BRITISH STANDARD

BS EN 14784-1:2005

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

Part 1: Classification of systems

The European Standard EN 14784-1:2005 has the status of a British Standard

ICS 19.100

British Standards

National foreword

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The UK participation in its preparation was entrusted to Technical Committee WEE/46, Non-destructive testing, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;
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English Version

Non-destructive testing - Industrial computed radiography with storage phosphor imaging plates - Part 1: Classification of systems

Essais non destructifs - Radiographie industrielle numérisée avec des plaques-images au phosphore - Partie 1 : Classification des systèmes

Zerstörungsfreie Prüfung - Industrielle Computer-Radiographie mit Phosphor-Speicherfolien - Teil 1: Klassifizierung der Systeme

This European Standard was approved by CEN on 1 July 2005.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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EUROPÄISCHES KOMITEE FÜR NORMUNG

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Contents

Foreword

This European Standard (EN 14784-1:2005) has been prepared by Technical Committee CEN/TC 138 “Non-destructive testing”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2006, and conflicting national standards shall be withdrawn at the latest by February 2006.

EN 14784 comprises a series of European Standards for industrial computed radiography with storage phosphor imaging plates which is made up of the following:

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

EN 14784-2 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

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

1 Scope

This European Standard specifies fundamental parameters of computed radiography systems with the aim of enabling satisfactory and repeatable results to be obtained economically. The techniques are based both on fundamental theory and test measurements. This document specifies the performance of computed radiography (CR) systems and the measurement of the corresponding parameters for the system scanner and storage phosphor imaging plate (IP). It describes the classification of these systems in combination with specified metal screens for industrial radiography. It is intended to ensure that the quality of images - as far as this is influenced by the scanner-IP system - is in conformity with the requirements of Part 2 of this document. The document relates to the requirements of film radiography defined in EN 584-1 and ISO 11699-1.

This European Standard defines system tests at different levels. More complicated tests are described, which allow the determination of exact system parameters. They can be used to classify the systems of different suppliers and make them comparable for users. These tests are specified as manufacturer tests. Some of them require special tools, which are usually not available in user laboratories. Therefore, simpler user tests are also described, which are designed for a fast test of the quality of CR systems and long term stability.

There are several factors affecting the quality of a CR image including geometrical un-sharpness, signal/noise ratio, scatter and contrast sensitivity. There are several additional factors (e.g. scanning parameters), which affect the accurate reading of images on exposed IPs using an optical scanner.

The quality factors can be determined most accurately by the manufacturer tests as described in this document. Individual test targets, which are recommended for practical user tests, are described for quality assurance. These tests can be carried out either separately or by the use of the CR Phantom (Annex B). This CR Phantom incorporates many of the basic quality assessment methods and those associated with the correct functioning of a CR system, including the scanner, for reading exposed plates and in correctly erasing IPs for future use of each plate.

The CR System classes in this document do not refer to any particular manufacturers Imaging Plates. A CR system class results from the use of a particular imaging plate together with the exposure conditions – particularly total exposure – the scanner type and the scanning parameters.

2 Normative references

The following referenced documents are indispensable for the application of this European standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 462-5, *Non-destructive testing — Image quality of radiographs — Part 5: Image quality indicators (duplex wire type), determination of image unsharpness value.*

EN 584-1, *Non destructive testing — Industrial radiographic film — Part 1: Classification of film systems for industrial radiography.*

3 Terms and definitions

For the purposes of this European Standard, the following terms and definitions apply:

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

3.2
computed radiography system class
particular group of storage phosphor imaging plate systems, which is characterised by a SNR (Signal-to-Noise Ratio) range shown in Table 1 and by a certain basic spatial resolution value (e.g. derived from duplex wire IQI) in a specified exposure range.

3.3
CEN speed S_{CEN}
defines the speed of CR systems and is calculated from the reciprocal dose value, measured in Grays, which is necessary to obtain a specified minimum SNR of a CR system

3.4
signal-to-noise ratio (SNR)
quotient of mean value of the linearised signal intensity and standard deviation of the noise at this signal intensity. The SNR depends on the radiation dose and the CR system properties.

3.5
modulation transfer function (MTF)
normalised Magnitude of the Fourier-transform (FT) of the differentiated edge spread function (ESF) of the linearised PSL (photo stimulated luminescence) intensity, measured perpendicular to a sharp edge. MTF describes the contrast transmission as a function of the object size. MTF characterises the un-sharpness of the CR system in dependence on the scanning system and IP-type.

3.6
CR phantom
device containing an arrangement of test targets to evaluate the quality of a CR system - as well as monitoring the quality of the chosen system

3.7
laser beam jitter
lack of smooth movement of the plate laser-scanning device, causing lines in the image consisting of a series of steps

3.8
scanner slippage
slipping of an IP in a scanner transport system resulting in fluctuation of intensity of horizontal image lines

3.9
aliasing
pre-sampled high spatial frequency signals beyond the Nyquist frequency (given by the pixel distance) reflected back into the image at lower spatial frequencies

3.10
gain/amplification
opto-electrical gain setting of the scanning system

3.11
linearised signal intensity
numerical signal value of a picture element (pixel) of the digital image, which is proportional to the radiation dose. The linearised signal intensity is zero, if the radiation dose is zero.

3.12
basic spatial resolution
read-out value of un-sharpness measured with duplex wire IQI according to EN 462-5 divided by 2 as effective pixel size of CR system

4 Personnel qualification

It is assumed that industrial computed radiography is performed by qualified and capable personnel. In order to prove this qualification, it is recommended to certify the personnel according to EN 473 or ISO 9712.

5 CR quality indicators

5.1 Description of CR quality indicators for user and manufacturer tests

5.1.1 General

The following is a description of CR quality indicators, which will be identified by reference to this document.

5.1.2 Contrast sensitivity quality indicator

The description of the selected contrast sensitivity targets corresponds to ASTM E1647-98a (see for details Annex B.4).

5.1.3 Duplex wire quality indicator

The description of the duplex wire quality indicator corresponds to EN 462-5. The IQI shall be positioned at a 5°angle to the direction of the scanned lines (fast scan direction) or the perpendicular direction (slow scan direction).

5.1.4 Converging line pair quality indicator

The target consist of 5 converging strips of lead (0,03 mm thickness) which can be used for spatial resolution test by reading the limit of recognisable line pairs. It shall cover a range from 1,5 to 20 line pairs per mm (lp/mm). Two quality indicators shall be used, one in direction of the scanned lines and the other one in the perpendicular direction.

5.1.5 Linearity quality indicators

Rulers of high absorbing materials are located on the perimeter of the scanned range. Two quality indicators shall be used, one in direction of the scanned lines and the other in the perpendicular direction. The scaling shall be at least in mm.

5.1.6 T-target

This CR quality indicator consists of a thin plate of brass or copper (≤ 0,5 mm thick) with sharp edges. This plate is manufactured in a T-shape with 5 mm wide segments. The T should have a size of at least 50 mm × 70 mm. It shall be aligned perpendicular and parallel respectively to the direction of the scanned lines (see Figure B.1).

5.1.7 Scanner slipping quality indicator

It consists of a homogenous strip of aluminium of 0,5 mm thickness. It has a shape of a rectangle (see Figure B.1) and shall be aligned perpendicular and parallel respectively to the direction of the scanned lines.

5.1.8 Shading quality indicator

Different shading quality indicators may be used.

One type is based on the homogeneous exposure of an imaging plate (IP) with a thin Al-plate (0,5 mm to 1,0 mm) above the IP. The exposure shall be made with low energy radiation (50 keV to 100 keV).

Another type is the shading quality indicator of the CR-test phantom (see Annex B).

5.1.9 Central beam alignment quality indicator (BAM-snail)

The alignment quality indicator consists of a roll (1,5 mm to 2,0 mm thick) of thin lead foil separated by a spacer of 0,1 mm to 0,2 mm of low absorbing material; (see Annex B.3). Honeycomb material may also be used.

5.2 Application procedures for CR quality indicators

5.2.1 General

The CR quality indicators are designed for fast evaluation of the quality of a CR system as well as for a periodical quality control. Annex C gives a guidance for application of various tests and test methods.

5.2.2 Exposure of CR quality indicators (user test)

The CR quality indicators should be positioned in a special arrangement as described in Annex B in the CR phantom. The CR quality indicators can be applied separately or all together in the CR phantom. The selected set of CR quality indicators or the CR phantom is placed on the cassette, which contains an Imaging Plate. The radiation source is set at a distance of 1 metre and the beam is aligned with the centre of the plate. Above a radiation energy of 100 keV a lead screen of 0,1 mm shall be applied between CR quality indicators or CR phantom and the IP to reduce scattered radiation. Test exposures are made and the radiation and CR system functions are optimised and the final image to be evaluated is agreed.

The exposure time and the parameter setting of the CR scanning unit determine the image quality as well as the type of imaging plate. These values and the type of IP have to be documented and agreed as well as the radiation energy (keV, gamma-source type), dose (e.g. in mAs) and quality (pre-filters, tube type and tube window).

NOTE High exposure time and low gain setting yield high contrast resolution and SNR. Furthermore, the contrast sensitivity is higher for large pixel size setting (high un-sharpness) than for small pixel size setting (low un-sharpness).

5.2.3 Initial assessment of CR quality indicators (user test)

For initial quality assessment, examine the radiographic image(s) of the CR phantom or the separated quality indicators on the monitor (or hard copy) for the features described in 5.1.2 to 5.1.9 and 6.3.2, 6.3.3, 6.4.1 to 6.4.7. The results can provide the basis of agreement between the contracting parties.

5.2.4 Periodical control (user test)

The CR quality indicators 5.1.2 to 5.1.8 (alignment by 5.1.9) or the CR phantom shall be radiographed and the results examined at any interval agreed between the contracting parties. For periodical control, ensure that the agreed quality values of the tests 6.3.2, 6.3.3, and 6.4.1 to 6.4.7 are achieved.

5.3 Imaging plate fading

The Intensity of the stored image in the imaging plate will decrease over time. This effect is known as image fading. The measurement of fading characteristics shall be done by performing the following steps:

a) expose a plate homogeneously using typical exposure conditions. For documentation the following parameters shall be recorded: kV, SDD, pre-filter and plate material and thickness. The exposed image shall have an intensity between 70% and 90% of the maximum possible intensity of the CR-reader at lowest gain and under linearised condition;

b) read-out the imaging plate 5 minutes after exposure;

c) set the linearised read-out intensity of this measurement as reference (100 %);

d) always expose the imaging plate with the same X-ray parameters (kV, mA*s, distance);

e) change the time between exposure and read-out. The time interval between exposure and readout will be doubled for every measurement; steps are 15 min, 30 min, 1h, 2h, 4h, etc. up to 128 h or depending on the application;

f) plot the linearised read-out intensity (grey value) versus time between exposure and read-out of the imaging plate.

The fading effect has to be considered to ensure correct exposure conditions.

To enable reproducible test results it is important to consider fading effects, which influence the required exposure time. The time between exposure and read-out for all tests shall correspond to the typical application of the CR system.

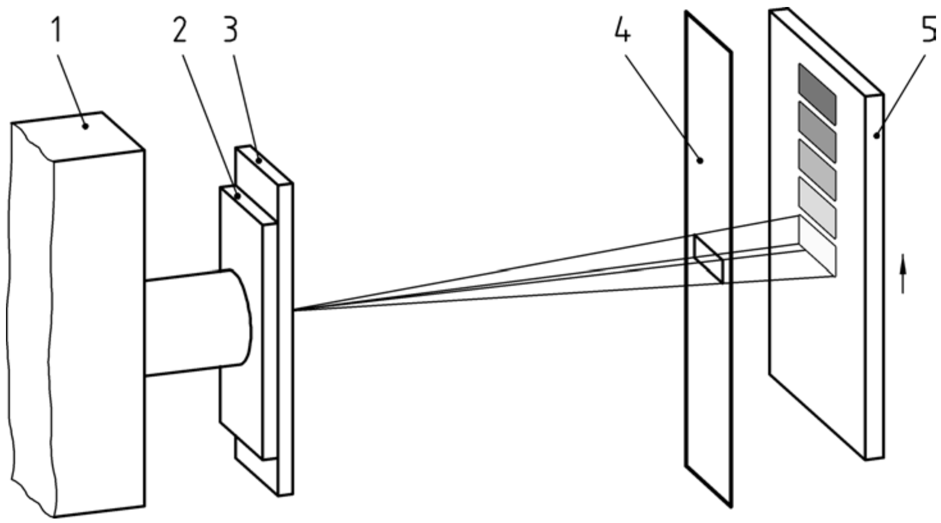
6 Procedure for quantitative measurement of image quality parameters

6.1 Measurement of the normalized Signal-to-Noise Ratio

6.1.1 Step Exposure Method (manufacturer test)

6.1.1.1 General

CR System evaluation depends on the combined properties of the phosphor imaging plate (IP) type, the scanner used and the selected scan parameters. Therefore, all measurements shall be performed with the same IP type, scanner and scan parameters and documented. The applied test equipment (Figure 1) and algorithm corresponds to EN 584-1 and ISO 11699-1.



Key

1 X-ray tube
2 Cu-Filter
3 Collimator
4 Diaphragm
5 IP in a cassette

Figure 1 — Scheme of experimental arrangement for the step exposure method

For measurement of the SNR, the following steps are taken (see also EN 584-1).

6.1.1.2 The IP, with a front and back screen from lead of 0,1 mm thickness in the typical exposure cassette, shall be positioned in front of an X-ray tube with tungsten anode. Make the exposures with an 8 mm copper filter at the X-ray tube and the kilo voltage set such that the half value layer in copper is 3,5 mm. The kilo voltage setting will be approximately 220 kV.

6.1.1.3 Determine the required exact kilo voltage setting by making an exposure (or an exposure rate) measurement with the detector placed at a distance of at least 750 mm from the tube target and an 8-mm copper filter at the tube. Then make a second measurement with a total of 11,5 mm of copper at the tube. These filters should be made of 99,9 % pure copper.

6.1.1.4 Calculate the ratio of the first and second readings. If this ratio is not 2, adjust the kilo voltage up or down and repeat the measurements until a ratio of 2 (within 5 %) is obtained. Record the setting of the kilo voltage for use with the further IP tests.

6.1.1.5 The sensitive layer of the IP shall face the X-ray source. For gamma radiography with Ir-192, the measurements shall be carried out with 0,3 mm lead screens in front and behind the IP. Also 8 mm Cu shall be used for pre-filtering (see Figure 1).

6.1.1.6 The scanner shall read with a dynamic of ≥ 12 Bit and operate at its highest spatial resolution - or a spatial resolution for which the classification shall be carried out. Background and anti-shading correction may be used before the analysis of data, if it relates to the standard measurement procedure for all measurements. In this case the procedure shall be carried out and documented for all gain and latitude ranges and all read-out pixel sizes if any of these parameters change the SNR-analysis.

6.1.1.7 IPs are exposed in a similar way to film radiography and under the conditions described: intensity and a noise (σ_{PSL}) or SNR over dose curve shall be measured. It is especially important that the exposure of the IP for the SNR measurements be spatially uniform. Any non-uniformities in X-ray transmission of the cassette front, or defects in the Pb foil or in the phosphor itself could influence the SNR measurement. No major scratches or dust shall be visible in the measurement area. Therefore exercise considerable care in selection and placement of the aperture, and selection and maintenance of the cassette, the lead screens and the phosphor screen. To achieve a uniform region of interest on to the IP, the following standard protocol is recommended. Other approaches may be used as long as a uniform exposure is created. At least 12 areas (test areas) of ≥ 400 mm^2 are evenly exposed on the same IP over the full working range of dose. Due to the different construction principles of scanners, the measurement shall be performed for all possible pixel sizes. The digital read-out intensity values (grey values) shall be calibrated in such a way, that they are linear in relation to the radiation dose that corresponds to the photo stimulated luminescence (PSL) intensity of the exposed IPs. These calibrated grey values shall be used for the calculation of the SNR. In order to get a reliable result at least six measurements shall be made on different samples, and the results are to be averaged for each of the 12 or more dose levels measured.

6.1.1.8 The signal intensity I_{meas} and standard deviation σ_{PSL} shall be computed from a region without shading or artifacts. Sample SNR values shall be taken in different regions of the image area under test to ensure that SNR values are within 10% stable. The size of the ROI used to measure the mean intensity and the noise shall be at least 20 by 55 pixels and it should be an area ROI. An example technique for assuring reliable signal to noise measurements is described below. This can be achieved using a commonly available image-processing tool. The signal and noise shall be calculated from a data set of 1100 values or more per exposed area. The data set is subdivided into 55 groups or more with 20 values per group. For each group with index i, the value $I_{\mathrm{meas\_i}}$ is calculated as mean of the unfiltered group values and the value σ_{PSLi} is calculated from the same group values. An increased number of groups yields a better (lower) uncertainty of the result. Due to the filtering effect of this grouping procedure, the σ_{PSLi}-values are corrected by the following equation:

$$\sigma_{\mathrm{PSLi\_corr}} = 1{,}0179 \cdot \sigma_{\mathrm{PSLi}} \tag{1}$$

NOTE The values σ_{PSLi} are multiplied with 1,0179 to correct for the following median unbiased estimation. Assume k is the number of consecutive observations within a group and C is the critical value of the chi-square distribution for α = 0,5 with k-1 degrees of freedom. In case of 20 observations the values σ_{PSLii} shall be multiplied with 1,0179 for statistical correction). The factor 1,0179 corresponds to the correction sqrt ((k-1)/c) for grouping with a group size of 20 elements (k = 20) for application of a median procedure (c = 18,33765)

6.1.1.9 The final value I_{meas} is obtained by the median of all I_{meas_i} values. The final σ_{PSL} value is obtained by the median of all σ_{PSLi_corr} values. σ_{PSL} shall be calculated as reference value to a resolution of 100 µm, measured with a circular aperture, or 88,6 µm measured with a squared aperture. The final value σ_{PSL100} is calculated by

$$\sigma_{PSL100} = \sigma_{PSL} \cdot (SR_{max} / 88,6) \quad (2)$$

where

SR_{max} is the maximum value of basic spatial resolution (in µm) measured in both directions perpendicular and parallel to the scanning directions of the laser.

NOTE EN 584-1 requires the use of a micro-photo densitometer with circular aperture of 100 µm diameter for the measurement of granularity σ_D. Because the pixels in digital images are organised in squares, the corresponding pixel size is calculated by sqrt ((100 µm)^2 π / 4) = 88,6 µm.

6.1.1.10 The normalised SNR is calculated by

$$SNR = I_{meas} / \sigma_{PSL100} \quad (3)$$

6.1.2 Step Wedge Method (manufacturer test and enhanced user test)

6.1.2.1 General

The measurement of the SNR can be performed with less accuracy using a step wedge. This method may also be of interest for users to determine the contrast sensitivity quantitatively:

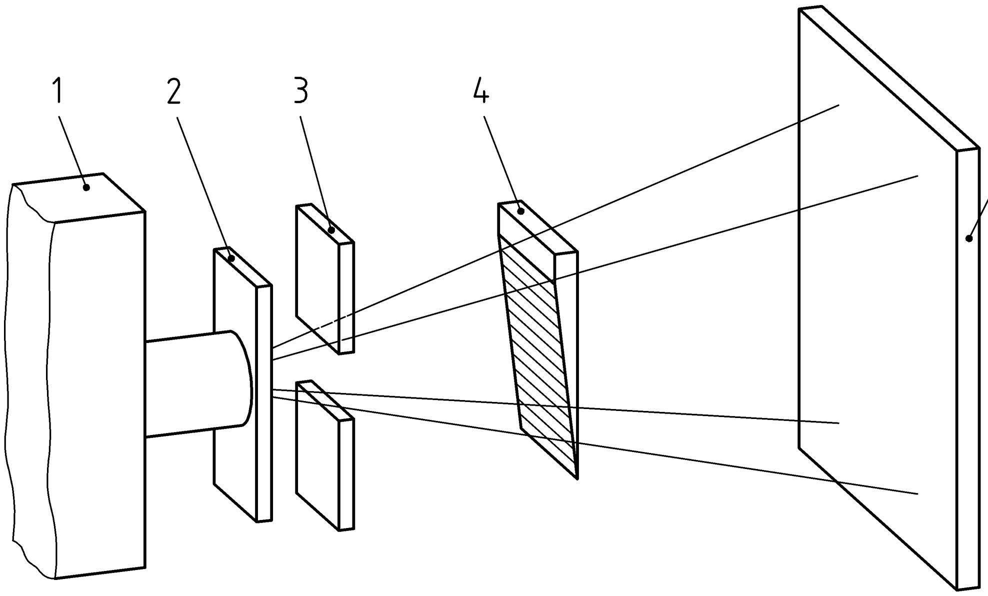
6.1.2.2 For that purpose a step wedge of Cu, with at least 12 equally increasing steps, may be used as in the arrangement shown in Figure 2. The maximum thickness of the step wedge shall absorb 90 % of the radiation of the central beam, which requires a thickness of 11,7 mm. To cover a range of two or more orders of magnitude at least two suitable and different exposures, with adequate exposure time or tube current (mA), shall be made. The distance between step wedge and IP shall be ≥ 500 mm to reduce the influence of scattered radiation. A magnification of 2x is recommended. A beam collimator shall be used. X-ray voltage and filtering shall be selected according to 6.1.1.2.

NOTE X-ray penetration through Cu-steps of different thickness is distorted by beam hardening and suitable adjustment of exposure is required.

6.1.2.3 The projected area of each step shall be about 20 mm × 20 mm (≥ 400 mm²). No values shall be taken from areas near the edges. At least two times the geometric un-sharpness shall be left between the edges of the projected area and the area for data acquisition.

6.1.2.4 All details for the measurement and calculation of the SNR shall correspond to 6.1.1.3 to 6.1.1.10. The graphical analysis shall be based on the plot of SNR = f (log (Exposure) - $\mu_{Cu} \cdot w_{Cu}$ · log (e)), where μ_{Cu} is the absorption coefficient, w_{Cu} is the wall thickness of the corresponding step of the step wedge and the value "Exposure" is calculated from exposure time (seconds), multiplied by tube current (mA); see also Annex A.

NOTE For accurate plots it is necessary to consider the wall thickness dependence of μ_{Cu} (beam hardening). The influence of scattered radiation should be reduced by exact collimation. Different exposures with different exposure time or mA-settings are recommended for the required plot. The exposure value (mAs) of the different exposures should deviate between 5 to 8 times to allow an overlap of the measured data. A waiting time of 30 minutes is recommended between exposure and scan of the IPs to avoid influences by fading effects.



Key

1 X-ray tube
2 Cu-Filter
3 Collimator
4 Cu-step wedge
5 IP in a cassette

Figure 2 — Scheme for the measurement of the SNR by the step wedge method

6.1.3 Contrast sensitivity measurement (manufacturer and user test)

ASTM E 1647-98a contrast sensitivity gauges are useful for visual and computer aided determination of contrast sensitivity for a selected wall thickness. Four levels of contrast sensitivity can be measured: 1 %, 2 %, 3 % and 4 %, independent of the imaging spatial resolution limitations. For interpretation see ASTM E 1647-98a. If image processing is available, a profile (width: 1 pixel) shall be taken through the target. The average noise of the profile shall be less than or equal to the difference in the intensity between the full and reduced wall thickness at the read-out percentage. The exposure conditions (kV, mAs, filters, distance, exposure time, date) and CR system settings and -type shall be documented.

6.2 Measurement of minimum read-out intensity of computed radiographs (manufacturer procedure)

Each CR-image shall have better or equal normalised SNR than defined by the minimum SNR_{IPx}-values of Table 1. Because these SNR-values cannot be measured easily, the minimum SNR_{IPx}-values shall be achieved by the application of minimum read-out intensities I_{Ipx}.

NOTE A classical quality assurance procedure in film radiography is based on the measurement of the film density. Exposed films are accepted only, if they have a minimum optical density. A similar procedure can be applied in CR. Each CR system (or any digital image processing system) provides intensity values or grey values of each picture element (pixel). All pixels in the region of interest (ROI), which is to be evaluated, should exceed a minimum intensity (or grey value), in a similar way as minimum density in film radiography should be exceeded. This permits basic quality assurance in CR in relation to contrast sensitivity.

System evaluations corresponding to Table 1 depend on the combined properties of the imaging plate (IP) type, the scanner used and the selected scan parameters. Therefore, all measurements must be performed with the same IP type and scanner with its parameters.

The determination of the read-out intensities is based on the step exposures as in 6.1.1 or on the step wedge exposures, with less accuracy, as described in 6.1.2. The determination of the read-out values shall be performed by the following steps:

a) The linearised signal intensity I_{meas} and standard deviation σ_{PSL} shall be measured and calculated as in 6.1.1 or 6.1.2.

b) The final value I_{IPx} for IP-scanner evaluation corresponds to the linearised signal intensity $I_{\text{IPx}} = I_{\text{meas}}$ for $I_{\text{meas}}/\sigma_{\text{DPSL100}}$ at the selected SNR_{IPx} value of Table 1 and for the selected scanner parameters.

c) The manufacturer shall provide the read-out values to the user in the original and/or applied system response function.

6.3 Determination of un-sharpness

6.3.1 General

The measurement of un-sharpness may depend on the radiation quality. For classification the test shall be performed with 220 kV (X-ray tube with Beryllium window, Tungsten target and no pre-filtering). For low energy applications the radiation quality shall be 90 kV (X-ray tube with Beryllium window, Tungsten target and no pre-filtering).

6.3.2 MTF-method (manufacturer test)

For testing of the basic spatial resolution and calculation of MTF, a CR image shall be made of an object of high density with a sharp edge and a constant thickness (sharp edge target or T-target of CR Phantom). The absorption shall be between 70 % and 90 % of the intensity of the primary beam. The exposure shall be performed at a distance of 1 m or more, with a focal spot size ≤ 1 mm. Focal spot size and focus to IP distance shall be selected to observe a geometric un-sharpness of less than 5 % of the resulting un-sharpness, related to the surface of the edge target. The object with the sharp edge shall be positioned in a direction perpendicular and parallel to the scanning direction of the laser beam.

The computed radiograph of the sharp edge target shall be analysed in the following way:

a) The digital CR-image shall be calibrated so that the signal intensity (grey value of the image) is linear in relation to the radiation dose, which corresponds to the photo stimulated luminescence (PSL) intensity. A profile shall be extracted from the linearised image of the sharp edge, perpendicular to the edge. For enhancement of the SNR of the profile, it is recommended to average several profiles (more than 10).

b) The MTF is calculated from the first derivative of the profile by calculating the Fourier magnitude spectrum and normalising it to 1 at frequency zero.

The basic spatial resolution shall be determined from the MTF-value at 20 %. The corresponding resolution value SR is calculated by the following equation:

$$\text{SR} = 1/(2 \cdot \text{MTF}_{20}) \tag{4}$$

The MTF method is a sensitive indicator of scatter effects in the detector cassette system. It also indicates changes of the electronic system in relation to the spatial frequency. The electronic system can be distorted, e.g. by non-linear amplification or high-pass or low-pass characteristics. The MTF curve and MTF 20 value should be used to indicate changes in the CR system after any modifications of the system by the manufacturer. The user may request this MTF curve and MTF20 value.

For test of the cassette/IP screen (if screens are used) the comparison of the MTF values of 100 kV (no pre-filtering) and 220 kV with 8 mm copper as a pre-filter should be compared. The reduction of the MTF_{20}-value at higher energy indicates scatter effects.

NOTE Scatter effects in the cassette/IP screen system are always present. The method can be used for detection of scatter effects and possible reduction, which may be required for specialised applications.

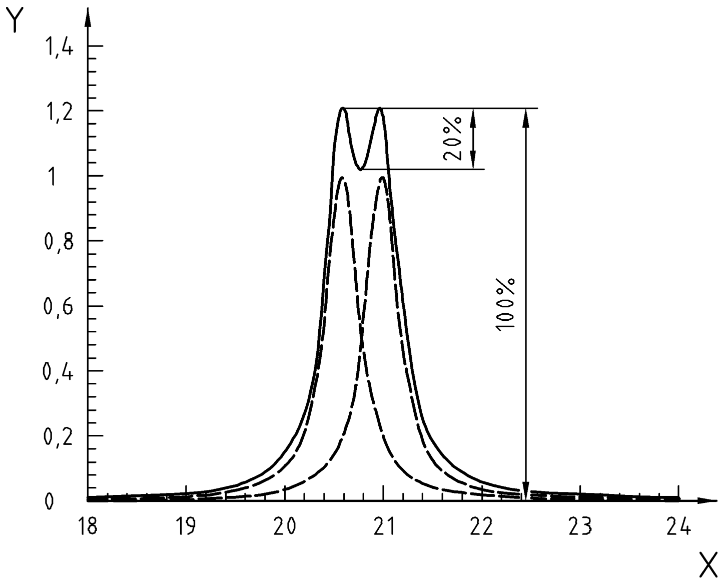
6.3.3 Duplex wire method (manufacturer and user test)

For testing of the basic spatial resolution, the duplex wire IQI corresponding to EN 462-5 can be applied. This has less accuracy than the MTF-method. The exposure shall be performed in a distance of 1 m or more with a focal spot size ≤ 1 mm. Focal spot size and focus detector distance shall be selected for a geometric un-sharpness of less than 10 % of the total measured un-sharpness. The duplex wire IQI shall be positioned directly on the cassette with the IP and lead screen. The measurement shall be performed perpendicular and parallel to the scanning direction of the laser beam. This requires two exposures with one IQI or one exposure with two IQIs. The duplex wire IQI shall be used in an angle of about 5° to the scanning direction of the laser beam and 5° to the perpendicular direction. The positioning and exposure of the IP shall be performed as described in 6.3.1.

The first unresolved wire pair shall be taken for determination of the un-sharpness value corresponding to EN 462-5. This is the first wire pair that is projected with a dip between the wires of less than 20 % (see Figure 3). The basic spatial resolution SR corresponds to one half of the measured un-sharpness.

If differences exist between the read-out value of the MTF-method and the duplex wire method, the duplex wire method value shall be taken for the classification.

NOTE Particularly for high-energy radiation above 100 keV with pre-filtering, the measured un-sharpness may be caused by different processes. If the un-sharpness is caused by a process with high and another process with low un-sharpness, the converging line pair quality indicator, and also the duplex wire IQI, indicate basically the lower un-sharpness process. This may cause a considerably difference to the MTF_{20} –value, which represents both processes.



Key

X length, in millimetres
Y signal intensity, in arbitrary units

Figure 3 — Resolution criterion for the evaluation of duplex wire profiles. The two wires of a wire pair are resolved, if the dip between the line maxima is greater than 20% of the maximum intensity

The duplex wire IQI read-out shall be documented and used for long-term stability test of the system.

6.3.4 Converging line pair quality indicators (manufacturer and user test)

Converging line pair quality Indicators shall be read both parallel and perpendicular to the scanned lines. If a converging line pair target is located 45° to the scanning direction, the read-out value shall be divided by 1.414.

These quality indicators consist of converging line pairs and a scale in lp/mm. The read-out value R in lp/mm is either taken (case a) at the location between separated and un-separated line pairs or (case b) at the location, where the number of lines is reduced by one or more.

In case a) the basic spatial resolution (SR) is calculated by equation (5)

$$SR = \frac{1}{2R} \tag{5}$$

where

R read-out value (in lp/mm).

In case b) the IQIs determine at what resolution aliasing (pre-sampled high frequency signals beyond the Nyquist frequency reflected back into the image at lower spatial frequencies) occurs. Usually this corresponds to the pixel size of the scanner. It is also calculated by equation (5).

The recommended quality assurance schedule shall be agreed between the contracting parties. However, the resolution test should also be assessed after any service of the optics of the CR reader.

6.4 Other tests

6.4.1 Geometric distortions (manufacturer and user test)

The spatial linearity of the CR system shall be checked by exposing a spatial linearity quality indicator (mm-scale or finer), which is made from high absorbing material) in x- and y-direction. The IP transport system should not allow the IP to tilt or twist during the scan resulting in a geometrical image distortion. The measured spatial non-linearities shall be less than 2 % related to each plate dimension.

6.4.2 Laser beam function (manufacturer and user test)

Laser beam scan line integrity, beam jitter, signal dropout, and focus are evaluated in this test.

Expose a T-target from high absorbing material (see 5.1.6). Laser beam jitter is evaluated by examining the edges of the “T” on the image. The T edges should be straight and continuous. Under- or overshoot of the scan lines in light to dark transitions along the T edge indicates a timing error, or laser beam modulation problem. View the image scan lines with a 10x (or greater) magnification on the computer screen, or the printed film (with a magnifying glass) in various areas across the image to check for uniform spacing. The “Stair step” characteristics of the straight edge are normal due to digitisation effects. Scan line dropout is detectable as a lucent straight line in the open field and likely represents dust/dirt particles on the pickup light guide, a fairly common artefact.

Image artefacts such as jitter indicate sub-optimal performance and necessitate corrective action by service personnel.

This process can be utilised to determine laser beam function in the CR system. The comparison of the computer image and the printed hard copy permits the evaluation of the hardcopy device.

6.4.3 Blooming or flare (manufacturer and user test)

Examine the computed radiographs of the T-target for the evidence of intensity overshoot or streaking in areas with high density contrast, which can be caused by saturation of the light detector, or intensity transfer from regions with high light intensities into dark regions with a low intensity. This test shall be done in comparison of an exposure with low exposure intensity (high read-out gain) and high exposure intensity (low read out gain), but with no saturation of the electronic system.

6.4.4 Scanner slipping (manufacturer and user test)

Slipping of imaging plates in the scanner or any distortion in the homogeneity of the scanning and reading system leads to different intensities between the read lines of a homogeneous exposed area. For this reason, the computed radiograph of the scanner-slipping target shall be inspected for deviations in the intensity of the scanned lines. The deviation between the line intensities shall be less than (or equal to) the noise, measured inside one of these lines. A possible test target, to detect slipping, is shown in the CR Phantom (Annex B).

6.4.5 Shading (manufacturer and user test)

This test is used to ensure that the scanning laser intensity is uniform across the scanning width of the imaging plate as well as checking for proper alignment of the light guide/photo-multiplier tube assembly.

An IP is exposed homogeneously to a source from large distance > 5 m as a manufacturer test. Users may apply this test for testing of the long-term stability with a SDD ≥ 1 m. On the computer, the average pixel value of the center and the edges of the IP is measured for a linearised intensity. On a printed film, the film density is measured with a densitometer. The outside areas should not have a pixel intensity value, or density, deviating ± 10% of the central area of the IP. The user may realise that the shading of an exposure with a SDD of 1m has an inherent shading of up to 8%. Therefore, users should allow ± 15% shading. The recommended quality assurance schedule for the application of this test is agreed by the contracting parties. However, shading correction should be assessed following any service to the optical system. The CR Phantom of Annex B contains quality indicators for a specialized shading test, which fulfils the above requirements.

6.4.6 Erasure (manufacturer and user test)

Upon completion of all the tests, the erased image plate shall be processed through the CR Reader without any exposure. If the CR system is used for a particular application (e.g. with high energy X-rays or, with gamma sources) a object of high absorption (e.g. tungsten or lead) shall be exposed in such a way, that the acquired image contains the projection of the object and an unabsorbed radiation area. For this application, the IP shall be erased and processed without exposure. If a latent image exists, the erasure time is not long enough or the erasure unit is malfunctioning. Possible ghost images shall have an intensity of less than 1 % of the maximum intensity after image conversion to a linearised intensity (grey level). The recommended quality assurance schedule for the application of this test shall be agreed between the contracting parties.

6.4.7 IP artefacts (user test)

All IPs in inventory should be serialised. Special attention and identification should be made for IPs that come into contact with unprotected screens. For the following test, all parameters, including scanning parameters and radiation conditions shall be recorded.

Expose each IP to the lowest kV used in inspection. Use sufficient exposure conditions (e.g. mAs) to produce a uniform exposure intensity (see also 6.4.5). Scan the IP and store the corresponding image file. A CR image file of each IP should be saved regularly to identify possible artefacts and be annotated with the IP serial number of the IP.

NOTE Interpreters should have access to the CR IP artefact image files to avoid problems in interpretation.

7 CR System Classification and Interpretation of Results

7.1 General

For classification it is important that the IP-samples evaluated yield the average results obtained by users. This requires the evaluation of several different samples periodically under conditions specified in this document. Prior to evaluation, the samples shall be stored according to manufacturer recommendations for a length of time in order to simulate the average age at which the product is normally used. Several independent evaluations of different IPs shall be made to ensure the proper calibration of equipment and processes. The objective in selecting and storing samples is to ensure that the IP-characteristics are representative of those obtained in practice by users.

The CR system shall be classified according to the Table 1.

7.2 Range of CR System Classification

For computed radiographic examination, CR system classes will be determined by the following procedures:

The CR system classification is defined by minimum normalised SNR-values (SNR_{IPx}) shown in Table 1 and the value of the achievable maximum basic spatial resolution SR_{max} in µm.

Table 1 — CR system evaluation according to the minimum normalised SNR at the minimum Signal Intensity I_{IPx}

System class CEN	Minimum normalised SNR
IP 1/Y	130
IP 2/Y	117
IP 3/Y	78
IP 4/Y	65
IP 5/Y	52
IP 6/Y	43
NOTE 1 The normalized SNR values of Table 1 are similar to those of EN 584-1. They are calculated by SNR = log(e) (Gradient/Granularity) of Table 1 in EN 584-1. The measured SNR values are calculated from linearised signal data. NOTE 2 Y is the maximum basic spatial resolution (see 6.3.2).	

The classification statement consists of two values:

a) The assignment to an IP-class in agreement with table 1. The measured normalised SNR shall be greater or equal to the assigned value of the minimum normalised SNR in Table 1.

b) The measured maximum basic spatial resolution, rounded to the nearest 10 µm step.

The statement shall be given in the following form:

IP_X/Y.

NOTE 1 For example, a system classified as IP 3/100 is characterised by a normalised SNR ≥ 78 (see table 1) and a maximum basic spatial resolution ≤ 100 µm.

The basic spatial resolution shall be determined with the duplex wire method (see 6.3.2) and the normalised SNR shall be calculated according to equation (3).

The basic spatial resolution shall be measured both perpendicular and parallel to the scanning direction of the laser. The higher value of both SR-values (SR_{max}) shall be used as maximum basic spatial resolution for classification.

NOTE 2 If a system has a spatial resolution of 200 µm in scan direction of the laser and 100 µm perpendicular to the scan direction, than the final maximum basic spatial system resolution is SR_{max} = 200 µm.

For system classification all manufacturer tests of 6.4 shall be performed, and shall meet the values where specified.

7.3 Determination of CEN Speed (manufacturer procedure)

The CEN speed SISO is calculated by the dose KS which is needed for exposure of an IP with the intensity value IIPx by SISO = KS-1 (KS in Gray). The CEN speed shall be given corresponding to the system class.

NOTE For the same CR system different CEN speeds are given for different system classes.

The CR system manufacturer will provide the CEN speeds and the IIPx values depending on the imaging plate type, the scanner used and its parameters. The CEN speed may be determined in steps corresponding to the values of Table 2.

Table 2 — Determination of CEN Speed S_{CEN} from dose K_S (in Gray) needed for an IP-read-out intensity of I_{IPx}

$Log_{10}K_S$		CEN Speed S_{CEN}
From	To	
-4,66	-4,56	40000
-4.55	-4,46	32000
-4,45	-4,36	25000
-4,35	-4,26	20000
-4,25	-4,16	16000
-4,15	-4,06	12500
-4,05	-3.96	10000
-3.95	-3.86	8000
-3.85	-3,76	6300
-3.75	-3,66	5000
-3,65	-3,56	4000
-3,55	-3,46	3200
-3,45	-3,36	2500
-3,35	-3,26	2000
-3,25	-3,16	1600
-3,15	-3,06	1250
-3,05	-2,96	1000
-2,95	-2,86	800
-2,85	-2,76	640
-2,75	-2,66	500
-2,65	-2,56	400
-2,55	-2,46	320
-2,45	-2,36	250
-2,35	-2,26	200
-2,25	-2,16	160
-2,15	-2,06	125
-2,05	-1,96	100
-1,95	-1,86	80
-1,85	-1,76	64
-1,75	-1,66	50
-1,65	-1,56	40

Annex A
(informative)

Example for I_{IPx} measurement

The IP system classes below do not refer to any specific manufacturer's phosphor imaging plates. These different IP classes from IP 1 to IP 6 refer to what is required (in performance parameters) of any manufacturer's CR system to qualify under these six specific classes.

For example, it is possible that a single IP or CR system, supplied by one manufacturer, could qualify to meet all six classes. With "film radiography" each specific film type falls into only one system class (EN 584-1). With computed radiography, the same IP could theoretically qualify for all six classes. This is due to the wide dynamic range of computed radiography versus that of a normal film/screen system. Short exposure can be compensated by a sensitive read-out scan. The classification is usually low (e.g. IP 6). The same plate could be given more exposure and be scanned with low gain of the electronic system. The thickness contrast sensitivity will be improved just by selection of these two parameters. The system can now be classified higher (e.g. IP 1).

This document shall provide a guide for the user to check the image quality and classification of a CR system by providing minimum read-out intensities for exposed and scanned IP images (read-out value: I_{IPx} or grey value). This is similar to the measurement of the optical density in film radiography. The read out values in Table A.1 correspond to values of comparable exposed and developed X-ray film systems having an optical Density of ≥ 2,0 over fog in the region of interest. Now the user can assume, that he obtains comparable image quality with IPs (IP 1 to IP 6), in analogy to film systems, classified by EN 584-1 (film system classes, C 1 to C 6). If the user still observes differences in the image quality, this may be basically due to differences in the spatial resolution of X-ray films and CR systems.

For clarification of the algorithm of determination of I_{IPx}–values (read-out values), the following procedure is presented, based on a measurement example:

a. Measure the *log (intensity) vs. log (exposure)* curve and the *SNR vs. log (exposure)* curve corresponding to Figure A.1 For gamma sources the exposure values are determined by *source activity* · *time* and for X-rays by *tube current* · *time*. The SDD shall be always constant (e.g. 1000 mm).

   If the step wedge method, as described in 6.1.2, is applied, the plots of *log (intensity) vs. [log (exposure) -* $\mu_{Cu} \cdot w_{Cu}$ *· log (e)]* and *SNR vs. [log (exposure) -* $\mu_{Cu} \cdot w_{Cu}$ *· log (e)]* shall be used, instead of the *log (intensity) vs. log (exposure)* curve and *SNR vs. log (exposure)* curve.

b. Take from the *SNR vs. log (exposure)* or *SNR vs. [log (exposure) -* $\mu_{Cu} \cdot w_{Cu}$ *· log(e)]* curve the exposure values for the IP-classes 1 to 6 (see Figure A.1).

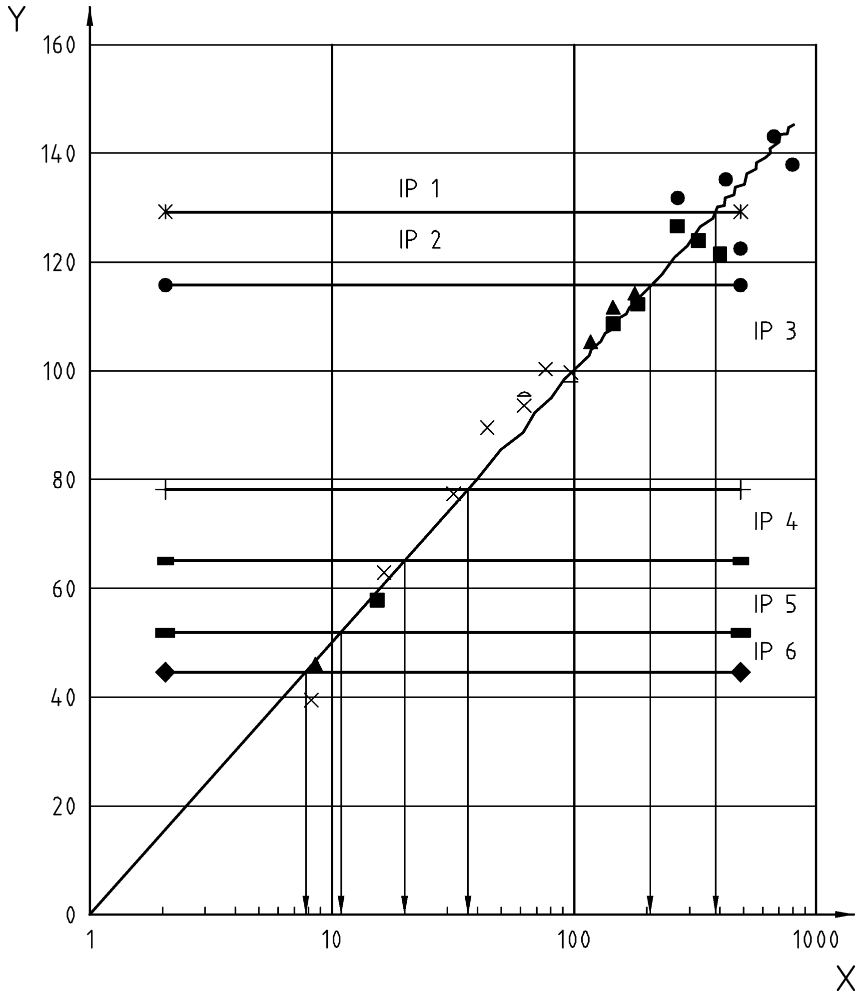
c. Measure from the determined exposure values the I_{IPx}–values in the *log (intensity) vs. log (exposure)* or *log (intensity) vs. [log (exposure) -* $\mu_{Cu} \cdot w_{Cu}$ *· log (e)]* curve (Figure A.2).

d. Read the I_{IPx}–values and document them in a table. Table A.1 shows a typical example, which is based on Figure A.1 and A.2.

Table A.1 — Minimum Read-out intensities for CR system classes of the system manufacturer A, system ABC 123, tested at a certain date and valid up to the next calibration date

CR system class	Minimum signal/noise ratio SNR_{IPx}	Minimum linear read-out intensity I_{IPx}	System parameters
IP 1/140	130	$7,3 \times 10^6$	All gains, basic spatial resolution 140 µm, scan speed 10 µs/pixel.
IP 2/140	117	$3,9 \times 10^6$	
IP 3/140	78	$0,67 \times 10^6$	
IP 4/140	65	$0,37 \times 10^6$	
IP 5/140	52	$0,20 \times 10^6$	
IP 6/140	43	$0,14 \times 10^6$	

NOTE The optimum scaling of the axis of diagrams corresponding to Figure A.1 in linear, logarithmic or another way may depend on the scanner type and manufacturer.



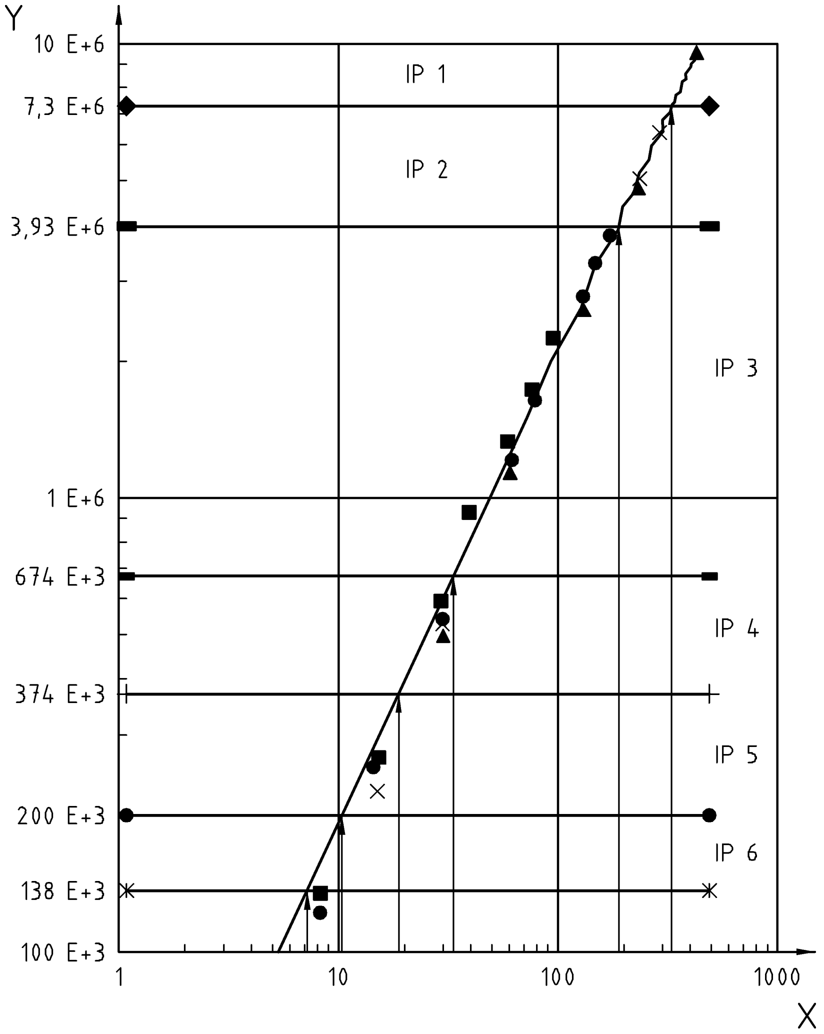
Key

● **Gain 2** ■ **Gain 4** ▲ **Gain 8** × **Gain 16**

X log (exposure time · tube current) in mAs using the step exposure method according to 6.1.1, or:
log (exposure time · tube current) - $\mu_{Cu} \cdot w_{Cu}$ log (e)) using the step wedge method according to 6.1.2 (*use* w_{Cu} *in decreasing order*)

Y normalised SNR

Figure A.1 — Scheme for the determination of minimum read-out intensities I_{IPx} for CR systems. (The X values for the different classes are determined from the intersections of the SNR-curve with the SNR_{IPx}-values of Table 1)



Key

●	**Gain 8**	■	**Gain 16**	▲	**Gain 2**	×	**Gain 4**

X log (exposure time · tube current) in mAs using the step exposure method according to 6.1.1, or Log (exposure time · tube current) - $\mu_{Cu} \cdot w_{Cu} \cdot \log(e)$) using the step wedge method according to 6.1.2 *(use w_{Cu} in decreasing order)*

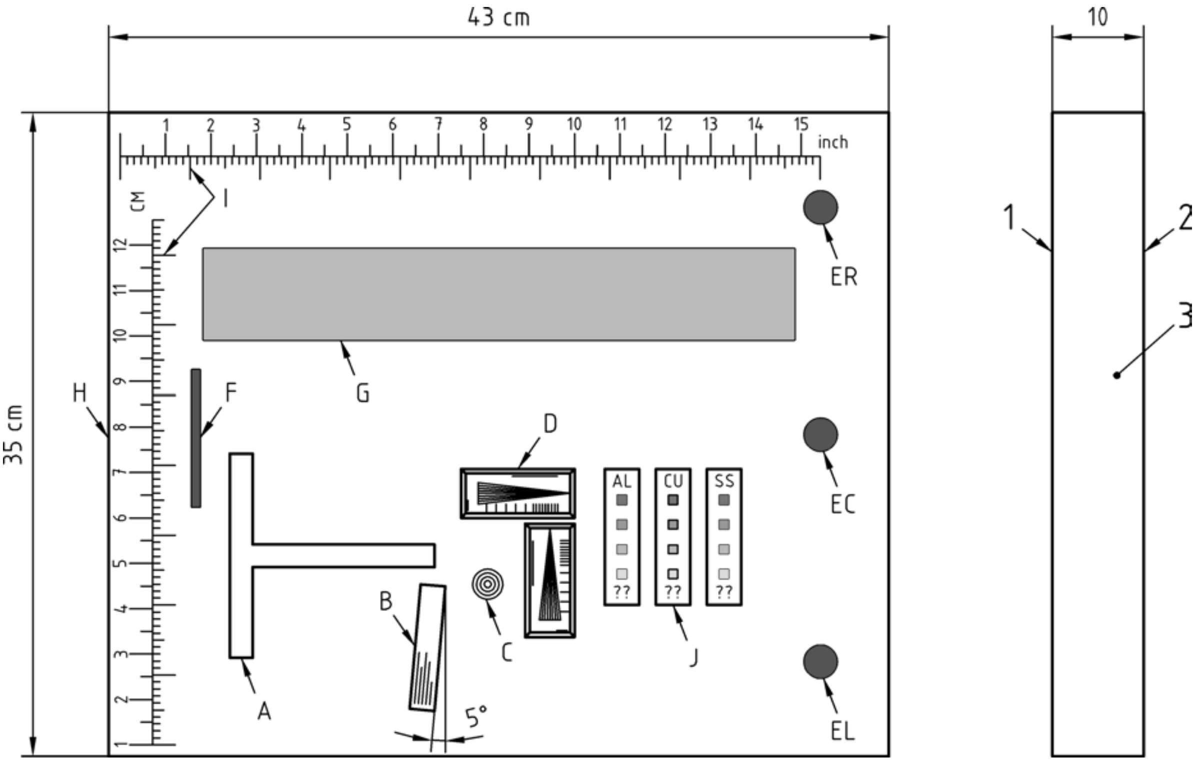
Figure A.2 — Scheme for the determination of minimum read-out intensities I_{IPx} for CR systems. (The I_{IPx}-values are measured from the intersections of the intensity curve with X value arrows taken from Figure A.1)

Annex B
(informative)

Example of CR test phantom

B.1 Location and alignment of CR Quality Indicators in a CR Phantom

All described CR Quality Indicators (see 5.1) are located in a test object, called a CR Phantom. It consists of a carrier plate of low absorbing material (e.g. Lucite). Figure B.1 shows the arrangement. The CR Quality Indicators shall be located on the IP-side.



Key

A T-target for laser jitter test and MTF-measurement (length 114 mm, 5 mm, brass)
B duplex wire IQI according to EN 462-5
C central beam alignment (BAM-snail)
D converging line pair quality indicators
E EL, EC, ER: measuring points for shading correction (19 mm diameter, 0,3 mm Lucite removed)
F cassette positioning locator (does not appear on radiographic image)
G homogeneous strip (Al, 0,5 mm)
H lucite plate
I inch/cm ruler for linearity check
J contrast sensitivity quality indicators (aluminium: 12,7 mm, copper: 6,4 mm, stainless steel: 6,4 mm thick)

1 Source side
2 Image plate side
3 Test object (CR phantom)

Figure B.1 — Example of CR phantom containing CR quality indicators for qualification of computed radiography systems (dimension approximately: 43 cm × 35 cm)

B.2 Shading test

B.2.1 General

Different shading tests are possible. The CR Phantom uses the following target and procedure:

B.2.2 Shading Quality Indicator

The quality indicator consists of a set of three holes of 19 mm and 0,3 mm depth in a Lucite plate (of the CR Phantom). These holes shall be separated by at least 10 cm. The holes shall be aligned parallel to the scanning direction of the laser beam.

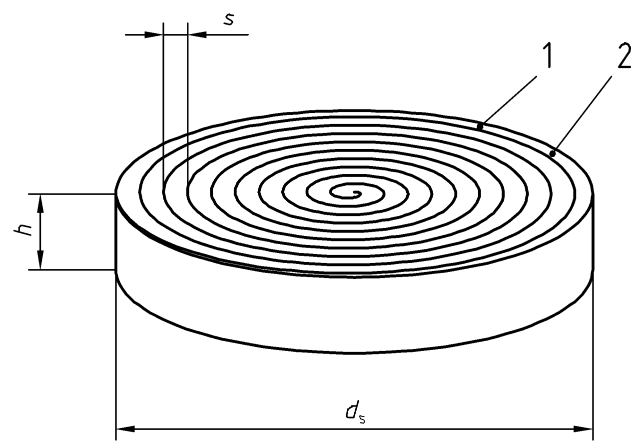
B.2.3 Procedure

There are three holes (EL, EC and ER) in the CR Phantom, measuring 19 mm in diameter and 0,3 mm deep. These holes are used to ensure that the scanning laser intensity is uniform across the scanning width of the imaging plate as well as checking for proper alignment of the light guide/photo-multiplier tube assembly. On the computer, the pixel value of the holes is measured with either a pixel value or a density profile tool. On the film, the film density of the circles is measured with a densitometer. The outside circles should not have a pixel value or density deviating from the value of the circle in the middle by more than 10 %. The recommended quality assurance schedule for the application of this test is agreed by the contracting parties. However, shading correction should be assessed following any service to the light guide/photo-multiplier tube assembly.

B.3 Central beam alignment

B.3.1 CR Alignment Quality Indicator (BAM-snail)

The target consists of a section of a roll (1,5 mm to 2,0 mm high) of thin lead foil separated by a spacer of 0,1 mm of low absorbing material (see Figure B.2. Honeycomb material may also be used.



Key

1 lead foil of thickness d_1

2 spacer foil

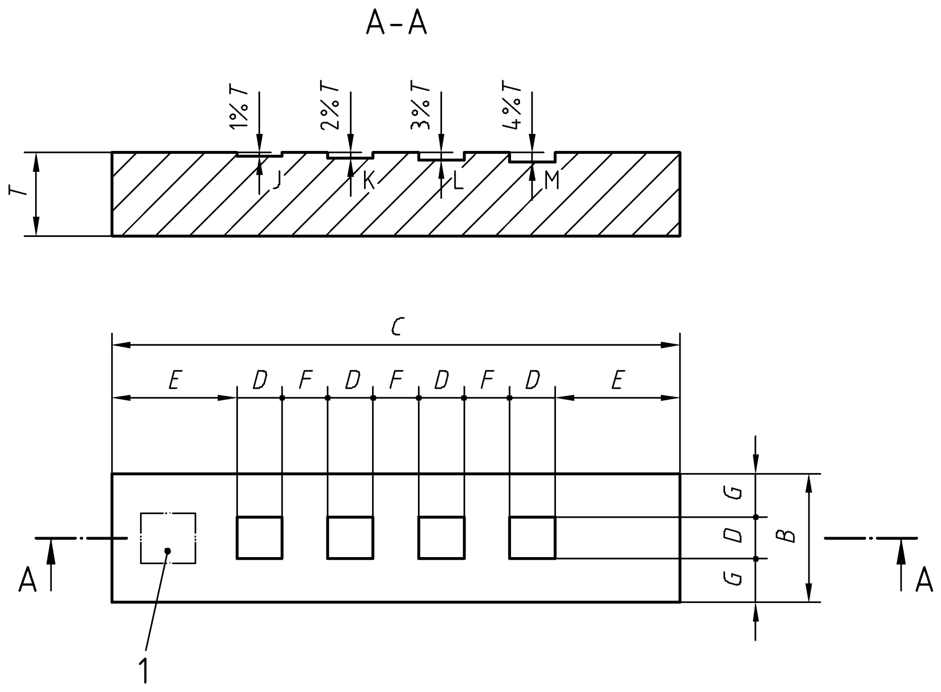
Figure B.2 — Alignment quality indicator and source position indicator "BAM-snail". Its radiographic image indicates deviations from the perpendicular position of the radiation source above the BAM-snail. The following dimensions are recommended: h = 1,5 – 2 mm, s = h/11,5 (structure disappears at deviations > 5°), d_s > 8 mm, d_i = 0,02 – 0,1 mm.

B.3.2 Procedure

The CR Phantom shall be aligned perpendicular to the central beam of the radiation source. The central beam shall meet the CR alignment quality indicator in the centre. The structure of the BAM-snail or the honeycomb shall be direction independent resolved.

B.4 Contrast sensitivity quality indicator

The contrast sensitivity quality indicators used are according to ASTM E 1647–98a. There are three indicators implemented into the CR Phantom, made from different material: Aluminium, Copper and Stainless Steel. The dimensions of the Indicator are given in Figure B.3. The wall thickness difference of the milled steps J, K, L and M are 1%, 2%, 3% and 4% of the total indicator thickness T (see Figure B.3).



Key

1 material specification (Al, Cu or SS for stainless steel)

Dimensions: B - 19 mm
C - 76,2 mm
D - 6,4 mm
E - 15,9 mm
F - 6,4 mm
G - 6,4 mm

Figure B.3 — Contrast sensitivity quality indicator according to ASTM E 1647 – 98a. The indicator thickness T is 12,7 mm for Al and 6,4 mm for Cu and stainless steel.

Annex C
(informative)

Guidance for application of various tests and test methods

C.1 Manufacturer tests

These tests are typically more complex, time consuming and require some specialized hardware and software. The test methods and tests shall be performed as described in this document to enable the comparison of system parameters and classification by different manufacturers and test laboratories.

C.2 Tests after repair, upgrade or the use of an improved IP

Since modifications, such as repair or upgrade of the CR scanner and improved IP may improve the functionality of the system, specialized tests are required to prove the proper performance of the CR system. These are typically all user tests and those tests, marked as "user and manufacturer" test, as well as other evaluations required to verify a CR system classification.

C.3 User tests for long-term stability

Quality assurance in test laboratories requires periodical tests of the CR-system to prove the proper performance of the system. The time interval depends on the degree of usage of the system and shall be defined by the user and consideration of the manufacturer's information. These tests are denoted as user tests.

The tests which are described under 6.4.1 to 6.4.6 by usage of the quality indicators of 5.1 or the CR test phantom shall be used regularly at shorter intervals to test the basic performance. The documentation shall contain:

a) spatial resolution (by duplex-wire method, optional converging line pairs)

b) contrast (recognized contrast percentage of the material to examine)

c) slipping (yes/no)

d) jitter (yes/no)

e) shading (percentage at selected distance)

f) radiation parameters of the performed tests

g) date and operator name.

h) fading tests should be performed only if the scanner or IP brand is changed without data of the manufacturer or the system is used under extreme temperature conditions. The fading should be less than 50% in the expected period between exposure and scan.

The IPs shall be checked for artifacts (6.4.7) and proper erasure (6.4.6).

Degradation of IPs or photo multipliers in the scanner may reduce the system sensitivity after extensive usage. For this reason, the SNR should be measured at longer intervals (e.g. annual period) by the user or service personnel. The SNR shall not be less than 90% of the original value. The increase of the SNR can be accepted without limits, if the system un-sharpness is not increased.

Procedure for SNR test: A step wedge shall be exposed according to 6.1.2. The SNR shall be measured at 90 % intensity of the maximum possible intensity of the reader image at lowest gain and linearised characteristic curve. The numeric procedure shall correspond to 6.1.1.8. If there is no step area which has been exposed to an intensity of 90%, the SNR shall be determined from the next three exposed neighbour step areas by quadratic interpolation. The measured and normalized SNR (see 6.1 to 6.2) shall be documented. This procedure (consisting of e.g. software, system setting and exposure data) should be provided by the manufacturer for the user. The user or service personnel does the exposure and applies the software for SNR-measurement.

The test shall be performed always with the same radiation quality (voltage and pre-filter), the same step wedge and the same distances and collimation. The step wedge exposure shall be done with a magnification of x2. The recommended step wedge material is copper, but steel is also acceptable. If the recommended values of 6.1.1.2 to 6.1.1.3 are not the typical exposure values, the user should use a typical kV-value below 220 kV (recommended value is 110 kV) with pre-filtering of at least 8 mm Al in front of the X-ray tube. All parameters and results shall be documented.

Bibliography

[1] EN 444, *Non-destructive testing - General principles for radiographic examination of metallic materials by X- and gamma rays.*

[2] EN 473, *Non destructive testing - Qualification and certification of NDT personnel — General principles.*

[3] ISO 5579, *Non-destructive testing — Radiographic examination of metallic materials by X- and gamma rays — Basic rules.*

[4] ISO 9712, *Non-destructive testing — Qualification and certification of personnel.*

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

[6] E 1647-98a, *ASTM Standard Practice for Determining Contrast Sensitivity in Radioscopy.*

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