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In-service inspections for primary coolant circuit components of light water reactors — Magnetic particle and penetrant testing

Contrôles périodiques des composants du circuit primaire des réacteurs à eau légère — 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.

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ISO -2 was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 6, *Reactor technology*.

This second/third/... edition cancels and replaces the first/second/... edition (), [clause(s) / subclause(s) / table(s) / figure(s) / annex(es)] of which [has / have] been technically revised.

ISO consists of the following parts, under the general title *In-service inspections for primary coolant circuit components of light water reactors — Magnetic particle and penetrant testing*:

- *Part 1: Mechanized ultrasonic testing*
- *Part 2: Magnetic particle testing and penetrant testing*
- *Part 3: Hydrotest*
- *Part 4: Visual testing*
- *Part 5: Eddy current testing of steam generator heating tubes*
- *Part 6: Radiographic testing*

In-service inspections for primary coolant circuit components of light water reactors — Magnetic particle and penetrant testing

1 Scope

This standard is applicable for in-service inspections of the surfaces using the magnetic particle testing and penetrant testing on components of the reactor coolant circuit of light water reactors. This standard 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 Data concerning the test section, test scope, test time, test interval and evaluation of indications is defined in the applicable national nuclear safety standards.

2 Normative references

The following documents quoted in this document, partly or in full, are indispensable for the application of this document. For dated references, only the edition to which reference is made is applicable. 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 8596, *Ophthalmic optics — Visual acuity testing — Standard optotype and its presentation*

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

ISO 9934-2:2002, *Non-destructive testing — Magnetic particle testing — Part 2: Detection media*

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

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

ISO 12706:2009, *Non-destructive testing — Penetrant testing — Vocabulary*

ISO 17638:2003, *Non-destructive testing of welds — Magnetic particle testing*

EN 1330-7:2005, *Non-destructive testing — Terminology — Part 7: Terms used in magnetic particle testing*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1330-7:2005-05 and ISO 12706 and the following apply.

- 3.1 penetrant system**
compatible group of test products including penetrant, remover and, if used, developer

[SOURCE: ISO 12706:2010-04, 2.18]
- 3.2 component**
part of a system delimited according to structural or functional aspects, which can still implement independent sub-functions
- 3.3 linear indication**
indication that is longer than 1.5 mm and has a length to width ratio greater than 3
- 3.4 non-linear indication**
indication whose length is less than or equal to three times the width

[SOURCE: EN 1291 :2002-09, 3.2]
- 3.5 test section**
part of the test range
- 3.6 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

[SOURCE: ISO xx-1:2015, 3.22]
- 3.7 test area**
area of the test object to be tested
- 3.8 test surface**
surface of the test object that is tested
- 3.9 test object**
part of a component to be tested
- 3.10 test medium**
<Magnetic particle testing> magnetic particles suspended in liquid or in dry powder form, ready for use

1) Luxemburg, Office for Official Publications of the European Communities, 2007. ISSN 1018-5593

[SOURCE: EN 1330-7:2005, 2.17]

3.11

test medium

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

[SOURCE: ISO 12706:2010, 2.19]

4 Requirements

4.1 Test personnel

The test personnel comprises test inspectors and the test supervisor.

The test supervisor shall have the knowledge required for his tasks as well as know the application options and limits 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.

The qualifications of the test personnel shall be validated according to Table 1.

Table 1 — 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 provide annual validation of their visual ability, which has been determined by an ophthalmologist, optician or other medically recognised person. The following requirements shall be fulfilled:

- a) The visual acuity testing shall be conducted in accordance using standard symbols according to ISO 8596 or equivalent. Here a near vision of 1.0 at 0.33 m test distance with at least one eye, with or without vision aid shall be validated;
- 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

- a) they enable a labelling for identification;
- b) an unintentional overwrite is prevented;
- c) 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 might render it necessary to transfer original data to other data storage medium types.

5 Standard test procedures

The standard test procedures shall contain:

- a) Scope of validity;
- b) Jointly applicable regulations, standards and instructions;
- c) Test objective;
- d) Personnel qualifications;
- e) Data on the test object and possibly data on the test scope and test time;
- f) Data on test preconditions;
- g) Test system (and other test media and auxiliaries to be used);
- h) Data on the test implementation and analysis as well as evaluation of indications;
- i) Type and scope of the recording and documentation.

6 Testing

6.1 Magnetic particle testing

6.1.1 Preparation

6.1.1.1 General

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

6.1.1.2 Requirements for surfaces

The test surfaces shall be accessible, cleaned and free of interfering impurities (e.g. loose colour residues, rust) and ground to be notch-free grinded.

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.

6.1.1.3 Equipment

Measuring instruments are used for determination of the

- a) illuminance,
- b) irradiance for the UV range,

c) tangential field strength.

The following test devices are used:

- 1) test device for magnetisation (mobile: yoke, coil, cable; stationary: test bench);
- 2) UV-A sources;
- 3) 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 magnets, 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.

6.1.1.4 Test media

Wet test media shall basically be used. Suspensions comprising carrier liquid and magnetic powder serve as test media here. Depending on the wet method applied, coloured or fluorescent magnetic powder is used. If the external conditions permit this, the method with fluorescent magnetic powder shall be used. In cases where non-fluorescent magnetic powder is used, contrast-improving substrate colours 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 complied with:

- a) Lower particle diameter: $\geq 1.5 \mu\text{m}$,
- b) Medium particle diameter: $\leq 8 \mu\text{m}$ and
- c) Upper particle diameter: $\leq 30 \mu\text{m}$.

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 D 96). Here the sedimentation volume for fluorescent test medium shall be from 0.1 ml/100 ml to 0.4 ml/100 ml and for non-fluorescent test medium from 1.2 ml/100 ml to 2.4 ml/100 ml.

The limit values according to ISO 9934-2 for corrosive elements (sulphur and halogens) shall be complied with. The corrosive property of the test medium shall be determined according to ISO 9934-2:2003-03, Annex C. Stage 0 according to Table C.1 shall be complied with for this.

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 $\geq 100 \text{ }^\circ\text{C}$), 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.

6.1.1.5 Magnetisation and field strength

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

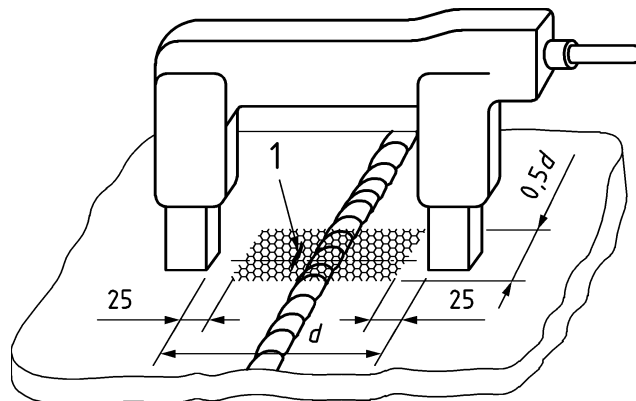
- a) Yoke magnetisation using hand magnet (AC);
- b) Magnetisation with current-carrying conductor (AC);
- c) Axial current flow.

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 shall be agreed in individual cases.

The tangential field strength on the surface shall be minimum 2×10^3 A/m and may not exceed 6.5×10^3 A/m 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).

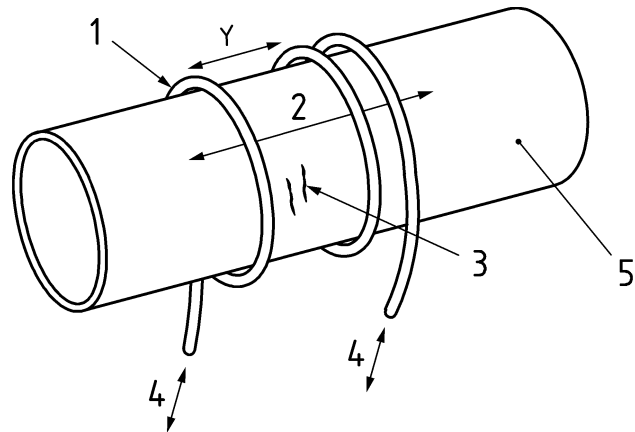
The validation of sufficient magnetisation shall be provided with a suitable medium, e.g. tangential field strength measuring device.



Key

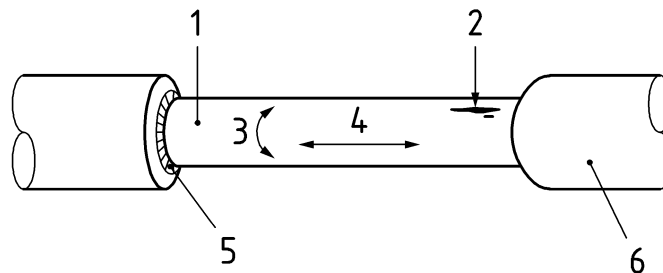
- 1 Crack
- d Distance for hand magnet/Attachment electrode

Figure 1 — Yoke magnetisation with hand magnet

**Key**

- 1 Insulated cable
- 2 Flux
- 3 Cracks
- 4 Current
- 5 Test object

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

6.1.1.6 Monitoring test

The magnetic particles or magnetic particle suspension shall be checked before testing using suitable premagnetised reference blocks, e.g. reference block type 1 according to 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.

6.1.2 Inspection performance

6.1.2.1 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.

6.1.2.2 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 clear evaluation of the indications, it can be necessary to improve the surface conditions, e.g. by cleaning or by localised fine grinding.

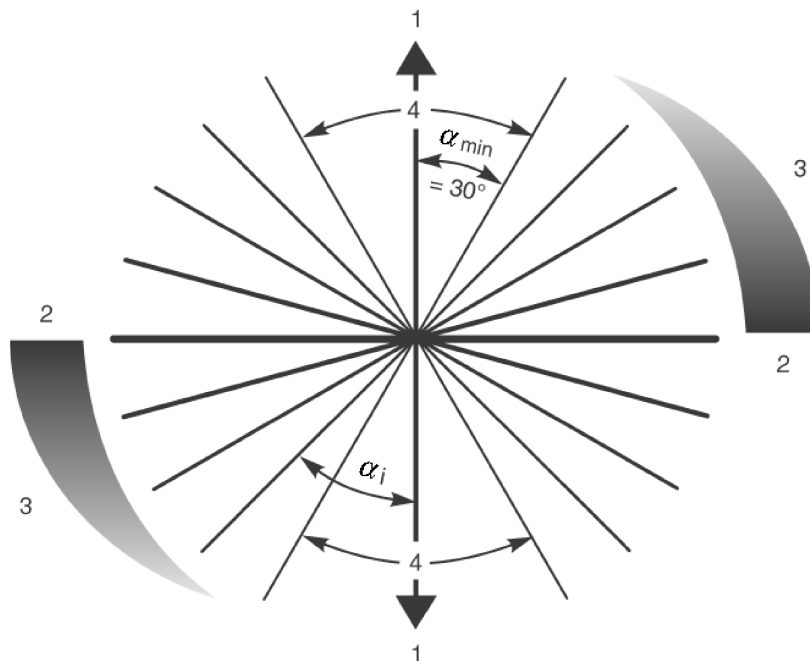
The material and surface may not be damaged by the cleaning and preparation of the test surface.

6.1.2.3 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 17638:2010-03, Figure 4).



Key

1	Direction of the magnetic field	α	Angle between the magnetic field and the direction of the inhomogeneity
2	Optimum detection sensitivity	α_{\min}	Smallest angle for detection of an inhomogeneity
3	Decreasing detection sensitivity	α_i	Example for orientation of an inhomogeneity
4	Insufficient detection sensitivity		

Figure 4 — Directions of the detectable inhomogeneities**6.1.2.4 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.

6.1.2.5 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 300 mm.

6.1.2.6 Monitoring the viewing conditions

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

6.1.3 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 specifications of the applicable standards.

6.1.4 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.

6.2 Penetrant testing**6.2.1 Preparation****6.2.1.1 General**

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

6.2.1.2 Requirements for surfaces

The test surfaces shall be accessible, cleaned and free of coatings and residues. 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.

6.2.1.3 Equipment

Measuring instruments are used for determination of the

- a) illuminance;
- b) irradiance for the UV range.

The following test devices are used:

- 1) 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);
- 2) UV-A sources.

The devices for portable test equipment and for stationary installations shall fulfil the requirements according to 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.

6.2.1.4 Test media

Colour penetrant media of sensitivity class 2 according to 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.

6.2.1.5 Monitoring test

The monitoring of the penetration system by the user shall be conducted with type 2 reference block according to ISO 3452-3. The indication pattern at type 2 reference block shall be compared with the reference images. The test medium is suitable if no essential deviations are discernible in the indication pattern between type 2 reference block and the corresponding reference images.

6.2.2 Inspection performance

6.2.2.1 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 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.

6.2.2.2 Performance

The penetrant testing shall be conducted according to ISO 3452-1.

The following applies supplementary to this:

- a) The penetration time of the penetrant medium shall be at least 30 min.
- 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;
- 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.

6.2.3 Inspections

6.2.3.1 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 more than 30° to the surface normal. The viewing distance should not exceed 300 mm.

6.2.3.2 Monitoring the viewing conditions

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

6.2.3.3 Auxiliary equipment for inspections

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

6.2.4 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.

6.2.5 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.

7 Recording

The recording shall be performed with plant-related record forms in such way that the test results are comparable. The test documentation should also be backed up in digital form in addition to paper form.

The test report shall contain data on

- a) Date of the testing;
- b) Name of the power station;
- c) Test basis (test instructions, standard test instructions or test specifications);
- d) Test object, test area and test section;
- e) Location of the test section (reference point, coordinates);
- f) Surface state (e.g. cleaned, not cleaned);
- g) Test system (e.g. magnetisation, test medium, penetrant system, type of test medium application, name of the test medium with batch number, observation conditions, date of the inspection);
- h) Result of the test and results comparison with the previous in-service testing;
- i) Deviations from the specifications of the test procedures/standard test procedures/test specifications;
- j) Place, date, name, signature, certificate number of the test inspectors and test supervisors of the operator or the test company commissioned by him and of the third party.

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