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Non-destructive testing of welds — Radiographic testing —

Part 2: X- and gamma-ray techniques with digital detectors

Essais non destructifs des assemblages soudés — Contrôle par radiographie —

Partie 2: Techniques par rayons X ou gamma à l'aide de détecteurs numériques

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 5, *Testing and inspection of welds*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 121, *Welding and allied processes*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 17636-2:2013), which has been technically revised.

The main changes are as follows:

- the normative references have been updated;
- the figures have been updated;
- manual and automated inspection with DDAs has been considered in 6.6, 6.7, and 7.8;
- references to Figures 1 to 19 have been updated throughout the document;
- in 6.7 a), the acceptance of a wire visibility shorter than 10 mm for pipes with an external diameter < 50 mm has been added;
- in 6.7.1, the use of ASTM wires and other IQIs by agreement of the contracting parties has been added;
- 6.8, "Evaluation of image quality" for digital radiography has been added;
- in 6.9 and 7.2.2, the lower thickness limit for Se-75 applications has been deleted;
- in 6.8, 6.9 and 7.3.1, a clarification for the IQI usage for DWDI technique has been added;
- permission to reduce SNR_N if the tube voltage is reduced or energy-resolving detectors are used to < 80 % of the values given in Figure 20 has been added in 7.3.1;

— in 7.3.2, the compensation principle II (CP II) has been extended to three wire pairs without the agreement of the contracting parties;

— Annex C has been shortened to avoid duplication with ISO 19232-5;

— in D.2, a new note on fading has been added;

— a new Annex F has been added;

— a new Annex G has been added.

A list of all parts in the ISO 17636 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html. Official interpretations of ISO/TC 44 documents, where they exist, are available from this page: https://committee.iso.org/sites/tc44/home/interpretation.html.

Non-destructive testing of welds — Radiographic testing —

Part 2:
X- and gamma-ray techniques with digital detectors

1 Scope

This document specifies techniques of digital radiography with the object of enabling satisfactory and repeatable results. The techniques are based on generally recognized practice and fundamental theory of the subject.

This document applies to the digital radiographic testing of fusion welded joints in metallic materials. It applies to the joints of plates and pipes. Besides its conventional meaning, “pipe”, as used in this document, covers other cylindrical bodies such as tubes, penstocks, boiler drums and pressure vessels.

This document specifies the requirements for digital radiographic X- and gamma-ray testing by either computed radiography (CR) or radiography with digital detector arrays (DDAs) of the welded joints of metallic plates and tubes for the detection of imperfections. It includes manual and automated inspection with DDAs.

Digital detectors provide a digital grey value image which can be viewed and evaluated using a computer (Annex E). This document specifies the recommended procedure for detector selection and radiographic practice. Selection of computer, software, monitor, printer and viewing conditions are important, but are not the main focus of this document. The procedure specified in this document provides the minimum requirements for radiographic practice which permits exposure and acquisition of digital radiographs with equivalent sensitivity for the detection of imperfections as film radiography (specified in ISO 17636-1).

This document does not specify acceptance levels for any of the indications found on the digital radiographs. ISO 10675 provides information on acceptance levels for weld inspection.

If contracting parties apply lower test criteria, it is possible that the quality achieved will be significantly lower than when this document is strictly applied.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5576, *Non-destructive testing — Industrial X-ray and gamma-ray radiology — Vocabulary*

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 16371-1:2011, *Non-destructive testing — Industrial computed radiography with storage phosphor imaging plates — Part 1: Classification of systems*

ISO 19232-1, *Non-destructive testing — Image quality of radiographs — Part 1: Determination of the image quality value using wire-type image quality indicators*

ISO 19232-2, *Non-destructive testing — Image quality of radiographs — Part 2: Determination of the image quality value using step/hole-type image quality indicators*

ISO 19232-4, *Non-destructive testing — Image quality of radiographs — Part 4: Experimental evaluation of image quality values and image quality tables*

ISO 19232-5, *Non-destructive testing — Image quality of radiographs — Part 5: Determination of the image unsharpness and basic spatial resolution value using duplex wire-type image quality indicators*

EN 12543 (all parts), *Non-destructive testing — Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing*

EN 12679, *Non-destructive testing — Radiographic testing — Determination of the size of industrial radiographic gamma sources*

ASTM E747, *Standard Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology*

JIS Z2306, *Radiographic image quality indicators for non-destructive testing*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5576 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
computed radiography
CR
complete system comprising a *storage phosphor imaging plate* (IP) (3.2) and a corresponding read-out unit (scanner or reader), which converts the information from the IP into a digital image

3.2
storage phosphor imaging plate
IP
photostimulable luminescent material capable of storing a latent radiographic image of a material being tested and which, upon stimulation by a source of red light of appropriate wavelength, generates luminescence proportional to radiation absorbed

Note 1 to entry: When performing *computed radiography* (3.1), an IP is used in lieu of a film. When establishing techniques related to *source size* (3.20) or focal geometries, the IP is referred to as a detector, i.e. *source-to-detector distance* (3.21).

3.3
digital detector array
DDA
electronic device converting ionizing or penetrating radiation into a discrete array of analogue signals which are subsequently digitized and transferred to a computer for display as a digital image corresponding to the radiologic energy pattern imparted upon the input region of the device

3.4
structure noise
<imaging plate> local sensitivity variations due to inhomogeneities in the sensitive layer (structure, graininess) and surface of an imaging plate

Note 1 to entry: After scanning of the exposed imaging plate, the inhomogeneities appear as overlaid fixed pattern noise in the digital image.

Note 2 to entry: This noise limits the maximum achievable image quality of digital CR images and can be compared with the graininess in film images.

3.5
structure noise
<digital detector array> local sensitivity variations due to different properties of detector elements (pixels)

Note 1 to entry: After read-out of the exposed uncorrected *digital detector array* (DDA) (3.3) image, the inhomogeneities of the DDA appear as overlaid fixed pattern noise in the digital image. Therefore, all DDAs require, after read-out, a software-based image correction (software and guidelines are provided by the manufacturer). A suitable correction procedure reduces the structure noise.

Note 2 to entry: The image correction is also called "calibration" in other documents.

3.6
grey value
GV
numeric value of a pixel in a digital image

Note 1 to entry: This is typically interchangeable with the terms "pixel value", "detector response", "analogue-to-digital unit" and "detector signal".

Note 2 to entry: For further information, see Annex E.

3.7
linearized grey value
numeric value of a pixel which is directly proportional to the detector exposure dose, having a value of zero if the detector was not exposed

Note 1 to entry: This is typically interchangeable with the terms "linearized pixel value" and "linearized detector signal".

3.8
basic spatial resolution of a digital detector
SR_b^{detector}
half of the measured detector unsharpness in a digital image, which corresponds to the effective pixel size and indicates the smallest geometrical detail which can be resolved with a digital detector at magnification equal to one

Note 1 to entry: For this measurement, the duplex wire IQI is placed directly on the *digital detector array* (3.3) or imaging plate.

Note 2 to entry: The measurement of unsharpness is described in ISO 19232-5. See also ASTM E1000 and ASTM E2736.

3.9
basic spatial resolution of a digital image
SR_b^{image}
half of the measured image unsharpness in a digital image, which corresponds to the effective pixel size and indicates the smallest geometrical detail which can be resolved in a digital image

Note 1 to entry: For this measurement, the duplex wire IQI is placed directly on the object (source side).

Note 2 to entry: The measurement of unsharpness is described in ISO 19232-5. See also ASTM E1000 and ASTM E2736.

3.10
signal-to-noise ratio
SNR
ratio of mean value of the *linearized grey values* (3.7) to the standard deviation of the linearized grey values (noise) in a given *region of interest* (3.25) in a digital image

3.11
normalized signal-to-noise ratio
SNR_N
signal-to-noise ratio (3.10) normalized by the *basic spatial resolution of a digital image*, SR_b^{image}, (3.9) and calculated from the measured signal-to-noise ratio by:

$$SNR_N = SNR \cdot \frac{88,6}{SR_b^{image}}$$

Note 1 to entry: If the duplex wire IQI is positioned directly on the detector without a test object, SR_b^{image} is equal to the measured $SR_b^{detector}$, which can be used instead of SR_b^{image}.

3.12
contrast-to-noise ratio
CNR
ratio of the difference of the mean signal levels between two image areas to the averaged standard deviation of the signal levels

Note 1 to entry: Signal levels are measured in *grey values* (3.6) or *linearized grey values* (3.7).

Note 2 to entry: The contrast-to-noise ratio describes a component of image quality and depends approximately on the product of radiographic attenuation coefficient and SNR. In addition to adequate CNR, it is also necessary for a digital radiograph to possess adequate unsharpness or basic spatial resolution to resolve desired features of interest.

3.13
normalized contrast-to-noise ratio
CNR_N
contrast-to-noise ratio (3.12) normalized by the basic spatial resolution of a digital image, SR_b^{image}, (3.9), as measured directly in the digital image with the duplex wire IQI on the object side and calculated from the measured contrast-to-noise ratio, CNR, i.e.

$$CNR_N = CNR \cdot \frac{88,6}{SR_b^{image}}$$

3.14
aliasing
artefacts that appear in an image when the spatial frequency of the input is higher than the output is capable of reproducing

Note 1 to entry: Aliasing often appears as jagged or stepped sections in a line or as moiré patterns.

3.15
cluster kernel pixel
CKP
bad pixel (3.29) which does not have five or more good neighbourhood pixels

Note 1 to entry: See ASTM E2597 for details of bad pixels and CKP.

3.16
nominal thickness
t
thickness of the parent material only where manufacturing tolerances do not have to be considered

3.17
penetration thickness change
Δt
change of *penetrated thickness* (3.18) relative to the *nominal thickness* (3.16) due to beam angle

3.18
penetrated thickness
w
thickness of material in the direction of the radiation beam, calculated on the basis of the *nominal thicknesses* (3.16) of all penetrated walls

3.19
object-to-detector distance
b
largest (maximum) distance between the radiation side of the radiographed part of the test object and the sensitive layer of the detector, measured along the central axis of the radiation beam

Note 1 to entry: The abbreviated term ODD is used in other documents.

3.20
source size
d
size of the radiation source or focal spot size

Note 1 to entry: See EN 12543 or EN 12679.

3.21
source-to-detector distance
SDD
distance between the source of radiation and the detector, measured in the direction of the beam

Note 1 to entry: $SDD = f + b$

where

f is *source-to-object distance* (3.22);

b is *object-to-detector distance* (3.19).

3.22
source-to-object distance
f
distance between the source of radiation and the source side of the test object, measured along the central axis of the radiation beam

Note 1 to entry: The abbreviated term SOD is used in other documents.

3.23
external diameter
D_e
nominal value of the external diameter of the pipe

3.24
geometric magnification
v
ratio of *source-to-detector distance* (3.21) to *source-to-object distance* (3.22)

3.25
region of interest
RoI
defined group of pixels from which measurements or statistics, or both, can be derived

3.26
weld area to evaluate
WAE
area to be evaluated on the radiograph, which contains the weld and the *heat-affected zone* (3.30) on both sides

3.27
area of interest
AoI
minimum area which should be evaluated on the radiograph and which contains the weld, the *heat-affected zone* (3.30) on both sides and all lead letters, markers and image quality indicators (IQIs)

3.28
raw image
image acquired with *digital detector arrays* (3.3) or computed radiography (3.1) systems after image correction, if a correction has been performed

3.29
bad pixel
underperforming detector element (pixel) of a *digital detector array* (3.3)

Note 1 to entry: Bad pixels are described in ASTM E2597.

3.30
heat affected zone
HAZ
area beside the weld influenced by the heating and cooling process of the welding, which is considered as the two areas beside the weld, each with the same width as the weld cap but at least 10 mm width to be considered for evaluation

4 Symbols and abbreviated terms

For the purposes of this document, the symbols and abbreviated terms given in Table 1 apply.

Table 1 — Symbols and abbreviated terms

Symbol or abbreviated term	Definition
α	angle subtended by half of the circumferential length of the AoI at the pipe centre, see Figure 22 a)
AoI	area of interest
β	opening angle of source window or collimator to central beam
b	object-to-detector distance
b'	object-to-detector distance perpendicular to test object
b_{ed}	maximum distance from the object surface nearest to the planar detector to the object surface most distant to the detector in the weld area to evaluate (WAE) of the pipe, see Figures 2 b), 8 b), 13 b), 14 b) and 22
b_{gap}	distance between the radiation sensitive layer of the detector and the outer pipe surface, see Figures 2 b) and 22
C_i	factor to correct f_{min} for using planar detectors for curved objects, if $b > t$
CKP	cluster kernel pixel
CNR	contrast-to-noise ratio
CNR_N	normalized contrast-to-noise ratio
CR	computed radiography
d	source size, focal spot size (see the EN 12543 series and EN 12679)

Table 1 *(continued)*

Symbol or abbreviated term	Definition
D	detector
D_e	external diameter
DDA	digital detector array
DWDI	double-wall double-image
DWSI	double-wall single-image
f	source-to-object distance
f_{min}	minimum source-to-object distance
f^*_{min}	minimum source-to-object distance for testing of curved objects with planar detectors
f'	source-to-object distance perpendicular to test object
GV	grey value
HAZ	heat-affected zone
IP	storage phosphor imaging plate
IQI	image quality indicator
r_e	external radius
r_i	internal radius
RoI	region of interest
S	radiation source
SDD	source-to-detector distance
SNR	signal-to-noise ratio
SNR_N	normalized signal-to-noise ratio
SR_b	basic spatial resolution which can be SR_b^{image} or $SR_b^{detector}$
$SR_b^{detector}$	basic spatial resolution of a digital detector
SR_b^{image}	basic spatial resolution of a digital image
t	nominal thickness
Δt	penetration thickness change
u_G	geometric unsharpness
u_d	inherent unsharpness of the detector system, excluding any geometric unsharpness, measured from the digital image with a duplex wire IQI adjacent to the detector
U_{Im}	image unsharpness, measured in the digital image at the object plane with a duplex wire IQI
u_T	total image unsharpness, including geometric unsharpness, measured in the digital image at the detector plane with a duplex wire IQI at the object plane
v	geometric magnification
v_o	optimum magnification
w	penetrated thickness
WAE	weld area to evaluate

NOTE The source-to-detector-distance (SDD), as used in digital radiography, is equivalent to SFD (see ISO 17636-1) in film radiography.

5 Classification of radiographic techniques and compensation principles

5.1 Classification

The radiographic techniques are divided into two testing classes:

— testing class A: basic techniques;

— testing class B: improved techniques.

Testing class B techniques are used when testing class A techniques are insufficiently sensitive.

Radiographic techniques providing higher sensitivity than testing class B are possible and may be agreed between the contracting parties by specification of all appropriate test parameters.

The choice of digital radiographic technique shall be agreed between the contracting parties.

The visibility of flaws using film radiography or digital radiography is equivalent when using testing class A and testing class B techniques, respectively. The visibility shall be proven by the use of IQIs according to ISO 19232-1 or ISO 19232-2 and ISO 19232-5.

If, for technical or industrial reasons, it is not possible to meet one of the conditions specified for testing class B, such as the type of radiation source or the source-to-object distance, f, it may be agreed by contracting parties that the condition selected can be that specified for testing class A. The loss of sensitivity shall be compensated by an increase of minimum grey value and SNR_N for CR or SNR_N for the DDA technique (recommended increase of SNR_N by a factor > 1,4). Because of the better sensitivity than that of testing class A, the test specimen may be regarded as being tested to testing class B if the correct IQI sensitivity is achieved. This does not apply if the special SDD reduction as described in 7.6 for test arrangements 7.1.4 and 7.1.5 (Figure 5 to Figure 10) are used.

5.2 Compensation principles, CP I, CP II or CP III

5.2.1 General

Three compensation principles (see 5.2.2 to 5.2.4) are applied in this document for radiography with digital detectors to achieve a sufficient contrast sensitivity.

Application of these principles requires the achievement of a minimum contrast-to-noise ratio, CNR_N, normalized to the detector basic spatial resolution per detectable material thickness difference Δw. If the required normalized contrast-to-noise ratio (CNR_N per Δw) cannot be achieved due to an insufficient value of one of the following parameters, this can be compensated by an increase in the SNR.

5.2.2 Compensation principle I (CP I)

Compensation for reduced contrast (e.g. by increased tube voltage) by increased SNR (e.g. by increased tube current or exposure time).

5.2.3 Compensation principle II (CP II)

Compensation for insufficient detector sharpness (the value of SR_b is higher than specified) by increased SNR (increase in the single IQI wire or step-hole value for each missing duplex wire pair value). SR_b is $SR_b^{detector}$ for detector selection (IQI on the detector without object) or SR_b^{image} for image quality evaluation of a production radiograph with the IQI on the source side of the object.

5.2.4 Compensation principle III (CP III)

Compensation for increased local interpolation unsharpness, due to bad pixel correction for DDAs, by increased SNR.

5.2.5 Theoretical background

These compensation principles are based on the approximation given in Formula (1) for small flaw sizes ($\Delta w << w$):

$$\frac{CNR_N}{\Delta w} = \mathrm{c} \cdot \frac{\mu_{\mathrm{eff}} \cdot SNR}{SR_b^{\mathrm{image}}} \quad (1)$$

where

c is a constant (0,088 6 mm);

μ_{eff} is the effective attenuation coefficient, which is equivalent to the specific material contrast, in mm^{-1};

CNR_N is the normalized CNR, as measured in the digital image;

SR_b^{image} is the basic spatial image resolution, in mm.

6 General preparations and requirements

6.1 Protection against ionizing radiation

WARNING — Exposure of any part of the human body to X-rays or gamma rays can be highly injurious to health. Wherever X-ray equipment or radioactive sources are in use, appropriate health and safety requirements shall be applied.

NOTE Local, national and international regulations and safety precautions provide additional information.

6.2 Surface preparation and stage of manufacture

In general, surface preparation is not necessary, but where surface imperfections or coatings can cause difficulty in detecting defects, the surface shall be ground smooth or the coatings shall be removed.

Unless otherwise specified, digital radiography shall be carried out after the final stage of manufacture, e.g. after grinding or heat treatment.

6.3 Location of the weld in the radiograph

Where the digital radiograph does not show the weld, high-density markers shall be placed on both sides of the weld outside the weld area to evaluate (WAE).

6.4 Identification of radiographs

Symbols shall be affixed to each section of the object being digitally radiographed. The images of these symbols shall appear in the digital radiograph outside the WAE where possible and shall ensure unambiguous identification of the section. Another identification system may be part of the contract agreement.

6.5 Marking

Permanent markings on the object to be tested shall be made in order to accurately locate the position of each digital radiograph, e.g. zero-point, direction, identification, measure.

Where the nature of the material and/or its service conditions do not permit permanent marking, the location may be recorded by means of accurate sketches or photographs or from automated positioning systems.

6.6 Overlap of digital images

When digitally radiographing an area with two or more separate detectors (imaging plates), they shall overlap sufficiently to ensure that the complete WAE is digitally radiographed. This shall be verified by a high-density marker on the surface of the object which is to appear on each digital image. If the radiographs are taken sequentially with CR or DDA, the high-density marker shall be visible on each of the radiographs.

This applies also for DDA in manual testing and automated testing in start/stop mode. It does not apply for automated testing in continuous mode. In the latter case, the use and number of high-density markers should be subject to an agreement between the contracting parties.

6.7 Types and positions of image quality indicators (IQIs)

6.7.1 General

The quality of radiographs shall be verified by use of image quality indicators (IQIs) in accordance with ISO 19232-5 and ISO 19232-1 or ISO 19232-2. IQIs according to ASTM E747 or JIS Z2306 may be used instead, if their material group fits better to the test object or component. Tables for the conversion of wire numbers of ASTM E 747, JIS Z2306 and ISO 19232-1 can be found in these documents. By agreement between contracting parties, other IQIs with the same radiographic attenuation as the test object and the same dimensions as defined in ISO 19232-1 or ISO 19232-2 may be used.

6.7.2 Duplex wire IQIs

Following the procedure outlined in Annex C, a reference image is required for the verification of the basic spatial resolution of the digital detector system (SR_b^{detector}). In this case, the duplex wire IQI (ISO 19232-5) shall be positioned directly on the digital detector. The basic spatial resolution or duplex wire value shall be determined to verify that the system hardware meets the requirements specified as a function of the penetrated material thickness in Tables B.13 and B.14. For double-wall double-image inspection, the SR_b^{detector} shall correspond to the values of Tables B.13 and B.14 chosen on the basis that the penetrated thickness is twice the nominal single-wall thickness.

The use of a duplex wire IQI (ISO 19232-5) on the object for production radiographs is required if the geometric magnification technique (see 7.7) is applied with $v > 1{,}2$. The value of the basic spatial resolution, measured in the digital image (see Annex C), shall not exceed the maximum SR_b^{image} values specified as a function of the penetrated material thickness in Table B.13 or Table B.14. Automated DDA inspection systems may use a detection mode as continuous movement (e.g. translation or rotation) or start/stop acquisition. The image unsharpness of moving or start/stop systems shall not exceed the values of Table B.13 or Table B.14.

For single-image inspection, the single-wall thickness is taken as the penetrated material thickness. For double-wall double-image inspection in accordance with 7.1.6 and 7.1.7 (Figure 11 or Figure 12), with the duplex wire on the source side of the pipe, the pipe diameter is taken as the value b for determination of f_{min} and for determination of the required basic spatial resolution (SR_b^{image}) from Table B.13 and Table B.14. The basic spatial resolution of the detector (SR_b^{detector}) for double-wall double-image inspection shall correspond to the values of Table B.13 and Table B.14, chosen on the basis of twice the nominal single-wall thickness as the penetrated material thickness.

The duplex wire IQI shall be positioned tilted by a few degrees (2° to 5°) to the digital rows or columns of the digital image.

In historical cases, where the IQI was positioned at 45° to the digital rows or columns, the obtained IQI number shall be reduced by one.

6.7.3 Single wire or step-hole IQIs

The contrast sensitivity of digital images shall be verified by use of IQIs, in accordance with the specific application as given in Tables B.1 to B.12 (see also ISO 19232-1 or ISO 19232-2).

The single wire or step-hole IQIs used shall be placed on the source side of the test object at the centre of the area of interest (AoI) on the parent metal beside the weld. The identification symbols and, when used, the lead letter F shall not be in the WAE, except when geometric configuration makes it impractical. The IQI shall be in close contact with the surface of the object. Its location shall be in a section of uniform thickness characterized by a uniform grey value (mean) in the digital image.

According to the IQI type used, cases a) and b) shall be considered.

a) When using a single wire IQI, the wires shall be directed perpendicular to the weld and its location shall ensure that at least 10 mm of the wire length shows in a section of uniform grey value or SNR_N, which is normally in the parent metal adjacent to the weld. For exposures in accordance with 7.1.6 and 7.1.7 (Figure 11 and Figure 12), the IQI should be placed with the wires across the pipe axis and they should not be projected into the image of the weld. The visible wire length may be shorter than 10 mm for external pipe diameters smaller than 50 mm. In that case, the visible wire length shall be ≥ 20 % of the external pipe diameter.

b) When using a step-hole IQI, it shall be placed in such a way that the required hole is placed close to the weld.

For single-wall exposures in accordance with 7.1.4 and 7.1.5 (Figures 5 to 10), the IQI type used may be placed either on the source side (use Tables B.1 to B.4) or on the detector side. If the IQIs cannot be placed on the source side, they are placed on the detector side and the image quality shall be determined at least once from comparison exposure with one IQI placed on the source side and one on the detector side under the same conditions. If filters are used in front of the detector, the IQI shall be placed in front of the filter.

For double-wall exposures in accordance with 7.1.6 and 7.1.7 (Figures 11 and 12), the IQI type used shall be placed on the source side (use Tables B.5 to B.8). By agreement between contracting parties, the IQI may be placed on the detector side (use Tables B.9 to B.12).

For double-wall exposures in accordance with 7.1.8 (Figures 13 to 16), the IQI type used may be placed on the detector side. When the IQI is placed on the detector side, refer to Tables B.9 to B.12.

Where the IQIs are placed on the detector side, the letter F shall be placed near the IQI and shall be visible in the radiographic image and this shall be stated in the test report.

The identification numbers and, when used, the lead letter F shall not be in the WAE, except when geometric configuration makes it impractical.

If steps have been taken to guarantee that digital radiographs of similar test objects and regions are produced with identical exposure and processing techniques, and no differences in the image quality value are likely, the image quality does not need to be verified for every digital radiograph. The extent of image quality verification should be subject to agreement between the contracting parties.

For exposures of pipes with the source centrally located, at least three IQIs should be placed equally spaced at the circumference. The digital radiograph(s) showing IQI images are then considered representative for the whole circumference.

6.8 Evaluation of image quality

The digital images shall be evaluated on a monitor. The monitor and the viewing conditions shall fulfil the requirements of 7.10.

From the testing of the radiographic image of the wire or step-hole IQI, the number of the smallest wire or hole which can be discerned shall be determined. The image of a wire is accepted if a continuous length of at least 10 mm is clearly visible in a section of uniform grey values, typically in the HAZ near the weld [see 6.7.3 a) for pipes with smaller diameters]. In the case of the step-hole-type IQI, if there are two holes of the same diameter, both shall be discernible, in order that the step be considered as visible. See also 6.7.3 a), for the exception of DWDI evaluation of small pipes.

The duplex wire IQI shall be evaluated with the profile function of the image processing system in the linear or linearized grey value image, as stated in Annex C and ISO 19232-5.

The image quality shall be determined in the unprocessed image, which is also called the raw image. The unprocessed (raw) image is considered to be the acquired image after image correction (calibration) by offset and gain images and/or firmware corrections. If the images are evaluated after application of digital filters, the wire or step-hole IQIs shall be evaluated and the achieved values shall fulfil the requirements of the relevant tables in Annex B.

The IQI values obtained shall be indicated in the test report of the radiographic testing. In each case, the type of indicator used shall be clearly stated, as shown on the IQI.

6.9 Minimum image quality values

Tables B.1 to B.14 show the minimum IQI values for metallic materials. For other materials, these requirements or corresponding requirements may be agreed upon by contracting parties and shall be noted in the report. The requirements shall be determined in accordance with ISO 19232-4.

In the case where Ir 192 or Se 75 sources are used for copper-based alloys, steel or nickel-based alloys, IQI values poorer than the ones listed in Tables B.1 to B.12 may be accepted exceptionally as follows. This shall be noted in the report.

For DWDI techniques, values shown in Tables B.5 to B.12, both testing class A and testing class B ($w = 2t$):

— 10 mm < w ≤ 25 mm: one wire value fewer or one step-hole value more for Ir 192;

— w ≤ 12 mm: one wire value fewer or one step-hole value more for Se 75.

For single-wall single-image and double-wall ($w = 2t$) single-image techniques, values shown in Tables B.1, B.2, B.9 and B.10, testing class A:

— 10 mm < w ≤ 24 mm: two wire values fewer or two step-hole values more for Ir 192;

— 24 mm < w ≤ 30 mm: one wire value fewer or one step-hole value more for Ir 192;

— w ≤ 24 mm: one wire value fewer or one step-hole value more for Se 75.

For single-wall single-image and double-wall single-image techniques, values shown in Tables B.3, B.4, B.11 and B.12, testing class B:

— 10 mm < w ≤ 40 mm: one wire value fewer or one step-hole value more for Ir 192;

— w ≤ 20 mm: one wire value fewer or one step-hole value more for Se 75.

For Se 75 and penetrated thicknesses with less than 12 mm, it can be difficult to achieve the IQI values required for testing class B. The loss of sensitivity shall be compensated by an increase of minimum grey value and SNR_N for CR or SNR_N for the DDA technique. The increase in SNR_N shall be > 1,4.

If the IQI values for Se 75 and penetrated thicknesses less than 12 mm cannot be achieved as described, the required IQI values and test conditions shall be agreed by the contracting parties based on ISO 19232-4.

6.10 Personnel qualification

Personnel performing non-destructive testing in accordance with this document shall be certified in radiographic testing in accordance with ISO 9712 or an equivalent internationally or nationally accepted certification scheme to an appropriate level in the relevant industrial sector. The personnel shall be able to prove they have undergone additional training in digital industrial radiology (see Syllabuses in ISO/TS 25107:2019, Clause 5).

7 Recommended techniques

7.1 Test arrangements

7.1.1 General

Radiographic techniques in accordance with 7.1.2 to 7.1.9 (Figures 1 to 19) shall be used, if possible.

The elliptical technique (double-wall and double-image) in accordance with 7.1.6 (Figure 11) should only be used for external diameter $D_e \leq 100$ mm and wall thickness $t \leq 8$ mm and weld width $\leq D_e/4$. Two 90° displaced images are sufficient if $t/D_e < 0{,}12$; otherwise, three elliptical images are needed. The distance between the two projected weld images shall be about one weld width. Due to the higher dynamic range of digital detectors than in film radiography, D_e and t may exceed the values given by 10 %.

When it is not possible to carry out an elliptical testing for $D_e \leq 100$ mm, the perpendicular technique in accordance with 7.1.7 (Figure 12) may be used. In this case, three exposures 120° or 60° apart are required, depending on the access around the pipe.

For test arrangements in accordance with 7.1.8 (Figures 13 and 14), the inclination of the beam shall be kept as small as possible and be such as to prevent superimposition of the two images. The source-to-object distance, *f'*, shall be kept as small as possible for the technique shown in Figures 13 and 14, in accordance with 7.6. The IQI shall be placed on the detector side close to the detector with a lead letter F.

Digital radiographic techniques other than those in 7.1.2 to 7.1.9 (Figures 1 to 19) may be agreed by the contracting parties when it is useful, for reasons such as the geometry of the piece or differences in material thickness. In 7.1.9 (Figures 17 to 19), an example of such a case is presented. Additionally, thickness compensation with the same material may be applied.

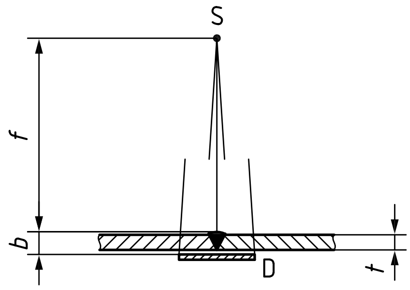
In Annex A, the minimum number of digital radiographs required is given in order to obtain an acceptable radiographic coverage of the total circumference of a butt weld in pipe.

If the geometric magnification technique is not used, the detector shall be placed as close as possible to the object.

If flexible detectors are not applicable and rigid cassettes or planar DDAs are used, as shown in Figures 2 b), 8 b), 13 b) and 14 b), the SDD shall be calculated from the wall thickness, *t*, the largest distance of the detector to the source side surface of the object, *b*, and the focal spot size or source size, *d*, as specified in 7.6, Formulae (2) to (13).

NOTE Unless otherwise noted, definitions of the symbols used in Figures 1 to 24 and in the annexes can be found in Clause 4.

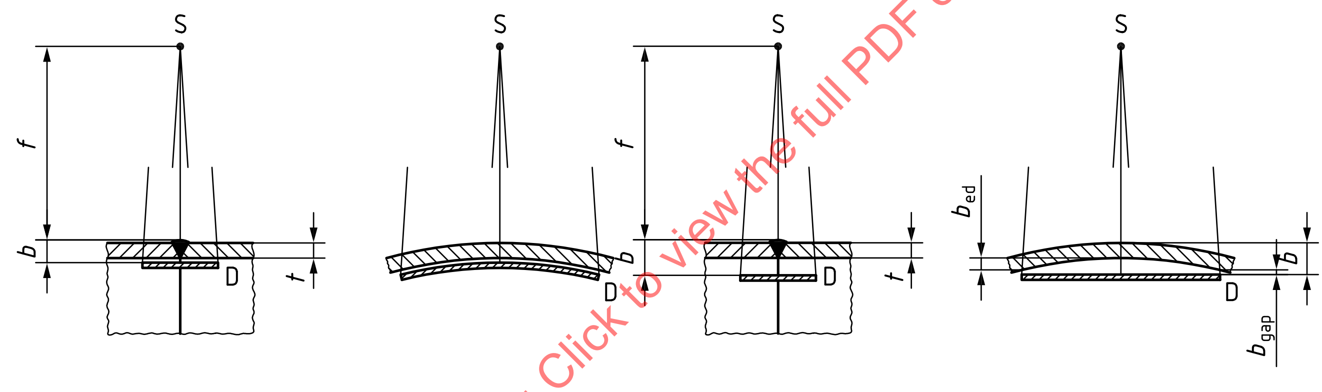
7.1.2 Single-wall penetration of plane objects (see Figure 1)



NOTE If the distance, *b*, in Figure 1 is less than 1,2 *t*, then the nominal thickness, *t*, can be used for *b* and *f* can be considered as the distance from the source to the parent material surface.

Figure 1 — Arrangement for testing of planar welds with radiation source on one side and the detector on the opposite side

7.1.3 Single-wall penetration of curved objects with the source outside the object (see Figures 2 to 4)



a) With curved detectors

b) With planar detectors

NOTE If the distance, *b*, in Figure 2 is less than 1,2 *t*, then the nominal thickness, *t*, can be used for *b* and *f* can be considered as the distance from the source to the parent material surface.

Figure 2 — Arrangement for testing of curved objects with the radiation source outside and the detector inside

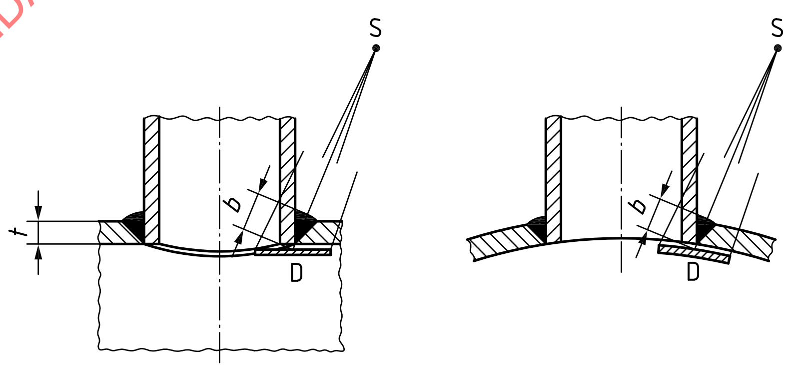


Figure 3 — Arrangement for testing of set-in welds with the radiation source outside and the detector inside

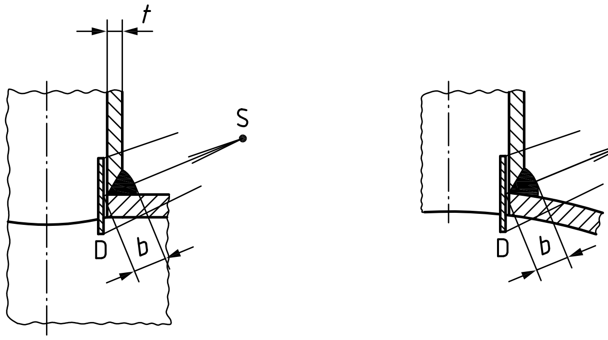
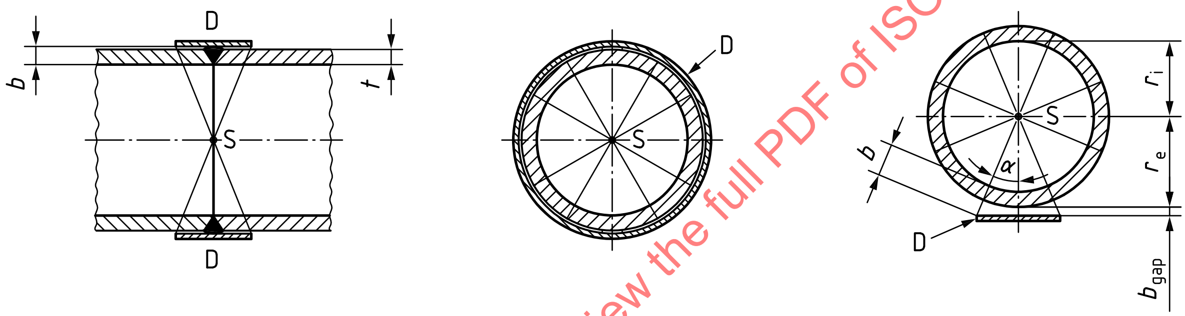


Figure 4 — Arrangement for testing of set-on welds with the radiation source outside and the detector inside

7.1.4 Single-wall penetration of curved objects with the source inside the object for panoramic exposure (see Figures 5 to 7)



a) With curved detectors

b) With planar detectors

Figure 5 — Arrangement for testing of welds with centrally located radiation source (central projection) and the detector outside

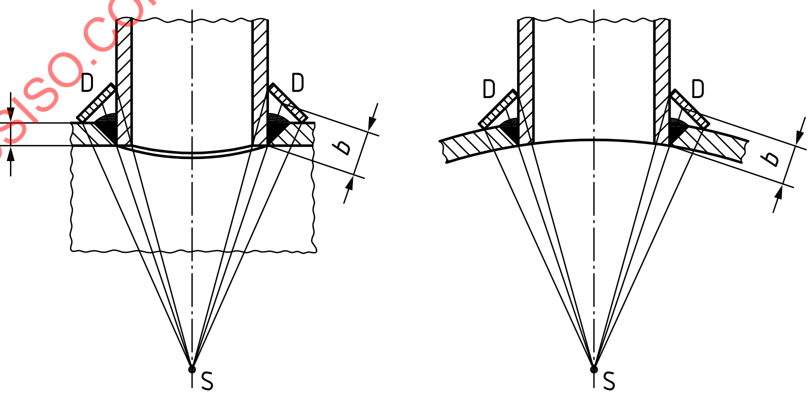


Figure 6 — Arrangement for testing of set-in welds with a radiation source, located on the central pipe axis and perpendicular to the weld centre, and the detector outside

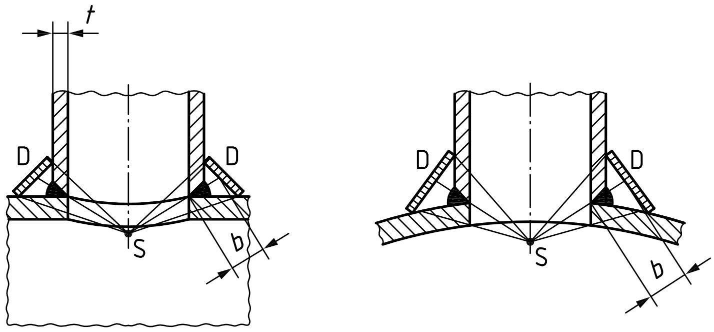
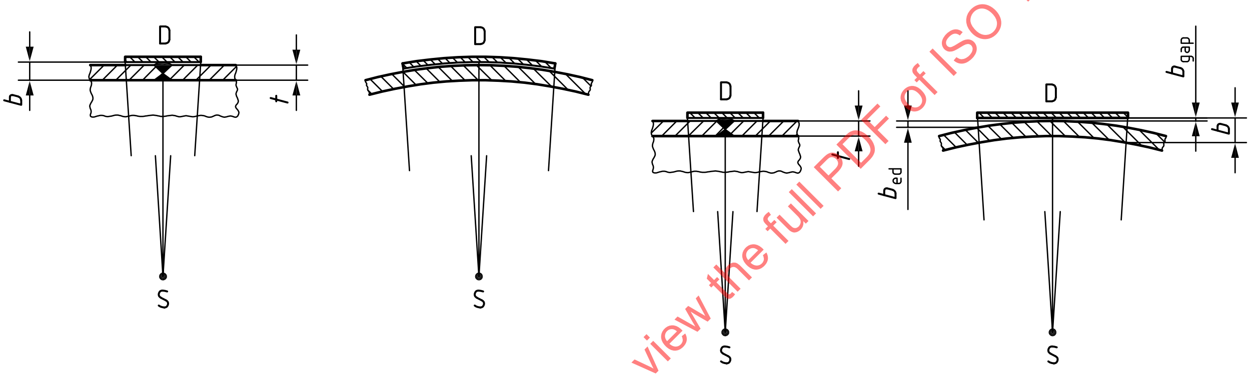


Figure 7 — Arrangement for testing of set-on welds with a radiation source, located on the central pipe axis and perpendicular to the weld centre, and the detector outside

7.1.5 Single-wall penetration of curved objects with the source located off-centre and inside the object (see Figures 8 to 10)



a) With curved detectors

b) With planar detectors

NOTE If the distance, *b*, in Figure 8 is less than 1,2 *t*, then the nominal thickness, *t*, can be used for *b*.

Figure 8 — Arrangement for testing of welds with the radiation source located off-centre inside the object and the detector outside

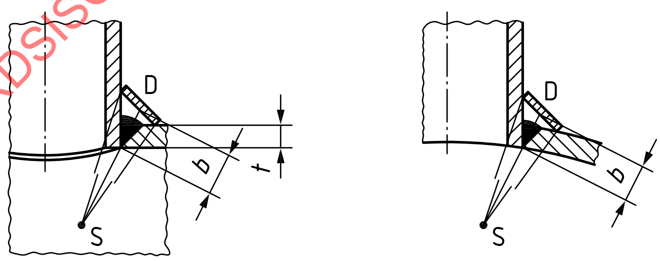


Figure 9 — Arrangement for testing of set-in welds with the radiation source located off-centre inside the object and the detector outside

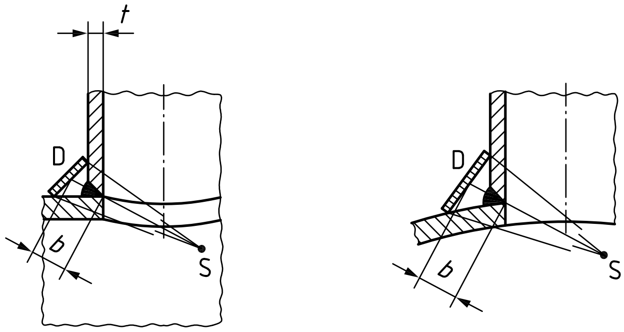
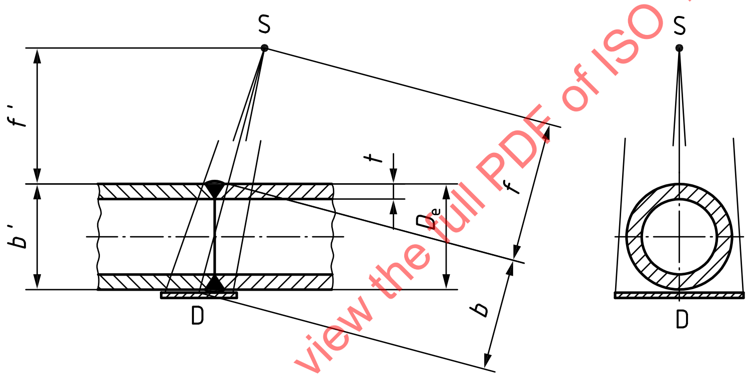


Figure 10 — Arrangement for testing of set-on welds with the radiation source located off-centre inside the object and the detector outside

7.1.6 Double-wall penetration and double-image evaluation (DWDI) of pipes with the elliptic technique and the source and the detector outside the object (see Figure 11)



NOTE The source-to-object distance can be calculated by the perpendicular distance *f* ', calculated from *b*'.

Figure 11 — Arrangement for testing of both walls of pipes with the elliptic technique

7.1.7 Double-wall penetration and double-image evaluation (DWDI) with the perpendicular technique and source and detector outside the object (see Figure 12)

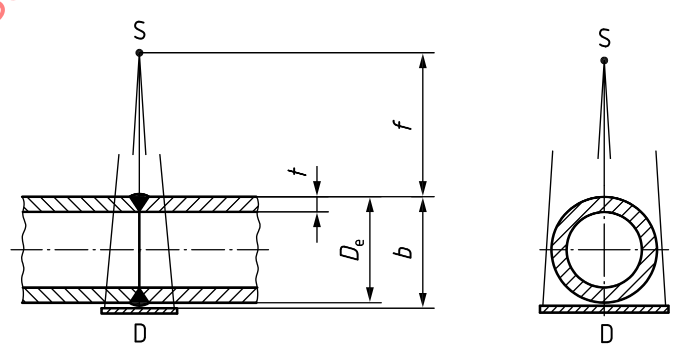
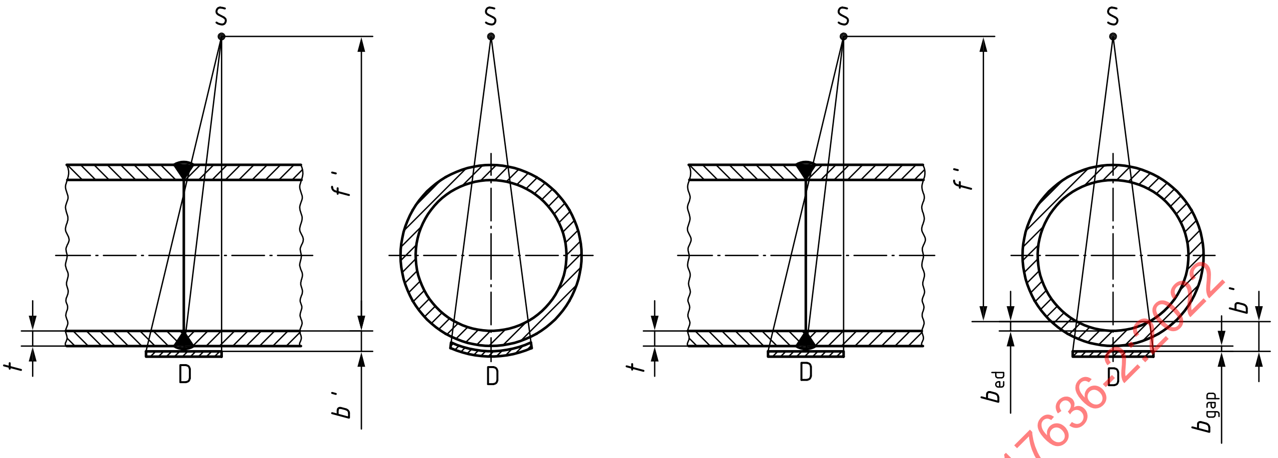


Figure 12 — Arrangement for testing of both walls of pipes with the perpendicular technique

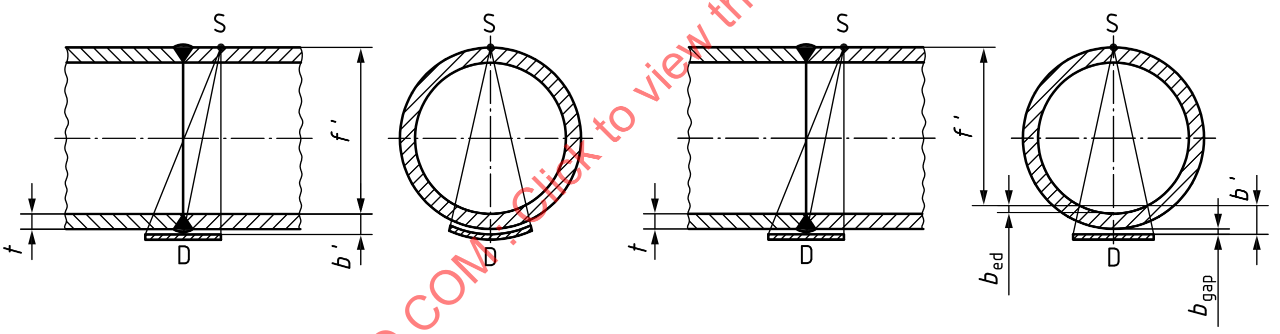
7.1.8 Double-wall penetration and single-image evaluation (DWSI) of curved objects for evaluation of the wall next to the detector (see Figures 13 to 16)



a) With curved detectors   b) With planar detectors

NOTE If the distance, *b*′, in Figure 13 is less than 1,2 *t*, then the nominal thickness, *t*, can be used for *b*′ and *f*′ can be considered as the distance from the source to the parent material surface.

Figure 13 — Arrangement for testing of curved objects with the radiation source outside and evaluation of the wall next to the detector with the IQI placed close to the detector



a) With curved detectors   b) With planar detectors

NOTE If the distance, *b*′, in Figure 14 is less than 1,2*t*, then the nominal thickness, *t*, can be used for *b*′ and *f*′ can be considered as the distance from the source to the parent material surface.

Figure 14 — Arrangement for testing of curved objects with the radiation source outside, located directly on the surface and evaluation of the wall next to the detector with the IQI placed close to the detector

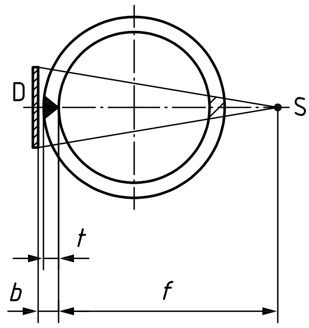


Figure 15 — Arrangement for testing of pipes with longitudinal welds with the radiation source outside and evaluation of the wall next to the detector with the IQI placed close to the detector

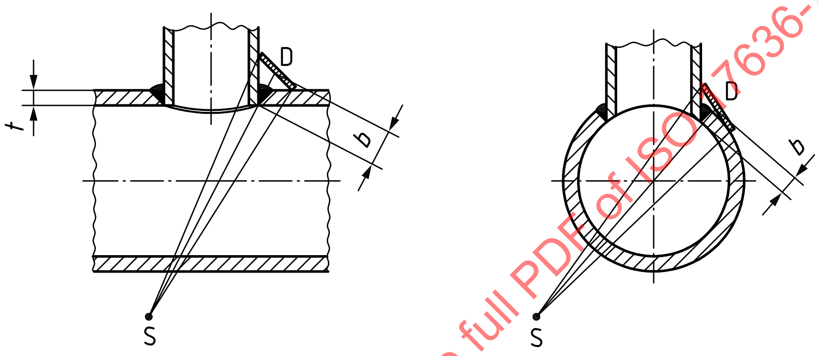


Figure 16 — Arrangement for testing of set-in welds with the radiation source outside and evaluation of the wall next to the detector with the IQI placed close to the detector

7.1.9 Penetration of objects with different material thicknesses (see Figure 17 to 19)

a) Arrangement for testing without compensating edge **b) Arrangement for testing with compensating edge**

Key

1 compensating edge

Figure 17 — Arrangement for testing of fillet welds with an oblique detector position

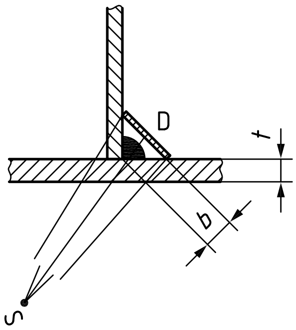


Figure 18 — Arrangement for testing of fillet welds with a perpendicular detector position

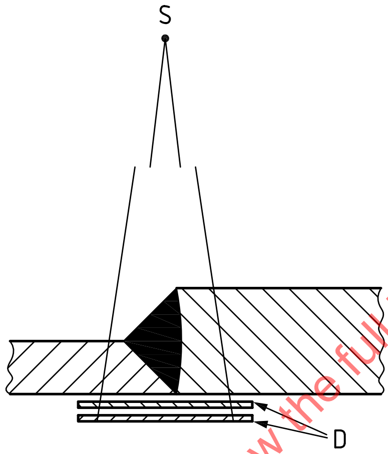


Figure 19 — Arrangement for testing with a multi-detector technique, applicable for CR

7.2 Choice of tube voltage and radiation source

7.2.1 X-ray devices up to 1 000 kV

To maintain a good flaw sensitivity, the X-ray tube voltage should be as low as possible and the SNR_N in the digital image should be as high as possible. Recommended values of X-ray tube voltage versus penetrated thickness are given in Figure 20. These values are best-practice values for film radiography.

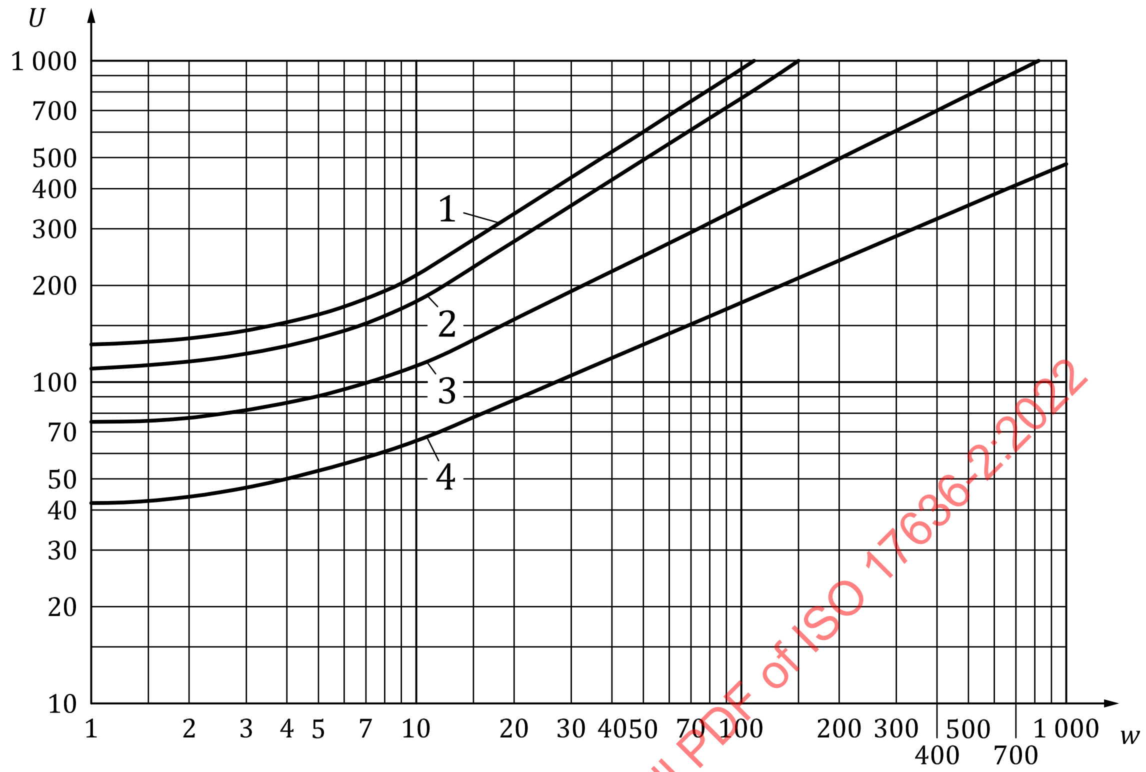
After accurate detector image correction (calibration), DDAs can provide sufficient image quality at significantly higher voltages than those shown in Figure 20.

Imaging plates with high structure noise in the sensitive IP layer (coarse grained) should be applied with about 20 % less X-ray voltage than indicated in Figure 20 for testing class B. High-definition imaging plates, which are exposed similarly to X-ray films and having low structure noise (fine grained), can be exposed with the X-ray voltages of Figure 20 or higher if the SNR_N is sufficiently increased.

NOTE CP I:

— An improvement in contrast sensitivity can be achieved by an increase in contrast at constant SNR_N, by reduction of tube voltage and compensation by higher exposure (e.g. milliampère minutes), or by an increase in SNR_N, by higher exposure (e.g. milliampère minutes), at constant contrast (constant kilovolt level).

— Increased tube voltage at a constant exposure (e.g. milliampère minutes) reduces the contrast and increases the SNR_N. The contrast sensitivity improves if the increase in SNR_N is higher than the contrast reduction due to the higher energy.



Key

U	X-ray tube voltage, kV	1	copper and nickel and its alloys
w	penetrated thickness, mm	2	steel
		3	titanium and its alloys
		4	aluminium and its alloys

NOTE The calculations for the curves are described in Annex G.

Figure 20 — Recommended X-ray tube voltage for X-ray devices up to 1 000 kV as a function of penetrated thickness and material

For some applications where there is a thickness change across the area of the object being radiographed, a modification of technique with a higher voltage may be used, but it should be noted that an excessively high tube voltage leads to a loss of defect detection sensitivity.

7.2.2 Other radiation sources

The recommended penetrated thickness ranges for gamma-ray sources and X-ray equipment above 1 MV are given in Table 2.

On a thin specimen, gamma rays from Se 75, Ir 192 and Co 60 sources do not produce digital radiographs having as good a defect detection sensitivity as X-rays used with appropriate technique parameters. However, because of the advantages of gamma-ray sources in handling and accessibility, Table 2 gives a range of thicknesses for which each of these gamma-ray sources may be used when the use of X-ray tubes is impractical and shall be noted in the report.

For certain applications, wider material thickness ranges may be permitted if sufficient image quality can be achieved.

In cases where digital radiographs are produced by CR using gamma rays, the total travel time to and from the source position shall not exceed 10 % of the total exposure time. Using DDAs, the exposure time shall start after the source is in position and shall end before the source is moved back.

Table 2 — Penetrated thickness ranges for gamma-ray sources and X-ray equipment with X-ray potential, *U*, above 1 MV for steel, copper and nickel-based alloys

Radiation source	Penetrated thickness *w* mm	
	Testing class A	Testing class B
Tm 170	$w \le 5$	$w \le 5$
Yb 169[a]	$1 \le w \le 15$	$2 \le w \le 12$
Se 75[b]	$10 \le w \le 40$	$14 \le w \le 40$
Ir 192	$20 \le w \le 100$	$20 \le w \le 90$
Co 60	$40 \le w \le 200$	$60 \le w \le 150$
X-ray potentials 1 MV < $U \le 4$ MV	$30 \le w \le 200$	$50 \le w \le 180$
X-ray potentials 4 MV < $U \le 12$ MV	$w \ge 50$	$w \ge 80$
X-ray potentials $U > 12$ MV	$w \ge 80$	$w \ge 100$

[a] For aluminium and titanium, the penetrated material thickness is 10 mm ≤ w ≤ 70 mm for testing class A and 25 mm ≤ w ≤ 55 mm for testing class B.

[b] For aluminium and titanium, the penetrated material thickness is 35 mm ≤ w ≤ 120 mm for testing class A.

By agreement between the contracting parties, the penetrated thickness for Ir 192 may further be reduced to 10 mm for testing class A or testing class B, provided the required image quality as stated in 6.9 is achieved.

By agreement between the contracting parties, the penetrated thickness for Se 75 may further be reduced for testing class A or testing class B, provided the required image quality as stated in 6.9 is achieved.

It is recommended to use higher SNR_N for testing of penetrated thicknesses below 10 mm with Se 75 than required in Tables 3 and 4.

7.3 Detector systems and metal screens

7.3.1 Minimum normalized signal-to-noise ratio (SNR_N)

SNR_N is calculated from $SR_b^{detector}$ or SR_b^{image}:

— SNR_N is determined from $SR_b^{detector}$ if the magnification is ≤ 1,2. This includes the test arrangements shown in Figure 11 and Figure 12 (DWDI).

— SNR_N is determined from SR_b^{image} if the magnification is > 1,2.

For digital radiographic testing, minimum SNR_N values as given in Table 3 and Table 4 or minimum grey values (CR only) shall be achieved (evaluable area). Annex D describes the procedure for measurement of SNR_N and provides a conversion table for users who prefer to use unnormalized measured SNR values instead of SNR_N values.

Equivalent minimum grey values for CR may be used instead of minimum SNR_N values if they are determined by means of the procedure of Annex D for the IP used, the scanner used and its settings and the required SNR_N of Table 3 and Table 4.

The SNR_N value shall be determined preferably beside the weld near the wire or step-hole IQI in the thicker part of the parent material, in a zone of homogeneous wall thickness and constant grey values. Alternatively, the SNR_N can be determined in the weld root if there are homogeneous areas. The grey values in CR (only) shall be measured in the WAE in the weldment near the wire or step-hole IQI.

NOTE 1 If the SNR_N is measured in the weld root, it is typically measured in the region of average root thickness.

As an exception, the determined SNR_N may fall to ≥ 80 % of the values of Table 3 or Table 4 provided the image quality as required in Annex B is achieved and the X-ray voltage is reduced down to 80 % or less of the values as provided in Figure 20 (CP I) or energy-resolving detectors are used for scatter reduction. The exception may be applied due to possible roughness (e.g. corrosion) or geometric distortions of the material, which influences the image noise and the achievable SNR_N.

The SNR_N values shall be increased by a factor of 1,4 from those in Table 3 and Table 4 if the SNR_N measurement is performed adjacent to the weld in the heat-affected zone or parent material, except if the weld cap and root are flush with the parent material. If the SNR_N measurement in the weld provides sufficient values in accordance with Table 3 or Table 4, no measurement in the heat affected zone (HAZ) or parent material is required.

NOTE 2 In film radiography, the optical density is typically between 3,5 and 4 if measured in the HAZ/parent material. This corresponds to an SNR_N about 1,4 times higher than that in the centre of the weld, which typically has an optical density of 2 or higher.

It is recommended, that the SNR_N is measured in the heat-affected zone, because this is typically an area of constant grey level and enables accurate measurements of the SNR_N.

Annex D describes the method for determination of equivalent minimum grey values (for CR only) in lieu of the required SNR_N.

Annex D also provides a conversion table for users who prefer the measurement of unnormalized SNR instead of SNR_N. The minimum unnormalized SNR is calculated from the achieved SR_b, which can be $SR_b^{detector}$ or SR_b^{image}, and the required SNR_N values in Table 3 and Table 4.

The user shall define minimum grey values or SNR_N or SNR values for CR (see Annex D) for acceptance of digital images. The user shall define minimum SNR_N or SNR values (see Annex D) for radiography with DDAs for acceptance of digital images in analogy to the minimum optical density for film radiography. If no special values are defined, the values of Table 3 and Table 4 shall be achieved. The minimum SNR_N values are given in Table 3 and Table 4 for different radiation sources and material thicknesses.

NOTE 3 In analogy to Annex D for CR, minimum grey values × frame number values can also be defined for DDAs as reference for minimum image quality, defined by SNR_N. However, this is only applicable if it is repeated after each DDA image correction (calibration).

NOTE 4 For details of SNR_N measurement, see ISO 16371-1 and ASTM E2446 for CR and ASTM E2597 for DDA and Annex D.

Table 3 — X-ray potentials, U, minimum SNR_N values (CR and DDA) and metal-front screens (screens for CR only) for digital radiography of steel, copper and nickel-based alloys

Radiation source	Penetrated material thickness w mm	Minimum SNR_N[c]		Type and thickness of metal-front screens mm
		Testing class A	Testing class B	
X-ray potentials ≤ 50 kV		100	150	None
X-ray potentials[d] 50 kV < U ≤ 150 kV		70	120	0 to 0,1 (Pb)
X-ray potentials[d] 150 kV < U ≤ 250 kV		70	100	0 to 0,1 (Pb)
X-ray potentials[d] 250 kV < U ≤ 1 000 kV	w ≤ 50	70	100	0 to 0,3 (Pb)
	w > 50	70	70	0 to 0,3 (Pb)
Yb 169[d] Tm 170[d]	w ≤ 5	70	120	0 to 0,1 (Pb)
	w > 5	70	100	0 to 0,1 (Pb)
Ir 192[d], Se 75[d]	w ≤ 50	70	100	0 to 0,3 (Pb)
	w > 50	70	70	0,1 to 0,4 (Pb)
Co 60[a,b] X-ray potentials[a,b] 1MV < U ≤ 5 MV	w ≤ 100	70	100	0,3 to 0,8 (Fe or Cu) + 0,6 to 2 (Pb)
	w > 100	70	70	0,3 to 0,8 (Fe or Cu) + 0,6 to 2 (Pb)
X-ray potentials[a, b] > 5 MV	w ≤ 100	70	100	0,6 to 4 (Fe, Cu or Pb)
	w > 100	70	70	0,6 to 4 (Fe, Cu or Pb)

[a] In the case of multiple screens (Fe+Pb), the steel screen shall be located between the IP and the lead screen.

[b] Instead of Fe or Fe+Pb, copper, tantalum or tungsten screens may be used if the image quality can be proven.

[c] If the SNR_N is measured in the HAZ/parent material, these values shall be multiplied by 1,4. No multiplication is required if the weld cap and root are flush with the parent material or if sufficient SNR_N is measured in the centre of the weld.

[d] Pb screens may be replaced completely or partially by Fe or Cu screens. The equivalent thickness for Fe or Cu is three times the Pb thickness.

Table 4 — X-ray potentials, U, minimum SNR_N values (CR and DDA) and metal-front screens (screens for CR only) for the digital radiography of aluminium and titanium

Radiation source	Minimum SNR_N[b]		Type and thickness of metal-front screens mm
	Testing class A	Testing class B	
X-ray potentials U ≤ 150 kV	70	120	≤ 0,03 (Pb)
X-ray potentials 150 kV < U ≤ 500 kV	70	100	≤ 0,2 (Pb)[a]
Yb 169, Tm 170	70	100	≤ 0,2 (Pb)[a]
Se 75	70	100	≤ 0,3 (Pb)[a]

[a] Instead of 0,2 mm lead, a 0,1 mm screen with an additional filter of 0,1 mm may be used outside of the cassette.

[b] If the SNR_N is measured in the HAZ/parent material, these values shall be multiplied by 1,4. No multiplication is required if the weld cap and root are flush with the parent material or if sufficient SNR_N is measured in the centre of the weld.

7.3.2 Compensation principle II

If the required duplex wire IQI sensitivity of Table B.13 or Table B.14 cannot be achieved by the detector system and exposure conditions used, an increase in single IQI wire visibility or step-hole visibility shall compensate for the exceeded unsharpness values (or exceeded SR_b values, which can be SR_b^{detector} or SR_b^{image}).

For example, if the required values of W16 and D12 (for 5 mm thickness, testing class B, see Table B.3 and Table B.14) are not achieved at the same time for a specific detector set-up, then the values W17 and D11 provide an equivalent detection sensitivity. The compensation shall be limited to a maximum increase of three single wires for three missing resolved duplex wire pairs.

For DDAs, the contrast sensitivity depends on the used frame time, number of frames and tube current (milliampères) for acquisition of the radiographic images for a given distance and tube voltage, so the single wire or step-hole IQI visibility can be increased by increased exposure time and/or tube current setting. This applies also for CR, but with a limitation due to the maximum achievable SNR_N due to the structure noise of the sensitive layer of imaging plates. The maximum achievable SNR_N for DDA radiography is limited by the quality of the image correction procedure (calibration).

The SR_b^{detector} of the DDA is fixed by design and hardware parameters.

If the magnification technique is used, the SR_b^{image} shall be taken from the magnified image with the duplex wire IQI on the object (see 7.7).

7.3.3 Metal screens for IPs and shielding

When using metal-front screens for CR, good contact between the sensitive detector layer and screens is required. This can be achieved either by using vacuum-packed IPs or by applying pressure. Lead screens not in intimate contact with the IPs can contribute to image unsharpness. The intensification obtained by use of lead screens in contact with imaging plates is significantly smaller than in film radiography.

Many IPs are very sensitive to low-energy backscatter and X-ray fluorescence of back-shielding from lead. This effect contributes significantly to edge unsharpness and reduced CNR and should be minimized. It is recommended that steel or copper shielding is used directly behind the IPs. In addition, a steel or copper shielding between a backscatter lead plate and the IP can improve the image quality. Modern cassette and detector designs can consider this effect and can be constructed in a way such that additional steel or copper shielding outside the cassette is not required.

NOTE Due to the protection layer between the lead and the sensitive layer of an IP, the effect of intensification by electrons is considerably reduced and appears at higher energies. Depending on the radiation energy and protection layer design, the effect of intensification amounts to between 20 % and 100 % (compared to no screen) at typical X-ray energies.

The small intensification effect generated by a lead screen in contact with an IP can be compensated by increased exposure time or milliampère minutes if no lead screens are used. Since lead screens in contact with IPs can generate scratches on IPs if not carefully separated for the scan process, lead screens should be used for intermediate filtering of scattered radiation outside of cassettes. No intermediate filtering is recommended for inspecting steel specimen having a thickness < 12 mm.

Table 3 and Table 4 show the recommended screen materials and thicknesses for different radiation sources and CR. Other screen thicknesses and material types may also be agreed between the contracting parties provided the required image quality is achieved. The usage of metal screens is recommended in front of IPs and they can also reduce the influence of scattered radiation when used with DDAs.

7.4 Alignment of beam

The beam of radiation shall be directed to the centre of the area being tested and should be perpendicular to the object surface (except for arrangements of Figures 11, 13 and 14) at that point, except when it can be demonstrated that certain imperfections are best revealed by a different alignment of the beam. In this case, an appropriate alignment of the beam is permitted. Other ways of digital radiographing may be agreed between the contracting parties.

For better detection of lack of side wall fusion, the beam direction should be aligned with the weld preparation angles.

7.5 Reduction of scattered radiation

7.5.1 Metal filters and collimators

In order to reduce the effect of scattered radiation, direct radiation shall be collimated as much as possible to the section under testing.

With Se 75, Ir 192 and Co 60 radiation sources or X-ray sources above 1 MV, or in the case of edge scatter, a sheet of lead may be used as a filter of low-energy scattered radiation between the object and the cassette or DDA. The thickness of this sheet is 0,5 mm to 2 mm in accordance with the penetrated material thickness. Materials other than lead, such as tin, copper or steel, can also be used as a filter. A thin steel or copper screen should be positioned between the lead sheet and the detector.

7.5.2 Interception of backscattered radiation

The presence of backscattered radiation shall be checked for each new CR test arrangement by means of a lead letter B (with a minimum height of 10 mm and a minimum thickness of 1,5 mm) placed immediately behind each cassette. This shall be outside the image of the weld and HAZ in the AoI. If the image of this symbol records as a lighter image on the digital radiograph (negative presentation, i.e. decreased linearized grey value), it shall be rejected. If the symbol is darker (increased linearized grey value) or invisible, the digital radiograph is acceptable and demonstrates good protection against backscattered radiation.

If necessary, the detector shall be shielded from backscattered radiation by a sheet of lead of at least 1 mm thickness or a sheet of tin of at least 1,5 mm thickness placed behind the detector. An additional shielding of steel or copper (about 0,5 mm thickness) shall be applied between the lead shield and the detector to reduce the influence of lead X-ray fluorescence radiation. No lead screens shall be used in contact with the backside of the detector for X-ray potentials above 80 kV.

7.6 Source-to-object distance

The minimum source-to-object distance, f_{min}, depends on the source size or focal spot size, *d,* and on the object-to-detector distance, *b* or *b'* (measured from source side of object to sensitive detector layer). The source size or focal spot size, *d,* shall conform to EN 12543 or EN 12679.

The manufacturer's values may be used if they conform to these documents.

When the source size or focal spot size is defined by two dimensions, the larger one shall be used.

For all exposure geometries, except for those in Figures 2 b), 8 b), 13 b) and 14 b), the distance, *f* or *f'*, shall be chosen so that the ratio of this distance to the source size or focal spot size, *d*, i.e. *f*/*d* or *f'*/*d*, is not less than the values given by Formulae (2) and (3).

For simplification, the following formulae use only *f* and *b*. The formulae apply also for *f'* and *b'* as shown in Figures 11, 13 and 14.

For testing class A use Formula (2):

$$\frac{f}{d} \geq 7{,}5 \cdot b^{2/3} \tag{2}$$

For testing class B use Formula (3):

$$\frac{f}{d} \geq 15 \cdot b^{2/3} \tag{3}$$

where d, f and b are expressed in millimetres.

If the distance, b, is less than 1,2 t, then the dimension, b, in Formulae (2) and (3) and Figure 21 shall be replaced by the nominal thickness, t.

For determination of the source-to-object distance, f_{min} or f'_{min}, the nomogram in Figure 21 can be used. This nomogram is based on Formulae (2) and (3).

For exposure geometries on the basis of Figures 2 b), 8 b), 13 b) and 14 b) (with magnification $v \leq 1{,}2$), the distance, f', shall be chosen so that the ratio of this distance to the source size, d, i.e. f'/d, is not below the values given by Formula (4) and Formula (5) if $b/t > 1{,}2$.

For testing class A use Formula (4):

$$\frac{f'}{d} \geq 7{,}5 \cdot \frac{b}{\sqrt[3]{t}} \tag{4}$$

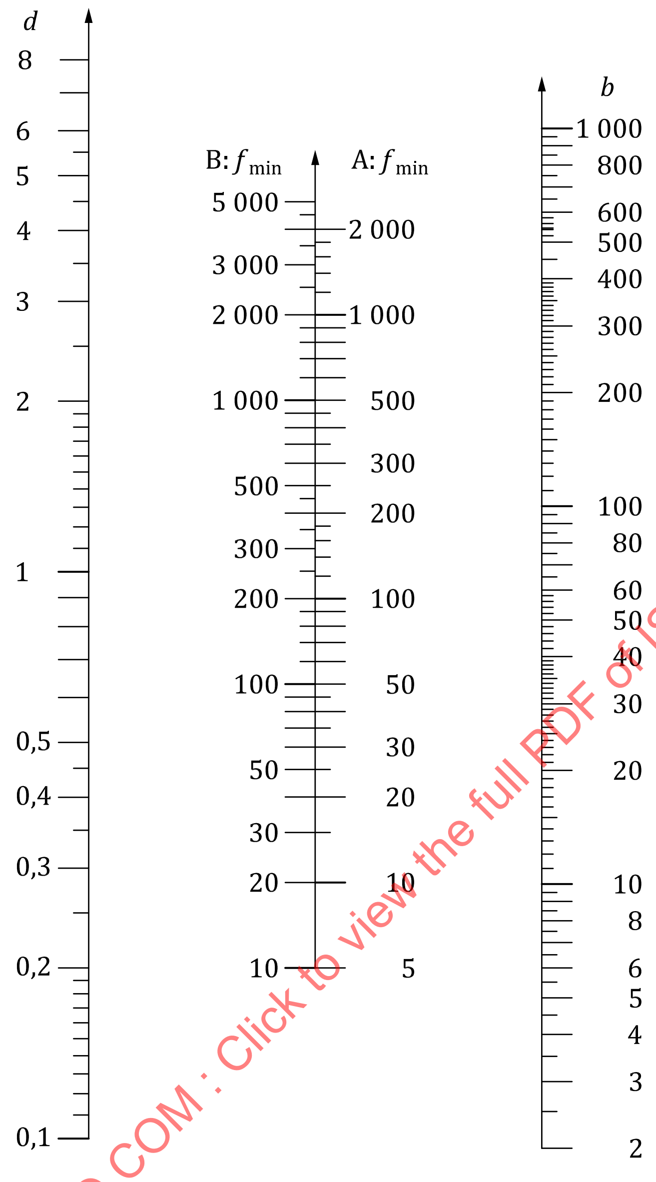
For testing class B use Formula (5):

$$\frac{f'}{d} \geq 15 \cdot \frac{b}{\sqrt[3]{t}} \tag{5}$$

where d, f, t and b are expressed in millimetres.

For testing class A, if detection of planar imperfections is a requirement, the minimum source-to-object distance, f_{min} or f'_{min}, shall be the same as for testing class B in order to reduce the geometric unsharpness by a factor of two.

In critical technical applications of crack-sensitive materials, more sensitive radiographic techniques than testing class B shall be used.



Key

f_{min} minimum source-to-object distance, in mm

d source size, in mm

b object-to-film distance, in mm

A testing class A

B testing class B

Figure 21 — Nomogram for the determination of minimum source-to-object distance, f_{min}, in relation to object-to-detector distance, *b*, and the source size, *d*, except for the test arrangements as shown in Figures 2 b), 8 b), 13 b) and 14 b)

If f_{min} is too small to expose the complete detector area, an increased SDD is recommended. In this case, the SDD is calculated from the opening angle 2β of the X-ray tube window or the collimator of gamma sources and the detector size (d_d) by Formula (6).

$$SDD \geq 0{,}5 \cdot \frac{d_d}{\tan(\beta)} \tag{6}$$

The typical opening angle of X-ray tube windows for NDT is 2β = 40° (±20°). Formula (6) is simplified for these tubes to Formula (7):

$$SDD \geq 1{,}4 \cdot d_d \tag{7}$$

Table B.13 and Table B.14 provide the maximum values for SR_b^{image} with the duplex wire IQI in the image or the $SR_b^{detector}$ value of a reference exposure (if v < 1,2) for sufficient image quality for testing class A and testing class B, respectively.

The calculation of b for the geometry of Figures 2 b), 8 b), 13 b) and 14 b) depends on the distance, b_{ed}, of the planar detector at the edge for Figures 8 b), 13 b) and 14 b) or at the centre for Figure 2 b) of the AoI, the gap between sensitive detector layer and closest pipe surface (b_{gap}) and the wall thickness at the edge of the AoI. The value b shall be calculated as shown in Figure 22 based on Formula (8) to Formula (10) or from a scaled drawing.

Testing class A:

$$b = b_{ed} + 1{,}2 \cdot t + b_{gap} \tag{8}$$

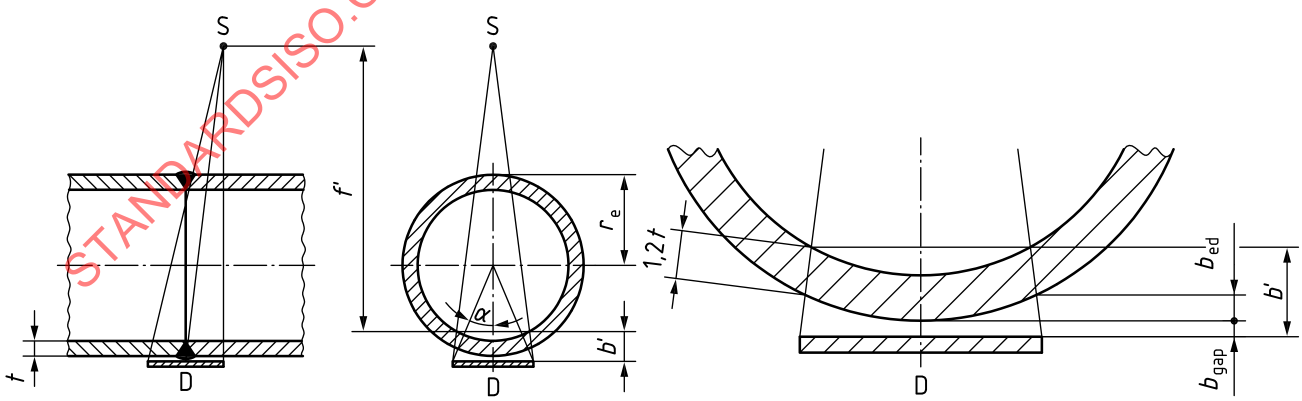
Testing class B:

$$b = b_{ed} + 1{,}1 \cdot t + b_{gap} \tag{9}$$

with

$$b_{ed} = (1 - cos(\alpha)) \cdot r_e \tag{10}$$

where r_e, b_{ed} and b_{gap} are expressed in millimetres.



a) Arrangement for testing of curved objects and DWSI evaluation for rigid detectors

b) Magnified presentation of the curved object to evaluate and the detector

NOTE The value b_{ed} is measured in Figure 2b) in the centre of the WAE.

Figure 22 — Scheme for the determination of *b* for DWSI exposures with rigid cassettes or rigid DDAs [Figures 13 b) and 14 b)] shown for Figure 13 b) and testing class A

The calculation of b for application of DDAs for panoramic testing in accordance with Figure 5 b) (central projection) depends on the distance of the planar detector at the edge (b_{ed}) of the AoI, the gap between detector and outer pipe surface (b_{gap}) and the wall thickness at the edge of the AoI. The value b shall be calculated in accordance with Formula (11) and Formula (12) or from a scaled drawing.

Testing class A and B:

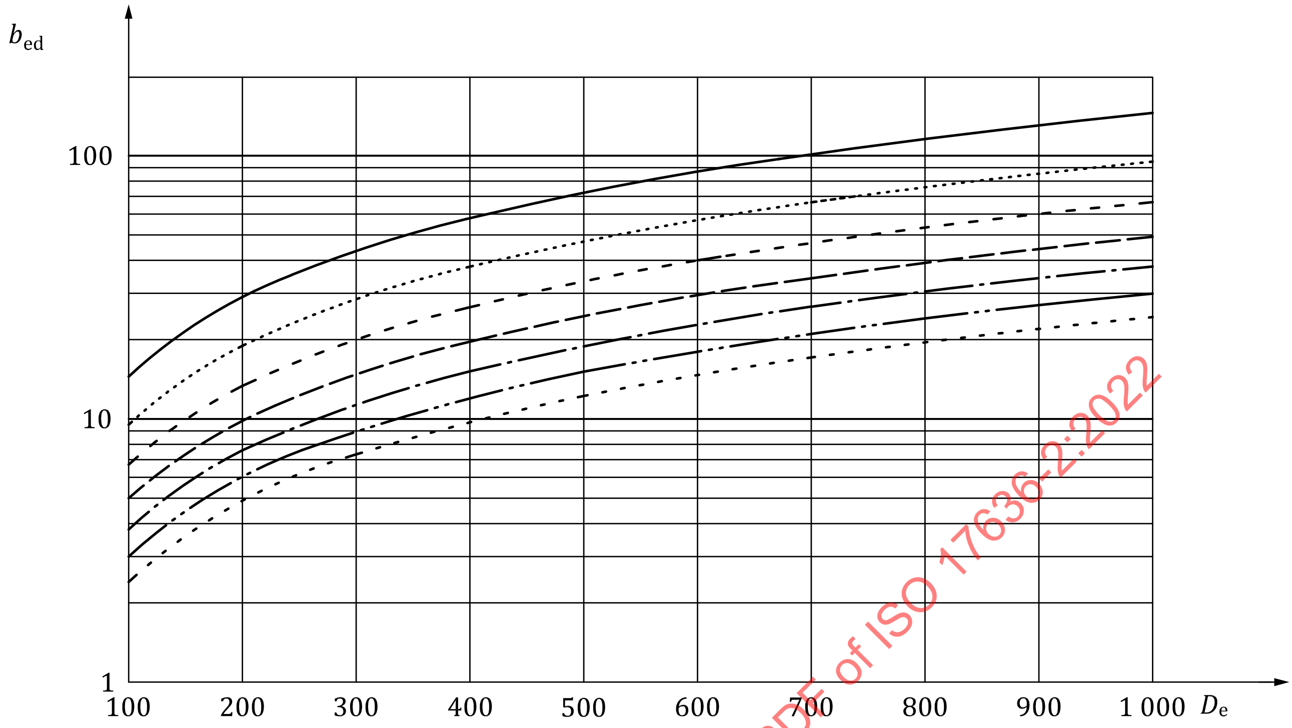
$$b = b_{ed} + t + b_{gap} \tag{11}$$

with

$$b = \frac{1}{\cos} \cdot \left(r_e + b_{gap}\right) - r_i \tag{12}$$

where b, b_{ed}, b_{gap}, r_e, r_i and t are expressed in millimetres.

Since Formula (10) is difficult to handle for practitioners, Figure 23 can be used to determine b_{ed} depending on the number of exposures (N) and the external diameter (D_e) of the pipe to test, in accordance with Figures 2 b), 8 b), 13 b) and 14 b). See Annex A for the determination of the required number of exposures (N).



Key

————	$N = 4$
············	$N = 5$
— — —	$N = 6$
—— —— ——	$N = 7$
—— · ——	$N = 8$
—— · · ——	$N = 9$
· · · · · · ·	$N = 10$
b_{ed}	distance of the planar detector at the edge of the pipe for Figures 8 b), 13 b), 14 b) and 22 b) or in the centre for Figure 2 b), in mm
D_e	external diameter of the pipe, in mm

Figure 23 — Graph for determination of b_{ed} depending on the required number of exposures (N) and the external diameter (D_e) of the pipe to test with the DWSI technique

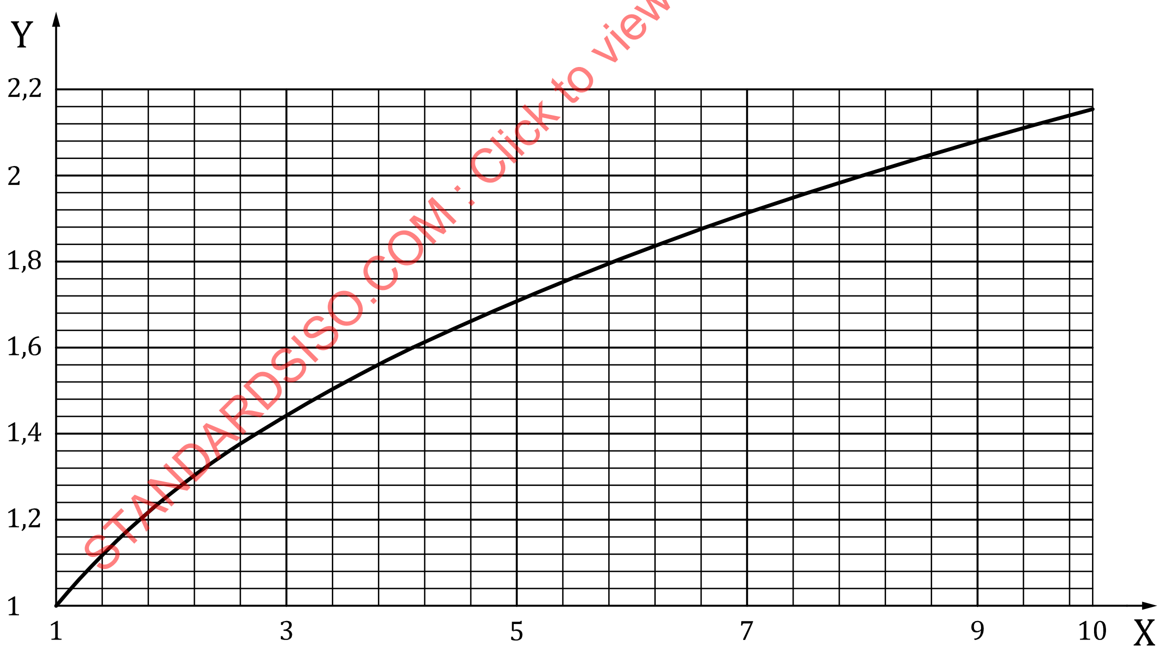
If $(b/t) > 1{,}2$, then the f_{min} for $b = t$, as determined from Figure 21, shall be increased by the increase factor, C_i, which is calculated by Formula (13) to conform to the unsharpness requirements for curved detectors in contact with the object depending on material thickness t [see also Formula (4) and Formula (5)]. Consequently, the minimum source to object distance f_{min}^{*} for planar detectors [see Figures 2 b), 5 b), 8 b), 13 b) and 14 b)] is calculated by Formula (13).

$$f_{min}^{*} = C_i \cdot f_{min}\,(b = t) = \left(\frac{b}{t}\right)^{\frac{1}{3}} \cdot f_{min}\,(b = t) \tag{13}$$

where f_{min}, f_{min}^{*}, b and t are expressed in millimetres.

The determination of f^*_{min} shall be performed as follows:

- Determine the value of b_{gap} from the requirements of the mechanical set-up, considering weld cap thickness, detector casing thickness or cassette thickness and location of the sensitive detector layer.
- Determine, for the planar detectors or planar cassettes, b_{ed} as function of the detector size and the number of required exposures:
  - Consider the required overlap in the images, which reduces the effective detector size.
  - Determine b_{ed} for the exposure geometries as given in Figures 2 b), 8 b), 13 b) or 14 b) using Formula (10), or determine b using Formula (12) for the exposure geometry given in Figure 5 b).
  - Alternatively, b_{ed} can be estimated from Figure 23 for the exposure geometries given in Figures 8 b), 13 b) or 14 b).
  - Alternatively, b_{ed} can be determined from scaled drawings.
  - b_{ed} corresponds to the increase in b due to the curvature of the object, if the exposure geometry is based on Figure 2 b).
- Calculate b considering t, b_{gap} and b_{ed} [see Formulae (8), (9) or (11)].
- Use Figure 21 or Formula (2) or Formula (3) (depending on testing class) to calculate f_{min}.
- Use Figure 24 to determine C_i from the ratio b/t (if $b/t > 1,2$) and calculate f^*_{min} using Formula (13).
  - Alternatively, Formula (4) or (5) can be used depending on the testing class.



Key

X ratio b/t

Y factor for increase, C_i

Figure 24 — Factor for increase of f_{min} as determined from Figure 21 if $b/t > 1,2$, as considered in Formulae (4), (5) and (13)

If the detector unsharpness is close to the permitted geometric unsharpness, the IQI visibility as defined in Tables B.1 to Table B.12 is achieved only by increased f_{min} or f^*_{min} (see Annex F) and/or higher SNR (CP II).

When using the elliptical technique specified in 7.1.6 (Figure 11) or the perpendicular technique specified in 7.1.7 (Figure 12), *b* or *b’* shall be replaced by the external diameter, D_e, of the pipe in Formula (2) and Formula (3) and in Figure 21.

When the source is outside the object and the detector is on the other side [the technique described in 7.1.8 (Figures 13 to 16) as double-wall penetration and single-image evaluation], the minimum source-to-object distance is determined only by the wall thickness (i.e. not by the pipe diameter).

Where possible, it is preferable to avoid usage of a double-wall technique (see 7.1.8, Figures 13 to 16) by placing the radiation source inside the object to be radiographed, to achieve a more suitable direction of penetration [see 7.1.4 and 7.1.5 (Figures 5 to 10)]. The reduction in minimum source-to-object distance should not be greater than 20 % provided that IQI requirements are met. When the source is located centrally inside the object and the detector outside (technique shown in 7.1.4, Figure 5) and provided that the IQI requirements are met, this percentage may be increased. However, the reduction in minimum source-to-object distance shall not be greater than 50 %. A further reduction may be agreed by the contracting parties provided that the IQI requirements are met.

For the central projection (Figure 5), an increased geometric unsharpness may be accepted, permitting one duplex wire pair value less than required in Table B.13 or B.14, provided that the IQI requirements of Tables B.1 to B.4 are met. This permits either the reduction of *f* as described (max 50 %) or the application of a detector with one basic spatial resolution value less than required by Table B.13 or B.14.

7.7 Geometric magnification technique

The usage of the magnification technique, as described in this subclause, is recommended if an exposure geometry is applied with $v > 1{,}2$.

An obstacle to the application of CR and DDA systems for weld radiography is the large (≥50 µm) pixel size of most DDAs and most IP-scanner systems compared with the small grain size in film (films have a very low inherent unsharpness). This difficulty can be circumvented by taking advantage of the property of DDAs to increase the SNR_N (CP II) in the image and/or the geometric magnification, if needed.

NOTE Geometric magnification is different from digital magnification (zoom) of displayed images. Only geometric magnification provides a reduction in image unsharpness.

If the required IQI sensitivity (proven by single wire or step-hole IQI) and SR_b^{image} (proven by duplex wire IQI, see also Annex C) do not meet the requirements given in the appropriate Tables B.1 to B.14, one option is to increase the image SNR (see 7.3.2, CP II).

Another option is the application of the geometric magnification technique with increased distance between the IP or DDA and the object combined with usage of an X-ray tube with a small focal spot or a gamma-ray source with small source size.

Finally, if the required IQI values are still not visible after employing both methods, the CR system or the DDA shall not be used for that testing.

The correct selection of magnification shall be proven by usage of the duplex wire IQI on the object in all production radiographs. The duplex wire IQI shall be positioned on the side of the object nearer to the detector, if $2 \cdot SR_b^{detector} < d$. Otherwise, the duplex wire IQI shall be positioned on the source side of the object. It is recommended that duplex wire IQIs are positioned on both sides of the object for selection of the magnification value, but only one needs to be seen in the final production radiographs after selection of the correct magnification factor and source size.

IQIs can disturb digital images if automated defect recognition is applied. If no IQIs are used for a series of production radiographs, the image quality shall be proven periodically by reference images with wire IQIs or step-hole IQIs and duplex IQIs.

The image unsharpness, u_{Im}, can be estimated from the magnification, v, the geometric unsharpness, u_G, and the $SR_b^{detector}$ using Formula (14) and Formula (15).

$$u_{Im} = \frac{1}{v}\sqrt{(u_G)^2 + \left(2 \cdot SR_b^{detector}\right)^2} \quad (14)$$

where

$$u_G = \left(\frac{SDD}{f} - 1\right) d = (v-1)\ d \quad (15)$$

The magnification shall be increased and/or the focal spot size shall be decreased to reduce the image unsharpness so that it is less than or equal to the appropriate value specified in Table B.13 or Table B.14. This shall be proven by a duplex wire IQI, positioned on the object, as described earlier in this subclause.

Magnification can be used to minimize the image unsharpness. The optimum magnification, v_o, which provides best sharpness for a given source size, d, and $SR_b^{detector}$ is given by Formula (16).

$$v_o = 1 + \left(\frac{2 \cdot SR_b^{detector}}{d}\right)^2 \quad (16)$$

The magnification factor is typically different for the source and the detector sides of the object. Therefore, the magnification, v, should be selected for the object centre. The variation of the magnification value between the source side and the detector side should be within ± 25 %. Smaller magnification values may be chosen if the CP II, as described in 7.3.2, is used.

7.8 Maximum area for a single exposure

The number of digital radiographs for complete testing and evaluation of flat welds (see Figures 1, 15, 17, 18 and 19) and of curved welds with the radiation source arranged off-centre (see Figures 2 to 4, 8 to 10 and 13 to 16) should be specified in accordance with technical requirements.

The ratio of the penetrated thickness at the outer edge of an evaluated area of uniform thickness to the thickness at the centre beam shall not be more than 1,1 for testing class B and 1,2 for testing class A as the area to be evaluated per exposure (WAE).

The SNR_N values resulting from any variation of penetrated thickness should not be lower than those indicated in Table 3 or Table 4. This is the evaluable area. Alternatively, grey values may be used instead of SNR_N values for CR, as shown in Annex D.

The size of the weld area to be tested and evaluated includes the weld and the heat-affected zones (WAE). Each single exposure shall comprise the WAE and all required IQIs, marks and identification letters in the AoI.

The determination of the numbers of radiographs that provide an acceptable testing of a circumferential butt weld shall be carried out as described in Annex A.

This subclause applies for manual testing and automated testing in start/stop mode. It does not apply for automated testing in continuous mode.

7.9 Processing

7.9.1 Scan and read-out of images

Detectors or scanners shall be used in accordance with the conditions recommended by the detector or scanner manufacturer to obtain the selected image quality. The digital radiographs should be free from artefacts due to processing and handling or other causes which interfere with interpretation.

7.9.2 Correction of acquired DDA images

If using DDAs, the detector image correction procedure (calibration) as recommended by the manufacturer shall be applied. The detector images shall be corrected with a background image (without radiation) and at least with one gain image (X-rays on and homogeneously exposed). Multi-gain image correction will increase the achievable SNR_N and linearity but takes more time. To minimize the noise due to image correction, all correction images (gain images and background image) shall be taken with an exposure dose (milliampere minutes or giga becquerel minutes) at least twice as large as the dose used for the inspection radiographs. Corrected images should be treated as original images for quality assurance if the procedure has been documented. The image correction shall be performed periodically and if the exposure conditions change significantly.

It is recommended that the DDA image correction is repeated if different frame times are selected separately. The number of frames of the correction images should be at least two times higher than used for the production radiographs.

7.9.3 Bad pixel interpolation

If using DDAs, the detector shall be mapped to determine the bad pixel map in accordance with the manufacturer guideline. This bad pixel map shall be documented. Bad pixel interpolation is acceptable and an essential procedure for radiography with DDAs. It is recommended that only DDAs having no cluster kernel pixels (CKPs) in the AoI be used.

DDAs without CKPs and CR which have a basic spatial resolution (SR_b^{detector}) of less than or equal to that required in Table B.13 or Table B.14 shall be applied for inspection. If the magnification technique is used then the SR_b^{image} shall be determined from the measured image, as described in Annex C, but with the duplex IQI directly on the test object (see 7.7). This SR_b^{image} value shall be less than or equal to the values given in Table B.13 or Table B.14. If the detector or image SR_b is higher than specified in Table B.13 or Table B.14, the CP II, as described in 7.2.3, may then be applied.

If using DDAs or imaging plates for inspection of flaw sizes of the order of the SR_b^{image}, the required SNR_N shall be increased significantly. The inspection shall be performed on the basis of an agreement between the contracting parties. The specified increase in SNR_N can compensate for locally increased unsharpness due to bad pixel interpolation.

The evaluation for bad pixels shall be performed periodically.

NOTE By analogy to the CP II, the increased SNR_N also compensates for the local unsharpness caused by bad pixel interpolation. This is considered as CP III.

7.9.4 Image processing

7.9.4.1 The digital data of the radiographic detector shall be evaluated with linearized grey value representation, which is directly proportional to the radiation dose for determination of SNR, image or detector SR_b and SNR_N. For optimal image display, contrast and brightness should be interactively adjustable. Optional filter functions, profile plots and an SNR, SNR_N tool shall be integrated into the software for image display and evaluation. For critical image analysis, the operator shall interpret the image with a zoom factor between 1:1 (meaning one pixel of the digital radiograph is presented by one monitor pixel) and 1:2 (meaning one pixel of the digital radiograph is presented by four monitor pixels).

7.9.4.2 Further means of image processing applied on the stored raw data (e.g. high-pass filtering for image display) shall be documented, be repeatable and be agreed between the contracting parties.

7.9.4.3 If further image processing (e.g. high-pass filtering) is used when evaluating single wire or step-hole IQI values, then the same filter parameters shall be used for both weld evaluation and IQI value determination.

7.10 Monitor viewing conditions and storage of digital radiographs

The digital radiographs shall be evaluated in a darkened room. The monitor set-up shall be verified with a suitable test image.

The display for image evaluation shall fulfil the minimum requirements a) to d):

a) minimal brightness of 250 cd/m^2;

b) display of at least 256 shades of grey;

c) minimum displayable light intensity ratio of 1:250;

d) display of at least 1 million pixels of a pixel size < 0,3 mm.

The original images shall be stored at the full resolution as delivered by the detector system. Only image processing connected with the detector image correction [e.g. offset (background) correction, gain correction for detector equalization and bad pixel correction, see ASTM E2597] to provide artefact-free detector images shall be applied before storage of these raw data.

The data storage shall be redundant and supported by suitable back-up strategies to ensure long-time storage using lossless data compression only.

8 Test report

For each exposure or set of exposures, a test report shall be made giving information on the digital radiographic technique used and on any other special circumstances which allow a better understanding of the results.

The test report shall include at least the following information:

a) a reference to this document, i.e. ISO 17636-2:2022;

b) name of the testing body;

c) test object;

d) material;

e) production stage, e.g. heat treatment, machining;

f) type of weld; optional photograph;

g) material thickness, *t*, and total weld thickness;

h) welding process;

i) testing specification, if different or additional to this document;

j) requirements for acceptance (e.g. ISO 10675-1 or ISO 10675-2);

k) radiographic technique in accordance with 7.1 (Figures 1 to 19) and testing class, required and achieved image quality values (IQI values) in accordance with this document (Annex B);

l) magnification;

m) system of marking used;

n) detector position;

o) type of radiation source and size of focal spot and identification of equipment used;

p) detector, screens and filters and detector basic spatial resolution;

q) achieved and required SNR_N for DDAs or achieved and required grey values and/or SNR_N for CR;

r) for CR: scanner type and set-up parameters, such as pixel size, scan speed, gain, laser intensity and laser spot size, if available;

s) for DDAs: type and parameters, such as gain, frame time, frame number, pixel size and image correction procedure (calibration), if available;

t) tube voltage used and current or source type and activity;

u) time of exposure and source-to-detector distance;

v) type and position (detector or source side) of IQIs;

w) results of evaluation, including data on software used and IQI readings;

x) image-processing parameters used, for example of the digital filters;

y) any deviation from this document, by special agreement;

z) name, certification and signature of the responsible person(s), e.g. RT operator or RT image interpreter;

aa) any unusual features observed;

bb) date(s) of exposure and test report.

Annex A
(normative)

Number of exposures for acceptable testing of a circumferential butt weld

The minimum number of exposures required is presented in Figures A.1 to A.4, which are valid for pipes except those tested using double-wall double-image techniques according to 7.1.6 and 7.1.7 (Figure 11 and Figure 12).

When the deviation of the wall thickness, $\Delta t/t$, of the joint to be tested using a single exposure does not exceed 20 % (testing class A), Figure A.3 and Figure A.4 are used. This technique is recommended only when the possibility of having transverse cracks is small or the weld is tested for such imperfections by other non-destructive test methods.

When $\Delta t/t$ is less than or equal to 10 % (testing class B), Figure A.1 and Figure A.2 are used. In this case, it is likely that transverse cracks are also detected.

If the object is tested for single transverse cracks then the required minimum number of digital radiographs shall be higher than the values in Figures A.1 to A.4.

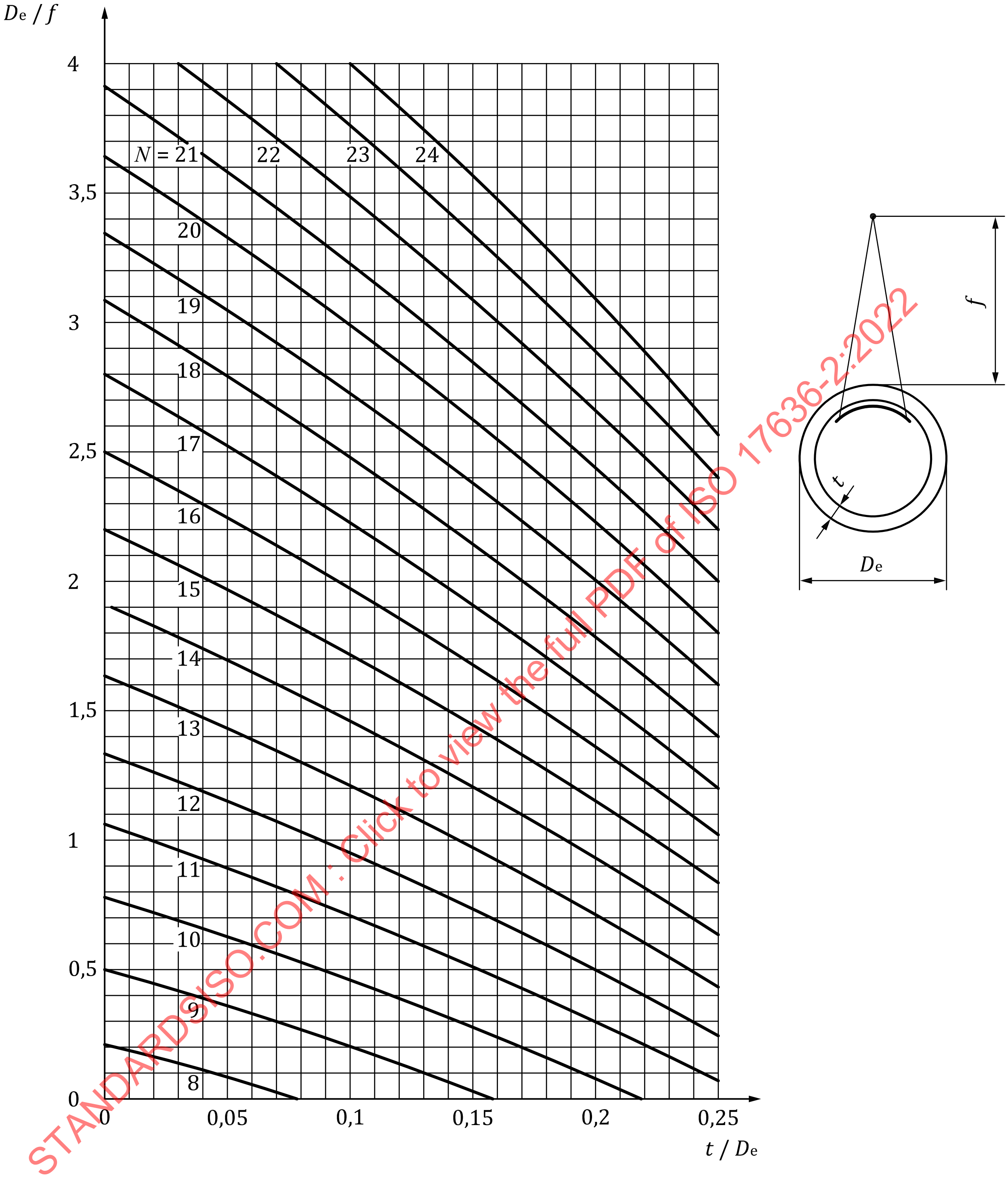
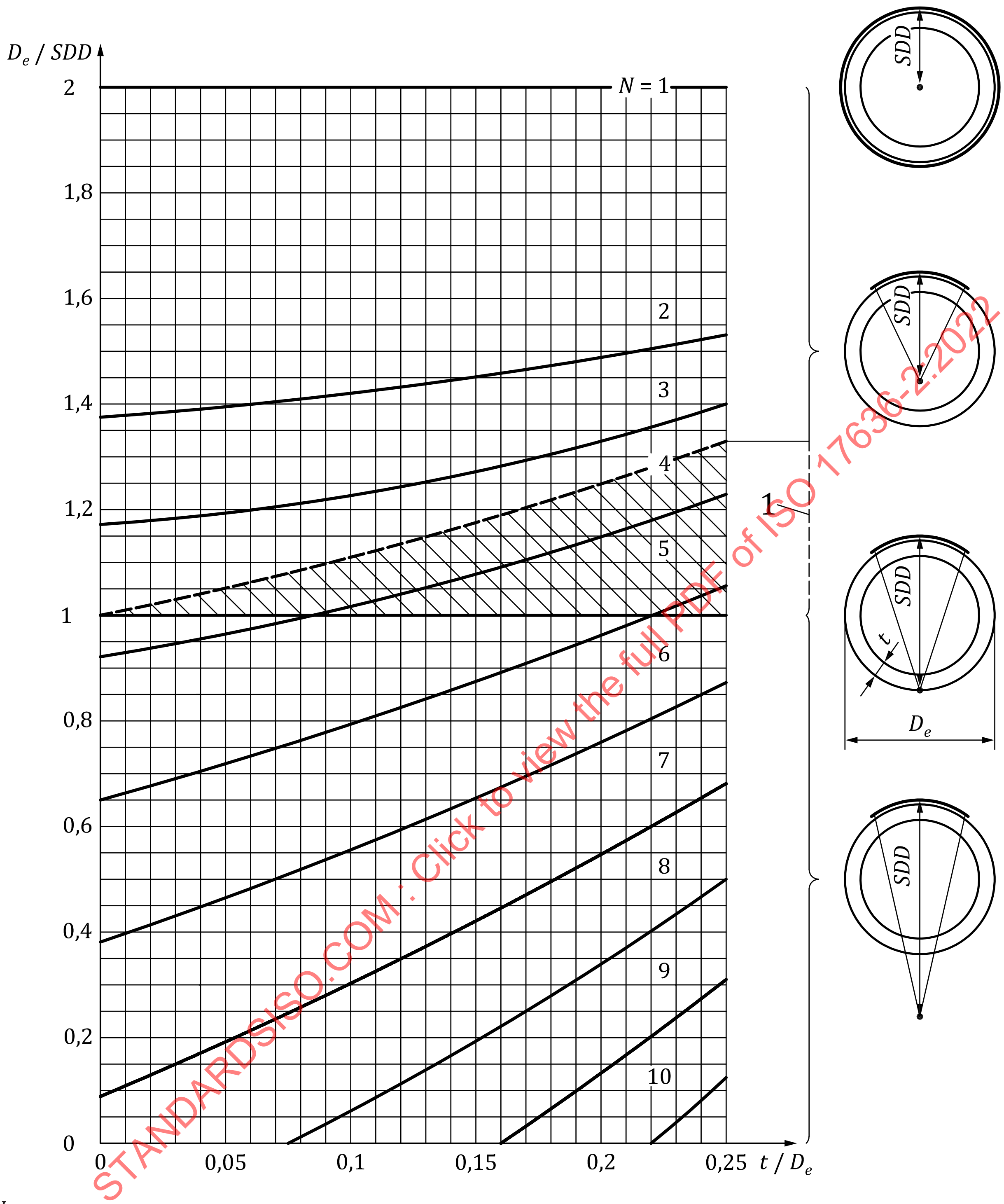


Figure A.1 — Minimum number of exposures, *N*, for single-wall penetration with source outside considering a maximum permissible increase in penetrated thickness of $\Delta t/t$ = 10 % (testing class B) as a function of ratios t/D_e and D_e/f, due to inclined penetration in the evaluable areas of sufficient SNR_N



Key

1 inside pipe wall (not accessible)

Figure A.2 — Minimum number of exposures, *N*, for off-centre penetration with source inside and for double-wall penetration considering a maximum permissible increase in penetrated thickness Δ*t*/*t* = 10 % (testing class B) as a function of ratios t/D_e and D_e/SDD, due to inclined penetration in the evaluable areas of sufficient SNR_N

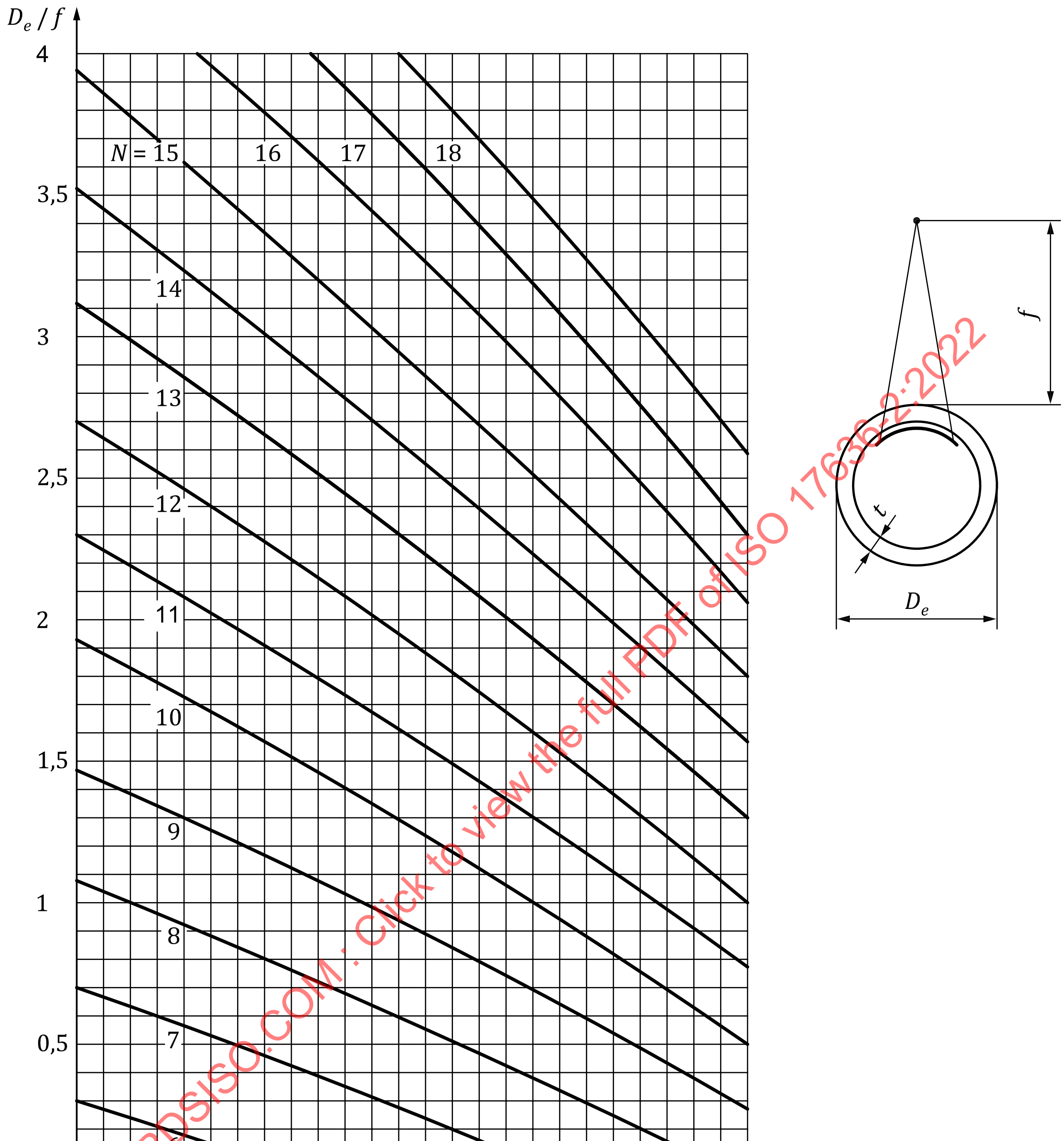
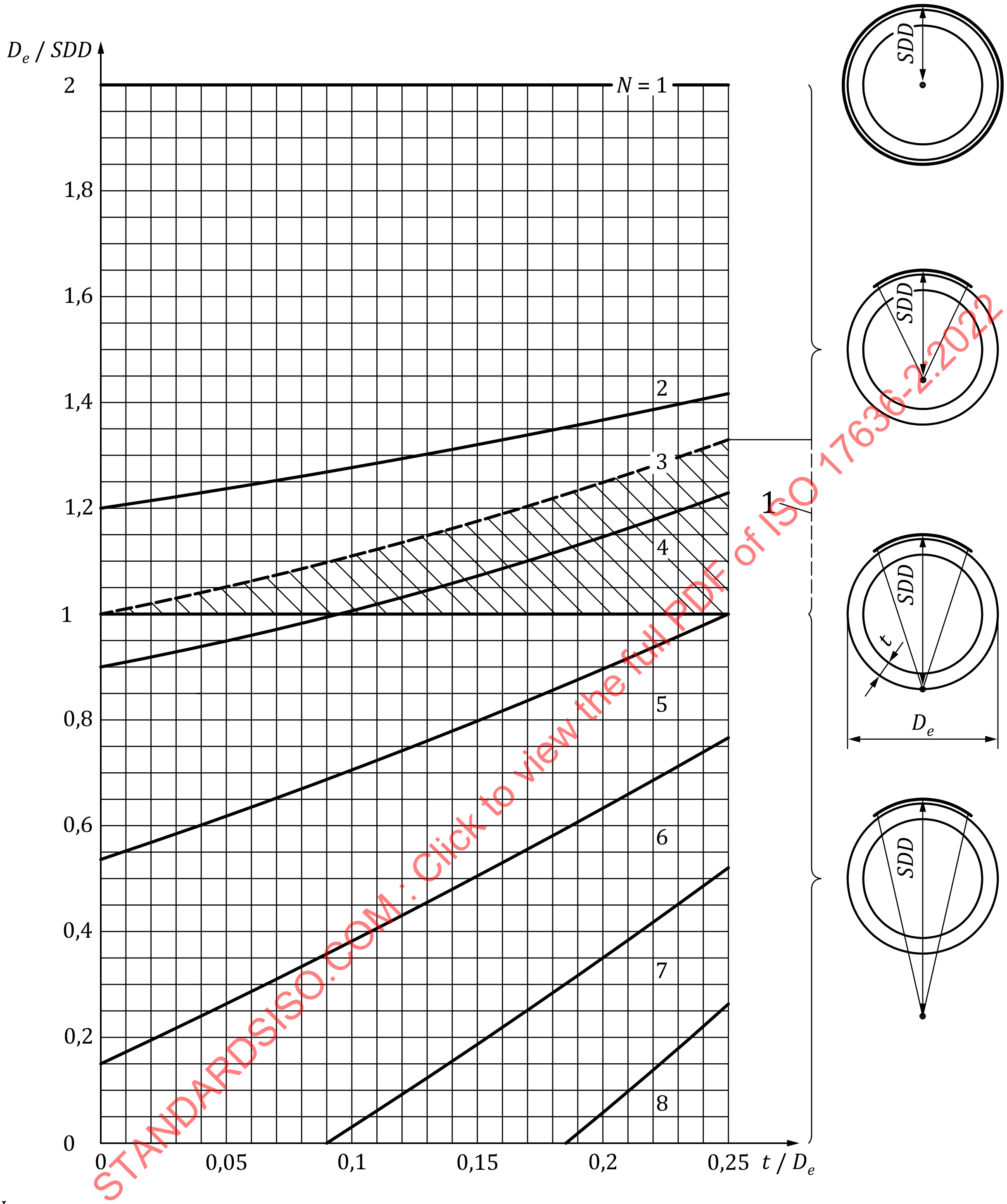


Figure A.3 — Minimum number of exposures, N, for single-wall penetration with source outside considering a maximum permissible increase in penetrated thickness $\Delta t/t$ = 20 % (testing class A) as a function of ratios t/D_e and D_e/f, due to inclined penetration in the evaluable areas of sufficient SNR_N



Key

1 inside pipe wall (not accessible)

Figure A.4 — Minimum number of exposures, N, for off-centre penetration with source inside and for double-wall penetration considering a maximum permissible increase in penetrated thickness $\Delta t/t$ = 20 % (testing class A) as a function of ratios t/D_e and D_e/SDD, due to inclined penetration in the evaluable areas of sufficient SNR_N

Annex B
(normative)

Minimum image quality values

B.1 General

The minimum image quality indicator values (IQI values) of Tables B.1 to B.14 shall be achieved or exceeded for acceptance of testing class A or testing class B testing quality.

B.2 Single-wall technique — IQI on source side

Table B.1 — Wire IQI

Minimum IQI values for testing class A				
Nominal thickness *t* mm				**IQI value**[a]
		to	1,2	W 18
above	1,2	to	2,0	W 17
above	2,0	to	3,5	W 16
above	3,5	to	5,0	W 15
above	5,0	to	7	W 14
above	7	to	10	W 13
above	10	to	15	W 12
above	15	to	25	W 11
above	25	to	32	W 10
above	32	to	40	W 9
above	40	to	55	W 8
above	55	to	85	W 7
above	85	to	150	W 6
above	150	to	250	W 5
above	250			W 4

[a] For exceptions when using gamma ray sources, see 6.9.

Table B.2 — Step and hole IQI

Minimum IQI values for testing class A				
Nominal thickness *t* mm				**IQI value**[a]
		to	2,0	H 3
above	2,0	to	3,5	H 4
above	3,5	to	6	H 5
above	6	to	10	H 6

a For exceptions when using gamma ray sources, see 6.9.

Table B.2 *(continued)*

Minimum IQI values for testing class A				
Nominal thickness *t* mm				IQI value[a]
above	10	to	15	H 7
above	15	to	24	H 8
above	24	to	30	H 9
above	30	to	40	H 10
above	40	to	60	H 11
above	60	to	100	H 12
above	100	to	150	H 13
above	150	to	200	H 14
above	200	to	250	H 15
above	250	to	320	H 16
above	320	to	400	H 17
above	400			H 18

a For exceptions when using gamma ray sources, see 6.9.

Table B.3 — Wire IQI

Minimum IQI values for testing class B				
Nominal thickness *t* mm				IQI value[a]
		to	1,5	W 19
above	1,5	to	2,5	W 18
above	2,5	to	4	W 17
above	4	to	6	W 16
above	6	to	8	W 15
above	8	to	12	W 14
above	12	to	20	W 13
above	20	to	30	W 12
above	30	to	35	W 11
above	35	to	45	W 10
above	45	to	65	W 9
above	65	to	120	W 8
above	120	to	200	W 7
above	200	to	350	W 6
above	350			W 5

[a] For exceptions when using gamma ray sources, see 6.9.

Table B.4 — Step and hole IQI

Minimum IQI values for testing class B				
Nominal thickness *t* mm				IQI value[a]
		to	2,5	H 2
above	2,5	to	4	H 3
above	4	to	8	H 4
above	8	to	12	H 5
above	12	to	20	H 6
above	20	to	30	H 7
above	30	to	40	H 8
above	40	to	60	H 9
above	60	to	80	H 10
above	80	to	100	H 11
above	100	to	150	H 12
above	150	to	200	H 13
above	200	to	250	H 14
[a] For exceptions when using gamma ray sources, see 6.9.				

B.3 Double-wall technique — Double-image evaluation (DWDI): IQI on source side

Table B.5 — Wire IQI

Minimum IQI values for testing class A				
Penetrated thickness *w* mm				IQI value[a]
		to	1,2	W 18
above	1,2	to	2	W 17
above	2	to	3,5	W 16
above	3,5	to	5	W 15
above	5	to	7	W 14
above	7	to	12	W 13
above	12	to	18	W 12
above	18	to	30	W 11
above	30	to	40	W 10
above	40	to	50	W 9
above	50	to	60	W 8
above	60	to	85	W 7
above	85	to	120	W 6
above	120	to	220	W 5
above	220	to	380	W 4
above	380			W 3
[a] For exceptions when using gamma ray sources, see 6.9.				

Table B.6 — Step and hole IQI

Minimum IQI values for testing class A				
Penetrated thickness *w* mm				**IQI value**[a]
		to	1	H 3
above	1	to	2	H 4
above	2	to	3,5	H 5
above	3,5	to	5,5	H 6
above	5,5	to	10	H 7
above	10	to	19	H 8
above	19	to	35	H 9

[a] For exceptions when using gamma ray sources, see 6.9.

Table B.7 — Wire IQI

Minimum IQI values for testing class B				
Penetrated thickness *w* mm				**IQI value**[a]
		to	1,5	W 19
above	1,5	to	2,5	W 18
above	2,5	to	4	W 17
above	4	to	6	W 16
above	6	to	8	W 15
above	8	to	15	W 14
above	15	to	25	W 13
above	25	to	38	W 12
above	38	to	45	W 11
above	45	to	55	W 10
above	55	to	70	W 9
above	70	to	100	W 8
above	100	to	170	W 7
above	170	to	250	W 6
above	250			W 5

[a] For exceptions when using gamma ray sources, see 6.9

Table B.8 — Step and hole IQI

Minimum IQI values for testing class B				
Penetrated thickness *w* mm				**IQI value**[a]
		to	1	H 2
above	1	to	2,5	H 3
above	2,5	to	4	H 4
above	4	to	6	H 5

[a] For exceptions when using gamma ray sources, see 6.9

Table B.8 *(continued)*

Minimum IQI values for testing class B				
Penetrated thickness *w* mm				IQI value[a]
above	6	to	11	H 6
above	11	to	20	H 7
above	20	to	35	H 8
[a] For exceptions when using gamma ray sources, see 6.9				

B.4 Double-wall technique — Single-image (DWSI) or double-image evaluation (DWDI): IQI on detector side

Table B.9 — Wire IQI

Minimum IQI values for testing class A				
Penetrated thickness *w* mm				IQI value[a]
		to	1,2	W 18
above	1,2	to	2	W 17
above	2	to	3,5	W 16
above	3,5	to	5	W 15
above	5	to	10	W 14
above	10	to	15	W 13
above	15	to	22	W 12
above	22	to	38	W 11
above	38	to	48	W 10
above	48	to	60	W 9
above	60	to	85	W 8
above	85	to	125	W 7
above	125	to	225	W 6
above	225	to	375	W 5
above	375			W 4
[a] For exceptions when using gamma ray sources, see 6.9				

Table B.10 — Step and hole IQI

Minimum IQI values for testing class A				
Penetrated thickness *w* mm				IQI value[a]
		to	2	H 3
above	2	to	5	H 4
above	5	to	9	H 5
above	9	to	14	H 6
above	14	to	22	H 7
[a] For exceptions when using gamma ray sources, see 6.9				

Table B.10 *(continued)*

Minimum IQI values for testing class A				
Penetrated thickness *w* mm				IQI value[a]
above	22	to	36	H 8
above	36	to	50	H 9
above	50	to	80	H 10

[a] For exceptions when using gamma ray sources, see 6.9

Table B.11 — Wire IQI

Minimum IQI values for testing class B				
Penetrated thickness *w* mm				IQI value[a]
		to	1,5	W 19
above	1,5	to	2,5	W 18
above	2,5	to	4	W 17
above	4	to	6	W 16
above	6	to	12	W 15
above	12	to	18	W 14
above	18	to	30	W 13
above	30	to	45	W 12
above	45	to	55	W 11
above	55	to	70	W 10
above	70	to	100	W 9
above	100	to	180	W 8
above	180	to	300	W 7
above	300			W 6

[a] For exceptions when using gamma ray sources, see 6.9

Table B.12 — Step and hole IQI

Minimum IQI values for testing class B				
Penetrated thickness *w* mm				IQI value[a]
		to	2,5	H 2
above	2,5	to	5,5	H 3
above	5,5	to	9,5	H 4
above	9,5	to	15	H 5
above	15	to	24	H 6
above	24	to	40	H 7
above	40	to	60	H 8
above	60	to	80	H 9

[a] For exceptions when using gamma ray sources, see 6.9

B.5 Unsharpness

Table B.13 — Maximum image unsharpness for all techniques, testing class A

Testing class A: Duplex wire ISO 19232-5		
Penetrated thickness w [a] mm	Minimum IQI value and maximum unsharpness (ISO 19232-5)[b,c] mm	Maximum basic spatial resolution (equivalent to wire thickness and spacing)[b,c] $SR_b^{detector}$ mm
$w \leq 1,0$	D 13 0,10	0,05
$1,0 < w \leq 1,5$	D 12 0,125	0,063
$1,5 < w \leq 2$	D 11 0,16	0,08
$2 < w \leq 5$	D 10 0,20	0,10
$5 < w \leq 10$	D 9 0,26	0,13
$10 < w \leq 25$	D 8 0,32	0,16
$25 < w \leq 55$	D 7 0,40	0,20
$55 < w \leq 150$	D 6 0,50	0,25
$150 < w \leq 250$	D 5 0,64	0,32
$w > 250$	D 4 0,80	0,4

[a] For double-wall technique, single-image, the nominal thickness, t, shall be used instead of the penetrated thickness, w.

[b] The IQI reading for system selection (see Annex C) applies for contact radiography. If the geometric magnification technique (see 7.7) is used, the IQI reading shall be performed in the corresponding reference radiographs.

[c] If magnification, v, is > 1,2, then SR_b^{image} shall be used instead of $SR_b^{detector}$.

Table B.14 — Maximum image unsharpness for all techniques, testing class B

Testing class B: Duplex wire ISO 19232-5		
Penetrated thickness *w*[a] mm	**Minimum IQI value and maximum unsharpness** **(ISO 19232-5)**[b,c] mm	**Maximum basic spatial resolution (equivalent to wire thickness and spacing)**[b,c] $SR_b^{detector}$ mm
$w \leq 1{,}5$	D 14 (D 13+)[d] 0,08	0,04
$1{,}5 < w \leq 4$	D 13 0,10	0,05
$4 < w \leq 8$	D 12 0,125	0,063
$8 < w \leq 12$	D 11 0,16	0,08
$12 < w \leq 40$	D 10 0,20	0,10
$40 < w \leq 120$	D 9 0,26	0,13
$120 < w \leq 200$	D 8 0,32	0,16
$w > 200$	D 7 0,40	0,20

[a] For double-wall technique, single-image, the nominal thickness, *t*, shall be used instead of the penetrated thickness, *w*.

[b] The IQI reading for system selection (see Annex C) applies for contact radiography. If the geometric magnification technique (see 7.7) is used, the IQI reading shall be performed in the corresponding reference radiographs.

[c] If magnification, *v*, is > 1,2, then SR_b^{image} shall be used instead of $SR_b^{detector}$.

[d] D 13+ is achieved if the duplex wire pair D 13 is resolved with a dip larger than 20 %.

NOTE The duplex wire IQIs can be used effectively with tube voltages up to 600 kV. The wire pairs > 13 can be used effectively at tube voltages lower than 225 kV. When using source voltages in the megavolt range, it can be possible that the results will not be completely satisfactory. $SR_b^{detector}$ values can be determined but it will be difficult to measure SR_b^{image} values.

Annex C
(normative)

Determination of basic spatial resolution

Linearized grey levels are the precondition for the measurement of correct basic spatial resolution values, i.e. the grey values need to be proportional to the radiation exposure at a given location of the image. This is typically supported by the manufacturer's software.

Some digital filters modify the unsharpness measurement. It is recommended that SR_b^{image} or $SR_b^{detector}$ is measured in the raw images only.

The duplex wire IQI shall be positioned directly on the detector surface or cassette surface and shall be evaluated in accordance with ISO 19232-5 for determination of the detector basic spatial resolution $SR_b^{detector}$. The evaluation shall be performed using the corrected unfiltered digital radiographs (raw data) of the duplex wire IQI with a profile function without interpolation, as described in ISO 19232-5.

NOTE If the duplex wire IQI is positioned on a test object instead of directly on the detector, a measurement of the image basic spatial resolution SR_b^{image} is then obtained, not the detector basic spatial resolution $SR_b^{detector}$.

The duplex wire IQI shall be positioned at an angle of approximately 2° to 5° towards the row or column orientation in order to avoid aliasing effects as shown ISO 19232-5.

Automated DDA inspection systems may use a detection mode as continuous movement (e.g. translation or rotation) or start/stop acquisition. The image unsharpness of moving or start/stop systems shall not exceed the values of Table B.13 or Table B.14.

Hence, for automated inspection systems, an additional SR_b^{image} measurement, where duplex IQI image is acquired with the continuous movement on, shall be provided too.

The determination of the basic spatial resolution for a digital detector system ($SR_b^{detector}$) shall be performed under one of the following exposure conditions without object:

a) inspection of light alloys:

— tube voltage 90 kV;

— prefilter 1 mm Al;

b) inspection of steel and copper alloys ≤ 20 mm penetrated thickness:

— tube voltage 160 kV;

— prefilter 1 mm Cu;

c) inspection of steel and copper alloys > 20 mm penetrated thickness:

— tube voltage 220 kV;

— prefilter 2 mm Cu;

d) gamma-radiography or high-energy radiography:

— use the gamma-ray source as specified or X-ray source > 1 MV;

— prefilter 2 mm Cu or 4 mm steel for Se 75, Ir 192 and 4 mm Cu or 8 mm steel for Co 60 or X-ray voltage > 1 MV.