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

**Part 1:
Tangential radiographic inspection**

*Essais non destructifs — Examen radiographique de la corrosion et
des dépôts dans les canalisations, par rayons X et rayons gamma —*

Partie 1: Examen radiographique tangentiel



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Foreword

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

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

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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.

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

Part 1: Tangential 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 steel pipes 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 the tangential inspection technique for detection and through-wall sizing of wall loss, including with the source:

- a) on the pipe centre line; and
- b) offset from pipe centre line by the pipe radius.

ISO 20769-2 covers double wall radiography, and note that the double wall double image technique is often combined with tangential radiography with the source on the pipe centre line.

This document applies to tangential radiographic inspection using industrial radiographic film techniques, computed 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 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

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

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

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

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*

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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 actual wall thickness

t_{act}
real thickness of the pipe wall which can differ from the nominal thickness

3.2 axial coverage

L_d
<on the detector> total axial extent of the evaluated section of the pipe radiograph measured on the detector (3.8)

3.3 axial coverage

L_p
<on the pipe central axis> total axial extent of the evaluated section of the pipe radiograph measured along the central axis of the pipe

3.4 basic spatial resolution

$SR_{b,detector}$
<digital detector> smallest geometrical detail, which can be resolved in a digital image at a magnification equal to 1; corresponds to half of the measured image unsharpness in a digital image; corresponds to the effective *pixel size* (3.19) of the magnified image; and is determined from the smallest number of the duplex wire pair, which is not separable by visual inspection or from the smallest number of the duplex wire pair with less than 20 % modulation depth in a linearized profile

Note 1 to entry: For this measurement, the duplex wire IQI is placed directly on the digital detector (3.8) array or imaging plate.

Note 2 to entry: The measurements of $SR_{b,detector}$ and unsharpness are described in ISO 19232-5. and ASTM E2002[17].

3.5 basic spatial resolution

$SR_{b,image}$
<digital image> smallest geometrical detail, which can be resolved in a digital image at a magnification >1; corresponds to half of the measured image unsharpness in a digital image; corresponds to the effective *pixel size* (3.19) of the magnified image; and is determined from the smallest number of the duplex wire pair, which is not separable by visual inspection or from the smallest number of the duplex wire pair with less than 20 % modulation depth in a linearized profile

Note 1 to entry: The measurements of $SR_{b,image}$ and unsharpness are described in ISO 19232-5. and ASTM E2002[17].

3.6 comparator

C
reference object of defined dimension c and material for dimensional calibration of a radiographic image

3.7**computed radiography****CR**

complete system comprising a *storage phosphor imaging plate (IP)* (3.23) and a corresponding read-out unit (scanner or reader), which converts the information from the IP into a digital image and the control software of the read-out unit

3.8**detector****D**

detection device, consisting of a NDT film system (see ISO 11699-1) or a digital radiography system using a 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.

3.9**digital detector array****DDA**

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

3.10**imaged comparator dimension** c'

dimension of the *comparator* (3.6) measured on the *detector* (3.8)

3.11**imaged outside diameter** D_e'

nominal outside diameter of the pipe measured on the detector

3.12**maximum penetrated thickness** $w_{\max}$

maximum thickness of material for a pipe which occurs for a tangent to the inner pipe surface

3.13**measured wall thickness** t_{meas}

thickness of the pipe wall as measured on the radiograph or digital image

3.14**nominal wall thickness** t

thickness of the pipe wall as given by the manufacturer, neglecting the manufacturing tolerances

3.15**normalized signal-to-noise ratio** SNR_N

ratio of signal-to-noise, normalized by the *basic spatial resolution*, SR_b^{image} , (3.5) as measured directly in the digital image and/or calculated from the measured SNR_{measured} , by:

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

Note 1 to entry: SR_b^{image} can be substituted by SR_b^{detector} (3.4) at magnification equal to 1.

3.16

outside diameter

D_e
nominal outer diameter of the pipe as given by the manufacturer, neglecting the manufacturing tolerances

3.17

pipe centre to detector distance

PDD
distance between the pipe centre and the *detector* ([3.8](#))

3.18

pixel size

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

[SOURCE: ISO 14096-2:2005, 3.2]

3.19

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

3.20

source size

d
size of the radiation source

[SOURCE: ISO 16371-2:2017, 3.15]

3.21

source-to-detector distance

SDD
distance between the source of radiation and the *detector* ([3.8](#)) measured in the direction of the beam

3.22

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

3.23

storage phosphor imaging plate

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

4 Classification of radiographic techniques

The tangential radiographic techniques are divided into two classes:

- class TA, basic techniques;
- class TB, improved techniques.

The basic techniques, class TA, are intended for tangential radiography of generalized wall loss, such as that due to erosion or large-scale corrosion.

The improved techniques, class TB, should be used for the more demanding tangential radiography of localized corrosion pitting flaws, which require higher sensitivity for detection and sizing.

Further technique improvements beyond TB 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

Personnel performing non-destructive examination in accordance with this document shall be qualified in accordance with ISO 9712 or equivalent to an appropriate level in the relevant industrial sector.

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 should be made on the object to be examined 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 are 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 or step hole IQIs

For tangential radiography, single wire or step hole IQIs are not applicable.

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 7.1.3 and Annex A). 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

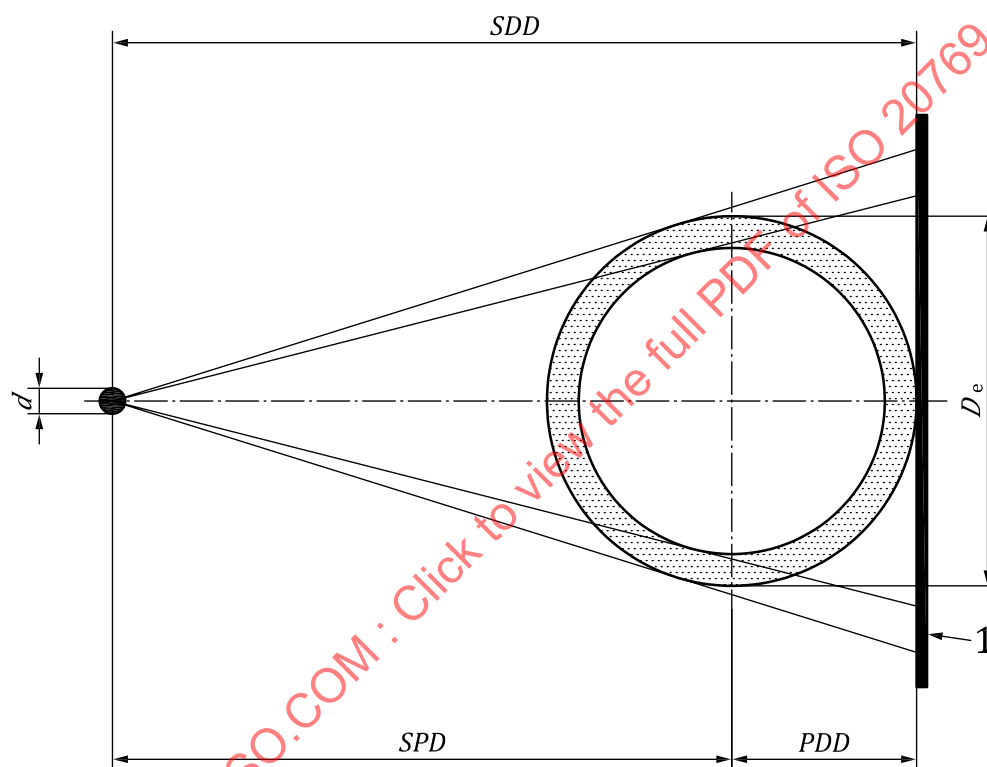
6.1 Test arrangements

6.1.1 General

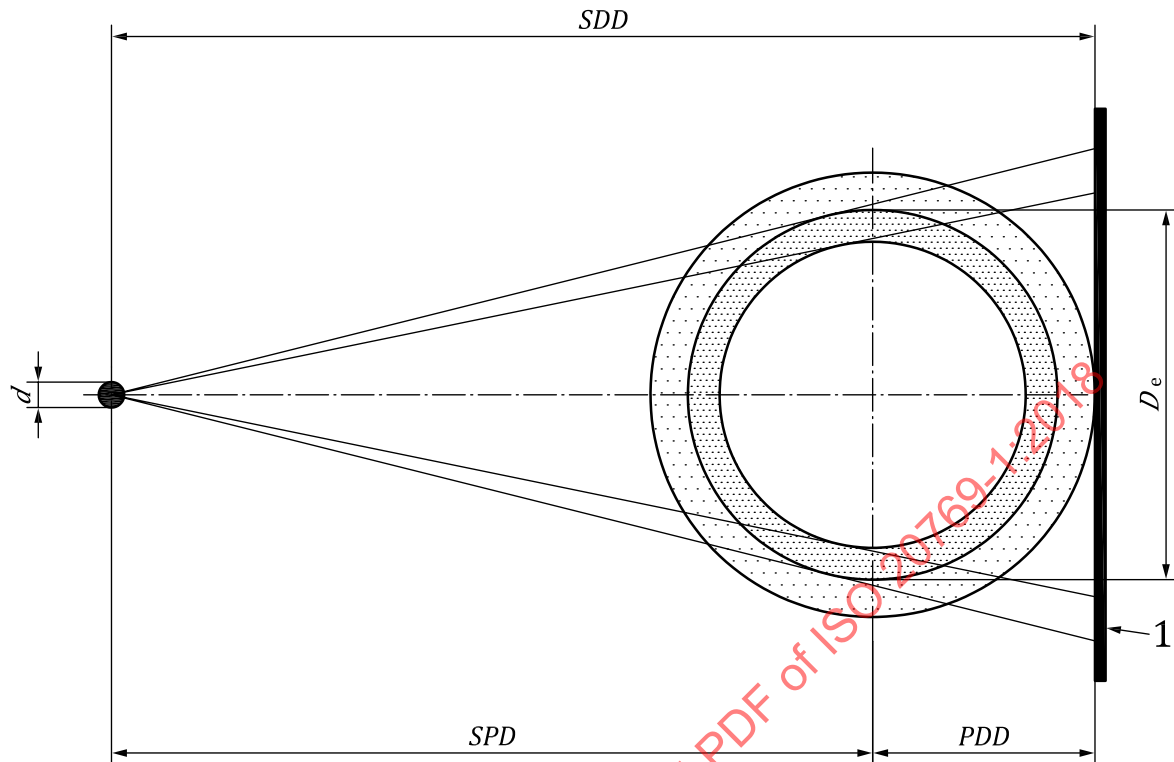
Normally, radiographic techniques in accordance with 6.1.2 and 6.1.3 shall be used. For both techniques, the film or digital detector shall be placed as close to the pipe as possible.

6.1.2 Radiation source located on the pipe centre line

For this arrangement, the source is located in front of the pipe and with the film/detector at the opposite side, as shown in Figure 1. The pipe can be non-insulated [Figure 1 a)] or insulated [Figure 1 b)].



a) Non-insulated pipe



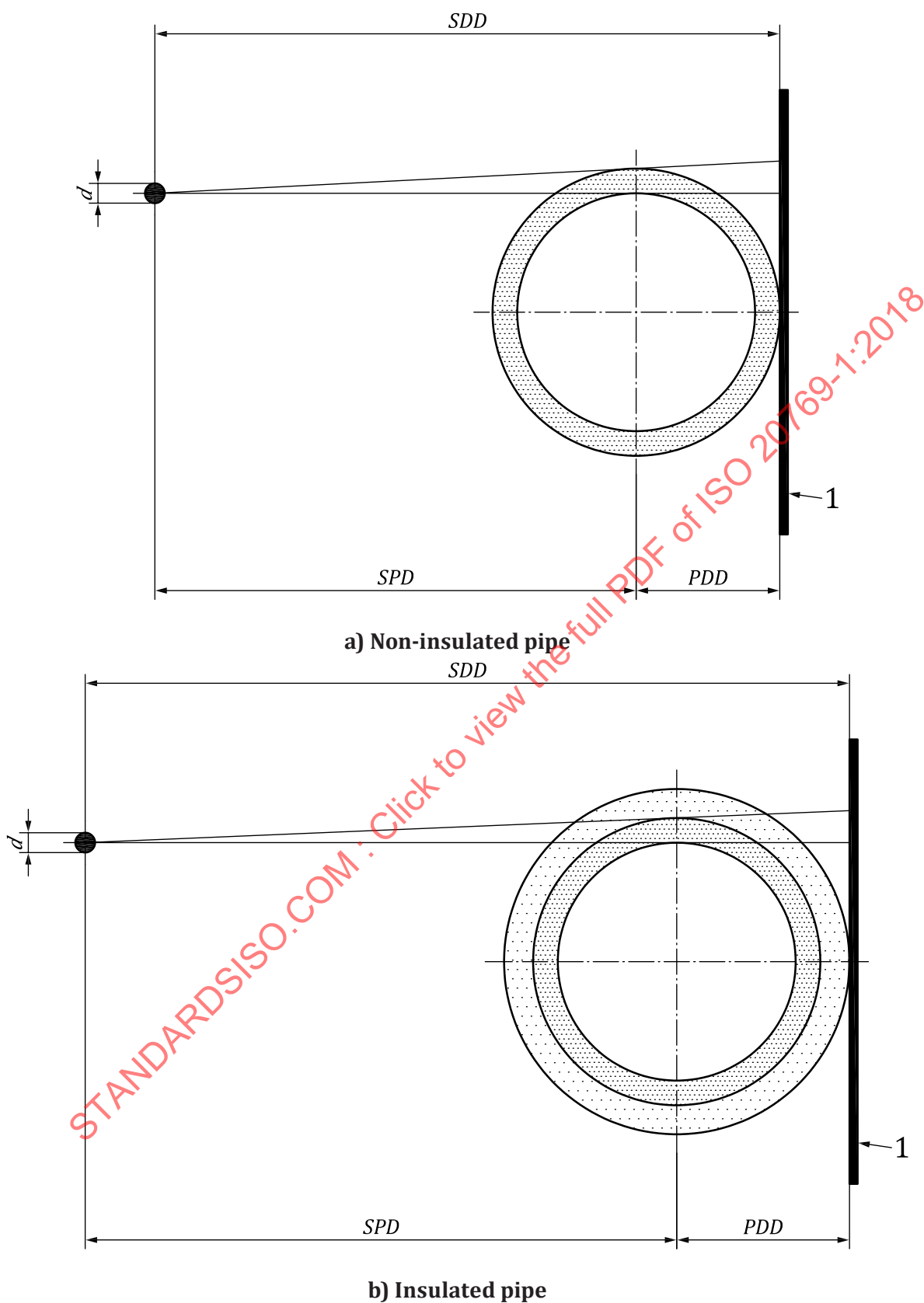
b) Insulated pipe

Key1 detector, D **Figure 1 — Test arrangement and distances for tangential radiography with the source on the pipe centre line**

Note that the wall loss can be located on either the inner diameter, outer diameter or both surfaces of the pipe.

6.1.3 Radiation source located offset from the pipe centre line

For this arrangement the radiation source is located in front of the pipe and with the film/detector at the opposite side, as shown in [Figure 2 a\)](#) (non-insulated pipe) and [Figure 2 b\)](#) (insulated pipe).



Key

1 detector, D

Figure 2 — Test arrangement and distances for tangential radiography with the source offset from the pipe centre line

In this test arrangement, the source is offset from the pipe centre line, and is aligned with the centre of the pipe wall, as shown in [Figure 2](#). Note that the wall loss can be located on either the inner diameter, outer diameter or both surfaces of the pipe.

6.1.4 Alignment of beam and film/detector

The beam of radiation shall be directed at the centre of the area being examined.

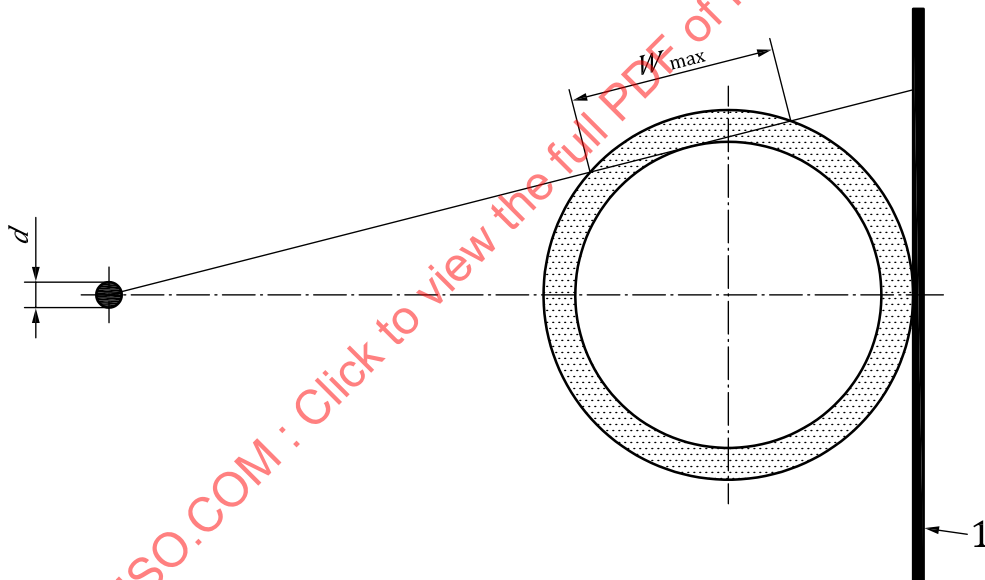
The film or detector should be aligned to be orthogonal to the centre of the radiation beam.

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

For tangential radiography, the choice of radiation source should be determined by the maximum penetrated thickness of the pipe, $w_{\max}$, which occurs for the path forming a tangent to the pipe inner diameter, as shown in [Figure 3](#).



Key

1 detector, D

Figure 3 — Maximum penetrated thickness, $w_{\max}$, for the tangential technique

The maximum penetrated thickness, $w_{\max}$, is given by [Formula \(1\)](#):

$$w_{\max} = 2\sqrt{t(D_e - t)} \quad (1)$$

where

t is the nominal thickness of the pipe;

D_e is the outside diameter of the pipe.

[Table 1](#) gives recommended limits on the maximum penetrated thickness for different radiation sources.

Some forms of insulation (e.g. highly absorbing) can lead to a reduction in the limits on maximum penetrated thickness, $w_{\max}$, given in [Table 1](#).

By agreement between the contracting parties, these values may vary provided the position of the inner diameter edge can be measured with acceptable accuracy on the resulting radiograph/digital image using the methods described in [7.6](#) or [7.7](#).

Table 1 — Maximum penetrated thickness range for different radiation sources for steel

Radiation source	Limits on maximum penetrated thickness, $w_{\max}$ mm	
	Basic (for generalized wall loss)	Improved (for pitting flaws)
X-ray (100 kV)	≤ 10	≤ 7
X-ray (200 kV)	≤ 30	≤ 20
X-ray (300 kV)	≤ 40	≤ 30
X-ray (400 kV)	≤ 50	≤ 35
Se 75	≤ 55	≤ 40
Ir 192	≤ 80	≤ 60
Co 60	≤ 120	≤ 85

For digital radiographs, somewhat higher values for the limits on maximum penetrated thickness than those given in [Table 1](#) may be used.

To determine the appropriate source(s) for a particular pipe, the maximum penetrated thickness, $w_{\max}$, should be determined using [Formula \(1\)](#) and compared with the values given in [Table 1](#). A graphical illustration of this procedure is given in [Annex B](#).

To avoid motion unsharpness, in cases where radiographs are produced using gamma rays, the total travel time of the source to the exposure position and rewind shall not exceed 10 % of the total exposure time.

6.3 Film systems and metal screens

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

The radiographic film system class and metal screens to use with films for different radiation sources are given in [Tables 2](#) and [3](#). See also ISO 17636-1:2013, Tables 2 and 3.

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 tangential radiography of steel, copper and nickel based alloy pipes

Radiation source	Film system class ^a		Type and thickness of metal screens
	Class TA	Class TB	
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 TA, 0,5 mm to 2,0 mm screens of lead may also be used.			
^d In class TA, 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 tangential radiography of aluminium and titanium pipes

Radiation source	Film system class ^a		Type and thickness of metal screens
	Class TA	Class TB	
X-ray potentials ≤150 kV	C 6	C 5	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			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.			

Different film systems 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 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. Also, a steel or copper shielding between a backscatter lead plate and the IP can improve the image quality. Modern cassette and detector designs can consider this effect and can be constructed in a way such that additional steel or copper shielding outside the cassette is not required.

NOTE Due to the protection layer between the lead and the sensitive layer of an IP, the effect of intensification by electrons is considerably reduced and appears at higher energies. Depending on the radiation energy and protection layer design, the effect of intensification amounts to between 20 % and 100 % 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 milliamperere.minutes, if no lead screens are used. Since lead screens in contact with IPs can generate scratches on IPs, if not carefully separated for the scan process, lead screens should be used for intermediate filtering of scattered radiation outside of cassettes.

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. The usage of metal screens is recommended in front of IPs, and they can also reduce the influence of scattered radiation when used with DDAs.

Table 4 — Metal front screens for CR for tangential radiography of steels, 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 1 000 kV	0 to 0,3 (lead)
Ir 192, Se 75 ^b	Class TA: 0 to 0,3 (lead)
	Class TB: 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.	

Table 5 — Metal front screens for CR for the digital tangential radiography of aluminium and titanium

Radiation source	Type and thickness of metal front screens
	mm
X-ray potentials <500 kV	≤0,2 (lead) ^{a,b}
Se 75	≤0,3 (lead) ^{a,b}
Ir 192	
^a E.g. 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.	

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 the 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, tantalum or steel can be used as a filter. It is recommended that in the case of a lead, tungsten or tantalum 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. 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

For tangential radiography, the source-to-detector distance, SDD , and the pipe centre to detector distance, PDD , are shown in [Figures 1](#) and [2](#).

The minimum source-to-detector distance, SDD , depends on the source size, d , the pipe outer diameter, D_e , and on the pipe centre to detector distance, PDD .

For tangential radiography with the source on the pipe centre line [as shown in [Figure 1](#) a) and [Figure 1](#) b)], the distances SDD shall be in accordance with the following.

For the basic techniques, class TA, SDD shall be at least the larger of the two values (in mm) determined from [Formula \(2\)](#) and [Formula \(3\)](#):

$$SDD \geq PDD + 3,5 \cdot D_e \quad (2)$$

$$SDD \geq \frac{d \cdot PDD}{0,6 \text{ mm}} \quad (3)$$

For the improved techniques, class TB, SDD shall be at least the larger of the two values (in mm) determined from [Formula \(2\)](#) and [Formula \(4\)](#):

$$SDD \geq \frac{d \cdot PDD}{0,3 \text{ mm}} \quad (4)$$

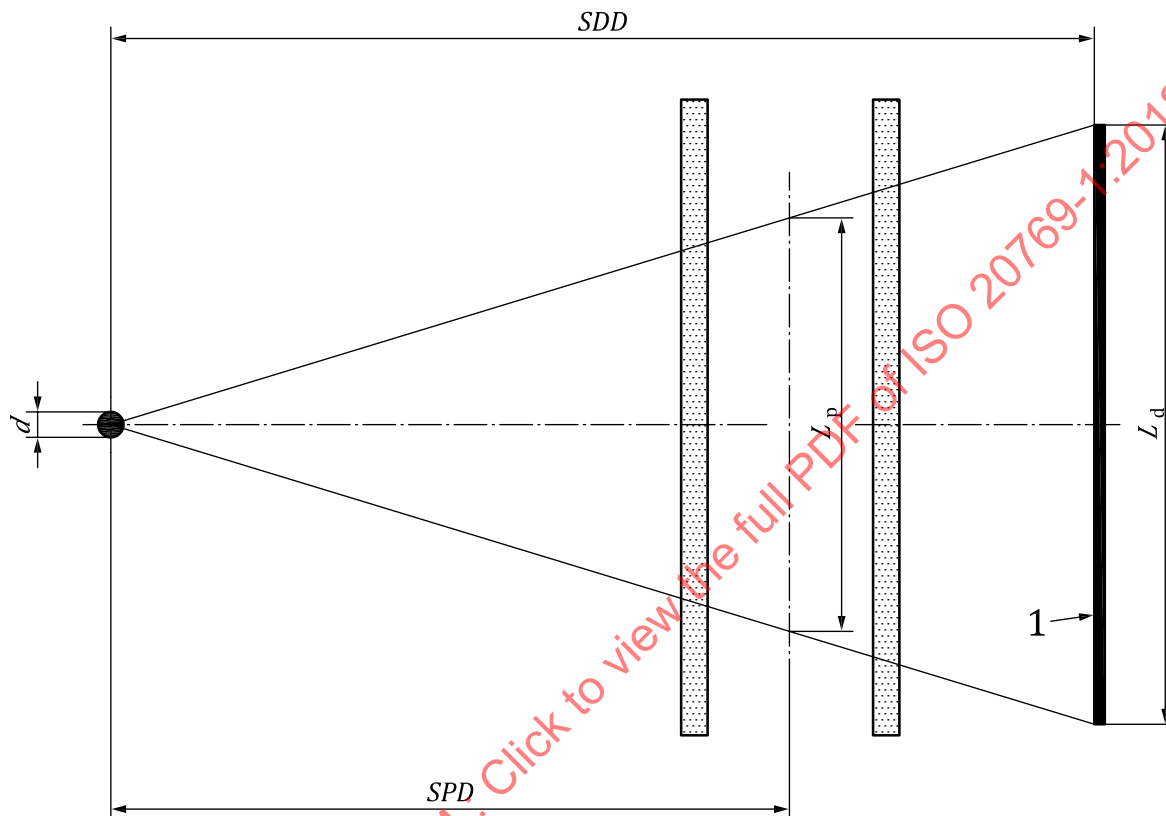
For tangential radiography with the source offset from the pipe centre line, as shown in [Figures 2](#) a) and [2](#) b), [Formula \(2\)](#) can be disregarded when determining the minimum SDD . Thus, [Formula \(3\)](#) gives the SDD for the basic technique TA, and [Formula \(4\)](#) gives the SDD for the improved technique TB.

NOTE [Formulae \(3\)](#) and [\(4\)](#) give geometric unsharpness values of 0,6 mm and 0,3 mm, respectively, projected to the plane corresponding to the pipe centre, which is close to where the measurements are made using the tangential technique. The corresponding unsharpness values measured at the detector are larger than these values due to the effects of projective magnification.

If tangential radiography is combined with the double wall double image technique, the source to detector centre distance shall be determined by also taking account of the criteria used for that technique, as given in ISO 20769-2. The larger of the two values shall be taken.

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 4](#).



Key

1 detector, D

Figure 4 — Axial cross section showing the maximum permissible axial length of the evaluated area for a single source position, on the detector, L_d , and along the pipe, L_p , at the tangent position

The total axial extent of the evaluated area on the detector, L_d , shall be given by [Formula \(5\)](#):

$$L_d \leq 1,32 SDD \quad (5)$$

The total axial extent of the evaluated area on the pipe, L_p , shall be given by [Formula \(6\)](#):

$$L_p \leq 1,32 SPD \quad (6)$$

The formula for L_p shall 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 $\pm 35^\circ$, L_p and L_d need to be reduced corresponding to the maximum available opening angle of the radiation cone beam.

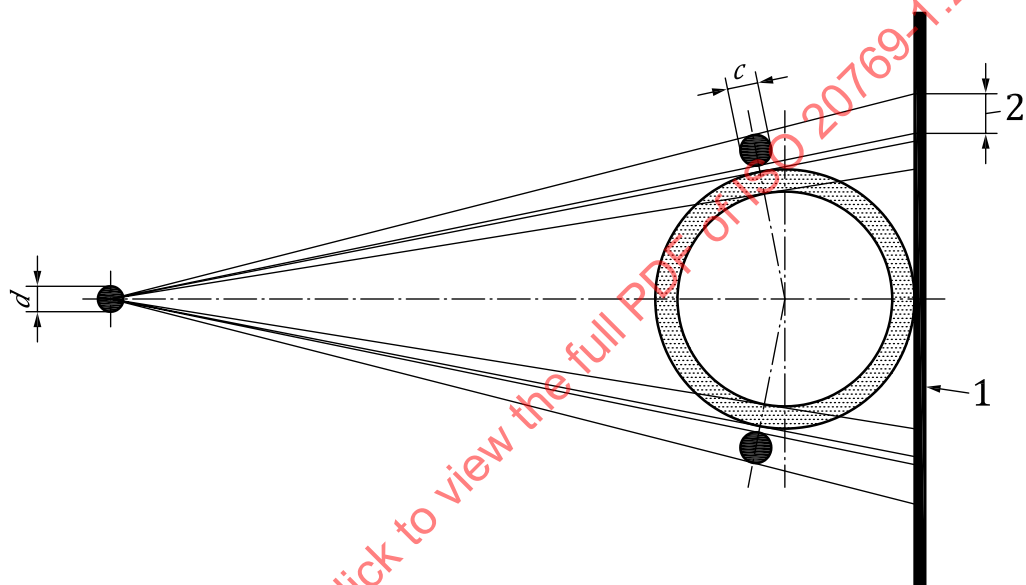
The separate films or digital images shall overlap sufficiently to ensure that no portion of the component remains un-examined. Unless otherwise specified, the minimum overlap shall be 25 mm axially either side of the diagnostic area, measured on the source side.

6.8 Dimensional comparators

For measurement of remaining wall thickness, the film radiographs or digital images shall be dimensionally calibrated to correct for the geometric magnification (or “blow-up”) caused by the geometrical arrangement of source, pipe and detector.

One method for dimensional calibration is the use of a ball bearing or other dimensional comparator. This is an effectively radiation opaque object (usually spherical) with a known diameter and the tolerance, which is placed close to the pipe, and in the same plane as the tangent position on the pipe wall, as illustrated in [Figure 5](#). The diameter and tolerance of the comparator shall be agreed between the contracting parties.

Note that other dimensional calibration methods (see [7.5](#)) do not require the use of these additional comparators.



Key

- 1 detector, D
- 2 projected dimension, c' of comparator, C

Figure 5 — Tangential radiography showing use of comparators for dimensional calibration (second comparator is optional)

Comparator(s) shall be placed in the tangent position, as close to the pipe wall as possible, without overlapping it.

Measurements of the imaged size of the comparator then allow the pipe wall thickness measurement to be calibrated (see [7.5](#)).

Note that if the comparator cannot be placed adjacent to the pipe tangent position, due to the presence of external insulation for example, it is recommended that the source be offset from the pipe centre line to be aligned with the pipe wall as shown in [Figure 6](#).

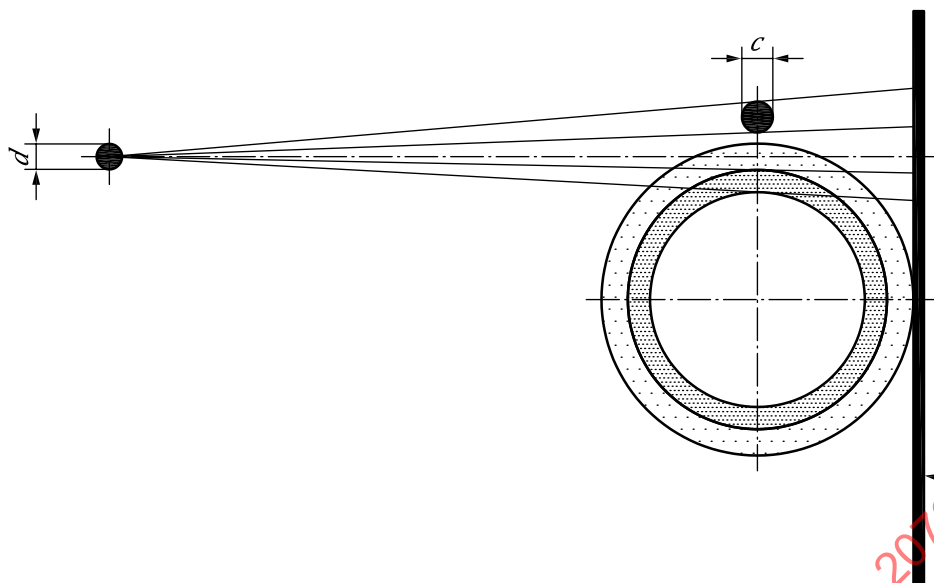
**Key**1 detector, *D*

Figure 6 — Tangential radiography showing use of offset source position with comparator for dimensional calibration, for insulated pipes, where the comparator shall be placed as close to the outside of the insulation as possible

The dimensional comparator shall not be wrapped in lead or similar material. However, if the pipe is insulated, and the free beam is saturated (see 6.9), then the comparator shall be wrapped in lead to avoid inaccurate calibration due to burn-off of the edges of the comparator.

6.9 Image saturation and use of lead strips to avoid burn-off

For digital radiography (CR or DDA), lead strips close to, or coincident with the edge of the pipe to avoid image burn-off effects at the pipe outer diameter should not be used. Burn-off should instead be minimized by ensuring the exposure time is adjusted according to 7.1.1.

In addition, the intensity range between the free beam and the radiograph of the pipe should be reduced by prefilters (close to the source) or intermediate filters (between the pipe and the imaging plate, see 6.4).

For insulated pipes, it may be permissible for the free beam beyond the insulation to be saturated, provided the grey levels adjacent to the pipe wall being measured are not greater than 90 % of the dynamic range of the digital system. In this case, if dimensional comparators are used, they shall be wrapped in lead or similar to avoid saturation of the image around the comparator.

6.10 Selection of digital radiographic equipment

6.10.1 General

The basic spatial resolution of the detector divided by magnification ($M = SDD / SPD$) shall not exceed 200 μm for class TA and 130 μm for class TB and shall not exceed 5 % of the nominal wall thickness, t . Different values may be agreed by contracting parties.

If the tangential technique (TA or TB) is used in conjunction with the double wall double image techniques described in ISO 20769-2 (DWA or DWB), then the magnification, M , above shall be set to one when finding the basic spatial resolution of the detector, SR_{detector} .

6.10.2 CR systems

The CR scanner pixel size of the dimensionally calibrated image (see 6.8) shall not exceed 100 μm for class TA and class TB. 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.

6.10.3 DDA systems

The pixel size of the dimensionally calibrated image (see 6.8) shall not exceed 200 μm for class TA and 130 μm for class TB. Different values may be agreed by contracting parties.

7 Radiograph/digital image sensitivity, quality and evaluation

7.1 Evaluation of image quality

7.1.1 General

For tangential radiography, conventional wire or step/hole IQIs are not directly applicable, because they cannot be positioned near to the tangential pipe position, and the rapid changes in penetrated thickness in this part of a radiographic image make it impossible to assess IQI visibilities in any meaningful way.

Evaluation of image quality is however required using the following methods to ensure reproducible results.

7.1.2 Maximum grey level in free beam (digital radiographs)

The exposure time and/or the system sensitivity should be adjusted so that the unimpeded radiation beam outside the pipe wall does not exceed 90 % of the imaging system's saturation.

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 measurement accuracy.

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 ISO 16371-1 using a measurement area of at least $(55 SR_b^{\text{detector}} / \text{pixel size of detector})$ pixels (vertically) $\times (20 SR_b^{\text{detector}} / \text{pixel size of detector})$ pixels (horizontally). SNR_N values shall be measured at a minimum of four separate positions, and the average value taken. The measurement shall be performed in areas of homogeneous grey value distributions. Estimated SR_b^{detector} values can be used for determination of the measurement area.

To derive the normalized SNR_N value, the basic spatial resolution, SR_b^{detector} , of the imaging system shall be measured using the duplex wire IQI method described in ISO 19232-5, or an equivalent method (ASTM E2002). The measurement shall be carried out before dimensional calibration. SR_b^{detector} shall be measured.

For the measurement of the detector basic spatial resolution, the duplex wire shall be placed on the source side of the imaging plate or on the source side of the digital detector array and positioned, a few degrees tilted (2° to 5°) to the digital rows or columns of the digital image. The measurement shall be performed with the same source as used for in-service measurements. For gamma radiography, a Cu

plate of 2 mm or a steel plate of 4 mm should be used as prefilter in front of the gamma source. If the accuracy of the SR_b^{detector} measurement is not sufficient, the iSR_b^{detector} measurement may be used instead of the SR_b^{detector} measurement in accordance with ISO 19232-5 or ASTM E 2002.

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 type, pixel size, radiation source, scan speed and the scanner's gain and laser intensity).

The average SNR_N values obtained in an unsaturated free beam area of the image outside the pipe shall be at least 70 for the basic class (TA) and shall be at least 100 for the improved class (TB).

If the pipe centre line is available for measurement of SNR_N (e.g. with combined tangential/double wall double image radiography), then minimum SNR_N values of 50 and 80 for the standard (TA) and higher qualities (TB) respectively can be used as an alternative to the above free beam SNR_N values.

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

For tangential film radiography, it shall be ensured that exposure conditions are as far as possible such that the following minimum optical densities are achieved for the film system classes as given in [Table 2](#).

- optical density on the pipe centre line $\geq 1,5$;
- optical density in the unimpeded beam (outside the pipe): 3,5 to 4 (maximum);
- optical density in a tangent position of the inner pipe wall $\geq 0,5$.

If the optical density in the unimpeded beam is greater than 4, then in the outer tangential position, one emulsion side shall be removed for measurements of outer wall position. If the optical density is less than or equal to 4 in the remaining emulsion, the radiograph can be accepted for wall thickness measurement.

A measuring uncertainty for the optical density of $\pm 0,1$ is permitted.

In order to avoid unduly high fog densities arising from film ageing, development or temperature, the base and 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 base and fog density shall not exceed 0,3.

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 0,8 on the pipe centre line.

7.3 Film processing

Films are processed in accordance with the conditions recommended by the film and chemicals manufacturers to obtain the selected film system class. Particular attention shall be paid to temperature, immersion (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.

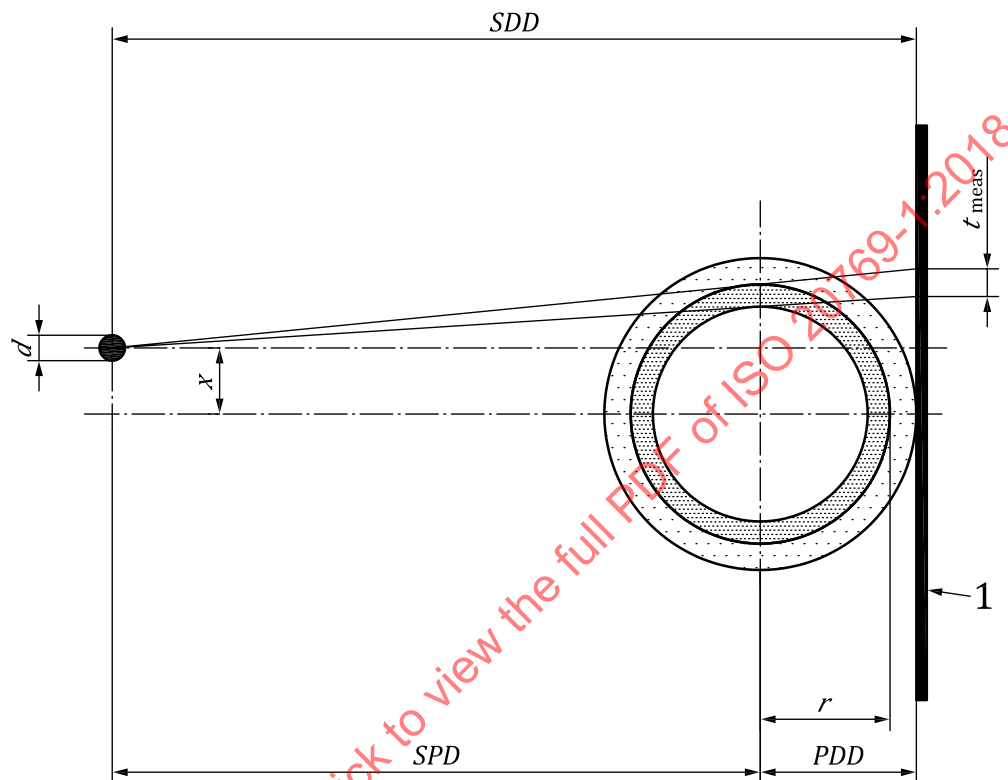
7.4 Film viewing conditions

The radiographs should be examined in a darkened room on an area of the viewing screen with an adjustable luminance in accordance with ISO 5580. The viewing screen should be masked to the area of interest.

7.5 Dimensional calibration of radiographs or digital images

7.5.1 General

For tangential radiography, when making dimensional measurements of wall thickness, it is necessary to calibrate the distances involved in the radiography, to allow for the image enlargement (magnification) or “blow-up”. The geometric magnification effect for tangential radiography is shown in [Figure 7](#).



Key

1 detector, D

Figure 7 — Geometric magnification for tangential radiography showing the measured wall thickness, t_{meas}

The following methods can be used for dimensional calibration, to calculate the actual wall thickness, t_{act} , from the measured value, t_{meas} .

7.5.2 Measurement of distances in radiographic setup

This method involves direct physical measurement of the key distances involved in the radiography. For calibration by the distances method, two of the following distances need to be measured accurately to obtain results with precision and bias of $\leq 5\%$:

- source to detector distance, SDD ;
- distance from source to pipe centre line, SPD ;
- distance from detector to pipe centre line, PDD .

In addition, the following distance shall also be recorded:

- lateral offset (if any) of source from pipe centre line, x .

For offset tangential radiography (with x approximately equal to r), the true wall thickness, t_{act} , at the tangential pipe position can be calculated from the measured wall thickness, t_{meas} , using [Formula \(7\)](#):

$$t_{\text{act}} = \frac{SPD}{SDD} \cdot t_{\text{meas}} \quad (7)$$

If x is approximately equal to 0, then [Formula \(8\)](#) can be used to calculate the wall thickness, t_{act} , from the measured value t_{meas} with higher accuracy:

$$t_{\text{act}} = r - \frac{SPD \left(\frac{r}{\sqrt{SPD^2 - r^2}} - \frac{t_{\text{meas}}}{SDD} \right)}{\sqrt{1 + \left(\frac{r}{\sqrt{SPD^2 - r^2}} - \frac{t_{\text{meas}}}{SDD} \right)^2}} \quad (8)$$

where r is half the pipe outside diameter ($= D_e / 2$).

For practical in-service radiography, the accurate physical measurements of distances can be difficult to achieve and document reliably. If it is considered to be the case, the alternative methods given below shall be used.

7.5.3 Measurement of pipe outside diameter

Provided the pipe outside diameter is known accurately at the measurement position in the image or radiograph, then dimensional calibration can be achieved by measurement of the imaged size of the pipe outside diameter, D_e' , on the radiograph or digital image.

The actual remaining wall thickness, t_{act} , can then be found from the measured remaining wall thickness value, t_{meas} , using the ratio of the actual to measured pipe outside diameter in [Formula \(9\)](#):

$$t_{\text{act}} = t_{\text{meas}} \cdot \frac{D_e}{D_e'} \quad (9)$$

7.5.4 Dimensional comparator

If the pipe outside diameter is not known accurately or reliably, then the alternative dimensional calibrator method, described in [6.8](#), shall be used.

With this method, the measured dimension of the comparator, c' , is used to calibrate the distances, so the actual remaining wall thickness, t_{act} , can then be found from the measured remaining wall thickness value, t_{meas} , using the ratio of the defined (c) to measured (c') comparator dimensions in [Formula \(10\)](#):

$$t_{\text{act}} = t_{\text{meas}} \cdot \frac{c}{c'} \quad (10)$$

Note that if the pipe outside diameter is known accurately, the method described in [7.5.3](#) is likely to provide more accurate measurements, since the calibration is made over a larger distance which can be measured more accurately in percentage terms than the smaller distance across a comparator.

7.6 Wall thickness measurements for film radiographs

Dimensional measurements from film radiographs can be made with callipers, of both the pipe wall thickness and an object of known dimension, for calibration purposes (i.e. the ball-bearing comparator or known pipe outside diameter. See [7.5.3](#) and [7.5.4](#)).

7.7 Wall thickness measurements for digital radiographs

7.7.1 Interactive on-screen measurements

CR/DDA systems contain software options which allow on-screen interactive dimensional measurements using a cursor overlaid on the digital images, without reference to the underlying grey level values in the images. The user then judges visually the locations in the image of the inner and outer edges of the pipe wall.

This method can be subject to significant errors as the apparent wall thickness depends on the contrast and brightness settings used to display the image. These errors are larger for pipes having maximum penetrated thickness values, $w_{\max}$, approaching the maximum of those recommended for the radiation source in use (see [Table 1](#)). To reduce these errors, the following techniques can be used:

- high-frequency spatial filtering (sharpening) which emphasises the positions of the edges of the pipe wall in the images, and reduces the dependence on the contrast and brightness settings on the image;
- for some images, display of the image using a logarithmic relation between radiation intensity and grey level reduces the overall image contrast and improves the definition of the inner diameter position. Some CR scanners give logarithmic images directly. For those scanners and DDA systems that provide non-logarithmic response images, an appropriate look-up table (LUT) can be used to obtain a digital image with a logarithmic response.

If this interactive on-screen measurement method is used, it shall be first checked for acceptable accuracy using the current contrast and brightness settings of the displayed image, by application to a section of the pipe with known wall thickness (e.g. known to be uncorroded or not eroded).

7.7.2 Grey-level profile analysis methods

7.7.2.1 General

In addition to on-screen measurements, covered in [7.7.1](#), many CR/DDA systems also allow wall thickness measurement methods based on analysis of a grey level profile taken in a direction orthogonal to the pipe wall axis. The software extracts a grey-level profile along this line, which is then generally presented on-screen, superimposed on the image, as illustrated in [Figure 8](#).

7.7.2.2 Automated routines

Automated analysis routines can increase the reliability of the measured wall thickness values, unless the maximum tangential penetrated thickness, $w_{\max}$, is approaching the maximum possible, given the radiation source in use (see [7.2](#)). In addition, other factors such as the presence of external scale, corrosion products or irregular internal/external corrosion can affect the accuracy of these automated routines.

In these cases, the automated routines are subject to uncertainties, and the operator should check the consistency of the derived values with the density profile and the digital radiographic image.

7.7.2.3 Interactive methods

As an alternative to automated routines for wall thickness analysis, the operator can use available interactive facilities for analysis of the grey level profile. Accuracy is likely to be improved, especially for pipes having higher $w_{\max}$ values, if the digital images have a logarithmic response and are high-pass filtered.

[Figure 8](#) shows an example of interactive measurement of wall thickness, using cursors on a grey level profile across the pipe wall, after applying a logarithmic look-up table to the CR image, and high-pass filtering to enhance details. The position of the outer diameter corresponds to a clear peak in the profile, and the location of the inner diameter is given by the minimum and pronounced change in gradient of the profile.

This method, combined with a visual assessment of the image, can in some circumstances give higher measurement accuracy than the automated routines described above.

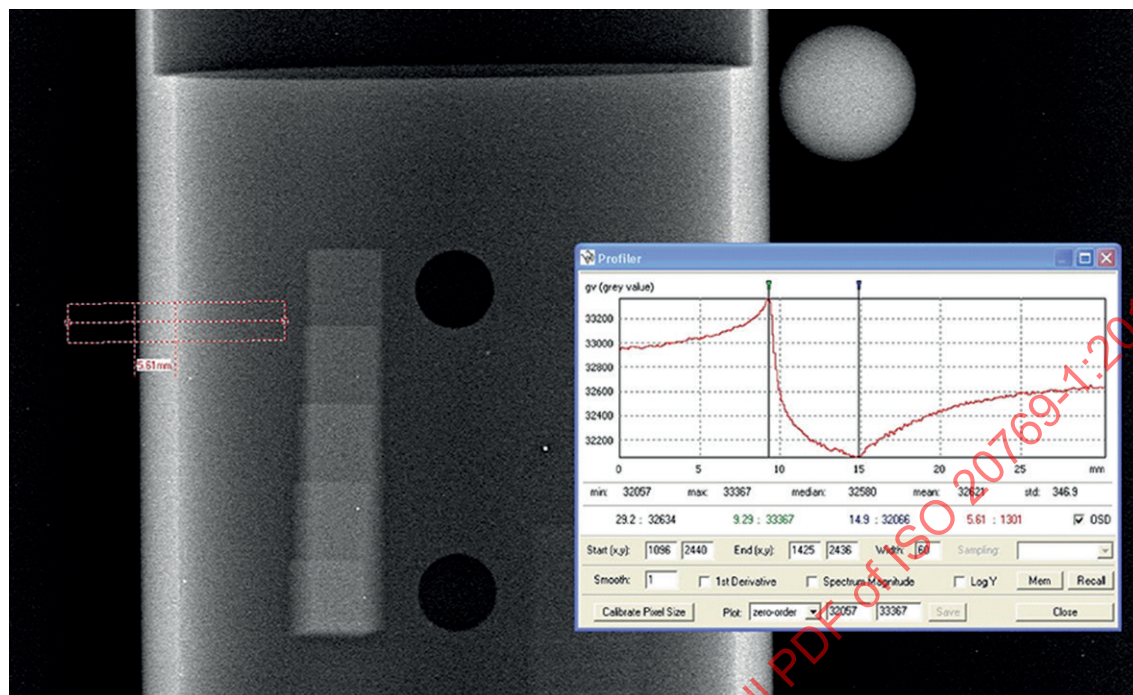


Figure 8 — Example of interactive wall thickness measurement using cursors superimposed on a grey level profile taken across the pipe wall

The accuracy of all measurement methods decrease as the tangential penetrated thickness, w_{max} , approaches the maximum value recommended for the X-ray source or isotope in use (see [Table 1](#)), since the location of the inner wall becomes increasingly difficult to determine with any reliability due to lack of contrast and increased noise.

7.8 Remaining thickness measurements for degradation

7.8.1 Measurements for internal degradation

For some applications, it is important to determine the minimum remaining wall thickness with high accuracy. It shall be determined, if required, for evaluation of degradation using the following procedure.

This requires minimization of any misalignment between the deepest part of the area of degradation from the tangential location.

NOTE 1 As the circumferential coverage of the tangential technique is limited, a reliable measurement of remaining wall thickness can only be achieved if the point of greatest severity on an area of internal degradation is accurately positioned at the point at which the radiation beam is tangential to the pipe wall, as illustrated in [Figure 9](#). In practice, in a field environment, it can be difficult to adjust the positions of the source and detector to achieve the required positional accuracy in a single exposure.

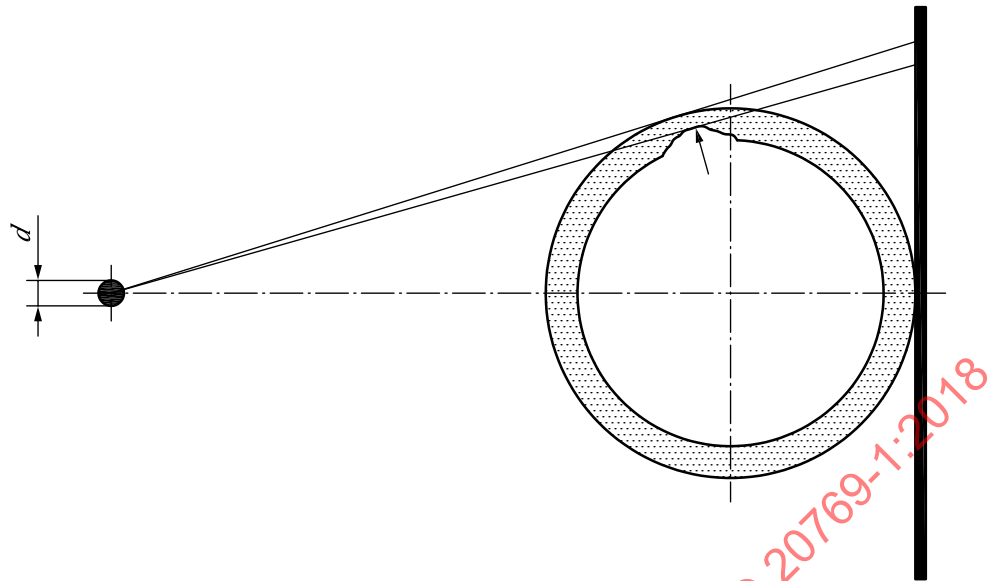


Figure 9 — Optimum location of source, detector and deepest point on an area of internal degradation for measurement of remaining wall thickness

The double wall technique (see ISO 20769-2), or other methods, should be used initially to identify areas of internal degradation and to determine the axial and circumferential location of the point in the degradation showing the greatest contrast, which should correspond to the point of greatest severity. The source and detector should then be rotated until this point is as close as possible to the position at which the radiation beam is tangential to the pipe (as shown in [Figure 9](#)).

The remaining wall thickness should then be measured on the resulting tangential radiograph. A number of exposures should be taken with source and detector moved to ensure the circumferential position of tangential location varies either side of the initial position.

NOTE 2 Evaluation of the tangential radiographs can also be used to minimize any misalignment effects that are apparent on the initial exposure. The required angular increment between exposures depends on the pipe diameter, the morphology of the degradation and the accuracy required.

The values should be in the range 5° to 15° depending on the pipe diameter. The larger diameters need smaller angle increments.

The measurements of remaining wall thickness from the multi angle tangential radiographs shall then be examined and the minimum value used (see [Figure 10](#)). For further information, see [Annex C](#).

NOTE 3 In this case, the overall minimum thickness of 5 mm was found at 10° to the initial measurement angle and a total of 4 measurements were needed to locate the position of the minimum wall thickness.

**Key**

- X circumferential angle of the tangent point from the highest point on the corrosion product (°)
 Y minimum wall thickness at each angle (mm)

Figure 10 — Example of tangential thickness measurements made at different angles to find the minimum remaining ligament of 5 mm for a corroded area

7.8.2 Measurements for external degradation

For some applications, it is important to determine the minimum remaining wall thickness with high accuracy. It shall be determined, if required, for evaluation of degradation using the following procedure.

The measurements of the remaining thickness shall be performed by tangential radiography to evaluate the areas of external degradation.

NOTE 1 For some forms of external degradation, tangential radiography is capable of providing reliable measurements of remaining wall thickness with an accuracy similar to that for uniform wall thickness pipes. However, significant unreliability in the measurements of remaining thickness can be obtained when using tangential radiography to inspect some areas of external corrosion in the following circumstances (see [Annex C](#)):

- when the deepest part of the corrosion is misaligned from the exact location of the tangent position of the radiation beam on the pipe;
- when the external corrosion morphology results in the profile of the uncorroded steel being concave in shape, compared with the normal convex curvature of the ungraded pipe OD;
- when the external corrosion consists of fine pitting superimposed on a more general areas of wall loss.

The following procedure should be applied, as shown in [Figure 11](#).

- a) Position the source and detector as accurately as possible to ensure that the most severe part of the degradation is as close as possible to the tangent position. For uninsulated components, this corresponds to the thickest part of the external corrosion scab. For insulated components, double wall images should be used to locate the position of the greatest wall loss.

- b) Obtain a radiograph that meets at the least the requirements of class TA. Class TB should be used if there is a likelihood that the remaining steel profile is concave.
- c) Assess the radiograph for:
 - features or structure in the image of the pipe wall under the corrosion (e.g. as shown in [Figure C.3](#)) which are indicative of a concave external profile of the remaining steel in the pipe wall;
 - fine pitting in the double wall portions of the image of the corrosion (e.g. as shown in [Figure C.5](#)).
- d) If either or both of the characteristics in c) are present, then these should be documented in the inspection report and only a corrosion severity reported.
- e) If neither of the characteristics in c) are seen on the radiograph, the minimum remaining wall thickness under the corroded area shall be found using the methods described in [7.7](#). Additional exposures should be taken with the source and detector positioned so as to rotate the tangential point around the circumference of the pipe, in both directions away from the initial position. Exposures should be taken at increments of about 5° to 15° depending on the pipe OD. The larger diameters need smaller angle increments.

NOTE 2 The increment can be about 5° for pipes with 150 mm (6 in) OD or larger. For smaller diameter 50 mm to 75 mm (2 in to 3 in) pipes the increment can be increased to about 10° to 15°.

- f) The minimum thickness values obtained in e) should be evaluated and the measurements continued for increasing angles away from the initial position, until the minimum wall thickness has been determined. The measurements of remaining wall thickness from the multi angle tangential radiographs shall then be examined and the minimum value used (see [Figure 10](#)). For further information, see [Annex C](#).

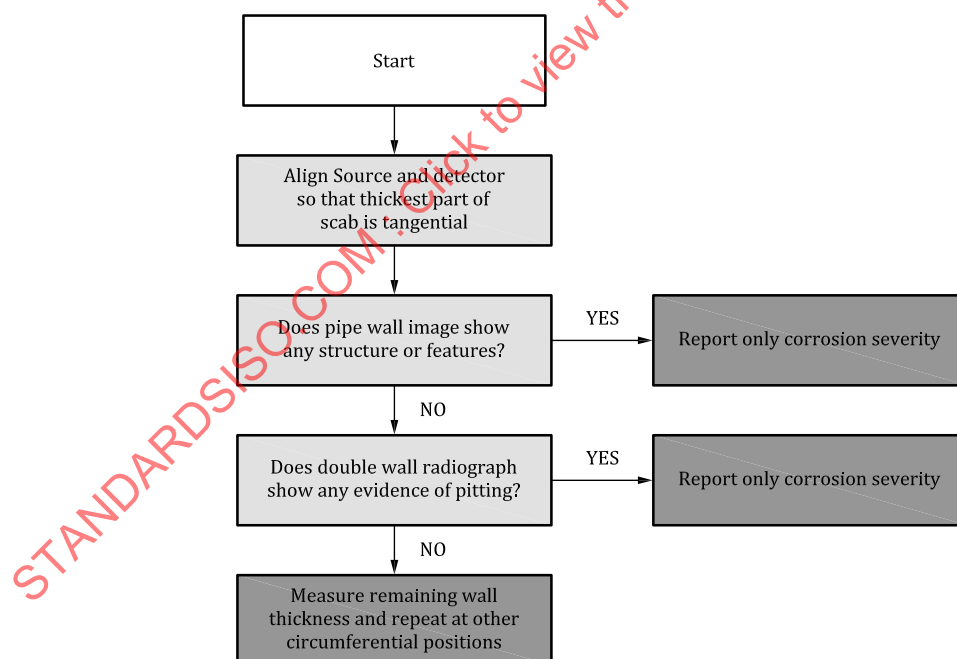


Figure 11 — Overview of procedure for tangential radiography of externally degraded pipes

8 Digital image recording, storage, processing and viewing

8.1 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.

8.2 Multi radiograph technique

Different digital radiographs at different exposure conditions may be used to optimize the SNR of the outer wall in one exposure and to optimize the SNR of the inner wall in a second exposure. The source and detector position shall not be changed for these exposures. The distance between the inner and outer surface may be determined from the different exposures in analogy to multi film viewing. A software tool may be used to measure the wall thickness from the different images or from an overlaid image. The performance of this technique and any applied software shall be demonstrated with an exposure of a reference pipe sample with known dimensions.

8.3 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 increases the achievable SNR_N and linearity but takes more time. All calibration images shall be taken at least with two 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.

8.4 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).

8.5 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.

8.6 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 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.

8.7 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.

9 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 20769-1);
- 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 conditions of insulation;
- f) the material, dimensions and position of the comparator, C;
- g) the specification of examination, including requirements for acceptance;
- h) the radiographic technique and class;
- i) the test arrangement in accordance with 6.1;
- j) the system of marking used;
- k) the detector position plan;
- l) the radiation source, type and size of focal spot and identification of equipment used;
- m) the detector, screens and filters;
- n) the tube voltage and current used or source activity;
- o) the time of exposure, SDD and PDD , magnification;
- p) the film type, film system and film processing;

- q) the CR system, IP type, scanner model, scanner parameters e.g. scan speed, gain, laser intensity, laser spot size, pixel size;
- r) the DDA type, operating parameters, pixel size;
- s) the basic spatial resolution of digital detectors;
- t) the measured image parameters:
 - 1) film densities measured at pipe centre (if applicable), in the pipe wall and outside pipe;
 - 2) SNR_N , achieved at the pipe centre (if applicable) and in the free beam;
- u) the measured wall thicknesses, including minimum measured wall thickness and its location;
- v) the material loss: inside, outside, pitting or generalized;
- w) additional observations;
- x) any deviation from this document, by special agreement;
- y) the name, certification and signature of the operator;
- z) the date(s) of exposure and test report.

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Annex A (informative)

Choice of radiation source for different pipes

Figure A.1 shows the maximum penetrated steel thickness, $w_{\max}$, as a function of pipe wall thickness for different pipe outside diameters, derived using Formula (1). The recommended limits on $w_{\max}$ are also shown for the application of the different radiation sources, which allows the appropriate source to be selected for a particular pipe, given the outside diameter and wall thickness.

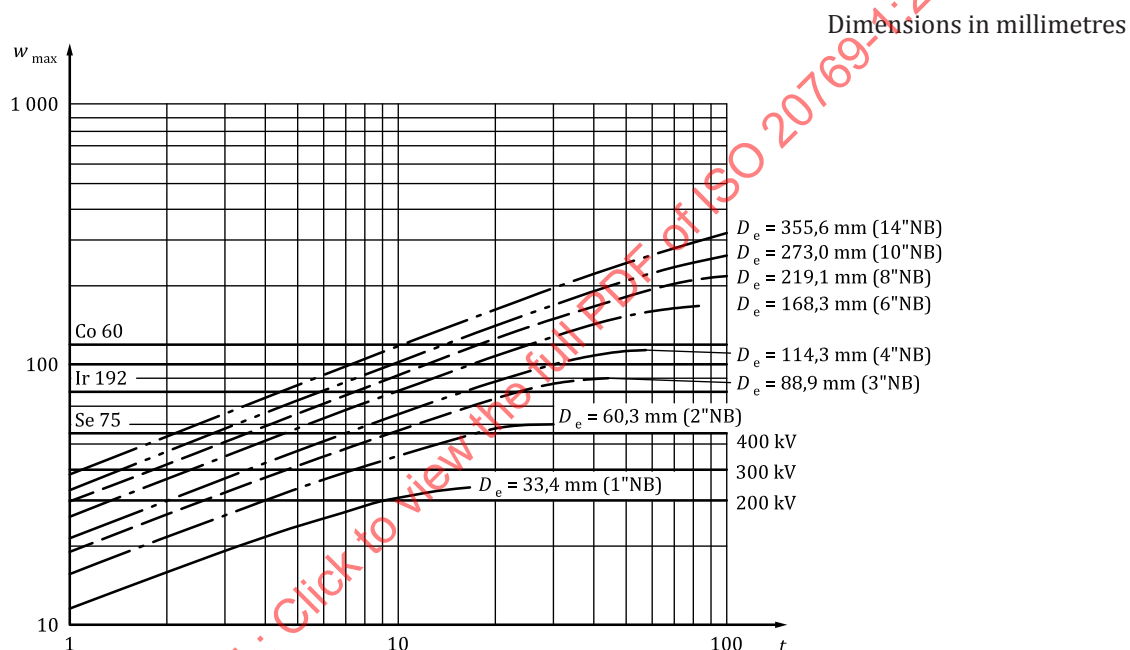


Figure A.1 — Maximum penetrated steel thickness, $w_{\max}$, as a function of wall thickness, t_{act}

The curves in Figure A.1 show the values for pipes of differing outside diameters, D_e , with dimensions given in millimetres and nominal bore, NB, according to ANSI B36.1. The limits for different radiation sources given in Table 1 for class TA are also illustrated. These limits can be increased if digital radiography is used.