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Principles for the establishment of hierarchy schemes for measuring instruments

Principes pour l'établissement des schémas de hiérarchie des instruments de mesure

OIML D 5 Edition 2022 (E)

ORGANISATION INTERNATIONALE DE MÉTROLOGIE LÉGALE

INTERNATIONAL ORGANIZATION OF LEGAL METROLOGY

Contents

Foreword

The International Organization of Legal Metrology (OIML) is a worldwide, intergovernmental organisation whose primary aim is to harmonise the regulations and metrological controls applied by the national metrological services, or related organisations, of its Member States.

The main categories of OIML publications are:

- **International Recommendations (OIML R),** which are model regulations that establish the metrological characteristics required of certain measuring instruments and which specify methods and equipment for checking their conformity. OIML Member States shall implement these Recommendations to the greatest possible extent;
- **International Documents (OIML D),** which are informative in nature and which are intended to harmonise and improve work in the field of legal metrology;
- **International Guides (OIML G),** which are also informative in nature and which are intended to give guidelines for the application of certain requirements to legal metrology; and
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International Recommendations, Documents, Guides and Basic Publications are published in English (E) and translated into French (F) and are subject to periodic revision.

Additionally, the OIML participates in Joint Committees with other Institutions for the development of **Vocabularies (OIML V)** and **Joint Guides** and periodically commissions legal metrology experts to write **Expert Reports (OIML E)**. Expert Reports are intended to provide information and advice, and are written solely from the viewpoint of their author, without the involvement of a Technical Committee or Subcommittee, nor that of the CIML. Thus, they do not necessarily represent the views of the OIML.

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1 Introduction

1.1 The discipline and function of metrology in general, and legal metrology particularly, have changed significantly over the last 20 years, both at national and international levels. Metrology is facing multiple developments such as the globalisation of economics and international trade, digitalisation, geopolitical changes, elimination of technical barriers to trade, liberalisation, privatisation and manufacturing.

Metrology evolves together with implementation of quality management systems in various organisations, accreditation of testing and calibration laboratories, and conformity assessment procedures based on production quality systems. The quality of products and services is increasingly dependent on reliable measurements.

Metrology plays a key role in the adoption of scientific and technological innovations, the design and efficient manufacture of products that comply with the needs of the marketplace, and the detection and avoidance of non-conformities. It also provides the basis for fair trading in a domestic economy and international trading in the global market place.

Internal markets as well as the globalization of trade, industry and society require comparability of calibration, measurement and test results through traceability to the International System of Units (SI), which represents the coherent and long-term stable fixed anchor points in measurement.

1.2 In legal metrology, measurements are important for conformity assessment in the legal control of measuring instruments. Metrological traceability enters into legal metrology as a part of conformity assessment. The results of measurements covered by regulations shall be expressed in legal units and shall be traceable to the SI [1].

The importance of measurements is also reflected in relevant international documented standards by the requirement that measurement results shall be traceable to the SI through the realisations in National Metrology Institutes (NMI) which are referred to as national or international measurement standards. So, for example, according to ISO/IEC 17025:2017 [2], when the measurement accuracy and measurement uncertainty affect the validity of the measurement result, or metrological traceability is a requirement, a measuring instrument shall be calibrated before being placed into service. The calibration program for a measuring instrument shall ensure that all results obtained by the laboratory are metrologically traceable to SI units.

In line with another standard, ISO 9001:2015 [3], when traceability of measurement result is a requirement, or the traceability is considered by the organisation to be an essential part of providing confidence in the validity of measurement results, a measuring instrument shall be calibrated or verified at specified intervals or prior to use, against measurement standards having the values that are traceable to international or national measurement standards.

1.3 Metrological traceability is based on demonstrated equivalence among national measurement standards, as stated in joint BIPM, OIML, ILAC and ISO declarations on the relevance of Mutual Recognition Arrangements (MRAs) [4] and on metrological traceability [5].

1.4 The traceability of measurement results is essential in order that the results of the measurement and the claimed measurement uncertainty are comparable and meaningful. National measurement systems provide the framework within which all associated values necessary for the proper performance of calibration, testing or verification are traceable to the SI or, if this is not possible, to the values of nationally or internationally agreed reference materials.

1.5 The quest for improved measurement quality is the main reason for the existence of hierarchy schemes for measuring instruments. While the quality is achievable in a number of ways, the classical scheme based on a direct calibration chain is widely used and accepted.

1.6 In legal metrology, special precaution must be taken for a complete evaluation of the measurement uncertainty to ensure the traceability of the measurement results. Verification is sometimes conducted without the explicitly stated corresponding measurement uncertainty evaluation. In such cases, the maximum permissible error (MPE) of the measuring instrument is specified taking into account the measurement uncertainty. Where verification is performed without any explicit or implicit consideration of the measurement uncertainty, then it may not be considered to preserve or assure traceability. Refer to OIML G 19 [6] for consideration of measurement uncertainty in legal metrology.

2 Scope

2.1 This Document provides some key principles and methods of metrological traceability. It proposes general rules for the establishment of hierarchy schemes for measuring instruments including specification of calibration chains and methods for the dissemination of units. These schemes then serve as evidence of the metrological traceability.

2.2 This Document provides guidance and assistance to organisations on how to comply with the metrological traceability requirements for relevant standards. It is primarily intended to be used by legal metrology laboratories where supervision of measuring instruments and test equipment is an important element of quality assurance. This Document may also be used by organisations involved in industrial production processes (development, manufacture, installation, final inspection) and by calibration and testing laboratories.

2.3 Depending on the circumstances, methods of achieving metrological traceability other than those described herein may be applicable. These other methods may be described in other OIML International Documents.

3 Terminology

Unless otherwise stated in the following sub-clauses, the terminology used in this Document conforms to the VIML [7], the VIM [8] and the GUM [9].

For the purpose of this Document, the definitions and abbreviations given below apply.

3.1 **International System of Units** [VIM, 1.16]
SI
system of units, based on the International System of Quantities, their names and symbols, including a series of prefixes and their names and symbols, together with rules for their use, adopted by the General Conference on Weights and Measures (CGPM)

For notes see [VIM, 1.16].

3.2 **metrology** [VIM, 2.2]
science of measurement and its application

Note: Metrology includes all theoretical and practical aspects of measurement, whatever the measurement uncertainty and field of application.

3.3 **measurement uncertainty** [VIM, 2.26]
uncertainty of measurement
uncertainty
non-negative parameter characterising the dispersion of the quantity values being attributed to a measurand, based on the information used

Note 1: 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: 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: 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 characterised 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: 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.

3.4 **expanded measurement uncertainty** [VIM, 2.35]
expanded uncertainty
product of a combined standard measurement uncertainty and a factor larger than the number one

Note 1: The factor depends upon the type of probability distribution of the output quantity in a measurement model and on the selected coverage probability.

Note 2: The term “factor” in this definition refers to a coverage factor.

Note 3: Expanded measurement uncertainty is termed “overall uncertainty” in paragraph 5 of Recommendation INC-1 (1980) (see the GUM) and simply “uncertainty” in IEC documents.

3.5 **calibration** [VIM, 2.39]
operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

For notes see [VIM, 2.39].

3.6 **calibration hierarchy** [VIM, 2.40]
sequence of calibrations from a reference to the final measuring system, where the outcome of each calibration depends on the outcome of the previous calibration

For notes see [VIM, 2.40].

3.7 metrological traceability [VIM, 2.41]
property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty

Note 1: For this definition, a ‘reference’ can be a definition of a measurement unit through its practical realisation, or a measurement procedure including the measurement unit for a non-ordinal quantity, or a measurement standard.

Note 2: Metrological traceability requires an established calibration hierarchy.

For other notes see [VIM, 2.41].

3.8 metrological traceability chain [VIM, 2.42]
traceability chain
sequence of measurement standards and calibrations that is used to relate a measurement result to a reference

Note 1: A metrological traceability chain is defined through a calibration hierarchy.

Note 2: A metrological traceability chain is used to establish metrological traceability of a measurement result.

Note 3: A comparison between two measurement standards may be viewed as a calibration if the comparison is used to check and, if necessary, correct the quantity value and measurement uncertainty attributed to one of the measurement standards.

3.9 metrological traceability to a measurement unit [VIM, 2.43]
metrological traceability to a unit
metrological traceability where the reference is the definition of a measurement unit through its practical realisation

Note: The expression “traceability to the SI” means ‘metrological traceability to a measurement unit of the International System of Units’.

3.10 verification [VIM, 2.44]
provision of objective evidence that a given item fulfils specified requirements

Example 1: Confirmation that a given reference material as claimed is homogeneous for the quantity value and measurement procedure concerned, down to a measurement portion having a mass of 10 mg.

Example 2: Confirmation that performance properties or legal requirements of a measuring system are achieved.

Example 3: Confirmation that a target measurement uncertainty can be met.

For notes see [VIM, 2.44].

3.11 measuring instrument [VIM, 3.1]
device used for making measurements, alone or in conjunction with one or more supplementary devices

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

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

3.12 measuring system [VIM, 3.2]
set of one or more measuring instruments 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: A measuring system may consist of only one measuring instrument.

3.13 indicating measuring instrument [VIM, 3.3]
measuring instrument providing an output signal carrying information about the value of the quantity being measured

Examples: Voltmeter, micrometer, thermometer, electronic balance.

Note 1: An indicating measuring instrument may provide a record of its indication.

Note 2: An output signal may be presented in visual or acoustic form. It may also be transmitted to one or more other devices.

3.14 material measure [VIM, 3.6]
measuring instrument reproducing or supplying, in a permanent manner during its use, quantities of one or more given kinds, each with an assigned quantity value

Examples: Standard weight, volume measure (supplying one or several quantity values, with or without a quantity-value scale), standard electric resistor, line scale (ruler), gauge block, standard signal generator, certified reference material.

Note 1 The indication of a material measure is its assigned quantity value.

Note 2 A material measure can be a measurement standard.

3.15 measurement standard [VIM, 5.1]
etalon
realisation of the definition of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference

For examples and notes see [VIM, 5.1].

3.16 national measurement standard [VIM, 5.3]
national standard
measurement standard recognised by a national authority to serve in a state or economy as the basis for assigning quantity values to other measurement standards for the kind of quantity concerned

3.17 primary measurement standard [VIM, 5.4]
primary standard
measurement standard established using a primary reference measurement procedure, or created as an artifact, chosen by convention

For examples see [VIM, 5.4].

3.18 reference measurement standard [VIM, 5.6]
reference standard
measurement standard designated for the calibration of other measurement standards for quantities of a given kind in a given organisation or at a given location

3.19 working measurement standard [VIM, 5.7]
working standard
measurement standard that is used routinely to calibrate or verify measuring instruments or measuring systems

Note 1: A working measurement standard is usually calibrated with respect to a reference measurement standard.

Note 2: In relation to verification, the terms “check standard” or “control standard” are also sometimes used.

3.20 reference material [VIM, 5.13]
RM
material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties

For examples and notes see [VIM, 5.13].

3.21 certified reference material [VIM, 5.14]
CRM
reference material, accompanied by documentation issued by an authoritative body and providing one or more specified property values with associated uncertainties and traceabilities, using valid procedures

For examples and notes see [VIM, 5.14].

3.22 maximum permissible measurement error [VIML, 0.05]
maximum permissible error
limit of error
extreme value of measurement error, with respect to a known reference quantity value, permitted by specifications or regulations for a given measurement, measuring instrument, or measuring system

Note 1: Usually the term “maximum permissible errors” or “limits of error” are used, where there are two extreme values.

Note 2: The term “tolerance” should not be used to designate ‘maximum permissible error’.

[OIML V2-200:2012, 4.26]

Note 3: Usually the term “maximum permissible error” is abbreviated to “MPE”, or “mpe”.

3.23 legal metrology [VIML, 1.01]
practice and process of applying statutory and regulatory structure and enforcement to metrology

Note 1: The scope of legal metrology may be different from country to country.

Note 2: Legal metrology includes

- setting up legal requirements,
- control / conformity assessment of regulated products and regulated activities,
- supervision of regulated products and of regulated activities, and
- providing the necessary infrastructure for the traceability of regulated measurements and measuring instruments to SI or national standards.

Note 3: There are also regulations outside the area of legal metrology pertaining to the accuracy and correctness of measurement methods.

3.24 legal metrological control [VIML, 2.01]
the whole of legal metrology activities

Note: Legal metrological control includes

- legal control of measuring instruments,
- metrological supervision,
- all the operations for the purpose of examining and demonstrating, e.g. to testify in a court of law, the condition of a measuring instrument and to determine its metrological properties, amongst others by reference to the relevant statutory requirements.

3.25 legal control of measuring instruments [VIML, 2.02]
generic term used to globally designate legal operations to which measuring instruments may be subjected, e.g. type approval, verification, etc.

3.26 type approval [VIML, 2.05]
decision of legal relevance, based on the review of the type evaluation report, that the type of a measuring instrument complies with the relevant statutory requirements and results in the issuance of the type approval certificate

Note: See also VIML, A.25.

3.27 verification of a measuring instrument [VIML, 2.09]
conformity assessment procedure (other than type evaluation) which results in the affixing of a verification mark and/or issuing of a verification certificate

Note: See also OIML V2-200:2012, 2.44.

3.28 hierarchy scheme
descriptive and graphical specification of metrological traceability chain for a given type of measuring instrument which serves to evidence their metrological traceability

3.29 national hierarchy scheme
hierarchy scheme for a given type of measuring instrument in the particular country, containing the specification of the recommended (permissible) types of measuring instruments for individual levels of metrological traceability, requirements for their metrological characteristics (accuracy class, maximum permissible error, etc.) and recommended (permissible) methods and means of dissemination of units

3.30 local hierarchy scheme
hierarchy scheme for a given type of measuring instrument at a given location, in a given organisation or in a given laboratory, containing the specification of the reference and working measurement standards, their metrological characteristics and the methods and means of dissemination of units

3.31 means of dissemination of units
technical devices, reference materials or material measures, which are necessary to carry out calibration by comparing the measurement standards and the measuring instruments to be calibrated

Note: These means influence uncertainties of dissemination of units.

3.32 National Metrology Institute (Designated Institute)
institute in a country that has a responsibility, sometimes set out legally, for the conservation of one or more national measurement standards

Note 1: The recommended role of a National Metrology Institute (NMI) is described in detail in OIML D 1:2012, 3.2.3 [10].

Note 2: The recommended role of a Designated Institute (DI) is described in CIPM 2005-07 [11] and CIPM 2005-06 (V4) [12].

3.33 legal metrology laboratory (legal metrology services)
laboratory of an authorised institute responsible for a legal control of measuring instruments, e.g. type approval, verification, etc.

Note 1: The recommended role of such an institute is described in detail in OIML D 1:2012, 3.2.2.3 [10].

Note 2: Legal metrology laboratories are generally laboratories of the state legal metrology services or private metrology laboratories charged (authorised) by the national (legal) metrology authority to carry out legal control of measuring instruments within a defined scope.

3.34 accredited calibration laboratory
laboratory that performs calibration of measuring instruments and that is formally recognised by an accreditation authority and that is competent to carry out the calibration (e.g. competence in accordance with ISO/IEC 17025:2017 [2])

4 Metrological traceability and its elements

4.1 Objectives of metrological traceability

Metrological traceability of the results obtained through the use of measuring instruments or reference materials and test equipment by means of traceable calibration or verification, which provides for the comparability of measurement results, is necessary:

a) to support the requirements of growing national and international trade;
b) to guarantee the product quality and compatibility of manufactured parts;
c) to protect the interests of individuals and enterprises;
d) to protect national interests; and
e) to protect public health and safety, including the environment, medical and related services.

4.2 Application in legal metrology

4.2.1 For the application of any laws and regulations prescribing requirements on measurements, on prepackages and on measuring instruments, metrological traceability to SI units is required. The traceability may be obtained through the system of national measurement standards and certified reference materials provided either by local sources or by any other internationally recognised sources.

4.2.2 The evaluation of the measurement uncertainty may be necessary to provide the metrological traceability for the application of legal metrology control.

4.3 Metrological traceability

Metrological traceability generally requires that measurement results are compared, in one or more stages, with the realisation of the SI for the measurand in question. In each of these stages, a calibration is performed against a measurement standard for which the value and uncertainty have already been determined by another calibration with a higher-level standard. Therefore there is a hierarchy of calibrations as shown in Fig. 1.

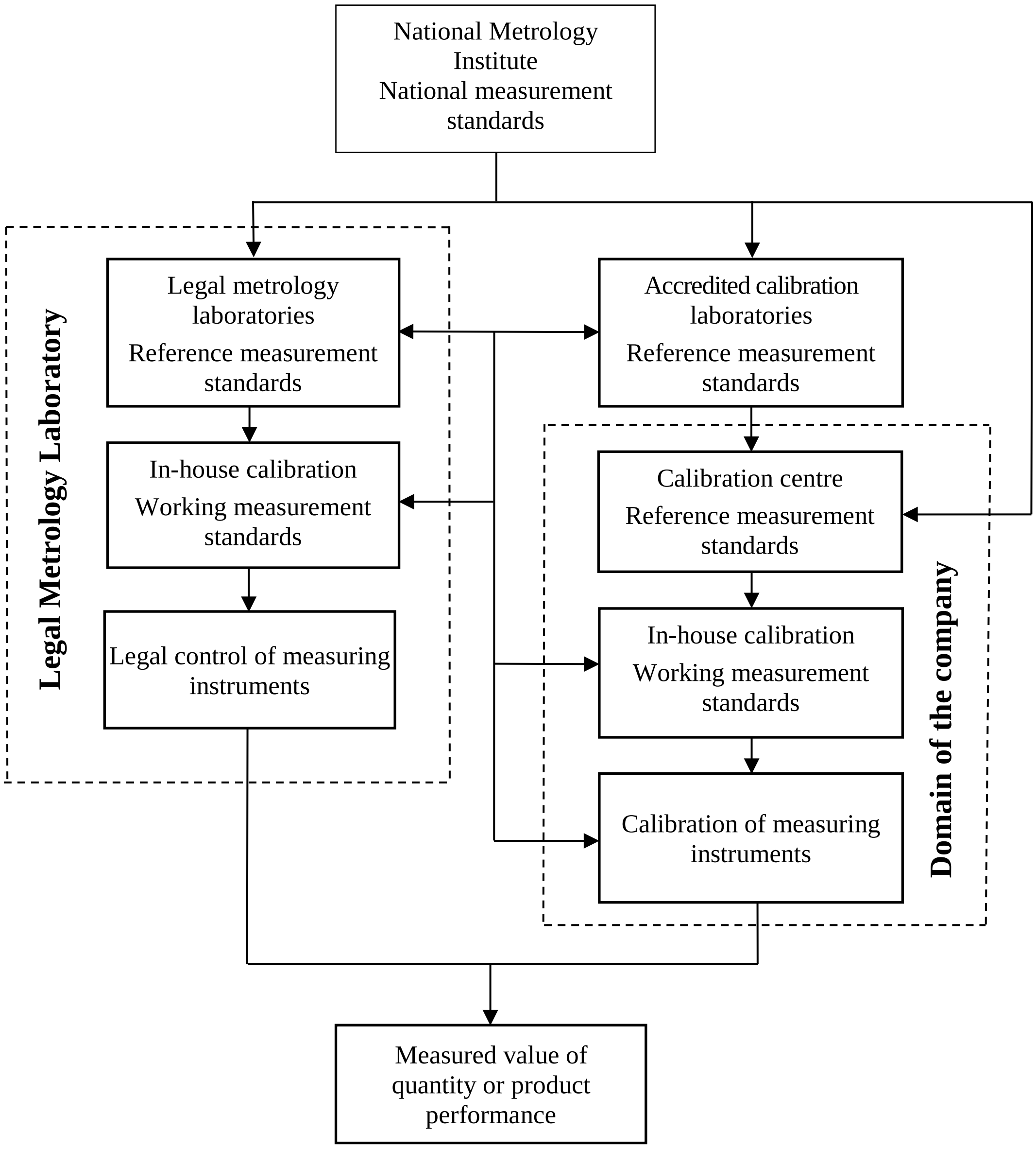


Fig. 1 Hierarchy of calibrations

The following essential elements are important to metrological traceability:

a) Measurement uncertainty: the measurement uncertainty for each step in the metrological traceability chain shall be evaluated according to agreed methods, based on the GUM [9] and shall be stated in such a way that an overall uncertainty for each subsequent stage of the chain may be evaluated.

b) Documentation: each step in the chain shall be performed according to documented and generally acknowledged procedures; the results shall also be documented.

c) Competence: the laboratories providing services in the chain shall supply evidence in support of their technical competence (equipment, skills of personnel, environmental conditions, etc.) and shall be accredited or peer assessed and/or their services are covered by the Mutual Recognition Arrangement of the International Committee of Weights and Measures (CIPM MRA) [13].

d) Specification of the measurand: the measurand is the main subject of the hierarchy of calibrations and it shall be defined or explained.

e) Reference to SI units: the unbroken chain of calibrations shall end at primary standards for the realisation of the SI units or at measurement standards, against which metrological traceability to primary standard is demonstrable (as far as technically possible or applicable).

f) Recalibration: calibration shall be repeated at specified intervals depending upon a number of variables, e.g. uncertainty required, frequency of use, way of use, stability of measuring instruments and this information shall be stated in the documentation of the standard.

g) Initial verification: verification of a measuring instrument which has not been verified previously.

h) Subsequent verification: verification of a measuring instrument after a previous verification according to the procedures specified by the regulations.

4.4 Maximum permissible error

For practical reasons, especially for verifications in legal metrology or for the case of repeated standard, routine calibrations or quality measurements, a maximum permissible error (MPE) of the measurement standard, reference material or measuring instrument is specified instead of the measurement uncertainty. In such a case, the MPE should be defined taking into account the measurement uncertainty. The compliance with the prescribed maximum permissible error alone should not necessarily be considered to demonstrate traceability. With respect to the metrological traceability, the MPE of the measuring instrument shall be accompanied with information on the measurement uncertainty related to that MPE.

4.5 Documentation

4.5.1 Reference and working measurement standards and means of dissemination of units have to be provided with documentation in accordance with the valid regulations.

4.5.2 The basic document for these measurement standards and means of dissemination of units is the valid calibration certificate issued either by an accredited calibration laboratory or by a laboratory demonstrating metrological traceability to the national measurement standard.

4.5.3 Other important parts of metrological traceability documentation are calibration or verification methods and procedures, which must clearly describe the metrological traceability of the measurement results. That is, the procedures have to clearly define which measurement standards and means of dissemination of units are used for the traceability. These procedures must also state the detailed procedure for evaluating measurement uncertainties in calibration or verification of measuring instruments.

4.6 Reference materials

In many fields, certified reference materials perform the role of reference and working measurement standards. It is equally important that the measurement results obtained by using such reference materials are traceable to relevant SI units realised by national or international measurement standards. Certification of reference materials is a method that is often used to demonstrate metrological traceability to national or international measurement standards.

Note 1: Additional information on the reference materials can be found in ISO 17034:2016 [14] or ISO Guide 35:2017 [15].

Note 2: Reference materials produced by RMPs (Reference materials producers) as per ISO 17034:2016 [14] may be considered as traceable to national or international standards if the policy of ILAC P10 [13] is followed.

5 Levels of dissemination of units of measurement

5.1 International level

At the international level, decisions concerning the International System of Units (SI) and the realisation of the primary standards are taken by the General Conference on Weights and Measures (CGPM). The International Bureau of Weights and Measures (BIPM) is charged with coordinating the development and maintenance of the realisation of the units and organises key comparisons (intercomparisons on the highest level).

5.2 National Metrology Institutes (NMI)

5.2.1 The National Metrology Institutes are the highest authorities in metrology in almost all countries. NMIs represent the country internationally in relation to the NMIs of other countries, the Regional Metrology Organisations and the BIPM. Some countries have a single authorised institute as their NMI, whereas others have a more distributed national metrological system (e.g. including one or more Designated Institutes).

5.2.2 In most cases the NMIs maintain the national measurement standards of the country that are the sources of metrological traceability for the associated physical quantities in that country. If the NMI of the country has facilities and skills to realise the corresponding SI base units and derived units, the national measurement standards may be equivalent to the primary standards realising the units. If the NMI of the country does not have this facility, it shall ensure that the measurement results are traceable to the SI through the standards maintained in another country, preferably to measurement standards realised at an NMI of another country which is a signatory to the Mutual Recognition Arrangement of the International Committee of Weights and Measures (CIPM MRA) for the relevant quantity. If this condition is fulfilled, then the calibration certificates issued by this NMI of the country are considered as internationally acceptable. The NMIs ensure that the realisation of the units themselves are internationally compared within the framework of the CIPM MRA. They are responsible for dissemination of the units of measurement to users, scientists, public authorities, laboratories or industrial enterprises and are therefore at the top level of the metrological infrastructure in a country.

5.2.3 Metrological traceability to the standards maintained by NMIs may be checked by reference to the Calibration and Measurement Capabilities (CMC) of NMIs held on the BIPM's key comparison database (KCDB) published on the BIPM web site (www.bipm.org).

5.3 Accredited calibration laboratories

5.3.1 Calibration laboratories accredited by accreditation bodies according to internationally established criteria (e.g. ISO/IEC 17025:2017 [2]) shall be able to demonstrate that the measurement results associated with the calibration of measuring instruments are traceable to SI units.

Note: Some calibration laboratories indicate that their service is covered by the ILAC Mutual Recognition Arrangement (ILAC MRA) by including the combined ILAC MRA mark on the calibration certificate. Alternatively, the accreditation mark of the accreditation body that is a signatory to the ILAC MRA or the reference to its accreditation status may be included on the calibration certificate. Both of these options may be taken as evidence of traceability [13].

5.3.2 Accredited calibration laboratories are often at the top of an organisation’s internal calibration hierarchy. Their task is to compare, at appropriate intervals, the organisation’s own working measurement standards with reference measurement standards calibrated by an NMI or an accredited laboratory with suitable calibration and measurement capability.

5.3.3 Many accredited calibration laboratories carry out calibrations for customers, e.g. for organisations that are not equipped with calibration facilities or for test laboratories, which work in the field of product certification. In this case the customer has to ensure that the measurement uncertainty achieved in the accredited calibration laboratory is suitable and sufficient for the intended use of the measuring instrument to be calibrated.

5.3.4 Accredited calibration laboratories generally document the calibration results in calibration certificates.

5.4 Legal metrology laboratories

5.4.1 Legal metrology laboratories shall ensure that measurement results used for type approval or verification within their scope of authorisation according to national legislation are traceable to the SI. Their reference measurement standards should be calibrated by an NMI with suitable calibration and measurement capabilities or by an accredited calibration laboratory.

Note 1: Further guidance may be found in ISO/IEC 17025:2017 [2] section 6.5.2.

Note 2: In some jurisdictions legal metrology laboratories may also be accredited calibration laboratories and perform the functions of both.

5.4.2 Legal metrology laboratories or services in some countries are accredited according to a relevant international standard, e.g. according to ISO/IEC 17025:2017 [2], ISO/IEC 17020:2012 [16], or ISO/IEC 17065:2012 [17].

5.5 In-house calibration

5.5.1 In-house calibration means regular calibration of own working measurement standards or measuring instruments which is performed by the metrology laboratory, the accredited calibration laboratory or the company itself against its own reference measurement standard with metrological traceability.

5.5.2 The scope of in-house calibration is at the discretion of the laboratory or company concerned. Even so, the results obtained using the measuring instruments and test equipment should be sufficiently accurate and reliable and metrologically traceable.

5.6 Hierarchy of measurement standards

The hierarchies of measurement standards and the responsible metrological organisations in each country are shown in Fig. 2.

Measurement standard (measuring instrument)	**Responsible organization(s)**	**Tasks for metrological control, calibration and measurements**	**Basis for the tasks**	**Outputs from the metrological control, calibration and measurements**
National measurement standards	National Metrology Institute (NMI)	Maintenance of the national measurement standards, dissemination of the measurement units, calibration of reference measurement standards and/or certification of reference materials	Statutory duty to represent SI units and ensure international comparability of the national measurement standard under CIPM MRA	Calibration certificates for reference standards and/or reference materials certificates
Reference measurement standards	Legal metrology laboratories, accredited calibration laboratories and reference material producers	Calibration of working measurement standards or production of certified reference materials	Calibration certificates or reference materials certificates from NMI or accredited laboratories	Calibration certificates or reference materials certificates for working measurement standard
Working measurement standards	Legal metrology laboratories, accredited calibration laboratories and other laboratories	Legal metrological control, calibration or in-house calibration of ordinary measuring instruments	Calibration certificates or reference materials certificates from NMI or legal metrology laboratories or accredited laboratories	Calibration, type approval or verification certificates for ordinary measuring instruments. Type approval, verification or calibration marks.
Ordinary instruments	Users	Measurement and tests performed by legally controlled or calibrated measuring instruments, or as a part of quality assurance measures	Verification or calibration certificates or verification or calibration marks of ordinary measuring instruments from legal metrology laboratories, accredited calibration laboratories or in-house calibration	Results of measurement and test

Fig. 2 The hierarchy of measurement standards and a resulting metrological organisation structure for tracing measurement and test results

6 General principles, structure and practical realisation for establishment of hierarchy schemes for measuring instruments

A hierarchy scheme for measuring instruments is a graphically illustrated system of gradually arranged measuring instruments determining the unbroken chains of calibrations from the national measurement standard down to measuring instruments, giving methods of dissemination of units, important metrological characteristics and mutual links.

6.1 General principles for the establishment of hierarchy schemes

6.1.1 The hierarchy scheme may cover either the overall field of measurements of a particular quantity or only a defined part of it, which is characterised by one or more of the following specifications:

a) purpose (e.g. scientific metrology, verification in legal metrology, calibration, quality measurement etc.);
b) range of values of measured quantity (e.g. high temperatures, low absolute pressures etc.);
c) specification of a certain field in the given quantity (e.g. DC voltage measurements as a part of electricity voltage measurements, power of AC current at certain range of frequencies or power of DC current etc.);
d) measuring instruments (e.g. line length measuring instruments etc.); and
e) measured quantity (e.g. gas flow rate, liquid density etc.).

6.1.2 Each hierarchy scheme for measuring instruments should deal with measuring instruments of one quantity or some interrelated quantities. If reference or working measurement standards of other quantities have to be used in the hierarchy scheme of the given quantity, it is recommended to include them in the scheme.

6.1.3 The hierarchy scheme for measuring instruments of a certain quantity may be divided into a number of autonomous schemes if it leads to its more efficient arrangement and more rational use.

6.1.4 When the hierarchy scheme is established, it is necessary to specify especially:

a) the measurement standards, measuring instruments or reference materials capable of fulfilling the role of reference and working measurement standards for different values or for different ranges of values of the given quantity;
b) the number of levels of reference and/or working measurement standards; and
c) the methods and means of dissemination of units.

Note: When establishing or reviewing a hierarchy scheme, the relevant authority should review and take into account the experience gained from the operation of existing schemes, at both national and international levels. In this comparative analysis, consideration should be given to the economic and societal context in which the new or revised scheme will be established, to ensure that any such experiences are applicable.

6.1.5 The choice of measuring instruments for fulfilling the role of reference and working measurement standards is determined by the appropriate level of their metrological and technical characteristics in accordance with the specification stated in OIML D 8 [18].

6.1.6 In order to technically and economically optimise the benefits of the hierarchy scheme the number of levels of reference standards, working standards and/or measuring instruments should be determined by considering at least the following:

a) the total number of measuring instruments and/or measurement standards of the given quantity as regards their types and metrological characteristics;
b) the productivity, the accuracy levels, the intervals between calibrations and the methods for dissemination of units associated with the measuring instruments and/or measurement standards; and
c) the necessary costs for the use and conservation of the measuring instruments and/or measurement standards and the dissemination of units, etc.

6.1.7 The method of calibration indicated in the hierarchy scheme should correspond to one of the following general methods:

a) direct measurements:
   - used in verification or calibration of an indicating measuring instrument against a material measure and/or a measurement standard; or
   - used in verification or calibration of a material measure against an indicating measuring instrument and/or a measurement standard;

b) direct comparison:
   - used in verification or calibration of an indicating measuring instrument against an indicating measuring instrument;

c) comparison with the help of a comparator:
   - used in verification or calibration of a material measure against a material measure;

d) indirect measurements:
   - used in calibration or verification of a measuring instrument using other measurement standards calibrated in terms of other physical quantities related functionally with the measurand.

6.1.8 For the calibration of measurement standards and measuring instruments or for the verification of measuring instruments, the characteristics of their uncertainty indicated in the hierarchy scheme are defined by calculations taking into consideration the characteristics of the total uncertainty of the higher-level measurement standard and methods for the dissemination of the unit.

6.1.9 For the verification of measuring instruments to determine their compliance with the specified requirements, the recommended ratio of the expanded measurement uncertainty to the MPE is 1:3 or better (e.g. 1:10).

6.2 Structure of hierarchy schemes

6.2.1 A hierarchy scheme consists of the graphic part of the scheme and a commentary on the scheme.

6.2.2 The graphic part provides a visual preview of the metrological traceability by listing the measuring instruments, including only basic information on some important characteristics. If the graphic part is too large and complicated, it is possible to divide it into sections, while the commentary remains common.

6.2.3 The commentary to the hierarchy scheme contains items such as explanations, hierarchy levels, metrological traceability, methods for placing measuring instruments, recommendations and comments. See 7.4 for the details of its contents.

6.2.4 National hierarchy schemes are usually divided into four fields:

a) national measurement standards field;
b) reference measurement standards field;,
c) working measurement standards field; and
d) measuring instruments field.

In local hierarchy schemes the national measurement standards field is usually omitted.

6.2.5 The field of working measurement standards can be divided into a number of levels according to accuracy.

Note: Levels of working measurement standards may by indicated by Arabic numbers where the 1st level mark belongs to the measurement standards of the highest level in the hierarchy.

6.2.6 Measuring instruments used as standards in the field of measuring instruments can be divided into a number of levels according not only to their types but also to their accuracies and measurement ranges.

7 Contents and practical realisation of hierarchy schemes

7.1 Content of a national hierarchy scheme

The national hierarchy scheme for a certain type of physical quantity or measuring instrument contains:

a) the name of the scheme, and if applicable, nominal values or ranges of values of the quantity;
b) the recommended types of measuring instruments capable of fulfilling the role of the measurement standards at different accuracy levels and, if applicable, measurement ranges and typical measuring instruments to be verified or calibrated;
c) the recommended methods and means of dissemination of units between the measurement standards and the measuring instruments (e.g. methods of calibration and calibration devices);
d) the recommended graduation of the accuracy level (uncertainties) of the reference and working measurement standards and the measuring instruments; and
e) the links between the elements of the scheme.

7.2 Content of a local hierarchy scheme

7.2.1 The local hierarchy scheme for a certain type of physical quantity or measuring instrument contains:

a) the name of the laboratory, and the reference and working measurement standards which are traced to the national measurement standards;
b) all the elements of the laboratory's metrological traceability (reference and working measurement standards, measuring instruments, means of dissemination of units);
c) the range of measurements of all the measurement standards and measuring instruments indicated in the hierarchy scheme and, if applicable, ranges of the most important conditions of measurements which define the procedure for the dissemination of the units;
d) the evaluation of the accuracy and uncertainty of all the measurement standards and methods of dissemination of the units;
e) all the links used among the elements of the laboratory's metrological traceability (verification or calibration procedures used);
f) the intervals between the calibrations of the measurement standards; and
g) the links among the elements of the scheme.

7.2.2 The local hierarchy scheme for (a) given type(s) of measuring instruments, along with the measurement procedures for the measurement standards included in the scheme, has to unambiguously demonstrate that all the requirements for metrological traceability in accordance with the relevant regulations and guidelines are fulfilled in the given laboratory.

Note: If the reference measurement standards are directly used for legal control or calibration of ordinary measuring instruments, then they also act as working measurement standards.

7.3 Graphic part of a hierarchy scheme

7.3.1 The name of the hierarchy scheme is usually given in the header. The fields for the national measurement standard, the reference and working measurement standards and for the measuring instruments should be separated in the graphic part of the hierarchy scheme by full lines. A description of the individual fields of the scheme is usually on the left side of the scheme. Horizontal dashed lines separate the individual levels of the standards in the working measurement standards field.

7.3.2 The measurement standards and measuring instruments should be presented as rectangles. The designation of the primary standard may be enclosed in a rectangle formed by a double line.

7.3.3 The methods and means of calibration and verification should be presented either in the measurement standard field to which a comparison is made, or at the lower border of this field as ovals.

7.3.4 The graphical representation of the procedure for disseminating the units should be performed in accordance with the following principles (see Annex C for examples):

a) if the calibration or verification of the measurement standard or measuring instrument is carried out by means of two or more measurement standards, solid lines representing the dissemination of the value of the unit (units) to an object of calibration are connected together into a point (e.g. item 8 of Annex C);
b) if the calibration or verification of a measurement standard or measuring instrument can be performed by means of any of the two or more methods or by the standards indicated in the scheme, then the solid lines representing the dissemination of the value of the unit are not connected into a point (e.g. item 6 of Annex C); and
c) intersection lines (to be avoided if possible) are to be shown by a symbol, as shown in item 1 of Annex C.

7.3.5 The form of numerical expression (using an absolute or relative value) for the metrological characteristics of the measurement standards and/or measuring instruments in a single hierarchy scheme should be as similar as possible.

Note: For example, expressions with gram and percent should not be mixed.

7.3.6 The description given in the graphic part of the local hierarchy scheme should contain the following data, especially:

a) for the measurement standards: type and name of the measurement standard, identification number of the measurement standard, measurement range, metrological characteristics specifying the measurement standards, the lower limits of the admitted values of the characteristics of their uncertainty, the range of the special condition of measurements;
b) for the methods and means of dissemination of units: name of the method, name and identification number of the means of dissemination of the units, characteristics of the uncertainty of the method;
c) for the measuring instruments: types of the verified or calibrated measuring instruments, their measurement ranges and basic metrological characteristics.

7.3.7 A simplified example of a national hierarchy scheme which contains three levels of measurement standards and the field of measuring instruments is given in Annex A. An example of the graphic part of a detailed local hierarchy scheme is given in Annex B.

7.4 Commentary to the hierarchy scheme

7.4.1 The commentary to the hierarchy scheme should contain all the data concerning metrological requirements and notes, which are not included in the graphic part of the scheme for any other reason and which cannot be ignored from a metrological traceability point of view.

7.4.2 The specification of the reference and working measurement standards should at least contain data as follows:

a) name and identification of the measurement standard;
b) nominal value(s) or measurement range(s) of the quantity(ies) value(s) reproduced by the standard and the measurement conditions; and
c) information on any important metrological characteristics of the measurement standard (accuracy class, errors, uncertainty of values of quantities reproduced by the measurement standard, time stability of standard etc.).

It is recommended to also include the following data in this specification:

a) name of the legal metrology laboratory or accredited laboratory to which the reference or working measurement standard is compared;
b) recalibration interval; and
c) location of the measurement standard.

7.4.3 The specification of the methods, means and conditions of dissemination of the units should contain at least the following data:

a) means of dissemination of the units – name of device, manufacturer, serial or identification number, and basic metrological characteristics;
b) method of verification or calibration;
c) verification or calibration procedure;
d) uncertainty of verification or calibration; and
e) specified measurement conditions of the verification or calibration (if necessary).

Note: Calibration devices which contain several function parts in one compact unit (e.g. multiquantity calibration devices with built in measurement standards for several quantities, multiquantity calibrators etc.) are usually calibrated as a whole. Such devices are usually a part of different working hierarchy schemes. The position of such a device in an individual scheme depends on its measurement ranges and its declared metrological characteristics.

7.4.4 The specification of the measuring instrument should contain at least the following data:

a) types of verified or calibrated measuring instruments and their measurement ranges,
b) metrological characteristics of the measuring instrument (accuracy class or maximum permissible errors, nominal range, instrument constant, discrimination threshold, resolution, stability, etc.).

8 References

[1] OIML D 2:2007 *Legal units of measurement under the terms of Resolution 1 of the 26th CGPM in 2018*

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

[3] ISO 9001:2015 *Quality management systems. Requirements*

[4] BIPM, OIML, ILAC *Common statement and declaration by BIPM, OIML and ILAC on the relevance of various international agreements on metrology to trade, legislation and standardization*, 23 January 2006

[5] BIPM, OIML, ILAC, ISO - Joint BIPM, OIML, ILAC and ISO declaration on metrological traceability, 13 November 2018

[6] OIML G 19:2017 *The role of measurement uncertainty in conformity assessment decisions in legal metrology*

[7] OIML V 1:2013 *International vocabulary of terms in legal metrology* (VIML)

[8] OIML V 2-200 VIM, 3rd edition, Edition 2012, (Edition 2010 with minor corrections) *International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM)*

[9] OIML G 1-100 *Evaluation of measurement data - Guide to the expression of uncertainty in measurement.* Edition 2008 (E). Corrected version 2010

[10] OIML D 1:2012 *Considerations for a Law on Metrology*

[11] CIPM 2005-07 *NMIs and other Designated Institutes*. 27 July 2005

[12] CIPM 2005-06 (V4) *The CIPM MRA*: 2005 Interpretation Document. August 2018

[13] ILAC-P10:07/2020 ILAC *Policy on Metrological Traceability of Measurement Results*

[14] ISO 17034:2016 *General requirements for the competence of reference material producers*

[15] ISO Guide 35:2017 (E) *Reference materials - Guidance for characterization and assessment of homogeneity and stability*

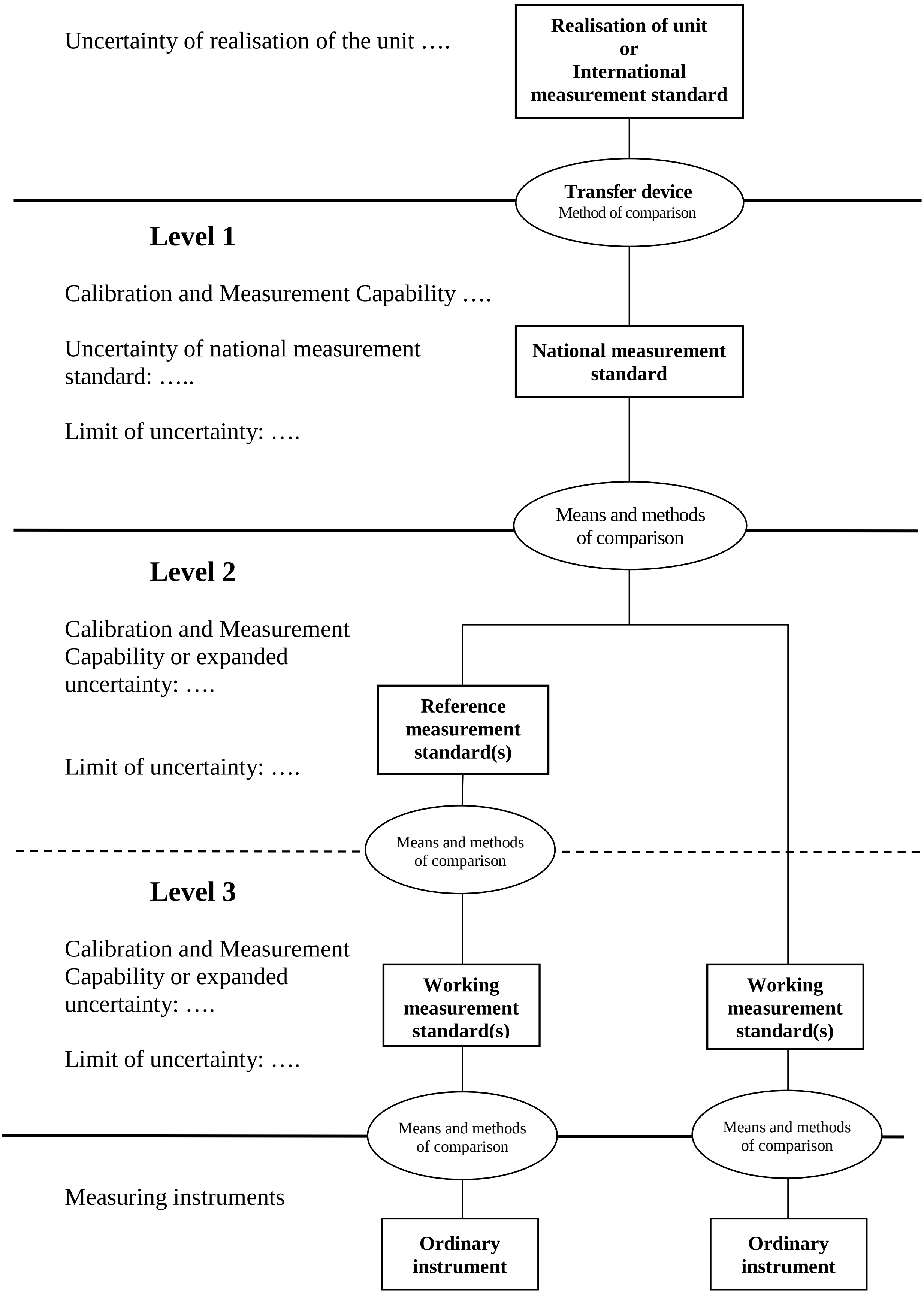
[16] ISO/IEC 17020:2012 *Conformity assessment. Requirements for the operation of various types of bodies performing inspection*

[17] ISO/IEC 17065:2012 *Conformity assessment. Requirements for bodies certifying products, processes and services*

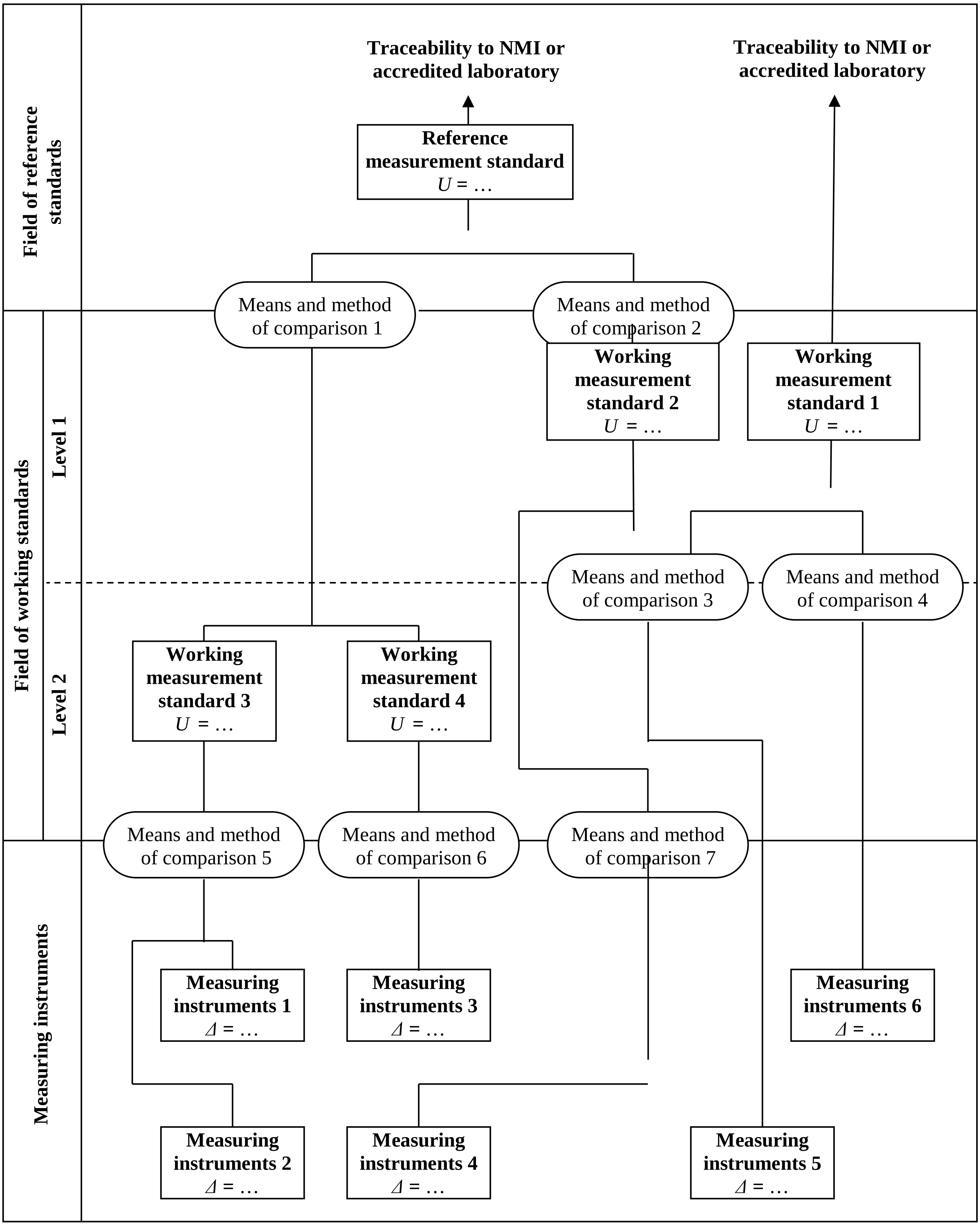
[18] OIML D 8:2004 *Measurement standards. Choice, recognition, use, conservation and documentation*, OIML

Annex A

Example of a simplified national hierarchy scheme
(Informative)

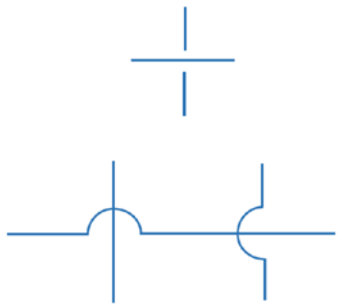
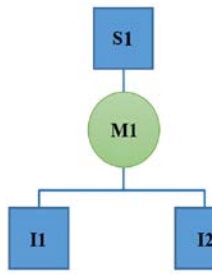
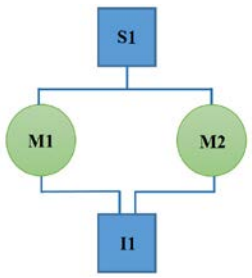
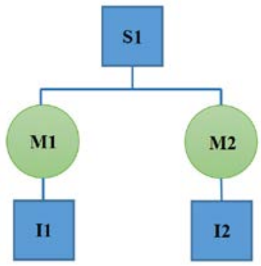
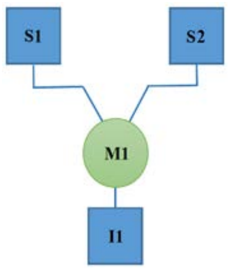
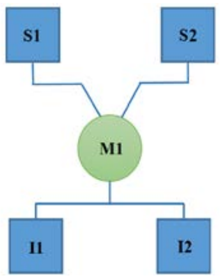
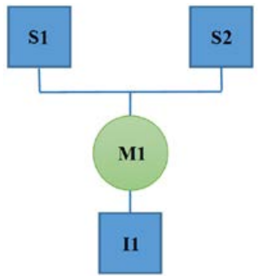
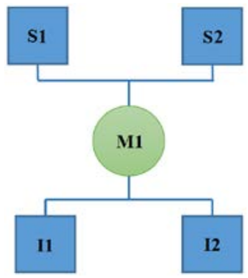
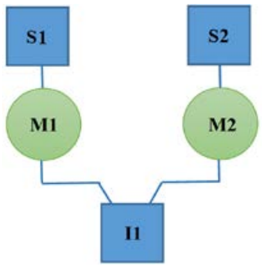
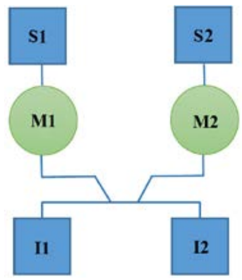
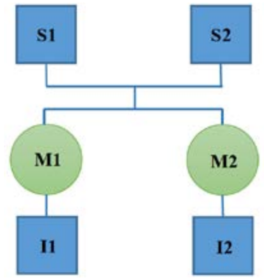


Annex B
Example of a detailed local hierarchy scheme for measuring instruments
(Informative)



Key: U - the expanded uncertainty; *Δ* - the error of indication

Annex C
Ways to express different links and disseminate units between structural elements in the graphic part of a hierarchy scheme
(Informative)

 1. Crossing lines	 2. From standard S1 to measuring instrument I1 by method M1	 3. From standard S1 to measuring instrument I1 and I2 by method M1
 4. From standard S1 to measuring instrument I1 by method M1 or method M2	 5. From standard S1 to measuring instrument I1 by method M1 and to measuring instrument I2 by method M2	 6. From standard S1 or from standard S2 to measuring instrument I1 by method M1
 7. From standard S1 or from standard S2 to measuring instruments I1 and I2 by method M1	 8. From standards S1 and S2 to measuring instrument I1 by method M1	 9. From standards S1 and S2 to measuring instrument I1 and I2 by method M1
 10. From standard S1 to measuring instrument I1 by method M1 or from standard S2 to measuring instrument I1 by method M2	 11. From standard S1 to measuring instruments I1 and I2 by method M1 or from standard S2 to measuring instruments I1 and I2 by method M2	 12. From standards S1 and S2 to measuring instrument I1 by method M1 or from standards S1 and S2 to measuring instrument I2 by method M2