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Principles for the establishment of hierarchy schemes for measuring instruments

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

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OIML D 5 Edition 1982 (E)

ORGANISATION INTERNATIONALE
DE MÉTROLOGIE LÉGALE

INTERNATIONAL ORGANIZATION
OF LEGAL METROLOGY

Foreword

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

The two 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; the OIML Member States shall implement these Recommendations to the greatest possible extent;

- **International Documents (OIML D),** which are informative in nature and intended to improve the work of the metrological services.

OIML Draft Recommendations and Documents are developed by technical committees or subcommittees which are formed by the Member States. Certain international and regional institutions also participate on a consultation basis.

Cooperative agreements are established between OIML and certain institutions, such as ISO and IEC, with the objective of avoiding contradictory requirements; consequently, manufacturers and users of measuring instruments, test laboratories, etc. may apply simultaneously OIML publications and those of other institutions.

International Recommendations and International Documents are published in French (F) and English (E) and are subject to periodic revision.

This publication – reference OIML D 5, edition 1982 (E) – which is under the responsibility of TC 4 *Measurement standards and calibration and verification devices*, was approved by the International Committee of Legal Metrology in 1982.

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PRINCIPLES for the ESTABLISHMENTof HIERARCHY SCHEMES for MEASURING INSTRUMENTS

1. Introduction

1.1. Calibration of a measuring instrument is the ensemble of operations for the purpose of assigning values to the errors of the instrument and, in some cases, to determine other metrological properties.

Calibration must be carried out at periodic intervals. It allows to follow the evolution of instruments, and to avoid disagreement either within the same company, or between purchasers and suppliers. It allows also to obtain a better knowledge of the quality of an instrument, and to provide information for potential purchasers.

Calibration can be carried out either by an absolute measurement method, or by comparison with a measurement standard (*) to which reference is made.

The standard can be a measuring instrument itself, an installation specially designed to materialize a unit, or a multiple or sub-multiple of this unit, or a reference material.

A reference value method and a transfer device for comparisons between standards are generally associated with the standard.

Example: interferometer for comparison of light wavelengths with krypton-86 standard radiation.

To materialize the units of measurement, one refers as much as possible to physical phenomena which are reproduced constantly with a high degree of accuracy (meter, second, ...). Certain equipment is then required to realize or conserve these units (krypton-86 lamp, time and frequency caesium-beam standard...).

1.2. Standards for the same quantity must be placed in a hierarchy, i.e. the uncertainty relating to them must be determined so that each standard is adapted for a particular use.

This hierarchy represents the sequence of stages, used to relate the metrological characteristics of any measuring instrument to the primary standard for the given quantity. The hierarchy of the measuring instruments for this quantity is put in concrete form of a calibration chain, the purpose of which is to maintain the accuracy of the instruments in service. The calibration chains may take different forms depending on the country.

1.3. This Document includes, in addition to the introductory Chapter 1, the following three parts:

— Chapter 2 which concerns the theoretical structure of a hierarchy scheme; it describes the different levels, corresponding standards, and the passage from one level to another; it also includes certain considerations relating to an international hierarchy scheme,

Note: The terminology used in this International Document conforms in principle to the Vocabulary of Legal Metrology, 1978 edition. However, the draft International Vocabulary of basic and general terms used in metrology (VIM) which is at present elaborated by a joint working group of BIPM, IEC, ISO and OIML, has also been taken into account. Terminology used in this International Document could be revised when the VIM is definitively established.

(*) in this Document called « standard ».

— Chapter 3 which, completed by Appendix I, gives the information which should be included in a hierarchy scheme and in the description of a calibration chain, enabling States to set up national calibration chains, in their own countries, according to their needs and according to their facilities,

— Appendix II which gives an example of a calibration chain, for measuring instruments for a given quantity; the calibration chain is a practical realization of the corresponding hierarchy scheme; the comments included in this part explain the different possibilities of a calibration chain structure.

1.4. The purpose of this Document is:

— to propose general rules for the establishment of hierarchy schemes for measuring instruments for different quantities. These schemes lead to practical realizations, described in the text as calibration chains,

— to define and explain the concepts used in these schemes.

Given its general nature, this Document will certainly not apply in all cases. Its principles may sometimes be questionned (see point 1.5). Nevertheless, OIML Reporting Secretariats must endeavour to follow the main guidelines, so that the hierarchy schemes presented are constructed with a certain degree of uniformity.

Possible divergencies from the general scheme should be underlined, to draw the attention of the States. Justification of such divergencies is desirable.

Reporting Secretariats must give neither too rigid a framework to the hierarchy schemes which they establish nor attribute certain mandatory values for the characteristics of the standards.

A hierarchy scheme is a model which contains the most recommended data, but which leaves the possibility for a certain freedom of choice in the realization of standards at different levels, and in the determination of the levels themselves (number of levels, interlevel links, sub-levels or parallel branches, etc.).

This Document must be suitable for use by the organizations wishing to set up calibration chains for their instruments, at national level, in accordance with the needs of each country, and in conformity with International Recommendations.

1.5. The only important objective of all hierarchy schemes for measuring instruments is to reduce as much as possible the measurement errors and to give maximum confidence in all measurements, including the most ordinary ones.

The quest for a better quality of ordinary measurements is the very reason for the existence of hierarchy schemes. This can be achieved in a number of ways, the classical scheme which is based on the direct calibration chain being the most widely used.

However, it is not the only hierarchy scheme available and, depending on circumstances, other ways of reaching this objective may be preferable. These are not discussed in this Document, but could be described in other International Documents.

2. Theoretical structure of a hierarchy scheme

2.1. Levels of a national hierarchy scheme

2.1.1. Level 1

At this level are the national primary standard as well as the duplicate standard or standards intended either to check the constancy of the primary standard or to replace this standard if it has lost its metrological qualities, or if it has been lost.

The primary standard is a standard of a given quantity, which has the highest metrological qualities in a given field.

This field may be either a field of use or a range of values of the quantity; with each field is associated a primary standard best suited to represent the unit, or a multiple or sub-multiple of the unit of this quantity.

Note: The primary standard does not necessarily represent the unit of the given quantity. In fact it may be easier to represent a multiple or sub-multiple of a unit, rather than the unit itself.

2.1.2. Level 2

At this level are the secondary standards obtained by comparison with the primary standard, using methods and means which vary according to the quantities concerned.

A secondary standard may be used to calibrate standards of a lower order of accuracy; it is then designated as a reference standard.

2.1.3. Level 3

At this level are the third order working standards obtained by comparison with reference standards. These standards can differ in nature or design from the reference standards, either to facilitate their handling or transport, or to reduce costs.

The methods and means used for comparison between secondary and working standards are all the more important, since they are not identical and their comparison is therefore a more delicate matter.

A working standard is used :

— either to verify ordinary working instruments with a lower degree of accuracy,

— or to calibrate measuring instruments, considered as working standards with a lower degree of accuracy. The working standard is then considered as a reference standard, and is conserved under good conditions so that its comparison with the secondary standard may be undertaken less frequently.

The choice between these two methods of using the working standards, depends on the geographical arrangement and the economic or political organization of the countries.

2.1.4. Level 4

At this level are the working standards obtained by comparisons with third order working standards considered as reference standards.

The accuracy of these standards is frequently sufficient in various sectors of industry. However, certain industries require the use of instruments of a higher metrological quality; in this case, third order working standards are used.

Note: An example of a national hierarchy scheme, omitting level 4, is given in Appendix I.

2.2. International hierarchy scheme

2.2.1. An international hierarchy scheme must indicate the links existing between the international standard and the national standard.

2.2.2. The establishment of an international hierarchy scheme assumes the existence of an international standard.

In the absence of an international standard, a country or a number of countries may decide to create a standard for the unit of a certain quantity, where a particular need for it exists. If this standard is recognized by other countries, it plays the part of an international standard. It is then necessary to define the geographical area in which this international recognition applies.

3. Content of a hierarchy scheme

The purpose of hierarchy schemes is to enable States to set up calibration chains. An example is given in Appendix II.

These schemes must contain sufficient information to ensure a certain degree of uniformity for calibration chains set up in the different countries thus making it possible to interrelate these schemes at international level.

In particular, hierarchy schemes must provide the following information concerning the different levels and the standards which may be included :

— known principles used for realization of the standards, with examples of practical execution,

— uncertainty concerning the freedom from bias of the standards, which should not be exceeded at each level, taking into account the state of scientific and technical progress in the field concerned,

— measurement fields in which the standards are valid,

— reference value methods and transfer devices recommended for the different levels, with a list and, where possible, evaluation of the measurements wich they may include,

— stability of standards and reproducibility of measurements with time, and methods used to ensure that the standards possess these qualities,

— periodicity of calibration,

— recommended provisions for the conservation of standards.

3.1. Principles of construction for standards and practical execution

A hierarchy scheme for a given quantity recommends, at each level, the principles of construction for standards which are generally known and used, and the methods for their use with the desired accuracy.

The forms of practical execution considered to be the best must be indicated.

It is advisable to supply bibliographical references, or annexes containing detailed descriptions, and where possible, methods of use for instruments or installations, the precautions to be taken in order to obtain good measurements, the errors to be avoided, etc.

3.2. Uncertainty on the true value of standards and of results of measurements made at each level of a hierarchy scheme

It is necessary to determine the nature of uncertainties, their order of magnitude and the limits which should not be exceeded, taking into account the state of scientific and technical progress in the field concerned.

These limits result from the combination of :

— the uncertainties in the application of the definition of the unit or on the value of its material representation, and

— the estimations of errors, both systematic and random, which may occur for measurements made at each level of the hierarchy scheme.

The maximum permissible errors for ordinary measuring instruments should not be indicated since they are already fixed by International Recommendations or national regulations and are likely to be modified at fairly regular intervals.

The passage from one level of the hierarchy scheme to the next, is accompanied by a reduction in accuracy of the standards. From the technical point of view, it does not appear realistic to attempt to fix the ratio between the inaccuracies of the standards of the two levels concerned.

This ratio can vary between 2 and 10, according to the quantities concerned. For certain quantities, measurement problems are so great that an improvement in accuracy by a factor of 2 constitutes considerable progress. On the other hand, for other quantities, it is sometimes technically possible to apply a ratio of 10 between two levels.

3.3. Standards for different ranges of values of a quantity

At certain levels in the hierarchy scheme, it is sometimes necessary to define a number of ranges for the quantity, in which the standards used are different.

In the case of pressure for example, the mercury pressure gauge with interferometric measurements constitutes an excellent standard instrument for pressures between 10^3 and 10^5 pascals. For higher pressures piston type pressure gauges (pressure balances) will be used. For very low pressures measurement techniques and instruments will be completely different.

It is therefore necessary to define, as closely as possible, the ranges of values for the quantity concerned and also the errors which may be encountered and which must not be exceeded, in each of these fields.

Neighbouring ranges must overlap, presenting a common zone in which the results of measurements made with the standards used in this common zone can be compared.

3.4. Liaison between standards

3.4.1. In general, the hierarchy schemes provide for passage from one level to another by calibrating an instrument (or measuring system) of level n using a level (n — 1) instrument.

3.4.2. Liaison between two standards of the same level can be made:

— by taking one standard to the other, or

— by using a transportable comparison standard, referred to as a travelling standard [*], which is compared successively to the two standards under examination, or

— by comparing simultaneously these two standards to the same physical phenomenon.

Each laboratory applies its own calibration methods, so that the comparison relates both to the standards themselves and to the laboratory methods used.

3.5. Stability of standards and reproducibility of measurements

Stability can be considered as the primary quality of a standard, being the « sine qua non » condition for measurement reproducibility; stability must be confirmed. Any existing drift must be evaluated and pointed out, to forewarn the metrology services against variations of varying rapidity and extent, in the value of the standard. Procedures used for verification of the stability of standards, should be specified.

3.6. Calibration periodicity at all levels

It is useful to indicate in the hierarchy schemes the periodicity to be applied, for the recalibration of standards of different levels, to maintain their accuracy. This periodicity is determined depending on the stability of the standards and their use, conservation and degree of accuracy.

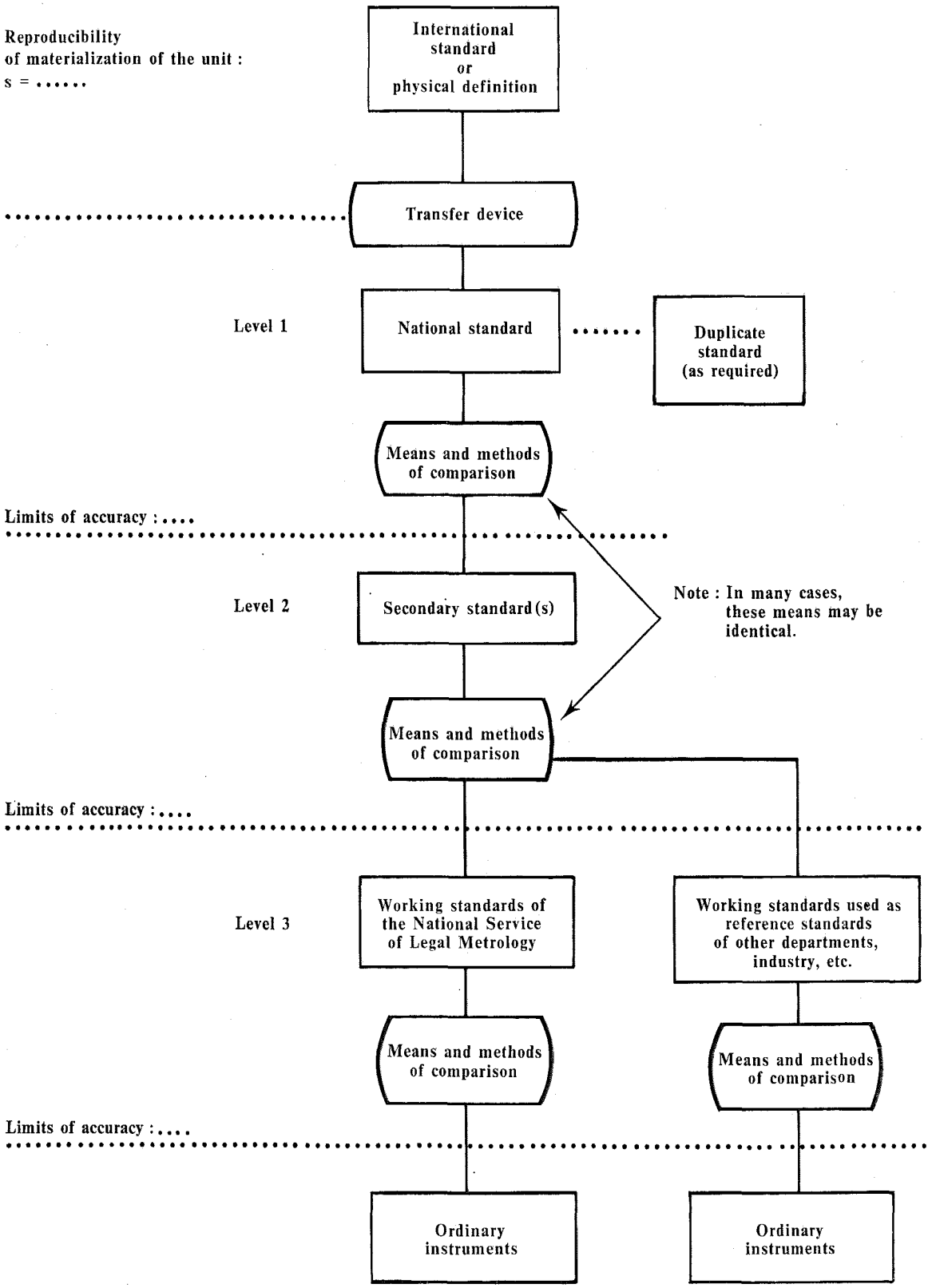
3.7. Recommended provisions for the conservation of standards

The general conditions for the conservation of standards must be mentioned in the hierarchy scheme as well as the special conditions for conservation, handling and use appropriate to standards of higher accuracy.

These conditions are specified and explained in the Document elaborated by the OIML Secretariat SP 23-Sr 2 « Principles concerning the official recognition, use, and conservation of standards ».

[*] Examples of travelling standards
- standard resistance,
- high pressure gas measuring system, where nozzle pipes, tested and calibrated successively in different countries, are circulated,
- transportable argon arcs and deuterium lamps, in radiometry, in the ultra-violet range,
- reference material: steel ball, crystal, etc.,
- acceleration measuring chains, each incorporating an acceleration transducer, load amplifier and connecting cable for comparison of medium frequency acceleration transducers.

APPENDIX I
NATIONAL HIERARCHY SCHEME
example omitting level 4



APPENDIX II
EXAMPLE OF A PRACTICAL REALIZATION OF A HIERARCHY SCHEME : CALIBRATION CHAINS

A calibration chain for a given quantity, comprises a set of standards, and the means for comparing these standards with each other, ensuring the traceability of measurements in industry with those of the laboratory which holds the primary national standard, namely the traceability of in-service measuring instruments with the national standard.

A calibration chain is set up in accordance with the basic theoretical scheme described in this Document, taking into account the peculiarities of different States which make use of it.

Thus, it includes the same levels as in the hierarchy scheme, but it is not possible to describe the standards without mention of the laboratories holding them and without indicating the role of these laboratories in the calibration chain.

The number of laboratories and their geographical location in the country, the number and nature of the standards they hold Will differ between a federation of states and a country with a Centralized structure, between a state with a vast territory and a country with a small area.

For this reason, the example given below, actually in existance at national level, is only for guidance.

1. Levels 1 and 2

1.1. These levels are generally represented by the same laboratories, designated « primary laboratories », which hold the primary and secondary standards of the given country.

National standards are standards recognized by official national decision to serve as basis for fixing the values of all other standards in a country.

1.2. The laboratory holding and conserving the national standard for a given quantity is called the national primary laboratory. It also holds the secondary standards, which constitute its reference standards.

The qualification « national » indicates that the laboratory concerned has received official recognition in its country, for conservation of the national standard for the given quantity.

Its task is:

— conservation and where possible improvement of levels 1 and 2 standards,
— optimum realization of the multiples and sub-multiples of units, either by their materialization or by reference-value methods,
— design and development of methods for the comparison of standards, and the determination of their uncertainties.

Notes :

a It is possible for other laboratories than the national primary laboratory to hold primary and secondary standards. All these primary standards must be traced to the national primary standards.

This situation is encountered in federated states, or states having a large territorial area. In such cases, there may be several primary laboratories, each holding primary and secondary standards. However there is only one national standard for a given quantity.

b — Where an international standard exists, such as the kilogramme prototype being held by the International Bureau of Weights and Measures, standards compared with the international standard can be considered, from the international point of view, as secondary standards. However, in the national context, these are still primary standards and one of them is the national standard.

2. Level 3

2.1. The standards held by laboratories having an official character, other than the primary laboratories, are used for calibration of working standards or ordinary measuring instruments.

These high level laboratories are frequently of a scientific character engaged in basic or applied research.

In exceptional cases, they also correspond to the metrological departments of certain major industries, officially recognized and having direct connections with the primary laboratories.

The National Service of Legal Metrology is generally placed at level 3, since its standards are linked to the secondary standards of the national primary laboratories for the different quantities.

Possession of level 3 standards is generally adequate for this Service, the activity of which concerns mainly instruments used in industry and for trade.

However, in certain countries, the National Service of Legal Metrology also holds the primary standards, and sometimes the national primary standards, in particular for basic quantities such as mass, length, etc. It thus becomes the national primary laboratory for these quantities.

This position in the hierarchy of laboratories gives the National Service of Legal Metrology the official competence for the calibration of all instruments used to measure these quantities.

2.2. A direct passage may exist from level 3 to ordinary measuring instruments, so that level 3 standards are used directly for the calibration or verification of ordinary measuring instruments, whether new, repaired or in service.

This situation is easy to conceive in countries with a low degree of industrialization, having a small number of laboratories specialized in metrology.

3. Level 4

In countries with powerful industries, the creation of a fourth level is recommended.

In fact, any major industrial firm holds a large number of measuring instruments for the needs of its laboratories and other departments. It is difficult to imagine that all these instruments are compared directly with level 3 standards.

Such a firm needs to hold its own standards, used for the calibration or verification of ordinary measuring instruments. These level 4 standards must be included in the calibration chain, and must therefore be calibrated by comparison with level 3 standards.

The metrological department of the firm is responsible for :

— conservation of level 4 standards, ensuring that these are compared with level 3 standards at periodic intervals,

— calibration of level 5 standards, used as working standards.

Internal calibration chains are thus set up in these firms, associated with the national chains, and also with the existing international standards via the primary laboratories.

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