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Standard Practice for Determining Relative Image Quality Response of Industrial Radiographic Imaging Systems[1]

This standard is issued under the fixed designation E746; 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.

1. Scope

1.1 This standard provides a practice whereby industrial radiographic imaging systems may be comparatively assessed using the concept of relative image quality response (RIQR). The RIQR method presented within this practice is based upon the use of equivalent penetrameter sensitivity (EPS) described within Practice E1025 and subsection 5.2 of this practice. Figure 1 illustrates a relative image quality indicator (RIQI) that has four different steel plaque thicknesses (.015, .010, .008, and .005 in.) sequentially positioned (from top to bottom) on a ¾-in. thick steel plate. The four plaques contain a total of 14 different arrays of penetrameter-type hole sizes designed to render varied conditions of threshold visibility ranging from 1.92 % EPS (at the top) to .94 % EPS (at the bottom) when exposed to nominal 200 keV X-ray radiation. Each "EPS" array consists of 30 identical holes; thus, providing the user with a quantity of threshold sensitivity levels suitable for relative image qualitative response comparisons.

1.2 This practice is not intended to qualify the performance of a specific radiographic technique nor for assurance that a radiographic technique will detect specific discontinuities in a specimen undergoing radiographic examination. This practice is not intended to be used to classify or derive performance classification categories for radiographic imaging systems. For example, performance classifications of radiographic film systems may be found within Test Method E1815.

1.3 This practice contains an alternate provision whereby industrial radiographic imaging systems may be comparatively assessed using Lucite plastic material exposed to nominal 30 keV X-ray radiation. The RIQI for this alternate evaluation is also illustrated in Fig. 1, except the plaque and base plate materials are constructed of Lucite plastic in lieu of steel. EPS values for Lucite plastic are provided in Section 5 based upon the use of a 1⅜-in. thick Lucite base plate. For high-energy X-ray applications (4 to 25 MeV), Test Method E1735 provides a similar RIQR standard practice.

1.4 The values stated in SI are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety concerns, 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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

- B152/B152M Specification for Copper Sheet, Strip, Plate, and Rolled Bar
- 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
- E1079 Practice for Calibration of Transmission Densitometers
- E1316 Terminology for Nondestructive Examinations
- E1735 Test Method for Determining Relative Image Quality of Industrial Radiographic Film Exposed to X-Radiation from 4 to 25 MeV
- E1815 Test Method for Classification of Film Systems for Industrial Radiography
- E2002 Practice for Determining Total Image Unsharpness in Radiology

2.2 *ANSI Standard*[3]:

- ANSI PH2.19 Photography Density Measurements-Part 2: Geometric Conditions for Transmission Density

2.3 *ISO Standards*[3]:

- ISO 5-2 Photography Density Measurements-Part 2: Geometric Conditions for Transmission Density
- ISO 7004 Photography- Industrial Radiographic Film, Determination of ISO Speed, ISO average gradient, and ISO

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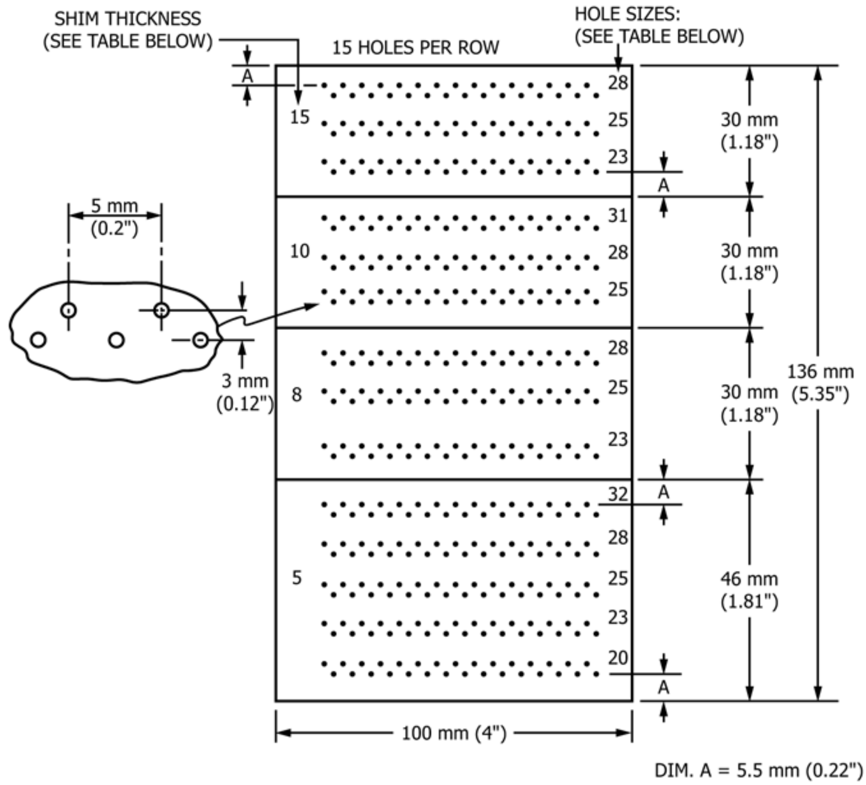
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.



Step Identification	Shim Thickness, mm (in.)	Hole Identification	Hole Size, mm (in.)
15	0.38 ± 0.012 (0.015 ± 0.0005)	32	0.81 ± 0.025 (0.032 ± 0.001)
10	0.25 ± 0.012 (0.010 ± 0.0005)	31	0.79 ± 0.025 (0.031 ± 0.001)
8	0.20 ± 0.012 (0.008 ± 0.0005)	28	0.71 ± 0.025 (0.028 ± 0.001)
5	0.13 ± 0.012 (0.005 ± 0.0005)	25	0.64 ± 0.025 (0.025 ± 0.001)
		23	0.58 ± 0.025 (0.023 ± 0.001)
		20	0.50 ± 0.025 (0.020 ± 0.001)

Hole Spacing (horizontal): 5 ± 0.1 mm (0.2 ± 0.004 in.) Nonaccumulative
Row Spacing: 3 ± 0.1 mm (0.2 ± 0.004 in.)
Spacing between hole sets: 5 ± 0.1 mm (0.2 ± 0.004 in.)
All other dimensions shall be in accordance with standard engineering practice.

FIG. 1 Relative Image Quality Indicator

gradients G2 and G4 when exposed to X- and gamma-radiation

3. Terminology

3.1 *Definitions*—The definitions of terms relating to gamma and X-radiology in Terminology E1316 shall apply to terms used in this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *detector*—an imaging device used to store a radiographic latent image or directly convert ionizing radiation into electrical signals in proportion to the quantity of radiation absorbed.

3.2.2 *cassette*—a device that is either flexible or rigid used to hold or protect a detector

3.2.3 *Relative Image Quality Indicator (RIQI)*— an image quality measuring device that is capable of determining meaningful differences between two or more radiographic imaging systems or changes of individual components of radiographic imaging systems.

3.2.4 *pixel intensity value (PV)*—a positive integer numerical value of gray scale level of a picture data element (pixel) directly proportional with originating digital image data values.

3.2.4.1 *Discussion*—PV is directly related to radiation dose received by a digital detector, that is, PV is "0" if radiation dose was "0". The number of available PV integers is associated with gray scale bit depth of the digital image. For example: a 12-bit gray scale image will have a range from "0" to "4095" levels (shades) of gray (4096 total pixel value integers) and will become saturated when PV reaches "4095".

4. Significance and Use

4.1 This standard provides a practice for RIQR evaluations of film and non-film imaging systems when exposed through steel or plastic materials. Three alternate data evaluation methods are provided in Section 9. Determining RIQR requires the comparison of at least two radiographs or radiographic processes whereby the relative degree of image quality difference may be determined using the EPS plaque arrangement of

Fig. 1 as a relative image quality indicator (RIQI). In conjunction with the RIQI, a specified radiographic technique or method must be established and carefully controlled for each radiographic process. This practice is designed to allow the determination of subtle changes in EPS that may arise to radiographic imaging system performance levels resultant from process improvements/changes or change of equipment attributes. This practice does not address relative unsharpness of a radiographic imaging system as provided in Practice E2002. The common element with any relative comparison is the use of the same RIQI arrangement for both processes under evaluation.

4.2 In addition to the standard evaluation method described in Section 9, there may be other techniques/methods in which the basic RIQR arrangement of Fig. 1 might be utilized to perform specialized assessments of relative image quality performance. For example, other radiographic variables can be altered to facilitate evaluations provided these differences are known and documented for both processes. Where multiple radiographic process variables are evaluated, it is incumbent upon the user of this practice to control those normal process attributes to the degree suitable for the application. Specialized RIQR techniques may also be useful with micro focus X-ray, isotope sources of radiation or with the use of non-film radiographic imaging systems. RIQR may also be useful in evaluating imaging systems with alternate materials (RIQI and base plate) such as copper-nickel or aluminum. When using any of these specialized applications, the specific method or techniques used shall be as specified and approved by the cognizant engineering authority.

5. Relative Image Quality Indicator

5.1 The relative image quality indicator (RIQI) illustrated in Fig. 1 shall be fabricated from mild steel plate for the 200 keV evaluation method and Lucite plastic for the 30 keV evaluation method. The RIQI steps may be fabricated as a single multi-step unit or separately and taped together to form the penetrameter type hole arrays shown in Fig. 1. If tape is used, the tape shall not cover or interfere with any of the holes in the RIQI. All dimensions of the RIQI shall conform to Fig. 1.

5.2 The RIQI shown in Fig. 1 consists of 14 arrays of 30 holes where all hole diameters are the same for each array. Hole diameters are based upon a "multiple" of each respective step thickness; therefore, each array of 30 holes has a unique "equivalent" penetrameter sensitivity (EPS) as defined by the following relationship (E1025):

$$EPS, \% = \frac{100}{X} \times \sqrt{\frac{Th}{2}} \tag{1}$$

where:

h = hole diameter, mm
T = step thickness of IQI, mm
X = thickness of test object, mm

Hole diameters within each EPS array are progressively smaller from the top to the bottom of Fig. 1; thus, providing descending EPS values ranging from 1.92 % to 0.94 % for the steel method and 1.05 % to .51 % for the plastic method (Fig. 1 illustrates EPS values for the steel method). Descending EPS values for Lucite plastic are: 1.05 %, 1.00 %, .96 %, .91 %, .86 %, .81 %, .77 %, .73 %, .70 %, .65 %, .61 %, .58 %, .55 % and .51 % for the plaque steps of Fig. 1.

5.3 The absorber base plate shall be made of mild steel for the 200 keV method and Lucite plastic for the 30 keV method. Both base plates shall be at least 200 by 250 mm (8 by 10 in.) wide and long. The steel plate shall be 19 ± 0.12 mm (0.750 ± 0.005 in.) thick and the plastic plate shall be 36 ± 0.12 mm (1.375 ± 0.005 in.) thick. The surface finish of both absorber base plates shall be a maximum of 6.3 μm (250 μin.) Ra, ground finish (both faces).

5.4 The RIQI shown in Fig. 1 shall be placed on the radiation source side and within the approximate center of the appropriate absorber base plate as illustrated in Fig. 2(B).

6. Calibration of X-Ray Source

6.1 Use a target to detector distance at least 750 mm (29.5 in.) for all exposures.

6.2 The voltage calibration of the X-ray source for 200–keV is based on ISO 7004. With an 8-mm (0.32-in.) copper filter at the X-ray tube, adjust the kilovoltage until the half value layer (HVL) in copper is 3.5 mm (0.14 in.) (see Specification B152/B152M). Using a calibrated ionization chamber or similar radiation measurement device, make a reading of the detector with 8 mm (0.32 in.) of copper at the tube, and then, make a second reading with a total of 11.5 mm (0.45 in.) of copper at the tube as shown in Fig. 2(A).

6.3 The voltage calibration of the X-ray source for 30–keV is based on ISO 7004 method for 100–keV calibration, modified for 30–keV. With a 7.62-mm (0.30-in.) aluminum filter at the X-ray tube port, adjust the kilovoltage until the half value layer (HVL) in aluminum is 1.52 mm (0.06 in.). That is, the intensity of the X-ray beam with 9.14–mm (0.36–in.) aluminum at the tube port shall be one-half that with 7.62–mm (0.30–in.) aluminum at the tube port.

6.4 For both 200–keV and 30–keV X-ray beam calibration methods, calculate the ratio of the two readings. If this ratio is not 2, adjust the kilovoltage up or down and repeat the measurement until a ratio of 2 (within 5 %) is obtained. Record the X-ray machine voltage settings and use these same values for the RIQR evaluations. Prior to RIQR performance evaluations for both 200–keV and 30–keV methods, remove all HVL and filter materials at the X-ray tube port.

7. Procedure

7.1 *Basic*—Use the physical set up as shown in Fig. 2(B). Position the X-ray tube directly over the approximate center of the RIQI and detector cassette. The plane of the detector and RIQI must be normal to the central ray of the X-ray beam. Use a diaphragm at the tube to limit the field of radiation to the film area.

7.2 Source-to-detector distance (SDD) is based upon achieving a geometrical unsharpness (Ug) of 0.05 mm (0.002 in.) or less on a 36 mm (1.375 in.) thick plastic plate for

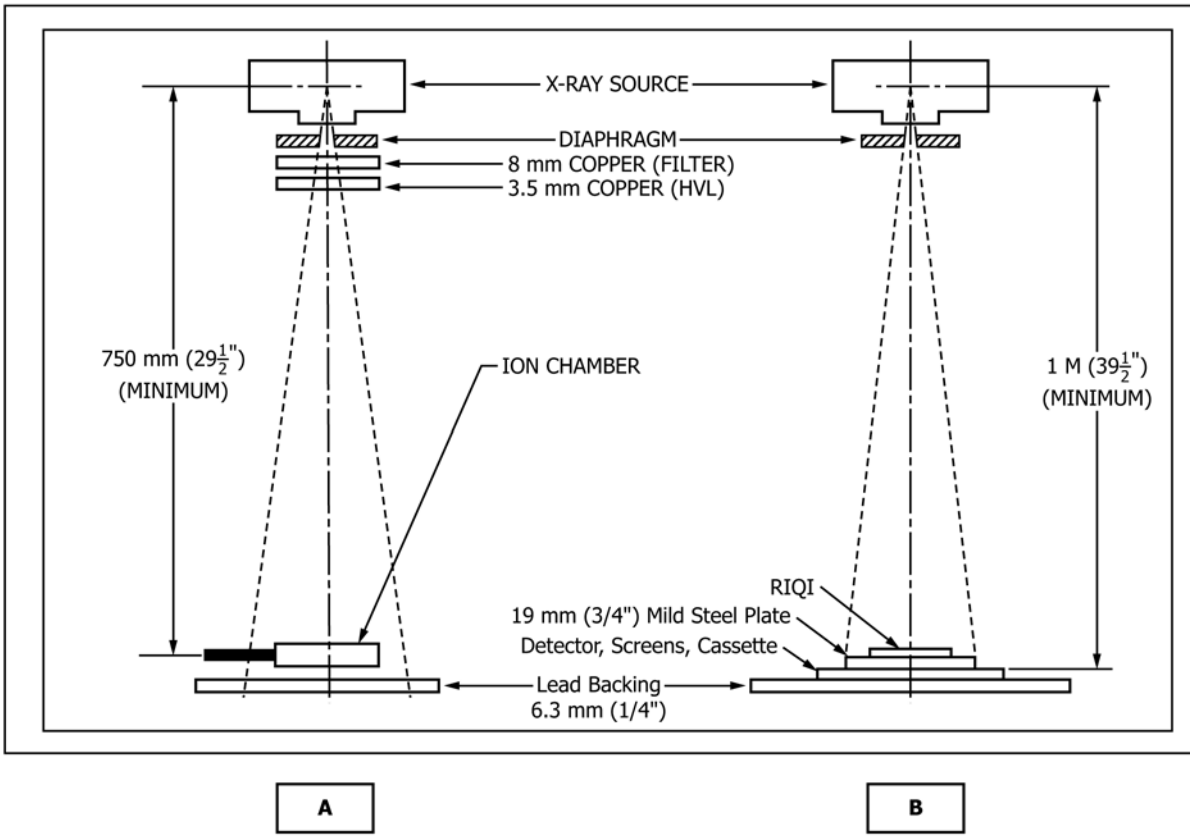


FIG. 2 (A) Setup for Energy Calibration (B) Setup for RIQR Exposures

30–keV and a 19 mm (0.750 in.) thick absorber plate for 200–keV. Calculate the minimum SDD, in millimetres, as follows:

$$SDD = 381\ \varphi$$

where:

SDD = source-to-detector distance, mm, and
φ = focal spot size, mm.

The SDD shall be not less than 1 m (39.4 in.).

7.3 *Detector Cassettes and Screens*—Low absorption cassettes shall be used to maximize the effectiveness of the RIQI and only a single detector shall be used within the cassette. For the 200–keV method, place the detector between lead-foil screens, the front screen being 0.130 ± 0.013 mm (0.005 ± 0.0005 in.) thick and the back screen 0.250 ± 0.025 mm (0.010 ± 0.001 in.) thick. The cassette shall provide a means for good detector-screen contact. No lead screens shall be used with the 30 keV method. The same type cassette and screens (absorption characteristics and thicknesses) shall be used to produce all exposures required for the relative image quality response evaluations. When using this practice with computed radiography systems, it is recommended that a minimum of 0.020 in. (.5 mm) steel plate be positioned between the backing lead and cassette.

7.4 *Backing Lead*—Use a 6.3 ± 0.8 mm (¼ ± 1⁄32 in.) thick lead "backup" behind the cassette. The backup lead shall exceed each edge of the cassette by at least 25 mm (1 in.).

7.5 Identify the detector number, type, exposure, and other technique data by means of lead letters, or numerals, placed in the upper right hand corner of the base absorber plate(s). Do not place so as to interfere with the image of the holes in the RIQI. Make these identification symbols as small and unobtrusive as possible. Record this identification number on the data sheet for this exposure (see Section 8).

7.6 Make three separate exposures as specified in 9.1 through 9.3. Expose the detector at the keV setting as determined in Section 6. Remove all filters at the tube before conducting exposures. Adjust exposure time to criteria specified in 7.2 (film systems) or 7.3 (non-film systems). In order to preclude any detector latent image instability, process (as applicable) any exposed detector within eight hours of exposure.

7.7 *Film Systems*—in addition to the basic requirements of 7.1, the following requirements apply:

7.7.1 Adjust the exposure time to render an optical film density of 2.00 ± 15 % within the approximate center of the radiograph as measured with a densitometer. Optical density shall be determined with a densitometer complying with requirements of Practice E1079.

7.7.2 The image quality response of the film system may vary with the processing variables such as chemistry, temperature and method of processing (manual or automatic). The solutions must be fresh and properly seasoned (see 7.7.2.1 and

7.7.2.2). Film processing and record requirements shall be in accordance with Guide E999.

7.7.2.1 *Automatic Processing*—Use industrial X-ray processing solutions for RIQR evaluations. Keep a record of:

(1) brand name of the processor;

(2) length of time (±1 s) that the film is in the developer, leading edge in to leading edge out;

(3) brand name of the developer, developer temperature measured to within 0.5°C (0.9°F) and the rate of replenishment to within ±5 %;

(4) method used (chemical starter solution or quantity of seasoning film) in seasoning fresh developer solution before processing films. Use film manufacturer's instructions for seasoning of processing chemistry solutions.

7.7.2.2 *Manual Processing*—When manual industrial X-ray film processing solutions are used, keep a record on the data sheet of:

(1) time of development (±2 s);

(2) temperature of developer measured within 0.5°C (0.9°F); method used (chemical starter solution or quantity of seasoning film) in seasoning fresh developer solution before processing films. Use film manufacturer's instructions for seasoning of processing chemistry solutions.

7.8 *Non-Film Systems*—In addition to the basic requirements of 7.1, the following requirements apply:

7.8.1 Use the same detector and electronic processing modality for all exposures required in 9.1 through 9.3.

7.8.2 Adjust the exposure time to render a target pixel intensity value (PV) of 50 % (±10 %) below detector saturation within the approximate center of the digital radiograph. Pixel intensity value shall be measured with an appropriate software tool in a minimum window of approximately 25 by 25 pixels and in an area of constant material thickness without holes (hole plaques may be slightly separated for this purpose). For example: the exposure PV of a 12 bit system would be 2048 (±205) or 32,768 (±3277) for 16 bit systems. Other target PV values can be selected when approved by the cognizant engineering authority. Pixel intensity values shall be documented as well as all settings of the scanner or data acquisition process affecting PV determination (that is, user adjustable photo-multiplier tube voltages). Record and use this same exposure method and scanner data acquisition parameters for all three exposures required in 9.1 through 9.3.

7.8.3 When employing digital image processing techniques, the type of processing techniques shall be defined and agreed upon by the cognizant engineering authority for all exposures required in 9.1 through 9.3.

7.8.4 Electronic display equipment shall be capable of consistent and stable image quality levels. Technical electronic display parameters shall be as agreed upon by the cognizant engineering authority.

8. Data Collection

8.1 Each of the three RIQR exposures (1 RIQR set) used for the evaluation shall be read independently by three readers (270 total possible holes visible for each EPS array). Each reader shall record the number of holes visible in each of the 14 arrays of the RIQI for each of three exposures (exposures #1, #2 and #3 in Fig. 3). Subsequent to review by all three readers and completion of a Fig. 3 data sheet by each reader, visible hole counts shall be summed from all three readers for each EPS hole array and entered in the space at the right of each array in Fig. 3. The viewing illuminator or electronic display should be masked to prevent stray light from distracting the reader and the viewing facility should be darkened with minimal background lighting. Magnification up to 3× is permitted.

8.2 When performing relative comparisons of radiographic processes, as described in Section 4, a second RIQR set of radiographic data is required. This data shall be collected in the same manner as prescribed in 9.1.

RIQR Reader No. ______							
EPS Array No.	RQI Step Size	Hole Size	EPS (%)	Number of Visible Holes in Array			Avg. # Holes Per Array
				Expos. #1	Expos. #2	Expos. #3	
1	.38 mm (.015")	.71 mm (.028")	1.92				
2		.64 mm (.025")	1.82				
3		.58 mm (.023")	1.71				
4	.25 mm (.010")	.79 mm (.031")	1.66				
5		.71 mm (.028")	1.57				
6		.64 mm (.025")	1.49				
7	.20 mm (.008")	.71 mm (.028")	1.41				
8		.64 mm (.025")	1.33				
9		.58 mm (.023")	1.25				
10	.13 mm (.005")	.81 mm (.032")	1.19				
11		.71 mm (.028")	1.12				
12		.64 mm (.025")	1.05				
13		.58 mm (.023")	1.00				
14		.50 mm (.020")	0.94				

FIG. 3 Individual Reader Data Collection Sheet

9. Data Evaluation

9.1 A graph is constructed similar to Fig. 4, with 14 values of EPS (from the RIQI of Fig. 1) on the horizontal axis and 14 values of array hole count ratios (from the data sheets of Fig. 3) on the vertical axis. Subsequent to determination of array hole count sums for three readers (composite sums), determine the array hole count ratios by dividing each composite sum by the total possible number of visible holes for the three readers (270 holes for each array). Plot each array hole count ratio for each respective EPS value from the RIQI. Extrapolate between the 14 data points on the graph to produce a curve that represents the best approximate "fit" of the data points. The relative image quality response (RIQR) for this data set is determined at a point (on the vertical axis) where the EPS array hole count ratio value is exactly 50 %.

NOTE 1—This value is derived from the vertical axis scale and not necessarily from any of the 14 data sets. The RIQR for this evaluation is determined from the EPS value (on the horizontal axis) that intersects with the curve for the 50 % EPS array hole count ratio (vertical axis).

9.1.1 Perform a similar graphical analysis of the second RIQR data set (see 8.2) using the same criteria prescribed in 9.1. The difference, if any, between the two EPS values thus determined is the relative image quality response for the two evaluations.

9.2 *Alternate-One Method for Data Evaluation*—In addition to the curve plotting method described in 8.2, the RIQR value may be calculated mathematically between two adjacent EPS hole arrays (for a single reader and one exposure) by interpolating between the EPS values of the row with more than 15 visible holes and the row with less than 15 visible holes by use of the formula:

$$C = Q_b + \frac{(15 - N_b)(Q_a - Q_b)}{N_a - N_b}$$

where:

C = RIQR EPS value,
N_a = the total number of visible holes in the row immediately above the midpoint, Q_a = the corresponding EPS value,
N_b = the total number of visible holes in the row immediately below the midpoint, Q_b = the corresponding EPS value.

The following example is given for illustration: A row having 23 visible holes has an EPS value of 1.57. An adjacent row has 12 visible holes and an EPS value of 1.49.

$$C = 1.49 + \frac{(15 - 12)(1.57 - 1.49)}{23 - 12}$$

$$C = 1.51$$

NOTE 2—The alternate-one method is intended for applications where it is determined that one radiograph and one reader are sufficient to determine relative image quality response. For some applications, the alternate-one method may not represent the degree of non-bias desired for the relative image quality evaluations.

9.3 *Alternate-Two Method for Data Evaluation*—In place of the curve plotting method described in 9.2, the data may be evaluated by averaging the number of visible holes of each EPS array for a given RIQR evaluation. This average is based on the evaluation by three readers of three radiographs for each RIQR evaluation (270 possible visible holes for each array). This same averaging procedure is repeated for each EPS array on the RIQI (an average for each of the 14 arrays). The hole count averages for each EPS array are then summed as illustrated in Table 1. This sum is the relative image quality response "index" value for this evaluation.

9.4 No statement is made about the precision and bias for determining relative image quality response of radiographs as the results merely state whether there is conformance to the criteria for success specified in this practice.

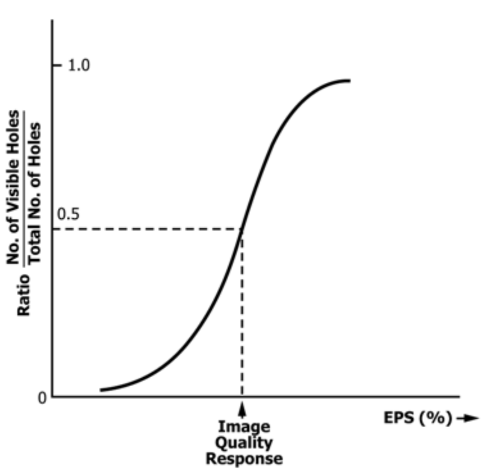


FIG. 4 Graph Method for Determining RIQI

10. Keywords

10.1 Relative Image Quality Indicator; Relative Image Quality Response; equivalent penetrameter sensitivity

TABLE 1 Relative Image Quality Response Index from EPS Array Averages

Evaluation Number	EPS Arrays														RIQR Index
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	30	30	30	23	12.7	0	0	0	0	0	0	0	0	0	125.7
2	30	27.7	25.2	12.2	0	0	0	0	0	0	0	0	0	0	95.1
3	30	26.5	21.7	8.7	0	0	0	0	0	0	0	0	0	0	86.9
4	30	25.2	15.7	1	0	0	0	0	0	0	0	0	0	0	76.2