SAE Aerospace
An SAE International Group

# AEROSPACE MATERIAL SPECIFICATION

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| AMS2750 | REV. E |
| Issued 1980-04<br>Revised 2012-07<br><br>Superseding AMS2750D | |

## (R) Pyrometry

RATIONALE

5 year update and review of specification with reorganization to improve access. Technical changes resolve issues determined in usage. Changes are extensive and not marked.

CONTENTS






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## 1. SCOPE

1.1 This specification covers pyrometric requirements for thermal processing equipment used for heat treatment. It covers temperature sensors, instrumentation, thermal processing equipment, 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 is not applicable to heating, or to intermediate thermal processing unless specifically referenced by a material or process specification.

1.3 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 canceled and no superseding document has been specified, the last published issue of that document shall apply.

### 2.1 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 E 29 Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

ASTM E 207 Standard Test Method for Thermal EMF Test of Single Thermoelement Materials by Comparison with a Reference Thermoelement of Similar EMF-Temperature Properties

ASTM E 220 Standard Test Method for Calibration of Thermocouples by Comparison Techniques

ASTM E 230 Standard Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples

ASTM E 608 Standard Specification for Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples

ASTM E 1129 Standard Specification for Thermocouple Connectors

ASTM MNL 7 Manual on Presentation of Data and Control Chart Analysis

ASTM MNL 12 Manual on the Use of Thermocouples in Temperature Measurement



### 2.2 Definitions

Terms used in AMS are clarified in ARP1917 and as follows:

2.2.1 ACCURACY: The maximum deviation of the instrumentation being tested from the corrected readings of a traceable standard.

2.2.2 BASE METAL THERMOCOUPLE: Thermocouple whose thermoelements are composed primarily of base metals and their alloys. Examples of base metal thermocouples include E, J, K, N, and T.

2.2.3 BIMONTHLY: In the context of this document, bimonthly is equal to once every two months.

2.2.4 BIWEEKLY: In the context of this document, biweekly is equal to once every two weeks.

2.2.5 CALIBRATION: The process of adjusting an instrument or compiling a deviation chart so its reading may be correlated to the actual value being measured.

2.2.6 CONTINUOUS FURNACE: A furnace where product is conveyed continuously from the charge area to the discharge area.

2.2.7 CONTROL INSTRUMENT: An instrument connected to a sensor and used to control the temperature of process equipment (including quench baths and refrigeration equipment). The instrument may or may not also record temperature.

2.2.8 CONTROL SENSOR: A sensor connected to the furnace temperature controller, which may or may not be recording.

2.2.9 CONTROL ZONE OR FURNACE CONTROL ZONE: A portion of the working zone in thermal processing equipment having a separate sensor/instrument/heat input or output mechanism to control its temperature. This portion of a furnace is independently controlled.

2.2.10 CONTROLLED TEMPERATURE LIQUID BATH: A furnace containing a liquid that is heated to the desired heat treat temperature. Product is normally immersed in the liquid.

2.2.11 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.

2.2.12 DATA ACQUISITION SYSTEM: An instrument system used to automatically collect and store process data as an electronic record.

2.2.13 DEAD BAND: The range within which the temperature input can be altered upscale and downscale without registering a change on the instrumentation.

2.2.14 DEVIATION: In the context of this document, the difference between the uncorrected indicated temperature and the true temperature.

2.2.15 DIGITAL INSTRUMENT: An instrument that presents process measurements in a digital (numeric) display format. Typical examples are mechanical recorders with digital displays, digital indicators, controllers with digital displays, etc. In the case of a recorder with digital temperature display and a recorder trace (line) the record (recorder trace) is analog while the display is digital. A recorder trace on a paper chart is an analog record.

2.2.16 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.

2.2.17 ELAPSED USAGE TIME: Number of calendar days from the first use of a sensor, (regardless of the number of cycles of use).

2.2.18 EXPENDABLE THERMOCOUPLES: Thermocouples made of fabric or plastic covered wire. The wire is provided in coils or on spools. Insulation usually consists of glass braid, or ceramic fiber cloth on each conductor plus glass braid overall.

2.2.19 FAILURE OF SURVEY THERMOCOUPLE: Obviously incorrect or erratic activity of a survey thermocouple indicated by extreme high readings, extreme low readings, and/or erratic changes in readings not reflected by other sensors.

2.2.20 FIELD TEST INSTRUMENT: An instrument that is portable, that meets the requirements of Table 3, has calibration traceable to secondary equipment or better and is used to conduct on-site tests of thermal processing equipment.

2.2.21 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. Product is normally immersed in the fluidized medium.

2.2.22 FURNACE: Equipment used for the thermal processing of materials and parts. The term furnace includes ovens.

2.2.23 GROUNDED JUNCTION: A sheathed thermocouple having the hot junction (measurement junction) end fused or welded to the end closure of the protective sheath.

2.2.24 HEAT SINK: A mass of material equivalent to the heat transfer characteristics of the thinnest section of the part being heat-treated. Heat sinks may be used during TUS (3.5.10.1) and during production (3.3.5).

2.2.25 INTERVAL: The calendar time between 2 tests or calibrations. Examples include: week or weekly requires the due date is the same day in the following week – a span of 7 calendar days; month or monthly to indicate the next test occurs on the same numerical day in the following month. If the monthly test is performed on the 31st day of a month followed by a month with 30 days, the due date is the last day of the following month (similar for tests on January 29-31 – the due date is the last day of the following month. Same definitions apply to the bi-weekly, quarterly, semiannual and annual intervals.

2.2.26 LABORATORY FURNACE: A furnace used only for determining response to heat treatment as required by material specifications.

2.2.27 LOAD SENSORS: Sensors that are attached to or in contact with production material, a representation of production material, or are buried in the load of production material and which supply temperature data of the production material to process instrumentation.

2.2.28 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 thermocouples must conform to standard thermocouple reference tables.

2.2.29 MATERIAL PRODUCER: The manufacturer that produces a product in accordance with a material specification that may require by reference conformance to a heat treat specification. Casting, extrusion and forging manufacturers and their approved vendors are considered material producers. Warehouses, distributors, or similar organizations are not considered material producers.

2.2.30 MEASURING JUNCTION: That area of a thermocouple joined together to complete a measurement circuit, which is used to measure an unknown temperature. Also called the hot junction.

2.2.31 MONITORING INSTRUMENT: An instrument connected to a controlling, monitoring, load or recording sensor that indicates process equipment temperature. Examples are an indicating device, chart recorder, electronic data recorder or a data acquisition system.

2.2.32 MONITORING SENSOR: A sensor connected to the monitoring instrument.

2.2.33 NOBLE METAL THERMOCOUPLE: Thermocouple whose thermoelements are composed primarily of noble metals (e.g., platinum/platinum-rhodium) and their alloys. Examples of noble metal thermocouples include types R, S and B.

2.2.34 NONEXPENDABLE THERMOCOUPLES: Thermocouples that are not covered with fabric or plastic insulations. One type consists of ceramic insulators over bare thermocouple wire, sometimes inserted in a tube for stability and protection. A second type consists of a combination of thermocouple wires, mineral insulation, and a protecting metal sheath compacted into a small diameter. The thermocouple thus constructed is protected, flexible and, within the temperature limits of the sheath material, may be used many times without insulation breakdown. This type of thermocouple, conforming to ASTM E 608, is available under many trade names.

2.2.35 OVER-TEMPERATURE INSTRUMENTATION: A separate sensor and instrument combination installed in the furnace, which is used to monitor 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 material and/or the furnace from overheating.

2.2.36 PARTS HEAT TREATMENT: Heat treatment by a source other than the raw material producer. Product is tested to the requirements of the heat treat processing specification or to selected requirements of other specifications.

2.2.37 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 furnace temperature uniformity. Frequency of PM checks is established based on experience to ensure that no major problems occur between PM's.

2.2.38 PRIMARY TEST SENSOR: Sensor with calibration directly traceable to a reference standard. Normally used to calibrate secondary test sensors.

2.2.39 PROCESS CHART RECORDER: See Recording Instrument definition.

2.2.40 PRIMARY TEST INSTRUMENT: An instrument that is calibrated directly against instruments calibrated by NIST or equivalent national standard. Normally used to calibrate secondary instrumentation.

2.2.41 QUALIFIED OPERATING TEMPERATURE RANGE: The temperature range of thermal processing equipment where temperature uniformity has been tested and found to be within required tolerances as specified in 3.3.

2.2.42 QUALIFIED WORK ZONE: The defined portion of a furnace volume where temperature variation conforms to the required uniformity tolerance.

2.2.43 QUALITY ORGANIZATION APPROVAL: Documented process for review and acceptance/rejection of a report or test which also defines any delegation of this approval.

2.2.44 QUENCH SYSTEM: A system that facilitates rapid cooling, usually accomplished using oil, water, water/polymer mixtures, or gaseous mediums. Quenchants are usually delivered by immersion, spray, or fog.

2.2.45 RAW MATERIAL HEAT TREATMENT (e.g., sheet, plate, bar, extrusions, forgings, castings): Heat treatment performed by or for the raw material producer and product is tested as required by a material specification.

2.2.46 RAW MATERIAL FURNACES: Equipment used by or for a material producer (or an approved supplier of a material producer) in accordance with a material specification which may require by reference conformance to a heat treat specification.

2.2.47 RECORDING INSTRUMENT: An instrument connected to a controlling, monitoring, load or recording sensor that indicates process equipment temperature data and generates a permanent process record. Examples are a chart recorder, electronic data recorder or a data acquisition system.

2.2.48 RECORDING SENSOR: A sensor that is connected to a recording instrument.

2.2.49 RECURRENT TEMPERATURE PATTERN: Cycling of furnace temperature due to temperature control.

2.2.50 REFERENCE STANDARD (NOBLE METAL): A standard that has been calibrated as required in Table 1 to a relevant National Standard.

2.2.51 RESIDENT SAT SENSOR: A test sensor that remains resident in the test location between system accuracy tests.

2.2.52 RETORT FURNACE: A furnace that contains a retort or muffle which normally contains a protective atmosphere and the product being heat treated. The furnace normally surrounds the retort.

2.2.53 RTD: Resistance Temperature Device.

2.2.54 SALT BATH FURNACE: A furnace containing molten salt that is heated to the desired heat treat temperature. Product is normally immersed in the molten salt.

2.2.55 SECONDARY TEST INSTRUMENT: An instrument with calibration directly traceable to a primary standard or reference standard and which is operated in a controlled test environment.

2.2.56 SECONDARY TEST SENSOR: Sensor with calibration directly traceable to a primary test sensor. Normally used to calibrate test sensors.

2.2.57 SEMI-CONTINUOUS FURNACE: A furnace where product is conveyed at regular time intervals from the charge area to the discharge area.

2.2.58 SENSITIVITY: The temperature change in the input that is required to activate a change, either upscale or downscale on the instrumentation. It is normally one-half the numerical value of the dead band, such as: a sensitivity of 1 °F (0.6 °C) is equivalent to a dead band of 2 °F (1.1 °C).

2.2.59 SENSOR: In the context of this document, a device designed to detect or measure temperature (e.g., thermocouple, RTD, etc.). As used in this specification, this term is identical with "Temperature Sensor."

2.2.60 SHEATHED-THERMOCOUPLE ASSEMBLY (MIMS): The cut-to-length finished assembly consisting of thermoelements having one end joined in a measuring junction, contained within and electrically isolated from, a protective sheath closed at the measuring end. The protective sheath has a moisture seal at the reference junction end of the sheath. The assembly may include a thermocouple connector but does not include a reference junction or extension leads mechanically joined to the thermoelements.

2.2.61 STABILIZATION (also referred to as equalization, equilibrium, steady state or soaked condition): Furnace stabilization occurs when all control thermocouples are within the allowable TUS tolerance span and controllers are cycling and/or maintaining the desired temperature in each zone. All survey thermocouples must be within the desired temperature range and must not be changing such that they may drift above or below the maximum or minimum temperature.

For unloaded furnaces: if the temperature readings of any TUS sensor exhibit an upward or downward trend that is not converging toward the set point the test period shall be extended as necessary until the trend is no longer evident.

For loaded furnaces: If a survey load is used during the TUS, some survey thermocouples may continue to rise in temperature and slowly approach the set temperature. This rise in temperature of survey thermocouples towards the set temperature meets the requirement for stabilization.

2.2.62 SYSTEM ACCURACY TEST (SAT) or PROBE CHECK: An on-site comparison of the instrument/leadwire/sensor readings or values, with the readings or values of a calibrated test instrument/leadwire/sensor to determine if the measured temperature deviations are within applicable requirements. Performed to assure the accuracy of the furnace control and recorder system in each control zone.

2.2.63 SYSTEM ACCURACY TEST (SAT) SENSOR: A calibrated and traceable sensor with known deviations, if any, used for system accuracy tests.

2.2.64 TEMPERATURE CONTROLLER: The instrument or PLC (Programmable Logic Controller) used to control the temperature within a furnace zone.

2.2.65 TEMPERATURE OVERSHOOT: The amount of temperature rise in the furnace work zone above the applicable positive TUS tolerance that occurs upon first reaching furnace set point temperature.

2.2.66 TEMPERATURE UNIFORMITY: The temperature variation (usually expressed as ± degrees) within the qualified furnace 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 temperature."

2.2.67 TEMPERATURE UNIFORMITY SENSOR: A calibrated and traceable sensor with known deviations if any, that are used for conducting Temperature Uniformity Surveys.

2.2.68 TEMPERATURE UNIFORMITY SURVEY (TUS): A test or series of tests where calibrated field test instrumentation and sensors are used to measure temperature variation within the qualified furnace work zone prior to and after thermal stabilization.

2.2.69 TEST INSTRUMENT: Instrument used to perform system accuracy tests, temperature uniformity surveys or calibrations of controllers, recorders, data acquisition instruments, or monitoring instruments.

2.2.70 TEST SENSOR: Sensor used in conjunction with a test instrument to perform a system accuracy test or temperature uniformity survey.

2.2.71 THERMAL PROCESSING: Any process in which materials are exposed to controlled heating, soaking, or cooling to change the structural nature, properties or condition of the material or part. The term excludes pre-heating and heating for forging, drying, and hot forming.

2.2.72 THERMAL PROCESSING EQUIPMENT: A term used to refer to any vessel (such as furnace, oven, freezer, liquid bath, etc.) used to process materials at controlled temperatures.

2.2.73 THERMOCOUPLE: A type of sensor consisting of two electrically conducting circuit elements of different thermoelectric characteristics joined at a junction.

2.2.74 THERMOCOUPLE CALIBRATION: The process of determining the emf developed by a thermocouple with respect to temperature established by a national standards organization.

2.2.75 TRACEABLE (or TRACEABILITY): The ability to relate measurement results through an unbroken chain of calibration to NIST or equivalent agencies in countries outside the United States.

2.2.76 TRANSVERSE PLANE: Plane perpendicular to the conveyance direction in a continuous or semi-continuous furnace.

2.2.77 USE (of a thermocouple – e.g., 3.1.3.3 and 3.1.5.2 to 3.1.5.3): One cycle of heating and cooling a thermocouple.

2.2.78 VACUUM FURNACE: A furnace capable of operation at any pressures lower than atmospheric pressure (760 mm Hg).

2.2.79 ZONED FURNACES: Furnaces with separately controlled temperature zones.

# 3. TECHNICAL REQUIREMENTS

## 3.1 Temperature Sensors

All temperature sensors shall comply with Table 1 and the following requirements. Exclusions for specific applications shall be as listed in the following paragraphs.

### 3.1.1 General Sensor Information and Requirements

3.1.1.1 Temperature shall be measured by the thermocouples listed in Table 2 or by other thermocouples or temperature sensors that possess equal or better accuracy (maximum permitted error). Thermocouples may be made either from bare or coated wire or MIMS (mineral insulated, metal sheathed) cable. Unless specifically noted, requirements apply to all temperature sensor materials. “Sensor” as used in this specification is identical with “temperature sensor“.

3.1.1.2 Conversion from millivolts to degrees or degrees to millivolts shall be in accordance with ASTM E 230 or other national standard.

3.1.1.3 Correction factors for sensors derived from their initial or subsequent calibration may be used to improve temperature accuracy and shall be used when required by this specification.

3.1.1.4 Thermocouple Usage

Thermocouples should only be used within the ranges listed in Tables 3.1 (Recommended Upper Temperature Limits for Protected Thermocouples) or 3.5 (Recommended Upper temperature Limits for Protected Thermoelements) of ASTM MNL 12, Table 6 (Suggested Upper Temperature limits for Protected Thermocouples) of ASTM E 230, or Table 1 (Suggested Upper Temperature Limits for Sheathed Thermocouples) of ASTM E 608 or other national standard and the sensor supplier.

3.1.1.4.1 Use of thermocouples not conforming to these recommendations shall be based upon calibration and recalibration intervals required in Table 1 of this document.

3.1.1.5 Extension wire in installations after September 1, 2006 shall conform to ASTM E 230 or national equivalent. Extension wire shall not be spliced. 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 thermocouple type – ASTM E 1129 may be used as a guide for round-pin connectors. Thermocouple composition and extension wire requirements are shown in Table 2.

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

3.1.2 Sensor Calibration

3.1.2.1 Sensors and calibration hierarchy shall comply with Table 1.

3.1.2.2 Calibration technique shall comply with ASTM E 220, ASTM E 207, or other national standard. Sensors shall have a certificate of compliance that identifies:

3.1.2.2.1 date of calibration,

3.1.2.2.2 the source of the calibration data,

3.1.2.2.3 nominal test temperature,

3.1.2.2.4 actual test temperature readings,

3.1.2.2.5 calibration technique, and

3.1.2.2.6 correction factor for each calibration temperature traceable to NIST or other recognized National Standard. Alternatively, deviation (error) for each calibration temperature may be listed. The certificate shall clearly state if it shows deviation or correction factor.



3.1.2.3 Thermocouple calibration intervals specified in Table 1, whether based on time, number of uses, or temperature are the maximums permitted. Compliance with these intervals does not relieve the user of the responsibility for ensuring that excessive drift has not occurred under the particular conditions (environment, time, and temperature) of exposure.

3.1.2.4 Users shall have supporting data such as, but not limited to, SAT, TUS, and re-calibration data and written procedures controlling the replacement of sensors including limits on maximum life and/or number of uses, as applicable.

3.1.2.5 Temperature sensors shall be calibrated in the nominal temperature range within which they are to be used.

3.1.2.5.1 Calibration intervals shall not exceed 250 °F (140 °C) for all thermocouples, except those that are calibrated at fixed points (in accordance with ASTM MNL 12, section 8.2, or other national standard for fixed point calibration).

3.1.2.5.2 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 National Standards calibration agency.

3.1.2.6 Thermocouples (expendable or non-expendable) made from rolls calibrated in accordance with this paragraph may be used in lieu of individually calibrated thermocouples.

3.1.2.6.1 The maximum amount of wire/cable in a roll at the time of calibration shall be as follows:

a. Primary Standard Sensors: 200 feet (60 m)

b. Other Noble Metal Sensors: 2000 feet (610 m)

c. Base Metal Secondary Standard Sensors: 2000 feet (610 m)

d. All Other Base Metal Sensors: 5000 feet (1525 m)

3.1.2.6.2 Rolls shall be sampled at both ends of the roll (See 3.1.2.2). Use the average correction factor calculated from both ends of the roll if the individual correction factors from each end are within acceptable limits of Table 1.

3.1.2.6.3 The roll calibration method shall not be used if the difference between the highest and lowest calibration readings of the sample thermocouples at any calibration temperature exceeds the following requirements.

3.1.2.6.3.1 1 °F (0.6 °C) for primary and secondary standard thermocouples.

3.1.2.6.3.2 2 °F (1.1 °C) for system accuracy test, temperature uniformity test, controlling, monitoring, recording, and load thermocouples.

3.1.2.6.4 For rolls not meeting 3.1.2.6.3 :

3.1.2.6.4.1 It is permissible to divide the roll into shorter length rolls that do meet the end to end tolerance difference specified in 3.1.2.6.3.

3.1.2.6.4.2 It is permissible to use individual thermocouples from the roll if they are calibrated in accordance with Table 1.

3.1.3 Reuse of Thermocouples (See Figure 1)

3.1.3.1 The salvage of damaged thermocouples is permitted if the discrepant portion (including the portion exposed above 500 °F (260 °C) for Types K and E thermocouples) is trimmed off, the hot junction remade and the thermocouple recalibrated.

3.1.3.1.1 If the salvaged thermocouple originated from a calibrated wire roll, the original roll calibration may be used in lieu of recalibration.

3.1.3.1.2 The number of uses prior to salvage shall be included in the total number of uses of the thermocouple (See 3.1.3.3).

3.1.3.2 Reuse of any thermocouple is prohibited unless the insulation remains intact and wires including the hot junction are not damaged.

3.1.3.3 Expendable test sensors may be reused if "U" in the following formula does not exceed 30. A “use” for test thermocouples is defined as one cycle of heating and cooling the thermocouple (2.2.77).

U = Number of uses below 1200 °F (650 °C) + 2 times number of uses from 1200 °F (650 °C) to 1800 °F (980 °C). Expendable base metal test thermocouples shall be limited to a single use above 1800 °F (980 °C).

3.1.3.4 Any base metal TUS thermocouple that is (1) used exclusively under 1200 °F (650 °C), (2) identified, and (3) preserved/protected from damage (i.e., crimping, excessive moisture contact, corrosion, etc.) between tests or remains installed on a rack that is protected between tests,) shall be limited to no more than 90 uses or 3 years, whichever comes first and may be reused subject only to the limitations of 3.1.3.1 to 3.1.3.2.

3.1.3.5 Nonexpendable base metal TUS thermocouples reinstalled for each TUS through ports in the furnace, used in the same location and depth of insertion for each TUS and used exclusively under 1200 °F (650 °C) shall be limited to no more than 90 uses or 3 years, whichever comes first and may be reused subject only to the limitations of 3.1.3.1 to 3.1.3.2.

3.1.4 Control, Monitoring, and Recording Sensors

3.1.4.1 Control, monitoring, and recording sensors shall be installed in thermal processing equipment within or as close as possible to the work zone.

3.1.4.2 When a Load Sensor is Used as a Control Sensor

3.1.4.2.1 Expendable load thermocouples used as a control sensor are limited to one use.

3.1.4.2.2 Nonexpendable load thermocouples may be used to control temperature, subject to the limitations of 3.1.5.

3.1.5 Load Sensors (2.2.27)

3.1.5.1 Load sensors may be used as control sensors in accordance with 3.1.4.2. When a load sensor is used as a control sensor, no monitoring or recording sensor in or representing the work zone shall exceed the maximum allowed processing temperature.

3.1.5.2 Expendable base metal load sensors may be used for up to 90 calendar days after first use and for no more than 30 uses when used at or below 1200 °F (650 °C) provided the requirements of 3.1.3 are satisfied, and are limited to one use above 1200 °F (650 °C).

3.1.5.3 The life of nonexpendable base metal load thermocouples shall be limited by the maximum operating temperature and calendar days since first use. Records shall be maintained of the accumulated thermocouple use (furnace load cycle). Number of uses or number of calendar days since first use, whichever occurs first, shall be limited as follows:

2300 °F (1260 °C) and above 1 use
2200 °F (1205 °C) to 2299 °F (1260 °C) 3 months or 10 uses
1801 °F (980 °C) to 2199 °F (1205 °C) 3 months or 90 uses
1200 °F (650 °C) to 1800 °F (980 °C) 3 months or 180 uses
Below 1200 °F (650 °C) 3 months or 270 uses

When used in multiple ranges, the shortest interval or usage shall apply.

Example 1:

- A sensor with 9 uses at 2250 °F has only one more use allowed in the 2200 to 2299 °F range or any lower operating range.
- No uses remain at 2300 °F or above.

Example 2:

- A sensor with 50 uses between 1400 and 1600 °F is then used at 1820 °F.
- It has already exceeded the use limits for all ranges above 2199 °F.
- It is now subject to the 90 use limit as it has been used in a higher temperature range.

Example 3:

- A sensor with 50 uses between 1400 and 1600 °F is then used at 1015 °F.
- It has already exceeded the use limits for all ranges above 2199 °F.
- It is subject to a 180 use limit as it has been used in the 1200 to 1800 °F temperature range.

3.2 Instrumentation (See Tables 3, 4, and 5)

Output of sensors shall be converted to temperature readings by instruments specified herein or instruments of equal or greater accuracy. Instruments shall be calibrated by NIST or an equivalent national standards organization, or against standards whose calibration is traceable to NIST or other recognized national equivalent(s) according to Table 3.

3.2.1 Users shall review all instrument requirements in AMS2750E as not all instruments approved for use in AMS2750C will meet the requirements of this revision and AMS2750D.

3.2.1.1 The following requirements (3.2.1.1.1 and 3.2.1.1.2) apply to control, monitoring or recording instruments purchased 1 year after Sept 2005, the issue date of AMS2750D. Control, monitoring or recording instruments purchased prior to September 2006 may meet the requirements of AMS2750C until 3 years after the issue date of AMS2750E (add date at publication

3.2.1.1.1 Temperature resolution requirements for chart recorders shall be in accordance with Table 4.

3.2.1.1.2 Process Recorder Print and Chart Speeds shall be in accordance with Table 5.

3.2.2 Test Instruments

Shall be digital and have a minimum readability of 1 °F or 1 °C.

3.2.3 Controlling, Monitoring, or Recording Instruments

3.2.3.1 At least one recording and/or controlling instrument for each zone shall have a minimum readability of 1 °F or 1 °C.

3.2.3.2 Installation of controlling, monitoring or recording instruments shall conform to the manufacturer's recommendations.

3.2.3.3 Controlling, monitoring and recording instruments shall receive an unmodified signal from sensors except for analog to digital and digital to analog conversions, or a digitally-processed, error-checked equivalent representation of a direct measured value.

3.2.4 Offsets

If offsets are used, a documented procedure shall exist, describing when and how to perform manual and electronic offsets. The procedure shall address how to account for and reintroduce any intentional offsets. Prior to reintroducing any intentional offsets, any instrument calibration error found shall be taken into account. Adjustments (offsets) greater than those shown in Tables 6 or 7 shall not be used.

3.2.4.1 If subsequent internal instrument adjustments or offsets are made to achieve TUS requirements, these internal adjustments or offsets must be applied during subsequent SATs per 3.4.5.3.1. In addition, if subsequent internal instrument adjustments or offsets are made to achieve SAT requirements, the effect on the TUS range or distribution shall be considered as the range will shift upwards or downwards in response to the internal adjustment or offset.

| Sensor Use | Sensor Type | Form | Recalibration (3) | Reuse (1)(2) |
|---|---|---|---|---|
| Test Sensors TUS | Base | Expendable | Recalibration of expendable base metal thermocouples is not permitted. | See 3.1.3.3 (U-formula) and 3.1.3.4 (protected use under 1200 °F) |
| | | Non-expendable | J & N: 3 months – See Table 1<br>E & K: 3 months - Permitted if used at or below 500 °F (260 °C) Not permitted if used above 500 °F | See 3.1.3.4 to 3.1.3.5 |
| | Noble | Expendable<br>Non-expendable | Every 6 months – See Table 1 | No other restrictions |
| Test Sensor Nonresident SAT | Base | Expendable | Recalibration of expendable base metal thermocouples is not permitted. | See 3.1.3.3 (U formula) |
| | | Non-expendable | J & N: 3 months – See Table 1<br>E & K: 3 months – Permitted if used at or below 500 °F (260 °C) Not permitted if used above 500 °F | No other restrictions |
| | Noble | Expendable<br>Non-expendable | Every 6 months – See Table 1 | No other restrictions |
| Test Sensors Resident SAT | Base | Expendable | Recalibration of expendable base metal sensor is not permitted. | N: Shall be used at or below 1000 °F (538 °C).<br>E, J, K, T: Shall only be used at or below 500 °F (260 °C) (3.4.5.2.1.1) |
| | | Non-expendable | 3 months – See Table 1 limitations | E, J, K, T: Shall only be used at or below 500 °F (260 °C) (3.4.5.2.1.1)<br>N: No other restrictions |
| | Noble | Expendable | Every 6 months – See Table 1 | Shall only be used at or below 1000 °F (538 °C) (3.4.5.2.1.1) |
| | | Non-expendable | | No other restrictions |
| Load sensors | Base | Expendable | Recalibration is not permitted. | Limited by number of uses, temperature of use, and calendar days since first use – See 3.1.5.2 |
| | | Non-expendable | Recalibration is not permitted. | Limited by number of uses, temperature of use, and calendar days since first use – See 3.1.5.3 for restrictions. |
| | Noble | Expendable<br>Non-expendable | Every 6 months – See Table 1 | No other restrictions |

(1) For reuse of any Type E or K sensor used above 500 °F (260 °C) depth of insertion shall be equal to or greater than any previous use.
(2) See 3.1.3.1 and 3.1.3.2 for general reuse restrictions
(3) Recalibration of any Type E or K sensor used above 500 °F (260 °C) is prohibited

FIGURE 1 – REUSE AND RECALIBRATION OF TEST AND LOAD SENSORS

3.2.5 Instrument Calibration

3.2.5.1 Calibration shall be performed on instrument(s) defined under the Instrument Type column in Table 3. Regardless of the calibration procedure used, it shall comply with the requirements of Table 3. Prior to any instrument alteration or calibration, document the instrument(s) “as-found condition”

3.2.5.2 Calibration accuracy and interval requirements shall be in accordance with Table 3.

3.2.5.3 Sensitivity shall be checked during calibration. See Table 3 footnote 4.

3.2.5.4 Calibration of secondary standard instruments and field test instruments shall be performed in accordance with the manufacturer’s instructions. These instruments shall be tested at a minimum of 6 simulated sensor inputs. These shall include the minimum and maximum of the operating range used for test or calibration and a minimum of 4 points in between either representing areas of normal operation or spaced at approximately equal intervals across the range in which the instrument is used for test or calibration.

3.2.5.4.1 The instrument shall be calibrated for each type of input and/or output used (e.g., each thermocouple type in use and for mV, mA, etc. if the instrument is used for these methods).

3.2.5.4.2 Calibration shall be performed on each channel in use that can be altered or adjusted individually, or on each group of channels that can be altered or adjusted as a group. It is recommended that channels not in use be blocked or tagged to stop unintentional use.

3.2.5.5 Calibration of Controlling, Monitoring and Recording Instruments

3.2.5.5.1 Check as-found condition at a minimum of three simulated sensor inputs which represent the minimum, maximum and at least one point in the middle 1/3rd of the furnace Qualified Operating Temperature Range. If necessary, calibrate the instrument in accordance with the manufacturer’s instructions.

3.2.5.5.1.1 Following any adjustments test the instrument at a minimum of three simulated sensor inputs which represent the minimum, maximum and at least one point in the middle 1/3 rd of the furnace Qualified Operating Temperature Range to document the as-left condition.

3.2.5.5.2 Calibration shall be performed on each channel in use that can be altered or adjusted individually, or on each group of channels that can be altered or adjusted as a group. It is recommended that channels not in use be blocked or tagged to stop unintentional use.

3.2.5.5.3 Chart recorder (circular and strip) speed(s) shall be verified annually and shall be accurate within ±3 minutes per hour. Result of chart speed measurement shall be documented.

3.2.5.5.4 Calibration of controlling, monitoring or recording instruments may be performed with a load in process (for a single temperature range) if the furnace temperature remains within the processing tolerance and the furnace temperature record is appropriately annotated to indicate that a calibration occurred, including time and date.

3.2.5.5.5 For furnaces used only at a single temperature, the calibration of controlling, monitoring or recording instruments may either be performed per manufacturer’s instructions at the single temperature of use, or with a minimum of 3 points: the temperature of use, and two (or more) points bracketing the temperature of use.

3.2.5.6 Wireless equipment which performs the analog to digital conversion at the furnace and transmits a digital signal to the recorder are allowed, but require use of the complete wireless system (wireless sender, wireless receiver and associated controlling, monitoring and recording instruments) during the calibration process (See 3.1.1.5.1).

3.2.6 Instrumentation Results and Records

3.2.6.1 A sticker affixed to or in close proximity to the instrument shall indicate the most recent successful calibration. As a minimum, the sticker shall include:

a. Date the calibration was performed

b. Due date of the next calibration

c. Technician who performed the calibration

d. Any limitations or restrictions of the calibration shall be indicated on the sticker.

3.2.6.2 The results of calibration shall be documented. At a minimum the report shall include:



a. Instrument number or furnace number

b. Make and model of instrument calibrated

c. Standard used during calibration

d. Method of calibration (manufacturer's instructions, three point, single point)

e. Required accuracy

f. As found and as left data at each calibration point

g. Offset as found and as left (as required)

h. Sensitivity (pass/fail or sensitivity found in test) (Table 3, Note 4)

i. Statement of acceptance or rejection

j. Any limitations or restrictions of the calibration shall be included

k. Date the calibration was performed

l. Due date of the next calibration

m. Technician who performed the calibration

n. Calibration company (if not performed in-house)

o. Signature of the calibration company (if not performed in-house)

p. Quality Organization approval.

3.2.7 Electronic Records

3.2.7.1 An "electronic record" is 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. When using a system (furnace control, recording, monitoring or data acquisition) that creates electronic records, systems purchased after Sept 2006 or any electronic record created after 2015 (3 years after release of this revision) shall meet the following requirements:

3.2.7.1.1 The system must create electronic records that cannot be altered without detection.

3.2.7.1.2 The system software and playback utilities shall provide a means of examining and/or compiling the record data, but shall not provide any means for altering the source data.

3.2.7.1.3 The system shall provide the ability to generate accurate and complete copies of records in both human readable and electronic form suitable for inspection, review, and copying.

3.2.7.1.3.1 The system shall be capable of providing evidence the record was reviewed – such as by recording an electronic review, or a method of printing the record for a physical marking indicating review.

3.2.7.1.4 The system shall support protection, retention and retrieval of accurate records throughout the record retention period. Ensure that the hardware and or software shall operate throughout the retention period as specified in 3.7.

3.2.7.1.5 The system shall provide methods (e.g., passwords) to limit system access to only individuals whose authorization is documented.

3.3 Thermal Processing Equipment:

3.3.1 Furnace classes are defined in Figure 2 and are based on the furnace class specified or when not specified, furnace class shall meet the temperature uniformity requirements established in the specification for the material being processed. Instrumentation types are defined by the level of instrumentation used by the heat treater to control, record or indicate the desired temperature.

Intervals for system accuracy tests, temperature uniformity surveys, and controlling, monitoring, and recording instrument calibrations are based on the combined furnace class and instrumentation type (Table 3, 6, 7, 8, or 9).

| Furnace Class | Temperature Uniformity Range (Degrees F) (1) | Temperature Uniformity Range (Degrees C) (1) |
|---|---|---|
| 1 | ±5 | ±3 |
| 2 | ±10 | ±6 |
| 3 | ±15 | ±8 |
| 4 | ±20 | ±10 |
| 5 | ±25 | ±14 |
| 6 | ±50 | ±28 |

(1) Uniformity range requirement is established by the specification for the material being processed.

FIGURE 2 – FURNACE CLASS UNIFORMITY RANGES

3.3.2 Requirements for Furnace Instrumentation Type classification are shown in Figure 3.

| Sensor(s) Required by Instrumentation Type | Instrumentation Type | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| One control sensor per zone that controls and displays temperature | ✓ | ✓ | ✓ | ✓ | ✓ |
| The temperature indicated by the control sensor in each control zone shall be recorded by a recording instrument.<br>Alternatively, the recording instrument may be connected to a second sensor contained in the same sheath or holder as the control sensor, and separated from the control sensor by no more than 0.38 inch (10 mm). | ✓ | ✓ | ✓ | ✓ | |
| At least two additional recording sensors in each control zone shall be located to best represent the coldest and hottest temperatures based on the results from the most recent temperature uniformity survey.<br>It is recognized that certain furnace designs/loading configurations can prevent the location of these sensors in the precise coldest and hottest locations, but these sensors shall be located as close as practical (See 3.3.5). These recording locations may change over time. See 3.5.18 for relocation requirements | ✓ | | ✓ | | |
| At least 1 recording load sensor in each zone<br>During production in multi-zone furnaces, empty zones (i.e., no material is placed in or intrudes into the zone) do not require a load sensor. However, a notation must be made to the furnace load record that the zone was entirely empty. | ✓ | ✓ | | | |
| Each control zone shall have over-temperature protection (2.2.35)<br>The recording sensor representing the hottest location may also be utilized as the over-temperature protection sensor. | ✓ | ✓ | ✓ | ✓ | |

FIGURE 3 – INSTRUMENTATION TYPE REQUIREMENTS

3.3.3 Instrumentation - Refrigeration Equipment and Quench Systems

3.3.3.1 Refrigeration equipment shall have a temperature controller. This temperature controller requirement is not applicable to liquid nitrogen, dry ice and dry ice/liquid-cooled containers. All refrigeration equipment shall be equipped with a temperature recorder where time-at-temperature (minimum or maximum) is required. The above requirements are not applicable during transportation of materials at sub-ambient temperatures.

3.3.3.2 Quench systems used for heat treatments that include a quenchant temperature requirement (minimum, maximum or both) shall be equipped with a recording instrument. Existing installations installed prior to September 2005 do not require recording instruments until 3 years after the release of this revision.

3.3.4 Additional Sensors

There is no limit on additional recording or load sensors in any control zone, but their use must be defined in controlled operating instructions.

3.3.5 High and low temperature sensors, when required (instrument types A and C – See Figure 3), may be inserted in heat sinks (See 2.2.24), positioned at the high and low temperature locations of the control zone based on the most recent TUS when heat sinks of similar configuration are used during the TUS.

3.3.6 For multiple zone vacuum furnaces with 225 cubic feet (6.4 $m^3$) or less in working volume that are instrumented with Types A, B, or C instrumentation, it is acceptable to treat the furnace working volume as a single work zone for the purpose of locating high and low temperature recording thermocouples and determining the number of load thermocouples required regardless of the number of control thermocouples or instruments within the vacuum furnace. The minimum sensors required are shown in Figure 4. Each furnace shall have over-temperature protection in the work zone.

3.3.6.1 Vacuum furnaces of volume greater than 225 cubic feet (6.4 $m^3$) may be treated in the same fashion by dividing the furnace into working zones that shall not exceed 225 cubic feet (6.4 $m^3$) – each of these zones shall contain all the required sensors as outlined in Figure 4 for a single zone.

| | Minimum Number Required | | |
|---|---|---|---|
| Instrumentation Type | High Temperature T/C | Low Temperature T/C | Load T/C |
| A | 1 | 1 | 1 |
| B | N/A | N/A | 1 |
| C | 1 | 1 | N/A |

FIGURE 4 – MINIMUM SENSORS REQUIRED PER ZONE

3.4 System Accuracy Tests (SATs)

The SAT (2.2.62) is an on-site comparison of the instrument/leadwire/sensor readings or values, with the readings or values of a calibrated test instrument/leadwire/sensor to determine if the measured temperature deviations are within applicable requirements. The SAT is performed to assure the accuracy of the furnace control and recording system in each control zone.

3.4.1 SATs shall be performed on the temperature control and recording systems in each control zone of each piece of thermal processing equipment that is used for production heat treatments. The SATs shall also be performed on the additional systems that qualify instrumentation as Types A, B, or C. See 3.3.2 Figure 3.

3.4.1.1 SATs shall be performed using a field test instrument meeting the requirements of Table 3 and a test sensor meeting the requirements of Table 1.

3.4.2 SATs shall be performed initially and periodically thereafter in accordance with the requirements of Table 6 or 7 and 3.4.5.

3.4.2.1 An SAT shall be performed after any maintenance that could affect the SAT accuracy. Examples include:

- replacement of the sensor,
- replacement of the controlling, monitoring or recording instrument
- re-calibration of the controlling, monitoring or recording instrument when any adjustment has been made.

Quality Assurance shall be consulted for direction on whether any other specific maintenance requires a new SAT.

3.4.2.2 An SAT is not required for sensors whose only function is over-temperature protection. If the over-temperature protection sensor is used as the additional monitoring sensor for SAT interval extension (see 3.4.3), or as the high temperature sensor for Instrumentation Type A or C (Figure 3), an SAT is required.

3.4.2.3 An SAT is not required for sensors not used for acceptance as part of production heat treatment.

3.4.2.4 If an SAT cannot be performed within the interval requirements of Table 6 or 7, the equipment shall be removed from service. An SAT shall be performed prior to putting the equipment back in use or during the first operation of the furnace.

3.4.3 SAT interval is based upon equipment class and instrumentation type. If a preventive maintenance program, defined in 2.2.37, is in effect, SAT interval may be extended to the maximum allowed SAT interval of Table 6 and 7 (e.g., weekly to biweekly, biweekly to monthly, etc.) if allowed in Table 6 or 7 under *either* of the following conditions:

3.4.3.1 Two sensors in each control zone are Type B, N, R, or S.

3.4.3.2 Weekly readings show that the relationship between the control sensor and an additional monitoring or recording sensor in each control zone remains within 2 °F (1 °C) of their relationship at the time of the last Temperature Uniformity Survey. In the event that a reading exceeds the allowance the SAT interval shall return to the normal interval (not maximum allowed SAT interval) until the next Temperature Uniformity Survey.

3.4.4 The SAT can be accomplished using any one of 3 methods:

3.4.4.1 Perform an SAT following the requirements in 3.4.5

3.4.4.2 Alternate SAT process defined in 3.4.6

3.4.4.3 SAT Waiver process, as described in 3.4.7

3.4.5 System Accuracy Test Procedure

3.4.5.1 The displayed temperature indication and/or recording of the sensor being tested as used in production, with appropriate offsets or correction factors, at any operating temperature, shall be compared with the corrected temperature indication of the test sensor on a test instrument.

3.4.5.2 The tip (measuring junction) of the SAT sensor shall be as close as practical to the tip (measuring junction) of the controlling, monitoring, or recording sensor, but the tip to tip distance shall not exceed 3 inches (76 mm). Subsequent SATs shall utilize test thermocouple(s) placed in the same locations/positions/depth as the initial test. The SAT sensor may be inserted temporarily for the test or may be a resident test sensor, subject to the limitations of 3.4.5.2.1.

3.4.5.2.1 Resident SAT thermocouples may be employed subject to the following limitations:

3.4.5.2.1.1 Resident SAT thermocouples shall be restricted to Type B, N, R or S at temperatures exceeding 500 °F (260 °C) and shall be nonexpendable if exposed to temperatures above 1000 °F (538 °C).

3.4.5.2.1.2 The resident SAT sensor type shall be different from that of the sensor being tested; additional limitations apply to types R and S (Figure 5).

| | Control Monitoring or Recording Sensor in Furnace | | | | |
|---|---|---|---|---|---|
| Resident SAT Sensor | B | R | S | N | All other sensor types |
| B | No | Yes | Yes | Yes | Yes |
| R | Yes | No | No | Yes | Yes |
| S | Yes | No | No | Yes | Yes |
| N | Yes | Yes | Yes | No | Yes |

FIGURE 5 – ALLOWABLE COMBINATIONS OF RESIDENT SAT SENSOR WITH SENSOR BEING TESTED FOR TEMPERATURES OVER 500 °F (260 °C)

3.4.5.3 System Accuracy Test Difference

The difference calculated between the reading of the furnace sensor system being tested (sensor, lead wire, and instrument) and the corrected reading of the test sensor system (after test sensor and test instrument correction factors are applied) shall be recorded as the *system accuracy test difference*. Applicable correction factors shall be applied algebraically.

3.4.5.3.1 The temperature from the furnace instrument/sensor being compared with the SAT instrument/sensor shall be the temperature used, read or recorded in routine production heat treatment. Certain correction factors, if consistently applied during production heat treatment in accordance with documented procedures, may be algebraically applied to the system being tested.

Examples (Figure 6) of correction factors that may be incorporated when routinely used in production heat treatment include:

- Sensor correction factor as listed on the initial calibration report, or recalibration report (whether recalibration was performed in a laboratory or in-situ). Only the most recent sensor correction factor may be applied.
- Control or recording instrument correction factor as listed on the most recent calibration report.
- Internal offset to the control or recording instrument solely to correct a skewed temperature uniformity distribution.
- A previously documented and specified offset to the control instrument to correct an SAT difference, if this offset is in the form of an intentional manual offset of the control set point (e.g., If the desired set point is 1000 °F, set control instrument set point at 1003 °F).

Correction factors that shall not be incorporated include:

- Previously applied internal adjustments or offsets to the control or recording instrument to correct an SAT difference. These internal adjustments or offsets are already reflected in the displayed or recorded temperature and shall not be applied twice.
- Manually applied offsets to the control instrument that have been specified for production heat treatment solely to correct a skewed temperature uniformity distribution. These manual offsets have no effect on the performance of an SAT or calculation of an SAT difference.



Examples

Example 1: No offsets in use for last TUS or SAT and no correction factors in use for instrument or sensor.

Example 2: No offsets in use for last TUS or SAT; correction factors from instrument calibration and from sensor calibration are added manually by the operator during production.

Example 3: No offsets in use for TUS or previous SAT; correction factors from instrument calibration and from sensor calibration are programmed into the control or recording instrument – the “corrected” reading is used during production.

Example 4: No offsets in use for previous SAT, but correction factors from instrument calibration and sensor calibration AND an offset from the last TUS are programmed into control or recording instrument – this “corrected” reading is used during production. In this example, the last TUS showed the furnace was +2 degrees (warmer) when compared to the control sensor, so a +2 degrees offset is programmed into the control instrument to show the working zone temperature on the controller.

Example 5: Offset of -1.5 degrees in use for previous SAT, and programmed into instrument. Correction factors from instrument calibration and previous sensor calibration AND the offset from the last TUS are programmed into control or recording instrument – this "corrected" reading is used during production. In this example, the last TUS showed the furnace was +4 degrees (warmer) when compared to the control sensor, so a +4 degrees offset is programmed into the control instrument to show the working zone temperature on the controller.

Note that the resulting calculation showed a -5.0 degree SAT Difference.

| (Determine if intentional prior internal control or recording instrument and sensor adjustments are used manually during operation or are programmed into the controller/recorder being tested | | | | | |
|---|---|---|---|---|---|
| Examples | 1 | 2 | 3 | 4 | 5 |
| Example conditions | | | | | |
| Offset in use for last TUS | No | No | No | Programmed Offset +2° | Programmed Offset +4° |
| Offset in use for last SAT | No | No | No | No | Programmed in instrument -1.5° |
| Instrument Correction Factor (**$B_{inst}$**) used during production | No | Manual | **$B_{inst}$** Programmed in instrument | **$B_{inst}$** Programmed in instrument | **$B_{inst}$** Programmed in instrument |
| Sensor Correction Factor (**$B_{tc}$**) used during production | No | Manual | **$B_{tc}$** Programmed in instrument | **$B_{tc}$** Programmed in instrument | **$B_{tc}$** Programmed in instrument |
| Instrument reading **(A)** | 1500° | 1011° | 2225° | 1502° | 2104° |
| Manual Correction factor from calibration of instrument **($B_{inst}$)** | | +3° | N/A | N/A | N/A |
| Manual thermocouple calibration correction factor **($B_{tc}$)** | | -1° | N/A | N/A | N/A |
| Correction factor from TUS offset of control or recording instrument **($B_{TUS}$)** | | | | -2° | -4° |
| A + $B_{inst}$ + $B_{tc}$ + $B_{TUS}$ = Corrected control or recording instrument temperature (C) | **1500°** | **1013°** | **2225°** | **1500°** | **2100°** |
| **Test** instrument reading (uncorrected) **(D)** | 1505.0° | 1013.3° | 2220.0° | 1505.0° | 2106° |
| **Test** thermocouple correction factor **(E)** | -1.0° | -1.0° | -1.0° | -1.0° | -1.4° |
| **Test** instrument correction factor **(F)** | +0.2° | +0.2° | +0.2° | +0.2° | +0.4° |
| (D) + (E) + (F) = True Test Temperature (G) | **1504.2°** | **1012.5°** | **2219.2°** | **1504.2°** | **2105.0°** |
| SAT Difference = (C) – (G) | **-4.2°** | **-0.5°** | **+5.8** | **-4.2°** | **-5.0°** |

FIGURE 6 – SAT CALCULATION EXAMPLES

3.4.5.4 If the SAT difference (including any prior adjustment allowed by Table 6 or 7 of the control or recording instrument) exceeds the allowable difference specified in Table 6 or 7 for the furnace class and instrumentation type being tested, the failure shall be documented, the cause of the difference determined, and corrective action taken before commencing additional thermal processing. Paragraph 4.2 shall apply.

3.4.5.5 Corrective Action

If the SAT difference exceeds the limits of Tables 6 or 7 as applicable, corrective action may include, but is not limited to, any of the following:

3.4.5.5.1 Replacement of the out-of-tolerance sensor and/or lead wire.

3.4.5.5.2 Recalibration of the out-of-tolerance instrument.

3.4.5.5.3 If the cause is, wholly or partially, as a result of movement of the sensor being tested from its documented position, the sensor shall be returned to its documented location and the SAT repeated.

3.4.5.6 Adjustment of the control or recording instrument calibration is permitted within the maximum adjustment limitations of Table 6 or 7. The effect of this adjustment over the entire operating temperature range shall be evaluated. Paragraph 4.2 shall apply.

3.4.5.7 After corrective action has been completed, and prior to any additional thermal processing, the SAT shall be repeated in accordance with 3.4.5.

3.4.6 Alternate SAT Process

For sensors used only once (single use) or for multiple use sensors replaced at an interval shorter than the appropriate SAT interval, define an operating process which:

3.4.6.1 Requires routine calibration in accordance with 3.2.5 of controlling, recording and monitoring instruments meeting requirements of Table 3 from the point at which the sensor will be connected (this will include the connector, leadwire and instrument for the calibration), and either:

3.4.6.1.1 Establish appropriate calibration limits for sensors which when combined with the calibration of the instrument/lead wire and connector, will meet the SAT requirements of Table 6 or 7, as appropriate, or

3.4.6.1.2 Use the appropriate correction factors applied manually or via programming, as allowed by calibration limits of Table 1, so that data used from the recording, monitoring or controlling instrument will meet the SAT requirements of Table 6 or 7, as appropriate.

3.4.7 SAT Waiver

The requirement for an SAT is waived when in compliance with all requirements of 3.4.7.1 through 3.4.7.6:

3.4.7.1 In addition to the required instrumentation of types A thru D there are always at least two recording load sensors in each control zone, one monitoring and one controlling.

3.4.7.1.1 In the case of Instrument type A and B, there would be one additional load sensor.

3.4.7.1.2 Manual adjustments to the controller set point, based on observed load sensor readings provide acceptable control. The controlling load sensor, in this context, does not need to be physically connected to the furnace controller.

3.4.7.2 Load sensors used for control shall comply with 3.1.4.2 and the monitoring load sensors shall comply with 3.1.5.

3.4.7.3 All noble metal load thermocouples in use shall be nonexpendable and shall be either replaced or recalibrated quarterly.

3.4.7.4 All base metal control and recording thermocouples in use shall be replaced annually.

3.4.7.5 All noble metal control and recording thermocouples in use shall be replaced every 2 years.

3.4.7.6 The load sensors are recalibrated or replaced anytime that observations, made and recorded at least weekly, reveal any unexplainable difference between their readings and the readings of other control, monitoring and recording sensors.

Weekly readings must also show that the relationship between the control sensor and an additional monitoring sensor in each control zone remains within 2 °F (1 °C) of their relationship at the time of the last Temperature Uniformity Survey.

3.4.8 Records

3.4.8.1 The system accuracy test report for each sensor shall include:

a. Identification of the sensor being tested

b. Identification of the test sensor

c. Identification of the test instrument

d. Date and time of day of the test

e. Set point of the furnace during test

f. Observed furnace instrument reading

g. Observed test instrument reading

h. Test sensor and test instrument correction factors

i. Corrected test instrument reading

j. Calculated system accuracy difference

k. Indication of test acceptance or failure

l. Identification of technician performing the test

m. SAT company (if not performed in-house)

n. Signature of the calibration company (if not performed in-house)

o. Quality Organization approval.

3.5 Furnace Temperature Uniformity Surveys (TUS)

3.5.1 An initial TUS shall be performed to measure the temperature uniformity and establish the acceptable work zone and qualified operating temperature range(s). Periodic TUS shall be performed thereafter in accordance with the interval shown in Table 8 or 9.

3.5.2 Multiple Qualified Operating Temperature Ranges

A furnace may have multiple qualified operating temperature ranges. For example, a furnace may be qualified to operate within ±10 °F from 600 to 1000 °F (±6 °C from 315 to 540 °C) and ±25 °F from 1000 to 1800 °F (±14 °C from 540 to 980 °C). This furnace contains two separate qualified operating temperature ranges. A furnace meeting ±10 °F at 1000 °F automatically meets ±25 °F at 1000 °F and therefore, a duplicate test at that temperature is not a requirement.

### 3.5.3 Furnace Modifications

An initial TUS shall also be performed after any furnace modification or adjustment that could have altered the temperature uniformity characteristics of the furnace. Examples where an initial TUS shall be required include, but are not limited to, the following:

a. Increase in the maximum qualified operating temperature or decrease in the minimum qualified operating temperature

b. Burner size, number, type or location change

c. Heating element number, type or location change

d. Changes to airflow pattern/velocity (baffle positions, fan speed, fan quantity, etc.)

e. Change of refractory thickness

f. New refractory with different thermal properties

g. Change of vacuum furnace hot zone design or materials

h. Change of control sensor location

i. Change of combustion pressure settings from original setting

j. Change of furnace pressure settings (damper system) from original settings

k. Temperature controller instrument/program change

   1. Proportional versus high-low/off-on

   2. Change of controller model or type

   3. PLC logic program change to the furnace heat control scheme

   4. Adjustment of tuning constants, parameters or rheostats

l. Work zone volume increase covering area not previously tested

m. Work zone location change covering area not previously tested.

All furnace modifications shall be documented and the responsible Quality Assurance organization shall make the determination whether an initial TUS is required based on the modifications made and the particular furnace configuration before returning the furnace to service.

3.5.4 Furnace Repairs

Minor repairs or replacements of damaged or malfunctioning components or scheduled preventive maintenance that restore the furnace to its original condition and are not expected to affect the temperature uniformity characteristics of the furnace shall not require repeating the TUS. Examples include, but are not limited to the following:

a. Replacing a burner/tile with another duplicate burner/tile

b. Refractory repair using material with similar thermal properties

c. Replacing a control or monitoring sensor to its previously documented location

d. Replacing heating system components (e.g., gas regulator, valve, metering device, heating elements, etc.)

e. Restoring original combustion pressure settings and tuning constants

f. Replacing a controller with an identical controller with the same tuning constants

g. System accuracy test failure

h. Correction of furnace pressure control problem

i. Repair of furnace door seals.

All furnace repairs shall be documented and the responsible Quality Assurance organization shall make the determination whether an additional TUS is required based on the repairs made and the particular furnace configuration before returning the furnace to service.

3.5.5 Initial TUS Temperatures

3.5.5.1 Initial survey temperatures shall be the minimum and maximum temperatures of the qualified operating temperature range(s).

3.5.5.2 Additional temperatures shall be added as required to ensure that no two adjacent survey temperatures are greater than 600 °F (335 °C) apart.

For example, if a furnace is used from 800 to 1800 °F (425 to 980 °C), the furnace may be surveyed at 800 °F (425 °C), 1800 °F (980 °C), and one intermediate temperature to meet the 600 °F (335 °C) range requirement. Surveying at any temperature from 1200 °F (650 °C) to 1400 °F (760 °C) would satisfy the 600 °F (335 °C) range requirement.

3.5.6 Periodic TUS temperatures shall be any temperature within each qualified operating range(s).

3.5.6.1 For single operating ranges greater than 600 °F (335 °C), during each periodic test TUS temperatures shall be selected so that one temperature is within 300 °F (170 °C) of the maximum and another temperature is within 300 °F (170 °C) of the minimum of qualified operating range and there are no more than 600 °F (335 °C) increments in between.

In addition, at least once within each calendar year a periodic test shall be performed at the minimum of each qualified temperature range and at least once each calendar year at the maximum temperature of each qualified operating temperature range.

For example, if the operating range is 200 to 1200 °F ±10 (93 to 649 °C ± 6) a temperature shall be selected between 200 and 500 °F (93 to 260 °C) and another between 900 and 1200 °F (482 to 649 °C); and the 2 temperatures must be no greater than 600 °F (335 °C) apart. So, tests at 350 °F (177 °C) and at 950 °F (510 °C) would be acceptable, but tests at 250 °F (121 °C) and 1000 °F (538 °C) exceed the 600 °F (335 °C) span.

3.5.6.2 For multiple qualified operating ranges, TUS shall be performed within each operating range during each test period and at the maximum and minimum of each operating range at least once each year.

For example if a furnace requires:

- ±10 °F (±6 °C) uniformity from 800 to 1025 °F (425 to 551 °C),
- ±15 °F (±8 °C) uniformity from 1026 to 1400 °F (552 to 760 °C) and
- ±25 °F (±14 °C) uniformity from 1401 to 1600 °F (761 to 870 °C),

once each year, the furnace would have to be tested at

- 800 °F (425 °C) and 1025 °F (550 °C) and meet ±10 °F (±6 °C),
- 1400 °F (760 °C) and meet ±15 °F (±8 °C) and
- 1600 °F (870 °C) and meet ±25 °F (±14 °C).

Other tests conducted during the year would only need to be conducted at a temperature within each of the three uniformity ranges.

3.5.7 Survey interval shall be in accordance with Table 8 or Table 9.

3.5.7.1 Extended TUS intervals are based on both instrument type and history of the required number of consecutive successful surveys. In addition, a documented preventive maintenance program, defined in 2.2.37, shall be in effect. As noted in 3.5.3, if a modification is made to the furnace, an initial TUS is required and TUS interval reverts to the initial TUS interval until the required number of consecutive successful surveys are completed.

3.5.8 Furnace Parameters during TUS

During each survey, except as outlined in 3.5.9, 3.5.10, 3.5.11, and 3.5.12, all parameters shall reflect the normal operation of the equipment in production. (Examples: If the doors of a continuous furnace are normally open during production, they shall also be open for the TUS; if slow heat up rates and stabilization temperatures are not used in production, they shall not be used during the TUS; if excess combustion air is used during production, it shall also be used during the TUS; if fans are operated during production, they shall also be operated during the TUS, etc.).

3.5.9 Furnace Temperature at Insertion of TUS Sensors

If the normal operation of the equipment in production is to load material into a hot furnace, it is acceptable to insert the TUS sensors into the furnace with the furnace cold or with the furnace stabilized at or below the survey temperature. If the normal operation of the equipment in production is to load material into a cold furnace, pre-heating the furnace to perform the TUS is prohibited.

3.5.10 Load Condition

A TUS may be performed with an actual production load, simulated production load, a rack, or empty. Once a method of surveying a furnace is established during an initial TUS, subsequent surveys shall be conducted using the same method. If changes are made to the established method, an initial TUS shall be performed to validate the revised method.

3.5.10.1 If the TUS is performed empty or with a rack, and if TUS sensors are attached to or inserted into heat sinks, the side-to-side thickness or diameter of the heat sink shall not exceed 0.5 inch (13 mm) and shall not exceed the thickness of the thinnest material being processed in that furnace. Heat sink material shall be the material with the highest room temperature thermal conductivity consistent with the predominant material processed in the furnace.

3.5.10.2 When the TUS is performed with a load, and the TUS sensors are attached to simulated product or parts, the load shall represent the thickness of the material normally processed.

3.5.11 Furnace atmosphere during a TUS shall be the normal atmosphere used for production. Furnaces used for those processes whose required atmospheres could contaminate the test sensors (i.e., carburizing, nitriding, endothermic, and exothermic) or atmospheres that could pose a safety hazard (i.e., hydrogen or ammonia containing) may be tested with an atmosphere of air or inert gas.

3.5.12 Furnace vacuum level during TUS shall be run at the lowest vacuum level used in production, but need not be less than 1 micron Hg ($1 \times 10^{-3}$ Torr, or $1.3 \times 10^{-3}$ millibar).

3.5.13 Batch Furnaces, Salt Baths, Controlled Temperature Liquid Baths and Fluidized Bed Furnaces (does not apply to Controlled Temperature Quench Baths)

3.5.13.1 Number of TUS Sensors

The number of TUS sensors shall be in accordance with Table 11.

3.5.13.2 Location of TUS Sensors

3.5.13.2.1 For furnace work zone volumes less than 3 cubic feet (0.085 $m^3$), four TUS sensors shall be located at the four corners and one at the center. If the furnace work zone volume is cylindrically shaped, four TUS sensors shall be located 90 degrees apart at the periphery and one shall be located at the center. In both cases, all TUS sensors shall be located to best represent the qualified work zone.

3.5.13.2.2 For furnace work zone volumes greater than 3 cubic feet (0.085 $m^3$), eight TUS sensors shall be located at the corners and one shall be located in the center. If the work zone volume is cylindrically shaped, three TUS sensors shall be located on the periphery of each end, 120 degrees apart. One of the remaining TUS sensors shall be located at the center; the other two shall be located to best represent the qualified work zone. For furnace work zone volumes greater than 225 cubic feet (6.4 $m^3$), the additional TUS sensors required by Table 11 shall be uniformly distributed to best represent the qualified work zone. When radiant heat from the periphery of the work zone is used to heat the product, the additional sensors shall be uniformly distributed at the periphery of the work zone.

3.5.13.2.3 The work zone volume tested shall be such that no material heat treated extends beyond the defined work zone boundaries.

3.5.13.3 TUS Data Collection

3.5.13.3.1 Data collection shall begin before the first furnace or TUS sensor reaches the lower tolerance limit of each test temperature so that any furnace or TUS sensor exceeding the upper temperature uniformity tolerance is clearly detected. If the furnace is prestabilized, data collection shall begin as soon as the test load or rack is loaded in the furnace.

3.5.13.3.2 Once data collection begins, temperature data shall be recorded from all TUS sensors at a frequency of at least one set of all readings every 2 minutes for the duration of the survey. Data from furnace sensors required by the applicable instrumentation type (See 3.3) shall be recorded as follows. (Sensors whose only function is over-temperature protection do not need to be recorded.)

If the normal frequency of temperature data recording in production is 2 minutes or less, or is continuous as in the case of analog recorders, the data shall be documented in the normal production format. If the normal frequency of temperature data recording in production is greater than 2 minutes, the recording frequency interval during the TUS shall not exceed 6 minutes.

3.5.13.3.3 At no time shall any test, control or recording sensor exceed the upper temperature uniformity tolerance. The furnace shall be held at the test temperature until all test sensors have stabilized (2.2.61). After stabilization, data collection shall continue for a minimum of 30 additional minutes.

3.5.13.3.4 When a retort is used, the temperature of the furnace in which the retort is inserted shall be controlled so that the specified heat treating temperature is maintained within the retort. TUS sensors shall be within the retort; at least one TUS sensor shall align within 2 inches (50 mm) of the sensor used to record temperature within the retort during operation.

3.5.13.4 Alternative Probing Method for Salt Baths, Controlled Temperature Liquid Baths, and Fluidized Bed Furnaces (does not apply to Controlled Temperature Quench Baths)

3.5.13.4.1 It is acceptable to probe salt baths, controlled temperature liquid baths and fluidized bed furnaces by relocating a single test probe containing one or more test sensors and measuring at the test locations described in 3.5.13.2.

3.5.13.4.2 All parameters shall reflect the normal operation of the equipment in production. The equipment shall be stabilized at the test temperature.

3.5.13.4.3 The first test location shall be monitored for at least 15 minutes so that any recurrent temperature pattern can be detected. If no recurrent temperature pattern is detected, readings at subsequent locations shall be taken at intervals of 2 minutes or less, for a minimum of 6 minutes at each test location. If a recurrent temperature pattern is detected, sufficient time shall be recorded at each location to document the extremes of five cycles of the recurrent temperature pattern. Total survey time shall not be less than 30 minutes. All readings shall meet the required temperature uniformity tolerance.



3.5.14 Continuous and Semi-continuous Furnaces

Continuous and semi-continuous furnaces may be surveyed with TUS sensors arranged volumetrically or in a plane. Using the volumetric method, TUS sensors are located in three dimensions to represent a portion (e.g., basket or tray) or the entire volume of the work zone. Using the plane method, TUS sensors are located in a single plane perpendicular to furnace conveyance direction such that passing the plane through the furnace measures the entire work zone volume of the zones to be tested. Either the volumetric or plane methods shall measure the full work zone volume. The difference is the arrangement and number of TUS sensors. When testing a portion of the work zone volume incrementally, the entire volume is measured as the TUS sensors traverse through the furnace. Regardless of which method is used, the full volume defined as the work zone shall be surveyed. Multiple runs may be required to accomplish measurement of the full work zone volume.

3.5.14.1 Number and Location of TUS Sensors in Continuous and Semi-continuous Furnaces – Volumetric Method

3.5.14.1.1 The number of TUS sensors shall be in accordance with Table 11 based on the volume of the TUS fixture(s).

3.5.14.1.2 The location of TUS sensors shall be in accordance with 3.5.13.2.1, 3.5.13.2.2, and 3.5.13.2.3, based on furnace volume.

3.5.14.2 Number of TUS Sensors in Continuous and Semi-continuous Furnaces - Plane Method

3.5.14.2.1 For furnaces having work zone heights of 1 foot (300 mm) or less, the minimum number of TUS sensors shall be 3, with 1 additional TUS sensor for each 2 feet (610 mm) of width over 8 feet (2.4 m).

3.5.14.2.2 For furnaces having work zone heights of over 1 foot (300 mm) and work zone cross sections up to 8 square feet (0.75 $m^2$), the minimum number of TUS sensors shall be 5.

3.5.14.2.3 For furnaces having cross sections greater than 8 square feet (0.75 $m^2$) and less than 16 square feet (1.5 $m^2$), the minimum number of TUS sensors shall be 7.

3.5.14.2.4 For work zone cross sections greater than or equal to 16 square feet (1.5 $m^2$), the minimum number of TUS sensors shall be 9.

3.5.14.3 Location of TUS Sensors – Plane Method

3.5.14.3.1 For furnaces having work zone heights of 1 foot (300 mm) or less, two TUS sensor locations shall be within 3 inches (76 mm) of opposite work zone side corners. One TUS sensor location shall be at the center. Additional TUS sensors shall be uniformly distributed throughout a plane perpendicular to the conveyance direction.

3.5.14.3.2 For furnaces having work zone heights of over 1 foot (300 mm) and work zone cross sections up to 8 square feet (0.75 $m^2$), four TUS sensor locations shall be within 3 inches (76 mm) of the work zone corners and the remainder shall be at the center and symmetrically distributed about the center of a plane perpendicular to the conveyance direction.

3.5.14.3.3 For furnaces having work zone cross section greater than 8 square feet (0.75 $m^2$), four TUS sensors shall be each within 3 inches (76 mm) of the work zone corners, one shall be at the center and the remainder shall be symmetrically distributed about the center of a plane perpendicular to the conveyance direction.

3.5.14.4 TUS Data Collection

3.5.14.4.1 All parameters shall reflect the normal operation of the equipment in production.

3.5.14.4.2 A TUS sensor for each test location shall be secured to a rack or in a load and traversed through the furnace. Initial surveys shall be performed at the highest and lowest traverse speeds used in production. Periodic tests may be performed at any traverse speed used in production. All required locations need not be traversed simultaneously; several traverses may be made to survey all locations.

3.5.14.4.3 Temperature readings of all TUS sensors and the control or monitoring sensor(s) shall be recorded for each surveyed zone. The traverse may be repeated as many times as necessary to ensure that any recurrent temperature pattern is determined at all test locations through the surveyed working zone(s). Readings shall be recorded at least every 2 minutes with at least three sets of readings recorded per zone.

3.5.14.4.4 Starting the TUS with the furnace temperature higher than the test temperature is prohibited unless (1) it is done in only the initial or preheating zones of multizone furnaces or (2) it is specifically permitted by all applicable process specifications. All TUS sensors shall meet the required temperature uniformity tolerance.

3.5.15 Alternative Testing Methods For Continuous or Semi-continuous Furnaces or Furnaces with Retorts or Muffles

Where it is impossible or impractical to traverse TUS sensors through a continuous or semi-continuous furnace, or to install TUS sensors into the retort or muffle of a furnace, it is acceptable to use alternative testing methods as described below:

3.5.15.1 Probing Method

In lieu of 3.5.14.4.2, it is acceptable to insert TUS sensors through the side walls, hearth or roof within 3 inches (76 mm) of the locations identified in 3.5.14.1.2. If this method is used, the number of TUS sensors shall be as described in Table 11 based on the volume of the work zones tested. Tested zones shall include all soak zones. Readings of all TUS sensors shall be taken every 2 minutes and reading of at least 1 controlling, monitoring, or recording sensor in each surveyed zone shall be taken every 5 minutes for a minimum of 30 minutes once zone temperature has stabilized. For continuous furnaces, traversing a load through the furnace during the test is not a requirement.

3.5.15.2 Property Surveys

This method requires (1) testing of material initially and annually thereafter and (2) monthly examination of property trends. The product analyzed shall be one whose properties are sensitive to variations in heat treating temperature and whenever possible, one that is heat treated frequently. Material thickness shall be within the normal process size range. If a 2-step treatment is required, it is permissible to perform the second step on the samples separately from the remainder of the lot (e.g., in a laboratory furnace).

3.5.15.2.1 Initial and annual property surveys shall be performed at the highest and lowest operating temperatures. Additional test temperatures shall be added to make sure no two test temperatures are more than 300 °F (165 °C) apart. Continuous furnace throughput speed shall be that normally used for processing. At least 10 tests shall be performed at each test temperature. Samples for tests shall be taken from the extremes and center of the load except for coils, from which samples shall be taken at both ends of the coil. Coil samples shall be tested at both edges and at the center of each cut off sample.

3.5.15.2.2 Monthly Property Surveys

Properties of heat-treated material shall be analyzed by a statistical technique such as described in ASTM MNL 7 or other statistical process control reference work. The trends of properties shall be examined at least monthly. Control limits shall be defined. If the trend of properties exhibits a shift outside of the upper or lower control limits, no further processing shall occur until the cause of the shift is determined and corrected. Paragraph 4.2 shall apply.

3.5.16 Temperature Uniformity Survey Sensor or Recorder Failures (2.2.19)



No TUS sensor or recording instrument failures at the corner locations of the work zone are permitted. A temporary condition such as a short or loose connection where normal temperature readout is restored shall not be considered a failed survey thermocouple. Failure of a TUS sensor (except at a corner location) during a TUS need not be cause for survey failure unless 2 adjacent TUS sensors fail or the number of TUS sensor failures exceeds the following:

- Survey with 3 to 9 sensors: No failures
- Survey with 10 to 16 sensors: 1 failure
- Survey with 17 to 23 sensors: 2 failures
- Survey with 24 to 39 sensors: 3 failures
- Survey with 40 or more sensors: no more than 10%

For test temperatures of 2000 °F (1093 °C) and above:

- Survey with 3 to 5 sensors: No failures
- Survey with 6 to 9 sensors: 1 failure
- Survey with 10 to 16 sensors: 2 failures
- Survey with 17 to 23 sensors: 3 failures
- Survey with 24 to 39 sensors: 4 failures
- Survey with 40 or more sensors: no more than 10%

3.5.16.1 The assignable cause shall be documented for each failed TUS sensor and corrective action taken (where possible) to prevent or decrease future failures from this cause.

3.5.17 Temperature Uniformity Pass/Fail Requirements

3.5.17.1 A survey shall be considered acceptable if all previous requirements are met including the following:

3.5.17.1.1 Control or monitoring sensor readings and corrected TUS sensor readings did not exceed the applicable positive temperature tolerance at any time.

3.5.17.1.2 All readings of all TUS sensors and control or monitoring sensors are within the temperature tolerance requirements shown in the applicable Table 8 or 9 during the soak period except as allowed by 3.5.16.

3.5.17.1.3 The time required to achieve recovery, stabilization, or recurrent temperature pattern did not exceed the time limit specified in any applicable process specifications.

3.5.17.1.4 TUS is run for the minimum required time.

3.5.18 Relocation of Hot or Cold Recording Sensors for Class A or C Instrumentation

When the hottest and coldest temperature locations change within the furnace (based on the final readings from the most recent Temperature Uniformity Survey), the recording sensor locations for types A and C instrumentation may need to be moved within the furnace to reflect the new hottest and coldest locations within the work zone. These sensors do not require relocation if the overall temperature uniformity does not exceed one half of the maximum temperature uniformity tolerance for the applicable furnace class at all temperatures surveyed, or if the difference between the measured temperature at the current recording locations and the actual respective hottest and coldest measured areas is less than the system accuracy test (SAT) tolerance for the applicable furnace class.

3.5.19 Temperature Uniformity Survey Failures

3.5.19.1 If the temperature uniformity is not within the tolerances of Table 8 or 9, the cause of the deviation shall be determined and documented and 4.2 shall apply. The equipment shall not be used for additional processing until the cause has been corrected and the TUS has been performed successfully.

3.5.19.1.1 For equipment tested at extended interval, failure of a temperature uniformity survey shall cause the test interval to revert to the initial test interval specified in Table 8 or 9. Interval shall not be extended until the specified number of successful consecutive tests in Table 8 or 9 have been completed.

3.5.19.1.2 If the correction takes the form of adjusting (offsetting) the control instrument, if the Qualified Operating Temperature Range does not exceed 300 °F (165 °C) a resurvey is not required, but the adjustment shall not exceed the limits established in Table 6 or 7 [Column titled Maximum Permitted Adjustment (Offset)]. The offset is in addition to any offset as allowed for SAT in 3.4.5.6.

3.5.19.1.2.1 If the Qualified Operating Temperature Range exceeds 300 °F (165 °C), a re-survey is required where uniformity is checked at the temperature extremes of the test range where the offset is applied. Test temperatures for each range where offsets are applied shall not be more than 600 °F (335 °C) apart.

3.5.19.1.2.2 Documentation of any adjustment (offset) is a requirement. In addition, any offsets or adjustments shall remain in place during all subsequent heat treatments in the temperature range where the offsets are applied. This will return the equipment to the requirements of 3.5.6 for subsequent TUSs.

3.5.20 Temperature Uniformity Survey Instrumentation

3.5.20.1 Temperature Uniformity Surveys shall be performed using calibrated independent test instrumentation meeting the requirements of Table 3, and independent TUS sensors meeting the requirements of Table 1. Process instruments of thermal processing equipment shall not be used to record TUS sensor data.

3.5.20.2 Compensation for known deviations in the test instrumentation shall be made by electronic methods or mathematical correction.

3.5.21 Temperature Uniformity Survey Report

3.5.21.1 The following items shall be included in the temperature uniformity survey report:

a. Furnace identification name or number

b. Survey temperatures

c. TUS sensor and location identification including a detailed diagram, description or photograph(s) of any load or rack used

d. Time and temperature data from all recorded sensors required for furnace instrumentation type for all zones tested (3.5.13.3.2)

e. Correction factors for TUS sensors at each survey temperature.

f. As found and as left TUS offsets (if used in production)

g. Corrected or uncorrected readings of all TUS sensors at each survey temperature. Readings shall be identified as corrected or uncorrected.

h. Testing company identification (if not performed in-house)

i. Signature for the testing company (if not performed in-house)

j. Identification of technician performing survey

k. Survey start date and time

l. Survey end date and time

m. Survey test instrument identification number

n. Indication of test pass or test fail

o. When required, documentation of furnace survey sensor failures (See 3.5.16)

p. Summary of corrected plus and minus TUS readings at each test temperature after stabilization.

q. Quality Organization approval.



3.5.21.2 Although not a required part of the uniformity survey report, the following shall be accessible on site:

a. Control instrument tuning parameters

b. TUS sensor calibration report

c. Control and recording sensor calibration report

d. Diagrams of control and recording sensors, load and TUS sensor locations in three dimensional space.

3.5.22 Surveys performed prior to the issue date of this revision, in accordance with previous AMS2750 revisions, may be considered equivalent to tests performed in accordance with this revision for the purpose of qualifying furnaces for (1) waiving initial temperature uniformity tests or (2) extending the interval of periodic temperature uniformity tests.

3.5.23 Radiation Surveys

For all aluminum alloy solution heat treating air furnaces, when the heat source (e.g., electrical elements or gas tubes) is in the walls, a radiation survey shall be conducted at the maximum operating temperature of the furnace. This survey shall be conducted initially and after any damage or repair that could affect the radiation characteristics of the side wall panels.

3.5.23.1 The radiation test sensor(s), which shall be added to the normal survey sensors, shall be peened into or welded to, the center of 6061 aluminum alloy panels, approximately 12 inches (305 mm) square and not more than 0.125 inch (3 mm) in nominal thickness. The panels shall have been heated to 970 to 1010 °F (520 to 545 °C) in air and air cooled prior to first use.

3.5.23.2 The panels, one for each 10 square feet (0.93 $m^2$) of heat wall area, shall be distributed symmetrically, with faces parallel to the heated walls, at the outer limits of the working zone. Either side of the radiation test panel(s) may face the heat source.

3.5.23.3 All radiation test sensor readings shall meet the requirements of 3.5.17.

3.6 Laboratory Furnaces

3.6.1 Laboratory furnace used for response to heat treating testing per material specifications and when a load sensor is used:

3.6.1.1 Require quarterly System Accuracy (SAT) testing

3.6.1.2 Load sensor shall comply with 3.1.5

3.6.1.3 Furnace control instruments shall be calibrated quarterly

3.6.1.4 After successful initial temperature uniformity survey (TUS) and two additional quarterly TUS surveys, the TUS interval may be extended to semi-annually.

3.6.2 If a load sensor is not used the Laboratory furnaces shall be tested as required for production equipment.

3.6.3 A laboratory furnace is not to be used for thermal processing of any production part or production raw material unless it meets all requirements of this specification.

3.7 Records

3.7.1 All calibration and test records including sensors, standard cells and instruments, system accuracy tests, and temperature uniformity surveys, including any test or survey failures shall be available for inspection and maintained for not less than 5 years.

3.7.2 Calibration records of sensors, standard cells, and instruments shall include traceability to the NIST or equivalent national standard.

3.8 Rounding

Rounding shall be in accordance with ASTM E 29 or other national standard.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The processor shall be responsible for the performance of all required tests and for conformance to all requirements specified herein. The purchaser reserves the right to witness any of the tests or calibrations specified herein to ensure that processing conforms to the prescribed requirements, but such witnessing shall not hinder operation of the facility.

4.1.1 Any instrument/sensor/test failing to meet these requirements, or that has exceeded its test interval including any applicable permissible extension period (See Table 10), shall be taken out of service.

4.1.1.1 Corrective action shall be documented including the actions taken to bring the instrument/sensor/test into compliance.

4.2 In the event of any test failure or out-of-tolerance condition, an evaluation of the possible effects of the non-conformance on product processed since the last successful corresponding test shall be performed and documented. The evaluation shall be documented per established material review procedures. Appropriate corrective action shall be taken, documented and maintained on file. When material processing conditions deviate from specification requirement affected purchaser(s) shall be notified.

4.2.1 A conforming corresponding test shall be required as evidence of adequate corrective action.

TABLE 1 - SENSORS AND SENSOR CALIBRATION

| Sensor | Sensor Type [1] | Use | Calibration [3] [4] | | Maximum Permitted Error [2] [12] |
|---|---|---|---|---|---|
| | | | Period | Against | |
| Reference Standard [7] | Types R and S noble metal | Primary standard calibration[8] | 5 years | NIST[5]/ Reference standard | None |
| Primary Standard [8] | Types R and S noble metal | Secondary standard calibration[9] | 3 years | Reference standard[7] | ±1.0 °F (±0.6 °C) or ±0.1% |
| Secondary Standard [9] | Base or Types R and S noble metal | Sensor calibration[10] | Before first use.<br>Recalibration:<br>2 years - Types R & S<br>1 year - Base metal [11] | Primary standard[8] | Base metal: ±2 °F (±1.1 °C) or ±0.4%<br>Noble metal: ±1.5 °F (±1.0 °C) or ±0.25% |
| | Type B noble metal | | 2 years - Type B | | ±1.0 °F (±0.6 °C) or ±0.5%, Type B |
| Temperature Uniformity Survey | Base or Types B, R, and S noble metal | Temperature uniformity surveys | Before first use.<br>Recalibration: [6]<br>6 months - Types B, R, & S<br>3 months - base metal<br>Types E&K Not permitted | Primary or secondary standard[10] | ±4 °F (±2.2 °C) or ±0.75% |
| System Accuracy Test | Base or Types B, R, and S noble metal | System accuracy tests | | Primary or secondary standard[10] | Base metal ±2 °F (±1.1 °C) or ±0.4%<br>Noble metal ±1.5 °F (±1.0 °C) or ±0.25% – or –<br>±0.25%, Type R, S<br>±0.50%, Type B |
| Control, Recording, and Monitoring | Base or Types B, R, and S noble metal | Installation in equipment | Before first use. | Primary or secondary standard[10] | Class 1&2: ±2 °F (±1.1 °C) or ±0.4%<br>Class 3 to 6: ±4 °F (±2.2 °C) or ±0.75% |
| Load | Base or Types B, R, and S noble metal | Load Sensing | Before first use.<br>Recalibration:<br>6 months - Types B, R, & S<br>not permitted - other base metal | Primary or secondary standard[10] | ±4 °F (±2.2 °C) or ±0.75% |