
**Marine environment sensor
performance — Specifications,
testing and reporting — General
requirements**

Navires et technologie maritime — Performances des capteurs marins

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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. 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 8, *Ships and marine technology*, Subcommittee SC 13, *Marine technology*.

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.

Introduction

Oceans are intertwined with many of humanity's priorities, including trade, food, energy, climate and security. Understanding what's going on below the sea surface is important for making decisions around maritime boundaries, exploiting energy and mineral resources, expanding waterways, and monitoring aquaculture. All depend on the availability of data produced by marine environment sensors that measure physical, ecological and chemical parameters of seawater, such as salinity, temperature, oxygen, carbon dioxide and acidity.

As an example of the growing importance of these data, marine business is increasingly mandated by law to record them to meet environmental regulations. But common definitions for even basic performance specifications of these sensors, such as accuracy or stability, don't exist. This weakens the utility of the laws and diminishes confidence in sensor performance. It also acts to dampen the market forces driving sensor innovation, as it is difficult for end-users to compare and reward true breakthroughs from existing manufacturers, or to trust new entrants. This document aims to address this by establishing a set of performance specifications common to all marine environment sensors, including terms, definitions and test methods.

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Marine environment sensor performance — Specifications, testing and reporting — General requirements

1 Scope

This document defines terms, specifies test methods and provides reporting requirements for marine sensor specifications to ensure a consistent reporting by manufacturers.

It is applicable to those devices known as conductivity-temperature-depth (CTDs), sound velocity probes, multi-parameter sondes and dissolved gas sensors, that measure parameters such as conductivity, temperature, pressure, sound speed, dissolved oxygen, turbidity, pH, and chlorophyll in seawater.

It is also generally applicable to all marine environment instruments.

NOTE 1 A 'CTD' directly measures conductivity, temperature, and pressure. Depth is derived from pressure using an equation.

NOTE 2 The term 'sound velocity probe' is widely used to describe instruments that measure sound speed. In this document the term 'sound velocity' is used when describing the type of sensor, and the term 'sound speed' is used when describing the parameter or measurand, but these terms can be used interchangeably.

2 Normative references

The following documents are referred to in the text in such a way that some or all 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 5725-2:2019, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO/IEC 17025:2017, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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

quantity

parameter

property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference

Note 1 to entry: A reference can be a measurement unit, a measurement procedure, a reference material, or a combination of such.

EXAMPLE Pressure, P

[SOURCE: ISO/IEC Guide 99:2007, 1.1, modified — The admitted term “parameter” has been added. All Notes have been removed except Note 2 to entry, renumbered as Note 1 to entry. The Example has been added.]

3.2 derived quantity

quantity (3.1) that has been calculated from one or more measurements of other quantities

EXAMPLE Absolute salinity, S_A , is calculated from conductivity, temperature and pressure (IOC 56:2010)[8].

3.3 quantity value

value
number and reference together, expressing magnitude of a *quantity* (3.1)

EXAMPLE 1 Conductivity of a volume of seawater: 35 mS/cm or 3, 5 S/m

EXAMPLE 2 Sound speed of a volume of seawater: 1 500 m/s

[SOURCE: ISO/IEC Guide 99:2007, 1.19, modified — All Examples and Notes have been removed. New Examples 1 and 2 have been added.]

3.4 measurand

quantity (3.1) intended to be measured

Note 1 to entry: The specification of a measurand requires knowledge of the kind of quantity, description of the state of the phenomenon, body, or substance carrying the quantity, including any relevant component, and the chemical entities involved.

Note 2 to entry: In the second edition of the VIM and in IEC 60050-300:2001, the measurand is defined as the 'particular quantity subject to measurement'.

Note 3 to entry: The measurement, including the measuring system and the conditions under which the measurement is carried out, might change the phenomenon, body, or substance such that the quantity being measured may differ from the measurand as defined. In this case, adequate correction is necessary.

EXAMPLE 1 The conductivity of a volume of seawater with the ambient Celsius temperature of 23 °C will be different from the conductivity at the specified temperature of 20 °C, which is the measurand. In this case, a correction is necessary.

EXAMPLE 2 The length of a steel rod in equilibrium with the ambient Celsius temperature of 23 °C will be different from the length at the specified temperature of 20 °C, which is the measurand. In this case, a correction is necessary.

[SOURCE: ISO/IEC Guide 99:2007, 2.3, modified — Note 4 has been removed. Example 2 has been changed.]

3.5 measurement

process of experimentally obtaining one or more *quantity values* (3.3) that can reasonably be attributed to a *quantity* (3.1)

[SOURCE: ISO/IEC Guide 99:2007, 2.1, modified — All Notes have been removed.]

3.6 measurement unit

unit
real scalar *quantity* (3.1), defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number

Note 1 to entry: Measurement units are designated by conventionally assigned names and symbols.

Note 2 to entry: Measurement units of quantities of the same quantity dimension may be designated by the same name and symbol even when the quantities are not of the same kind. For example, joule per kelvin and J/K are respectively the name and symbol of both a measurement unit of heat capacity and a measurement unit of entropy, which are generally not considered to be quantities of the same kind. However, in some cases special measurement unit names are restricted to be used with quantities of a specific kind only. For example, the measurement unit 'second to the power minus one' (1/s) is called hertz (Hz) when used for frequencies and becquerel (Bq) when used for activities of radionuclides.

EXAMPLE 1 meters per second (m/s)

EXAMPLE 2 millisiemens percentimetre (mS/cm).

EXAMPLE 3 degrees Celsius (°C).

[SOURCE: ISO/IEC Guide 99:2007, 1.9, modified — Notes 3 and 4 have been removed. The Examples have been added.]

3.7

measurement principle

principle of measurement

phenomenon serving as a basis of a *measurement* (3.5)

EXAMPLE 1 Thermoelectric effect applied to the measurement of temperature.

EXAMPLE 2 Photoluminescence effect applied to the measurement of dissolved oxygen.

[SOURCE: ISO/IEC Guide 99:2007, 2.4, modified — All original Examples and Notes have been removed. New Examples 1 and 2 have been added.]

3.8

measurement result

set of *quantity values* (3.3) being attributed to a *measurand* (3.4) together with any other available relevant information

Note 1 to entry: A measurement result generally contains "relevant information" about the set of quantity values, such that some may be more representative of the measurand than others. This may be expressed in the form of a probability density function (PDF).

Note 2 to entry: A measurement result is generally expressed as a single measured quantity value and a measurement uncertainty. If the measurement uncertainty is considered negligible for some purpose, the measurement result may be expressed as a single measured quantity value. In many fields, this is the common way of expressing a measurement result.

[SOURCE: ISO/IEC Guide 99:2007, 2.9, modified — Note 3 has been removed.]

3.9

measurement accuracy

closeness of agreement between a measured quantity value and a true quantity value of a *measurand* (3.4)

Note 1 to entry: The concept "measurement accuracy" is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.

Note 2 to entry: The term "measurement accuracy" should not be used for measurement trueness and the term "measurement precision" should not be used for 'measurement accuracy', which, however, is related to both these concepts.

Note 3 to entry: "Measurement accuracy" is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

Note 4 to entry: The admitted term "accuracy" has been removed to reduce ambiguity between the concept of 'measurement accuracy' described in ISO/IEC Guide 99, and the method for calculating a marine environment sensor's datasheet accuracy as described in 5.4.

[SOURCE: ISO/IEC Guide 99:2007, 2.13, modified — The admitted term “accuracy” has been removed. Note 4 has been added.]

3.10

measurement trueness

trueness

closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value

Note 1 to entry: Measurement trueness is not a quantity and thus cannot be expressed numerically, but measures for closeness of agreement are given in ISO 5725.

Note 2 to entry: Measurement trueness is inversely related to systematic measurement error, but is not related to random measurement error.

Note 3 to entry: “Measurement accuracy” should not be used for 'measurement trueness'.

[SOURCE: ISO/IEC Guide 99:2007, 2.14]

3.11

measurement precision

precision

closeness of agreement between *indications* (3.27) or measured quantity values obtained by replicate *measurements* (3.5) on the same or similar objects under specified conditions

Note 1 to entry: Measurement precision is usually expressed numerically by measures of imprecision, such as standard deviation, variance, or coefficient of variation under the specified conditions of measurement.

Note 2 to entry: The 'specified conditions' can be, for example, repeatability conditions of measurement, intermediate precision conditions of measurement, or reproducibility conditions of measurement (see ISO 5725-1:1994).

Note 3 to entry: Measurement precision is used to define measurement repeatability, intermediate measurement precision, and measurement reproducibility.

Note 4 to entry: Sometimes “measurement precision” is erroneously used to mean measurement accuracy.

[SOURCE: ISO/IEC Guide 99:2007, 2.15]

3.12

measurement error

error

measured quantity value minus a reference quantity value

Note 1 to entry: The concept of 'measurement error' can be used both a) when there is a single reference quantity value to refer to, which occurs if a calibration is made by means of a measurement standard with a measured quantity value having a negligible measurement uncertainty or if a conventional quantity value is given, in which case the measurement error is known, and b) if a measurand is supposed to be represented by a unique true quantity value or a set of true quantity values of negligible range, in which case the measurement error is not known.

Note 2 to entry: Measurement error should not be confused with production error or mistake.

[SOURCE: ISO/IEC Guide 99:2007, 2.16]

3.13

systematic measurement error

component of *measurement error* (3.12) that in replicate *measurements* (3.5) remains constant or varies in a predictable manner

Note 1 to entry: A reference quantity value for a systematic measurement error is a true quantity value, or a measured quantity value of a measurement standard of negligible measurement uncertainty, or a conventional quantity value.

Note 2 to entry: Systematic measurement error, and its causes, can be known or unknown. A correction can be applied to compensate for a known systematic measurement error.

Note 3 to entry: Systematic measurement error equals measurement error minus random measurement error.

[SOURCE: ISO/IEC Guide 99:2007, 2.17, modified — The admitted term “systematic error” has been removed.]

3.14 measurement bias

bias

estimate of a *systematic measurement error* (3.13)

[SOURCE: ISO/IEC Guide 99:2007, 2.18]

3.15 repeatability condition of measurement

repeatability condition

condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate *measurements* (3.5) on the same or similar objects over a short period of time

[SOURCE: ISO/IEC Guide 99:2007, 2.20, modified — The Notes have been removed.]

3.16 intermediate precision condition of measurement

intermediate precision condition

condition of measurement, out of a set of conditions that includes the same measurement procedure, same location, and replicate *measurements* (3.5) on the same or similar objects over an extended period of time, but may include other conditions involving changes

Note 1 to entry: The changes can include new calibrations, calibrators, operators, and measuring systems.

[SOURCE: ISO/IEC Guide 99:2007, 2.22, modified — Notes 2 and 3 have been removed.]

3.17 reproducibility condition of measurement

reproducibility condition

condition of [measurement](#), out of a set of conditions that includes different locations, operators, measuring systems, and replicate *measurements* (3.5) on the same or similar objects

[SOURCE: ISO/IEC Guide 99:2007, 2.24, modified — The Notes have been removed.]

3.18 level of the test in a precision experiment

level

average of *measurements* (3.5) from all *sensors* (3.45) for one reference material or measurement standard

[SOURCE: ISO 5725-1:1994, 3.3, modified — The admitted term “level” has been added. The definition has been adapted.]

3.19 cell of a precision experiment

cell

measurement result (3.8) at a single *level* (3.18) obtained by one *sensor* (3.45)

[SOURCE: ISO 5725-1:1994, 3.4, modified — The admitted term “cell” has been added. The definition has been adapted.]

3.20

measurement uncertainty

uncertainty

non-negative parameter characterizing the dispersion of the *quantity values* (3.3) being attributed to a *measurand* (3.4), based on the information used

Note 1 to entry: Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated.

Note 2 to entry: The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

Note 3 to entry: Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

Note 4 to entry: In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

[SOURCE: ISO/IEC Guide 99:2007, 2.26]

3.21

standard measurement uncertainty

standard uncertainty

measurement uncertainty (3.20) expressed as a standard deviation

[SOURCE: ISO/IEC Guide 99:2007, 2.30]

3.22

combined standard uncertainty

combined uncertainty

standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other *quantities* (3.1), equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the *measurement result* (3.8) varies with changes in these quantities

[SOURCE: ISO/IEC Guide 98-3:2008, 2.3.4, modified — The admitted term “combined uncertainty” has been added.]

3.23

calibration

operation that establishes a relation between the *quantity values* (3.3) and corresponding *indications* (3.27) of a *sensor* (3.45)

Note 1 to entry: A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

Note 2 to entry: Calibration should not be confused with adjustment of a measurement system, often mistakenly called “self-calibration”, nor with verification of the calibration.

Note 3 to entry: Often, the step of conducting the operation to establish a relation between quantity values and corresponding sensor indications alone is already perceived as being calibration.

[SOURCE: ISO/IEC Guide 99:2007, 2.39, modified — The definition has been truncated for clarity.]

3.24**influence quantity**

quantity (3.1) that, in a direct measurement, does not affect the quantity that is actually measured, but affects the relation between the *indication* (3.27) and the *measurement result* (3.8)

EXAMPLE Temperature of the sound velocity sensor, but not the temperature of the surrounding seawater which would enter into the definition of the measurand.

Note 1 to entry: An indirect measurement involves a combination of direct measurements, each of which may be affected by influence quantities.

Note 2 to entry: In the GUM, the concept “influence quantity” is defined as in the second edition of the VIM, covering not only the quantities affecting the measuring system, as in the definition above, but also those quantities that affect the quantities actually measured. Also, in the GUM this concept is not restricted to direct measurements.

[SOURCE: ISO/IEC Guide 99:2007, 2.52, modified — The original Examples have been removed, and a new Example has been added.]

3.25**measuring system**

set of one or more measuring *instruments* (3.47) and often other devices, including any reagent and supply, assembled and adapted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds

Note 1 to entry: A measuring system may consist of only one measuring instrument.

[SOURCE: ISO/IEC Guide 99:2007, 3.2]

3.26**adjustment of a measuring system**

adjustment

set of operations carried out on a measuring system so that it provides prescribed *indications* (3.27) corresponding to given *values* (3.3) of a *quantity* (3.1) to be measured

Note 1 to entry: Types of adjustment of a measuring system include zero adjustment of a measuring system, offset adjustment, and span adjustment (sometimes called gain adjustment)

Note 2 to entry: Adjustment of a measuring system should not be confused with calibration, which is a prerequisite for adjustment.

Note 3 to entry: After an adjustment of a measuring system, the measuring system must usually be recalibrated.

[SOURCE: ISO/IEC Guide 99:2007, 3.11]

3.27**indication**

signal

quantity value (3.3) provided by a *sensor* (3.45) or *instrument* (3.47)

Note 1 to entry: An indication may be presented in visual or acoustic form or may be transferred to another device. An indication is often given by the position of a pointer on the display for analogue outputs, a displayed or printed number for digital outputs, a code pattern for code outputs, or an assigned quantity value for material measures.

Note 2 to entry: An indication and a corresponding value of the quantity being measured are not necessarily values of quantities of the same kind.

[SOURCE: ISO/IEC Guide 99:2007, 4.1, modified — The admitted term “signal” has been added. In the definition, the words “measuring instrument or a measuring system” have been replaced with “sensor or instrument”.]

3.28

indication range

range

set of *quantity values* (3.3) bounded by extreme possible *indications* (3.27)

Note 1 to entry: An indication range is usually stated in terms of its smallest and greatest quantity values, for example "0 mS/cm to 100 mS/cm".

[SOURCE: ISO/IEC Guide 99:2007, 4.3, modified — The original term "indication interval" has been replaced with "indication range" and "range". Note 1 to entry has been adapted ("indication interval" has consistently been replaced with "indication range", and the example "99 V to 201 V" has been replaced with 0 mS/cm to 100 mS/cm"). Note 2 to entry has been removed.]

3.29

calibrated range

set of values of quantities of the same kind bounded by rounded or approximate extreme *levels* (3.18) measured by a given *instrument* (3.47) during calibration

3.30

measuring range

set of values of quantities of the same kind bounded by rounded or approximate extreme *levels* (3.18) measured by a given *instrument* (3.47) during determination of accuracy

[SOURCE: ISO/IEC Guide 99:2007, 4.7, modified — The original term "measuring interval" has been replaced with "measuring range". The definition has been aligned to the definition of *calibrated range* (3.29). The Notes have been removed.]

3.31

maximum range

set of *quantity values* (3.3) of the same kind bounded by rounded or approximate theoretical extreme *levels* (3.18) capable of being measured by a given *instrument* (3.47)

Note 1 to entry: The maximum range is limited only by the sensor model, such as the sensitivity or sensor digitizing electronics.

Note 2 to entry: The maximum range is often larger than the measuring range.

3.32

sensitivity of a measuring system

sensitivity

quotient of the change in an *indication* (3.27) of a measuring system and the corresponding change in a value of a *quantity* (3.1) being measured

Note 1 to entry: Sensitivity of a measuring system can depend on the value of the quantity being measured.

Note 2 to entry: The change considered in a value of a quantity being measured must be large compared to the resolution.

[SOURCE: ISO/IEC Guide 99:2007, 4.12]

3.33

resolution

smallest change in a *quantity* (3.1) being measured that causes a perceptible change in the corresponding *indication* (3.27)

Note 1 to entry: Resolution can depend on, for example, noise (internal or external) or friction. It may also depend on the value of a quantity being measured.

[SOURCE: ISO/IEC Guide 99:2007, 4.14]

3.34**resolution of a displaying device**

digital display

smallest difference between displayed *indications* (3.27) that can be meaningfully distinguished

[SOURCE: ISO/IEC Guide 99:2007, 4.15, modified — The admitted term “digital display” has been added.]

3.35**stability of a measuring instrument**

stability

property of a measuring instrument, whereby its metrological properties remain constant in time

Note 1 to entry: Stability consists of the inherent properties of the measuring system related to component ageing or degradation over time and of external factors like biofouling. In both cases it is influenced by the environmental conditions, i.e. the measuring conditions.

Note 2 to entry: Stability is quantified as an “instability”, known as drift.

[SOURCE: ISO/IEC Guide 99:2007, 4.19, modified — The original Note has been removed. New Notes 1 and 2 to entry have been added.]

3.36**instrumental drift**

drift

continuous or incremental change over time in *indication* (3.27), due to changes in the metrological properties of a measuring instrument

Note 1 to entry: Instrumental drift is related neither to a change in a quantity being measured nor to a change of any recognized influence quantity.

[SOURCE: ISO/IEC Guide 99:2007, 4.21, modified — The admitted term “drift” has been added.]

3.37**calibration curve**expression of the relation between *indication* (3.27) and corresponding measured quantity value

Note 1 to entry: A calibration curve expresses a one to one relation that does not supply a measurement result as it bears no information about the measurement uncertainty.

Note 2 to entry: For a digital sensor, an indication is usually the digital count from an analog to digital convertor.

[SOURCE: ISO/IEC Guide 99:2007, 4.31, modified — Note 2 to entry has been added.]

3.38**instrumental measurement uncertainty**

instrument uncertainty

component of *measurement uncertainty* (3.20) arising from a measuring instrument or measuring system in use

Note 1 to entry: Instrumental measurement uncertainty is obtained through calibration of a measuring instrument or measuring system, except for a primary measurement standard for which other means are used.

Note 2 to entry: Instrumental measurement uncertainty is used in a Type B evaluation of measurement uncertainty.

Note 3 to entry: Information relevant to instrumental measurement uncertainty may be given in the instrument specifications.

[SOURCE: ISO/IEC Guide 99:2007, 4.24]

3.39

measurement standard

realization of the definition of a given *quantity* (3.1), with stated *quantity value* (3.3) and associated *measurement uncertainty* (3.20), used as a reference

EXAMPLE 1 1 kg mass measurement standard with an associated standard measurement uncertainty of 3 μg .

EXAMPLE 2 100 Ω measurement standard resistor with an associated standard measurement uncertainty of 1 $\mu\Omega$.

Note 1 to entry: A “realization of the definition of a given quantity” can be provided by a measuring system, a material measure, or a reference material.

Note 2 to entry: A measurement standard is frequently used as a reference in establishing measured quantity values and associated measurement uncertainties for other quantities of the same kind, thereby establishing metrological traceability through calibration of other measurement standards, measuring instruments, or measuring systems.

Note 3 to entry: The term “realization” is used here in the most general meaning. It denotes three procedures of “realization”. The first one consists in the physical realization of the measurement unit from its definition and is realization *sensu stricto*. The second, termed “reproduction”, consists not in realizing the measurement unit from its definition but in setting up a highly reproducible measurement standard based on a physical phenomenon, as it happens, e.g. in case of use of frequency-stabilized lasers to establish a measurement standard for the metre, of the Josephson effect for the volt or of the quantum Hall effect for the ohm. The third procedure consists of adopting a material measure as a measurement standard. It occurs in the case of the measurement standard of 1 kg.

Note 4 to entry: A standard measurement uncertainty associated with a measurement standard is always a component of the combined standard measurement uncertainty (see ISO/IEC Guide 98-3:2008, 2.3.4) in a measurement result obtained using the measurement standard. Frequently, this component is small compared with other components of the combined standard measurement uncertainty.

Note 5 to entry: Quantity value and measurement uncertainty must be determined at the time when the measurement standard is used.

Note 6 to entry: Several quantities of the same kind or of different kinds may be realized in one device which is commonly also called a measurement standard.

Note 7 to entry: The word “embodiment” is sometimes used in the English language instead of “realization”.

Note 8 to entry: In science and technology, the English word “standard” is used in at least two different meanings: as a specification, technical recommendation, or similar normative document and as a measurement standard. This document is concerned solely with the second meaning.

[SOURCE: ISO/IEC Guide 99:2007, 5.1, modified — Examples 3 to 6 have been deleted. Note 8 to entry has been adapted for simplicity. Note 9 has been removed.]

3.40

primary measurement standard

primary standard

measurement standard (3.39) established using a primary reference measurement procedure, or created as an artifact, chosen by convention

Note 1 to entry: A measuring instrument that can be used alone is a measuring system.

Note 2 to entry: A measuring instrument may be an indicating measuring instrument or a material measure.

EXAMPLE 1 Primary measurement standard for pressure based on separate measurements of force and area.

EXAMPLE 2 Triple-point-of-water cell as a primary measurement standard of thermodynamic temperature.

[SOURCE: ISO/IEC Guide 99:2007, 5.4, modified — Notes 1 and 2 to entry have been added. The original Examples 1, 3 and 5 have been removed, and Examples 2 and 4 have been renumbered as Examples 1 and 2.]

3.41**secondary measurement standard**

secondary standard

measurement standard (3.39) established through *calibration* (3.23) with respect to a primary measurement standard for a *quantity* (3.1) of the same kind

Note 1 to entry: Calibration may be obtained directly between a primary measurement standard and a secondary measurement standard, or involve an intermediate measuring system calibrated by the primary measurement standard and assigning a measurement result to the secondary measurement standard.

Note 2 to entry: A measurement standard having its quantity value assigned by a ratio primary reference measurement procedure is a secondary measurement standard.

[SOURCE: ISO/IEC Guide 99:2007, 5.5]

3.42**reference material**

reference

material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in *measurement* (3.5) or in examination of nominal properties

Note 1 to entry: Examination of a nominal property provides a nominal property value and associated uncertainty. This uncertainty is not a measurement uncertainty.

Note 2 to entry: Reference materials with or without assigned quantity values can be used for measurement precision control whereas only reference materials with assigned quantity values can be used for calibration or measurement trueness control.

Note 3 to entry: "Reference material" comprises materials embodying quantities as well as nominal properties.

EXAMPLE 1 Examples of reference materials embodying quantities:

- a) microspheres of uniform size suspended in aqueous solution embody turbidity level;
- b) distilled water of certain purity at a specific temperature embody sound speed.

Note 4 to entry: A reference material is sometimes incorporated into a specially fabricated device.

EXAMPLE 2 Substance of known triple-point in a triple-point cell.

Note 5 to entry: Some reference materials have assigned quantity values that are metrologically traceable to a measurement unit outside a system of units. Such materials include vaccines to which International Units (IU) have been assigned by the World Health Organization.

Note 6 to entry: In a given measurement, a given reference material can only be used for either calibration or quality assurance.

Note 7 to entry: The specifications of a reference material should include its material traceability, indicating its origin and processing (Accred. Qual. Assur.:2006)^[4].

[SOURCE: ISO/IEC Guide 99:2007, 5.13, modified — The admitted term "reference" has been added. The original Examples under the Notes have adapted. Note 8 has been removed.]

3.43**Neptunian waters**

intercommunicating waters of the world, specifically with respect to the domain of applicable temperatures, salinity and pressures encountered there

Note 1 to entry: Practical quantity ranges include: temperatures of -2 °C to 45 °C, Absolute Salinities of 2 g/kg to 42 g/kg and equivalent hydrostatic pressures at depths of 0 m to 11 000 m, but the extremes of each rarely occur simultaneously (J. Acoust. Soc. Am.:1968)^[6]. The reference^[6] defines the ranges in terms of Practical Salinity, which has been deprecated in favour of Absolute Salinity.

3.44

transducer

element of a *sensor* (3.45) that is directly affected by the phenomenon, providing an output quantity having a specified relation to the input quantity

EXAMPLE Thermistor, electric current transformer, strain gauge, pH electrode, Bourdon tube, bimetallic strip, sensing coil of a platinum resistance thermometer, rotor of turbine flow-meter, Bourdon tube of a pressure gauge, float of a level-measuring instrument, photocell of a spectrometer, thermotropic liquid crystal which changes color as a function of temperature.

[SOURCE: ISO/IEC Guide 99:2007, 3.7, modified — The term "measuring transducer" has been replaced with "transducer". In the definition, the words "device, used in measurement," have been replaced with "element of a sensor that is directly affected by the phenomenon,". The Examples have been adapted.]

3.45

sensor

device used for making *measurements* (3.5) that processes the output quantity from a *transducer* (3.44) and converts it into an analog or digital signal

EXAMPLE Thermistor and any of the digitizing electronics, such as the analog to digital convertor and microchip with associated digital signal processing.

Note 1 to entry: In this document, the terms "signal" and "indication" are interchangeably used.

3.46

marine environment sensor

sensor (3.45) intended to make *measurements* (3.5) in *Neptunian waters* (3.43)

EXAMPLE Sensors to measure conductivity, temperature, pressure, pH, turbidity, dissolved CO₂ or CO₂ partial pressure, dissolved O₂ or O₂ partial pressure, chlorophyll, pH, PAR, ADCP, and acoustic speed log; subsurface radiometer; underwater seismometer; vessel noise monitor; underwater geophone.

Note 1 to entry: In this document, the term "sensor" with or without the qualifier "marine environment" is intended to refer to a marine environment sensor.

3.47

instrument

device used for making *measurements* (3.5), consisting of one or more *sensors* (3.45) and that may include additional components

EXAMPLE A CTD is a single instrument with 3 sensors measuring different parameters: conductivity, temperature, and pressure.

Note 1 to entry: Additional components can include, but are not limited to, post-processing of sensor signals, communication telemetry, data storage, batteries, and an indicating display.

3.48

step response time

response time

duration between the instant when an input quantity value of a measuring *instrument* (3.47) or measuring system is subjected to an abrupt change between two specified constant *quantity values* (3.3) and the instant when a corresponding *indication* (3.27) settles within specified limits around its final steady value

[SOURCE: ISO/IEC Guide 99:2007, 4.23, modified — The admitted term "response time" has been added.]

3.49

time constant

t_{63}

step response time where the *indication* (3.27) reaches 63,2 % of its final steady state value

Note 1 to entry: Reported in units of seconds.

Note 2 to entry: The time constant concept stems from an exponential response behaviour and where the time constant represents the time at which the actual signal has reached “ $1-\exp(-1)$ ” of the final level, i.e. 63,2 %.

3.50

sample

single value obtained during *measurement* (3.5)

3.51

sample rate

number of samples per unit of time for uniformly sampled data

Note 1 to entry: Reported in units of hertz.

3.52

sample period

duration of time between two successive samples

Note 1 to entry: Typically measured in milliseconds.

3.53

sample averaging

situation where a sample is a function of itself and at least one preceding sample, and where that function is equivalent to the arithmetic mean

Note 1 to entry: The most common type of sample averaging is the n -point simple moving average, where n is the number of samples in the average.

Note 2 to entry: This definition refers to the finite sample of digital sensors.

3.54

depth rating

specified depth below mean sea level at which a corresponding pressure rating is not exceeded under the assumption of deployment within *Neptunian waters* (3.43), leading to assumed limits on temperature and salinity

Note 1 to entry: Reported in units of meters.

3.55

maximum depth rating

max depth

depth below mean sea level above which the *instrument* (3.47) may not operate correctly but will not suffer permanent damage

Note 1 to entry: Reported in units of meters.

3.56

operating depth rating

operating depth

depth below mean sea level at which the *instrument* (3.47) is expected to function normally while continuing to meet stated limits of accuracy.

Note 1 to entry: Reported in units of meters.

3.57

weight in water

difference between the gravitational and buoyant forces divided by the gravitational constant

Note 1 to entry: It is an industry convention to refer to mass as weight.

Note 2 to entry: Reported in units of kilograms. Customary units can be listed in addition.

Note 3 to entry: If the force of gravity is greater than the buoyancy, the instrument sinks and the sign of the reported mass is positive. In the opposite case, the instrument floats and the reported mass is negative.

3.58

sensor model

specific embodiment of a *sensor* (3.45), its supporting mechanical parts, electronics and embedded software, including choice of calibration curve and calibration procedure

Note 1 to entry: A sensor model is specified by mechanical drawings, electrical schematics, software code, and manufactured according to assembly instructions with quality assurance steps. It is sold using a unique product code and each unit manufactured has a unique serial number.

3.59

outlier

member of a set of values which is inconsistent with the other members of a set

Note 1 to entry: ISO 5725-2 specifies the statistical tests and the significance level to be used to identify outliers in trueness and precision experiments.

[SOURCE: ISO 5725-1:1994, 3.21]

3.60

field

outside of reproducible conditions typically found in a laboratory

EXAMPLE A month-long survey where the instrument spends 10 % of its time profiling in 100 m depths and the remainder on the deck of the vessel.

3.61

field stability

stability (3.35) observed in the *field* (3.60)

EXAMPLE "Field stability" can be published by a manufacturer based on "field drift", or drift calculated from calibrations of a large sample population of sensors coming back from the field.

3.62

field drift

drift (3.36) calculated from use in the *field* (3.60)

4 Specifications

4.1 General

This Clause specifies requirements for marine environment sensors for the same sensor model.

If a sensor model is significantly different from another model, or undergoes a design revision, a manufacturer is required to consider and re-test all specifications that can be affected.

EXAMPLE 1 A manufacturer decides to update to a new thermistor in the transducer of a temperature sensor. Because the thermistor is within the transducer, and affects most aspects of a temperature sensor's performance, it is necessary to consider all specifications. The manufacturer decides to re-test all specifications.

EXAMPLE 2 A mechanical housing on a sensor is updated. Because the housing does not affect the transducing element, the manufacturer decides to re-test the maximum depth rating only.

4.2 Calibration

Prior to undergoing a test to determine a specification as per this Clause, a sensor shall have been calibrated in accordance with 5.3.

4.3 Range

4.3.1 Calibrated range

The calibrated range shall be determined during calibration, according to [5.3](#).

4.3.2 Measuring range

The measuring range shall be determined during the assessment of accuracy, according to [5.4.5.2](#).

4.3.3 Maximum range

The maximum range shall be determined, but the calculation is left up to the manufacturer.

4.4 Accuracy

The reproducibility standard deviation and bias shall be determined according to [5.4](#).

4.5 Resolution

The noise resolution of the sensor shall be determined according to [5.5](#).

The resolution of the digital display is the smallest incremental change reported by the digital display.

EXAMPLE The digital display of a temperature sensor has 4 significant digits after the decimal sign. The resolution of the digital display is thus 0,000 1 °C.

4.6 Response time

The time constant of the sensor shall be determined according to [5.6](#).

4.7 Depth and pressure

4.7.1 Maximum depth rating

The maximum depth rating and safety factor shall be determined in accordance with [5.7.1](#).

4.7.2 Crush depth rating

The tested safety factor shall be at minimum $1,1 \times$ equivalent pressure as determined in accordance with [5.7.2](#).

4.8 Sample rate

Determine the maximum sample rate indicated by the sensor and settable by the user.

4.9 Mechanical

4.9.1 Wetted materials

Determine all materials in contact with the water during immersion, according to [5.8.1](#).

4.9.2 Exterior dimensions

The total length, width and height of the instrument shall be reported in m.

NOTE 1 Other order of magnitude, multiples of the m, can be used to report dimensions where appropriate, such as cm or mm.

NOTE 2 Customary units can be listed in addition.

4.9.3 Mass or weight in air

The mass of the instrument in air, M_{air} , shall be reported in kg.

NOTE 1 It is an industry convention to refer to mass as weight.

NOTE 2 Customary units can be listed in addition.

NOTE 3 Other order of magnitude, multiples of the kg, can be used to report masses where appropriate, such as g.

4.9.4 Weight in freshwater

The total weight of the instrument in freshwater shall be determined in accordance with [5.8.2](#).

4.9.5 Weight in seawater

The total weight of the instrument in seawater shall be determined in accordance with [5.8.3](#).

4.9.6 Operating temperature range

The instrument shall function over the temperature range published in the datasheet according to [5.8.4](#).

4.10 Electrical

4.10.1 Input voltage range

The operating range shall be specified in terms of the minimum and maximum recommended supply voltages and verified according to [5.9.1](#).

The rated voltage shall also be specified, if different from the operating range, as the voltage above which the unit can be permanently damaged.

If an instrument requires more than one power supply for correct operation, the nominal voltage (for identification purposes) and input voltage range for each supply shall be specified. The tests specified in [5.9.1](#) shall be applied to each supply.

If an instrument requires multiple power supplies for correct operation, any sequencing requirements shall be specified.

If performing a test in this subclause would violate the sequencing requirements for instruments with multiple supply pins, the portion of the test that would violate the sequencing requirements shall not be performed. All other tests compatible with the sequencing requirements shall still be performed.

NOTE 1 Proper operation of the instrument is not guaranteed when powered at a supply voltage above or below the specified range.

Manufacturers may give additional operating points outside the recommended, such as minimum voltage after startup, load dump (above maximum) for a specified duration, etc. Instrument performance specifications shall be valid over the entire specified operating range unless otherwise stated.

4.10.2 Operating power consumption

Manufacturers may specify either the current consumption or power consumption of the instrument according to [5.9.2](#). Instruments with switched-mode power converters that require substantially constant power over the input voltage range should be specified in terms of input power required. Instruments employing linear regulators may be specified using either power or current consumption.

Regardless of the method used (power or current consumption), the quantity specified shall be indicative of the maximum value encountered over the entire input voltage rating.

4.10.3 Startup power consumption

For instruments where the power consumption varies significantly at startup, for example instruments which charge internal batteries, employ heating elements for temperature stability, etc., the manufacturer may specify the steady-state power or current consumption per [4.10.2](#) and shall also specify the maximum operating power and duration of the startup interval.

4.11 Interface

4.11.1 Electrical connections

The wiring diagram (pinout) for every exposed connector or cable shall be provided. If the instrument is terminated with a cable, the wire color or other method of identification shall be specified. If the instrument employs a connector, the connector pin locations shall be documented by assigning pin numbers to the connector's face view, and the pin positions indicated as either male (pins) or female (sockets).

Each pin shall be identified as either a voltage supply pin, a reference pin, or a signaling pin. In the case of supply pins, the nominal supply voltage and return terminal number should be identified. In the case of signaling pins, the relevant signal voltage standard (e.g. 100Base-Tx, TTL, RS-232, RS-422, etc.) shall be stated.

Each pin shall be identified as either isolated or non-isolated with respect to seawater. Isolated pins are those pins through which less than 1 μ A current flows when a 100 V supply is applied in accordance with [5.10.3](#).

Any commands, software or other information needed to connect to the instrument for the purposes of performing the tests of this document shall be provided to the test laboratory. The title (and version if applicable) of the provided document should be included with the test report.

4.11.2 Communications protocol

For instruments which return fewer than 100 samples per second, an ASCII command interface should be employed.

If proprietary and/or binary communication protocols are employed, the manufacturer shall either make the protocol details available or shall provide software for controlling and receiving data from the instrument.

Any relevant information required to communicate with the instrument and interpret the reported data shall be contained in a reference manual available to users of the instrument, including personnel operating the equipment to implement the test procedures of [Clause 5](#).

4.12 Stability

The bias that develops over time due to immersion in seawater and in an on-state shall be determined according to [5.11](#).

4.13 Shelf-life

The bias that develops over time while the sensor is in an off-state and exposed only to air shall be determined according to [5.12](#).

5 Test methods

5.1 Overview

This Clause specifies the test methods to determine sensor specifications for a specific sensor model.

5.2 General experimental design

5.2.1 General

This subclause specifies experimental design requirements common to all test methods.

5.2.2 Sensor settings

Marine environment sensors allow selection of settings which can significantly alter performance, such as sample rate. All tests in [Clause 5](#) require settings as described in a) to c) below, unless noted.

a) Sample rate

The sample rate shall be set to the highest rate available to the user.

b) Averaging

The averaging shall be set to the lowest level available to the user.

NOTE Manufacturers can oversample and average prior to indication. This oversampling and averaging is not available to the user, and is not covered in this clause.

c) Bit depth

For instruments with selectable bits per sample, the bit depth shall be set to the highest setting available to the user.

5.2.3 Reference

Tests requiring a reference measurement shall use the method known as the calibration method, described in [5.3.1](#).

EXAMPLE If, during calibration of a conductivity cell, a manufacturer uses a reference which includes a stirred bath of seawater, a guildline autosalinometer, and a high-accuracy PRT temperature probe, the same experimental setup (but not necessarily the identical model numbers) must be used when conducting accuracy, resolution, and stability tests, etc.

5.2.4 Re-calibration

Sensors shall not be recalibrated at any point during a test.

5.3 Calibration

5.3.1 General

One or more sensors are compared to a reference. From this comparison, a one-to-one mathematical relationship, often linear, is established between sensor indications and quantity values.

5.3.2 Calibration method

The calibration method delimits a broad category of calibration operations. Calibrations should be done according to International Standards, if available. If no International Standard is available, a national standard in the country of design or manufacture can be used. If no national standard exists in the country of design or manufacture, any national standard may be used. If no international or national standards for calibration exist, the manufacturer may employ an internal procedure but shall make the details of the procedure publicly available. Regardless of the method employed, the manufacturer shall clearly state the method used.

EXAMPLE The use of distilled water with the formula in reference^[9] would satisfactorily define a method for sound speed calibration.

5.3.3 Experimental design — Layout of the calibration

5.3.3.1 Number of levels and calibrated range

There are no requirements on the number of levels or their range.

The minimum and maximum levels determine the calibrated range.

NOTE 1 The minimum and maximum quantity values of the calibrated range can be rounded, or be approximations of the minimum and maximum levels achieved during calibration.

EXAMPLE A thermometer is calibrated in a stirred bath with temperature ranging from just above freezing to just below boiling. The calibrated range may be given as 0 °C to 100 °C even though the lowest temperature achieved is 0,13 °C and the highest temperature achieved is only 99,5 °C.

NOTE 2 A manufacturer can calibrate at many levels to initially characterize the relationship between indication and quantity value but find that only a single level adjustment is required during calibration of serialized sensors. In this case, the calibration range is the minimum and maximum levels tested during the characterization calibration.

5.3.3.2 Reference

The reference shall be a measurement standard, traceable according to ISO/IEC 17025 to a reference quantity value, preferably to a primary measurement standard of the International System of Units.

EXAMPLE 1 The reference during a temperature sensor calibration can be a stirred bath with a high accuracy PRT-based temperature probe with measurement units of degrees Celsius and stated accuracy. The temperature probe is a measurement standard, in this case a secondary measurement standard. It is traceable to a reference quantity value, in this case the triple point of water and other chemicals (ITS-90), that is also a primary measurement standard with SI units. The reference thus meets all requirements and the preference of this document.

EXAMPLE 2 The reference during a marine turbidity sensor calibration can be the use of a microsphere aqueous solution with a stated accuracy. The reference (micro-polymer bead aqueous solution) is a measurement standard, in this case a primary measurement standard because it is prepared by mixing by weight. It is traceable to a reference quantity value NTU^[2] but is not an SI unit. The reference meets all the requirements, but not the preference of this document.

5.3.4 Calibration curve

The choice of the mathematical relationship is left to the discretion of the manufacturer.

NOTE 1 Linear, higher-order polynomials and exponential functions are commonly used to relate indications to quantity values.

NOTE 2 The calibration curve is considered a part of the sensor model.

5.3.5 Post-calibration operations

The sensor with new calibration should be verified at minimum one level.

5.4 Accuracy

5.4.1 General

The accuracy of a marine sensor relative to a reference is determined by a test method based on ISO 5725 (all parts), with exceptions as noted in [5.4.2](#). An example accuracy experiment can be found in [Annex A](#).

NOTE 1 In this document, the accuracy of the sensor is determined relative to a measurement standard. Therefore, the trueness of the measurement standard itself is not a component of the accuracy of the sensor. Some manufacturers refer to this as “relative accuracy”.

NOTE 2 The accuracy of the sensor model is determined a short interval of time after calibration. Some manufacturers refer to this as “initial accuracy”, or “calibration accuracy”. The stability of the sensor is considered separately in [5.11](#).

NOTE 3 The accuracy of the sensor model is determined without a post-deployment calibration in accordance with [5.2.4](#). Manufacturers often recommend performing a post-deployment calibration to be used (possibly averaged) with the pre-deployment calibration, thereby achieving a lower measurement uncertainty. This improved uncertainty can be discussed in a footnote within the datasheet.

5.4.2 Modifications to ISO 5725

5.4.2.1 General

To determine the accuracy of a measurement method, ISO 5725 (all parts) determines precision and trueness. “Trueness” refers to closeness of agreement between the average of many replicate measurements and a reference, while “precision” refers to the closeness of agreement between measurements on the same or similar bodies. Trueness is expressed as bias. In the case where bias is shown to be insignificant, the precision of a measurement determines its accuracy.

In this document, as discussed in later clauses, the same reference used during calibration in [5.3](#) shall be used to assess accuracy. This has two effects: 1) the precision experiment is conducted relative to a measurement standard and, 2) the calibration operation removes any significant bias according to ISO 5725 (all parts).

5.4.2.2 Inter-sensor variability

ISO 5725 (all parts) considers precision further, highlighting the factors that cause its variability in ISO 5725-1:1994, 0.3. These factors include changes in the operator, equipment, calibration of the equipment, environment, and time elapsed between measurements. All these factors constitute a “laboratory”, which is the measuring system being assessed. Under repeatability conditions these factors are held constant (same laboratory), while under reproducibility conditions they are not (multiple laboratories). These two conditions of repeatability and reproducibility thus represent the extreme cases of precision, with repeatability conditions producing the minimum variability and reproducibility conditions producing the maximum variability.

These concepts and their accompanying statistical methods, such as those described in ISO 5725-2, can be leveraged to the context of marine environment sensors with slight modification. In this context, the measuring system requiring characterization is not the laboratory, but the sensor. To adapt ISO 5725 (all parts), the word “laboratory” is replaced with “sensor”. Therefore, in this document repeatability conditions require that the same sensor be used, while reproducibility conditions require that multiple sensors be used.

Additionally, this document requires the use of the terms and definitions in [Clause 3](#), which are based on ISO/IEC Guide 99 and compete with those in ISO 5725 (all parts). The manufacturer is directed to [Table 1](#) for terminology equivalences.

Table 1 — Terminology equivalences between this document and ISO 5725 (all parts)

This document	ISO 5725
measurement	observed value
measurement result	test result
level	level of the test in a precision experiment
cell	cell in a precision experiment
reference quantity value	accepted reference value
measurement accuracy	accuracy
measurement trueness	trueness
measurement precision	precision
measurement bias	bias
repeatability condition of measurement	repeatability conditions
reproducibility condition of measurement	reproducibility conditions
number of sensors of the same design participating in an experiment, p	number of laboratories participating in an experiment, p
inter-sensor, L	inter-laboratory, L
To read the relevant clauses in ISO 5725 (all parts), the terms in the left column can replace the corresponding terms in the right column.	

5.4.3 Statistical model

ISO 5725-1:1994, Clause 5, gives an overview of the statistical model.

5.4.4 Determination of precision

5.4.4.1 General

Precision is determined as a special case of ISO 5725-2. The two conditions of precision that shall be tested for are repeatability and reproducibility.

5.4.4.2 Repeatability conditions

Repeatability conditions are in accordance with ISO 5725-1, where all the factors remain the same: the same reference is measured at the same site by the same operator with the same equipment with the same calibration of the equipment and with the same sensor over a short interval of time.

The reference shall be the same as was used in [5.3](#).

A group of (n) replicate measurements on a reference conducted under repeatability conditions shall be performed independently, as if they were measurements on separate references.

NOTE The aim of this subclause is to make sure that no variability is removed from the test that customers cannot avoid.

EXAMPLE 1 When performing an accuracy experiment on a conductivity sensor, the reference is a measuring system which typically includes a stirred bath of seawater. Conductivity transducers, known as bridges, contain electrical terminals that can be influenced by how chemically wetted they are. To satisfy the phrase “performed independently” above, a manufacturer must consider whether the instrument must be removed from the bath between measurements to include this wetting affect. If it is deemed that a customer can avoid this effect —e.g. by submerging the instrument prior to deployment— or that the effect is negligible, the instrument may not need to be removed from the bath between measurements during the determination of accuracy.

EXAMPLE 2 When performing an accuracy experiment on a pressure sensor, the reference is a measuring system which typically includes a more precise quartz-based pressure sensor, and a dead-weight tester to change the pressure of the system. It is well known that pressure sensors are affected by hysteresis induced by pressure cycling. To satisfy the phrase “performed independently” above, the dead-weight tester must be cycled back to zero between measurements to include the variability associated with this unavoidable effect.

5.4.4.3 Reproducibility conditions

Reproducibility conditions are intermediate conditions in accordance with ISO 5725-3, where one of the repeatability condition factors is changed. Instead of the same sensor, multiple sensors of the same model are used.

Therefore, in this document, reproducibility conditions refer to use of the same reference measured at the same site by the same operator with the same equipment with the same calibration of the equipment, over a short interval of time, but using multiple sensors of the same model.

All additional requirements in [5.4.4.2](#) apply.

5.4.5 Experimental design — Layout of the precision experiment

5.4.5.1 Number of sensors

A minimum of 3 sensors of the same model (p) shall be tested.

5.4.5.2 Number of levels and range

Three or more levels shall be tested.

The minimum and maximum levels determine the measuring range of the sensor.

NOTE The minimum and maximum quantity values of the measuring range can be rounded, or approximations of the minimum and maximum levels can be made.

5.4.5.3 Environmental conditions

There is no requirement to determine the effect of influencing quantities on accuracy, but it is recommended that they be considered by the manufacturer, and preferably temperature, pressure and salinity over the range found in Neptunian waters.

EXAMPLE An accuracy experiment on a turbidity sensor model is performed at 3 levels of nephelometric turbidity unit (ISO 7027-1:2016) using a micropolymer bead aqueous solution as reference. Each level is at ambient temperature and pressure, in this case $T = 21\text{ }^{\circ}\text{C}$, $P = 101,325\text{ kPa}$, and $S_A = 0\text{ g/kg}$. This satisfies the requirements of this document.

Manufacturers should test levels at combinations of temperature, pressure and salinity found in Neptunian waters where a reference is available.

NOTE Influencing quantities, such as temperature and pressure, can affect the sensitivity of transducers independently of the measurand.

5.4.5.4 Number of replicates

The number of replicate measurements (n) shall be large enough for the uncertainty factor, A_r , from ISO 5725-1:1994, 6.3.2.1 Formula (9), which is reproduced below, to be less than 0,41.

$$A_r = 1,96 \sqrt{\frac{1}{2p(n-1)}}$$

NOTE 1 The number of replicates calculated from the formula above can also be used in determining the reproducibility standard deviation in this document. The uncertainty in the reproducibility standard deviation in ISO 5725-1:1994, Formula (10) (not shown), is not considered.

NOTE 2 To satisfy the above formula with p equal to 3, n must be greater than or equal to 5. With n equal to 5, the estimated repeatability standard deviation can be expected to be within ± 41 % of the true repeatability standard deviation 95 % of the time. See ISO 5725-1:1994, Table 1, to see the effect of different values of n and p on A_r . The uncertainty in the reproducibility standard deviation can be calculated using ISO 5725-1:1994, Formula (10) (not shown).

5.4.5.5 Calibration of sensors

Sensors shall have been calibrated in accordance with [5.3](#).

5.4.6 Reference

The reference shall be in accordance with [5.2.3](#).

5.4.7 Determination of trueness (bias)

Bias is determined as a special case of ISO 5725-4, where [5.4.5](#) and [5.4.8.2](#) in this document apply.

Additionally, the reference in [5.4.6](#) shall be a measurement standard, traceable according to ISO/IEC 17025 to a primary measurement standard.

5.4.8 Statistical analysis

5.4.8.1 Precision

The repeatability standard deviation and reproducibility standard deviation shall be calculated according to ISO 5725-2:2019, Clause 8.

5.4.8.2 Trueness

Bias is calculated according to ISO 5725-4:2020, 5.5.3. An example calculation can be found in [Annex A](#).

If bias is determined to be insignificant at all levels using a 95 % confidence interval, the accuracy of the sensor is the reproducibility standard deviation.

NOTE Formula (17) in ISO 5725-4:2020 is ignored.

5.5 Resolution

5.5.1 General

Measurements are made on a reference under reproducibility conditions, and the standard deviation of sensor indications associated with noise, known as the noise standard deviation (s_{noise}), is calculated.

5.5.2 Experimental design

The layout of the resolution experiment shall be in accordance with [5.4.5](#).

5.5.3 Calculation of s_{noise}

s_{noise} is the general mean of $s_{\text{noise}_{ij}}$, which shall be calculated individually for (p) sensors called (i) ($i=1, 2, \dots, p$), for (m) levels called (j) ($j=1, 2, \dots, m$), for (n) replicate sets of indications called (k) ($k=1, 2, \dots, n$).

$$s_{\text{noise}} = \frac{1}{p} \frac{1}{m} \sum_{j=0}^m \sum_{i=0}^p s_{\text{noise}_{ij}}$$

5.5.4 Calculation of $s_{\text{noise}_{ij}}$

When measuring the reference, the steady-state indication ($\bar{I}$) shall be determined by an average of indications over a period of at least 10 time constants, as determined in accordance with [5.6](#).

The residual (e) is calculated by taking the difference of the indication (I) and the steady-state indication ($\bar{I}$) for that sensor (i), for that level (j), for that replicate (k):

$$e_{ijk} = I_{ijk} - \bar{I}_{ijk}$$

$$s_{\text{noise}_{ij}} = \sqrt{\frac{1}{n} \sum_{k=0}^n e_{ijk}^2}$$

5.6 Response time

5.6.1 General

A response curve is developed that shows how indications respond to an instantaneous step change in quantity value. The response curve is determined from combination of experiment, and knowledge of the physics of the measurement principle and any digital processing. The time constant (t_{63}), the time for the indication to reach 63,2 % of the final steady-state indication, is calculated from the response curve. Examples are found in [Annex B](#).

NOTE The response time is a property of quasi-static sensors designed to measure time-varying quantities that can be more appropriately characterized by their frequency response. This is outside the scope of this document.

5.6.2 Experimental design

5.6.2.1 General

The layout of the response time experiment shall be in accordance with [5.4.5](#), except for [5.4.5.2](#), and, additionally, it shall meet the requirements of [5.6.2.2](#) to [5.6.2.5](#).

NOTE Because it is not a requirement to meet [5.4.5.2](#), it is only necessary to perform the step experiment across one level (having an initial and final step level) within the measuring range of the sensor.

5.6.2.2 Medium

The substance carrying the quantity shall be an aqueous solution.

EXAMPLE 1 Distilled water is an example of substance that meets this document.

EXAMPLE 2 Although it possible to measure the response time of gaseous quantities, such as oxygen, in air, this is an example of a substance that does not meet this document.

5.6.2.3 Sample period

The sample period of the sensor used in the experiment shall be less than the time constant.

NOTE It is common for manufacturers to sample at a rate higher than indicated to filter the signal. This “over-sampling” period can be used in the determination of the response time.

EXAMPLE The response time of a temperature sensor is 35 ms. The highest sample rate indicated in the datasheet is 25 Hz or a sample period of 40 ms. The sensor over-samples at a rate of 100 Hz, or every 10 ms, and filters the output prior to indication. Because the over-sampling period of 10 ms is less than the time constant of 35 ms, this experiment satisfies the requirements of this document.

5.6.2.4 Flow

The flow conditions should be controlled, typical of the application, and recorded during the experiment.

5.6.2.5 Step change

For the requirements for speed, levels, polarity and continuity of the step change, see a) to d) below.

a) Speed

The speed of the step change shall be less than the response time of the sensor.

b) Step levels

The references used at initial and final step levels during the step change shall have an associated quantity value, and shall be within the measuring range of the sensor.

At least 10-time constants at initial and final step levels should be acquired during the test and used in the calculation of initial and final steady-state indications.

c) Rising vs. falling step

There is no requirement that the step change be from low quantity value to high quantity value, or vice versa.

Response time dependence on polarity should be considered by the manufacturer, and if deemed to be dependent, both rising and falling steps should be tested and published.

d) Continuity

The sensors shall not transit out of the medium during the step change experiment unless it can be scientifically proven that the determined response time is still within the stated uncertainty for the same conditions.

EXAMPLE The sensor may not transit through air between beakers of differing levels to induce the step change.

5.6.3 Response curve

5.6.3.1 General

The response curve is an expression of the relation of sensor indications and time in response to an instantaneous step change in quantity.

NOTE The response curve can include “oversamples” not indicated.

5.6.3.2 Determination of the response curve

Choice of an appropriate mathematical relationship and fitment to experimentally determined indications from each replicate is left to the discretion of the manufacturer.

The closeness of data fit to the response curve is left to the discretion of the manufacturer.

EXAMPLE The response curve can be based on an exponential function. This is the case with PRT-based temperature sensors, which show a 1st order response.

5.6.3.3 Determination without experiment

If it is impractical or not possible to conduct a response time experiment in accordance with 5.6.2, the response curve shall still be modelled. An example determination of time constant without a step experiment can be found in Annex B.

EXAMPLE Sound velocity and conductivity sensors are two examples that have response times on the order of milliseconds. There are few practical methods available to manufacturers to induce a step change in the parameter that is significantly lower than the response time of the sensor. Therefore, an estimate of the response time based solely on the modelled response curve can be made.

In the case of sound speed sensors, the time constant is less than the indicated sample period. The response curve can be fit to oversamples derived from knowledge of the transducer and digital processing steps prior to indication. These include the transit time of the acoustic pulse, digital correlation and filtering (see Annex B).

5.6.3.4 Calculation of t_{63}

t_{63} is the general mean of t_{63ik} which shall be calculated individually directly from the response curve for (p) sensors called (i) ($i=1, 2, \dots, p$), for (n) replicate sets of indications called (k) ($k=1, 2, \dots, n$).

$$t_{63} = \frac{1}{p} \frac{1}{n} \sum_{k=1}^n \sum_{i=1}^p t_{63ik}$$

If no experimental data was collected in accordance with 5.6.2 in support of the determination of the response curve, a footnote shall be added to the time constant in the datasheet of 6.2 with the word "modelled only".

In addition to t_{63} , determinations of t_{90} and t_{99} should be made directly from the response curve.

5.7 Depth and pressure

5.7.1 Maximum depth rating

The rated pressure shall be given in units of hydrostatic depth (meters).

If rated pressure is given in meters, the equivalent test pressure is calculated according to the following simplified formula:

$$P_{\text{static}} = (d + 10,0 \text{ m}) \times 10,1 \text{ kPa/m}$$

where P_{static} is the required test pressure and d is the depth in meters.

The simplified formula approximates absolute pressure at depth and includes a correction for atmospheric pressure at sea level.

The test shall include at least one cycle at $1,1 \times P_{\text{static}}$ held for 1 min and may be cycled to other intermediate values at the discretion of the manufacturer.

The instrument shall function normally before and after the test. There is no requirement that the instrument be monitored during the test. If function is verified during the test, the manufacturer may indicate this.

In the case where only design verification testing is performed, the manufacturer shall specify the number of instruments tested.

The manufacturer shall indicate whether the test is performed as a serialized test or for design verification purposes only. In the event serialized testing is performed, a certificate with the date of the test, serial number of the instrument and test result, along with any other pertinent information, should be provided with the instrument.

5.7.2 Crush depth rating

The mechanical, wetted envelope of the instrument shall be tested to $1,25 \times P_{\text{static}}$. The instrument need not be functional before or after the test, as the purpose of this test is only to verify the design of the pressure housing.

Gradually increase the test vessel pressure to $1,25 \times P_{\text{static}}$, and hold for at least 1 min. If the mechanical envelope is compromised before the test pressure is reached, record the pressure at which the failure occurs. Otherwise, record the maximum test pressure. The test may be repeated using any number of units, and the median result should be taken.

The manufacturer shall indicate whether the test was performed, the date, number of replicates and result.

The manufacturer shall not perform this test on a serialized basis. Specifically, instruments which have been used for this test should not be sold as new instruments.

5.7.3 Pressure case void

The manufacturer should disclose whether the sensor or instrument has an atmospheric housing or fluid-filled housing. Format of the publication is left to the discretion of the manufacturer.

5.8 Mechanical

5.8.1 Wetted materials

All materials in contact with water when the instrument is submerged are considered wetted.

NOTE If a material is coated, the material is still considered wetted, e.g. "anodized aluminium".

5.8.2 Weight in freshwater

Weight in freshwater shall agree numerically with the following, and is determined as follows:

$$M_{\text{fresh}} = (M_{\text{air}} - V \times 1\,000 \text{ kg/m}^3)$$

where

M_{fresh} is the weight in freshwater, reported in units of kg;

M_{air} is the mass or weight in air, reported in units of kg;

V is the volume, in cubic meters.

NOTE 1 It is an industry convention to refer to mass as weight.

NOTE 2 Customary units can be listed in addition.

NOTE 3 Other order of magnitude, multiples of the kg, can be used to report weight in water where appropriate, such as g.

NOTE 4 The displaced volume can be determined from this formula if the weight in water and weight in air are known.

NOTE 5 If the force of gravity is greater than the buoyancy, the instrument sinks and the sign of the reported mass is positive. In the opposite case, the instrument floats and the reported mass is negative.

5.8.3 Weight in seawater

Weight in seawater shall agree numerically with the following, and is determined as follows:

$$M_{\text{sea}} = (M_{\text{air}} - V \times 1\,026 \text{ kg/m}^3)$$

where

M_{sea} is the weight in seawater, reported in units of kg;

M_{air} is the mass or weight in air, reported in units of kg;

V is the volume in cubic meters.

NOTE 1 It is an industry convention to refer to mass as weight.

NOTE 2 Customary units can be listed in addition.

NOTE 3 Other orders of magnitude, multiples of the kg, can be used to report weight in water where appropriate, such as g.

NOTE 4 The displaced volume can be determined from this formula if the weight in water and weight in air are known.

NOTE 5 If the force of gravity is greater than the buoyancy, the instrument sinks and the sign of the reported mass is positive. In the opposite case, the instrument floats and the reported mass is negative.

NOTE 6 A seawater density of 1 026 kg/m³ is used for this calculation. It is the density reported in reference^[8] for $T = 15\text{ }^{\circ}\text{C}$, $S_A = 35,17\text{ g/kg}$ and pressure at sea level.

5.8.4 Operating temperature range

The instrument shall turn on from a cold start and perform basic functions for a period of 24 h at each of the min., max. and one point within the stated operating temperature range.

5.9 Electrical

5.9.1 Input voltage range

With the minimum input voltage applied, verify that normal startup occurs. Gradually increase the voltage supply and verify that the unit is still operating normally at at least two additional points.

5.9.2 Operating power consumption

If power consumption is to be given in terms of nominal and startup power consumption, allow the instrument startup to complete (internal battery charging, warmup, etc.) before proceeding with the remainder of this test.

Measure the input current while slowly increasing the applied voltage from the specified minimum input voltage to the specified maximum input voltage. Record the highest current observed as I_{max} . Operating current consumption may be given simply as I_{max} .

Alternatively, the input current can be tabulated over at least 10 points more or less equally spaced between the minimum and maximum input voltages. Multiply the current consumption by the input voltage used for each current measurement and find the maximum value. This value is P_{max} .

5.9.3 Startup power consumption

With the instrument in a cold, discharged (if applicable) state, apply the minimum specified input voltage and observe the maximum input current. If the instrument employs significant input capacitance, the measurement may be made using a series resistance, current limiter, or other means only if doing so does not prevent the instrument from starting normally. Since the purpose of this test is to ensure that normal startup will occur even over long instrument leads, using current- or power- limited conditions, the only requirements imposed on this test are:

- a) normal startup shall not be prevented;
- b) the conditions of the test (current limit, series resistance, etc.) shall be reported.

The test should be repeated at maximum input voltage. Either the maximum power or current may be reported, but the reported value shall be the largest value observed during both minimum and maximum input voltage conditions.

5.10 Interface

5.10.1 General

Full testing of the communications capability of the instrument is generally outside the scope of this document, except for the exceptions in [5.10.2](#) and [5.10.3](#).

5.10.2 Power on/standby

If a telemetry method is provided to permit the instrument to be switched on, off or placed into standby, the correct operation of these functions shall be verified at the design stage.

5.10.3 Galvanic isolation test

Identify a pin or other point of contact that is electrically connected to any exposed metal on the case, or which is identified as earth, ground or seawater ground; this terminal shall be the reference terminal.

Identify any pins identified as being “isolated” from the case, ground, or seawater; these terminals shall be identified as test terminals.

For each of the test terminals, place a 100 V supply in series with a 1 M Ω resistor between each test terminal and the reference terminal in sequence. If the voltage measured across the 1 M Ω resistor is less than 1 V, the test is passed (less than 1 μ A of current is flowing between the test terminal and the reference terminal). Repeat for all test terminals.

The test shall be repeated but with the polarity of the applied voltage reversed.

5.11 Stability

5.11.1 General

Sensors are subjected to an ambient temperature and pressure seawater bath until significant bias is observed and a minimum of one month has elapsed. Bias is calculated at the end of the experiment and drift (d) is calculated as bias per month. The duration of the test in months, Δt , is also reported.

5.11.2 Experimental design

The layout of the stability experiment shall be in accordance with [5.4.5](#), except for [5.4.5.2](#), and additionally in accordance with a) to e) below.

a) Reference

The reference measurement shall be in accordance with [5.2.3](#).

b) Medium

The sensors shall be placed in seawater for the test.

There are no requirements on the type of seawater or for the salinity to remain constant throughout the test.

There are no requirements on the temperature or pressure of the test, but ambient conditions are recommended.

NOTE The sensors can be removed from the seawater bath for short periods of time to determine bias.

EXAMPLE Seawater is acquired from the Pacific Northwest, near Seattle, US. A bath is setup in a room where the temperature and pressure are uncontrolled, varying from approximately 15 °C to 25 °C and 100 Pa to 102 kPa over the duration of the test, which lasts 6 months.

c) Duration of test

The test shall continue until the bias at all levels is significant, as determined by [5.4.7](#), and at least one month has elapsed.

d) Sensor state

The sensor shall be on and taking measurements for the entire test.

e) Post-processing

No post-processing that makes use of a posteriori knowledge shall be performed on the measurement results in the determination of stability.

NOTE 1 "A posteriori knowledge" refers to any information gained after the sensor has made a measurement.

EXAMPLE Manufacturers often recommend performing a post-deployment calibration. This allows to improve the stability of the measurements previously conducted by interpolating the calibration curve between the pre- and post-calibrations. This post-processing requires knowledge of the metrological properties of the sensor after the measurements were taken and is not allowed in the determination of stability. Additionally, the post calibration is considered a re-calibration as per [5.2.4](#), which is not allowed during any of the tests in this document.

NOTE 2 A manufacturer can additionally determine stability with a post-calibration and post-processing, and add a footnote to the datasheet discussing the improved stability that can be achieved.

5.11.3 Calculation of d

For a level j , the drift per month (d_j) is calculated as follows:

$$d_j = \frac{\delta_{\max} - \delta}{\Delta t}$$

where

$\delta_{\max}$ is the average bias of all sensors detected at the end of the experiment;

δ is the average bias of all sensors at the beginning of the experiment in accordance with [5.4.8.2](#);

Δt is the number of months.

The calculations for remaining levels shall be carried out similarly. d is then the RMS of all d_j .

NOTE As the sensors begin the test after undergoing a calibration, δ is expected to be small.

5.11.4 Field stability

5.11.4.1 General

Manufacturers recalibrate sensors returning from the field several times over the lifespan of a sensor. It is thus possible to calculate the drift occurring over a large sample population of users and sensors. Because field use is unknown, and can vary significantly between users and manufacturers, the bias developed between calibrations is poorly suited for comparison between manufacturers, and as such is not a required specification. This field stability remains of significant interest to users and manufacturers as an indicator of maintenance intervals, such as for the frequency of recalibration, and generally for field performance. This subclause provides guidelines on how to calculate this drift.

5.11.4.2 Guidelines on determination

Outliers, such as data from malfunctioning sensors, should be considered and removed.

The number of sensors and average number of years outside of the factory of the data set should be included in the publication.

A general mean should be reported as an average of all levels, per year, as opposed to per month.

5.11.4.3 Publication

Field stability shall not be published as a specification in the data sheet.

NOTE Field stability can be published as a footnote in the datasheet, ideally with a link to a test report.

5.12 Shelf-life

5.12.1 General

Sensors are subjected to room temperature and atmospheric pressure in an off state until significant bias is observed and a minimum of one month has elapsed. Bias is calculated at the end of the experiment and drift (d) is calculated as bias per month. The duration of the test in months, Δt , is also reported.

5.12.2 Experimental design

The layout of the shelf-life experiment shall be in accordance with [5.11.2](#) except for [5.11.2 b\)](#). The sensors shall not be submerged in a seawater bath, but left in air.

5.12.3 Calculation of d

The calculation shall be in accordance with [5.11.3](#).

6 Publication

6.1 General

This Clause specifies publication requirements, which are given in two subclauses. Data sheets are used to publish required design specifications for a sensor model listed in [Clause 4](#). Test reports describe the experiments in [Clause 5](#) conducted in support of the specification values published in the data sheets. Calibration certificates are a special type of test report, generated for an individual sensor model every time it is calibrated.

6.2 Data sheets

6.2.1 General

To meet this document, all specifications listed in the recommended data sheet, shown in [Table 2](#), shall be published and made publicly available by the manufacturer. An example data sheet is shown in [Annex C](#).

The phrase “Specifications conform to ISO 22013:YYYY”, where “YYYY” is the most recent year of the standard that the manufacturer conforms to, should be included in the data sheet.

NOTE 1 A manufacturer can publish additional specifications not covered by this document.

NOTE 2 It is not a requirement that the reference clauses for each specification in [Table 2](#), highlighted in dark grey, be published by the manufacturer. These are for reference in this document only.

NOTE 3 It is not a requirement to match the format or the order of the specifications given in [Table 2](#).

Table 2 — Recommended data sheet format for publication of specifications

		Model or series name: XXX-XX-XXX specifications											
Ref. clause			Min.	Max.	Units		Min.	Typ	Max.	Units	Ref. clause		
Req. ^{a)}	T.M. ^{a)}	General					Electrical				Req. ^{a)}	T.M. ^{a)}	
4.3.3		Range, max.				Input voltage range, startup				V	4.10.1	5.9.1	
4.3.1	5.3.3.1	Range, calibrated				Input voltage range, operating				V	4.10.1	5.9.1	
4.4	5.2.2	Repeatability				Power consumption, startup				W	4.10.3	5.9.3	
4.4	5.2	Accuracy				Power consumption, operating				W	4.10.2	5.9.2	
4.5	5.5	Resolution, s_{noise}											
		Digital display											
		Sample rate, max.				Hz	Mechanical/Physical						
4.6	5.6	Response time, t_{63}				ms	Wetted materials					4.9.1	5.8.1
4.7.1	5.7.1	Depth rating, max.				m	Operating temperature range				°C	4.9.6	5.8.4
4.12	5.11	Stability, d			month	Mass (weight in air)					4.9.3		
4.13	5.12	Shelf life, d			month	Weight in freshwater					4.9.4	5.8.2	
						Weight in seawater					4.9.5	5.8.3	
		Specifications conform to ISO 22013:YYYY.											
		Additional manufacturer information (having no tests in the standard, i.e. field stability, special handling instructions, recommendations, etc.): - Example 1 - Example 2											
		a) Req.: requirement; T.M.: Test method.											

It is permissible to express customary units alongside SI units in the datasheet. In the case of a discrepancy between a specification expressed using SI units and the same value expressed using customary units, the SI value shall be taken as correct.

If a specification is not applicable, the specification value shall be listed as “not applicable” in the data sheet.

6.2.2 Test reports

This subclause provides recommendations for reporting testing conducted in accordance with [Clause 5](#).

The test reports should include the experimental design, and any significant intermediate quantitative results.

The test reports should be in accordance with ISO/IEC 17025:2017, 7.8, and be made available to customers on request.

6.3 Calibration certificates

This subclause specifies requirements for reporting calibrations conducted in accordance with [5.3](#).

To be in accordance with this document, all calibration certificates shall have the following:

- a title indicating “Calibration certificate”;
- the name and address of the laboratory;
- the location of the performance of the laboratory activities, including when performed at a customer facility or at sites away from the laboratory permanent facilities, or in associated temporary or mobile facilities;
- a unique identification that all its components are recognized as a portion of a complete report, and a clear identification of the end;
- the name and contact information of the customer;
- the identification of the method used;
- a description, unambiguous identification, and, when necessary, the condition of the item;
- the date of receipt of the calibration item, and the date of sampling, where this is critical to the validity and application of the results;
- the date of performance of the calibration;
- the date of issue of the report;
- a reference to the sampling plan and sampling method used by the laboratory or other bodies, where these are relevant to the validity or application of the results;
- a statement to the effect that the results relate only to the items calibrated;
- the results with the units of measurement;
- the additions to, deviations, or exclusions from the method;
- the identification of the persons authorizing the report;
- a clear identification when results are from external providers;
- the measurement uncertainty of the measurement results, presented in the same unit as that of the measurand or in a term relative to the measurand (e.g. percent)
- the conditions (e.g. environmental) under which the calibrations were made that have an influence on the measurement results;
- a statement identifying how the measurements are metrologically traceable;

- the results before and after any adjustment or repair, if available;
- where relevant, a statement of conformity with requirements or specifications;
- where appropriate, opinions and interpretations.

All calibration certificates should be in accordance with ISO/IEC 17025:2017, 7.8.1, 7.8.2, 7.8.3 and 7.8.4.

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Annex A (informative)

Determination of the accuracy (precision and trueness) — Example

A.1 Description

The accuracy of a sound velocity sensor is assessed. A total of 6 sound velocity sensors of the same model were tested at 3 levels with reference to a primary measurement standard. The minimum and maximum of the levels span the measuring range of the sensor (1 412 m/s to 1 509 m/s). 20 replicate measurements were taken for each sensor, at each level, and a statistical analysis of precision and trueness was performed.

A.2 Precision assessment

A.2.1 Cell means

The cell means of the residuals are given, in units of m/s, in [Table A.1](#) in the format of Form B in ISO 5725-2:2019. Using the residuals has no effect on the calculation of the repeatability and reproducibility standard deviations.

The residual (e) was determined by finding the difference between the test result (y) and the reference quantity value (μ):

$$e = y - \mu$$

A.2.2 Computation of standard deviations

The standard deviations are given, in units of m/s, in [Table A.2](#) in the format of Form C in ISO 5725-2:2019.

Table A.1 — Cell means of residuals

Sensor i	Level j					
	1		2		3	
	$\bar{e}_{ij}$	n_{ij}	$\bar{e}_{ij}$	n_{ij}	$\bar{e}_{ij}$	n_{ij}
1	-0,016 1	20	0,023 0	20	-0,026 5	20
2	-0,009 1		0,004 7		-0,002 7	
3	-0,031 2		0,005 9		-0,002 6	
4	0,004 2		0,018 1		0,013 8	
5	0,004 8		-0,009 3		-0,027 1	
6	0,012 0		-0,000 8		-0,019 4	