INTERNATIONAL

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Standard Guide for Radiographic Examination[1]

This standard is issued under the fixed designation E 94; 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 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 E 999, Practice E 1025, Test Methods E 1030 and E 1032.

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 secific 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 E 543.

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing[3]

E 746 Test Method for Determining Relative Image Quality Response of Industrial Radiographic Film[3]

E 747 Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology[3]

E 801 Practice for Controlling Quality of Radiological Examination of Electronic Devices[3]

E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing[3]

E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology[3]

E 1030 Test Method for Radiographic Examination of Metallic Castings[3]

E 1032 Test Method for Radiographic Examination of Weldments[3]

E 1079 Practice for Calibration of Transmission Densitometers[3]

E 1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films[3]

E 1316 Terminology for Nondestructive Examinations[3]

E 1390 Guide for Illuminators Used for Viewing Industrial Radiographs[3]

E 1735 Test Method for Determining Relative Image Quality of Industrial Radiographic Film Exposed to X-Radiation from 4 to 25 MV[3]

E 1742 Practice for Radiographic Examination[3]

E 1815 Test Method for Classification of Film Systems for Industrial Radiography[3]

2.2 *ANSI Standards:*

[1] This guide is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.01 on Radiology (X and Gamma) Method.

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

[3] *Annual Book of ASTM Standards*, Vol 03.03.

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 E 1316.

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 E 747, E 801, E 1025, and E 1742.

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 E 1025, Table 1). Other levels of inspection are available in Practice E 1025 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 E 1025 unless a higher or lower quality level is agreed upon between purchaser and supplier. Table 4 of Practice E 747 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 E 747 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 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.

[4] Available from American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.
[5] Available from U.S. Government Printing Office, Superintendent of Documents, Vashington, DC 20402.
[6] Available from the National Technical Information Service, 5285 Port Royal Road, 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)

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 E 746, and Practices E 747 and E 801). 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 E 1815 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 E 1815. Additional specific details regarding classification of film systems is provided in Test Method E 1815. 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.

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

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

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 flourescent 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 Contrast

14.1 The various radiation intensities that penetrate an object are rendered as different photographic densities in a radiograph. Using transmitted or reflected light to view a radiograph, an observed change in film density over a background is defined as contrast. Radiographic contrast depends mostly upon subject contrast and the film gradient.

14.2 Subject contrast is the ratio of radiation intensities transmitted by two selected portions of a specimen.

14.3 The film gradient is the value of the slope of the tangent line drawn to a particular density point on the characteristic curve to the abscissa. Film manufacturers can furnish characteristic curves of their products.

14.4 The quality of radiography is influenced by many variables; the effects of changes in some of these variables are illustrated in Fig. 1.

15. Geometry

15.1 The source to film distance necessary to reduce geometric unsharpness to a negligible amount depends upon the film or film-screen combinations, focal-spot size, and object-film distance. Geometric unsharpness is given (see Fig. 2(*a*)) by the equation:

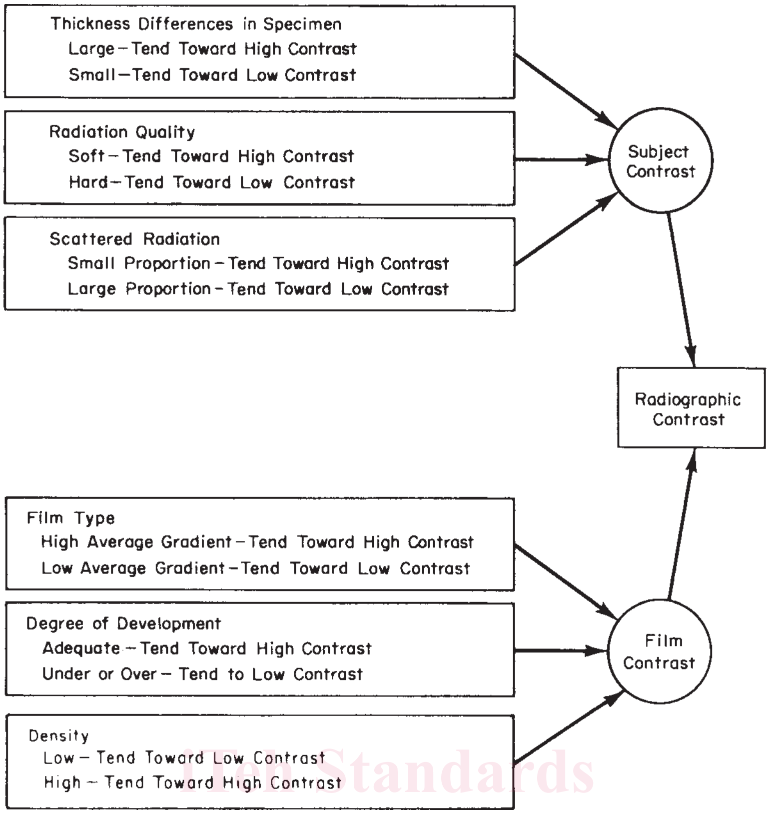
$$U_g = Ft/d_o \quad (1)$$

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.



NOTE 1—The maximum usable density on Class 1, 2, and 3 film depends on the illuminator available.

FIG. 1 Effects of Changes in Variables on Quality of Radiography

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.

15.2 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*)).

15.3 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*)).

15.4 Geometric unsharpness (Ug) can have a significant effect on the quality of the radiograph, therefore source to film distance (SFD) selection is important. The geometric unsharpness (Ug) equation in 15.1 is for information and guidance and provides a means for determining geometric unsharpness values. The amount or degree of unsharpness should be minimized when establishing the radiographic technique.

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,

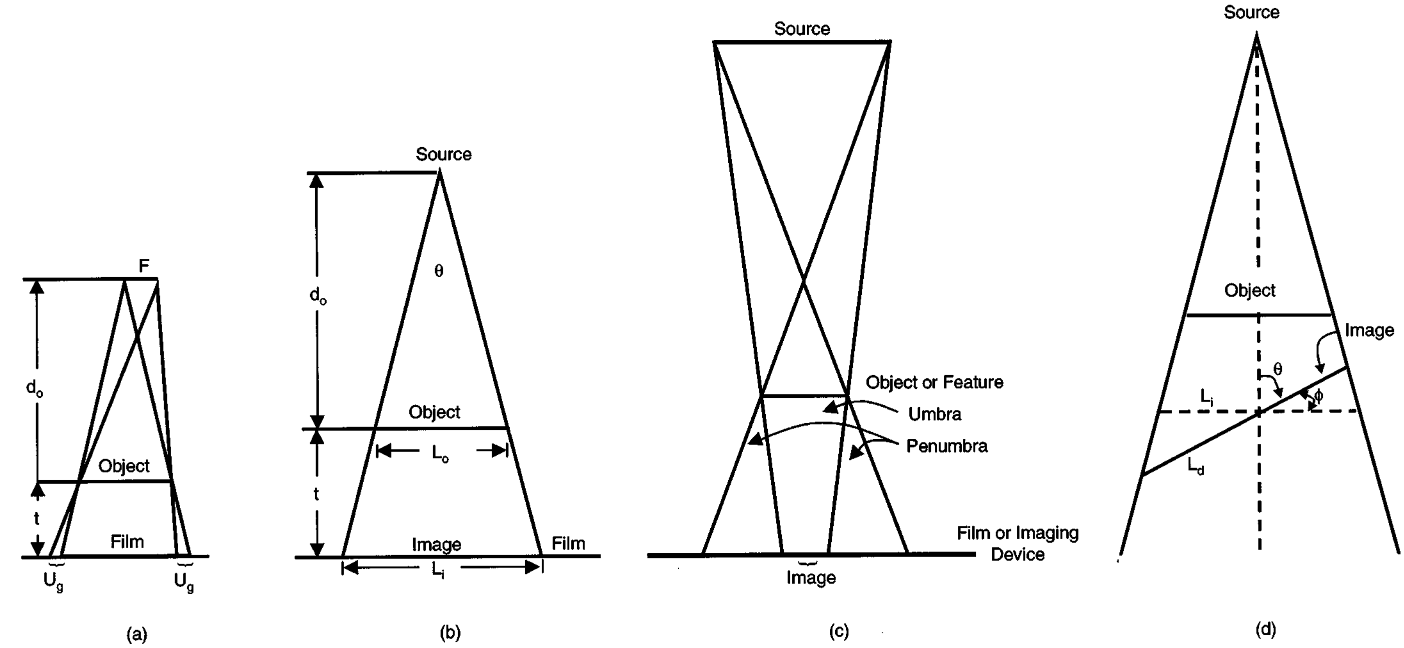
NOTE 5—For detailed information on film density and density measurement calibration, see Practice E 1079.

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),



(a) Geometric Unsharpness
Legend for (a) and (b)
d_o = source to object distance
t = object to film distance
L_o = dimension of object
L_i = dimension of image
$U_g = Ft/d_o$

(b) Object or feature larger than the source
$L_i - L_o = \Delta L = 2t \times \tan 1/2\, \theta$
$\Delta L/L_o \times 100$ = percentage enlargement

(c) Object or feature smaller than source
Image will be smaller than object or feature

(d) Radiographic Distortion Legend for (d)
L_i = dimension of undistorted image
L_d = dimension of distorted image
$L_d - L_i = \Delta L$
Percentage distortion = $(\Delta L/L_i) \times 100$

FIG. 2 Effects of Object-Film Geometry

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 E 747, E 801, E 1025, and E1742 should be consulted for detailed information on the design, manufacture and material grouping of IQI's. Practice E 801 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 E 746 and E 1735 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