International Standard 1106/3

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Recommended practice for radiographic examination of fusion welded joints — Part 3 : Fusion welded circumferential joints in steel pipes of up to 50 mm wall thickness

Pratique recommandée pour l'examen radiographique de joints soudés par fusion — Partie 3 : Joints circulaires soudés par fusion de tubes d'acier d'épaisseur inférieure ou égale à 50 mm

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 1106/3 was prepared by Technical Committee ISO/TC 44, *Welding and allied processes.* It cancels and replaces ISO Recommendation R 947-1969, of which it constitutes a technical revision.

Recommended practice for radiographic examination of fusion welded joints — Part 3 : Fusion welded circumferential joints in steel pipes of up to 50 mm wall thickness

0 Introduction

The detection of flaws in an item submitted to X- or γ-radiographic examination depends on the particularities of the technique employed.

Since the quality of the radiograph cannot be fully ensured by the use of an image quality indicator (IQI), this part of ISO 1106 indicates the procedures necessary to obtain comparable radiographs from different origins (see 6.7).

This part of ISO 1106 should have the effect of ensuring more unified practice and thus simplify the interpretation of radiographs.

1 Scope

This part of ISO 1106 specifies general techniques of weld radiography with the object of enabling satisfactory results to be obtained economically. The techniques are based on generally accepted practice and the fundamental theory of the subject.

2 Field of application

This part of ISO 1106 applies to the radiographic examination of circumferential welded joints in steel pipes of up to 50 mm wall thickness.

It does not lay down radiographic criteria of acceptance for the joints, but is concerned with the radiographic techniques to be used.

NOTES

1 Besides its conventional meaning, "pipe" as used in this part of ISO 1106 should be understood to cover other cylindrical bodies, such as tubes, penstocks, boiler drums and pressure vessels.

2 The IQI values to be accepted for the different types of welded structures are not within the scope of this part of ISO 1106. However, if the techniques described are used correctly, it should be possible to obtain, without difficulty, the IQI values listed in ISO 2504 as minimum requirements.

However, for double wall techniques (see 7.1.1.3 and 7.1.1.4; 7.1.2.3 and 7.1.2.4), the steel thickness indicated in ISO 2504 refers to the double wall thickness.

3 References

ISO 1027, *Radiographic image quality indicators for non-destructive testing — Principles and identification.*

ISO 2504, *Radiography of welds and viewing conditions for films — Utilization of recommended patterns of image quality indicators (IQI).*

ISO 5576, *Industrial radiology — Non-destructive testing — Vocabulary.* [1]

ISO 5579, *Non-destructive testing — Radiographic examination of metallic materials by X- and gamma-rays — Basic rules.* [2]

ISO 5580, *Non-destructive testing — Industrial radiographic illuminators — Minimum requirements.* [2]

ISO 7004, *Photography — Industrial radiographic film — Determination of ISO speed and ISO average gradient when exposed to X- and γ-radiation.* [2]

IRCP Publication 9, *Recommendations of the International Commission on Radiological Protection.*

1) At present at the stage of draft. (Revision of Appendix-1969 to ISO/R 947, ISO/R 1027 and ISO/R 1106.)

2) At present at the stage of draft.

4 Definitions

For the purpose of this part of ISO 1106, the definitions given in ISO 5576 apply.

5 Classification of radiographic techniques

The radiographic techniques are divided into two classes :

class A : general techniques for X- and γ-ray examination;

class B : techniques for X- and γ-ray examination with greater sensitivity in the detection of defects.

Most applications are covered by the use of class A techniques. Class B techniques are intended for more important and difficult applications where those of class A may be insufficiently sensitive to reveal all the defects desired to be detected. Class B comprises techniques in which only fine-grain films and lead screens are used; they therefore generally require longer exposures.

Further details are given in clause 7; in particular the final paragraph of 7.9 should be noted.

6 General

6.1 Protection against ionizing radiations

WARNING — Exposure of any part of the human body to X-rays or γ-rays can be highly injurious to health. Wherever X-ray equipment or radioactive sources are in use, adequate precautions shall be taken to protect the radiographer and any other person in the vicinity.

Local or national safety precautions at present in force against X- and γ-rays shall be strictly observed.

In default of such regulations, reference shall be made to IRCP Publication 9.

6.2 Surface preparation

In order to simplify interpretation of the radiographs, it is advisable to remove surface irregularities before taking radiographs. In general, surface preparation is not necessary for radiography, but where surface irregularities might cause difficulty in detecting internal defects, the surface should be ground smooth.

6.3 Location of the weld in the radiograph

Markers, usually in the form of lead arrows or other symbols, should be placed on each side of the weld, so that its position can be identified on the radiograph. This may not be necessary if the reinforcement is retained.

6.4 Identification of radiographs

Lead letters or symbols should be affixed to each section of the weld being radiographed. The images of these letters should appear in the radiograph to ensure unequivocal identification of the section.

6.5 Marking

In general, permanent markings on the piece will provide reference points for the accurate relocation of the position of each radiograph. Where the nature of the material and its service conditions render stamping impossible, other suitable means for relocating the radiographs should be sought. This may be done by paint marks or by accurate sketches.

6.6 Overlap of films

When radiographing a continuous length of weld with separate films, the separate films should overlap by at least 10 mm to ensure that no portion of the weld length remains unexamined.

6.7 Image quality indicator

An image quality indicator (IQI) of mild steel, of a type specified in ISO 1027 and agreed between the contracting parties, should be placed on the surface facing the source of radiation, and, depending upon its type, adjacent to or across the weld. Only where this surface is inaccessible should the IQI be placed on the film side. If this has to be done, a lead letter "F" should be placed near the IQI, and this should also be mentioned in the test report, as the IQI indication does not have the same meaning when the IQI is placed in this position. In these cases it may be necessary to make special comparison exposures with an IQI in the two locations. For details of the recommended types of IQI, see ISO 1027.

In cases where a continuous strip of film is used, wrapped round the pipe, with the source located centrally, three IQI approximately equally spaced should be used, unless otherwise agreed between the contracting parties.

If the film is to be cut into shorter lengths for processing, the number of IQI used should be sufficient for an IQI image to appear on each length of film.

In the case of the set-up described in 7.1.1.3, the IQI should be placed close to the weld on the surface of the pipe facing the radiation source.

For further details, refer to ISO 2504.

7 Recommended techniques for making radiographs

7.1 Setting-up of the films and of the source of radiation

7.1.1 Relative position of films and sources, depending on the size and accessibility of the joints

7.1.1.1 Film inside, source of radiation outside (see figure 1)

The source of radiation should be placed at a distance from the weld as defined below (see 7.6), the axis of the cone of radiation being normal to the surface under examination at the weld centre.

The cassette should be placed on the corresponding area inside the pipe, in close contact with the weld.

7.1.1.2 Film outside, source of radiation inside (see figures 2 and 3)

The source of radiation should be set up inside the pipe, on the axis of the pipe if possible, though otherwise it may be placed eccentrically in the plane of the weld, the axis of the cone of radiation being normal to the surface under examination at the weld centre.

The cassette should be placed on the corresponding area outside the pipe, in close contact with the weld.

7.1.1.3 Film and source of radiation outside : double wall, double image (see figure 4)

The source of radiation should be placed at a distance as defined below (see 7.6) in a position so that the axis of the cone of radiation is inclined to the axis of the pipe, and passes through the centre of the plane of the weld.

The cassette containing the film, which should be of sufficient dimensions to contain the images of the weld, should be placed against the pipe wall further from the source, and disposed in such a manner that the axis of the cone of radiation passes through the weld centre.

7.1.1.4 Film and source of radiation outside : double wall, single image (see figure 5)

The source of radiation should be placed so as to achieve the minimum focus-to-film distance compatible with the source size and wall thickness to be examined. If possible, the source should be in contact with the pipe, with the radiation passing through the parent metal adjacent to the weld, but this may not be possible with small diameter pipes.

The film should be placed on the side of the pipe furthest from the source of radiation, in close contact with the weld, the axis of the cone of radiation passing through the centre of the portion of weld under examination.

7.1.2 General guidance on the selection of the appropriate technique

7.1.2.1 Film inside, source of radiation outside (see figure 1)

The technique should be used for large cylindrical bodies, where the limitation (see 7.7) of maximum area to be examined permits the use of long films whilst keeping the source-to-film distance within reasonable limits.

7.1.2.2 Film outside, source of radiation inside (see figures 2 and 3)

Where applicable, this technique should be considered as the most convenient, because with the source situated at or near the centre, there is no restriction regarding the length of weld examined. For large diameter pipes, conventional equipment may be used and for small diameters special hollow-anode X-ray tubes or γ-ray sources may be used. This technique is particularly recommended for thick-wall pipes of small diameter.

7.1.2.3 Film and source of radiation outside — double wall, double image (see figure 4)

This technique should only be used for pipes having a diameter not exceeding approximately 100 mm, the necessary source-to-film distance being too large with larger diameters; it should also be noted that the increase of wall thickness to be penetrated, off-normal, restricts the length of weld which can be properly radiographed with a single exposure.

7.1.2.4 Film and source of radiation outside — double wall, single image (see figure 5)

This technique will give the best result for pipes not accessible from the inside, with diameters larger than approximately 100 mm.

NOTE — Whenever possible, in particular when a large part of the radiation beam is used for covering the area to be irradiated, it is recommended that operators should set up the equipment in such a way that the axis of the X-ray tube is parallel to the pipe to be radiographed. This ensures the best image definition even at the extremities of the film, and a more uniform distribution of the intensity of the radiation.

7.2 Films and screens

The films (see ISO 5579 and ISO 7004) to be used for class A shall be at least medium-grain, while for class B they shall be at least fine-grain.

For X- and γ-rays using iridium-192(^{192}Ir), front and back intensifying lead screens shall have, for both class A and class B, a thickness between 0,02 and 0,25 mm.

In general, with X-rays, thinner screens will permit shorter exposure times.

For X-ray voltages below 120 kV, no front screen is necessary, although a thin lead screen is sometimes useful to reduce scattered radiation.

For γ-rays from cobalt-60 (^{60}Co), front and back screens of copper, steel or other metals or alloys of medium atomic number or also lead may be used.

For these screens, the thickness shall be 0,2 to 0,5 mm.

In cases where a double film technique is used, the intermediate screen should also be within the thickness range specified above.

The use of salt-intensifying screens is not recommended, but if, owing to unavoidable circumstances, they have to be used, they should be of the "high definition" type. Their use shall be recorded in the test report as, in general, they cause a loss of definition in the radiographic image.

7.3 Cassettes

Films, and screens (if used), should be placed in cassettes, which may be either rigid or flexible. In view of the difficulty of procuring rigid cassettes with curvatures such as to bring the whole length of the film in close contact with the welded joint, preference should be given to flexible cassettes, provided that adequate precautions are taken to ensure good overall film-screen contact. This can be best achieved with vacuum packed films. When low-voltage X-rays are used, it is necessary to ensure that the front of the cassette does not cause excessive X-ray absorption.

This clause is not intended to preclude the use of prepacked strip film with integral intensifying screens.

7.4 Alignment of beam

The beam of radiation should be directed to the middle of the section under examination and should be normal to the pipe surface at that point, except when especially seeking certain imperfections which it is known are best revealed by a different alignment of the beam; such imperfections are those at a fusion face, and the exposure should then be made with the beam directly along the fusion face.

This general rule should be applied with the following two exceptions.

a) When using the double-wall, double-image technique, the inclination of the beam should be such as to avoid a superimposition of the two images. This inclination will depend on the diameter of the pipe, its wall thickness and the width of the weld.

b) For the double-wall, single-image technique, the displacement of the source from the plane of the weld should be just sufficient to avoid superimposition of the images of the two portions of the weld and the inclination of the axis of the beam should be such that the axis passes through the middle of the portion of weld under examination.

In order to eliminate possible interference when a backing ring has been used, and to provide the best possibility of fine cracks in the root run being revealed, it is suggested that, where the diameter of the pipe permits, the beam should be normal to the weld, not inclined, and centred in the plane of the weld. Figures 6 to 10 show the recommended alignments for various types of weld joint.

7.5 Interception of unwanted and scattered radiation

No back-scattered radiation should reach the film. In order to achieve this, when necessary, the film shall be shielded from all back-scattered radiation by an adequate thickness of lead, say 1 mm or more, placed behind the film-screen combination.

In addition, in order to reduce the effect of internally scattered radiation, adequate masking should be provided so as to limit the area irradiated to the section under examination.

When using the double-wall techniques (7.1.1.3 and 7.1.1.4; 7.1.2.3 and 7.1.2.4), in particular on small diameter pipes, adequate masking should be provided to ensure that only direct radiation strikes the film.

NOTE — In particular cases, for example double-wall, single-image with cobalt-60 γ-rays, a filter of 2 mm thickness of lead may be used between the specimen and the film. This filter can be external or inside the cassette. Where intensifying screens of metal other than lead are used, this filter can be replaced by a thicker front intensifying screen, if this is more convenient.

7.6 Source-to-film distance

The distance between the film and the adjacent weld surface should be as small as possible. The minimum source-to-specimen distance, d (i.e. the distance between the radiation source and the surface of the specimen facing the X-ray tube or γ-ray source), depends on the effective dimension, f, of the focal spot or source of radiation and on the distance, b, between the film and the surface of the specimen (which normally is identical to the thickness, t, of the specimen).

The effective focal spot dimension, f, is determined as shown in figure 11 from a projected focal spot image.[1)]

The minimum source-to-specimen distance, d, should be chosen so that the ratio of this distance to the effective dimension of focal spot f, i.e. d/f, is not below the values given by the following equations.

For class A

$$d/f = 7{,}5\, t^{2/3}$$

For class B

$$d/f = 15\, t^{2/3}$$

These relationships are presented graphically in figure 12 and as a nomogram in figure 13.

If the distance, b, between the surface of the specimen and the film is large compared with the thickness, t, on the abscissa of figure 12 or on the right-hand scale of figure 13, t shall be replaced by b.

When using the technique described in 7.1.1.3 and 7.1.2.3, t shall be replaced by the external diameter of the pipe in both figures 12 and 13.

When using the technique described in 7.1.1.4 and 7.1.2.4, only the actual wall thickness of the section of circumference under examination should be considered for calculation of the ratio d/f.

1) This projected image can be produced for example according to IIS/IIW/183/65, *Recommendation for the determination of the focal spot size of X-ray tubes.*

In the cases where the double-wall techniques shown in figures 4 and 5 can be replaced by the technique shown in figures 2 and 3 with only a small reduction in source-film distance (s.f.d.) from the minimum value determined from figures 12 or 13, this method should be preferred. The reduction in s.f.d. should not be greater than 20 % for the techniques shown in figure 3.

For the technique shown in figure 2, by prior agreement between the contracting parties, and providing there is no diminution in defect sensitivity for the particular welds as proved by appropriate tests, this percentage may be increased. However, it is recommended that the reduction in s.f.d. shall not be greater than 50 %.

7.7 Size of the area examined

The maximum length of weld to be taken into consideration at each exposure should be determined by the difference between the thickness of the material penetrated in the centre of the radiation beam and that at the extremities of the film measured in the direction of the beam at those points. The differences in density resulting from this variation of thickness and recorded on the film should result in values not lower than those indicated in clause 7.8 and not higher than those allowed by the available illuminator, providing suitable masking is possible.

For figures 3 and 5, a minimum number of three exposures is necessary to cover effectively the full circumference.

7.8 Density of radiograph

Exposure conditions should be such that the density of the radiograph of the sound weld metal in the area under examination, including fog density, is greater than that given in table 1.

Table 1 — Density of radiographs

Class	Density
A	1,7 or more[1)]
B	2,0 or more

1) May be reduced to 1,5 by special agreement between the contracting parties.

Higher densities may be used with advantage where the viewing light is sufficiently bright to permit adequate interpretation. The upper limit of density depends on the luminance of the available film viewing screen, and ISO 2504 should be followed.

Masking precautions should be taken to avoid glare.

In order to avoid unduly high fog densities arising from film ageing, development or temperature, the fog density should be checked from time to time 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 should not exceed 0,3.

Fog density here is defined as the total density (emulsion and base) of a processed, unexposed film.

7.9 X-ray tube voltage and type γ-ray source

To maintain a good sensitivity of defect detection, the X-ray tube voltage should be as low as possible. As a basis for choosing an appropriate voltage, the maximum values given in figure 14 should not be exceeded.

For some applications where there is a thickness change across the area of specimen being radiographed, a modification of technique, using a slightly higher voltage, may be used (in any case, the increment shall be no more than 50 kV), but it should be noted that an excessively high tube voltage will lead to a loss of defect sensitivity.

γ-Ray sources should not be used on weld thicknesses below the limits given in table 2.

Table 2 — Minimum thickness for γ-rays

Class	Thickness, mm	
	^{192}Ir	^{60}Co
A	20	40
B	40	—

The lower single wall thickness limit for iridium-192 γ-rays may be reduced in applications where the use of X-rays is not practicable or if the use of γ-rays makes a more suitable radiation beam direction possible. This should only be done with the prior approval of the contracting parties, but the use of iridium-192 γ-rays is not recommended for weld thicknesses below 5 mm for class A or 10 mm for class B.

It should be noted that the sensitivity of flaw detection attainable with γ-rays is generally inferior to that obtained with X-rays. The difference in sensitivity is greatest on thin welds and becomes less marked on thicker sections. At the upper-thickness limit of this part of ISO 1106, the difference in attainable sensitivity between X- and γ-ray techniques can be expected to be small.

The use of γ-rays should therefore be limited, as far as possible, to applications where the shape, thickness or accessibility of the welds makes X-ray examination impracticable.

7.10 Processing

Films should be processed in accordance with the manufacturer's instructions. Particular attention should be paid to temperature and developing time. The radiographs should be free from imperfections due to processing or other causes which would interfere with interpretation.

7.11 Viewing

The radiographs should be examined in a darkened room on an illuminated diffusing screen and the illuminated area should be masked to the minimum required for viewing the radiograph image. The brightness of the viewing screen should preferably be adjustable so as to allow satisfactory reading of the radiographs. For detailed regulations on film viewing conditions, see ISO 2504 and ISO 5580.

8 Test report

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

The test report shall include at least the following information :

a) type of X-ray equipment, the voltage applied and the anodic current intensity (if applicable);

b) characteristics of the radioactive source (nature, size, nuclear activity, etc.) (if applicable);

c) time of exposure, type of film and screen and target-(source-)to-specimen distance;

d) system of marking used;

e) processing technique;

f) weld geometry, wall thickness and welding process used;

g) the radiograph geometry showing the position of the focus and of the film (sketch);

h) the IQI used and the quality of the image obtained in accordance with ISO 2504;

j) results of interpretation;

k) any deviation, by agreement or otherwise, from the procedures specified;

m) the date of the examination and the endorsement by the inspector.

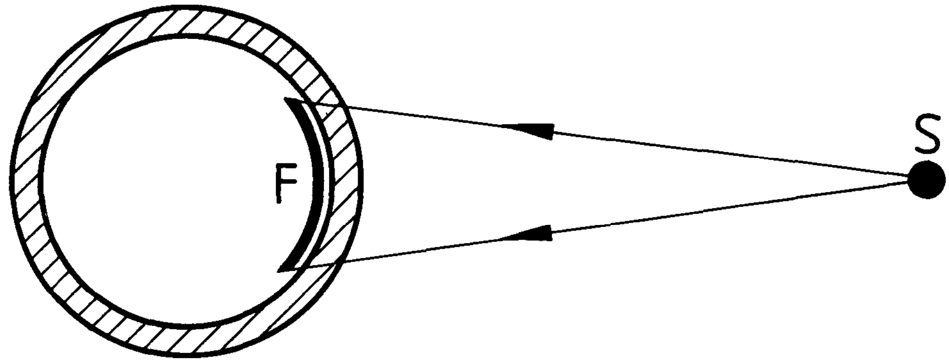


Figure 1 — Film inside, source of radiation outside

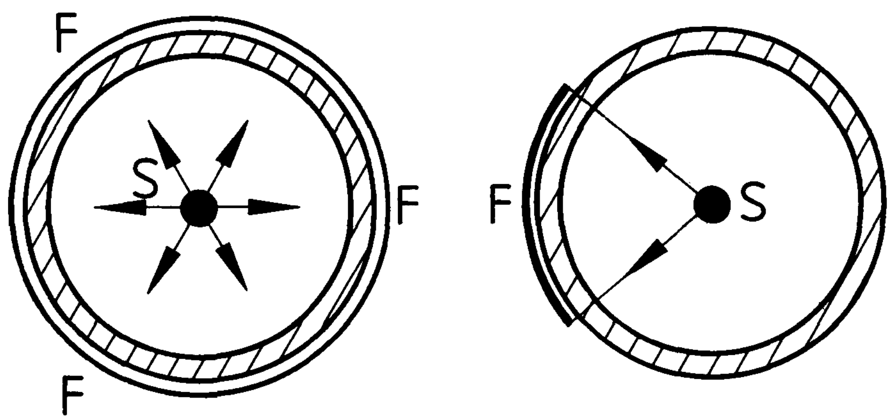


Figure 2 — Film outside, source of radiation inside (source central)

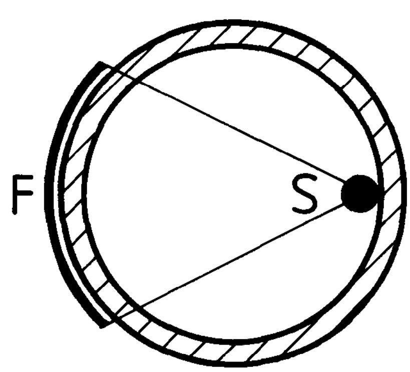


Figure 3 — Film outside, source of radiation inside (source off-centre)

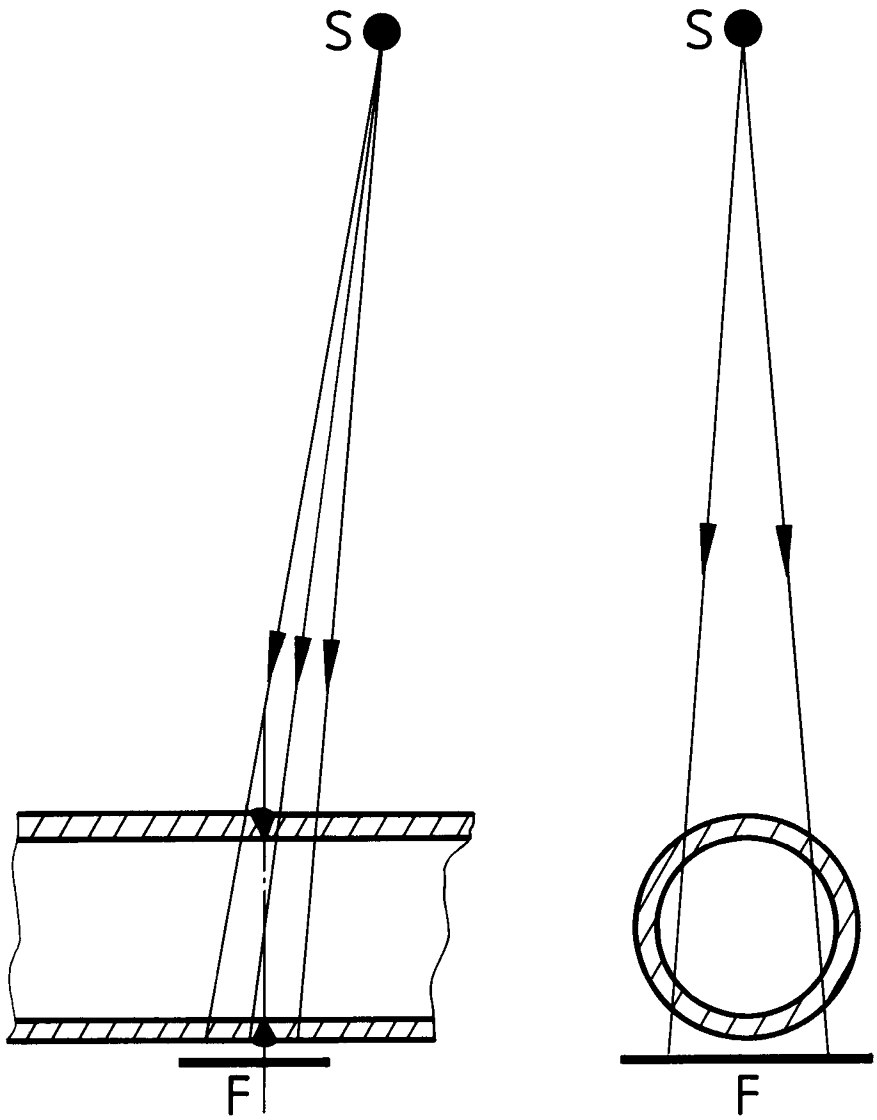


Figure 4 — Film and source of radiation outside : double wall, double image

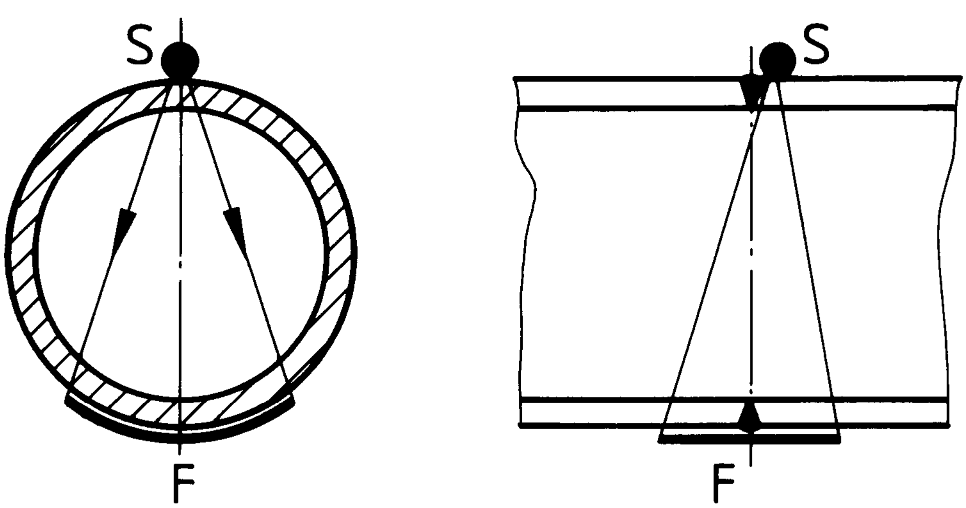


Figure 5 — Film and source of radiation outside : double wall, single image

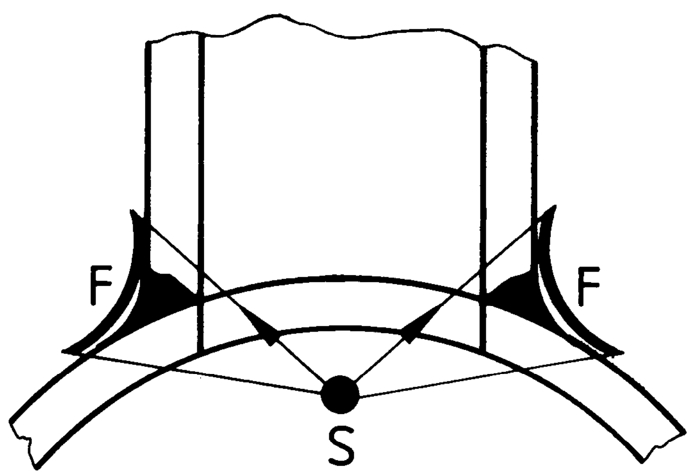


Figure 6 — Film outside, source of radiation inside (source central)

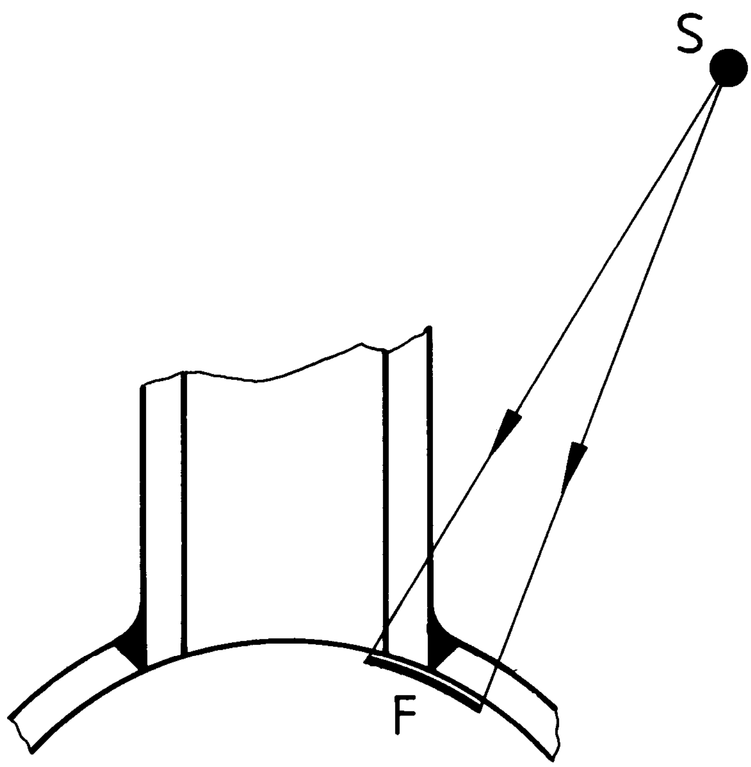


Figure 7 — Film inside, source of radiation outside : single-wall penetration

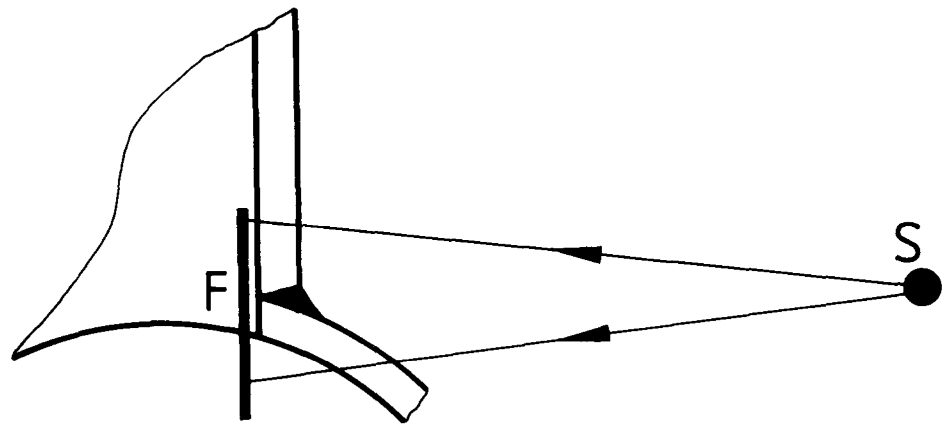


Figure 8 — Film inside, source of radiation outside : single-wall penetration

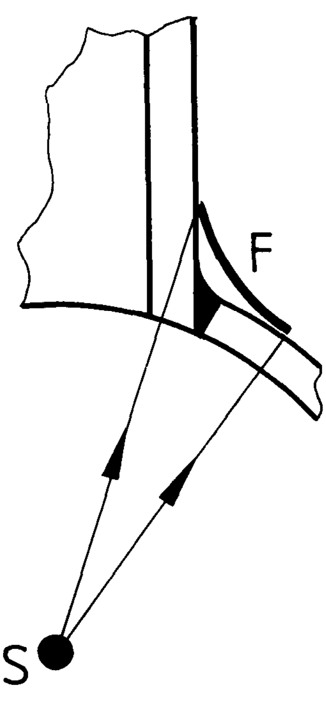


Figure 9 — Film outside, source of radiation inside (source central)

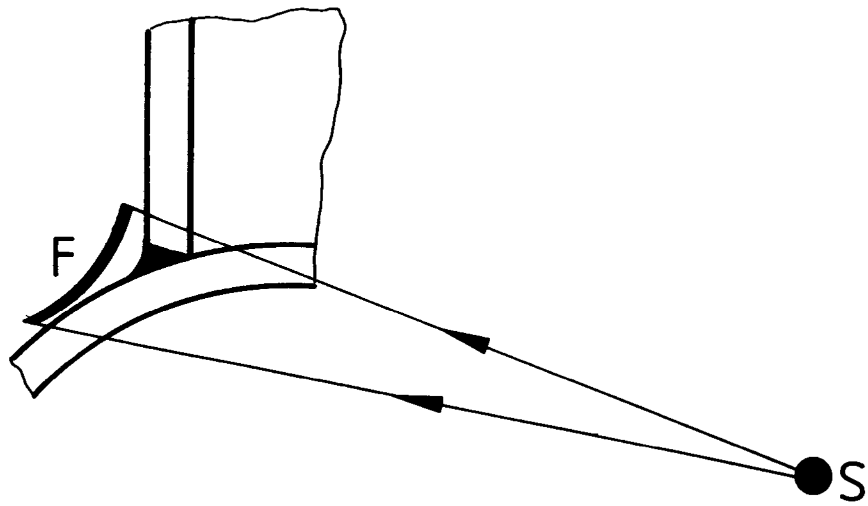


Figure 10 — Film outside, source of radiation inside (source off-centre)

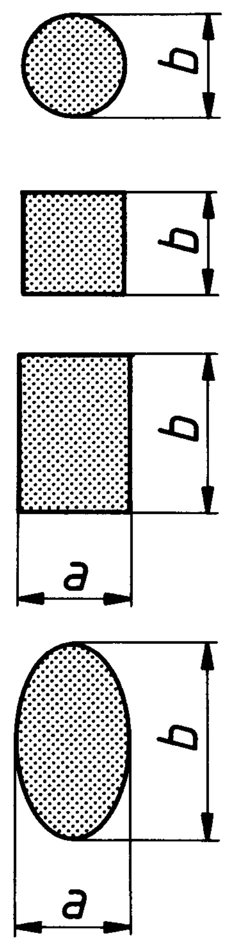
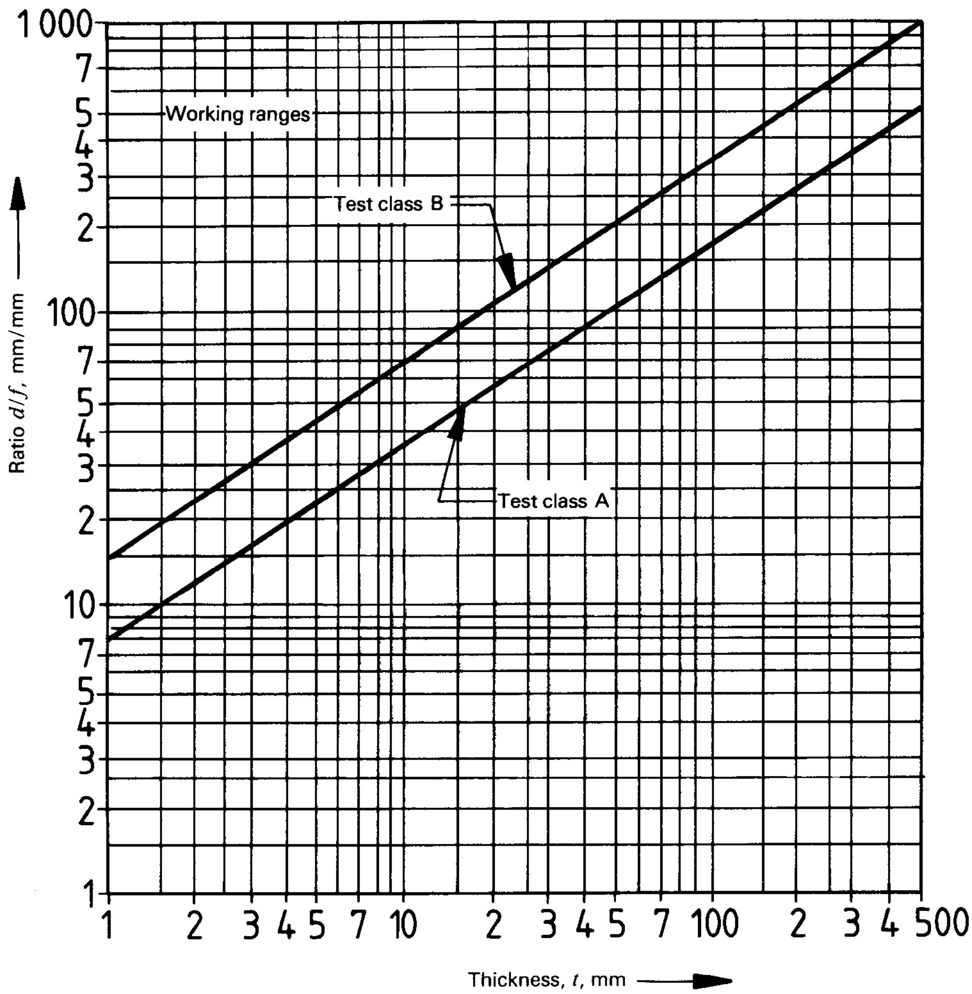


Figure 11 — Determination of effective focal spot size from projected focal spot images of various shapes
(effective width of focal spot, $f = (a + b)/2$)



d = Distance between the source of radiation and the surface of the specimen facing the source of radiation.

f = Effective size of the source of radiation.

t = Specimen thickness in the direction of the radiation beam.

Figure 12 — Required minimum values of ratio *d*/*f* plotted against thickness *t*

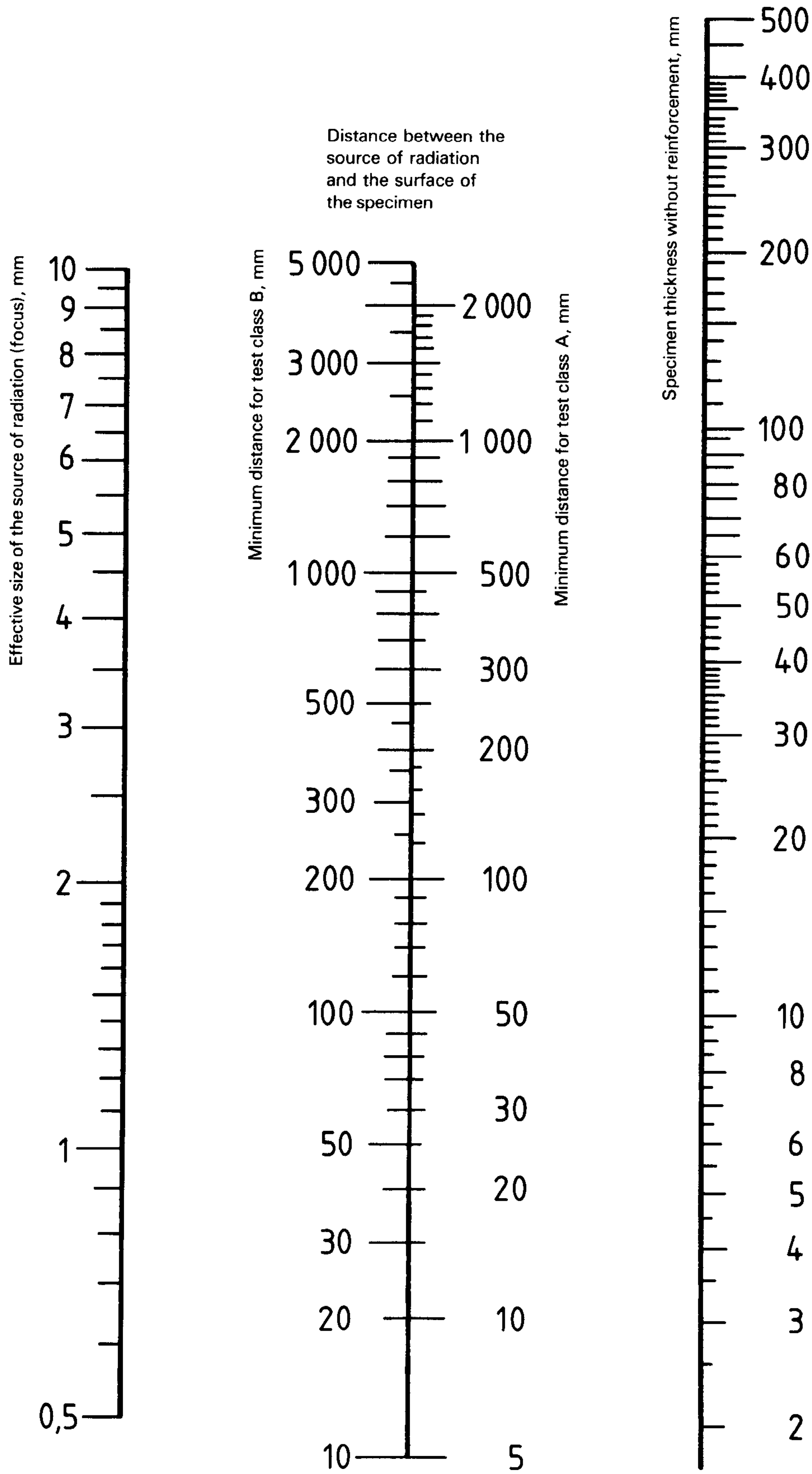


Figure 13 — Nomogram for the determination of the minimum distance between the source of radiation and the surface of the specimen in terms of the specimen thickness and the effective size of the source of radiation

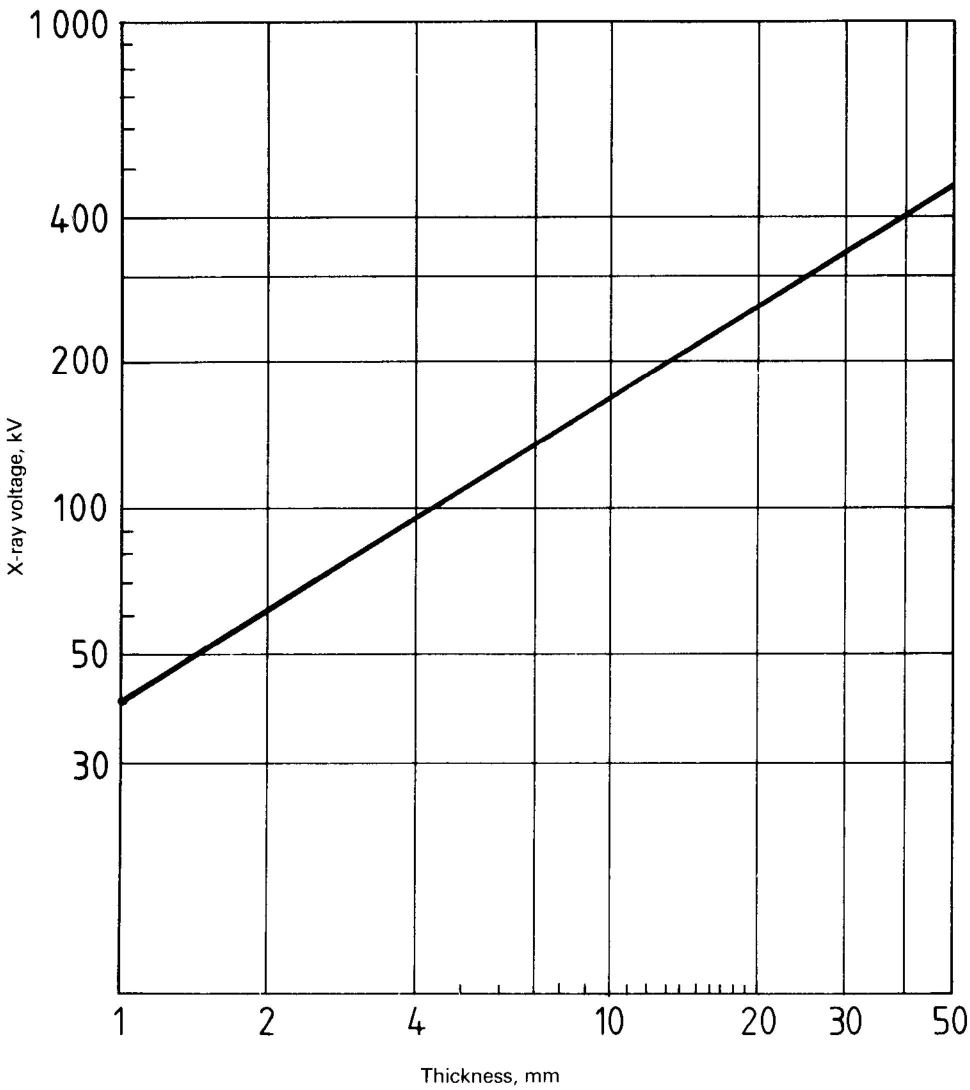


Figure 14 — Permissible maximum X-ray voltage