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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

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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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

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

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
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
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
SNR_N	normalized signal-to-noise ratio
SR_b	basic spatial resolution, which may be SR_b^{image} or $SR_b^{detector}$ depending on the context
$SR_b^{detector}$	basic spatial resolution as determined with a duplex wire IQI adjacent to the detector
SR_b^{image}	basic spatial resolution as determined with a duplex wire IQI on the source side of the object
t	nominal thickness
$u_G t$	geometric unsharpness
u_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_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, Δw. If the required normalized contrast-to-noise ratio (CNR_N per Δw) 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):

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

where

c	is a constant;
μ_{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 ($\mathrm{SR}_b^{\mathrm{image}}$) (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 ($\mathrm{SR}_b^{\mathrm{image}}$) from Table 5. The basic spatial resolution of the detector ($\mathrm{SR}_b^{\mathrm{detector}}$) 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.

