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Standard Guide for Measuring Electromotive Force (emf) Stability of Base-Metal Thermoelement Materials with Time in Air[1]

This standard is issued under the fixed designation E601; 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 This guide provides a method for measuring the emf stability of base-metal thermoelement materials in air referenced to platinum at specified constant elevated temperatures using dual, simultaneous, emf indicators, or using a single emf indicator, with the test and reference emf measured alternately. This test is conducted over a period of weeks.

1.2 A calibrated platinum-rhodium/platinum thermocouple is used as a reference standard to establish the test temperature.

1.3 The useful life of a thermocouple depends on the stability of the emf generated at given temperatures for a required time interval. This method provides a quantitative measure of the stability of individual thermoelements. By combining the results of the positive (P) and negative (N) thermoelements, the stability of a thermocouple comprised of both P and N thermoelements may be obtained. The emf of an individual thermoelement is measured against platinum, which may be the platinum leg of the platinum-rhodium/platinum reference thermocouple, or an additional platinum reference.

NOTE 1—Some thermoelements may show insignificant emf drift while undergoing relatively rapid oxidation. In these cases, failure of the thermoelement may be indicated only by a large rise in the electrical resistance between joined thermoelements, as measured at the reference junctions.

NOTE 2—See ASTM MNL 12 for recommended upper temperature limits in air.[2]

NOTE 3—This guide is only applicable for initially new thermoelements. Base-metal thermoelements exposed to temperatures above 200°C become thermoelectrically inhomogeneous, and stability testing of inhomogeneous thermoelements will give ambiguous results.

1.4 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E220 Test Method for Calibration of Thermocouples By Comparison Techniques

E230 Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples

E344 Terminology Relating to Thermometry and Hydrometry

E563 Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature

E1159 Specification for Thermocouple Materials, Platinum-Rhodium Alloys, and Platinum

2.2 *Other Referenced Documents*

NIST Monograph 175

3. Terminology

3.1 *Definitions*—The definitions given in Terminology E344 shall apply to this guide.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *emf indicator, n*—an instrument that measures the emf and displays the value, for example, a digital voltmeter (DVM).

3.2.2 *emf stability, n*—change in emf (or in equivalent temperature) with time, with the thermocouple junctions held at fixed temperatures and with the thermal profile along the thermoelements held constant.

3.2.3 *half-maximum heated length, n*—the distance between the tip of the temperature sensor and the position along the length of the sensor leads or sheath where the temperature equals the average of the calibration-point and ambient temperatures.

3.2.4 *gradient zone, n*—the section of a thermocouple that is exposed during a measurement to temperatures in the range from $t_{amb} + 0.1(t_m - t_{amb})$ to $t_{amb} + 0.9(t_m - t_{amb})$, where t_{amb} is ambient temperature and t_m is the temperature of the measuring junction.

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[2] *Manual on the Use of Thermocouples in Temperature Measurement: Fourth Edition*, Available from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428, www.astm.org.

[3] 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.

3.2.5 *reference thermocouple, n*—calibrated Type S or Type R thermocouple.

3.2.6 *test thermocouple, n*—thermocouple composed of the thermoelement being tested and the platinum reference thermoelement.

3.2.7 *normalize, v*—to mathematically adjust experimental emf data acquired at a set of temperatures to values corresponding to a common reference temperature.

4. Summary of Test

4.1 In this test, the emf of a test thermocouple, comprised of a base-metal thermoelement relative to a platinum reference thermoelement, is determined as a function of time for a specified test temperature and thermal profile. If care is taken to maintain the chemical purity and annealed metallurgical state of the platinum thermoelement, the platinum will be thermoelectrically stable. In that case, variation in this emf value is attributed to instability of the base-metal thermoelement. The emf of the reference thermocouple (E_{ref}) is used to measure the test temperature, and the emf (E_{test}) of the test thermocouple is measured either simultaneously or alternately with E_{ref}. The test consists of the measurement of E_{test} at specified time intervals and at a specified constant value of E_{ref} which corresponds to a specified, constant temperature, until the required time of the test is exceeded or until an open circuit in the base-metal thermoelement results.

4.2 This test is based on Method A of Test Method E220, where the reference thermocouple of Test Method E220 becomes the reference thermocouple used to measure the test temperature and one specified constant temperature replaces the series of measured temperatures of Test Method E220.

5. Significance and Use

5.1 This test is important because the accuracy of a temperature measurement by a thermocouple is directly related to the emf stability of the thermoelements.

5.2 This test is used to verify that the tested thermoelements meet the intended requirements.

5.3 This test is useful in comparing the emf stability of two base metal thermoelements under the same conditions. The test and reference emf may be measured either simultaneously or alternately.

5.4 The relative stabilities of base metal thermoelements determined by this test are valid only under the specified test conditions. Results will be affected by changes in any of the following conditions: (*1*) temperature profile or gradient along the length of the thermoelements; (*2*) abundance, velocity and composition of the air surrounding the test pieces; (*3*) thermoelectric inhomogeneity of the test thermoelements; (*4*) stability of the platinum thermoelement.

5.5 The test does not address the determination of base metal thermoelement stabilities over a series of temperature changes.

5.6 The reliability of this test depends on the emf stability of the reference platinum thermoelement. For testing the relative emf stability of base-metal thermoelements, a reference element of platinum that has sufficient thermoelectric stability to determine any significant change in emf of base-metal thermoelements shall be used. To ascertain that the experimental method protects the platinum sufficiently from degradation, the method shall be validated by performing the procedure described in Appendix X1 prior to the actual test.

5.7 The test result does not apply to applications in which the temperature distribution, for a given measuring junction temperature, changes with time.

6. Apparatus

6.1 *Thermocouple Used to Measure the Test Temperature*—A reference Type S or Type R thermocouple with 0.50 mm diameter (24 AWG) thermoelements or larger shall be used to measure the test temperature. The reference thermocouple shall consist of either standard tolerance or special tolerance wire as per Table 1 in Specification E230. The choice of tolerance will not affect the determination of thermoelement drift. This thermocouple shall be of sufficient length to minimize the effect of heat conduction along the lengths of the wires upon the measuring junction temperature. (Note: platinum is a better heat conductor than most base metal thermocouple wires.) The length shall be sufficient to enable the reference thermocouple's measuring junction to be located within the test furnace's zone of nearly uniform temperature (refer to 6.5.2).

6.2 *Platinum Reference Thermoelement*—The emf of the test thermoelements shall be measured relative to a 0.50 mm diameter (24 AWG) platinum wire. This wire may be the platinum wire of the Type S or R reference thermocouple or a second 0.50 mm diameter (24 AWG) platinum wire. The length of this wire shall exceed that of the test specimen to minimize the transfer of heat from the measuring junction to the reference junction during testing (see 6.3). For more information concerning a platinum reference thermoelement, Specification E1159 may be consulted.

6.3 *Test Specimens*—The test specimens shall be lengths of wires, rods, ribbons, or strips of the coils or spools of the base-metal thermoelements to be evaluated. Their lengths shall be adequate to minimize the transfer of heat from the measuring junctions to the reference junctions during the period of test. The lengths shall be at least 0.8 m (30 in.) depending on the length of the testing medium and the transverse sizes of the thermoelements. The specimens shall be free of kinks or other defects due to mechanical deformation, and shall be continuous without splices between the measuring and reference junctions.

6.4 *Reference Junction Temperature*—The reference junction ends of the test specimens, of the platinum reference element, if used, and of the reference thermocouple shall be maintained at a known constant temperature during a measurement cycle. The uncertainty attributable to the reference junction temperature shall be less than ±0.1°C. Ice point reference junction baths provide a relatively simple and reliable means for maintaining the reference junction at 0°C (32°F) when proper precautions are exercised in their use. Practice E563 provides an acceptable method for utilizing the ice point as a reference junction bath. Subsection 7.3 of Test

Method E220 may be consulted for alternative methods of providing a reference junction temperature.

6.5 *Tube Furnace*—The test shall be conducted in an electrically heated tube furnace such as described in subsection 7.2.3 of E220. The furnace tube shall be long enough to permit a depth of immersion of the thermocouple measuring junctions that is sufficient to assure that the temperature of the measuring junctions is not affected by heat conduction along the thermoelements.

6.5.1 Means shall be provided to control the temperature of the furnace to within ±10°C (±18°F) of a nominal temperature during the performance of the test.

6.5.2 The test shall be conducted in a uniformly heated furnace providing a nearly isothermal work zone sufficiently large to maintain all junctions at the same temperature.

6.5.3 To determine the uncertainty resulting from temperature non-uniformities in the work zone, measure the temperature profile along the thermocouple axis in the vicinity of the work zone, using a platinum-rhodium alloy thermocouple or a platinum resistance thermometer prior to commencement of the test. If the furnace temperature is not sufficiently stable to obtain a temperature profile with a single thermometer, it may be useful to place one thermometer at a fixed half-maximum heated length, and to move a second thermometer along the furnace-tube axis. Adjust the readings of the moveable thermometer by adding the correction $-(t_{\text{fixed}}(\text{time}) - t_{\text{fixed}}(\text{initial}))$, where t_{fixed} is the temperature indication of the thermometer at fixed half-maximum heated length.

6.5.3.1 A thermoelement extending from ambient temperature into an isothermal zone of a furnace will come to equilibrium with the temperature of the isothermal zone through radiative, convective, and conductive heat transfer between the thermoelement and the surrounding furnace environment. The distance of immersion, L_{eq}, into the isothermal zone needed to achieve thermal equilibrium depends significantly on both the thermoelement diameter and its thermal conductivity. The characteristic length for a wire to achieve thermal equilibrium with its surroundings is given by the approximate correlation:

$$L_{eq} = (2.5\ \text{cm})\left(\frac{d}{1\ \text{mm}}\right)^{1/2}\left(\frac{k}{100\ W/(\text{m}\cdot\text{K})}\right)^{1/2} \quad (1)$$

where:

k = the thermal conductivity of the thermoelement, and
d = the diameter of the thermoelement.

Calculate the distance L_{eq} for each tested thermoelement in units of W/(m · K), and d is the diameter of the thermoelement in millimeters. The equivalent equation in English units, with d in units of inches and k in units of BTU/(hr·ft·°F) is:

$$L_{eq} = (1\ \text{in})\left(\frac{d}{0.04\ \text{in}}\right)^{1/2}\left(\frac{k}{58\ BTU/(\text{hr.}\cdot\text{ft}\cdot{}^\circ\text{F})}\right)^{1/2} \quad (2)$$

Calculate the distance L_{eq} for each tested thermoelement and the platinum reference thermoelement. The approximate thermal conductivities listed in Table 1 may be used for this purpose. Measure the diameter d_{mj} of the measuring junction assembly (see 7.1). Identify the maximum L_{max} of the set of all calculated L_{eq} values and d_{mj}.

NOTE 4—Eq 1 was derived for a temperature of 200°C, which is near the lower limit of observable thermoelement drift. For higher temperatures, the value of L_{eq} from Eq 1 will give an upper limit on the actual equilibration length.

TABLE 1 Approximate Thermal Conductivities of Thermoelement Materials at 200°C

Thermoelement Type	*k* (W/(m · K))
Pt	72
EP, KP	21
EN, JN, TN	31
JP	62
KN	32
NP	19
NN	31
TP	380

6.5.3.2 The standard uncertainty due to thermal non-uniformity is the maximum temperature variation in the profile from subsection 6.5.3 between the measuring junction location and a distance L_{max} away from the measuring junction.

6.5.3.3 Alternative methods may be used to determine the standard uncertainty due to thermal non-uniformity, such as comparison of results in the test furnace with results obtained either in fixed-point cells or in a stirred liquid bath of high temperature uniformity; or numerical heat-transfer calculations.

6.6 *Electromotive Force Indicator*—The emf-measuring instrumentation shall have a measurement uncertainty of not more than 1 µV at 1 000 µV and 12 µV at 50 000 µV for this test. The emf indicators may be potentiometers or digital voltmeters. Subsections 6.2 and 7.4 of Test Method E220 may be consulted for further discussions of thermal emf indicators and methods of emf measurement.

6.7 *Connecting Wires*—Connecting wires from the reference junctions to the emf indicator or indicators shall be electrically insulated copper. If the test is sensitive to electrostatic interference, the wires shall be electrically shielded. If electromagnetic interference is present, the conductors shall be twisted to minimize this effect.

6.8 *Selector Switches*—When more than one thermoelement is to be tested, a selector switch is introduced into the copper part of the circuit between the reference junctions and the thermal-emf indicators. These switches shall comply with subsection 7.5.1 of Test Method E220.

6.9 *Thermocouple Insulation*—For the segment of the thermoelements exposed to temperatures above ambient, ceramic tubing may be used to support and electrically insulate the test thermoelement, the thermocouple used to measure the test temperature, and the platinum reference thermoelement, if used.

6.9.1 For the test thermoelements, the ceramic tubing shall be aluminum oxide (Al_2O_3) with total impurities of less than 0.5 % (mass), and the maximum limit for specific impurities shall be 0.04 % (mass) for Fe_2O_3.

6.9.2 For the thermocouple used to measure the test temperature and for the platinum reference thermoelement, the ceramic tubing shall be aluminum oxide (Al_2O_3) with total impurities of less than 0.5 % (mass), and the maximum limit for specific impurities shall be 0.04 % (mass) for Fe_2O_3 and 0.08 % (mass) for Si.

6.9.3 To avoid unnecessary mass and to minimize axial heat conduction in the region of the measuring junction, the ceramic tubing should be relatively thin-walled and should have bore diameters large enough to allow threading of the thermoelements without bending or straining them and to avoid binding. If possible the test thermocouple(s) and the reference thermocouple should be welded individually and then the measuring junctions welded all together to create a loose fitting bundle with a common measuring junction.

6.9.4 To minimize contamination, single lengths of ceramic insulation and not short pieces shall be used. Additionally, if using ceramics that were previously used, insert only thermocouples of the same type as previously used. Insert the positive and negative thermoelement into the bore previously used for that thermoelement to prevent cross contamination from previous testing.

7. Procedure

7.1 *Preparation of Thermocouples for Test*—The thermoelement junction shall be prepared by welding, using a procedure proven by experience, or by testing, to produce junctions that are mechanically secure and electrically conductive at the test temperature for the life of the test.[4] The measuring junctions of all of the thermocouples may be welded together into a common bead to provide good thermal contact between the junctions of the different thermocouples. Weld a reference thermocouple to the test specimen to form a mechanically sound junction assembly. If a platinum wire other than the reference thermocouple platinum leg is to be used as the platinum reference then it shall be welded to the junction assembly. If it is not convenient to weld the junctions together, the junction of each thermocouple shall be welded separately and the junctions brought into good electrical and thermal contact by wrapping them with a thermally-conductive wire or platinum foil.

7.1.1 Electrically insulate the test specimens from each other, except at the junction, and insulate the reference thermocouple and the additional platinum leg from the test specimens with ceramic insulators (sufficiently loose to thread the thermoelements through the bore without bending or straining them). Slip the insulating tubes down on the thermoelements as close to the measuring junctions as possible without stressing the wires. Thermoelements may be inserted into the insulating tubes before or after fabrication of the measuring junction. The number of test specimens joined to the platinum reference may be as many as the volume of the testing medium permits, provided that thermal conduction along the thermoelements does not impair isothermal conditions.

7.1.2 To prepare the reference junction, make the electrical connection between the individual legs of the test thermocouple and their respective copper leads using a screw or spring connector, or by soldering, welding, or crimping, or any other suitable means. These connections are then placed into individual clean glass, plastic, or metal tubes. If metal tubes are used, the thermoelements must be electrically insulated from the tubes, and the tubes shall be fabricated from stainless steel or another alloy that will not have excessive thermal conductance with the ambient environment. As stated in Test Method E220 care must be taken to keep thermal conduction losses within the limits of experimental error typically by immersing the thermocouple into the bath until no further change in indicated emf is noted. Completely clean finished junctions of any harmful contaminants, especially if any soldering or brazing fluxes have been used.

7.2 Heat the tube furnace to the test temperature. Insert the measuring junction end of the assembly into the furnace after the test temperature has been established, so that the junction is in the uniform temperature zone. Avoid bending or kinking of the wire in a zone of temperature gradient. Copper extension wires shall connect the emf-measuring instrument and reference junctions. Take care to ensure that the thermocouple assemblies do not move within the furnace with time in such a manner as to change the temperature distribution along the wires.

7.3 Make the initial emf readings as soon as the system has reached steady-state thermal conditions, especially if the recording of early drift is desired. Inspection of the variation of the reference thermometer readings will indicate whether the furnace and sensor elements have been adequately stabilized. The actual test temperature, as measured by the reference thermocouple, must be within ±10°C of the nominal test temperature. Measure and record the test temperature as indicated by the emf of the reference thermocouple. Measure and record the emf of the test specimens versus the platinum reference thermoelement while maintaining the test temperature. Measure the emf with the temperature changing at a rate not exceeding 0.5°C/min (1°F/min). A minimum of three consecutive readings that yield the same emf value within measurement uncertainty is required.

7.4 When using a single emf indicator to make measurements, either an automated method (method A) or a manual method (method B) may be used. Figure 1 in Test Method E220 is a schematic of a typical data acquisition system using a thermocouple as the reference thermometer.

7.4.1 *Method A*—This method permits the rapid testing of any number of thermocouples. The thermocouples to be tested and the reference thermocouple are connected to insulated copper lead wires at the reference junction temperature unit. This unit must meet the requirements of subsection 6.4. The copper lead wires are routed to a scanning unit that sequentially connects each thermocouple to the input of a voltmeter. The voltmeter must meet the requirements of subsection 6.6. In the time interval between a reading of the reference thermocouple and of a test thermocouple the temperature of the common measuring junction will drift. Measurements shall be made rapidly enough so that this drift in temperature is small in comparison to the uncertainty of the temperature measurement. The emf–measuring system is comprised of a voltmeter, a display, and a data storage system. It may be desirable to provide a calibrated emf source and a zero (or shorted) input to the data acquisition system as references to improve the accuracy of the measurement. For a set of n test thermocouples, the recommended order of readings is: reference thermocouple,

[4] For more information on welding of measuring junctions, see *Manual on the Use of Thermocouples in Temperature Measurement: Fourth Edition*.[2]

test thermocouple 1, test thermocouple 2, ... test thermocouple *n*, reference thermocouple, test thermocouple n, ... test thermocouple 1, reference thermocouple. If the variations in temperature indicated by the reference thermocouple are greater than desired with the above method, an alternative order of reading may be made, provided that the reference thermocouple is read at least once for every reading of the test thermocouple and that the order of readings is symmetric in both forward and reverse directions.

7.4.2 *Method B*—Manual Method: This method may be used when one or more thermocouples are to be calibrated with manually operated switches. Each thermocouple is connected to the voltmeter in sequence. The reference thermocouple should be read just before and just after the reading of each thermocouple under calibration. After measuring the emf of each test thermocouple, the entire sequence should be repeated at the same temperature.

7.4.3 When using dual emf indicators the system requirements are the same as for a system with a single emf indicator except that there are now two voltmeters. In simultaneous measurements, one voltmeter will read the reference thermocouple while the other voltmeter reads the test thermocouple; then the voltmeters are interchanged for the second pair of readings. The process of interchanging the voltmeters is continued until an adequate number of readings are obtained to achieve the desired measurement uncertainty.

7.5 After the initial readings are made, repeat them after 4 h, then every 24 h for 4 weeks, and then twice weekly until the test is completed.

8. Calculation

8.1 This test measures the emf versus time of a base-metal thermoelement relative to platinum.

8.2 Thermoelectric stability may be reported on the basis of the nominal test temperature or on the basis of the actual temperature at which the data was taken.

8.3 Compute the temperature T_{ref} (temperature at which measurements were made) from the measured emf of the reference thermocouple. Depending on the form of the calibration report for the reference thermocouple, calibration corrections may be required.

8.4 The fractional error of the thermocouple formed by referencing an individual test thermoelement to the platinum thermoelement is computed by obtaining the reference table emf (E_{tref}) for the test combination at that temperature (T_{ref}) from the single-leg tables in Specification E230 or NIST Monograph 175. Using these table values, calculate the percentage deviation of the measured test thermocouple emf (E_m) from the reference table values using the equation:

$$\%\ error = \frac{E_m - E_{tref}}{E_{tref}} \quad (3)$$

where:

E_m = measured emf of test specimen, and
E_{tref} = table emf for the test specimen at T_{ref}.

8.5 If the nominal-temperature method is used, proceed as follows: since the test temperature may depart ±10°C (±18°F) from the nominal test temperature, the measured temperature and emf at the time of reading must be normalized to the specified test temperature using the Seebeck coefficient of the test thermoelement versus the platinum thermoelectric standard NIST SRM 1967, more commonly known as Pt-67 (for more information see NIST Monograph 175). For standard thermoelements, the Seebeck coefficient S_e may be obtained from the thermoelement temperature-emf tables in Specification E230 or NIST Monograph 175. Using these or other established tables, the emf deviation from the emf at the nominal test temperature can be determined and used as the correction. For thermoelements not covered by these or other established tables, the Seebeck coefficient S_e, may be determined by taking emf readings 10°C (18°F) below or above, and at, the test temperature, and then dividing the emf difference by the temperature difference. It should be noted that, for certain thermocouples, in certain temperature ranges, the change in the Seebeck coefficient with temperature is large and a calculation based on a 10°C range may result in an increased uncertainty in the measurement. Given the Seebeck coefficient S_e, the emf of a thermoelement versus platinum may be normalized from the actual test temperature to the nominal test temperature by the use of the following equation:

$$E_T = E_{T'} + S_e(T - T') \quad (4)$$

where:

T = nominal test temperature,
T' = actual test temperature,
S_e = Seebeck Coefficient of the thermoelement versus Pt-67 = (ΔE/ΔT),
E_T = emf versus Pt-67 normalized to nominal test temperature, T, and
$E_{T'}$ = emf versus Pt-67 at actual test temperature, T'.

8.5.1 *Example:*

Assume that a Type KP thermoelement is to be tested for stability at a nominal temperature of 1000°C. The emf reading 32.653 mV corresponds to a measured temperature of 1005°C with the reference thermocouple. The emf of the thermoelement versus Pt is corrected to 1000°C using Eq 4.
Using:

T = 1000°C
T' = 1005°C
$E_{T'}$ = 32.647 mV

and

$$S_e = \frac{(E(1010°C) - E(1000°C))}{10°C} = 0.0308\ mV/°C \quad (5)$$

one obtains:

$$E_T = 32.647\ mV + (0.0308\ mV/°C)(1000°C - 1005°C) = 32.493\ mV \quad (6)$$

8.6 There is an alternative method for correcting the emf reading at the actual test temperature to the specified test temperature if several samples of nearly the same thermoelectric response are being tested. This method eliminates the need to maintain the test temperature constant during a series of tests and provides sufficient accuracy provided the temperature fluctuation is within ±10°C (18°F).

8.6.1 For any particular apparatus, the necessary stability may be determined by performing comparison measurements at a variety of drift rates of the reference thermometer temperature. These measurements should be performed prior to the actual drift test, using separate thermoelement samples. A plot of the test thermocouple reading (normalized), versus drift rate will indicate what magnitude of temperature drift can be tolerated without unacceptable variation in the calibration results. The normalization of the test thermocouple readings to a single temperature is performed using the procedure in 8.5.

8.6.2 The temperature as indicated by the reference thermocouple is measured, and the emf of one test specimen is measured against the reference platinum. The emfs of the subsequent test specimens are then measured against the first test specimen. The emf reading of each of the other specimens may now be corrected to the specified test temperature by applying the emf difference between each test specimen and the first specimen to the corrected emf of the first specimen. Observe the sign of the difference when making these corrections.

9. Report

9.1 The calibration report shall provide a description of the thermoelement, including any lot or tag information, and shall state the type of reference thermometer used, the platinum reference used, the reference junction temperature, the temperature scale, and the calibration uncertainty and the corresponding level of confidence. The uncertainty budget should include factors such as reference thermometer calibration, reference thermometer repeatability, reference thermometer measurement, bath or furnace temperature gradients, bath or furnace stability, and emf measurement. A table which includes the emf of the test thermoelement at specified times, and temperature (or normalized temperature) at each time should be provided.

9.2 From the reported results, % drift = % error at time – % error initial, can be calculated.

9.3 The emf change can be converted to an equivalent change in temperature, for the thermocouple with which the thermoelement is to be associated, by dividing the change in emf by the Seebeck Coefficient (emf per degree at the given temperature) for the intended thermocouple.

NOTE 5—The temperature stability of each thermocouple is determined on the basis of the drift of each of its thermoelements. Therefore, it is the Seebeck Coefficient of the thermocouple, S, that should be used in this case, and not the Seebeck Coefficient of the thermoelement versus platinum, S_e.

9.3.1 The appropriate equation for a positive thermoelement is:

$$\Delta T_D = \frac{E_e(\tau) - E_i}{S} = \frac{E_e(\tau) - E_i}{\Delta E/\Delta T} \tag{7}$$

9.3.2 For a negative thermoelement, the equation is:

$$\Delta T_D = \frac{(E_i - E_e(\tau))}{S} \tag{8}$$

where:

ΔT_D = temperature drift of thermoelement as it affects the associated thermocouple,
$E_e(\tau)$ = emf versus Pt of the thermoelement after elapsed time τ,
E_i = initial emf versus Pt of the thermoelement, and
S = Seebeck Coefficient of the associated thermocouple at the test temperature.

9.3.2.1 *Example:* A positive Type K thermoelement being tested at 1000°C has an initial emf reading versus Pt of 32.523 mV. After 500 h, the reading has changed to 32.609 mV.

$$S(1000°C) = \frac{\Delta E}{\Delta T} = \frac{E(1005°C) - E(995°C)}{10°C} = \frac{41.470 - 41.081}{10}\ \text{mV/°C} = 0.0389\ \text{mV/°C} \tag{9}$$

The temperature drift in degrees Celsius due to changes in the positive (P) thermoelement is:

$$\Delta T_p = \frac{32.609\ \text{mV} - 32.523\ \text{mV}}{S} = \frac{0.086\ \text{mV}}{0.039\ \text{mV/°C}} = +2.2°C \tag{10}$$

9.3.2.2 *Example*—A negative Type K thermoelement being tested at 1000°C has an initial emf reading versus Pt-67 of –8.745 mV and after 500 h a reading of –8.768 mV. The drift in degrees Celsius which this negative (N) thermoelement contributes to the Type K thermocouple is determined from Eq 8 as follows:

$$\Delta T_N = \frac{-8.745\ \text{mV} - (-8.768\ \text{mV})}{S} = \frac{0.023\ \text{mV}}{0.039\ \text{mV/°C}} = 0.6°C \tag{11}$$

9.3.3 When the drifts of the positive and negative thermoelements of a thermocouple have been determined, the stability of the thermocouple can be determined from the algebraic sum of the drifts of the individual thermoelements, as follows:

$$\Delta T_c = \Delta T_P + \Delta T_N = 2.2\ °C + 0.6\ °C = 2.8°C \tag{12}$$

where:

ΔT_c = temperature drift of the thermocouple,
ΔT_P = temperature drift of the positive thermoelement as it affects the associated thermocouple, and
ΔT_N = temperature drift of the negative thermoelement as it affects the associated thermocouple.

9.4 If the thermocouple fails due to breakage of the measuring junction or due to breakage of either one of the thermoelements, the time of failure shall be reported, and no data shall be given beyond this point of time.

9.5 The report shall give a description of the gradient zone and the depth of immersion used during the test.

10. Precision and Bias

10.1 This test procedure is designed to give values only for particular samples run under the same conditions. The precision of this test depends in detail on many variables (those listed in Section 5, the type of thermoelement tested, and the test temperature), and the test is not sufficiently prescriptive to allow a general statement on attainable precision. Because this test measures the stability of a thermoelement relative to a measurement at the start of the test, many systematic errors in the emf measurement cancel out. No test is known for quantitatively determining the bias, but if sufficient care is taken that the platinum is not contaminated (see Appendix X1), the bias is expected to be negligible.

APPENDIX

(Nonmandatory Information)

X1. DETERMINATION OF CHANGE IN PLATINUM REFERENCE DURING TESTING

X1.1 At the conclusion of the stability test, the platinum reference, if used, and the platinum-rhodium/platinum thermocouple may be checked for stability as follows:

X1.1.1 Remove the entire test assembly from the furnace. Weld an unused platinum-rhodium/platinum thermocouple made from adjacent lengths of the same lots of thermocouple wires as was assembled for the original thermocouple to the hot junction bead of the test assembly. Place the test assembly in the furnace of the test temperature so that the original thermocouple will be located in the same position as it was during the test. This should ensure that the same temperature gradient pattern will exist along the original thermocouple legs. After temperature stability has been obtained, measure the emf deviation between the new and the original thermocouples. Assuming that the platinum reference, if used, is from the same lot as the thermocouple platinum, measure its deviation from the new platinum. A standard uncertainty equal to the observed deviation of the platinum reference must be added to the uncertainty of the test thermoelement emf, for data spanning the duration of the test. The data may be corrected for this deviation, assuming that the deviation is a linear function of time over the duration of the test; however, the test report must indicate that such a correction was made. It is important to maintain the same conditions throughout this checking procedure as prevailed for the stability test.