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Translating calibration certificates into alarm limits for controlled environments in medical laboratories: a practical workflow and spreadsheet calculator

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Title: Translating calibration certificates into alarm limits for controlled environments in medical laboratories: a practical workflow and spreadsheet calculator

Short title: Calibration and Alarm Limits in Medical Laboratories

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Abstract

Background: Calibration certificates provide instrument offsets and measurement uncertainty, but translating this information into monitoring alarm limits requires an explicit decision rule.
Objective: To describe a reproducible workflow for deriving alarm limits from calibration information and provide a freely available spreadsheet calculator.
Methods: A three-step workflow was developed using established calibration, traceability and conformity-assessment principles. Specified environmental limits were translated onto the instrument's indicated scale using the signed calibration offset, narrowed by expanded uncertainty, and bounded within the numerical specification range under an additional local governance policy. The workflow was implemented in Excel and illustrated using representative inputs for six environments in an accredited private medical laboratory in Abu Dhabi: refrigeration, two freezer conditions, incubation, controlled room temperature and humidity. Positive and negative offset scenarios were evaluated.

Results: Calculated alarm limits differed from the specified ranges in all scenarios. Uncertainty guard bands alone reduced interval widths by 1–30%. The additional specified-range bound constrained the lower threshold for positive offsets and the upper threshold for negative offsets in four environments; it produced no further change for room temperature or humidity. The calculator displays intermediate calculations and final thresholds alongside the relevant inputs.
Conclusions: The workflow integrates calibration interpretation and alarm-limit calculation into a documented process. The calculator supports reproducible implementation, subject to instrument-specific inputs and local verification. The examples illustrate the method but do not establish its effectiveness in routine practice.

Keywords: Metrological traceability; calibration; measurement uncertainty; decision rule; environmental monitoring; medical laboratories.

1. Introduction

Metrological traceability underpins the comparability and reliability of laboratory measurements. Its application to analytical measurands, including the roles of reference materials, reference measurement procedures, calibration hierarchies and measurement uncertainty, is well established [1,2,3]. These principles are also relevant to the instruments monitoring refrigerators, freezers, incubators, controlled room temperature and humidity in medical laboratories. Errors in these measurements can compromise storage or processing conditions and affect the integrity of specimens, reagents, calibrators and quality-control materials.

Controlled environments support several stages of laboratory practice. Refrigeration and frozen storage preserve materials awaiting analysis or use, while incubators provide conditions required for microbial growth and temperature-dependent reactions. Room temperature and humidity influence the stability of materials stored outside enclosed chambers. Deviations from specified conditions may remain unnoticed until material deterioration or analytical performance changes become apparent. Reliable monitoring therefore requires an understanding of the relationship between instrument indications and the conditions being measured. Table 1 summarises the calibration or verification of relevant non-analytical equipment and its potential influence on patient results.

Table 1. Calibration of non-analytical laboratory equipment and its route of influence on patient results.

Device	Calibration or verification approach	Route of influence on results
Micropipettes	Gravimetric calibration at the volumes used, with a traceable balance under controlled water and ambient conditions	Delivered volume of samples, calibrators, controls and reagents; affects trueness and imprecision

Centrifuges	Tachometer-based verification of rotational speed; timer and temperature verification where relevant	Completeness and reproducibility of plasma, serum and cellular-component separation
Analytical balances	Calibration with traceable reference masses and intermediate checks appropriate to use	Gravimetric preparation of standards and reagents; supports pipette calibration
Refrigerated and frozen storage	Calibrated probe thermometers and data loggers traceable to the kelvin at relevant working points, with mapping at commissioning and after repair or relocation	Stability and integrity of specimens, reagents, calibrators and control materials
Incubators	Calibrated probes at the working temperature, with mapping of the usable chamber volume	Microbial growth and reaction kinetics; unsuitable conditions may contribute to false-negative results
Humidity-controlled storage	Calibrated thermo-hygrometers covering the working range	Integrity of moisture-sensitive reagents, strips and lyophilised materials

Metrological traceability relates a measurement result to a stated reference through a documented, unbroken chain of calibrations, each contributing to measurement uncertainty [4]. Traceability to the International System of Units (SI) requires a calibration hierarchy linked to the appropriate SI reference. For laboratory measurands for which SI traceability is unavailable, the applicable higher-order reference system must be identified [5]. Traceability concerns measurement results and reference quantity values, rather than the identity of the organisation providing calibration [6]. This common reference framework supports comparison between laboratories while accounting for their measurement uncertainties.

For temperature measurements, the relevant SI unit is the kelvin, defined through the fixed numerical value of the Boltzmann constant. National metrology institutes provide the reference infrastructure supporting traceable calibration; in the United Arab Emirates, this role is fulfilled by the Emirates Metrology Institute [7]. Calibration laboratories transfer reference values to working standards and subsequently to laboratory probes and data loggers. Figures 1 and 2 illustrate the traceability chain and calibration hierarchy, respectively. Table 2 summarises the seven SI base units, their defining constants and their relevance to laboratory practice.

Table 2. The seven SI base units and their defining constants under the 2019 definitions, with examples of their relevance to medical laboratory practice.

Base quantity	SI unit	Defining constant, fixed exact value	Relevance in a medical laboratory

Time	second (s)	Caesium-133 hyperfine transition frequency, $\Delta\nu Cs = 9\ 192\ 631\ 770$ Hz	Incubation intervals, reaction kinetics, coagulation timing and centrifugation
Length	metre (m)	Speed of light in vacuum, c = 299 792 458 m/s	Optical path length in photometry, chromatography column geometry and dimensional checks
Mass	kilogram (kg)	Planck constant, $h = 6.626\ 070\ 15 \times 10^{-34}$ J s	Analytical balances, gravimetric pipette calibration and preparation of standards and reagents
Electric current	ampere (A)	Elementary charge, $e = 1.602\ 176\ 634 \times 10^{-19}$ C	Ion-selective electrodes, electrophoresis and amperometric biosensors
Thermodynamic temperature	kelvin (K)	Boltzmann constant, $k = 1.380\ 649 \times 10^{-23}$ J/K	Refrigerated and frozen storage, incubators and controlled room temperature
Amount of substance	mole (mol)	Avogadro constant, $N_A = 6.022\ 140\ 76 \times 10^{23}$ mol^{-1}	Analyte concentrations in mol/L and value assignment of certified reference materials
Luminous intensity	candela (cd)	Luminous efficacy, Kcd = 683 lm/W for radiation of frequency 540×10^{12} Hz	Optical measurement systems used in laboratory instrumentation

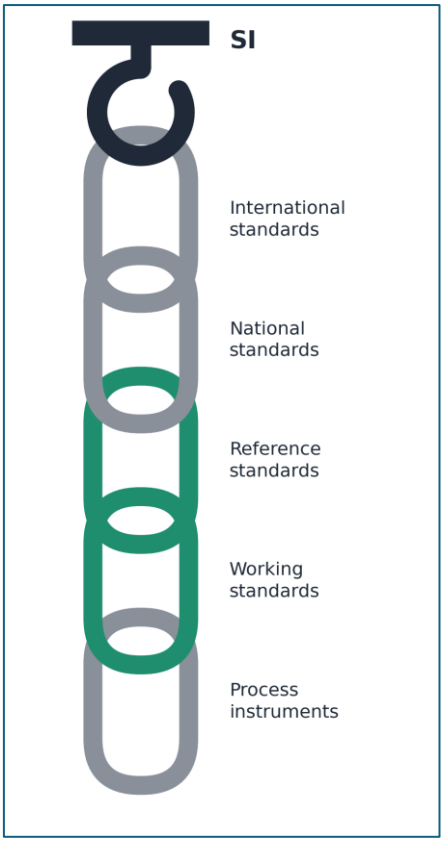
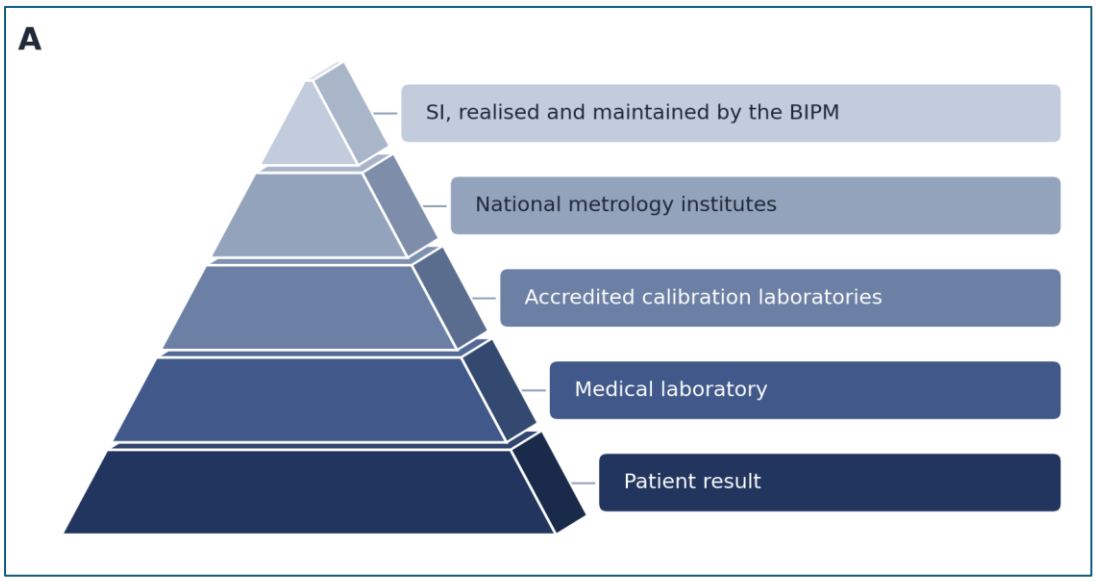


Figure 1. The metrological traceability chain. Documented calibrations relate instrument measurements to a stated reference through successive levels of measurement standards, with each calibration contributing to measurement uncertainty. An interruption in the documented chain prevents demonstration of traceability through that route.



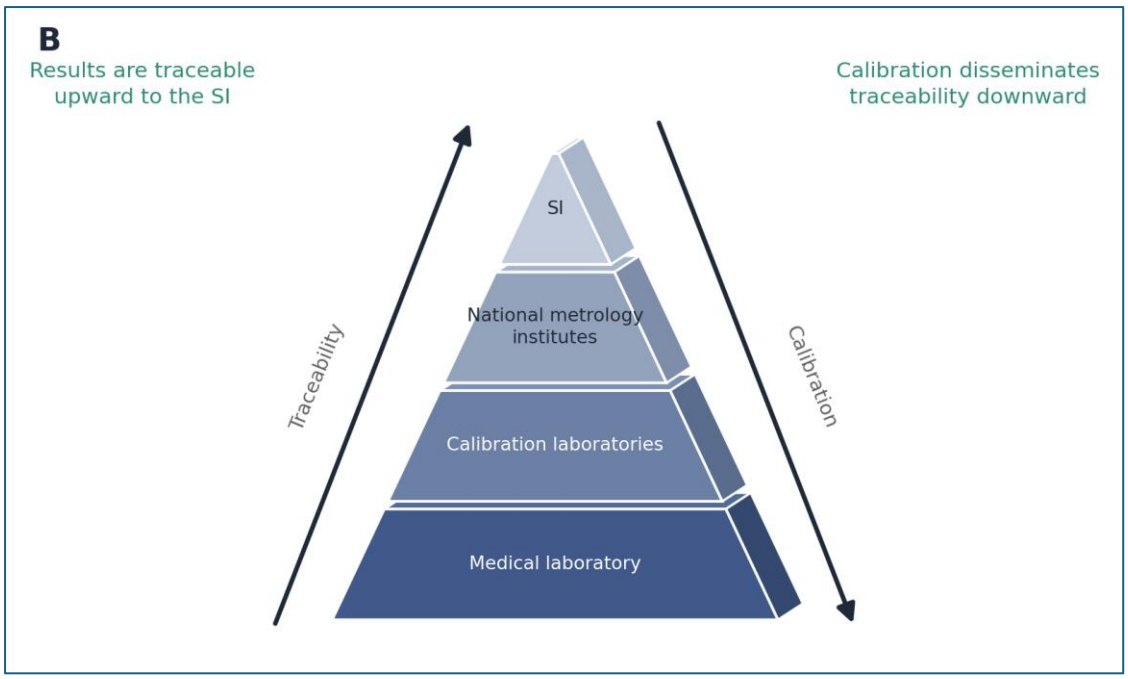


Figure 2. The metrological traceability hierarchy. (A) Schematic relationships between SI references, national metrology institutes, calibration laboratories and medical laboratory measurements. (B) Traceability is established from measurement results towards the stated reference, while calibration transfers reference values towards routine measurement systems.

Each calibration contributes to the uncertainty associated with the resulting measurement.
ISO 15189:2022 addresses the calibration and metrological traceability of equipment affecting laboratory results [8]. However, obtaining a calibration certificate does not itself establish appropriate monitoring alarm limits. The certificate documents the relationship between indication and reference value, together with the associated uncertainty. Where alarms operate on uncorrected instrument indications, limits specified for the environmental quantity must be translated onto the indicated scale. Accounting for both the calibration offset and its uncertainty is a conformity-assessment task informed by established decision-rule and guard-banding guidance [9,10].
The practical challenge addressed here is the translation of calibration information into documented, reproducible alarm settings. This article presents a workflow combining calibration-offset adjustment, uncertainty-based guard bands and an additional local policy that bounds programmed thresholds within the numerical specification range. The workflow is illustrated across six controlled environments used in an accredited private medical laboratory in Abu Dhabi. An accompanying spreadsheet, provided under a Creative Commons Attribution 4.0 licence, supports consistent calculation and documentation of the resulting limits.

2. Methods

2.1 Calibration interpretation and decision framework

Calibration establishes the relationship between instrument indications and reference values, whereas adjustment changes the instrument's performance [4]. The present workflow

distinguishes calibration, correction and acceptance decisions: calibration documents the offset and associated uncertainty; correction accounts for the offset; and the acceptance decision defines the indicated values considered acceptable. Documenting these operations supports equipment control under ISO 15189:2022 [8]. ISO/TS 20914:2019 provides complementary guidance on measurement uncertainty in medical laboratories [11].
Specified environmental limits were treated as requirements established by the stored product manufacturer, a validated procedure or another applicable source. The decision framework followed conformity-assessment principles described in ILAC-G8:09/2019 and ISO/IEC Guide 98-4:2012 [9,10]. A guard band narrows the acceptance interval relative to the tolerance interval to account for measurement uncertainty. Here, the guard-band width was set equal to the expanded uncertainty, U. The workflow comprised transfer of the specified limits onto the instrument's indicated scale, inward application of the guard band, and an additional local policy bounding programmed thresholds within the numerical specification range.

2.2 Sign convention

The signed offset, d, was defined as the reference value minus the instrument indication:
d = reference value − instrument indication
Accordingly, the indicated value corresponding to a specified reference value was calculated by subtracting d. For positive d, the limits shift downward; for negative d, subtracting d shifts them upward by its magnitude. If a certificate defines measurement error as indication minus reference, its sign must be reversed before applying this convention.
The calculator requires the offset magnitude as a positive entry, with its direction determined by selecting the appropriate worksheet. The convention must be confirmed against the certificate's reference and indicated values rather than inferred from labels such as "error" or "correction."

2.3 Three-step calculation

Let Lspec and Hspec denote the specified lower and upper limits, Sspec the nominal set point, d the signed offset, and U the expanded measurement uncertainty at the coverage factor or coverage probability stated on the calibration certificate [12].

Step 1: Transfer to the indicated scale
Lrev = Lspec − d
Hrev = Hspec − d
Srev = Sspec − d

Step 2: Apply the uncertainty guard band
Lnew = Lrev + U
Hnew = Hrev − U

Step 3: Apply the specified-range bound
Lprog = max(Lnew, Lspec)
Hprog = min(Hnew, Hspec)

Step 1 translates the specification into instrument indications. The revised set point represents the expected monitored indication at the nominal target condition; it does not automatically prescribe a controller adjustment, particularly when monitoring and control use different sensors. Step 2 applies U inward at both ends of the translated interval.

Step 3 represents an additional local governance choice, rather than a universal metrological requirement. Under this policy, programmed thresholds cannot extend numerically beyond the specified range. An indication outside that range does not necessarily imply a nonconforming environmental condition, because the indication and reference value differ by d. The bound therefore adds conservatism where it constrains a threshold. The calculation record identifies whether each programmed limit was determined by the uncertainty-adjusted limit or the additional bound.

The calculator reports unrounded limits. Where the monitoring system requires fixed increments, the lower threshold should be rounded upward and the upper threshold downward, with the final settings documented. Before implementation, the resulting interval must remain usable, with Lprog < Hprog; otherwise, the monitoring arrangement or decision rule requires reassessment.

For the refrigerator example, the specified range was 2–8 °C, the nominal set point was 5.00 °C, d was +0.23 °C and U was 0.10 °C. Step 1 produced a revised range of 1.77–7.77 °C and a revised set point of 4.77 °C. Step 2 narrowed the interval to 1.87–7.67 °C. Step 3 raised the lower threshold to 2.00 °C, yielding programmed limits of 2.00–7.67 °C. Figure 3 illustrates this sequence.

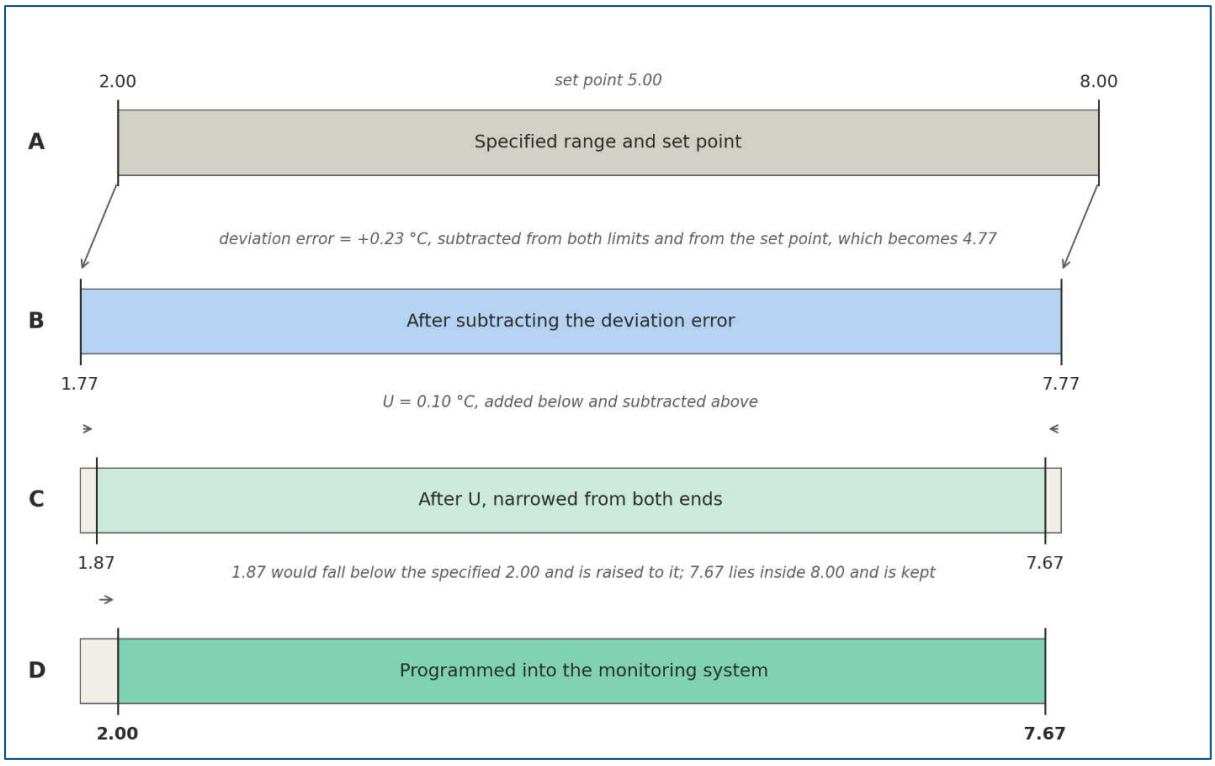


Figure 3. Three-step calculation for a refrigerator specified at 2–8 °C, with d = +0.23 °C and U = 0.10 °C. (A) Specified range and nominal set point. (B) Transfer to the indicated scale gives limits of 1.77–7.77 °C and a set point of 4.77 °C. (C) Inward uncertainty guard bands

give limits of 1.87–7.67 °C. (D) The additional specified-range bound gives programmed limits of 2.00–7.67 °C. Horizontal displacements are schematic and not to scale.

2.4 Calculator implementation

Supplementary File S1 implements the workflow in an Excel workbook containing twelve calculation worksheets and an instructions worksheet. Each of the six environments has separate worksheets for positive and negative offsets. Inputs include equipment identification, specified limits, nominal set point, offset magnitude and expanded uncertainty. Formula-based columns display the intermediate calculations and final programmed limits, allowing the basis of each threshold to be reviewed.

All temperature inputs retain their signs; for example, the −20 °C freezer range is entered as −25.00 to −15.00 °C. Entering unsigned magnitudes would misrepresent the interval and invalidate the calculations. Users must also confirm that uncertainty is expressed as expanded uncertainty at the documented coverage factor; standard uncertainty must not be substituted without the appropriate conversion.

Additional rows contain predefined limits, set points and formulae. Where offset and uncertainty inputs are blank, the workbook displays the original limits; these outputs must not be interpreted as completed calibration-based assessments. The instructions worksheet documents the sign convention, calculation steps, worked examples and limitations.

2.5 Application to controlled environments

The workflow was illustrated for six environments used in an accredited private medical laboratory in Abu Dhabi: refrigeration at 2–8 °C, −20 °C and −80 °C freezers, incubation at 35–37 °C, controlled room temperature and controlled relative humidity. Calculations used representative certificate values, with offset magnitudes of 0.23 °C for temperature and 0.23 % RH for humidity. Positive and negative offset scenarios were evaluated for each environment using the same magnitude and uncertainty. Freezer limits were entered as signed temperatures. The specified ranges, uncertainty inputs, intermediate calculations and programmed limits are presented in Table 3. These examples illustrate the workflow; implementation requires the applicable specification and current calibration information for each individual instrument.

3. Results

The calculated alarm limits differed from the specified ranges in all six environments under both positive and negative offset scenarios (Table 3). For the refrigerator, the final limits were 2.00–7.67 °C with a positive offset and 2.33–8.00 °C with a negative offset, compared with the specified range of 2.00–8.00 °C.

The additional specified-range bound affected four environments: the refrigerator, both freezers and the incubator. For positive offsets, it retained the lower threshold at the specified lower limit; for negative offsets, it retained the upper threshold at the specified upper limit. For controlled room temperature and humidity, both thresholds were already within the specified range after uncertainty adjustment, so Step 3 produced no further change.

Table 3. Calculated alarm limits for six controlled environments under positive and negative offset scenarios. Here, d is the signed offset defined as reference value minus

instrument indication, and U is the expanded measurement uncertainty. Values are expressed in °C for temperature and % RH for humidity. The examples illustrate the calculation workflow and are not universal alarm settings.

(A) Positive offset scenarios

Environment	Specified range	d	U	After Step 1	After Step 2	Final programmed limits
Refrigerated, 2–8 °C	2.00 to 8.00	+0.23	0.10	1.77 to 7.77	1.87 to 7.67	2.00 to 7.67
Freezer, −20 °C	−25.00 to −15.00	+0.23	0.10	−25.23 to −15.23	−25.13 to −15.33	−25.00 to −15.33
Ultra-low freezer, −80 °C	−90.00 to −70.00	+0.23	0.10	−90.23 to −70.23	−90.13 to −70.33	−90.00 to −70.33
Incubator, 35–37 °C	35.00 to 37.00	+0.23	0.10	34.77 to 36.77	34.87 to 36.67	35.00 to 36.67
Controlled room temperature	18.00 to 22.00	+0.23	0.60	17.77 to 21.77	18.37 to 21.17	18.37 to 21.17
Controlled humidity	40.0 to 65.0	+0.23	0.60	39.77 to 64.77	40.37 to 64.17	40.37 to 64.17

(B) Negative offset scenarios

Environment	Specified range	d	U	After Step 1	After Step 2	Final programmed limits
Refrigerated, 2–8 °C	2.00 to 8.00	−0.23	0.10	2.23 to 8.23	2.33 to 8.13	2.33 to 8.00
Freezer, −20 °C	−25.00 to −15.00	−0.23	0.10	−24.77 to −14.77	−24.67 to −14.87	−24.67 to −15.00
Ultra-low freezer, −80 °C	−90.00 to −70.00	−0.23	0.10	−89.77 to −69.77	−89.67 to −69.87	−89.67 to −70.00
Incubator, 35–37 °C	35.00 to 37.00	−0.23	0.10	35.23 to 37.23	35.33 to 37.13	35.33 to 37.00
Controlled room temperature	18.00 to 22.00	−0.23	0.60	18.23 to 22.23	18.83 to 21.63	18.83 to 21.63
Controlled humidity	40.0 to 65.0	−0.23	0.60	40.23 to 65.23	40.83 to 64.63	40.83 to 64.63

Step 1 transfers the specified limits onto the indicated scale; Step 2 applies the uncertainty guard band; Step 3 bounds the calculated thresholds within the numerical specification range. The table displays signed offsets, whereas the calculator requires a positive magnitude entered into the worksheet corresponding to the offset direction.

The uncertainty adjustment alone reduced the interval width by 2U, corresponding to 1–30% of the specified range across the six examples. The smallest proportional reduction occurred for the −80 °C freezer and the largest for controlled room temperature. The subsequent specified range bound further narrowed the interval in the four environments identified above. Figure 4 illustrates the calculation sequence for the five environments other than the refrigerator, which is shown in Figure 3.

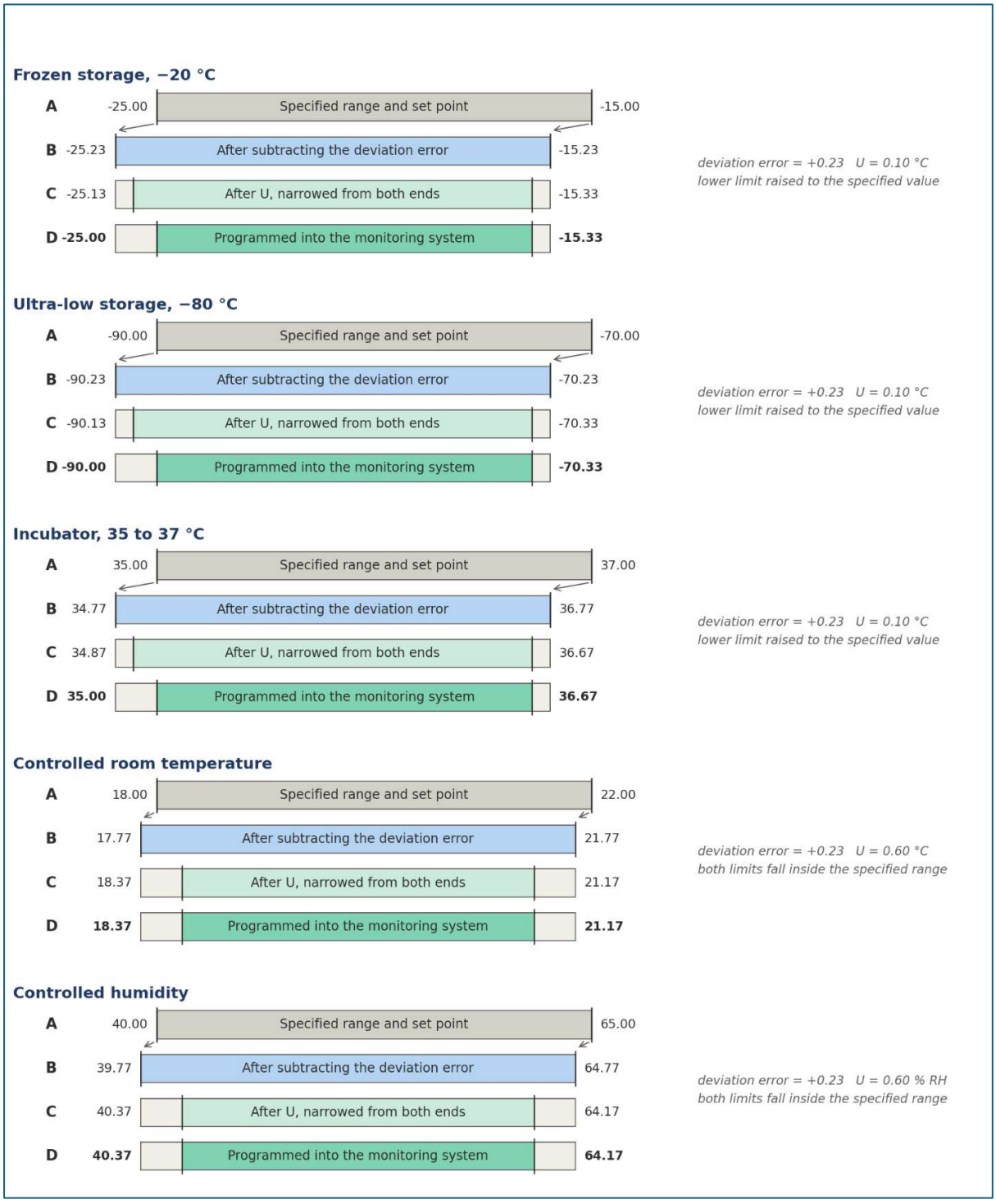


Figure 4. Three-step calculation for the −20 °C freezer, −80 °C freezer, incubator, controlled room temperature and controlled humidity, using positive offsets of 0.23 °C or 0.23 % RH, as applicable. Each panel shows (A) the specified range and nominal set point; (B) transfer onto the indicated scale; (C) inward application of expanded uncertainty; and (D) the final limits after the additional specified range bound. Freezer temperatures retain their negative signs. Annotations identify the offset, uncertainty and any threshold constrained by the specified range bound. Horizontal displacements are schematic and are not comparable between panels.

4. Discussion

The worked examples demonstrate how calibration offsets and measurement uncertainty can be translated into documented alarm thresholds for controlled laboratory environments. The calculated limits differed from the specified ranges in all scenarios, illustrating the importance of distinguishing environmental specifications from instrument indications. The contribution is an explicit implementation workflow and accompanying calculator, rather than a new principle of calibration or conformity assessment.

Guard-banded alarm limits are established in controlled-temperature applications. An ISPE concept paper describes their application to pharmaceutical chambers, including an example in which a 2–8 °C acceptable range is narrowed to alarm limits of 2.25–7.75 °C [13]. EIAC-RQ-LB-004 also provides medical-laboratory examples combining calibration deviations and uncertainty when adjusting operating ranges [14]. More recently, Pradella discussed decision rules under ISO/IEC 17025 and ISO 15189 across testing and medical laboratories [15].

The present workflow combines a signed calibration-offset correction, an uncertainty guard band and an additional numerical bound within a single calculation record. The calibration offset translates the specification onto the indicated scale and is distinct from allowances for spatial temperature differences within a chamber. The additional bound in Step 3 represents a local governance policy, not a requirement inherent in guard-banding guidance. Its purpose is to retain programmed thresholds within the numerical specification range, even when calibration correction would otherwise permit indications outside that range.

This distinction is important because an indication outside the specified range does not necessarily represent an unacceptable environmental condition. Step 3 can therefore impose additional conservatism and reduce the usable interval. Its application should be justified and documented separately from the calibration correction and uncertainty allowance.

Programming the specified range directly into an alarm system does not, by itself, demonstrate that calibration offset and uncertainty have been considered. The equipment record should identify the applicable specification, certificate values, sign convention, decision rule and final programmed settings. ISO/IEC 17025:2017 addresses the documentation and reporting of decision rules when statements of conformity are provided [16]. Although such statements and operational alarm settings serve different purposes, explicit documentation supports transparent interpretation of both.

Table 4 summarises the standards and guidance informing the workflow. These documents support its underlying principles but should not be interpreted as collectively prescribing the complete three-step algorithm. EIAC requirements should be applied where relevant to the laboratory's accreditation arrangements [14,17,18].

Table 4. Standards and guidance informing the workflow. Annex D of EIAC-RQ-LB-004 and the ISPE concept paper provide informative guidance rather than mandatory requirements for the proposed algorithm.

Document	Scope	Relevance to the workflow
ISO 15189:2022	Quality and competence of medical laboratories	Equipment calibration, metrological traceability and documented equipment control
ISO/IEC 17025:2017	Competence of testing and calibration laboratories	Calibration reporting, measurement uncertainty, traceability and decision rules for statements of conformity
ILAC-G8:09/2019	Decision rules and statements of conformity	Tolerance limits, acceptance limits, guard bands and binary or non-binary decision rules
ISO/IEC Guide 98-4:2012	Measurement uncertainty in conformity assessment	Statistical framework for evaluating conformity and associated decision risks
ILAC-P10:07/2020	Metrological traceability policy	Traceability of measurement results through documented calibration chains to stated references
ILAC-G24:2022	Recalibration intervals	Selection and review of calibration intervals based on equipment performance and risk
ISO/TS 20914:2019	Measurement uncertainty in medical laboratories	Complementary guidance on uncertainty estimation and use in routine examinations
EIAC-RQ-LB-004, EIAC-RQ-GEN-005 and EIAC-RQ-LB-011	EIAC accreditation requirements	Applicable calibration, uncertainty and traceability requirements, including worked examples for medical laboratories
ISPE controlled-temperature chamber guidance	Pharmaceutical controlled-temperature chambers	Prior application of guard-banded decision limits to controlled environments

The reliability of calculated thresholds depends on whether the calibration offset and uncertainty remain representative during use. ILAC-G24:2022 identifies equipment stability, drift history, required uncertainty, manufacturer specifications, usage and environmental exposure as relevant considerations when determining recalibration intervals [19]. Laboratories

should also comply with applicable equipment-specific calibration frequencies under their accreditation requirements [14].

Intermediate checks can help identify changes between calibrations. Maintenance, relocation, repair, unexplained alarms or changes in chamber configuration should prompt investigation and, where appropriate, recalibration or mapping. Following recalibration, the limits should be recalculated and the settings reviewed, even if the resulting thresholds remain unchanged.

4.3 Limitations

The workflow assumes that a single calibration offset adequately represents the relevant working range and remains sufficiently stable between calibrations. Where the offset varies materially with temperature or humidity, calculations require calibration information appropriate to the relevant limits or working points. Devices serving different operating conditions may therefore require separate assessments.

The adopted guard-band width equals the expanded uncertainty. This provides a defined binary decision rule but does not establish a universal probability of false acceptance. Laboratories requiring a different risk level should select and document an appropriate guard band. A larger numerical margin can be entered into the calculator, but it should be distinguished from the certificate uncertainty. The workbook does not implement non-binary outcomes such as conditional acceptance.

The additional specified-range bound may constrain one threshold independently of changes in uncertainty while that bound remains active. This does not mean that improved monitoring performance has no value: it may affect the opposite threshold or remove the need for the bound. The basis of each final threshold should therefore remain visible in the calculation record.

The calculator addresses instrument indications and does not account for spatial variation within a storage unit. Temperature mapping and appropriate probe placement remain necessary complementary activities. Furthermore, certificate uncertainty alone may not capture all uncertainty contributions arising during routine use.

Finally, the examples illustrate calculations for conditions represented in one laboratory, with paired positive and negative offset scenarios. They do not establish performance across devices, laboratories or operating conditions, nor demonstrate reductions in storage excursions or patient-related errors. Each implementation requires instrument-specific calibration information and local verification. The principal contribution is the integration of established concepts into a reproducible, openly available workflow.

5. Conclusion

Calibration information can support reproducible alarm settings when the instrument offset, measurement uncertainty and decision rule are explicitly considered. The proposed workflow translates environmental specifications onto the indicated scale, applies uncertainty guard bands and incorporates an additional, locally selected numerical bound. Its application to six controlled environments illustrates how calculated thresholds differ from the specified ranges. The accompanying calculator supports consistent calculation and documentation; implementation requires instrument-specific calibration information, verification of the

resulting settings and periodic review. The worked examples demonstrate the method rather than establish its effectiveness in routine practice.

Tool availability

The calculator is provided as Supplementary File S1 under a Creative Commons Attribution 4.0 International licence, permitting reuse and adaptation under the licence terms. Users may adapt the input values to other operating conditions, provided the calibration information and decision rule are appropriate to the intended application. Adapted calculations and programmed settings require local verification. Requests for assistance, feedback and proposed improvements may be directed to the corresponding author.

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Supplementary material

Supplementary File S1. Controlled-environment limit calculator, version 4.0. Microsoft Excel workbook containing twelve calculation worksheets, one for a positive and one for a negative deviation error for each of 2 to 8 °C, −20 °C, −80 °C, incubator 35 to 37 °C, controlled room temperature and controlled relative humidity, together with an instruction's worksheet setting out the three steps, the worked example and the limitations. Single-environment versions of each worksheet are available from the corresponding author on request. Released under CC BY 4.0.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- S1SupplementaryCalculator.xlsx