Practical Use of Dry Block Calibrators

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A dry block can give a temperature reading that looks more certain than it is. The difference between a casual measurement and a defensible one lies in understanding the measurement zone, the way heat moves through the probe, and the evidence behind the stated uncertainty.

Introduction

A block calibrator display reads 200.00°C. A calibrated reference thermometer, positioned at the specified depth within the defined measurement zone, reads 199.84°C. Neither indication is necessarily wrong. The display reports the temperature seen by the internal control sensor, whereas the reference thermometer reports the temperature realized at its specified position in the block. Any difference between that position and the position of a sensor under test must be understood through characterization and allowed for where relevant. The 0.16°C difference is not simply an error in either instrument. It is the beginning of an uncertainty budget.

Dry blocks are among the most widely used tools in temperature calibration. They are portable, clean, quick to set up, and free of the handling problems that come with stirred liquid baths. That convenience can also be misleading. A dry block is not simply a hot or cold hole in a metal

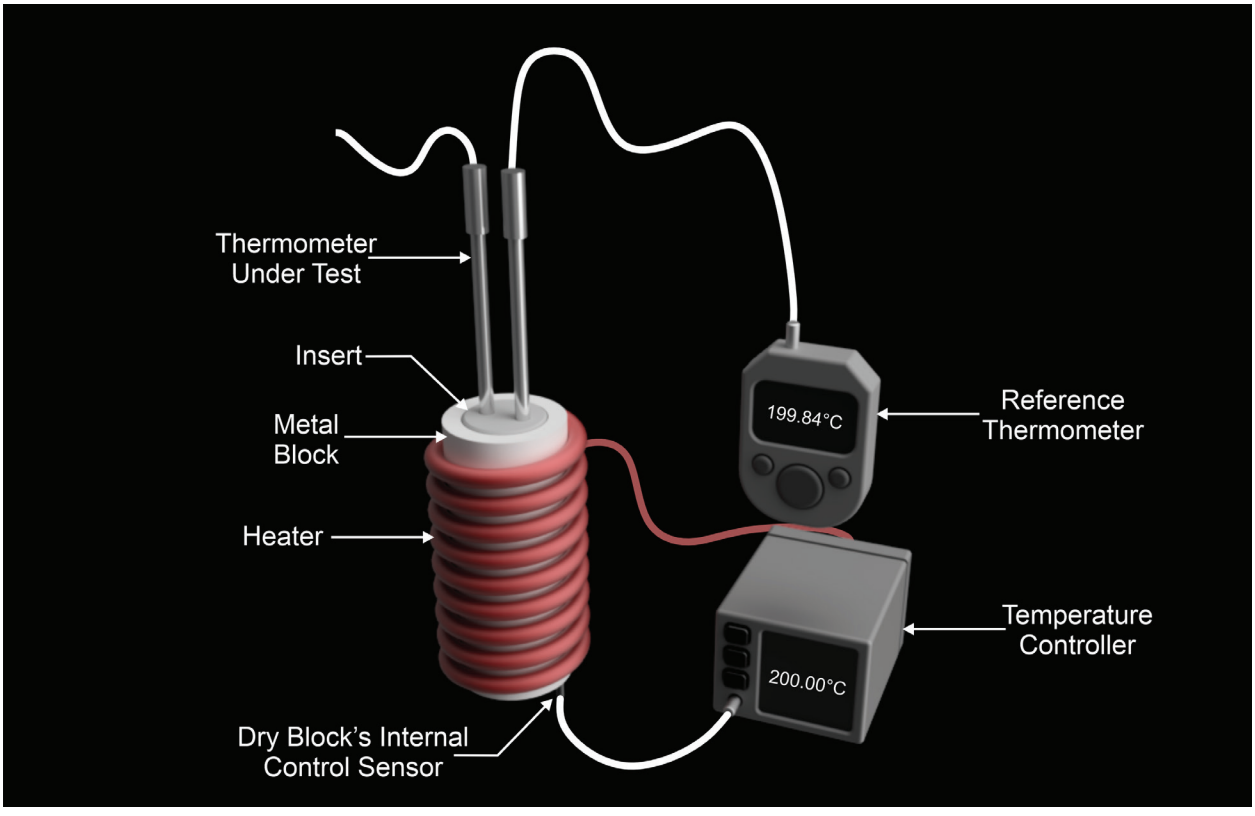

Figure 1. Simplified dry block arrangement. Metal block, insert, reference thermometer, unit under test, and internal control sensor.

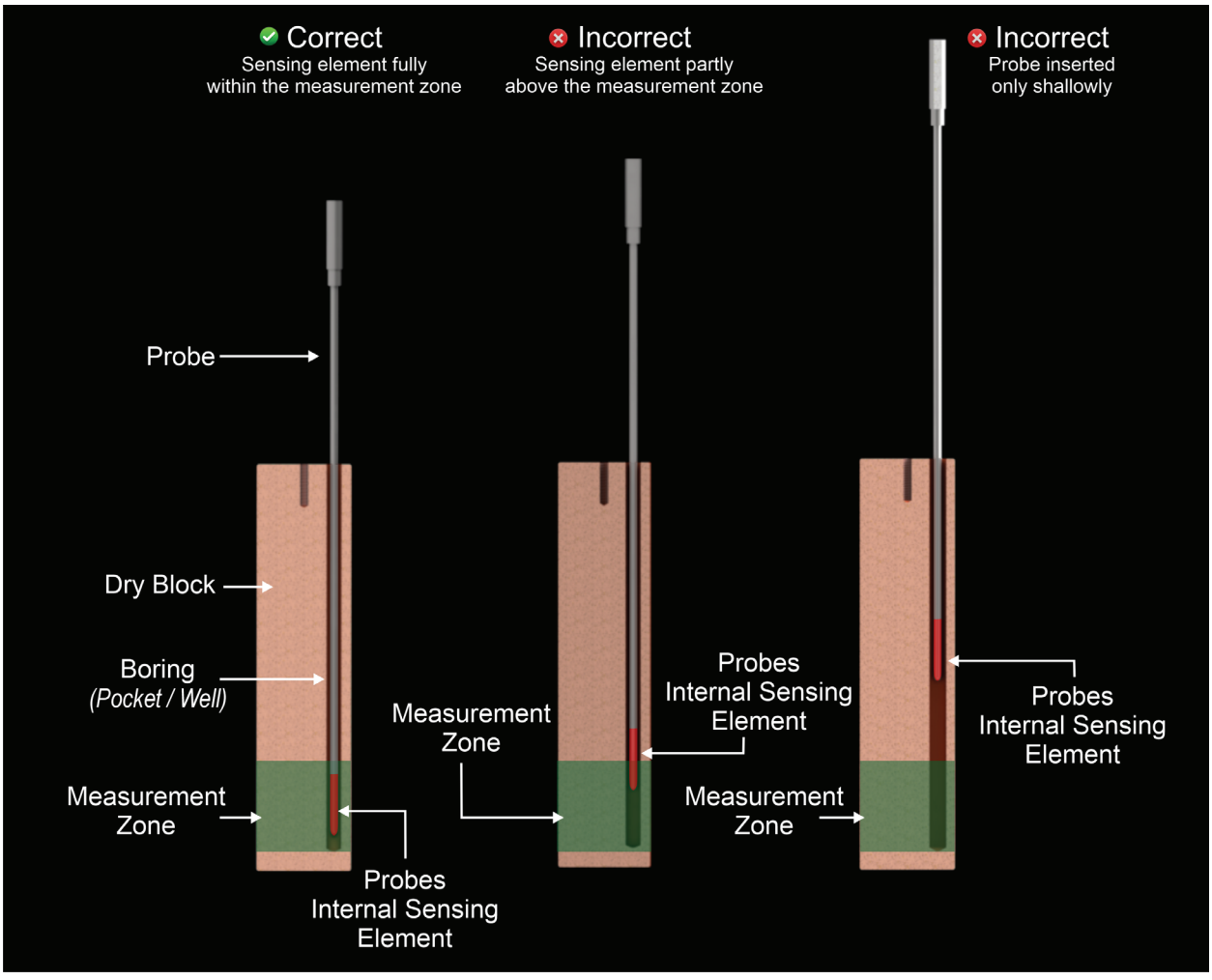

Figure 2. Immersion and sensing element position. Correct placement within the measurement zone, and two incorrect cases.

block. It is a temperature source with a defined measurement zone, real temperature gradients and several uncertainty contributions that need to be understood before a result can be trusted. This article looks at how to use a dry block successfully, rather than what one is.

The principles below are general and apply under any accreditation regime working to ISO/IEC 17025. EURAMET Calibration Guide No. 13, *Guidelines on the Calibration of Temperature Block Calibrators* (CG-13), is used throughout as the primary technical reference. The guide provides practical guidance on calibrating and characterizing dry-block calibrators, including the assessment of temperature distribution, stability, loading effects and the uncertainty associated with their use.

What a Dry Block Does, and Does Not, Tell You

A dry block calibrator is a solid metal block, heated electrically or cooled (often via Peltier modules at lower temperatures), to a temperature set by a controller. Probes are placed into the block, usually via an interchangeable insert that fits inside it, allowing a range of probe types to be inserted into the insert's pockets, wells or borings (the latter being the term used in the EURAMET CG-13 guide).

The controller uses its internal control sensor to drive the block to the set point, and the display shows the temperature reported by that sensor.

This is the first distinction worth making clearly. The display indicates the temperature sensed by

the internal control sensor. It does not necessarily indicate the temperature at every point in every boring where a probe might be placed. The block is a temperature source, allowing a thermometer under test to be compared against either the internal control sensor or, better still, a reference thermometer placed in the block alongside it. Assuming the displayed temperature is the temperature the probe is actually experiencing is one of the most common sources of avoidable error.

The Measurement Zone

The temperature in a dry block is not uniform from top to bottom. The block is heated or cooled through its body, the open end loses heat to the surrounding air, and the result is an axial gradient along the boring. The meaningful calibration region is the zone of known temperature homogeneity, whose position is specified, usually the lower end of the boring. Calibration is meaningful only when the sensing element of the thermometer being calibrated actually sits within that zone.

A short sensor and a long sensor placed in the same boring will experience the block differently. A thermometer can appear perfectly stable, and still read the wrong temperature, simply because its sensing element is not where the calibration assumes it to be.

Immersion, Probe Fit, and Thermal Contact

A dry block transfers heat by conduction through the block, the insert, any air gap, and into the probe. Two things govern the quality of that path: how deep the probe sits, and how well it fits.

Insufficient immersion is one of the largest and least understood sources of error in thermal calibration. Heat flows along the thermometer stem between the measurement zone and the cooler world outside, and that flow biases the temperature the sensing element reaches. A working definition is useful: a thermometer is sufficiently immersed when further immersion produces no change in the indicated temperature, within a constant environment. If raising the probe slightly changes the reading significantly, then the immersion depth is likely to be insufficient.

Fit matters for the same reason. As a practical guide, the thermometer pocket should be no more than about 0.5 mm larger than the thermometer diameter up to 660°C, and no more than about 1.0 mm above that. In practice this means choosing the closest insert that still allows safe insertion and removal, keeping borings and inserts clean, not forcing probes, and treating unusual geometries with care. Short probes, surface sensors, angled probes, and large diameter assemblies do not behave like a well fitted straight probe, and should be considered individually.

Practical issue	Likely metrology effect	Good practice response
Probe too loose in the insert	Poor thermal contact, increased uncertainty	Use a closer fitting insert
Probe not deep enough	Stem conduction error	Confirm the sensing element sits in the measurement zone
Too many probes loaded	Loading effect, altered temperature distribution	Evaluate loading, or reduce the number of probes
Reading taken too soon	Stability error	Allow adequate soak time
Relying only on the controller display	Possible offset from true zone temperature	Use a calibrated reference thermometer
Mixed probe types and diameters	Different response and conduction behavior	Treat each probe design separately

Table 1. Common dry block problems and good practice.

Stability and Stabilization or Soak Time

The controller may report that the block is at set point well before the inserted probes have reached equilibrium. Set point stability is a property of the calibrator; the time for the probe to reach stability is a property of the whole assembly, including the probe's mass, its sheath, and the quality of its fit. Larger probes, heavier sheaths, and loose inserts all take longer.

A common error is to begin recording as soon as the display reaches set point, when the indicated value may still move for some minutes. The direction of approach matters too, since arriving at the set point from below rather than from above can reveal hysteresis and thermal lag. Good practice is to wait for both reference and test readings to settle, then capture a short series of readings rather than a single value. This discipline matters most on site, where time pressure is greatest.

Why Use a Reference Thermometer?

The internal control sensor does its job, which is to help control the block. It does not represent every boring or every position perfectly, and the deviation between what it shows and what the measurement zone realizes is exactly the quantity that calibration of the block exists to establish. The more defensible arrangement compares the thermometer under test to a calibrated reference thermometer situated alongside it. Traceability is then carried by the reference thermometer and its readout, together with the method and the uncertainty budget. Returning to the opening example, a block displaying 200.00°C against a reference reading of 199.84°C should be worked from the reference value, with appropriate uncertainty.

Characterization Supports the Calibration Uncertainty

It is tempting to treat characterization and calibration as separate, or even competing, activities. This approach is unhelpful. Characterization is the evidence that makes the calibration uncertainty meaningful: a previous characterization of the device is necessary for associating the uncertainties of the calibration.

The two answer different questions. Calibration establishes the relationship between the indicated temperature, whether from the block display or a reference thermometer, and the temperature realized in a specified measurement zone, expressed as a deviation with an uncertainty. Characterization investigates the thermal behavior behind that relationship: the axial gradient along the boring, the differences between borings, the effect of loading, and the stability with time. Those results are not background detail. They are the input quantities for the uncertainty budget. Without them, a calibration can still produce a correction, but the stated uncertainty may be optimistic and poorly supported. This is why laboratories accredited to ISO/IEC 17025 are expected to summarize the axial distribution, boring differences, loading effects, and stability behind a reported result.

Element	Question it answers	How it supports the result
Axial and radial characterization	How uniform is the temperature field across the relevant borings and depths?	Provides uncertainty components for gradients and boring differences
Stability and loading checks	How much does the realized temperature change with time or probe loading?	Provides components for time stability and normal use
Comparison calibration of the thermometer under test	What correction does the thermometer under test require at each calibration point?	Combines reference value, corrections, and characterized source behavior

Table 2. How characterization supports calibration uncertainty.

Uncertainty in Plain Sight

A full uncertainty budget is beyond the scope of an introductory article, but the contributors are worth naming, because most are physical effects already discussed rather than abstract statistical terms. A comparison calibration in a dry block typically draws on the reference thermometer and its readout, the drift of that reference, the axial non-uniformity along the boring, radial or boring to boring differences, loading effects, stability with time, heat conduction along the stem, hysteresis between increasing and decreasing temperature, and the resolution and repeatability of the indicator in use.

The relative size of these terms changes with temperature, and this is where a data sheet accuracy figure can mislead. Near ambient, the budget may be dominated by the reference thermometer and the indicator, with an expanded uncertainty of a few tenths of a degree. At the upper end of the range, axial gradients and stem-conduction effects can become dominant. Depending on the block, probe, insertion geometry and method, the resulting expanded uncertainty can increase to several degrees. A headline accuracy specification does not, on its own, show how the practical uncertainty changes across the range.

A Practical Checklist

- Select a dry block suited to the temperature range and the uncertainty the task actually requires.
- For traceable low uncertainty results use a calibrated reference thermometer.
- Choose inserts that fit the probes closely, and confirm the sensing element reaches the measurement zone.
- Allow adequate stabilization and soak time before recording, judged from the probes, not the display.
- Record set point, reference reading, unit under test reading, immersion depth, insert used, and ambient conditions.
- Apply corrections where appropriate, and do not claim an uncertainty the method cannot support.

Conclusion

Used casually, a dry block can give a number that looks more certain than it is. Used carefully, with a suitable reference thermometer, attention to the measurement zone, and an honest uncertainty budget built from thermal surveys, it becomes a practical and powerful tool for traceable temperature calibration. The strengths of portability, speed, and cleanliness are genuine. The limitations are manageable, provided the user pays attention to where the sensor actually sits, how heat moves through it, and what the stated uncertainty really rests on.

Further Reading

[1] ISO/IEC 17025:2017, *General Requirements for the Competence of Testing and Calibration Laboratories.*

[2] JCGM 100:2008, *Evaluation of Measurement Data: Guide to the Expression of Uncertainty in Measurement (GUM).*

[3] EURAMET, *Calibration Guide No. 13: Guidelines on the Calibration of Temperature Block Calibrators*, Version 4.0, 2017.

[4] *Supplementary Information for the International Temperature Scale of 1990*, BIPM.

[5] J. V. Nicholas and D. R. White, *Traceable Temperatures: An Introduction to Temperature Measurement and Calibration*, 2nd ed., Wiley.

[6] J. P. Tavener, "Temperature Calibration: Depths of Immersion," *2006 Test and Measurement Conference*, available at www.isotech.co.uk

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