This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: E898 − 20

Standard Practice for
Calibration of Non-Automatic Weighing Instruments[1]

This standard is issued under the fixed designation E898; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice applies to the calibration of electronic non-automatic weighing instruments. A non-automatic weighing instrument is a measuring instrument that determines the mass of an object by measuring the gravitational force acting on the object. It requires the intervention of an operator during the weighing process to decide whether the weighing result is acceptable.

1.2 Non-automatic weighing instruments have capacities from a few grams up to several thousand kilograms, with a scale interval typically from 0.1 micrograms up to 1 kilogram. Note that non-automatic weighing instruments are usually referred to as either balances or scales. In this practice, for brevity, non-automatic weighing instruments will be referred to as balances; however, the scope of this practice also includes scales.

1.3 This practice only covers electronic non-automatic weighing instruments where the indication is obtained from a digital display. The measuring principle is usually based on the force compensation principle. This principle is realized either by elastic deformation, where the gravitational force of the object being weighed is measured by a strain gauge that converts the deformation into electrical resistance, or by electromagnetic force compensation, where the gravitational force is compensated for by an electromagnetic counterforce that holds the load cell in equilibrium.

1.4 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to be suitable as the sole testing process for weighing systems designated for commercial service under weights and measures regulation. The legal requirements for such instruments vary from region to region, and also depend on specific applications. To determine applicable legal requirements, contact the weights and measures authority in the region where the device is located.*

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E617 Specification for Laboratory Weights and Precision Mass Standards

2.2 *ISO Standards:*[3]

ISO 9001 Quality Management Systems – Requirements

ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories

2.3 *OIML Documents and Recommendations:*[4]

D28 Conventional Value of the Result of Weighing in Air

R76-1 Non-automatic Weighing Instruments – Part 1: Metrological and Technical Requirements – Tests

R111-1 Weights of classes E_1, E_2, F_1, F_2, M_{1-2}, M_2, M_{2-3} and M_3 – Part 1: Metrological and Technical Requirements

2.4 *EURAMET Guide:*[5]

Calibration Guide No. 18 Guidelines on the Calibration of Non-automatic Weighing Instruments

2.5 *JCGM Guides:*[6]

JCGM 100 Evaluation of Measurement Data – Guide to the Expression of Uncertainty in Measurement (GUM)

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[1] This practice is under the jurisdiction of ASTM Committee E41 on Laboratory Apparatus and is the direct responsibility of Subcommittee E41.06 on Laboratory Instruments and Equipment.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[4] Available from the Organisation Internationale de Métrologie Légale (OIML), 11 Rue Turgot, 75009 Paris, France, https://www.oiml.org/en.

[5] Available from EURAMET e.V., Bundesallee 100, 38116 Braunschweig, Germany, https://www.euramet.org.

[6] Available from the Bureau International des Poids et Mesures, Pavillon de Breteuil, 92312 Sèvres, France, https://www.bipm.org.

JCGM 200 International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM)

2.6 *ILAC Guideline:*[7]

ILAC-G24 Guidelines for the Determination of Calibration Intervals of Measuring Instruments, ILAC-G24

2.7 *USP General Chapters:*[8]

USP General Chapter 41 Balances

USP General Chapter 1251 Weighing on an Analytical Balance

2.8 *UKAS Guide:*[9]

UKAS LAB 14, Edition 5 In-house Calibration and Use of Weighing Machines

2.9 *Code of Federal Regulations:*[10]

CFR Part 58 Good Laboratory Practice for Nonclinical Laboratory Studies

CFR Part 211 Current Good Manufacturing Practice for Finished Pharmaceuticals

2.10 *FDA Guidance:*[11]

FDA Questions and Answers on Current Good Manufacturing Practices, Good Guidance Practices, Level 2 Guidance – Equipment

For dated references, only the dated version applies to this practice. For undated references, the latest edition (including all amendments) applies to this practice.

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 In this section, the official definitions of the terms are provided, as are, where appropriate, simplified definitions that relate the terms to the scope of this practice.

3.1.2 *accuracy class of weights, n*—class designation of a weight or weight set which meets certain metrological requirements intended to maintain the mass values within specified limits.[12]

3.1.3 *calibration, n*—operation that establishes a relation between the indication of the weighing instrument and the reference weights, including the associated measurement uncertainties.

3.1.3.1 *Discussion*—An operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.[13]

3.1.4 *conventional mass value, n*—mass value indicated in the calibration certificate of the weight.

3.1.4.1 *Discussion*—The conventional mass value of a body is equal to the mass of a standard that balances this body under conventionally chosen conditions, that is, at 20 °C, a density of the standard of 8000 kg/m^3 in air of density 1.2 kg/m^3.[14]

3.1.5 *coverage factor (k), n*—number larger than one by which a combined standard measurement uncertainty is multiplied to obtain an expanded measurement uncertainty.

3.1.5.1 *Discussion*—The coverage factor (k) is typically calculated based on the applicable degrees of freedom (ν).[13]

3.1.6 *eccentric loading error, n*—error when the load is not placed in the center of the weighing platform.

3.1.6.1 *Discussion*—The deviation in the measurement value caused by asymmetrical placement of the center of gravity of the load relative to the load receptor.[15]

3.1.7 *error, n*—difference between the indicated quantity and the applied quantity.

3.1.7.1 *Discussion*—Error is the measured quantity value minus a reference quantity value.[13]

3.1.8 *linearity, n*—ability of a weighing instrument to follow the linear relationship between a load and the indication.[15]

3.1.9 *maximum capacity, n*—maximum weighing capacity, that is, the maximum capacity whose weight can be determined on a balance.[16]

3.1.10 *maximum permissible error (mpe), n*—limit by which the measured quantity indication can deviate from the nominal applied value.

3.1.10.1 *Discussion*—The extreme value of measurement error, with respect to a known reference quantity value, permitted by specifications or regulations for a given measurement, measuring instrument, or measuring system.[13]

3.1.11 *measurement standard, n*—realization of the definition of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference.[13]

3.1.12 *measurement uncertainty, n*—parameter that quantifies how far a measurement value might be away from the true (unknown) value.

3.1.12.1 *Discussion*—The non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.[13]

3.1.13 *minimum weight, n*—smallest sample weight required for a weighment to just achieve a specified relative accuracy of weighing.[15]

3.1.14 *nominal capacity, n*—nominal value of the weighing capacity, derived from the maximum capacity by rounding it down to a number with less significant digits.[15]

3.1.15 *repeatability, n*—ability of a weighing instrument to provide indications that are close together when weighing the same object several times under reasonably constant test conditions.

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[7] Available from the International Laboratory Accreditation Cooperation, ILAC Secretariat, PO Box 7507, Silverwater NSW 2128, Australia, https://ilac.org.

[8] Available from U.S. Pharmacopeial Convention (USP), 12601 Twinbrook Pkwy., Rockville, MD 20852-1790, http://www.usp.org.

[9] Available from the United Kingdom Accreditation Service (UKAS), 2 Pine Trees, Chertsey Lane, Staines-upon-Thames, TW18 3HR, UK, https://www.ukas.com.

[10] Available from the United States Federal Register, https://www.archives.gov/federal-register.

[11] Available from U.S. Food and Drug Administration (FDA), 10903 New Hampshire Ave., Silver Spring, MD 20993, http://www.fda.gov.

[12] Definition from OIML R111-1.

[13] Definition from JCGM 200 (VIM).

[14] Definition from OIML D28.

[15] Nater, R., Reichmuth, A., Schwartz, R., Borys, M., and Panagiotis, Z., *Dictionary of Weighing Terms*, Springer, ISBN 978-3-642-02013-1, 2009.

[16] Definition from OIML R76-1.

3.1.15.1 *Discussion*—The ability of an instrument to provide results that agree one with the other when the same load is deposited several times and in a practically identical way on the load receptor under reasonably constant test conditions.[16]

3.1.16 *scale interval, n*—the difference between two consecutive indicated values.[16]

3.1.17 *sensitivity, n*—change in indication divided by change in the applied quantity.

3.1.17.1 *Discussion*—The quotient of the change in an indication of a measuring system and the corresponding change in a value of a quantity being measured.[13]

3.2 *Symbols:*

d—scale interval

D—drift, value change with time

d_I—smallest scale interval

E—error of indication

I —indication

k—coverage factor

L—load

m —object mass

Max—maximum capacity

Max_I—upper limit of partial weighing range with smallest scale interval

m_c—conventional value of mass

m_{min}—minimum weight

m_N—nominal mass

mpe—maximum permissible error of a measured quantity

m_{ref}—reference mass

n—number of repeated weighings

R—reading

s—standard deviation

SF—safety factor

T—temperature (unit K)

u—standard uncertainty

U—expanded uncertainty

u_c—combined standard uncertainty

α—intercept (for uncertainty in use)

β—slope (for uncertainty in use)

ν—degrees of freedom

ν_{eff}—effective degrees of freedom for combined standard uncertainty

ρ—density

ρ_0—reference density of air, ρ_0 = 1.2 kg/m^3

ρ_c—reference density of mass, ρ_c = 8000 kg/m^3

ρ_S—density of standard weights

3.3 *Symbol Subscripts and Definitions*

Subscript	Related
B	air buoyancy
conv	convection
D	drift
L	load
N	nominal value
dig	digitization
ecc	load in different locations on the weighing pan
i, j	number
max	maximum
min	minimum
ref	reference
rep	repeatability
0	no load

4. Significance and Use

4.1 This practice will enable calibration laboratories and the user to calibrate electronic non-automatic weighing instruments and quantify the error of the balance throughout the measurement range, usually from zero to maximum capacity. The error of indication is accompanied by a statement on measurement uncertainty, which is individually estimated for every measurement point. This practice is based on the test procedures and uncertainty estimation described in the EURAMET calibration guide cg-18. However, while EURAMET cg-18 allows for a very flexible execution of the measurements, the test procedures described in this practice are more fixed to enable a better comparability between calibrations executed by different calibration laboratories or users. This practice may also serve as basis for accreditation of calibration laboratories for calibration of electronic non-automatic weighing instruments.

4.2 This practice allows the user to decide whether the calibrated balance is fit for its intended purpose, based on the assessment of the calibration results. Usually, this assessment is done by ensuring that the measurement uncertainty of all weighings the user performs on the instrument is smaller than a specified relative tolerance established by the user. This approach is commensurate to assuring that the smallest net amount of substance that the user weighs on the instrument (so-called smallest net weight) is larger than the minimum weight, which is derived from the calibration results.

4.3 This practice, in Appendix X2, provides information on the periodic performance verification on the balance that should be carried out by the user between the calibrations. Calibration together with periodic performance verification allows the user to ensure with a very high degree of probability that the balance meets the user requirements during its day-to-day usage. It helps users comply with requirements from other standards or regulations that stipulate periodic tests and calibrations of quality-relevant instruments.

5. Calibration Conditions

5.1 *Standard Weights*

5.1.1 *General Requirements*—Test loads shall consist of standard weights that are traceable to the SI unit of mass, with the possible exception of test loads used for measurements of a comparative nature—for example, measurement of eccentric loading or repeatability.

5.1.2 *Standard Weight Traceability*—The traceability of weights to be used as standards shall be demonstrated by calibration consisting of:

5.1.2.1 Determination of the conventional value of mass m_c or the correction δm_c to its nominal value m_N:$\delta m_c = m_c - m_N$, or both, together with the expanded uncertainty of the calibration U, or

5.1.2.2 Confirmation that m_c is within specified maximum permissible errors mpe: $m_N - (mpe - U) \leq m_c \leq m_N + (mpe - U)$.

5.1.2.3 The standards should further satisfy the following requirements to an extent appropriate to their accuracy:

(1) Density ρ_s sufficiently close to $\rho_c = 8000\ \frac{kg}{m^3}$,

(2) Surface finish suitable to prevent a change in mass through contamination by dirt or adhesion layers, and

(3) Magnetic properties such that interaction with the instrument to be calibrated is minimized.

5.1.2.4 Weights that comply with the relevant specifications of OIML R111-1 or Specification E617 should satisfy all these requirements.

5.1.3 *Recommendation for the Selection of Weight Classes*—It is recommended selecting the weights in order to minimize their uncertainty contribution to the balance uncertainty as far as reasonably possible so that user tolerance requirements are met. The following selection criteria for weight classes could be considered:

5.1.3.1 *1 000 000 < Max/d:* Select an OIML E_2 or ASTM Class 1 weight, or a weight with uncertainty not worse than the permitted OIML E_2 or ASTM Class 1 uncertainty, which is one-third or less of the maximum permissible error; it is recommended to always use the conventional mass value as the reference value;

5.1.3.2 *150 000 < Max/d ≤ 1 000 000:* For a weight where the nominal value is used as the reference value, select an OIML F_1 or ASTM Class 2 weight or better; for a weight where the conventional mass value is used as the reference value, select an OIML F_2 or ASTM Class 4 weight or better;

5.1.3.3 *15 000 < Max/d ≤ 150 000:* For a weight where the nominal value is used as the reference value, select an OIML F_2 or ASTM Class 4 weight or better; for a weight where the conventional mass value is used as the reference value, select an OIML M_1 or ASTM Class 5 weight or better; and

5.1.3.4 *Max/d ≤ 15 000:* For a weight where the nominal value is used as the reference value, select an OIML M_1 or ASTM Class 5 weight or better; for a weight where the conventional mass value is used as the reference value, select an OIML M_2 or ASTM Class 6 weight or better.

5.1.3.5 For multi-interval and multiple range balances, *Max* and *d* refer to the interval/range with the smallest scale interval, abbreviated as Max_1 and d_1, respectively.

5.2 *Substitution Loads*

5.2.1 Calibration requiring substitution loads is not within the scope of this practice. Substitution is discussed elsewhere (see EURAMET cg-18).

5.3 *Other Measuring Instruments Used for Calibration*

5.3.1 Thermometer for monitoring air temperature with a resolution of 0.5 °C or better.

5.3.2 Hygrometer for monitoring ambient relative humidity with a resolution of 5 % RH or better.

5.4 *Calibration Environmental Conditions*

5.4.1 Environmental temperature and relative humidity shall be recorded and reported.

5.4.2 Calibration shall be carried out under stable environmental conditions, where possible. Calibration shall be carried out within the normal working environmental conditions of the installation site.

5.4.3 The test loads should be acclimatized to the environmental conditions in the vicinity of the balance before calibration. Non-acclimatized weights trigger a convection effect of the surrounding air that may impact the indication of the balance. Information on acclimatization times may be found, for example, in EURAMET cg-18, Specification E617, or OIML R111-1.

6. Calibration Practice

6.1 *Measurement Parameters General*—This practice includes the following measurement parameters:

Repeatability;
Eccentric loading; and
Error of indication.

6.1.1 These three measurements may be performed in any order to accommodate efficient usage of weights and detect potential defects of the weighing instrument at an early stage.

6.2 *Calibration*

6.2.1 *Calibration Range*—The calibration range is typically from the zero point of the balance to maximum capacity, or the weighing range specified by the customer.

6.2.2 *Calibration Location*—Calibration shall be performed at the location of use of the balance. If calibration at the location of use is not possible, then this exception shall be noted in the calibration certificate. If the balance is moved to another location after calibration, the following situations may occur:

(1) Difference in local gravitational acceleration;

(2) Changes in environmental conditions; and

(3) Impact (damage) during transport.

NOTE 1—Each of the above may cause the performance of the balance to change and can invalidate the calibration. Therefore, moving the balance after calibration should be avoided. Recalibration of the balance is recommended after it has been moved if evidence of altered performance cannot be excluded.

6.2.3 *Preparation Before Calibration*—Check the balance nameplate or product identification. Identify the model, scale interval, maximum capacity, serial number, manufacturer, and other applicable information. The balance shall be energized at an appropriate time prior to calibration, such as the warm-up time specified in the balance instructions or the time set by the user.

6.2.3.1 If there is no such rule, the balance warm-up time should be no less than 30 min.

6.2.3.2 If as-found data is to be collected, do not level prior to as-found calibration. The balance should be levelled before as-left calibration.

6.2.3.3 If the balance is equipped with an auto-zero function, this function should be turned off before calibration, if possible.

6.2.4 *Measurement of Repeatability*—Under repeatability conditions, the same load is placed on the balance pan several times in a practical and consistent manner in a short time period. This provides an indication of the balance ability to produce consistent results, expressed as a standard deviation. Repeatability conditions include:

(1) The same measurement procedure;

(2) The same operator;

(3) The same measurement system; and

(4) The same operating conditions and the same location.

6.2.5 The test load should consist of a single weight whenever possible.

6.2.6 For balances with only a single scale interval, the test load is usually chosen between approximately 50 % of the maximum capacity and approximately 100 % of the maximum capacity. If the customer requires a special measurement point, the test load value can be adjusted. A typical application for which the repeatability test load may be adjusted is weighing quantities on the balance with mass values significantly smaller than maximum capacity.

6.2.7 For multi-interval/multiple range balances, the test loads are usually chosen between approximately 50 % to approximately 100 % of the upper limit of each interval/range. If the customer requires a special measurement point, the test load value can be adjusted. A typical application for which the repeatability test load may be adjusted is weighing quantities on the balance with mass values significantly smaller than maximum capacity.

6.2.8 Before each measurement, set the balance to zero, load the test load in the middle of the balance weighing pan, and record the indication after stabilization. For all balances with a scale interval of 0.1 mg and finer, complete a minimum of 10 measurements. For all balances with a scale interval larger than 0.1 mg, complete a minimum of 5 measurements. For multi-interval/multiple range balances, the number of measurements shall be the same in all intervals/ranges. The smallest scale interval shall be taken as reference for defining the minimum number of measurements.

6.2.9 *Measurement of Eccentric Loading*—The error of indication of the same load at different positions on the weighing pan is expressed by the maximum difference between the indication of the different positions and the indication of the center position. A single weight should be used when possible. For multi-interval/multiple range as well as single range balances, the test load is preferably approximately one-third of the maximum capacity. Measurements include placing the test load at different locations on the pan in such a way as to ensure that the center of gravity of the applied load is at the positions shown in Fig. 1, or as close as possible. The number and location of measurement points can vary depending on the shape of the pan.

6.2.10 Depending on the mechanical construction of the balance, the eccentricity test might not be possible or required, for example, for balances with a hanging weighing pan or hopper scales. Care must be taken when performing this test on balances with leveling pans to position weights so that they do not tip off the tilted pan surface.

6.2.11 The measurement can be performed with the following methods:

6.2.11.1 *Method 1 (Recommended for Single Range Balances)*—Set the value to zero before measuring. Place the test load at position 1 and then move to the other positions in sequence. The indication is recorded for each position.

6.2.11.2 *Method 2 (Recommended for Multi-interval/Multiple Range Balances)*—First place the test load in position 1 and perform a tare operation on the balance. The test load is then moved sequentially to the other positions. The indication is recorded for each position.

6.2.11.3 *Method 3 (Recommended for Single Range Balances that Might Easily Show Drift)*—Set the value to zero before measuring. First place the test load in position 1, remove it, then place it in the next position, remove it, and so on, until it is removed from the last position. For each position, record the indication. The indication is set to zero each time the load is removed.

6.2.11.4 *Method 4 (Recommended for Multi-interval/Multiple Range Balances that Might Easily Show Drift)*—First place the test load in position 1 and perform a tare operation on the balance. Move the test load to the first off-center position and then move back to position 1. Record the indication for the off-center position. When the load is back at position 1 and if the display is not zero, then the indication is set to zero before continuing. Move the test load to the next off-center position, and back to position 1. Continue until the test load has been removed from the last off-center and center positions.

NOTE 2—If the weighing system auto-zero is activated, the eccentric loading test results can be affected, resulting in a falsely small error. The

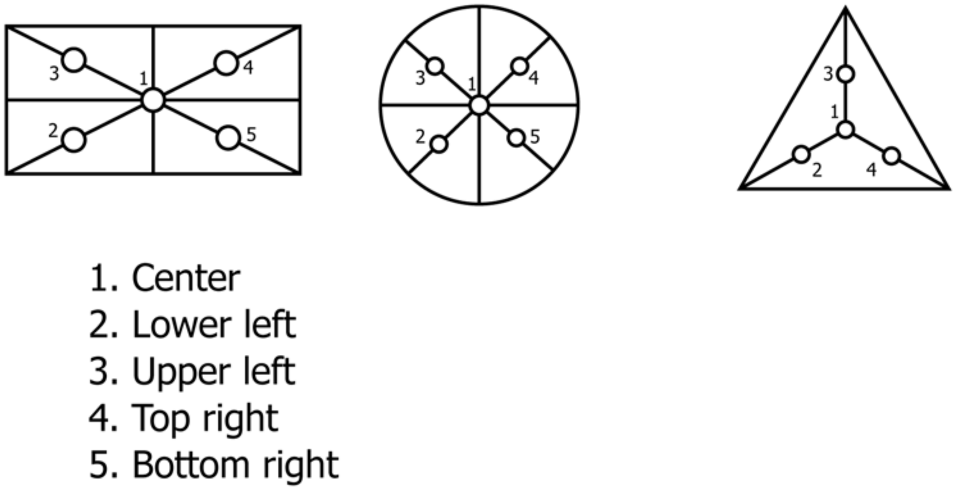

FIG. 1 Load Positions

calibration technician must be observant of such effects and disable the auto-zero, if necessary, to obtain correct results (see 6.2.3).

6.2.12 *Measurement of Error of Indication*—The measuring points should be uniformly selected within the weighing range to be calibrated, as far as reasonably possible. At least 5 different test loads shall be required, including zero and maximum capacity or close to the maximum capacity (for example, 0, 25, 50, 75, and 100 % of maximum capacity). Measurement points may be added according to customer needs. Ideally, each test load should consist of a single weight; however, multiple weights may be used when necessary to achieve the appropriate test load. Before each measurement, the indication value is set to zero. The measurement can be selected according to the following methods:

6.2.12.1 *Method 1*—Increase from zero load to maximum capacity. Unload the weights at each step of the measurement process. After unloading, check the zero point. If the zero point is not zero, set the value to zero.

6.2.12.2 *Method 2*—Increase from zero load to maximum capacity; no need to unload the weights during the measurement. This method may produce creep effects in the results.

6.2.12.3 *Method 3*—If the customer requests, the measurement can also be performed from maximum capacity to zero load, without unloading weights after each measurement. As in Method 2, this may produce creep effects in the results.

7. Calibration Results

7.1 *Error of Indication Measurement Results*—For each test load, the error of indication (E) is calculated as follows:

$$E = I - m_{ref} \tag{1}$$

7.1.1 For the value of the reference mass, the nominal mass of the test load can be taken:

$$m_{ref} = m_N \tag{2}$$

7.1.2 Alternatively, the conventional mass value of the test load can be taken:

$$m_{ref} = m_c = m_N + \delta m_c \tag{3}$$

7.2 *Repeatability Measurement Results*—The standard deviation, s, is calculated from the load indications of the repeatability test.

$$s = \sqrt{\frac{1}{n-1}\Sigma_{i=1}^{n}\left(I_i - \bar{I}\right)^2} \tag{4}$$

where:

$$\bar{I} = \frac{1}{n}\Sigma_{i=1}^{n} I_i \tag{5}$$

In the formulas:

s = standard deviation,
I_i = indication when the ith load is applied, and
$\bar{I}$ = the average of n indications.

7.3 *Eccentric Loading Measurement Results*

7.3.1 The error of eccentric loading is calculated based on the indication values obtained in different load positions $\Delta I_{ecc,i}$

$$\Delta I_{ecc,i} = I_{Li} - I_{L1} \tag{6}$$

In the formula:

I_{Li} = ith position indication (i = 2, 3, …), and
I_{L1} = center position indication.

7.3.2 The maximum error of eccentric loading is the value reported and included in uncertainty calculations.

8. Evaluation of Measurement Uncertainty

While the following sections document the likely uncertainty for the balance calibration, error sources contributing to uncertainty may be added or removed as appropriate for the situation. The error sources described in this practice are the most likely to consider.

8.1 *Standard Uncertainty of the Error of Indication During Calibration*—The measurement model of the error of indication is:

$$E = I - m_{ref} \tag{7}$$

The formula for calculating the combined standard uncertainty is:

$$u_c^2(E) = u^2(I) + u^2(m_{ref}) \tag{8}$$

8.1.1 *Standard Uncertainty of the Indication $u(I)$*—The measurement model for the indication is:

$$I = I_L + \delta I_{digL} + \delta I_{rep} + \delta I_{ecc} - I_0 - \delta I_{dig0} \tag{9}$$

8.1.1.1 Standard uncertainty caused by the rounding error of the no-load indication $u(\delta I_{dig0})$. δI_{dig0} represents the rounding error of the no-load indication. The half width of the scale interval is $d_0 / 2$, a rectangular distribution is assumed:

$$u(\delta I_{dig0}) = \frac{d_0}{\left(2\sqrt{3}\right)} \tag{10}$$

8.1.1.2 Standard uncertainty caused by the rounding error of the indication at load $u(\delta I_{digL})$. δI_{digL} represents the rounding error of the indication at load. The half width of the scale interval is $d_L / 2$, a rectangular distribution is assumed:

$$u(\delta I_{digL}) = \frac{d_L}{\left(2\sqrt{3}\right)} \tag{11}$$

NOTE 3—On multiple range / multi-interval balances, d_L can change with the indicated value.

8.1.1.3 Standard uncertainty caused by repeatability $u(\delta I_{rep})$. δI_{rep} indicates the repeatability error of the balance, as determined in 7.2, a normal distribution is assumed:

$$u(\delta I_{rep}) = s(I) \tag{12}$$

(1) For a single range balance, a repeatability measurement may be taken at only one load, and this measurement may be used to represent the repeatability uncertainty of the entire range of the balance. Multiple repeatability measurements at different loads may be performed.

(2) For multi-interval/multiple range balances, repeatability measurements shall be made separately for each partial weighing range, and the uncertainty of each interval/range will be represented by the uncertainty of the repeatability test in the respective interval/range.

8.1.1.4 Standard uncertainty caused by measurement of eccentric loading $u(\delta I_{ecc})$. δI_{ecc} indicates the error due to the change of the center of gravity of the test load. This effect may occur when the test load is composed of multiple weights and can be based on the following assumptions:

(1) The difference $\Delta I_{ecc,i} = I_{Li} - I_{L1}$ is proportional to the distance from the center of gravity of the load to the center of the pan and is proportional to the load value. The maximum difference $|\Delta I_{ecc,i}|_{max}$ is determined according to 7.3, and a rectangular distribution is assumed. As the standard uncertainty is expressed as a function of the indication, *I*, the proportionality constant—the load value—is with a very good approximation substituted by the indication:

$$u(\delta\ I_{ecc}) = \frac{I\ |\Delta I_{ecc,i}|_{max}}{\left(2L_{ecc}\sqrt{3}\right)} \tag{13}$$

where:

L_{ecc} = test load used for the eccentricity test.

8.1.1.5 The standard uncertainty of the indication is obtained by the following formula:

$$u^2(I) = u^2(\delta\ I_{dig0}) + u^2(\delta\ I_{digL}) + u^2(\delta\ I_{rep}) + u^2(\delta\ I_{ecc}) \tag{14}$$

8.1.2 *Standard Uncertainty of Reference Mass $u(m_{ref})$*—The measurement model for the reference mass is:

$$m_{ref} = m_N + \delta m_c + \delta m_B + \delta m_D + \delta m_{conv} \tag{15}$$

8.1.2.1 *Standard Uncertainty of Standard Weights $u(\delta m_c)$*

(1) If the conventional mass of the standard weight is used as the reference mass, where the calibration uncertainty, *U*, and the coverage factor are given in the weight calibration certificate, the standard uncertainty is:

$$u(\delta m_c) = \frac{U}{k} \tag{16}$$

(2) If the nominal mass of the standard weight is used as the reference mass, assuming a rectangular distribution, the standard uncertainty is:

$$u(\delta m_c) = \frac{mpe}{\sqrt{3}} \tag{17}$$

(3) If the test load consists of multiple standard weights, the standard uncertainty is the arithmetic sum of the standard uncertainty of each standard weight.

8.1.2.2 *Standard Uncertainty Caused by Air Buoyancy $u(\delta m_B)$*

(1) If the sensitivity of the balance is adjusted prior to calibration, the standard uncertainty for air buoyancy is:

$$u(\delta m_B) = \frac{mpe}{\left(4\sqrt{3}\right)} \tag{18}$$

(2) If the sensitivity of the balance is not adjusted prior to calibration, the standard uncertainty for air buoyancy is:

$$u(\delta m_B) = \frac{\left(0.1 \cdot m_N \cdot \dfrac{\rho_0}{\rho_c} + \dfrac{mpe}{4}\right)}{\sqrt{3}} \tag{19}$$

(3) If information on the temperature variation on the balance calibration site is available, Eq 19 can be replaced by:

$$u(\delta m_B) = \sqrt{1.07 \times 10^{-4} + 1.33 \times 10^{-6}\ K^{-2} \Delta T^2} \cdot m_N \cdot \frac{\rho_0}{\rho_c} + \frac{mpe}{\left(4\sqrt{3}\right)} \tag{20}$$

where ΔT is the maximum change in ambient temperature assumed for the site between two consecutive calibrations.

8.1.2.3 *Standard Uncertainty Caused by Weight Drift $u(\delta m_D)$ (Optional)*

(1) The value change with time (*D*) can be estimated from the mass change after successive calibrations of the standard weight. The difference between the mass of the weights in the last two calibration cycles or the difference in the mass of the weights in the recent consecutive multiple calibration cycles may be used. At least three calibration values are recommended to establish trends in the weight stability.

(2) In the absence of standard weight drift information, *D* may be, in the worst case, selected as the maximum permissible error of the standard weight; however, this selection might result in an overestimation of the uncertainty.

(3) The standard uncertainty caused by weight drift, assuming a rectangular distribution, is:

$$u(\delta\ m_D) = \frac{D}{\sqrt{3}} \tag{21}$$

8.1.2.4 *Standard Uncertainty Caused by Convection*—If the weights are not sufficiently acclimatized to the environmental temperature in the vicinity of the balance, the convection effect of the surrounding air on the weights should be considered. If not negligible, the convection effect shall be included in the standard uncertainty of the reference mass. The uncertainty due to convection is most relevant for non-acclimatized weights of classes OIML F_1 or better, and ASTM 3 or better. Further information can be found in EURAMET cg-18, Appendix F.

8.1.2.5 The standard uncertainty of the reference mass is:

$$u^2(m_{ref}) = u^2(\delta\ m_c) + u^2(\delta\ m_B) + u^2(\delta\ m_D) + u^2(\delta\ m_{conv}) \tag{22}$$

8.1.3 *Combined Standard Uncertainty of the Error of Indication $u_c(E)$:*

$$u_c^2(E) = u^2(I) + u^2(m_{ref}) \tag{23}$$

Then substitute using Eq 14 and Eq 22.

$$u_c^2(E) = u^2(\delta\ I_{dig0}) + u^2(\delta\ I_{digL}) + u^2(\delta\ I_{rep}) + u^2(\delta\ I_{eec}) + u^2(\delta\ m_c) + u^2(\delta\ m_B) + u^2(\delta\ m_D) + u^2(\delta\ m_{conv}) \tag{24}$$

8.2 *Expanded Uncertainty of the Error of Indication*

8.2.1 The expanded uncertainty of the error of indication error is:

$$U(E) = k \cdot u_c(E) \tag{25}$$

8.2.2 The coverage factor, *k*, shall be selected using 8.2.2.1, 8.2.2.2, or 8.2.2.3.

8.2.2.1 *Option 1:* Select the coverage factor, *k*, from Table 1 based on the degrees of freedom associated with the repeatability measurement in the calibration. Degrees of freedom are the number of repeatability weighings minus one.

TABLE 1 Coverage Factor *k* for Different Effective Degrees of Freedom v_{eff}

v_{eff}	4	5	6	7	8	9	10	15	20	50	∞
k	2.87	2.65	2.52	2.43	2.37	2.32	2.28	2.18	2.13	2.05	2.00