6.5 Technical Criteria for Thermometer Laboratories[1]

6.5.1 Scope

6.5.1.1 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.

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

Echelon: Level of performance associated with the level of total uncertainty, according to the following table:

Echelon	Expanded Uncertainty
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 at Echelon II in some cases and Echelon III or IV in other cases because of the temperature ranges involved. Also, the echelon assigned is dependent on the types of thermometers calibrated.

6.5.2 References

[1] ASTM Annual Book of Standards, Volume 14.03, Standards Relating to Temperature Measurement (2007).

[2] NIST Handbook 105-6, Specifications and Tolerances for Field Standard Thermometers (1997).

[3] NIST SP 250-23, Liquid-In-Glass Thermometer Calibration Service (1988).

[4] NBS Monograph 174, Thermometer Calibration, A Model for State Calibration Laboratories (Appendix A: NBS Monograph 150, Liquid-In-Glass Thermometry) (1985).

6.5.3 Statistical process control

6.5.3.1 Fixed-point cell and triple point of water as the reference standards

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

6.5.3.1.1 Records of complete phase equilibrium plateaus obtained for each cell upon receipt and every six months thereafter should be maintained. This should include either manually recorded temperatures at consistent intervals, or a graphical representation of the equilibrium plateau, as measured by the monitoring sensor.

6.5.3.1.2 A separate check thermometer should be used for each cell and control charts maintained.

6.5.3.1.3 The triple point of water should be measured after every measurement at another temperature.

[1] This section is adapted from the NVLAP Calibration Laboratories Draft Technical Guide (NIST HB 150-2H); it is modified here for WMD application.

Item	Echelon				
	I	II	III	IV	V
6.5.3.1.1	X	X	X	X	
6.5.3.1.2	X	X	X	X	
6.5.3.1.3	X				

6.5.3.2 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 recommended as indicated by the application table that follows them.

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

6.5.3.2.2 If a digital voltmeter (DVM), digital multi-meter (DMM), or digital temperature indicator is used, the calibration of the temperature indicating system (indicator and sensor) should be checked periodically at either the water triple point or at the ice point.

Item	Echelon				
	I	II	III	IV	V
6.5.3.2.1	2 mK	2 mK	5 mK	10 mK	10 mK
6.5.3.2.2	X		X	X	X

6.5.3.3 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.

6.5.3.3.1 The calibration of the thermistor thermometer should be checked frequently (monthly or weekly) depending on the particular application, and control charts should be kept.

6.5.3.3.2 If, since the last calibration, the resistance of the thermistor thermometer has changed at a reference check point (fixed-point, preferably) by the equivalent shown in the next table, a new calibration should be done.

Item	Echelon				
	I	II	III	IV	V
6.5.3.3.1		x	x	x	x
6.5.3.3.2		2 mK	5 mK	10 mK	

6.5.3.4 Thermocouple as the reference standard

When the reference standard used by the laboratory is a thermocouple, control charts should show the reproducibility at appropriate fixed points.

6.5.3.4.1 Liquid-in-glass thermometer as the reference standard

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

6.5.3.4.1.1 The total-immersion mercury-in-glass thermometer should be checked according to good laboratory practice. One method is to check at the ice point on a daily basis after use and maintain records.

6.5.3.4.1.2 The total-immersion liquid-in-glass thermometer should be checked according to good laboratory practice. One method is to check at the ice point weekly and maintain control charts.

Item	Echelon				
	I	II	III	IV	V
6.5.3.4.1.1			X	X	
6.5.3.4.1.2					X

6.5.4 Accommodation and environment

6.5.4.1 For all echelons, the environmental conditions of the laboratory should be controlled.

6.5.4.2 The temperature of the laboratory should be controlled to ± 2 °C.

6.5.4.3 The relative humidity should be controlled between 40 % and 60 %.

6.5.4.4 Vibrations in the laboratory should be minimized.

6.5.5 Equipment and reference materials

6.5.5.1 Reference standards

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

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

6.5.5.2 Fixed-point cell as the reference standard

6.5.5.2.1 The purity of the fixed-point material should be at least 99.999 9 % 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.

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

6.5.5.3 SPRT or RIRT as the reference standard

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

6.5.5.3.2 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:

Echelon	Claimed expanded uncertainty	Minimum bridge resolution
I	≤ ± 0.01 °C	10 μΩ
II	± 0.05 °C	50 μΩ
III	near ± 0.20 °C	200 μΩ
IV	near ± 1.0 °C	1 mΩ

6.5.5.3.3 Alternatively, 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.

Echelon	DVM or DMM resolution (digits)
I	6.5
II	6.5
III	6.5
IV	6.5

6.5.5.4 Thermocouple as the reference standard

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

6.5.6 Measurement traceability and calibration

6.5.6.1 Fixed-point cell as the reference standard

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

6.5.6.1.1 The cell should be evaluated by NIST; or

6.5.6.1.2 The cell may have been evaluated by the supplier, if the supplier documented in detail the preparation and evaluation, showing direct traceability to NIST, or is NVLAP accredited; or

6.5.6.1.3 The cell should have been evaluated by a NVLAP accredited supplier.

6.5.6.1.4 The maximum uncertainty of the temperature of the cell should be as indicated in the next table:

Item	Echelon			
	I	II	III	IV
6.5.6.1.1	X	X*		
6.5.6.1.2		X**		
6.5.6.1.3			X	X
6.5.6.1.4	± l mK	≤ □± 0.005 °C	0.01 °C	± 0.02 °C

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

6.5.6.2 SPRT or RIRT as the reference standard

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

6.5.6.2.1 The SPRT or RIRT should be calibrated by NIST or a NVLAP accredited laboratory every 2 years but may be calibrated by NIST every 2 to 5 years if adequate measurement process data is evident.

6.5.6.2.2 The SPRT or RIRT should be calibrated annually, and all reference resistors used with the bridge should be calibrated traceable to NIST.

6.5.6.2.3 If a bridge is used, it should be calibrated annually, and all reference resistors used with the bridge should be calibrated traceable to NIST.

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

Item	Echelon				
	I	II	III	IV	V
6.5.6.2.1	X	X	X	X	
6.5.6.2.2					X
6.5.6.2.3	X	X	X	X	
6.5.6.2.4	X	X	X	X	X

6.5.6.3 If a thermistor thermometer is the reference standard, it should be calibrated traceable to NIST.

6.5.6.4 If a thermocouple is the reference standard, documentation should show that its calibration is traceable to NIST and indicate the annealing procedure used during the thermocouple's use.

6.5.6.5 If a liquid-in-glass thermometer is the reference standard, it should be calibrated traceable to NIST.

6.5.7 Calibration methods

6.5.7.1 All computer programs used in data logging and analysis should be documented in detail. Also, all algorithms and equipment should be correct for the task.

6.5.7.2 When calibrations are performed by comparison against an SPRT or an RIRT, or a thermistor thermometer, or a liquid-in-glass thermometer, the five action items described below are recommended as indicated by the application table that follows them.

6.5.7.2.1 f a liquid medium is used, it should be stirred vigorously and a comparison block should be located in the bath to aid in improving the uniformity.

6.5.7.2.2 If a liquid medium is used, it should be adequately stirred and a comparison block should be located in the bath to aid in improving the uniformity.

6.5.7.2.3 If the comparison medium is a liquid, it should be adequately stirred.

6.5.7.2.4 The uniformity of the comparison medium should be measured by means of a fast-responding thermometer.

6.5.7.2.5 The temperature stability and uniformity of the comparison medium should be as shown in the next table.

Item	Echelon				
	I	II	III	IV	V
6.5.7.2.1	X	X			
6.5.7.2.2			X	X	
6.5.7.2.3					X
6.5.7.2.4			X	X	
6.5.7.2.5	± 0.5 mK	± 0.5 mK*	(a)	(a)	(a)

*For claimed expanded uncertainty < ± 0.01 °C. For claimed expanded uncertainty > ± 0.01 °C, at least 10 times better than the claimed expanded uncertainty.
(a) At least 10 times better than the claimed expanded uncertainty.

6.5.7.3 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.

6.5.7.4 The ice-point bath should be made according to accepted procedures from ice made from distilled water. This applies to Echelons III, IV and V.

6.5.8 Handling of calibration items

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