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Principles of metrological control of equipment used for verification

Principes du contrôle métrologique des équipements utilisés pour la vérification

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OIML D 23 Edition 1993 (E)

ORGANISATION INTERNATIONALE
DE MÉTROLOGIE LÉGALE

INTERNATIONAL ORGANIZATION
OF LEGAL METROLOGY

Contents

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 23, edition 1993 (E) – which is under the responsibility of OIML TC 4 *Measurement standards and calibration and verification devices*, was approved by the International Committee of Legal Metrology in 1991.

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PREFACE

This International Document is intended as a guideline for organizations concerned with the metrological control of all kinds of apparatus and measuring installations used for the verification of measuring instruments. These controls are applied in order to ensure that the verification equipment performs correctly and that the working standards are properly calibrated; the procedures may include the issuance of a document that states that the required tests have been performed, if the national rules require it. In the framework of these controls such equipment can be, for example, calibrated or officially certified or checked. The terms used by individual countries for these operations are not yet uniformly defined internationally and should be clarified in a separate document. For the performance of the metrological tasks, authorization by a national organization may be required.

As stated in the title, this paper is concerned with the principles of metrological control of "equipment used for verification". Whenever the term "verification equipment" is used below it should be understood to mean "equipment used for verification".

The Document is intended mainly for services of legal metrology and for organizations officially approved for calibration services, but it may be found useful more generally in laboratories for the calibration of measuring instruments and material measures.

In view of the great diversity of verification equipment (different measurable quantities and influence quantities, various kinds of measuring instruments and calibration methods, different measuring ranges, etc.), this Document comprises only general principles, rules and methods that are common to several or all cases of intended application. The Document aims to provide a basis for the international harmonization of existing special regulations, to aid the development of new ones, and to facilitate calibration where such special regulations do not yet exist. In concrete cases more details may be obtained from special regulations already in force for specific kinds of verification equipment.

PRINCIPLES of METROLOGICAL CONTROL of EQUIPMENT USED for VERIFICATION

1 Introduction

1.1 This Document deals with "verification equipment" i.e. equipment used for the verification of measuring instruments in the field of legal metrology.

The technical equipment considered to be verification equipment may vary greatly in complexity, size, manner of installation, transportability, etc., hence the use of particular terms such as verification apparatus, verification station, verification installation, automated verification equipment, etc.

1.2 Verification equipment may include

- measurement standards,
- auxiliary measuring instruments,
- auxiliary equipment.

The auxiliary equipment consists of a variety of technical apparatus and, according to its influence on the result of verification, is further subdivided into

- auxiliary technical equipment that directly or significantly affects the result (correctness) of verification,
- auxiliary technical equipment whose influence is of an indirect nature or negligible,
- auxiliary metrological equipment for the provision of standard (reference) conditions or for the control of influence quantities.

Examples of verification equipment are given in Table 1. The Table demonstrates the large differences in structure, from verification equipment with many kinds of components to equipment comprising only a measurement standard and auxiliary technical equipment. For the verification of certain measuring instruments only standards are required, and there is no need for any other kind of verification equipment (for example, area-measuring instruments, certain weighing instruments, some materials-testing machines, etc.).

Table 1 also demonstrates differences in assemblies of important components of verification equipment, extending from simple assemblies with easily interchangeable components to integrated systems (for example, a measurement standard and auxiliary metrological equipment of a verification station for gas meters).

1.3 The measuring method used with the verification equipment (either direct or indirect) may influence the results. For this reason, it is important that the measuring method chosen best meet the metrological requirements of the verification tests.

1.4 The metrological control of the verification equipment may include testing, pattern approval (if required by legislation), calibration, and the issuing of certificates of test and of calibration for

- the measurement standards,
- the auxiliary measuring instruments,
- the auxiliary equipment, and
- the equipment as a whole.

The certificate should contain a statement of how the equipment fulfils the metrological requirements.

The testing of verification equipment is subdivided with regard to technical characteristics into the following:

a) Functional tests (quality and reliability of technical operation) which are applied to:

- all components capable of operating independently, and
- the verification equipment as a whole.

Nevertheless it is possible to dispense with some functional tests of individual components when they have already been tested (for example, by the manufacturer) or when it is evident that they operate correctly. Functional testing of the verification equipment as a whole is always necessary.

b) Checking of metrological characteristics.

1.5 The equipment that is used by the verification authorities for the verification of measuring instruments (either of the authorities' own equipment or that of manufacturers, repair companies or users) must be either in the constant possession of the verification authorities or kept locked by a key that is in their possession, or it shall be checked or tested by them immediately prior to use if they deem it necessary.

2 Measurement standards

2.1 The measurement standards that are used for the verification of measuring instruments, and that are consequently part of the verification equipment, are classified as working standards, regardless of their intrinsic level. They must be calibrated and certified.

Standards must be treated and maintained with special care, and they must be checked at appropriate intervals so as to ensure that they are sufficiently accurate for their purpose at the time of use. After certain periods of time or of use, working standards are compared with standards ranging higher in the hierarchy scheme of standards (see also International Documents OIML D 6 and D 8). In the calibration of working standards, the errors of the reference standard are to be considered only if required by regulations.

Working standards may be recalibrated after a period of one year, unless otherwise stipulated (examples are given in Table 2). The period of validity of standards depends on a number of factors; mechanical or electronic standards of high precision, for example, may be influenced in their accuracy by many factors, with the result that their measuring accuracy can be guaranteed for only a relatively short period of time. Operator use is also an important factor; clumsy handling can lead to a change of metrological characteristics. Other standards, for example material measures, are comparatively robust, so longer periods of validity may be indicated.

Standards must be recalibrated after each repair if measuring properties may have been affected.

2.2 Verification equipment using a direct method of measurement includes at least one standard of the same quantity as the measurand (sometimes several standards of different nominal values or different measuring ranges).

Verification equipment using an indirect method of measurement includes at least two or more standards of quantities different from that of the measurand. The total error of the installation, to be computed from individual errors, must be taken into consideration.

2.3 During calibration and certification of standards, account should be taken of the following principles (see also International Document OIML D 9).

2.3.1 The standards should be calibrated exclusively by institutions and personnel competent and authorized to deal with standards of a given kind and hierarchical level (level of accuracy).

2.3.2 The level of accuracy assigned to each standard used in the verification equipment should conform to the hierarchy scheme valid for the measurand or for measuring instruments of the same category as that of the instrument to be verified. When an indirect verification method is used and the verification equipment includes standards of different quantities, each of those standards should be classified in conformity with its own hierarchy scheme. In the absence of appropriate hierarchy schemes and if the accuracy of the standard is not specified by regulation, it should be such that the accuracy of verification itself is ensured. All error influences and all uncertainties of measurement must be taken into account.

2.3.3 For portable standards, calibration in a laboratory authorized by national authorities is preferred to calibration in situ.

2.3.4 During calibration of the standard itself the official metrological requirements of the relevant category and hierarchy level should be complied with. Moreover, additional requirements may result from the use of the standard in or with the verification equipment (see also International Document OIML D 8).

2.3.5 When reference materials are used as measurement standards they should be certified if possible.

2.3.6 In the absence of appropriate regulations it is desirable to comply with the general principles for the official recognition of standards included in some national regulations, and also in the International Document OIML D 8.

2.3.7 The certificate of each standard should include

- all data on the important metrological characteristics resulting from the calibration, including any specified method of use,

- the level of accuracy (classification according to the appropriate hierarchy scheme),

- the period of validity (a number of examples of periods of validity of standards as applied in some countries are given in Table 2 - see also International Document OIML D 10),

- if applicable, a statement that the standard is intended for use in or with the specified verification equipment.

Other details of documents that, it is recommended, should accompany standards are specified in the International Document OIML D 6.

2.4 Regulations may sometimes be required for the use and conservation of each measurement standard included in a verification equipment. These regulations may be

- unique for each standard,

- common to a particular category, group or set of standards,

- included in instructions for the use and conservation of the verification equipment.

The aims and general principles for the preparation of such regulations are given in the International Document OIML D 8.

3 Auxiliary measuring instruments

Auxiliary measuring instruments in verification equipment must be tested and checked regularly. The requirements for these tests can vary, depending on the importance of the individual measuring instrument. For example a regulation could prescribe an official verification, or a calibration, or simply a functional test to be performed by the user. If the requirements for these tests are not specified in primary metrological requirements, they can be included, in the specific requirements of the particular verification equipment.

An instrument should be accompanied by a document giving the following information:

a) its metrological characteristics,

b) the manner of its use in the specific application,

c) whether the instrument is used permanently and regularly or occasionally under certain conditions or for certain purposes,

d) tests to be applied regularly,

e) identification data.

4 Auxiliary equipment (metrological and technical)

4.1 From the three subgroups of auxiliary equipment listed in 1.2, the most important is the metrological equipment. The treatment of auxiliary metrological equipment is very similar to that of measurement standards or of auxiliary measuring instruments, although they are not measuring instruments. The similarity is due to the following requirements that are frequently stipulated:

a) pattern evaluation and approval,

b) examination and testing of each individual item of equipment,

c) evaluation of additional errors introduced by this equipment during verification using the verification equipment. In other words, evaluation of the error of transfer of the measurement unit from the standard to the verified instrument, estimation of comparison errors, etc.,

d) issue of a certificate, marking or stamping,

e) periodic testing,

f) regulations concerning use and conservation.

4.2 The choice of auxiliary metrological equipment, of its important properties and characteristics, of the parameters to be examined and the overall uncertainty introduced during verification, is made according to:

a) the hierarchy scheme appropriate to the measurand (or the instruments to be verified),

b) the regulations for the verification of the instruments concerned,

c) the regulations for the calibration of the type of verification equipment concerned,

d) the special regulations for the calibration of the auxiliary metrological equipment concerned.

Requirements from different sources should be taken into account and harmonized, if possible.

Notes and examples

a) Hierarchy schemes of measuring instruments introduced in several countries include some specifications or limitations applied to comparison equipment and permissible uncertainties of comparison, as does, to a certain extent, the International Document OIML D 5. A permissible uncertainty of comparison may also be added to the uncertainty specified for the level in the relevant hierarchy scheme.

b) See examples in the International Recommendations OIML R 7, R 37, R 38, R 39 and R 49.

c) See an example in the International Recommendation OIML R 5.

d) See regulations for the calibration of standard equal-arm balances existing in several countries.

4.3 The testing of auxiliary metrological equipment is of equal importance to the calibration of standards used in verification equipment; therefore this testing should be considered to be an operation of a higher level than that of the verification of ordinary measuring instruments. It should be done only by competent personnel of a legal metrology service or of an authorized organization.

4.4 Auxiliary technical equipment required for verification purposes is of various kinds. There is equipment in general use for the following purposes:

- supply of energy and working material,
- cleaning and installation of instruments to be verified,
- improved observation of indications,
- evaluation and recording of results,
- automation of procedures,
- stamping or marking of verified instruments, etc.

Some examples of specific auxiliary technical equipment are given in Table 1.

4.5 Auxiliary technical equipment is subject to functional testing (see 1.4) with the aim of ensuring that it operates correctly and reliably. Some specific aspects are usually checked, such as

- possible influence on the results of verification, etc.,
- leakages, impurities (inside, outside) and all kinds of environmental pollution,
- reliability,
- effectiveness.

4.6 Auxiliary equipment for the provision and stabilization of reference conditions, such as

- environmental and working temperatures (*),
- insulation against vibration and shock (passive and active),
- pressure, temperature, composition of working medium,
- voltage, frequency, absence of higher harmonic components in the electrical current, etc.,

is associated with the influence quantities. If, however, the quantity to be tested is the measurand of verification equipment, the auxiliary equipment forms part of the metrological equipment (because of direct and significant effects on the verification result).

(*) Working temperatures: temperatures of installations, standards, instruments to be verified, etc.

Auxiliary equipment for the provision of reference conditions is subject to functional tests

a) with the same aims and aspects as given in 4.5 for auxiliary technical equipment, and in addition,
b) with the aim of ensuring and checking that the deviation (**) and fluctuation (***) of reference quantities keep within permissible (acceptable) limits.

Metrological assurance for functional tests under (b) above is transferred to the control measuring instruments, which belong to the category of measuring instruments and which should be verified or periodically tested.

4.7 Reference conditions are usually specified as reference values (of influence quantities) or as reference ranges (of influence quantities). Preferred reference values for the influence quantities should be specified within the limits of a reference range of values. When calibrating verification equipment a distinction should be made between

a) a reference range for which the effect of the influence quantity on the verification result is or is required to be negligible. The limits of this reference range are usually also specified as the permissible limits for fluctuations,

b) a nominal range of use within which the application of corrections to values of the indication is permitted. A correction is computed as a function of the difference between the single value or mean value of the influence quantity and the reference value. The use of verification equipment outside this reference range is not permissible.

Reference conditions are

- either prescribed by regulations, or

- not given by regulations, and the aim of the test is to determine them for the verification equipment being tested.

5 Overall metrological control of verification equipment

5.1 The testing of a verification equipment as a whole comprises

- an external administrative examination,

- a functional test,

- a metrological examination,

- calibration.

(**) Deviation = measured value – reference value (of influence quantity).

(***) Fluctuation = instantaneous measured value – mean of measured values (of influence quantity).

5.2 The aim of the external administrative examination is to confirm that the verification equipment conforms to statutory requirements and is ready for the metrological examination. During the administrative examination the following main points are checked:

a) legality, conformity with the approved pattern if prescribed, and suitability for intended use,

b) completeness of the equipment,

c) correctness of location, installation and assembly,

d) that required preliminary and partial tests, examinations and calibrations (see also earlier chapters) have been completed,

e) completeness and correctness of required documents,

f) authority of institution and of personnel to verify the equipment (unless obvious), assumption of personal responsibility for use and conservation of the verification equipment concerned.

5.3 The aim of the functional tests is to check by selected experiments that the verification equipment as a whole operates correctly and reliably. It may sometimes be useful to combine the operational tests with the metrological examination; nevertheless some additional tests, for example under extreme conditions, are often required.

5.4 The metrological examination of the verification equipment as a whole is very important and should always be done; it cannot be replaced by any set of partial examinations, however comprehensive. The tests should be selected to achieve the specific goals of the metrological examination.

The influence of the verification equipment must be determined by metrological examination. If, during verification of a measuring instrument, it causes an error, it must be considered accordingly.

The main aims of the metrological examination are

a) to check interactions between components of the verification equipment, and their possible influence on the result (correctness) of the verification,

b) to check interactions between the verification equipment and the instruments being verified (transparency),

c) to check whether the equipment performs correctly under the prescribed reference conditions (some tests should be performed with unfavourable combinations of values of the influence quantities), or to determine the reference conditions for the calibrated verification equipment (see 4.7),

d) to determine any important characteristics of dynamic behaviour of the verification equipment, with their possible influences on the accuracy of the verification, and hence to determine the resulting requirements regarding periods for warming up, switching, etc.

e) to check experimentally the overall uncertainty of the verification equipment and of the verification,

f) to check the equipment completely to ensure that during verification all required conditions are maintained,

g) to check the absence of significant hysteresis.

Note: If the verification equipment is manufactured according to a prescribed or well-defined pattern, it may be sufficient to perform some of the tests on the pattern only (there may be no need to repeat all the tests on each individual equipment). If the verification equipment is a measuring instrument acceptable for verification, all tests prescribed for the pattern approval shall be performed. It must be ensured, though, that the minimum requirements for measuring instruments and standards needed for the testing of the verification equipment are met.

5.5 The metrological examination comprises

a) a series of measurements on the verification equipment according to a prescribed or selected programme. Elements of the programme i.e. individual measurements, are specified combinations of values of selected variables (factors). The main matters to be considered are

- the measurand (quantity measured by the verification equipment),
- the influence quantities,
- the number of instruments being verified at the same time,
- the positions of these instruments,
- sometimes the number, combination and possibly the positions of standards and auxiliary instruments used to measure the most important influence quantities,

b) the evaluation of measurements, the estimation of important parameters, errors, uncertainties and limitations,

c) the issue of a calibration certificate.

The methodical aspects of the examination of verification equipment (measurement methods, procedures, etc.) are very closely connected with the individual aims and situations. Nevertheless, although not always applicable or effective, the direct measurement method based on the substitution of standards, or specially calibrated instruments of the same type, for the instruments being verified, and comparing their indications with those of the verification equipment, is the one generally preferred and most frequently applied.

5.6 Special problems arise during calibration of verification equipment when the values of the measurand differ from those of the standards. In such a case, the following principles should be observed:

a) extrapolation beyond the limits of the range of values reproduced by the standards is not permitted; only interpolation is allowed,

b) the means of interpolation should be studied and selected with particular care and with due regard to traceability,

c) a check of some interpolated values should be included in the metrological examination of the verification equipment as a whole.

5.7 Verification equipment with integrated microprocessors requires special tests. In addition to the computer and its interfaces, the software must be tested to demonstrate that unintended functions cannot be invoked.

a) Tests of the software

The software may be stored in read-only storage locations (i.e. PROM). In this case a test of the program and a functional test are sufficient. In the case of freely programmable computers, not only must the software be tested, but there must be a check that unintended functions caused by manual maloperation during use are either recognized as such or cannot occur. In addition there must be repeated checks that no modifications of the software have occurred. It is advisable to interlock the tested program (with regard to hardware and to software) so that access by unauthorized persons is impossible.

b) Tests of the hardware

Computer-controlled processing and transfer of measuring data, as well as the computer control of measuring instruments, require either

- microprocessors which have been tested for their reliability and correctness, or standard busses and interfaces, or

- a special test program by means of which the security of the hardware can be tested according to general requirements or to those for the particular verification equipment.

Appropriate steps must be taken to ensure that an alteration or loss of data by the hardware is impossible.

Table 1
Examples of verification equipment

No	Type of equipment used for verication	Method	Measurement standard	Auxiliary measuring instruments	Auxiliary equipment		Prerequisite for reference conditions
					metrological	technical(*)	
1	verification facility for precision measuring tapes	direct	measuring tape	thermometers	test bank with microscopes and tension weights		stabilisation of room temperature, air-conditioning
2	verification equipment for gauge blocks of high accuracy classes	direct	secondary radiation sources (spectral)	thermometers, barometers, hygrometers	interferometer, glass plates	light source,computing aids	high-quality air-conditioning
3	verification equipment for high accuracy weights	direct	weights, equal-arm balance	tare weights, thermometer, barometer, hygrometer		forceps, weight holders, magnifying glass, lighting	air-conditioning
4	verification installation for weigh bridges	direct	weights			lorry with lifting and handling equipment, fork lift	no rain, no wind
5	stop watch verification equipment	indirect (**)	frequency generator, counting equipment	test console with stop operating mechanism	magnifying glass		
6	computerized verification equipment for clinical thermometers	direct	mercury-in-glass thermometers	graduated scales or gauges for dimension control	thermostat	centrifuge, special lighting, magnifying glasses, stand-by thermometer holder, computer for operation	thermostat or air-conditioned laboratory
7	verification installation for heat meters	indirect	thermometers, weighing or volume measure	flowmeters, thermometers pressure gauges	test stand, thermostats	reservoir, pumps, pipe fitting, power supply equipment	insulation against vibrations in hydraulic systems
8	barometer verification facility	direct	barometers	thermometers	pressure chamber	indicating equipment	
9	verification equipment for diaphragm gas meters	direct	bell prover	thermometers, stop watch, flow meters, pressure gauges	test stand, buoyancy compensating equipment of bell prover		air-conditioning
10	verification facility for electrical energy meters	indirect	electrical power meters, chronometers, current and voltage transducers	electrical current, voltage, phase and frequency measuring instruments		current and voltage sources	air-conditioning

Notes: (1) Some verification equipment may operate automatically.
(2) Computer-controlled equipment for verification may periodically and regularly verify its own measuring instument(s) during pauses in the operation.

(*) Only some (special) technical auxiliary equipment is shown.
(**) May also be considered as a direct method when "counting" and "measuring", or "counting equipment" and "measuring instrument", cannot be confused.

TABLE 2

Examples of periods of validity (maximum values)
for working standards and auxiliary measuring instruments
where the period exceeds one year

Note: The periods listed below are only examples applicable to the climatic conditions prevailing in Central Europe and to standards that are carefully handled. In principle each state must determine appropriate periods of validity after careful metrological examination, and include them in the respective regulations.

Measuring instruments for length	years
steel graduated rules	10
plastic graduated rules (as auxiliary measuring instruments)	2
steel measuring tapes	5
dial gauges	5
graduated dial with magnifier for thickness and divisions	10
inside micrometer, outside micrometer, or micrometer depth gauge	5
sliding calliper	5
feeler gauge	2
calliper gauge	5
gauges for instruments for measuring the hectolitre weight of cereal grain	5
Instruments for measuring areas	
metal standard plane	5
rubber or plastic standard plane	2
Measuring instruments for the volume of liquids	
glass provers used as standards or for verification	unlimited
metal provers and measures	2
stationary metal provers and measures	5
metal provers fixed to a trolley	3
gauging apparatus for barrels	2
apparatus with volume meter	(*)
instruments for testing of butyrometers	10
instruments for testing of capillary pipettes	10
glass burettes	unlimited
glass pipettes	unlimited
glass measuring cylinders	unlimited
Measuring instruments for the volume of gas	
bell prover	5
wet gas meter	5
rotary piston (or displacement) gas meters, up to G 1000	5
rotary piston (or displacement) gas meter, greater than G 1600	8
turbine (wheel) gas meters, up to G 1000	3
turbine (wheel)) gas meters, greater than G 1600	5
positive displacement (piston) meters	5
oil displacement apparatus with oval wheels	5

(*) No retesting periods; however, these measuring instruments must be retested after each repair. The errors must be determined each time prior to use.

Instruments for measuring the density of cereals	
standard instrument for determining the hectolitre weight of cereal grain	5
Measuring instruments for density	
standard hydrometer	10
standard saccharimeter	10
standard alcoholometer	10
Temperature-measuring instruments	
thermometers as auxiliary measuring instruments	5
thermometers with solid stems or enclosed scales	5
Pressure-measuring instruments	
liquid manometers	5
pressure balances	5
mercury barometers	5
aneroid barometers	(*)
Measuring instruments for intraocular pressure	
measuring instruments for applanation and impression tonometers	3
Electricity-measuring instruments	
DC potentiometers including voltage dividers and shunts	8
standard cells	5
precision current transformers and precision voltage transformers of test stands	15
auxiliary equipment for error indication	5
equipment for the indication of voltage symmetry	5
precision instruments for electrical power measurement	5
DC precision ammeters with shunts	(**)
measuring installations for voltage- and current-transformers	5
load-measuring instruments	5
standards loads	5
standard resistance dividers	5
standard capacity dividers	5
voltmeters for testing insulation	
a) peak-to-peak measuring instruments	5
b) RMS measuring instruments	5
standard current transformers	16
standard voltage transformers	16

(*) No retesting periods; however, these measuring instruments must be retested after each repair. The errors must be determined each time prior to use.

(**) No retesting periods; however, these measuring instruments must be retested after each repair (as all other electrical measuring instruments).

BIBLIOGRAPHY

The OIML publications mentioned in this Document, as references or as examples, are the following.

OIML International Recommendations:

R 5 Meters for liquids other than water with measuring chambers

R 7 Clinical thermometers, mecury-in-glass with maximum device

R 37 Verification of hardness testing machines (Brinell system)

R 38 " " " " (Vickers system)

R 39 " " " " (Rockwell systems B,F,T C,A,N)

R 49 Water meters intended for the metering of cold water

OIML International Documents:

D 5 Principles for the establishment of hierarchy schemes for measuring instruments

D 6 Documentation for measurement standards and calibration devices

D 8 Principles concerning choice, official recognition, use and conservation of measurement standards

D 9 Principles of metrological supervision

D 10 Guidelines for the determination of recalibration intervals of measuring equipment used in testing laboratories