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Non-destructive testing of welds — Radiographic testing —

Part 1:
X- and gamma-ray techniques with film

Essais non destructifs des assemblages soudés — Contrôle par radiographie —

Partie 1: Techniques par rayons X ou gamma à l'aide de film

Reference number
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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 17636-1:2013), which has been technically revised.

The main changes are as follows:

— the normative references have been updated;

— the Figures have been updated;

— references to Figures 1 to 19 have been updated throughout the document;

— in 6.7 the use of ASTM wires and other image quality indicators (IQIs) by agreement of contracting parties has been added;

— in 6.7 a) the acceptance of a shorter wire visibility than 10 mm for pipes with an external diameter < 50 mm has been added;

— in 6.7, 6.8 and 6.9 a clarification for the IQI usage for the double-wall double-image (DWDI) technique has been added;

— in 6.9 and 7.2.2 the lower thickness limit for Se 75 applications has been deleted;

— measurement of optical density in the root of the weld has been clarified;

— IQI use for the DWDI technique has been clarified.

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 1: **X- and gamma-ray techniques with film**

1 Scope

This document specifies techniques of radiographic testing of fusion-welded joints in metallic materials using industrial radiographic film techniques with the object of enabling satisfactory and repeatable results. The techniques are based on generally recognized practice and fundamental theory of the subject.

It applies to the joints of plates and pipes in metallic materials. 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 does not specify acceptance levels for any of the indications found on the radiographs. The ISO 10675 series provides information on acceptance levels for weld evaluation.

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 11699-1, *Non-destructive testing — Industrial radiographic film — Part 1: Classification of film systems for industrial radiography*

ISO 11699-2, *Non-destructive testing — Industrial radiographic films — Part 2: Control of film processing by means of reference values*

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*

ASTM E 747, *Standard Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology*

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*

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

3.2
penetration thickness change
Δt
change of *penetrated thickness* (3.3) relative to the *nominal thickness* (3.1) due to beam angle

3.3
penetrated thickness
w
thickness of material in the direction of the radiation beam calculated on the basis of the *nominal thicknesses* (3.1) of all penetrated walls

3.4
object-to-film distance
b
distance between the radiation side of the radiographed part of the test object and the film surface, measured along the central axis of the radiation beam

Note 1 to entry: The abbreviated term OFD can also be used.

3.5
source size
d
size of the radiation source or focal spot size

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

3.6
source-to-film distance
SFD
distance between the source of radiation and the film, measured in the direction of the beam

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

where

f is *source-to-object distance* (3.7);

b is *object-to-film distance* (3.4).

3.7
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 can also be used.

3.8
external diameter
D_e
nominal diameter of the outer surface of the pipe

3.9
weld area to evaluate
WAE
area to be evaluated on the radiograph, which contains the weld and the *heat-affected zone* (3.11) on both sides

3.10
area of interest
AoI
minimum area which should be evaluated on the radiograph and which contains the weld, the *heat-affected zone* (3.11) on both sides and all lead letters, markers and image quality indicators (IQIs)

3.11
heat-affected zone
HAZ
area beside the weld influenced by the heating and cooling process of the welding

Note 1 to entry: This is considered to be the two areas beside the weld, each with the same width as the weld cap but with at least 10 mm 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
AoI	area of interest
b	object-to-film distance
b'	object-to-film distance perpendicular to test object
d	source size, focal spot size (see EN 12679 and the EN 12543 series)
D_e	external diameter
d_f	value of the diagonal extension of the film, used for testing
DWDI	double-wall double-image
DWSI	double-wall single-image
f	source-to-object distance
f'	source-to-object distance perpendicular to test object
F	film
f_{min}	minimum source-to-object distance
NOTE The source-to-detector-distance (SDD), as used in digital radiography (see ISO 17636-2), is equivalent to SFD in film radiography.	

Table 1 *(continued)*

Symbol or abbreviated term	Definition
HAZ	heat-affected zone
IQI	image quality indicator
S	radiation source
SFD	source-to-film distance
t	nominal thickness
Δt	penetration thickness change
w	penetrated thickness
WAE	weld area to evaluate
β	opening angle of source window or collimator to central beam
NOTE The source-to-detector-distance (SDD), as used in digital radiography (see ISO 17636-2), is equivalent to SFD in film radiography.	

5 Classification of radiographic techniques

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 radiographic technique shall be agreed between the contracting parties.

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 density to 3,0 or by selection of a better film system testing class with a minimum optical density of 2,6. The other conditions for testing class B remain unchanged, especially the image quality achieved (see Tables B.1 to B.12 and 6.9). Because of the better sensitivity than testing class A, the test specimen may be regarded as being tested to testing class B. This does not apply if the special SFD reductions as described in 7.6 for test arrangements 7.1.4 and 7.1.5 (Figures 5 to 10) are used.

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, radiography shall be carried out after the final stage of manufacture, for example after grinding or heat treatment.

6.3 Location of the weld in the radiograph

Where the radiograph does not show the weld, high-density markers shall be placed on both sides of the weld outside the WAE.

6.4 Identification of radiographs

Symbols shall be affixed to each section of the object being radiographed. The images of these symbols shall appear in the 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 radiograph, for example 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.

6.6 Overlap of films

When radiographing an area with two or more separate films, the films shall overlap sufficiently to ensure that the complete WAE is radiographed. This shall be verified by a high-density marker on the surface of the object which is to appear on each film.

6.7 Types and positions of image quality indicators (IQIs)

The quality of images shall be verified by the use of IQIs in accordance with ISO 19232-1 or ISO 19232-2. IQIs according to ASTM E 747 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.

The single wire or step hole IQIs used shall be placed on the source side of the test object at the centre of the 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 made in a section of uniform thickness characterized by a uniform optical density on the film.

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

a) When using a 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 optical density, which is normally in the parent metal adjacent to the weld. For exposures in accordance with 7.1.6 and 7.1.7 (Figures 11 and 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 this 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 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 film side. If the IQIs cannot be placed at the source side, the IQIs are placed on the film side and the image quality shall be determined at least once from comparison exposure, with one IQI placed at the source side and one at the film side under the same conditions.

For double-wall exposures in accordance with 7.1.6 and 7.1.7 (Figures 11 to 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 film 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 film side. When the IQI is placed on the film side, refer to Tables B.9 to B.12.

Where the IQIs are placed on the film 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.

If steps have been taken to guarantee that 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 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 films showing IQI images are then considered representative for the whole circumference.

6.8 Evaluation of image quality

The films shall be viewed in accordance with 7.10.

From the evaluation of the image of the IQI on the radiograph, 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 optical density, typically in the HAZ near the weld [see 6.7 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 a), for the exception of DWDI evaluation of small pipes.

The IQI value 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

The minimum image quality values given in Annex B shall be used. Tables B.1 to B.12 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 cases 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;

— $w \leq 24$ 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 < $w \leq 40$ mm: one wire value fewer or one step hole value more for Ir 192;

— $w \leq 20$ mm: one wire value fewer or one step hole value more for Se 75.

For Se 75 and penetrated thicknesses less than 12 mm, it can be difficult to achieve the IQI values required for testing class B. In this particular case, the minimum optical density shall be increased to 3,0 and at least one film system class better shall be used than required in Table 3 or Table 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.

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. Films shall be placed as close as possible to the object.

The elliptical technique (double-wall and double-image) in accordance with Figure 11 should only be used for $D_e \leq 100$ mm, 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.

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 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 film side close to the film with a lead letter F.

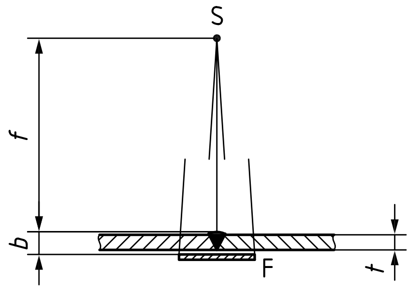
Radiographic techniques other than those in 7.1.2 to 7.1.9 (Figures 1 to 19) may be agreed by the contracting parties when it is useful, for example for reasons such as the geometry of the piece or differences in material thickness. In 7.1.9 (Figures 17 to 19) an example of such a case is presented. Additionally, thickness compensation with the same material may be applied. Multi-film techniques shall not be used to reduce exposure times on uniform sections.

If radiation protection is a major concern, a maximum of two films may be exposed during one exposure by agreement of contracting parties.

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

NOTE Unless otherwise noted, definitions of the symbols used in Figures 1 to 21 and in the annexes can be found in Clause 4.

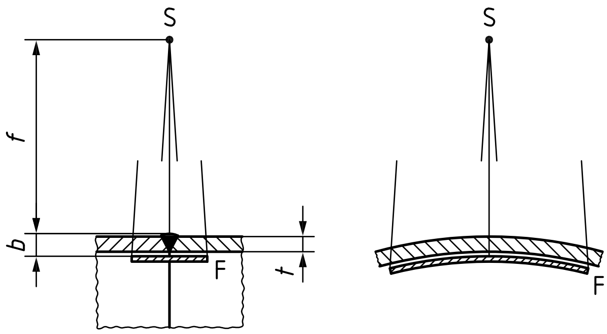
7.1.2 Single-wall penetration of plane objects (see Figure 1)



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 the radiation source on one side and the film on the opposite side

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



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 film inside

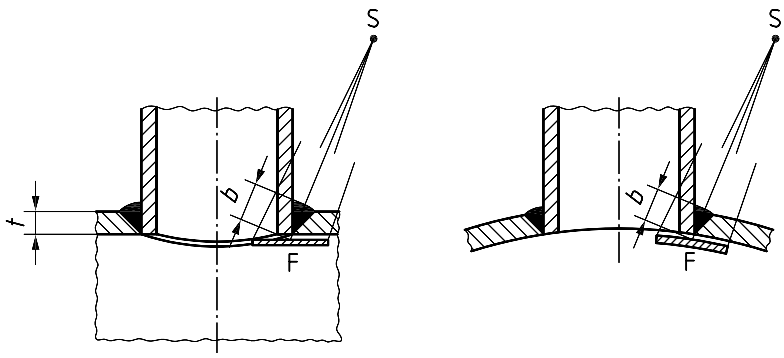


Figure 3 — Arrangement for testing of set-in welds with the radiation source outside and the film inside

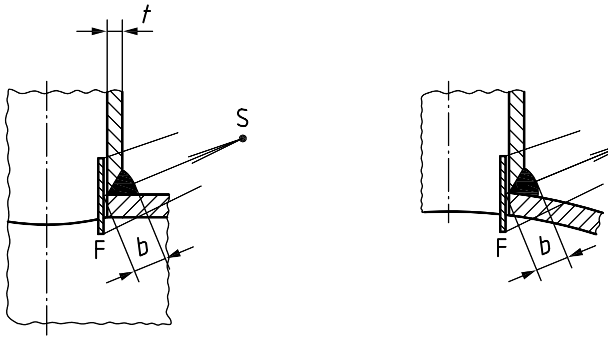


Figure 4 — Arrangement for testing of set-on welds with the radiation source outside and the film inside

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

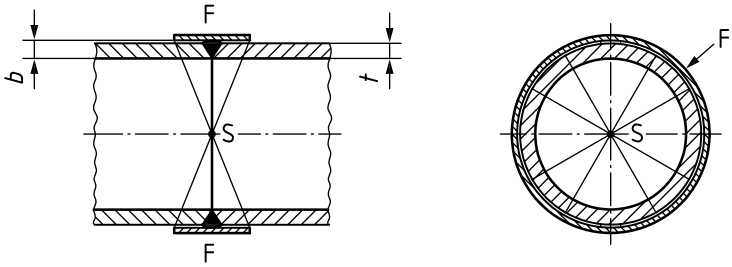


Figure 5 — Arrangement for testing of welds with a centrally located radiation source (central projection) and the film outside

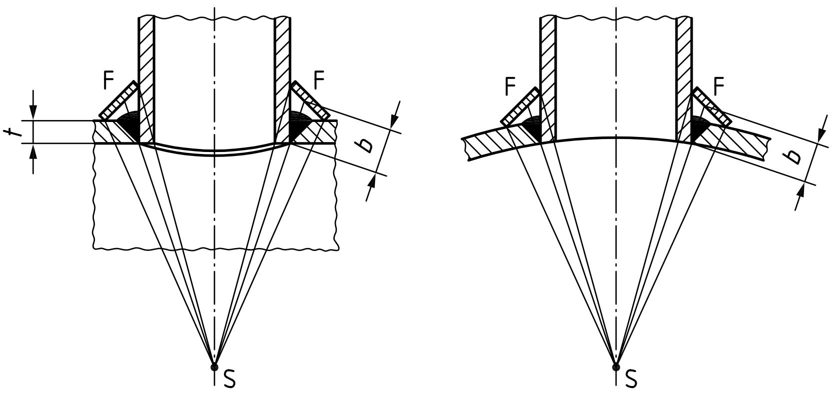


Figure 6 — Arrangement for testing of set-in welds with a radiation source, located on the central pipe axis and perpendicular to the weld centre, and the film outside

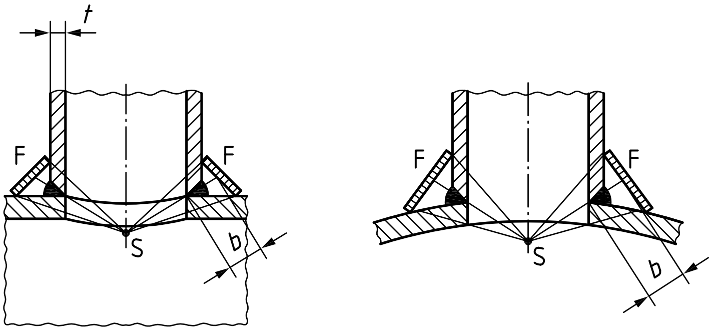


Figure 7 — Arrangement for testing of set-on welds with a radiation source, located on the central pipe axis and perpendicular to the weld centre, and the film outside

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

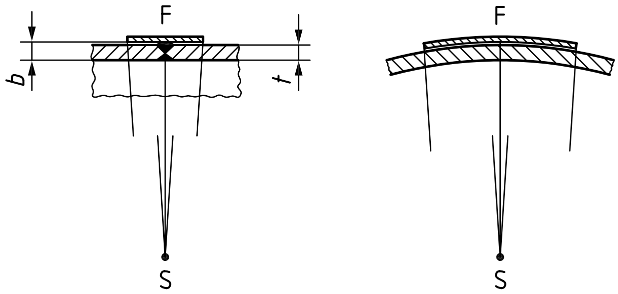


Figure 8 — Arrangement for testing of welds with the radiation source located off-centre inside the object and the film outside

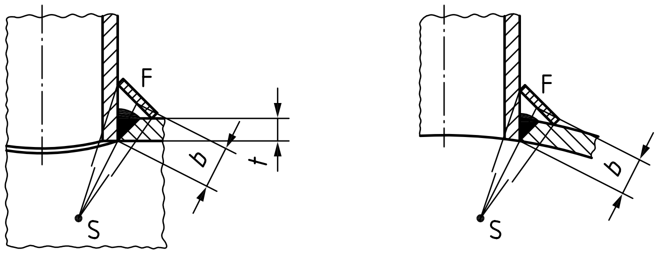


Figure 9 — Arrangement for testing of set-in welds with the radiation source located off-centre inside the object and the film outside

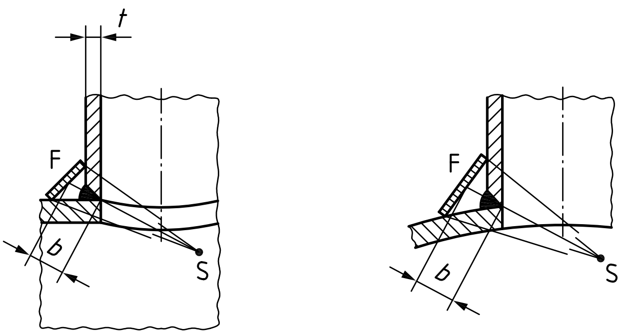
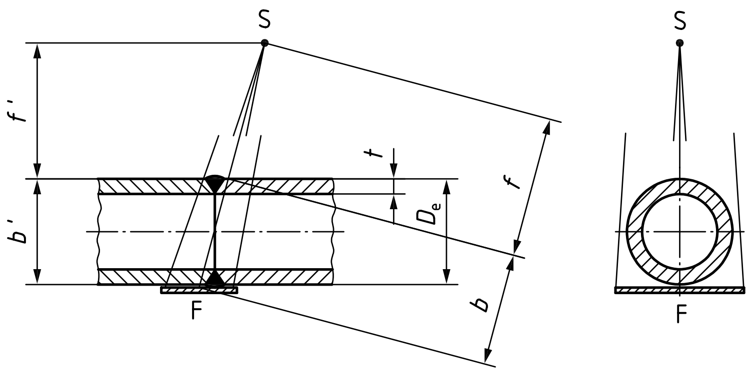


Figure 10 — Arrangement for testing of set-on welds with the radiation source located off-centre inside the object and the film outside

7.1.6 Double-wall penetration and double-image evaluation (DWDI) of pipes with the elliptic technique and the source and the film 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 film outside the object (see Figure 12)

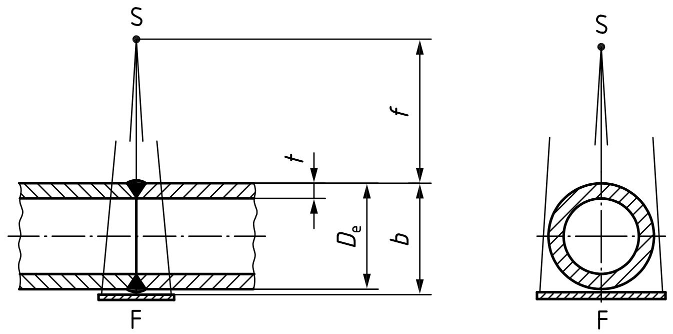


Figure 12 — Arrangement for testing of both walls of pipes with the perpendicular technique

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

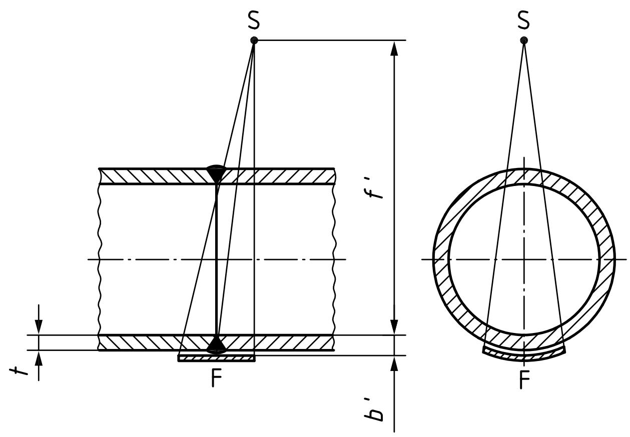


Figure 13 — Arrangement for testing of curved objects with the radiation source outside and evaluation of the wall next to the film with the IQI placed close to the film

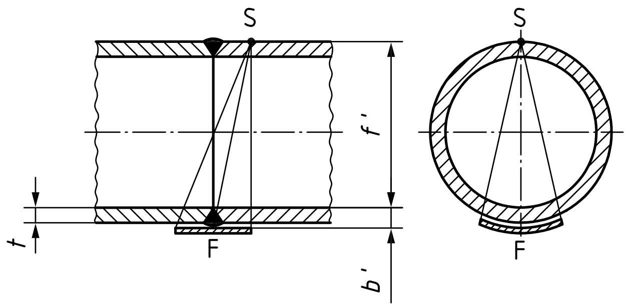


Figure 14 — Arrangement for testing of curved objects with the radiation source outside, located directly on the surface and evaluation of the wall next to the film with the IQI placed close to the film

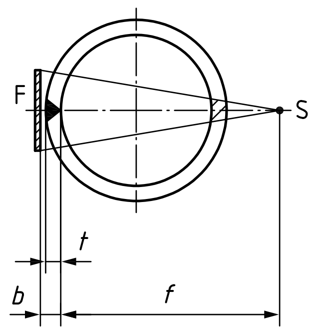


Figure 15 — Arrangement for testing of pipes with longitudinal welds with the radiation source outside and evaluation of the wall next to the film with the IQI placed close to the film

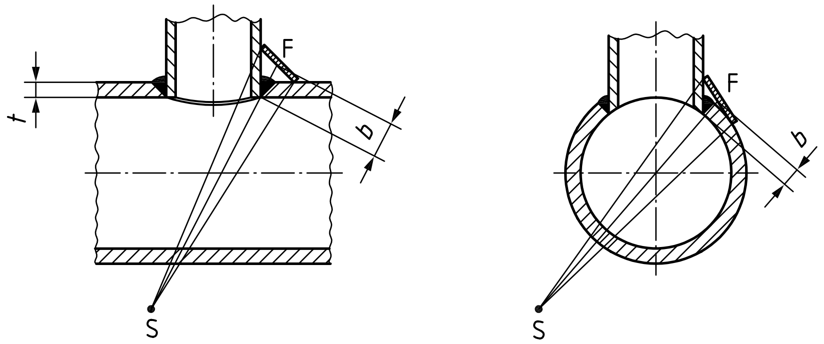


Figure 16 — Arrangement for testing of set-in welds with the radiation source outside and evaluation of the wall next to the film with the IQI placed close to the film

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 film position

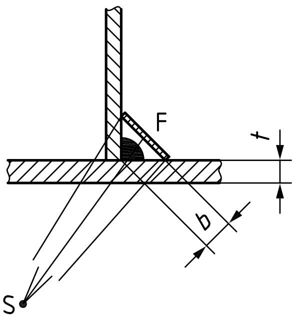


Figure 18 — Arrangement for testing of fillet welds with a perpendicular film position

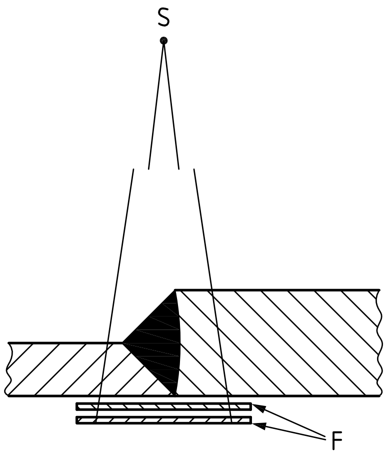
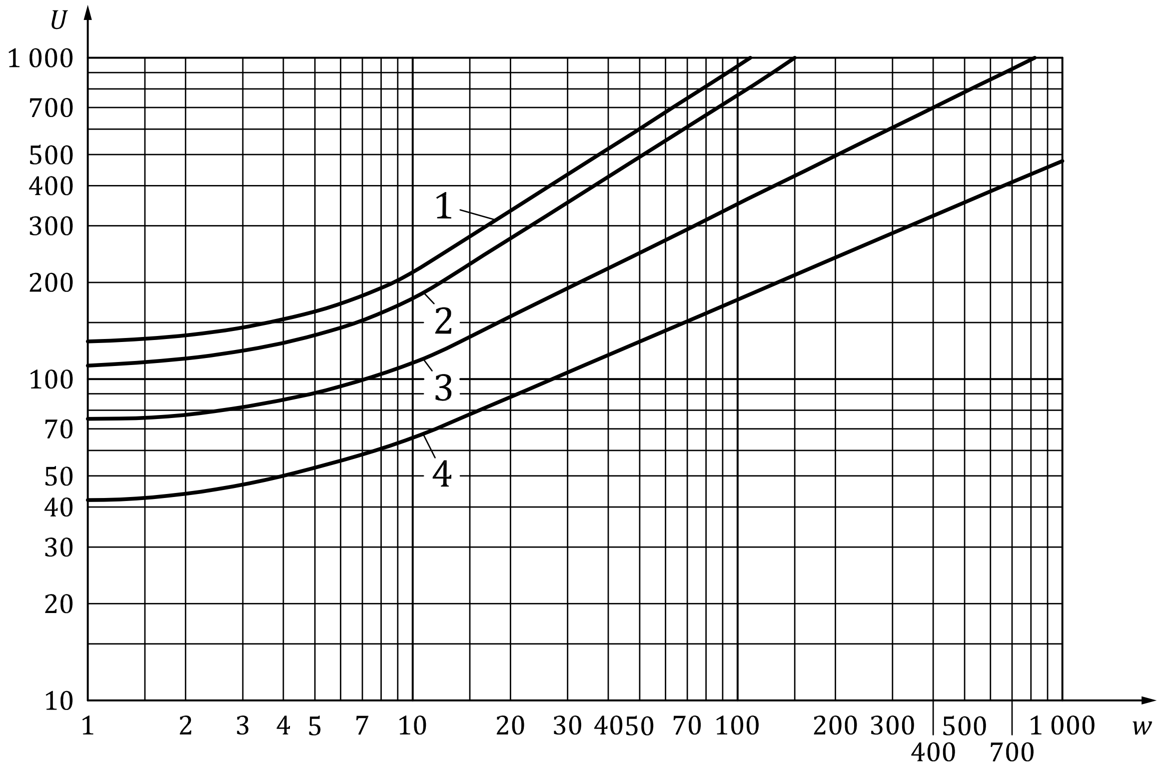


Figure 19 — Arrangement for testing with a multi-film technique

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. The maximum values of X-ray tube voltage versus penetrated thickness are given in Figure 20.



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 in Figure 20 are described in Annex C.

Figure 20 — Maximum 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 slightly higher voltage may be used, but it should be noted that an excessively high tube voltage leads to a loss of defect detection sensitivity. For copper, nickel and its alloys, the increment shall be not more than 60 kV. For steel, the increment shall be not more than 50 kV, for titanium and its alloys not more than 40 kV and for aluminium and its alloys not more than 30 kV. These increments should be applied proportionally to the differences between weld and base material thickness.

7.2.2 Other radiation sources

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

On a thin specimen, gamma-rays from Se 75, Ir 192 and Co 60 sources do not produce 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.

In cases where radiographs are produced using gamma-rays, the total travel time to and from the source position shall not exceed 10 % of the total exposure time.

Table 2 — Penetrated thickness ranges for gamma-ray sources and X-ray equipment with tube 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	$w \leq 5$	$w \leq 5$
Yb 169[a]	$1 \leq w \leq 15$	$2 \leq w \leq 12$
Se 75[b]	$10 \leq w \leq 40$	$14 \leq w \leq 40$
Ir 192	$20 \leq w \leq 100$	$20 \leq w \leq 90$
Co 60	$40 \leq w \leq 200$	$60 \leq w \leq 150$
X-ray potentials 1 MV < U ≤ 4 MV	$30 \leq w \leq 200$	$50 \leq w \leq 180$
X-ray potentials 4 MV < U ≤ 12 MV	$w \geq 50$	$w \geq 80$
X-ray potentials U > 12 MV	$w \geq 80$	$w \geq 100$

[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 and testing class B, provided the required image quality as stated in 6.9 is achieved.

It is recommended that better film system classes are used for testing of penetrated thicknesses below 10 mm with Se 75 than required in Tables 3 and 4.

7.3 Film systems and metal screens

For radiographic testing, film system classes shall be used in accordance with ISO 11699-1.

For different radiation sources, the minimum film system classes are given in Tables 3 and 4.

When using metal screens, good contact between films and screens is required. This can be achieved either by using vacuum-packed films or by applying pressure.

For different radiation sources, Tables 3 and 4 show the recommended screen materials and thickness.

Other screen thicknesses may be also agreed between the contracting parties, provided the required image quality is achieved.

Table 3 — X-ray potentials, *U*, film system classes and metal screens for film radiography of steel, copper and nickel-based alloys

Radiation source	Penetrated material thickness *w*	Film system class[a]		Type and thickness of metal screens[b]	
		Testing class A	Testing class B	Testing class A	Testing class B
X-ray potentials $U \leq 100$ kV		C 5	C 3	none or up to 0,03 mm front and back screens of lead	
X-ray potentials 100 kV < $U \leq 150$ kV				up to 0,15 mm front and back screens of lead	
X-ray potentials 150 kV < $U \leq 250$ kV			C 4	0,02 mm to 0,15 mm front and back screens of lead	
Yb 169 Tm 170	$w \leq 5$ mm	C 5	C 3	none or up to 0,03 mm front and back screens of lead	
	$w > 5$ mm		C 4	0,02 mm to 0,15 mm front and back screens of lead	
X-ray potentials 250 kV < $U \leq 500$ kV	$w \leq 50$ mm	C 5	C 4	0,02 mm to 0,2 mm front and back screens of lead	
	$w > 50$ mm		C 5	0,1 mm to 0,2 mm front screens of lead 0,02 mm to 0,2 mm back screens of lead	
X-ray potentials 500 kV < $U \leq 1\,000$ kV	$w \leq 75$ mm	C 5	C 4	0,25 mm to 0,7 mm front and back screens of steel or copper[c]	
	$w > 75$ mm	C5	C 5		
Se 75		C 5	C 4	0,02 mm to 0,2 mm front and back screens of lead	
Ir 192		C 5	C 4	0,02 mm to 0,2 mm front screens of lead	0,1 mm to 0,2 mm front screens of lead
				0,02 mm to 0,2 mm back screens of lead	
Co 60	$w \leq 100$ mm	C 5	C 4	0,25 mm to 0,7 mm front and back screens of steel or copper[c]	
	$w > 100$ mm		C 5		
X-ray potentials 1 MV < $U \leq 4$ MV	$w \leq 100$ mm	C 5	C 4	0,25 mm to 0,7 mm front and back screens of steel or copper[c]	
	$w > 100$ mm		C 5		
X-ray potentials 4 MV < $U \leq 12$ MV	$w \leq 100$ mm	C 4	C 4	up to 1 mm front screen of copper, steel or tantalum[d]	
	100 mm < $w \leq 300$ mm	C 5	C 4		
	$w > 300$ mm		C 5	back screen of copper or steel up to 1 mm and tantalum up to 0,5 mm[d]	
X-ray potentials $U > 12$ MV	$w \leq 100$ mm	C 4	Not applicable	up to 1 mm front screen of tantalum;[e] no back screen	
	100 mm < $w \leq 300$ mm	C 5	C 4		
	$w > 300$ mm		C 5	up to 1 mm front screen of tantalum[e] up to 0,5 mm back screen of tantalum	

[a] Better film system classes may also be used, see ISO 11699-1.

[b] Ready-packed films with a front screen up to 0,03 mm may be used if an additional lead screen of 0,1 mm is placed between the object and the film.

[c] In testing class A, 0,5 mm to 2,0 mm screens of lead may also be used.

[d] In testing class A, lead screens 0,5 mm to 1 mm may be used by agreement between the contracting parties.

[e] Tungsten screens may be used by agreement.

Table 4 — X-ray potentials, *U*, film system classes and metal screens for aluminium and titanium

Radiation source	Film system class[a]		Type and thickness of metal screens[b]
	Testing class A	Testing class B	
X-ray potentials $U \leq 150$ kV	C 5	C 3	none or up to 0,03 mm front and up to 0,15 mm back screens of lead
X-ray potentials 150 kV < $U \leq 250$ kV			0,02 mm to 0,15 mm front and back screens of lead
X-ray potentials 250 kV < $U \leq 500$ kV			0,1 mm to 0,2 mm front and back screens of lead
Yb 169, Tm 170			0,02 mm to 0,15 mm front and back screens of lead
Se 75			0,2 mm front and 0,1 mm to 0,2 mm back screens of lead

[a] Better film system classes may also be used, see ISO 11699-1.

[b] Instead of one 0,2 mm lead screen, two 0,1 mm lead screens may be used.

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, 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 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 test.

With Se 75, Ir 192 and Co 60 radiation sources 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. The thickness of this sheet is 0,5 mm to 2 mm in accordance with the penetrated material thickness.

7.5.2 Interception of backscattered radiation

The presence of backscattered radiation shall be checked for each new 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 film or 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 radiograph, it shall be rejected. If the symbol is darker or invisible the radiograph is acceptable and demonstrates good protection against backscattered radiation.

If necessary, the film 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 film–screen combination.

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-film distance (measured from source side of object to the film) *b* or *b'*. The source size or focal spot size, *d,* shall conform to the EN 12543 series or EN 12679.

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.

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 (1) and (2).

For simplification, these 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 (1):

$$\frac{f}{d} \geq 7{,}5 \cdot b^{2/3} \qquad (1)$$

For testing class B use Formula (2):

$$\frac{f}{d} \geq 15 \cdot b^{2/3} \qquad (2)$$

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 (1) and (2) 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 (1) and (2).

The opening angle 2*β* of the X-ray tube window and the film size (diagonal) limit the applicable SFD. Therefore, according to Formula (3), SFD should be:

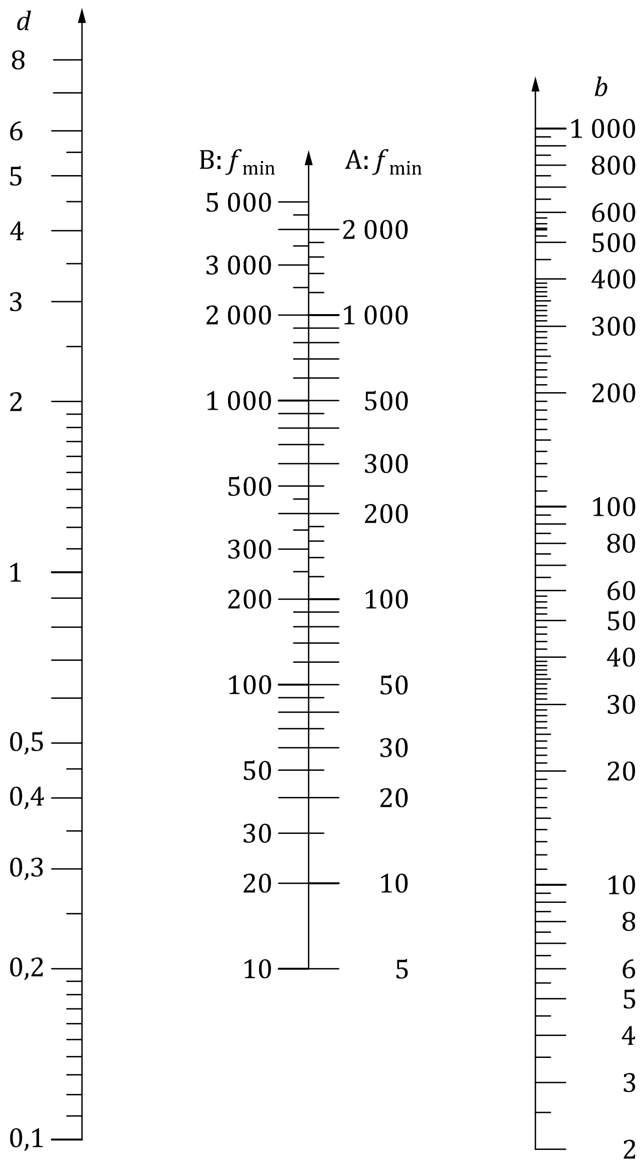
$$SFD \geq 0{,}5 \cdot \frac{d_{\mathrm{f}}}{\tan(\beta)} \qquad (3)$$

The typical opening angle of the X-ray tube window for NDT is 2*β* = 40° (±20°). Formula (3) is simplified for these tubes to Formula (4):

$$SFD \geq 1{,}4 \cdot d_{\mathrm{f}} \qquad (4)$$

For testing class A, if detection of planar imperfections is a requirement, the minimum 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 2.

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

B testing class B

A testing class A

Figure 21 — Nomogram for the determination of minimum source-to-object distance f_{min} in relation to object-to-film distance *b* and the source size *d*

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 Formulae (1) and (2) and in Figure 21.

When the source is outside the object and film on the other side [technique specified 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 film 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.

7.7 Maximum area for a single exposure

The number of 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 optical densities resulting from any variation of penetrated thickness should not be lower than those indicated in 7.8 and not higher than those allowed by the available illuminator, provided suitable masking is possible. This is the evaluable area.

The size of the weld area to be tested and evaluated includes the weld and the HAZs. 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.

7.8 Optical density of radiograph

Exposure conditions should be such that the minimum optical density of the radiograph in the area to be evaluated is greater than or equal to those given in Table 5 (evaluable area).

NOTE The minimum optical density is typically measured in the region of average penetration bead thickness (centre of weld).

Table 5 — Optical density of the radiographs

Testing class	Optical density[a]
A	≥ 2,0[b]
B	≥ 2,3[c]

[a] A measuring tolerance of ±0,1 is permitted.

[b] The value may be reduced to 1,5 by special agreement between the contracting parties.

[c] The value may be reduced to 2,0 by special agreement between the contracting parties.

High optical densities should preferably be used, where the viewing light is sufficiently bright in accordance with 7.10. The maximum readable film density depends on the film illuminator (viewing screen) used and its maximum luminance (see ISO 5580). The maximum readable density shall be posted on the film illuminator used.

In order to avoid unduly high fog densities arising from film ageing, development or temperature, the fog density shall be checked periodically on a non-exposed sample taken from the films being used and handled and processed under the same conditions as the actual radiograph. The fog density shall not exceed 0,3. Fog density here is defined as the total density (emulsion and base) of a processed, unexposed film.

When using a multi-film technique with interpretation of single films, the optical density of each film shall be in accordance with Table 5.

If double film viewing is requested, the optical density of one single film shall not be lower than 1,3.

7.9 Processing

Films are processed in accordance with the conditions recommended by the film and chemistry manufacturer to obtain the selected film system class. Particular attention shall be paid to temperature, developing time and washing time. The film processing shall be controlled regularly in accordance with ISO 11699-2. The radiographs should be free from defects due to processing or other causes which would interfere with interpretation.

7.10 Film viewing conditions

The radiographs should be evaluated in a darkened room on an area of the viewing screen with an adjustable luminance in accordance with ISO 5580. The viewing screen should be masked to the AoI or WAE, depending on the evaluation required.

8 Test report

For each exposure, or set of exposures, a test report shall be made, giving information on the radiographic technique used and on any other special circumstances, to 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 17636-1:2022;

b) name of the testing body;

c) 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 and ISO 10675-2);

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

l) system of marking used;

m) film position;

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

o) film type and system, screens and filters;

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

q) time of exposure and SFD;

r) processing technique: manual or automatic and development conditions;

s) type and position (film or source side) of IQIs;

t) results of evaluation, including data on film density, IQI readings;

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

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

w) any unusual features observed;

x) 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 (Figures 11 and 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), Figures A.3 and 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 testing methods.

When $\Delta t/t$ is less than or equal to 10 % (testing class B), Figures A.1 and 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 radiographs shall be higher than the values in Figures A.1 to A.4.

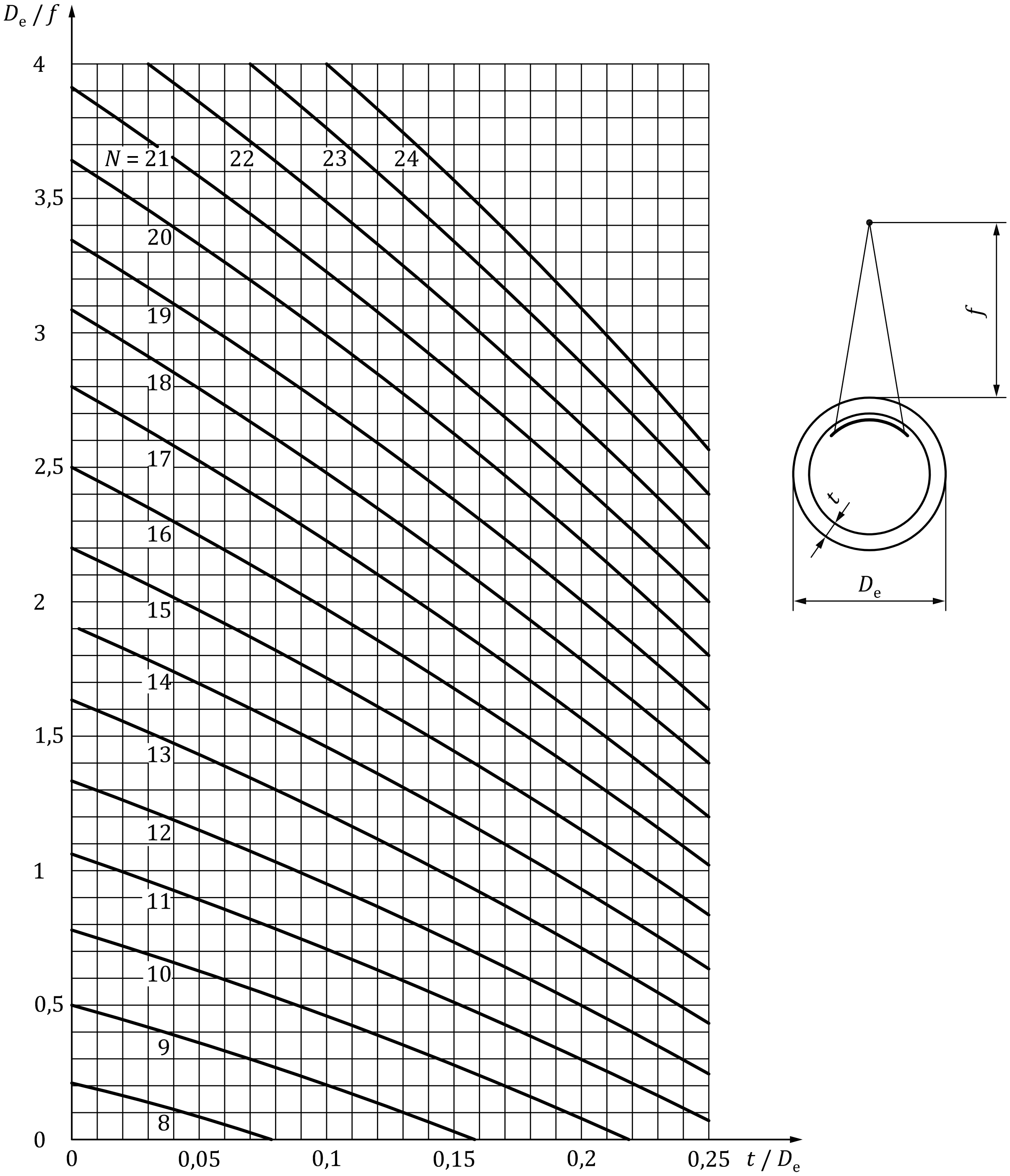
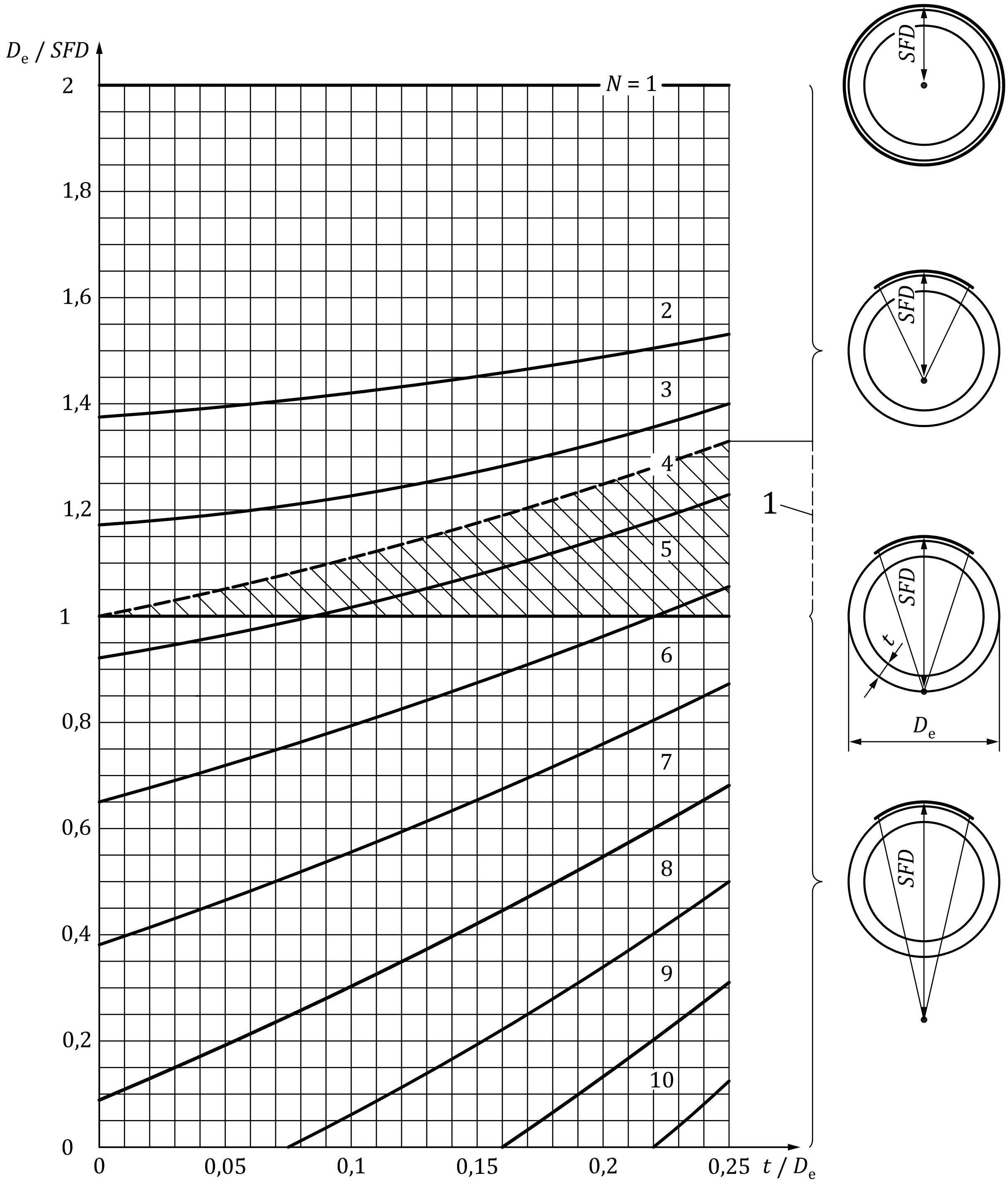


Figure A.1 — Minimum number of exposures *N* for single-wall penetration with source outside considering a maximum permissible increase in penetrated thickness of $\Delta t/t$ = 10 % (testing class B) as a function of ratios t/D_e and D_e/f, due to inclined penetration in the evaluable areas of sufficient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



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 $\Delta t/t$ = 10 % (testing class B) as a function of ratios t/D_e and D_e/SFD, due to inclined penetration in the evaluable areas of sufficient optical density

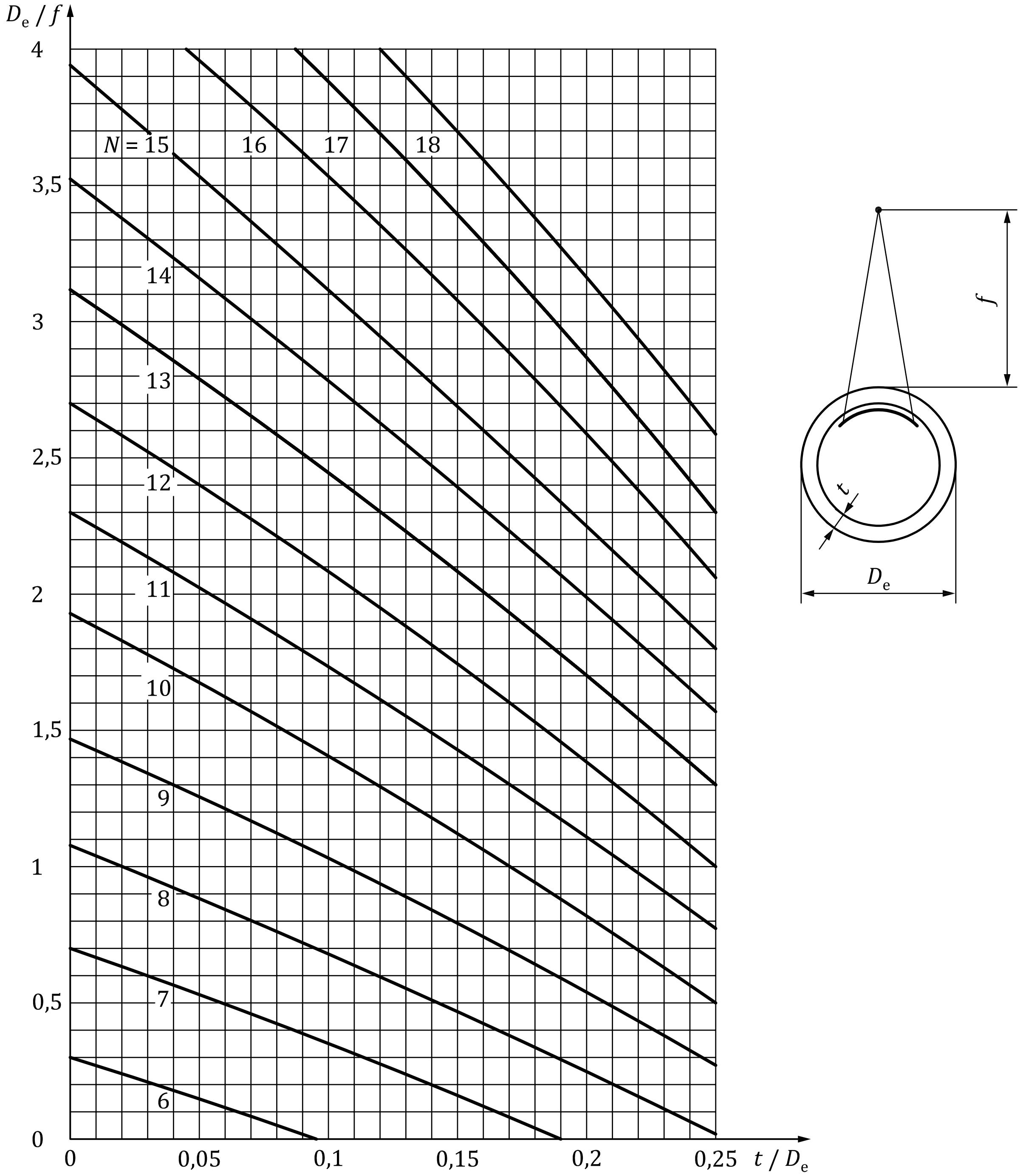
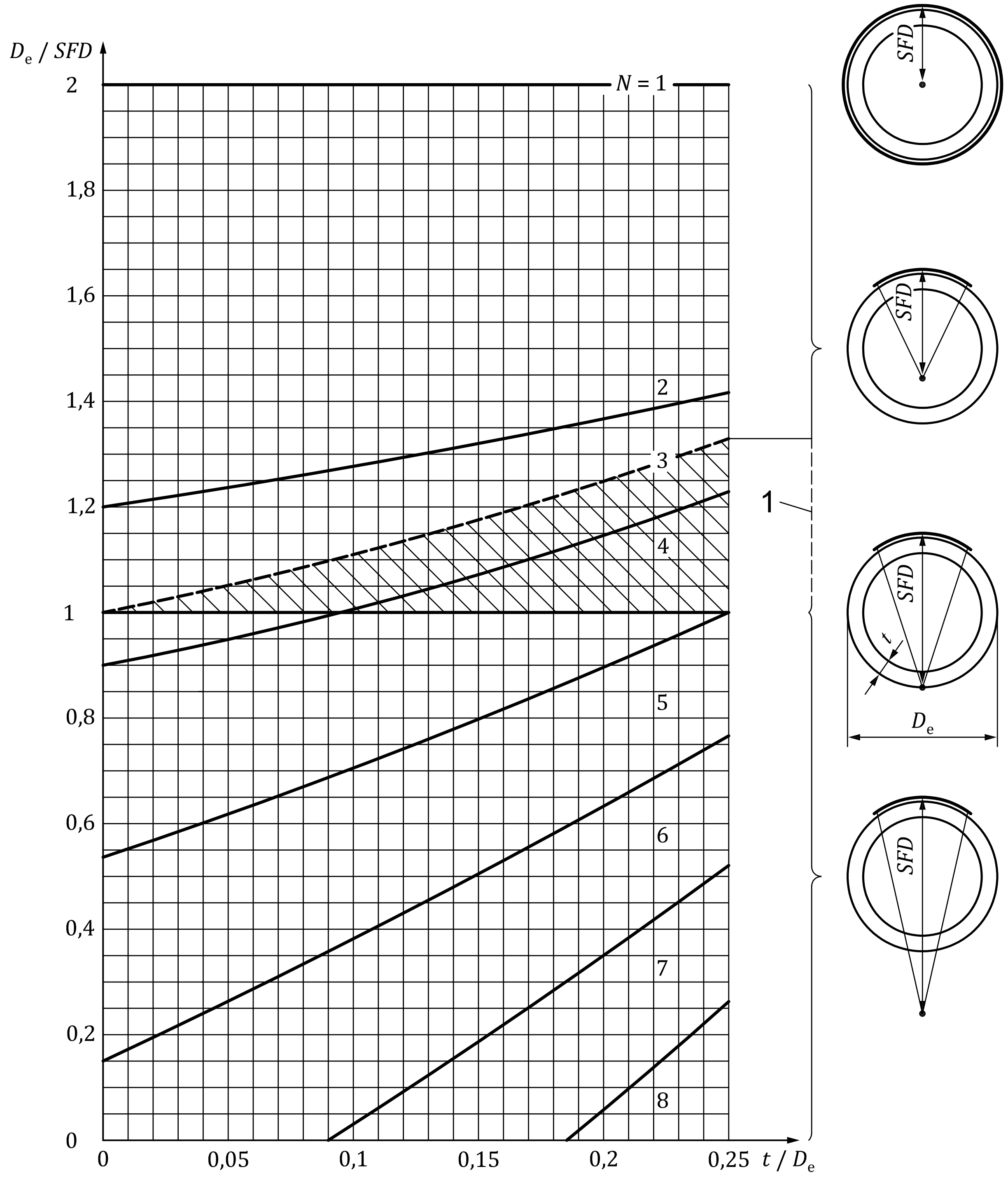


Figure A.3 — Minimum number of exposures N for single-wall penetration with source outside considering a maximum permissible increase in penetrated thickness $\Delta t/t$ = 20 % (testing class A) as a function of ratios t/D_e and D_e/f, due to inclined penetration in the evaluable areas of sufficient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



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/SFD, due to inclined penetration in the evaluable areas of sufficient optical density

Annex B
(normative)

Minimum image quality values

B.1 General

The minimum IQI values of Tables B.1 to B.12 shall be achieved or exceeded for acceptance of class A or 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
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
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 (DWDI) evaluation — IQI on film 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
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.

Annex C
(informative)

Calculation of maximum X-ray tube voltages from Figure 20

The X-ray tube voltages as shown in Figure 20 are calculated differently in the w range of 0 mm to 10 mm and in the range of $w > 10$ mm, see Table C.1. The increased X-ray tube voltage requirements in the w range of 0 mm to 10 mm were introduced considering the thickness difference between base material and weld in the range $w < 10$ mm in the 1970s. This allows the weld and base material to be radiographed with one film without the requirement for the multi-film technique.

Table C.1 — Approximation formulae for calculation of maximum tube voltages as used in Figure 20

	Maximum tube voltage according to penetrated thickness, *w* kV	
	***w* ≤ 10 mm**	***w* > 10 mm**
Copper, nickel and its alloys	$U = 120 + 9w$	$U = 48 \cdot w^{0,65}$
Steel[a]	$U = 100 + 7{,}5w$	$U = 40 \cdot w^{0,64}$
Titanium and its alloys	$U = 70 + 4w$	$U = 35 \cdot w^{0,50}$
Aluminium and its alloys	$U = 40 + 2{,}5w$	$U = 24 \cdot w^{0,43}$

[a] For steel applications, practitioners can also use the less accurate approximation up to 45 mm thickness: $U_{steel} \approx 100 + 8w$.

Bibliography

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[3] ISO 10675-1, *Non-destructive testing of welds — Acceptance levels for radiographic testing — Part 1: Steel, nickel, titanium and their alloys*

[4] ISO 10675-2, *Non-destructive testing of welds — Acceptance levels for radiographic testing — Part 2: Aluminium and its alloys*

[5] ISO 19232-3, *Non-destructive testing — Image quality of radiographs — Part 3: Image quality classes*

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