Designation: E1165 – 12

Standard Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging[1]

This standard is issued under the fixed designation E1165; 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 The image quality and the resolution of X-ray images highly depend on the characteristics of the focal spot. The imaging qualities of the focal spot are based on its two dimensional intensity distribution as seen from the detector plane.

1.2 This test method provides instructions for determining the effective size (dimensions) of standard and mini focal spots of industrial x-ray tubes. This determination is based on the measurement of an image of a focal spot that has been radiographically recorded with a "pinhole" technique.

1.3 This standard specifies a method for the measurement of focal spot dimensions from 50 µm up to several mm of X-ray sources up to 1000 kV tube voltage. Smaller focal spots should be measured using EN 12543-5 using the projection of an edge.

1.4 This test method may also be used to determine the presence or extent of focal spot damage or deterioration that may have occurred due to tube age, tube overloading, and the like. This would entail the production of a focal spot radiograph (with the pinhole method) and an evaluation of the resultant image for pitting, cracking, and the like.

1.5 Values stated in SI units are to be regarded as the standard.

1.6 *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]

E1000 Guide for Radioscopy
E1255 Practice for Radioscopy
E2002 Practice for Determining Total Image Unsharpness in Radiology
E2033 Practice for Computed Radiology (Photostimulable Luminescence Method)
E2698 Practice for Radiological Examination Using Digital Detector Arrays

2.2 *European Standards:*[3]

EN 12543-2 Non-destructive testing—Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing—Part 2: Pinhole camera radiographic method
EN 12543-5 Non-destructive testing—Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing—Part 5: Measurement of the effective focal spot size of mini and micro focus X-ray tubes

2.3 *Papers:*

Klaus Bavendiek, Uwe Heike, Uwe Zscherpel, Uwe Ewert And Adrian Riedo, "New measurement methods of focal spot size and shape of X-ray tubes in digital radiological applications in comparison to current standards," WC-NDT 2012, Durban, South Africa

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *actual focal spot*—the X-ray producing area of the target as viewed from a position perpendicular to the target surface (see Fig. 1).

3.1.2 *effective focal spot*—the X-ray producing area of the target as viewed from a position perpendicular to the tube axis in the center of the X-ray beam (see Fig. 1).

3.1.3 *effective size of focal spot*—focal spot size measured in accordance with this standard.

4. Summary of Test Method

4.1 This method is based on a projection image of the focal spot using a pinhole camera. This image shows the intensity distribution of the focal spot. From this image the effective size of the focal spot is computed. A double integration of a profile

[1] This test method 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 European Committee for Standardization (CEN), Avenue Marnix 17, B-1000, Brussels, Belgium, http://www.cen.eu.

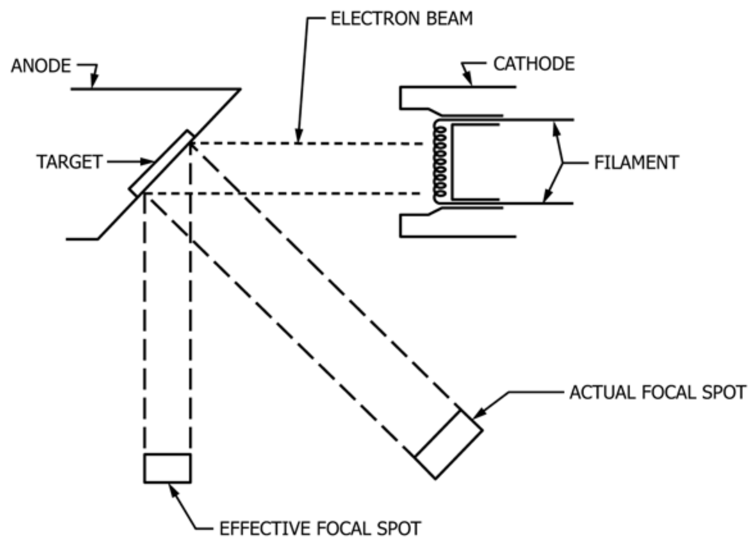


FIG. 1 Actual/Effective Focal Spot

across the pinhole image transforms the pinhole image into an edge profile. The X- and Y-dimension of the edge unsharpness is used for calculation of the size of the focal spot. This method provides similar results as the method described in EN 12543-5 using an edge target instead of a pinhole camera. The measured effective spot sizes correspond to the geometrical image unsharpness values at given magnifications as measured with the ASTM E2002 duplex wire gauge in practical images using equation:

$$u_G = \Phi(v - 1) \quad (1)$$

with geometrical unsharpness u_G, focal spot size Φ and magnification v (see ASTM E1000 for details of this equation). For a full description see Reference 2.3.

4.2 Additionally, a simplified test method is described in the annex A for users of X-ray tubes who may not intend to use a pinhole camera. This alternative method is based on the edge method in accordance with EN 12543-5 using a plate hole IQI as described in ASTM E1025 or E1742 instead of a pinhole camera.

5. Significance and Use

5.1 One of the factors affecting the quality of radiologic images is the geometric unsharpness. The degree of geometric unsharpness is dependent on the focal spot size of the radiation source, the distance between the source and the object to be radiographed, and the distance between the object to be radiographed and the detector (imaging plate, Digital Detector Array (DDA) or film). This test method allows the user to determine the effective focal size of the X-ray source. This result may then be used to establish source to object and object to detector distances appropriate for maintaining the desired degree of geometric unsharpness and/or maximum magnification for a given radiographic imaging application. Some ASTM standards require this value for calculation of a required magnification, for example, E1255, E2033, and E2698.

6. Apparatus

6.1 *Pinhole Diaphragm*—The pinhole diaphragm shall conform to the design and material requirements of Table 1 and Fig. 3.

6.2 *Camera*—The pinhole camera assembly consists of the pinhole diaphragm, the shielding material to which it is affixed, and any mechanism that is used to hold the shield/diaphragm in position (jigs, fixtures, brackets, and the like).

6.3 *Alignment and Position of the Pinhole Camera*—The angle between the beam direction and the pinhole axis (see Fig. 4) shall be smaller than ±1.5°. When deviating from Fig. 4, the direction of the beam shall be indicated. The incident face of the pinhole diaphragm shall be placed at a distance *m* from the focal spot so that the variation of the magnification over the extension of the actual focal spot does not exceed ±5 % in the beam direction. In no case shall this distance be less than 100 mm.

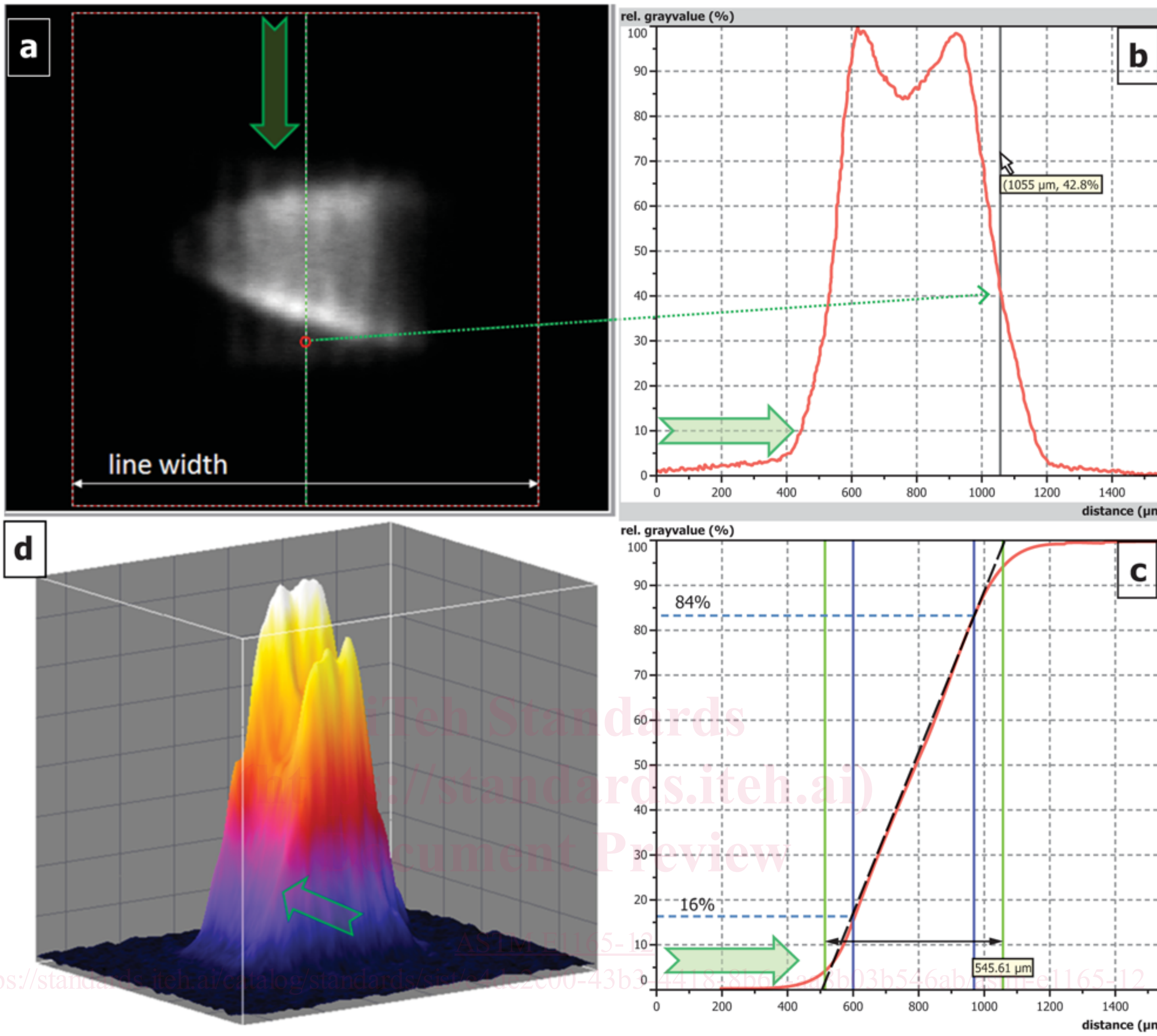
6.4 *Position of the Radiographic Image Detector*—The radiographic image detector (film, imaging plate or DDA) shall be placed normal to the beam direction at a distance *n* from the incident face of the pinhole diaphragm determined from the applicable magnification according to Fig. 5 and Table 2.

TABLE 1 Pinhole Diaphragm Design Requirements (Dimension)[A]

NOTE 1—The pinhole diaphragm shall be made from one of the following materials: *(1)* An alloy of 90 % gold and 10 % platinum, *(2)* Tungsten, *(3)* Tungsten carbide, *(4)* Tungsten alloy, *(5)* Platinum and 10 % Iridium Alloy, or *(6)* Tantalum.

Focal Spot Size mm	Diameter P µm	Height H µm
0.05 to 0.3	10 ± 5	50 ± 5
0.3 to 0.8	30 ± 5	75 ± 10
>0.8	100 ± 5	500 ± 10

[A] See Fig. 3.



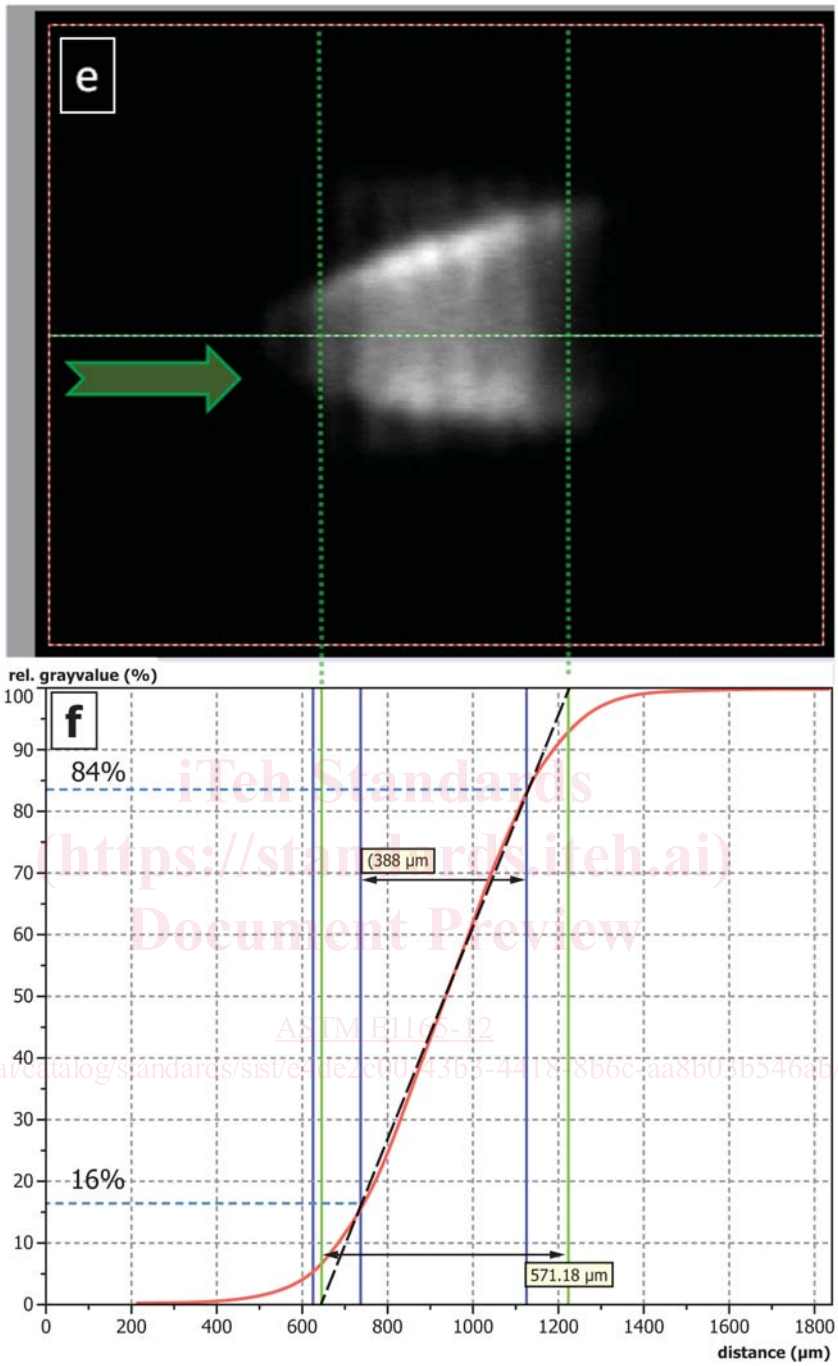
(a) Image of a double line Focal Spot with the Location and Size of the Line Profile in Length Direction.
(b) Line Profile in the direction of the large arrow averaged over the dotted rectangle of Fig. 2a.
(c) Integrated Line Profile with Markers (blue) for 16 % and 84 % of the Profile Intensity, Markers (green) for 0 % and 100 % Extrapolation and the Extrapolation Line (dotted black), corresponding to the Klasens method of E1000.
(d) Pseudo 3D Image of the Focal Spot; the large arrow points in the direction of the Line Profile.
(e) Image of a double line Focal Spot with the Location and Size of the Line Profile in Width Direction.
(f) Integrated Line Profile with Markers (blue) for 16 % and 84 % of the Profile Intensity, Markers (green) for 0 % and 100 % Extrapolation and the Extrapolation Line (dotted black) for the Width Direction.

FIG. 2 Example for the Measurement of Effective Focal Spot Length and Width with the Integrated Line Profile (ILP) Method

6.5 *Radiographic Image Detector*—Analogue or digital radiographic image detectors may be used, provided sensitivity, dynamic range and detector unsharpness allow capturing of the full spatial size of the focal spot image without detector saturation. The maximum allowed detector unsharpness is given by the geometrical unsharpness u_G of the pinhole and the pinhole diameter P. It is calculated according to (see Fig. 5).

$$u_G = P(1 + n/m) \quad (2)$$

6.5.1 The detector unsharpness shall be determined with the duplex wire IQI in accordance with ASTM E2002. The minimum projected length and width of the focal spot image should be covered always by at least 20 detector pixels in digital images. The signal-to-noise ratio of the focal spot image (ratio of the maximum intensity value inside the focal spot and the standard deviation of the background signal outside) should be at least 50. The maximum intensity inside the focal spot



(e) Image of a double line Focal Spot with the Location and Size of the Line Profile in Width Direction.
(f) Integrated Line Profile with Markers (blue) for 16 % and 84 % of the Profile Intensity, Markers (green) for 0 % and 100 % Extrapolation and the Extrapolation Line (dotted black) for the Width Direction.

FIG. 2 Example for the Measurement of Effective Focal Spot Length and Width with the Integrated Line Profile (ILP) Method *(continued)*

should be above 30 %, but lower than 90 % of the maximum linear detector output value. The grey value resolution of the detector shall be in minimum 12 Bit.

6.5.2 Imaging plate systems (Computed Radiography, CR) or digital detector arrays (DDA) may be used as digital image detectors following practices E2033 or E2698. The pixel values shall be linear to the dose.

6.5.3 If radiographic film is used as image detector, it shall meet the requirements of E1815 film system class I or Special and shall be packed in low absorption cassettes using no screens. The film shall be exposed to a maximum optical density between 1.5 and 2.5. The film shall be digitized with a maximum pixel of 50 µm or a smaller size, which fulfills the requirements of the above unsharpness conditions and be

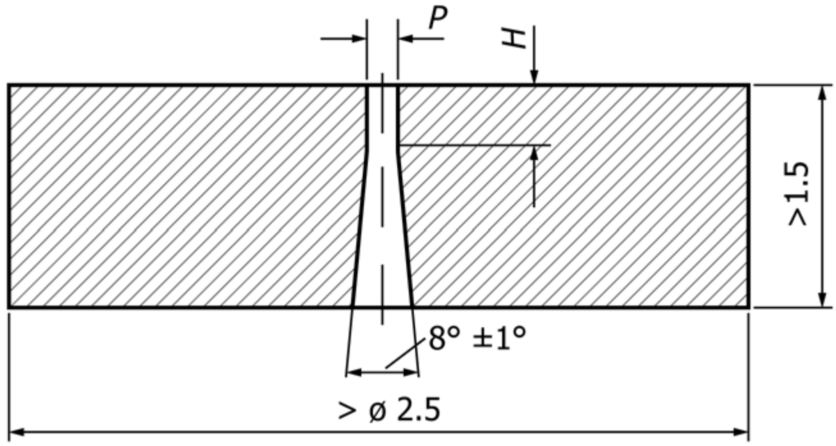


FIG. 3 Essential Dimensions of the Pinhole Diaphragm

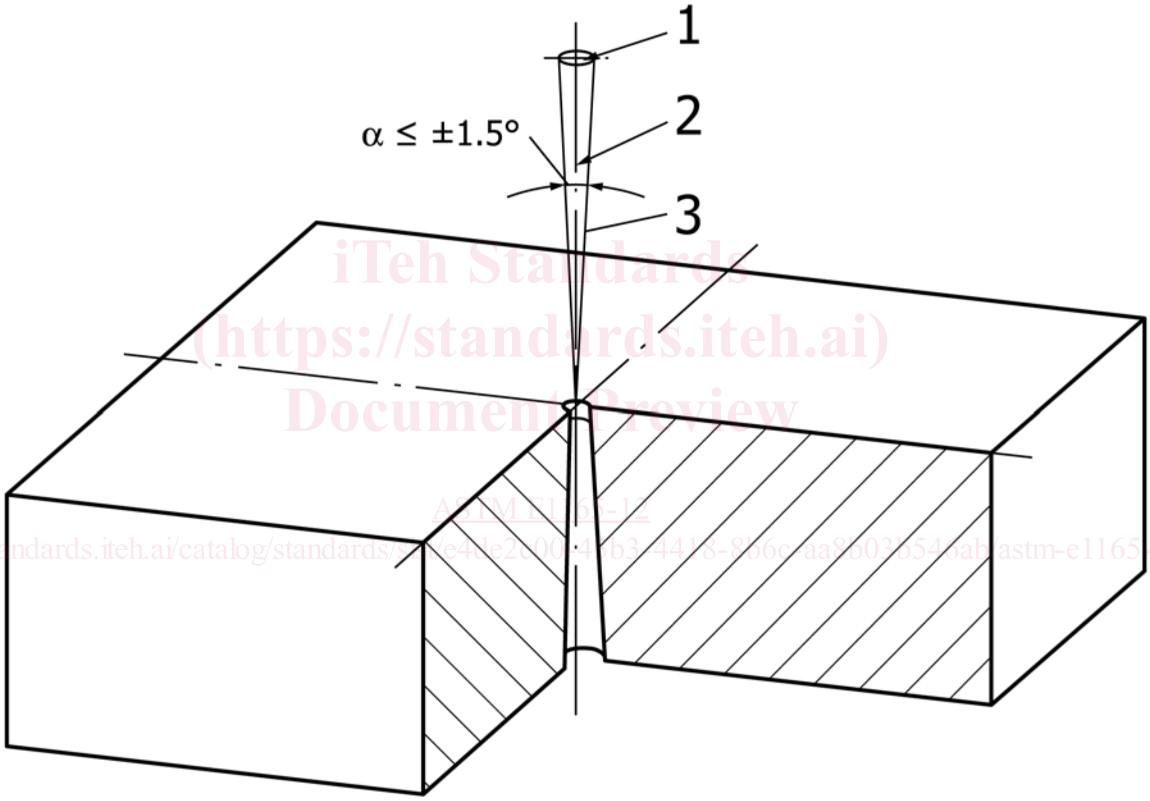


FIG. 4 Alignment of the Pinhole Diaphragm

evaluated according to Eq 2. If the user has no digital equipment the film may be evaluated visually; the procedure is shown in 7.9. The film shall be processed in accordance with Guide E999.

6.6 *Image Processing Equipment*—This apparatus is used to capture the images and to measure the intensity profile of the focal spot in the projected image. The image shall be a positive image (more dose shows higher grey values) and linear proportional to the dose. The equipment shall be able:

(1) to calibrate the pixel size with a precision of 2 µm or 1 % of the pixel size,

(2) to draw line profiles and average the line profiles over a preset area,

(3) to integrate line profiles by the length of the line profile,

(4) to subtract the background using a linear interpolation (straight line) of both ends of the line profile using at least the average of 10 % of the line profile as support on both ends, and

(5) to calculate the X- and Y-dimension of the focal spot in the image with two threshold values of 16 % and 84 % of the integrated line profile and extrapolate the width to 100 % (see Fig. 2).

NOTE 1—The software for this calculation can be downloaded from

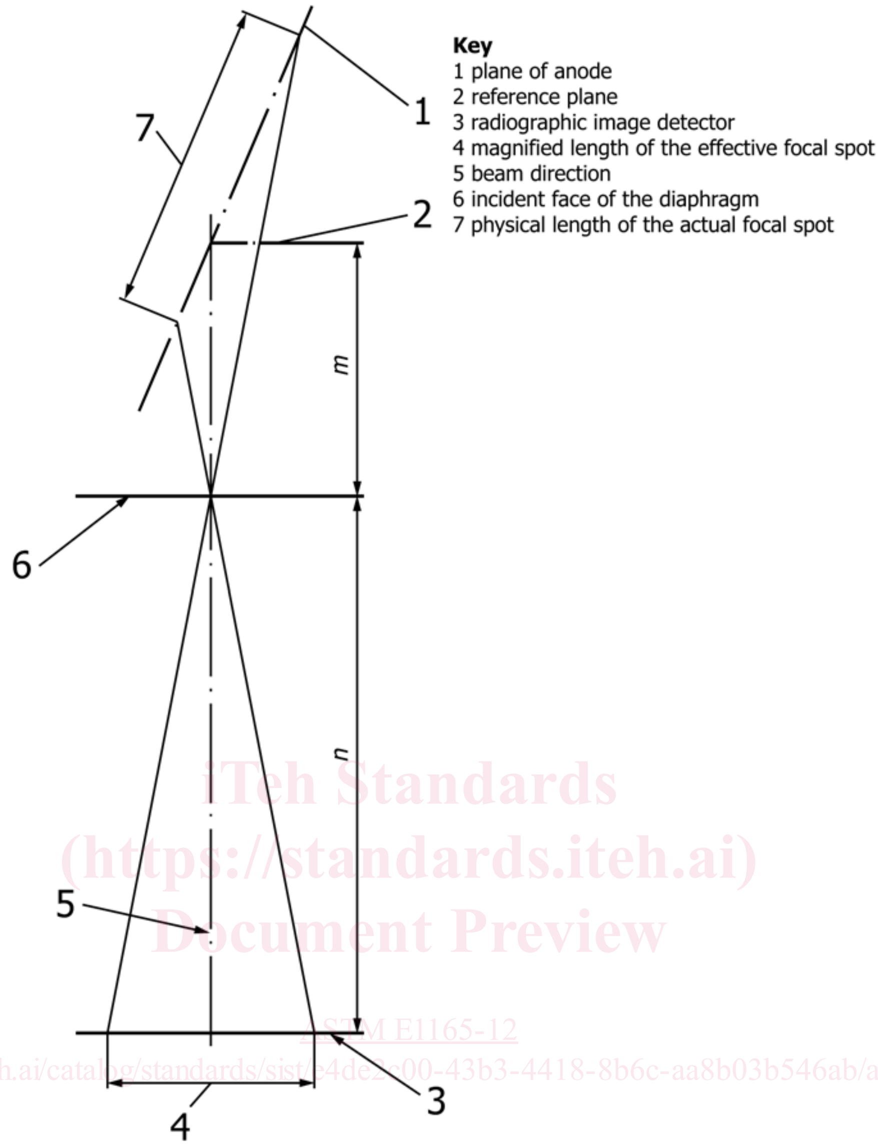


FIG. 5 Beam Direction Dimensions and Planes

TABLE 2 Magnification for Focal Spot Pinhole Images

Anticipated Focal Spot Size d [mm]	Minimum Magnification n/m	Distance between Focal Spot and Pinhole [m][A]	Distance between Pinhole and Detector [n][A]
0.05 to 2.0	3 : 1	0.25	0.75
>2.0	1 : 1	0.5	0.5

[A] When using a technique that entails the use of enlargement factors and a 1 m focal spot to detector distance (FDD = *m*+*n*) is not possible (see 7.1), the distance between the focal spot and the pinhole (*m*) shall be adjusted to suit the actual focal spot to detector distance (FDD) used (for example, if a 600 mm FDD is used, *m* shall be 150 mm for 3:1 enlargement, 300 mm for 1:1 enlargement, and the like).

http://dir.bam.de/ic (or http://www.kb.bam.de/~alex/ic/index.html).

6.6.1 When using CR technology or digitized film where outliner pixel may occur, a median 3×3 filter shall be available.

7. Procedure

7.1 If possible, use a standard 1 m (40 in.) focal spot to detector distance (FDD = *m*+*n*) for all exposures. If the machine geometry or accessibility limitations will not permit the use of a 1 m FDD, use the maximum attainable FDD (in these instances adjust the relative distances between focal spot, pinhole, and detector accordingly to suit the image enlargement factors specified in Table 2). For small focal spots FDD may be larger than 1 m (40 in.) to meet the requirements in 6.5 and 7.5. The distance between the focal spot and the pinhole is based on the anticipated size of the focal spot being measured and the desired degree of image enlargement (see Fig. 5). The specified focal spot to pinhole distance (*m*) for the different focal spot size ranges is provided in Table 2. Position the pinhole such that it is within ±1.5° of the central axis of the X-ray beam.

NOTE 2—The accuracy of the pinhole system is highly dependent upon the relative distances between (and alignment of) the focal spot, the pinhole, and the detector. Accordingly, a specially designed apparatus may be necessary in order to assure compliance with the above requirements. Fig. 6 provides an example of a special collimator that can be used to ensure conformance even with ±1° alignment tolerance.