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# Standard Guide for Accuracy Verification of Industrial Platinum Resistance Thermometers[1]

This standard is issued under the fixed designation E2593; 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 describes the techniques and apparatus required for the accuracy verification of industrial platinum resistance thermometers constructed in accordance with Specification E1137/E1137M and the evaluation of calibration uncertainties. The procedures described apply over the range of -200 °C to 650 °C.

1.2 This guide does not intend to describe procedures necessary for the calibration of platinum resistance thermometers used as calibration standards or Standard Platinum Resistance Thermometers. Consequently, calibration of these types of instruments is outside the scope of this guide.

1.3 Industrial platinum resistance thermometers are available in many styles and configurations. This guide does not purport to determine the suitability of any particular design, style, or configuration for calibration over a desired temperature range.

1.4 The evaluation of uncertainties is based upon current international practices as described in JCGM 100:2008 "Evaluation of measurement data—Guide to the expression of uncertainty in measurement" and ANSI/NCSL Z540.2-1997 "U.S. Guide to the Expression of Uncertainty in Measurement."

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *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]

E344 Terminology Relating to Thermometry and Hydrometry

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

E644 Test Methods for Testing Industrial Resistance Thermometers

E1137/E1137M Specification for Industrial Platinum Resistance Thermometers

E1502 Guide for Use of Fixed-Point Cells for Reference Temperatures

E1750 Guide for Use of Water Triple Point Cells

E2623 Practice for Reporting Thermometer Calibrations

E2488 Guide for the Preparation and Evaluation of Liquid Baths Used for Temperature Calibration by Comparison

2.2 *ANSI Publications:*[3]

ANSI/NCSL Z540.2-1997 U.S. Guide to the Expression of Uncertainty in Measurement

ANSI/NCSL Z540.3-2006 Requirements for the Calibrations of Measuring and Test Equipment

2.3 *Other Publication:*[4]

JCGM 100:2008 Evaluation of measurement data—Guide to the expression of uncertainty in measurement

## 3. Terminology

3.1 *Definitions*—The definitions given in Terminology E344 shall be considered as applying to the terms used in this guide.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *annealing, v*—a heat treating process intended to stabilize resistance thermometers prior to calibration and use.

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[1] This guide is under the jurisdiction of ASTM Committee E20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.03 on Resistance Thermometers.

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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] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] JCGM 100:2008, Evaluation of measurement data—Guide to the expression of uncertainty in measurement. Available from the BIPM, Sevres, France, http://www.bipm.org/en/publications/guides/gum.html.

3.2.2 *check standard, n*—a thermometer similar in design to the unit under test, but of superior stability, which is included in the calibration process for the purpose of quantifying the process variability.

3.2.3 *coverage factor, n*—numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty.

3.2.4 *dielectric absorption, n*—an effect in an insulator caused by the polarization of positive and negative charges within the insulator which manifests itself as an in-phase current when the voltage is removed and the charges recombine.

3.2.5 *expanded uncertainty, U, n*—quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand.

3.2.5.1 *Discussion*—Typically, *U* is given at a coverage factor of 2, approximating to a 95.45 % confidence interval for a normal distribution.

3.2.6 *hysteresis, n*—property associated with the resistance of a thermometer whereby the value of resistance at a temperature is dependent upon previous exposure to different temperatures.

3.2.7 *normal distribution, n*—a frequency distribution characterized by a bell-shaped curve and defined by two parameters: mean and standard deviation.

3.2.8 *platinum resistance thermometer (PRT), n*—a resistance thermometer with the resistance element constructed from platinum or platinum alloy.

3.2.9 *rectangular distribution, n*—a frequency distribution characterized by a rectangular-shaped curve and defined by two parameters: mean and magnitude (semi-range).

3.2.10 *standard deviation of the mean, n*—an estimate of the standard deviation of the sampling distribution of means, based on the data from one or more random samples.

3.2.10.1 *Discussion*—Numerically, it is equal to the standard deviation obtained (*s*) when divided by the square root of the size of the sample (*n*).

$$\text{Standard Deviation of the Mean} = \frac{s}{\sqrt{n}} \quad (1)$$

3.2.11 *standard platinum resistance thermometer (SPRT), n*—a specialized platinum resistance thermometer constructed in such a way that it fulfills the requirements of the ITS-90.[5]

3.2.12 *standard uncertainty, n*—uncertainty of the result of a measurement expressed as a standard deviation, designated as *S*.

3.2.13 *Type A evaluation (of uncertainty), n*—method of evaluation of uncertainty by the statistical analysis of a series of observations.[4]

3.2.14 *Type B evaluation (of uncertainty), n*—method of evaluation of uncertainty by means other than statistical analysis of a series of observations.[4]

3.2.15 *test uncertainty ratio (TUR), n*—the ratio of the tolerance of the unit under test to the expanded calibration uncertainty.

3.2.16 *uncertainty budget, n*—an analysis tool used for assembling and combining component uncertainties expected in a measurement process into an overall expected uncertainty.

3.2.17 *unit under test (UUT), n*—the platinum resistance thermometer to be calibrated.

## 4. Summary of Guide

4.1 The UUT is calibrated by determining the electrical resistance of its sensing element at one or more known temperatures covering the temperature range of interest. The known temperatures may be established by means of fixed-point systems or by using a reference thermometer. Either an SPRT or a PRT is recommended for use as the reference thermometer. However, a liquid in glass (LIG) thermometer, thermistor, or thermocouple may be acceptable, depending upon the temperature of calibration, required accuracy, or other considerations.

4.2 The success of the calibration depends largely upon the ability of the UUT to come to thermal equilibrium with the calibration temperature of interest (fixed point cell or comparison system) and upon accurate measurement of the sensing element resistance at that time. Instructions are included to guide the user in achieving thermal equilibrium and proper resistance measurement, including descriptions of apparatus and instrumentation.

4.3 Industrial platinum resistance thermometers are available in many styles and configurations. This guide includes limited instructions pertaining to the preparation of the UUT into a configuration that facilitates proper calibration.

4.4 Proper evaluation of calibration uncertainties is critical for the result of a calibration to be useful. Therefore, a considerable portion of this guide is devoted to uncertainty budgets and the evaluation of uncertainties.

## 5. Significance and Use

5.1 This guide is intended to be used for verifying the resistance-temperature relationship of industrial platinum resistance thermometers that are intended to satisfy the requirements of Specification E1137/E1137M. It is intended to provide a consistent method for calibration and uncertainty evaluation while still allowing the user some flexibility in the choice of apparatus and instrumentation. It is understood that the limits of uncertainty obtained depend in large part upon the apparatus and instrumentation used. Therefore, since this guide is not prescriptive in approach, it provides detailed instruction in uncertainty evaluation to accommodate the variety of apparatus and instrumentation that may be employed.

5.2 This guide is intended primarily to satisfy applications requiring compliance to Specification E1137/E1137M. However, the techniques described may be appropriate for applications where more accurate calibrations are needed.

[5] Mangum, B. W., NIST Technical Note 1265, Guidelines for Realizing the International Temperature Scale of 1990 (ITS-90).

5.3 Many applications require tolerances to be verified using a minimum test uncertainty ratio (TUR). This standard provides guidelines for evaluating uncertainties used to support TUR calculations.

## 6. Sources of Error

6.1 Uncertainties are present in all calibrations. Errors arise when the effects of uncertainties are underestimated or omitted. The predominant sources of uncertainty are described in Section 12 and listed in Table 2.

## 7. Apparatus

7.1 *Resistance Measuring Instruments*—The choice of a specific instrument to use for measuring the UUT and reference thermometer resistance will depend upon several factors. Some of these factors are ease of use, compatibility with computerized data acquisition systems, method of balancing, computation ability, and so forth. All of the instruments listed are commercially available in high precision designs and are suitable for use. They require periodic linearity checks or periodic calibration. (Refer to Appendix X2 for detailed descriptions and schematics.) The uncertainty of the resistance measurements directly impacts the uncertainty of the temperature measurement as shown in Eq 2.

$$Uncertainty_t = \frac{Uncertainty_\Omega}{Sensitivity} \tag{2}$$

where:.

$Uncertainty_t$ = equivalent temperature uncertainty at temperature (t), °C,
$Uncertainty_\Omega$ = resistance uncertainty at temperature (t), Ω, and
*Sensitivity* = sensitivity at temperature (t), Ω $°C^{-1}$

7.1.1 *Bridge*—Precision bridges with linearity specifications ranging from 10 ppm of range to 0.01 ppm of range and with 6½ to 9½ digit resolution are available. These instruments are available in models using either alternating current (AC) or direct current (DC) excitation. The linearity is typically based upon resistive or inductive dividers and is generally quite stable over time. Modern bridges are convenient automatic balancing instruments but manual balancing types are also suitable. These instruments typically require external reference resistors and do not perform temperature calculations.

7.1.2 *Digital Thermometer Readout*—Digital instruments designed specifically to measure resistance thermometers are available. Modern versions function essentially as automatic potentiometers and reverse the current to minimize DC offset errors caused by thermal emf and residual voltages inherent to the electronic components and related circuitry. Precision instruments with linearity specifications ranging from 20 ppm of indication to 1 ppm of indication and with 6½ to 8½ digit resolution are commercially available. Some models have extensive internal computation capability, performing both temperature and statistical calculations. Periodic calibration is required.

7.1.3 *Digital Multimeter (DMM)*—Digital multimeters are convenient direct indication instruments typically able to indicate in resistance or voltage. Some models have extensive internal computation ability, performing both temperature and statistical calculations. The use of DC offset compensation is recommended. Caution must be exercised to ensure that the excitation current is appropriate for the UUT and reference thermometer to avoid excessive self-heating. Periodic calibration is required.

7.1.4 *Reference Resistor*—Reference resistors are specially designed and manufactured to be stable over long periods of time. Typically, they have significant temperature coefficients of resistance and require maintenance in a temperature-enclosed air or oil bath. Some have inductive and capacitive characteristics that limit their suitability for use with AC bridges. Periodic (yearly or semi-yearly) calibration is required. Resistors (AC or DC) are required to match the type of measurement (AC or DC) system in use.

7.2 *Reference Thermometers*—The choice of a specific instrument to use as the reference thermometer will depend upon several factors, including the uncertainty desired, temperature range of interest, compatibility with existing instrumentation and apparatus, expertise of staff, cost limitations, and so forth. All of the instruments listed are commercially available in various levels of precision and stability and may be suitable for use. They all require calibration. The frequency of calibration depends a great deal upon the manner in which they are used and the uncertainty required in use.

7.2.1 *SPRT*—SPRTs are the most accurate reference thermometers available and are used in defining the ITS-90 from approximately -260 °C to 962 °C. The SPRT sensing element is made from nominally pure platinum and is supported essentially strain-free. These instruments are extremely delicate and are easily damaged by mechanical shock. They are available sheathed in glass or metal and in long-stem and capsule configurations. The design and materials of construction limit the temperature range of a specific instrument type. Some sheath materials can be damaged by use at high temperatures in metal blocks or molten salt baths. Calibration on the ITS-90 is required.

7.2.2 *Secondary Reference PRT*—Secondary Reference PRTs are specially manufactured PRTs designed to be suitable calibration standards. These instruments are typically less delicate than SPRTs but have higher measurement uncertainties and narrower usage ranges. They are typically sheathed in metal to allow immersion directly into metal furnaces or molten salt baths. Calibration on the ITS-90 is required.

7.3 *Fixed Point Systems*—Fixed point systems are required in the ITS-90 calibration of SPRTs. Very low uncertainties are attainable with these systems, but their complex procedures and design criteria may limit their application to other types of thermometers. However, certain adaptations are suitable for the calibration of industrial platinum resistance thermometers.

7.3.1 *Triple Point of Water (TPW) Cell and Apparatus*—The triple point of water cell is a critical thermometric fixed point for calibration and control of SPRTs. These devices can be useful in the calibration of industrial resistance thermometers but typically are not used because of limited throughput capabilities. For further information refer to Guide E1750.