Designation: E94 – 04

Standard Guide for Radiographic Examination[1]

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

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

[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.

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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] 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.

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 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)

[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)

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.

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

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

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.

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 $\leq$ 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

Radiographic Image Quality				
Radiographic Contrast		Film System Granularity	Radiographic Definition	
Subject Contrast	Film Contrast	• 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.)	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)		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

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:

$$U_g = Ft/d_o \tag{1}$$

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 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

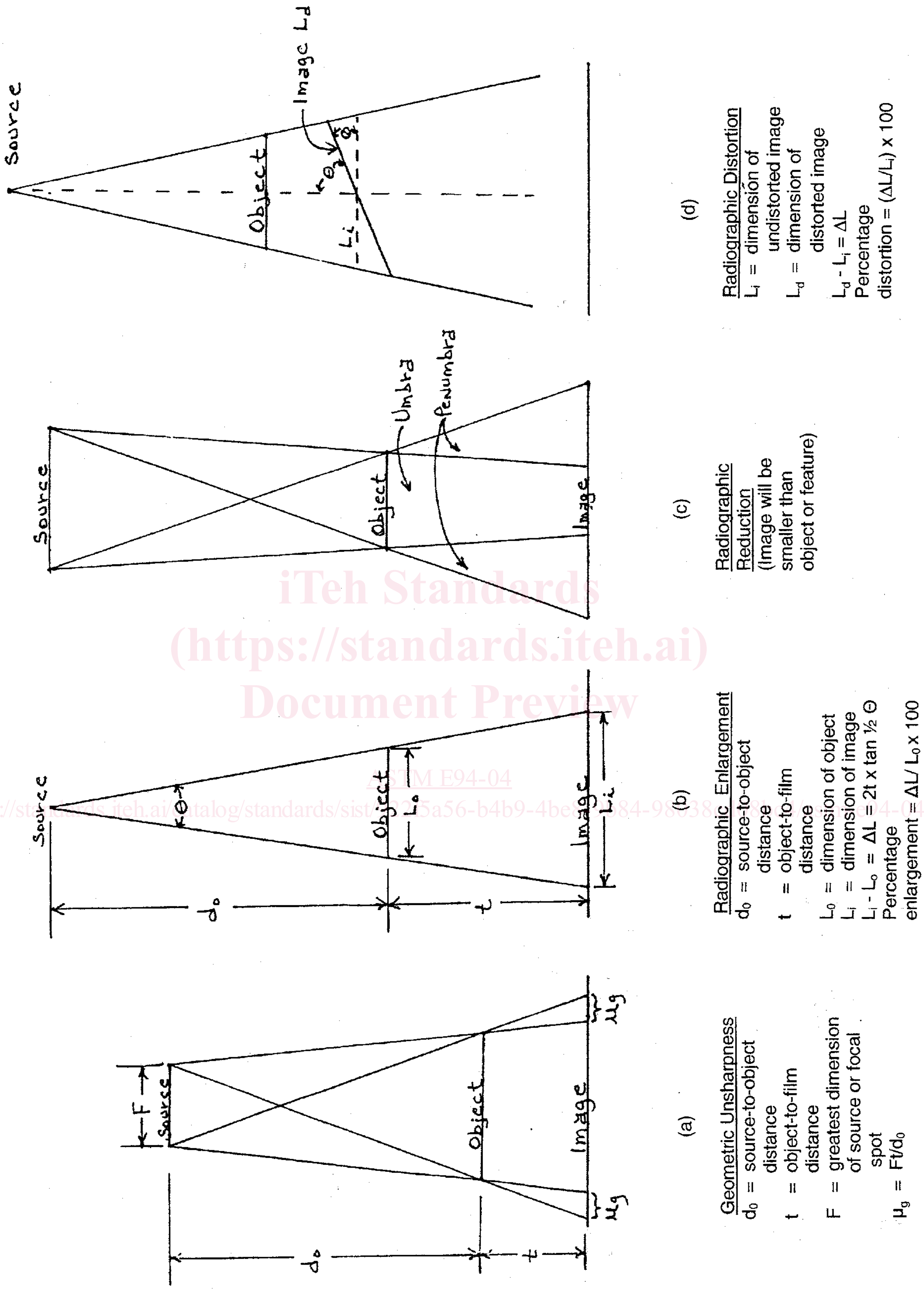

FIG. 2 Effects of Object-Film Geometry