

BODY OF KNOWLEDGE:

ROLE DESCRIPTION: Operator

SPECIAL PROCESS: Titanium Alloy Heat Treatment

METHOD: Performance of Titanium Alloy Heat Treat Requirements

All PRI QualificationSM program examinations are created using the applicable PRI QualificationSM program Body of Knowledge (BoK), which defines the baseline knowledge and experience required to be considered competent to perform the specified job role in aerospace special process manufacturing.

All BoKs are created by subject matter experts who participate in the PRI QualificationSM Body of Knowledge Review Boards. All BoKs are updated periodically according to the latest revision of PRI QualificationSM program documentation (PD6100: Industry Managed Special Process Bodies of Knowledge) to ensure consistency with current industry practice.

1. INTRODUCTION

This document has been created by the PRI QualificationSM program Heat Treat Body of Knowledge Review Board (HT-BoKRB) according to the requirements of PD6100.

This document constitutes the PRI QualificationSM program BoK for Titanium Alloys Operator. It defines the baseline knowledge and experience required to be considered competent to perform this role.

Unless otherwise stated, the HT-BoKRB has followed guidelines as detailed in the current version of IAQG Guidance PCAP 001 (Competence Management Guideline) to develop this BoK.

The information in this BoK will provide guidance for the following:

- Training providers who wish to develop training courses intended to support PRI QualificationSM program examination candidate preparation
- Heat Treat Examination Review Board (HT-ERB) for the development of PRI QualificationSM program examinations
- Candidates taking PRI QualificationSM program examinations who wish to prepare in advance

2. REFERENCES

PRI QualificationSM program documents:

PD6000	Governance & Administration of PRI Qualification SM Program Industry Managed
PD6100	Special Process Bodies of Knowledge
PD6200	Industry Managed Special Process Examinations System

IAQG documents:

IAQG Guidance PCAP 001 Competence Management Guideline

3. DEFINITIONS

Definitions described within are specific to the Special Process BoK. For program-specific definitions, please refer to either the PD 6000 or the PRI QualificationSM Dictionary.

BODY OF KNOWLEDGE (BoK): Baseline knowledge and experience required to be considered competent for a target position.

GENERAL EXAMINATION: The General Examination is designed to ascertain the candidate's general knowledge required for a particular job, role or activity. All of the questions will be derived from the corresponding BoK.

EXPERIENCE: The accumulation of knowledge or skill that results from direct participation in events or activities over a period of time.

KNOWLEDGE: Information / understanding acquired over a period of time. Information acquired through study and retained over that period of time (education, training, experience etc.) The combination of data and information, to which is added expert opinion, skills and experience, to result in a valuable asset which can be used to aid decision making and problem solving.

LEVEL: A class or division of a group based on education, training and experience. There are 3 levels: Operator/Technician, Planner and Owner. Please refer to the current version of PD 6000 for definitions.

METHOD: A well-defined division of a SPECIAL PROCESS widely recognised by industry. A specific area of a special process for example anodizing within Chemical Processing

NON-SPECIAL PROCESS RELATED REQUIREMENTS: Miscellaneous requirements such as Health and Safety, Environmental, etc.

PERSONAL ATTRIBUTES: A quality or characteristic expected and required for a particular job, role or activity.

PRACTICAL EXAMINATION: The Practical Examination shall consist of a demonstration of proficiency in performing tasks that are typical of those to be accomplished in the performance of the candidate's duties. The examination content is derived from the corresponding BoK.

SKILL: Ability to perform a particular task. The quality of being able to do something that is acquired or developed through training or experience.

SPECIFIC EXAMINATION: The Specific Examination shall cover requirements and use of the specifications, codes, equipment, operating procedures and test techniques the candidate may use in the performance of his/her duties with the employer. Examination content will be derived from the corresponding BoK where applicable

WEIGHTING: The "weighting" of each line item, using a scale of 1, 3, 7, 10, (1 being least important; 10 being most important) indicates the relative importance of that aspect of the BoK and will determine the likelihood and frequency of a question on that topic appearing in the examination

4. GUIDANCE TO EXAMINATION CANDIDATES

All PRI QualificationSM program examination candidates are recommended to read all documents referenced in section 2 of this document.

As stated in PRI QualificationSM program document PD6200, every exam question shall relate directly to and be derived from the information as detailed in the current version of the BoK.

Re-assessment to this BoK is required every 5 years, unless otherwise specified.

Candidates are therefore advised to ensure familiarity with all aspects of the BoK as detailed in Table 1. This can be done through:

- Self-study
- Completion of internal training
- Completion of external training (a list of Approved Training Providers can be found at <https://p-r-i.org>)

Records of all qualified personnel shall be maintained and include:

- Date of Qualification
- Results of Written Exam
- Results of Practical Exam (if applicable)
- Summary of Experience (Owner Level only)

5. LEVELS

Level			
<i>Descriptors</i>	<i>Operator (OP)/Technician(T)</i> <i>For descriptions, please refer to current version of PD6000</i>	<i>Planner (PL)</i> <i>For descriptions, please refer to current version of PD6000</i>	<i>Owner (OW)</i> <i>For descriptions, please refer to current version of PD6000</i>
Titanium Alloy Specific Criteria	Basic understanding of the HT / Titanium Alloy process including Quenching, Annealing, Aging, Over Aging and when vacuum HT is required	In addition to knowing what the Operator does, the Planner must: Be capable of interpreting customer requirements and converting them into clear work instructions at the proper level of operator understanding.	In addition to knowing what the Operator and Planner do, the Owner must: Manage people that perform the work and evaluate and reviews reports; must have knowledge of "how" to run the testing.
Technical Knowledge	Basic knowledge of the special process, its main processes, methods and tools.	Good level of knowledge in all aspects of the special process, all its processes, methods and tools. Ability to coach others on contents and methods in the context of their workplace.	High or extensive knowledge in all aspects of the special process, all its processes, methods and tools to assess and validate improvements. Able to contribute to set externally recognized standards. Ability to define contents and methods for using knowledge effectively in influencing and developing international processes. Ability to influence the process with one's knowledge.
Experience	Sufficient experience to deal with recurrent activity.	Has enough experience to deal with unforeseen issues.	Wide proven experience of the subject. Is recognized specialist within the special process.
Personal Attributes		Takes into consideration behavioral characteristics such as but not limited to: team working, communication, direction and purpose, innovation and problem solving, mutual trust and respect, confidentiality and trustworthiness.	
Skills		Describes the activities necessary to perform each level of job function to comply with the Body of Knowledge	
Non-Special Process Related Requirements		Health & Safety, Environmental, Quality System Requirements.	

6. TABLE 1

ROLE DESCRIPTION: Titanium Alloy Heat Treatment---Operator

SPECIAL PROCESS: Titanium Alloy Heat Treatment

METHOD: Performance of Titanium Alloy Heat Treat Requirements

REFERENCE GUIDELINES: Addendum 1 is a list of the International Standards and Reference Documents applicable to Titanium Alloy Heat Treating.

Row #	COMPETENCE	Weight (1,3,7,10)	Exam Type: Written or Practical	Reference Guidelines
	KNOWLEDGE: The basic knowledge of the special processes, methods and tools			
	General Quality Systems Knowledge:		Written	
1	Awareness and understanding of Aerospace Quality Systems and compliance in so far as it applies to their day to day work.	7	Written	AS9100, AC7102, AC7102/8
2	Full and complete understanding of company practices for content of internal work instructions as well as a working understanding of industry standards as they apply to internal work instructions (see Addendum -1 of this document)	7	Written	AS9100, AC7102, AC7102/8
3	Awareness and understanding of safety compliance requirements as applicable.	7	Written	AS9100, AMS2769
4	Awareness and understanding that identification, count and quality discrepancies resolved prior to processing of parts and that incoming customer documents remain traceable to specific jobs, as applicable.	7	Written	AC7102
5	Awareness and understanding that the acceptance status and any test data are recorded on the shop paper only after the operation for that job has been completed.	7	Written	AC7102
6	Awareness and understanding that current operating manuals or instructions should be available to furnace operators, maintenance personnel and other personnel requiring the information.	7	Written	AC7102
7	Awareness and understanding that all components of each furnace that can affect the functionality are inspected and maintained in accordance with a documented preventative maintenance schedule.	7	Written	AC7102
8	Awareness and understanding that internal procedures should specify how atmospheres are to be controlled and monitored to ensure conformance to requirements of specifications and customer requirements.	7	Written	AC7102
9	Awareness and understanding that flow meters be operational and appropriate for the gas and flow rates used, that inspection and maintenance schedule include periodic checks of flow meters, and that there should be an internal procedure to address the safety shut-off valves and the emergency gas purges.	7	Written	AC7102
10	GENERAL METALLURGICAL KNOWLEDGE RELATED TO HEAT TREATING TITANIUM ALLOYS (Applicable to all specifications):		Written	
11	Understand the importance of complying with pyrometry requirements including temperature sensors, instrumentation, thermal processing equipment, system accuracy tests, and temperature uniformity surveys and reporting of non-conformance.	7	Written	AS9100, AMS2750, AC7102
	Understanding of Heat Treatments applied to Titanium Alloys:		Written	
12	Anneal Solution Heat Treat Beta Anneal Beta Solution Heat Treat Recrystallization Anneal Duplex Anneal Age Stress Relief Cold Work and Age Beta Solution Treat and Overage Solution Treat and Age Solution Treat and Overage	7	Written	AMS-H-81200, AMS2801
13	Understanding of the importance of meeting and documenting Quench Delay times.	7	Written	AMS-H-81200, AMS2801, AC7102
	Understanding of the definitions and importance of terms applicable to Heat Treatment of Titanium Alloys		Written	
14	Set Temperature Recovery Time Start of Soak End of Soak	7	Written	AMS-H-81200, AMS2801, AMS2769, AC7102

	Quench Delay Alpha Case Beta Transus Leak Rate Hydrogen Pickup or Contamination Alpha Alloys Beta Alloys Alpha-Beta Alloys			
15	Understanding of why adherence to set temperatures and furnace uniformity is important.	7	Written	AMS-H-81200, AMS2801, AMS2769, AC7102
16	Understanding of the importance of complying with minimum and maximum treatment times, including how start and end of soak are determined and whether they are based on furnace (controller) readings or actual metal temperature (load thermocouples).	7	Written	AMS-H-81200, AMS2801, AC7102
17	Awareness and understanding that some processes require the use of a vacuum or vacuum must be maintained in accordance with instructions provided	7	Written	AMS-H-81200, AMS2810
18	Awareness and understanding that heat treating equipment and instruments for the heat treatment of titanium alloys must be in accordance with applicable specifications.	7	Written	AC7102, AC7102/8
19	Awareness and understanding that heat treating facilities must possess the correct temperature uniformity, instrument accuracy and resolution for the heat treating of titanium alloys in accordance with applicable specifications.	7	Written	AC7102, AC7102/8
	Racking, Fixturing and Spacing		Written	
20	Awareness that specially designed fixturing and racking methods must be used for the specific parts or raw material they were designed for.	7	Written	AMS-H-81200, AMS2801, AMS7102
21	Awareness and understanding that planning available to operators include internal procedures, racking sketches or other means to ensure spacing is adequate for circulation of the heating medium and coolant/quenchant as required by the applicable specification.	7	Written	AMS-H-81200, AMS2801, AMS7102
22	Awareness and understanding that there must be internal procedures to require that racks are examined for integrity, cleanliness (as required by specification) and repaired or scrapped as necessary.	7	Written	AAMS-H-81200, AMS2801, AMS2769, AMS7102
23	Awareness and understanding that material requirements exist for racks, support or fixturing.	7	Written	AMS-H-81200, AMS2769
	Quench Delay		Written	
24	Awareness that quench mechanisms must be capable of meeting the maximum quench delay provisions of the applicable specifications	7	Written	AC7102
	Quenchant Maintenance			
25	Awareness and understanding that quenchant temperature must be controlled and documented for applicable specifications.	7	Written	AMS2750, AMS2801, AC7108/8, AC7102
26	Awareness and understanding that quenchant temperature, the recording and controlling equipment must be calibrated.	7	Written	AMS2750, AMS2801, AC7102
27	Awareness and understanding that certain specifications require agitation or circulation.	7	Written	AMS2801, AC7102
	Polymer Quenchants		Written	
28	Awareness that polymer quenching can only be used when permitted by specification for the alloy and metal thickness.	7	Written	AMS2801, AC7102
29	Awareness and understanding that polymer concentration must be defined when used and that concentration be recorded.	7	Written	AMS2801, AMS2769, AC7102
	Quench Effectiveness/Testing		Written	
30	Awareness and understanding that the quench effectiveness and its consistency per the applicable specification must include testing for validation.	7	Written	AMS2801, AMS-H-81200, AC7102
31	General awareness that the frequency and method for testing oil quenchants can be specified by customer requirements.	7	Written	AC7102
32	Awareness and understanding that there must be a system to control test coupons/specimens/blanks and their use when required.	7	Written	AMS-H-81200, AMS2801, AMS2769, AC7102
33	General awareness that there is documentation to support the use of coupon/specimens/blanks is in accordance with procedures and applicable specifications	7	Written	AC7102, AMS-H-81200, AMS2801
34	General awareness that the control of hydrogen pickup/ contamination must meet the method and frequency of customer requirements and applicable specifications.	7	Written	AMSH-81200, AMS2801, AC7102
	Cleanliness		Written	
35	General awareness that procedures for cleaning Titanium alloys must exclude the use of halogenated substances or require additional cleaning.	7	Written	AMS2801, AMS-H-81200, AC7102
36	General awareness that the cleaning requirements of both finished and non-finished surfaces depending on the applicable specification.	7	Written	AMS2801, AMS-H-81200, AC7102
37	Awareness and understanding that there are procedures specifying cleaning of parts and baskets/fixtures/racking/tooling to ensure freedom from contamination during vacuum heat treating.	7	Written	AMS2769, AC7102
	Vacuum Furnaces		Written	
38	Awareness and understanding that there must be leak testing per applicable specification.	7	Written	AMS2769, AMS-H-81200, AMS2801,

				AC7012																										
39	Awareness and understanding that there must be a condition cycle (clean-up, bake-out, burn-out) per applicable specification.	7	Written	AMS2769, AMS7102																										
40	Awareness and understanding that there must be periodic checking of the dew point for partial pressure atmosphere, as the gas enters the furnace per the applicable specification(s).	7	Written	AMS2769, AMS-H-81200, AMS2801, AC7102																										
41	Awareness and understanding that the calibration interval and acceptance criteria of the vacuum system's sensor, recorder and control panel meet the applicable specifications.	7	Written	AMS2769, AC7102																										
	REQUIREMENTS SPECIFIC TO PRODUCT PROCESSED (in accordance with the relevant AMS):		Written																											
	SPECIFIC REQUIREMENT RELATED TO HEAT TREATMENT OF TITANIUM AND TITANIUM ALLOY MILL PRODUCTS (RAW MATERIAL) INCLUDING WROUGHT AND CAST PRODUCTS TO AMS-H-81200 (ONLY APPLICABLE IF PROCESSING TO AMS-H-82100)		Written																											
42	Awareness and understanding that this specification covers the heat treatment of titanium and titanium alloy mill products (raw material), including wrought and cast products, by material producers. AMS-H-81200 also covers furnace equipment requirements, test procedures, and general information for heat treating procedures, heat treating temperatures and material test procedures for the heat treatment of titanium and titanium alloys. AMS-H-81200 also describes procedures that, when followed, have produced the desired properties within the limitations of the respective alloys.	7	Written	AMS-H-81200																										
	REQUIREMENTS		Written																											
	Batch Furnaces		Written																											
43	Awareness and understanding that only certain heat sources and atmospheres for batch furnaces are allowable.	7	Written	AMS-H-81200																										
44	Awareness and understanding that inert gases must be circulated and that there is a dew point requirement for inert gases.	7	Written	AMS-H-81200																										
45	Awareness and understanding that furnaces heated by the combustion of gas or oil in air contain a slightly oxidizing gas mixture and that no flame shall impinge on the furnace charge.	7	Written	AMS-H-81200																										
46	Awareness and understanding that there are prohibited atmospheres for batch furnaces.	7	Written	AMS-H-81200																										
47	Awareness and understanding of that there are purging requirements and they differ depending on the atmosphere to be used.	7	Written	AMS-H-81200, AC7102																										
48	Awareness and understanding that batch furnaces are controlled to maintain a temperature applicable to the material and heat treatment being processed. (Table 1, 3, 4 or 5). Awareness that the minimum and maximum temperatures given in said tables are valid set points and that, for a given process and set point, applying offsets as applicable, the temperature uniformity tolerances are:	7	Written	AMS-H-81200																										
	<table border="1"> <thead> <tr> <th rowspan="2">Heat Treatment</th> <th colspan="2">Temperature Uniformity Tolerance</th> </tr> <tr> <th>°F</th> <th>°C</th> </tr> </thead> <tbody> <tr> <td>Annealing</td> <td>±25</td> <td>±14</td> </tr> <tr> <td>Beta annealing or beta solution heat treating</td> <td>±25</td> <td>±14</td> </tr> <tr> <td>Recrystallization annealing</td> <td>±25</td> <td>±14</td> </tr> <tr> <td>Duplex annealing</td> <td>±25</td> <td>±14</td> </tr> <tr> <td>Solution heat treating</td> <td>±25</td> <td>±14</td> </tr> <tr> <td>Stress relieving</td> <td>±25</td> <td>±14</td> </tr> <tr> <td>Aging</td> <td>±15</td> <td>± 8</td> </tr> </tbody> </table>	Heat Treatment	Temperature Uniformity Tolerance		°F	°C	Annealing	±25	±14	Beta annealing or beta solution heat treating	±25	±14	Recrystallization annealing	±25	±14	Duplex annealing	±25	±14	Solution heat treating	±25	±14	Stress relieving	±25	±14	Aging	±15	± 8			
Heat Treatment	Temperature Uniformity Tolerance																													
	°F	°C																												
Annealing	±25	±14																												
Beta annealing or beta solution heat treating	±25	±14																												
Recrystallization annealing	±25	±14																												
Duplex annealing	±25	±14																												
Solution heat treating	±25	±14																												
Stress relieving	±25	±14																												
Aging	±15	± 8																												
49	Continuous Furnaces		Written																											
50	General awareness that only certain heat sources for continuous furnaces are allowable.	7	Written	AMS-H-81200																										
51	General awareness that continuous induction heating shall be applied only to the annealing of thin-walled tubing and extrusions of thin sections and that the technique shall be such that the work piece being heated is of uniform temperature around the perimeter of its cross-section. Also prior to production, values of the process parameters that produce acceptable product shall be determined and documented.	7	Written	AMS-H-81200																										
	Quenching		Written																											
52	Awareness and understanding that quenching baths are primarily designed to meet properties after subsequent aging and that mechanical stirring is allowed.	7	Written	AMS-H-81200																										
53	Awareness and understanding that the use of salt baths for quenching is prohibited.	7	Written	AMS-H-81200																										
54	General awareness that quench delay times are critical in order for product to meet mechanical property requirements after subsequent aging (see Table 2).	7	Written	AMS-H-81200																										
	Thermal Treatment Parameters		Written																											
55	Awareness and understanding that for heat treatments not covered explicitly by AMS-H-81200, all units of a lot shall be heated uniformly and on the whole piece, never on a portion only. For coiled product heated within a continuous furnace or straight product heated within an induction coil, the product shall be heated uniformly in its cross-section.	7	Written	AMS-H-81200																										

56	Awareness and understanding that surfaces of material to be heat treated must be free of anything that will cause the product to become noncompliant. However, material coated with light oils need not be cleaned prior to thermal treatment, provided that the oil either vaporizes or burns off during preheating. Furthermore, halogenated solvents and methanol can be used to degrease work pieces, provided work pieces are subsequently cleaned using an alkaline solution or an acid pickle before thermal treatment.	7	Written	AMS-H-81200
57	Awareness and understanding that excessive hydrogen concentration found in a lot may be reduced to an acceptable concentration by heating the lot in a vacuum furnace conforming to AMS-H-81200 requirements. However, such action shall be reported to the purchaser. Also heating under vacuum that results in over aging of a lot shall be cause for rejection of that lot. Salvage by re-solution heat treating and aging shall be performed only with the consent of the purchaser. Records of all re-heat treatments shall be prepared and maintained in accordance with other furnace record requirements.	7	Written	AMS-H-81200
58	Awareness and understanding that surface contamination after heat treatment must be removed by chemical or mechanical means. The surfaces of machined, ground, blasted or acid-pickled work pieces shall not exhibit the effects of absorbed oxygen or nitrogen to the degree that the surface contamination of the product exceeds the levels specified in the acquisition documents when tested metallographically in accordance with AMS-H-81200	7	Written	AMS-H-81200
	Monitoring		Written	
59	Awareness and understanding that periodic monitoring of heat treated work pieces to determine compliance with specification must include evaluation of tensile and bend properties, as applicable.	7	Written	AMS-H-81200
	QUALITY ASSURANCE PROVISIONS		Written	
60	Awareness and understanding that the following periodic tests are requirements and UOS by customer, the frequencies, as applicable to furnace type, are: a. Daily check of the dew point of the inert gases. b. Weekly checks for hydrogen pickup or contamination, except for processes wherein every thermally treated lot is analyzed, or for treatments in a vacuum furnace or in inert gas. c. At least one surface contamination examination weekly of product thermally treated in a vacuum furnace or in inert gas, in order to detect possible leakage. d., e., f. Instrument calibration, SATs and TUS's in accordance with AMS2750.	7	Written	AMS-H-81200
61	Awareness and understanding that preproduction tests are required before any production heat treating can occur and that those tests, as applicable to furnace type, are: a. Furnace temperature uniformity or distribution IAW with paragraph 4.4.(survey requirements), as applicable. b. Pyrometer system accuracy IAW AMS2750. c. Furnace instrument calibration IAW AMS2750. d. Dew point of the inert gas when such gas is used. e. Hydrogen contamination. f. Leak rate	7	Written	AMS-H-81200
62	Awareness and understanding that pyrometric calibration, heat treating equipment testing and procedures for checking the accuracy of pyrometric systems shall be IAW AMS2750	7	Written	AMS-H-81200
	Record Retention		Written	
63	Awareness and understanding that unless otherwise specified in the acquisition documents, inspection records shall be on file for 5 years and shall be available for examination by the purchaser.	7	Written	AMS-H-81200
64	Awareness and understanding that furnace records relative to the identification and history of usage of each furnace shall be maintained as evidence of compliance with AMS-H-81200. Information recorded shall include as a minimum the furnace number or description, size, temperature range of usage, type(s) of thermal treatment applied (solution heat treatment, annealing, etc.), temperature(s) that uniformity was surveyed, dates of each survey, number and locations of thermocouples during each survey, and dates and other specifics of substantial repairs or alterations. These records shall be kept for 5 years after the date of performance or as otherwise specified in the acquisition documents.	7	Written	AMS-H-81200
65	Awareness and understanding that during a hydrogen outgassing treatment, the working temperature, the soaking time, and absolute pressure within the furnace shall be recorded.	7	Written	AMS-H-81200
	Noncompliance		Written	AMS-H-81200
66	Awareness and understanding that if any test result fails to meet the requirements specified herein, the cause of failure shall be determined and the equipment repaired if applicable. If tests indicate improper heat treatment, the equipment and process shall not be used for heat treatment of titanium alloys until the deviation(s) is corrected and satisfactory performance is re-established. Questionable material shall be investigated, categorized as conforming or non-conforming and disposed of accordingly. Evaluation of the equipment and/or material shall be documented and the appropriate corrective action shall be taken and documented. The quality assurance organization shall notify the purchaser of nonconformance when previously heat treated lots are suspect.	7	Written	AMS-H-81200
	SPECIFIC REQUIREMENT RELATED TO HEAT TREATMENT OF TITANIUM AND TITANIUM ALLOY PARTS TO AMS2801 (ONLY APPLICABLE IF PROCESSING TO AMS2801)		Written	
	TECHNICAL REQUIREMENTS		Written	
67	Awareness and understanding that pyrometry shall conform to AMS 2750.	7	Written	AMS 2801
68	Awareness and understanding that temperature uniformity shall be:	7	Written	AMS 2801

	Heat Treatment	Temperature Uniformity Tolerance				
		°F	°C			
	Annealing	±25	±14			
	Solution heat treating	±25	±14			
	Stress relieving	±25	±14			
	Aging	±15 ⁽¹⁾	±8			
	(1) ±10 °F (t6 °C) for parts made from the following five alloys if temperature is 1025 °F (552 °C) or lower: 6Al-6V-2Sn, 13V-11Cr-3Al, 15V-3Cr-3Al-3Sn, 10V-2Fe-3Al, and 3Al-8V-6Cr-4Mo-4Zr.					
	Heating Media				Written	
69	Awareness and understanding that air and non-inert atmospheres shall be free of reducing gases and other contaminants which may produce surface contamination in excess of that to be removed (descaled) or which may result in excess hydrogen pickup/contamination. Direct fired furnaces shall be controlled so that the flame is slightly oxidizing and there is no flame impingement on the parts. A coupon as defined in paragraph 3.1.2.2.5 shall accompany one load each week, heated above 1200 °F (649 °C), and be subsequently tested for excess hydrogen pickup and for surface contamination in excess of that to be removed. Parts with net dimensions shall not be heated above 1000 °F (538 °C) in air or non-inert atmosphere furnaces unless coated with a protective coating approved by the cognizant engineering organization.			7	Written	AMS 2801
70	Awareness and understanding that air and non-inert atmosphere furnaces to be used above 1200 °F (649 °C) which have contained a contaminating atmosphere (e.g., endothermic, dissociated ammonia) shall be equipped so as to prevent leakage of the contaminating atmosphere into the working zone. Such furnaces shall be purged and tested for hydrogen pickup before heat treating the first load of titanium parts.			7	Written	AMS 2801
71	Awareness and understanding that inert atmospheres (Helium and Argon) shall meet the composition requirements of MIL-PRF-27407, Type I, MIL-A-18455, or BB-H-1168 as applicable. The dew point of the gas shall be -65 °F (-54 °C) or lower as it enters the furnace. For loads to be heated above 1000 °F (538 °C), containing parts having surfaces from which no material will be removed, one coupon as defined in paragraph 3.1.2.2.5 shall accompany each load and be subsequently tested for alpha case. Test coupons are not needed for heat treatments under 1000 °F (538 °C).			7	Written	AMS 2801
72	Awareness and understanding that for vacuum furnaces, vacuum pressure and leak rate shall be determined at room temperature before heating each load. Vacuum pressure shall be lower than 0.1 µm of mercury and leak rate shall be lower than 3 µm of mercury per one-quarter hour with the vacuum pump isolated from the furnace chamber. Cooling may be accelerated by back-filling with inert gas conforming to paragraph 3.1.2.2.2. For loads to be heated above 1000 °F (538 °C) containing parts having surfaces from which no material will be removed, one coupon as defined in paragraph 3.1.2.2.5 shall accompany each load and be subsequently tested for alpha case. Test coupons are not needed for heat treatments under 1000 °F (538 °C).			7	Written	AMS 2801
73	Awareness and understanding that molten salt and fluidized beds are prohibited			7	Written	AMS 2801
74	Awareness and understanding of that coupons (for hydrogen and/or surface contamination) be of AMS 4901 (Titanium Sheet, Strip, and Plate, Commercially Pure, Annealed, 70.0 ksi (485 MPa)) composition, nominally 0.020 inch (0.51 mm) thick by 1 inch (25 mm) wide shall be used to confirm conformance with heating media requirements.			7	Written	AMS 2801
75	Awareness and understanding that for heat treat loads containing small parts (e.g., fastener components; rivets, bolts, nuts) such parts may be substituted for the coupons specified in paragraph 3.1.2.2.5.			7	Written	AMS 2801
	Quenching				Written	
76	Awareness and understanding that quench tanks shall be of sufficient size to permit complete immersion of parts and free movement of the quench medium adjacent to all surfaces of parts. Equipment shall be provided for agitation or circulation of the quench medium and/or the parts. The volume of quenchant, and any auxiliary cooling equipment, shall be sufficient to maintain (1) a water quench below 100 °F (38 °C) during the quench, (2) a polymer quench below 120 °F (49 °C), and (3) an oil quench between 60 and 160 °F (16 and 71 °C) at the start of the quench and below 200 °F (93 °C) during a quench. In addition, quench oils shall be used within the temperature range recommended by the oil manufacturer.			7	Written	AMS 2801
77	General awareness that quench delay times are critical in order for product to meet mechanical property requirements after subsequent aging (see Table 3)			7	Written	AMS 2801
	Cleaning					
78	Awareness and understanding that parts shall be cleaned, prior to heat treatment, in accordance with ASTM B 600 or other method approved by the cognizant engineering organization. Part surfaces shall be free of halogen compounds, such as residue from halogenated solvents and coolants, and salt from perspiration. Surfaces of parts, fixtures, racks, etc. shall be clean and free of dirt, water, oil, grease, paint, ink, crayon markings, die pick-up, fingerprints, and other foreign			7	Written	AMS 2801

	material. After cleaning and prior to heat treatment in inert gas or vacuum furnaces, personnel handling parts shall wear clean, white cotton gloves, or equivalent.			
	Racking		Written	
79	Awareness and understanding that parts, other than rivets, bolts, nuts, and other small parts, shall be racked to ensure uniform heating and cooling throughout the load. These parts shall not be nested unless tests with load thermocouples (1) have established the necessary additional soaking time required and (2) have demonstrated that the arrangement will not affect uniformity of heating and cooling.	7	Written	AMS 2801
80	Awareness and understanding that rivets, bolts, nuts, and other small parts, with maximum thickness of 0.5 inch (13 mm), may be racked as parts, or heated and soaked in baskets or continuous furnaces. When processed in baskets, maximum thickness of layers and minimum space between layers shall be 1 inch (25 mm). When processed in continuous furnaces, parts shall not be layered.	7	Written	AMS 2801
	Control Instruments			
81	Awareness and understanding that control instruments shall be set either at the set temperature specified or at an offset temperature based on the last temperature uniformity determination. The offset temperature shall be within 5 °F (3 °C) for aging and 10 °F (6 °C) for other treatments of the specified set temperature and shall be posted on the instrument. The offset temperature shall be selected to optimize the temperature distribution within the furnace so that the highest and lowest temperatures are equidistant from the set temperature. For solution heat treatment of loads without load thermocouples in air and atmosphere (inert and non-inert), furnaces shall be stabilized at the set or offset temperature before loading parts.	7	Written	AMS 2801
82	Awareness and understanding that the posting of offset temperatures shall preclude misinterpretation by specifying both the “desired” temperature and the corresponding “set” temperature (e.g., “When 700 °F is desired, set at 704 °F”).	7	Written	AMS 2801
	Start of Soaking Time		Written	
83	Awareness and understanding that for batch furnaces there are four methods for determining the start of soak. Method 1 is: When the furnace temperature, as shown by the controlling indicating or recording instrument(s), reaches the set or offset temperature.	7	Written	AMS 2801
84	Awareness and understanding that for batch furnaces, determining the start of soak by Method 2 is: When the furnace temperature, as shown by the controlling indicator or recording instrument(s), reaches the <i>minimum of the applicable range</i> defined as the temperature described by the set or offset temperature minus the tolerance specified for furnace temperature uniformity.	7	Written	AMS 2801
85	Awareness and understanding that for batch furnaces when Method 2 is used for determining the start of soak, at least 75% of soaking time shall be after the furnace temperature has reached the <i>half-tolerance temperature</i> . The <i>half-tolerance temperature</i> is the temperature described by the set or offset temperature minus half of the tolerance specified for furnace temperature uniformity.	7	Written	AMS 2801
86	Awareness and understanding that for batch furnaces, determining the start of soak by Method 3 is: When the temperature of at least two load sensors in contact with parts reaches the <i>minimum of the applicable range</i> defined as the temperature described by the set or offset temperature minus the tolerance specified for furnace temperature uniformity.	7	Written	AMS 2801
87	Awareness and understanding that for batch furnaces, determining the start of soak by Method 4 is: When the temperature of at least two load sensors in contact with parts, positioned so as to reflect the temperature at the center of the <i>coldest parts</i> , reaches the <i>half-tolerance temperature</i> . If this method is used, the soaking time may be reduced to that shown in Table 2 for 0.10 inch (2.5 mm) thickness. The <i>coldest parts</i> are those in the coldest portion of the furnace as shown by the last temperature uniformity test. The <i>half-tolerance temperature</i> is the temperature described by the set or offset temperature minus half of the tolerance specified for furnace temperature uniformity.	7	Written	AMS 2801
88	Awareness and understanding that for continuous furnaces the soaking time starts when parts enter the zone of the furnace shown by the last temperature uniformity test to be within the range described by the set temperature and the applicable tolerance.	7	Written	AMS 2801
	Thermal Treatment Parameters		Written	
89	Awareness and understanding that solution heat treating shall be performed in accordance with Table 2 of AMS2801. Re-solution treatment is permitted only when approved by the cognizant engineering organization.	7	Written	AMS 2801
90	Awareness and understanding that aging shall be performed in accordance with Table 4 of AMS2801. The environment during cooling after aging shall be compatible with the heating environment, i.e., it shall not increase alpha case thickness.	7	Written	AMS 2801
91	Awareness and understanding that descaling is required for parts heated above 1000 °F (538 °C) in an environment other than an inert atmosphere or vacuum. Sufficient material shall be removed to ensure uncontaminated material on all surfaces. Metal removal may be accomplished mechanically, by immersion in molten salt, by a chemical method in accordance with ASTM B 600, or by other method acceptable to purchaser. It need not be done immediately after heat treatment. It may be postponed until later in the manufacturing schedule. Table 5 provides an approximate guide for metal removal after heating in air.	7	Written	AMS 2801
	QUALITY ASSURANCE PROVISIONS		Written	
	Record Retention		Written	

92	Awareness and understanding that records shall be available to purchaser for not less than five years after heat treatment. The records shall contain all data necessary to verify conformance to the requirements of this specification.	7	Written	AMS 2801
	Logs		Written	
93	Awareness and understanding that a record (written or electronic storage media), traceable to temperature recording information (chart(s) or electronic storage media) and to shop travelers or other documentation, shall be kept for each furnace and load. The information on the combination of documents shall include: equipment identification; approved personnel's identification; date; part number or product identification; number of parts; alloy; lot identification; actual thermal processing times and temperatures used. When applicable, atmosphere control parameters, quench delay, maximum thickness, quenchant type, polymer concentration and quenchant temperature shall be recorded. The maximum thickness recorded shall be the minimum dimension of the heaviest section of the part. The heat treat processor shall document instructions for measuring, logging, and reporting actual processing times and temperatures.	7	Written	AMS 2801
	Report/Certification		Written	
94	Awareness and understanding that the heat treating processor shall furnish, with each shipment of parts, a certified quality assurance report, traceable to the heat treat control number(s), stating that the parts were processed in accordance with the requirements of this specification. The report shall include: purchase order number; part number or product identification; alloy; temper/strength designation; quantity of parts in the shipment; identification of furnace(s) used; actual thermal processing times and temperatures used. When applicable, the report shall include: atmosphere type; quenchant (including polymer concentration range); hot straightening temperature and method of straightening (e.g. press, fixtures); actual test results, (e.g., hardness, conductivity, tensile, shear, etc.) and their conformance/nonconformance to requirements. The heat treat processor shall document instructions for measuring, logging, and reporting actual processing times and temperatures.	7	Written	AMS 2801
	PREPARATION FOR DELIVERY		Written	
95	Awareness and understanding that identification of parts provided to the heat treatment processor shall be maintained on the parts at delivery and that parts shall be packaged to ensure protection from damage during shipment and storage.		Written	AMS 2801
	REJECTIONS		Written	
96	Awareness and understanding that parts not meeting the requirements of this specification, or to modifications authorized by the cognizant engineering organization, will be subject to rejection and shall be submitted for disposition in accordance with purchaser's procedures for nonconformance.		Written	AMS 2801
	SKILLS: Defined within these rolls describes the range of skills. The skills required to perform a particular special process task			
97	Has knowledge and understanding to be able to recognize and report in real time, deviations from process parameters or other events which may have a negative impact on product quality	7	Written	AS9100, AC7102, AC7102/8
98	Read and understand written instructions.	7	Written	General Industry
99	Ability to follow provided specification requirements and customer flow down requirements.	7	Written	AS9100, AC7102, AC7102/8
100	Recognition of the importance of following work instructions.	7	Written	AC7102, AC7102/8
101	Understands the safety concerns involved with heat treatment including the proper use of handling tools and personal protective equipment.	7	Written	AS9100
102	Understands precautions to be taken when handling thermocouples to avoid damage.	7	Written	AC7102, AC7102/8
103	Capable of generating and maintaining accurate and complete records required to demonstrate compliance with customer requirements including: <ul style="list-style-type: none"> • Set temperature • Soak Time • Quench delay time • Quench concentration • Quench temperature before and after quench • Cooling rate • Leak rate • Dew point • Periodic and lot acceptance test requirements and results 	7	Written	AC7102, AC7102/8
104	If properly delegated, ability to review and approve heat treatment processing records.	7	Written	AC7102, AC7102/8
105	Basic understanding of the operation, maintenance and calibration requirements for equipment used for testing, evaluation and acceptance or the specifications used for such testing, evaluation and acceptance (e.g., tensile testing, hydrogen pickup)	7	Written	AC7102, AC7102/8
106	Basic understanding of pyrometry testing requirements including instrument calibrations, SAT and TUS testing. With proper training may perform SAT test.	7	Written	AC7102, AC7102/8
107	Awareness and understanding of the Preventive Maintenance Program.	7	Written	AS9100, AC7102
	Sequencing		Written	
108	Has a working understanding of where titanium heat treating and contingent processes fall in the sequence of events and why it should not deviate without customer and/or end user permission.	7	Written	AMS-H-81200, AMS2801, AMS7102
	PERSONAL ATTRIBUTES: Are statements that will enable judgment of the person's personal attributes			

109	Willingness to train and mentor co-workers	7	Written													
110	Good communicator at all levels.	7	GEN													
111	Takes responsibility to challenge work instructions that do not appear to conform to specifications or customer requirements.	10	GEN	AS9100												
112	Personal integrity	7	GEN													
113	Attentive to details	7	GEN													
	EXPERIENCE: Are the minimum experience requirements expected to demonstrate their competence.															
114	NOTE: ARP 1962 (Aerospace Recommended Practice -Training and Approval of Heat-Treating Personnel) requires that suppliers have a documented personnel training program including documented training to an established outline and initial and periodic evaluation of the competency. Evaluation to the requirements of this program should be used in completing this section. The following are recommendations and would be superseded by the supplier's specific documented program. The supplier program may define alternative criteria, waivers and equivalences.		Written	ARP1962												
115	Recommended Minimum Classroom Training Heat Treatment – 80 hours; Paperwork – 40 hours; Test, Inspection, Maintenance – 40 hours or Continuing Education Unit (CEU) Heat Treatment – 8 hours; Paperwork – 4 hours; Test, Inspection, Maintenance – 40 hours or Heat Cap Lessons (Heat Treating Certificate of Educational Achievement Program) Heat Treatment – 20 hours; Paperwork – 10 hours; Test, Inspection, Maintenance – 10 hours	10	Written	ARP1962												
116	Recommended Minimum On-the-Job-Training <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 50%;">Material or Process Category (1)</th> <th style="width: 50%;">Minimum Months of Total On-The-Job Training (2)(3)</th> </tr> </thead> <tbody> <tr> <td>Air atmosphere</td> <td style="text-align: center;">9</td> </tr> <tr> <td>Controlled atmosphere</td> <td style="text-align: center;">12</td> </tr> <tr> <td>Inert gas atmosphere</td> <td style="text-align: center;">12</td> </tr> <tr> <td>Vacuum</td> <td style="text-align: center;">12</td> </tr> <tr> <td>Titanium alloys</td> <td style="text-align: center;">12</td> </tr> </tbody> </table> <p>(1) If two or more categories apply to the same job, the more stringent category applies. (2) Training in multiple alloys and processes may be covered concurrently providing substantial time is devoted to each category and function. (3) On-the-job training for various categories may run concurrently; however, all categories must be thoroughly covered.</p>	Material or Process Category (1)	Minimum Months of Total On-The-Job Training (2)(3)	Air atmosphere	9	Controlled atmosphere	12	Inert gas atmosphere	12	Vacuum	12	Titanium alloys	12	10	Written	ARP 1962
Material or Process Category (1)	Minimum Months of Total On-The-Job Training (2)(3)															
Air atmosphere	9															
Controlled atmosphere	12															
Inert gas atmosphere	12															
Vacuum	12															
Titanium alloys	12															
117	Testing and Evaluation Initial and periodic evaluation of personnel is required. The type of frequency of the evaluation shall be determined by the company employing the individual, except that each individual shall be evaluated at least every 5 years. This shall be defined in a formal written program. Personnel shall be evaluated as necessary to ensure adequate knowledge of those functions, materials, and processes for which they are responsible and will be approved. Evaluation may consist of any combination of written or oral examination or testing, structured checklist review, employee performance appraisal, company employee specific audit program or other appropriate methodology defined in the formal written program.	10	Written	ARP 1962												
	NON-SPECIAL PROCESS RELATED REQUIREMENTS: Defined within these rolls are other general or prerequisite needed															
118	Must understand the role of an operator in meeting product compliance in everyday work within Company's quality management system.	7	Written	AS9100												
119	Must recognize that different customers may have differing requirements for the same process step and that they must be respected.	7	Written	AS9100, AC7102, AC7102/8												
120	Must have a thorough understanding of Control of Nonconformance for equipment and product including containment, customer notification and disposition.	7	Written	AS9100, AC7102, AC7102/8												

7. DOCUMENT REVISION HISTORY

REVISION DATE	SUMMARY
19 April 2018	Updated template, added new logo, updated web address
7 September 2018	BoK reviewed and updated by eQualified Content Developer
4 December 2019	Editorial revision to update program name from eQualified to PRI Qualification SM .

ADDENDUM 1

LIST OF INTERNATIONAL STANDARDS & REFERENCE DOCUMENTS FOR TITANIUM ALLOY SERVICE

SPECIAL PROCESS	DOCUMENT TITLE	DOCUMENT NUMBER
Heat Treating	Nadcap Audit Criteria for Heat Treating	AC7102 J1
Heat Treating	Nadcap Audit Criteria for Heat Treating Pyrometry	AC7102/8 N/A
Heat Treating	SAE Aerospace Material Specification - Pyrometry	AMS2750 E
Heat Treating	SAE Aerospace Material Specification – Heat Treatment of Parts in a Vacuum	AMS2769 B
Heat Treating	SAE Aerospace Material Specification – Heat Treatment of Titanium Alloy Parts	AMS2801 B
Heat Treating	SAE Aerospace Material Specification - Heat Treatment of Titanium and Titanium Alloys	AMS-H-81200 D
Heat Treating	SAE Aerospace Recommended Practice - Training and Approval of Heat Treating Personnel	ARP1962 A
Quality	SAE Aerospace Standard - Quality Management Systems - Requirements for Aviation, Space and Defense Organizations	AS9100 D