INTERNATIONAL STANDARD

ISO 11699-1

Second edition
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Non-destructive testing — Industrial radiographic film —

Part 1: Classification of film systems for industrial radiography

Essais non destructifs — Film pour radiographie industrielle —

Partie 1: Classification des systèmes films pour radiographie industrielle

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 11699-1 was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 5, *Radiation methods*.

This second edition cancels and replaces the first edition (ISO 11699-1:1998), which has been technically revised.

ISO 11699 consists of the following parts, under the general title *Non-destructive testing — Industrial radiographic film*:

— *Part 1: Classification of film systems for industrial radiography*

— *Part 2: Control of film processing by means of reference values*

Non-destructive testing — Industrial radiographic film —

Part 1: Classification of film systems for industrial radiography

1 Scope

The purpose of this part of ISO 11699 is to establish the performance of film systems.

This part of ISO 11699 is applicable for the classification of film systems in combination with specified lead screens for industrial radiography (non-destructive testing). This part of ISO 11699 is intended to ensure that the image quality of radiographs — as far as this is influenced by the film system — is in conformity with the requirements of International Standards such as ISO 5579, ISO 17636 and EN 12681.

This part of ISO 11699 does not apply to the classification of films used with fluorescent intensifying screens. The measurement of film systems in this part of ISO 11699 is restricted to a selected radiation quality to simplify the procedure. The properties of films will change with radiation energy, but not the ranking of film system quality.

Additional methods for evaluating the photographic process are described in ISO 11699-2, by which the performance of film systems can be controlled under the conditions given in industry.

2 Normative references

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

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

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
film system
combination of film and film processing which is carried out in accordance with the instructions of the film manufacturer and/or the manufacturer of the processing chemicals

3.2
film gradient
G
slope of the characteristic curve of a film at a specified optical density D

3.3
granularity
σ_D
stochastic density fluctuations in the radiograph, superimposed on the image of the object

NOTE The limiting values given in this part of ISO 11699 are related to fixed radiation energies and specified screens.

3.4
characteristic curve
curve showing the relationship between the common logarithm of exposure log K, and the optical density D

3.5
specular density
quantitative measure of film blackening (optical density) when light passing the optics of a microdensitometer transmits the film

3.6
diffuse density
quantitative measure of film blackening (optical density) as determined by a densitometer

NOTE It is the sum of all transmitted and scattered light into the half sphere behind the film.

3.7
signal/noise ratio
⟨industrial radiography⟩ ratio of a local film density to the granularity σ_D at this density level

NOTE It is correlated to the gradient/noise ratio.

3.8
ISO speed
S
reciprocal value of the dose, K_s, expressed in Gy, which results in a specified diffuse optical transmission density $(D - D_0 = 2)$ on the processed film, where D_0 is the fog and base density:

$$S = \frac{1}{K_s} \tag{1}$$

3.9
film system class
classification which takes account of limiting values given in Table 1

3.10
gradient/noise ratio
G/σ_D
ratio of the gradient, G, and the granularity σ_D

NOTE It relates directly to the signal/noise ratio. All further parameters determining the signal, such as the modulation transfer function or the energy of the radiation, are considered to be constant.

4 Sampling and storage

For product specification, it is important that the samples evaluated yield the average results obtained by users. This will require the evaluation of several different batches periodically under conditions specified in this part of ISO 11699. Prior to evaluation, the samples shall be stored in accordance with the manufacturers' recommendations for a length of time, in order to simulate the average age at which the product is normally used. The basic objective in selecting and storing samples as described above is to ensure that the film characteristics are representative of those obtained by a consumer at the time of use.

5 Test method

5.1 Preparation

The film samples shall be exposed to X-rays from tungsten target tubes. Inherent filtration of the tube, together with an additional copper filter located as close to the X-ray tube target as possible, shall provide filtration equivalent to (8,00 ± 0,05) mm of copper. The potential across the X-ray tube shall be adjusted until the half-value-absorption is obtained with (3,5 ± 0,2) mm of copper. A potential of approximately 220 kV generally meets this requirement.

The film system shall include a front and a back screen of 0,02 mm to 0,04 mm lead. If single coated films are used, the emulsion coated surface shall face the X-ray tube. Good film screen contact shall be ensured.

Exercise care to ensure that the film specimen does not contain density variations arising from the exposing equipment (such as non-uniform beam filters or damaged, or defective lead screens) or processing system. During and after exposure, prior to processing, maintain the film specimen at the temperature of (23 ± 5) °C and relative humidity of (50 ± 20) %. The film processing chemicals and procedures shall be the same for determining gradient and granularity, and they shall be used and described completely as specified.

Use manufacturer certified film test strips in accordance with ISO 11699-2 to test the specified developer system with the specified immersion time and developer temperature. The speed index S_x shall be within ± 5 % of the manufacturer's certificate. The developer temperature may differ by ± 1 °C from the certified value to adjust S_x within ± 5 % of the manufacturer certificate value. The obtained S_x and used developer temperature shall be documented in the test report. This test shall be done, on a daily basis, before and after the development of the exposed films for classification with the same developer temperature and immersion time.

If a manufacturer certificate is not available, film test strips shall be manufactured and calibrated in accordance with ISO 11699-2 by the user.

5.2 Measurement of gradient G

Gradient G relates to a D versus $\log_{10} K$ curve. Within the scope of this part of ISO 11699, G is calculated from the slope $\frac{\mathrm{d}D}{\mathrm{d}K}$ of a D versus K curve at density $(D - D_0)$, i.e.

$$G = \frac{\mathrm{d}D}{\mathrm{d}\log_{10} K} = \frac{K}{\log_{10} \mathrm{e}} \cdot \frac{\mathrm{d}D}{\mathrm{d}K} \tag{2}$$

where

K is the measured dose, expressed in Gy, required for density $(D - D_0)$;

D_0 is the measured optical density of an unexposed and processed film including base (fog and base density).

The D versus K curve is approximated by a polynomial of third order. To obtain a reliable curve, a series of exposures are made with the same film sample to obtain at least 12 uniformly distributed measuring points covering at least density 1,0 and 4,5 above D_0. The polynomial approximation shall include all measured values between 1,0 and 4,5. For the numerical approximation (fit procedure) no zero value shall be included. At least six gradient measurements shall be made on different film samples to determine the mean gradient value G. The densitometer used shall be calibrated regularly up to a diffuse density of $D \geqslant 4{,}8$. For the calibration, a certified film step tablet shall be used. This shall be generated from double sided X-ray film of C3 class or higher (C1 or C2).

NOTE Densitometers can have limited accuracy for measurements at $D > 4$ and need careful calibration correction in the full range. Small deviations of the density values at $D > 4$ have considerable influence on the accuracy of the value of G at $(D - D_0 = 4)$ due to the properties of the polynomial approximation procedure.

The mean gradient values shall be determined with a maximum uncertainty of ± 5 % for the gradient at $D = 2$ above fog and base (G_2) at a confidence level of 95 % and ± 7 % for the gradient at $D = 4$ above fog and base (G_4) at a confidence level of 95 %.

Measurement laboratories, which certify film systems, shall participate in a proficiency test on a periodical basis. A new film, exposed in accordance with this part of ISO 11699, shall be used in all participating labs and for each periodical test.

5.3 Measurement of granularity σ_D

The granularity is measured by linear or circular scanning of a film of constant diffuse optical density with a microdensitometer. Both emulsion layers shall be recorded, which means that the depth of focus of the microdensitometer has to include both layers.

The granularity value shall be determined in terms of diffuse density.

If the optical density is measured as specular density, it shall be converted into diffuse optical density, using the plot of the curve of diffuse density versus specular density at the mean density value of the granularity film specimen. The diffuse density of each step shall be measured with the calibrated densitometer.

Determine this curve using a film having a stepped series of densities, which is prepared using the same type of film, exposure, and processing techniques as used for the granularity film specimen. The specimen film shall be scanned using identical microdensitometer settings. A limited range of densities can typically be measured for a given microdensitometer gain setting. The stepped series of densities shall lie within that range.

The calibration shall be made from the diffuse versus specular density plot with at least 5 values between diffuse density 1,5 and 2,8 (including fog and base). The conversion can be performed on basis of a linear regression analysis of the log (diffuse density) versus log (specular density) plot. The determined coefficients shall be used for the conversion of the specular density into diffuse density values.

The conversion shall be performed before the numerical determination of the standard deviation, σ_D, which is a measure of the granularity. σ_D is calculated as follows:

$$\sigma_D = \sqrt{\frac{1}{N-1} \cdot \sum_{i=1}^{N} \left(D_i - \bar{D}\right)^2} \tag{3}$$

The diffuse optical density of the measured film shall be $\bar{D} = 2{,}00 \pm 0{,}05$ above fog and base. The determined value of σ_D shall be corrected on the basis of the diffuse mean density $\bar{D}$ above fog and base of this film. The corrected value of σ_D ($\sigma_{D,\mathrm{corr}}$) is calculated as follows:

$$\sigma_{D,\mathrm{corr}} = \sigma_D \cdot \sqrt{(2/\bar{D})} \tag{4}$$

As an alternative, three or more samples of the film specimen at different density levels may be measured within the range from 1,80 to 2,20, and the granularity value at a diffuse density of 2,00 above base plus fog shall be taken from a linear regression analysis of the plot of granularity as a function of the square root of diffuse density above fog and base.

The scanning length on the radiographic film shall be at least 116 mm. The diameter of a circular measuring aperture of the microdensitometer shall be (100 ± 5) µm. A square aperture of 88,6 µm × 88,6 µm has the same area as a circular one of 100 µm diameter. The measured granularity is equivalent to that of a circular one with 100 µm diameter.

The determined value of $\sigma_{D,\mathrm{corr}}$ shall be corrected on the basis of the real (measured) aperture diameter d_A (in µm) of a circular aperture. The corrected value of σ_D ($\sigma_{D,\mathrm{corr,a}}$) is calculated as follows:

$$\sigma_{D,\mathrm{corr,a}} = \sigma_{D,\mathrm{corr}} \cdot \frac{d_\mathrm{A}}{100} \tag{5}$$

If a square aperture of the microdensitometer is used, the corrected value of σ_D ($\sigma_{D,\text{corr,b}}$) is calculated as follows:

$$\sigma_{D,\text{corr,b}} = \sigma_{D,\text{corr}} \cdot \sqrt{\frac{4 \cdot A_\text{A}}{\pi \cdot 10\,000}} \tag{6}$$

where A_A is the aperture area in μm^2.

The scan path of the microdensitometer may be linear or circular. If circular, the radius of the path shall not be less than 16 mm. In either case, the total scan length shall not be less than 116 mm.

In order to limit the low frequency noise the data, measured with the microdensitometer, shall be filtered after conversion to diffuse density with a highpass filter with a cut-off spatial frequency of 0,1 line pairs per millimetre (3 dB). This shall be performed by subtraction of the measured scan values minus the smoothed measured scan values. The smoothing shall be performed by convolution with a rectangular window function with a width of 6,0 mm (61 values with 0,1 mm distance). The scanning step width shall be 100 μm in that case. The first and last 30 data points of the scan shall not be used after filtering for the further calculation of σ_D. The filter is based on the following formula:

$$D_{i,\text{filter}} = D_{i,\text{meas}} - \frac{1}{61} \sum_{j=-30}^{30} D_{i+j,\text{meas}} \tag{7}$$

Due to the risks of errors in the measured data during the scan, resulting from artefacts in the film such as dust and other sources of distortion, the filtered scan shall be divided into n groups of 1,9 mm length (20 values with 0,1 mm distance) and 0,1 mm distance between groups. σ_D shall be determined for each group, whereby at least 55 groups shall be used. The calculated values of σ_D are rearranged according to size and the central value is the median of all groups. In the case of 55 groups, the median is the 28th value. The median value, $\sigma_{D,\text{med}}$, shall be multiplied by 1,017 9 to get the median unbiased estimation σ_D.

NOTE 1 k is the number of consecutive observations within a group and C is the critical value of the chi-square distribution for $\alpha = 0{,}5$ with k–1 degrees of freedom. For the σ_D estimation, the median value $\sigma_{D,\text{med}}$ is multiplied by $\sqrt{(k-1)/C}$. In the case of 20 observations, the median value $\sigma_{D,\text{med}}$ is multiplied by 1,017 9 for statistical correction.

NOTE 2 An increased number of data points and groups yields a better (lower) uncertainty of the result. It is important not to modify the group length of 1,9 mm (plus 0,1 mm distance between groups) and the statistical correction if using 1,017 9 as correction value.

Subdivision of the scanned data in groups, determination of σ_D and median procedure have an inherent filter effect which is equivalent to the described highpass filter of scanned data. Therefore, the highpass filtering may be omitted if the median procedure is applied. Differences in the determined granularity will be less than ± 1,5 %.

At least six measurements shall be made on different samples to estimate the mean value of granularity. The determined granularity mean value shall not exceed an uncertainty of ± 10 % at a confidence level of 95 %.

Measurement laboratories, which certify film systems, shall participate in a proficiency test on a periodical basis. A new film, exposed in accordance with this part of ISO 11699, shall be used in all participating laboratories and for each periodical test.

5.4 Measurement of ISO speed S

The ISO speed S is determined for a diffuse optical density $(D - D_0 = 2)$ above fog and base D_0. The ISO speed shall be given in accordance with Table 2.

5.5 Other equipment and procedures

Measurement equipment other than that described above can be used for classification if that equipment and the corresponding procedures provide the same results

— with an uncertainty of less than 5 % and a confidence of 95 % for gradient G_2,

— with an uncertainty of less than 7 % and a confidence of 95 % for gradient G_4, and

— with an uncertainty of less than 10 % and a confidence of 95 % for granularity.

The requirements of ISO/IEC 17025 shall be met with respect to the test method of 5.1 to 5.4 for the film systems to be classified.

6 Limiting values for classification

The film system classes are defined by limiting values, which are determined in accordance with Clause 5.

In order to assign a film system class, the determined parameters of the film system shall meet all the limiting values of the gradient, the granularity and the gradient/noise-ratio of the system class in accordance with Table 1.

For classification of film systems the following procedure shall be applied.

All determined mean values of G at $(D - D_0 = 2)$ and $(D - D_0 = 4)$ shall exceed or equal the minimum values of a system class in accordance with Table 1. The mean value of G at $(D - D_0 = 2)$ and $(D - D_0 = 4)$ may fall below the values of Table 1 by ± 5 % if the mean value of the minimum gradient/noise ratio, $(G/\sigma_D)_{\text{min}}$, at $(D - D_0 = 2)$ is greater than or equal to the minimum value of Table 1.

The mean value of the measured granularity may exceed the values of Table 1 by 10 % to account for measurement uncertainty, if the mean value of $(G/\sigma_D)_{\text{min}}$ at $D = 2$ above D_0 is greater than or equal to the minimum value of Table 1.

NOTE 1 The value of $(G/\sigma_D)_{\text{min}}$ at $(D - D_0 = 2)$ determines the human perceptibility of flaws shown by the radiograph as seen on an illuminator. Increased values of G compensate increased granularity, just as decreased granularity compensates low values of G in a certain range. Furthermore, $(G/\sigma_D)_{\text{min}}$ at $(D - D_0 = 2)$ is chosen in Table 1 to be always greater than the quotient of G/σ_D at $(D - D_0 = 2)$.

NOTE 2 Changes of the developer activity cause a systematic error due to the shift of the values of G at $(D - D_0 = 2)$ and $(D - D_0 = 4)$ and σ_D. However, the effect of the developer does not influence the quotient G/σ_D at $(D - D_0 = 2)$ as much as the values G at $(D - D_0 = 2)$ and $(D - D_0 = 4)$ and σ_D. Consequently, the uncertainty for G/σ_D at $(D - D_0 = 2)$ is less than the uncertainty of σ_D.

Table 1 — Limiting values for gradient, gradient/noise-ratio and granularity

Film system class	Minimum gradient G_{min} at		Minimum gradient/noise-ratio $(G/\sigma_D)_{min}$ at $D = 2$ above D_0	Maximum granularity $\sigma_{D,max}$ at $D = 2$ above D_0
	$D = 2$ above D_0	$D = 4$ above D_0		
C1	4,5	7,5	300	0,018
C2	4,3	7,4	230	0,020
C3	4,1	6,8	180	0,023
C4	4,1	6,8	150	0,028
C5	3,8	6,4	120	0,032
C6	3,5	5,0	100	0,039

The classification is only valid for the complete film system. In general, the classification for X-rays as described under 5.1 can be transferred to other radiation energies and metallic screen types as well as films without screens and single coated films.

A certificate shall contain the following information:

a) reference to this part of ISO 11699;

b) date;

c) measured values of gradient at $D = 2$ and $D = 4$ above fog and base;

d) measured granularity at $D = 2$ above fog and base;

e) calculated value of (G/σ_D) at $D = 2$ above fog and base;

f) dose K_S for $D = 2$ above fog and base;

g) processing conditions:

- manual or automatic;
- type of chemistry;
- developer immersion time;
- developer temperature;

h) classification in accordance with Table 1.