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

Part 1: Mechanized ultrasonic testing

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

Partie 1: Contrôle mécanique par ultrasons

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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 of 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 www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee 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 1:
Mechanized ultrasonic testing

1 Scope

This document gives guidelines for pre-service-inspections (PSI) and in-service inspections (ISI) with mechanized ultrasonic test (UT) devices on components of the reactor coolant circuit of light water reactors. This document is also applicable on other components of nuclear installations.

Mechanized ultrasonic inspections are carried out in order to enable an evaluation in case of

— fault indications (e.g. on austenitic weld seams or complex geometry),

— indications due to geometry (e.g. in case of root concavity),

— complex geometries (e.g. fitting weld seams), or

— if a reduction in the radiation exposure of the test personnel can be attained in this way.

Ultrasonic test methods are defined for the validation of discontinuities (volume or surface open), requirements for the ultrasonic test equipment, for the preparation of test and device systems, for the implementation of the test and for the recording.

This document is applicable for the detection of indications by UT using normal-beam probes and angle-beam probes both in contact technique. It is to be used for UT examination on ferritic and austenitic welds and base material as search techniques and for comparison with acceptance criteria by the national referencing nuclear safety standards. Immersion technique and techniques for sizing are not in the scope of this document and are independent qualified.

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

Unless otherwise specified in national nuclear safety standards the minimum requirements of this document are applicable. This document does not define:

— extent of examination and scanning plans;

— acceptance criteria;

— UT techniques for dissimilar metal welds and for sizing (have to be qualified separately);

— immersion techniques;

— time-of-flight diffraction technique (TOFD).

It is recommended that UT examinations are nearly related to the component, the type and size of defects to be considered and are reviewed in specific national inspection qualifications.

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 5577, *Non-destructive testing — Ultrasonic testing — Vocabulary*

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

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

ISO 16811, *Non-destructive testing — Ultrasonic testing — Sensitivity and range setting*

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

EN 12668-1, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment — Part 1: Instruments*

EN 12668-2, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment — Part 2: Probes*

ISO 18563-1, *Non-destructive testing — Characterization and verification of ultrasonic phased array equipment — Part 1: Instruments*

ISO 18563-2, *Non-destructive testing — Characterization and verification of ultrasonic phased array equipment — Part 2: Probes*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5577 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
analysis scan
test scan with adopted parameters that is required for more precise characterisation of an *indication* (3.3)

3.2
analysis technique
test technique that is applied for more precise characterisation of *indications* (3.3) subject to analysis

3.3
indication
representation or signal from a discontinuity in the format allowed by the NDT method used

[SOURCE: ISO/TS 18173:2005, 2.14]

Note 1 to entry: Signal that is initiated by operationally induced damage mechanisms, geometrical as well as, material or design induced influences

3.4
evaluation
assessment (3.5) of *indications* (3.3) revealed by NDT against a predefined level

Note 1 to entry: Inspection of the recorded measured data in respect to completeness and analysis capacity, localisation and registration of indications according to defined criteria, representation of the test results

[SOURCE: EN 1330-2:1998, 2.10]

3.5
assessment
comparison of the analysed measuring results with specified criteria

3.6
data storage medium
storage medium for storing digital media

3.7
focal length
focal distance
distance from the probe to the focal point

[SOURCE: ISO 5577:2017, 4.2.13]

3.8
focus range
focal zone
zone in sound beam of a probe in which the sound pressure remains above a defined level related to its maximum

[SOURCE: ISO 5577:2017, 4.2.14]

Note 1 to entry: During measurement with the electrodynamic probe in sound transmission, this value corresponds to a decrease in the signal level by 3 dB in comparison to the maximum value.

Note 2 to entry: In general limitation by the decline in the signal level by 6 dB.

3.9
focus depth
focal point
point where the sound pressure on the beam axis is at its maximum

[SOURCE: ISO 5577:2017, 4.2.12]

3.10
adjustment
setting the ultrasonic test device based on specified parameters

3.11
calibration
<ultrasonic testing> determination of the measuring value range of an ultrasonic test device in relation to a calibrated test standard

3.12
calibration block
<ultrasonic testing> piece of material of specified composition, surface finish, heat treatment and geometric form, by means of which *ultrasonic test equipment* (3.43) can be assessed and calibrated

[SOURCE: ISO 5577:2017, 5.4.1]

Note 1 to entry: The calibration blocks according to ISO 2400 and ISO 7963 can be used as calibration blocks according to this document.

3.13
calibration reflector
reflector of a known geometry and size in or on the *calibration block* (3.12), test *reference block* (3.15) on the test *calibration block*, for distance or sensitivity adjustment of the *ultrasonic test instrument* (3.44)

3.14
component
part of a system delimited according to structural or functional aspects, which can still implement independent sub-functions

3.15
reference block
block of material representative of the material to be tested with similar acoustic properties containing well-defined reflectors, used to adjust the sensitivity and/or time base of the *ultrasonic instrument* (3.44) in order to compare detected discontinuity *indications* (3.3) with those arising from the known reflectors

[SOURCE: ISO 5577:2017, 5.4.2]

3.16
time of flight
time it takes an ultrasonic pulse to travel from the transmitter probe through the *test object* (3.27) to the receiver probe

[SOURCE: ISO 5577:2017, 3.2.6]

Note 1 to entry: This comprises the lead time in the UT probe and the time of flight in the component; it is the time that an ultrasonic pulse requires from the oscillator to a reflector and back to the oscillator.

3.17
LLL technique
test technique based on the reflection of the sound package at the back wall and at a planar reflector in the inspection volume using /utilizing longitudinal waves

Note 1 to entry: See Annex A, no. 7.

3.18
LLT technique
test technique based on reflection of the sound bundle at the back wall and at a planar reflector in the inspection volume using/utilizing the mode conversion of longitudinal waves and transversal waves

Note 1 to entry: See Annex A, no. 7.

3.19
measurement scan
movement of the UT probes with simultaneous recording of measured data

3.20
raw data
all measured data and setting parameters saved by the ultrasonic test equipment during the measurement run (recorded and saved data)

Note 1 to entry: Examples of raw data include amplitude, time of flight, and coordinates.

3.21
test section
part of the *test area* (3.23)

3.22
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* (3.24)

3.23
test area
defined area on the *test object* (3.27) over which the tests are to be conducted

[SOURCE: ISO 5577:2017, 6.2.2]

3.24
test result
summarising evaluation of all measured data and comparison with the previous test

3.25
test scan
measuring run with the characteristics specified in the test specifications

3.26
test function
test task assigned to a UT probe or UT probe combination, e.g. coupling check

3.27
test object
object to be tested; object under test or examination; part of a component to be tested

3.28
test robots
scanner
mechanical device with control for guiding the UT probes

3.29
noise level
amplitudes of background noise in an ultrasonic system

Note 1 to entry: 95 % value of the sum frequency of the amplitudes, measured during the reference run or test run in an indication-free range

[SOURCE: ISO 5577:2017, 6.5.16]

3.30
signal to noise ratio
ratio of the amplitude of a signal arising from a discontinuity in a material to the amplitude of the average background *noise level* (3.29)

[SOURCE: EN 1330-2:1998, 2.16]

3.31
reference scan
measuring run for the functional control and functional adaptation of the ultrasonic test equipment

3.32
hysteresis correction
correction to the decrease in the calibration level resulting during the tandem test or during the test with a comparable test system, if the planar reflectors are not oriented vertically to the surface or vertically to the sound incidence level

3.33
transmitter-receiver technique (TR-technique)
pitch and catch technique
double probe technique
ultrasonic testing technique involving the use of two probes both of which can be used as transmitter and receiver

3.34
track offset correction
correction to the decrease in the calibration level of planar reflectors in the middle between two tracks

3.35
tandem zone correction
correction to the decrease in the calibration level of the calibration reflector to the tandem zone edges

3.36
test block
defined piece of material which allows tests for the accuracy and/or performance of an *ultrasonic test system* (3.43)

[SOURCE: ISO 5577:2017, 5.4.3]

Note 1 to entry: Specimen for examining properties of a test method, an ultrasonic test instrument or a test system.

3.37
depth zone
sub-range of the wall thicknesses to be tested

3.38
transfer correction
correction of the gain setting of the *ultrasonic test instrument* (3.44) when transferring the probe from a *calibration* (3.12) or *reference block* (3.15) to the test object

[SOURCE: ISO 5577:2017, 5.4.5]

3.39
trigger distance
path that the UT probes travels between two test cycles of the same test function following in succession

3.40
scan without couplant
measurement scan (3.19) without coupling between the UT probe and *test object* (3.27)

3.41
TTT technique
test technique based on reflection of the sound bundle at the back wall and at a planar reflector in the test volume using / utilizing shear waves

Note 1 to entry: See Annex A, no. 7.

3.42
ultrasonic test equipment
equipment consisting of an *ultrasonic instrument* (3.44), probes, cables and all devices connected to the instrument during testing

[SOURCE: ISO 5577:2017, 5.3.1]

Note 1 to entry: Connected devices consist also test robot and analysis unit including software, digitalisation unit and, if necessary, operating PC including software.

3.43
ultrasonic test instrument
instrument used together with the probe or probes, which transmits, receives, processes and displays ultrasonic signals for NDT purposes

[SOURCE: ISO 5577:2017, 5.1.1]

3.44
ultrasonic test technique
application-relevant technique for the localisation of discontinuities (internal or surface open)

Note 1 to entry: In relation to the application, requirements result for these ultrasonic test techniques in respect to the test parameters such as oscillation variable, beam angle, wave type and frequency.

Note 2 to entry: Test techniques are e.g. pulse-echo system (PE), transmitter-receiver system (TR), tandem system, phased-array system (PA).

3.45
reference reflector
reflector (natural or artificial) with known form, size and distance from the test surface in the *calibration block* (3.12) or *reference block* (3.15), which is used for calibration or assessment of detection sensitivity

Note 1 to entry: A reference reflector can also be used as a calibration reflector.

3.46
angle-dependent amplification compensation
correction to the echo level for compensation of the sound pressure change in relation to the beam angle at phased-array probes

Note 1 to entry: See Figures D.2 and D.3.

[SOURCE: ISO 5577:2017, 6.4.2]

4 Test systems

4.1 Preliminary remark

The suitability of the test technique and the test device system shall be validated corresponding to the requirements of the applicable national nuclear safety standards.

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

A general test procedure shall be prepared. Annex E contains the items of the general test procedure.

4.2 General

The test techniques described below are used to locate discontinuities (search techniques). Test techniques for the analysis of indications can be found in 6.4.

The relevant test sections shall be checked so that the required registration thresholds are complied with in even the least favourable case. This results in requirements e.g. for the track offset correction, the transfer correction, the trigger distance and the travel speed, that depend on the relevant selection of probes (e.g. oscillation variable, test frequency, beam angle) and the depth range to be tested.

Depending on the test assignment, the following probes shall be used in contact technique:

— Single transducer probes;

— TR-probes;

— Phased-array probes;

— Electromagnetic acoustic transducer (EMAT).

NOTE The specific requirements for the use of EMAT probes are not discussed in this document.

In the case of tests on austenitic components and dissimilar metal welds, the test capacity can be impaired by the weld metal structure (e.g. inherent coarse-grained and/or a directionally-oriented structure). This can cause variations in attenuation, reflection, refraction at grain boundaries and velocity changes within the grains. It usually is necessary to modify and/or supplement the general settings of this standard when examining such welds or base materials. Additional items could be weld mock-ups with reference reflectors in the weld deposit and weld area and single or dual longitudinal angle beam probes.

4.3 Validation and localisation of reflectors

4.3.1 Pulse-echo technique (PE technique)

The PE technique (see Annex A, No. 1 and No. 2) records the total wall thickness range. It is used with longitudinal and transversal/shear waves and with various beam angles and test frequencies.

A reflector is localised via the measurement of the sound path at known UT probe position, known beam direction and known beam angle. For setting the test sensitivity for the area of interest see 6.1.6.3.

4.3.2 Transmitter-Receiver technique (TR-technique)

The TR-technique (see Annex A, No. 3 and No. 4) records the wall thickness range in which the sound fields of transmission and reception converters overlap. The TR-technique is used with longitudinal waves (TRL) or transversal waves (TRT) with various beam angles and test frequencies.

A reflector is localised via the measurement of the sound path at known UT probe position, known beam direction and known beam angle.

4.3.3 Tandem technique

The tandem technique (see Annex A, No. 5) is used when testing in test areas with plane-parallel or concentric surfaces. This technique primarily serves for the detection of planar reflectors oriented normally to the surface. This utilises two UT probes that transmit and receive transversal waves each with nominal beam angle of 45°. To prevent mode conversions, beam angle and reflection angle should be in the range from 40° to 50° when applying transversal wave UT probes for the tandem technique. It is recommended that also probes with longitudinal waves can be used, but mode conversion can be occurred.

The localisation of a reflector in respect to the depth location is possible by indication of the depth zone. It depends on

— the wall thickness,

— the distance of the two UT probes, and

— the angles of incidence of the transmitter probe and the receiver probe.

In the case of the tandem technique, the depth zones shall cover the reflector expectation range with consideration of surface irregularities and, if necessary, wall thickness changes.

In case of curved surfaces, the change in the sound path due to the geometry shall be considered.

4.3.4 Inspection technique with mode conversion

An ultrasonic inspection technique that uses the conversion of longitudinal waves in transversal/shear waves or vice versa (LLT technique), is used for the validation of surface connected and embedded indications (see Annex A, No. 7). It is also possible to use a technique which reflect the UT sound by utilizing only longitudinal waves (LLL technique) or only transversal waves (TTT technique).

The reflector location is determined by measuring the time of flight at known UT probe position, known sound direction and known beam angle in relation to the wave mode. The actual sound path cannot be read off directly owing to the conversion into wave modes with different sound velocities. An ultrasonic test technique with mode conversion shall be verified with measurements at a reference block.

In the mode conversion technique, the depth zones shall cover the indication expectation range with consideration of flaw inclined positions, surface irregularities and, if applicable, wall thickness changes.

NOTE In practice, test techniques are used, which are characterised by two spatially separated transducers with the same beam direction and usually with different angles of incidence, whereby one transducer serves for transmission and the other for reception.

4.3.5 V-transmission technique

The V-transmission technique (see Annex A, No. 8) is used for recording the coupling and transfer fluctuations and for the validation of large material separations (in relation to the sound beam) when testing components.

4.3.6 Phased-Array technique (PA)

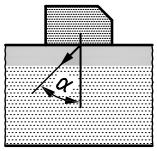
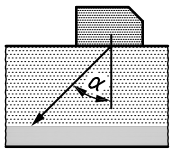
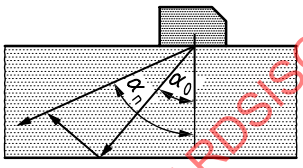
The PA-technique (see Annex A, No. 6) can be used as a fixed angle probe α (E-scan) or as a group radiation system with a swivel angle range α_0 to α_n (S-scan) using linear array as preferred search units.

Other than linear array probes can be used. The usage and the comparability to PE- or linear PA-technique shall be shown on the basis of a qualification.

4.3.7 Preferred angles of incidence and wave modes for search techniques

Taking the optimum incidence angle into consideration, the beam angles and wave modes shall preferably be selected according to Table 1 for the search techniques.

Table 1 — Preferred beam angle and wave modes

Location of the reflector		Beam angle[a]	PE system[d]	TR system[d]	EMAT
Close to surface	close to probe 	0°	—	L	—
		45°	T[c]	T	—
		≥ 65°	—	L	**TH**[b]
	far from probe 	0°	L	—	—
		30° to 70°	T	T (L[e])	**TH**[b]
In the volume 		0°	L	L	—
		40° to 70°	T	T (L[e])	**TH**[b]

Inspection techniques to be used are marked by L, T or TH (see Annex A). Those not to be used are marked by a dash (—).

[a] Depending on the geometry of the test object, other beam angles may also be used.

[b] Electromagnetically excited horizontally polarised transversal waves (TH). The equivalence shall be validated by a qualification.

[c] When testing over the full path.

[d] Both techniques can also be implemented by using PA probes.

[e] For austenitic welds or base material the longitudinal waves are less effected by coarse grain structure of austenitic material.

For the testing of materials that are difficult to test, for inspection techniques with mode conversion as well as in the case of complicated geometries, the beam angle and the test frequency shall be adapted to the test assignment and their suitability validated by measurements on reference block.

5 Requirements

5.1 Test personnel

5.1.1 Task of NDT personnel

NDT personnel[4] 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 2).

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

5.1.2 Personnel requirements

The test personnel comprise operating personnel for test robots, operating personnel for ultrasonic test devices and analysts as well as the test supervisor.

Those personnel, using qualified NDT procedures and equipment, shall be qualified through one or any combination of the following:

a) certification through a national NDT personnel certification scheme;

b) theoretical and/or open trials;

c) blind trials.

Any personnel certification requirements invoking relevant national NDT personnel certification schemes (e.g. see ISO 9712) shall be validated according to Table 2. 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 operation-induced flaws. Indications that reach or exceed the acceptance level 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 operating personnel for test robots and ultrasonic test devices shall be trained for the special requirements of the work to be performed. In particular, they shall have adequate experience in the implementation of automated ultrasonic tests and knowledge about the test object in respect to these requirements.

The analysts shall be trained for the special requirements of the work to be performed and have experience in the analysis and evaluation of UT indications as well as knowledge of the test object and the characteristic appearance of indications.

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 2 — Minimum requirements for the test personnel

Test personnel	Qualification
Operating personnel for test robots	Validation by training
Operating personnel for ultrasonic test devices (test inspector)	Certified with at least level 2 according to ISO 9712 or comparable qualification
Analysts	Certified with at least level 2 according to ISO 9712 or comparable qualification
Test supervisor	Certified with level 3 according to ISO 9712

The test personnel shall fulfil the vision requirements of 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 vision requirements of ISO 9712 shall be fulfilled. The following modifications can be used as substitutes to ISO 9712.

d) The visual acuity testing shall be conducted with standard signs in accordance with 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.

e) 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.

5.2 Test object

The weld crown condition shall be ground flush or machined to allow for unobstructed access to the weld (scan over weld deposit). The examination surfaces shall be free of irregularities, loose material, or coatings, which interfere with the ultrasonic wave transmission. Areas where ultrasonic contact is inadequate shall be documented as limitations.

Reference points shall be permanently marked on the component for positioning and calibration.

5.3 Ultrasonic test equipment

5.3.1 Preliminary remark

The ultrasonic test equipment shall fulfil the requirements for electromagnetic compatibility.

5.3.2 Test robot

The test robot (also called remote handling manipulator) shall fulfil the requirements for occupational safety and enable a time-saving, non-mix-up assembly and operation, to limit the radiation exposure of the test personnel.

The test robot shall be designed so that:

— the test section specified in the test procedures is recorded;

— a reproducible local tolerance of 3 mm is not exceeded within a measurement for the mechanical components;

— an assembly global tolerance of 5 mm to the component coordinate system on the component is not exceeded;

— the track pitch upon meander measurement does not deviate from the target value by more than 20 %;

NOTE Test system requirements can make higher accuracies necessary.

— an encounter with obstacles is prevented (e.g. by limit switch);

— all components are secured against automatic or unintended loosening, falling or tipping;

— the UT probe or UT probe system is moved with the required contact pressure over the entire test area;

— the position data with a resolution of less than or equal to 1 mm is continuously available;

— the position data can be converted in component-related coordinates;

— the electrical interference level resulting from drive and control elements is below the level of the joint indications in the relevant test section;

— the cable connections are designed to prevent mix-ups (e.g. by marking);

— the robot can be extensively decontaminated.

5.3.3 Ultrasonic test device

The characteristics of the ultrasonic test device shall be verified in accordance with EN 12668-1 for analogue and digital ultrasonic instruments for pulse operation and in automated systems and with ISO 18563-1 for phased-array ultrasonic instruments.

The following device system properties shall be documented by the manufacturer:

— number of transmitter and receiver channels;

— raw data type (e.g.: RF., A-Scan);

— amplitude and time progression of the transmitted signal;

— maximum transmitting pulse repetition frequency;

— scanning rate;

— frequency filter;

— output impedance of the transmitter;

— input impedance of the receiver;

— cross-talk between transmitter and receiver channels;

— amplifier type (linear, logarithmic);

— dynamic range;

— resolution for the signal amplitude;

— frequency bandwidth of the receiver;

— software version;

— data reduction algorithm;

— protection standard (e.g. splash waterproof, immersion-proof).

The ultrasonic test device shall fulfil the following requirements.

— The relative measuring uncertainty of the time of flight shall not exceed 1 %. The manufacturer shall ensure that this requirement is fulfilled in the entire frequency range of the ultrasonic test device.

— Mix-up of the storage of raw data shall be prevented.

— The option of monitoring measuring value for each test channel during the data collection/ acquisition shall be provided.

— If a depth or angle dependent amplification correction is possible: Mix-up of the storage of the compensation curves shall be prevented (see Annex D).

At least before commencement and after completion of the in-service inspection, the ultrasonic test device shall undergo a functional check and adjustment. Depending on the test assignment, the time points for further functional checks shall be defined. The functional checks shall include:

— Monitoring of the transmission channels (transducer probe, cable, amplifier);

— Linearity of the amplifiers;

— Amplification reserve (total dynamics of the ultrasonic test device);

— Linearity of the time of flight measurement.

The results of this functional check shall be documented. This functional check may be executed in the form of a self-check.

5.3.4 Data acquisition and analysis

Data acquisition systems (DAS) shall be used, with which the signals, position data and parameter files supplied by the ultrasonic test equipment can be saved digitalised.

The DAS shall be selected in the way that all data recorded from the ultrasonic test instrument can be processed at the given data transfer rate. The DAS shall be used for the assessment of measured UT data.

The operating system version and software including software version, of data processing, shall be documented.

Data losses during the data acquisition shall be recognisable during the online or offline data analysis.

5.3.5 UT probe

5.3.5.1 General

UT probe data sheets on which all-essential transducer probe properties are documented shall be provided for the applied UT probes.

The material at which these were determined shall be indicated in case of sound field relevant parameters. The underlying sound velocity shall be indicated.

In case of curved test surfaces, the UT probes shall be adapted to the curvature in accordance with ISO 16811.

The UT probe parameter (e.g. beam angle) may not be changed without monitoring. Modifications to the UT probe and resultant changes to relevant UT probe characteristics shall be identified and documented (see Annex B).

In case of TRL- probes, it shall be taken into consideration that the effective beam angle changes with the length of the sound path. In addition, these TRL-probes shall only be used in the sensitivity range indicated by the manufacturer in accordance with ISO 16811.

5.3.5.2 UT probe data sheets

5.3.5.2.1 General information

The following data in the data sheets applies both for conventional transducer probes as well as for phased-array probes:

— manufacturer;

— transducer probe type;

— serial no.;

— year of manufacture;

— housing external dimensions;

— wave mode;

— nominal angle (phased-array probes: beam angle without time-delayed excitation of the individual oscillation elements);

— contact surface;

— crystal material;

— wedge material, sound velocity in the wedge (integrated wedges and attachment wedges);

— nominal frequency;

— centre frequency;

— frequency spectrum;

— bandwidth;

— electrical connection including the following:

  — firmly connected cable (if available), cable length, cable material;

  — connector type;

  — connection position;

— impedance at nominal frequency;

— pulse form;

— permissible transmission voltage;

— squint/skew angle;

— permissible temperature range;

— water resistance;

— coupling medium supply;

— application points for probe holder;

— adaptation to the surface with indication of the curvature radius (if listed);

— transceiver probe diagram.

Transceiver probe properties for conventional probes shall be determined according to EN 12668-2.

Transceiver probe properties for phased-array probed shall be determined according to ISO 18563-2.

5.3.5.2.2 Conventional transceiver probes

The following data are required for conventional UT probes:

— focal length for focussing probes;

— focus range for TR-probes;

— near field length;

— transducer/crystal dimensions;

— divergence angle;

— arrangement of the Transducer/crystals;

— roof angle (for TR-probes);

— alignment characteristics;

— sound exit point.

5.3.5.2.3 Phased-array probes

The following data are additionally required for phased-array probes:

— number of elements;

— arrangement of the elements;

— element dimensions;

— element distances;

— delay path[1)];

— sound exit point[1)];

— alignment characteristics[1)];

— minimum and maximum focal length (in relation to the wave mode);

— horizontal/vertical nominal swivel range;

— pin assignment;

— element assignment matrix.

5.3.6 UT probe holders

The UT probe holders shall be designed so that

— the UT probes couple and the contour of the coupling area of the test object can occur without hindrance,

— the probes can be easily installed and removed, and

— the probes are not damaged when encountering an obstacle.

1) Determined for the natural beam angle and for at least three further swivel angles.

5.3.7 UT probe cable (ultrasonic cable)

The ultrasonic cables shall be adapted to the test assignment. Only ultrasonic cables whose technical data is recorded and documented may be used (see Annex B).

The following requirements shall be observed:

— no mixing up the connectors;

— shielding against electrical interference;

— surface that can be decontaminated;

— absence of halogenides;

— capability of withstanding against hostile environment (damage protection);

— flexibility to allow free movement of the UT probe and probe holders;

— availability of spare wires (if possible);

— splash water protection or immersion suitability.

5.4 Couplant

Only the media released by the operator of the power station may be used as coupling media. The coupling media may not

— damage the test object (ensure absence of halogenides),

— leave any disturbing residues behind.

The contain of halides (chlorides plus fluorides) and sulfur of couplant used on austenitic stainless steel or nickel base alloys shall not more than 200 mg/kg or 200 ppm.

When coupling with flowing water, it shall be ensured that the coupling medium is collected.

During performance of the measurement scan also a scan without couplant shall be performed.

5.5 Reference reflectors

The following can be used as reference reflectors:

— back walls;

— side-drilled holes (SDH);

— flat-bottomed holes (FBH);

— notches;

— hemispherical-bottomed holes.

It shall be possible to establish a clear physical reference to the required registrations thresholds. If planar reflectors are not oriented vertically to the surface or vertically to the sound incidence level (e.g. reflectors for tandem test) a hysteresis correction is recommended. Natural reference reflectors are also approved corresponding to the test assignment, e.g.:

— cracks;

— inclusions;

— lack of fusion.

The requirements for reference reflectors when applying the distance-gain-size (DGS) method can be found in ISO 16811:2012, Annex B.

NOTE The German abbreviation AVG (Abstand-Verstaerkung-Groesse) is sometimes used in place of DGS.

5.6 Calibration block and reference or test block

The calibration block to be used is specified by standard ISO 2400 and ISO 7963.

Reference block or test block shall be manufactured in accordance with the requirements coming out from qualification procedure and documented in the applicable specification or standard test procedure. For materials see 3.15 and 3.36. The block scanning surfaces shall be machined. Ra roughness shall not exceed 6,3 µm. Block geometry, as well as the size and position of reflectors, when required, are specified for each case in the relevant specification or standard test procedure. The position and number of reflectors, when required, shall be such that the entire thickness of the part can be inspected.

5.7 Data storage medium

Data storage medium shall be designed in such way that

— they enable a labelling for identification,

— an unintended overwrite is prevented (e.g. by usage of non-erasable media), and

— the suitability of storage is ensured.

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

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

It shall be ensured that automatically collected data recordings could not be unintended overwrite.

6 Testing

6.1 Preparation

6.1.1 General

The test personnel shall be trained in the special requirements of the test. All requisite documents, such as test procedures, drawings or piping isometric drawings necessary for conducting the testing shall be made available.

Before using the ultrasonic test equipment in areas exposed to radiation, training for rapid assembly and disassembly shall be realised for reducing the time personnel remain in such areas. The training shall be documented and, if necessary, validated by the test service provider.

6.1.2 Probe data sheets

The characteristic variables essential for the test assignment from 5.3.5 shall be available for all transducer probes.

6.1.3 Probe system

The probes shall be installed in a test system corresponding to the data defined in the standard test procedures. The following points shall be considered:

— assembly of the probe holders at the indicated distances to the coordinate data reference point;

— installation of the UT probes in the relevant probe holder with consideration of the specified test equipment;

— checking the contact force of the UT probes.

During assembly, it shall be ensured that the connecting cables and hoses for the couplant do not affect the movements of the test robot and probes and the probes can follow the surface of the test object without obstruction.

6.1.4 Test robot

After assembly, the test robot shall be calibrated at reference points of the test object. The position data for the test robot at the reference points shall be recorded.

It shall be ensured that the test robot fulfils the requirements indicated in 5.3.2 under test conditions.

6.1.5 Ultrasonic test device

It shall be ensured that the ultrasonic test devices fulfil the requirements indicated in 5.3.3 under test conditions.

The fulfilment of the requirements according to 5.3.3 shall be verified and documented by functional checks.

The ultrasonic test device shall be checked regularly. The time of the last performed check may not be longer than 12 months in the past. The check shall be based on the verification in accordance with EN 12668-1.

The ultrasonic test instrument shall be checked regularly as part of the quality assurance.

After repair work, functional checks shall be repeated and documented, preferably by a self-test.

If repair work for compliance with the test sequence is necessary in a test phase, the functional checks may be conducted in integral form (e.g. by a reference run at a test section with known indications).

6.1.6 Setting the test level

6.1.6.1 General

The calibration of the ultrasonic test instrument shall be carried out with the equipment used during the test (probe, connecting cable, couplant, ultrasonic test device, data backup device) at the calibration block defined in the test specifications or standard test procedures. The test object, calibration, reference block may not exceed a temperature difference of +15 °C when setting the testing level to the later test performance condition.

In case of phased-array probes, the function of each element shall be checked. The procedure upon failure of elements shall be defined specific to the probe, depending on the test assignment.

No separate measures are necessary up to component temperatures ≤45 °C. Above a temperature of 45 °C, the applicability of the probe for this temperature range shall be proved (by qualification procedure). The test temperature shall be considered during the calibration of the test sensitivity and analysis of the test results.

6.1.6.2 Sound path

The sound path shall be calibrated at the ultrasonic test instrument with a UT probe of each wave type (e.g. transversal, longitudinal) on a calibration specimen, reference block.

6.1.6.3 Testing level and recording level

The sensitivity of the ultrasonic test instrument shall be set for each test system based on calibration reflectors defined in the standard test procedures. The UT probes to be utilised for the test shall be used here. The difference between the test object and calibration specimen, reference block shall be determined by a transfer measurement. The transfer correction and the test block for evaluation of the coupling shall be determined by measuring the through-transmission signals at representative points of the relevant test section. Amplitude corrections (e.g. track offset correction, inclined position correction, tandem zone correction, depth correction) shall be indicated.

The definition of the relevant recording levels can be found in the test specifications or standard test procedures.

6.1.6.4 Recording the calibration

Every calibration shall be recorded (see Annex B). The record shall contain the following:

— UT probe identification;

— drawings of the calibration specimens, reference block;

— parameter settings for the testing sensitivity of the ultrasonic test instrument (e.g. channels used, basic amplification, transmission voltage, filter, cable length);

— drawing of the probe arrangement (e.g. Tandem, V-transmission);

— temperature of the calibration specimens, reference block;

— characteristic data of the ultrasonic test device (e.g. amplitude characteristic curve, time of flight characteristic curve, amplification characteristic curve).

6.1.7 Data acquisition system (DAS)

The DAS shall be used to ensure that all signals relevant to the evaluation are recorded.

6.1.8 Ultrasonic test equipment

The functional capability of the ultrasonic test equipment shall be verified at the test object. The verification shall be done by a reference scan and by plausibility checks of the evaluated UT data. The installation of the UT probes in the probe holder (check of the direction of incidence) shall be checked.

It shall be ensured that the test functions have been programmed as specified.

6.2 Implementation

The test shall be conducted according to the data contained in the standard test procedures. It shall be ensured that the entire test area is recorded with the specified testing sensitivity.

To ensure a reliable test implementation, the functions of the ultrasonic test equipment shall be inspected and documented before the test start (reference scan), accompanying the test and after completion of the test (test scan). These control steps are defined with scope and frequency in the standard test procedures or specifications. The test shall be interrupted if a functional change occurs outside the specified functional range of the ultrasonic test equipment. It shall be clarified whether the cause of the functional change has to be rectified or whether the changes can be considered retrospectively when evaluating the measuring data. Once the cause of the functional change is rectified, the test run during which the functional change has occurred shall be repeated after a possible recalibration. A deviation of maximum 3 dB in relation to the input calibration is permissible.

The ambient temperature in the immediate working range should not be greater than 40 °C with consideration of the test personnel. Special arrangements shall be agreed for higher temperatures.

After the start of the test run, it shall be ensured that all parameters associated with the data acquisition can no longer be changed.

6.3 Visualisation of the digitized and saved measuring data

The UT data to be evaluated shall be visualised clearly. All data in the visualisations, in particular the test section, component-relevant position data, test functions, direction and beam angle, shall be comprehensible and intelligible.

In the case of recorded indications, the results shall be printed out in a scale that permits a clear evaluation of the extent of indication.

The measuring results are shown in the form of A-, B- or C-images for their evaluation. An assignment to the component coordinates shall be ensured.

6.4 Analysis of indications

The evaluation of indications shall be conducted corresponding to the requirements of the applicable national nuclear code (evaluation and record level).

Indications that reach or exceed the evaluation level shall be evaluated as findings and documented in the findings record (see Annex C).

Changes to the findings are specified in national regulations. Indications subject to registration shall be documented in a record of indications.

Indications that are due to the geometric form of the test object or which can be clearly demonstrated not to result from defects (e.g. wave splits in the cladding) are evaluated as geometric indications, then marked and documented as such. In case of periodically occurring geometric indications the documentation of a single period is sufficient. Further arrangements are not necessary.

Indications that are due to external influences (e.g. electromagnetic interference signals from welding work) and which do not restrict the evaluation capacity are evaluated as disturbance indications and marked as such. Further arrangements are not necessary.

NOTE If suitable, the UT data of the conducted test run can be used for further analysis of findings or an analysis scan is performed. If determination of the indication size (length and depth extension), the form or the orientation are necessary for findings qualified test or analysis systems, e.g. the synthetic aperture focusing technique (SAFT), time-of-flight diffraction technique (TOFD), crack tip signal technique, can be used. Other, supplementary qualified tests with other physical interactions or visual inspection can also be conducted for the analysis of findings. If the signal-to-noise-ratio is not suitable for an assessment based only on the amplitude a further analysing of the indication pattern is recommended.

6.5 Final measures

After completing the testing, couplant residues shall be cleaned from the test objects. Auxiliary materials attached to the test object (e.g. adhesive tapes, labels) shall be removed completely.

It shall be verified that all test sections have been recorded with the test sensitivity defined in the standard test procedures. The test scope shall be monitored by a target-actual comparison of the run program.

Before disassembly of the ultrasonic test equipment, it is necessary to check whether all test runs have been carried out with sufficient coupling and can be evaluated.

7 Recording

7.1 Recording the setup for the ultrasonic test equipment

The minimum data contained in the forms in Annex B shall be considered to simplify the recording of device and calibration data. Additional data and the type of forms shall be defined in the standard test procedures. The technical descriptions of the ultrasonic test equipment shall be available.

NOTE A further example of a probe data sheet can be found in ISO 16811.

The test documentation should also be backed up in digital form in addition to paper form.

7.2 Test record and test report

A test record or test report shall be compiled concerning the testing. The following data shall be included:

— date of the testing;

— name of the power plant;

— test basis (standard test procedures);

— Test object, test area and test section with reference point and coordinates;

— surface state (e.g. ground);

— test system;

— test result with indication list and, insofar as necessary, findings record;

— comparison of the test results with those of the previous test;

— deviations from the specifications of the standard test procedures;

— place, date, name, signature, certificate number of the inspectors and test supervisors of the operator or the test company commissioned by him and the third party.

7.3 Indication list

The indication list shall include, as a minimum:

— consecutive numbering of the indications;

— representations of the digitized and saved measured data (see 6.3);

— indication coordinates in relation to the component (x-, y- and z-coordinates);

— test functions with which the indication was verified;

— echo level on the recording level (with and without corrections);

— length of the indication by 6 dB drop technique (maximum echo height technique);

— name of the raw data file.

NOTE There is a possibility of usage of other length determination like 12 dB or 20 dB drop or drop to noise level are. The usage of other than the 6 dB drop is documented.

7.4 Findings record

The findings record (see Annex C) lists those indications from the indication list, which have reached or exceeded the acceptance level/evaluation level according to national nuclear code and which have not been analysed as geometric indications. In addition to the data in the indication list, the following is required for the findings record:

— representation of the test area;

— evaluated colour-coded projection image or time displacement image (TD image);

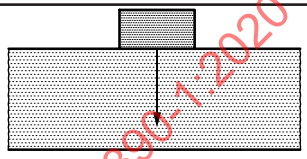
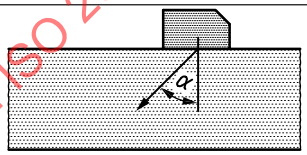
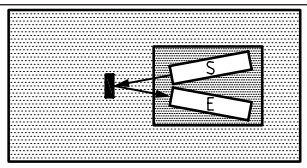
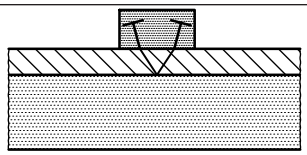
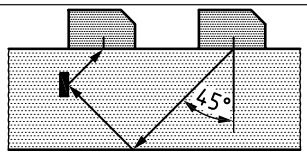
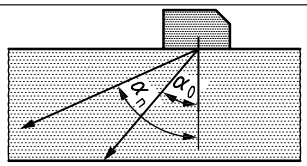
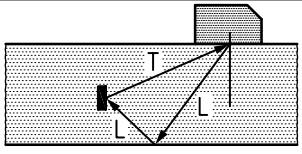
— evaluated A-image of the indication amplitude maximum and, if possible, additionally from opposite direction of incidence;

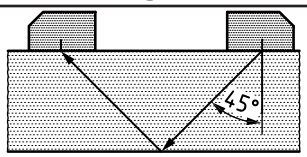
— implemented analysis for first findings or change to the indication.

A comparison with the previous tests shall be done for findings.

Annex A
(informative)

Examples of test systems and transceiver probe arrangements

No.	Test technique	Diagram of the transceiver probe arrangement
1	0° single oscillator technique for longitudinal waves (see 4.3.1)	 Figure 1
2	Single oscillator technique for transversal waves, e.g. with α of 45°, 60°, 70° (see 4.3.1)	 Figure 2
3	TR longitudinal wave or transversal wave technique (see 4.3.2)	 Figure 3
4	TR technique for the adhesion testing of the cladding	 Figure 4
5	Tandem system (see 4.3.3)	 Figure 5
6	Group radiation system (phased-array technique) Swivel range α_0 to α_n	 Figure 6
7	Test technique with mode conversion, e.g. LLT technique (see 4.3.4) Also possible is a LLL technique (see 3.17)	 Figure 7
TR = Transmitter and receiver separate L = Longitudinal wave T = Transversal wave		

No.	Test technique	Diagram of the transceiver probe arrangement
8	V-transmission technique (see 4.3.5)	 **Figure 8**
TR = Transmitter and receiver separate L = Longitudinal wave T = Transversal wave		

Annex B
(informative)

Forms

Form for transceiver probe data

Designation		Value/Designation
UT probe	Type	
	No. in the test system	
	Serial no.	
	Consecutive no.	
	Year of manufacture	
	Housing dimensions	
	Curvature radius of the probe base marking	
Pin assignment	Make	
	Type	
Probe connection	on the housing	
	fixed on the cable	
	Cable length	
Date of the last check		

Form for the transceiver probe connection or connecting cable to the transceiver probe

Designation			Value/Designation
Cable	Type (e.g. RG 58)		
	Type (e.g. coaxial)		
	Number of wires (e.g. 5)		
	Diameter (for cable bundle)		
Pin assignment	Probe side	Make	
		Type	
	Device side	Make	
		Type	
Cable length			
Application range (e.g. watertight)			
Date of the last check			

Form for calibration block, reference block

Designation	Value/Designation
Identification (Type)	
Material	
Dimensions[a]	
Sound velocity for transversal waves and longitudinal waves	
Coupling area[a]	
Calibration reflectors[a] Electrical conductivity and relative permeability shall be indicated for EMUS	
Temperature of the test or calibration block	
[a] A diagram shall be enclosed as an annex.	

Form for the ultrasonic test device

Designation	Value/Designation
Type	
Serial no.	
Consecutive no.	
Software version	
List of device parameter settings	
Date of the last check	

Form for the test robot

Designation	Value/Designation
Type[a]	
Serial no.	
Consecutive no.	
Scope	
Software version	
Date of the last check	
[a] Technical description	