Non-destructive testing — General principles for radiographic examination of metallic materials by X- and gamma-rays

The European Standard EN 444:1994 has the status of a British Standard

UDC 620.179.152:669.1

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This British Standard, having been prepared under the direction of the Welding Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 May 1994

The following BSI references relate to the work on this standard:
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Contents

National foreword

This British Standard has been prepared under the direction of the Welding Standards Policy Committee and is the English language version of EN 444:1994 *Non-destructive testing — General principles for radiographic examination of metallic materials by X- and gamma-rays* published by the European Committee for Standardization (CEN).

EN 444 was produced as a result of international discussion in which the UK took an active part.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 10, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

EUROPEAN STANDARD

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EN 444

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Descriptors: Metallurgical products. nondestructive tests, radiographic analysis, X rays, gamma radiation, defects, radiographic film, filing

English version

Non-destructive testing — General principles for radiographic examination of metallic materials by X- and gamma-rays

Essais non destructifs — Principes généraux de l'examen radiographique à l'aide de rayons X et gamma des matériaux métalliques

Zerströrungsfreie Prüfung — Grundlagen für die Durchstrahlungsprüfung von metallischen Werkstoffen mit Röntgen- und Gammastrahlen

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Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

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CEN

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

Ref. No. EN 444:1994 E

Foreword

This European Standard was drawn up by CEN TC 138 "Non-destructive testing", the secretariat of which is held by (AFNOR).

It was submitted for Formal Vote, and the result was positive.

This European Standard has been prepared under a mandate given to CEN by the Commission of the European Communities and the European Free Trade Association, and supports essential requirements of the EC Directive(s).

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 August 1994, and conflicting national standards shall be withdrawn at the latest by August 1994.

According to the CEN/CENELEC Internal Regulations, the following countries are bound to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

Contents

Introduction

This 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.

1 Scope

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

The examination shall be carried out by competent personnel qualified and certified according to EN 473 where applicable.

It does not lay down acceptance criteria of the imperfections.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 462-1, *Non-destructive testing — Image quality of radiographs — Part 1: Image quality indicators (wire type), determination of image quality value.*

EN 462-2, *Non-destructive testing — Image quality of radiographs — Part 2: Image quality indicators (step/hole type), determination of image quality value* [1].

EN 462-3, *Non-destructive testing — Image quality of radiographs — Part 3: Image quality classes for ferrous metals*[1].

EN 462-4, *Non-destructive testing — Image quality of radiographs — Part 4: Experimental evaluation of image quality values and image quality tables*[1].

EN 473, *Qualifications of certification of non-destructive personnel — General principles.*

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

EN 25580, *Non-destructive testing — Industrial radiographic illuminators — Minimum requirements* (ISO 5580:1985).

3 Definitions

For the purpose of this standard, the following definition apply:

3.1
nominal thickness, *t*

the nominal thickness of the material in the region under examination

manufacturing tolerances do not have to be taken into account

3.2
penetrated thickness, *w*

the thickness of material in the direction of the radiation beam calculated on basis of the nominal thickness

for multiple wall techniques the penetrated thickness shall be calculated from the nominal thickness

3.3
object-to-film distance, *b*

the distance between the radiation side of the test object and the film surface measured along the central axis of the radiation beam

3.4
source size*, d*

the size of the source of radiation

3.5
source-to-film distance (SFD)

the distance between the source of radiation and the film measured in the direction of the beam

3.6
source-to-object distance, *f*

the 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:

Classes A: basic techniques

Classes B: improved techniques

Class B techniques will be used when class A may be insufficiently sensitive.

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

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

[1] In preparation.

If, for technical reasons, it is not possible to meet one of the conditions specified for the class B, such as the type of radiation source or the source-to-object distance *f*, it may be agreed between the contracting parties that the condition selected may be that specified for class A. The loss of sensitivity shall be compensated by an increase of minimum density to 3,0 or by choice of a higher contrast film system. Because of the better sensitivity compared to class A, the test sections may be regarded as examined within class B.

5 General

5.1 Protection against ionizing radiations

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

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

5.2 Surface preparation and stage of manufacture

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

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

5.3 Identification of radiographs

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

5.4 Marking

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

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

5.5 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.

5.6 Image quality indicator (IQI)

The quality of image shall be verified by use of IQI in accordance with specific application standards and EN 462-1, EN 462-2, EN 462-3 and EN 462-4.

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.

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.

On thin steel specimens, gamma rays from Ir 92 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 travel-time to position the source shall not exceed 10 % of the total exposure time.

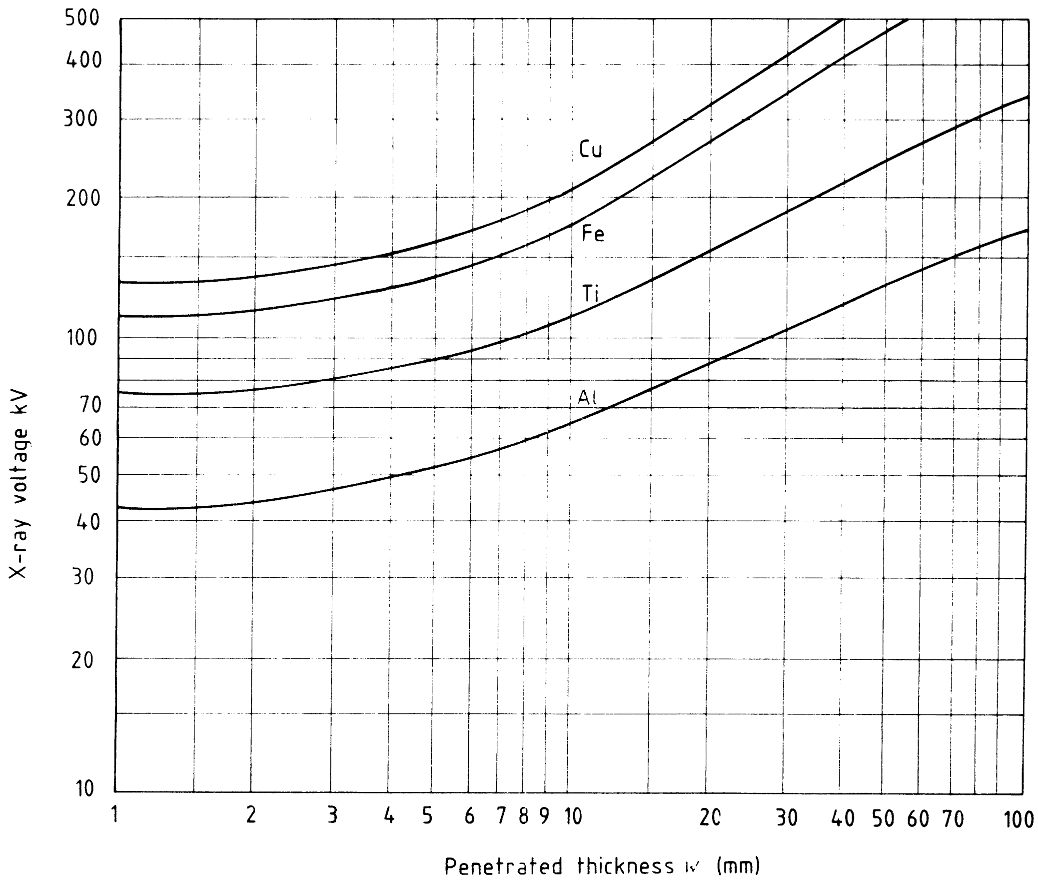

Figure 1 — Maximum X-ray voltage for X-ray devices up to 500 kV as a function of penetrated thickness and material

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

Radiation source	Penetrated thickness, w, in mm	
	Test class A	Test class B
Tm 170	$w \leq 5$	$w \leq 5$
Yb 169[a]	$1 \leq w \leq 15$	$2 \leq w \leq 12$
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 above 4 MeV to 12 MeV	$w \leq 50$	$w \leq 80$
X-ray equipment with energy above 12 MeV	$w \leq 80$	$w \leq 100$

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

6.3 Film systems and screens

For radiographic examination film system classes shall be used according to EN 584-1.

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, Table 2 and Table 3 show the recommended screen materials and thickness.

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

6.4 Alignment of beam

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

Between the contracting parties other ways of radiographing may be agreed upon.

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 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 height of minimum 10 mm and a thickness of minimum 1,5 mm) placed immediately behind each cassette. If the image of this symbol records as a lighter image on the radiograph, it shall be rejected. If the symbol is darker or invisible the radiograph is acceptable and demonstrates good protection against scattered radiation.

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

<table>
<tr><th rowspan="2">Radiation source</th><th>Penetrated thickness</th><th colspan="2">Film system class[a]</th><th colspan="2">Type and thickness of metal screens</th></tr>
<tr><th>w</th><th>Class A</th><th>Class B</th><th>Class A</th><th>Class B</th></tr>
<tr><td>X-ray potentials ≤ 100 kV</td><td rowspan="3"></td><td rowspan="3">C 5</td><td rowspan="2">C 3</td><td colspan="2">None or up to 0,03 mm front and back screens of lead</td></tr>
<tr><td>X-ray potentials 100 kV to 150 kV</td><td colspan="2">Up to 0,15 mm front and back screens of lead (max.)</td></tr>
<tr><td>X-ray potentials 150 kV to 250 kV</td><td>C 4</td><td colspan="2">0,02 to 0,15 mm front and back screens of lead</td></tr>
<tr><td rowspan="2">Yb 169
Tm 170</td><td>w < 5 mm</td><td rowspan="2">C 5</td><td>C 3</td><td colspan="2">None or up to 0,03 mm front and back screens of lead</td></tr>
<tr><td>w ≥ 5 mm</td><td>C 4</td><td colspan="2">0,02 to 0,15 mm front and back screens of lead</td></tr>
<tr><td rowspan="2">X-ray potential > 250 kV to 500 kV</td><td>w ≤ 50 mm</td><td rowspan="2">C 5</td><td>C 4</td><td colspan="2">0,02 to 0,2 mm front and back screens of lead</td></tr>
<tr><td>w > 50 mm</td><td>C 5</td><td colspan="2">0,1 to 0,2 mm front screen of lead[b]</td></tr>
<tr><td rowspan="2">Ir 192</td><td rowspan="2"></td><td rowspan="2">C 5</td><td rowspan="2">C 4</td><td>0,02 to 0,2 mm front screen of lead</td><td>0,1 to 0,2 mm front screen of lead[b]</td></tr>
<tr><td colspan="2">0,02 to 0,2 mm back screens of lead</td></tr>
<tr><td rowspan="2">Co 60</td><td>w ≤ 100 mm</td><td rowspan="2">C 5</td><td>C 4</td><td colspan="2" rowspan="2">0,25 to 0,7 mm front and back screens of steel or copper[c]</td></tr>
<tr><td>w ≥ 100 mm</td><td>C 5</td></tr>
<tr><td rowspan="2">X-ray equipment with energy from 1 MeV to 4 MeV</td><td></td><td rowspan="2">C 5</td><td>C 3</td><td colspan="2" rowspan="2">0,25 to 0,7 mm front and back screens of steel or copper[c]</td></tr>
<tr><td>w > 100 mm</td><td>C 5</td></tr>
<tr><td rowspan="3">X-ray equipment with energy above 4 MeV to 12 MeV</td><td>w ≤ 100 mm</td><td>C 4</td><td>C 4</td><td colspan="2" rowspan="3">Up to 1 mm front screen of copper, steel or tantalum[d] (max.)
Back screen of copper or steel up to 1 mm and tantalum up to 0,5 mm[d]</td></tr>
<tr><td>100 mm < w ≤ 300 mm</td><td rowspan="2">C 5</td><td>C 4</td></tr>
<tr><td>w > 300 mm</td><td>C 5</td></tr>
<tr><td rowspan="3">X-ray equipment with energy > 12 MeV</td><td>w ≤ 100 mm</td><td>C 4</td><td>—</td><td colspan="2">Up to 1 mm front screen of tantalum[e]</td></tr>
<tr><td>100 mm < w ≤ 300 mm</td><td rowspan="2">C 5</td><td>C 4</td><td colspan="2">No back screen</td></tr>
<tr><td>w > 300 mm</td><td>C 5</td><td colspan="2">Up to 1 mm front screen of tantalum[e]
Up to 0,5 mm back screen of tantalum</td></tr>
</table>

[a] Better film system classes may also be used

[b] Ready packed films with a front screen 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 also 0,1 to 0,5 mm screens of lead may be used

[d] In class A lead screens 0,5 to 1 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			None or up to 0,03 mm front and up to 0,15 mm back screens of lead (max.)
X-ray potentials > 150 kV to 250 kV	C 5	C 3	0,02 to 0,15 mm front and back screens of lead
X-ray potentials > 250 kV to 500 kV			0,1 to 0,2 mm front and back screens lead
Yb 169			0,02 to 0,15 mm front and back screens of lead

[a] Better film system classes may also be used

6.6 Source-to-object distance

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

The distance f, shall, where practicable, be chosen so that the ratio of this distance to the source size d, i.e. f/d, is not below the values given by the following equations:

$$\text{For class A}: f/d \geq 7{,}5 \quad \left(\frac{b}{\text{mm}}\right)^{2\;3} \qquad (1)$$

$$\text{For class B}: f/d \geq 15 \quad \left(\frac{b}{\text{mm}}\right)^{2\;3} \qquad (2)$$

b is given in millimetres (mm).

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

For determination of the source-to-object distance, f_{min}, the nomogram in Figure 2 may be used.

The nomogram is based on equations (1) and (2).

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

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

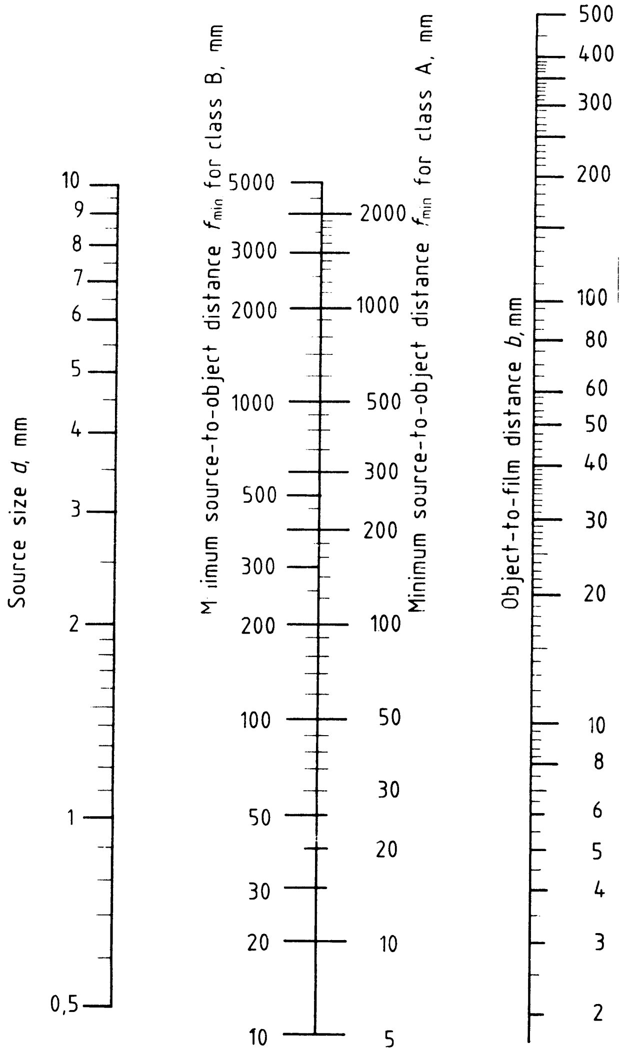

Figure 2 — Nomogram for determination of minimum source-to-object distance f_{min} in relation to of object-to-film distance and the source size

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 clause **6.8** and not higher than those allowed by the available illuminator, provided suitable masking is possible.

6.8 Density of radiographs

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 — Minimum density of radiographs

Class	Density[a]
A	≥ 2,0
B	≥ 2,3

[a] A measuring tolerance of ± 0.1 is permitted.

High densities may be used with advantage where the viewing light is sufficiently bright in accordance with clause **6.10**.

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 density of each film shall be in accordance with Table 4.

If double film viewing is requested the 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 is to be paid to temperature, developing time and washing time. The radiographs should be free from imperfections 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 with an adjustable luminance according to EN 25580. 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 inspection is carried out exclusively to this standard then the test report shall contain at least the following topics:

a) name of the testing company;

b) unique report number;

c) object;

d) material;

e) stage of manufacture;

f) nominal thickness;

g) radiographic technique and class;

h) system of marking used;

i) film position plan, if required;

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

k) selected film systems, screens and filters;

l) tube voltage and current or source activity;

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

n) type and position of image quality indicator:

o) reading of I.Q.I and minimum film density;

p) conformance to EN 444;

q) any deviation from agreed standard;

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

s) date of exposure and report.

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National annex NA (informative) Committees responsible

The United Kingdom participation in the preparation of this European Standard was entrusted by the Welding Standards Policy Committee (WEE/-) to Technical Committee WEE/46, upon which the following bodies were represented:

Aluminium Federation
Associated Offices Technical Committee
Association of Consulting Engineers
BNF (Fulmer Materials Centre)
British Airways
British Chemical Engineering Contractors' Association
British Gas plc
British Institute of Non-destructive Testing
British Non-Ferrous Metals Federation
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Electricity Association
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Royal Society of Chemistry
Society of British Aerospace Companies Limited
Society of Motor Manufacturers and Traders Limited
Steel Casting Research and Trade Association
Welding Institute

National annex NB (informative) Cross-references

Publication referred to	Corresponding British Standard
EN 462-1:1994	BS EN 462-1:1994 *Non-destructive testing — Image quality of radiographs —* Part 1: *Image quality indicators (wire type), determination of image quality value*
EN 473:1993	BS EN 473:1993 *Qualification and certification of non-destructive personnel — General principles*
EN 25580:1992	BS EN 5580:1992 *Non-destructive testing — Industrial radiographic illuminators — Minimum requirements*

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