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Standard Test Method for Calibration of Thermocouples By Comparison Techniques[1]

This standard is issued under the fixed designation E220; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method describes the principles, apparatus, and procedure for calibrating thermocouples by comparison with a reference thermometer. Calibrations are covered over temperature ranges appropriate to the individual types of thermocouples within an overall range from approximately −195 °C to 1700 °C (−320 °F to 3100 °F).

1.2 In general, this test method is applicable to unused thermocouples. This test method does not apply to used thermocouples due to their potential material inhomogeneity—the effects of which cannot be identified or quantified by standard calibration techniques. Thermocouples with large-diameter thermoelements and sheathed thermocouples may require special care to control thermal conduction losses.

1.3 In this test method, all values of temperature are based on the International Temperature Scale of 1990. See Guide E1594.

1.4 *This standard ~~may involve hazardous materials, operations and equipment. 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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory ~~requirements~~limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1 Specification for ASTM Liquid-in-Glass Thermometers
E77 Test Method for Inspection and Verification of Thermometers
E230 Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples
E344 Terminology Relating to Thermometry and Hydrometry
E452 Test Method for Calibration of Refractory Metal Thermocouples Using a Radiation Thermometer
E563 Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature
E644 Test Methods for Testing Industrial Resistance Thermometers
E1129/E1129M Specification for Thermocouple Connectors
E1594 Guide for Expression of Temperature
E1684 Specification for Miniature Thermocouple Connectors
E1751 Guide for Temperature Electromotive Force (emf) Tables for Non-Letter Designated Thermocouple Combinations
E2846 Guide for Thermocouple Verification

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

[1] This test method is under the jurisdiction of ASTM Committee E20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.11 on Thermocouples - Calibration.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.1 *check standard, n*—a measurement instrument or standard whose repeated results of measurement are used to determine the repeatability of a calibration process and to verify that the results of a calibration processes are statistically consistent with past results.

3.2.2 *isothermal block, n*—a piece of solid material of high thermal conductivity used to promote thermal equilibrium between two or more thermometers.

3.2.3 *reference junction compensation, n*—the adjustment of the indication of a thermocouple such that the adjusted indication is equivalent to the emf or temperature that the thermocouple would indicate if the reference junctions were maintained at ~~0°C.~~0 °C.

3.2.3.1 *Discussion—*

In most cases, the thermocouple indication is adjusted by measuring the temperature of a terminal block where the thermocouple is connected, and then adding to the thermocouple emf an additional emf equal to the emf of the thermocouple reference function evaluated at the temperature of the terminal block. Because the emf-temperature relationship of any actual thermocouple differs slightly from that of the reference function, reference junction compensation typically introduces higher uncertainties compared to the use of a ~~well-prepared~~ well prepared ice bath.

3.2.4 *reference junction compensator, n*—a device that implements reference junction compensation.

3.2.5 *reference thermometer, n*—thermometer that establishes the value of temperature in a given system containing additional temperature sensors.

3.2.5.1 *Discussion—*

In a calibration system the reference thermometer is a calibrated thermometer capable of indicating values of temperature with known uncertainty. The reference thermometer provides the standard temperature for the system at the time of test.

3.2.6 *thermocouple type, n*—a standardized thermoelectric class of thermoelement materials that, used as a pair, have a normal relationship between relative Seebeck emf and temperature.

3.2.6.1 *Discussion—*

For common, commercially available thermocouples, a thermocouple type is identified by a letter designation (types B, C, E, J, K, N, R, S, and T). The letter designation scheme is given in Guide E2846. The tables in E1751 ~~and E1751~~give temperature-EMF relationships for a number of additional thermocouple compositions that are not identified by a letter designation.

4. Summary of Test Method

4.1 Comparison calibration consists of measuring the emf of the thermocouple being calibrated in an isothermal medium while simultaneously measuring the temperature of the medium with a reference thermometer. The reference thermometer may be any thermometer with sufficient accuracy at the temperature of calibration.

5. Significance and Use

5.1 For users or manufacturers of thermocouples, this test method provides a means of verifying the emf-temperature characteristics of the material prior to use.

5.2 This test method can be used to calibrate a thermocouple for use as a reference, or it can be used to calibrate thermocouples representing a batch of purchased, assembled thermocouples.

5.3 This test method can be used for the verification of the conformance of thermocouple materials to temperature tolerances for specifications such as the tables in Specification E230 or other special specifications as required for commercial, military, or research applications.

6. Interferences

6.1 Since the success of this test method depends largely upon the ability to maintain the measuring junction of the thermocouple being calibrated and the reference thermometer at the same temperature, considerable care must be taken in choosing the media and conditions under which the comparisons are made. Stirred liquid baths, uniformly heated metal blocks, tube furnaces, and dry fluidized baths, properly used, are acceptable temperature comparison environments. In the case of large diameter thermoelements and sheathed thermocouples, special attention must be given to effects of thermal conduction.

6.2 Voltage measurement instruments with sufficiently high input impedance must be used for measuring thermocouple emf to eliminate instrument loading as a significant source of error. The ratio of input impedance to thermocouple loop resistance should be significantly (at least 10^4) greater than the ratio of the measured emf to the desired emf uncertainty.

6.3 The test method relies on the assumption that test thermoelements are homogeneous. If so, their output voltage at a given measuring junction temperature is independent of temperature variations along the length of the thermocouple. Departures from this ideal contribute to uncertainty in the use of test results. The effects typically are negligibly small for new, unused thermocouple material, but not for used thermocouples, especially those of base-metal composition. The effects of inhomogeneity can be identified, but not accurately quantified, by the techniques described in Appendix X4 in this test method and in section 8.2 of Guide E2846. Descriptions of the testing of used thermocouples may be found Guide E2846 and Manual MNL 12 (**1**).)[3].

6.4 This test method presumes that the tested thermocouples are suitable for use in air throughout the range of calibration temperatures. To avoid oxidation of the thermoelements, refractory-metal thermocouples that have not been hermetically sealed in a sheath suitable for use in air should be tested in an inert gas environment at temperatures above approximately 500 °C. In this case, use of this test method is recommended in combination with the furnaces and related procedures described in Test Method E452.

7. Apparatus

7.1 The choice of apparatus used for the comparison test will depend primarily on the temperature range to be covered and on the desired calibration uncertainty. The apparatus required for the application of this test method will depend in detail upon the temperature range being covered but in all cases shall be selected from the equipment described as follows:

7.2 *Comparison Baths and Furnaces*—A controlled temperature comparison medium (bath or furnace) shall be used in which the measuring junction of the thermocouple to be calibrated is brought to the same temperature as a reference thermometer. The spatial uniformity of temperature within the nominally isothermal calibration zone shall be established. Acceptable methods include measurements of the calibration zone at the time of testing or the use of control charts that display the periodic calibration of check standards or the periodic characterization of the calibration zone. The frequency of such testing will depend on the inherent stability of the bath or furnace. The uniformity of the calibration zone shall be remeasured sufficiently often such that any deviations in uniformity may be corrected prior to significant adverse affect on the readings. All thermocouples being calibrated and the reference thermometer must be immersed into this zone to an extent sufficient to ensure that the measuring junction temperature is not significantly affected by heat conduction along the thermocouple and reference thermometer assemblies. To avoid contaminating the thermoelements and insulation of unsheathed thermocouples, direct contact with calibration bath fluids should be avoided.

7.2.1 *Liquid Baths*—In the range from −150−150 °C to 630 °C (−240 °F to 1170 °F) the comparator bath shall usually consist of a well stirred liquid bath provided with controls for maintaining a constant and uniform temperature. Suitable types are described in the appendix to Test Method E77. At the liquid nitrogen boiling point, −196 °C (−321 °F), an isothermal block of copper suspended in an open dewar of liquid nitrogen can provide a very effective single-point liquid bath. In the range between −196 °C (−321 °F) and −150 °C (−240 °F), the bath construction is relatively complex, and commercial systems that rely on liquid nitrogen for cooling are recommended. A properly constructed liquid bath will have temperature gradients that are small relative to either fluidized powder baths or tube furnaces. A disadvantage of liquid baths is the relatively small operating range of any one bath fluid. The temperature gradients in a liquid bath will be repeatable provided that the bath liquid does not thermally decompose at high temperatures and that the conditions of bath heating and cooling are comparable to those that existed when the bath gradients were characterized. Periodic evaluation of bath gradients is necessary when using oil baths, since oil viscosity can increase significantly after use at high temperatures. Baths with multiple heaters require a monitoring system that enables the user to readily determine that all heaters are operational.

7.2.2 *Fluidized Powder Baths*—In the range from −70 °C to 980 °C (−100 °F to 1800 °F) the comparator bath may consist of a gas-fluidized bath of aluminum oxide or similar powder. Temperature equalizing blocks are almost always necessary within fluidized baths to minimize spatial and temporal temperature variations. The repeatability of thermal gradients within such a block depends on maintaining a constant fill level of powder in the bath and maintaining a uniform gas flow through the powder. The thermal gradients of a fluidized powder bath shall be verified by including either a second reference thermometer or a check-standard thermocouple in each comparison test.

7.2.3 *Tube Furnaces*—At temperatures above approximately 620 °C (1150 °F) an electrically heated tube furnace with a suitable nominally isothermal zone will usually be used. Laboratory type tube furnaces may be used at any temperature provided that the increased uncertainty due to their spatial temperature variance is accounted for. Any one of a wide variety of designs may be suitable, but it shall be demonstrated that the furnace chosen can maintain a temperature stability of ±1 °C °C over a period of 10 min at any temperature in the range over which the furnace is to be used. The axial temperature profile of a tube furnace shall be mapped to determine the location of the region with the best temperature uniformity. Furnaces with multiple heaters require a monitoring system that enables the user to visually determine that all heaters are operational and will require periodic remeasurement of the axial temperature profile. Single-zone furnaces may vary in temperature profile slowly as the heater element ages and will require only infrequent remapping of the temperature profile.

NOTE 1—Further discussions of suitable tube furnaces are given in Appendix X1.

[3] The boldface numbers in parenthesis refer to the list of references at the end of this standard.

7.2.4 *Other Baths*—The one essential design feature of any bath to be used with this test method is that it brings the measuring junction of the thermocouple being calibrated to the same temperature as the reference thermometer. Copper blocks immersed in liquid nitrogen have been used successfully at low temperatures. The blocks are provided with wells for the test thermocouples and the reference thermometer. Similarly, uniformly heated blocks have been used at high temperatures. Such baths are not excluded under this test method, but careful explorations of existing temperature gradients must be made before confidence may be placed in such an apparatus.

7.2.5 *Isothermal Blocks*—The use of an isothermal block can substantially reduce the temperature differences between the reference thermometer and the test thermocouples. Such a block should be manufactured from a material of high thermal conductivity that will not contaminate the thermocouples under test. High thermal conductivity reduces the spatial temperature variations in the block, resulting in better thermal equilibrium between the reference thermometer and the test thermocouples. An isothermal block may also be used to reduce temporal fluctuations of the thermometers. The fluctuations will decrease as either the heat capacity of the block is increased or the heat transfer to the surrounding furnace or bath is decreased. A consequence of this decrease in fluctuations is an increase in the time for the isothermal block to reach a steady-state temperature, so care must be exercised that the block is neither too large nor too well insulated. The temperature differences between the test thermocouples and the reference thermometer should be evaluated over the full temperature range of the apparatus by performing calibrations of check-standard thermocouples at a variety of immersions in the block and with the various thermometers inserted into different bores of the block. Similar temperature differences should also be measured as a function of time, following an adjustment of the furnace or bath temperature, to determine the length of time needed to reach thermal steady-state following a temperature change. Welding the measuring junctions of the test thermocouples and of a thermocouple used as a reference thermometer is a special case of an isothermal block formed by the common measuring junction.

7.3 *Reference Junction Temperatures*— A controlled temperature medium in which the temperature of the thermocouple reference junctions is maintained constant during a measurement cycle at a known or measured value shall be provided. A commonly used reference temperature is 0 °C (32 °F), usually realized through use of the ice point, but other temperatures may be used if desired. Reports of data taken with reference temperatures other than the ice point should be corrected to reflect the results that would have been obtained if the reference junction had been at the ice point, and the report shall state both the reference junction temperature and whether the correction is based on the reference function for that type of thermocouple or on the emf-versus-temperature response of the particular thermocouple under test. As an alternative, calibration data taken with a reference junction temperature other than the ice point may be reported without correction, but in such cases the calibration report must clearly state the actual reference junction temperature. With the exception of thermocouples that have very small Seebeck coefficients at the reference junction temperature (such as Type B thermocouples), a large uncertainty in the reference junction temperature will introduce a corresponding large uncertainty in the thermocouple calibration. Whatever reference junction technique is used, its uncertainty must be accounted for in the uncertainty of the thermocouple calibration being performed. An uncertainty in the reference junction temperature,
$u(t_{\mathrm{ref}})$, will introduce an uncertainty in the measured temperature, $u_{\mathrm{rj}}(t)$:

$$u_{rj}(t) = (S(t_{ref})/S(t))\, u(t_{ref})$$

where: $S(t_{ref})$ and $S(t)$ are the Seebeck coefficients of the thermocouple at temperatures t_{ref} and t, respectively.

7.3.1 *Method to Form a Reference Junction*—Reference junctions are formed by electrically connecting the ends of the thermoelements opposite the measuring junction to copper wires that lead to the emf measuring device. Any method that gives a reliable electrical connection may be used. The connection may be formed by welding, brazing, or soldering the wires, by a screw clamp, by crimping the wires together, or by a spring-loaded connector. Completely clean finished junctions of any harmful contaminants, especially if any soldering or brazing fluxes have been used.

7.3.2 *Use of an Ice-Point Bath to Maintain Reference Junction Temperature*—An acceptable method for utilizing the ice point as a reference junction is given in Practice E563. Each joined thermoelement/copper-wire pair leading to a reference junction shall be immersed in the reference junction bath to a sufficient depth ~~such~~ that the reference junction is in thermal equilibrium with the ice-point bath. The wires shall not be immersed directly into the ice-point bath, but shall be kept dry. For this purpose, a glass, plastic, or metal protection tube is usually used to contain the thermoelement/copper pair. If a metal protection tube is used, the wires shall be fully electrically insulated from the metal tube. In all cases, the thermoelements and the copper wires above the junction itself shall be insulated with a water-resistant insulation. If more than one reference junction is placed into a single protection tube, the junctions shall be electrically insulated from each other. A test to determine an appropriate depth of immersion into the ice-point bath is as follows: Prepare two ice-point baths, one containing the measuring junction of a thermocouple in an appropriate protection tube, and the other containing the reference junctions. Record the emf of the thermocouple at varying immersions of the reference junctions, allowing 10 min for thermal equilibration after each change of depth. A plot of emf-versus-immersion depth will show the minimum immersion depth necessary such that further increases in depth give negligible changes in emf. To promote good thermal equilibrium between the ice bath and the reference junctions, it is desirable to use copper leads of 0.5 mm ~~(24 AWG)~~ 24 American Wire Gauge (AWG) diameter or less, and to use protection tubes with the smallest inner diameter that still permits ready insertion of the reference junctions.

7.3.3 *Isothermal and Electronic Reference Junction Compensation*—For the rapid calibration of large numbers of thermocouples, the reference junctions can be made at an isothermal multiterminal strip. This avoids the thermal loading of the ice bath resulting from the large number of thermocouple and copper connecting wires. The temperature and isothermal condition of the strip shall be established and monitored by the use of a separate, reference temperature sensor. The spatial temperature variation across the terminations on the isothermal unit shall be mapped and accounted for. If desired, the thermocouple emf values obtained with use of an isothermal terminal strip may be compensated such that the compensated emf is equivalent to the thermocouple emf created by a thermocouple with reference junctions at ~~0°C (32°F).~~0 °C (32 °F). An electronic reference junction compensator accomplishes this task by accurately monitoring the temperature of the reference junctions and adding to the thermocouple emf an additional emf such that the sum is equivalent to the thermocouple emf produced with reference junctions at ~~0°C.~~0 °C. The addition of emf to the thermocouple emf may be accomplished through software methods, as well as through addition of an actual emf. To minimize the uncertainty of an electronic reference junction emf as a source of error, the temperature equivalent of the emf produced by the electronic reference junction shall be known and measured with uncertainty less than that expected from the thermocouple calibration.

7.3.4 *Extension of Thermoelements to Reference Temperature* —Whenever possible, the thermoelements under test shall be continuous, extending from the measuring point through the temperature gradient, to the reference junction without any intermediate connections. In cases where this is not possible, several options exist:

7.3.4.1 *Matched Thermoelements*—Additional lengths of thermoelement materials from the same wire lots as those being calibrated may be used to extend the device under test to the reference bath. In such circumstances, no additional corrections are required.

7.3.4.2 *Thermoelements of the Same Type with Known Thermoelectric Response, but from a Different Lot*—Thermoelements being calibrated may be extended using thermoelement materials of the same type as the thermocouple under test. Such materials may be of thermocouple or extension grade, but shall have a known emf versus temperature relationship over the temperature interval to which they will be subjected, and corrections for the deviations of the extension material relative to the material under test over that interval shall be made. In general, it will be necessary to calibrate the test wire in the temperature range spanned by the extension wire and to measure the temperature of the junctions between the different materials in order to make this correction. It is acceptable to not apply a correction if the uncertainty budget for the calibration includes an appropriate allowance for temperature variations of the junction between the thermocouple and the extension material, and the calibration report specifies the range of transition junction temperatures for which the calibration is valid. This allowance may be experimentally determined by maintaining the measuring junction of the thermocouple at a fixed temperature, such as ~~0°C,~~0 °C, and varying the temperature of the transition junction over a specified range.

7.3.4.3 *Thermocouple Connectors*—In all cases where there are junctions between the thermocouple under test and thermocouple lead wires, the temperature variations across the junctions shall be minimized. Thermocouple connectors as described in Specifications E1684 and E1129/E1129M will introduce no more than ~~1.1°C (2°F)~~1.1 °C (2 °F) error for a ~~40°C (70°F)~~40 °C (70 °F) temperature difference across the connector. This error will be proportionately reduced for smaller temperature differences.

7.3.4.4 *Circumstances with Small Temperature Differences*—In special cases where the temperature differences from end-to-end along the length of the wires used to extend a thermocouple for calibration purposes are very small (less than ~~±2°C),~~±2 °C), thermocouple or extension grade wires of matching thermocouple type may be used in calibration circuits without correction.

7.4 *Emf-Measuring Instruments*—The choice of a specific instrument to use for measuring the thermocouple emf will depend on the accuracy required of the calibration being performed. Generally the thermocouple emf will be measured using a digital voltmeter. For the highest level of accuracy, voltmeters shall have a maximum uncertainty no greater than 10^{-4} times the emf reading and shall have input impedances larger than the thermocouple loop resistance by at least a factor of 10^4. Reference junction compensation is required for thermocouple measurement with voltmeters. In order to avoid forming unintended reference junctions at voltmeter terminals whose temperature may be poorly controlled, thermocouples must not be connected directly to the input terminals of voltmeters without the use of appropriate electronic reference junction compensation and connection of the voltmeter to the compensator with untinned copper wires.

7.5 *Connecting Wire Assembly*—Connecting wires from the reference junction to the voltmeter shall be insulated copper and shall be configured as twisted pairs for wire lengths greater than 0.3 m (1 ft.), to reduce electromagnetic noise pickup. If the environment contains substantial electromagnetic noise, it may also be useful to run the wires in a grounded electrical shield or braided cable. Copper connections should be clean and free from oxides.

7.5.1 Scanner systems may be used to switch between the reference thermometer and the different thermocouples being calibrated. Such switches shall be of rugged construction and designed so that both connecting wires are switched when switching from one thermocouple to the next, leaving thermocouples not in use electrically isolated. All of the scanner switches shall be constructed of the same material and shall be free of extraneous emf production (see Appendix X3). Precautions should be taken to protect the switches from temperature fluctuations due to convection, conduction, or radiation. Scanning performance shall be evaluated to ensure adequate settling time before measurement.

7.5.2 It is preferable to use wire-to-wire connections in calibration circuits, but if terminal blocks are used for convenience, they shall be protected against the development of temperature gradients across the blocks.

7.6 *Thermocouple Insulation and Protection Tubes* —In the case where bare wire thermocouples are tested, two-hole insulation tubing may be used to support and electrically insulate the immersed portion of the two bare thermoelements. Use only insulation material that will not contaminate the thermocouple (for example, clean, high-purity insulators such as 99.8 % aluminum oxide) and that will provide the necessary electrical insulation at the highest temperature of the calibration. To prevent contamination of thermocouples by residues left by previously tested thermocouples, each insulator shall only be used with thermocouples of one type and the positive and negative thermoelements shall always be inserted in the same bore. The only exceptions allowed are: type R and type S thermocouples may be calibrated in the same insulators, and the thermoelements of type B thermocouples may be mounted in either bore. To avoid unnecessary mass and to minimize axial heat conduction in the region of the measuring junction, the tubing should be relatively thin walled. Bore diameters should provide a loose fit for the thermocouple wires. During the test, the thermocouples may be inserted in a protection tube that is resistant to thermal shock, and noncontaminating to the thermocouple materials.

7.6.1 Sheathed thermocouples may be tested without further protection or support in liquid or dry fluidized baths, provided that the bath medium is compatible with the sheath material. Thermocouples insulated with fibrous insulation must not be immersed directly into any bath liquid. 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 indication ~~in~~of temperature change is noted.

8. Reference Thermometers

8.1 The reference thermometer to be used for the comparison calibration of thermocouples will depend upon the temperature range covered, the type of calibration apparatus, the accuracy desired, or in cases where more than one type of thermometer will suffice, the preference of the calibrating laboratory. All reference thermometers shall be calibrated to indicate values of temperature corresponding to the International Temperature Scale of 1990. The condition of the reference thermometer shall be verified both before and after a calibration or a documented number of calibrations by checking its indication at a thermometric fixed point or by using a comparison measurement of total uncertainty less than the allowed uncertainty of the reference thermometer. Specific methods of verification for each type of reference thermometer are described in 8.10~~8.10.~~.

8.2 *Platinum Resistance Thermometers*— Platinum Resistance thermometers are an excellent choice as a reference in cases where the highest accuracy is required. Standard platinum resistance thermometers (SPRTs) are the most accurate reference thermometers for use at temperatures from approximately −196 °C to 962 °C (−310 °F to 1764 °F), with calibration uncertainties as low as 0.001 °C (0.002 ° F). SPRTs must meet a set of criteria specified by the ITS-90. In addition, there are a variety of platinum resistance thermometers that do not meet the criteria for SPRTs that have sufficient accuracy for use as a reference thermometer with this test method. Standard platinum resistance thermometers are described in X2.1, other platinum resistance thermometers are described in X2.2, and measurement instruments are described in X2.3.

8.3 *Thermistors*—For temperatures in the approximate range −40 °C (−40 °F) to 150 °C (300 ° F), a thermistor may serve as a reference thermometer with uncertainty of 0.001 to 0.01 °C. Section X2.5 provides additional information.

8.4 *Liquid-in-Glass Thermometers*—Liquid-in-glass thermometers may be used from –80 °C (−110 °F), or lower, to 400 °C (750 °F), or even higher with special types. Generally, the accuracy of these thermometers is less below −60 °C, where organic thermometric fluids are used, and above 400 °C where dimensional changes in the bulb glass may be relatively rapid, requiring frequent calibration. Further discussion of liquid-in-glass thermometers is given in X2.4. Specifications for ASTM thermometers are given in Specification E1.

8.5 *Types R and S Thermocouples (Platinum-Rhodium versus Platinum)*—The platinum-10 % rhodium versus platinum (Type S), or the platinum-13 % rhodium versus platinum thermocouple (Type R) of 0.5-mm (24-gauge) diameter wire is recommended as the reference thermometer for temperatures from 960 °C (1760 °F) to 1200 °C (2190 °F). Their use may also be extended down to room temperature. Uncertainties attainable with careful use are given in Tables 1 and 2.

8.6 *Type B Thermocouples (Platinum-Rhodium versus Rhodium-Platinum)*—The platinum-30 % rhodium versus platinum-6 % rhodium (Type B) thermocouple, of 0.5-mm (24-gauge) or larger diameter wire, is recommended as the reference thermometer for temperatures above 1200 °C (2190 °F). The uncertainties of temperature measurements with this type of thermocouple are given in Tables 1 and 2.

8.7 *Type T Thermocouples (Copper versus Constantan)* —The type T thermocouple may serve as a useful reference thermometer in the range of −195 °C to 370 °C (−320 °F to 700 °F) in some instances, although its accuracy is, in general, limited by the stability of the wire at temperatures above approximately 200 °C (390 °F), and by the accuracy of the emf measurements and the inhomogeneity of the wire below 200 °C. One-half millimeter diameter (24 gauge) wire is a useful compromise between the lesser stability of smaller wire and the greater heat conduction of large wire.

8.8 *Gold versus Platinum Thermocouples*— The gold versus platinum thermocouple is useful as a reference thermometer over the range 0 °C to 1000 °C (32 °F to 1830 °F). With proper construction and annealing, a gold versus platinum thermocouple will have uncertainties of approximately 0.01 °C to 0.02 °C (0.02 °F to 0.04 °F). To attain this performance, care in the emf measurements and protection of the thermoelements from contamination is necessary.

8.9 *Single-use Base-metal Thermocouples*—For tests to elevated temperature, a base metal thermocouple taken from a calibrated lot of wire of verified homogeneity may be used as a reference thermometer. Lot homogeneity may be determined by calibrating thermocouples fabricated from a statistical sample of the wire lot, and determining the standard deviation of emf values