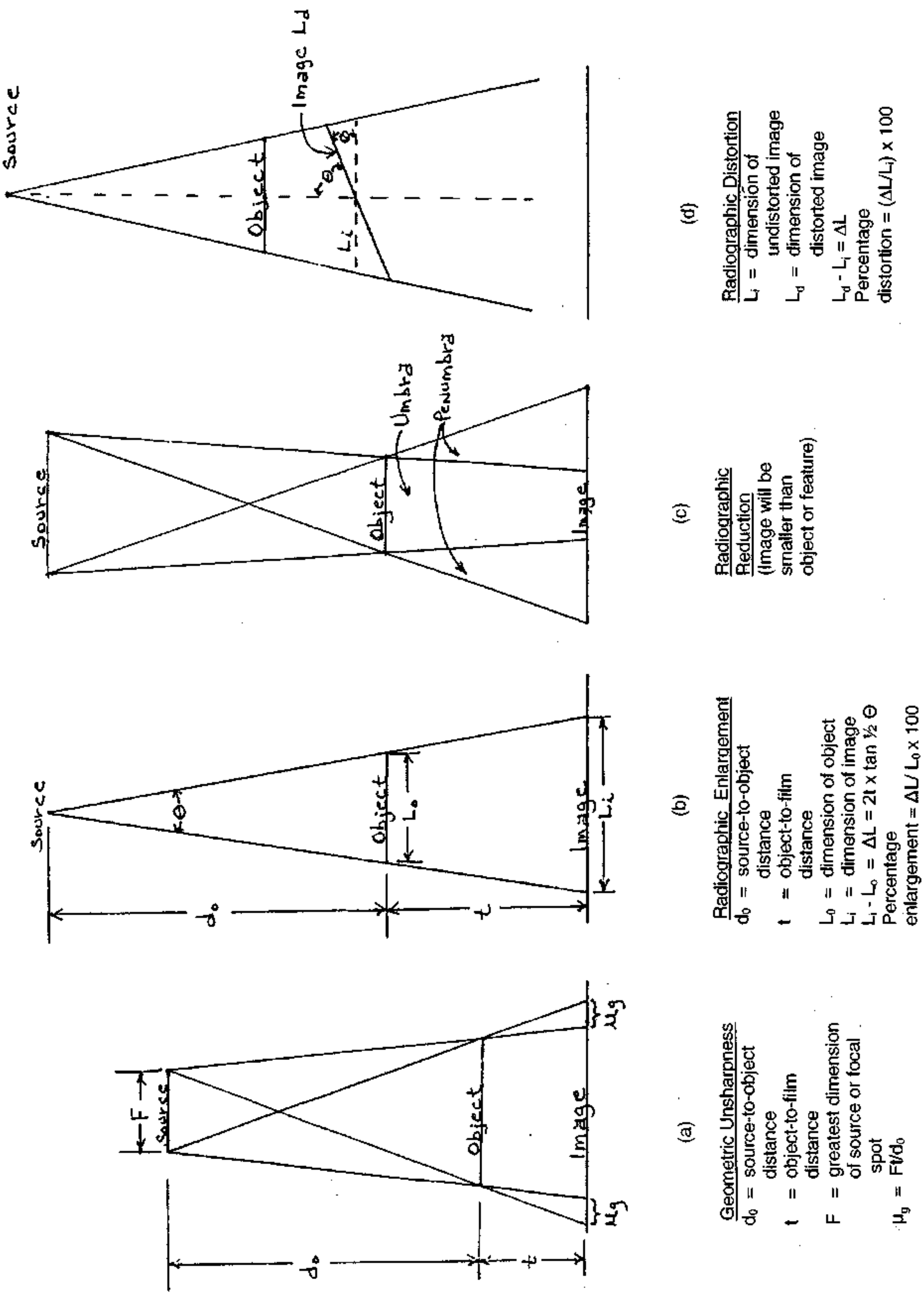

FIG. 2 Effects of Object-Film Geometry

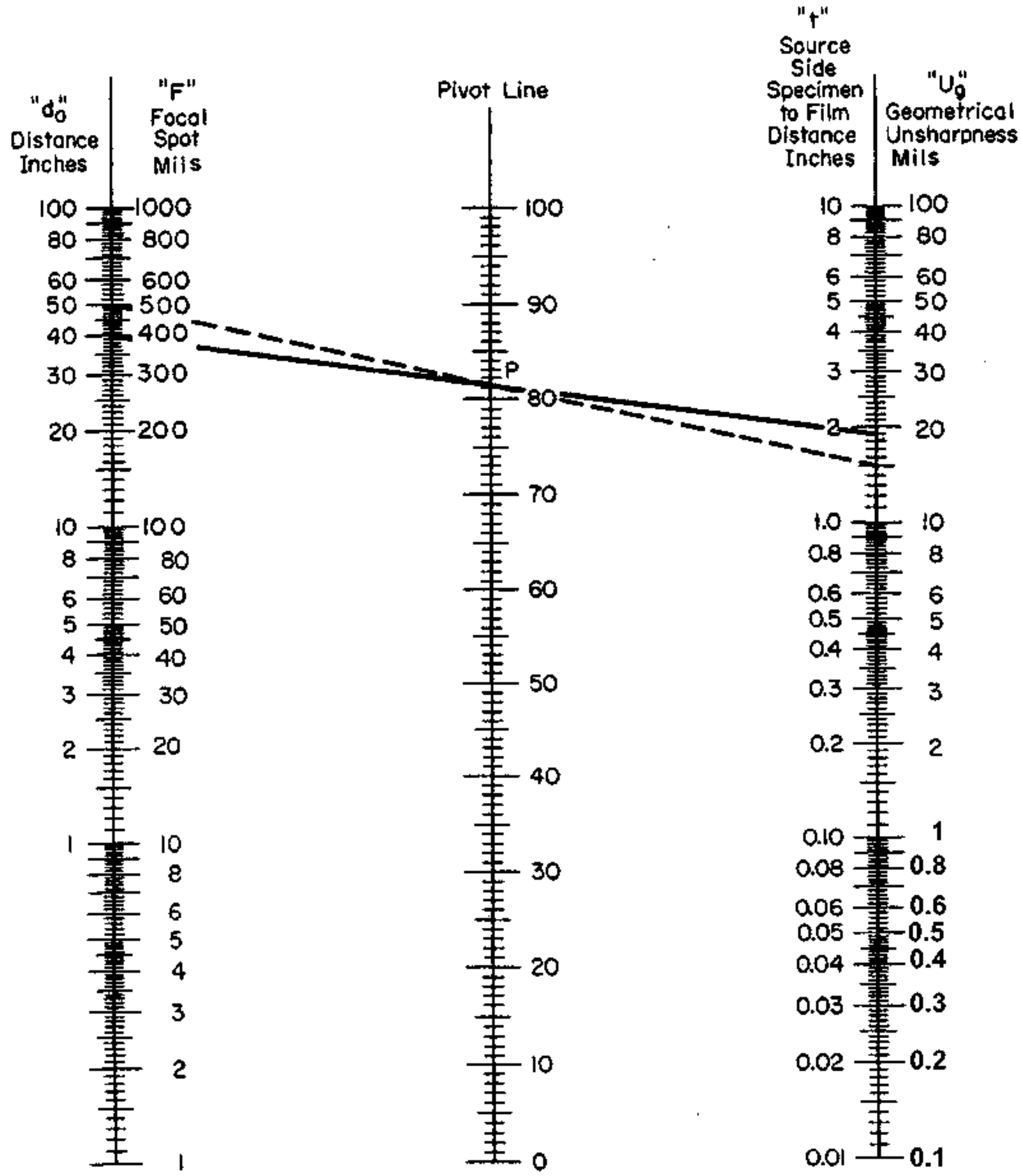

FIG. 3 Nomogram for Determining Geometrical Unsharpness (Inch-Pound Units)

amount or degree of unsharpness should be minimized when establishing the radiographic technique.

15. Radiographic Distortion

15.1 The radiographic image of an object or feature within an object may be larger or smaller than the object or feature itself, because the penumbra of the shadow is rarely visible in a radiograph. Therefore, the image will be larger if the object or feature is larger than the source of radiation, and smaller if object or feature is smaller than the source. The degree of reduction or enlargement will depend on the source-to-object and object-to-film distances, and on the relative sizes of the source and the object or feature (Fig. 2(*b*) and (*c*)).

15.2 The direction of the central beam of radiation should be perpendicular to the surface of the film whenever possible. The object image will be distorted if the film is not aligned perpendicular to the central beam. Different parts of the object image will be distorted different amount depending on the extent of the film to central beam offset (Fig. 2(*d*)).

16. Exposure Calculations or Charts

16.1 Development or procurement of an exposure chart or calculator is the responsibility of the individual laboratory.

16.2 The essential elements of an exposure chart or calculator must relate the following:

16.2.1 Source or machine,

16.2.2 Material type,

16.2.3 Material thickness,

16.2.4 Film type (relative speed),

16.2.5 Film density, (see Note 5),

16.2.6 Source or source to film distance,

16.2.7 Kilovoltage or isotope type,

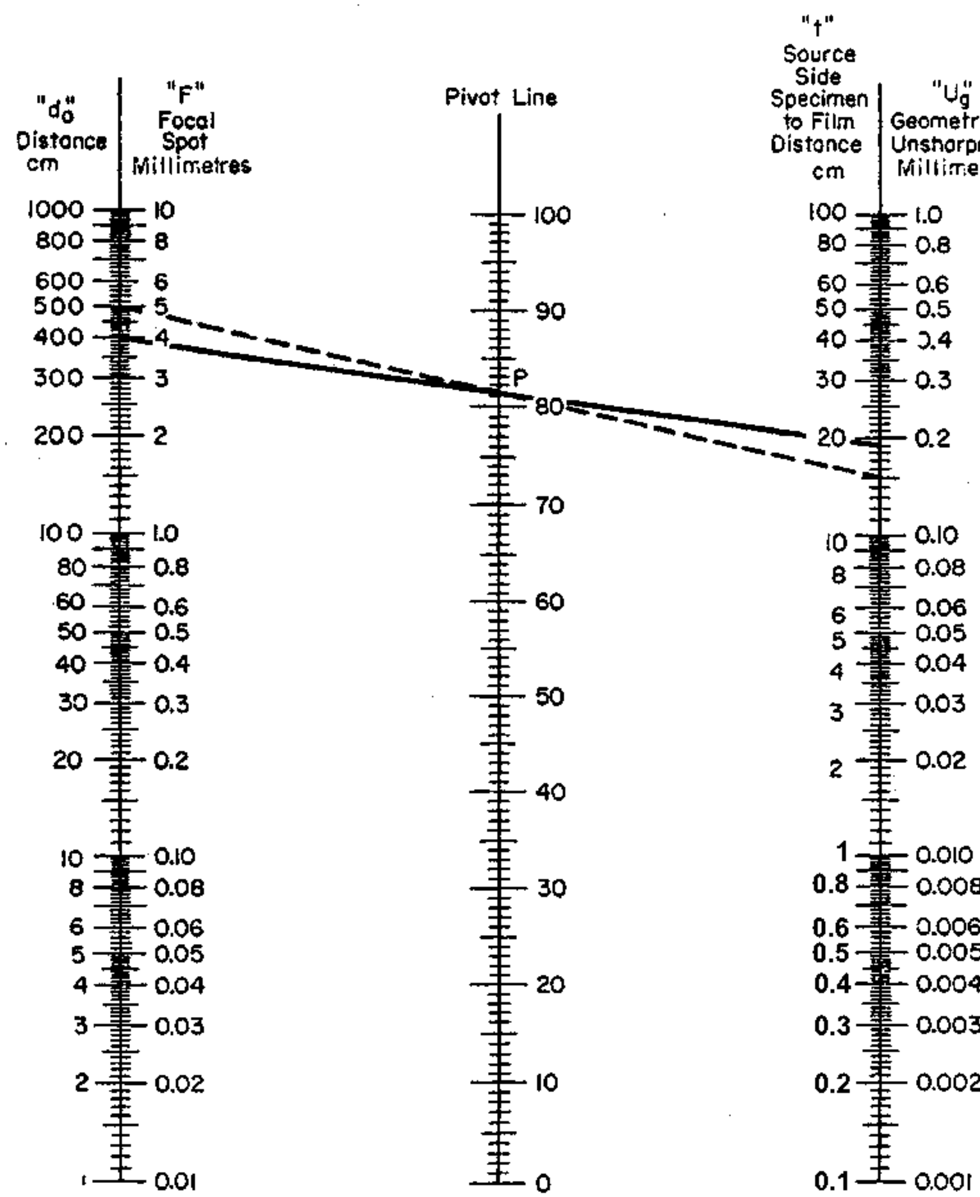

FIG. 4 Nomogram for Determining Geometrical Unsharpness (Metric Units)

NOTE 5—For detailed information on film density and density measurement calibration, see Practice E1079.

16.2.8 Screen type and thickness,

16.2.9 Curies or milliampere/minutes,

16.2.10 Time of exposure,

16.2.11 Filter (in the primary beam),

16.2.12 Time-temperature development for hand processing; access time for automatic processing; time-temperature development for dry processing, and

16.2.13 Processing chemistry brand name, if applicable.

16.3 The essential elements listed in 16.2 will be accurate for isotopes of the same type, but will vary with X-ray equipment of the same kilovoltage and milliampere rating.

16.4 Exposure charts should be developed for each X-ray machine and corrected each time a major component is replaced, such as the X-ray tube or high-voltage transformer.

16.5 The exposure chart should be corrected when the processing chemicals are changed to a different manufacturer's brand or the time-temperature relationship of the processor may be adjusted to suit the exposure chart. The exposure chart, when using a dry processing method, should be corrected based upon the time-temperature changes of the processor.

17. Technique File

17.1 It is recommended that a radiographic technique log or record containing the essential elements be maintained.

17.2 The radiographic technique log or record should contain the following:

17.2.1 Description, photo, or sketch of the test object illustrating marker layout, source placement, and film location.

17.2.2 Material type and thickness,

17.2.3 Source to film distance,

17.2.4 Film type,
17.2.5 Film density, (see Note 5),
17.2.6 Screen type and thickness,
17.2.7 Isotope or X-ray machine identification,
17.2.8 Curie or milliampere minutes,
17.2.9 IQI and shim thickness,
17.2.10 Special masking or filters,
17.2.11 Collimator or field limitation device,
17.2.12 Processing method, and
17.2.13 View or location.

17.3 The recommendations of 17.2 are not mandatory, but are essential in reducing the overall cost of radiography, and serve as a communication link between the radiographic interpreter and the radiographic operator.

18. Penetrameters (Image Quality Indicators)

18.1 Practices E747, E801, E1025, and E1742 should be consulted for detailed information on the design, manufacture and material grouping of IQI's. Practice E801 addresses IQI's for examination of electronic devices and provides additional details for positioning IQI's, number of IQI's required, and so forth.

18.2 Test Methods E746 and E1735 should be consulted for detailed information regarding IQI's which are used for determining relative image quality response of industrial film. The IQI's can also be used for measuring the image quality of the radiographic system or any component of the systems equivalent penetrameter sensitivity (EPS) performance.

18.2.1 An example for determining and EPS performance evaluation of several X-ray machines is as follows:

18.2.1.1 Keep the film and film processing parameters constant, and take multiple image quality exposures with all machines being evaluated. The machines should be set for a prescribed exposure as stated in the standard and the film density equalized. By comparison of the resultant films, the relative EPS variations between the machines can be determined.

18.2.2 Exposure condition variables may also be studied using this plaque.

18.2.3 While Test Method E746 plaque can be useful in quantifying relative radiographic image quality, these other applications of the plaque may be useful.

19. Identification of and Location Markers on Radiographs

19.1 *Identification of Radiographs:*

19.1.1 Each radiograph must be identified uniquely so that there is a permanent correlation between the part radiographed and the film. The type of identification and method by which identification is achieved shall be as agreed upon between the customer and inspector.

19.1.2 The minimum identification should at least include the following: the radiographic facility's identification and name, the date, part number and serial number, if used, for unmistakable identification of radiographs with the specimen. The letter *R* should be used to designate a radiograph of a repair area, and may include – 1, – 2, etc., for the number of repair.

19.2 *Location Markers:*

19.2.1 Location markers (that is, lead or high-atomic number metals or letters that are to appear as images on the radiographic film) should be placed on the part being examined, whenever practical, and not on the cassette. Their exact locations should also be marked on the surface of the part being radiographed, thus permitting the area of interest to be located accurately on the part, and they should remain on the part during radiographic inspection. Their exact location may be permanently marked in accordance with the customer's requirements.

19.2.2 Location markers are also used in assisting the radiographic interpreter in marking off defective areas of components, castings, or defects in weldments; also, sorting good and rejectable items when more than one item is radiographed on the same film.

19.2.3 Sufficient markers must be used to provide evidence on the radiograph that the required coverage of the object being examined has been obtained, and that overlap is evident, especially during radiography of weldments and castings.

19.2.4 Parts that must be identified permanently may have the serial numbers or section numbers, or both, stamped or written upon them with a marking pen with a special indelible ink, engraved, die stamped, or etched. In any case, the part should be marked in an area not to be removed in subsequent fabrication. If die stamps are used, caution is required to prevent breakage or future fatigue failure. The lowest stressed surface of the part should be used for this stamping. Where marking or stamping of the part is not permitted for some reason, a marked reference drawing or shooting sketch is recommended.

20. Storage of Film

20.1 Unexposed films should be stored in such a manner that they are protected from the effects of light, pressure, excessive heat, excessive humidity, damaging fumes or vapors, or penetrating radiation. Film manufacturers should be consulted for detailed recommendations on film storage. Storage of film should be on a "first in," "first out" basis.

20.2 More detailed information on film storage is provided in Guide E1254.

21. Safelight Test

21.1 Films should be handled under safelight conditions in accordance with the film manufacturer's recommendations. ANSI PH2.22 can be used to determine the adequacy of safelight conditions in a darkroom.

22. Cleanliness and Film Handling

22.1 Cleanliness is one of the most important requirements for good radiography. Cassettes and screens must be kept clean, not only because dirt retained may cause exposure or processing artifacts in the radiographs, but because such dirt may also be transferred to the loading bench, and subsequently to other film or screens.

22.2 The surface of the loading bench must be kept clean. Where manual processing is used cleanliness will be promoted by arranging the darkroom with processing facilities on one side and film-handling facilities on the other. The darkroom will then have a wet side and a dry side and the chance of chemical contamination of the loading bench will be relatively slight.

22.3 Films should be handled only at their edges, and with dry, clean hands to avoid finger marks on film surfaces.

22.4 Sharp bending, excessive pressure, and rough handling of any kind must be avoided.

23. Film Processing, General

23.1 To produce a satisfactory radiograph, the care used in making the exposure *must* be followed by equal care in processing. The most careful radiographic techniques can be nullified by incorrect or improper darkroom procedures.

23.2 Sections 24 – 26 provide general information for film processing. Detailed information on film processing is provided in Guide E999.

24. Automatic Processing

24.1 *Automatic Processing*—The essence of the automatic processing system is control. The processor maintains the chemical solutions at the proper temperature, agitates and replenishes the solutions automatically, and transports the films mechanically at a carefully controlled speed throughout the processing cycle. Film characteristics must be compatible with processing conditions. It is, therefore, essential that the recommendations of the film, processor, and chemical manufacturers be followed.

24.2 *Automatic Processing, Dry*—The essence of dry automatic processing is the precise control of development time and temperature which results in reproducibility of radiographic density. Film characteristics must be compatible with processing conditions. It is, therefore, essential that the recommendations of the film and processor manufacturers be followed.

25. Manual Processing

25.1 Film and chemical manufacturers should be consulted for detailed recommendations on manual film processing. This section outlines the steps for one acceptable method of manual processing.

25.2 *Preparation*—No more film should be processed than can be accommodated with a minimum separation of ½ in. (12.7 mm). Hangers are loaded and solutions stirred before starting development.

25.3 *Start of Development*—Start the timer and place the films into the developer tank. Separate to a minimum distance of ½ in. (12.7 mm) and agitate in two directions for about 15 s.

25.4 *Development*—Normal development is 5 to 8 min at 68°F (20°C). Longer development time generally yields faster film speed and slightly more contrast. The manufacturer's recommendation should be followed in choosing a development time. When the temperature is higher or lower, development time must be changed. Again, consult manufacturer-recommended development time versus temperature charts. Other recommendations of the manufacturer to be followed are replenishment rates, renewal of solutions, and other specific instructions.

25.5 *Agitation*—Shake the film horizontally and vertically, ideally for a few seconds each minute during development. This will help film develop evenly.

25.6 *Stop Bath or Rinse*—After development is complete, the activity of developer remaining in the emulsion should be neutralized by an acid stop bath or, if this is not possible, by rinsing with vigorous agitation in clear water. Follow the film manufacturer's recommendation of stop bath composition (or length of alternative rinse), time immersed, and life of bath.

25.7 *Fixing*—The films must not touch one another in the fixer. Agitate the hangers vertically for about 10 s and again at the end of the first minute, to ensure uniform and rapid fixation. Keep them in the fixer until fixation is complete (that is, at least twice the clearing time), but not more than 15 min in relatively fresh fixer. Frequent agitation will shorten the time of fixation.

25.8 *Fixer Neutralizing*—The use of a hypo eliminator or fixer neutralizer between fixation and washing may be advantageous. These materials permit a reduction of both time and amount of water necessary for adequate washing. The recommendations of the manufacturers as to preparation, use, and useful life of the baths should be observed rigorously.

25.9 *Washing*—The washing efficiency is a function of wash water, its temperature, and flow, and the film being washed. Generally, washing is very slow below 60°F (16°C). When washing at temperatures above 85°F (30°C), care should be exercised not to leave films in the water too long. The films should be washed in batches without contamination from new film brought over from the fixer. If pressed for capacity, as more films are put in the wash, partially washed film should be moved in the direction of the inlet.

25.9.1 The cascade method of washing uses less water and gives better washing for the same length of time. Divide the wash tank into two sections (may be two tanks). Put the films from the fixer in the outlet section. After partial washing, move the batch of film to the inlet section. This completes the wash in fresh water.

25.9.2 For specific washing recommendations, consult the film manufacturer.

25.10 *Wetting Agent*—Dip the film for approximately 30 s in a wetting agent. This makes water drain evenly off film which facilitates quick, even drying.

25.11 *Residual Fixer Concentrations*— If the fixing chemicals are not removed adequately from the film, they will in time cause staining or fading of the developed image. Residual fixer concentrations permissible depend upon whether the films are to be kept for commercial purposes (3 to 10 years) or must be of archival quality. Archival quality processing is desirable for all radiographs whenever average relative humidity and temperature are likely to be excessive, as is the case in tropical and subtropical climates. The method of determining residual fixer concentrations may be ascertained by reference to ANSI PH4.8, PH1.28, and PH1.41.

25.12 *Drying*—Drying is a function of (*1*) film (base and emulsion); (*2*) processing (hardness of emulsion after washing, use of wetting agent); and (*3*) drying air (temperature, humidity, flow). Manual drying can vary from still air drying at ambient temperature to as high as 140°F (60°C) with air circulated by a fan. Film manufacturers should again be contacted for recommended drying conditions. Take precaution to tighten film on hangers, so that it cannot touch in the dryer. Too hot a drying temperature at low humidity can result in uneven drying and should be avoided.

26. Testing Developer

26.1 It is desirable to monitor the activity of the radiographic developing solution. This can be done by periodic development of film strips exposed under carefully controlled conditions, to a graded series of radiation intensities or time, or by using a commercially available strip carefully controlled for film speed and latent image fading.

27. Viewing Radiographs

27.1 Guide E1390 provides detailed information on requirements for illuminators. The following sections provide general information to be considered for use of illuminators.

27.2 *Transmission*—The illuminator must provide light of an intensity that will illuminate the average density areas of the radiographs without glare and it must diffuse the light evenly over the viewing area. Commercial fluorescent illuminators are satisfactory for radiographs of moderate density; however, high light intensity illuminators are available for densities up to 3.5 or 4.0. Masks should be available to exclude any extraneous light from the eyes of the viewer when viewing radiographs smaller than the viewing port or to cover low-density areas.

27.3 *Reflection*—Radiographs on a translucent or opaque backing may be viewed by reflected light. It is recommended that the radiograph be viewed under diffuse lighting conditions to prevent excess glare. Optical magnification can be used in certain instances to enhance the interpretation of the image.

28. Viewing Room

28.1 Subdued lighting, rather than total darkness, is preferable in the viewing room. The brightness of the surroundings should be about the same as the area of interest in the radiograph. Room illumination must be so arranged that there are no reflections from the surface of the film under examination.

29. Storage of Processed Radiographs

29.1 Guide E1254 provides detailed information on controls and maintenance for storage of radiographs and unexposed film. The following sections provide general information for storage of radiographs.

29.2 Envelopes having an edge seam, rather than a center seam, and joined with a nonhygroscopic adhesive, are preferred, since occasional staining and fading of the image is caused by certain adhesives used in the manufacture of envelopes (see ANSI PH1.53).

30. Records

30.1 It is recommended that an inspection log (a log may consist of a card file, punched card system, a book, or other record) constituting a record of each job performed, be maintained. This record should comprise, initially, a job number (which should appear also on the films), the identification of the parts, material or area radiographed, the date the films are exposed, and a complete record of the radiographic procedure, in sufficient detail so that any radiographic techniques may be duplicated readily. If calibration data, or other records such as card files or procedures, are used to determine the procedure, the log need refer only to the appropriate data or other record. Subsequently, the interpreter's findings and disposition (acceptance or rejection), if any, and his initials, should also be entered for each job.

31. Reports

31.1 When written reports of radiographic examinations are required, they should include the following, plus such other items as may be agreed upon:

31.1.1 Identification of parts, material, or area.

31.1.2 Radiographic job number.

31.1.3 Findings and disposition, if any. This information can be obtained directly from the log.

32. Identification of Completed Work

32.1 Whenever radiography is an inspective (rather than investigative) operation whereby material is accepted or rejected, all parts and material that have been accepted should be marked permanently, if possible, with a characteristic identifying symbol which will indicate to subsequent or final examiners the fact of radiographic acceptance.

32.2 Whenever possible, the completed radiographs should be kept on file for reference. The custody of radiographs and the length of time they are preserved should be agreed upon between the contracting parties.

33. Keywords

33.1 exposure calculations; film system; gamma-ray; image quality indicator (IQI); radiograph; radiographic examination; radiographic quality level; technique file; X-ray

APPENDIX

(Nonmandatory Information)

X1. USE OF FLUORESCENT SCREENS

X1.1 *Description*—Fluorescent intensifying screens have a cardboard or plastic support coated with a uniform layer of inorganic phosphor (crystalline substance). The support and phosphor are held together by a radiotransparent binding material. Fluorescent screens derive their name from the fact that their phosphor crystals "fluoresce" (emit visible light) when struck by X or gamma radiation. Some phosphors like calcium tungstate ($CaWO_4$) give off blue light while others known as rare earth emit light green.

X1.2 *Purpose and Film Types*—Fluorescent screen exposures are usually much shorter than those made without screens or with lead intensifying screens, because radiographic films generally are more responsive to visible light than to direct X-radiation, gamma radiation, and electrons.

X1.2.1 Films fall into one of two categories: non-screen type film having moderate light response, and screen type film specifically sensitized to have a very high blue or green light response. Fluorescent screens can reduce conventional exposures by as much as 150 times, depending on film type.

X1.3 *Image Quality and Use*—The image quality associated with fluorescent screen exposures is a function of sharpness, mottle, and contrast. Screen sharpness depends on phosphor crystal size, thickness of the crystal layer, and the reflective base coating. Each crystal emits light relative to its size and in all directions thus producing a relative degree of image unsharpness. To minimize this unsharpness, screen to film contact should be as intimate as possible. Mottle adversely affects image quality in two ways. First, a "quantum" mottle is dependent upon the amount of X or gamma radiation actually absorbed by the fluorescent screen, that is, faster screen/film systems lead to greater mottle and poorer image quality. A" structural" mottle, which is a function of crystal size, crystal uniformity, and layer thickness, is minimized by using screens having small, evenly spaced crystals in a thin crystalline layer. Fluorescent screens are highly sensitive to longer wavelength scattered radiation. Consequently, to maximize contrast when this non-image forming radiation is excessive, fluorometallic intensifying screens or fluorescent screens backed by lead screens of appropriate thickness are recommended. Screen technology has seen significant advances in recent years, and today's fluorescent screens have smaller crystal size, more uniform crystal packing, and reduced phosphor thickness. This translates into greater screen/film speed with reduced unsharpness and mottle. These improvements can represent some meaningful benefits for industrial radiography, as indicated by the three examples as follows:

X1.3.1 *Reduced Exposure (Increased Productivity)*—There are instances when prohibitively long exposure times make conventional radiography impractical. An example is the inspection of thick, high atomic number materials with low curie isotopes. Depending on many variables, exposure time may be reduced by factors ranging from 2× to 105× when the appropriate fluorescent screen/film combination is used.

X1.3.2 *Improved Safety Conditions (Field Sites)*—Because fluorescent screens provide reduced exposure, the length of time that non-radiation workers must evacuate a radiographic inspection site can be reduced significantly.

X1.3.3 *Extended Equipment Capability*—Utilizing the speed advantage of fluorescent screens by translating it into reduced energy level. An example is that a 150 kV X-ray tube may do the job of a 300 kV tube, or that iridium 192 may be used in applications normally requiring cobalt 60. It is possible for overall image quality to be better at the lower kV with fluorescent screens than at a higher energy level using lead screens.

BIBLIOGRAPHY ON INDUSTRIAL RADIOGRAPHY

For conciseness, this bibliography has been limited to books and specifically to books in English published after 1950.

(1) Clark, G. L., *Applied X-Rays,* 4th ed., McGraw Hill Book Co., Inc., New York, 1955.

(2) Clauser, H. R., *Practical Radiography for Industry,* Reinhold Publishing Corp., New York, 1952.

(3) Hogarth, C. A., and Blitz, J. (Editors), *Techniques of Nondestructive Testing,* Butte Worth and Co., Ltd., London, 1960.

(4) McMaster, R. C. (Editor), *Nondestructive Testing Handbook,* The Ronald Press, New York, 1960.

(5) Morgan, R. H., and Corrigan, K. E. (Editors), *Handbook of Radiology,* The Year Book Publishers, Inc., Chicago, 1955.

(6) Reed, M. E., *Cobalt-60 Radiography in Industry,* Tracer-lab, Inc., Boston, 1954.

(7) Robertson, J. K., *Radiology Physics,* 3rd ed., D. Van Nostrand Company, New York, 1956.
(8) Weyl, C., and Warren, S. R., *Radiologic Physics,* 2nd ed., Charles C. Thomas, Springfield, IL, 1951.
(9) Wilshire, W. J. (Editor), *A Further Handbook of Industrial Radiology,* Edward Arnold and Company, London, 1957.
(10) McGonnagle, W. J., *Nondestructive Testing,* McGraw Hill Book Co., Inc., New York, 1961 .
(11) *Handbook on Radiography,* Revised edition, Atomic Energy of Canada Ltd. Ottawa, Ont., 1950 .
(12) *Papers on Radiography, ASTM STP 96,* ASTM, 1950.
(13) *Symposium on the Role of Nondestructive Testing in the Economics of Production, ASTM STP 112,* ASTM, 1951.
(14) *Radioisotope Technique,* Vol II, H. M. Stationery Office, London, 1952.
(15) *Symposium on Nondestructive Testing, ASTM STP 145,* ASTM, 1953.
(16) *Memorandum on Gamma-Ray Sources for Radiography,* Revised edition, Institute of Physics, London, 1954.
(17) *Papers on Nondestructive Testing,* see *Proceedings,* ASTM, Vol 54, 1954.
(18) *Radiography in Modern Industry* (3rd edition), Eastman Kodak Co., Rochester, NY, 1969.
(19) *Symposium on Nondestructive Tests in the Field of Nuclear Energy, ASTM STP 223,* ASTM, 1958.
(20) *Radiographer's Reference* (3rd edition), E. I. du Pont de Nemours & Co., Inc., Wilmington, DE, 1974 (or latest revision).