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Standard Guide for Radiographic Examination Using Industrial Radiographic Film[1]

This standard is issued under the fixed designation E94/E94M; 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, Practice E1030/E1030M, and Practice E1032.

1.3 The use of digital radiography has expanded and follows many of the same general principles of film based radiography but with many important differences. The user is referred to standards for digital radiography [E2597, E2698, E2736, and E2737 for digital detector array (DDA) radiography and E2007, E2033, E2445/E2445M, and E2446 for computed radiography(CR)] if considering the use of digital radiography.

1.4 *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.

1.5 *Safety Practices*—Problems of personnel protection against X-rays and gamma-rays are not covered by this guide. 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.

1.6 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system should be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.7 If an NDT agency is used, the agency should be qualified in accordance with Specification E543.

1.8 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this guide should be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard and certified by the employer or certifying agency, as applicable.

1.9 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* (See 1.5.)

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

[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.

*A Summary of Changes section appears at the end of this standard

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 Radiographic Examination of Electronic Devices

E999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

E1000 Guide for Radioscopy

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

E1030/E1030M Practice for Radiographic Examination of Metallic Castings

E1032 Practice for Radiographic Examination of Weldments Using Industrial X-Ray Film

E1079 Practice for Calibration of Transmission Densitometers

E1165 Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging

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

E1453 Guide for Storage of Magnetic Tape Media that Contains Analog or Digital Radioscopic Data

E1475 Guide for Data Fields for Computerized Transfer of Digital Radiological Examination Data

E1735 Practice for Determining Relative Image Quality Response of Industrial Radiographic Imaging Systems from 4 to 25 MeV

E1742/E1742M Practice for Radiographic Examination

E1815 Test Method for Classification of Film Systems for Industrial Radiography

E1817 Practice for Controlling Quality of Radiological Examination by Using Representative Quality Indicators (RQIs)

E1936 Reference Radiograph for Evaluating the Performance of Radiographic Digitization Systems

E2007 Guide for Computed Radiography

E2033 Practice for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)

E2339 Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE)

E2445/E2445M Practice for Performance Evaluation and Long-Term Stability of Computed Radiography Systems

E2446 Practice for Manufacturing Characterization of Computed Radiography Systems

E2597 Practice for Manufacturing Characterization of Digital Detector Arrays

E2698 Practice for Radiographic Examination Using Digital Detector Arrays

E2736 Guide for Digital Detector Array Radiography

E2737 Practice for Digital Detector Array Performance Evaluation and Long-Term Stability

E2903 Test Method for Measurement of the Effective Focal Spot Size of Mini and Micro Focus X-ray Tubes

E3169 Guide for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE)

2.2 *ANSI Standard:*[4]

ANSI/I3A/PIMA IT 2.26 Determination of Safelight Conditions

2.3 *Federal Standards:*[5]

Title 21, Code of Federal Regulations (CFR) 1020.40, Safety Requirements of Cabinet X-Ray Systems

Title 29, Code of Federal Regulations (CFR) 1910.96, Ionizing Radiation (X-Rays, RF, etc.)

2.4 *ISO Standards:*[6]

ISO 14096-2 Non-destructive Testing — Qualification of Radiographic Film Digitization Systems — Part 2: Minimum Requirements

ISO 18901 Imaging Materials — Processed Silver-Gelatin-type Black-and-white Films — Specifications for Stability

ISO 18902 Imaging Materials — Processed Imaging Materials — Albums, Framing and Storage Materials

ISO 18917 Photography—Determination of Residual Thiosulphate and Other Related Chemicals in Processed Photographic Materials—Methods Using Iodine-amylose, Methylene Blue and Silver Sulfide

2.5 *Other Document:*[7]

NBS Handbook ANSI N43.3 General Radiation Safety Installations Using NonMedical X-Ray and Sealed Gamma-Ray Sources up to 10 MeV

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 the benefits and limitations of nonfilm radiography such as

[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.

[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 International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

[7] Available from National Technical Information Service (NTIS), U.S. Department of Commerce, 5301 Shawnee Rd, Alexandria, VA 22312.

radioscopy, digital detector arrays, or computed radiography. Refer to Guides E1000, E2736, and E2007.

4.3 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.

4.4 Radiography will be consistent in image quality (contrast sensitivity and definition) only if all details of techniques, such as geometry, film, filtration, viewing, etc., are obtained and maintained.

5. Equipment and Configuration

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 Energy selection,

5.1.3 Source size (X-ray focal spot dimension or gamma source size),

5.1.4 Ways and means to eliminate scattered radiation,

5.1.5 Film system class,

5.1.6 Source-to-film and object-to-film distance,

5.1.7 Image quality indicators (IQIs),

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 Image Quality Indicators (IQIs) are devices placed within a radiographic set-up to indicate that a certain contrast sensitivity and definition has been achieved. IQIs demonstrating the required sensitivity level do not guarantee that a similar size flaw in a part will be detected but indicate that the radiographic quality has been met. Information on the design and manufacture of image quality indicators (IQIs) can be found in Practices E747, E801, E1025, and E1742/E1742M.

6.2 Radiographic quality level is usually expressed in percent of part thickness and diameter of feature to be detected. If a single percent number is given, the feature diameter is assumed to be twice the given percent thickness of the part. For example, if 2% is given for one inch [25.4 mm] thick part, the feature diameter is 2 × 0.02 × 1 in. [25.4 mm] or 0.04 in. [1.016 mm]. Image quality levels using hole-type IQIs (see Practice E1025) are designated by a two part expression *X-YT*. The first part of the expression *X* refers to the IQI thickness expressed as a percentage of the specimen thickness. The second part of the expression *YT* refers to the diameter of the hole and is expressed as a multiple of the IQI thickness, *T*. The image quality level 2-2*T* means that the IQI thickness *T* is 2% of the specimen thickness and that the diameter of the IQI imaged hole is 2 times the IQI thickness. If using wire IQIs, the wire set and wire number are designated. Correspondence between hole-type and wire-type IQIs is given in Practice E747. Hole- and wire-type IQIs are the major types used for industrial radiography. Other types may also be used (for example, see Practice E1817). The quality level usually required for radiography is 2 % (2-2*T* when using hole type IQI) unless a higher or lower quality is agreed upon between the purchaser and the supplier. The level of inspection specified should be based on the service requirements of the product. Great care should be taken in specifying quality levels 2-1*T*, 1-1*T*, and 1-2*T* by first determining that these quality levels can be maintained in production radiography.

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

6.4 The quality level required using wire IQIs should 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 provides a list of various hole-type IQIs and the corresponding diameter of the wires to achieve the Equivalent Penetrameter Sensitivity (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 excessive dose 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) which has the same absorption. Radiographic equivalence

TABLE 1 Typical Steel HVL Thickness in Inches [mm] for Common Energies

kV/MV	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 (Se 75)	0.35 [8.9]
750 kV (Ir 192)	0.51 [12.5]
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]

factors of several of the more common metals are given in Table 2, with steel arbitrarily assigned a factor of 1.0.
Example: To radiograph 1.0 in. [25.4 mm] of aluminum at 220 kV, multiply 1.0 by the 0.18 (equivalence factor for aluminum at 220 kV) and this indicates that 1.0 in. [25.4 mm] of aluminum is equivalent to 0.18 in. [4.57 mm] of steel when using 220 kV.
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 for one metal from exposure techniques for other metals.

9. Film

9.1 Various industrial radiographic films 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 Practices E746, 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 consists 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 are provided in Test Method E1815. ISO 18901, ISO 18902, and ISO 18917 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, thereby increasing radiographic latitude.

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 and Collimation

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.

11.2 Collimating the beam by restricting its size with heavy metal beam blockers to only that area needed to expose the area of interest is helpful in restricting scatter from areas in the part outside the area of interest and the surrounding environment, including air scatter. Collimators are usually placed close to the source to minimize size and weight; however, collimators may be placed anywhere in the beam to help with scatter control.

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	kV / MV										
	100 kV	150 kV	220 kV	250 kV	400 kV	1 MV	2 MV	4 to 25 MV	^{192}Ir	^{60}Co	^{75}Se
Magnesium	0.05	0.05	0.08								
Aluminum	0.08	0.12	0.18						0.35	0.35	0.5
Aluminum alloy	0.10	0.14	0.18						0.35	0.35	0.5
Titanium		0.54	0.54		0.71	0.9	0.9	0.9	0.9	0.9	0.6
Iron/all steels	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Copper	1.5	1.5	1.4	1.4	1.4	1.1	1.1	1.2	1.1	1.1	1.4
Zinc		1.4	1.3		1.3			1.2	1.1	1.0	1.2
Brass		1.4	1.3		1.3	1.2	1.1	1.0	1.1	1.0	1.3
Inconel X		1.4	1.3		1.3	1.3	1.3	1.3	1.3	1.3	1.3
Monel	1.7		1.2								1.1
Zirconium	2.4	2.3	2.0	1.7	1.5	1.0	1.0	1.0	1.2	1.0	1.6
Lead	14.0	14.0	12.0			5.0	2.5	2.7	4.0	2.3	8.0
Hafnium			14.0	12.0	9.0	3.0					11.0
Uranium			20.0	16.0	12.0	4.0		3.9	12.6	3.4	14.0

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 should 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 with a lower optical density than background, it is an indication that protection against back-scattered radiation is insufficient and that additional precautions should 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. [0.13 mm] 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 optical 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 optical 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 variation in optical density 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 pattern apparent to a viewer who sees small local optical density variations in an area of overall uniform optical 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

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) • Optical density (that is, the greater the optical density, the greater the resultant contrast) • Type of screens (that is, fluorescent, lead or none) •The contrast increases approximately linearly with the optical density above fog and base	• 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, metal, or none) • Radiation quality (that is, energy level, filtration, etc.) • Exposure quanta (that is, intensity, dose, etc.) •The granularity increases approximately with the square root of the optical density above fog and base	Affected by: • Degree of screen-film contact • Total film thickness • Single or double emulsion coatings • Radiation quality • Type and thickness of screens (fluorescent, metal, 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

(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. The focal spot size of an X-ray tube should be measured using Test Method E1165. Mini and micro focus X-ray tube focal spot sizes should be measured per Test Method E2903. 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 2—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 3—A nomogram for the determination of U_g is given in Fig. 3 (inch-pound units). Fig. 4 represents a nomogram in SI 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 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 amounts depending on the extent of the film to central beam offset (Fig. 2(*d*)).

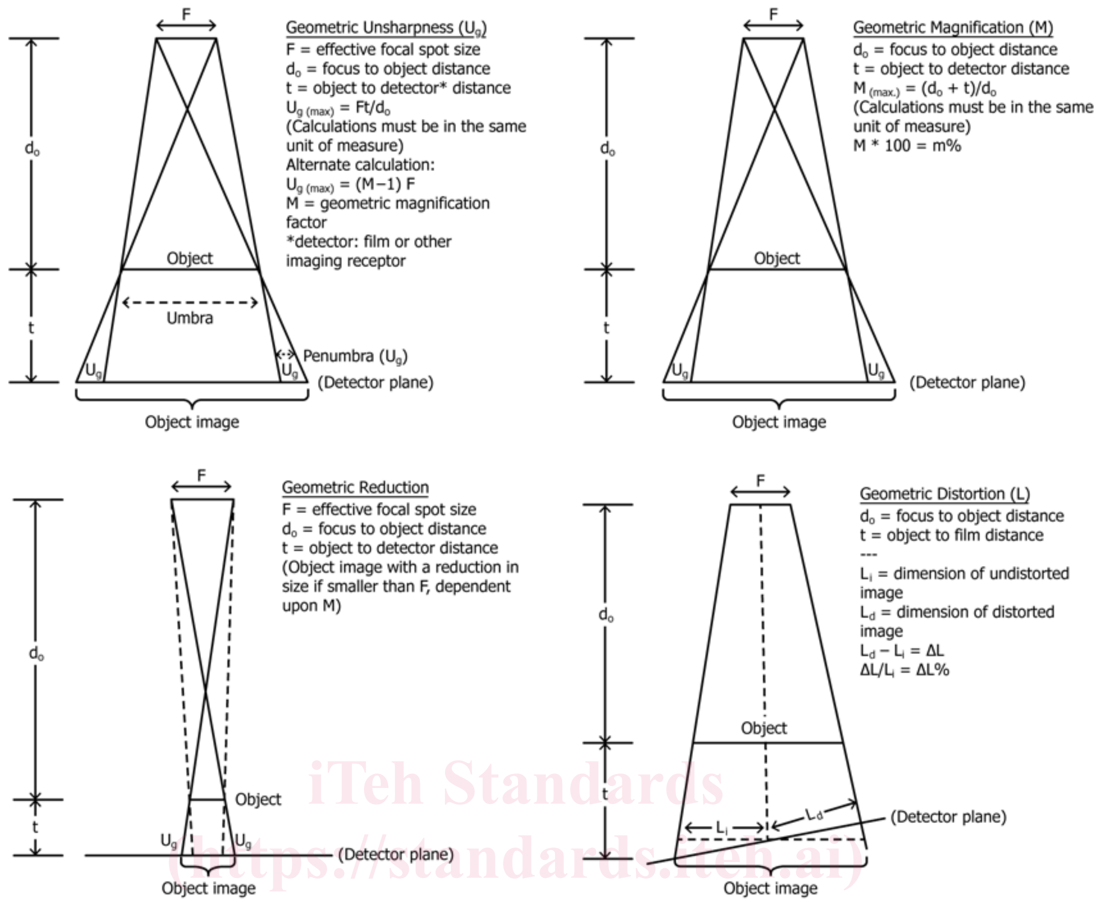

FIG. 2 Effects of Object-Film Geometry

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 should 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 Optical density, (see Note 4),

16.2.6 Source or source to film distance,

16.2.7 Kilovoltage or isotope type,

NOTE 4—For detailed information on optical density and calibration of optical density measurement equipment, see Practice E1079.

16.2.8 Screen type and thickness,

16.2.9 Curies or milliamperes,

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 and object-to-film distance,

17.2.4 Film type,

17.2.5 Optical density, (see Note 4),

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,