1. Objective

1.1. The purpose of this document is to clearly define acceptance criteria for thermometers for AASHTO Accreditation purposes and to define thermometer calibration and standardization requirements.

1.2. The type of thermometer required is dependent upon the application for which the thermometer is used. The individual test method requirements must be understood before selecting an appropriate thermometer.

2. Terminology

2.1. *Accuracy, n*- how close the indication of the thermometer is to the "true" value.

2.2. *Measurement uncertainty, n*- a numerical representation of the dispersion of values attributed to a measured quantity.

2.3. *Calibration, n*- the process of determining the estimated measurement uncertainty and comparing the measured values of a thermometer to the values assigned to the reference thermometer.

2.4. *Standardization, n*- the process of comparing the measured values of a thermometer to the values assigned to the reference thermometer.

2.5. *Measurement Error (Bias), n*- the difference between the measured value of the test thermometer and the reference thermometer.

2.6. *Test Uncertainty Ratio (TUR), n*- the comparison between the tolerance requirement of the test method and the estimated calibration uncertainty of the reference thermometer.

Discussion: "Tolerance" is often identified as accuracy in many ASTM and AASHTO standards. The accuracy of the test thermometer will be the tolerance in most cases.

2.7. *Reference Thermometer*- High accuracy thermometers that are ideal for checking the accuracy of temperature testing equipment, such as other thermometers, dataloggers, ovens, etc.

Note 1 — Visit the Bureau International des Poids et Mesures International Vocabulary of Metrology (BIPM VIM) for more information: www.bipmg.org/en/publications/guides/vim.html

3. General Requirements

3.1. For laboratories that are using digital thermometers, AASHTO re:source will be looking for documentation from the manufacturer to determine the type of digital device that is being used (thermocouple, platinum resistance thermometer (PRT), thermistor). If the type of digital

thermometer cannot be determined, it will be deemed unacceptable until documentation can be provided showing the type of thermometer.

Note 2—Various types of digital thermometers are described in ASTM E2877.

3.2. AASHTO re:source will use the information contained in the following tables to qualify the manufacturer's accuracy claim and measurement uncertainty statements on the calibration reports of thermometers. Table 1 lists the values attainable by the National Institute of Standards and Technology (NIST), as published in the Bureau International des Poids et Mesures (BIPM) Key Comparison Database (KCDB), as the absolute best estimated measurement uncertainty (EMU) achievable for these devices. Table 2 lists the values attainable by NIST for base-metal thermocouple (Types K and N) calibrations at different temperatures, as published in NIST IR 5340. AASHTO re:source will use the measurement uncertainty listed in the tables below or the measurement uncertainty listed on the most recent calibration record, whichever is higher in value, for this determination.

Note 3- Laboratories are urged to use caution when reviewing statements of accuracy supplied by equipment manufacturers. These estimates may be unrealistic, and several important factors have been found not to be used in developing these estimates.

Table 1- BIPM Key Comparison Database Values

Type of Device	Measurement Uncertainty
Industrial Platinum Resistance Thermometers (IPRTs), ASTM E1137	0.0023°C
Film-Type Industrial Platinum Resistance Thermometers	0.01°C
Thermistors	0.0018°C
Thermocouples, Type B	0.3°C
Thermocouples, Type E	0.9°C
Thermocouples, Type J	0.7°C
Thermocouples, Type K*	1°C
Thermocouples, Type N*	1°C
Thermocouples, Type R	0.13°C
Thermocouples, Type S	0.13°C
Thermocouples, Type T	0.4°C
Liquid-in-Glass Thermometer, Hg, Partial, 0.1°C graduations	0.02°C

* 1°C was determined for temperatures up to 1000°C. See table 2 for more specific values.

Table 2- NIST IR 5340 Values for Type K and N Thermocouples

Temperature (°C)	Measurement Uncertainty
-200	0.4°C
-100	0.2°C
0	0.02°C
100	0.1°C
200	0.2°C
300	0.3°C
400	0.4°C
419.58 (Zn)	0.4°C
500	0.5°C

3.3. Thermistors will only be accepted for use within the range of -50 to 120°C, regardless of what is listed in the manufacturer's specifications.

4. Reference Thermometers

4.1. *Reference Thermometer Policy*

4.2. AASHTO re:source considers a reference thermometer to be a thermometer of suitable range, accuracy, and resolution that is calibrated and traceable to the International System of Units (SI) by an entity accredited to ISO/IEC 17025, with measurement uncertainty appropriate for the application. The reference thermometer is used to calibrate or standardize other thermometers that are used for daily testing by a laboratory.

4.3. If a laboratory does not possess their own reference thermometer(s), the laboratory shall select a calibration agency that has had its reference thermometer(s) calibrated by an ISO/IEC 17025 accredited calibration agency.

4.4. AASHTO R 18 requires laboratory-owned reference thermometers to be calibrated by an ISO/IEC 17025 accredited calibration agency that is accredited for thermodynamic calibrations. The laboratory shall confirm with the calibration agency, as part of contract review, that the calibration agency will be able to provide measurement uncertainty that is appropriately small enough to support the accuracy required by the standard test methods the laboratory performs. See Section 4.10.1. of this document for more information on the measurement uncertainty requirements for reference thermometers.

4.5. Reference thermometers shall be mercury-in-glass, thermistors such as those meeting the requirements of ASTM E879, platinum resistance thermometers (PRTs) meeting the requirements of ASTM E1137, or thermocouples meeting the requirements of ASTM E2181. The selection of the thermometer depends on the accuracy required in the test methods performed by the laboratory and the range of use.

4.6. Sprit-filled thermometers shall not be used as reference thermometers as they are not addressed by the KCDB and are known to have issues with evaporation, condensation, and separation of the liquid column.

4.7. For laboratories using in-house reference thermometers with questionable accuracy claims, the laboratory will be informed that they must replace these devices, and the laboratory will be provided with a deadline for replacement. See the scenarios in Section 7 for more information about reasonable timeframes.

4.8. The reference thermometer(s) utilized must encompass the range of temperatures used in the testing laboratory.

4.9. The readability of the reference thermometer must be the same as, or preferably better than, the testing thermometer that is being standardized or calibrated.

Example: A thermometer with a readability of 0.1° C cannot be used to calibrate or standardize a thermometer with a readability of 0.01°C with any confidence in its full readability. See ASTM E1 for more information on the readability of liquid-in-glass thermometers.

4.10. A reference thermometer calibration record shall state an estimated measurement uncertainty that is appropriate for its intended use.

4.10.1. If a test uncertainty ratio (TUR) has not been established in the test standard, the readings of reference thermometers used to standardize or calibrate working thermometers shall have estimated measurement uncertainties that are less than or equal to one-half (TUR of 2:1) the accuracy required of the working thermometers.

Example: If the most stringent requirement for accuracy in a test method performed by the laboratory specifies a 0.5°C accuracy for the working thermometer, the reference thermometer used to standardize that working thermometer must show an estimated measurement uncertainty no larger than 0.25°C.

4.10.2. If the accuracy requirement listed in a test method is unrealistically stringent, AASHTO re:source may decide to accept a reference thermometer with a TUR that is less than 2:1

4.11. Laboratories shall not use the reference thermometer as a testing thermometer. When the thermometer starts to be used regularly, the error involved in potential misuse increases greatly. That error would be transferred to every test in which the working thermometer is used.

4.12. Unless the test standard specifies otherwise, it is acceptable to use a standardized working thermometer for standardizing ovens and volume determinations (molds, unit weight buckets, specific gravity flasks, etc.).

4.13. *Reference Thermometer Selection*

4.13.1. For selection of the proper reference thermometer used to standardize working thermometers, multiply the estimated measurement uncertainty value on the reference thermometer's calibration record by 2. If that value is less than the accuracy required by the test method, the reference thermometer is acceptable for use.

4.13.2. There are situations where laboratories are using liquid-in-glass thermometers for reference and testing, and one reads in °C and the other reads in °F. If the reference thermometer is only readable and calibrated in °C, and the working thermometer is only readable to °F, the laboratory can convert the units mathematically.

5. Calibration and Standardization Requirements

5.1. *Reference Thermometer Calibration Policy*

5.2. Frequency: Reference thermometers shall be calibrated (not standardized) at least every 3 years or as required by the test method or specification in which it is used, whichever interval is smaller, and if there is doubt about the accuracy of measurement.

Example: ASTM C1064 states that the reference thermometer must be calibrated every year. If the laboratory is accredited for ASTM C1064 and uses that reference thermometer for all calibrations and standardizations, it must be calibrated every year.

5.3. Mercury-in-glass thermometers can be calibrated once (if the EMU is clearly stated on the calibration record) followed by ice-point verifications using ASTM E563 and guidance from NIST SP-1088. If the ice point verification reveals that the ice point varies by more than the maximum allowable scale error identified in ASTM E1, or the allowable error listed in the standard or specification in which the thermometer is used, the thermometer will need to be replaced.

5.4. Measurement Uncertainty: The calibration records presented shall clearly indicate the estimated measurement uncertainties at the range of measurement in which the thermometer is used.

5.5. *Calibration and Standardization Policy for Both Working and Reference Thermometers*

5.5.1. The calibration or standardization of a digital thermometer must be performed with the central processing unit (readout device) and the probe (sensor) as one unit. The records presented shall indicate the measurements were taken using the probe and meter together.

5.5.2. Method: The calibration or standardization of a thermometer must be performed by a thermodynamic method (fixed point or comparison). A calibration performed by comparison must be performed using either a dry block or a stirred liquid bath in accordance with ASTM E77 or E644. Calibrations performed by electrical means, such as comparing the thermometer readout to resistors, or use of an electronic calibrator that simulates temperature output through electrical resistance, will not be accepted.

5.5.3. The accreditation certificate of the calibration provider must be reviewed closely by the testing laboratory before hiring them to perform calibrations to ensure that the agency is capable of providing a thermodynamic calibration. There are accredited calibration agencies that exist that are accredited only for performing temperature calibrations by electrical simulation, which is not acceptable for AASHTO accreditation.

Note 4– If the record shows readings at extremely high or low temperatures (ex. 600°C), this is a sign that the calibration was performed by electrical means.

5.5.4. Number of Calibration or Standardization Points: The number of calibration or standardization points depends on the type of thermometer and the way it is used. The requirements below are presented to give guidance to the agency who will be calibrating or standardizing your thermometers.

5.5.4.1. If any thermometer is only being used to measure temperatures at one point, the thermometer can be calibrated or standardized at that point (within 5℃ (10℉)). If two or more points are included, the point at which the working thermometer is used must be within 20 °C of one of the calibration or standardization points.

5.5.4.2. If the thermometer is read over a wide range of more than two temperatures, the thermometer shall be calibrated or standardized accordingly based on the type of thermometer:

5.5.4.3. Liquid-in-glass thermometers must be calibrated or standardized at a minimum of two points bracketing the range of use. If E77 is required by the standard in which the thermometer is used, there shall be no more than 100 scale divisions between the test points.

Example: If the thermometer has a range of -1 to 51°C in 0.1 divisions (a common reference thermometer), and it will be used across a range from 4 degrees to 37 degrees, it needs to be calibrated or standardized at 0, 10, 20, 30 and 40°C to include all the required points per scale divisions.

5.5.4.4. Thermistors must be calibrated or standardized every 20°C throughout and bracketing the range of use. This is because thermistors have an inverse and non-linear thermal coefficient of expansion of the resistor.

5.5.4.5. Platinum resistance thermometers must be calibrated or standardized at a minimum of two points bracketing the range of use. For ranges over 100 °C, at least 3 test points shall be included.

5.5.4.6. Thermocouples must be calibrated or standardized at a minimum of two points bracketing the range of use. For ranges over 100 °C, at least 3 test points shall be included.

5.5.5. Systematic Error (bias): The calibration or standardization records presented shall clearly indicate the error or correction of the measurements of the thermometer being calibrated or standardized at each point along with a statement of acceptance or rejection based on criteria of conformance (usually identified as tolerance or acceptance limit, which is based on accuracy requirements). The test methods may include the proper acceptance criteria for the calibration or standardization. This information needs to be conveyed to the calibration agency for proper delivery of services.

5.5.6. Expanded Measurement Uncertainty: If the working thermometer has been calibrated or standardized by a calibration agency, the laboratory shall confirm with the calibration agency that the reference thermometer has a TUR of at least 2:1.

Example: If the test method specifies a 0.5°C accuracy for the working thermometer, the reference thermometer's calibration record shall show an expanded measurement uncertainty of 0.25°C or smaller.

6. Working Thermometers

6.1. *Working Thermometer Policy*

6.2. Many test methods include requirements for thermometers. Laboratories can standardize their testing thermometers using their own reference thermometers and internal procedures as long as the reference thermometers conform to the requirements of the test methods and this document.

6.3. There may be some test methods that require the working thermometers to include calibrations with estimated measurement uncertainties stated. For those thermometers, the laboratory shall determine their own uncertainty budgets or have the device calibrated externally by a qualified calibration agency that documents its measurement uncertainties on the calibration records.

6.4. Thermometers that may be accepted as working thermometers depending upon the specific requirements in the test method include: Liquid-in-glass thermometers, bi-metallic thermometers, thermistors such as those meeting the requirements of ASTM E879, platinum resistance thermometers (PRTs) meeting the requirements of E1137, and thermocouples meeting the requirements of ASTM E2181 or ASTM E230.

6.4.1. Infrared thermometers will not be accepted as working thermometers unless specifically allowed by a test standard, practice, or specification.

6.4.2. The accuracy of the working thermometer must be equal or less than the accuracy required by the test method. If the working thermometer has been calibrated, the estimated measurement uncertainty shall be equal or less than the accuracy required by the test method.

6.4.3. Systematic Error (bias)- If during the calibration or standardization process, the systematic error (bias) exceeds the accuracy requirement of the test method, the laboratory must offset the bias by applying a correction.

Example: If during standardization or calibration, a working thermometer used for a test method that has an accuracy requirement of 0.5 °C reads 25.6°C and the reference thermometer reads 25.0 °C, the bias should be offset by applying a correction of -0.6°C to the readings of the working thermometer.

6.5. *Working Thermometer Selection Guidance*

6.5.1. To determine whether a thermometer is acceptable for use for a test method, use the following procedure:

6.5.2. Review the measurement uncertainty tables in Section 3.2 for the type of working thermometer being used. Make sure that the measurement uncertainty for the type of thermometer being used does not exceed the accuracy requirement in the test method.

6.5.3. Determine the accuracy requirement of the working thermometer. This is often listed in the test method, specification, or procedure. Make sure that the manufacturer or vendor lists an

accuracy for the thermometer that is no less than this value at the testing range required for the laboratory.

6.5.4. Many test methods include an accuracy requirement for the thermometer(s) listed. These accuracy statements will be the basis for the selection of the working thermometer. However, it is unclear in some cases if the author of the standard intended the word "accuracy" to mean trueness, maximum scale error, or readability. It is also unclear if measurement uncertainty or equipment capabilities were considered. In these cases, AASHTO re:source will attempt to provide guidance to the laboratories based on the most reliable information available.

6.5.5. AASHTO re:source will not require estimates of measurement uncertainty for working thermometers unless a test procedure, practice, or specification specifically requires it. However, AASHTO re:source reserves the right to reject a laboratory's working thermometer if it is deemed not to be fit for purpose. If a laboratory decides to appeal this decision, they shall have the device calibrated by an ISO/IEC 17025-accredited calibration agency and have the measurement uncertainty of the thermometer determined to prove it is fit for purpose.

7. AASHTO Accreditation Program Scenarios

7.1. The following common scenarios are being presented for the purpose of showing how this thermometer policy is being implemented. Almost all situations are addressed using the normal corrective action resolution deadline, but when there are changes or commonly misunderstood areas, additional time may be provided if there is not a significant risk to the reliability of testing by the laboratory because of this issue.

7.1.1. A laboratory had their reference thermometer calibrated incorrectly by a calibration agency. If this situation cannot reasonably be resolved by the stated deadline in the accreditation file, the laboratory is permitted to have a 30-day continuation for recalibration if they submitted a plan of action.

7.1.2. A reference thermometer issue was discovered during a corrective action review from a separate finding. If this situation cannot reasonably be resolved by the stated deadline in the accreditation file, the laboratory is permitted to have additional time to resolve the issue, if approved by the AASHTO Accreditation Program with a plan of action over a reasonable timeframe.

7.1.3. A third-party provided standardization or calibration services without providing adequate documentation. If this situation cannot reasonably be resolved by the stated deadline in the accreditation file, the laboratory is permitted to have additional time to resolve the issue, if approved by the AASHTO Accreditation Program with a plan of action over a reasonable timeframe.

7.1.4. The laboratory was using an unsuitable thermometer as a reference device, and they stated that they are no longer calibrating/standardizing their own thermometers. The laboratory shall present an updated equipment table and procedures showing that an external agency will now be used and submit new standardization records for their thermometers.

8. Frequently Asked Questions

8.1. How do I know if my thermometer is a PRT, thermistor, or something else? Check the user manual or consult with your vendor. If they are not sure, it is best to look elsewhere.

8.2. I have a certificate from the manufacturer with measured data and uncertainty measurements? Is this acceptable? It might be acceptable, but often the stated estimate of measurement uncertainty may be unrealistic. Sometimes, calibration agencies or vendors will list the estimated measurement uncertainty for their reference equipment on the calibration record rather than the estimated measurement uncertainty for the thermometer you have just purchased. You may want to ask your calibration provider if the Unit Under Test (UUT) was considered in developing the measurement uncertainty estimate.

8.3. We just throw out our working thermometers and buy new ones every year. Can I still do that? You could, but we don't advise that practice since it is wasteful. Before you throw the next ones out, read over this guide to see if you can get a proper reference thermometer and perform your own standardizations from now on.

8.4. We get all our thermometers calibrated by an external agency. Do we need to do anything differently? You must use a calibration agency that holds an ISO/IEC 17025 accreditation for your reference thermometers based on the direct comparison or thermodynamic method. If you use a non-accredited calibration agency for your working thermometers, you should confirm that they are using measurement standards that have been calibrated by an ISO/IEC 17025 accredited calibration agency by requesting that they send you the calibration records for their reference thermometers. You should be able to see the calibration capabilities of the agency in question on the accreditation directory of the accrediting body so that you can know if they suit your needs. Please make sure you communicate your needs with the calibration company, so you receive the appropriate services for which you have paid.

9. Useful References

9.1. AASHTO R 18 - Establishing and Implementing a Quality System for Construction Materials Testing Laboratories
9.2. AASHTO R 61 - Standard Practice for Establishing Requirements for Equipment Calibrations, Standardizations, and Checks
9.3. BIMP Key Comparison Database - http://kcdb.bipm.org/
9.4. Euramet Guide cg-13 – Calibration of Temperature Block Calibrators
9.5. International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM)
9.6. ASTM C511 – Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
9.7. ASTM C1064 – Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete
9.8. ASTM D2726 – Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures
9.9. ASTM E1 - Standard Specification for ASTM Liquid-in-Glass Thermometers
9.10. ASTM E77 – Standard Test Method for Inspection and Verification of Thermometers
9.11. ASTM E230 - Standard Specification and Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples
9.12. ASTM E563 – Standard Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature
9.13. ASTM E644 – Standard Test Methods for Testing Industrial Resistance Thermometers

9.14. ASTM E879 – Standard Specification for Thermistor Sensors for General Purpose and Laboratory Temperature Measurements
9.15. ASTM E1137 – Standard Specification for Industrial Platinum Resistance Thermometers
9.16. ASTM E2251 – Standard Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids
9.17. ASTM E2488 – Standard Guide for the Preparation and Evaluation of Liquid Baths Used for Temperature Calibration by Comparison
9.18. ASTM E2877 – Standard Guide for Digital Contact Thermometers