
**Guidelines for in-service inspections
for primary coolant circuit
components of light water reactors —**

**Part 2:
Magnetic particle and penetrant testing**

*Lignes directrices pour les contrôles périodiques des composants du
circuit primaire des réacteurs à eau légère —*

Partie 2: Contrôle par poudre magnétique et ressuage



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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 editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 6, *Reactor technology*.

A list of all parts in the ISO 20890 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Guidelines for in-service inspections for primary coolant circuit components of light water reactors —

Part 2: Magnetic particle and penetrant testing

1 Scope

This document gives guidelines for pre-service inspections (PSI) and in-service inspections (ISI) of the surfaces using the magnetic particle testing and penetrant testing on components of the reactor coolant circuit of light water reactors. This document is also applicable to other components of nuclear installations.

Test systems for the localisation of surface inhomogeneities and requirements for test personnel, test devices, test media, accessories as well as optical auxiliaries, the preparation and implementation of the test as well as the recording are defined.

NOTE 1 Data concerning the test section, test extent, inspection period, inspection interval and evaluation of indications are defined in the applicable national nuclear safety standards.

NOTE 2 In general, this document is in accordance with ISO 3452 and ISO 9934 series. This document provides details to be considered in the standard test procedure (see [Annex A](#)).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 3059, *Non-destructive testing — Penetrant testing and magnetic particle testing — Viewing conditions*

ISO 3452-1, *Non-destructive testing — Penetrant testing — Part 1: General principles*

ISO 3452-2, *Non-destructive testing — Penetrant testing — Part 2: Testing of penetrant materials*

ISO 3452-3, *Non-destructive testing — Penetrant testing — Part 3: Reference test blocks*

ISO 3452-4, *Non-destructive testing — Penetrant testing — Part 4: Equipment*

ISO 3452-5, *Non-destructive testing — Penetrant testing — Part 5: Penetrant testing at temperatures higher than 50 °C*

ISO 3452-6, *Non-destructive testing — Penetrant testing — Part 6: Penetrant testing at temperatures lower than 10 °C*

ISO 8596, *Ophthalmic optics — Visual acuity testing — Standard and clinical optotypes and their presentation*

ISO 9934-1, *Non-destructive testing — Magnetic particle testing — Part 1: General principles*

ISO 9934-2:2015, *Non-destructive testing — Magnetic particle testing — Part 2: Detection media*

ISO 9934-3, *Non-destructive testing — Magnetic particle testing — Part 3: Equipment*

ISO 9712:2012, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 12706, *Non-destructive testing — Penetrant testing — Vocabulary*

ISO 12707, *Non-destructive testing — Magnetic particle testing — Vocabulary*

ISO 18490, *Non-destructive testing — Evaluation of vision acuity of NDT personnel*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12706, ISO 12707 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 component

part of a system delimited according to structural or functional aspects, which can still implement independent sub-functions

3.2 test section

part of the *test area* ([3.4](#))

3.3 test supervisor

responsible for application of the test method and for the individual details of the test implementation including monitoring of the activities for preparation and implementation of the test as well as analysis of the test results

3.4 test area

defined area on the *test object* ([3.6](#)) over which the tests are to be conducted

[SOURCE: ISO 5577:2017, 6.2.2]

3.5 test surface

surface of the *test object* ([3.6](#)) to be tested

3.6 test object

part of a *component* ([3.1](#)) to be tested

3.7 test medium

<magnetic particle testing> magnetic particles suspended in liquid or in dry powder form, ready for use

[SOURCE: ISO 12707:2016, 2.17]

3.8 test medium

<penetrant testing> products consisting of cleaner, penetrants, removers and developers

[SOURCE: ISO 12706:2009, 2.19]

4 Requirements

4.1 Test personnel

4.1.1 Task of NDT personnel

NDT personnel^[3] have a great responsibility, not only with respect to their employers or contractors but also under the rules of good workmanship. The NDT personnel shall be independent and free from economic influences with regard to his test results, otherwise the results may be compromised. The NDT personnel should be aware of the importance of his signature and the consequences of incorrect test results for safety, health and environment. Under legal aspects, the falsification of certificates is an offence and judged according to the national legal regulations. A tester may find himself in a conflicting situation about his findings with his employer, the responsible authorities or legal requirements.

Finally, the NDT personnel is responsible for all interpretations of test results carrying his signature. NDT personnel should never sign test reports beyond their certification (see [Table 1](#)).

NOTE For reasons of readability, the male form is used with personal names; however the female form is also always intended.

4.1.2 Personnel requirements

The test personnel comprise test inspectors and the test supervisor.

Those personnel, using qualified non-destructive testing (NDT) procedures and equipment, shall be qualified through one or any combination of the following:

- certification through a national NDT personnel certification scheme;
- theoretical and/or open trials.

Any personnel certification requirements invoking relevant national NDT personnel certification schemes (e.g. ISO 9712) shall be validated according to [Table 1](#). Any additional personnel training requirements shall also be specified in the qualification dossier.

If no relevant scheme exists or if extra personnel qualification is needed, the qualification body shall determine the additional practical and theoretical examinations needed beyond those in the national certification scheme, include these in the qualification procedure and ensure that the NDT procedure also includes the necessary requirements. The qualification procedure shall describe the proposed system.

The test supervisor is responsible for the application of the NDT qualified system and shall have the knowledge required for his tasks as well as sufficient knowledge of the application options and limitations of the test methods and have knowledge about the characteristic appearances of operationally induced faults. Indications beyond the evaluation limit shall be evaluated by the test supervisor, who has the requisite experience in respect to the test object, test assignment, test method and device system.

The test inspectors shall have the skills to perform the work they are to carry out. In particular, they shall have adequate experience in the implementation of magnetic particle testing, penetrant testing and knowledge about the test object in respect to this.

Test personnel performing NDT and the evaluation of the results shall be qualified in accordance with ISO 9712 or equivalent at an appropriate level in the relevant industrial sector.

Table 1 — Minimum requirements for the test personnel

Test personnel	Qualification
Test inspector	Certified with at least level 2 according to ISO 9712
Test supervisor	Certified with at least level 2 according to ISO 9712

The test personnel shall fulfil the vision requirements of ISO 9712:2012, 7.4 or comparable.

The test personnel shall provide annual validation of their visual ability, which has been determined by an ophthalmologist, optician or other medically recognised person. The vision requirements of ISO 9712 shall be fulfilled. The following modifications can be used as substitutes to ISO 9712.

- a) The visual acuity testing shall be conducted in accordance using standard symbols according to ISO 8596 (Landolt rings) or ISO 18490 (E shaped character). Here a near vision acuity of 1,0 at a test distance of 0,33 m with at least one eye, with or without optical aid shall be validated; or
- b) The ability to distinguish between colours and between grey shadowing shall be validated with colour sense test boards. The validation can typically be conducted with the help of Ishihara colour boards as well as the "shades of grey test". In case of anomalies, the employer shall decide whether the ability to see colours is sufficient for the test assignment.

If disorders in the adaptability are determined, these shall be considered.

4.2 Data storage medium

Data storage medium shall be designed in such way that

- they enable a labelling for identification,
- an unintentional overwrite is prevented, and
- the suitability of storage is ensured.

It shall be ensured that measuring data can be read and processed by the next in-service test.

NOTE The operating system or hardware modifications could render it necessary to transfer original data to other data storage medium types.

5 Testing

5.1 Preliminary remark

Most of the technical requirements of this document are referencing to other ISO standards and are accepted in applicable national nuclear safety standards. Whilst all mandatory parameter for PSI/ISI specified in a general test procedure following to this document no system qualification has to be performed. Otherwise application of the selected parameter shall be validated by special qualification.

NOTE The procedure for the qualification is described in ENIQ report no. 31^[6].

A general test procedure shall be prepared. [Annex A](#) contains the items of the standard test procedure.

The test media to be used shall be certified by supplier and monitored and released by the licensee/operator.

5.2 Magnetic particle testing

5.2.1 Preparation

5.2.1.1 General

The specifications in accordance with ISO 9934-1, ISO 9934-2 and ISO 9934-3 shall apply in respect to the general preparation for the magnetic particle testing.

5.2.1.2 Requirements for surfaces

The test surfaces shall be accessible, cleaned and free of interfering impurities (e.g. loose colour residues, rust, dirt, grease, oil) and ground to be notch-free grinded where surface irregularities could mask indications due to discontinuities or weld root leads to pseudo exposure.

NOTE Surfaces with a thin non-magnetic colour layer, e.g. paint, can also be tested, on condition that the colour layer is firmly adhesive, not interrupted and the thickness of the layer does not exceed 50 µm.

The temperature of the test surface should be between 10 °C and 50 °C. The precise range of the surface temperature in the test area is specified by the test medium to be used. The ambient temperature in the immediate working range should not be greater than 40 °C with consideration of the test personnel (to ensure their safety and health). Special arrangements shall be agreed for higher temperatures.

5.2.1.3 Equipment

Measuring instruments are used for determination of the

- illuminance,
- irradiance for the UV range, and
- tangential field strength.

The following test devices are used:

- a) test device for magnetisation (mobile: yoke, coil, cable; stationary: test bench);
- b) UV-A sources;
- c) Artificial light source when using non-fluorescent test media and in the absence of daylight (monochromatic sources such as sodium vapour lamps may not be used).

The technical data of the measuring and test devices used shall be provided. The corresponding occupational health and safety regulations shall be complied with (e.g. protective low voltage, protective partition, protective insulation, UV-A radiation).

It shall be possible to use the measuring and test devices in the prevailing temperature range. In the case of hand electromagnets or portable electromagnets, the relative duty cycle shall be minimum 20 % and the duty time shall be minimum 5 s. In case of transportable current generators, the relative duty cycle shall be minimum 10 % and the duty time shall be minimum 5 s.

Valid calibration certificates shall be provided for the measuring devices to be used. Certificates from the test media monitoring shall be provided for test devices. These shall not be older than 12 months.

5.2.1.4 Test media

Wet test media shall basically be used because of the smaller magnetic particles to locate smaller discontinuities than dry test media. Suspensions comprising carrier liquid (light petroleum distillate or water with conditioning agents) and magnetic particles serve as test media here and use in spray cans (ready-to-use) or open containers as mixed suspensions. Depending on the wet method applied, coloured or fluorescent magnetic powder is used. If the external conditions allow, the method with fluorescent magnetic medium shall be used. In cases where nonfluorescent magnetic medium is used, contrast-improving substrate colours (e.g. white background) may be applied.

The particle size distribution is described by the particle diameter (lower, medium, upper). The particle size distribution, magnetic particle content and content of corrosive elements in the test medium as well as the applied measuring method shall be indicated by the manufacturer in writing. The following nominal particle diameters shall be applicable.

Table 2 — Particle size of magnetic particles for magnetic test medium

Test Medium	Fluorescent	Nonfluorescent
lower particle diameter d_l	$\geq 1,5 \mu\text{m}$	$\geq 0,5 \mu\text{m}$
average particle diameter d_a	$\leq 8 \mu\text{m}$	$\leq 8 \mu\text{m}$
upper particle diameter d_u	$\leq 30 \mu\text{m}$	$\leq 30 \mu\text{m}$

In case of mixed test medium suspensions, the magnetic particle content can be determined by ascertaining the sedimentation volume in a centrifuge tube; see ASTM D4007^[4]. Here the sedimentation volume for fluorescent test medium shall be from 0,1 ml/100 ml to 0,4 ml/100 ml and for nonfluorescent test medium from 1,2 ml/100 ml to 2,4 ml/100 ml.

The limit values for corrosive elements (sulphur and halogens) shall be complied with ISO 9934-2:2015, 7.15. The corrosive property of the test medium shall be determined in accordance with ISO 9934-2:2015, Annex C. Therefore Stage 0 specified in Table C.1 regarding of this annex shall be observed.

If oil is used as a carrier medium, this shall be easy to remove and may not leave disturbing residues behind.

In justified cases (e.g. at high temperatures $\geq 100^\circ\text{C}$), dry test medium can be used for the test. Here it shall be noted that the lower particle diameter is generally $\geq 40 \mu\text{m}$. The validation sensitivity is reduced in this way. Only metallic dry powder is permissible as a test medium.

5.2.1.5 Magnetisation and field strength

The magnetisation methods indicated below shall be applied (these illustrated as examples in [Figures 1, 2 and 3](#)):

- Yoke magnetisation using hand electromagnets (AC) or portable electromagnets (AC);
- Magnetisation with current-carrying conductor (AC); and
- Axial current flow.

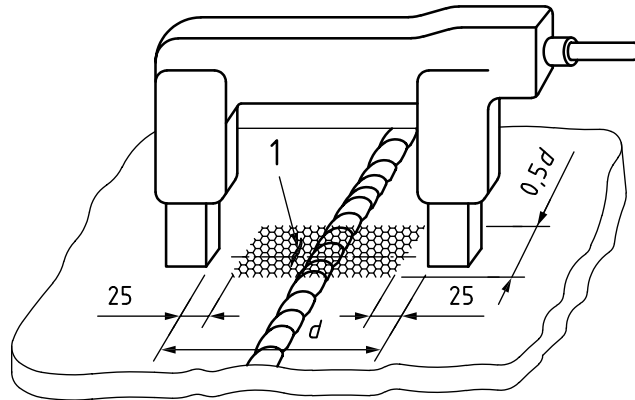
The magnetisation method shall be selected in relation to the form and geometry of the test object as well as the expected defect position. Alternating current magnetisation shall be applied. The application of direct current magnetisation or rectified current shall be agreed in individual cases. Magnetisation with electrodes is not allowed due to the risks of cracks.

The tangential field strength on the surface shall be minimum $2 \times 10^3 \text{ A/m}$ and may not exceed $6 \times 10^3 \text{ A/m}$ (rms-value) in the case of alternating current magnetisation.

NOTE The required flux density in the surface of the test object of minimum 1 T is attained with a tangential field strength of 2 kA/m in low-alloy or low-carbon unalloyed steels with high relative permeability. Higher field strength can be necessary for other steels with low permeability. If the magnetisation is too high, relevant indications can be covered by structurally induced indications (apparent indications).

The validation of sufficient magnetisation shall be provided with a suitable medium, e.g. tangential field strength measuring device.

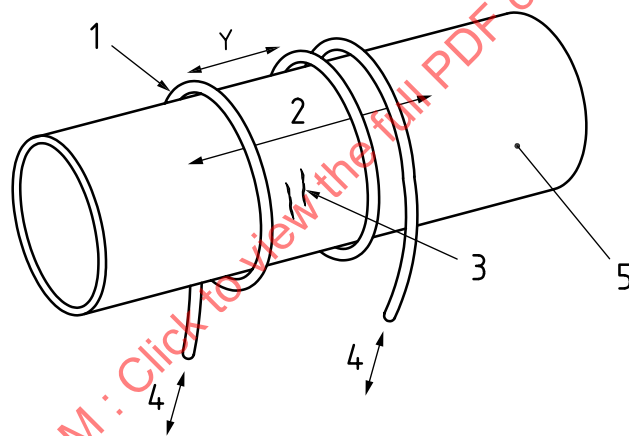
Dimensions in millimetres



Key

- 1 crack
- d distance for hand magnet/attachment electrode

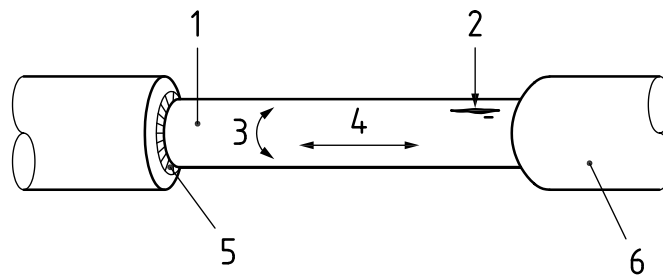
Figure 1 — Yoke magnetisation with hand magnet



Key

- 1 insulated cable
- 2 flux
- 3 cracks
- 4 current
- 5 test object
- Y coil width

Figure 2 — Magnetisation with current-carrying line (as coil)



Key

- 1 test object
- 2 crack
- 3 flux
- 4 current
- 5 contact point
- 6 clamping point

Figure 3 — Axial current flow

5.2.1.6 Monitoring test

The magnetic particles or magnetic particle suspension except spray cans (ready-to-use) shall be checked before testing using suitable pre-magnetised reference blocks, e.g. reference block type 1 in accordance with ISO 9934-2. Here the test medium is placed on the reference block used. The indication pattern is compared with the reference images that were determined for the reference block and the relevant test medium. The test medium is suitable if no essential deviations are visible in the indication pattern between the reference block and the corresponding reference images.

The tangential field strength, irradiance and illuminance shall be monitored by measurements on the surface to be tested.

During the test, the test system, consisting of test device and test medium, shall undergo a functional check on a random basis at least once every working day.

5.2.2 Inspection performance

5.2.2.1 General

The test personnel shall be instructed in adequate time concerning the implementation, scope and target objectives of the testing. All requisite documents, such as test instructions, drawings or piping isometries necessary for conducting the testing shall be made available.

The test devices shall be checked in respect to suitability for use before commencing work. It shall be ensured that the test areas are adequately accessible. If necessary, sufficient air supply ventilation shall be ensured.

5.2.2.2 Preparation of the test surfaces

The surfaces to be tested shall be free of scale, oil, lubricant, weld spatters, machining grooves, dirt, thick and loose paint and other foreign substances that can affect the sensitivity of the test method.

For the performance of examination, it can be necessary to improve the surface conditions, e.g. by cleaning or by localised fine grinding/polishing in some cases.

During surface examination, fine grinding/polishing is used if additional surface preparation is required locally before coming to a decision concerning an indication or to prevent for pseudo exposure.

The terms fine grinding/polishing refers to light preparation carried out with a brush or other fine abrasive papers.

The material and surface may not be damaged by the cleaning and preparation of the test surface.

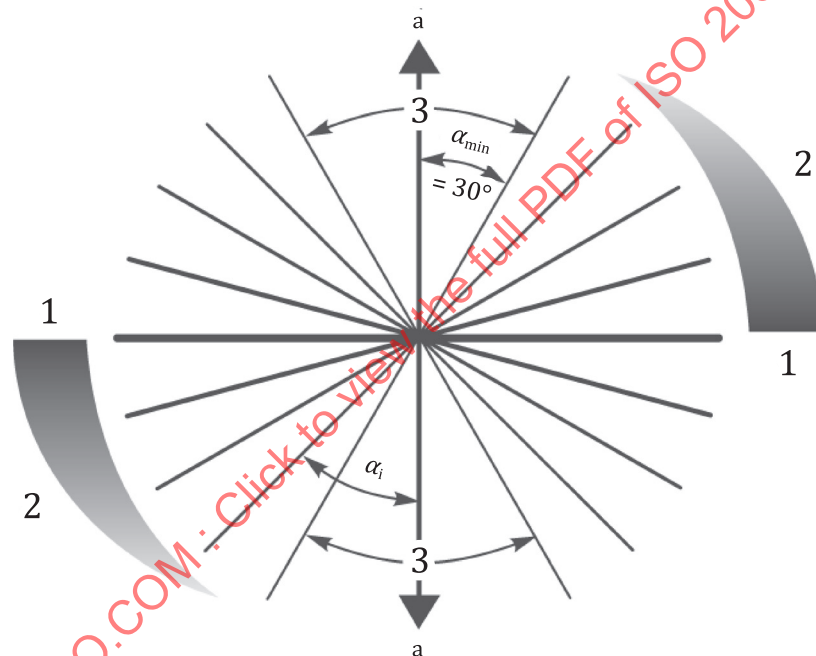
This surface preparation process is not considered to be a repair operation.

5.2.2.3 Magnetisation direction

The magnetisation direction is determined by orientation of the inhomogeneities to be detected.

When testing for inhomogeneities of any orientation, the test surface shall be magnetised in two directions more or less perpendicular to each other. The maximum permissible deviation is 30° . If inhomogeneities are to be detected with a preferred direction (e.g. longitudinal flaws in a weld seam), one magnetisation direction will be sufficient.

The test sections in the test area shall overlap (see also ISO 17638:2016, Figure 4).



Key

- 1 optimum detection sensitivity
- 2 Decreasing detection sensitivity
- 3 Insufficient detection sensitivity
- α angle between the magnetic field and the direction of the inhomogeneity
- $\alpha_{\min}$ smallest angle for detection of an inhomogeneity
- α_i Example for orientation of an inhomogeneity
- a Direction of the magnetic field.

Figure 4 — Directions of the detectable inhomogeneities

5.2.2.4 Applying the test medium and duration of magnetisation

The test surface shall be flushed with the test medium for at least 3 s during the magnetisation. Immediately before flushing the test area, it shall be ensured that the magnetic powder is evenly distributed in the carrier liquid and held in suspension (e.g. by shaking the test medium container). It

shall be ensured that the wet test medium can flow as slowly and evenly over the surface as possible. The duration of the follow-up magnetisation is minimum 5 s.

The dry test medium is applied with auxiliaries enabling a fine dispersion so that no powder accumulations result due to the application.

5.2.2.5 Viewing conditions

The specifications according to ISO 3059 apply for the viewing conditions.

Photo-chromatic glasses may not be worn during testing with fluorescent test media.

During the inspection, the viewing angle should not deviate more than 30° to the surface normal. The viewing distance should not exceed 600 mm in accordance with the requirement of direct inspection (VT) at ISO 17637:2016, Clause 4.

5.2.2.6 Monitoring the viewing conditions

Compliance with the required viewing conditions shall be monitored and logged as part of the tests by measurements in accordance with ISO 3059.

5.2.3 Evaluation

The evaluation shall be conducted during the follow-up magnetisation. The result of the evaluation shall be logged.

The evaluation of indications shall be conducted corresponding to the applicable national safety standard. For clear evaluation of the indications, it can be necessary to improve the surface conditions, e.g. by cleaning or by applying a thin layer of contrast-improving substrate colours.

5.2.4 Final measures

After completing the testing, residues of the test media shall be cleaned from the test objects. The cleaning agent shall be selected corresponding to the material of the test object so that damage due to corrosion is prevented.

5.3 Penetrant testing

5.3.1 Preparation

5.3.1.1 General

The specifications in accordance with ISO 3452-1, ISO 3452-2, ISO 3452-3 and ISO 3452-4 shall apply in respect to the general preparation for the penetrant testing.

5.3.1.2 Requirements for surfaces

The test surfaces shall be accessible, cleaned and free of coatings and residues. The surface roughness (R_a) shall correspond to the dimension of the smallest indication taken into account. The test surfaces shall be in such condition that removal of the excess penetrant is possible with a non-fraying cloth. The penetrant shall be able to penetrate into material separations. The temperature of the test surface should be between 10 °C and 50 °C. The ambient temperature in the immediate working range should not be greater than 40 °C with consideration of the test personnel (to ensure their safety and health). Special arrangements shall be agreed for higher temperatures.

Only penetrant media made for appropriate temperature range may be used. For temperatures outside the range 10 °C to 50 °C, inspection shall be carried out in accordance with ISO 3452-5 or ISO 3452-6, as applicable.

5.3.1.3 Equipment

Measuring instruments are used for determination of the

- illuminance, and
- irradiance for the UV range.

The following test devices are used:

- Artificial light source when using non-fluorescent test media and in the absence of daylight (monochromatic sources such as sodium vapour lamps may not be used);
- UV-A sources.

The devices for portable test equipment and for stationary installations shall fulfil the requirements in accordance with ISO 3452-4.

The technical data of the measuring and test devices used shall be provided. The corresponding occupational health and safety regulations shall be complied with (e.g. protective low voltage, protective partition, protective insulation, UV-A radiation).

It shall be possible to use the measuring and test devices in the prevailing temperature range.

Valid calibration certificates shall be provided for the measuring devices to be used. Certificates for the test equipment from the test equipment monitoring shall be provided for test devices. These shall not be older than 12 months.

5.3.1.4 Test media

Colour penetrant media of sensitivity class 2 in accordance with ISO 3452-2 shall be used as penetrant media. Fluorescent colour penetrant media are also permissible. Sensitivity class 3 shall be complied with as a minimum here.

Solvents, water or a combination of both may be used as removers.

Solvent-based wet developers shall be used as developers.

Only approved penetrant systems type tested according to ISO 3452-2 may be used. The penetrant medium, remover and developer shall be from the same manufacturer here.

The corrosive elements are determined according to ISO 3452-2.

5.3.1.5 Monitoring test

The monitoring of the penetration system by the user shall be conducted with type 2 reference block in accordance with ISO 3452-3. It is not necessary when penetrant, remover and developer spray cans are used. The indication pattern at type 2 reference block shall be compared with the reference images. Inspection performance.

5.3.2 Inspection performance

5.3.2.1 General

The test personnel shall be instructed in adequate time concerning the implementation, scope and target objectives of the testing. All requisite documents, such as test instructions, drawings or pipe geometries necessary for conducting the testing shall be made available.

The test devices shall be checked in respect to suitability for use before commencing work. It shall be ensured that the test areas are adequately accessible. If necessary, sufficient air supply ventilation shall be ensured.

5.3.2.2 Performance

The penetrant testing shall be conducted in accordance with ISO 3452-1.

The following supplementary information applies.

- a) The penetration time of the penetrant medium shall be at least 30 min and depends on the material type tested. The needed penetration time shall be recorded in the standard test procedure.

NOTE During the penetration time the test personnel leaves the radiation area and wait in a less radiated area.

- b) Intense spraying with water is not permissible during the removal of the excess penetrant. A relieving medium may not be added to the water; For the water-washable penetrant, the surface shall be dried before application of developer (no residual water). Drying conditions specified in ISO 3542-1, 8.5.7 shall apply.
- c) The first inspection shall take place immediately after the developer has dried. A second inspection shall be performed 30 min after the first inspection at the earliest. Further inspection times are necessary, if indications are determined during one of the two inspection times or if essential changes in indications or additional indications were determined in comparison to the previous inspection.

5.3.3 Inspections

5.3.3.1 Viewing conditions

The specifications according to ISO 3059 apply for the viewing conditions.

Photo-chromatic glasses may not be worn during testing with fluorescent test media.

During the inspections, the viewing angle should deviate not more than 30° to the surface normal. The viewing distance should not exceed 600 mm.

5.3.3.2 Monitoring the viewing conditions

Compliance with the required viewing conditions shall be monitored and logged as part of the tests by measurements in accordance with ISO 3059.

5.3.3.3 Auxiliary equipment for inspections

Auxiliary equipment (e.g. magnifying glass, mirror) is permissible for the inspections.

5.3.4 Evaluation

The evaluation shall be conducted with consideration of the results of all inspections.

The evaluation of indications shall be conducted corresponding to the specifications of the applicable standards.

5.3.5 Final measures

After completing the testing, residues of test media shall be thoroughly cleaned from the test objects. The cleaning agent shall be selected corresponding to the material of the test object so that damage due to corrosion is prevented.