Measurement Uncertainty Budget

Calibration of a 1 kg OIML Class E2 Mass Standard

Report No.	NMS-UB-2026-0417
Issuing Laboratory	Nexa Metrology Services
Accreditation	ISO/IEC 17025:2017, Cert. NAB-MET-0182
Client	Vertex Precision Instruments Ltd.
Item under test	1 kg stainless steel weight
Serial number	VPI-1KG-014
Calibration method	OIML R 111-1:2004, mass comparison
Report date	17 April 2026
Prepared by	Dr. Farhana Chowdhury, Metrologist
Reviewed by	Imran Kabir, Quality Manager
Environment	20.100 °C ± 0.300 °C, 45 % RH
Reference standard	Nexa RS-1KG-A, Cert. NMS-CAL-1198

1 Scope and Purpose

This budget documents the evaluation of measurement uncertainty for the calibration of a nominal 1 kg OIML Class E2 stainless steel mass standard (serial VPI-1KG-014), submitted by Vertex Precision Instruments Ltd. for routine recalibration. The calibration was performed by substitution weighing against Nexa Metrology Services' in-house reference standard RS-1KG-A on a Mettler-class 1 kg mass comparator, model NX-C1000, resolution 0.100 µg.

The uncertainty evaluation follows the method of the *Guide to the Expression of Uncertainty in Measurement* [1] and the weighing-design guidance of OIML R 111-1 [2]. All uncertainty components are propagated as standard uncertainties, combined by root-sum-of-squares, and expanded using a coverage factor appropriate to the effective degrees of freedom of the combined estimate, consistent with EURAMET Calibration Guide No. 18 [3].

This budget applies specifically to the ABBA substitution-weighing design used for a single 1 kg E2 standard against a directly traceable reference of the same nominal value and material. It should be re-derived, not reused verbatim, for masses of different nominal value, class, or comparison method.

At a glance

Measurand	Conventional mass correction, δm, of item VPI-1KG-014 relative to nominal 1 kg
Result	$\delta m = -1.245\,\mathrm{mg}$
Combined standard uncertainty	$u_c(y) = 0.083\,\mathrm{mg}$
Expanded uncertainty	$U = 0.17\,\mathrm{mg}$ ($k = 2$, approx. 95 % level of confidence)

2 Measurement Model

The conventional mass correction of the test item, δm_X, is obtained from the mean comparator reading difference Δ_m between the test item and the reference standard, corrected for the reference standard's own known correction δm_S, drift since its last calibration δm_D, air buoyancy δm_B, and residual instrument effects (resolution, eccentricity, thermal, and magnetic interaction), each treated as an additive correction with an associated sensitivity coefficient.

$$\delta m_X = \Delta_m + \delta m_S + \delta m_D + \delta m_B + \delta m_R + \delta m_E + \delta m_T + \delta m_M \tag{1}$$

where Δ_m is the mean of n ABBA comparison cycles (Type A) and every other term on the right-hand side is a Type B correction drawn from calibration certificates, manufacturer specification, or engineering judgement.

2.1 Type A Evaluation

The repeatability component is the experimental standard deviation of the mean of $n = 10$ ABBA comparison cycles:

$$u_A = \frac{s(\Delta_m)}{\sqrt{n}}, \qquad s(\Delta_m) = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n}\left(\Delta_{m,k} - \overline{\Delta_m}\right)^2} \tag{2}$$

with $n - 1 = 9$ degrees of freedom.

2.2 Type B Evaluation

Each Type B input x_i is characterised by an assumed probability distribution (normal, from a calibration certificate stating an expanded uncertainty U and coverage factor k; or rectangular, for a bound a with no further information on the value's location) and converted to a standard uncertainty $u(x_i) = U/k$ or $u(x_i) = a/\sqrt{3}$, respectively.

2.3 Propagation

For each input quantity x_i the contribution to the combined standard uncertainty of the measurand $y = f(x_1, \ldots, x_N)$ is

$$u_i(y) = c_i\, u(x_i), \qquad c_i = \frac{\partial f}{\partial x_i} \tag{3}$$

Because the model in Eq. (1) is purely additive in mass units, every sensitivity coefficient in this budget is $c_i = 1$ or $c_i = -1$ (dimensionless), so each $u_i(y)$ is numerically equal to $u(x_i)$.

3 Sources of Uncertainty

Repeatability of comparison (δm_A)

Scatter of the ten ABBA comparator readings, dominated by short-term air turbulence in the weighing chamber and residual comparator noise. Evaluated as Type A from the observed standard deviation of the mean.

Reference standard certificate (δm_S)
: The calibration certificate for RS-1KG-A (Cert. NMS-CAL-1198, national metrology institute) states an expanded uncertainty $U = 0.150\,\mathrm{mg}$ at $k = 2$. This is the single largest contributor to the budget.

Drift of the reference standard (δm_D)
: Estimated from the history of the last four calibrations of RS-1KG-A. The maximum observed drift between successive certificates, taken as a rectangular bound, is $\pm 0.030\,\mathrm{mg}$ over the calibration interval.

Air buoyancy correction (δm_B)
: Arises from the density difference between the test item (stainless steel, $\rho \approx 7950.000\,\mathrm{kg/m^3}$) and the reference standard, combined with ambient air density computed from measured temperature, pressure, and humidity via the CIPM 1981/91 formula. Bound estimated at $\pm 0.018\,\mathrm{mg}$.

Comparator display resolution (δm_R)
: Digital readability of $0.100\,\mathrm{\mu g}$ rounds each reading; half the resolution is taken as a rectangular half-width and the divisor is $2\sqrt{3}$ to avoid double-counting the rounding of both the load and tare readings.

Eccentricity / off-centre loading (δm_E)
: Residual sensitivity of the comparator to loading position, bounded by the manufacturer's corner-load specification and the operator's positioning repeatability, assumed rectangular.

Thermal expansion differential (δm_T)
: Volume mismatch induced by the residual temperature gradient ($\pm 0.300\,^\circ\mathrm{C}$) between test item and reference during equilibration, assumed rectangular.

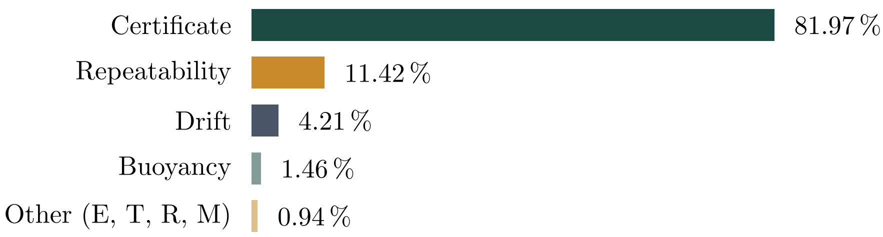
Magnetic susceptibility interaction (δm_M)
: Interaction between the comparator's internal load cell magnet and the ferromagnetic content of the stainless-steel test item, bounded per OIML R 111-1 Annex D and assumed rectangular.

4 Uncertainty Budget

Symbol	Source	Type	Distribution	Divisor	c_i	$u_i(y)$ [mg]	Contrib. [%]
δm_A	Repeatability of comparison (n = 10)	A	Normal	$\sqrt{n}$	1	0.028	11.420
δm_S	Reference standard certificate	B	Normal	2	1	0.075	81.970
δm_D	Drift of reference standard	B	Rectangular	$\sqrt{3}$	1	0.017	4.210
δm_B	Air buoyancy correction	B	Rectangular	$\sqrt{3}$	1	0.010	1.460
δm_E	Eccentricity / off-centre loading	B	Rectangular	$\sqrt{3}$	1	0.006	0.520
δm_T	Thermal expansion differential	B	Rectangular	$\sqrt{3}$	1	0.004	0.230
δm_R	Comparator display resolution	B	Rectangular	$2\sqrt{3}$	1	0.003	0.130
δm_M	Magnetic susceptibility interaction	B	Rectangular	$\sqrt{3}$	1	0.002	0.060

Contribution is the share of the combined variance, $100 \times u_i(y)^2/u_c(y)^2$. Rows are ordered by decreasing weight; the reference-standard certificate and the repeatability term together account for over 93 % of the combined uncertainty.

Relative contribution to combined variance



5 Combined and Expanded Uncertainty

5.1 Combined Standard Uncertainty

As all inputs are uncorrelated and every $c_i = 1$, the combined standard uncertainty is the root-sum-of-squares of the eight contributions in Section 3:

$$\begin{aligned} u_c(y) &= \sqrt{\sum_{i=1}^{8} u_i(y)^2} \\ &= \sqrt{0.028^2 + 0.075^2 + 0.017^2 + 0.010^2 + 0.006^2 + 0.004^2 + 0.003^2 + 0.002^2}\ \text{mg} \\ &= 0.083\ \text{mg} \end{aligned} \tag{4}$$

5.2 Effective Degrees of Freedom

The Welch–Satterthwaite equation combines the finite degrees of freedom of the Type A and certificate terms with the large, conservatively assumed degrees of freedom of the remaining Type B terms:

$$\nu_{\text{eff}} = \frac{u_c(y)^4}{\displaystyle\sum_{i=1}^{8} \frac{u_i(y)^4}{\nu_i}} \approx \frac{u_c(y)^4}{\dfrac{u_A^4}{9} + \dfrac{u_S^4}{118}} \approx 140 \tag{5}$$

where $\nu_A = n - 1 = 9$ (Type A) and $\nu_S = 118$ (from the reliability stated on the reference standard's certificate); the six remaining Type B terms are assigned $\nu_i \geq 50$ and contribute negligibly to the sum.

5.3 Expanded Uncertainty

With $\nu_{\text{eff}} \approx 140$, the Student's-$t$ coverage factor for a 95 % level of confidence is $t_{95}(140) \approx 1.98$, indistinguishable in practice from the normal-distribution value $k = 2$ used throughout the laboratory's calibration mass programme:

$$U = k \cdot u_c(y) = 2 \times 0.083\ \text{mg} = 0.166\ \text{mg}\ \approx\ 0.17\ \text{mg} \tag{6}$$

Reported result

$$\delta m_X = -1.245\ \text{mg}\ \pm\ 0.17\ \text{mg} \qquad (k = 2,\ \text{approx. } 95\,\%\ \text{confidence})$$

The expanded uncertainty is rounded up to two significant figures per laboratory procedure QP-14; the reported value is rounded to the same decimal place. No further rounding is applied before comparison with the manufacturer's Class E2 tolerance of ±1.600 mg for a 1 kg weight.

6 Statement of Compliance

The measured conventional mass correction of item VPI-1KG-014, $\delta m_X = -1.245\,\mathrm{mg}$ with expanded uncertainty $U = 0.17\,\mathrm{mg}$ ($k = 2$), lies well inside the OIML R 111-1 maximum permissible error of $\pm 1.600\,\mathrm{mg}$ for a Class E2 weight of nominal 1 kg. The item is therefore judged to **comply** with the requested class, with a test uncertainty ratio (tolerance / U) of 9.4:1.

6.1 Traceability

Measurements are traceable to the SI kilogram through reference standard RS-1KG-A (Cert. NMS-CAL-1198), itself traceable through an unbroken chain of calibrations to the national mass standard maintained by the accrediting metrology institute, in accordance with ISO/IEC 17025 [4].

6.2 Approval

Prepared by	**Reviewed and approved by**
Dr. Farhana Chowdhury Metrologist, Mass & Volume Laboratory	Imran Kabir Quality Manager

This report shall not be reproduced except in full without the written approval of Nexa Metrology Services. It relates only to the item calibrated and identified above.

References

[1] Joint Committee for Guides in Metrology. Evaluation of measurement data — guide to the expression of uncertainty in measurement. Technical Report JCGM 100:2008, BIPM, 2008. GUM 1995 with minor corrections.

[2] International Organization of Legal Metrology. Weights of classes e1, e2, f1, f2, m1, m1-2, m2, m2-3, and m3 — part 1: Metrological and technical requirements. Technical Report OIML R 111-1, OIML, 2004.

[3] EURAMET. Guidelines on the calibration of non-automatic weighing instruments. Technical Report EURAMET Calibration Guide No. 18, EURAMET e.V., 2015.

[4] International Organization for Standardization. General requirements for the competence of testing and calibration laboratories, 2017. ISO/IEC 17025:2017.