SAE Aerospace
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AEROSPACE MATERIAL SPECIFICATION

SAE AMS 2750D

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Superseding AMS 2750C

(R)

Pyrometry

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, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959 or www.astm.org.

ASTM E 207	Thermal EMF Test of Single Thermoelement Materials by Comparison with a Reference Thermoelement of Similar EMF-Temperature Properties
ASTM E 220	Calibration of Thermocouples by Comparison Techniques
ASTM E 230	Standard Specification and Temperature-Electromotive Force (EF) Tables for Standardized Thermocouples
ASTM E 608	Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples
ASTM E 1129	Standard Specification for Thermocouple Connectors
ASTM MNL 7	Presentation of Data and Control Chart Analysis
ASTM MNL 12	Use of Thermocouples in Temperature Measurement

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3. TECHNICAL REQUIREMENTS

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3.1 Temperature Sensors:

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 Temperature shall be measured by the thermocouples specified herein, 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“. 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.

3.1.1.1 Calibration: Sensors shall have a certificate of compliance that identifies the source of the calibration data, nominal test temperature, actual test temperature readings, calibration technique, and correction factor for each calibration temperature traceable to NIST or other recognized National Standard. Calibration technique shall comply with ASTM E 220, ASTM E 207, or other national standard.

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 Temperature sensors shall be calibrated in the temperature range within which they are to be used. 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 or other national standard. Recalibration after use above 500 °F (260 °C) of Type K and Type E thermocouples is prohibited. Extrapolation of calibration correction factors above the highest calibration temperature and below the lowest calibration temperature is prohibited.

3.1.1.4 Thermocouples and Their Usage: Thermocouples should only be used within the ranges listed in ASTM MNL 12 Table 3.1 (Recommended Upper Temperature Limits for Protected Thermocouples) or 3.5 (Recommended Upper Temperature Limits for Protected Thermoelements), ASTM E 230 Table 6 (Suggested Upper Temperature Limits for Protected Thermocouples), ASTM E 608 Table 1 (Suggested Upper Temperature Limits for Sheathed Thermocouples), or other national standard and the sensor supplier. Use of thermocouples not conforming to these recommendations shall be based upon calibration and recalibration intervals required in Table 1 of this document.

3.1.1.4.1 Thermocouple calibration intervals specified herein, whether based on time, number of uses, or temperature are the maximums permitted. However, 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. 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.

3.1.1.5 Extension wire in new installations (one year after the issue of this revision) 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.

3.1.1.6 Thermocouples made from calibrated rolls may be used in lieu of individually calibrated thermocouples. Rolls up to 1000 feet (305 meters) in length may be sampled at one end; rolls over 1000 feet shall be sampled at both ends of the roll (see 3.1.1.1). 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.

3.1.1.6.1 The roll calibration method shall not be used for rolls over 1000 feet (305 meters) if the difference between the highest and lowest calibration readings of the sample thermocouples at any calibration temperature exceeds the requirements in 3.1.1.6.2 or 3.1.1.6.3, as applicable.

3.1.1.6.2 1 °F (0.6 °C) for primary and secondary standard thermocouples.

3.1.1.6.3 2 °F (1.1 °C) for system accuracy test, temperature uniformity test, controlling, monitoring, recording, and load thermocouples.

3.1.1.6.4 For rolls not meeting 3.1.1.6.2 or 3.1.1.6.3:

3.1.1.6.4.1 It is permissible to divide the roll into shorter length rolls that do meet the end to end tolerance specified in 3.1.1.6.2 or 3.1.1.6.3.

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

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

Primary Standard Sensors	200 feet (60 meters)
Other Noble Metal Sensors	2000 feet (610 meters)
Base Metal Secondary Standard Sensors	2000 feet (610 meters)
All Other Base Metal Sensors	5000 feet (1525 meters)

3.1.1.8 For reuse of Types K and E thermocouples above 500 °F (260 °C) depth of insertion shall be equal to, or greater than, depth of insertion of any previous use.

3.1.1.9 Reuse of any thermocouple is prohibited unless the insulation remains intact and wires including the hot junction are not damaged. 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. If the salvaged thermocouple originated from a calibrated wire roll, the original roll calibration may be used in lieu of recalibration. The number of uses prior to salvage shall be included in the total number of uses of the thermocouple.

3.1.1.10 Recalibration of any expendable base metal test thermocouples (SAT or TUS) is prohibited. Reuse is permitted so long as "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.

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

3.1.1.11 Recalibration of nonexpendable base metal Type E and K thermocouples used below 500 °F (260 °C), Type J, Type N, and all noble metal thermocouples (SAT or TUS) shall be in accordance with Table 1.

3.1.2 Reference standard sensors shall comply with Table 1.

3.1.2.1 The reference standard sensor together with a primary standard instrument shall be used to calibrate primary standard sensors.

3.1.3 Primary standard sensors shall comply with Table 1.

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

3.1.4 Secondary standard sensors shall comply with Table 1.

3.1.4.1 Use shall be limited to calibration of temperature uniformity, system accuracy, controlling, monitoring, recording, and load sensors.

3.1.5 Temperature uniformity survey sensors shall comply with Table 1.

3.1.5.1 Calibration of temperature uniformity survey sensors shall have been performed with a primary or secondary standard instrument against a primary or secondary standard sensor in accordance with Table 1 except as specified in 3.1.5.2. See 3.1.1.8 and 3.1.1.9 for limits on reuse of thermocouples. Recalibration of Types K and E thermocouples that have been exposed to temperatures above 500 °F (260 °C) is prohibited.

3.1.5.2 Expendable base metal TUS thermocouples that are (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 remain installed on a rack that is protected between tests, may be reused subject only to the limitations of 3.1.1.9 and 3.1.1.10. Nonexpendable base metal TUS thermocouples installed on racks and used exclusively under 1200 °F (650 °C) shall be limited to no more than 90 uses or 3 years, whichever comes first.

3.1.6 System accuracy test sensors shall comply with Table 1.

3.1.6.1 Calibration of SAT sensors shall have been performed with a primary or secondary standard instrument against a primary or secondary standard sensor in accordance with Table 1. See 3.1.1.8, 3.1.1.9, and 3.1.1.10 for limits on reuse of thermocouples. Recalibration of Types K and E thermocouples that have been exposed to temperatures above 500 °F (260 °C) is prohibited.

3.1.7 Control, monitoring, and recording sensors shall comply with Table 1. Expendable thermocouples may be used, subject to the limitations of 3.1.1.9 and 3.1.1.10.

3.1.7.1 Controlling, monitoring, and recording sensors shall be installed in thermal processing equipment within the work zone, or as close as possible, for controlling and/or monitoring of temperature, in conjunction with controlling and/or monitoring instruments.

3.1.7.2 When a Load Sensor is used as a Control Sensor:

3.1.7.3 Calibration shall have been performed before use. Recalibration of base metal load thermocouples is prohibited (see 3.1.8.3).

3.1.7.4 Expendable thermocouples, when used as a control sensor are limited to one use.

3.1.7.5 Nonexpendable load thermocouples may be used to control temperature, subject to the limitations of 3.1.8.

3.1.8 Load sensors shall comply with Table 1.

3.1.8.1 Load sensors, used for measurement of temperature of parts, simulated parts, or raw material, shall be in contact with or buried in the load during thermal processing.

3.1.8.2 Load sensors may be used as control sensors in accordance with 3.1.7.2. When a load sensor is used as a control sensor, no control, monitoring, or recording sensor shall exceed the maximum allowed processing temperature.

3.1.8.3 Recalibration of base metal load thermocouples is prohibited. Recalibration frequency of noble metal thermocouples shall be every six months after first use.

3.1.8.4 Expendable base metal load thermocouples may be used up to 30 times when used at or below 1200 °F (650 °C) provided the requirements of section 3.1.1.9 are satisfied; they are limited to one use above 1200 °F (650 °C). Nonexpendable base metal load thermocouples may be used as specified in 3.1.8.5.

3.1.8.5 The life of nonexpendable base metal load thermocouples shall be determined by the operating temperature(s). Records shall be maintained of the accumulated thermocouple use (furnace load cycle). Maximum number of uses or maximum elapsed usage time, whichever occurs first, shall be as follows:

2300 °F (1260 °C) and above	1 use
2200 °F (1205 °C) to 2299 °F (1260 °C)	10 uses
1801 °F (980 °C) to 2199 °F (1205 °C)	30 days or 90 uses
1200 °F (650 °C) to 1800 °F (980 °C)	90 days or 180 uses
Below 1200 °F (650 °C)	90 days or 270 uses

When used in multiple ranges, the shortest frequency or usage shall apply. Replacement of a load sensor earlier than the required SAT frequency satisfies the SAT requirement for the load sensor.

Example 1:

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

Example 2:

- A sensor with 50 uses between 1400-1600 °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 1400-1600 °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 1200-1800 °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 AMS 2750D as not all instruments approved for use in AMS 2750C will meet the requirements of this revision.

3.2.2 The following requirements (3.2.2.1 and 3.2.2.2) apply to control, monitoring, or recording instruments purchased one year after the issue date of AMS 2750D. Control, monitoring, or recording instruments purchased prior to one year after the publication of AMS 2750D may meet the requirements of AMS 2750C.

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

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

3.2.3 Test instruments shall be digital and have a minimum readability of 1 °F or 1 °C.

3.2.4 Controlling, Monitoring, or Recording Instruments:

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

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

3.2.4.3 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.

3.2.4.3.1 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 3.4.4.3.1. 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.

3.2.4.4 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.

3.2.5 Instrument Calibration:

3.2.5.1 Calibration shall be performed on the instrument(s) listed in the Instrument Type column of Table 3. Regardless of the calibration procedure used, it shall comply with the requirements of Table 3.

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

3.2.5.3 Calibration shall be performed to the manufacturer's instructions.

3.2.5.3.1 Calibration of controlling, monitoring or recording instruments shall be performed to the manufacturer's instructions or, if the manufacturer's instructions are not used, a minimum of three simulated sensor inputs shall be used at the minimum, midpoint and maximum of the furnace Qualified Operating Temperature Range.

3.2.5.3.2 Calibration of furnace controlling, monitoring or recording instrument(s) 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.

3.2.5.3.3 Calibration shall be performed on each channel in use that can be altered or adjusted, or group of channels that can be altered or adjusted.

3.2.5.4 Chart recorder (circular and strip) speed(s) shall be verified annually and shall be accurate within ± 3 minutes per hour.

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

3.2.6 Instrumentation Records:

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

- Date the calibration was performed
- Due date of the next calibration
- Technician who performed the calibration
- 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:

- Instrument number or furnace number
- Make and model of instrument calibrated
- Standard used during calibration
- Method of calibration (manufacturer's instructions, three point)
- Required accuracy
- As found and as left data at each calibration point
- Offset as found and as left (as required)
- Any intentional offset as left
- Sensitivity (as required by Table 3, Note 4)
- Statement of acceptance or rejection
- Any limitations or restrictions of the calibration shall be included
- Date the calibration was performed
- Due date of the next calibration
- Technician who performed the calibration
- Calibration company (if not performed in-house)

3.2.6.2 (Continued)

- Signature of the calibration company representative (if not performed in-house)
- 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 one year after the issue date of this revision shall meet the following requirements:

3.2.7.1.1 The system must create write-once, read only 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.

3.2.7.1.4 The system shall support protection, retention, and retrieval of accurate records throughout the record retention period. 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 A and are based on the minimum requirements for temperature uniformity. Instrumentation types are based on the level of instrumentation used to control, record or indicate the desired temperature. Frequencies for system accuracy tests, temperature uniformity surveys, and controlling, monitoring, and recording instrument calibrations are based on the furnace class and instrumentation type (Table 3, 6, 7, 8, or 9).

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

FIGURE A - Furnace Classes

3.3.1.1 Instrumentation Type A:

3.3.1.1.1 Each control zone shall have at least one control sensor connected to a control instrument that displays and controls temperature.

3.3.1.1.2 The temperature indicated by the control sensor in each control zone shall be recorded by a recording instrument.

3.3.1.1.3 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. 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.

3.3.1.1.3.1 These recording locations may change over time. See 3.5.18 for relocation requirements.

3.3.1.1.4 At least one recording load sensor shall be located in each control zone.

3.3.1.1.5 Each control zone shall have over-temperature protection. The sensor representing the hottest location per 3.3.1.1.3 may also be utilized as the over-temperature protection sensor.

3.3.1.2 Instrumentation Type B:

3.3.1.2.1 Each control zone shall have at least one control sensor attached to a control instrument that displays and controls temperature.

3.3.1.2.2 The temperature indicated by the control sensor in each control zone shall be recorded by a recording instrument.

3.3.1.2.3 At least one recording load sensor shall be located in each control zone.

3.3.1.2.4 Each control zone shall have over-temperature protection.

3.3.1.3 Instrumentation Type C:

3.3.1.3.1 Each control zone shall have at least one control sensor attached to a control instrument that displays and controls temperature.

3.3.1.3.2 The temperature indicated by the control sensor in each control zone shall be recorded by a recording instrument.

3.3.1.3.3 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. 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.

3.3.1.3.3.1 These recording locations may change over time. See 3.5.18 for relocation requirements.

3.3.1.3.4 Each control zone shall have over-temperature protection. The sensor representing the hottest location per 3.3.1.3.3 may also be utilized as the over-temperature protection sensor.

3.3.1.4 Instrumentation Type D:

3.3.1.4.1 Each control zone shall have at least one control sensor attached to a control instrument that displays and controls temperature.

3.3.1.4.2 The temperature indicated by the control sensor in each control zone shall be recorded by a recording instrument.

3.3.1.4.3 Each control zone shall have over-temperature protection.

3.3.1.5 Instrumentation Type E:

3.3.1.5.1 Each control zone shall have at least one control sensor attached to a control instrument that displays and controls temperature.

3.3.1.6 Instrumentation - Refrigeration Equipment and Quench Systems:

3.3.1.6.1 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 if it is used for a treatment where time-at-temperature is required. The above requirements are not applicable during transportation of materials at sub-ambient temperatures.

3.3.1.6.2 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 at the release date of this revision do not require recording instruments.

3.4 System Accuracy Tests (SATs):

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 additional systems that qualify instrumentation as Types A, B, or C. See 3.3.1.1, 3.3.1.2, and 3.3.1.3.

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

3.4.1.2 An SAT is not required for sensors whose only function is over-temperature control, load sensors that are limited to a single use (one furnace load/cycle), sensors not used for acceptance as part of production heat treatment, or load sensors whose replacement frequency is shorter than the SAT frequency. See 3.1.8.4 and 3.1.8.5.

3.4.1.3 A new SAT shall be performed after any maintenance that could affect the SAT accuracy. Examples include replacement of the thermocouple and recalibration of the instrument when any adjustment has been made. Quality Assurance shall be consulted for direction on whether specific maintenance requires a new SAT.

3.4.2 SATs shall be performed upon installation and periodically thereafter in accordance with the requirements of Table 6 or 7. SAT frequency is based upon equipment class and instrumentation type. If a preventive maintenance program (see 8.2.35) is in effect, frequency may be reduced one step (e.g., weekly to biweekly, biweekly to monthly, etc.) if allowed in Table 6 or 7 under either of the following conditions:

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

3.4.2.2 Weekly readings 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.

3.4.3 SAT Waiver: The requirement for an SAT is waived if all of the following (3.4.3.1 through 3.4.3.6) apply:

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

3.4.3.2 Load sensors used for control shall comply with 3.1.7.2 and the monitoring load sensors shall comply with 3.1.8.

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

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

3.4.3.5 All noble metal control and recording thermocouples in use shall be replaced every two years.

3.4.3.6 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.

3.4.4 System Accuracy Test Procedure

3.4.4.1 The uncorrected temperature indication and/or recording of the sensor being tested, at any operating temperature, shall be compared with the corrected temperature indication of the test sensor on a test instrument.

3.4.4.2 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 SAT tests shall utilize SAT 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 3.4.4.2.1.

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

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

3.4.4.2.1.2 The resident SAT sensor type shall be different from that of the sensor being tested. Furthermore, a resident Type R sensor shall not be used to check a Type S sensor, and a resident Type S sensor shall not be used to check a Type R sensor.

3.4.4.2.1.3 Resident SAT sensors shall be subject to the replacement and recalibration requirements of 3.1.6.

3.4.4.3 The difference between the uncorrected reading of the sensor system being tested (sensor, leadwire, and instrument) and the corrected reading (after test sensor and test instrument correction factors are applied) of the test sensor system shall be recorded as the system accuracy difference. Applicable correction factors shall be applied algebraically.

3.4.4.3.1 Certain correction factors may be algebraically applied to the sensor system being tested when calculating the system accuracy difference, provided that these correction factors are consistently applied during production heat treatment in accordance with documented procedures.

Examples of correction factors that may be incorporated 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.
- Intentional internal adjustment 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 setpoint (e.g., If the desired setpoint is 1000 °F, set control instrument setpoint 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.

Example 1 (No intentional prior internal control or recording instrument adjustment)	
Indicated (uncorrected) control or recording instrument reading **(A)**	1500 °F
Indicated (uncorrected) test instrument reading **(D)**	1503.0 °F
Test thermocouple correction factor **(E)**	-1.0 °F
Test instrument correction factor **(F)**	+0.2 °F
(D) + **(E)** + **(F)** = True Test Temperature **(G)**	1502.2 °F
SAT Difference = **(A)** – **(G)**	-2.2 °F

Example 2 (With intentional prior internal control or recording instrument adjustment)	
Indicated (uncorrected) control or recording instrument reading **(A)**	1500 °F
Correction to balance prior intentional internal adjustment to control or recording instrument **(B)**	+5 °F
Control Sensor correction factor	-1 °F
(A) + **(B)** + **(B[1])** = Corrected control or recording instrument temperature **(C)**	1504 °F
Indicated (uncorrected) test instrument reading **(D)**	1507.0 °F
Test thermocouple correction factor **(E)**	-1.0 °F
Test instrument correction factor **(F)**	+0.2 °F
(D) + **(E)** + **(F)** = True Test Temperature **(G)**	1506.2 °F
SAT Difference = **(C)** – **(G)**	-2.2 °F

3.4.4.4 If the 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.

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

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

3.4.4.5.2 Recalibration of the out-of-tolerance instrument.

3.4.4.5.3 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.

3.4.4.6 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.

3.4.4.7 After corrective action has been effected, and prior to any additional thermal processing, the SAT shall be repeated in accordance with 3.4.4.

3.4.4.8 As an alternative to the SAT procedure of 3.4.4.1 to 3.4.4.3, the same objective may be accomplished either by (1) replacing the sensor being tested at or more frequently than the required SAT frequency and checking the balance of the system (lead wire and instrument combination) or (2) testing the sensor and the balance of the system (lead wire and instrument combination) separately and combining the results. For either method, the combined result shall be within the tolerances specified in Table 6 or 7.

3.4.5 System Accuracy Test Instrumentation:

3.4.5.1 System accuracy tests shall be performed using a test instrument meeting the requirements of Table 3 and a test sensor meeting the requirements of Table 1.

3.4.6 Records:

3.4.6.1 The system accuracy test report shall include:

- Identification of the sensor being tested
- Identification of the test sensor
- Identification of the test instrument
- Date and time of day of the test
- Observed control or recording instrument reading
- Observed test instrument reading
- Test sensor and test instrument correction factors
- Corrected test instrument reading
- Calculated system accuracy difference
- Indication of test acceptance or failure
- Identification of technician performing the test
- SAT company (if not performed in-house)
- Signature of the calibration company representative (if not performed in-house)
- 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 frequency 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 °F to 1000 °F (±6 °C from 315 °C to 540 °C) and ± 25 °F from 1000 °F to 1800 °F (±14 °C from 540 °C 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:

- Increase in the maximum qualified operating temperature or decrease in the minimum qualified operating temperature
- Burner size, number, type, or location change
- Heating element number, type, or location change
- Changes to airflow pattern/velocity (baffle positions, fan speed, fan quantity, etc.)
- Change of refractory thickness
- New refractory with different thermal properties
- Change of vacuum furnace hot zone design or materials
- Change of control sensor location
- Change of combustion pressure settings from original setting
- Change of furnace pressure settings (damper system) from original settings
- Temperature control scheme change (proportional versus high-low/off-on)
- Adjustment of tuning constants
- Work zone volume increase covering area not previously tested
- 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.

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:

- Replacing a burner/tile with another duplicate burner/tile
- Refractory repair using material with similar thermal properties
- Replacing a control or monitoring sensor to its previously documented location
- Replacing heating system components (e.g., gas regulator, valve, metering device, heating elements, etc.)
- Restoring original combustion pressure settings and tuning constants
- Replacing a controller with an identical controller with the same tuning constants
- System accuracy test failure
- Correction of furnace pressure control problem
- Repair of furnace door seals.

3.5.4 (Continued)

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.

3.5.5 Initial survey temperatures shall be the minimum and maximum temperatures of the qualified operating temperature range(s). 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 °F to 1800 °F (425 °C 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 survey temperatures shall be any temperature within each qualified operating range(s). Temperatures shall be added as required to ensure that no two adjacent survey temperatures are greater than 600 °F (335 °C) apart. Additionally, at least once within each calendar year periodic tests shall be performed at the minimum and maximum temperatures of each qualified operating temperature range. For example if a furnace requires ±10 °F (± 6 °C) uniformity from 800 °F to 1025 °F (425 to 550 °C), ±15 °F (±8 °C) uniformity from 1026 °F to 1400 °F (590 to 760 °C) and ±25 °F (± 14 °C) uniformity from 1401 °F to 1600 °F (795 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 frequency shall be in accordance with Table 8 or Table 9.

3.5.7.1 Frequency reductions are based on both instrument type and history of the required number of successful surveys. In addition, a documented preventive maintenance program shall be in effect.

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, preheating 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 thickness 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 (1×10^{-3} Torr, or 1.3×10^{-3} millibar).

3.5.13 Batch Furnaces, Salt Baths, Controlled Temperature Liquid Baths and Fluidized Bed Furnaces:

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 ft^3 (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 ft^3 (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 ft^3 (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 two 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.)

a) If the normal frequency of temperature data recording in production is two minutes or less, or is continuous as in the case of analog recorders, manually recorded data shall be reported at two minute intervals.

b) If the normal frequency of temperature data recording in production is greater than two minutes, data shall be recorded at the normal production frequency, but whether temperature data is recorded manually or automatically, in no case shall the furnace sensor recording frequency intervals exceed six 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. After stabilization, data collection shall continue for a minimum of 30 additional minutes. 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.

a) For unloaded furnaces: If the temperature readings of any TUS sensor exhibit an upward or downward trend (continuously higher highs or continuously lower lows) the test period shall be extended as necessary until the trend is no longer evident.

b) 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.

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:

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 two minutes or less, for a minimum of six 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 – 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.

3.5.14.2 Number of TUS Sensors - 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 three, with one 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 five.

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 seven.

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

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 the work zone 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.

3.5.14.4 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 two 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 two minutes and readings of at least one controlling, monitoring, or recording sensor in each surveyed zone shall be taken every five 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.

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 Failures: No TUS sensor 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. Catastrophic 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:

- TUS sensor readings and control or monitoring sensor readings did not exceed the applicable positive temperature tolerance at any time.
- All readings of all TUS sensors and control or recording 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.
- The time required to achieve recovery, stabilization, or recurrent temperature pattern did not exceed the time limit specified in any applicable process specifications.
- 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 the requirements of 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 reduced frequency, failure of a temperature uniformity survey shall cause the test frequency to revert to the initial test frequency specified in Table 8 or 9. Frequency shall not be reduced 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, and 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 3.4.4.6. 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. 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 TUS's.

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. 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:

- Furnace identification name or number
- Survey temperatures
- TUS sensor and location identification including a detailed diagram, description or photograph(s) of any load or rack used
- Correction factors as well as corrected or uncorrected readings of all TUS sensors at each survey temperature. Readings shall be identified as corrected or uncorrected.
- Testing company identification (if not performed in-house)
- Signature for the testing company (if not performed in-house)
- Name of technician performing survey
- Survey start date and time
- Survey end date and time
- Survey test instrument identification number
- Indication of test pass or test fail
- Documentation of furnace survey sensor catastrophic failures (see 3.5.16)
- Time and temperature profile data showing TUS sensors and control or monitoring sensors for all zones tested
- Summary of final plus and minus readings at each test temperature
- Quality Organization approval.

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

- Control instrument tuning parameters
- TUS sensor calibration report
- Control and recording sensor calibration report
- 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 AMS 2750C section 3.4.2, 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) reducing frequency 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 qualified 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 used for response to heat treating testing per material specifications and when a load sensor is used:

- Require quarterly System Accuracy (SAT) testing
- Load sensor shall comply with 3.1.8
- Furnace control instruments shall be calibrated quarterly
- After successful initial temperature uniformity survey (TUS) and two additional quarterly TUS surveys, the TUS frequency may be extended to semi-annually.

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

3.6.2 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 five years.

3.7.2 Calibration records of sensors, standard cells, and instruments shall include traceability to the NIST or equivalent 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) (3)	Use	Calibration (4) (5)		Maximum Permitted Error (2) (3)
			Period	Against	
Reference Standard (3.1.2)	Types R and S noble metal	Primary standard calibration	Before first use. Recalibration: 5 years	NIST(6)/ Reference standard	None
Primary Standard (3.1.3)	Types R and S noble metal	Secondary standard calibration	Before first use. Recalibration: 3 years	Reference standard	±1.0 °F (±0.6 °C) or ±0.1%
Secondary Standard (3.1.4)	Base or Types R and S noble metal	Test sensor calibration	Before first use. Recalibration: 2 years - Types R & S 1 year - Base metal	Primary standard	Base metal: ± 2 °F (±1.1 °C) or ±0.4% Noble metal: ±1.0 °F (±0.6 °C) or ±0.1%
	Type B noble metal		Before first use. Recalibration: 2 years - Type B		±1.0 °F (±0.6 °C) or ± 0.25%, Type B
Temperature Uniformity Survey (3.1.5)	Base or Types B, R, and S noble metal	Temperature uniformity surveys	Before first use. Recalibration: (7) (8) 6 months - Types B, R, & S 3 months - Types J & N not permitted - other base metal	Primary or secondary standard	±4 °F (±2.2 °C) or ± 0.75%
System Accuracy Test (3.1.6)	Base or Types B, R, and S noble metal	System accuracy tests	Before first use. Recalibration: (8) 6 months - Types B, R, & S 3 months - Types J & N not permitted - other base metal	Primary or secondary standard	Base metal ±2 °F (±1.1 °C) or ±0.4% Noble metal ±1.0 °F (±0.6 °C) or ± 0.10%, Type R, S ± 0.25%, Type B
Control, Recording, and Monitoring (3.1.7)	Base or Types B, R, and S noble metal	Installation in equipment	Before first use.	Primary or secondary standard	Class 1&2: ±2 °F (±1.1 °C) or ±0.4% Class 3 to 6: ±4 °F (±2.2 °C) or ± 0.75%
Load (3.1.8)	Base or Types B, R, and S noble metal	Load Sensing	Before first use. Recalibration: 6 months - Types B, R, & S not permitted - base metal	Primary or secondary standard	±4 °F (±2.2 °C) or ±0.75%

(1) Temperature sensors that possess equal or better accuracy (maximum permitted error) are acceptable.

(2) Percent of reading or correction factor in degrees, whichever is greater.

(3) Type T thermocouples are normally used below 32 °F (0 °C) with a tolerance of ±1 °F (0.6 °C) or ± 0.8%, whichever is greater.

(4) Recalibration requirements are outlined in the appropriate paragraphs and in 3.1.1.3 and 3.1.1.4.1.

(5) A reference standard sensor (3.1.2) may be used to calibrate any lower level sensor.

(6) NIST or equivalent National Standard.

(7) See 3.1.5.2 for exceptions.

(8) See 3.1.1.10 and 3.1.1.11 for expendable and nonexpendable base metal requirements.

TABLE 2 - Thermocouples and Extension Wire

Type	Thermocouple			Extension Wire	
	Positive Element Composition (Nominal wt%)	Negative Element Composition (Nominal wt%)	Element Color Code (1)	Wire Code (positive/negative)	Jacket Color Code (1)
J	Fe	55Cu/45Ni	White/Red	JPX/JNX	Black
E	90Ni/10Cr	55Cu/45Ni	Purple/Red	EPX/ENX	Purple
K	90Ni/10Cr	95Ni/5, Al+Si	Yellow/Red	KPX/KNX	Yellow
N	84.5Ni/14Cr/1.5Si	95.4Ni/4.5Si/0.1Mg	Orange/Red	NPX/NNX	Orange
R	87Pt/13Rh	Pt	Black/Red	RPX/RNX or SPX/SNX	Green
B	70Pt/30Rh	94Pt/6Rh	Gray/Red	BPX/BNX	Gray
S	90Pt/10Rh	Pt	Black/Red	PRX/RNX or SPX/SNX	Green
T	Cu	55Cu/45Ni	Blue/Red	TPX/TNX	Blue

(1) All color codes stated are in accordance with ASTM E 230. Color codes in accordance with other national standard(s) may be used.

TABLE 3 - Instruments and Instrument Calibration

Instrument	Instrument Type	Maximum Calibration Period (Months)	Standard	Calibration [1] Accuracy	Use
Reference Standard	Zener voltage reference	36	NIST[9]	Per NIST[9]	Limited to primary standard calibration
Primary Standard	Potentiometer, digital voltmeter [1]	36	Reference Standard	±0.1 °F (±.05 °C) or ±0.015% of reading, whichever is greater	Limited to laboratory calibration of secondary standard and test instruments and primary and secondary standard sensors
	4 or more Weston-type cells [3] or equivalent solid state DC standards	12 [2]	Reference Standard	±0.005% of millivoltage rating of cell.	Limited to laboratory calibration of instruments and secondary standard cells and standardization of instruments
Secondary Standard Instrument	Potentiometer or digital voltmeter [1]	12	Primary standard or primary standard cell	±0.3 °F(±0.2 °C) or ±0.05% of reading, whichever is greater	Limited to laboratory calibration of field test instruments, system accuracy test sensors, temperature uniformity survey sensors, load sensors, and controlling, monitoring, or recording sensors [7]
Secondary Standard Cell	2 or more saturated or unsaturated Weston-type cells or equivalent solid state DC standards	12 [2]	Primary standard cell	±0.005% 0f millivoltage rating of cell.	Limited to laboratory standardization of secondary standard instruments and calibration of test instruments
Field Test Instrument	SAT/TUS Portable [1] potentiometer or digital instrument, electronic data recorder, or data acquisition system	3	Primary or secondary standard	±1 °F (±0.6 °C) or ±0.1% of reading in °F, whichever is greater	Limited to controlling, monitoring, or recording instrument calibration, performance of system accuracy tests, and temperature uniformity surveys [7]
Controlling, Monitoring, or Recording Instrument	Digital instrument [4] [5] [6] [8]	See note [5]	Test	±2 °F (±1.1 °C)	Limited to measuring, recording, and controlling temperature of thermal processing equipment
	Electro mechanical instrument [4] [5] [6] [8]	See note [5]	Test	±2 °F (±1.1 °C) or ±0.3% of the maximum survey temperature of the equipment, whichever is greater	Limited to measuring, recording, and controlling temperature of thermal processing equipment
	Mechanical or Thermal Element	6	Comparative Test (same as for SAT)	±5 °F (±3 °C)	Limited to measuring temperature of refrigeration and quench bath thermal processing equipment

Table 3 Notes:

(1) Instruments of equivalent or greater accuracy are acceptable.

(2) Comparison checks among the cells shall be performed monthly.

(3) Cells having temperature control of ±0.02 °F (±0.01 °C).

(4) Class 1 & 2 instruments shall have a minimum sensitivity of 1 °F (1 ° C). Class 3 through 6 instruments shall have a minimum sensitivity of 3 °F (2 °C).

(5) Control, monitor and record instrument calibration frequency in accordance with 3.2.4 shall be:

Digital	Analog (Electromechanical)
Furnace Class 1 - Monthly	Furnace Class 1 - Monthly
Furnace Class 2 - Quarterly	Furnace Class 2 - Monthly
Furnace Class 3 - Quarterly	Furnace Class 3 - Quarterly
Furnace Class 4 - Quarterly	Furnace Class 4 - Quarterly
Furnace Class 5 - Semiannually	Furnace Class 5 - Quarterly
Furnace Class 6 - Semiannually	Furnace Class 6 - Quarterly

(6) Furnace Control, Recording, Monitoring or Data Acquisition Instruments.

(7) Field Test instruments meeting accuracy requirements of secondary standards may be used to calibrate SAT and TUS test instruments in the field.

(8) Over temperature instruments used solely for furnace over temperature protection do not need to be calibrated.

(9) NIST or equivalent National Standard.

TABLE 4 - Resolution Requirements for Furnace Chart Recorders (1) (2)

Furnace Class	Temperature Uniformity		Maximum Degrees per Inch (cm) of Chart Paper		Maximum Chart Recording Increment	
	°F	°C	°F/ inch	°C/ cm	°F/ line	°C/ line
1	±5	±3	50	11	2	1
2	±10	±6	150	33	5	3
3	±15	±8	150	33	5	3
4	±20	±10	250	55	10	5
5	±25	±14	250	55	10	5
6	±50	±28	350	77	25	15

(1) Requirements apply to instruments purchased one year after publication of AMS 2750D, see 3.2.1 and 3.2.2.

(2) Digital instruments shall have a readability of 1 °F or 1 °C.

TABLE 5 - Process Recorder Print and Chart Speeds (1)

Recorder Type	Print Interval (2) (3) (5)	Chart Speed (4)	
Circular	Print intervals shall be a minimum of 6 times during each time at temperature cycle. Print intervals shall not exceed 15 minutes.	For cycles less than one hour time at temperature = maximum of 8 hours per complete revolution	For cycles one hour or more at temperature = maximum of 24 hours per complete revolution
Strip		For cycles less than one hour = 2 inches/hour minimum	For cycles one hour or more = 1 inch/hour minimum
Digital		Not applicable	

(1) Requirements apply to instruments purchased one year after publication of AMS 2750D, see 3.2.1 and 3.2.2.

(2) Recorder shall be operating during the entire time that product is in the furnace.

(3) The sampling technique used for all points recorded on chart shall be documented if other than the instantaneous value at the sampling rate time fixed by the manufacturer.

(4) “Cycles” refers to heat treating time at temperature cycles.

(5) Print interval minimums may need to be changed in order to demonstrate conformance to cooling rate minimums.

TABLE 6 - Parts Furnace Class, Instrument Type, and System Accuracy Test (SAT) Interval

Furnace Class	Temperature Uniformity		Minimum Instrument Type	Normal SAT Interval	Max Allowable SAT Interval	Maximum SAT Difference [2]			Maximum Permitted Adjustment (Offset) [1] [2] [3]		
	°F	°C				°F	°C	% of reading	°F	°C	% of maximum qualified operating temperature
1	±5	±3	D	Weekly	Weekly	±2	±1.1	0.2	±2.5	±1.5	-
			B, C	Weekly	Biweekly						
			A	Biweekly	Monthly						
2	±10	±6	D	Weekly	Weekly	±3	±1.7	0.3	±5	±3	-
			B, C	Biweekly	Monthly						
			A	Monthly	Quarterly						
3	±15	±8	D	Biweekly	Monthly	±4	±2.2	0.4	±8	±5	0.38
			B, C	Monthly	Quarterly						
			A	Quarterly	Semiannually						
4	±20	±10	D	Biweekly	Monthly	±4	±2.2	0.4	±10	±6	0.38
			B, C	Monthly	Quarterly						
			A	Quarterly	Semiannually						
5	±25	±14	D	Biweekly	Monthly	±5	±2.8	0.5	±13	±7	0.38
			B, C	Monthly	Quarterly						
			A	Quarterly	Semiannually						
6	±50	±28	E	Semiannually	Semiannually	±10	±5.6	1.0	-	-	0.75

(1) The maximum permitted adjustment (offset) shall be the same for manual and electronic methods
(2) Whichever is greater (°F or °C, or % of reading).
(3) Offsets for SAT and TUS are separate and the maximum is allowed for each.

TABLE 7 - Raw Material Furnace Class, Instrument Type, and System Accuracy Test (SAT) Interval

Furnace Class	Temperature Uniformity		Minimum Instrument Type	Normal SAT Interval	Max Allowable SAT Interval	Maximum SAT Difference [2]			Maximum Permitted Adjustment (Offset) [1] [2] [3]		
	°F	°C				°F	°C	% of reading	°F	°C	% of maximum qualified operating temperature
1	±5	±3	D	Weekly	Monthly	±2	±1.1	0.2	±2.5	±1.5	-
			B, C	Monthly	Quarterly						
			A	Monthly	Quarterly						
2	±10	±6	D	Weekly	Monthly	±3	±1.7	0.3	±5	±3	-
			B, C	Monthly	Quarterly						
			A	Monthly	Quarterly						
3	±15	±8	D	Weekly	Monthly	±4	±2.2	0.4	±8	±5	0.38
			B, C	Monthly	Quarterly						
			A	Monthly	Quarterly						
4	±20	±10	D	Monthly	Quarterly	±4	±2.2	0.4	±10	±6	0.38
			B, C	Quarterly	Semiannually						
			A	Quarterly	Semiannually						
5	±25	±14	D	Monthly	Quarterly	±5	±2.8	0.5	±13	±7	0.38
			B, C	Quarterly	Semiannually						
			A	Quarterly	Semiannually						
6	±50	±28	E	Semiannually	Semiannually	±10	±5.6	1.0	-	-	0.75

(1) The maximum permitted adjustment (offset) shall be the same for manual and electronic methods
(2) Whichever is greater (°F or °C, or % of reading).
(3) Offsets for SAT and TUS are separate and the maximum is allowed for each.