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

Essais non destructifs — Contrôle radiographique des matériaux métalliques au moyen de film et de rayons X et gamma — Règles de base

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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 rules given in the ISO/IEC Directives, Part 2. www.iso.org/directives

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The committee responsible for this document is ISO/TC 135, *Non-destructive testing*, Subcommittee SC 5, *Radiation methods*.

This third edition cancels and replaces the second edition (ISO 5579:1998), which has been technically revised.

Changes from the second edition include:

— introduction of film in the title — this International Standard is valid only for NDT films as image detectors and not for digital radiographic detectors;

— reference to the state-of-the-art image quality detectors, according to ISO 19232-1 to ISO 19232-4;

— omission of figures with test arrangements (these test arrangements are described in the corresponding application standards);

— extension of applicable X-ray voltages from 500 kV up to max. 1 000 kV, depending on the penetrated wall thickness and material;

— modification of the nomogram of minimum source distances for focal spot sizes from 0,1 mm up to 8 mm;

— update of film system classes (old ISO classes T2 and T3 have been replaced by new classes C3 to C5, according to ISO 11699-1:2008);

— several editorial changes.

Introduction

This International Standard specifies fundamental techniques of radiography, with the object of enabling satisfactory and repeatable results to be obtained economically. The techniques are based on generally accepted practice and the fundamental theory of the subject.

Standards relating to specific applications should conform to these basic rules.

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

1 Scope

This International Standard outlines the general rules for industrial X- and gamma-radiography for flaw-detection purposes, using film techniques, applicable to the inspection of metallic products and materials.

It does not lay down acceptance criteria of the imperfections.

2 Normative references

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

ISO 5576, *Non-destructive testing — Industrial X-ray and gamma-ray radiology — Vocabulary*

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

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

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

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

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

ISO 19232-4, *Non-destructive testing — Image quality of radiographs — Part 4: Experimental evaluation of image quality values and image quality tables*

EN 12543 (all parts), *Non-destructive testing — Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing — Part 2: Pinhole camera radiographic method*

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 terms and definitions in ISO 5576 and the following apply.

3.1
nominal thickness
t
nominal thickness of the material in the region under examination

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

3.2
penetrated thickness
w
thickness of material in the direction of the radiation beam calculated on basis of the nominal thicknesses of all penetrated walls

3.3
object-to-film distance
b
distance between the radiation side of the radiographed part of the test object and the film surface measured along the central axis of the radiation beam

3.4
source size
d
size of the radiation source or focal spot size

Note 1 to entry: Source size is according to EN 12543 for X-ray tubes or EN 12679 for gamma ray sources.

3.5
source-to-film distance
SFD
distance between the source of radiation and the film measured in the direction of the beam

Note 1 to entry: SFD is the sum of the source-to-object distance (3.6) and the object-to-film distance (3.3).

3.6
source-to-object distance
f
distance between the source of radiation and the source side of the test object measured along the central axis of the radiation beam

4 Classification of radiographic techniques

The radiographic techniques are divided into two classes:

1) Class A: basic techniques;

2) Class B: improved techniques.

Class B techniques will be used when class A might 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.

If, for technical or industrial 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 by contracting parties that the condition selected may be what is specified for class A. The loss of sensitivity shall be compensated by an increase of minimum density to 3,0 or by selection of a better film system class with a minimum density of 2,6. The other conditions for class B remain unchanged, especially the image quality achieved (see 5.7). Because of the better sensitivity compared to class A, the test specimen may be regarded as being examined to class B.

5 General

5.1 Personnel qualification

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

5.2 Protection against ionizing radiation

WARNING — Exposure of any part of the human body to X-rays or gamma ray 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.

5.3 Surface preparation and stage of manufacture

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

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

5.4 Identification of radiographs

Symbols shall be affixed to each section of the object being radiographed. The images of these symbols shall appear in the radiograph outside the region of interest where possible and shall ensure unambiguous identification of the section.

5.5 Marking

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

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

5.6 Overlap of films

When radiographing an area with two or more separate films, the films shall overlap sufficiently to ensure that the complete region of interest is radiographed. This shall be verified by a high-density marker on the surface of the object which will appear on each film.

5.7 Image quality indicator (IQI)

The quality of image shall be verified by use of an IQI in accordance with specific application standards and ISO 19232-1, ISO 19232-2, ISO 19232-3, and ISO 19232-4.

6 Recommended techniques for making radiographs

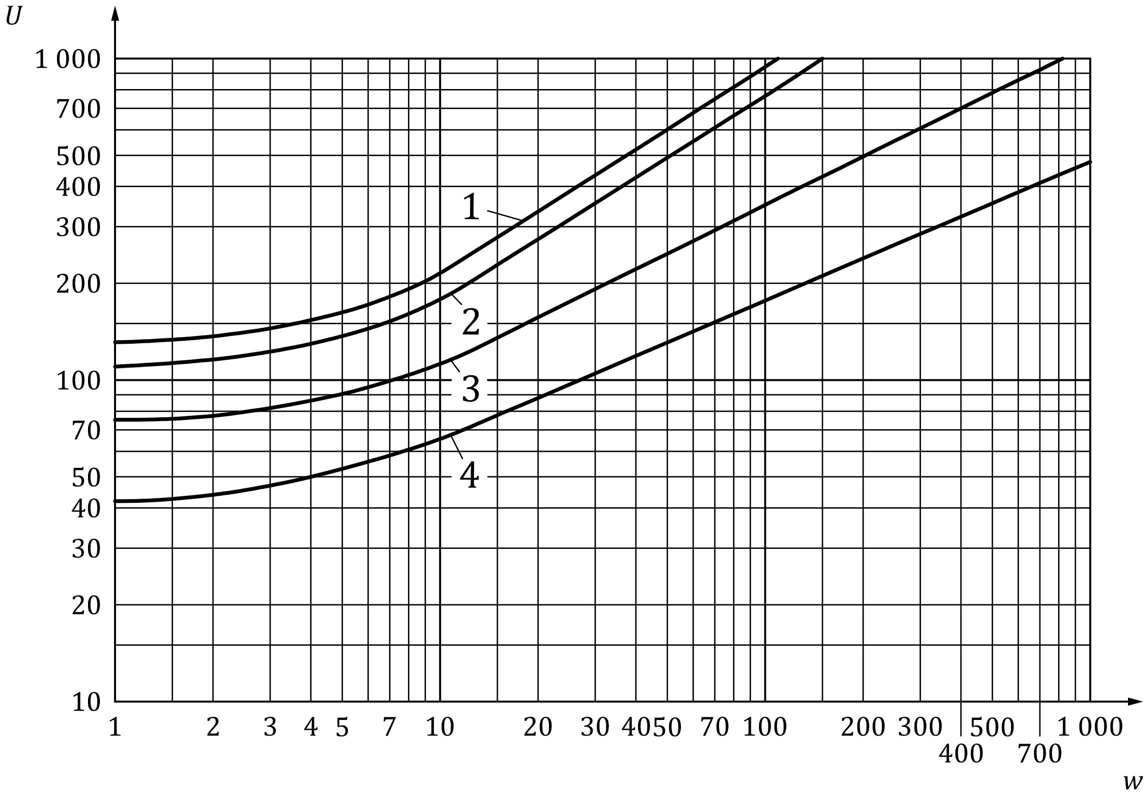
6.1 Test arrangements

Test arrangements shall be determined by the specific application standards.

6.2 Choice of X-ray tube voltage and radiation source

6.2.1 X-ray equipment

To maintain a good flaw sensitivity, the X-ray tube voltage should be as low as possible. The maximum values of tube voltage versus thickness are given in Figure 1.



Key

1 copper/nickel and alloys
2 steel
3 titanium and alloys
4 aluminium and alloys
U X-ray voltage in kV
w penetrated thickness in mm

Figure 1 — Maximum X-ray voltage *U* for X-ray devices up to 1 000 kV as a function of penetrated thickness, *w*, and material

6.2.2 Other radiation sources

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

By agreement between the contracting parties, the penetrated thickness minimum value may be reduced

— to 10 mm for Ir 192, and

— to 5 mm for Se 75.

On thin steel specimens, gamma rays from Se 75, Ir 192, and Co 60 will not produce radiographs having as good a defect detection sensitivity as X-rays used with appropriate technique parameters. However, because of the advantages of gamma ray sources in handling and accessibility, Table 1 gives a range of thicknesses for which each of these gamma ray sources may be used when the use of X-rays is not practicable.

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

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

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

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

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

[b] For aluminium and titanium, the penetrated material thickness is 35 mm ≤ w ≤ 120 mm for class A. These sources are not recommended for class B testing.

6.3 Film systems and screens

For radiographic examination, film system classes (C1 – C5) shall be used according to ISO 11699-1.

For different radiation sources, the minimum film system classes are given in Table 2 and Table 3.

When using metal screens, good contact between film and screens is required. This may be achieved either by using vacuum-packed films or by applying pressure.

For different radiation sources, Table 2 and Table 3 show the recommended screen materials and thicknesses.

Other screen thicknesses may also be agreed between the contracting parties provided the required image quality is achieved.

Table 2 — Film system classes and metal screens for the radiography of steel-, copper-, and nickel-based alloys

Radiation source	Penetrated thickness w	Film system class[a]		Type and thickness of metal screens	
		Class A	Class B	Class A	Class B
X-ray potentials ≤ 100 kV		C5	C3	None or up to 0,03 mm front and back screens of lead	
X-ray potentials > 100 kV to 150 kV				Up to 0,15 mm front and back screens of lead	
X-ray potentials > 150 kV to 250 kV			C4	0,02 mm to 0,15 mm front and back screens of lead	
Yb 169 Tm 170	w < 5 mm	C5	C3	None or up to 0,03 mm front and back screens of lead	
	w ≥ 5 mm		C4	0,02 mm to 0,15 mm front and back screens of lead	
X-ray potentials > 250 kV to 500 kV	w ≤ 50 mm	C5	C4	0,02 mm to 0,2 mm front and back screens of lead	
	w > 50 mm		C5	0,1 mm to 0,2 mm front screen of lead[b] 0,02 mm to 0,2 mm back screen of lead[b]	
X-ray potentials > 500 kV to 1000 kV	w ≤ 75 mm	C5	C4	0,25 mm to 0,7 mm front and back screens of steel or copper[c]	
	w > 75 mm	C5	C5		
Se 75		C5	C4	0,02 mm to 0,2 mm front and back screens of lead	
Ir 192		C5	C4	0,02 mm to 0,2 mm front screen of lead	0,1 mm to 0,2 mm front screen of lead[b]
				0,02 mm to 0,2 mm back screens of lead	
Co 60	w ≤ 100 mm	C5	C4	0,25 mm to 0,7 mm front and back screens of steel or copper[c]	
	w > 100 mm		C5		
X-ray equipment with energy from 1 MeV to 4 MeV	w ≤ 100 mm	C5	C3	0,25 mm to 0,7 mm front and back screens of steel or copper[c]	
	w > 100 mm		C5		
X-ray equipment with energy from 4 MeV to 12 MeV	w ≤ 100 mm	C4	C4	Up to 1 mm front screen of copper, steel or tantalum[d] Back screen of copper or steel, up to 1 mm and tantalum up to 0,5 mm[d]	
	100 mm < w ≤ 300 mm	C5	C4		
	w > 300 mm		C5		
X-ray equipment with energy above 12 MeV	w ≤ 100 mm	C4	not applicable	Up to 1 mm front screen of tantalum[e] No back screen	
	100 mm < w ≤ 300 mm	C5	C4		
	w > 300 mm		C5	Up to 1 mm front screen of tantalum[e] Up to 0,5 mm back screen of tantalum[e]	

[a] Better film system classes may also be used.

[b] Ready-packed films with a front screen of up to 0,03 mm may be used if an additional lead screen of 0,1 mm is placed between the object and the film.

[c] In class A, 0,5 mm to 2 mm screens of lead may also be used.

[d] In class A, lead screens 0,5 mm to 1,0 mm may be used by agreement between the contracting parties.

[e] Tungsten screens may be used by agreement.

Table 3 — Film system classes and metal screens for aluminium and titanium

Radiation source	Film system class[a]		Type and thickness of intensifying screens
	Class A	Class B	
X-ray potentials ≤ 150 kV	C5	C3	None or up to 0,03 mm front and up to 0,15 mm back screens of lead
X-ray potentials > 150 kV to 250 kV			0,02 mm to 0,15 mm front and back screens of lead
X-ray potentials > 250 kV to 500 kV			0,1 mm to 0,2 mm front and back screens of lead
Yb 169			0,02 mm to 0,15 mm front and back screens of lead
Se 75			0,2 mm front[b] and 0,1 mm to 0,2 mm back screens of lead

[a] Better film system classes may also be used (see ISO 11699-1).

[b] Instead of one 0,2 mm lead screen, two 0,1 mm lead screens may be used.

6.4 Alignment of beam

The beam of radiation shall be directed to the centre of the area being inspected and should be perpendicular to the object surface at that point except when it can be demonstrated that certain imperfections are best revealed by a different alignment of the beam. In this case, an appropriate alignment of the beam can be permitted.

Other ways of radiographing may be agreed between the contracting parties.

6.5 Reduction of scattered radiation

6.5.1 Filters and collimators

In order to reduce the effect of back-scattered radiation, direct radiation shall be collimated as much as possible to the section under examination.

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

6.5.2 Interception of back-scattered radiation

If necessary, the film shall be shielded from back-scattered radiation by an adequate thickness of lead at least 1 mm, or of tin at least 1,5 mm, placed behind the film-screen combination.

The presence of back-scattered radiation shall be checked for each new test arrangement by a lead letter "B" (with a minimum height of 10 mm and a minimum thickness of 1,5 mm) placed immediately behind each cassette. If the image of this symbol records as a lighter image on the radiograph, it shall be rejected. If the symbol is darker or invisible, the radiograph is acceptable and demonstrates good protection against scattered radiation.

6.6 Source-to-object distance

The minimum source-to-object distance, f_{min}, depends on the source size or focal spot size, d, and on the object-to-film distance, b.

The source size or focal spot size, d, shall be in accordance with EN 12543 or EN 12679. When the source size or focal spot size is defined by two dimensions, the larger value shall be used.

The distance f shall, where practicable, be chosen so that the ratio of this distance to the source size or focal spot size d, i.e. f/d, is not less than the values given by the following formulae:

For class A:

$$\frac{f}{d} \geq 7{,}5 \left(\frac{b}{\text{mm}} \right)^{2/3} \tag{1}$$

For class B:

$$\frac{f}{d} \geq 15 \left(\frac{b}{\text{mm}} \right)^{2/3} \tag{2}$$

where b is given in millimetres (mm).

If the distance b is less than 1,2 t, then the dimension b in Formula (1), Formula (2), and Figure 2 shall be replaced by the nominal thickness t.

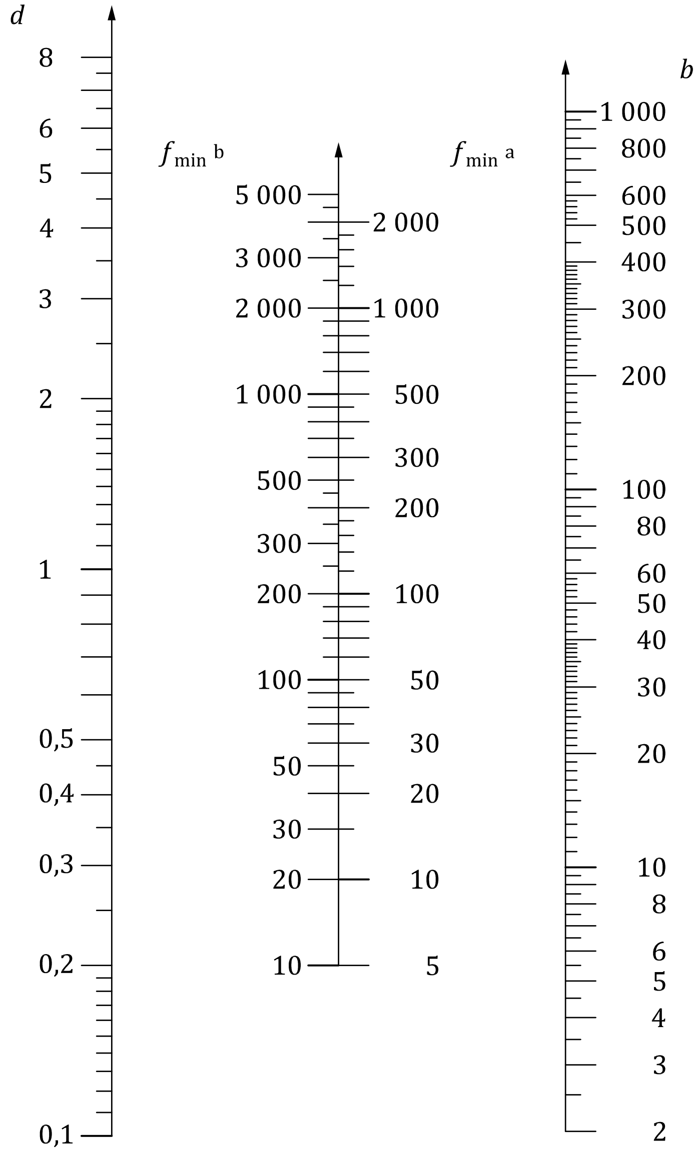
For the determination of the source-to-object distance f_{min}, the nomogram in Figure 2 may be used by drawing a line from axis b to axis d and reading the resulting f_{min} value from the central scale, depending on the testing class.

This nomogram is based on Formula (1) and Formula (2).

If class A is used primarily for detection of planar imperfections, then the minimum distance f_{min} shall be the same as for class B in order to reduce the geometric unsharpness by a factor of 2.

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

Dimensions in millimetres



Key

a f_{min} for class A

b f_{min} for class B

Figure 2 — Nomogram for determination of minimum source-to-object distance, f_{min}, in relation to object-to-film distance, *b*, and the source size, *d*

6.7 Maximum area for a single exposure

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

The densities resulting from any variation of penetrated thickness should not be lower than those indicated in 6.8 and not higher than those allowed by the available illuminator, provided suitable masking is possible.

6.8 Density of radiograph

Exposure conditions should be such that the total density of the radiograph (including base and fog density) in the inspected area is greater than or equal to that given in Table 4.

Table 4 — Optical density of radiographs

Class	Optical density[a]
A	≥ 2,0[b]
B	≥ 2,3[c]

[a] A measuring tolerance of ± 0,1 is permitted.

[b] May be reduced by special agreement between the contracting parties to 1,5.

[c] May be reduced by special agreement between contracting parties to 2,0.

High optical densities can be used with advantage where the viewing light is sufficiently bright in accordance with 6.10. The maximum readable density depends on the film viewer and its maximum luminance (see ISO 5580). The maximum readable density shall be posted on the viewer.

In order to avoid unduly high fog densities arising from film ageing, development, or temperature, the fog density shall be checked periodically on a non-exposed sample taken from the films being used, and handled and processed under the same conditions as the actual radiograph. The fog density shall not exceed 0,3. Fog density here is defined as the total density (emulsion and base) of a processed, unexposed film.

When using a multifilm technique with interpretation of single films, the optical density of each film shall be in accordance with Table 4.

If double film viewing is requested, the optical density of one single film shall not be lower than 1,3.

6.9 Processing

Films are processed in accordance with the conditions recommended by the film and chemical manufacturer to obtain the selected film system class. Particular attention shall be paid to temperature, developing time, and washing time. The film processing shall be controlled regularly in accordance with ISO 11699-2. The radiographs should be free from defects due to processing or other causes which would interfere with interpretation.

6.10 Film viewing conditions

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

7 Test report

For each radiograph, or set of radiographs, a test report shall be made, giving information on the radiographic technique used and on any other special circumstances which would allow a better understanding of the results.

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

a) name of the inspection body;

b) unique report number;

c) object;

d) material;

e) stage of manufacture;

f) nominal thickness;

g) radiographic technique and class, required IQI sensitivity;

h) system of marking used;

i) test arrangement and film position plan, if required;

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

k) film type and system, screens, and filters;

l) tube voltage and current or source type and activity;

m) time of exposure and source-to-film distance;

n) film-processing technique: manual/automatic and development conditions;

o) type and position of IQI;

p) test results, including data on film density and IQI reading;

q) conformity with this International Standard (i.e. ISO 5579:2013);

r) any deviation from this International Standard, by special agreement;

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

t) date(s) of exposure and test report.

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