BS EN 16407-2:2014

BSI Standards Publication

Non-destructive testing — Radiographic inspection of corrosion and deposits in pipes by X- and gamma rays

Part 2: Double wall radiographic inspection

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National foreword

This British Standard is the UK implementation of EN 16407-2:2014.

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A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Essais non destructifs - Examen radiographique de la corrosion et des dépôts dans les canalisations, par rayons X et rayons gamma - Partie 2: Examen radiographique double paroi

Zerstörungsfreie Prüfung - Durchstrahlungsprüfung auf Korrosion und Ablagerungen in Rohren mit Röntgen- und Gammastrahlen - Teil 2: Doppelwand Durchstrahlungsprüfung

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COMITÉ EUROPÉEN DE NORMALISATION
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Foreword

This document (EN 16407-2:2014) has been prepared by Technical Committee CEN/TC 138 “Non-destructive testing”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2014, and conflicting national standards shall be withdrawn at the latest by July 2014.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

EN 16407 consists of the following parts, under the general title *Non-destructive testing — Radiographic inspection of corrosion and deposits in pipes by X- and gamma rays:*

— *Part 1: Tangential radiographic inspection*;

— *Part 2: Double wall radiographic inspection*.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This European Standard specifies fundamental techniques of film and digital radiography with the object of enabling satisfactory and repeatable results to be obtained economically. The techniques are based on generally recognized practice and fundamental theory of the subject.

This European Standard applies to the radiographic examination of pipes in metallic materials for service induced flaws such as corrosion pitting, generalized corrosion and erosion. Besides its conventional meaning, “pipe” as used in this standard should be understood to cover other cylindrical bodies such as tubes, penstocks, boiler drums and pressure vessels.

Weld inspection for typical welding process induced flaws is not covered, but weld inspection is included for corrosion/erosion type flaws.

The pipes may be insulated or not, and can be assessed where loss of material due, for example, to corrosion or erosion is suspected either internally or externally.

This part of EN 16407 covers double wall inspection techniques for detection of wall loss, including double wall single image (DWSI) and double wall double image (DWDI).

Note that the DWDI technique described in this part of EN 16407 is often combined with the tangential technique covered in EN 16407-1.

This European Standard applies to in-service double wall radiographic inspection using industrial radiographic film techniques, computed digital radiography (CR) and digital detector arrays (DDA).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 14784-1, *Non-destructive testing — Industrial computed radiography with storage phosphor imaging plates — Part 1: Classification of systems*

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

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

EN ISO 17636-2:2013, *Non-destructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors (ISO 17636-2:2013)*

EN 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 19232-1)*

EN ISO 19232-5, *Non-destructive testing — Image quality of radiographs — Part 5: Determination of the image unsharpness value using duplex wire-type image quality indicators (ISO 19232-5)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
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 or imaging plate.

Note 2 to entry: The measurement of unsharpness is described in EN ISO 19232-5, see also ASTM E2736 [18] and ASTM E1000 [16].

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

3.3
detector
D
radiographic image detector consisting of a NDT film system (see EN ISO 11699-1) or a digital radiography system using an imaging plate system (CR system) or a DDA system

Note 1 to entry: Film systems and IPs can be used as flexible and curved detectors or in planar cassettes.

3.4
digital detector array system
DDA system
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

3.5
DWDI
double wall double image technique
technique where the radiation source is located outside the pipe and away from the pipe, with the detector on the opposite side of the pipe and where the radiograph shows details from both the pipe walls on the detector and source sides of the pipe

Note 1 to entry: See Figure 3.

3.6
DWSI
double wall single image technique
technique where the radiation source is located outside the pipe close to the pipe wall, with the detector on the opposite side of the pipe and where the radiograph shows only detail from the pipe wall on the detector side

Note 1 to entry: See Figure 1.

3.7
nominal wall thickness
t
thickness of the pipe material only where manufacturing tolerances do not have to be taken into account

3.8
normalized signal-to-noise ratio
SNR_N
signal-to-noise ratio, SNR, normalized by the basic spatial resolution, SR_b, as measured directly in the digital image and/or calculated from the measured SNR, $SNR_{measured}$, by:

$$SNR_N = SNR_{measured} \frac{88{,}6 \mu m}{SR_b}$$

3.9
object-to-detector distance
b
distance between the radiation side of the test object and the detector surface measured along the central axis of the radiation beam

3.10
outside diameter
D_e
nominal outside diameter of the pipe

3.11
penetrated thickness
w
thickness of material in the direction of the radiation beam calculated on the basis of the nominal thickness

Note 1 to entry: For double wall radiographic inspection of a pipe, the minimum value for *w* is twice the pipe wall thickness. For multiple wall techniques, the penetrated thickness is calculated from the nominal wall thickness *t*.

3.12
pipe centre to detector distance
PDD
distance between the pipe centre and the detector

3.13
pixel size
geometrical centre-to-centre distance between adjacent pixels in a row (horizontal pitch) or column (vertical pitch) of the scanned image

[SOURCE: EN 14096-2:2003, 3.2]

3.14
signal-to-noise ratio
SNR
ratio of mean value of the linearized grey values to the standard deviation of the linearized grey values (noise) in a given region of interest in a digital image

3.15
source size
d
size of the radiation source

[SOURCE: EN 12679:1999, 2.1]

3.16
source-to-detector distance
SDD
distance between the source of radiation and the detector measured in the direction of the beam

3.17
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

3.18
source-to-pipe centre distance
SPD
distance between the source of radiation and the pipe centre (pipe axis) measured in the direction of the beam

3.19
storage phosphor imaging plate
IP
photostimulable luminescent material capable of storing a latent radiographic image of a material being examined and, upon stimulation by a source of red light of appropriate wavelength, generates luminescence proportional to radiation absorbed

3.20
total effective penetrated thickness
w_{tot}
total equivalent thickness of metallic material in the direction of the radiation beam calculated on the basis of the nominal thickness, with allowance for any liquid or other material present in the pipe and any insulation

4 Classification of radiographic techniques

The double wall radiographic techniques are divided into two classes:

— basic techniques DWA;

— improved techniques DWB.

The basic techniques are intended for double wall radiography of generalized and localized wall loss.

For the basic techniques, DWA, when using Ir 192 sources for pipes with penetrated thicknesses between 15 mm and 35 mm, the sensitivity for detection will be high for imperfections, provided their diameters are ≥ 2 mm and the material loss is typically ≥ 5 % of the pipe penetrated thickness, in the absence of liquid or other products in the pipe. When using Se 75, the corresponding detection sensitivity will be high for 2 mm diameter or larger imperfections with material loss ≥ 4 % of the pipe penetrated thickness. The detection sensitivity will be improved for flaws with larger diameters, whereas the presence of liquid or other products, and external insulation, may reduce the sensitivity for material loss depending on their properties. Different detection sensitivities may apply for penetrated thicknesses < 15 mm and > 35 mm.

These techniques can also be used for detection of deposits inside the pipe.

The improved techniques should be used where higher sensitivity is required such as for radiography of fine, localized corrosion pitting.

Further improvements, beyond the improved techniques described herein, 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 concerned parties.

5 General

5.1 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 legal requirements shall be applied. Local or national or international safety precautions when using ionising radiation shall be strictly applied.

5.2 Personnel qualification

Testing shall be carried out by proficient, suitably trained and qualified personnel and, where applicable, shall be supervised by competent personnel nominated by the employer or, by delegation of the employer, the inspection company in charge of testing. To demonstrate appropriate qualification it is recommended that personnel be certified according to EN ISO 9712 or an equivalent formalized system. Operating authorization for qualified persons shall be issued by the employer in accordance with a written procedure.

NDT operations, unless otherwise agreed, shall be authorized by a competent and qualified NDT supervisory individual (Level 3 or equivalent) approved by the employer.

The personnel shall prove additional training and qualification in digital industrial radiology if digital detectors are being used.

5.3 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 region of interest where possible and shall ensure unambiguous identification of the section.

5.4 Marking

Permanent markings on the object to be examined should be made in order to accurately locate the position of each radiograph.

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.

5.5 Overlap of films or digital images

When radiographing an area with two or more films or separate detectors, the films or detectors shall overlap sufficiently to ensure that the complete region of interest is radiographed. This shall be verified by a high density marker on the surface of the object which will appear on each film or detector. If the radiographs will be taken sequentially, the high density marker shall be visible on each of the radiographs.

5.6 Types and positions of image quality indicators (IQI)

5.6.1 Single wire IQI

The quality of image shall be verified by use of IQIs in accordance with EN ISO 19232-1.

For DWDI, the single wire IQI used shall be placed preferably on the source side of the test object at the centre of the area of interest. The IQI shall be in close contact with the surface of the object. If the IQIs cannot be placed in accordance with the above conditions (insulated pipes), the IQIs will be placed on the detector side and the image quality shall be determined at least once from a comparison exposure with one IQI placed at the source side and one at the detector side under the same conditions.

For DWSI, the single wire IQI used shall be placed on the detector side of the test object at the centre of the area of interest. If possible, the IQI shall be in close contact with the surface of the object. However, if this is not possible due for example to the presence of insulation, the IQI shall be in contact with the film/detector.

For both DWDI and DWSI, the wire IQIs shall be aligned across the pipe, with their long axis angled at a few degrees (2° to 5°) to the orthogonal to the pipe axis. The IQI location should be in a section of uniform thickness, near to the pipe centre line.

For DWDI, where the IQI's are placed at the detector side, the letter "F" shall be placed near the IQI and it shall be noted in the test report.

The extent of image quality verification for repeat exposures of closely similar objects under identical conditions shall be subject to agreement between the contracting parties.

5.6.2 Duplex wire IQI (digital radiographs)

IQIs in accordance with EN ISO 19232-5 should be used for measurement of the basic spatial resolution of the CR/DDA system in a reference radiograph (see 7.1.2 and Annex C). The duplex wire IQI shall be placed adjacent to the imaging plate or detector array and positioned a few degrees tilted (2° to 5°) to the digital rows or columns of the digital image.

6 Recommended techniques for making radiographs

6.1 Test arrangements

6.1.1 General

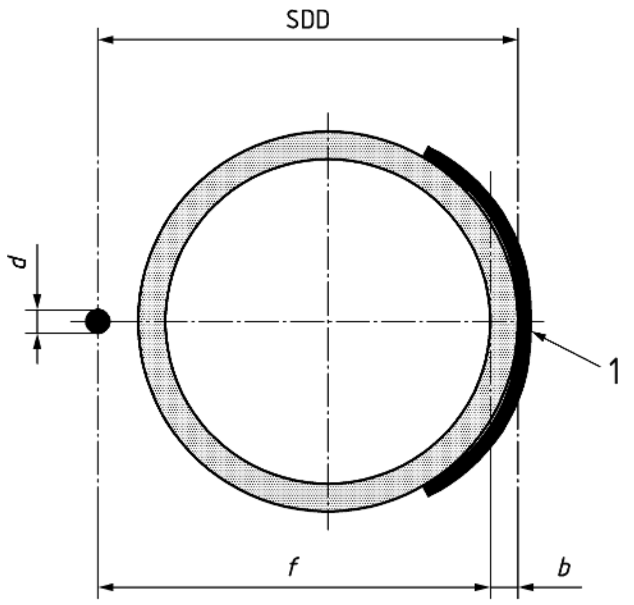
Normally radiographic techniques in accordance with 6.1.2 and 6.1.3 shall be used.

Technique 6.1.2 is normally used for larger diameter pipes. Technique 6.1.3 is generally used for smaller diameter pipes (less than typically about 150 mm outside diameter).

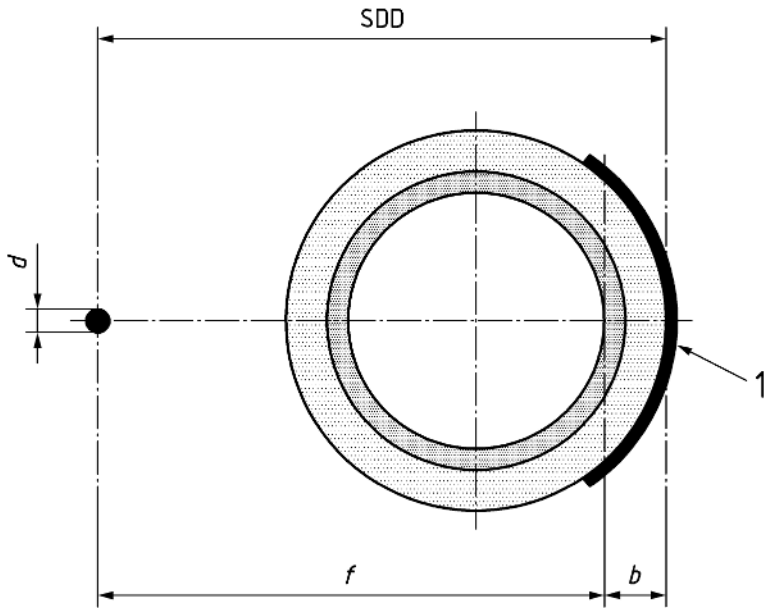
For both techniques, the film or digital detector shall be placed as close to the pipe as possible.

6.1.2 Double wall single image (DWSI)

For this arrangement with curved detectors or film, the source is located near to the pipe and with the film/detector on the opposite side, as shown in Figure 1 a) (without insulation) and Figure 1 b) (with insulation). The relevant distances for determination of source to detector distance, SDD (see 6.6), are also shown.



a) Non insulated pipe



b) Insulated pipe

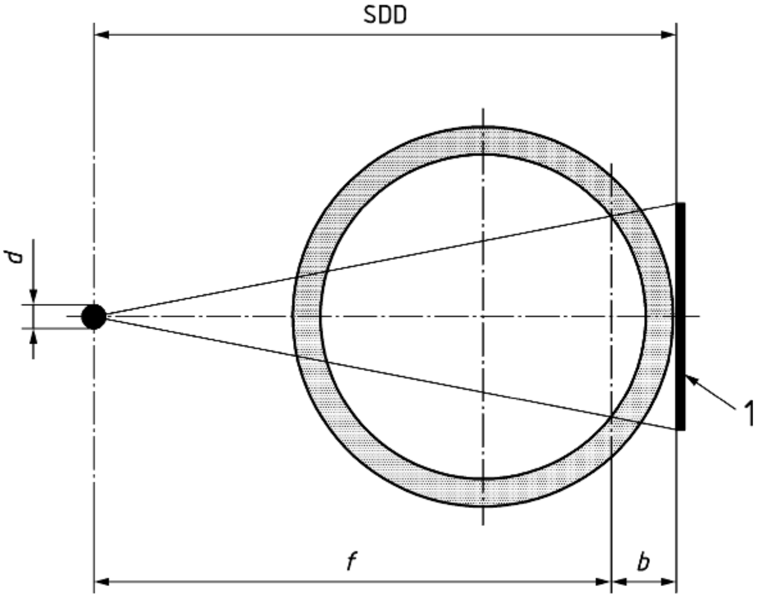
Key

1 detector

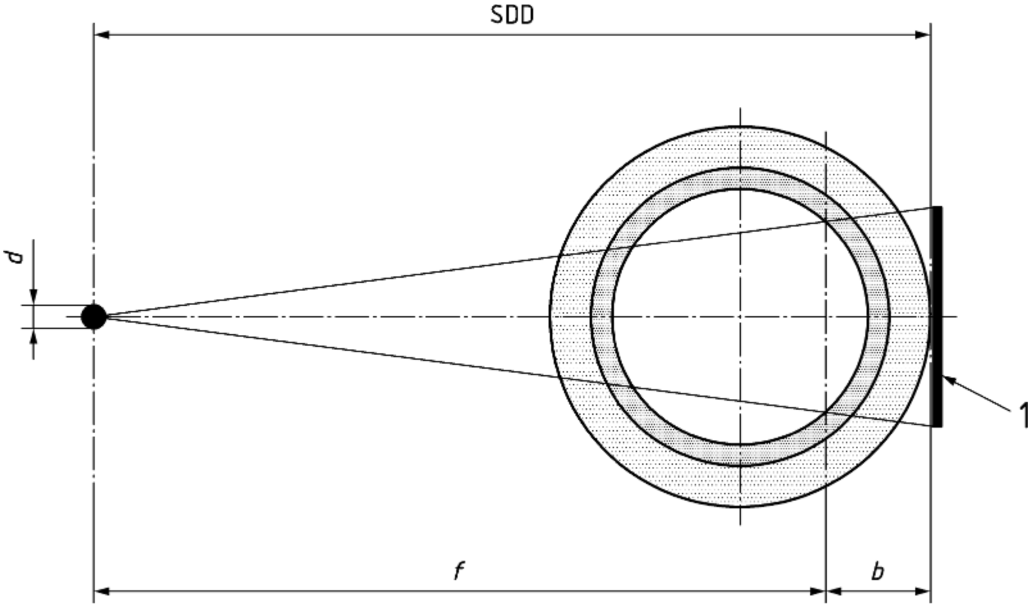
Figure 1 — Test arrangement for double wall single image radiography (DWSI) using a curved detector

Note that the wall loss can be located on either the inner diameter, outer diameter or both surfaces of the pipe wall adjacent to the detector. Wall loss on the source side of the pipe is not imaged.

For rigid planar detectors, DWSI can also be applied as shown in Figure 2a) and Figure 2 b), although with this arrangement a smaller fraction of the pipe circumference can be inspected at each position.



a) Non insulated pipe



b) insulated pipe

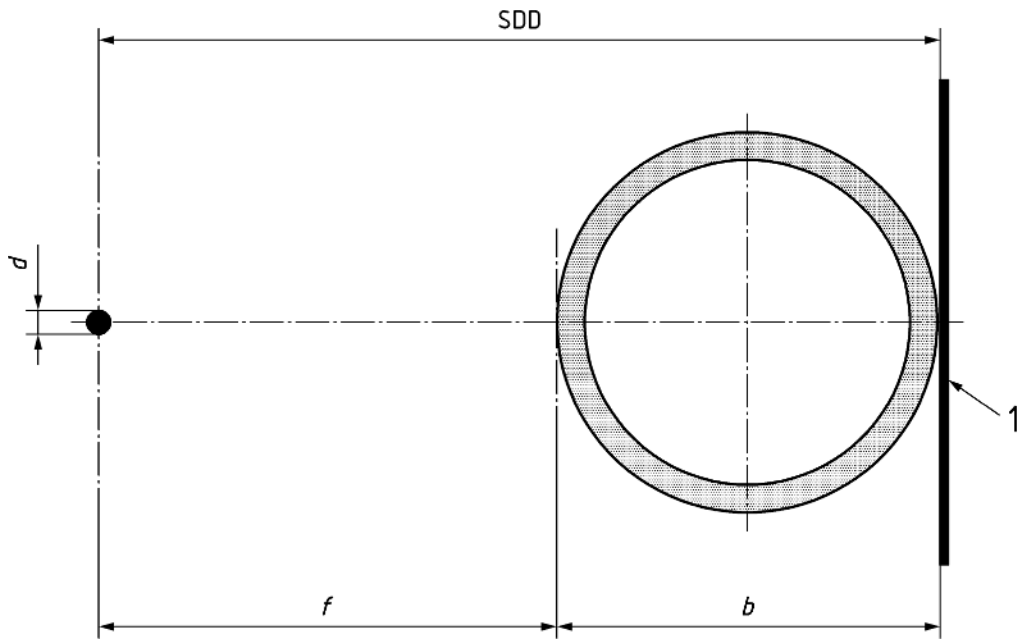
Key

1 detector

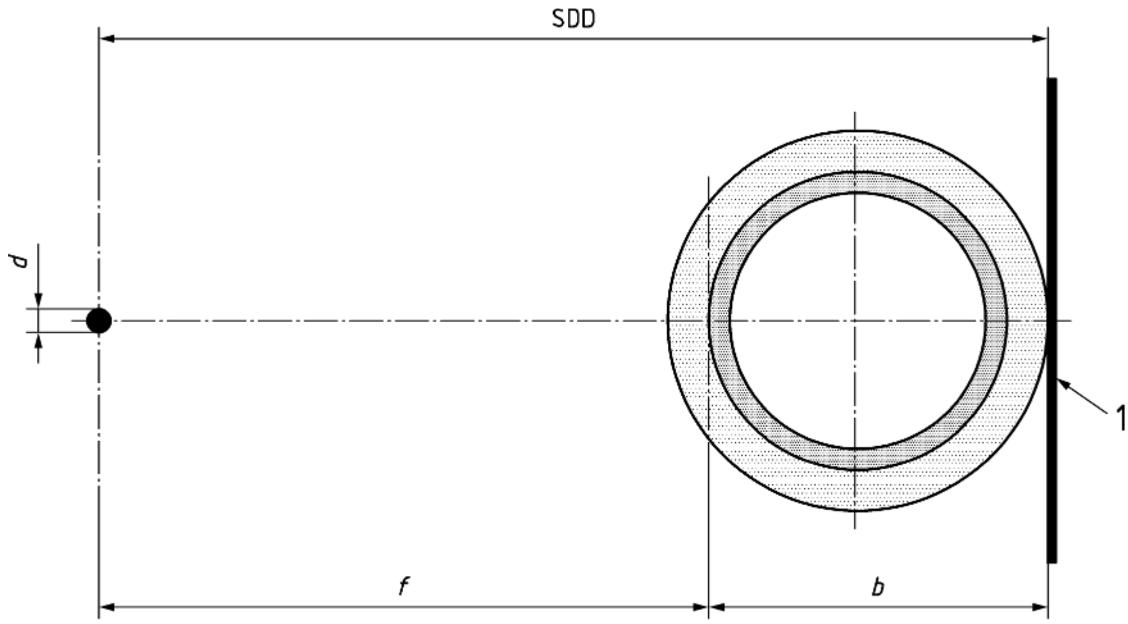
Figure 2 — Test arrangement for double wall single image radiography (DWSI) using a planar detector

6.1.3 Double wall double image (DWDI)

For this arrangement, the radiation source is located in front of the pipe and with the planar film/detector at the opposite side, as shown in Figure 3a) (non insulated pipe) and Figure 3b) (insulated pipe).



a) Non insulated pipe



b) Insulated pipe

Key

1 detector

Figure 3 — Test arrangement for double wall double image radiography (DWDI)

With DWDI, the wall loss can be located on either the inner diameter, outer diameter or both surfaces of the pipe, and on either the source or detector side of the pipe.

If DWDI and tangential radiographic techniques are combined, the requirements of EN 16407-1 shall also be met.

6.1.4 Alignment of beam and film/detector

The beam of radiation shall be directed at the centre of the area being examined and should be perpendicular to the pipe axis.

For DWDI, the film or detector should be aligned to be orthogonal to the centre of the radiation beam.

Modifications to these alignments and the test arrangements given in 6.1.2 and 6.1.3 may be needed in special cases, due for example to the presence of obstructions.

Other ways of radiographing may be agreed between contracting parties.

6.2 Choice of radiation source

Penetrated thickness ranges for X-ray and gamma ray sources are given in Table 1 and Figure 4. By agreement between contracting parties, these ranges can be extended.

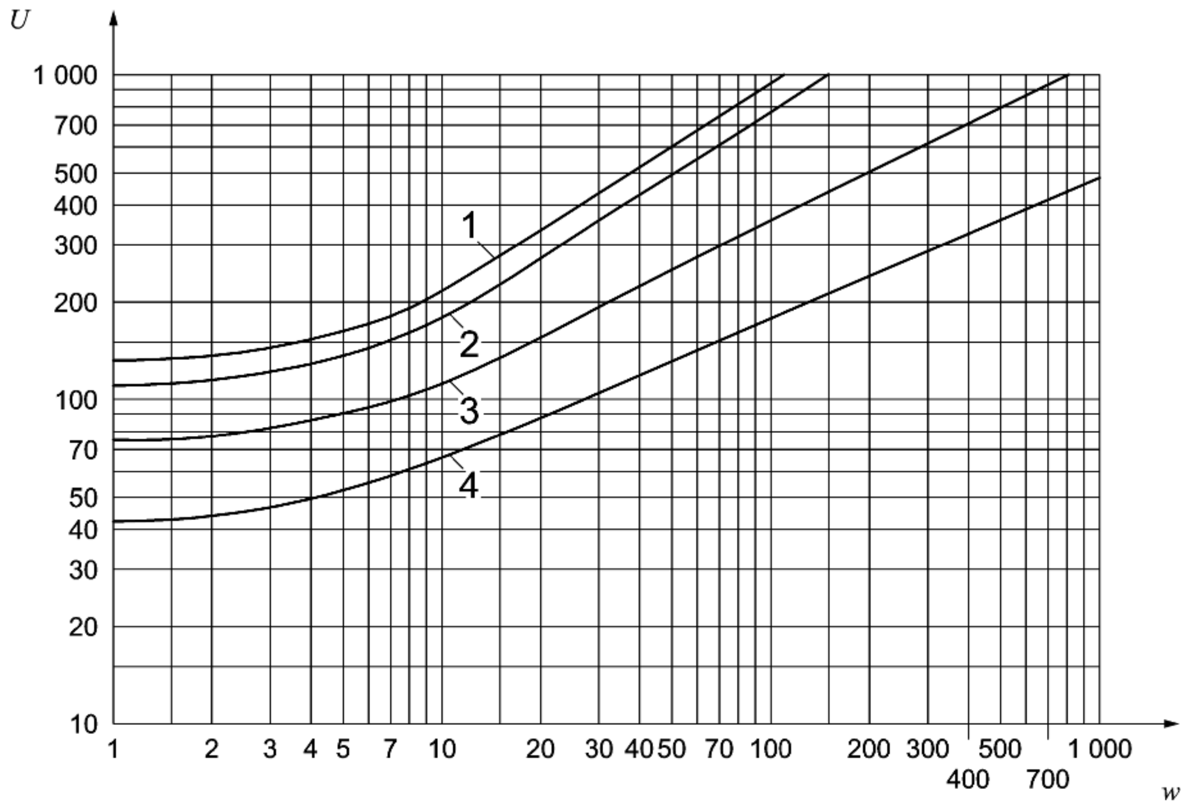
The maximum X-ray voltages shown in Figure 4 are best practice values for film radiography of welds. If DDAs with accurate calibration are used, sufficient image quality can still be obtained using higher X-ray voltages than those shown in Figure 4. For CR applications reduced X-ray voltages by at least 20 % are recommended in comparison to Figure 4.

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

By agreement between the contracting parties the penetrated thickness minimum value for Ir 192 and Se 75 may be reduced to 5 mm of steel.

Table 1 — Total effective penetrated thickness ranges for gamma-ray and high energy X-ray sources for steel pipes

Radiation source	Total effective penetrated thickness w_{tot} mm	
	basic technique DWA	improved technique DWB
Yb 169	$1 \leq w_{tot} \leq 15$	
Se 75 [a]	$5 \leq w_{tot} \leq 55$	$10 \leq w_{tot} \leq 40$
Ir 192	$10 \leq w_{tot} \leq 100$	$20 \leq w_{tot} \leq 90$
Co 60	$40 \leq w_{tot} \leq 200$	
X-ray equipment with energy from 1 MeV to 4 MeV	$30 \leq w_{tot} \leq 200$	
X-ray equipment with energy from 4 MeV to 12 MeV	$w_{tot} \geq 50$	
X-ray equipment with energy above 12 MeV	$w_{tot} \geq 80$	
[a] For aluminium and titanium the penetrated material thickness is 35 mm $\leq w_{tot} \leq$ 120 mm for class DWA and DWB testing.		



Key

1 copper/nickel and alloys

2 steel

3 titanium and alloys

4 aluminium and alloys

w penetrated thickness in mm

U X-ray voltage in kV

Figure 4 — Maximum X-ray voltage *U* for X-ray devices up to 1 000 kV as a function of penetrated thickness *w* and material

For product filled pipes, the additional radiation attenuation caused by the product shall be allowed for in the selection of sources. For a water-filled pipe, the penetrated thickness, w, for steel tested with Ir 192 shall be increased by approximately one-ninth of the path length in the water to calculate w_{tot}. For an oil-filled pipe, the penetrated thickness, w, shall be increased by approximately one-eleventh of the path length in the oil to calculate w_{tot}.

For insulated pipes the additional radiation attenuation caused by the insulation shall be allowed for in the selection of sources.

6.3 Film systems and screens

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

The radiographic film system class and metal screens for different radiation sources are given in Table 2.

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

Table 2 — Film system classes and metal screens for double wall radiography of steel, copper and nickel based alloy pipes

Radiation source	Film system class [a]		Type and thickness of metal screens
	Class DWA	Class DWB	
X-ray potentials ≤ 250 kV	C 5	C 4	0,02 mm to 0,15 mm front and back screens of lead
X-ray potentials > 250 kV to 500 kV	C 5	C 4	0,1 mm to 0,2 mm front screens of lead [b] 0,02 mm to 0,2 mm back screens of lead
X-ray potentials > 500 kV to 1 000 kV	C 5	C 4	0,25 mm to 0,7 mm front and back screens of steel or copper [c]
Se 75 Ir 192	C 6	C 5	0,02 mm to 0,2 mm front and back screens of lead [b]
Co 60	C 6	C 5	0,25 mm to 0,7 mm front and back screens of steel or copper [c]
X-ray equipment with energy from 1 MeV to 4 MeV	C 6	C 5	0,25 mm to 0,7 mm front and back screens of steel or copper [c]
X-ray equipment with energy above 4 MeV	C 6	C 5	Up to 1 mm front screen of copper, steel or tantalum [d] Back screen of copper or steel up to 1 mm and tantalum up to 0,5 mm [d]

[a] Better film system classes may also be used.

[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 class DWA 0,5 mm to 2,0 mm screens of lead may also be used.

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

Table 3 — Film system classes and metal screens for double wall radiography of aluminium and titanium pipes

Radiation source	Film system class [a]		Type and thickness of intensifying screens
	Class DWA	Class DWB	
X-ray potentials ≤ 150 kV	C 5	C 4	None or up to 0,03 mm front and up to 0,15 mm back screens of lead
X-ray potentials > 150 kV to 500 kV			0,02 mm to 0,2 mm front and back screens of lead [b]
Se 75 Ir 192 [c]			0,02 mm to 0,2 mm front and back screens of lead [b]

a Better film system classes may also be used.

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

c Ir 192 may be applied by agreement of contracting parties.

Different film system classes may be used by agreement of the contracting parties, provided the required optical densities defined in 7.2 are achieved.

6.4 Screens and shielding for imaging plates (computed radiography only)

When using metal front screens, good contact between the sensitive detector layer and screens is required. This may be achieved either by using vacuum-packed IPs or by applying pressure. Lead screens not in intimate contact with the IPs may 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 SNR, and should be minimized. It is recommended that steel or copper shielding be used directly behind the IPs. A steel or copper shielding between a backscatter lead plate and the IP may also improve the image quality. Modern cassette and detector designs may 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 % only (compared to no screen).

The small intensification effect generated by a lead screen in contact with an IP can be compensated for by increased exposure time or milliampere minutes, if no lead screens are used. Since lead screens in contact with IPs may 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 specimens having a thickness < 12 mm.

Table 4 and Table 5 show the recommended screen materials and thicknesses for different radiation sources. Other screen thicknesses may be also 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 may also reduce the influence of scattered radiation when used with DDAs.

Table 4 —Metal front screens for CR for double wall radiography for pipes of steel, copper and nickel based alloys

Radiation source	Type and thickness of metal front screens mm
X-ray potentials[b] ≤ 250 kV	0 to 0,1 (lead)
X-ray potentials[b] > 250 kV to 1000 kV	0 to 0,3 (lead) [c]
Ir 192, Se 75[b]	Class DWA: 0 to 0,3 (lead) [c] Class DWB: 0,3 to 0,8 (steel or copper)
Co 60 [a]	0,3 to 0,8 (steel or copper) + 0,6 to 2,0 (lead)
X-ray potentials [a] > 1 MV	0,3 to 0,8 (steel or copper) + 0,6 to 2,0 (lead)

a In the case of multiple screens (steel+lead), the steel screen shall be located between the IP and the lead screen. Instead of steel or steel and lead screens, those composed of copper, tantalum or tungsten may be used if the image quality can be proven.

b 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.

c For total penetrated thickness above 50 mm the front screen thickness should be larger than 0,1 mm Pb.

Table 5 — Metal front screens for CR for the double wall radiography of aluminium and titanium

Radiation source	Type and thickness of metal front screens mm
X-ray potentials < 150 kV	≤ 0,03 (lead)[a, b]
X-ray potentials ≥ 150 to 500 kV	≤ 0,2 (lead)[a, b]
Se 75 Ir 192 [c]	≤ 0,3 (lead)[a, b]

a For example, 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 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.

c Ir 192 may be applied by agreement of contracting parties.

6.5 Reduction of scattered radiation

6.5.1 Filters and collimators

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

For computed radiography and radiography with DDAs, with Ir 192, Co 60 and other MeV radiation sources or in case of edge scatter an additional sheet of lead can be used as a filter of low energy scattered radiation between the pipe and the DDA or CR cassette. The thickness of this sheet is 0,5 mm to 2,0 mm in accordance with the penetrated thickness.

Materials other than lead such as tin, copper, tungsten or steel can be used as a filter. It is recommended that in the case of a lead filter an additional steel or copper filter is used between the lead and the detector of thickness 0,3 mm to 1,0 mm. The filter should be as close as possible to the sensitive plate.

6.5.2 Interception of back scattered radiation

The presence of back scattered radiation shall be checked for each new test arrangement by a lead letter B (with a minimum height of 10 mm and a minimum thickness of 1,5 mm) placed immediately behind each film, CR cassette or DDA. If the image of this symbol records as a lighter image on the radiograph (negative presentation), it shall be rejected. If the symbol is darker or invisible the radiograph is acceptable and demonstrates good protection against scattered radiation.

For digital radiography, if necessary, the detector shall be shielded from back scattered radiation by lead of at least 1 mm, or tin of at least 1,5 mm, placed behind the detector. In some configurations, up to 6 mm of lead may be necessary. An additional shielding of steel or copper (about 0,5 mm) 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 to the back side of the detector above 80 keV.

6.6 Source-to-detector distance

6.6.1 Double wall single image

The dimensions involved for source to detector determination for the DWSI technique are shown in Figure 1.

For the basic technique, DWA, the source to detector distance SDD (in millimetres) shall be, where practicable:

$$\text{SDD} \geq \frac{d \cdot b}{0{,}6\ \text{mm}} \qquad (1)$$

where

b is the distance between the source side of the pipe and the detector in millimetres;

d is the source size in millimetres.

For the improved technique, DWB, the source to detector distance SDD (in millimetres) shall be, where practicable:

$$\text{SDD} \geq \frac{d \cdot b}{0{,}3\ \text{mm}} \qquad (2)$$

Formula (1) and Formula (2) give geometric unsharpness values of 0,6 mm and 0,3 mm respectively, projected onto a plane corresponding to the source side of the pipe wall nearest the detector. The corresponding unsharpness values measured at the detector are slightly larger than these values due to the effects of projective magnification.

NOTE The outside diameter of the pipe often means that the achievable source to detector distances will be greater than the values given in Formula (1) and Formula (2).

6.6.2 Double wall double image

The distances involved for source to detector determination for the DWDI technique are shown in Figures 3a) and 3b). The object plane is the source side of the pipe wall nearer the detector.

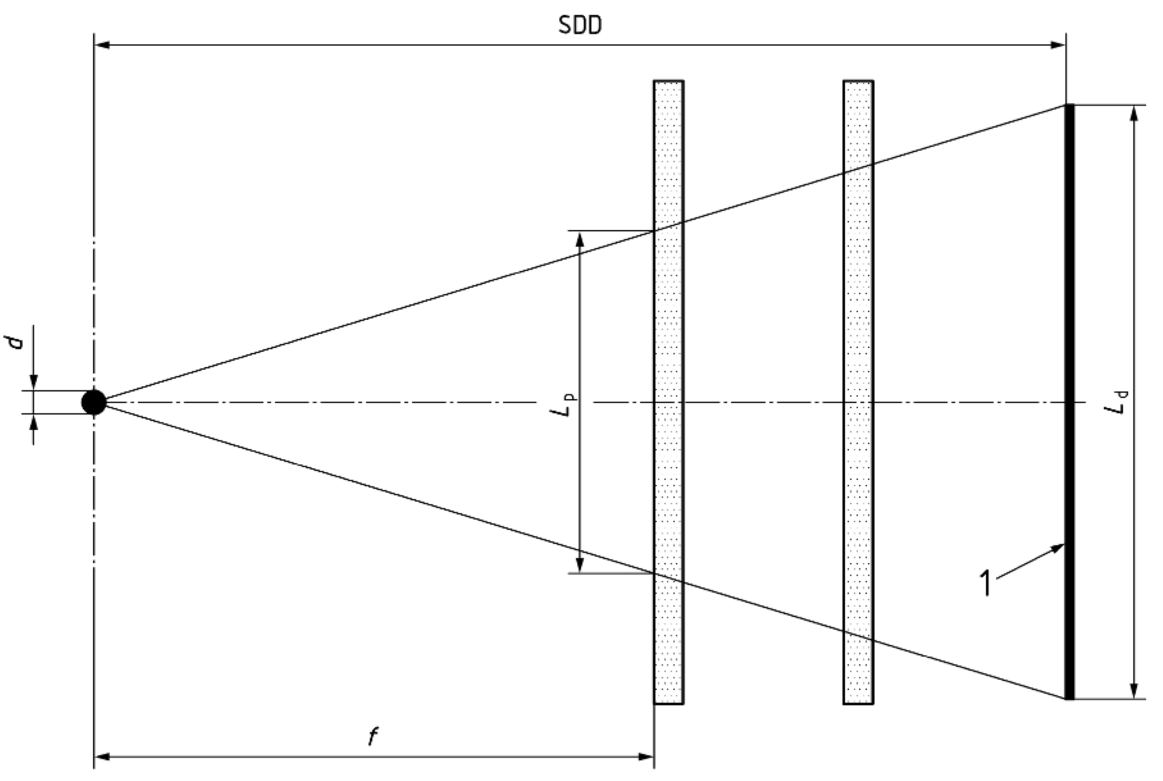
For the basic technique, DWA, the source to detector distance SDD shall be, where practicable by given by Formula (1) above. For the improved technique, DWB, the source to detector distance SDD shall be given by Formula (2).

Note however that the dimension b is measured differently for DWSI and DWDI, and is shown in Figure 1, Figure 2 and Figure 3 respectively for these techniques.

If the double wall double image technique is combined with tangential radiography, the source to pipe centre distance should be determined by also taking account of the criteria used for the tangential technique, as given in Part 1 of this standard. The larger of the two values shall be taken where practicable.

6.7 Axial coverage and overlap

The maximum axial coverage of the pipe for a single image or film is based on a 20 % increase in penetrated thickness at the edge of the area to be inspected, as illustrated in Figure 5.



Key

1 detector

Figure 5 — Axial cross section showing the maximum permissible axial length of the evaluated area for a single source position, on the film/detector, L_d, and along the pipe, L_p, on the source side of the pipe

The total axial extent of the evaluated area on the detector, L_d, should be no greater than:

$$L_d \leq 1{,}32 \text{ SDD} \quad (3)$$

The total axial extent of the evaluated area on the source side of the pipe, L_p, should be no greater than:

$$L_p \leq 1{,}32 f \quad (4)$$

For DWSI, f shall be measured as shown in Figure 5.

The formula for L_p should be used for determining the interval between exposures along a pipe. If the collimator of gamma sources or the window collimation of X-ray sources are smaller than ± 35°, L_p and L_d have to be reduced corresponding to the maximum available opening angle of the radiation cone beam.

The separate films or digital images shall overlap sufficiently to ensure that no portion of the component remains un-examined. Unless otherwise specified, the minimum overlap shall be 25 mm axially either side of the diagnostic area, measured on the source side.

6.8 Circumference coverage

6.8.1 General

When using the DWDI and DWSI techniques, then full circumferential coverage of a pipe is achieved by taking a number of different exposures around the pipe circumference.

6.8.2 DWSI

For DWSI, the number of circumferential exposures is calculated on the basis of a 20 % increase in penetrated thickness due to inclined penetration at the edges of the diagnostic area. The number of exposures is a function of the source to pipe centre distance (SPD), the pipe outside diameter (D_e) and the pipe wall thickness (t).

Figure 6 shows the number of exposures needed, as a function of two dimensionless variables – t/D_e and D_e/SPD. This figure is applicable if the detector is offset from the pipe due to the presence of insulation.

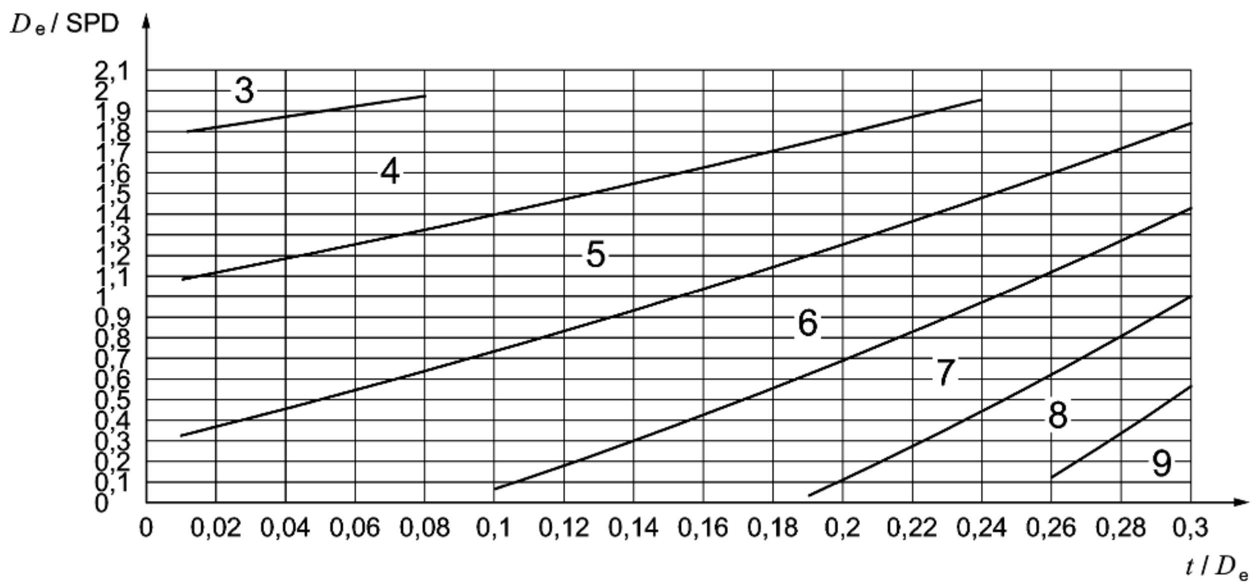


Figure 6 — Minimum number of DWSI exposures circumferentially around a pipe, as a function of the ratios t/D_e and D_e/SPD, where SPD is the distance from the source to the pipe axis (centre)

To obtain the circumferential angular difference, $\Delta\theta$, (degrees) between exposures, the following formula should be used for DWSI:

$$\Delta\theta = \frac{360°}{N} \quad (5)$$

where

N is the number of exposures given in Figure 6. Alternative values may be used by agreement between contracting parties.

6.8.3 DWDI

To inspect the full circumference of the pipe, at least two exposures are needed for DWDI, separated in circumferential angle by at least 45° (for best results the angle would be 90°). A single exposure may be sufficient if only a fraction of the circumference needs to be inspected.

Alternative values may be used by agreement between contracting parties.

6.9 Selection of digital radiographic equipment

6.9.1 General

The basic spatial resolution of the detector shall not exceed 200 µm for class DWA and 130 µm for class DWB and shall not exceed 5 % of the nominal wall thickness t. Different values can be agreed by contracting parties.

6.9.2 CR systems

The CR scanner pixel size shall not exceed 100 µm. For a given radiographic exposure, increasing the CR scanner gain or sensitivity increases the grey levels, but has negligible effect on the image quality, as measured by the normalized signal to noise ratio (SNR_N). To increase SNR_N, the exposure shall be increased, not the scanner gain.

For scanners with linear responses between radiation dose and grey level, use of low gain/sensitivity reduces the likelihood of image saturation. For higher scanner gains, image saturation may occur, especially in the free beam areas, for relatively short exposures, which do not give sufficiently high image SNR_N values to meet the image quality criteria given in 7.1.

6.9.3 DDA systems

The detector pixel size shall not exceed 200 µm for class DWA and 130 µm for class DWB. Different values can be agreed by contracting parties.

7 Radiograph/digital image sensitivity, quality and evaluation

7.1 Minimum image quality values

7.1.1 Wire image quality indicators

The requirements for IQI values for Ir 192 and Se 75 for testing of selected thickness ranges of steel pipes are given in Annex A. Requirements for other thickness ranges, radiation sources, pipe materials and highly absorbing insulation may be taken from EN ISO 19232-3, class A or may be derived according to EN ISO 19232-4.

For DWDI, if the IQIs cannot be placed on the source side of the object (e.g. due to the presence of insulation), the IQIs shall be placed on the detector side, and Table A.2 and Table A.4 for DWSI shall be used for minimum quality values.

Reference radiographs should be taken to qualify the technique depending on the inspected material, the material thickness, the used radiation quality, filters, screens and the used detector.

7.1.2 Duplex wire IQIs (digital radiographs)

Duplex wire IQIs (EN ISO 19232-5) shall be used for determination of the basic spatial resolution of the digital detector from a reference image according to Annex C, see 7.1.3.

7.1.3 Minimum normalized signal to noise ratio (digital radiographs)

Digital radiographic images become "noisy" when exposed under sub-optimal conditions (e.g. due to short exposure times). Excessive image noise can become a significant obstacle in the achievement of acceptable detection sensitivity.

To ensure that the digital image from CR and DDA systems have acceptable noise levels, the normalized signal to noise ratio, SNR_N, shall be measured using appropriate software and methods as defined in EN 14784-1 using an area of at least 55 (vertically) × 20 (horizontally) pixels. SNR_N values shall be measured at a minimum of four separate positions, and the average value taken.

To derive the normalized SNR_N value, the basic spatial resolution, SR_b, of the imaging system shall be measured using the duplex wire IQI method described in EN ISO 19232-5, or an equivalent method (see Annex C). If it is impractical to include a duplex wire IQI on each exposure, the basic spatial resolution can be determined in advance for the same imaging system, provided exactly the same system settings are used (for a CR system, these settings include the same CR scanner, imaging plate, pixel size and radiation source).

The average SNR_N values obtained on the pipe centre line shall be at least 50 for the Basic Technique, DWA, and shall be at least 80 for the Improved Technique, DWB. The SNR shall be measured on the pipe centre line in a zone of homogeneous wall thickness and grey values.

For certain objects, such as those containing large-scale irregular corrosion, or other forms of wall thickness variations, there may be no homogeneous regions suitable for measurement of SNR_N. In these cases, the mean image grey level on the pipe centre line shall be measured. This mean grey level shall exceed that found by a calibration technique that allows derivation of a minimum grey level equivalent to the required SNR_N value (50 for DWA, 80 for DWB) for the same detector used with the same gain/sensitivity and other user settings as the test image (see EN ISO 17636-2:2013, Annex D).

Note that in all cases when measuring SNR_N, it is important that the image is in a form having the image grey levels directly proportional to radiation intensity, otherwise the values will be incorrect.

7.2 Density of film radiographs

Exposure conditions should be such that the minimum optical density of the radiograph in the area examined is greater than or equal to 2,0. A measuring tolerance of ± 0,1 is permitted. This may be reduced by special agreement between the contracting parties to 1,5.

High optical densities can be used with advantage where the viewing light is sufficiently bright in accordance with 7.4.

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

7.3 Film processing

Films are processed in accordance with the conditions recommended by the film and chemical 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 EN ISO 11699-2. The radiographs should be free from defects due to processing or other causes which would interfere with interpretation.

7.4 Film viewing conditions

The radiographs should be examined in a darkened room on an area of the viewing screen with an adjustable luminance in accordance with EN 25580. The viewing screen should be masked to the area of interest.

8 Measurement of differences in penetrated thickness

8.1 Principle of technique

To a first approximation, the radiation intensity transmitted through an object is related to penetrated thickness by:

$$I(w) = I(0)\ \exp(-\mu\ w) \tag{6}$$

where

- $I(w)$ is the intensity for penetrated thickness w;
- $I(0)$ is the unimpeded radiation intensity incident on the object;
- μ is the effective linear attenuation coefficient of the object material.

Differences in penetrated thickness within a component therefore give rise to corresponding changes in film density or image grey level for digital images.

In principle, for digital images, software can be used to estimate these changes in penetrated thickness from analysis of the corresponding grey level values. Consider two different penetrated thickness values w_1 and w_2. Assuming equal incident radiation intensities and attenuation coefficients for these two penetrated thickness values, application of Formula (6) then gives:

$$w_2 - w_1 = \frac{1}{\mu}\ln\left(\frac{I(w_1)}{I(w_2)}\right) \tag{7}$$

Formula (7) shows that the difference in penetrated thickness, $w_2 - w_1$, can be derived from the ratio of the two radiation intensities and the effective linear attenuation coefficient of the material.

The ratio of radiation intensities in film radiography shall be determined from the measured netto optical densities by the following formula:

$$I(w_1)/I(w_2) = ((D_1 - D_0)/(D_2 - D_0)) \quad (8)$$

where

D_0 is the optical density of film base and fog.

In applying this method to digital radiographs it is therefore important to ensure that the image grey levels are directly proportional to the detected radiation intensity.

8.2 Measurement of attenuation coefficient

The effective linear attenuation coefficient for the material under test can be affected by scattered radiation, and therefore shall be measured for each test object by means of a small step wedge. The step wedge shall have steps each with an area of about 10 mm x 10 mm, and each step should have an accurately machined known thickness (e.g. 1 mm and 2 mm).

The step wedge shall be positioned on the pipe so as to be imaged as close as possible to the area of interest. For the DWDI method, the step wedge can be positioned on the source or detector side of the pipe. For DWSI, the step wedge needs to be positioned between the pipe wall and detector. However any significant distortion/bending of the IP or film should be avoided.

8.3 Source and detector positioning

For application of this technique, the source and detector shall be positioned so that the area of interest lies as close as possible to the pipe centre line and in the centre of the radiographic image. This is particularly important for smaller diameter pipes, where the penetrated thickness increases rapidly with distance away from the pipe centre line.

8.4 Image grey level profiles

The shape of the underlying image grey level profile between the two areas in the image being measured shall be assessed and allowed for if necessary as described in Annex B.

8.5 Validation

This technique for measurement of penetrated thickness changes shall be validated by means of exposures using calibration objects closely representative of the test object. A suitable validation object would have the same diameter, wall thickness and material as the test object, and contain machined flat-bottomed holes of accurately known depths, both smaller than and greater than the loss of wall in the test object.

Validation radiographs shall be taken under identical radiographic conditions to the test radiographs, and the measurements of the wall loss of the holes, made with the available software tool, shall be demonstrated to agree with the known values to the required degree of accuracy.

8.6 Key Points

The key points for this technique are:

— The method can only give measurements of the change in penetrated thickness between two different locations in a radiographic image, not an absolute value of penetrated thickness.

— The digital image grey levels shall be linearized such that the grey levels are directly proportional to incident radiation intensity.

— The effective attenuation coefficient of the object shall be measured by means of a small step wedge located close to the area of thickness change being measured.

— The underlying image grey level profile between the two measurement positions needs to be assessed and any variations taken into account.

— The accuracy of the method shall be validated by means of analysis of radiographs of a validation object with dimensions closely matching the test object. The radiographic conditions and software tool used for the validation object shall be the same as those used for the test object.

9 Digital image recording, storage, processing and viewing

9.1 Scan and read out of image

Detectors or scanners are used in accordance with the conditions recommended by the detector and 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 would interfere with interpretation.

9.2 Calibration of DDAs

If using DDAs, the detector calibration procedure as recommended by the manufacturer shall be applied. The detector shall be calibrated with a background image (without radiation) and at least with one gain image (radiation on and homogeneously exposed). Multi gain calibration will increase the achievable SNR_N and linearity but takes more time. All calibration images shall be taken at least with 2 times larger exposure dose (mA.min or GBq.min) as finally used for the production radiographs to minimize the noise introduction of the calibration procedure. Calibrated images should be treated as unprocessed raw images for quality assurance if the procedure has been documented. The calibration and a bad pixel interpolation shall be performed periodically and if the exposure conditions are changed significantly.

9.3 Bad pixel interpolation

Bad pixels are underperforming detector elements of DDAs. They are described in ASTM E2597. 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. The bad pixel interpolation is acceptable and an essential procedure of radiography with DDAs. It is recommended to apply only detectors which have no cluster kernel pixels (CKP) in the region of interest (ROI).

9.4 Image processing

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, 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 should 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 1 pixel of the digital radiograph is presented by one monitor pixel) and 1:2 (meaning 1 pixel of the digital radiograph is presented by four monitor pixels).

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.

9.5 Digital image recording and storage

CR/DDA images should be stored in a file format which supports a minimum of 12-bits/pixel.

The original images shall be stored in full resolution as delivered by the detector system. Only image processing connected with the detector calibration (e.g. off-set correction, gain calibration for detector equalisation and bad pixel correction (see also ASTM E2597) to provide artefact free detector images shall be applied before storage of the raw data.

The data storage shall be redundant and be supported by suitable back-up strategies to ensure “loss-less” data storage.

Any data compression techniques used in the storage of these files shall be “loss-less”, i.e. it shall be possible to reconstruct the exact original data from the compressed data.

9.6 Monitor viewing conditions

The digital radiographs shall be examined in a dimmed room. The monitor setup shall be verified with a suitable test image.

The display for image evaluation shall fulfil the following minimum requirements:

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

b) display of at least 256 shades of grey;

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

d) display of at least 1 megapixel resolution, with a pixel pitch of < 0,3 mm.

10 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 which would allow a better understanding of the results.

The test report shall include as a minimum the following information:

a) reference to this standard;

b) name of the examination body;

c) object and pipe isometric and pipe content;

d) material type, outer diameter D_e and nominal wall thickness t of pipe;

e) material, thickness and condition of insulation;

f) specification of examination including requirements for IQI acceptance;

g) radiographic technique and class;

h) test arrangement in accordance with 6.1;

i) system of marking used;

j) detector position plan;

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

l) detector, screens and filters;

m) used tube voltage and current or source activity;

n) time of exposure, SDD and PDD;

o) film type, film system and film processing;

p) CR system, IP type, scanner model, scanner parameters, e.g. scan speed, gain, laser intensity, laser spot size, pixel size;

q) DDA type, operating parameters, pixel size;

r) basic spatial resolution of digital detectors;

s) measured image parameters:

    1) film densities measured at pipe centre;

    2) SNR_N, achieved at the pipe centre;

    3) IQI reading;

t) measured wall thickness differences in penetration direction;

u) additional observations;

v) any deviation from this standard, by special agreement;

w) name, certification and signature of the operator;

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

Annex A
(normative)

Minimum image quality values

The requirements for IQI values for Ir 192 and Se 75 for testing of selected thickness ranges of steel pipes are given in Table A.1, Table A.2, Table A.3 and Table A.4. Requirements for other thickness ranges, radiation sources, pipe materials and highly absorbing insulation may be derived according to EN ISO 19232-4.

Table A.1 — DWDI Iridium 192 – source side wire IQIs

Basic technique		Improved technique	
Total effective penetrated thickness mm	IQI value	Total effective penetrated thickness mm	IQI value
$5 \leq w_{tot} < 15$	W 9	$5 \leq w_{tot} < 8$	W 12
$15 \leq w_{tot} < 25$	W 8	$8 \leq w_{tot} < 12$	W 11
$25 \leq w_{tot} < 40$	W 7	$12 \leq w_{tot} < 15$	W 10
$40 \leq w_{tot} < 60$	W 6	$15 \leq w_{tot} < 20$	W 9
		$20 \leq w_{tot} < 35$	W 8

Table A.2 — DWSI Iridium 192 – detector side wire IQIs

Basic technique		Improved technique	
Total effective penetrated thickness mm	IQI value	Total effective penetrated thickness mm	IQI value
$5 \leq w_{tot} < 10$	W 11	$15 \leq w_{tot} < 20$	W 10
$10 \leq w_{tot} < 15$	W 10	$20 \leq w_{tot} < 35$	W 9
$15 \leq w_{tot} < 25$	W 9	$35 \leq w_{tot} < 60$	W 8
$25 \leq w_{tot} < 30$	W 8		
$30 \leq w_{tot} < 60$	W 7		

Table A.3 — DWDI Selenium 75 – source side wire IQIs

Basic technique		Improved technique	
Total effective penetrated thickness mm	**IQI value**	**Total effective penetrated thickness** mm	**IQI value**
5 ≤ w_{tot} < 12	W 11	5 ≤ w_{tot} < 10	W 12
12 ≤ w_{tot} < 18	W 10	10 ≤ w_{tot} < 20	W 11
18 ≤ w_{tot} < 25	W 9		
25 ≤ w_{tot} < 35	W 8		

Table A.4 — DWSI Selenium 75 - detector side wire IQIs

Basic technique		Improved technique	
Total effective penetrated thickness mm	**IQI value**	**Total effective penetrated thickness** mm	**IQI value**
5 ≤ w_{tot} < 15	W 11	5 ≤ w_{tot} < 25	W 11
15 ≤ w_{tot} < 25	W 10	25 ≤ w_{tot} < 40	W 10
25 ≤ w_{tot} < 30	W 9	40 ≤ w_{tot} < 45	W 9
30 ≤ w_{tot} < 55	W 8		

Annex B
(informative)

Penetrated thickness measurements from image grey levels

A number of effects cause spatial variations in the image grey level across a radiographic image. These include (i) the angular dependence to the radiation beam intensity emitted by the source, (ii) changes in object penetrated thickness and (iii) the variations in the distances between the source and the different points in the detector.

For measurements of changes in penetrated thickness, it is necessary to ensure that the unimpeded radiation intensities (I_0), as defined in Formula (6), are the same for the two thickness values being measured. This inevitably requires extrapolation or interpolation of grey levels measured in one position in an image to another adjacent position, as illustrated in Figure B.1 and Figure B.2.

Figure B.1 shows a DWDI digital radiograph of a pipe containing a small well defined circular area of wall loss, and also a small step wedge used for the measurement of the effective attenuation coefficient. A profile extracted in the along pipe axis direction shows that the grey level profile corresponding to the pipe base material (without wall loss) is approximately constant. In this case, a reference measurement of the image grey level corresponding to the base material can be made with reasonable accuracy at a position adjacent to the area of wall loss in the direction parallel to the pipe axis (e.g. above the area of wall loss on Figure B.1).

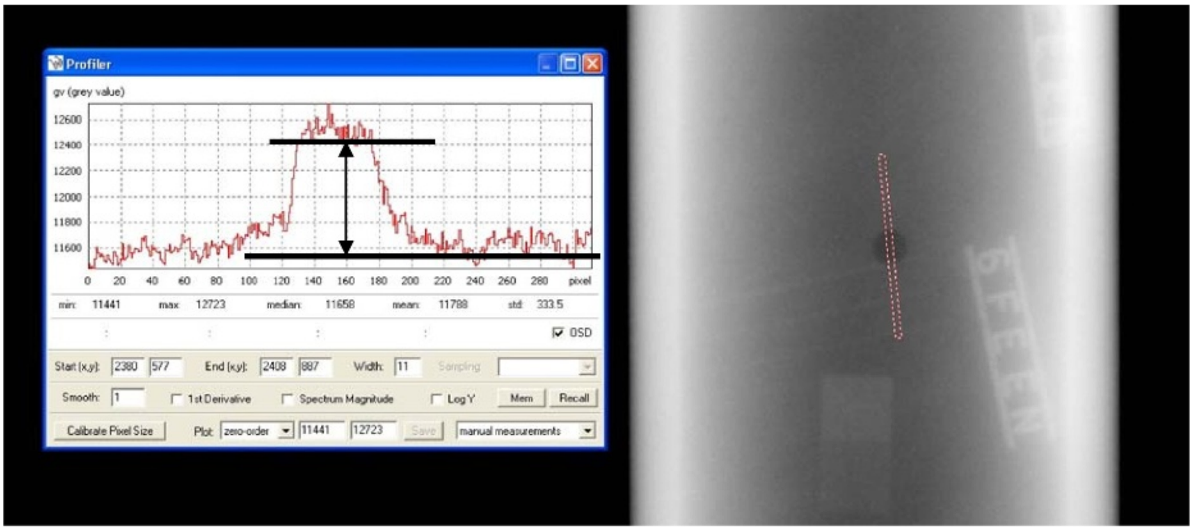


Figure B.1 — CR image of a 3” test pipe containing internal holes and showing a step wedge for calibration of the attenuation coefficient

In Figure B.1, the grey level profile taken in the pipe axis direction shows a relatively constant background level, that can be measured using a reference area on one side of the flaw only.

Consider however Figure B.2 which shows the same digital radiograph as in Figure B.1, but with a grey level profile taken in the orthogonal direction, i.e. across the pipe axis. In this case, the grey level profile corresponding to the base material shows a pronounced curvature, primarily due to the increase in penetrated thickness away from the pipe centre line.

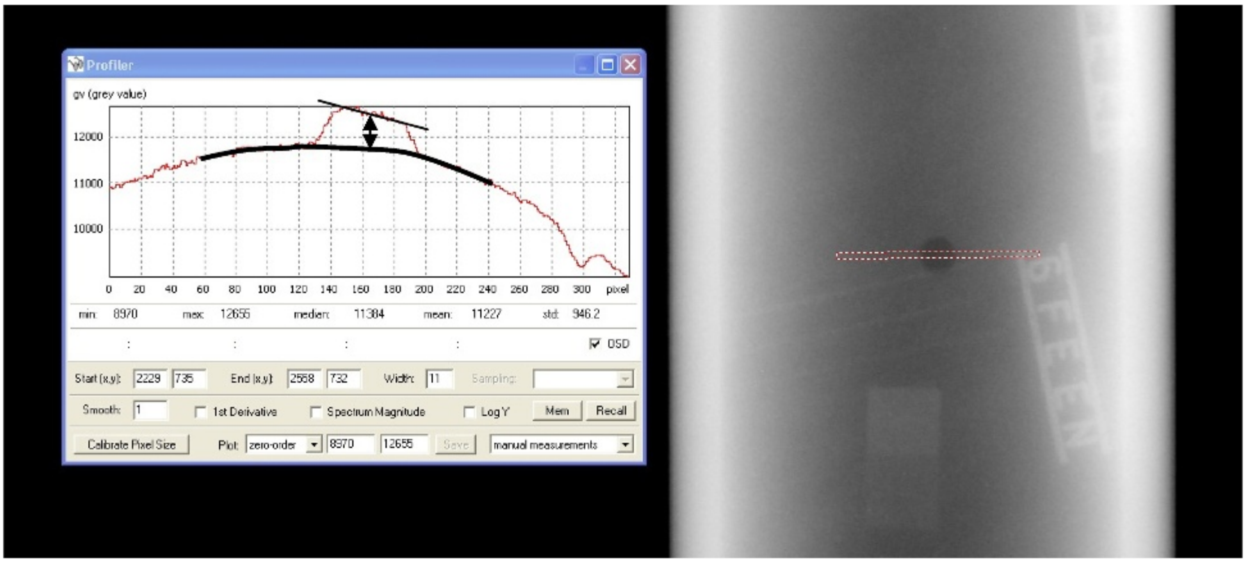


Figure B.2 — CR image of a 3” test pipe containing internal holes and showing a step wedge for calibration of the attenuation coefficient

In Figure B.2, the grey level profile taken in the across pipe direction shows a curved background level which cannot be measured adequately using a single reference area.

In Figure B.2 it can be seen that, due to the curvature in the underlying grey-scale profile, measurements either side of the area of wall loss will not give an adequate measure of the grey level corresponding to the base material, at the position of the area of wall loss. Instead more sophisticated interpolation/extrapolation techniques would be needed to measure the grey levels at the image location indicated by the arrow on the profile shown in Figure B.2.

Any software method used to estimate the grey level corresponding to the base material, at the position of an area of change in thickness, should be capable of assessing and, if necessary, taking account of the shape of this grey level profile between any defined reference areas and the centre of the area of the change in thickness. The user should assess the shape of the grey level profile and hence determine its effect on the accuracy of the method.

Note that a single reference area is insufficient to allow for the curved profile shown in Figure B.2, but may be sufficient for the almost constant profile shown in Figure B.1.

It shall also be noted that similar issues apply when measuring the effective attenuation coefficient from the step wedge response (i.e. a localized area of known increase in penetrated thickness).

Annex C
(normative)

Determination of basic spatial resolution

Linearized grey levels are the precondition for the measurement of correct basic spatial resolution values. This means 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 software.

The duplex wire IQI shall be positioned directly on the detector surface or cassette surface and shall be read in accordance with EN ISO 19232-5 for determination of the detector basic spatial resolution SR_b.

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

If the first unsharp wire pair cannot be recognised clearly (see EN ISO 19232-5), the 20 % dip method shall be applied as follows:

On the digital radiograph, the first wire pair giving a modulation (dip) of less than 20 % in relation to the double peak size (see Figure C.1) shall be documented as the result of the IQI test (e.g. D8 as shown in Figure C.1a). A profile function of the image processing software shall be used to recognize the first wire pair with a dip of less than 20 % (when averaged over both minima – see Figure C.1(d)). The profile shall also be averaged (see Figure C.1 b-c) over at least 21 single line profiles to improve the SNR in the profile plot.

By usage of the duplex wire IQI, conforming to EN ISO 19232-5, the inherent image unsharpness u_i shall be determined and the basic spatial resolution SR_b of the detector shall be calculated with:

$$SR_b = \frac{1}{2}\mu_i \qquad (C.1)$$

The duplex wire IQI shall be positioned at an angle of approximately 2° to 5° towards the pixel line or column orientation in order to avoid aliasing effects as shown in Figure C.1.

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

a) Inspection of light alloys:

   1) Tube voltage 90 kV;

   2) prefilter 1 mm Al.

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

   1) Tube voltage 160 kV;

   2) prefilter 1 mm Cu.

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

   1) Tube voltage 220 kV;

   2) prefilter 2 mm Cu.

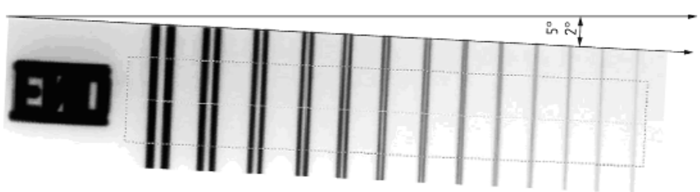
d) Gamma radiography or high energy radiography:

1) Use the gamma source as specified or X-ray source > 1 MV;

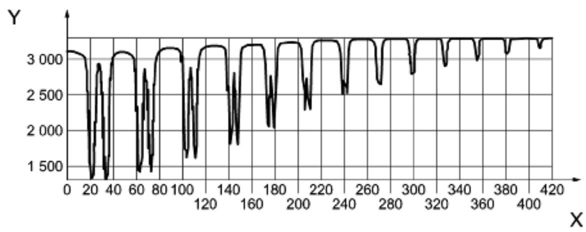
2) prefilter 2 mm Cu or 4 mm steel for Se 75, Ir 192, and 4 mm Cu or 8mm steel for Co 60 or X-ray voltage > 1 MV.

The duplex wire shall be positioned directly on the detector surface or cassette surface. The source to detector distance shall be (1 000 ± 50) mm. The mean grey value in the digital image shall exceed 50 % of the maximum grey value or the SNR shall exceed 100 for standard systems with pixel size ≥ 80 µm or 70 for high resolution systems with pixel size < 80 µm in the reference radiograph. The basic spatial resolution (see Formula C.1) as measured in the reference radiograph for the used digital system and the system settings shall be documented in the examination report.

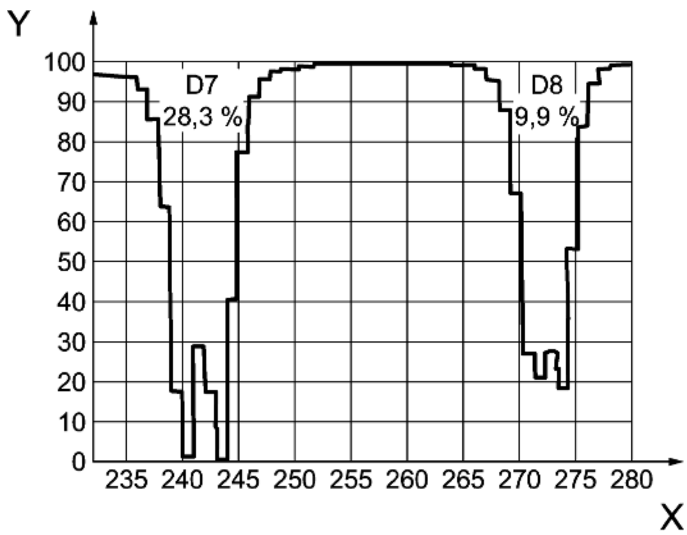
The detector basic spatial resolution of CR systems shall be measured both perpendicular and parallel to the scanning direction of the laser. The higher value of the two SR_b-values shall be used as resulting detector basic spatial resolution (SR_b or $SR_b^{detector}$).



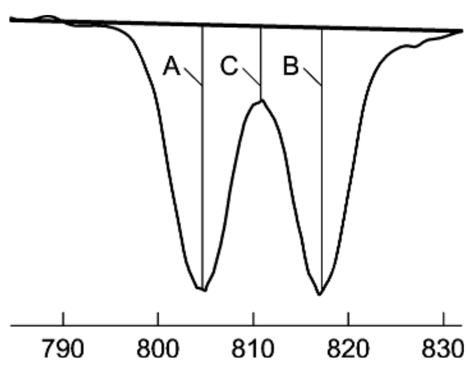
a) Image of the duplex wire IQI as shown in a radiograph



b) Profile of the duplex wire IQI averaged from at least 21 lines



c) Zoomed profile of wire pair D7 and D8



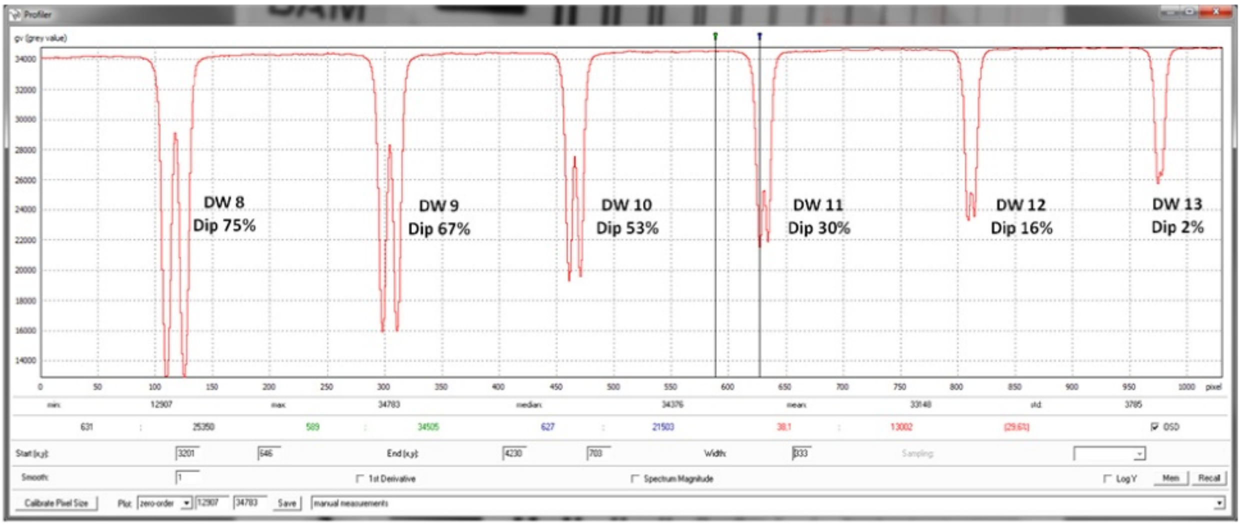
d) Scheme for calculation of the dip value (in %) with: dip = 100 x (A+B-2C)/(A+B)

Key

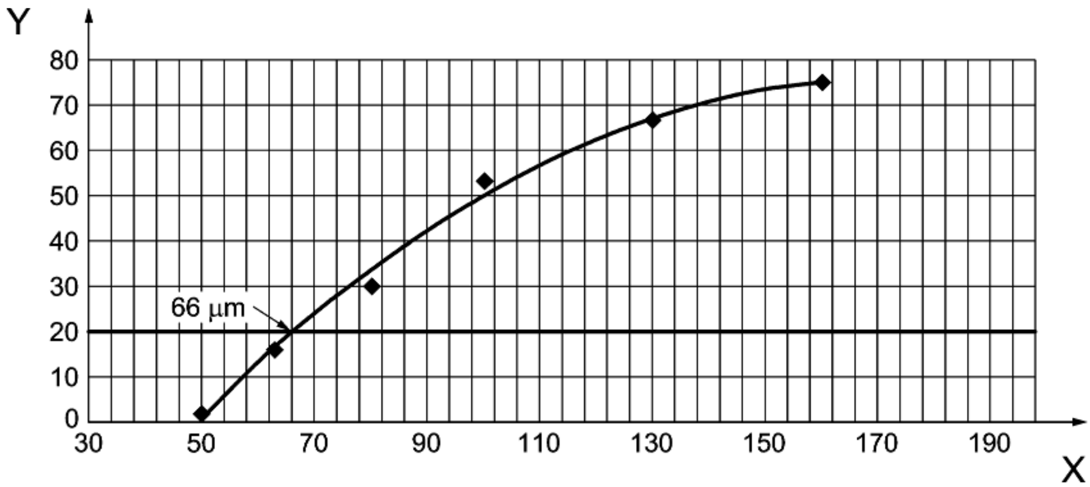
D7, D8 duplex wire IQI values X distance Y amplitude

Figure C.1 — Example for duplex wire IQI evaluation with resulting IQI value D8, being the first one with a dip < 20 %

For improved accuracy in the measurement of the SR_b or SR_b^{image} value, the 20 % dip value should be interpolated from the modulation depth (dip) of the neighbour duplex wire modulations. Figure C.2 represents the corresponding procedure for a high resolution CR system.



a) Profile plot of measured profile of a high resolution system with determined modulation depths (dips)



b) Interpolation of modulation depth vs. duplex wire diameter.

NOTE The 20 % value is determined from the intersection with the 20 % line resulting in iSR_b = 66 µm.

Figure C.2 – Example for determination of the interpolated basic spatial resolution (iSR_b) by interpolation from the measured modulation (dip) of the neighbour duplex wire elements

The dependence of modulation (dip) from wire diameter should be fitted with a polynomial of second order for calculation of the intersection with the 20 % line as indicated in Figure C.2. Modulation values greater than zero shall be used for the interpolation only.

The interpolated SR_b value (see Figure C.2) shall be documented as “interpolated SR_b value” or iSR_b. This value may be used instead of the non-interpolated value SR_b by agreement of contracting parties.

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