ETHIOPIAN ACCREDITATION SERVICE	**Guidance Document on Calibration of Mass (Weights)**	**Copy No.**
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Contents

1 Classification of Groups and Sub groups

1.1 Name of the Product/Device under Calibration

Table-1

S. No.	Description	Relevant Standard	Permanent facility	Onsite calibration	Mobile facility
1.	Weights (E1, E2, F1, F2, M1, M2, M3, M1–2 and M2–3)	OIML-R 111-1	Yes	No	No

Note: *Classification of weights is as per OIML R-111-1*

1.2 Maximum Permissible Errors on Verification

The accuracy class for weights used as standards for the verification of weights or weighing instruments should be in accordance with the requirements of OIML R-111-1 (Table 2).

1.2.1 Maximum permissible errors on initial and subsequent verification or in-service inspection

1.2.2 Maximum permissible errors for initial verification of individual weights are given in Table 2 and relate to conventional mass.

1.2.3 Maximum permissible errors for subsequent verification or in-service verification are left to the discretion of each state. If, however, the maximum permissible errors allowed are greater than those in Table 2, the weight cannot be declared as belonging to the corresponding OIML class.

1.2.4 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.

1.3 Minimum accuracy class of weights

1.3.1 The OIML weight classes are defined as follows:

a) **Class E1:** Weights intended to ensure traceability between national mass standards and weights of class E2 and lower. Class E1 weights or weight sets shall be accompanied by a calibration certificate (see note 2)

b) **Class E2:** Weights intended for use in the verification or calibration of class F1 weights and for use with weighing instruments of special accuracy class I. Class E2 weights or weight sets shall be accompanied by a calibration certificate (see note 3). They may be used as class E1 weights if they comply with the requirements for surface roughness, magnetic susceptibility and magnetization for class E1 weights and if their calibration certificate gives the appropriate data as specified in note 2.

c) **Class F1:** Weights intended for use in the verification or calibration of class F2 weights and for use with weighing instruments of special accuracy class I and high accuracy class II.

d) **Class F2:** Weights intended for use in the verification or calibration of class M1 and possibly class M2 weights. Also intended for use in important commercial transactions (e.g. precious metals and stones) on weighing instruments of high accuracy class II.

e) **Class M1:** Weights intended for use in the verification or calibration of class M2 weights, and for use with weighing instruments of medium accuracy class III.

f) **Class M2:** Weights intended for use in the verification or calibration of class M3 weights and for use in general commercial transactions and with weighing instruments of medium accuracy class III.

g) **Class M3:** Weights intended for use with weighing instruments of medium accuracy class III and ordinary accuracy class IIII.

h) **Classes M1–2 and M2–3:** Weights from 50 kg to 5 000 kg of lower accuracy intended for use with weighing instruments of medium accuracy class III.

Table-2

Nominal value*	Class E_1	Class E_2	Class F_1	Class F_2	Class M_1	Class M_{1-2}	Class M_2	Class M_{2-3}	Class M_3
5 000 kg			25 000	80 000	250 000	500 000	800 000	1 600 000	2 500 000
2 000 kg			10 000	30 000	100 000	200 000	300 000	600 000	1 000 000
1 000 kg		1 600	5 000	16 000	50 000	100 000	160 000	300 000	500 000
500 kg		800	2 500	8 000	25 000	50 000	80 000	160 000	250 000
200 kg		300	1 000	3 000	10 000	20 000	30 000	60 000	100 000
100 kg		160	500	1 600	5 000	10 000	16 000	30 000	50 000
50 kg	25	80	250	800	2 500	5 000	8 000	16 000	25 000
20 kg	10	30	100	300	1 000		3 000		10 000
10 kg	5.0	16	50	160	500		1 600		5 000
5 kg	2.5	8.0	25	80	250		800		2 500
2 kg	1.0	3.0	10	30	100		300		1 000
1 kg	0.5	1.6	5.0	16	50		160		500
500 g	0.25	0.8	2.5	8.0	25		80		250
200 g	0.10	0.3	1.0	3.0	10		30		100
100 g	0.05	0.16	0.5	1.6	5.0		16		50
50 g	0.03	0.10	0.3	1.0	3.0		10		30
20 g	0.025	0.08	0.25	0.8	2.5		8.0		25
10 g	0.020	0.06	0.20	0.6	2.0		6.0		20
5 g	0.016	0.05	0.16	0.5	1.6		5.0		16
2 g	0.012	0.04	0.12	0.4	1.2		4.0		12
1 g	0.010	0.03	0.10	0.3	1.0		3.0		10
500 mg	0.008	0.025	0.08	0.25	0.8		2.5		
200 mg	0.006	0.020	0.06	0.20	0.6		2.0		
100 mg	0.005	0.016	0.05	0.16	0.5		1.6		
50 mg	0.004	0.012	0.04	0.12	0.4				
20 mg	0.003	0.010	0.03	0.10	0.3				
10 mg	0.003	0.008	0.025	0.08	0.25				
5 mg	0.003	0.006	0.020	0.06	0.20				
2 mg	0.003	0.006	0.020	0.06	0.20				
1 mg	0.003	0.006	0.020	0.06	0.20				

Note:

1. *The error in a weight used for the verification of a weighing instrument shall not exceed 1/3 of the maximum permissible error for an instrument. These values are listed in section 3.7.1 of OIML R 76 Non automatic Weighing Instruments (1992).*
2. *The certificate for class E1 weights shall state, as a minimum, the values of conventional mass, mc, the expanded uncertainty, U, and the coverage factor, k, and the density or volume for each weight. In addition, the certificate shall state if the density or volume was measured or estimated.*

3. *The certificate for class E2 weights shall state, as a minimum, the following information:*

   The values of conventional mass, mc, of each weight, the expanded uncertainty, U, and the coverage factor, k;

1.4 Classification of balances based on scale interval

Table 3

Accuracy Class		Verification of Scale Interval, e	Number of Verification Scale Intervals, n = Max/e		Minimum Capacity, Min (Lower limit)
			Minimum	Maximum	
Special	I	0.001 g ≤ e*	50 000**	-	100 e
High	II (II)	0.001 g ≤ e ≤ 0.05 g 0.1 g ≤ e	100 5000	100 000 100 000	20 e 50 e
Medium	III	0.1 g ≤ e ≤ 2 g 5 g ≤ e	100 500	10 000 10 000	20 e 20 e
Ordinary	(IIII)	5 g ≤ e	100	1000	10 e

1.5 Selection of Reference weights

The reference weight should generally be of a higher class of accuracy (1.3) than the weight to be calibrated. In the calibration of weights of class E1, the reference weight shall have similar or better metrological characteristics (magnetic properties, surface roughness) than the weights to be calibrated.

Table 4

Weights that can be used	Class of Weights that can be calibrated						
	E1	E2	F1	F2	M1	M2	M3

as Reference							
E1	Yes	Yes	Yes	Yes	Yes	Yes	Yes
E2	-	-	Yes	Yes	Yes	Yes	Yes
F1	-	-	-	Yes	Yes	Yes	Yes
F2	-	-	-	-	Yes	Yes	Yes

Note: 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 20 kg with coarser uncertainty.

2. Selection of Comparator/Balance

The metrological characteristics of the weighing instruments used should be known from earlier measurements and its resolution, linearity repeatability, and eccentricity should be such that the required uncertainty can be reached.

2.1 Example:

Table 5

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	E2	0.006 mg	0.002 mg	(0.002)/3 mg S ≤ 0.00067 mg

2.2 Selection of comparator balance for calibration of weights depending on class of accuracy

Table 6

Nominal Value	**E1**	**E2**	**F1**	**F2**	**M1**	**M2**	**M3**

		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		

3. Environmental Conditions: (At Lab & At Site)

3.1 **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.

3.2 **Illumination**; The recommended level of illumination is 250-500 lux on the working table.

3.3 **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.

3.4 **Mains Power supply**- an instrument operated form a mains power supply shall comply with the metrological requirements if the power supply varies:

a) In voltage from – 15% to + 10% of the value marked on the instrument,

b) In frequency from – 2% to +2% of the value marked on the instrument, if AC is used.

3.5 Effective mains earthing shall be provided preferably earth resistance shall be less than 1 Ω.

3.6 If the air density deviates from 1.2 kg/m3 by more than 10 %, mass values should be used in calculations and the conventional mass should be calculated from the mass.

3.7 For E1 and E2 class weights, the temperature should be within 18 °C to 27 °C. The environmental conditions should be within the specifications of the weighing instrument.

3.8 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:

Table 6

Weight Class	Temperature change during Calibration (2)	Range of Relative Humidity of the Air (3)
E1	± 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
E2	± 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
F1	± 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
F2	± 2˚C per hour with a maximum of ± 3.5˚C per 12 hours	
M1	± 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. Keep 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 (see Table 10) also requires an appropriate temperature stability of the laboratory for 24 hours before calibration.*

Note 3: *The upper limit is mainly important when storing the weights.*

4. Metrological Requirements

4.1 Kilogram Definition

The kilogram is defined in terms of three fundamental physical constants: The speed of light *c*, a specific atomic transition frequency Δv_{Cs}, and the Planck constant *h*.

4.1.1 The kilogram, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant *h* to be 6.62607015×10^{-34} when expressed in the unit J·s, which is equal to $kg\cdot m^2\cdot s^{-1}$, where the meter and the second.

4.1.2 This definition makes the kilogram consistent with the older definitions: the mass remains within 30 ppm of the mass of one litre of water.

5. Calibration Method

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

5.1 Comparison Method

Usually the test weight should be calibrated by comparison against one or more reference weights. In each comparison, the nominal mass of the test weight and the reference weight should be equal.

Note: *Special problems may arise when calibrating class E1 weights of less than one gram. This is partially due to a relatively large uncertainty of the reference weights in this range. Further, the instability of the weighing instruments and a large surface area are factors that negatively influence the uncertainty of measurement. Therefore, the subdivision method is strongly recommended for such weights.*

5.2 Sub -Division/Sub-Multiplication Method

An entire set of weights can be calibrated against one or more reference weights. This method requires several weighing within each decade in the set. In these weighing, different combinations of weights of equal total nominal mass are compared. This method is mainly used to calibrate sets of class E1 weights when the highest accuracy is required. If with this method, only one reference weight is used, the number of weighing equations should be larger than the number of unknown weights and an appropriate adjustment calculation should be performed in order to avoid propagating errors. If more than one reference weight is used, the number of equations may be equal to the number of unknown weights. In this case, no adjustment calculation is necessary. The advantage of such methods lies in the fact that they include a certain redundancy that offers greater confidence in the results. However, these methods, particularly the adjustment calculation, require more advanced mathematics. A typical weighing design for a set of masses of 5, 2, 2*, 1, 1* ($\times 10^n$g) as below:

Table 7

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*

6. Calibration Procedure

6.1. Visual inspection (class E, F and M weights)

6.1.1 Apparatus

a) A well-lit room

b) Laboratory gloves

c) Lint-free cloths

6.1.2 Measurement procedure

6.1.2.1 New weights

a) For all classes, visually inspect the surface of the weight:

   i) Note any “dings” or dents in its surface or deep scratches;

   ii) The surfaces shall be smooth;

   iii) The edges shall be round;

   iv) For weights from 1 g to 10 kg the surface of the weight shall not be porous.

b) For classes E and F, visually inspect the surface of the weight:

   i) The surfaces shall not be porous;

   ii) The surfaces shall be glossy.

c) For class M cylindrical weights from 1 g to 50 kg, the surface of the weight shall be smooth and not porous.

d) For class M rectangular weights (5 kg, 10 kg, 20 kg and 50 kg), the finish of the surface shall be like grey cast iron.

e) For class M3 weights greater than or equal to 50 kg, the surface may be coated with materials suitable for providing protection against corrosion by rendering the surface impermeable. This coating shall withstand shock and other atmospheric conditions.

6.1.2.2 Used weights

In addition to **6.1.2.1**, inspect the surface of the weight for traces of use as follows;

Visually inspect the surface of the weight. Used weights will normally have scratches, particularly on the bottom surface:

a) If the number and depth of the scratches is compatible with the adequate stability of the weight, the weight may be accepted;

b) During the assessment of surface roughness, individual scratches and other defects shall not be taken into account; or

c) If the scratches are too numerous to assess the surface roughness, the weight shall not be accepted.

6.2 Cleaning of Weights

It is important to clean weights before any measurements are made because the cleaning process may change the mass of the weight. Cleaning should not remove any significant amounts of weight material. Weights should be handled and stored in such a way that they stay clean. Before calibration, dust and any foreign particles shall be removed. Care must be taken not to change the surface properties of the weight (i.e. by scratching the weight).

If a weight contains significant amounts of dirt that cannot be removed by the methods cited above, the weight or some part of it can be washed with clean alcohol, distilled water or other solvents. Weights with internal cavities should normally not be immersed in the solvent to avoid the possibility that the fluid will penetrate the opening. If there is a need to monitor the stability of a weight in use, the mass of the weight should, if possible, be determined before cleaning.

6.3 After weights are cleaned with solvents they must be stabilized for the times given in Table 8.

Table 8

Stabilization time after cleaning

Weight class	**E1**	**E2**	**F1**	**F2 to M3**
After cleaning with alcohol	**7-10 days**	**3-6 days**	**1-2 days**	**1 hour**
After cleaning with distilled	**4-6 days**	**2-3 days**	**1 day**	**1 hour**

water				

6.4 Measurement Process

a) Clean the surface of the comparison specimen with clean lint-free cloth dipped in alcohol. If the surface of the weight does not appear to be clean, it must be cleaned as well.

Note: Cleaning may change the mass of a weight significantly. See 6.2 on the cleaning of weights.

b) Hold the weight up against a section of the comparison specimen with the lays of the two surfaces being parallel

c) Look simultaneously at the two surfaces at different angles.

d) Assess whether the roughness of the weight appears to be smaller or larger than the particular section's roughness of the comparison specimen.

e) Repeat with different samples within the comparison specimen and determine the upper limit

6.5 Thermal Stabilization Requirement for Test Weights

6.5.1 Prior to performing any calibration, the weights need to be acclimated to the ambient conditions of the laboratory. In particular, weights of classes E1, E2 and F1 shall be close to the temperature in the weighing area.

6.5.2 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 9.

Table 9

Thermal stabilization in hours

Δ*T* *	**Nominal value**	**Class E1**	**Class E2**	**Class F1**	**Class F2**
± 20 °C	1000, 2000, 5000 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
	< 10g	1		0.5	
± 5 °C	1000, 2000, 5000 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, 500 g	6	4	2	0.5
	10, 20, 50 g	2	1	1	0.5
	< 10g	0.5			
± 2 °C	1000, 2000, 5000 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
	< 100g	2	1		0.5
± 0.5 °C	1000, 2000, 5000 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
	< 100g	1	0.5		

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

6.6 Weighing Cycles

Accepted procedures for three different weighing cycles for a single comparison weighing are described below in 6.6.1 and 6.6.2.

Note: Other procedures and weighing cycles may be used. If in particular, weighing cycles are used that are not independent from each other, such as A1 B2 A2, A2 B2 A3, ..., the uncertainty has to be evaluated by considering covariance terms and the formula given in C.6.1 has to be modified correspondingly.

In the weighing cycles, “A” represents weighing the reference weight and “B” represents weighing the test weight.

The cycles ABBA and ABA are normally used when calibrating class E and F weights.

The cycle AB1...B*n*A is often used when calibrating class M weights, but generally not recommended for class E and F weights. If, however, a mass comparator with an automatic weight exchange mechanism is used and if the system is installed in a protecting housing, this cycle can also be accepted for class E and F weights calibrations.

Only cycles ABBA and ABA are useful in subdivision weighing. More than one reference weight can be used, in this case the weighing cycle can be applied for each reference weight separately. The reference weights may then be compared against one another.

The Minimum Weighing Cycles for different accuracy class of weights is as below:

Table 10

Minimum Number of Weighing Cycles (as per OIML R-111-1)					
Class	E1	E2	F1	F2	M1, M2, M3
Min. number of ABBA	3	2	1	1	1
Min. number of ABA	5	3	2	1	1
Min. number of	5	3	2	1	1

AB1...BnA					

6.6.1 Comparison of the test weight with one reference weight (recommended for class E and F weights)

A variety of weighing cycles can be utilized. For two weights the following cycles, which are best known as ABBA and ABA are possible. These cycles eliminate linear drift.

Cycle ABBA ($r_1t_1t_2$): $I_{r\,11}$, I_{t11}, I_{t21}, I_{r21}, ..., I_{r1n}, I_{t1n}, I_{t2n}, I_{r2n}

$\Delta I_i = (I_{t1i} - I_{r1i} - I_{t2i} + I_{t2i})/2$

Where i = 1,….., n

Cycle ABA ($r_1t_1r_2$): $I_{r\,11}$, I_{t11}, I_{r21}, ..., I_{r1n}, I_{t1n}, I_{r2n}

$\Delta I_i = I_{t1i} - (I_{r1i} - I_{t2i})/2$

Where i = 1,….., n

In cycles ABBA and ABA, n is the number of sequences. The i values are given in the order in which the weights should be placed on the weighing pan. Here the subscripts "r" and "t" denote the reference weight and test weight respectively. ΔLi is the indication difference from measurement sequence i.

6.6.1.1 The time interval between weighing should be kept constant.

6.6.1.2 If there is a need to determine the sensitivity of the weighing instrument during the weighing process, the sequence ABBA can be modified to the form I_r, I_t, I_{t+ms}, I_{r+ms}, where "ms" is the sensitivity weight.

6.6.2 Comparison of several test weights of the same nominal mass with one reference weight (cycle $AB_1 \ldots B_nA$). If several test weights t(j) (j = 1, ..., J) with the same nominal mass are to be calibrated simultaneously the weighing cycle ABA can be modified into $AB_1 \ldots B_nA$ as follows:

Cycle $AB_1 \ldots B_nA$: I_{r11}, $I_{t(1)1}$, $I_{t(2)1}$, ..., $I_{t(J)1}$, I_{r21}, I_{r12}, $I_{t(J)2}$, $I_{t(J-1)1}$...,$I_{t(1)2}$, I_{r22}, …

$\{I_{r1i-1}, I_{t(1)i-1}, I_{t(2)i-1}, \ldots, I_{t(J)i-1}, I_{t2\,i-1}, I_{r1i}, I_{t(J)i}, I_{t(J-1)i}, \ldots\ldots, I_{t(1)I}, I_{r2i}\}$

where i = 1, ….n

$\Delta I_i(J) = I_{t(J)i}\,(I_{r1i} - I_{t2i})/2$

Where $i = 1, \ldots n$

If the drift in weighing indication is negligible, i.e. less than or equal to one third of the required uncertainty, it is not necessary to invert the order of the test weights in AB1…BnA when repeating the sequence.

The number of weights should normally not be more than 5 ($J \leq 5$).

6.7 National/ International Standards, References and Guidelines

OIML R111-1-2004; Metrological and technical requirement of weights Classes E1, E2, F1, F2, M1, M2, M3.

7. Recommended Calibration Interval

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

Table 11

Reference Equipment	Recommended interval
Weights of E1 to F2 class	3 years
Weights of class M1	2 years
Comparator / Balance	1 years

(Based on the historical data validity of reference weights may be extended up to 5 years for E1)

Note: Recommendation is based on present practice of NPL, India. However, laboratory may refer ISO 10012 and ILAC G24 for deciding the periodicity of calibration other than above recommendations.

8. Measurement Uncertainty

The uncertainty calculations are based on the *Guide to the expression of uncertainty in measurement* 1993(E) and the corresponding European cooperation for Accreditation (EA) document. In References uncertainty calculations are applied for mass comparisons. The

uncertainty is evaluated either by the Type A or by the Type B method of evaluation. Type A evaluation is based on a statistical analysis of a series of measurements whereas Type B evaluation is based on knowledge.

8.1 Standard uncertainty of the weighing process, u_w (Type A)

The standard uncertainty of the weighing process, $\overline{u_w}$ (Δm_c), is the standard deviation of the mass difference. For *n* cycles of measurements:

$$u_w\left(\overline{\Delta m_c}\right) = \frac{s(\Delta m_{ci})}{\sqrt{n}} \qquad (1)$$

8.1.1 For classes F2, M1, M2 and M3, cycles ABBA, ABA or $AB_1 \ldots B_nA$ are often applied. For these classes of weights, if the standard deviation of mass difference measurements is not known from historical data, it can be estimated as:

$$s(\Delta m_c) = \frac{\max(\Delta m_{ci}) - \min(\Delta m_{ci})}{2 \times \sqrt{3}} \qquad (2)$$

from $n \geq 3$cycles of measurements.

The standard deviation can also be calculated as described in 8.1.2.

8.1.2 For weight classes E1, E2 and F1, the variance of the mass difference, Δmc, of the weighing process, $s^2(\Delta mc)$, is estimated from *n* cycles of measurements by:

$$s^2(\Delta m_c) = \frac{1}{n-1}\sum_{i=1}^{n}\left(\Delta m_{ci} - \overline{\Delta m_c}\right)^2 \qquad (3)$$

with n–1 degrees of freedom.

8.1.3 If only a few measurements are made, the estimate of $s(\Delta mc)$ can be unreliable. A pooled estimate, obtained from earlier measurements made under similar conditions, should be used. If this is not possible, *n* should not be less than 5.

8.1.4 In the case where there are *J* series of measurements (where $J > 1$), the variance of Δmc is calculated by pooling over the *J* series so that:

$$s^2(\Delta m_c) = \frac{1}{J}\sum_{j=1}^{J} s_j^2(\Delta m_{ci}) \qquad (4)$$

with $J(n-1)$ degrees of freedom

Note: The subscript "*j*" is appended to $s_i^{\,2}(\Delta mc)$ to differentiate between the standard deviations for each series.

8.2 Uncertainty of the reference weight, $u(m_{cr})$ (Type B)

The standard uncertainty, $u(m_{cr})$, of the mass of the reference weight should be calculated from the calibration certificate by dividing the quoted expanded uncertainty, U, by the coverage factor, k (usually k = 2), and should be combined with the uncertainty due to the instability of the mass of the reference weight, $u_{inst}(m_{cr})$.

$$u(m_{cr}) = \sqrt{\left(\frac{U}{k}\right)^2 + u_{inst}^2(m_{cr})} \qquad (5)$$

The uncertainty due to instability of the reference weight, $u_{inst}(m_{cr})$, can be estimated from observed mass changes after the reference weight has been calibrated several times. If previous calibration values are not available, the estimation of uncertainty has to be based on experience.

8.2.1 If a verified weight of F_1or lower accuracy class is used as a reference weight and it has an OIML R 111certificate of conformity which does not state its mass and uncertainty, the uncertainty can be estimated from the maximum permissible error, δm of that specific class:

$$u(m_{cr}) = \sqrt{\frac{\delta m^2}{3} + u_{inst}^2(m_{cr})} \qquad (6)$$

8.2.2 If a combination of reference weights is used for a mass comparison and their covariance are not known, a correlation coefficient of 1 can be assumed. This will lead to linear summation of uncertainties:

$$u(m_{cr}) = \Sigma_i\, u(m_{cri}) \qquad (7)$$

where $u(m_{cri})$ is the standard uncertainty of reference weight i. This is an upper limit for the uncertainty.

8.3 Uncertainty of the air buoyancy correction, u_b (Type B)

The uncertainty of the air buoyancy correction can be calculated from equation

$$u_b^2 = \left[m_{cr}\frac{(\rho_r - \rho_t)}{\rho_r \rho_t}u(\rho_a)\right]^2 + [m_{cr}(\rho_a - \rho_0)]^2\frac{u^2(\rho_t)}{\rho_t^4} + m_{cr}^2(\rho_a - \rho_0)[(\rho_a - \rho_0) - 2(\rho_{al} - \rho_0)]\frac{u^2(\rho_r)}{\rho_r^4} \quad (8)$$

where ρ_{al} is the air density during the (previous) calibration of the reference weight by use of a higher order reference weight. When using equation *(8)* be sure to use the same value for the uncertainty of the density of the reference weight, $u(\rho_r)$, that was used in the uncertainty calculation of the previous calibration. A larger uncertainty cannot be arbitrarily chosen.

8.3.1 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 $u_b \geq u_c / 3$

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

8.3.3 For classes $F_1$and F_2, the densities of the weights have to be known with sufficient accuracy.

8.3.4 If the air density is not measured and the average air density for the site is used, then the uncertainty for the air density is to be estimated as:

$$u(\rho_a) = \frac{0.12}{\sqrt{3}} \text{ [kg m}^{-3}\text{]} \quad (9)$$

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

At sea level the density of air should be assumed to be 1.2 kg m^{-3}.

8.3.5 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 (1981/91) [3] or an approximation can be used for the calculation of air density.

8.3.6 The variance of the air density is:

$$u^2(\rho_a) = u_F^2 + \left(\frac{\partial \rho_a}{\partial p}u_p\right)^2 + \left(\frac{\partial \rho_a}{\partial t}u_t\right)^2 + \left(\frac{\partial \rho_a}{\partial hr}u_{hr}\right)^2 \quad (10)$$

At relative humidity of *hr* = 0.5 (50 %), a temperature of 20 °C and a pressure of 101 325 Pa, the following numerical values apply approximately

u_F= [uncertainty of the formula used] (for CIPM formula: $u_F = 10^{-4}\rho_a$)

$$\frac{\partial \rho_a}{\partial \rho} = 10^{-5}\rho_a Pa^{-1} \quad (11)$$

$$\frac{\partial \rho_a}{\partial t} = -3.4 \times 10^{-3} K^{-1} \rho_a \qquad (12)$$

$$\frac{\partial \rho_a}{\partial h_r} = -10^{-2} \rho_a \qquad (13)$$

where *hr* = relative humidity, as a fraction.

8.3.7 The density of the reference weight, ρ_r, and its uncertainty should be known from its calibration certificate.

8.3.8 For class E_2weights, the density, ρ_t, is not always known, so it must be either measured or taken from Table 12

Table 12

List of alloys most commonly used for Weights

Alloy/material	Assumed density	Uncertainty (*k* = 2)
Platinum	21 400 kg m^{-3}	± 150 kg m^{-3}
Nickle silver	8 600 kg m^{-3}	± 170 kg m^{-3}
Brass	8 400 kg m^{-3}	± 170 kg m^{-3}
Stainless steel	7 950 kg m^{-3}	± 140 kg m^{-3}
Carbon steel	7 700 kg m^{-3}	± 200 kg m^{-3}
Iron	7 800 kg m^{-3}	± 200 kg m^{-3}
Cast Iron (white)	7 700 kg m^{-3}	± 400 kg m^{-3}
Cast Iron (grey)	7 100 kg m^{-3}	± 600 kg m^{-3}
Aluminium	2 700 kg m^{-3}	± 130 kg m^{-3}

8.4 Uncertainty of the balance u_{ba} (Type B)

8.4.1 Uncertainty due to the test of balances and mass comparators

The recommended approach to determine this component is to test the balances and mass comparators at reason-able time intervals and use the results from the test in the

uncertainty calculations. When calibrating class E_1 weights, it is recommended to perform several test measurements at different times to ensure that there is enough information about the uncertainty at the time of the measurement.

8.4.2 Uncertainty due to the sensitivity of the balance

If the balance is calibrated with a sensitivity weight (or weights) of mass m_s, and of standard uncertainty $u(m_s)$, the uncertainty contribution due to sensitivity is:

$$u_s^2 = (\overline{\Delta m_c})^2 \left(\frac{u^2(m_s)}{m_s^2} + \frac{u^2(\Delta I_s)}{\Delta I_s^2} \right) \quad (14)$$

Where: I_s is the change in the indication of the balance due to the sensitivity weight; $u(I_s)$ is the uncertainty of I_s; and m_c is the average mass difference between the test weight and the reference weight.

If the sensitivity is not constant with time, temperature and load, its variation must be included in the uncertainty.

8.4.3 Uncertainty due to the display resolution of a digital balance

For a digital balance with the scale interval, d, the uncertainty due to resolution is:

$$u_d = \left(\frac{d/2}{\sqrt{3}} \right) \times \sqrt{2} \quad (15)$$

The factor √2 comes from the two readings, one with the reference weight and one with the test weight.

8.4.4 Uncertainty due to Eccentric Loading

If this contribution is known to be significant, the magnitude must be estimated and if necessary, the contribution must be included in the uncertainty budget.

8.4.4.1 Acceptable solution for the uncertainty due to eccentricity:

$$u_E = \frac{\frac{d_1}{d_2} \times D}{2 \times \sqrt{3}} \quad (16)$$

Where: D is the difference between maximum and minimum values from the eccentricity test performed according to OIML R 76-2;

a) d_1 is the estimated distance between the center of the weights; and

b) d_2 is the distance from the center of the load receptor to one of the corners.

c) In most cases, the uncertainty contribution u_E is already covered by the uncertainty u_w of the weighing process and may be neglected.

8.4.4.2 When using balances with an automatic weight exchange mechanism, the indication difference, ΔI, between two weights may be different when the positions are interchanged: $\Delta I_1 \neq \Delta I_2$. This may be interpreted as an eccentric loading error and the corresponding uncertainty should be estimated using equation *(17)*. This uncertainty contribution is applicable, if it is known from previous interchanging measurements with weights of the same nominal value. In cases when the interchange is performed during a calibration procedure, the average of the two indication differences shall be taken as the weighing result and u_E can be neglected.

$$u_E = \frac{|\Delta I_1 - \Delta I_2|}{2} \qquad (17)$$

8.4.5 Uncertainty due to magnetism, u_{ma}

If a weight has a high magnetic susceptibility and/or is magnetized, the magnetic interaction can often be reduced by placing a non-magnetic spacer between the weight and the load receptor. If the weights satisfy the requirements of this Recommendation, the uncertainty due to magnetism, u_{ma}, may be assumed to be zero.

8.4.6 Combined standard uncertainty of the balance, u_{ba}

The uncertainty components are added quadratically as follows:

$$u_{ba} = \sqrt{u_s^2 + u_d^2 + u_E^2 + u_{ma}^2} \qquad (18)$$

8.5 Expanded uncertainty, $U(m_{ct})$

The combined standard uncertainty of the conventional mass of the test weight is given by:

$$u_c(m_{ct}) = \sqrt{u_w^2(\overline{\Delta m_c}) + u^2(m_{cr}) + u_b^2 + u_{ba}^2}$$

(19)

If the buoyancy correction, $m_{cr}C$, is not applied, a corresponding contribution for buoyancy has to be added to the combined uncertainty in addition to u_b :

$$u_c(m_{ct}) = \sqrt{u_w^2(\overline{\Delta m_c}) + u^2(m_{cr}) + u_b^2 + (m_{cr}C)^2 + u_{ba}^2} \quad (20)$$

The expanded uncertainty, U, of the conventional mass of the test weight is as follows:

$$U(m_{ct}) = \sqrt{u_w^2}(\overline{\Delta m_c}) + u^2(m_{cr}) + u_b^2 + (m_{cr}C)^2 + u_{ba}^2$$

(21)

The expanded uncertainty, U, of the conventional mass of the test weight is as follows:

$$U(m_{ct}) = ku_c(m_{ct}) \quad (22)$$

8.5.1 Usually the coverage factor, k = 2, should be used. However, if a pooled standard deviation of the weighing process is not known and the number of measurements cannot reasonably be increased up to 10 (as for very large weights and long weighing procedures), and the uncertainty, u_w ($\overline{\Delta m}$), is the dominant component in the uncertainty analysis, i.e. u_w ($\overline{\Delta m}$)>$\frac{u_c(m_t)}{2}$ then the coverage factor, k, should be calculated from the t-distribution assuming a 95.5 % confidence level and the effective degrees of freedom, v_{eff} as calculated from the Welch- Satterthwaite formula. The coverage factor, k, for different effective degrees of freedom, v_{eff}, is given in Table 13 below. If it can be assumed that the type B uncertainty estimates are conservative with infinite degrees of freedom, the formula has the form:

$$v_{eff} = (n-1) \times \frac{u_c^4(m_{ct})}{u_w^4(\overline{\Delta m_c})} \quad (23)$$

Table 13

Coverage factor, *k*, for different effective degrees of freedom, v_{eff}

v_{eff}	1	2	3	4	5	6	8	10	20	∞

k	13.97	4.53	3.31	2.87	2.65	2.52	2.37	2.28	2.13	2.00

9. 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.

10. Sample Scope

An illustrative example: Correct Presentation of Scope

Sr. No.	Parameter/ Product name/ Device under Calibration /Class/Least Count	Standard used	Range	Calibration and Measurement Capability (CMC)			Remarks/ Method Used
				Claimed by Laboratory	Observed by Assessor	Recommended by Assessor	
1	Mass – Weights. F2 accuracy class and coarser	E 2 Class weights and Electronic Balance, Readabili	1 mg to 500 mg	± 0.005mg	± 0.006 mg	± 0.006mg	By direct comparison method as per OIML R 111-1

		ty 0.001mg					

Revision No.	Date approved	Revision History
1	2022-05-10	• The document is revised due to the name Ethiopian National Accreditation Office (ENAO) change to Ethiopian Accreditation Service (EAS) and new logo developed.
1.1	2023-02-07	• Correction done on page 1 that, this document was prepared by Meseret Tessema replaced by Zewdu Ayele (new quality manager). • Former director general was resigned and replaced by Mrs. Meseret Tessema.