



AEROSPACE MATERIAL SPECIFICATION

AMS2750™**REV. H**

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Superseding AMS2750G

Pyrometry

RATIONALE

AMS2750H results from a Two-Year Review and update of this specification with changes to Definitions (see 2.4.21, 2.4.25, 2.4.36, 2.4.47, and 2.4.84); General Sensor Requirements (see Table 3); Sensor Calibration (see 3.1.4.6 and Table 5); SAT and TUS Sensor Reuse (see 3.1.7.4 and 3.1.7.5); Base Metal Load Sensors (see 3.1.10.3); General Instrumentation Requirements (see 3.2.1.4.1, 3.2.1.5, and Table 7); Control, Recording, and Over-Temperature Instruments (see 3.2.3.4, 3.2.3.5, 3.2.3.16, and 3.2.3.18); Instrumentation Calibration Results and Records (see 3.2.5.1); General Instrument Correction and Modification Offset Requirements (see 3.2.6.1.2 and 3.2.6.1.8); Thermal Processing Equipment (see 3.3.7); General SAT Requirements (see Table 11, Table 12, and 3.4.1.2.1); Performing an SAT (see 3.4.2.2); Alternate SAT Frequency (see 3.4.8.3); SAT Waiver (see 3.4.9.6.3); SAT Difference Pass/Fail Requirements (see 3.4.10.4); Comparison SAT (see 3.4.11.1.e); Parts furnace class, instrument type, and TUS internal (see Table 15); Raw material furnace class, instrument type, and TUS internal (see Table 16); Initial TUS Temperatures (see 3.5.2.4); TUS Requirements for Batch Furnaces, Salt Baths, Controlled Temperature Liquid Baths, and Fluidized Bed Furnaces (Excluding Controlled Temperature Quench Baths) (see Table 17); TUS Data Collection (see 3.5.10.1 and 3.5.10.2); Relocation of Hot or Cold Recording Sensors for Type A and C Instrumentation (see 3.5.15.2); Radiation Survey (see 3.5.17, 3.5.17.1, and 3.5.17.2); TUS Interval Deviations (see 3.5.18); Rounding (see 3.8); and Quality Assurance Provisions (see 4.2, 4.4, and Table 22). Deleted Zener Voltage Reference (was 3.5.87).

1. SCOPE

- 1.1 This specification covers pyrometric requirements for equipment used for the thermal processing of metallic materials. Specifically, it covers temperature sensors, instrumentation, thermal processing equipment, correction factors and instrument offsets, system accuracy tests, and temperature uniformity surveys. These are necessary to ensure that parts or raw materials are heat treated in accordance with the applicable specification(s).
- 1.2 This specification may be used in other non-heat-treating applications when specified.
- 1.3 This specification is not applicable to heating or to intermediate thermal processing unless otherwise specified.
- 1.4 This specification applies to laboratory furnaces to the extent specified in 3.6.

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

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2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AS7766 Terms Used in Aerospace Metals Specifications

2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E29 Using Significant Digits in Test Data to Determine Conformance with Specifications

ASTM E207 Standard Test Method for Thermal EMF Test of Single Thermoelement Materials by Comparison with a Reference Thermoelement of Similar EMF-Temperature Properties

ASTM E220 Calibration of Thermocouples by Comparison Techniques

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

ASTM E608 Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples

ASTM E1137 Industrial Platinum Resistance Thermometers

ASTM E1751 Standard Guide for Temperature Electromotive Force (emf) Tables for Non-Letter Designated Thermocouple Combinations

ASTM MNL7 Presentation of Data and Control Chart Analysis

ASTM MNL12 Use of Thermocouples in Temperature Measurement

2.3 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 60751 Industrial Platinum Resistance Thermometers and Platinum Temperature Sensors

ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories

2.4 Definitions

Terms used in AMS2750 are defined in AS7766 and as follows:

2.4.1 ACCURACY

The maximum deviation of the instrument or sensor being tested from the values of a traceable standard.

2.4.2 ADJUSTMENT

Any change to an instrument's parameters.

2.4.3 AUTOCLAVE

An oven capable of operating at pressures higher than atmospheric pressure (nominally 760 mm Hg), commonly used in the processing of materials. It may be pressurized with steam, compressed air, or inert gas.

2.4.4 BASE METAL SENSOR

Sensor whose thermoelements are composed primarily of base metals and their alloys. Examples of base metal sensors include Types E, J, K, N, M, and T.

2.4.5 BATCH FURNACE

A furnace where parts or raw material are stationary during the soak.

NOTE: Some batch furnaces may oscillate material within a stationary work zone.

2.4.6 BIAS or INPUT SHIFT

The act of making an adjustment to an instrument to add, remove, or alter an offset.

2.4.7 BIMONTHLY

See FREQUENCY.

2.4.8 BIWEEKLY

See FREQUENCY.

2.4.9 CALIBRATION

An assessment of the accuracy of a sensor or an instrument to a traceable standard sensor and/or field test or standard instrument, based on one or more measurements, and potentially adjusting an instrument and/or compiling a deviation chart for a sensor or instrument in order to ensure compliance with requirements.

2.4.10 CONTINUOUS FURNACE

A furnace where parts or raw material are conveyed continuously or semi-continuously from the charge area to the discharge area. Examples include: bump furnace, shaker furnace, belt furnace, roller furnace, and rotary hearth furnace.

2.4.11 CONTROL INSTRUMENT

An instrument connected to a control sensor used to control the temperature of thermal processing equipment. The instrument may or may not also record temperature data.

2.4.12 CONTROL SENSOR

A sensor connected to a control instrument on thermal processing equipment, the temperature of which may or may not be recorded.

2.4.13 CONTROL ZONE

A portion of the working zone in thermal processing equipment having a separate sensor, instrument, and heating or cooling system to control its temperature. This portion of the thermal processing equipment is independently controlled.

2.4.14 CONTROLLED TEMPERATURE LIQUID BATH

A furnace containing a liquid that is heated to the desired heat-treat temperature. Parts and raw material are normally immersed in the liquid.

2.4.15 CONTROLLER

A digital or mechanical device that controls the temperature of thermal processing equipment (e.g., furnace control instruments, quench mechanical thermostat, freezer pressure controls, etc.).

2.4.16 CORRECTION FACTOR

The number of degrees, determined from the most recent calibration, that must be added to, or subtracted from, the temperature reading of a sensor, or an instrument, or a combination thereof (system) to obtain true temperature. The correction factors of sensors and instruments are usually kept separately and added together algebraically when a combination is used. Correction factor is the algebraic opposite of deviation (error).

2.4.17 DATA ACQUISITION SYSTEM

An instrument system used to automatically collect and store process data as an electronic record; for example, a Programmable Logic Controller (PLC).

2.4.18 DEVIATION/ERROR

In the context of this specification, the difference between the uncorrected indicated temperature and the true temperature (Indicated Temperature - True Temperature = Deviation/Error).

2.4.19 DIGITAL INSTRUMENT

An instrument that records process measurements in a digital (numeric) display format or an instrument that prints both the scale (graph) and trend line simultaneously. Examples include recorders with pre-printed scales and printed tabular data meeting 3.2.1.4 data collection intervals and recorders that create scales and trend line or tabular data and also display indicated temperature.

2.4.20 ELECTRONIC RECORD

Any combination of text, graphics, data, audio, pictorial, or other information representation in digital form that is created, modified, maintained, archived, retrieved, or distributed by a computer system.

2.4.21 EXPENDABLE SENSORS

Sensors where any portion of the thermoelements are exposed to the thermal process equipment environment. Sensors with braided fiberglass insulation or plastic insulation are not designed to be inserted into a closed protection tube as the confined space causes drift when the additives (e.g., Teflon, color dies, and other chemicals) burn off. Therefore, these sensors are expendable even when installed into a closed protection tube.

2.4.22 EXTENSION WIRE

Wire used for transmitting an unmodified signal from the sensor to the instrumentation system. Wire is generally of the same sensor type, except for some sensor types that allow compensated extension wire.

2.4.23 FIELD TEST INSTRUMENT

An instrument meeting the requirements of Table 7 that has calibration traceable to a secondary standard instrument or better and is used to conduct on-site calibrations or tests of thermal processing equipment.

2.4.24 FLUIDIZED BED FURNACE

A furnace that contains a medium that becomes suspended or fluidized due to atmosphere gas or products of combustion passing upward through the medium. Parts and raw material are normally immersed in the fluidized medium.

2.4.25 FREQUENCY (INTERVAL)

The calendar days from the day/date a calibration, test, or sensor replacement was performed and the next day/date a calibration, test, or sensor replacement is due (inclusive). In the context of this specification, the following shall apply:

Frequency	Equal to Once Every	Shall Be Completed On or Before
Weekly	Week	The same day of the week every week
Biweekly	2 weeks	The same day of the week every 2 weeks
Monthly	Month	The same date of the month every month ⁽¹⁾
Bimonthly	2 months	The same date of the month every 2 months ⁽¹⁾
Quarterly	3 months	The same date of the month every third month ⁽¹⁾
Semiannually	6 months	The same date of the month every 6 months ⁽¹⁾
Annually	Year	The same date of the year every year ⁽¹⁾

⁽¹⁾ If the next calibration, test, or sensor replacement is due on a calendar date not contained in that month, then the last day of that calendar month shall be used for the next calibration (e.g., a monthly calibration, test, or sensor replacement performed on January 31 is due on the last day of February).

2.4.26 FURNACE

Equipment used for the thermal processing of parts or raw material. The terms “furnace” and “oven” can be used interchangeably.

2.4.27 HEAT SINK

A mass of material with an embedded sensor or sensors that supplies temperature data of that mass to recording instruments.

2.4.28 INTERVAL

See FREQUENCY.

2.4.29 LABORATORY THERMAL PROCESSING EQUIPMENT

Equipment used exclusively for thermal processing of samples, specimens, or test parts as required by materials and processing specifications.

2.4.30 LOAD SENSOR

Sensor that is attached to, or in contact with, parts or raw material, a representation of parts or raw material, or is buried in the load of parts (e.g., fasteners) or raw material and which supplies temperature data of the parts or raw material to recording instruments that may be used to control the sequence of the production process, such as the start of soak.

2.4.31 MATERIAL PRODUCER (METALLIC)

The manufacturer of raw material as stated in 2.4.53.

2.4.32 MAXIMUM PERMITTED ERROR

A tolerance band for the thermal electric response expressed in degrees or percentages. Maximum permitted error provides a tolerance within which various types of sensors shall conform to standard sensor reference tables, or equivalent.

2.4.33 MEASURING JUNCTION

The location of a sensor where the wire elements are joined together to complete a measurement circuit, which is used to measure an unknown temperature. Also called the “hot junction.”

2.4.34 MULTIPLE ZONED FURNACES

Furnaces with multiple separate temperature control zones.

2.4.35 NOBLE METAL SENSOR

Sensor whose thermoelements are composed primarily of noble metals (e.g., platinum/platinum-rhodium) and their alloys. Examples of noble metal sensors include Types R, S, B, and RTDs.

2.4.36 NONEXPENDABLE SENSORS

Sensors having no portion of the thermoelements exposed to the thermal process equipment environment. Sensors with ceramic insulators over bare wire inserted into a closed protection tube to prevent exposure to the thermal process equipment environment are considered nonexpendable sensors.

2.4.37 NONMETALLIC MATERIALS

In the context of this specification, this term refers to the curing of composite or adhesive bonded assemblies that are typically processed in autoclaves, air ovens, or heated presses.

2.4.38 OFFSET

Any manual or electronic adjustment to an instrument made to alter either the desired set point or the displayed value of the instrument's calculated temperature. Manufacturer specific terminology may also include "bias," "input shift," etc.

2.4.38.1 CORRECTION OFFSET

Manual or electronic adjustment of an instrument to compensate for known errors of the measurement system (instrument, extension wire/connectors, sensor) to make the system more accurate.

2.4.38.2 MODIFICATION OFFSET

Manual or electronic adjustment of an instrument to compensate for known conditions such as, but not limited to, a skewed TUS result or control thermocouple placement in a retort or muffle.

2.4.39 OVEN

Equipment used for the thermal processing of materials and parts. The terms "oven" and "furnace" can be used interchangeably.

2.4.40 OVER-TEMPERATURE INSTRUMENTATION

An independent sensor and instrument combination installed in the thermal processing equipment that is used to detect any over-temperature occurrence and generate an alarm and/or cut back or shut down heat input. The purpose for this control is to protect parts or raw material and/or the thermal processing equipment from overheating. Integrated control/recording/over-temperature instruments are permitted provided it can be demonstrated that the over-temperature instrument/module of an integrated system is separated from the furnace control/recording system.

2.4.41 PARTS

Usually identified by a part number, produced from raw material in accordance with the requirements of an engineering drawing, and usually tested by nondestructive techniques only. Parts are heat treated, by or for a fabricator, in accordance with a drawing, purchase order, fabrication order, or heat-treat specification.

NOTE: The cognizant engineering organization has the authority to assign the terms "parts" or "raw material."

2.4.42 PREVENTIVE MAINTENANCE PROGRAM or PM PROGRAM

A program for evaluating, taking corrective action as required, and documenting the condition of items that have potential to adversely affect thermal processing equipment conformance to any requirement of this specification. Frequency of PM checks is established based on experience to ensure that no major problems occur between periodic PMs.

2.4.43 PRIMARY STANDARD INSTRUMENT

An instrument that is calibrated directly against a reference standard instrument and meeting the requirements of Table 7.

2.4.44 PRIMARY STANDARD SENSOR

Sensor calibrated directly against a reference standard and meeting the requirements of Table 1.

2.4.45 PROCESS CHART RECORDER

See RECORDING INSTRUMENT.

2.4.46 PROGRAMMABLE LOGIC CONTROLLER (PLC)

A digital computer control system that continuously monitors the state of input devices and makes decisions based upon a programmed input (recipe) to control the state of output devices.

2.4.47 QUALIFIED OPERATING TEMPERATURE RANGE

The nominal set point temperature range of thermal processing equipment where temperature uniformity has been tested within a qualified work zone and found to be compliant with required tolerances (i.e., qualified operating temperature range = nominal range of TUS set points).

2.4.48 QUALIFIED WORK ZONE

The portion of a thermal processing equipment volume where temperature variation conforms to the required uniformity tolerance within the qualified operating temperature range as defined by the placement of sensors during the most recent temperature uniformity survey.

2.4.49 QUALITY ORGANIZATION APPROVAL

Objective evidence of review and acceptance or rejection of a calibration or test as defined by a documented process within the user's quality system, which also defines any delegation of this approval.

2.4.50 QUENCH SYSTEM

A system that provides rapid cooling, usually accomplished using oil, water, water/polymer mixtures, or gaseous mediums.

2.4.51 RADIATION SURVEY

Initial survey of aluminum alloy thermal processing equipment used above 800 °F or 427 °C when the heat source (e.g., electrical elements or gas tubes) is exposed to the qualified work zone or only separated by a metal baffle.

2.4.52 RADIATION SURVEY SENSOR

A TUS sensor, typically a base metal (Types E, J, K, N, M, and T) sensor, used in conjunction with a test panel for determining the heating characteristics of furnaces used for solution heat treating aluminum alloys.

2.4.53 RAW MATERIAL

Usually includes, but is not limited to, such items as sheet, plate, wire, rod, bar, forgings, castings, and extrusions. Raw material is usually identified by a heat or lot number and is usually tested destructively for acceptance. Raw material is heat treated, by or for a material producer, in accordance with a process or material specification.

NOTE: The cognizant engineering organization has the authority to assign the terms “parts” or “raw material.”

2.4.54 RAW MATERIAL FURNACES

Equipment used in accordance with a process or material specification to process raw material.

2.4.55 RECORDING INSTRUMENT

An instrument connected to a controlling, load, and/or recording sensor that documents process equipment temperature data and generates a permanent process record. Examples are a chart recorder, electronic data recorder, or a data acquisition system.

2.4.56 RECORDING SENSOR

A sensor that is connected to a recording instrument or connected to a control instrument of an integrated control/recording system.

2.4.57 RECURRENT TEMPERATURE PATTERN

Cycling of furnace temperature due to operation of the temperature control instrument.

2.4.58 REFERENCE STANDARD INSTRUMENT

A standard test instrument that has been calibrated by NIST or other internationally recognized standards organization meeting Table 7 requirements.

2.4.59 REFERENCE STANDARD SENSOR (NOBLE METAL)

A noble metal standard sensor that has been calibrated by NIST or other internationally recognized standards organization meeting Table 1 requirements.

2.4.60 REFRACTORY SENSOR

A sensor whose thermoelements are composed primarily of refractory metals (e.g., Tungsten, Rhenium, Tantalum, Niobium, and Molybdenum) and their alloys.

Example: Type C sensors.

2.4.61 REFRIGERATION EQUIPMENT

A compartment, cabinet, or room that may be held below room temperature and $>32^{\circ}\text{F}$ or 0°C (refrigerator) or $\leq 32^{\circ}\text{F}$ or 0°C (freezer), depending on the temperature range of use. This equipment may be used for retarding or advancing metallurgical transformation or for storage of metallic materials.

2.4.62 RESIDENT SAT SENSOR

A test sensor that remains resident in the test location between system accuracy tests.

2.4.63 RESISTANCE TEMPERATURE DEVICE (RTD)

A device (for example, PT100, PRT, etc.) that produces a change in resistance across an element in response to the temperature at the element (usually in the tip).

2.4.64 RETORT FURNACE

A furnace that contains a retort or muffle that isolates the parts or raw material being heat treated from the heating elements. The furnace normally surrounds the retort.

2.4.65 SALT BATH

A furnace containing molten salt that is heated to the desired heat-treat temperature. Parts or raw material are normally immersed in the molten salt.

2.4.66 SECONDARY STANDARD TEST INSTRUMENT

An instrument calibrated directly against a primary standard or reference standard meeting Table 7 requirements and which is operated in a controlled test environment.

2.4.67 SECONDARY STANDARD TEST SENSOR

A sensor calibrated directly against a primary standard test sensor meeting the requirements of Table 1.

2.4.68 SEMI-CONTINUOUS FURNACE

See CONTINUOUS FURNACE.

2.4.69 SENSOR OR TEMPERATURE SENSOR

In the context of this specification, a device designed to detect or measure temperature (e.g., thermocouple, RTD, etc.).

2.4.70 SPECIAL LIMITS OF ERROR SENSOR WIRE

Sensors and extension wires whose initial calibration accuracy meets or exceeds the requirements of ASTM E230, Tables 2 and 3 for special tolerances.

2.4.71 STABILIZATION (also referred to as EQUALIZATION, EQUILIBRIUM, STEADY STATE, or SOAKED CONDITION)

Equipment stabilization occurs when all control and recording sensors are within the allowable temperature uniformity survey tolerance span and controllers are cycling and/or maintaining the desired temperature in each zone. Temperature uniformity survey stabilization occurs when all temperature uniformity survey sensors have reached the desired uniformity range and are not exhibiting a continual upward or downward trend away from the set point during and after the stabilized period of the temperature uniformity survey.

2.4.72 SYSTEM ACCURACY TEST (SAT)

An assessment of the sum of the combined errors or correction factors of the sensor, extension wire (and connectors), and instrument to ensure compliance with Table 11 or Table 12 requirements.

2.4.72.1 COMPARISON SAT

An assessment by comparison of the difference between the readings of the thermal process equipment sensor system being tested (sensor, extension wire, and instrument) and the corrected reading of the test sensor system (test sensor, extension wire, and field test instrument) after test sensor and field test instrument correction factors are applied (see 3.4.7). Also referred to as a "probe check."

2.4.72.2 ALTERNATE SAT

A mathematical assessment of the sum of the errors or correction factors of the thermal processing equipment sensor and the calibration error or correction factor of the connector, extension wire, and instrument channel (see 3.4.8).

2.4.72.3 SAT WAIVER

Additional requirements and comparisons to be made when the comparison or alternate SAT methods are not performed (see 3.4.9).

2.4.73 SYSTEM ACCURACY TEST SENSOR

A calibrated and traceable sensor meeting the requirements of Table 1 used for an SAT.

2.4.74 TEMPERATURE OVERSHOOT

When any temperature sensor exceeds the upper temperature tolerance as defined by the applicable thermal processing equipment class as stated in Table 8.

2.4.75 TEMPERATURE SENSOR PASS-THROUGH

Installed wiring connecting sensors (typically thermocouples) inside the thermal processing equipment to the instrumentation outside, usually with sockets, jacks, or terminals at each end.

2.4.76 TEMPERATURE UNIFORMITY

The temperature variation (usually expressed as $\pm$ degrees) within the qualified work zone with respect to set point temperature. For retort furnaces where a sensor in the retort is used to control temperature, the temperature variation is with respect to the sensor in the retort and not to the furnace set point temperature. The requirement is established by the required thermal processing equipment class as stated in Table 8.

2.4.77 TEMPERATURE UNIFORMITY RECORDER

Independent digital recording instrument meeting the requirements of Table 7 for a field test instrument and used to perform temperature uniformity surveys.

2.4.78 TEMPERATURE UNIFORMITY SENSOR

A calibrated and traceable sensor meeting the requirements of Table 1.

2.4.79 TEMPERATURE UNIFORMITY SURVEY (TUS)

An assessment of the temperature variation within the qualified work zone of thermal processing equipment prior to and after stabilization using a field test instrument (TUS recorder) meeting Table 7 requirements and sensors meeting the requirements of Tables 1, 17, and 18, as applicable.

2.4.80 THERMAL PROCESSING

Any process in which parts or raw material are exposed to controlled heating, soaking, or cooling to achieve the specified properties or condition of the parts or raw material for which there is no exception stated in 1.3.

2.4.81 THERMAL PROCESSING EQUIPMENT

A term used to refer to any vessel (such as autoclave, furnace, oven, quench and refrigeration equipment, liquid bath, heated press, etc.) used to process parts or raw material at controlled temperatures.

2.4.82 THERMOCOUPLE

A temperature sensor consisting of two wires (thermoelements) of dissimilar thermoelectric characteristics connected at a measuring junction. An EMF is developed between the two junctions in proportion to the temperature gradient.

2.4.83 TRACEABLE OR TRACEABILITY

The ability to relate measurement results through an unbroken chain traceable to the International System of Units (SI) through internationally recognized standards organizations such as, but not limited to:

National Institute of Standards and Technology (NIST)
National Physical Laboratory (NPL)
Physikalisch-Technische Bundesanstalt (PTB)
Swedish National Authority for Testing, Inspection, and Metrology
China National Calibration Technology Specification (CNAS)
National Institute of Advanced Industrial Science and Technology (AIST)
Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (INMETRO)
Bureau International des Poids et Mesures (BIPM)

2.4.84 USE (OF A SENSOR)

One cycle of heating or cooling upon the sensor being placed into service (see Table 5 note 5, 3.1.4.2, 3.1.7.2, 3.1.7.5, and 3.1.11.1).

2.4.85 VACUUM FURNACE

A furnace that processes parts or raw material at any pressure lower than atmospheric pressure (nominally 760 mm Hg) during soak.

2.4.86 WIRELESS TRANSMITTER

A device for sending electromagnetic waves; the part of a broadcasting apparatus that generates and modulates the radio frequency current and conveys it to a receiver.

3. TECHNICAL REQUIREMENTS

3.1 Temperature Sensors

3.1.1 General Sensor Requirements

- 3.1.1.1 Unless specifically noted, the requirements defined in this specification shall apply to all sensors.
- 3.1.1.2 All sensors shall comply with the requirements of Table 1. Other sensors that possess equal or better calibration accuracy may be used. Thermocouple composition shall comply with the requirements of ASTM E230 or ASTM E1751 and Table 2.
- 3.1.1.3 Resistance temperature devices (RTDs) shall be noble metal, shall comply with the requirements of Table 1, and shall be considered nonexpendable.
- 3.1.1.4 Sensors may be made either from bare or coated wire or mineral insulated/metal sheathed (MIMS) cable as described in Tables 2 and 3.

3.1.1.5 Measuring junctions shall be made by either of the following methods:

- Any combination of twisting and/or welding the thermoelements provided there is no addition of filler metal (including ungrounded and grounded MIMS).
- Spot welding the thermoelements directly to a part, simulated part, or heat sink is permitted for temperatures ≤ 2000 °F or 1100 °C.

Table 1 - Sensors and sensor calibration⁽¹²⁾

Sensor	Use	Type ⁽¹⁾⁽¹⁰⁾	Calibration		Calibration Accuracy ⁽²⁾
			Interval	Standard	
Reference standard	Primary standard calibration ⁽⁵⁾	B, R, S	Before first use; 5 years	NIST ⁽⁴⁾ reference standard	Refer to NIST or equivalent calibration report
Primary standard	Secondary standard calibration ⁽⁶⁾	B, R, S	Before first use; 3 years	Reference standard ⁽⁵⁾	Type R, S: ± 1.0 °F or ± 0.6 °C or $\pm 0.1\%$ Type B: $\pm 0.25\%$
Secondary standard ⁽⁷⁾	Sensor calibration	B, R, S, RTD ⁽¹⁰⁾	Before first use; 2 years	Primary standard ⁽⁶⁾	Type R, S: ± 1.0 °F or ± 0.6 °C or $\pm 0.1\%$ ⁽¹³⁾ Type B: $\pm 0.25\%$ ⁽¹³⁾ Refractory ⁽⁹⁾ Base metal: ± 2.0 °F or ± 1.1 °C or $\pm 0.4\%$ ⁽¹¹⁾ RTD ⁽¹⁰⁾
System accuracy test ⁽³⁾		B, R, S, RTD, base metal, and refractory	Before first use ⁽³⁾	Primary or secondary standard ⁽⁸⁾	
Temperature uniformity survey ⁽³⁾					
Control and recording ⁽³⁾	Installation in thermal processing equipment	B, R, S, RTD, base metal, and refractory	Before first use ⁽³⁾	Primary or secondary standard ⁽⁸⁾	
Load ⁽³⁾	Sensing part or raw material temperature		Before first use ⁽³⁾		

⁽¹⁾ Sensors of equal or better calibration accuracy are acceptable.

⁽²⁾ Percent of reading or correction factor in °F or °C, whichever is greater.

⁽³⁾ Sensor recalibration and reuse requirements are provided in Table 5.

⁽⁴⁾ NIST or other internationally recognized standards organization.

⁽⁵⁾ A reference standard sensor together with a primary standard instrument shall be used to calibrate primary standard sensors.

⁽⁶⁾ A primary standard sensor together with a primary standard instrument shall be used to calibrate secondary standard sensors.

⁽⁷⁾ Use shall be limited to the calibration of control, recording, and load sensors, and SAT and TUS sensors.

⁽⁸⁾ A primary or secondary standard sensor together with a primary or secondary standard instrument shall be used to calibrate these sensors.

⁽⁹⁾ For refractory sensors Type C: ± 8.0 °F or ± 4.4 °C or $\pm 1\%$, the sensor correction factor shall be used for all applications.

⁽¹⁰⁾ RTDs, when used, shall be platinum type and meet Class/Grade A tolerances given in ASTM E1137 or IEC 60751. This does not apply to RTDs used in conjunction with a refrigeration equipment controller.

⁽¹¹⁾ For temperatures < 32 °F or < 0 °C for Types K, E, and T only, calibration accuracy shall meet the following:

- Type K: -328 to 32 °F, ± 4.0 °F or -200 to 0 °C, ± 2.2 °C, or $\pm 2.0\%$ for either, whichever is greater.
- Type E (MIMS): -328 to 32 °F, ± 4.0 °F or -200 to 0 °C, ± 2.2 °C, or $\pm 2.0\%$ for either, whichever is greater.
- Type E (all other): -328 to 32 °F, ± 3.0 °F or -200 to 0 °C, ± 1.7 °C, or $\pm 1.0\%$ for either, whichever is greater.
- Type T: -328 to 32 °F, ± 1.8 °F or -200 to 0 °C, ± 1.0 °C, or $\pm 1.5\%$ for either, whichever is greater.

⁽¹²⁾ Sensors and sensor materials are normally supplied to meet the tolerances specified in the table for temperatures above 32 °F or 0 °C. The same materials, however, may not fall within the tolerances for temperatures below 32 °F or 0 °C. Two separate sensors may be required, one for each range.

⁽¹³⁾ When correction factors are used during production:

- Type B sensors shall meet a calibration accuracy of $\pm 0.5\%$,
- Types R and S sensors shall meet calibration accuracy of ± 2.7 °F or ± 1.5 °C or $\pm 0.25\%$, whichever is greater.

Table 2 - Sensor and extension wire/connector

Sensor					Extension Wire		
Classification	Type	Positive Element Composition Nominal wt. %	Negative Element Composition Nominal wt. %	Element Color Code ⁽¹⁾	Wire Code Positive/Negative	Jacket Color Code ⁽¹⁾	Connector Color Code ⁽¹⁾
Base Metal	J	Fe	55Cu/45Ni	White/Red	JPX/JNX	Black	Black
	E	90Ni/10Cr	55Cu/45Ni	Purple/Red	EPX/ENX	Purple	Purple
	K	90Ni/10Cr	95Ni/5, Al + Si	Yellow/Red	KPX/KNX	Yellow	Yellow
	N	84.5Ni/14Cr/1.5Si	95.4Ni/4.5Si/0.1Mg	Orange/Red	NPX/NNX	Orange	Orange
	M ⁽³⁾	82Ni/18Mo	Ni	Yellow/Red	KPX/KNX	Yellow	Yellow
	T	Cu	55Cu/45Ni	Blue/Red	TPX/TNX	Blue	Blue
Noble Metal ⁽²⁾	R	87Pt/13Rh	PT	Black/Red	RPX/RNX or SPX/SNX	Green	Green
	B	70Pt/30Rh	94Pt/6Rh	Gray/Red	BPX/BNX	Gray	Gray
	S	90Pt/10Rh	PT	Black/Red	RPX/RNX or SPX/SNX	Green	Green
Refractory ⁽²⁾	C	95W/5Re	74W/26Re	Green/Red	CPX/CNX	Red	Red

⁽¹⁾ All color codes stated are in accordance with ASTM E230. Color codes in accordance with other internationally recognized standards organizations are acceptable.

⁽²⁾ Most base metal extension wires have the same nominal composition as the sensor wires with which they are intended to be used, whereas the compensating extension wires for noble metal (Types S, R, and B) or refractory metal sensors (Type C) are usually of a different, more economical composition whose relative thermoelectric properties as a pair nonetheless closely approximate those of the noble metal or refractory metal sensors with which they are to be used over a limited temperature range.

⁽³⁾ The designation "Type M" may not be recognized by all international standards. Type K extension wire and connectors shall be used for Type M sensors.

Table 3 - Sensor classification

Sensor Cover	Sensor Classification ⁽¹⁾
Fiberglass, plastic, or trade name	Expendable
Multiple hard fired ceramic beads	Expendable
Metal over-braid	Expendable
Shielded from the process atmosphere by a closed metal/ceramic protective tube	Nonexpendable
Mineral insulated; metal sheathed (MIMS)	Nonexpendable
Mineral insulated; metal sheathed (MIMS) with an exposed measuring junction	Expendable

⁽¹⁾ See definitions for expendable and nonexpendable sensors.

3.1.2 Sensor Temperature Range of Use

Guidelines for sensor temperature range usage can be found in ASTM MNL12, ASTM E230, ASTM E608, ASTM E1137, ASTM E1751, IEC 60751, or other internationally recognized standards, and the sensor supplier.

3.1.3 Extension Wire and Connectors

3.1.3.1 Extension wire shall be of the same nominal composition as the sensor and instrumentation used, except when compatible compensating extension wire is allowed (e.g., noble metals). Extension wire shall meet the requirements of Table 2.

3.1.3.2 Extension wire shall not be spliced other than using a compatible connector.

3.1.3.3 Connectors, plugs, jacks, and terminal strips are permitted if they are the compatible type, i.e., they have thermoelectric properties conforming to the characteristics of the corresponding sensor type.

3.1.3.4 Wireless transmitters may be used as an alternative to extension wire.

3.1.4 Sensor Calibration

3.1.4.1 The sensor calibration technique shall comply with ASTM E207, ASTM E220, or other internationally recognized standards.

3.1.4.2 Sensors shall be calibrated before their first use.

3.1.4.3 Sensor calibration intervals, whether based on time, number of uses, or temperatures, are the maximums permitted.

3.1.4.4 Users shall have procedures that control the replacement of thermal process equipment sensors including limits on maximum life and/or number of uses based on supporting data such as, but not limited to, SAT, TUS, recalibration data, and/or trend analysis.

3.1.4.5 Sensors shall be calibrated or recalibrated at, or lower than, the lowest temperature of use and at, or higher than, the highest temperature of use. Sensors used at a single temperature may be calibrated at the single temperature of use.

3.1.4.6 Intervals between calibration or recalibration temperatures provided by the calibration agency shall not exceed 250 °F or 140 °C for all sensors. The fixed point calibration method in ASTM MNL12 or other internationally recognized standards may be used. No matter what standard is used, the calibration agency shall provide additional calibration points that do not exceed 250 °F or 140 °C for all sensors.

- 3.1.4.7 Extrapolation of calibration correction factors above the highest calibration temperature and below the lowest calibration temperature is prohibited by any calibration source except NIST or other internationally recognized standards organization.
- 3.1.4.8 Interpolation of correction factors between two known calibration points is permitted using the linear method.
- 3.1.4.9 Alternatively, the correction factor of the nearest calibration point shall be used.
- 3.1.4.10 Whichever method is used shall be defined and applied consistently.
- 3.1.4.11 For recalibration of sensors when permitted in Table 5, it is acceptable to use either the date of recalibration or the date of first use following recalibration as the beginning of the calibration period. Procedures shall identify how the practice is applied and documented to ensure compliance.

3.1.5 Wire/Cable Rolls

- 3.1.5.1 Calibrated expendable or nonexpendable sensors made from rolls may be used in lieu of individually calibrated sensors.
- 3.1.5.2 The maximum length of wire/cable in a roll at the time of calibration shall comply with Table 4.

Table 4 - Maximum permitted length of wire/cable in a roll

Sensor	Maximum Permitted Length of Wire/Cable in a Roll
Primary standard	200 feet or 60 m
All other noble metal	2000 feet or 610 m
All other base metal	5000 feet or 1525 m
Refractory	2000 feet or 610 m

- 3.1.5.3 Rolls shall be sampled and calibrated at both ends. The individual correction factors from each end shall be within the requirements of Table 1, and the average correction factor shall be calculated from both ends of the roll at each calibration temperature and used for the entire length of the roll.
- 3.1.5.4 The roll shall not be used if the difference between the correction factors from each end of the sample sensors at any individual calibration temperature exceeds:
- 1.0 °F or 0.6 °C for primary and secondary standard sensors.
 - 2.0 °F or 1.1 °C for control, recording, and load sensors, and SAT and TUS sensors.
- 3.1.5.5 The following shall apply to rolls not meeting the requirements of 3.1.5.4:
- It is permitted to divide the roll into shorter lengths provided the shorter lengths meet the requirements of 3.1.5.4.
 - It is permitted to use individual sensors from the roll provided they are calibrated to the requirements of Table 1.

3.1.6 General Sensor Reuse Requirements

Reuse of any sensor is not permitted unless the insulation remains intact and the wire/cable including the measuring junction are not damaged (see Table 5).

Table 5 - Sensor reuse and recalibration

Sensor Use	Sensor Type	Form	Recalibration ⁽³⁾	Reuse ⁽¹⁾⁽²⁾⁽⁵⁾
Test Sensors TUS	Base and Refractory	Expendable	Recalibration of expendable base metal sensors is not permitted	- Quarterly when used at or below 500.0 °F or 260.0 °C - M, C, T, K, E: Limited by number of uses, temperature of use, and calendar days since first use (see 3.1.7.3) - J, N: Limited by number of uses, temperature of use, and calendar days since first use (see 3.1.7.3)
		Nonexpendable	M, C, T, J & N: Quarterly (see Table 1) E & K: Quarterly; permitted if used at or below 500.0 °F or 260.0 °C; not permitted if used above 500.0 °F or 260.0 °C	No other restrictions
	Noble ⁽⁴⁾	Expendable	Semiannually (see Table 1)	No other restrictions
		Nonexpendable		
Test Sensor Nonresident SAT	Base and Refractory	Expendable	Recalibration of expendable base metal sensors is not permitted	- Quarterly when used at or below 500.0 °F or 260.0 °C - M, C, T, K, E: Limited by number of uses, temperature of use, and calendar days since first use (see 3.1.7.3) - J, N: Limited by number of uses, temperature of use, and calendar days since first use (see 3.1.7.3)
		Nonexpendable	M, C, T, J & N: Quarterly (see Table 1) E & K: Quarterly; permitted if used at or below 500.0 °F or 260.0 °C; not permitted if used above 500.0 °F or 260.0 °C	No other restrictions
	Noble ⁽⁴⁾	Expendable	Semiannually (see Table 1)	No other restrictions

Sensor Use	Sensor Type	Form	Recalibration ⁽³⁾	Reuse ⁽¹⁾⁽²⁾⁽⁵⁾
		Nonexpendable		
Test Sensors Resident SAT	Base	Expendable	Recalibration of expendable base metal sensor is not permitted	M, E, J, K, T: Shall only be used at or below 500.0 °F or 260.0 °C N: Shall only be used at or below 1000.0 °F or 538.0 °C and is limited by the number of uses, temperature, and calendar days (see 3.1.7.3)
		Nonexpendable	M, T, J, N: Quarterly E & K: Quarterly; permitted if used at or below 500.0 °F or 260.0 °C (see Table 1)	M, E, J, K, T: Shall only be used at or below 500.0 °F or 260.0 °C N: No other restrictions
	Noble ⁽⁴⁾	Expendable	Semiannually (see Table 1)	Shall only be used at or below 1000.0 °F or 538.0 °C
		Nonexpendable		No other restrictions
Control and Recording Sensors	All	All	Before first use	Replaced as stated in 2.4.42, 3.1.4.4, 3.4.8, and 3.4.9
Load Sensors	Base and Refractory	Expendable	Recalibration is not permitted	Limited by number of uses, temperature of use, and calendar days since first use (see 3.1.10.1, 3.4.8, and 3.4.9)
		Nonexpendable	M, C, T, J & N: Quarterly E & K: Quarterly; permitted if used at or below 500.0 °F or 260.0 °C; not permitted if used above 500.0 °F or 260.0 °C	Limited by number of uses, temperature of use, and calendar days since first use (see 3.1.10.2, 3.4.8, and 3.4.9)
	Noble ⁽⁴⁾	Expendable	Semiannually except as stated in 3.4.8 and 3.4.9 (see Table 1)	No other restrictions except as stated in 3.4.8 and 3.4.9
		Nonexpendable		

Sensor Use	Sensor Type	Form	Recalibration ⁽³⁾	Reuse ⁽¹⁾⁽²⁾⁽⁵⁾
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- (1) For reuse of any Type E or Type K sensor used above 500.0 °F or 260.0 °C, the depth of insertion shall be equal to or greater than any previous use (see 3.1.7.1).
- (2) See 3.1.6 and 3.1.7 for general reuse restrictions.
- (3) Recalibration of any Type E or Type K sensor used above 500.0 °F or 260.0 °C is prohibited.
- (4) Includes RTDs.
- (5) Reuses: Example 1: Begin at room temperature, ramp to 900 °F or 480 °C for first TUS temperature, then ramp to 1200 °F or 650 °C for TUS max temperature, then cool back to room temperature. This is a single use.
 Example 2: Begin at room temperature, ramp to 1325 °F or 718 °C for first production temperature, then cool to 1150 °F or 621 °C for the second production temperature, then cool back to room temperature. This is a single use.
 Example 3: Begin at room temperature, ramp to 1900 °F or 1038 °C for first production temperature, then cool to 300 °F or 150 °C, then ramp up to 1100 °F or 593 °C for second production temperature, then cool back to room temperature. This is two uses even if the load remained closed inside the equipment.

3.1.7 SAT and TUS Sensor Reuse

3.1.7.1 During the reuse of Type E or Type K sensors when used above 500.0 °F or 260.0 °C, the depth of insertion shall be equal to or greater than any previous use.

3.1.7.2 Expendable base metal, noble metal, and refractory SAT and TUS sensors may be reused:

- Base metal and refractory sensors may be used for up to 3 months from first use, without limit to number of uses, when used exclusively at or below 500.0 °F or 260.0 °C.
- Noble metal sensors may be used for up to 6 months from first use, without limit to number of uses or temperature of use.

3.1.7.3 Expendable Base Metal and Refractory SAT and TUS Sensors

- Types M, C, T, K, and E shall be limited to 3 months or five uses, whichever occurs first, between 500.0 °F and 1200.0 °F or between 260.0 °C and 650.0 °C and limited to a single use above 1200.0 °F or 650.0 °C.
- Types J and N shall be limited to 3 months or ten uses, whichever occurs first, between 500.0 °F and 1200.0 °F or between 260.0 °C and 650.0 °C and limited to a single use above 1200.0 °F or 650.0 °C.

3.1.7.4 Records shall be maintained of the accumulated sensor reuse including sensor batch number, temperature, and use count.

Example 1: Sensors are replaced after a single use. Sensor batch number shall be recorded for the SAT and/or TUS.

Example 2: Sensors are reused. Sensor batch number, temperature, and use count shall be recorded for each use.

3.1.7.5 Base metal or refractory TUS sensors shall be limited to no more than the maximum number of uses defined in 3.1.7.3 for expendable sensors, 270 uses for nonexpendable sensors, or 6 months from first use, whichever occurs first, and may be reused subject to the limitations of 3.1.6 and 3.1.8 that are:

- Used exclusively at ≤1200 °F or ≤650 °C.
- Identified by the date of installation and by the number and temperatures of accumulated uses.
- Preserved/protected from damage (i.e., crimping, excessive moisture contact, corrosion, etc.) between each TUS or remain installed on a rack that is protected between each TUS.