a) ~~The sensors should be installed in the test chamber of the humidity generator.~~

b) ~~The test chamber of the humidity generation system should be maintained at a stable temperature and pressure for a sufficient period of time before measurement such that the temperature and pressure are satisfactorily stated for the uncertainties quoted.~~

c) ~~The relative humidity measurement should not be obtained until adequate thermal and water vapor pressure equilibrium conditions are reached.~~

~~**2.2.8.5** When calibrations are performed for psychrometers, the four action items described below are required.~~

a) ~~The fluid stored in the reservoir of the sensor head should be distilled or high purity water.~~

b) ~~The sensor head should be installed in the test chamber of the humidity generator.~~

c) ~~The test chamber of the humidity generator system should be maintained at a stable temperature and pressure for a sufficient period of time before measurement.~~

d) ~~The volume flow rate of the sample gas passing through the sensor head should be approximately 140 liters per minute.~~

~~2.2.9 Assuring the quality of test and calibration results~~

~~For the purposes of proficiency testing of laboratories seeking or maintaining accreditation, the laboratory should calibrate a hygrometer over the accreditation range of dew/frost-points and/or relative humidities, and at calibration intervals of 10 °C and/or 10 % relative humidity at a given dry-bulb temperature. Proficiency testing may consist of round-robin testing among other accredited laboratories, or may consist of submission of a calibrated hygrometer and its calibration to NIST.~~

2.3 Thermometer calibrations

2.3.1 Scope

2.3.1.1 This section contains the specific technical criteria in accordance with which a laboratory should demonstrate that it operates, if it is to be recognized as competent to carry out thermometer calibrations.

2.3.1.2 This section may also be used as a guide by thermometer calibration laboratories in the development and implementation of their quality systems.

2.3.1.3 For Accuracy Class I (see section 2.3.3), additional requirements beyond the scope of this handbook are necessary. Further information on these requirements may be obtained from:

Dr. Dean Ripple
NIST, 100 Bureau Dr., Stop 8363
Gaithersburg, MD 20899-8363
301-975-4801

2.3.2 References

a) ASTM Annual Book of Standards, Volume 14.03, *Standards Relating to Temperature Measurement*, ASTM, Philadelphia, PA.

b) Burns, G.W., Scroger, M.G., NIST SP 250-35, *The Calibration of Thermocouples and Thermocouple Materials*, April 1989.

c) Wise, J.A., NIST SP 250-23, *Liquid-In-Glass Thermometer Calibration Service,* Sept. 1988.

d) Wise, J.A., Soulen, R.J., NBS Monograph 174, *Thermometer Calibration, A Model for State Calibration Laboratories* (Appendix A: NBS Monograph 150, *Liquid-In-Glass Thermometry*), Jan. 1986.

e) Mangum, B. W., Furukawa, G. T., NIST TN1265, *Guidelines for Realizing the International Temperature Scale of 1990 (ITS-90)*, August 1990.

f) BIPM – *Supplementary Information for the International Temperature Scale of 1990*, Bureau International des Poids et Mesures, Pavillon de Breteuil, F-92310 Sevres, France, 1990.

g) BIPM – *Techniques for Approximating the ITS-90*, Bureau International Des Poids et Mesures, Pavillon de Breteuil, F-92310 Sevres, France, 1990.

h) Strouse, G. F. and Tew, W. L., NISTIR 5319, *Assessment of Uncertainties of Calibration of Resistance Thermometers at the National Institute of Standards and Technology,* 1994.

i) Meyer, C. W., Strouse, G. F., Tew, W. L.,NISTIR 6138, *A Revised Assessment of Calibration Uncertainties for Capsule Type Standard Platinum and Rhodium-Iron Resistance Thermometers,* 1998.

j) Mangum, B. W., NIST Technical Note 1411, *Reproducibility of the Temperature of the Ice Point in Routine Measurements,* 1995.

k) Wise, J.A., NISTIR 5341, *Assessment of Uncertainties of Liquid-in-Glass Thermometer Calibrations at the National Institute of Standards and Technology,* Jan. 1994.

l) Ripple, D., Burnes, G.W., Scroger, M.G., NISTIR 5340, *Assessment of Uncertainties of Thermocouple Calibrations at NIST*, 1994.

2.3.3 Definitions

Accuracy class: Level of performance associated with the level of total expanded uncertainty (k=2), should conform to the following table:

Accuracy Class	Total Expanded Uncertainty (k=2)		
I	≤ ±	0.005 °C	
II	> ±	0.005 °C	to ≤ ± 0.05 °C
III	> ±	0.05 °C	to ≤ ± 0.20 °C
IV	> ±	0.20 °C	to ≤ ± 1.0 °C
V	> ±	1.0 °C	to ≤ ± 5.0 °C

NOTE The uncertainty of thermometers calibrated by the laboratory will vary depending upon the temperature range of application, even for the same thermometer. Thus, a laboratory may perform calibrations of Accuracy Class II in some cases and Accuracy Class III or IV in other cases because of the temperature ranges involved. Also, the accuracy class assigned is dependent on the types of thermometers calibrated.

2.3.4 Assuring the quality of test and calibration results

2.3.4.1 Fixed-point cell as the reference standard

When the reference standard used by the laboratory is a fixed-point cell, the four action items described below are required, at the minimum, as indicated by the application table that follows their description.

a) Records of complete phase equilibrium plateaus obtained for each cell (except for the triple point of water) upon receipt and once per year thereafter should be maintained.

b) A check thermometer should be used for each fixed point, and control charts maintained.

c) The triple point of water or ice point should be measured after every check thermometer measurement at another fixed point temperature.

d) Any thermometer used in a fixed-point cell should adequately track the hydrostatic head correction over the bottommost 3 cm.

Item	Accuracy class to which item applies				
	I	II	III	IV	V
a)	x	x	x	x	
b)	x	x	x		
c)	x	x			
d)	x	x			

2.3.4.2 SPRT or RIRT as the reference standard

When the reference standard used by the laboratory is a standard platinum resistance thermometer (SPRT) or a rhodium-iron resistance thermometer (RIRT), the two action items described below are required as indicated by the application table that follows them.

a) There should be documentation (i.e., control charts) to show that the resistance of the instrument at the triple point of water or ice point has not changed since its last calibration by more than the equivalent shown in the table below. If, since the last calibration, the resistance of the thermometer has changed at the triple point of water or ice point by the equivalent shown in the table below, a new calibration should be performed.

b) If a digital temperature indicator is used to determine temperature, the calibration of the measured thermometer and the indicator calibration should be checked periodically at the triple point of water or ice point. If, since the last calibration, the readout of the indicator from measuring the thermometer at the triple point of water or ice point has changed by the equivalent shown in the table below, a new calibration should be performed.

Item	Accuracy class				
	I	II	III	IV	V
a)	0.002 °C	0.003 °C	0.005 °C	0.05 °C	0.1 °C*
b)	0.002 °C	0.003 °C	0.005 °C	0.05 °C	0.1 °C*

* at the ice point

2.3.4.3 IPRT as the reference standard

When the reference standard used by the laboratory is an industrial platinum resistance thermometer (IPRT), the two action items described below are recommended as indicated by the application table that follows them.

a) There should be documentation (i.e., control charts) to show that the resistance of the instrument at the triple point of water or ice point has not changed since its last calibration by more than the equivalent shown in the table below. If, since the last calibration, the resistance of the thermometer has changed at the triple point of water or ice point by the equivalent shown in the table below, a new calibration should be performed.

b) If a DVM, DMM, or digital temperature indicator is used to determine temperature, the calibration of the measured thermometer and the indicator calibration should be checked periodically at the triple point of water or ice point. If, since the last calibration, the readout of the indicator from measuring the thermometer at the triple point of water or ice point has changed by the equivalent shown in the table below, a new calibration should be performed.

Item	Accuracy class				
	I	II	III	IV	V
a)	0.002 °C	0.003 °C	0.005 °C*	0.05 °C*	0.1 °C*
b)	0.002 °C	0.003 °C	0.005 °C*	0.05 °C*	0.1 °C*

* at the ice point

2.3.4.4 Thermistor thermometer as the reference standard

When the reference standard used by the laboratory is a thermistor thermometer, the two action items described below are recommended as indicated by the application table that follows them.

a) There should be documentation (i.e., control charts) to show that the resistance of the instrument at the triple point of water or ice point has not changed since its last calibration by more than the equivalent shown in the table below. If, since the last calibration, the resistance of the thermometer has changed at the triple point of water or ice point by the equivalent shown in the table below, a new calibration should be performed.

b) If a DVM, DMM, or digital temperature indicator is used to determine temperature, the calibration of the measured thermometer and the indicator calibration should be checked periodically at the triple point of water or ice point. If, since the last calibration, the readout of the indicator from measuring the thermometer at the triple point of water or ice point has changed by the equivalent shown in the table below, a new calibration should be performed.

Item	Accuracy class				
	I	II	III	IV	V
a)	0.002 °C	0.003 °C	0.005 °C*	0.02 °C*	0.1 °C*
b)	0.002 °C	0.003 °C	0.005 °C*	0.02 °C*	0.1 °C*

* at the ice point

2.3.4.5 Thermocouple as the reference standard

a) When the reference standard used by the laboratory is a thermocouple, special techniques must be used to ensure the reliability of the thermocouple as a reference standard. Unlike other thermometer types, recalibration of a reference standard thermocouple in a thermal environment different than the environment of use may give highly misleading results. This occurs because thermoelectric variations from contamination, material loss, or mechanical cold-working will result in thermoelectric inhomogeneity of the thermocouple, and the response of the thermocouple will depend on the details of the thermal profile along the length of the thermocouple.

b) Examples of acceptable tests of the reliability of thermocouple reference standards include:

1) Periodic measurement of inhomogeneity of the thermocouple, at a temperature sufficiently low or a duration sufficiently short that the inhomogeneity test does not itself change the thermocouple properties.

2) In situ calibration of the reference standard thermocouple. For example, when a new TC is begun in service as a standard, it may first be used to check the calibration of the previous standard.

3) Calibration of test thermometers or check thermometers using standards that are both new and used.

c) Control charts of tests similar to the ones above should be maintained. The results of these tests will dictate the lifetime of the reference standards. Once the acceptable limit of drift has been exceeded, recalibration is not recommended. A new reference thermocouple should be used.

d) Measurement of thermocouples at fixed-points near ambient (triple point of water (TPW), Ga melting point) are poor indicators of thermocouple drift at significantly higher temperatures.

2.3.4.6 Liquid-in-glass thermometer as the reference standard

Only total-immersion, mercury-in-glass thermometers should be used as reference standard thermometers. The stability of these thermometers is limited by the stability of the bulb volume, which may slowly change over long periods of time at temperatures near ambient, or may change more rapidly upon exposure to higher temperatures. Bulb stability should be monitored by checking the ice point on a regular basis and maintaining appropriate control charts that indicate both calendar date of the ice point reading and the time of exposure above 100 °C. The interval between ice point checks should be determined by the rate of change in ice point readings observed on the control charts. The initial interval for ice point checks of thermometers of unknown stability is indicated in the chart below.

	Accuracy class				
	I	II	III	IV	V
Interval			(after each thermal cycle)	weekly	monthly

2.3.5 Personnel

2.3.5.1 For accuracy class I, one of the persons working in the laboratory should have attended the NIST Precision Thermometry Workshop and the NIST Fixed-point Cell Mini-Workshop, or have an equivalent background.

2.3.5.2 For accuracy classes II through IV, one of the persons working the laboratory should have specialized training or experience in the field of thermometry.

2.3.6 Accommodation and environmental conditions

2.3.6.1 For all of the accuracy classes, the environmental conditions of the laboratory should be controlled.

2.3.6.2 The effects of variation in the temperature and humidity of the laboratory should be accounted for in the uncertainty budget. This may be accomplished by measuring the repeatability of thermometer calibrations under varying environmental conditions, or by referring to manufacturers' specifications for the laboratory equipment used in calibrations.

2.3.6.3 The temperature and humidity of the laboratory should be controlled such that the environment meets all manufacturers' specifications for the laboratory equipment used in the calibrations.

2.3.7 Equipment

2.3.7.1 Reference standards

The following table indicates which reference standard is acceptable for each class.

Acceptable reference standard	Accuracy class I	II	III	IV	V
Fixed-point cell	x	x	x		
SPRT and/or RIRT	x	x	x	x	x
IPRT	x	x	x	x	x
Thermistor thermometer	x	x	x	x	x
Gold/platinum thermocouple		x	x	x	x
Type S, R or B thermocouple				x	x
Total-immersion liquid-in-glass			x	x	x

2.3.7.2 Fixed-point cell as the reference standard

a) The purity of the fixed-point material should be ≥99.9999 % and the other starting materials of construction of the cells should be of ultra-high purity also. If the cells are unsealed, they should be filled at all times with an inert gas, such as argon.

b) The cells should be of the defining fixed points of the ITS-90, or well-characterized, stable and reproducible secondary fixed points.

2.3.7.3 SPRT or RIRT as the reference standard

a) A system having adequate resolution and uncertainty for the desired accuracy class should be used to measure a reference SPRT or RIRT. Recommendations for specific situations are given below.

b) A resistance bridge having at least the resolution shown below is recommended. A ratio bridge and standard resistors may also be used:

Accuracy class	Claimed total expanded uncertainty (k=2)	Minimum bridge resolution
I	±0.002 °C	0.000 01 Ω
II	≤±0.01 °C	0.000 1 Ω
III	±0.05 °C	0.000 5 Ω
IV	near ±0.20 °C	0.001 Ω
V	near ±1.0 °C	0.02 Ω

c) A DVM or DMM with the resolution shown below, and a constant-current source with provision for reversing the current, may be used. The current should be known to the same accuracy as the DVM or DMM. Alternatively, a DMM with offset compensation may be used. In either case, the current used should be equal to the current used in the calibration of the reference standard.

Accuracy class	DVM or DMM resolution (digits)
I	8 1/2
II	8 1/2
III	6 1/2
IV	6 1/2

d) A digital temperature indicator having adequate resolution and uncertainty for the desired accuracy class may be used to measure a reference SPRT or RIRT.

2.3.7.4 IPRT as the reference standard

a) A system having adequate resolution and uncertainty for the desired accuracy class should be used to measure a reference IPRT, SPRT or RIRT. Recommendations for specific situations are given below.

b) A resistance bridge having at least the resolution shown below, as a function of claimed total uncertainty, is recommended. A ratio bridge and standard resistors may also be used:

Accuracy class	Claimed total expanded uncertainty (k=2)	Minimum bridge resolution
I	±0.002 °C	0.000 01 Ω
II	±0.01 °C	0.000 1 Ω
III	±0.05 °C	0.000 5 Ω
IV	near ±0.20 °C	0.002 Ω
V	near ±1.0 °C	0.01 Ω

c) A DVM or DMM with the resolution shown below, and a constant-current source with provision for reversing the current, may be used. The current should be known to the same accuracy as the DVM or DMM. Alternatively, a DMM with offset compensation may be used. In either case, the current used should be equal to the current used in the calibration of the reference standard.

Accuracy class	DVM or DMM resolution (digits)
I	8 1/2
II	8 1/2
III	6 1/2
IV	6 1/2

d) A digital temperature indicator having adequate resolution and uncertainty for the desired accuracy class may be used to measure a reference IPRT.

2.3.7.5 Thermistor as the reference standard

a) A system having adequate resolution and uncertainty for the desired accuracy class should be used to measure a reference thermistor.

b) A resistance bridge or resistance ratio bridge having adequate resolution and uncertainty for the desired accuracy class may be used to measure a reference thermistor.

c) A DVM or DMM with the resolution shown below, and a constant-current source with provision for reversing the current, may be used. The current should be known to the same accuracy as the DVM or DMM. Alternatively, a DMM with offset compensation may be used. In either case, the current used should be equal to the current used in the calibration of the reference standard.

Accuracy class	DVM or DMM resolution (digits)
I	8 1/2
II	8 1/2
III	6 1/2
IV	6 1/2

d) A digital temperature indicator having adequate resolution and uncertainty for the desired accuracy class may be used to measure a reference thermistor.

2.3.7.6 Liquid-in-glass as the reference standard

When a liquid-in-glass thermometer is used as a reference standard, and the thermometer is read to better than one-half of a scale division, the optical magnification of scale graduations and procedures to avoid parallax errors should be suitable for the desired resolution and accuracy.

2.3.7.7 Thermocouple as the reference standard

a) If the reference standard is a noble metal thermocouple used with a scanner, a scanner with low-thermal switches should be used.

b) Any method for reference junction compensation must be demonstrated to give results equivalent to a true 0 °C reference junction temperature.

c) The effects of thermal emf of any wiring or instrumentation between the thermocouple readout and the actual reference thermocouple must be accounted for, and uncertainties for these effects included in the uncertainty budget.

d) The offset voltage of the thermocouple readout (i.e., the reading of the instrument when the inputs are appropriately shorted) should be monitored, and corrected for, if necessary.

Item	Accuracy class to which item applies			
	II	III	IV	V
a)	x	x	x	
b)	x	x	x	
c)	x	x	x	
d)	x	x		

e) A DVM or DMM with the resolution shown below, or an equivalent digital readout, may be used.

Accuracy class	DVM or DMM resolution (digits)
II	8 1/2
III	7 1/2
IV	6 1/2
V	5 1/2

2.3.8 Measurement traceability

2.3.8.1 Fixed-point cell as the reference standard

When the reference standard is a fixed-point cell, the five action items described below are recommended as indicated by the application table that follows them.

a) The cell should be certified by an NMI that has participated in the appropriate CCT key comparison (certification in this context means that the cell is tested and found to be acceptable as an ITS-90 defining standard to within some stated uncertainty) or

b) The cell may have been certified by the supplier, if the supplier either documented in detail the preparation and certification, showing direct traceability to an NMI or through a laboratory accredited by an ILAC signatory, or is accredited as a temperature calibration laboratory by an accrediting body recognized by ILAC.

c) The maximum expanded uncertainty (k=2) of the temperature of the cell should be as indicated below.

d) Fixed-point cells should be recertified or compared with a cell of certification less than one year old, at the indicated intervals.

e) An alternative to having fixed-point cells certified is to perform a Measurement Assurance Program (MAP) with NIST using SPRTs as the transfer standard to provide a total calibration system check to verify the stated calibration uncertainties. The interval between MAPs is indicated below. Because the accuracy of a fixed-point realization depends on many factors in addition to the accuracy of the cell itself, a MAP is a superior test of proficiency at realizing the ITS-90. For information on a MAP, please contact G. Strouse at 301-975-4803 or at gstrouse@nist.gov.

Item	Accuracy class			
	I	II	III	IV
a)	x	x*		
b)		x**		
c)	±0.001 °C	±0.005 °C	±0.01 °C	±0.02 °C
d)	5 years	7 years		
e)	3 years	5 years		

* for total uncertainties ≤±0.01 °C
** for total uncertainties in range ±0.01 °C to ±0.05 °C

2.3.8.2 SPRT or RIRT as the reference standard

When the reference standard is an SPRT or RIRT, the three action items described below are recommended as indicated by the application table that follows them.

a) The minimum calibration interval for the SPRT or RIRT is determined by the results of the statistical process control specified in section 2.3.4.2 b). Calibration of the SPRT or RIRT shall be performed by an NMI or a laboratory accredited by an ILAC signatory.

b) If a bridge is used, it should be validated annually, and all reference resistors used with the bridge should be calibrated traceable to national standards.

c) If a DVM or DMM is used, it should be calibrated annually.

Item	Accuracy class				
	I	II	III	IV	V
a)	x	x	x	x	x
b)	x	x	x	x	
c)	x	x	x	x	x

2.3.8.3 IPRT as the reference standard

When the reference standard is an IPRT, the four action items described below are recommended as indicated by the application table that follows them.

a) The minimum calibration interval of the IPRT is determined by the results of the statistical process control specified in section 2.3.4.3 b). Calibration of the IPRT shall be performed by an NMI or a laboratory accredited by an ILAC signatory.

b) As an alternative to 2.3.8.3 a), the IPRT may be calibrated annually by an NMI or a laboratory accredited by an ILAC signatory.

c) If a bridge is used, it should be validated annually, and all reference resistors used with the bridge should be calibrated traceable to national resistance standards.

d) If a DVM or DMM is used, it should be calibrated annually.

Item	Accuracy class				
	I	II	III	IV	V
a)	x	x	x	x	x
b)				x	x
c)	x	x	x		
d)	x	x	x	x	x

2.3.8.4 Thermistor as the reference standard

When the reference standard is an thermistor, the four action items described below are recommended as indicated by the application table that follows them.

a) The minimum calibration interval of the thermistor is determined by the results of the statistical process control specified in section 2.3.4.4 b). Calibration of the thermistor shall be performed by an NMI or a laboratory accredited by an ILAC signatory.

b) As an alternative to 2.3.8.4 a), the thermistor may be calibrated annually by an NMI or a laboratory accredited by an ILAC signatory.

c) If a bridge is used, it should be validated annually, and all reference resistors used with the bridge should be calibrated traceable to national standards.

d) If a DVM or DMM is used, it should be calibrated annually.

Item	Accuracy class				
	I	II	III	IV	V
a)	x	x	x	x	x
b)				x	x
c)	x	x			
d)	x	x	x	x	x

2.3.8.5 Thermocouple as the reference standard

a) Documentation should show that the thermocouple calibration is traceable to national standards, indicate the annealing procedure used prior to and during the thermocouple's use, and document the total duration of use at elevated temperatures.

b) If reference standard thermocouples are cut from a larger lot of thermocouple material and the calibration of the thermocouple taken as equal to that of a sample of the lot, the homogeneity of each lot of thermocouple material shall be tested and documented. The readout used to measure the thermocouple emf should be calibrated at least annually.

c) The thermocouple material should be protected from chemical contamination at high temperature from such sources as metal or oxide vapors. A small amount of contamination is allowable near the measuring junction, if that junction is in a region of the calibration apparatus with small thermal gradients.

2.3.8.6 Liquid-in-glass thermometer as the reference standard

If a liquid-in-glass thermometer is the reference standard, it should have been calibrated traceable to national temperature standards. Periodic inspection of the thermometer for separated columns and monitoring and/or correction of the ice-point depression (see section 2.3.4.6) is required to ensure continued traceability.

2.3.9 Test and calibration methods and method validation

2.3.9.1 All computer programs used in data logging and analysis should be documented in detail. Documentation should include:

a) The scope, purpose, and application of each program; and

b) For specialized software, evidence of the correctness of calculations and algorithms by comparison of results computed by independent means.

2.3.9.2 Methods should be in place to prevent unintended and unvalidated modification of programs.

2.3.9.3 When calibrations are performed by comparison against a reference thermometer, the accuracy of the calibration often depends on the degree of thermal equilibrium between the test and reference thermometers, rather than the accuracy of the calibration of the reference thermometer. To address the issues of proper thermal equilibrium, the following actions should be taken.

a) The uncertainty budget should include components for the temperature stability and uniformity of the comparison medium.

b) The stability and uniformity of the comparison medium should be determined by direct measurement in the actual apparatus used for calibrations.

c) When the comparison apparatus is a stirred liquid bath, with a medium consisting of a fluidized bed, oil, or a hygroscopic liquid (such as chilled alcohol), check standards should be used to verify the continued uniformity and stability of the bath. The implementation of check standards should be designed so that the measurements of these check standards are sensitive to variations in the stability and uniformity of the comparison medium. For example, in a liquid bath, check standard thermometers should be placed farther away from the reference thermometer than the test thermometers. Similarly, the sequence of reading the check thermometers should be chosen to ensure that these measurements are at least as sensitive to fluctuations in the temperature of the medium as the measurements of the test thermometers.

d) As an alternative to 2.3.9.3 c), 2.3.9.3 b) may be performed at the indicated intervals.

Item	Accuracy class				
	I	II	III	IV	V
a)	x	x	x	x	x
b)	x	x	x		
c)	x	x	x	x	x
d)	2 mon	4 mon	6 mon	1 year	1 year

e) When the reference standard is a total-immersion mercury-in-glass thermometer, corrections obtained from measurements at the ice point should be made for all temperature measurements.

f) The ice-point bath should be made according to accepted procedures from ice made from distilled water. This applies to accuracy classes III, IV and V.

2.3.10 Handling of test and calibration items

In addition to the general requirements set forth in the Program Handbook, it should be noted that SPRT's are susceptible to and need protection from shock and vibration in shipping, handling, and storage.