PROCEDURE

Evaluation of Measurement Uncertainty

SOP-16 | Revision 1.0 | [LABORATORY NAME]

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Revision history

Rev	Date	Description of change	Author	Approved
1.0	[DATE]	Initial issue of the ValiTrac template (pack v2.0).	ValiTrac	

1. Purpose

To define how the Laboratory identifies, evaluates, combines, expands, reports and reviews measurement uncertainty for every calibration it performs, in accordance with the GUM and the principles of UKAS M3003 and ILAC-P14, and how the uncertainties claimed in the scope of accreditation (CMCs) are supported and applied.

2. Scope

Applies to all calibrations performed by the Laboratory, including internal calibration of working standards and on-site work, and to the evaluation of the Calibration and Measurement Capability (CMC) for each entry in the scope of accreditation.

3. References

- ISO/IEC 17025:2017, clause(s) 7.6
- QM-01 Quality Manual, section(s) 7.6
- JCGM 100:2008 Evaluation of measurement data - Guide to the expression of uncertainty in measurement (GUM)
- JCGM 101:2008 Supplement 1 - Propagation of distributions using a Monte Carlo method
- UKAS M3003 The expression of uncertainty and confidence in measurement
- ILAC-P14 ILAC policy for measurement uncertainty in calibration
- EA-4/02 Evaluation of the uncertainty of measurement in calibration
- EURAMET calibration guides for discipline-specific budgets
- FRM-26 Uncertainty Budget Worksheet; ValiTrac Uncertainty Calculator workbook

4. Definitions

Term	Definition
Standard uncertainty, u(x)	Uncertainty of an input quantity expressed as a standard deviation.
Type A evaluation	Evaluation by statistical analysis of a series of observations (for example the standard deviation of the mean of repeated readings).
Type B evaluation	Evaluation by means other than statistical analysis of a series of observations: calibration certificates, specifications, previous data, experience, handbooks. Each Type B input is assigned a probability distribution (normal, rectangular, triangular, U-shaped) and a divisor.
Sensitivity coefficient, c	The partial derivative of the measurand with respect to an input quantity; converts the input's uncertainty into the units of the measurand.
Combined standard uncertainty, uc(y)	The positive square root of the sum of the squares of the contributions c*u(x), assuming uncorrelated inputs.
Expanded uncertainty, U	uc(y) multiplied by a coverage factor k; the Laboratory reports U at a coverage probability of approximately 95 %, normally k = 2.
Effective degrees of freedom	A measure of the reliability of uc(y), calculated by the Welch-Satterthwaite formula; when small (< 30), k is taken from the t-distribution.
CMC	Calibration and Measurement Capability: the smallest uncertainty the Laboratory can achieve for a near-ideal item under normal conditions, as stated in the scope of accreditation.

5. Responsibilities

Role	Responsibility under this procedure
Technical Manager	Approves uncertainty budgets and CMCs; ensures consistency between budgets, procedures and the scope; reviews budgets at least annually and after any change.
Discipline lead	Prepares and maintains the uncertainty budget for each procedure and range; validates the calculation tools; trains engineers in the budget.
Calibration personnel	Evaluate job-specific uncertainty using the approved budget and the actual conditions, item characteristics and Type A data; record it on the worksheet.
Authorised signatory	Checks that the reported uncertainty is correctly evaluated, not smaller than the CMC, rounded and stated correctly on the certificate.

6. Procedure

6.1 Policy

The Laboratory evaluates and reports measurement uncertainty for every calibration result. The evaluation follows the GUM as interpreted in UKAS M3003, and the reported uncertainty is an expanded uncertainty at a coverage probability of approximately 95 %. All contributions of significance are included; the Laboratory does not omit a contribution on the grounds that it is difficult to evaluate. Where a rigorous evaluation is impracticable for an influence quantity, a conservative estimate based on experience and published data is used and documented. The uncertainty reported on a certificate is never smaller than the CMC for that entry in the scope.

6.2 Evaluation method - eight steps

1. **Specify the measurand and the model.** State what is being measured (for example the correction to the indication of a thermometer at a stated temperature) and write the measurement model y = f(x1, x2, ... xn) relating the measurand to the input quantities: reference value and its correction, indications of reference and item, environmental corrections, drift, resolution, and so on.
2. **Identify all uncertainty sources.** Use the discipline checklist in section 6.4, the procedure, the equipment records and experience. Include the reference standard's calibration uncertainty; drift of the reference since calibration; resolution of the reference readout and of the item; repeatability (Type A); reproducibility between operators, days and set-ups where relevant; environmental effects (temperature, humidity, pressure, gravity, gradients, stability); item-specific effects (hysteresis, stem conduction, self-heating, loading, alignment, thermal expansion, buoyancy); method effects (interpolation, timing, stabilisation, curve fitting); and, where applicable, sampling.
3. **Quantify each contribution and assign a distribution.** Type A: standard deviation of the mean of n readings (s / sqrt(n)), or a pooled standard deviation from validation data where the number of readings in routine use is small. Type B: certificate uncertainties are normal with the stated k (divisor = k); manufacturer's tolerances, resolution (half the least significant digit), and drift limits are rectangular (divisor sqrt(3)); values with a known central tendency are triangular (divisor sqrt(6)); sinusoidal influences (temperature cycling) are U-shaped (divisor sqrt(2)).
4. **Compute the standard uncertainty of each input** as the half-width divided by the divisor, in the input's units.
5. **Determine the sensitivity coefficient** for each input (1 where the input is in the units of the measurand; otherwise from the model, for example a thermal expansion coefficient times length for a temperature effect on a dimensional measurement) and compute each contribution ui(y) = ci * u(xi) in the units of the measurand.
6. **Combine.** uc(y) = sqrt(sum of ui(y)^2) for uncorrelated inputs. Where inputs are correlated (for example the same reference standard used for two measurements whose difference is the measurand), the correlation is treated explicitly per M3003 or the model is reformulated to remove it.
7. **Expand.** Calculate the effective degrees of freedom (Welch-Satterthwaite) where any Type A contribution is dominant with few readings; otherwise take k = 2. Where effective degrees of freedom are below 30, take k from the t-distribution table in M3003 for 95.45 %. U = k * uc(y). Where the output distribution is markedly non-normal (a single dominant rectangular contribution), apply the M3003 treatment for dominant contributions or use the Monte Carlo method (JCGM 101) with the validated ValiTrac calculator.
8. **Report.** Round U to two significant figures (rounding up where the third figure is 5 or more); round the result to the same decimal place as U. State the result, U, the coverage factor and the coverage probability

using the wording in section 6.6. Record the budget on FRM-26 or in the validated workbook and file it with the job.

6.3 Procedure budgets and job-specific budgets

For each calibration procedure and range the discipline lead maintains an approved **procedure budget** (FRM-26) representing normal conditions and a typical item, evaluated at representative points across the range. The procedure budget defines which contributions are fixed (reference certificate, drift, environment at the limits, method) and which are evaluated per job (Type A repeatability, item resolution, item-specific effects such as hysteresis). For each job the engineer evaluates the **job-specific uncertainty** by combining the fixed contributions with the job-specific values on the worksheet or in the validated calculator; where the item's resolution or performance is worse than the typical item, the reported uncertainty increases accordingly. Where the job-specific conditions differ from those assumed in the procedure budget (for example an environmental excursion), the affected contribution is re-evaluated at the actual conditions.

6.4 Discipline checklists of contributions

Discipline	Contributions that must be considered (not exhaustive)
Temperature (comparison)	Reference PRT/thermocouple certificate; reference drift; bridge or readout certificate and resolution; reference self-heating; bath or block temporal stability and spatial gradients (radial and axial); immersion / stem conduction for reference and item; item resolution and repeatability; item hysteresis; interpolation between certificate points; cold-junction compensation and reference junction for thermocouples; electrical noise and thermal EMFs.
Humidity	Reference hygrometer certificate; reference drift; chamber temperature and humidity stability and uniformity; temperature difference between reference and item sensors converted to RH via the sensitivity dRH/dT; item resolution, repeatability and hysteresis; stabilisation time; pressure effects for dew-point references.
Pressure	Pressure balance effective area and its temperature coefficient; mass values and their uncertainty; local gravity; air buoyancy on masses; head correction (height difference and fluid density); piston temperature; reference transducer certificate, drift, resolution; item resolution, repeatability, hysteresis and zero drift; leak effects; thermal effects on the item.
Electrical	Calibrator or reference DMM certificate at the point (or interpolated specification); drift since calibration (manufacturer's 1-year specification treated as rectangular unless history supports less); reference resolution; item resolution and repeatability; loading and lead resistance; thermal EMFs; temperature coefficient for the difference between reference conditions and actual; noise and line frequency effects for AC.
Dimensional	Reference gauge or instrument certificate; reference drift and wear; comparator or indicator certificate and resolution; temperature difference from 20 degC for item and reference, thermal expansion coefficients and their uncertainty; temperature measurement uncertainty; item resolution and repeatability; measuring force and alignment (Abbe, cosine); flatness and parallelism of contact surfaces; operator influence for hand-held instruments.
Mass	Reference weight certificate and drift; comparator or balance repeatability, resolution, eccentricity and linearity; air buoyancy correction (air density from temperature, pressure, humidity, and densities of reference and item); magnetic effects; thermal equilibrium; for balances, the calibration weights used at each load, the repeatability at the load, eccentricity contribution, rounding error of the balance display at zero and at load, and the reference weight's uncertainty.

6.5 CMC evaluation and consistency

For each scope entry the CMC is derived from the procedure budget evaluated for the best existing device (a stable, well-behaved item with high resolution) that the Laboratory could reasonably be asked to calibrate, at the best routine conditions, following ILAC-P14. The CMC includes the contributions from the Laboratory's references, method, environment and the best-existing-device repeatability, but excludes contributions specific to a poorer item. The CMC is expressed as an absolute value, a relative value, or a function of the measurand (for example a + b x) consistent with the format required by the accreditation body (GD-05). The Technical Manager verifies annually, and after any change of reference standard, method or environment, that: every procedure budget supports the CMC; the CMC is not smaller than the uncertainty of the reference standard's certificate divided by an appropriate factor; and routine job uncertainties are consistent with the CMC (a job uncertainty smaller than the CMC indicates an error). The evidence is filed with the scope.

6.6 Reporting

Certificates state the expanded uncertainty for each result in the same unit as the measurand or as a relative value, with the statement: "The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, providing a coverage probability of approximately 95 %. The uncertainty evaluation has been carried out in accordance with UKAS requirements." Where k differs from 2 because of low effective degrees of freedom or a non-normal distribution, the actual k and the basis are stated. Uncertainty is reported to two significant figures. The certificate also states the conditions under which the calibration was performed, because they define the applicability of the uncertainty. Statements of conformity apply the decision rule with the reported uncertainty (SOP-29).

6.7 Validation of calculation tools

The uncertainty calculator workbook and any spreadsheet used for combination are validated under SOP-19 and FRM-49 using the worked examples in M3003 and independent hand calculation, with cell protection and version control. The identity and version of the tool used are recorded on the worksheet.

6.8 Review

Budgets are reviewed by the discipline lead and approved by the Technical Manager: annually; when a reference standard is recalibrated with a different uncertainty or drift; when the method, equipment, environment or software changes; after a PT result with $|E_n| > 0.7$ (which suggests the uncertainty may be underestimated) or persistently very small $|E_n|$ (which suggests overestimation); and after any nonconforming work attributable to uncertainty. The review is recorded on FRM-26.

Records generated by this procedure

The following records are generated when this procedure is applied. Each is a quality or technical record controlled under SOP-02 Control of Records; retention periods are minimums and may be extended by contract or regulation.

Record	Form / location	Minimum retention
Procedure uncertainty budgets with approval and review history	FRM-26 / validated workbook	Life of procedure + 6 years
Job-specific uncertainty evaluations	Worksheets FRM-36 to FRM-41	As the job file
CMC support evidence and consistency checks	Scope file (GD-05)	Life of scope + 6 years
Calculator validation	FRM-49	Life of tool + 6 years

Monitoring and performance indicators

The Quality Manager monitors the following indicators and reports them at management review (SOP-04). Adverse trends are treated as inputs to risk review (SOP-06) and, where appropriate, corrective action (SOP-05).

- Percentage of procedures with an approved budget reviewed within 12 months (target: 100 %).
- Certificates found at review with uncertainty below CMC or incorrectly rounded (target: zero).
- PT results with $|E_n| > 1$ attributable to uncertainty underestimation (target: zero).

Assessment readiness notes

The points below summarise what an accreditation-body assessor (for example a UKAS assessment manager or technical assessor) will typically sample when assessing this process. They are included as guidance for the laboratory and may be deleted from the controlled version of the procedure.

- Working through a budget line by line with the engineer: where each number came from, why that distribution, what the sensitivity coefficient is, whether the dominant contribution is realistic.
- Checking that the environmental and drift contributions match the actual limits and the observed history.
- Comparing the CMC with the reference standard's certificate uncertainty and with routine job uncertainties.
- Asking the engineer (not only the Technical Manager) to explain the uncertainty on a certificate they produced.
- Checking the wording of the uncertainty statement and rounding on certificates.

Related documents

- SOP-13 Selection, Verification and Validation of Methods
- SOP-17 Ensuring the Validity of Results
- SOP-18 Reporting of Results and Calibration Certificates
- SOP-19 Control of Data and Information Management
- SOP-29 Decision Rules and Statements of Conformity
- FRM-26 Uncertainty Budget Worksheet
- FRM-49 Software and Spreadsheet Validation Record
- GD-05 Scope of Accreditation and CMC Drafting Guide