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.

INTERNATIONAL

**Designation: E3186 − 19**

# Standard Guide for
# Use and Testing of Dry-Block Temperature Calibrators[1]

This standard is issued under the fixed designation E3186; 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 The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.2 *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.*

1.3 This guide is intended for use with dry-block temperature calibrators without the use of fluids or thermal contact-enhancing media over a range of -100 °C to 1700 °C.

1.4 In this guide, the essential features of dry-block calibrators used for the purpose of thermometer calibration in either the direct or comparison mode are described. The direct mode is defined as using the dry-block calibrator as a standalone instrument with the control sensor and the calibrator display serving as the reference while the comparison mode uses an external sensor and ancillary measurement system as the reference.

1.5 Measurement practices to optimize the accuracy of a dry-block calibrator to obtain optimum results are proposed in this guide.

1.6 Tests that can be performed to define uncertainty limits and how they may be used in creating uncertainty budgets are proposed in this guide.

1.7 Dry-block calibrator accessories such as built-in reference thermometers, switch testing circuitry, computer communications, or current loops will not be discussed.

1.8 It is advised that liquid-in-glass thermometers not be used in dry-block calibrators, as using liquid-in-glass thermometers with a metal block may cause damage to the readout of the thermometer.

1.9 *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]

E344 Terminology Relating to Thermometry and Hydrometry

E644 Test Methods for Testing Industrial Resistance Thermometers

2.2 *Other Documents:*

JCGM 100:2008 "Evaluation of Measurement Data – Guide to the Expression of Uncertainty in Measurement", BIPM, Severes, France, 2008.[3]



## 3. Terminology

3.1 *Definitions:*

3.1.1 The definitions given in Terminology E344 shall be considered as applying to the terms used in this guide.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *axial temperature uniformity, n*—temperature differences along the immersed length of the thermometer boring under test.

3.2.1.1 *Discussion*—Axial temperature uniformity is sometimes referred to as axial temperature homogeneity.

3.2.2 *block-loading error, n*—temperature reading error as a result of temperature uniformity profile in the block changes with the number and size of thermometers in the block.

3.2.3 *boring, n*—machined hole in the dry block that can accommodate various sizes of thermometers and removable sleeves.

3.2.3.1 *Discussion*—These are also referred to as wells.

3.2.4 *hysteresis, n*—property of a device or instrument whereby it gives different output values in relation to its input values depending upon the directional sequence in which the thermal input values have been applied.

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[1] This test method is under the jurisdiction of ASTM Committee E20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.07 on Fundamentals in Thermometry.

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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] Availible for download from http://www.bipm.org.

3.2.4.1 *Discussion*—In practice hysteresis it is typically defined as the absolute value of the difference between the temperatures at the same set point arrived at from the two directions. Hysteresis is typically largest at the midpoint between maximum and minimum temperature scans.

3.2.5 *measurement zone, n*—zone in the thermal boring corresponding to the location of the sensitive element of the temperature probe.

3.2.5.1 *Discussion*—The zone may be long enough to cover a range of typical sensors calibrated or used as reference thermometers.

3.2.6 *radial temperature uniformity, n*—temperature differences between borings in the isothermal block or a removable sleeve that is inserted into the block.

3.2.6.1 *Discussion*—Radial temperature uniformity is sometimes referred to as temperature differences between the borings.

3.2.7 *sleeves, n*—removable inserts that can be inserted into dry block borings to improve thermal contact and reduce thermal gradient errors.

3.2.7.1 *Discussion*—They may also be referred to as adapter sleeves.

3.2.7.2 *Discussion*—Sleeves may be made of metal or ceramic.

3.2.8 *stem conduction, n*—errors created as a result of heat conducting up the thermometer stem.

3.2.8.1 *Discussion*—This is largely a property of the thermometer itself but is influenced by the immersion depth available on the thermometer and the clearance between the thermometer and the boring.

3.2.8.2 *Discussion*—It is also known as conduction error.

3.2.9 *temperature stability, n*—temperature variations in the block as a result of the temperature control function.

3.2.9.1 *Discussion*—Stability can also be influenced by external changes in ambient temperature, drafts, and line voltage fluctuations.

## 4. Summary of Practice

4.1 This guide describes the practices and procedures that will enable the user to evaluate various dry-block calibrator capabilities, test for and evaluate various uncertainties, and create a user-defined uncertainty budget.

## 5. Significance and Use

5.1 This guide applies to temperature sources with controlled temperature solid blocks. They are known under various names such as dry-well calibrators, dry-block calibrators, and temperature block calibrators. They are typically comprised of solid block materials such as metal or ceramic, a temperature-regulating device, a control sensor, and some built-in indicator of temperature in a portable package. Dry-block calibrators are commonly used for calibration of industrial thermometers. These calibrators are commonly used in either two modes: (1) the direct mode in which the calibrator is used as the calibrated reference, or (2) comparison mode in which the calibrator is an isothermal temperature source for comparing thermometers under test to a separate calibrated reference thermometer. The uncertainty of these calibrations is dependent on which of these two modes is used and a variety of thermal properties of the specific dry-block designs.

5.2 A thermally uniform, stable, and accurate temperature zone for calibration may be achieved with given measurement uncertainty. Various thermal properties of dry-block calibrator blocks have been identified that shall be characterized and/or quantified to determine uncertainty of measurements and care taken during the calibration process to optimize results appropriately. Temperature stability has been long recognized as a variable to be characterized. Others include axial temperature uniformity, radial temperature uniformity, stem conduction, block loading, hysteresis, and controller accuracy. External factors that influence results include ambient temperature, drafts, and power fluctuations. Recognizing and testing these properties will greatly improve calibration results.

## 6. Apparatus

6.1 A dry-block calibrator system is a controlled temperature system typically comprised of solid block materials such as metal or ceramic, a temperature-regulating device, a control sensor, and some built-in indicator of temperature in a portable package. When used in comparison mode, the system also includes a calibrated reference thermometer.

6.2 An example of a dry-block calibrator is shown in Fig. 1. This is an example of a system that is operating in the comparison mode, as the reference thermometer is providing traceability to the SI. The key features shown in this figure will be discussed throughout this standard. The term UUT refers to the unit under test.



6.3 The mechanical design of the dry-block calibrator and the materials used in the construction determine the limits of the working temperature range as well as the overall stability and uniformity of the dry-block calibrator system. A poorly designed calibrator will not provide the desired level of uncertainty needed for precision calibration. However, the performance of a marginal unit may be improved to acceptable levels of uncertainty by the use of sleeves to improve thermal contact and reduce errors due to radiation or convection.

6.4 Thermal insulation at the entrance to the boring may influence both axial uniformity and stem conduction. This is due to the flow of heat in the block and the stem in the vertical direction. Axial temperature uniformity is discussed more in depth in 8.6. Stem conduction is covered in 8.7.

6.5 Proper fit between the probe under test and the dry-block borings is essential. Too loose of a fit means that there will be poor thermal contact between the probe under test and the dry- block. Too tight of a fit may mean the probe may get either damaged or permanently stuck inside the dry block boring. Great care must be used when selecting the proper size boring for a specific probe.

## 7. Procedure

7.1 *Minimum Immersion Length:*

7.1.1 The immersion length for a probe greatly influences the stem conduction uncertainty. Stem conduction applies both to the reference thermometer and the UUT. Tests shall be done

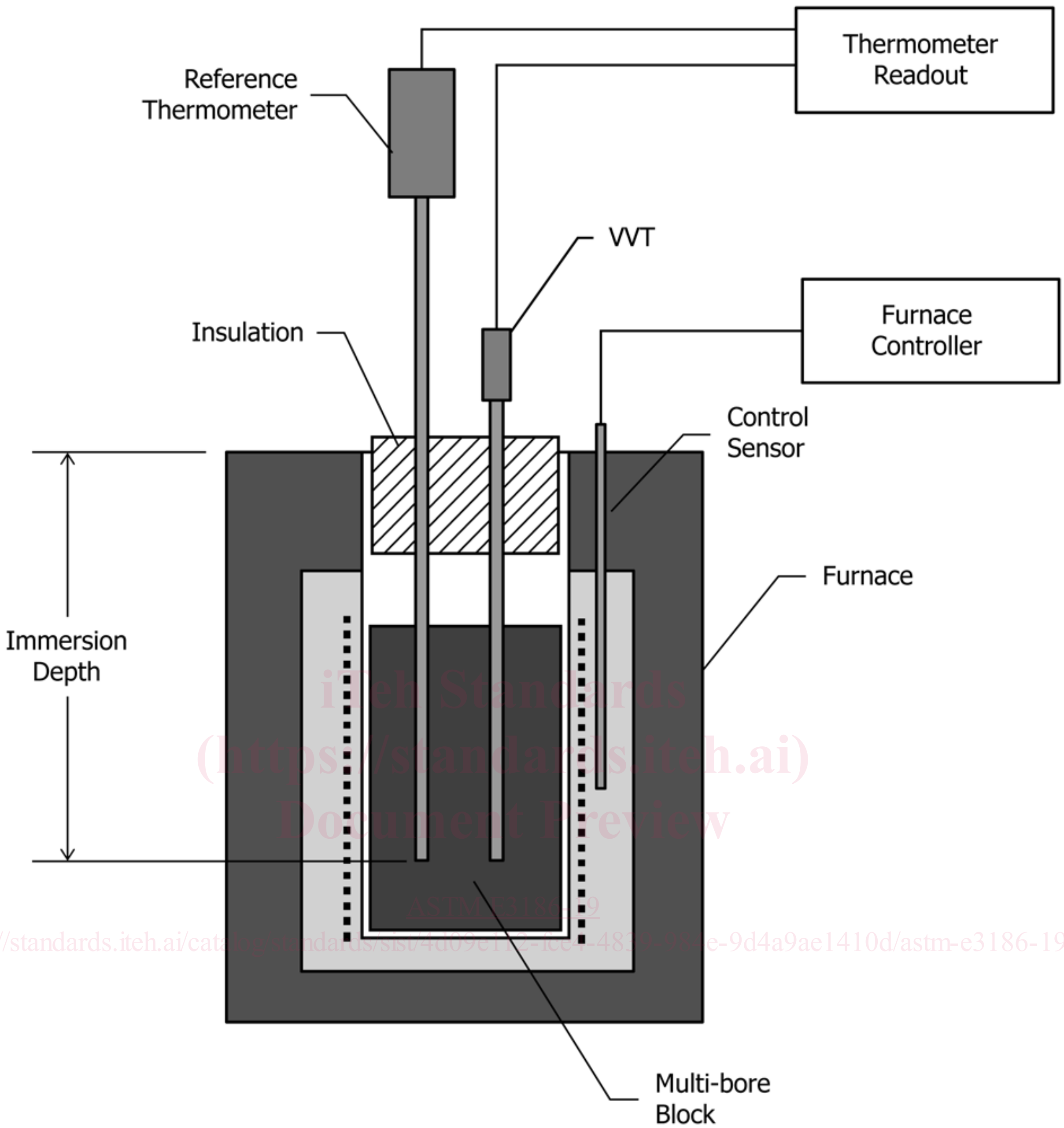



FIG. 1 Example of a Dry-block Calibrator System



for each family of probes that is used in the dry-block calibrator to determine a minimum immersion length and to determine stem-conduction uncertainty. A family of sensors may be distinguished by the outside diameter of the sheath, the sensor length, the sheath thickness and the materials used for the sheath, insulators and lead wires.

7.1.2 *Minimum Immersion Length Test:*

7.1.2.1 Insert the test thermometer into the ice-point bath until no further insertion causes significant change in output. This insertion may include the mounting flange, threads, etc. The purpose of this requirement is to maximize heat transfer between the upper part of the thermometer and the bath so that the stem conduction error is negligible.

7.1.2.2 Use normal operating current (typically 1 mA) if specified. Otherwise, use an operating current which results in no significant self-heating, Record the readout of the test thermometer when equilibrium is reached.

7.1.2.3 Slowly withdraw the thermometer from the bath in small increments until the readout increases equivalent to the specified measured uncertainty. Pause long enough after each incremental change in immersion depth to assure thermal equilibrium is reached.

7.1.2.4 The ice-point bath and dry well have different heat transfer characteristics. The minimum immersion length determined using the E644[4] ice-bath method described above will likely under estimate the length required for the dry-well. The ice-bath method is still useful as a relative measure. This is especially important for direct mode when the reference thermometer and UUT have different thermal cross sections.

## 8. Measurement Uncertainty

8.1 *Overview:*

8.1.1 While it is beyond the scope of this document to provide tests and methods to determine each element of the uncertainty budget, the format shown here should provide a basic framework for uncertainty budget calculations. Any calculations of measurement uncertainty should follow local uncertainty budget calculation guidelines such as the “Evaluation of Measurement Data – Guide to the Expression of Uncertainty in Measurement.”

8.1.2 The uncertainties as presented in this guide are listed in Tables X1.1 and X1.2. Application of these uncertainties to the direct calibration scheme is reported in Table X1.1. Application of these uncertainties to the comparison calibration scheme is reported in Table X1.2

8.2 *Electronic Measurement:*

8.2.1 This is the contribution in uncertainty caused by the thermometer readout and electrical noise in the system. It takes into the account the noise from the readout, the noise from the probes, and the calibration of the readout.

8.2.2 For the direct calibration scheme, this uncertainty applies only to the measurement of the UUT.

8.2.3 For the comparison calibration scheme, this method applies to both the reference probe and the UUT. In other words, these two uncertainties shall be considered and combined to estimate the electronic measurement uncertainty.

8.3 *Reference Thermometer Calibration Uncertainty and Reference Thermometer Drift Uncertainty:*

8.3.1 This uncertainty only applies to the comparison calibration scheme. This is the contribution of uncertainty caused by the reference thermometry. This uncertainty has two components. The first comes from the thermometer’s uncertainty from its calibration. The second comes from the long-term stability of the reference probe. Drift of temperature sensors is discussed more in 8.12.

8.4 *Dry-Block Calibration Uncertainty and dry-block drift Uncertainty:*

8.4.1 This uncertainty only applies to the direct calibration scheme. This is the contribution of uncertainty caused by the dry block’s calibration. This uncertainty has two components. The first comes from the dry block’s uncertainty from its calibration. The second comes from the long term stability of the dry-block. Drift of temperature sensors is discussed more in 8.12.

8.5 *Display Resolution Uncertainty:*

8.5.1 Display resolution uncertainty is specific to the direct calibration scheme. This is the contribution due to quantization error of the thermometer readout.

8.5.2 To calculate display resolution uncertainty, take the display resolution and divide by two. This result has a rectangular distribution. Use standard practice to determine the expanded uncertainty of a rectangular distribution. For example, if a thermometer has a display resolution of 0.1 °C, then the rectangular distribution is ±0.05 °C and the expanded uncertainty is 0.058 °C with a coverage factor of 2 ($k = 2$).

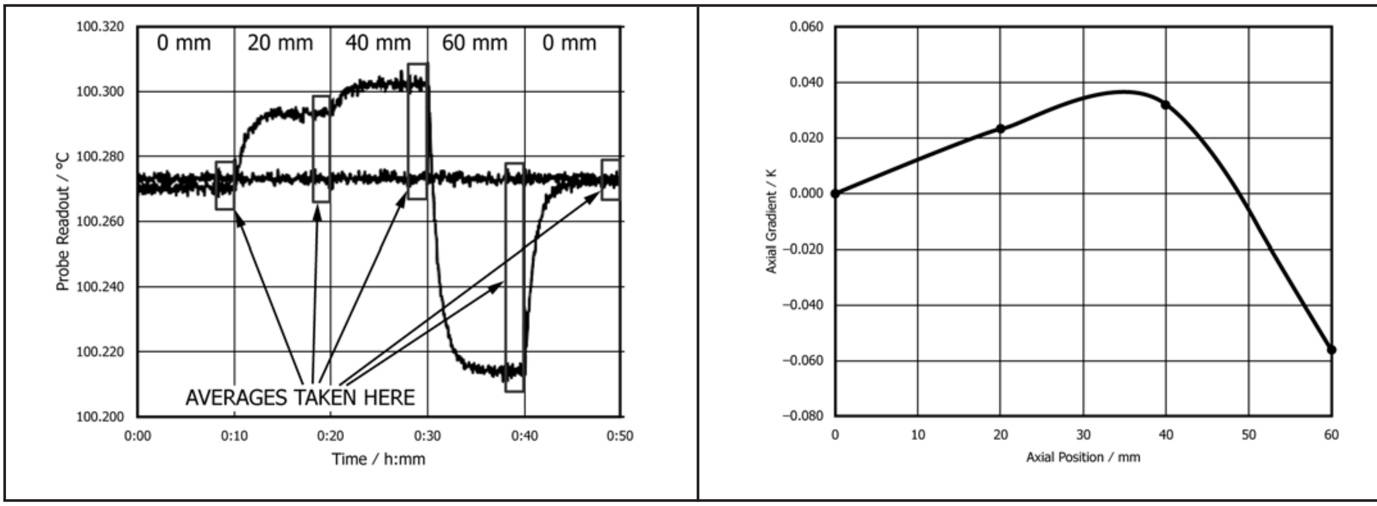
8.6 *Axial Temperature Uniformity:*

8.6.1 These errors are the result of a gradient along the length of the thermometer boring of the block or adapter sleeve. This temperature gradient will inadvertently cause different temperatures to be measured when calibrating thermometers with different length sensors or immersion depths. The greatest temperature difference in the measurement zone is measured with a specifically designed thermometer using a readout with sufficient resolution and stability to provide the desired data. Measurements are made starting with the gradient thermometer immersed to the greatest depth of the boring and withdrawing it in regular increments. Increments of 20 mm are usually adequate. Immersion depths should be accurate to 1 mm. Each measurement should be taken when the block temperature has settled reestablishing the temperature equilibrium and stability within the boring. The immersion depths measured should represent those anticipated to be covered by the sensitive lengths of the thermometers to be calibrated. Some thermometers may have sensors nearly 60 mm in length. Therefore, it is recommended to measure temperatures at the bottom or 0, 20, 40, and 60 mm then back to 0 mm to verify that the temperature in the boring has not drifted. Axial uniformity is typically worse at the limits of the temperature range. Measurements at the lower, midpoint, and upper end of the calibrator’s temperature range are recommended. Heavily loading the boring may also influence the uniformity adversely. Even more accurate results can be obtained by simultaneously using a reference thermometer in addition to the gradient measurement thermometer. The reference thermometer remains at the bottom of one boring while the gradient thermometer is moved up and down in another boring. The difference between the two readings will provide the desired gradient data without the fluctuations caused by phenomena such as instabilities from the controller and drift. Refer to Fig. 2a. Separately plotting the data from the average values referred to in Fig. 2a establishes the gradient profile curve. This curve should be smooth and regular. Poor fit is often the result of not compensating for instability of the block. Careful use of this second technique while making accurate immersion depth measurements will provide smooth regular gradient profile curves, which is a good check of the gradient measurement. See Fig. 2b.

8.6.2 *Design Consideration for Axial Gradient Probes*—The gradient thermometer shall be one with a very short sensor length in order to detect changes in gradiant over a small distance. A maximum sensor length of 5 mm is recommended to establish a value for small sensor lengths and thermometer designs. The stem conduction of the probe shall be minimal. A



[4] ASTM E644 Test Methods for Testing Industrial Resistance Thermometers.




a b

FIG. 2 Axial Gradient Data

maximum diameter of 6.35 mm is recommended with smaller diameters helping to reduce stem conduction. The sensor for the design may be a platinum resistance thermometer (PRT), thermistor, or thermocouple with an adequate temperature range to cover the calibration range. Thermocouples are subject to inhomogeneity errors. If a thermocouple is used, it is recommended to use a new thermocouple. For greater sensitivity it is recommended that where practical PRTs, rather than thermocouples, be used. The stability of the thermometer is not critical as long as it is sufficiently stable over the duration of the test to make an accurate temperature difference measurement.

8.6.3 Normally the maximum uncertainty from the axial temperature uniformity measurement will be used for establishing total uncertainty. However, in some cases, the uncertainty may be reduced.

8.6.4 The best calibration results will be achieved when the thermal characteristics including physical size of the reference thermometer and UUT are identical. It is assumed that the sensing element in a thermometer integrates the effect of the gradient profile over its effective length. As such, the temperature measured by two different probes immersed into the boring may be different. The temperature error as a result of gradient profiles over specific length sensors can be estimated by integrating the gradient profile over each sensor length desired. In this example, a known profile was integrated over the two sensor lengths of interest. Error deviations at their centers were determined and their differences calculated to establish a smaller uncertainty. In the case of comparing thermometers with the same sensing element length, the error caused by axial non-uniformity would be zero since they are exposed to the same integrated temperature value.

8.6.5 In the estimate described here, some allowance in the estimate described here shall be made for uncertainties in the location and length of the sensing element.

8.6.6 Calibrations typically take place with the thermometers under test inserted to the greatest depth of the boring. However, sensors with widely different sensor lengths or large axial gradient errors or both may benefit from insertions that align the centers of the sensitive portions. This is only of benefit if the location and length of the sensors are known with some degree of accuracy. In the case that the calibrator itself has been calibrated and is serving as the reference, the center of the reference thermometer is not that of the control sensor but the center location of the sensor with which the dry block was calibrated.



8.7 *Radial Temperature Uniformity:*

8.7.1 These errors result from temperature gradients between multiple borings as a result of hot or cold variations in the block or sleeve. This error is strongly influenced by the difference between the block and ambient temperatures. The larger the temperature difference, the larger the potential gradient. Immersion depth of the sensor into the heated zone of the device should be at a minimum of 10 cm (4 inches) to mitigate this influence. Measuring the radial gradient requires stable thermometers and readout instruments. Secondary level standard thermometers or standard platinum resistance thermometers (SPRTs) work best. The test shall be performed with boring diameters that match the thermometers to be used. In its simplest form, the measurement may be made by moving a single thermometer from boring to boring. With this method of study, the level of control stability of the heated bore over time is critical to reduce influence of temperature cycling. The calibrator shall be allowed to re-stabilize each time before the temperature is read. A more precise approach is to use two thermometers. One thermometer is used as a reference thermometer leaving it in the same boring for the duration of the test. The second thermometer is moved from boring to boring, allowing the calibrator to stabilize at each location sufficiently. If it is not safe due to temperature levels, or there are risks of damaging the thermometry probes used for the test, the study should be performed by evaluating each temperature level while left in the boring under study. Once the sensor is cooled to a safe point to relocate, it may be transferred to the next boring in the study. Calibrators with a large number of borings should have at least three borings measured in as uniformly distributed a pattern as possible. At a minimum the low, mid, and maximum temperature levels for the device's operating range should be evaluated.

8.7.2 *Data Collection and Analysis:*

8.7.2.1 Once the data output has shown it has stabilized, an average of the readings over the stable time period should be recorded for each sensor. It is recommended averaging a minimum of 30 points over a minimum time period of 1 min.

8.7.2.2 Since the ASTM method for calibration is a comparison method, the exact temperature of the calibration device is not critical, but rather it is a relative value. What is critical is the true temperature of the second probe as compared to the fixed located sensor, stability of the device, and the uniformity. In the example in the chart below it would appear that Bore 3 has a negative skew relative to the average of Bores 1 and 2. Looking more carefully, Bore 2 actually has the largest variance for uniformity at twice the standard deviation of Bores 1 and 3 as the readings of the two sensors are compared. In this example, there is an unknown influence that is resulting in lower actual temperature of the device at the same set point at the time the study was performed on Bore 3. Since the mean shift affects the results of both sensors equally, it does not indicate that there is any affect of stability or uniformity when comparing the sensor readings.

8.7.3 For calibrators having fewer than four borings, it may be necessary to determine differences by cyclic exchange. The average difference between two borings with two thermometers may be determined with Eq 1.

$$\Delta T_{avg} = \frac{(T_{P1B1} - T_{P1B2}) + (T_{P2B1} - T_{P2B2})}{2} \quad (1)$$

where:

$\Delta T_{avg}$ = average difference between borings,
$T_{P1B1}$ = readout temperature of Probe 1 in Boring 1,
$T_{P1B2}$ = readout temperature of Probe 1 in Boring 2,
$T_{P2B1}$ = readout temperature of Probe 2 in Boring 1, and
$T_{P2B2}$ = readout temperature of Probe 2 in Boring 2.

8.8 *Temperature Stability:*

8.8.1 Stability is the measure of the temperature deviations over the measured period of time. The indicated stability depends on the thermal time response of the thermometers and sampling frequency. In practice, the influence of instability may be minimized by averaging over a period of time. Temperature stability may vary at different temperatures. Specific temperatures of interest by the user should be incorporated.

8.8.2 *Calculating Stability Uncertainty:*

8.8.2.1 First, subtract the value of the secondary probe from the value of the primary probe for all of the selected points for each bore. Take the standard deviation of the difference from the primary to the secondary for all bore readings and multiply by 2 for a 95.4% confidence level. In the above example, the standard deviation for the reported difference of the 90 readings is 0.024 K which results in 0.048 K reported uncertainty.

8.8.2.2 This analysis method actually shows the impact of the radial variance (uniformity) as the amount of observed variance changes from boring to boring which will impact the standard deviation result. In addition, the long term stability will also impact the standard deviation. This also means the error amount increases when a different rate of response in a boring exists which will increase the uncertainty.

8.8.3 *Measurement Noise:*

8.8.3.1 Additional uncertainty budget values of measurement noise may also be obtained from this data. Measurement noise may include influences such as lead wires, connectors, and system noise. The measurement noise uncertainty should be assessed independently in the laboratory's budget for the reference and UUT.

8.8.3.2 As an example, considering a calculation of noise based on the data in Fig. 3, first calculate the standard deviation for each individual boring temperature reading. Then take the average of those standard deviations and multiply by 2 for a 95.4% confidence level. In our example from Fig. 3, Eq 2 would show the noise for the fixed sensor.