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ADOPTION NOTICE

PYROMETRY

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AEROSPACE MATERIAL SPECIFICATION

SAE AMS 2750 REV C

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Submitted for recognition as an American National Standard

PYROMETRY

1. SCOPE: This specification covers temperature sensors, instrumentation, thermal processing equipment, system accuracy tests, and temperature uniformity tests. These are necessary (See 8.2) to ensure that parts or raw materials (See 8.3.7) are heat treated in accordance with the applicable specification(s). It is applicable to all heat treatment of parts and to those heat treatments by producers of raw material which could affect fabrication or properties of parts.

1.1 This specification is not applicable to heating, or to intermediate heat treatment, by raw material producers to facilitate subsequent operations (e.g., hot or cold working). It is also not applicable to brazing, hot isostatic pressing and coating.

1.2 The requirements herein pertaining to system accuracy tests and temperature uniformity tests are waived for laboratory equipment used to heat treat specimens in accordance with material specifications providing test instrument(s) and sensor(s) in contact with, or in close proximity to, specimen(s) are used to measure specimen temperature(s).

1.3 Conformance of raw material heat treating equipment to the requirements herein pertaining to readability of working instruments is waived for a transition period of one year after the date of publication of this document. Conformance of raw material heat treating equipment to other requirements herein is waived for a transition period of six months providing pyrometry conforms to appropriate industry or U.S. Government specifications (e.g. MIL-STD-1684).

2. APPLICABLE DOCUMENTS: The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order.

2.1 ASTM Publications: Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM E 207 - Thermal EMF Test of Single Thermoelement Materials by Comparison with a Secondary Standard of Similar EMF-Temperature Properties
ASTM E 220 - Calibration of Thermocouples by Comparison Techniques
ASTM E 230 - Standard Temperature Electromotive Force (EMF) Tables for Standardized Thermocouples
ASTM E 344 - Terminology Relating to Thermometry and Hydrometry
ASTM E 608 - Standard Specification for Metal Sheathed Base-Metal Thermocouples
ASTM STP 15D - Manual on Presentation of Data and Control Chart Analysis
ASTM STP 470 - Manual on the Use of Thermocouples
ASTM Book of Standards - Vol 14.03 - Temperature Measurement

2.2 U.S. Government Publications: Available from Naval Publications and Forms Center, Attn: NPODS, 5801 Tabor Avenue, Philadelphia, PA 19120-5099.

2.2.1 Military Standards:

MIL-STD-1684 - Control of Heat Treatment

2.3 Instrument Society of America Publications: Available from Instrument Society of America, Box 12277, Research Triangle Park, NC 27709

ANSI-MC96.1 - Temperature Measurement Thermocouples

3. TECHNICAL REQUIREMENTS:

CONTENTS

3.1 Temperature Sensors (See Table I):

3.1.1 General: Temperature shall be measured by the thermocouples specified herein, or by other thermocouples or sensors of equivalent or better accuracy and limits of error. Limits of error and correction factors specified herein are applicable to types E, J, K, N, R and S thermocouples. When it is necessary to use other types of thermocouples, they shall be of the same grade (i.e., special or standard limits) as those specified herein. Sensors shall be calibrated by the National Institute of Standards and Technology (NIST) (formerly National Bureau of Standards) or against sensors whose calibration is traceable, as specified herein, to NIST by a technique compatible with, or equivalent to, that of ASTM E 220 or ASTM E 207 (See 8.5).

3.1.1.1 Limits of error, correction factors and deviations are from ASTM E 230 tables and they may be converted from degrees to millivolts or vice versa.

3.1.1.2 Sensors shall be calibrated in the temperature ranges in which they are used. Calibration intervals shall not be more than 200°F (111°C) for primary and secondary standards and 500°F (278°C) for other sensors.

3.1.1.3 Thermocouples and Their Usage: Should consider the recommendations of the ASTM Book of Standards - Vol 14.03, ASTM STP 470 and ASTM E 344. Use of thermocouples not conforming to these recommendations should be based on data generated by comparison, under processing conditions, against a stable sensor.

3.1.1.3.1 Thermocouple calibration intervals specified herein, whether based on time or number of uses, are the maximums permitted. However, compliance with them 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. Shorter intervals should be used until an operating history is developed to justify the maximum limits or establish limits for the particular normal, and extremes of, exposure conditions.

3.1.1.4 Extension Wires: Should conform to ANSI MC96.1. They shall not be spliced, but connectors, plugs, jacks, and terminal strips are permissible.

3.1.1.5 Thermocouples Made from Calibrated Wire Rolls: May be used in lieu of individually calibrated thermocouples; the roll calibration shall be the average of sample thermocouples made from both ends of the roll (See 8.7).

3.1.1.5.1 The roll calibration shall not be used if the difference between the highest and lowest readings of the sample thermocouples at any calibration temperature exceeds the following:

3.1.1.5.1.1 1°F (0.6°C) for primary and secondary standard thermocouples.

3.1.1.5.1.2 2°F (1°C) or 0.2% of reading, whichever is greater, for system accuracy test, temperature uniformity test, working and load thermocouples.

3.1.1.5.2 Maximum Amount of Wire in a Roll: At the time of calibration shall be based upon the material and application as follows:

Primary Standard Sensors	200 feet	(60 metres)
Other Noble Metal Sensors	2000 feet	(610 metres)
Base Metal Secondary Standard Sensors	2000 feet	(610 metres)
All Other Base Metal Sensors	200 pounds	(91 kg)

3.1.1.6 Re-Use of Types K and E Thermocouples: For tests, calibrations, or heat treatments shall be limited as follows:

3.1.1.6.1 When used as secondary standard or system accuracy test sensors, each re-use above 500°F (260°C) shall be at a temperature equal to, or higher than, any previous use temperature above 500°F (260°C).

3.1.1.6.2 For solution heat treating of aluminum alloys and aging of PH stainless steels at 1025°F (552°C) and below, depth of insertion shall be equal to, or greater than, depth of insertion of any previous use.

3.1.1.7 Re-use of Thermocouples Other Than Metal-Sheathed, Ceramic Packed Insulation-Types: Is prohibited unless the insulation remains intact, the wires are not kinked or damaged, and the hot junction is undamaged.

3.1.1.7.1 Thermocouples which do not meet the above criteria shall be discarded or salvaged. Salvage shall consist of trimming off the discrepant portion and the portion heated above 500°F (260°C), remaking the hot junction, and recalibrating. If from a calibrated roll, the roll calibration may be used in lieu of recalibrating.

3.1.1.7.2 For test and load thermocouples made from base metal, recalibration is required before "U" in the following formula exceeds 30:

U = Number of uses below 1200°F (649°C) + 2 times number of uses between 1200°F (649°C) and 2000°F (1094°C) inclusive + 7 times number of uses over 2000°F (1094°C).

3.1.2 Reference Standard Sensors: Shall be platinum/platinum plus 10%, or 13%, rhodium thermocouples.

3.1.2.1 Calibration: Shall have been performed against the standards maintained by NIST and shall be checked with a primary standard instrument against another reference standard at least every five years thereafter.

3.1.2.2 Use: Shall be limited to calibration of primary standard sensors.

3.1.3 Primary Standard Sensors: Shall be platinum/platinum plus 10%, or 13%, rhodium thermocouples.

3.1 3.1 Limits of Error: Shall not exceed, upon initial calibration, ±2.7°F (±1.5°C) or ±0.25% of reading, whichever is greater.

3.1.3.2 Calibration: Shall have been performed with a primary standard instrument against a reference standard sensor, before first use and at least every three years thereafter. Upon recalibration, change from the initial calibration shall not exceed ±1°F (±0.6°C).

3.1.3.3 Use: Shall be limited to calibration of secondary standard sensors, test sensors, load sensors, and working sensors.

3.1.4 Secondary Standard Sensors: Shall be expendable or non-expendable base or noble metal thermocouples.

3.1.4.1 Limit of Error: Of base metal thermocouples shall not exceed, upon initial calibration, ±2°F (±1°C) or ±0.4% of reading, whichever is greater. Limit of error of noble metal thermocouples shall not exceed, upon initial calibration, ±2.7°F (±1.5°C) or 0.25% of reading, whichever is greater.

3.1.4.1.1 Upon recalibration, change from the initial calibration shall not exceed ±1°F (±0.6°C) for noble metal thermocouples and ±2°F (±1°C) for base metal thermocouples. (See 3.1.1.6 and 3.1.1.7 for limits on reuse of thermocouples.)

3.1.4.2 Calibration: Shall have been performed with a primary standard instrument, against a primary standard sensor or Pt-67, as maintained by NIST, before first use and thereafter at least every year for base metal, and at least every two years for noble metal, thermocouples.

3.1.4.3 Use: Shall be limited to calibration of test sensors, load sensors, and working sensors.

3.1.5 Temperature Uniformity Test Sensors: Shall be expendable or non-expendable, base or noble metal thermocouples.

3.1.5.1 Calibration: Shall have been performed with a primary or secondary standard instrument, against a primary or secondary standard sensor, before first use and within three months prior to any re-use (except six months if Type R or S thermocouple) thereafter. (See 3.1.1.6 and 3.1.1.7 for limits on re-use of thermocouples.)

3.1.5.2 Correction Factors: Shall not exceed ±4°F (±2°C) or ±0.75% of reading, whichever is greater.

3.1.5.3 Use: Temperature uniformity tests.

3.1.6 System Accuracy Test Sensors: Shall be expendable or non-expendable base or noble metal thermocouples.

3.1.6.1 Calibration: Shall have been performed with a primary or secondary standard instrument, against a primary or secondary standard sensor, before first use and within three months prior to any re-use (except six months if Type R or S thermocouple) thereafter.

3.1.6.2 Correction Factors: Shall not exceed ±2°F (1°C) or ±0.4% of reading, whichever is greater, for initial calibration. Upon recalibration, change from the initial calibration shall not exceed ±2°F (±1°C) if used on Class 1 equipment and ±4°F (±2°C) if only used on Class 2 equipment.

3.1.6.3 Use: System accuracy tests.

3.1.7 Working Sensors: Shall be non-expendable, base or noble metal thermocouples. Alternatively, expendable thermocouples may be used, subject to the limitations of 3.1.1.7.

3.1.7.1 Calibration: Shall have been performed before installation, against a primary or secondary standard sensor, using a secondary standard instrument. Deviations from the standard values shall not exceed, for Class 1 equipment, ±2°F (±1°C) or ±0.4% of reading, whichever is greater and, for Class 2 equipment, ±4°F (±2°C) or ±0.75% of reading, whichever is greater.

3.1.7.2 Use of Load Sensors: Expendable thermocouples (limited to one use) and non-expendable thermocouples in the load may be used as, or in combination with, working sensors to control temperature, subject to the limitations of 3.1.8. Calibration shall have been performed before use. Recalibration of base metal load sensors is not recommended.

3.1.7.3 Use of Radiation Pyrometers: As working sensors/instruments are permissible for equipment used only for continuous Class 2 heat treatments of raw material providing (1) their accuracy is at least ±1% of reading and (2) they have been calibrated within the previous three months.

3.1.7.4 Use: Installed in thermal processing equipment for control and recording of temperature, in conjunction with working instruments.

3.1.8 Load Sensors: Shall be calibrated, expendable or non-expendable base or noble metal thermocouples.

3.1.8.1 Calibration: Shall have been performed using a primary or secondary standard instrument, against a primary or secondary standard sensor, before first use and quarterly (except semi-annually if Type N, R or S) after first use, except that frequency shall be at least that required for system accuracy tests. Deviations from the standard values shall not exceed ±4°F (±2°C) or ±0.75% of reading, whichever is greater.

3.1.8.2 Use as Working Sensors: Expendable thermocouples (limited to one use) and non-expendable thermocouples in the load, may be used as working sensors, within the limitations of 3.1.7.2.

TABLE I

Outline of Sensors

Nomenclature	Description*	Calibration Period	Calibration Against	Use/Max Error Limit Correction Factor (°F)
Reference standard	Platinum/ Platinum-Rhodium	5 years	NIST/Reference standard	Primary standard calibration/None
Primary standard	Platinum/ Platinum-Rhodium	3 years	Reference standard	Secondary standard calibration/ ±2.7° or ±0.25%**
Secondary standard	Base or noble metal	1 year base 2 years noble	Primary standard	Test sensor calibration/ base - ±2° or ±0.4%** noble - ±2.7° or ±0.25%**
Temperature uniformity test	Base or noble metal	3 months base 6 months noble	Primary or secondary standard	Temperature uniformity tests/ ±4° or ±0.75%**
System accuracy test	Base or noble metal	3 months base 6 months noble	Primary or secondary standard	System accuracy tests/ ±2° or ±0.4%**
Working	Base or noble metal	Before installation	Primary or secondary standard	Installation in equipment"/" Class 1 - ±2° or ±0.4%** Class 2 - ±4° or ±0.75%**
Load	Base or noble metal	6 months N, R, S 3 months other	Primary or secondary standard	Insertion in loads/ ±4° or ±0.75%**

*Sensors of equivalent or greater accuracy are acceptable
**Percent of reading, if greater than correction factor in degrees

3.1.8.3 Use: Measurement of temperature of parts, or simulated parts, or raw material by contact during thermal processing except, for heavy loads of raw material, thermocouples may be buried in the load without assured contact.

3.2 Instrumentation (See Table II):

3.2.1 General: Output of sensors shall be converted to temperature readings by instruments specified herein or instruments of equivalent or greater accuracy. Instruments shall be calibrated by NIST, or against instruments whose calibration is traceable to NIST as specified herein (See 8.5).

3.2.2 Primary Standard Instruments: Shall be calibrated potentiometers, digital voltmeters, or instruments of equivalent accuracy.

3.2.2.1 Calibration: Shall have been performed within three years of use against reference standards. The reference standards shall have been calibrated by the NIST within the previous three years.

3.2.2.2 Accuracy: Shall be ±0.015% of reading or better at the time of calibration.

3.2.2.3 Use: Shall be limited to calibration of secondary standard and test instruments and primary and secondary standard sensors.

3.2.3 Primary Standard Cells: Shall be groups of four or more calibrated, saturated Weston-type cells with temperature control of ±0.02°F (±0.01°C), or equivalent solid state DC standards.

3.2.3.1 Calibration: Shall have been performed, against reference standards calibrated by the NIST, within one year of use. Intercomparison checks among the cells shall be performed monthly.

3.2.3.2 Use: Shall be limited to calibration of instruments and secondary standard cells and standardization of instruments.

3.2.4 Secondary Standard Instruments: Shall be calibrated potentiometers, or digital voltmeters, or instruments of equivalent accuracy.

3.2.4.1 Calibration: Shall have been performed within one year of use against a primary standard instrument or a primary standard cell.

3.2.4.2 Accuracy: Shall be ±0.05 of reading or better at the time of calibration.

3.2.4.3 Use: Shall be limited to calibration of test instruments, system accuracy test sensors, temperature uniformity test sensors, load sensors, and working sensors.

3.2.5 Secondary Standard Cells: Shall be groups of two or more calibrated, saturated or unsaturated, Weston-type cells, or equivalent solid state DC standards.

3.2.5.1 Calibration: Shall have be en performed within one year of use against a primary standard cell. Intercomparison checks among the cells shall be performed monthly.

3.2.5.2 Use: Shall be limited to standardization of secondary standard instruments and calibration of test Instruments.

3.2.6 Test Instruments: Shall be calibrated, portable potentiometers, or digital equipment, or instruments of equivalent accuracy. For temperature uniformity tests, they may be supplemented with multipoint strip chart recorders, data loggers or electronic data recorders.

3.2.6.1 Readability (See 8.3.8): Shall be ±1°F or ±0.5°C for scales, data loggers, and digital equipment. Readability of charts shall be ±4°F or ±2°C.

3.2.6.1.1 To meet the readability requirements, it is permissible to do any one or a combination of the following:

3.2.6.1.1.1 Scribe intermediate lines between scale divisions.

3.2.6.1.1.2 Sharpen indicator pointers or read center or edge of pointers.

3.2.6.1.1.3 Interpolate.

3.2.6.1.1.4 Add parallax-reducing reflective strips behind indicator needles.

3.2.6.1.1.5 Read the center or edge of recorded lines or dots (whichever corresponds most closely to the scale reading).

3.2.6.2 Calibration: Shall have been performed within three months of use against a primary or secondary standard instrument.

3.2.6.3 Accuracy: Shall be within ±1°F (±0.6°C) or ±0.2% of reading, whichever is greater, at the time of calibration.

3.2.6.4 Use: System accuracy tests, temperature uniformity tests, and calibration of working instruments.

3.2.7 Working Instruments for Heat Treating Furnaces: Shall be calibrated controlling, recording, and indicating potentiometers of the automatically functioning, electronic null-balance type having a constant voltage unit, or instruments or solid state devices of equivalent or greater accuracy. Instruments shall be sensitive (exhibit indicator movement) to a millivoltage increase or decrease equal to 10% of the applicable tolerance range (e.g., ±10° tolerance range requires sensitivity to a change of ±2°) specified in 3.4.2.2.1, 3.4.2.2.2, or 3.4.2.2.3.

3.2.7.1 Calibration: Shall have been performed against a test instrument:

3.2.7.1.1 Within one month of use on furnaces used for solution heat treatment of aluminum alloy parts and aluminum alloy raw material except as specified in 3.2.7.1.1.1.

3.2.7.1.1.1 Within three months of use if instrument is computer controlled and self-standardizing or if properties are analyzed as described in 8.6.

3.2.7.1.2 Within three months of use on furnaces used for other heat treatments.

3.2.7.2 Accuracy: Shall be ±0.3% of range at the time of calibration.

3.2.7.3 Readability (See 8.3.8):

3.2.7.3.1 Digital Instruments: Readability shall be ±1°F or ±1°C.

3.2.7.3.2 Scalar Instruments:

3.2.7.3.2.1 Furnaces for Heat Treating Parts:

Uniformity Requirement	Readability Requirement
±10°F (±6°C)	±2°F or ±1°C
±15°F (±8°C)	±3°F or ±1.5°C
±25°F (±14°C)	±5°F or ±3°C*

* ±10°F or ±6°C for 1800°F (982°C) and above

3.2.7.3.2.2 Furnaces for Heat Treating Raw Material:

Equipment Class	Readability Requirement
1	±5°F or ±3°C*
2	+10°F or ±6°C

*±10°F or ±6°C for 1800°F (982°C) and above

3.2.7.3.3 To improve readability, the techniques of 3.2.6.1.1 are permissible.

3.2.7.4 Operation:

3.2.7.4.1 Installations: Shall conform to the manufacturer's recommendations.

3.2.7.4.2 Instruments: Shall receive an unmodified signal from sensors except for analog to digital and digital to analog conversions. They shall be serviced and their sensitivity shall be checked each time they are calibrated.

3.2.7.4.3 Heat Treatment Temperature: Shall be that indicated by an indicating instrument which meets the requirements of 3.2.7.3.

3.2.7.4.4 Recordings: Shall be a legible mark on a chart. Chart paper shall not be re-used. During the thermal treatment (soaking) period, recordings shall be within the applicable temperature range except as follows:

3.2.7.4.4.1 If a recorded temperature mark is outside the applicable range, the temperature indicated by the indicating control instrument shall be documented on the chart or furnace log or traveller (1) during thermal treatment of each load for batch furnaces or (2) during each 4 hours of continuous furnace operation.

3.2.7.5 Use of Radiation Pyrometers: As working sensors/instruments are permissible for equipment used only for continuous Class 2 heat treatments of raw material providing (1) their accuracy is at least ±1% of reading and (2) they have been calibrated within the previous three months.

3.2.7.6 Use: Control, indicating, and recording of temperature of thermal processing equipment.

TABLE II

Outline of Instruments

Nomenclature	Description (1)	Calibration Period	Against	Use/Accuracy (1)
Reference standard	Resistance	3 years	NIST	Calibration of primary standard/Per NIST
Primary standard instrument	Potentiometer or digital voltmeter	3 years	Reference standard	Secondary standard calibration/±0.015% of reading
Primary standard cell	4 Weston-type cells	1 year	Reference standard	Secondary standard cell calibration and instrument standardization
Secondary standard instrument	Potentiometer or digital voltmeter	1 year	Primary standard	Test instrument calibration/±0.05% of reading
Secondary standard cell	2 Weston-type cells	1 year	Primary standard	Secondary standard and test instrument standardization
Test instrument	Portable potentiometer or digital instrument	3 months	Primary or secondary standard	Working instrument calibration, system accuracy & temperature uniformity tests/±1°F or ±0.2% of reading, whichever is greater
Working instrument	Electronic null-balance potentiometer	(2)	Test instrument	Measuring & controlling temperature of equipment/(3)

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

(2) One month for aluminum solution heat treating furnaces, three months for other heat treating furnaces, and six months for embrittlement relief furnaces, quench baths, and refrigeration equipment.

(3) ±0.3% of range for heat treating furnaces and ±10°F for embrittlement relief furnaces, quench baths and refrigeration equipment.

3.2.8 Working Instruments for Equipment Other Than Heat Treating Furnaces:

3.2.8.1 For Refrigeration Equipment and Quench Baths: Shall be a temperature indicator. This requirement is not applicable to liquid nitrogen, dry ice, and dry ice/liquid refrigerators.

3.2.8.2 For Embrittlement Relief Furnaces: Shall be both indicating and recording instrument(s).

3.2.8.3 Calibration: Shall have been performed within the previous six months.

3.2.8.4 Accuracy: Shall be within ±10°F or ±6°C of the calibrating equipment at the time of calibration.

3.2.8.5 Readability: Shall be ±10°F or ±6°C.

3.2.8.5.1 To improve readability, the techniques of 3.2.6.1.1 are permissible.

3.2.8.6 Use: Indicating and recording temperature of equipment.

3.3 Thermal Processing (See 8.3.1) Equipment:

3.3.1 Classification: Raw material (Type RM) furnaces are divided into Classes 1 and 2, depending on the thermal treatments performed in them. Furnaces used for thermal treatment of parts are all Class 1 and heat treating furnaces are divided into Types A and AA, depending on the number of sensors and instruments used.

3.3.1.1 Class 1 Furnaces: Furnaces used for heat treating raw material, other than Class 2 furnaces, and all furnaces used for any heat treating of parts, are designated Class 1 (See 8.3.7).

3.3.1.2 Class 2 Furnaces: Furnaces used exclusively for Class 2 heat treatments of raw material. These are treatments (1) which only affect the material's fabricability or (2) whose effects on final properties are not significantly affected by minor deviations outside specified temperature ranges.

3.3.1.3 Class 1 Heat Treatments of Raw Material:

(1) solution heat treating - aluminum alloys

(2) annealing - aluminum alloys within ±15°F (±8°C) of the solution heat treating set, or mid-range, temperature

(3) aging - Aluminum alloys and beryllium copper alloys
- PH stainless steels at 1025°F (552°C) and below
- 6Al-6V-2Sn titanium alloy at 1025°F (552°C) and below
- beta titanium alloys at 1025°F (552°C) and below

(4) tempering (after hardening) - D6AC and 9Ni-4Co alloy steels
- other alloy steels - 220 Ksi (1241 MPa) UTS and higher
- carburized steels

3.3.1.4 Class 2 Heat Treatments of Raw Material: Includes any aging, tempering, solution heat treating, and annealing not designated "Class 1" in 3.3.1.3. Class 2 heat treatments of raw material also include stress relieving, normalizing, normalize and tempering, austenitizing, solution annealing, and subcritical annealing.

3.3.2 Type A Furnaces for Parts: Shall be equipped with at least one working sensor in each control zone, attached to a working instrument which controls the temperature. The temperature of the control working sensor (or load sensors as specified in 3.3.5), shall be recorded by the controller, or other working instrument(s). In addition, each control zone should have a high limit, power shut-off controller/sensor for equipment protection.

3.3.3 Type AA Furnaces for Parts: Shall be equipped with the minimum sensors and instruments required for Type A furnaces, plus at least one additional recording working instrument attached to an additional working sensor or load sensor in each control zone. The additional sensor shall be positioned as close as possible to (1) the controlling working sensor or (2) the hottest or coldest location based on the last temperature uniformity test. A single multipoint recorder, or equivalent, may be used as the additional instrument for several control zones in one or more furnaces.

3.3.4 Type RM Furnaces for Raw Materials: As a minimum, shall be equipped as specified in 3.3.2 and shall be used for heat treatment of raw materials.

3.3.5 Use of Load Sensors: The requirement for recording the temperature of the control working sensor in 3.3.2 is waived when load sensors, whose readings are recorded, are used in loads of parts or raw materials. In such cases, sensors, at least two in each control zone, shall be placed at the locations in the load which are as close as possible to those shown, by the last temperature uniformity test, to be the hottest and coolest, and their recorded readings shall become a part of the thermal processing record.

3.3.6 Refrigeration Equipment: Shall have a temperature controller. This requirement is not applicable to liquid nitrogen, dry ice and dry ice/liquid cooled refrigerators.

3.3.7 Quench Baths: Used for heat treatments which include a quenchant temperature requirement (minimum, maximum or both) shall be controlled to meet these requirements.

3.3.8 Embrittlement Relief Furnaces: Shall be equipped with an instrument or instruments attached to working sensor(s) to record and control temperature.

3.4 Tests:

3.4.1 System Accuracy Tests (See Table III): Shall be performed on the temperature control system (load or working sensor/working instrument combination) in each control zone of each piece of thermal processing equipment. Tests shall also be performed on additional systems which qualify furnaces as Type AA.

3.4.1.1 The requirement for system accuracy tests is waived if all of the following apply:

3.4.1.1.1 There are always at least two load sensors in each control zone, one controlling and one monitoring with either recording.

3.4.1.1.2 The load sensors are recalibrated or replaced monthly.

3.4.1.1.3 The load sensors are recalibrated or replaced anytime that observations, made and recorded at least weekly, reveal any unexplainable difference between their readings.

3.4.1.1.4 Working sensors are replaced at least every two years or whenever normal remedies (e.g., replacing door seals) are unsuccessful in correcting temperature uniformity problems.

3.4.1.2 Frequency of Testing: Shall be upon installation and (1) weekly thereafter for Class 1, and (2) quarterly thereafter for Class 2 furnaces except the frequency may be reduced under the following conditions:

3.4.1.2.1 If each control zone always contains two or more working or load sensors connected to two or more working instruments, the frequency may be reduced to monthly for Class 1 furnaces and semi-annually for Class 2 furnaces.

3.4.1.2.2 If the conditions of 3.4.1.2.1 are met and properties are analyzed as described in 8.6, the frequency for Class 1 raw material furnaces may be reduced to quarterly.

3.4.1.2.3 If weekly readings recorded in the furnace log show that the relationship between two working sensors in each control zone remains within ±2°F (±1°C) of their relationship at the time of the last temperature uniformity test, the frequency may be reduced to quarterly for Class 1, and annually for Class 2, furnaces.

3.4.1.2.4 If two sensors in each control zone are Type N, R or S thermocouples, the frequency may be reduced to quarterly for Class 1, and annually for Class 2, furnaces.

3.4.1.2.5 If a furnace is used only for embrittlement relief, the frequency may be reduced to semiannually.

3.4.1.3 Procedure: The temperature indication of the load sensor or working sensor on the working instrument, at any operating temperature, shall be compared with that indicated on a test instrument by a test sensor. The test sensor may be inserted in the well of the working sensor, in a separate port, or introduced with a load, but it must be within 3 inches (76 mm) (Class 1 equipment) or 12 inches (305 mm) (Class 2 equipment) of the load or working sensor being tested. Any difference between the readings (after test sensor correction factors are applied) shall be recorded.

3.4.1.3.1 If the difference (including any prior adjustment of the working instrument as in 3.4.1.3.2) exceeds ±5°F (±3°C) for Class 1 equipment, or ±10°F (±6°C) for Class 2 equipment, the cause of the difference shall be determined and corrected before commencing additional thermal processing. Alleviating the difference by adjustment or offsetting, without determining the cause of the difference and correcting it, is prohibited.

3.4.1.3.1.1 In addition, the quality assurance organization responsible for the equipment shall evaluate whether possible effects of the deviation on raw material and parts processed since the last successful test warrants initiating a formal material review. The evaluation shall be documented and, where necessary, shall include consultation with metallurgists and engineering personnel. Appropriate corrective action shall be taken and documented.

3.4.1.3.2 If the difference read is less than specified in 3.4.1.3.1, and the cause is wholly or partially a drift of the working sensor or instrument, the working instrument shall be adjusted to compensate for the drift. The amount of adjustment shall be recorded and 3.4.1.3 shall be repeated. If adjustment of the working instrument is not possible, the difference, if greater than ±2°F (±1°C) if Class 1 or ±5°F (+3°C) if Class 2, shall be posted on the instrument and appropriate compensation shall be made by the heat treater.

3.4.1.3.2.1 If the cause is, wholly or partially, movement of the working sensor from its position during the most recent temperature uniformity test, any compensation for that difference, or portion of the difference, is prohibited. However, the working sensor may be repositioned to the location it occupied during the most recent temperature uniformity test and 3.4.1.3 repeated.

3.4.1.3.2.2 Drift of the working sensor shall be determined by attaching it to the test instrument and comparing its reading to that of the test sensor. Drift of the working instrument shall be determined by comparing it to the test instrument.

3.4.1.4 As an alternate to the system accuracy test of 3.4.1.3, the same objective may be accomplished by testing the components (working sensor, working instrument) separately and combining results.

TABLE III

Outline of Heat Treating Furnace System Accuracy Test Frequencies

Minimum Number and Type of Sensors/ Instruments in each Control Zone + other conditions	Minimum Test Frequency Class 1	Minimum Test Frequency Class 2
1 Working/1 working	Weekly	Quarterly
2 Working or load/2 working	Monthly	Semi-annually
2 Working or Load/2 working + 95/99 analysis (See 8.6)	Quarterly	-
2 Working/2 working + weekly conformity check	Quarterly	Annually
2 Type N, R or S Working or Load/ 2 working	Quarterly	Annually

3.4.2 Temperature Uniformity Tests (See Table IV): Shall be performed or shall have been performed, in accordance with the Appendix, on each furnace initially (prior to production use or after any repair or adjustment, e.g. to power controls, or baffles, which might have altered the temperature uniformity characteristics) (See 8.4) and periodically thereafter. The requirement for initial tests is waived for raw material furnaces which have a history of at least five consecutive successful quarterly or semi-annual uniformity tests in accordance with the Appendix or 3.4.2.7, without any major repairs or adjustments.

3.4.2.1 Continuous and Semi-Continuous Raw Material Furnaces: Where it is impossible or impractical to perform temperature uniformity tests, it is permissible to substitute analysis of test results in accordance with the Appendix. The analysis shall consist of (1) monthly examination of trends of properties and (2) extensive tensile testing of a single lot of material, initially and annually thereafter.

3.4.2.2 Uniformity Requirements: Unless a furnace temperature uniformity requirement is specified in the applicable material, heat treating or processing specification, the temperature uniformity (deviations of test sensor readings from the mean of the specified temperature range or from the specified set temperature) shall be within the plus or minus tolerances of 3.4.2.2.1, 3.4.2.2.2 or 3.4.2.2.3. Any offset or thermal head employed (with respect to the specified set temperature or the mean of the specified temperature range) during the uniformity test shall be also used for production.

3.4.2.2.1 ±10°F (±6°C) for furnaces to be used for:

(1) solution heat treating - aluminum alloys

(2) annealing - aluminum alloys within 15°F (8°C) of the solution heat treating set, or mid-range, temperature

(3) aging
- aluminum alloys and beryllium copper alloys
- PH stainless steels at 1025°F (552°C) and below
- 6Al-6V-2Sn titanium alloy at 1025°F (552°C) and below
- beta titanium alloys at 1025°F (552°C) and below

(4) tempering (after hardening)
- D6AC and 9Ni-4Co alloy steels
- other low steels - 220 ksi (1241 MPa) UTS and higher
- carburized steels

3.4.2.2.2 ±15°F (±8°C) for furnaces to be used for other aging of titanium alloys and PH stainless steels

3.4.2.2.3 ±25°F (±14°C) for other furnaces

3.4.2.2.4 Temperature Uniformity Test Failures: If the temperature uniformity is not within the applicable limits, the cause of the deviation shall be determined and the equipment shall not be used for additional processing until the cause has been corrected and the test has been performed successfully except:

3.4.2.2.4.1 If the correction takes the form of adjusting or offsetting the control instrument, retesting is not required but the correction shall not exceed 5°F (3°C) for Class 1, or 10°F (6°C) for Class 2, furnaces and the correction shall be applied to all subsequent heat treatments.

3.4.2.2.4.2 In addition, the quality assurance organization responsible for the equipment shall evaluate possible effects of the deviation on raw material and parts processed since the last successful test. The evaluation shall be documented and, where necessary, shall include consultation with metallurgists and engineering personnel. Appropriate corrective action shall be taken and documented.

3.4.2.2.5 Analysis of Tensile Test Results - Failures: For continuous and semi-continuous furnaces, when the monthly examination indicates a significant change in the trend of properties which cannot be ascribed to another cause, adjustments shall be made to improve temperature uniformity. When the extensive tensile test results show the highest ultimate strength to be more than 1.1 times the lowest, or the highest yield strength to be more than 1.15 times the lowest, action shall be taken identical to that required upon failure to meet temperature uniformity criteria (See A.3.3.3, A.3.3.4, A.3.3.5, 3.4.2.1, and 3.4.2.2.4.

3.4.2.2.5.1 As an exception to 3.4.2.2.5, for material whose lowest yield strength is 50 ksi (345 MPa) or lower, the highest yield strength shall be not more than 8 ksi (55 MPa) higher than the lowest.

3.4.2.3 Initial Test Temperatures: Shall be the highest and lowest temperatures for which the equipment will be used and the following:

3.4.2.3.1 If the highest and lowest use temperatures are more than 600°F (333°C) apart, additional tests shall be performed at one or more intermediate temperatures so that test temperatures are not more than 600°F (333°C) apart.

3.4.2.3.2 Furnaces used for solution heat treating of aluminum alloys shall be tested at the highest and lowest solution heat treating temperatures.

3.4.2.3.3 Furnaces used for aging of aluminum alloys shall be tested at the highest and lowest aging temperatures.

3.4.2.3.4 Any offset or thermal head employed (with respect to the specified set temperature or the mean of the specified temperature range) during the uniformity test shall be also used for production.

3.4.2.4 Periodic Test Temperatures: Shall be any temperature within each temperature range, as described in 3.4.2.3.1, 3.4.2.3.2 and 3.4.2.3.3 except that at least once each year, the test shall be performed within 100°F (56°C) of the maximum temperature of each range. However, the test need not be performed above 2000°F (1094°C) even though the maximum use temperature is above 2100°F (1149°C).

3.4.2.4.1 Any offset or thermal head employed (with respect to the specified set temperature or the mean of the specified temperature range) during the uniformity test shall be also used for production.

3.4.2.5 Periodic Test Frequency:

3.4.2.5.1 For equipment used for heat treatment of raw materials or parts and not qualified for a reduced frequency (see 3.4.2.5.2 and 3.4.2.5.3), frequency shall be:

3.4.2.5.1.1 Monthly for furnaces used for:

3.4.2.5.1.1.1 Solution heat treatment of aluminum alloys.

3.4.2.5.1.1.2 Annealing aluminum alloys within +15°F (±8°C) of the solution heat treating set, or mid-range, temperature.

3.4.2.5.1.1.3 Aging of aluminum alloys.

3.4.2.5.1.1.4 Aging of PH stainless steels at 1025°F (552°C) and below.

3.4.2.5.1.2 Quarterly for furnaces used for heat treatments of 3.4.2.5.1.1 if properties are analyzed as described in 8.6.

3.4.2.5.1.3 Quarterly for furnaces used for the following heat treatments of parts: (1) solution and aging treatments other than those of 3.4.2.5.1.1, (2) austenite conditioning, (3) austenitizing and (4) tempering.

3.4.2.5.1.4 Semi-annually for furnaces used for heat treatment of parts other than those of 3.4.2.5.1.1 and 3.4.2.5.1.3.

3.4.2.5.1.5 Semi-annually for Class 1 raw material furnaces used only for heat treatments other than those of 3.4.2.5.1.1.

3.4.2.5.1.6 Annually for furnaces used only for Class 2 heat treatments, except that a test shall be performed within 5 - 7 months after an initial test. (The exception may be disregarded if the initial test is waived in accordance with 3.4.2.)

3.4.2.5.1.7 Semi-annually for embrittlement relief furnaces.

3.4.2.5.2 Frequency Reductions - One Level: Frequency may be reduced to one level lower than that required in 3.4.2.5.1 (from monthly to quarterly or quarterly to semi-annually or semi-annually to annually) under the following conditions:

3.4.2.5.2.1 For Furnaces Employing Load Sensors in Each Load: After completion of two consecutive, successful periodic tests in accordance with the Appendix, providing that a written preventive maintenance plan is established which includes a schedule for replacing working sensors and recording of all maintenance operations.

3.4.2.5.2.2 For Type A Furnaces (See 3.3.2): After completion of six consecutive, successful periodic tests in accordance with the Appendix, providing that a written preventive maintenance plan is established which includes a schedule for replacing working sensors and recording of all maintenance operations.

3.4.2.5.2.3 For Type AA Furnaces (See 3.3.3): After completion of three consecutive, successful periodic tests in accordance with the Appendix.

3.4.2.5.2.4 For Class 1 Raw Material Furnaces (See 3.3.1): After completion of five consecutive, successful periodic tests, in accordance with the Appendix or 3.4.2.7 without any major repairs or adjustments.

3.4.2.5.2.5 For Class 1 Raw Material Furnaces (See 3.3.1): If properties are analyzed as described in 8.6, except this provision is not applicable to furnaces qualified for quarterly frequency in accordance with 3.4.2.5.1.2.

3.4.2.5.3 Frequency Reductions - Two Levels: Frequency may be reduced to two levels lower than that required in 3.4.2.5.1 (from monthly to semi-annually or quarterly to annually) under the following conditions:

3.4.2.5.3.1 For Furnaces Employing Load Sensors in Each Load: After completion of two consecutive, successful periodic tests, in addition to those of 3.4.2.5.2.1, in accordance with the Appendix.

3.4.2.5.3.2 For Class 1 Raw Material Furnaces (See 3.3.1): In accordance with either of the following:

3.4.2.5.3.2.1 After seven consecutive, successful periodic tests in accordance with the Appendix or 3.4.2.7 without any major repairs or adjustments.

3.4.2.5.3.2.2 If each control zone contains two sensors attached to recording instruments, and load sensors are employed in accordance with 3.3.5 in each load.

TABLE IV

Outline of Periodic Temperature Uniformity Test Frequencies

Usage Code (a)	Equipment Type (b)	Equipment Class (c)	Normal (d) Frequency	Conditional Reduced (e) Frequency	2nd (f) Reduction
1	A	1	Monthly (g)	Quarterly	N/A
1	AA	1	Monthly (g)	Quarterly	N/A
1	RM	1	Monthly (g)	Quarterly	Semi-Annually
2	A	1	Quarterly	Semi-Annually	N/A
2	AA	1	Quarterly	Semi-Annually	N/A
2	RM	1	Semi-Annually	Annually	N/A
3	A	1	Semi-Annually	Annually	N/A
3	AA	1	Semi-Annually	Annually	N/A
3	RM	1	N/A	N/A	N/A
All	RM	2	Annually (H)	N/A	N/A

(a) Usage Codes:

1. Solution treating, aging and annealing at the solution treating temperature of aluminum alloys; aging of PH stainless steels at 1025°F (552°C) and below.

2. Raw material - Class 1 treatments not included in 1.
Parts - Solution and aging treatments not included in 1 plus austenite conditioning, austenitizing, and tempering.

3. Treatments other than those in 1 and 2.

(b) See 3.3.2, 3.3.3 and 3.3.4

(c) See 3.3.1

(d) See 3.4.2.5.1

(e) See 3.4.2.5.2 - After two successful tests if load sensors in every load
- After six successful tests if Type A furnace
- After three successful tests if Type AA furnace
- After five successful tests if Class 1 RM furnace
- If 95/99 analysis and Usage Code 2, Class 1 RM furnace

(f) See 3.4.2.5.3 - After two additional successful tests if load sensors in every load
- After seven successful tests if Class 1 RM furnace
- If two working sensors in each control zone, load sensors always used, and Class RM furnace

(g) Except quarterly if 95/99 analysis

(h) Except 5 - 7 months after initial test

3.4.2.5.4 Frequency Reductions - Test Failures: If a reduced frequency, periodic test fails to meet the applicable uniformity requirements for any reason other than an invalid test, the test frequency shall be increased to a level specified by the quality assurance organization responsible for the furnace and the increased frequency shall remain in effect until the furnace is again eligible for frequency reduction (see 3.4.2.5.2 and 3.4.2.5.3). If the increased frequency is not that of 3.4.2.5.1, the frequency, and the rationale for its selection, shall be documented.

3.4.2.5.4.1 For the purpose of 3.4.2.5.4, an invalid test failure is one which has a cause unrelated to the temperature uniformity of the equipment, e.g., malfunction of test or working sensor(s) or instrument(s), test procedure error, misadjustment of controls. An example of a valid test failure is one caused by shift of a vane or baffle which resulted from vibration during production operations.

3.4.2.5.4.2 Determination of the validity of a test shall be made by the quality assurance organization responsible for the furnace.

3.4.2.6 Load Condition: Shall be unloaded (racks are permissible), except as specified in 3.4.2.6.1 and 3.4.2.6.2.

3.4.2.6.1 Tests of furnaces used exclusively for heat treatment of heavy loads of parts or raw material may be performed with any load. A load shall be considered heavy if the volume of the parts or raw material exceeds 10% of the volume of all working zones.

3.4.2.6.2 Tests of furnaces used for heat treatment of light or medium loads of parts or raw material, particularly those of alloy/gage combinations which are detrimentally affected by short duration, over-temperature excursions of the furnace (e.g. solution heat treatment of 0.025 inch (0.64 mm) thick 2024 aluminum alloy), shall be performed either without a load, except for racks, or with a load no heavier than the lightest load which will be heat treated.

3.4.2.6.3 A detailed diagram, description, or photograph(s), of any load used and a diagram of test sensor locations shall be included in the documentation.

3.4.2.7 Recognition of Pre-Publication Tests: Tests performed prior to the publication of AMS-2750C, in accordance with appropriate industry or U.S. Government specifications (e.g., MIL-STD-1684), may be considered equivalent to tests performed in accordance with the Appendix for the purpose of qualifying furnaces for (1) waiving initial temperature uniformity tests or (2) reducing frequency of periodic temperature uniformity tests.

3.5 Records: Calibration records of sensors, standard cells, and instruments, as well as all system accuracy and temperature uniformity tests (including failed tests), and diagrams of loads and test sensor locations, shall be kept on file and available for inspection for not less than five years.

3.5.1 Calibration records of sensors, standard cells, and instruments shall include traceability to the NIST standards.

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection: The processor shall be responsible for performing all required tests and for conformance to all requirements specified herein. The processor's equipment and personnel may be used or those of any commercial testing organization acceptable to the purchaser. 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.

5. PREPARATION FOR DELIVERY: Not applicable.

6. ACKNOWLEDGMENT: Not applicable.

7. REJECTIONS: Not applicable.

8. NOTES:

8.1 Marginal Indicia: The phi (Ø) symbol is not used in this revision to identify changes with respect to the previous issue of this specification due to the extensive nature of the changes.

8.2 Approach:

8.2.1 Control and recording of temperature of thermal processing equipment is necessary to ensure that parts or raw materials being processed are subjected to the proper temperature. Automatic working instruments are utilized (1) to translate the signals from working sensors located in the equipment to temperature indications or recordings, and (2) to activate heating or cooling control mechanisms which maintain the desired temperature.

8.2.2 Working instruments and sensors are calibrated (not necessarily by the heat treater) against test instruments and sensors which are themselves calibrated against chains of standard instruments and sensors linked to the National Institute of Standards and Technology (NIST). By applying requirements for instrument accuracy and sensor correction factors, determined during calibration of each link of the chain, the deviation of working instrument/sensor readings from true temperature is reduced to an insignificant level.

8.2.3 Working instrument/sensor systems used for temperature control and recording are tested periodically, while installed, by comparison with test instrument/sensor systems to ensure continuous accuracy of temperature measurements. In addition, periodically, the uniformity of temperature within each furnace is checked to ensure that the readings of working instrument/sensor systems reflect a consistent and acceptable temperature distribution pattern.

8.2.4 The frequency requirements for the periodic tests are based upon the type and number of sensors and instruments, the criticality of the heat treatments performed, the history of prior tests of the equipment and the frequent analysis of results of physical tests of production material.

8.3 Definitions:

8.3.1 "Thermal Processing" is any process in which metals are exposed to controlled heating, soaking, or cooling. The term normally excludes heating for forging, drying, and hot forming.

8.3.2 "Expendable Thermocouples" are those thermocouples made of fabric or plastic covered wire. The wire is provided in coils or on spools. Insulation usually consists of glass braid, asbestos, or ceramic fiber cloth on each conductor plus glass braid overall.

8.3.3 "Non-expendable Thermocouples" are those 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.

8.3.4 "Working Zone" is that portion of the enclosed volume of a piece of thermal processing equipment occupied by parts or raw material during the soaking portion of a thermal treatment. It is usually, but not always, a high percentage of the total enclosed volume. It may include more than one control zone.

8.3.5 "Control Zone" is a portion of the working zone of a piece of thermal processing equipment having a separate sensor/instrument/heat input or output mechanism to control its temperature.

8.3.6 "Correction Factor" or "Deviation" is that number of degrees, determined from the most recent calibration, which must be added to, or subtracted from, the temperature reading of a sensor, or an instrument, or a combination thereof (system) to obtain NIST true temperature. When expressed as a percent, it means percent of reading. The correction factors of sensors and instruments are usually kept separately and added together algebraically when a combination is used.

8.3.6.1 Example of test sensor correction factor of +2°F at 1000°F: During calibration, test sensor reading was 998°F when secondary standard sensor reading was 1000°F. Of course, these readings incorporate consideration of correction factors of the instrument(s) and the secondary standard sensor.

8.3.7 "Heat Treatment of Raw Material" is heat treatment, usually performed by or for a material producer, in accordance with a material specification, which may require, by reference, conformance to a heat treating specification. "Heat Treatment of Parts" is performed by or for a fabricator in accordance with a drawing, purchase order, fabrication outline, or heat treating specification. "Heat treatment of parts" may include heat treatment, by or for a fabricator, of pieces which resemble raw material.

8.3.7.1 Raw material (e.g. sheet, plate, bar, forgings, castings) is usually destructively tested in accordance with the requirements of a material specification. Parts are produced from raw material, in accordance with the requirements of a drawing, and are usually tested by nondestructive techniques only.

8.3.7.2 Raw material is usually identified by a heat or lot number; parts are usually identified by a part number.

8.3.8 Readability is the uncertainty applicable to the temperature read. It is dependent on the scale division spacing, the width of the indicator point, and the operator's skill in discerning the ratio of the widths of the spaces between the indicator and the two nearest scale markings. (For example, the temperature reading of a 0.01 inch wide needle located between two scale divisions 0.06 inch and 10 degrees apart would probably have a readability (uncertainty) of ±2° or ±3°.) It may be determined by comparing many operator readings with the interpolated reading obtained by measuring an enlarged photograph.

8.4 A new initial temperature uniformity test is not required after minor repairs (e.g., replacing furnace bricks or other parts) which could not alter temperature uniformity characteristics.

8.5 A foreign equivalent of NIST may be used in lieu of NIST for sensors and instruments to be employed with Class 2 equipment. It may also be used for sensors and instruments to be employed with Class I equipment providing it is acceptable to the cognizant engineering organization.

8.6 Properties of production lots are analyzed, at least semi-annually, in accordance with MIL-HDBK-5 or ASTM STP 15D to ensure a 95% confidence level that 99% of material equals or exceeds specified properties.