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# Non-destructive testing — Industrial computed radiography with storage phosphor imaging plates —

## Part 2: General principles for testing of metallic materials using X-rays and gamma rays

*Essais non destructifs — Radiographie industrielle numérisée avec écrans photostimulables à mémoire —*

*Partie 2: Principes généraux de l'essai radiographique des matériaux métalliques au moyen de rayons X et gamma*



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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).

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

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

This document was prepared by the European Committee for Standardization (CEN) in collaboration with ISO Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 5, *Radiographic testing*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all parts in the ISO 16371 series can be found on the ISO website.

This corrected version of ISO 16371-2:2017 incorporates the following correction:

— Figure A.1 b) has been corrected.

# Non-destructive testing — Industrial computed radiography with storage phosphor imaging plates —

# Part 2: General principles for testing of metallic materials using X-rays and gamma rays



## 1 Scope

This document specifies fundamental techniques of computed radiography with the aim of enabling satisfactory and repeatable results to be obtained economically. The techniques are based on the fundamental theory of the subject and tests measurements. This document specifies the general rules for industrial computed X-rays and gamma radiography for flaw detection purposes, using storage phosphor imaging plates (IP). It is based on the general principles for radiographic examination of metallic materials on the basis of films, as specified in ISO 5579. The basic set-up of radiation source, detector and the corresponding geometry are intended to be applied in accordance with ISO 5579 and corresponding product standards such as ISO 17636 for welding and EN 12681 for foundry.

This document does not lay down acceptance criteria of the imperfections. Computed radiography (CR) systems provide a digital grey value image which can be viewed and evaluated on basis of a computer only. This practice describes the recommended procedure for detector selection and radiographic practice. Selection of computer, software, monitor, printer and viewing conditions are important but not the main focus of this document.

The procedure it specifies provides the minimum requirements and practice to permit the exposure and acquisition of digital radiographs with a sensitivity of imperfection detection equivalent to film radiography and as specified in ISO 5579. Some application standards, e.g. EN 16407, can require different and less stringent practice conditions.

## 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 5579, *Non-destructive testing — Radiographic testing of metallic materials using film and X- or gamma rays — Basic rules*

ISO 5580, *Non-destructive testing — Industrial radiographic illuminators — Minimum requirements*

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

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

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

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

ISO 19232-3:2013, *Non-destructive testing — Image quality of radiographs — Part 3: Image quality classes*

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

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

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

## 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 http://www.iso.org/obp

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

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

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

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

**3.3**
**structure noise of imaging plate**
**structure noise of IP**
fixed pattern noise measured due to IP structure which is inherent from inhomogeneities in the sensitive layer (graininess) and surface of a *storage phosphor imaging plate* (3.2)

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

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

**3.4**
**grey value**
**GV**
numeric value of a pixel in a digital image

Note 1 to entry: This is equivalent to the term pixel value as defined in ASTM E 2033, E 2445, E 2446 and E 2007.



**3.5**
**linearized grey value**
$GV_{lin}$
numeric value of a pixel which is directly proportional to the detector exposure dose, having a value of zero if the detector was not exposed

Note 1 to entry: This is equivalent to the term linearized pixel value as defined in ASTM E 2033, E 2445, E 2446 and E 2007.

**3.6**
**basic spatial resolution of CR system**
$SR_b^{detector}$
corresponds to half of the measured detector unsharpness in a digital image and corresponds to the effective pixel size and indicates the smallest geometrical detail, which can be resolved with a CR system at magnification equal to one

Note 1 to entry: For this measurement, the duplex wire IQI is placed directly on the CR imaging plate.

Note 2 to entry: The measurement of unsharpness is described in ISO 19232-5; see also ASTM E 2002.

**3.7**
**basic spatial resolution of a digital image**
$SR_b^{image}$
corresponds to half of the measured image unsharpness in a digital image and corresponds to the effective pixel size in the image and indicates the smallest geometrical detail, which can be resolved in a digital image

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

Note 2 to entry: The measurement of unsharpness is described in ISO 19232-5; see also ASTM E 2002.

Note 3 to entry: The effective pixel size of the image (basic spatial resolution of the digital image) depends on pixel pitch, geometrical unsharpness, detector unsharpness and magnification.

**3.8**
**signal-to-noise ratio**
**SNR**
quotient of mean value of the *linearized grey values* (3.5), which is the signal intensity to the standard deviation of the linearized grey values (noise) in a given region of interest in a digital image

Note 1 to entry: The SNR depends on the radiation dose and the CR system properties.

**3.9**
**normalized signal-to-noise ratio**
$\mathbf{SNR_N}$
*signal-to-noise ratio* (3.8), normalized by the basic spatial resolution, $SR_b$, which may be $SR_b^{image}$ or $SR_b^{detector}$, as measured directly in the digital image and/or calculated from the measured SNR, $SNR_{measured}$, by

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



**3.10**
**contrast-to-noise ratio**
**CNR**
ratio of the difference of the mean signal levels between two image areas to the averaged standard deviation of the signal levels

Note 1 to entry: The contrast-to-noise ratio describes a component of image quality and depends approximately on the product of radiographic attenuation coefficient and SNR. In addition to adequate CNR, it is also necessary for a digital radiograph to possess adequate unsharpness or basic spatial resolution to resolve desired features of interest.

**3.11**
**normalized contrast-to-noise ratio**
**$CNR_N$**
*contrast-to-noise ratio* (3.10), normalized by the basic spatial resolution, $SR_b$, as measured directly in the digital image and/or calculated from the measured CNR, by

$$CNR_N = CNR \cdot \frac{88{,}6 \mu m}{SR_b}$$

**3.12**
**aliasing**
artefacts that appear in an image when the spatial frequency of the input is higher than the output is capable of reproducing

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

**3.13**
**nominal thickness**
*t*
thickness of the material in the region under examination

Note 1 to entry: Manufacturing tolerances do not have to be taken into account.

**3.14**
**penetrated thickness**
*w*
thickness of material in the direction of the radiation beam calculated on basis of the *nominal thickness* (3.13) of all penetrated walls

Note 1 to entry: For multiple wall techniques, the penetrated thickness is calculated from the nominal thickness of all penetrated walls.

**3.15**
**source size**
*d*
size of the radiation source or focal spot size

Note 1 to entry: See EN 12543 (X-ray-sources) or EN 12679 (gamma ray sources). Manufacturer's values may be used if they conform to these standards.

**3.16**
**object-to-detector distance**
*b*
largest (maximum) distance between the radiation side of the radiographed part of the test object and the sensitive layer of the detector along the central axis of the radiation beam



**3.17**
**source-to-detector distance**
**SDD**
distance between the source of radiation and the detector, measured in the direction of the beam

Note 1 to entry: SDD = $f + b$, where $f$ is the *source-to-object distance* (3.18) and $b$ is the *object-to-detector distance* (3.16).

**3.18**
**source-to-object distance**
$f$
distance between the source of radiation and the source side of the test object, most distant from the detector, measured along the central beam

**3.19**
**geometric magnification**
$v$
ratio of *source-to-detector distance* (3.17) to *source-to-object distance* (3.18)

## 4 Symbols and abbreviated terms

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

**Table 1 — Symbols and abbreviated terms**

| Symbol | Term |
|---|---|
| $b$ | object-to-detector distance |
| CNR | contrast-to-noise ratio |
| $\mathrm{CNR_N}$ | normalized contrast-to-noise ratio |
| CR | computed radiography |
| $d$ | source size, focal spot size |
| D | detector (imaging plate) |
| $f\,d$ | source-to-object distance |
| GV | grey value |
| $\mathrm{GV_{lin}}$ | linearized grey value |
| IP | storage phosphor imaging plate |
| IQI | image quality indicator |
| S | radiation source |
| SDD | source-to detector-distance |
| SNR | signal-to-noise ratio |
| $\mathrm{SNR_N}$ | normalized signal-to-noise ratio |
| $\mathrm{SR_b}$ | basic spatial resolution, which may be $\mathrm{SR_b^{image}}$ or $\mathrm{SR_b^{detector}}$ depending on the context |
| $\mathrm{SR_b^{detector}}$ | basic spatial resolution as determined with a duplex wire IQI adjacent to the detector |
| $\mathrm{SR_b^{image}}$ | basic spatial resolution as determined with a duplex wire IQI on the source side of the object |
| $t$ | nominal thickness |
| $u_{\mathrm{G}}t$ | geometric unsharpness |
| $u_{\mathrm{i}}$ | inherent unsharpness of the detector system, excluding any geometric unsharpness, measured from the digital image with a duplex wire IQI adjacent to the detector |
| $u_{\mathrm{T}}$ | total image unsharpness, including geometric unsharpness, measured in the digital image at the detector plane with a duplex wire IQI at the object plane |

**Table 1** *(continued)*

| Symbol | Term |
|---|---|
| $u_{Im}$ | image unsharpness, including geometric unsharpness, measured in the digital image with a duplex wire IQI at the object plane normalized to magnification |
| $v$ | geometric magnification |
| $w$ | penetrated thickness |

## 5 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.

NOTE Training content for digital industrial radiology can be found in TCS-60 document of IAEA[10].



## 6 Classification of computed radiographic techniques and compensation principles

### 6.1 Classification

Computed radiographic techniques are subdivided into two classes:

— Class A: basic technique;

— Class B: improved technique.

Class B technique is used when class A may be insufficiently sensitive.

Better techniques, compared with class B, are possible and may be agreed between the contracting parties by specification of all appropriate test parameters.

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

Nevertheless, the perception of flaws using film radiography or computed radiography is comparable by using class A and class B techniques, respectively. The perceptibility shall be proven by the use of IQIs according to ISO 19232-1, ISO 19232-2 and ISO 19232-5.

If, for technical reasons, it is not possible to meet one of the conditions specified for class B, such as the type of radiation source or the source-to-object distance, *f*, it may be agreed between the contracting parties that the condition selected may be that specified for class A. The loss of sensitivity shall be compensated by an increase of minimum grey value and $SNR_N$ (recommended increase of $SNR_N$ by a factor > 1,4). Because of the resulting improved sensitivity compared to class A, the test object may be regarded as examined within class B if the correct IQI sensitivity is achieved.

### 6.2 Compensation principles, CP I and CP II

**6.2.1 General**. Two rules (see 6.2.2 and 6.2.3) are applied in this document for radiography with CR to achieve a sufficient contrast sensitivity.

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

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

**6.2.3 CP II**. Compensation for insufficient detector sharpness (the value of $SR_b^{detector}$ higher than specified) by increased SNR (increase in the single IQI wire or step hole value for each missing duplex wire pair value).

**6.2.4 Theoretical background**. These compensation principles are based on the following approximation for small flaw sizes ($\Delta w << w$) as shown in Formula (1):

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

where

$c$ is a constant;

$\mu_{eff}$ is the effective attenuation coefficient, which is equivalent to the specific material contrast.

# 7 General

## 7.1 Protection against ionizing radiation

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

Local or national or international safety precautions when using ionizing radiation shall be strictly applied.

## 7.2 Surface preparation and stage of manufacture

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

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

## 7.3 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.

## 7.4 Marking

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

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

## 7.5 Overlap of phosphor imaging plates

When radiographing an area with two or more separate phosphor imaging plates (IP), the IPs 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 that will appear on each image. If the radiographs will be taken sequentially, the high density marker shall be visible on each of the radiographs.

### 7.6 Types and positions of image quality indicators and IQI values

The quality of images shall be verified by use of image quality indicators (IQIs) in accordance with ISO 19232-5 and ISO 19232-1 or ISO 19232-2. If not otherwise specified by the contracting parties, the required IQI values of ISO 19232-3 shall be achieved. The IQIs shall be placed on the source side of the object. If this is not possible, the IQIs shall be placed on the detector side of the object with an additional letter F.

NOTE Positioning of IQIs on the detector side would apply, for example, for double wall single image in-service inspection.

Following the procedure outlined in Annex A, a reference image is required for the verification of the basic spatial resolution of the CR system. The basic spatial resolution or duplex wire value shall be determined to verify whether the system hardware meets the requirements specified as a function of the penetrated material thickness in Table 5. In this case, the duplex wire IQI shall be positioned directly on the imaging plate or imaging plate cassette.

The use of a duplex wire IQI (ISO 19232-5) for production radiographs is not compulsory. The requirement for using a duplex wire IQI additionally to a single wire IQI for production radiographs may be part of the agreement between the contracting parties. If used on production radiographs, the duplex wire IQI shall be positioned on the object. The measured basic spatial resolution of the digital image ($SR_b^{image}$) (see Annex A), shall not exceed the maximum values specified as a function of the penetrated material thickness (Table 5). For single image inspection, the single wall thickness is taken as the penetrated material thickness. For double wall double image inspection (ISO 19232-3), with the duplex wire on the source side of the object, the penetrated material thickness is taken as the outer object dimension for determination of the required basic spatial resolution ($SR_b^{image}$) from Table 5. The basic spatial resolution of the detector ($SR_b^{detector}$) for double wall double image inspection shall correspond to the values of Table 5 chosen on the basis of twice the nominal single wall thickness as the penetrated material thickness.

If the geometric magnification technique is applied with $v > 1,2$, then the duplex wire IQI (ISO 19232-5) shall be used on all production radiographs.

The duplex wire IQI shall be positioned tilted by a few degrees (2° to 5°) to the digitally achieved rows or columns of the digital image. If the IQI is positioned at 45° to the digital lines or rows, the obtained IQI number shall be reduced by one.

The contrast sensitivity of digital images shall be verified by use of IQIs, in accordance with the specific application as given in ISO 19232-3.

The single wire or step hole IQIs 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. Its location shall be in a section of uniform thickness characterized by a uniform grey value (mean) in the digital image.

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

a) When using a single wire IQI, the wires shall be on a location of constant thickness, which shall ensure that at least 10 mm of the wire length shows in a section of uniform grey value or $SNR_N$.

b) When using a step hole IQI, it shall be placed in such a way that the hole number required is placed close to the region of interest.

For double wall double image exposures, the IQI type used can be placed either on the source or on the detector side. If the IQIs cannot be placed in accordance with the above conditions, the IQIs are placed on the detector side and the image quality shall be determined at least once from comparison exposure with one IQI placed at the source side and one at the detector side under the same conditions. If filters are used in front of the detector, the IQI shall be placed in front of the filter.

For double wall exposures, when the IQI is placed on the detector side, the above test is not necessary. In this case, refer to the corresponding tables of ISO 19232-3.

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

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

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

For exposures of pipes with diameter 200 mm and above with the source centrally located, at least three IQIs should be placed equally spaced at the circumference. The IQI images are then considered representative for the whole circumference.

If the IQI cannot be placed inside a hollow object or a pipe for inspection (e.g. with source centrally located), it can be located outside. The required IQI values shall be determined by a reference exposure with IQIs on the source and the detector sides of the pipe or a hollow object.

# 8 Recommended techniques for making computed radiographs

## 8.1 Test arrangements

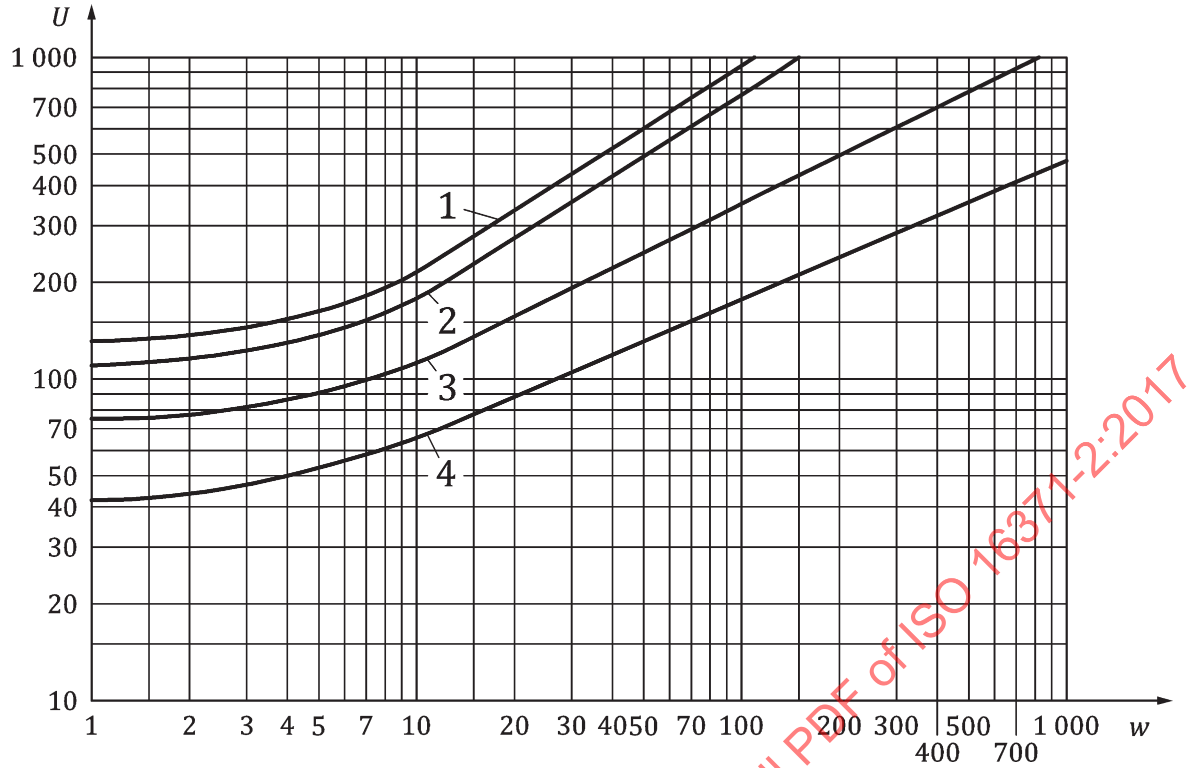
Test arrangements shall be determined from the specific application standards, e.g. ISO 17636-2 and EN 12681.

## 8.2 Choice of X-ray tube voltage and radiation source

### 8.2.1 X-ray equipment

To maintain good flaw sensitivity, the X-ray tube voltage should be as low as possible and the $SNR_N$ in the digital image should be as high as possible. Recommended maximum values of tube voltage versus thickness are given in Figure 1. These maximum values are best practice values for film radiography.

Imaging plates with high structure noise of the sensitive IP layer (coarse grained) should be applied with about 20 % less X-ray voltage as indicated in Figure 1 for class B testing. High definition imaging plates, which are exposed similar to X-ray films and having low structure noise (fine grained) should be exposed with X-ray voltages of Figure 1 or higher if the $SNR_N$ is sufficiently increased (see Note below).




**Key**

1 copper/nickel and alloys

2 steel

3 titanium and alloys

4 aluminium and alloys

*w* penetrated material thickness in mm

*U* X-ray voltage in kV

**Figure 1 — X-ray voltage for X-ray devices up to 1 MV as function of penetrated material thickness and material**

NOTE An improvement in contrast sensitivity can be achieved by an increase in contrast at constant $SNR_N$ [by reduction of tube voltage and compensation by higher exposure (e.g. milliampère · minutes)]; or improvement in contrast sensitivity by an increase in $SNR_N$ [by higher exposure (e.g. milliampère · minutes)] at constant contrast (constant kilovolt level); increased tube voltage [at a constant exposure (e.g. milliampère · minutes)] reduces the contrast and increases the $SNR_N$. The contrast sensitivity improves if the increase in $SNR_N$ is higher than the contrast reduction due to the higher energy.

### 8.2.2 Other radiation sources

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

By agreement of the contracting parties, the value for Ir-192 may be reduced furthermore to 10 mm and for Se-75 to 5 mm penetrated wall thickness, provided the required image quality of ISO 19232-3 is met.

On thin specimens, gamma rays from Ir-192 and Co-60 will not produce computed radiographs having as good defect detection sensitivity as X-rays used with appropriate technique parameters. However, because of the advantages of gamma ray sources in handling and accessibility, Table 2 gives a range of thickness for which each of these gamma ray sources may be used when the use of X-rays is difficult.

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



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

**Table 2 — Penetrated material thickness range for gamma ray sources and X-ray equipment with energy from 1 MeV and above for steel, copper and nickel-based alloys**

| Radiation source | Penetrated material thickness, $w$ mm | |
|---|---|---|
| | Class A | Class B |
| Tm-170 | $w \leq 5$ | $w \leq 5$ |
| Yb-169 [a] | $1 \leq w \leq 15$ | $2 \leq w \leq 12$ |
| Se-75 [b] | $10 \leq w \leq 40$ | $14 \leq w \leq 40$ |
| Ir-192 | $20 \leq w \leq 100$ | $20 \leq w \leq 90$ |
| Co-60 | $40 \leq w \leq 200$ | $60 \leq w \leq 150$ |
| X-ray equipment with energy 1 to 4 MeV | $30 \leq w \leq 200$ | $50 \leq w \leq 180$ |
| X-ray equipment with energy 4 to12 MeV | $50 \leq w$ | $80 \leq w$ |
| X-ray equipment with energy > 12 MeV | $80 \leq w$ | $100 \leq w$ |

[a] For aluminium and titanium, the penetrated material thickness is $10 \leq w \leq 70$ for class A and $25 \leq w \leq 55$ for class B.

[b] For aluminium and titanium, the penetrated material thickness is $35 \leq w \leq 120$ for class A.

The maximum penetrated thicknesses as given in Table 2 may be exceeded if sufficient IQI sensitivity can be proven.

## 8.3 CR systems and screens

### 8.3.1 Minimum normalized signal-to-noise ratio

For digital radiographic examination, minimum $SNR_N$ values as given in Tables 3 and 4 or minimum grey values shall be achieved. Annex C describes the procedure for measurement of $SNR_N$ and provides a conversion table for users who prefer to use unnormalized measured SNR values instead of normalized $SNR_N$ values.

Equivalent minimum grey values may be used instead of minimum $SNR_N$ values if they are determined by means of the procedure of Annex C for the IP used, the scanner used and its settings and the required $SNR_N$ of Tables 2 and 3.

The $SNR_N$ value shall be measured in the region of interest near the wire or step hole IQIs in the thicker part of the test object in a zone of homogeneous wall thickness and constant grey values. Since the roughness of the material influences image noise and $SNR_N$, the values in Tables 3 and 4 are recommended values only. The values may fall short up to 20 % of the values of Tables 3 and 4, provided the required image quality of ISO 19232-3 is met.

Annex C describes the method for determination of equivalent minimum grey values in lieu of the required $SNR_N$.

### 8.3.2 Metal screens and shielding

When using metal front screens, good contact between detectors and screens is required. This should be achieved either by using vacuum-packed detectors or by applying pressure. Lead screens not in intimate contact with the IPs may contribute to image unsharpness. The intensification by using lead screens in contact with imaging plates is significantly smaller than in film radiography.

Many IPs are very sensitive to low energy back scatter and X-ray fluorescence of back shieldings from lead. This effect contributes significantly to edge unsharpness and reduced CNR and should be minimized. It is recommended to use steel or copper shielding directly behind the IPs. Also, a steel or copper shielding between back scatter lead plate and IP may improve the image quality. Modern cassette and detector designs may consider this effect and are constructed in a way 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) at typical X-ray energies.

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

Tables 3 and 4 show the recommended screen materials and thicknesses for different radiation sources. Other screen thicknesses and materials 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.

**Table 3 — Minimum $SNR_N$ and metal front screens for the computed radiography of steel, copper- and nickel-based alloys**

| Radiation source | Penetrated material thickness, *w* | Minimum $SNR_N$ | | Recommended type and thickness of metal front screens |
|---|---|---|---|---|
| | mm | Class A | Class B | mm |
| X-ray potentials ≤ 50 kV | | 100 | 150 | None |
| X-ray potentials[c] > 50 kV to 150 kV | | 70 | 120 | 0 – 0,1 (Pb) |
| X-ray potentials[c] > 150 kV to 250 kV | | 70 | 100 | 0 – 0,1 (Pb) |
| X-ray potentials[c] > 250 kV to 350 kV | ≤50 | 70 | 100 | 0 – 0,25 (Pb) |
| | >50 | 70 | 70 | 0,1 – 0,3 (Pb) |
| X-ray potentials[c] > 350 kV to 1 000 kV | ≤50 | 70 | 100 | 0,1 – 0,3 (Pb) |
| | >50 | 70 | 70 | 0,1 – 0,3 (Pb) |
| Yb-169[c] | ≤5 | 70 | 120 | 0 – 0,1 (Pb) |
| | >5 | 70 | 100 | 0 – 0,1 (Pb) |
| Ir-192[c], Se-75[c] | ≤50 | 70 | 100 | 0,1 – 0,3 (Pb) |
| | >50 | 70 | 70 | 0,1 – 0,4 (Pb) |
| Co-60[a, b] | ≤100 | 70 | 100 | 0,5 (Fe) + 1,5 (Pb) |
| | >100 | 70 | 70 | 0,5 (Fe) + 2,0 (Pb) |
| X-ray potentials[a,b] >1 MV | ≤100 | 70 | 100 | 0,5 (Fe) + 1,5 (Pb) |
| | >100 | 70 | 70 | 0,5 (Fe) + 2,0 (Pb) |

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

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

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



**Table 4 — Minimum $SNR_N$ values and metal screens for aluminium and titanium**

| Radiation source | Minimum $SNR_N$ | | Type and thickness of metal front screens |
|---|---|---|---|
| | Class A | Class B | mm |
| X-ray potentials ≤ 150 kV | 70 | 120 | ≤0,03 (Pb) |
| X-ray potentials > 150 kV to 250 kV | 70 | 100 | ≤0,2 (Pb)[a] |
| X-ray potentials > 250 kV to 500 kV | 70 | 100 | ≤0,2 (Pb)[a] |
| Yb-169 | 70 | 100 | ≤0,15 (Pb)[a] |
| Se-75 | 70 | 100 | ≤0,3 (Pb)[a] |

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

## 8.4 Maximum unsharpness and basic spatial resolution for CR system selection

### 8.4.1 System selection

Computed radiography systems shall provide sufficient image quality for a certain probability of detection of material inhomogeneities. Table 5 defines the required maximum unsharpness and basic spatial resolution values and minimum duplex wire IQI-values of the CR system to be selected depending on penetrated material thickness and testing class. CR systems for digital radiography shall not exceed the minimum unsharpness and basic spatial resolution values given in Table 5 or shall not fall below the required duplex IQI value.

The unsharpness and basic spatial resolution (or the duplex wire IQI value according to ISO 19232-5) of the used CR system shall be confirmed by a reference exposure to determine $SR_b^{detector}$. $SR_b^{image}$ shall be determined if the magnification is > 1,2.

The basic spatial resolution of the detector ($SR_b^{detector}$) or the basic spatial resolution in the digital image ($SR_b^{image}$) is calculated from the unsharpness value ($u_T$) as determined by the procedure of ISO 19232-5) and Annex A. Flaws should be inspected by a CR system which are larger or equal than 3 × 3 pixels for spot like indications and larger or equal than 2 × 6 pixels for linear indications in the digital image.

Testing can be performed with CR systems, which have a higher unsharpness than required in Table 5, if the compensation principle II is applied.

### 8.4.2 Compensation principle II

If both IQI sensitivities (contrast sensitivity by single IQI wires or step holes on the one hand and spatial resolution of the detector by duplex wire IQIs on the other) of Table 5 cannot be achieved by the detector system and exposure conditions used, an increase in single IQI wire visibility or step hole visibility shall compensate for the exceeded unsharpness values (or exceeded $SR_b$ values).

For example, if the required values of D12 and W16 (for 5 mm thickness, class B — Table 5 or ISO 19232-3:2013, Table 3) are not achieved at the same time for a specific detector set-up, then the values D11 and W17 provide an equivalent detection sensitivity. The compensation shall be limited to a maximum increase of two single wires for two missing resolved duplex wire pairs. If the required flaw sensitivity can be demonstrated for the specific application, by agreement between the contracting parties, the compensation may be extended to a maximum of three single wires for three missing resolved duplex wire pairs.



**Table 5 — Maximum image unsharpness for all techniques**

| Penetrated thickness $w$[a]<br>mm | Maximum IQI value and maximum unsharpness (ISO 19232-5)[b]<br>mm | Maximum basic spatial resolution (equivalent to wire thickness and spacing)[b]<br>mm |
|---|---|---|
| **Image quality class A** | | |
| $t \leq 1{,}0$ | D 13<br>0,10 | 0,05 |
| $1{,}0 < t \leq 1{,}5$ | D 12<br>0,125 | 0,063 |
| $1{,}5 < t \leq 2$ | D 11<br>0,16 | 0,08 |
| $2 < t \leq 5$ | D 10<br>0,20 | 0,10 |
| $5 < t \leq 10$ | D 9<br>0,26 | 0,13 |
| $10 < t \leq 25$ | D 8<br>0,32 | 0,16 |
| $25 < t \leq 55$ | D 7<br>0,40 | 0,20 |
| $55 < t \leq 150$ | D 6<br>0,50 | 0,25 |
| $150 < t \leq 250$ | D 5<br>0,64 | 0,32 |
| $t > 250$ | D 4<br>0,80 | 0,4 |
| **Image quality class B** | | |
| $t \leq 1{,}5$ | D 13+<br>0,08 | 0,04 |
| $1{,}5 < t \leq 4$ | D 13<br>0,10 | 0,050 |
| $4 < t \leq 8$ | D 12<br>0,125 | 0,063 |
| $8 < t \leq 12$ | D 11<br>0,16 | 0,08 |
| $12 < t \leq 40$ | D 10<br>0,20 | 0,10 |
| $40 < t \leq 120$ | D 9<br>0,26 | 0,13 |
| $120 < t \leq 200$ | D 8<br>0,32 | 0,16 |
| $t > 200$ | D 7<br>0,40 | 0,20 |

NOTE "D 13+" is achieved if the duplex wire pair D 14 of Table A.1 is achieved or D 13 is resolved with a dip larger than 20 %.

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

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

The $SR_b^{detector}$ is fixed by design and hardware parameters.

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



## 8.5 Alignment of beam

The beam of radiation shall be directed to the centre of the area being inspected and should be normal to the object surface at that point, except when it can be demonstrated that certain flaws are best revealed by a different alignment of the beam. In this case, an appropriate alignment of the beam can be permitted. Other ways of digital radiographing may be agreed between the contracting parties.

## 8.6 Reduction of scattered radiation

### 8.6.1 Metal 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.

With Se-75, Ir-192 and Co-60 radiation sources, or in case of edge scatter, a sheet of lead can be used as a filter of low energy scattered radiation between the object and the IP. The thickness of this sheet is 0,5 mm to 2 mm in accordance with the penetrated thickness. Between lead and IP, a 0,5 mm steel filter or 0,2 mm Cu filter is recommended to shield X-ray fluorescence of the lead filter.

### 8.6.2 Interception of back scattered radiation

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

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

## 8.7 Source to object distance

### 8.7.1 General requirements

The minimum source-to-object distance, $f_{\mathrm{min}}$, depends on the source size, $d$, and on the object-to-detector (IP) distance, $b$. The source size or focal spot size, $d$, shall be in accordance with EN 12543 or EN 12679. Manufacturer's values may be used if they conform to these standards.

### 8.7.2 Testing of planar objects and curved objects with flexible IPs

For testing of planar objects and curved objects with flexible IPs on basis of Figure 2 a), the distance, $f$, shall, where practicable, be chosen so that the ratio of this distance to the source size, $d$, i.e. $f/d$, is not below the values given by Formula (2) and Formula (3):

For class A: $f/d \geq 7{,}5\ (b)^{2/3}$ (2)

For class B: $f/d \geq 15\ (b)^{2/3}$ (3)

where $b$ is the maximum distance between the detector and the source side of the object (in mm).

If the distance $b < 1{,}2\ t$, the dimension, $b$, in Formula (2) and Formula (3) and Figure 2 shall be replaced by the nominal thickness, $t$.



For determination of the source-to-object distance, $f_{min}$, the nomogram in Figure 3 may be used.

The nomogram is based on Formula (2) and Formula (3) and is valid for testing of objects with the IP in contact [see Figure 2 a)] only.

In class A, if planar imperfections have to be detected, the minimum distance, $f_{min}$, shall be the same as for class B in order to reduce the geometric unsharpness by a factor of 2.

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

### 8.7.3 Testing of curved objects with IPs in cassettes

For exposure geometries on the basis of Figure 2 b), the distance, *f*, shall, where practicable, be chosen so that the ratio of this distance to the source size, *d*, i.e. *f*/*d*, is not below the values given by Formula (4) and Formula (5):

For class A: $$f/d \geq 7{,}5\frac{b}{\sqrt[3]{t}} \quad (4)$$

For class B: $$f/d \geq 15\frac{b}{\sqrt[3]{t}} \quad (5)$$

where

*t* is the nominal material thickness to inspect (mm);

*b* is the maximum distance between detector and the source side of the object (in mm).

In class A, if planar imperfections have to be detected, the minimum distance, $f_{min}$, shall be the same as for class B in order to reduce the geometric unsharpness by a factor of 2.

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

Both the inherent unsharpness ($u_i = 2SR_b^{detector}$) of a CR system system and the geometric unsharpness ($u_G$) contribute to the total unsharpness ($u_T$) in the image if not corrected by means of geometric magnification as shown in Formula (6):

$$u_T = \sqrt{u_i^2 + u_G^2} \quad (6)$$

Therefore, it is recommended that the distance, $f_{min}$, be increased to compensate for any additional unsharpness of the CR system. For more details, see ISO 17636-2.

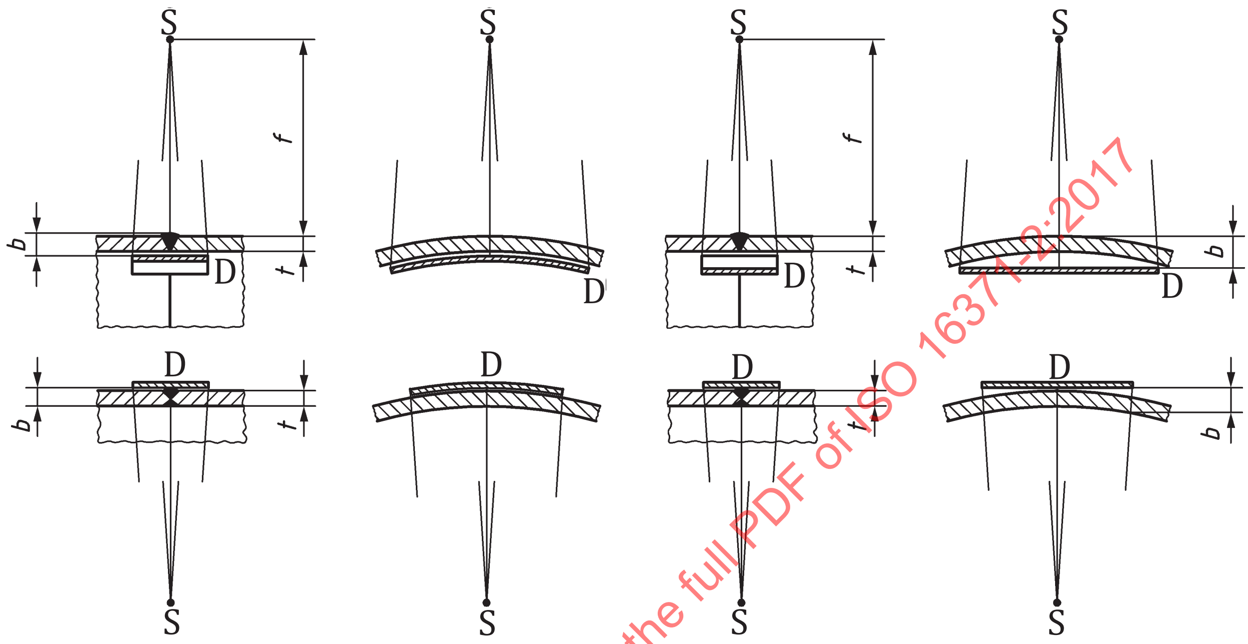
If magnification technique is used with $v > 1{,}2$, the image unsharpness, $u_{Im}$, shall be used instead of $u_T$ in Table 5 with Formula (7):

$$u_{Im} = u_T / v \quad (7)$$

### 8.7.4 Exceptions for panoramic projection exposures with the source in the centre of the pipe

Where possible, it is preferable to avoid usage of a double wall technique by placing the radiation source inside the object to be radiographed, to achieve a more suitable direction of examination. The reduction in minimum source-to-object distance should not be greater than 20 %. When the source is located centrally inside the object and the detector outside and provided that the IQI requirements are met, this percentage may be increased and a CR system may be used with one duplex wire value less than required in Table 5 based on the system qualification (see Note). However, the reduction in minimum source-to-object distance shall not be greater than 50 %. A reference exposure under the same geometric conditions with the IQI on source size should be taken to verify the achieved image quality in reference to ISO 19232-3, if the IQI cannot be placed in the pipe. A further reduction of SOD can be agreed by the contracting parties provided that the IQI requirements are met.

NOTE The system qualification can be based on the manufacturer's statement or on a reference exposure with the duplex wire IQI directly on the detector.




a) With flexible imaging plates

b) With planar cassettes

**Key**

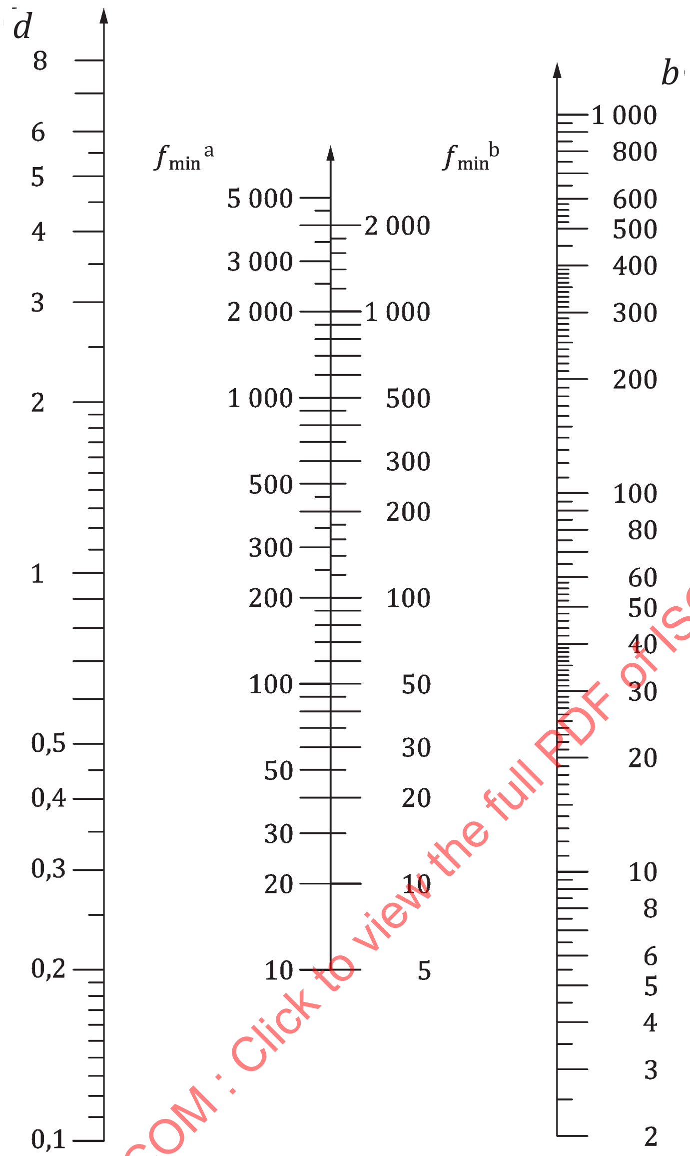
D detector (imaging plate)

S radiation source

**Figure 2 — Test arrangement for single-wall penetration of curved objects**






**Key**

a Class B.

b Class A.

*d* focal spot size or source size in mm

*b* distance detector to maximum object source side in mm

**Figure 3 — Nomogram for determination of minimum source-to-object distance, $f_{min}$, in relation to the object-IP distance (b) and the source size (d) for planar objects and curved objects using flexible IPs as shown in Figure 2 a)**

NOTE For testing of curved objects using planar cassettes, larger $f_{min}$ values than those determined by this nomogram are needed when $b > t$.

## 8.8 Maximum area for a single exposure

The ratio of the penetrated thickness at the outer edge of an evaluated area of uniform thickness to that at the centre beam shall not be more than 1,1 for class B and 1,2 for class A.

The $SNR_N$ values resulting from any variation of penetrated thickness should not be lower than those indicated in Table 2 or Table 3. Alternatively, GVs may be used for CR as shown in Annex C.



## 8.9 Erasure of imaging plates

In order to avoid unduly high background intensities arising from exposure by natural radiation, IPs shall always be erased before use if the last erasure was more than two weeks ago. If IPs are used for high-energy application or gamma radiography, they shall be checked for sufficient erasure by a test read out, after erasure.

## 8.10 Data processing

### 8.10.1 Image processing

The data of the digital radiographs shall be evaluated with linearized grey value representation which is directly proportional to the radiation dose for determination of SNR, $SR_b^{image}$, $SR_b^{detector}$ and $SNR_N$. For optimal image display, contrast and brightness should be interactively adjustable. Optional filter functions, profile plots and an SNR, the $SNR_N$ 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 one pixel of the digital radiograph is presented by one monitor pixel) and 1:2 (meaning one pixel of the digital radiograph is presented by four monitor pixels).

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

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

### 8.10.2 Monitor, viewing conditions and storage of digital radiographs

The computed radiographs shall be examined in a dimmed room on a monitor.

Alternatively, printed film hardcopies shall be examined on a viewing station corresponding to ISO 5580 and shall have a resolution better or equal to the requirements of Table 5.

The monitor setup shall be verified with a suitable test image.

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

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

b) display of minimal 256 shades of grey;

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

d) display of minimal 1 million pixels of a size <0,3 mm.

The original images (region of interest) shall be stored at the full resolution as delivered by the CR system.

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

# 9 Test report

For each computed radiograph or set of computed radiographs, 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.

Details concerning form and contents should be specified in special application standards or be agreed on by the contracting parties. If inspection is carried out exclusively to this guideline, then the test report shall contain at least the following information:

a) name of the test house;

b) number of test report;

c) object under test;

d) material tested;

e) stage of manufacture;

f) nominal thickness;

g) radiographic technique and class;

h) system of marking used;

i) IP position plan and photograph, if required;

j) radiation source, type and size of focal spot or gamma source and equipment used;

k) selected IP system and its basic spatial resolution as qualified, screens and filters;

l) tube voltage and current or source activity;

m) time of exposure, b and SDD;

n) type and position of image quality indicators;

o) reading of IQIs, minimum $SNR_N$ or minimum grey value in ROI;

p) conformity with this document;

q) any deviation from agreed standards and this document;

r) name, certification and signature of the responsible person(s);

s) date of exposure and report;

t) a reference to this document, i.e ISO 16371-2.

# Annex A
(normative)

## Determination of basic spatial resolution, $SR_b^{detector}$

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

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

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

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

On the digital radiograph, the first wire pair giving a modulation (dip) of less than 20 % in relation to the double peak size (see Figure C.1) shall be documented as result of the IQI test [e.g. D8 as shown in Figure A.1 c)]. A profile function of the image-processing software shall be used to recognize the first wire pair with a dip of less than 20 % [when averaged over both minimal — see Figure A.1 d)]. The profile shall also be averaged [see Figure A.1 b) and c)] over at least 21 single line profiles (recommended 30% to 60 % of duplex wire length) to improve the SNR in the profile plot.

By usage of the duplex wire IQI, conforming to ISO 19232-5, the inherent image unsharpness, $u_i$, shall be determined and the basic spatial resolution, $SR_b^{detector}$, of the detector shall be calculated with Formula (A.1):

$$SR_b^{detector} = \frac{1}{2} \cdot u_i \qquad (A.1)$$

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

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

a) inspection of light alloys:

   1) tube voltage 90 kV;

   2) prefilter 1 mm Al;

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

   1) tube voltage 160 kV;

   2) prefilter 1 mm Cu;

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

   1) tube voltage 220 kV;



2) prefilter 2 mm Cu ;

d) gamma radiography or high energy radiography:

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

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

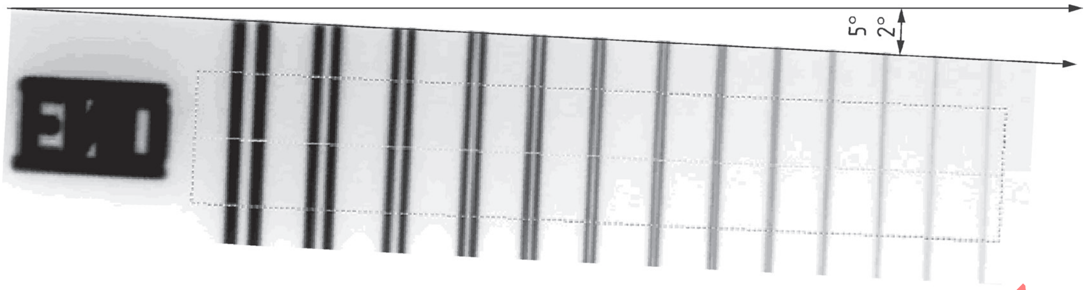
The duplex wire shall be positioned directly on the detector surface or cassette surface. The source to detector distance shall be (100 ± 5) cm. The mean grey value in the digital image shall exceed 50 % of the maximum grey value and the SNR shall exceed 100 for standard systems with pixel size ≥ 80 µm or 70 for high-resolution systems with pixel size < 80 µm in the reference radiograph. The basic spatial resolution (see Formula A.1) as measured in the reference radiograph for the digital system used and the system settings shall be recorded in the test report.

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

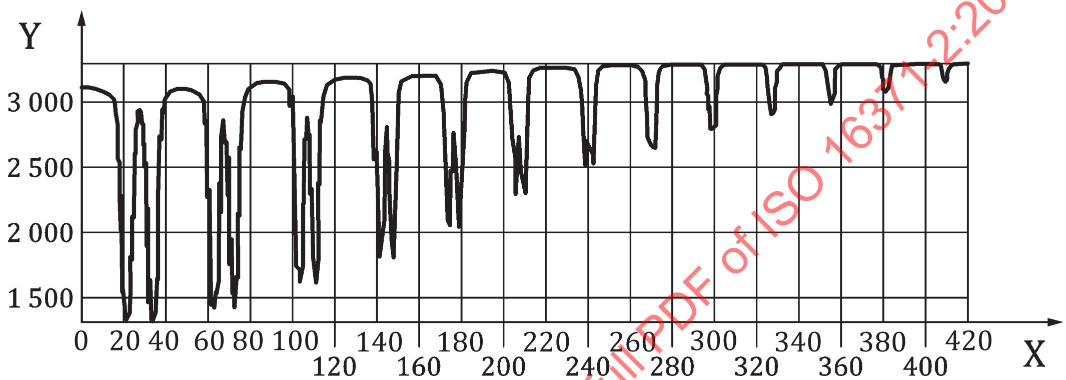
Table A.1 provides the unsharpness values and duplex wire numbers as given in ISO 19232-5.



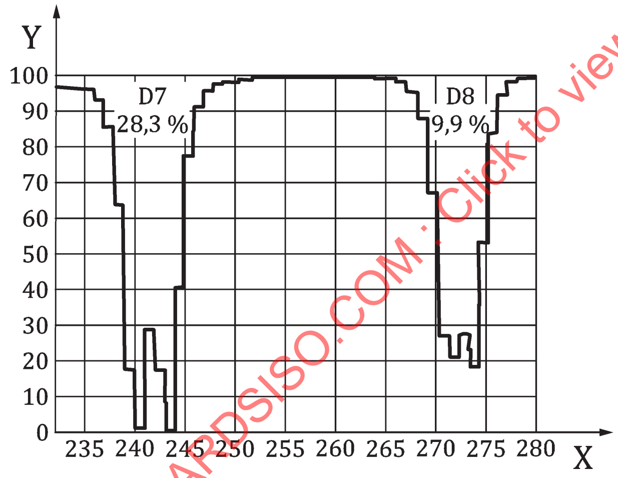
 



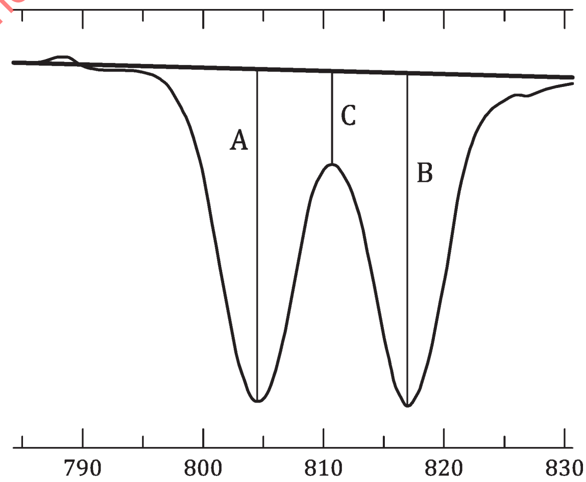

a) Image of the duplex wire IQI as shown in a radiograph




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




c) Zoomed profile of wire pair D7 and D8




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

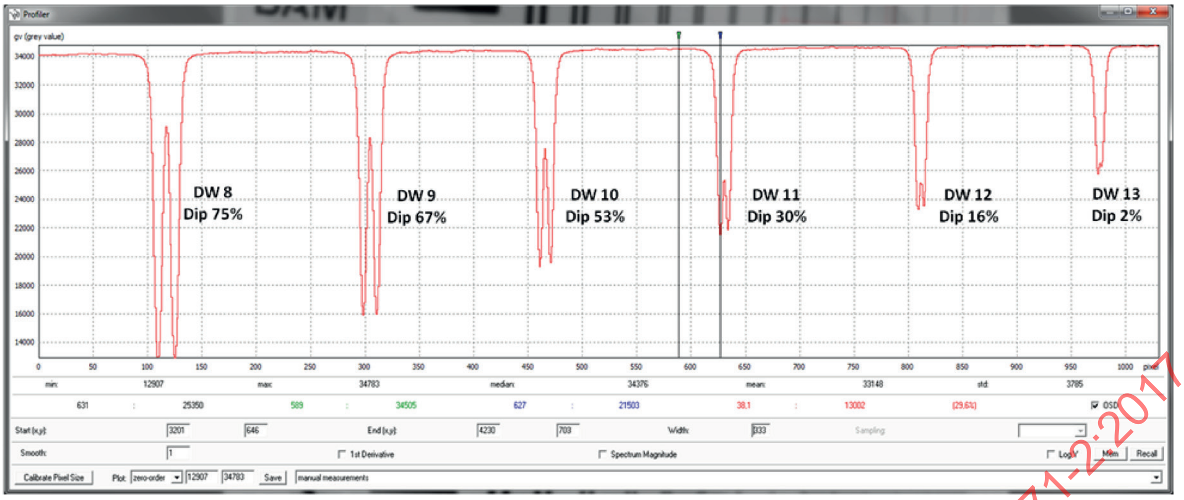


**Key**

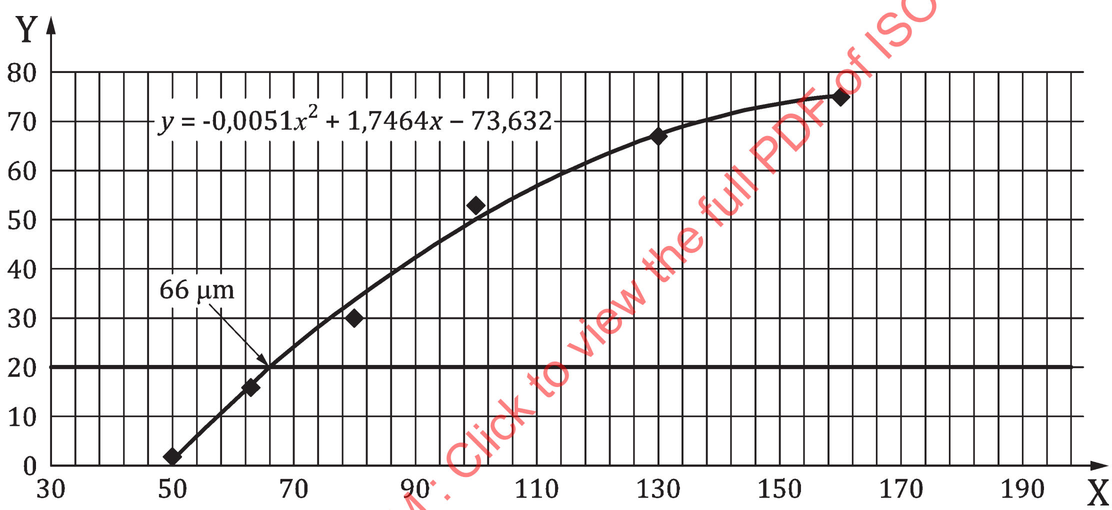
D7 duplex wire IQI values
D8 duplex wire IQI values
X distance
Y amplitude

**Figure A.1 — Example for duplex wire IQI evaluation with resulting IQI value D8**

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




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




**b) Interpolation of modulation depth vs. duplex wire diameter (corresponds to $SR_b$)**

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

**Figure A.2 — Example of the determination of the interpolated basic spatial resolution ($iSR_b^{detector}$) by interpolation from the measured modulation (dip) of the neighbour duplex wire elements**



The dependence of modulation (dip) from wire diameter should be fitted with a polynomial of second order for calculation of the intersection with the 20 % line as indicated in Figure C.2. Modulation values greater than zero shall be used for the interpolation only. If no values are available with dip less than 20 %, the next wire pair value with the dip of zero shall be used. If the measured $iSR_b^{detector}$ is smaller than the pixel size, e.g. due to aliasing effects, $iSR_b^{detector}$ shall be qualified as $iSR_b^{detector}$ = pixel size.

The interpolated $SR_b$-value (see Figure C.2) shall be recorded as "interpolated $SR_b$-value" or $iSR_b^{detector}$. This value may be used instead of the non-interpolated $SR_b$ value by agreement of the contracting parties.