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

Part 2:
Double wall radiographic inspection

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

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Foreword

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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).

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This document was prepared by Technical Committee ISO/TC 135 *Non-destructive testing*, Subcommittee SC 5 *Radiographic testing*.

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.

A list of all parts in the ISO 20769 series can be found on the ISO website.

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

Part 2:
Double wall radiographic inspection

1 Scope

This document 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 document 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 document is 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 can 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 document 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 document is often combined with the tangential technique covered in ISO 20769-1.

This document 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 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 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 17636-2, *Non-destructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors*

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

ISO 20769-1, *Non-destructive testing of welds — Radiographic inspection of corrosion and deposits in pipes by X- and gamma rays — Part 1: Tangential radiographic inspection*

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

3   Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20769-1 and the following apply.

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

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

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

3.1
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

3.2
double wall double image technique
DWDI
technique where the radiation source is located outside 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.

3.3
double wall single image technique
DWSI
technique where the radiation source is located outside the pipe and 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.

3.4
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

3.5
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 (pipes in pipe or liners), the penetrated thickness is calculated from the nominal wall thicknesses *t*.

3.6
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

3.7
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 is high for imperfections, provided their diameters are greater than or equal to 2 mm and the material loss is typically greater than or equal to 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 is high for 2 mm diameter or larger imperfections with material loss greater than or equal to 4 % of the pipe penetrated thickness. The detection sensitivity is improved for flaws with larger diameters, whereas the presence of liquid or other products, and external insulation, can reduce the sensitivity for material loss depending on their properties. Different detection sensitivities may apply for penetrated thicknesses less than 15 mm and greater than 35 mm.

The presence of external corrosion product can reduce the techniques sensitivity to corrosion due to the increased radiation attenuation in the product, which can even exceed the reduced attenuation caused by the loss of steel. Build-up of internal solid material (e.g. scale) in pipes can similarly reduce sensitivity to internal degradation.

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 measures shall be taken to ensure the safety and health of personnel.

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 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 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 appears on each film or detector. If the radiographs is 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 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), they shall be placed on the detector side. 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 IQIs 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 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 on the source side of 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.

The technique presented in 6.1.2 is normally used for larger diameter pipes. The technique presented in 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
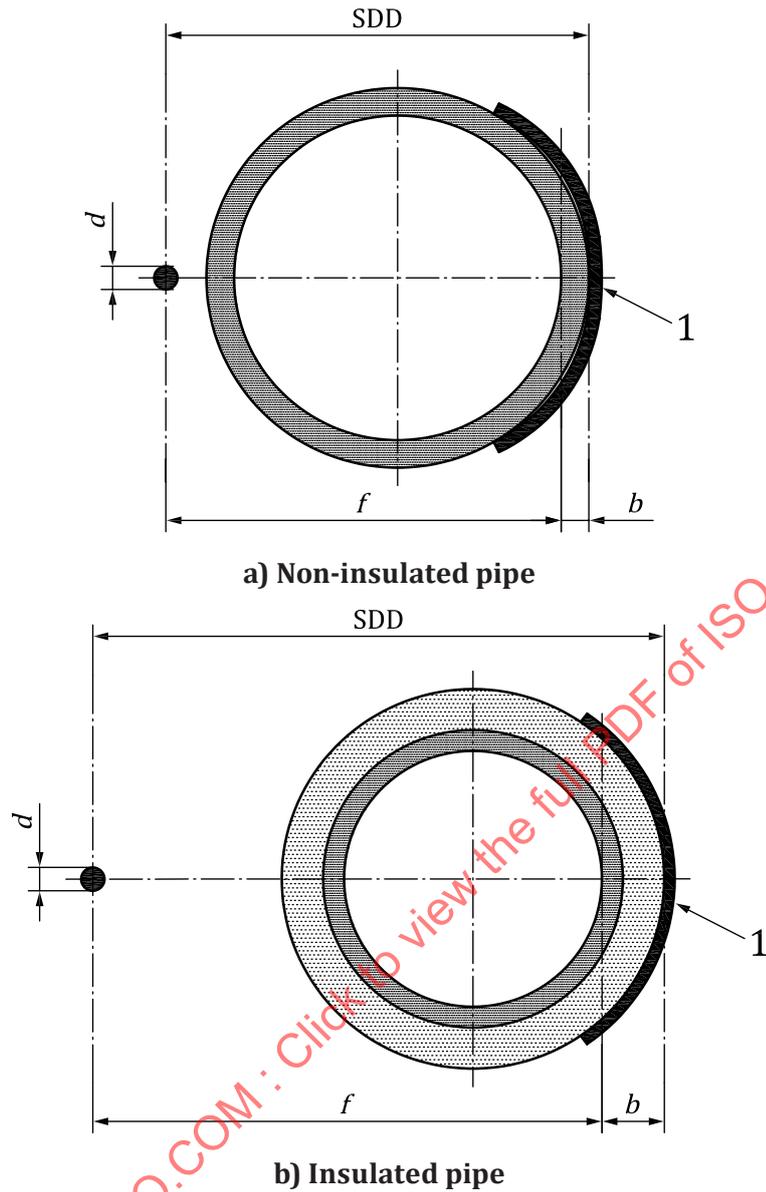
1   detector

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 2 a) 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
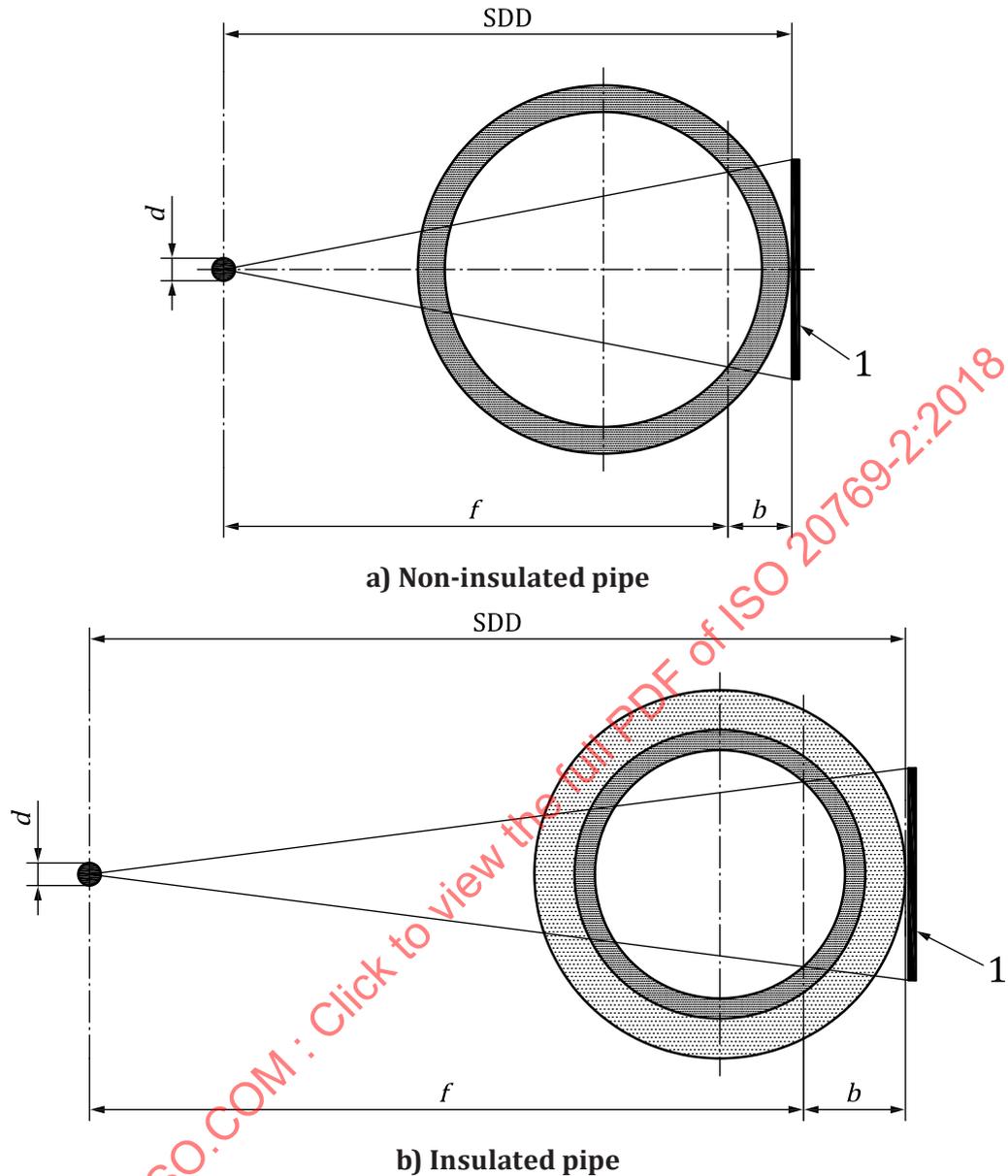
1   detector

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 3 a) (non-insulated pipe) and Figure 3 b) (insulated pipe).
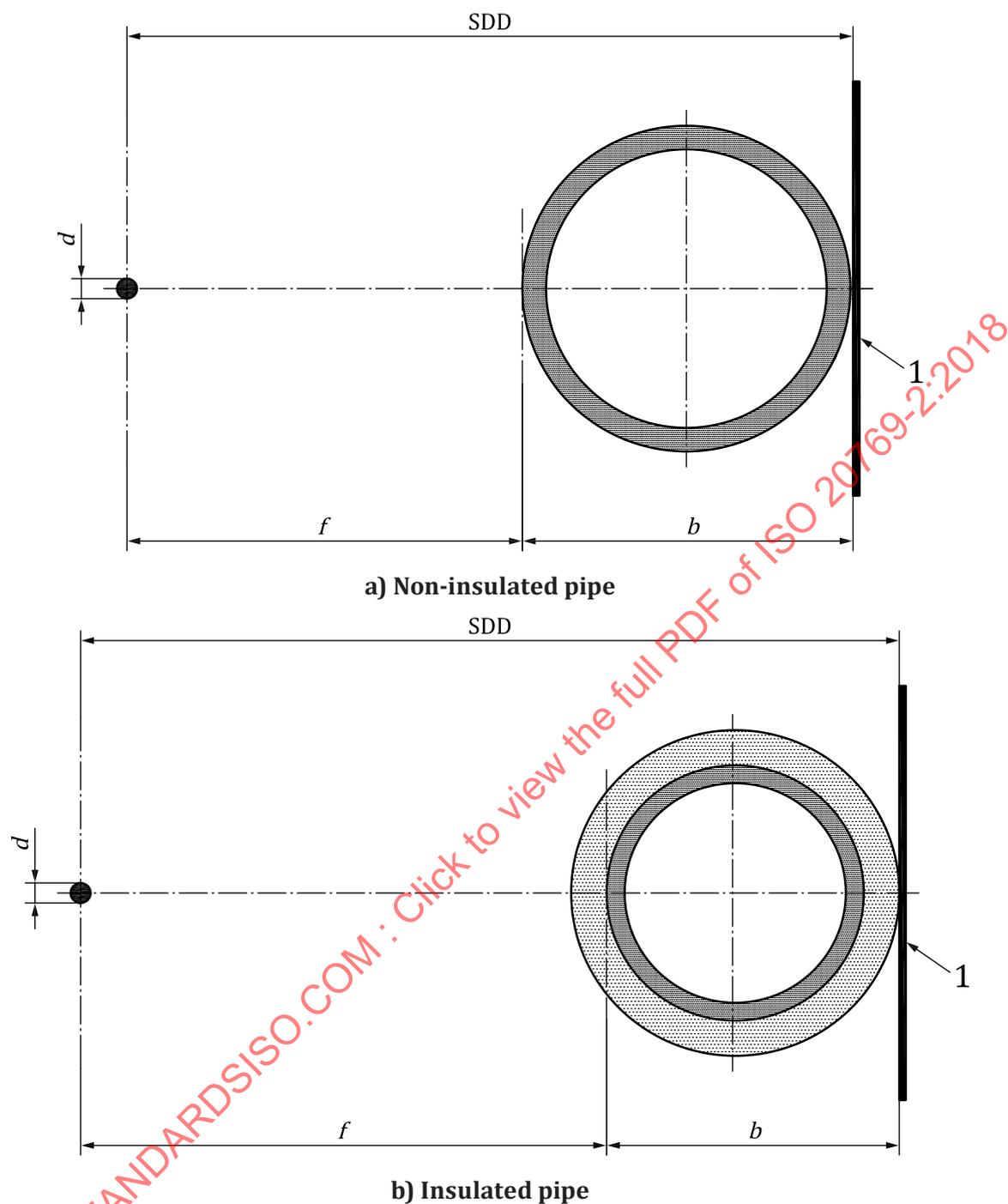
Key
1   detector

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 ISO 20769-1 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 can 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.		
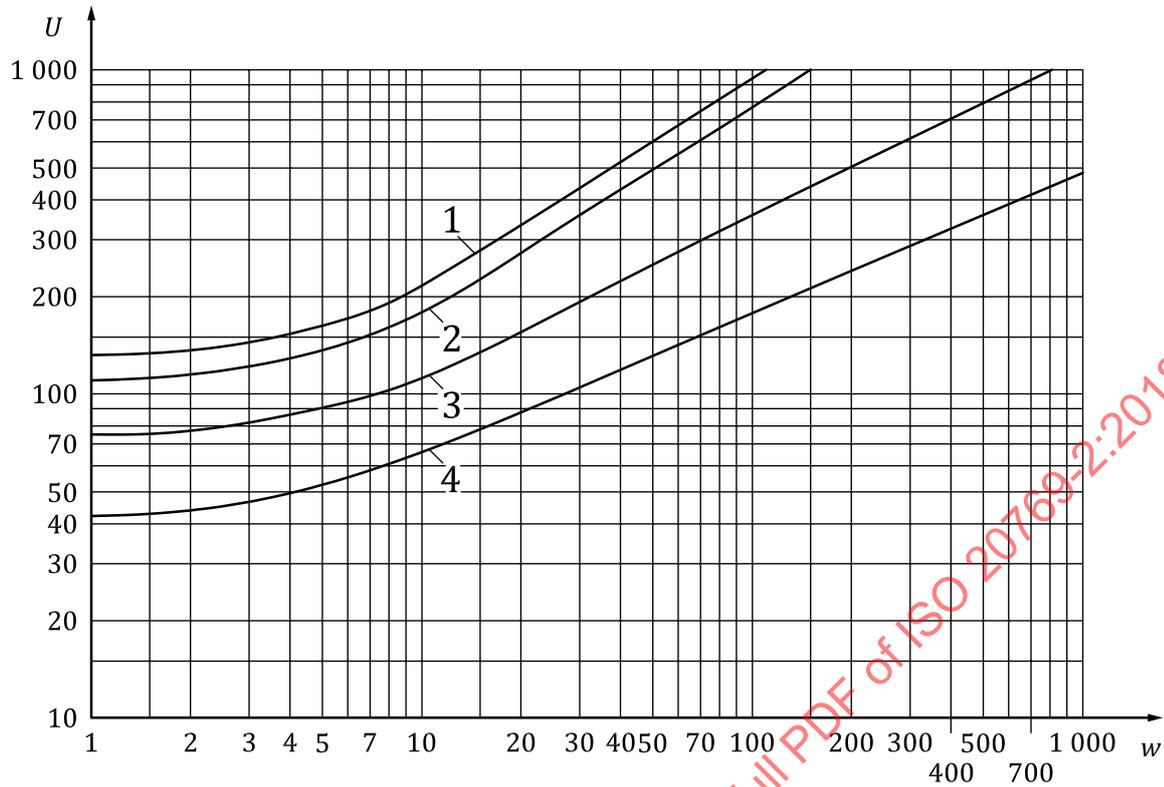
Key

1	copper/nickel and alloys	4	aluminium and alloys
2	steel	w	penetrated thickness in mm
3	titanium and alloys	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, 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 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 can 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	C 5	C 4	0,02 mm to 0,2 mm front and back screens of lead[b]
Se 75 Ir 192[c]	C 5	C 4	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 and required minimum image quality values in Annex A 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 can be achieved either by using vacuum-packed IPs or by applying pressure. Lead screens

not in intimate contact with the IPs can contribute to image unsharpness. The intensification obtained by use of lead screens in contact with imaging plates is significantly smaller than in film radiography.

Many IPs are very sensitive to low energy backscatter and X-ray fluorescence of back-shielding from lead. This effect contributes significantly to edge unsharpness and reduced 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 can also improve the image quality. Modern cassette and detector designs can consider this effect and can be constructed in a way such that additional steel or copper shielding outside the cassette is not required.

NOTE   Due to the protection layer between the lead and the sensitive layer of an IP, the effect of intensification by electrons is considerably reduced and appears at higher energies. Depending on the radiation energy and protection layer design, the effect of intensification amounts to between 20 % and 100 % 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 less than 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[a] ≤ 250 kV	0 to 0,1 (lead)
X-ray potentials[a] > 250 kV to 1 000 kV	0 to 0,3 (lead)[c]
Ir 192, Se 75[a]	Class DWA: 0 to 0,3 (lead)[c] Class DWB: 0,3 to 0,8 (steel or copper)
Co 60[b]	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]   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.

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

[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 kV 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, or CR cassette. This is impractical for DDAs. 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 can 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:

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

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:

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

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 is 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 3 a) and 3 b). 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, 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 ISO 20769-1. 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
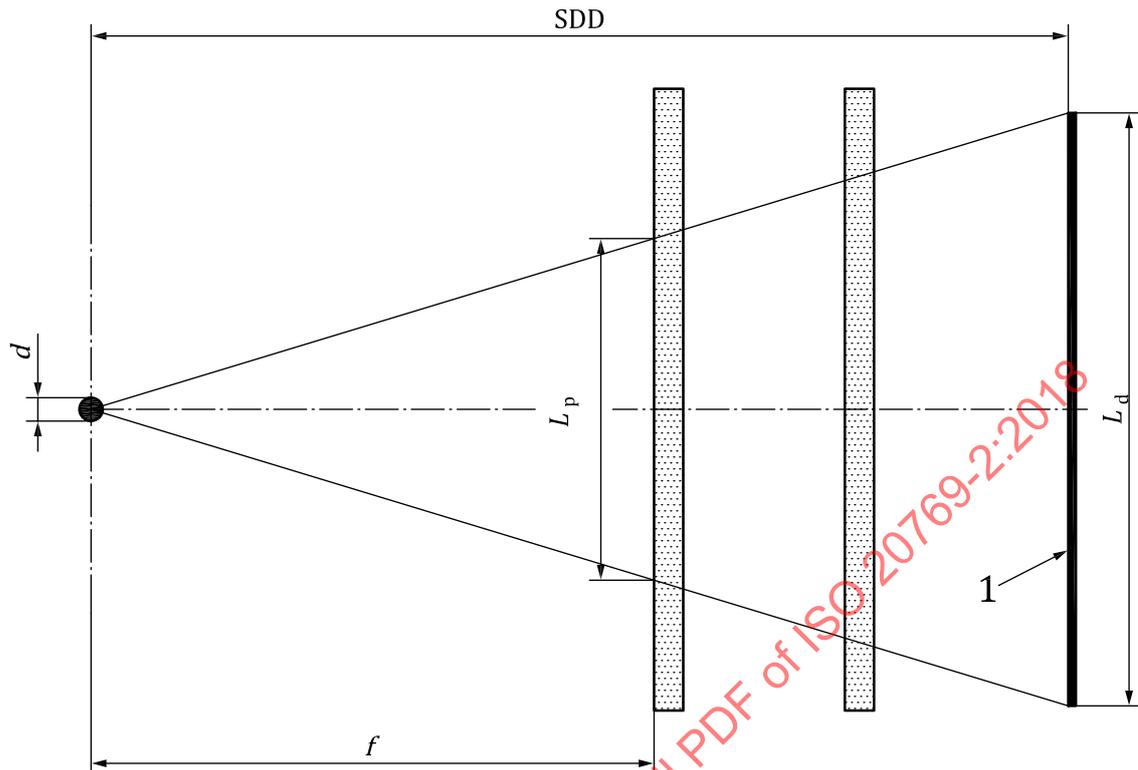
1   detector

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 Formula (3):

$$L_d \leq 1{,}32 \; SDD \tag{3}$$

The total axial extent of the evaluated area on the source side of the pipe, L_p, should be no greater than Formula (4):

$$L_p \leq 1{,}32 \, f \tag{4}$$

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

Formula (4) 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 need 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.
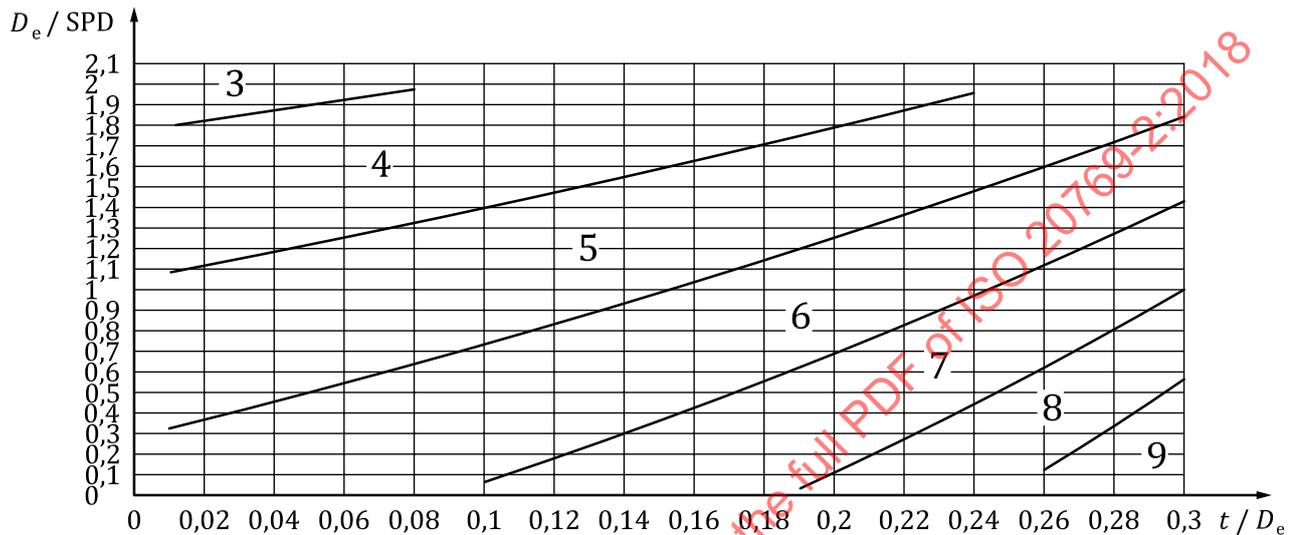
Figure 6 — Minimum number of DWSI exposures circumferentially around a pipe, as a function of the ratios t / D_e and D_e / SPD, where SPD is the distance from the source to the pipe axis (centre)

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

$$\Delta\theta = \frac{360°}{N} \tag{5}$$

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 can 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 can 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 ISO 19232-3, class A or derived according to 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 Tables A.2 and 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 (see 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 pixels (vertically) × 20 pixels (horizontally). 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 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 at least 80 for the improved technique, DWB. The SNR_N 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 can 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 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 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 Formula (6):

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

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 Formula (7):

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

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 Formula (8):

$$I(w_1)/I(w_2) = \left[(D_1 - D_0)/(D_2 - D_0)\right] \tag{8}$$

where D_0 is the optical density of film base and fog.

In applying this method to digital radiographs, it is 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 × 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.

— The method will significantly underestimate the extent of any external wall loss with associated corrosion product due to the additional radiation attenuation in the corrosion product. Measurement of internal degradation can also be similarly affected by build-up of internal solid material (e.g. scale).

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 artifacts 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, repeatable and 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 equalization and bad pixel correction (see also ASTM E2597) to provide artifact-free detector images shall be applied before storage of the raw data.

The data storage shall be redundant and 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/m²;

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 less than 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) a reference to this document, i.e. ISO 20769-2;

b) the name of the examination body;

c) the object and pipe isometric and pipe content;

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

e)   the material, thickness and condition of insulation;

f)   the specification of examination including requirements for IQI acceptance;

g)   the radiographic technique and class;

h)   the test arrangement in accordance with 6.1;

i)   the system of marking used;

j)   the detector position plan;

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

l)   the detector, screens and filters;

m) the tube voltage and current used or source activity;

n)   the time of exposure, SDD and PDD;

o)   the film type, film system and film processing;

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

q)   the DDA type, operating parameters, pixel size;

r)   the basic spatial resolution of digital detectors;

s)   the measured image parameters:

   1)   film densities measured at pipe centre;

   2) SNR_N, achieved at the pipe centre;

   3)   IQI reading;

t)   the measured wall thickness differences in penetration direction;

u)   additional observations;

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

w)   the name, certification and signature of the operator;

x)   the 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 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
$5 \le w_{tot} < 15$	W 9	$5 \le w_{tot} < 8$	W 12
$15 \le w_{tot} < 25$	W 8	$8 \le w_{tot} < 12$	W 11
$25 \le w_{tot} < 40$	W 7	$12 \le w_{tot} < 15$	W 10
$40 \le w_{tot} < 60$	W 6	$15 \le w_{tot} < 20$	W 9
		$20 \le w_{tot} < 35$	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
$5 \le w_{tot} < 10$	W 11	$15 \le w_{tot} < 20$	W 10
$10 \le w_{tot} < 15$	W 10	$20 \le w_{tot} < 35$	W 9
$15 \le w_{tot} < 25$	W 9	$35 \le w_{tot} < 60$	W 8
$25 \le w_{tot} < 30$	W 8		
$30 \le w_{tot} < 60$	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
$5 \le w_{tot} < 12$	W 11	$5 \le w_{tot} < 10$	W 12
$12 \le w_{tot} < 18$	W 10	$10 \le w_{tot} < 20$	W 11
$18 \le w_{tot} < 25$	W 9		
$25 \le w_{tot} < 35$	W 8		

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

Basic technique		Improved technique	
Total effective pen-etrated thickness mm	IQI value	Total effective pen-etrated thickness mm	IQI value
$5 \leq w_{tot} < 15$	W 11	$5 \leq w_{tot} < 25$	W 11
$15 \leq w_{tot} < 25$	W 10	$25 \leq w_{tot} < 40$	W 10
$25 \leq w_{tot} < 30$	W 9	$40 \leq w_{tot} < 45$	W 9
$30 \leq w_{tot} < 55$	W 8		