NABL 122-02

NATIONAL ACCREDITATION BOARD FOR TESTING AND CALIBRATION LABORATORIES

SPECIFIC CRITERIA for CALIBRATION LABORATORIES IN MECHANICAL DISCIPLINE : MASS (Weights)

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AMENDMENT SHEET

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1 General Requirement:

- The purpose of this document is to specify requirements with which a laboratory has to operate and demonstrate its competency to carry out calibration in accordance with ISO/IEC 17025:2005.

- To achieve uniformity between the laboratories, assessors and assessment process in terms of maximum permissible error, CMC, measurement uncertainty etc in line with National/International standards.

- To achieve uniformity in selection of equipment's, calibration methods, maintaining required environmental conditions, personnel with relevant qualification and experience.

1.1 Scope

This specific criteria lays down the specific requirements in calibration of weights under mechanical discipline. This part of the document thus amplifies the specific requirements for calibration of weights and supplements the requirements of ISO/IEC 17025:2005.

1.2 Calibration and Measurement Capability (CMC)

1.2.1 CMC is one of the parameters that is used by NABL to define the scope of an accredited calibration laboratory, the others being parameter/quantity measured, standard/master used, calibration method used and measurement range. The CMC is expressed as "the smallest uncertainty that a laboratory can achieve when calibrating the best existing device". It is an expanded uncertainty estimated at a confidence level of approximately 95% corresponding to a coverage factor k=2.

1.2.2 For evaluation of CMC laboratories should follow NABL 143 - Policy on Calibration and Measurement Capability (CMC) and Uncertainty in Calibration.

1.3 Personnel, Qualification and Training

1.3.1 Technical Personnel:

1.3.1.1 Qualification required for carrying out calibration activity:

The following are the specific requirements. However, qualification and experience will not be the only criteria for the required activity. They have to prove their skill, knowledge and competency in their specific field of calibration activity.

a) B.E / B.Tech or M.Sc. (having Physics as one of the subject) degree with 3 months experience in Basics of Mass Metrology.

b) B.Sc (with Physics as one of the subject) or Diploma with 6 months experience in Basics of Mass Metrology.

c) ITI with 1 year of experience in Basics of Mass Metrology.

1.3.1.2 Training and experience required:

a) Training may be external/ internal depending on the expertise available in the field.

b) Training in Mass Metrology and in Uncertainty Measurements, CMC including statistical analysis for Technical Manager.

c) Experience and competence in Basics of Mass Metrology.

d) Sufficient knowledge about handling of reference equipment, maintenance, traceability, calibration procedure and effect of environmental conditions on the results of calibration.

e) During training calibration activity should be done under supervision.

1.3.2 Authorised Signatory:

1.3.2.1 Qualification required for interpretation of results and signing the calibration certificates:

The following are only guidelines. However, qualification and experience will not be the only criteria for the required activity. They have to prove their skill, knowledge and competency in analysis and interpretation of calibration results.

a) B.E / B.Tech or M.Sc. (with having Physics as one of the subject) degree with 6 months experience in Mass Metrology.

b) B.Sc. (with Physics as one of the subject) or Diploma with 1 year experience in Mass Metrology.

1.3.2.2 Training and experience required:

a) Training may be external/ internal depending on the expertise available in the field

b) Training, Experience and Competence in Mass Metrology and Training in Uncertainty Measurements, CMC including statistical analysis for Technical Manager.

c) Sufficient knowledge and competence in effective implementation of ISO/IEC 17025, specific criteria and NABL guidelines.

d) Competency in reviewing of results, giving opinion and interpretations.

e) During training the relevant activity has to be done under supervision

1.4 Accommodation and Environmental Conditions

Accommodation and environmental conditions adversely affect the results of calibration and measurement accuracy unless they are controlled and monitored. Hence, they play a very important role.

The influencing parameters may be one or more of the following i. e. temperature, relative humidity, atmospheric pressure, vibration, acoustic noise, dust, air currents/draft, illumination (wherever applicable), voltage fluctuations, electrical earthing and direct sunlight etc., depending on the nature of calibration services provided. The variables described above can play a major factor on calibration results.

The laboratories are advised to follow the requirement of accommodation and environment depending on the types of services provided as recommended

- By the manufacturers of the reference equipment.

- By the manufacturers of the Unit under calibration.
- As specified in the National/ International Standards or guidelines followed for the calibration.

The environmental monitoring equipments used should also meet the requirement of manufacturers' recommendations and specifications as per the relevant standards followed.

If, accommodation and environmental conditions are not specified either by manufacturer or by National/International standards / guidelines, the laboratory shall follow the below recommendations.

1.4.1 Vibration

The calibration area shall be free from vibrations generated by central air-conditioning plants, vehicular traffic and other sources to ensure consistent and uniform operational conditions. The laboratory shall take all special/ protective precautions like mounting of sensitive apparatus on vibration free tables and pillars etc., isolated from the floor, if necessary.

1.4.2 Acoustic Noise

Acoustic noise level in the laboratory shall be maintained to facilitate proper performance of calibration work. Noise level shall be maintained less than 60 dBA, wherever it affects adversely the required accuracy of measurement.

1.4.3 Illumination

The calibration area shall have adequate level of illumination. Where permissible, fluorescent lighting is preferred to avoid localized heating and temperature drift. The recommended level of illumination is 250-500 lux on the working table.

1.4.4 Environmental Conditions and Monitoring

The environmental conditions for the activity of the laboratory shall be such as not to adversely affect the required accuracy of measurement. Facilities shall be provided whenever necessary for recording temperature, pressure and humidity values prevailing during calibration. The atmospheric conditions maintained in the laboratory during calibration shall be reported in the calibration report/ certificate.

1.5 Special Requirements of Laboratory

1.5.1 The calibration laboratory shall make arrangements for regulated and uninterrupted power supply of proper rating. The recommended voltage regulation level is ±2% or better, and Frequency variation ± 2.5Hz or better on the calibration bench.

1.5.2 The reference standards shall be maintained at temperatures specified for their maintenance on order to ensure their conformance to the required level of operation.

1.5.3 The laboratory shall take adequate measures against dust and external air pressure.

1.6 Safety Precautions

1.6.1 Relevant fire extinguishing equipment for possible fire hazards, shall be available in the corridors or convenient places in the laboratory. Adequate safety measures against electrical, chemical fire hazards must be available at the work place. Laboratory rooms/ areas where highly inflammable materials are used/ stored shall be identified. Access to the relevant fire equipment shall be assured near these rooms/ areas.

1.6.2 Specification SP 31- 1986, a special publication in the form of a wall chart, giving the method of treatment in case of electric shock, should be followed. The chart shall be placed near the power supply switchgear and at other prominent places as prescribed under Indian Electricity Rules 1956.

1.6.3 Effective mains earthing shall be provided in accordance with relevant specification IS: 3043. This shall be periodically checked to ensure proper contact with earth rod.

1.7 Other Important Points

1.7.1. Entry to the Calibration Area: As far as possible, only the staff engaged in the calibration activity shall be permitted entry inside the calibration area.

1.7.2. Space in Calibration Area: The calibration Laboratory shall ensure adequate space for calibration activity without adversely effecting the results.

1.8 Proficiency Testing

To give further assurance to the accuracy or Uncertainty of measurements, a laboratory will be required to participate, from time to time, in Proficiency Testing Program. The laboratory shall remain prepared to participate in the Proficiency Testing Program through inter-laboratory, inter-comparison schemes wherever it is technically feasible. (Ref. NABL 162, 163 and 164 for further details)

2. Specific Requirement – Calibration of Weights

2.1 Scope: Calibration of Weights

Specific Requirements for calibration of weights with following details:

Sl. No.	**Description**	**Relevant Standard**	**Permanent facility**	**Onsite calibration**	**Mobile facility**
1	Weights (E_1, E_2 , F_1, F_2, M_1, M_2, M_3)	OIML-R 111-1	√	X	X

Note 1: Newton weights, non-metric weights can also be calibrated to accuracy class equivalent to OIML R111 -1. However, the conventional mass values and its uncertainty should be given in SI units.

Note 2: This technical requirement is based on the above mentioned guideline. Lab may follow any relevant standard, however care shall be taken to follow the requirements in totality.

Note 3: ASTM standard weights can also be calibrated if the relevant standard is followed in total.

Note 4: Laboratory shall apply for calibration and not for verification of Weights. Verification may require approval from Dept. of Legal Metrology, Regulatory Bodies, etc.

2.2 National/ International Standards, References and Guidelines

- OIML R111-1-2004 Metrological and technical requirement of weights Classes E_1, E_2, F_1, F_2, M_1, M_2, M_3.
- OIML D28 2004: Conventional value of the result of weighing in air.
- ASTM E617 - 13 Standard Specifications for Laboratory Weights and Precision Mass Standards.
- OIML R 47 Edition 1079(E) - Standard weights for testing of high capacity weighing machines.

2.3 Metrological Requirements

2.3.1 For Each weight, the expanded uncertainty, U, for k=2, of the conventional mass, shall be less than or equal to one third of the maximum permissible error.

2.3.2 For each weight, the conventional mass, m_c (determined with an expanded uncertainty, U, according to 5.2 of OIML R-111-1) shall not differ from the nominal value of the weights, m_0 by more than the maximum permissible error, δm minus the expanded uncertainty.

$$m_0 - (\delta m\text{-}U) \le m_c \le m_0 + (\delta m\text{-}U)$$

2.3.3 For class E_1 and E_2 weights, which are always accompanied by certificates giving the appropriate data, the deviation from the nominal value, m_c-m_0, shall be taken into account by the user.

2.3.4 Calibration certificate shall state, as a minimum: the conventional mass of each weight, m_c an indication of whether a weight has been adjusted prior to calibration, its expanded uncertainty U and the values of the coverage factor k.

2.3.5 The certificate for class E_1 weights shall state, as a minimum, the values of conventional mass, m_c, the expanded uncertainty, U, and the coverage factor k and density or volume for each weight. In addition, the certificate shall state if the density or volume was measured or estimated.

2.3.6 The certificate for class E_2 weights shall state, as a minimum, the value of conventional mass $m_{c,}$ of each weight, the expanded uncertainty, U, and the coverage factor k.

2.3.7 Altitude and corresponding changes in air density can affect the measurement error when using the conventional mass of weight; therefore, the buoyancy correction shall be used, which requires the density of the weight to be known. If class E weights are to be used above 330 m, the density of the weights shall be provided along with their associated uncertainty for Class F1 the same is true above 800 m. Otherwise, the manufacturer shall take the lowered buoyancy affect at higher altitude in to consideration in specifying the weights class for the standards of conventional mass.

2.4 Terms & Definitions

Accuracy Class

- Class designation of a Weight or Weight set which meets certain metrological requirements intended to maintain the mass values within the specified limit.

Buoyancy Correction

- A buoyancy correction is the correction applied when Weights of different densities are compared with each other during the calibration process, the buoyancy being a result of the upward force when the weight is immersed in a fluid / air during the weighing process.

Conventional Mass (Conventional Value of the Mass)

- Conventional value of the result of weighing in air, in accordance with OIML D-28 (conventional value of the result of weighing in air) for a weight taken at a reference temperature of 20°C, The conventional mass of a body is the mass of a standard weight of density 8000 kg/m^3 at 20°C which balances this body in air of density 1.2 kg/m^3.

True Mass

- The true mass of a body relates to the amount of material it contains. The prefix true is added to the word mass where it is important to make it clear that a particular mass being considered is not a conventional mass value and it is important to avoid potential ambiguity. The International prototype kilogram, on which the International mass scale is realized, is defined as a true mass of exactly 1 kilogram. Most high accuracy comparisons are performed on a true mass basis, and converted to conventional mass when quoted on a certificate.

- The concept of true mass (mass in vacuum) might be appropriately described as a theoretical comparison of a mass against a reference standard mass (with a known value) on a equal arm balance inside a vacuum chamber. Although this scenario is impossible to achieve, one can easily understand that such an arrangement, were it possible, would remove any influence on the weighing process from the buoyant effect of air.

Discriminations / Sensitivity

- Sensitivity is the smallest change in mass that can be detected by the weighing Instrument. For practical purpose discrimination is synonymous with readability. Discrimination is also synonymous with the sensitivity of an analog weighing Instrument.

Readability

- The smallest scale division or digital interval of the weighing Instrument. For same mechanical weighing Instruments the scale marks may be sufficiently far apart for an estimation to be made of the actual weighing instrument reading when the pointer lies between two scale marks. The estimated readability may therefore be lower than the marked readability.

Resolution

- The readability expressed as a portion of the capacity. For example a weighing Instrument with a capacity of 3000g and a readability of 0.1g has a resolution of 1 part in 30000.

Scale Interval

- The value expressed in units of Mass of in the case of analog indication, the difference between the values that correspond to two scale marks. In the case of digital Indication, the difference between two consecutively indicated values.

Weight

- A material measure of mass, regulated in regard to its physical and metrological characteristics: Shape, Mass, material, surface quality, nominal value and maximum permissible error.

2.5 Selection of Reference Weights

The reference weight shall generally be of a higher class of accuracy than the weight to be calibrated. In the calibration of weights of class E_1, the reference weight shall have similar or better metrological characteristics (magnetic properties, surface roughness) than the weights to be calibrated [refer C.2.3 of OIML R 111-1, 2004 for more details].

Weight that can be used as Reference	**Class of Weights that can be Calibrated**						
	$\mathbf{E_1}$	$\mathbf{E_2}$	$\mathbf{F_1}$	$\mathbf{F_2}$	$\mathbf{M_1}$	$\mathbf{M_2}$	$\mathbf{M_3}$
E_1	√	√	√	√	√	√	√
E_2	-	-	√	√	√	√	√
F_1	-	-	-	√	√	√	√
F_2	-	-	-	-	√	√	√

Note: Standard weights of each class shall have the technical requirements such as shape, construction, material, marking etc as per OIML R111. M1, M2, and M3 class weights are not recommended to be used as a reference for the calibration of weights. However, M1 weights can be used for above 20kg with coarser uncertainty.

2.6 Selection of Comparator/Balance

On the basis of the accuracy class, a mass comparator is to be selected in such a way that its uncertainty component is balanced in proportion to the overall uncertainty of the weighing result. The most important uncertainty component of a mass comparator is calculated from its standard deviation. The specification of the manufacturer can be selected as a first approximation for the value of a standard deviation. It must be taken into account. However, that this indication is decisive for the smallest nominal value. It should therefore not exceed an amount of 30% of the combined standard uncertainty u1 (k=2).

2.6.1 Example:

Weight to be Calibrated	Class	Permissible Error as per OIML R 111	Uncertainty required (1/3 of the error) with k=2	Standard Deviation of the Comparator required =
1 mg	E_2	0.006 mg	0.002 mg	(0.002)/3 mg $S \leq 0.00067$ mg

Note: It is not recommended to calibrate a higher accuracy class weight with a lower accuracy class of reference weight and comparator/balance with coarser resolution without the consent of the customer.

2.6.2 Selection of comparator balance for calibration of weights depending on class of accuracy:

Nominal Value		**E_1**	**E_2**	**F_1**	**F_2**	**M_1**	**M_2**	**M_3**
		Standard Deviation of Repeatability in mg						
5000	kg			2778	8889	27778	88889	277778
2000	kg			1111	3333	11111	33333	111111
1000	kg		178	556	1778	5556	17778	55556
500	kg		89	278	889	2778	8889	27778
200	kg		33	111	333	1111	3333	11111
100	kg		17.8	56	178	556	1778	5556
50	kg	2.78	8.9	28	89	278	889	2778
20	kg	1.11	3.3	11	33	111	333	1111
10	kg	0.56	1.78	6	18	56	178	556
5	kg	0.28	0.89	2.8	8.9	28	89	278
2	kg	0.11	0.33	1.11	3.3	11.1	33	111
1	kg	0.056	0.178	0.556	1.78	5.56	17.8	56
500	g	0.028	0.089	0.278	0.89	2.78	8.89	28
200	g	0.011	0.033	0.111	0.33	1.11	3.33	11.1
100	g	0.006	0.018	0.056	0.18	0.556	1.78	5.56
50	g	0.0033	0.011	0.034	0.11	0.333	1.11	3.33
20	g	0.0028	0.009	0.028	0.089	0.278	0.889	2.78
10	g	0.0022	0.007	0.022	0.067	0.222	0.667	2.22
5	g	0.0018	0.006	0.018	0.056	0.178	0.556	1.78
2	g	0.0013	0.004	0.013	0.044	0.133	0.444	1.33
1	g	0.0011	0.0034	0.011	0.033	0.111	0.333	1.11
500	mg	0.0009	0.0028	0.009	0.028	0.089	0.278	8.89
200	mg	0.0007	0.0022	0.007	0.022	0.067	0.222	
100	mg	0.0006	0.0018	0.006	0.018	0.056	0.178	
50	mg	0.0004	0.0013	0.004	0.013	0.044		
20	mg	0.0003	0.0011	0.0034	0.011	0.034		
10	mg	0.0003	0.0009	0.0028	0.009	0.028		
5	mg	0.0003	0.0007	0.0022	0.006	0.022		
2	mg	0.0003	0.0007	0.0022	0.006	0.022		
1	mg	0.0003	0.0007	0.0022	0.006	0.022		

2.7 Calibration Interval

For the reference Weights and comparators used in calibration of Weights at permanent lab facility

Reference Equipment	**Recommended Interval**
Weights of E_1 and E_2 class	3 years
Weights of class F_1 to M_1	2 years
Comparator / Balance	1 year

Note: Based on the historical data validity of reference weights may be extended upto 5 years for E_1.

2.8 Legal Aspects

Calibration of weights done by any accredited laboratories is meant for scientific and industrial purpose only. However, if used for commercial trading, additional recognition/ approval shall be complied as required by Dept. of Legal metrology, Regulatory bodies, etc. This should be clearly mentioned in the calibration certificate issued to the customer.

2.9 Environmental Conditions required for Calibration and Requirement of Environment Monitoring System

2.9.1 Environmental Conditions

2.9.1.1 Laboratory is advised to follow Manufacturer's recommendation for environmental conditions, operation and maintenance of weights, weighing balance, comparator, etc.

2.9.1.2 Accuracy or reliability of weighing results is closely connected with the place where, mass comparators are installed, and also with the weights used, with the measuring room conditions and operator's skill. The place of installation (measuring room) for mass comparators shall be designed in such a way that, the disturbances of the environment do not affect the result. Manufacturer's recommendation shall be considered.

2.9.2 The calibration of weights shall be performed at suitable conditions under ambient atmospheric pressure at temperatures closer to room temperature (1) Typical recommended values are given below:

Weight Class	Temperature change during Calibration(2)	Range of Relative Humidity of the Air(3)
E_1	± 0.3°C per hour with a maximum of ± 0.5°C per 12 hours	40% to 60% with a maximum of ± 5% per 4 hours
E_2	± 0.7°C per hour with a maximum of ± 1°C per 12 hours	40% to 60% with a maximum of ± 10% per 4 hours
F_1	± 1.5°C per hour with a maximum of ± 2°C per 12 hours	40% to 60% with a maximum of ± 15% per 4 hours
F_2	± 2°C per hour with a maximum of ± 3.5°C per 12 hours	
M_1	± 3°C per hour with a maximum of ± 5°C per 12 hours	

Note (1): It is also important that the difference in temperature between the weights and the air inside the mass comparator is as small as possible. Keeping the reference weight and the test weight inside the mass comparator before and during the calibration to reduce the temperature difference.

Note (2): This is the change in the temperature of the laboratory. Thermal stabilization of balances and weights also requires an appropriate temperature stability of laboratory for 24 hours before calibration.

Note (3): The upper limit is mainly important when storing the weight.For E1 and E2 class weights, the temperature should be within 18°C to 27°C. The environmental conditions shall be within the specifications of the weighing instruments.

2.9.3 Recommended Environment Monitoring Equipments

- Temperature with a resolution of 0.1 °C.

- Humidity with a resolution of 1% RH
- Barometer with 1 mbar

However, laboratory shall evaluate the requirement of accuracy, resolution and uncertainty depending on the CMC aimed at.

2.9.4 Thermal Stabilization Requirement for Test Weights

2.9.4.1 Thermal stabilization

- Prior to performing any calibration, the weights need to be acclimated to the ambient conditions of the laboratory. In particular, weights of classes E_1, E_2 and F_1 shall be close to the temperature in the weighing area.

- The mandatory minimum times required for temperature stabilization (depending on weight size, weight class and on the difference between the initial temperature of the weights and the room temperature in the laboratory) are shown in Table below. As a practical guideline, a waiting time of 24 hours is recommended.

2.9.4.2 Thermal stabilization in hours:

ΔT*	Nominal value	Class E1	Class E2	Class F1	Class F2
± 20 °C	1 000, 2 000, 5 000 kg	-	-	79	5
	100, 200, 500 kg	-	70	33	4
	10, 20, 50 kg	45	27	12	3
	1, 2, 5 kg	18	12	6	2
	100, 200, 500 g	8	5	3	1
	10, 20, 50 g	2	2	1	1
	< 10 g	1		0.5	
± 5 °C	1 000, 2 000, 5 000 kg	-	-	1	1
	100, 200, 500 kg	-	40	2	1
	10, 20, 50 kg	36	18	4	1
	1, 2, 5 kg	15	8	3	1
	100, 200, 500g	6	4	2	0.5
	10, 20, 50 g	2	1	1	0.5
	< 10 g	0.5			
± 2 °C	1 000, 2 000, 5 000 kg	-	-	1	0.5
	100, 200, 500 kg	-	16	1	0.5
	10, 20, 50 kg	27	10	1	0.5
	1, 2, 5 kg	12	5	1	0.5
	100, 200, 500 g	5	3	1	0.5
	< 100 g	2	1		0.5
± 0.5°C	1 000, 2 000, 5 000 kg	-	-	-	-
	100, 200, 500 kg	-	1	0.5	0.5
	10, 20, 50 kg	11	1	0.5	0.5
	1, 2, 5 kg	7	1	0.5	0.5
	100, 200, 500 g	3	1		0.5
	< 100 g	1	0.5		

ΔT* = Initial difference between weight temperature and laboratory temperature.

Note: Thermal stabilization hours before calibration should be clearly mentioned in the certificate issued to the customer.

2.10 Calibration Methods

There are two methods for determination of conventional mass of weights in a weight set.

2.10.1 Direct Comparison Method

Minimum Number of Weighing Cycles (as per OIML R-111-1)					
Class	E_1	E_2	F_1	F_2	M_1, M_2, M_3
Min. number of ABBA	3	2	1	1	1
Min. number of ABA	5	3	2	1	1
Min. number of $AB_1...B_nA$	5	3	2	1	1

2.10.2 Sub -Division/Sub-Multiplication Method (Ref. C.3.2 of OIML)

Reference Weights	Vs	5+2+2*+1
Reference Weights	Vs	5+2+2*+1*
5	Vs	2+2*+1
5	Vs	2+2*+1*
2+1	Vs	2*+1*
2+1	Vs	2+1
2+1*	Vs	2*+1
2+1*	Vs	2*+1
2	Vs	1+1*
2	Vs	1+1*
2*	Vs	1+1*
2*	Vs	1+1*

Note: Method used for calibration should be clearly mentioned in the calibration certificate issued to the customer.

2.11 Determination of Air Density and its Uncertainty

2.11.1 In 2008 CIPM recommended that the following equation be used to determine ρa the density of Air

$$\rho_a = [3.483740+1.4446*(x_{co2} - 0.0004)]*10^{-3} *p/ZT*(1-0.378*x_v)$$

Where, ρ_a : Density of air in kg/m^3
x_{CO2} : The mole fraction of carbon diaoxide (assumed 400 ppm, if not measured)
p : pressure
Z : compressibility
x_v : mole fraction of water vapor
T : Thermodynamic temperature using ITS-90

2.11.1.1 Mole fraction of water vapor, x_v

The mole fraction of water vapor, *x*v that is a function of the relative humidity, *rh* or dew-point temperature *t*r, an enhancement factor, *f* and the moist air saturation vapor pressure, *p*sv is given as follows:

$$x_v = rhf(p,t)* p_{sv}(t)/p = f(p,t_r) * p_{sv}(t_r)/p$$

Where, *rh* : relative humidity in fraction

p : pressure in mbar
t : temperature in °C
$psv(t)$: saturation vapor pressure of moist air
tr : dew-point temperature

2.11.1.2 The moist air saturation vapor pressure, psv can be calculated using the following equation:

$$p_{sv} = 1Pa * e^{(AT2+BT+C+D/T)}$$

Where A, B, C, D are the vapor pressure constant parameters at saturation. The recommended values are as given in Table 2.

2.11.1.3 Enhancement Factor, f

The enhancement factor can be calculated using the following equation:

$$f = \alpha + \beta p + \gamma t^2$$

Where α, β, γ are constants of enhancement factor. The recommended values are as given in Table below.

2.11.1.4 The compressibility factor, Z

The compressibility factor, *Z*, can be calculated using the following equation:

$$z = 1 - \frac{p}{T}[a_0+a_1t+a_2t^2+(b_0+b_1t)x_v+(c_0+c_1t)\,x_v^2] + \frac{p^2}{T^2} * (d + e x_v^2)$$

Where a_0, a_1, a_2, b_0,b_1, c_0, c_1, d, e are the compressibility factor constants. The recommended values are as given in Table below.

2.11.1.5 Table: Recommended Values for Constants of Psv (A, B, C, D), f (α, β, γ) and Z (a_0, a_1, a_2, b_0, b_1, c_0, c_1, d, e)

Psv			f			Z		
Constant	1991 Recommended value	Unit	Constant	1991 Recommended value	Unit	Constant	1991 Recommended value	Unit
A	1.2378847×10^{-5}	K^{-2}	α	1.00062		a_0	1.58123×10^{-6}	KPa^{-1}
B	$-1.9121316 \times 10^{-2}$	K^{-1}	β	3.14×10^{-8}	Pa^{-1}	a_1	-2.9331×10^{-8}	Pa^{-1}
C	33.93711047		γ	5.60×10^{-7}	K^{-2}	a_2	1.1043×10^{-10}	$K^{-1}Pa^{-1}$
D	-6.3431645×10^{3}	K				b_0	5.707×10^{-6}	KPa^{-1}
						b_1	-2.051×10^{-8}	Pa^{-1}
						c_0	1.9898×10^{-4}	KPa^{-1}
						c_1	-2.376×10^{-6}	Pa^{-1}
						d	1.83×10^{-11}	K^2Pa^{-2}
						e	-7.65×10^{-8}	K^2Pa^{-2}

2.11.2 Approximation Formula as per OIML R-111-1: 2004 (Page No. 76)

$$\rho_a = \frac{0.34848p - 0.009*h*\exp(0.061*t)}{273.15+t} \qquad \text{(E-3.1 OIML)}$$

Where, Pressure (p) in mbar, temperature (t) in° C and humidity (h) in % Equation(E-3.1) has a relative uncertainty of 2 X 10^{-4} in the range 900hPa < p<1100hPa, 10 ° C<t<30 ° C and rh< 80%.

2.11.3 For class E1 weights, the density of air should always be determined based o corresponding measurements. However, the following approximation equation is a way to estimate air density at laboratories that have no means of determining the air density at the site. The height above sea level is always known. Therefore, if the air density is not measured, it should be calculated as a mean value for the laboratory site as follows:

$$\rho_a = \rho_0 * \exp\left[\frac{-\rho_0}{P_0} * gh\right]$$

Where p_0 = 101325 Pa
ρ_0 = 1.2 kg/m^3
g = 9.81 m/s^2
h = height above sea level expressed in meter.

2.11.4 The Standard Uncertainty of Air Density is given by:

[From OIMLR111-1:2004(E),page 68,equation C.6.3-3]

$$u^2\rho_a = u^2_F + (\delta\rho_a/\delta p * u_P)^2 + (\delta\rho_a/\delta T * u_T)^2 + (\delta\rho_a/\delta rh * u_{rh})^2$$

Where,

u_F =	$10^{-4}\ \rho_a$, uncertainty of the formula used to calculate air density
$\delta\rho a/\delta p$ =	$10^{-5}\ \rho_a * Pa^{-1}$
$\delta\rho a/\delta T$ =	$(-3.4*10^{-3} * \rho_a * K^{-1})$
$\delta\rho a/\delta rh$ =	$(-10^{-2}\ \rho_a)$
u_p =	uncertainty of pressure in mbar
u_T =	uncertainty of temperature in ° C
u_{rh} =	uncertainty of relative humidity %RH

2.12 Equations for Determination of Conventional Mass, True mass and their uncertainties

2.12.1 Determination of Conventional Mass with reference to volume of the reference and test Weights

2.12.1.1 Equation for Determination of Conventional Mass

$$\mathbf{m_{ct} = [m_{cr} + (V_t - V_r)(\rho_a - \rho_0) + \Delta m_w]}$$

Where,
V_t = Volume of the test weight
V_r = Volume of the reference weight
m_{ct} = Conventional mass of test weight
m_{cr} = Conventional mass of reference weight
ρ_a = Density of Air during calibration in kg/m^3
ρ_0 = Density of Air (Conventional) 1.2 kg/m^3
Δm_w = difference in mass observed using ABBA weighing cycle.

Note: Vt and Vr can be calculated from density and the nominal mass of the weights.

2.12.1.2 Equation for Air Buoyancy Correction

From the equation of the Clause 8.12.1.1, the term air buoyancy correction (B.C.) is:

$$B.C. = (Vt - Vr).(\rho a - \rho_0)$$

2.12.1.3 Equation for Determining the Uncertainty due to Air Buoyancy Correction

$$u'b^2 = (V_t - V_r)^2 * u\rho_a^2 + (uv_t^2 + uv_r^2) * (\rho_a - \rho_0)^2$$

Note: If, the volume is determined from known density and mass values and their uncertainties, uncertainty of volume (uV_t) can be calculated by the relation $uV_t = u\rho_t/\rho_\tau * V_t$ for test weight and similarly for the reference weight.

2.12.2 Determination of Conventional Mass with reference to Density of the Reference and Test Weights

2.12.2.1 Equation for Determination of Conventional Mass

$$\mathbf{m_{ct} = m_{cr}(1+C) + \Delta m_w}$$

Where,

$m_{ct} =$	Conventional mass of test weight
$m_{cr} =$	Conventional mass of reference weight
C =	Buoyancy correction factor
$\Delta m_w =$	Difference in weight by ABBA method

2.12.2.2 Buoyancy Correction Factor for Conventional Mass

$$\mathbf{C = [(\rho_a - \rho_0)(1/\rho_t) - (1/\rho_r)]}$$

Where,

$\rho_r =$	Density of Reference Weight in kg/m^3
$\rho_t =$	Density of Test Weight in kg/m^3
$\rho_a =$	Density of Air during Calibration in kg/m^3
$\rho_0 =$	Density of Air (Conventional) 1.2 kg/m^3

2.12.2.3 Uncertainty in Air Buoyancy Correction

Formula for calculation of uncertainty in air Buoyancy correction in Conventional Mass calculation to be verified:

$$\mathbf{u'_b{}^2 = \{(m_{cr}*(\rho_r-\rho_t)/\rho_r*\rho_t))*u\rho_a)\}^2)+\{(m_{cr}*(\rho_a-\rho_0))^2*[(u^2\rho_t/\rho^4)\}+m^2{}_{cr}*(\rho_a-\rho_0)*[(\rho_a-\rho_0)-2(\rho_{a1}-\rho_0)]*(u^2\rho_r/\rho_r{}^4)\}}$$

Where,

$u'_b =$	Uncertainty of air buoyancy correction of conventional mass
$m_{cr}=$	Conventional mass of reference weight in kg
$\rho_r =$	Density of reference weight in kg/m^3
$\rho_t =$	Density of test weight in kg/m^3

ρ_a = Density of Air during calibration in kg/m^3
ρ_{a1} = Density of Air during earlier calibration of reference wt in kg/m^3
$u\rho_r$ = Uncertainty in Density of reference weight in kg/m^3
$u\rho_t$ = Uncertainty in Density of test weight in kg/m^3
$u\rho_a$ = Uncertainty in Density of air in kg/m^3
ρ_0 = Density of air (conventional) 1.2 kg/m^3

- In case where air buoyancy correction is estimated to be negligible i.e. if $C_i \leq 1/3*U/m_0$.

- Even if the air buoyancy correction is negligible the uncertainty contribution of the buoyancy effect may not be negligible and shall be taken into account if $u_b \geq u_c/3$.

- For classes M_1, M_2 and M_3 the uncertainty due to air buoyancy correction is negligible and can usually be omitted.

- If the air density is not measured and the average air density for the site is used, than the uncertainty for the air density is to be estimated as: u(pa)= $0.12/\sqrt{3}$.

- A lower value of uncertainty may be used if supporting data can be provided.

- At sea level the density of air shall be assumed to be 1.2.kg per m^3.

- For class E weights, the density of air should be determined. Its uncertainty is usually estimated from the uncertainties for temperature, pressure, and air humidity. For class E_1, the CIPM formula or an approximation can be used for the calculation of air density.

Note: Where the air density is 1.2 kg/m^3 within ±10%, conventional mass value shall be used in calculation and true mass shall be calculated from conventional mass (OIML R- 111 C.2.1.2).

2.12.3 True Mass with reference to Volume of the Reference and Test Weights

2.12.3.1 Equation for Determination of Mass

$$m_{tt} = [m_{cr} + (V_t - V_r)(\rho_a) + \Delta m]$$

2.12.3.2 Equation for Determining the Uncertainty due to Air Buoyancy Correction

$$ub^2 = (V_t - V_r)^2 * u\rho_a^2 + (uv_t^2 - uv_r^2) * \rho_a^2$$

Note: If, the volume is determined from known density and mass values and their uncertainties, uncertainty of volume (uV_t) can be calculated by the relation $uV_t = u\rho_t/\rho_\tau * V_t$ for test weight and similarly for the reference weight.

2.12.4 True Mass with reference to Density of the Reference and Test Weights

2.12.4.1 Equation for Determination of Mass

$$M_{tt} = m_{tr}(1+B) + \Delta m_w$$

Where,

$M_{tt} =$	True mass of test weight
$m_{tr} =$	True mass of reference weight
B =	Buoyancy correction factor for true mass
$\Delta_{mw} =$	Difference in weight by ABBA method

2.12.4.2 Buoyancy Correction Factor for Calibration of Mass on True Mass basis

$$B = [(\rho_a)*(1/\rho_t)-(1/\rho_r)]$$

Where,

$\rho_r =$ Density of reference weight in kg/m^3
$\rho_t =$ Density of test weight in kg/m^3
$\rho_a =$ Density of air in kg/m^3

2.12.4.3 Equation for Calculation of Uncertainty in Buoyancy Correction in True Mass

$$u_b^2 = \{(m_r*(\rho_r-\rho_t)/\rho_r*\rho_t))*u\rho_a)\}^2 + \{(m_r*\rho_a)^2*[(u^2\rho_t/\rho_t^4)-(u^2\rho_r/\rho_r^4)]\}$$

Where,

$u_b =$	Uncertainty in buoyancy correction in true mass
$m_r =$	Mass of reference weight in kg
$\rho_r =$	Density of reference weight in kg/m^3
$\rho_t =$	Density of test weight in kg/m^3
$\rho_a =$	Density of air in kg/m^3
$u\rho_r =$	Uncertainty in density of reference weight in kg/m^3
$u\rho_t =$	Uncertainty in density of test weight in kg/m^3
$u\rho_a =$	Uncertainty in density of air in kg/m^3

Note 1: As per the standard if the air density deviates from 1.2 kg/m^3 by more than 10%, true mass values shall be used for calculations and the conventional mass shall be calculated from the true mass.

Note 2: True mass is required for the realization of force, pressure and torque etc by using dead weights.

Note 3: Calibration of weights in terms of Newton, bar, pascal etc (local "g" value shall be known to be sufficient accuracy).

2.12.4.4 Conversion from Conventional Mass to True Mass

$$m_t = m_c \times \frac{1-\rho_0/\rho_c}{1-\rho_0/\rho}$$

Where,

$m_t =$	True mass
$m_c =$	Conventional mass
$\rho_0 =$	Density of conventional Air (1.2) in kg/m^3
$\rho_c =$	Conventional density of Mass (8000) in kg/m^3
$\rho =$	Density of mass in kg/m^3

2.13 Measurement Uncertainty

2.13.1 Contribution of Uncertainty in Calibration of Weights:

The estimation of the uncertainty measurement for the weight calibrated by a laboratory shall consider at least the following contributions.

(a) Repeatability-standard deviation of weighing result
(b) The contribution of the reference standard weight.
(c) The air buoyancy correction
(d) The uncorrected drift of the reference standard weight
(e) The resolution of the balance

2.13.2 Uncertainty Equation for Calibration Results

Type A Standard uncertainty,

Type B Standard uncertainty,

$$\mathbf{u_c = \sqrt{(u_1^2 + u_2^2 + u_3^2 + u_4^2 + u_5^2)}}$$

Where,
$\mathbf{u_1}$= standard uncertainty associated with standard deviation of weighing
$\mathbf{u_2}$= Standard uncertainty associated with air buoyancy correction
$\mathbf{u_3}$= standard uncertainty associated with drift of the reference standard weight
$\mathbf{u_4}$= standard uncertainty associated with resolution of the comparator/balance
$\mathbf{u_5}$= Standard uncertainty associated with reference standard weight

Expanded uncertainty $\mathbf{U = k \times u_c}$

Note: For k value, students t table is to be referred.

2.14 Reporting of Results

The calibration certificates issued to the customer shall be in accordance with clause 5.10 of ISO/IEC/17025:2005. Apart from that it shall also include the following:

a. Thermal stabilization hours taken (as per 2.9.4.2) before calibration.
b. Specific calibration method followed (as per 2.10).
c. Density of Reference weight (whether assumed or measured).
d. Density of Test weight (whether assumed or measured).
e. Declaration that, the calibration certificate issued for weights/Mass used for scientific or industrial purposes only.

2.15 Evaluation of CMC

2.15.1 Refer NABL 143 for CMC evaluation.

2.15.2 CMC value is not the same as expanded uncertainty reported in the calibration Certificate/Report. CMC values exclude the uncertainties which are attributed to the DUC (Device under calibration).

2.15.3 For the purpose of CMC evaluation the following components should be considered:

- Repeatability-standard deviation of weighing result (for minimum 10 readings).
- Uncertainty of the reference standard weight.
- Drift in reference standard weight.
- Uncertainty due to air buoyancy correction.
- Uncertainty due to resolution of Balance.

2.16 Sample Scope

2.16.1 An illustrative example for right representation of scope

<table>
<tr><td colspan="6">Laboratory: XYZ</td><td colspan="2">Date(s) of Visit:</td></tr>
<tr><td colspan="8">Discipline: Mechanical</td></tr>
<tr><th rowspan="2">S. No</th><th rowspan="2">Parameter*/ Device under calibration</th><th rowspan="2">Master Equipment Used</th><th rowspan="2">Range(s) of Measurement</th><th colspan="3">Calibration and Measurement Capability **</th><th rowspan="2">Remarks+/ Method used</th></tr>
<tr><th>Claimed by Laboratory</th><th>Observed by Assessor</th><th>Recommended by Assessor</th></tr>
<tr><td>1.</td><td>Mass – Weights.</td><td>F1 Class Standard Weights and Mass Comparator (Readability : 0.001mg)</td><td>1 mg
2 mg
5 mg
10 mg
20 mg
50 mg
100 mg</td><td>0.02 mg
0.02 mg
0.02 mg
0.027 mg
0.033 mg
0.04 mg
0.053 mg</td><td>0.02 mg
0.02 mg
0.02 mg
0.027 mg
0.033 mg
0.04 mg
0.053 mg</td><td>0.02 mg
0.02 mg
0.02 mg
0.027 mg
0.033 mg
0.04 mg
0.053 mg</td><td>Calibration of weights of Class F2 accuracy and coarser as per OIML R-111</td></tr>
<tr><td colspan="8">* Only for Electro-technical discipline; scope shall be recommended parameter wise (where applicable) and the ranges may be mentioned frequency wise.
** NABL 143 shall be referred for the recommendation of CMC
+ Remarks shall also include whether the same scope is applicable for site calibration as well. NABL 130 shall be referred while recommending the scope for site calibration.</td></tr>
<tr><td colspan="2">Signature, Date & Name of Lab Representative</td><td colspan="3">Signature, Date & Name of Assessor(s)</td><td colspan="3">Signature, Date & Name of Lead Assessor</td></tr>
</table>

Note: CMC value shall be reported in absolute value i.e. in mg only.

2.17 Minimum Requirement for Accreditation

2.17.1 Laboratory shall have minimum F2 class of reference Weights for the calibration below 20 kg along with appropriate comparator / balance. However, M1 class reference weights may be used for calibration above 20 kg.

2.17.2 Demonstration of any CMC values doesn't automatically qualify for granting accreditation until the lab satisfies the stipulated requirement given above.

2.18 Maximum Permissible Error & Uncertainty Chart

2.18.1 Permissible error for classification weights as per OIML R-111-1, 2004.

Note: For each weight expanded uncertainty U, for k=2 the conventional mass, shall be as per the standard less than or equal to one-third of the maximum permissible error **(U = 1/3 δm)**

Class ⇨		E_1		E_2		F_1		F_2		M_1		M_2		M_3	
Nominal Value		Error ± mg	Uncertainty	Error ± mg	Uncertainty	Error ± mg	Uncertainty	Error ± mg	Uncertainty	Error ± mg	Uncertainty	Error ± mg	Uncertainty	Error ± mg	Uncertainty
5000	kg					25000	8333	80000	26667	250000	83333	800000	266667	2500000	833333
2000	kg					10000	3333	30000	10000	100000	33333	300000	100000	1000000	333333
1000	kg			1600	533	5000	1667	16000	5333	50000	16667	160000	53333	500000	166667
500	kg			800	267	2500	833	8000	2667	25000	8333	80000	26667	250000	83333
200	kg			300	100	1000	333	3000	1000	10000	3333	30000	10000	100000	33333
100	kg			160	53	500	167	1600	533	5000	1667	16000	5333	50000	16667
50	kg	25	8.3	80	27	250	83	800	267	2500	833	8000	2667	25000	8333
20	kg	10	3.3	30	10	100	33	300	100	1000	333	3000	1000	10000	3333
10	kg	5.0	1.7	16	5	50	17	160	53	500	167	1600	533	5000	1667
5	kg	2.5	0.8	8	3	25	8	80	27	250	83	800	267	2500	833
2	kg	1.0	0.3	3	1.0	10	3	30	10	100	33	300	100	1000	333
1	kg	0.5	0.2	1.6	0.5	5	2	16	5	50	17	160	53	500	167
500	g	0.25	0.08	0.8	0.3	2.5	1	8.0	3	25	8	80	27	250	83
200	g	0.10	0.03	0.3	0.10	1.0	0.3	3.0	1	10	3	30	10	100	33
100	g	0.05	0.02	0.16	0.05	0.5	0.2	1.6	0.5	5	2	16	5	50	17
50	g	0.03	0.01	0.10	0.03	0.3	0.1	1.0	0.3	3	1	10	3	30	10
20	g	0.025	0.01	0.08	0.03	0.25	0.1	0.8	0.3	2.5	1	8	3	25	8
10	g	0.020	0.01	0.06	0.02	0.20	0.1	0.6	0.2	2	1	6	2	20	7
5	g	0.016	0.01	0.05	0.02	0.16	0.1	0.5	0.2	1.6	1	5	2	16	5
2	g	0.012	0.004	0.04	0.01	0.12	0.04	0.4	0.1	1.2	0.4	4	1	12	4
1	g	0.010	0.003	0.03	0.01	0.10	0.03	0.3	0.1	1.0	0.3	3	1	10	3
500	g	0.008	0.003	0.025	0.008	0.08	0.03	0.25	0.1	0.8	0.3	2.5	1		
200	g	0.006	0.002	0.020	0.007	0.06	0.02	0.20	0.1	0.6	0.2	2.0	1		
100	mg	0.005	0.002	0.016	0.005	0.05	0.02	0.16	0.1	0.5	0.2	1.6	1		
50	mg	0.004	0.001	0.012	0.004	0.04	0.01	0.12	0.04	0.4	0.1				
20	mg	0.003	0.001	0.010	0.003	0.03	0.01	0.10	0.03	0.3	0.1				
10	mg	0.003	0.001	0.008	0.003	0.025	0.01	0.08	0.03	0.25	0.1				
5	mg	0.003	0.001	0.006	0.002	0.020	0.01	0.06	0.02	0.20	0.1				
2	mg	0.003	0.001	0.006	0.002	0.020	0.01	0.06	0.02	0.20	0.1				
1	mg	0.003	0.001	0.006	0.002	0.020	0.01	0.06	0.02	0.20	0.1				

2.19 Calibration of Newton Weights, Pressure Balance Weights and Non-metric Weights

2.19.1 Weights used for realization of Pressure in Dead weight pressure balance or weights used for realization of force in Newton are to be calibrated on true mass basis.

2.19.2 If, weights are calibrated on conventional mass basis equation for conversion from conventional mass to true mass to be mentioned to enable the user to apply appropriate buoyancy correction.

2.19.3 Newton or Force weights are typically of a slotted design or with a centre hole and are typically marked with a nominal Force in Newton. Force is calculated with respect to Local gravity 'g_L' during calibration using the formula given below:

$$\mathbf{F = m\,(1-\rho_a/\rho_m)*g_{LC}} \qquad [2.19.3a]$$

Where

F = Force in Newton
m = True Mass in Kg
ρ_a = air density in kg/m^3
ρ_m = density of weights in kg/m^3
g_L = Local gravity in m/sec^2 (value of 'g' at the customer's site)

The force values can be converted either to the standard 'g' value or to the customer's 'g' value using the formula given below:

<u>To convert Force to standard 'g' value:</u>

$$\mathbf{F = m\,(1-\rho_a/\rho_m)*\,g_S\,/g_{LC}} \qquad [2.19.3b]$$

Where, g_S = Standard gravity in m/sec^2 (9.80665 m/sec^2)
g_{LC} = Local gravity in m/sec^2 (value of 'g' at the site of calibration).

<u>To convert Force to 'g' value at customer's site:</u>

$$\mathbf{F = m\,(1-\rho_a/\rho_m)*g_L\,/g_{LC}} \qquad [2.19.3c]$$

Where, g_L = Local gravity in m/sec^2 (value of 'g' at the customer's site)

This conversion can be done if; the customer provides 'g' value at his site.

2.19.4 When the customer requires the force weight with respect to his local 'g' value he has to provide the same with uncertainty. Then the force value shall be calculated using the local 'g' value and declare in the certificate in terms mass value along with the calculated value in Newton. 'g' value of the calibration laboratory shall also be known to sufficient accuracy.

2.19.5 The Laboratory may calibrate weights of non-metric units (e.g. Pound or Ounce etc.) However, the results shall be reported in SI units like kg, g, mg, etc. along with the calculated equivalent value in the non-metric unit or mention the conversion factor to be used.

2.20 Key Points:

Demonstration of any CMC values doesn't automatically qualify for granting accreditation until the lab satisfies the stipulated requirement given in this document.

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