S9074-A2-GIB-010/AM-PBF

REVISION 1

NAVSEA TECHNICAL PUBLICATION

REQUIREMENTS FOR METAL POWDER BED FUSION ADDITIVE MANUFACTURING

Supersedure Notice: This revision supersedes S9074-A2-GIB-010/AM-PBF dated 21 January 2020.

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RECORD OF REVISIONS

REVISION NO.	DATE	TITLE OR BRIEF DESCRIPTION/PREPARING ACTIVITY
0	21 JAN 2020	Initial issue.
1	19 JAN 2024	This revision streamlines the qualification process for Powder Bed Fusion (PBF) Additive Manufacturing procedures and components and added allowances for additional PBF technologies. The requirement for approval of the PBF Procedure prior to execution of procedure qualification builds has been removed. The requirement to perform nondestructive testing for procedure qualification has been rescinded, and nondestructive testing requirements have been revised for other areas. Destructive testing requirements have been streamlined for procedure qualification and part verification. Electron beam PBF requirements have been added. Other clarifications to requirements have been made throughout the document.

FOREWORD

This document covers general requirements, provisions for quality assurance and process control plans, test procedures, and instructions for preparation for delivery for powder bed fusion-produced parts.

TECHNICAL MANUAL FEEDBACKS

Ships, training activities, supply points, depots, Naval Shipyards and Supervisors of Shipbuilding are requested to arrange for the maximum practical use and evaluation of NAVSEA technical manuals. All errors, omissions, discrepancies and suggestions for improvement to NAVSEA technical manuals shall be submitted via one of the following methods:

1. The preferred method is to submit the Feedback directly into MBPS at https://mbps.navseaplm.navy.mil/Windchill/. MBPS is an unclassified system, do not include U-NNPI or Classified data as attachments to a feedback. See option 5 for classified data. To request a MBPS account submit a ticket to the National Help Desk Service Management (NHDSM) at https://nhdsm.navair.navy.mil/ (DoD PKI Certificate required).
2. Submit a ticket via NHDSM. When submitting the ticket, include a completed copy of NAVSEA 4160/1 (TMDER Form). All data submitted via NHDSM shall be unclassified only.
3. Email a completed copy of NAVSEA 4160/1 to nav_helpdesk.fct@navy.mil. All data submitted shall be unclassified only.
4. For non-Help Desk account holders, submit the feedback via the following link (CAC or ECA Cert Required): https://nhdsm.navair.navy.mil/HEAT/alp.aspx?Scope=SelfService&CommandId=NewServiceRequestByOfferingId&Tab=ServiceCatalog&Template=1DE99338DBF9480D9CD3F6EE57B08124 When submitting the ticket, include a completed copy of NAVSEA 4160/1. All data submitted shall be unclassified only.
5. For NNPI and Classified data, continue to use the paper copy of NAVSEA 4160/1 and submit using the current process.

All feedback comments shall be thoroughly investigated, and originators will be advised of action resulting therefrom. One copy of NAVSEA form 4160/1 is at the end of each separately bound technical manual 8-1/2 x 11 inches or larger.

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CHAPTER 1
SCOPE AND APPLICABILITY

1-1 SCOPE.

This document provides the minimum qualification requirements, part verification requirements, and performance requirements for fabricating metal parts using powder bed fusion (PBF) additive manufacturing (AM). This document also covers general requirements, provisions for quality assurance and process control plans, test procedures, and instructions for preparation for delivery of PBF-produced parts. Procedure qualification, part verification, and operator qualification requirements, as well as completion of all assessments and requirements for NAVSEA's use of AM shall be met prior to any production fabrication. The requirements in this document are devised to demonstrate that sound PBF parts can be produced. This document does not purport to address all the safety concerns, if any, associated with the use of PBF. It is the responsibility of the user of this document to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1-2 NON-APPLICABILITY.

1-2.1 NAVAL NUCLEAR PROPULSION. This document does not apply to naval nuclear propulsion plant systems, equipment, and facilities under the cognizance of the Deputy Commander, Naval Nuclear Propulsion Directorate (SEA 08). As outlined in EO 12344, the SEA 08 Deputy Commander has responsibilities and authorities over all facilities and activities which comprise the Naval Nuclear Propulsion Program, which is a joint Department of Energy and Navy organization. These responsibilities and authorities include all technical and logistical matters related to naval nuclear propulsion. Accordingly, nothing in this document supersedes or changes those authorities, and SEA 08 shall be consulted concerning all matters related to naval nuclear propulsion.

1-2.2 STRATEGIC SYSTEMS PROGRAMS. This document does not apply to Strategic Weapons Systems, Attack Weapons Systems, and associated spare and repair parts under the cognizance of Strategic Systems Programs.

1-2.3 NON-CRITICAL APPLICATIONS. This document does not apply to applications covered by NAVSEA ltr Ser 05Z/191 or applications with service condition level severities of level 7 and N/A in accordance with NAVSEA's Guidance on the Use of AM.

1-3 REQUIREMENTS SUBJECT TO NAVSEA APPROVAL

Any items contained in this document specifically requiring NAVSEA approval shall be forwarded to Naval Sea Systems Command, SEA 05T1, 1333 Isaac Hull Ave, SE, Stop 5142, Washington Navy Yard, DC 20376-5142 via the AM authorized representative. Subcontractors shall submit such items to the contracting activity in accordance with the contract or purchase order. Contracting activities and authorized representatives shall thoroughly review and make recommendations as to the acceptability of the item submitted.

1-4 REFERENCED DOCUMENTS.

1-4.1 GOVERNMENT DOCUMENTS.

1-4.1.1 Standards. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-2035 - Nondestructive Testing Acceptance Criteria

(Copies of this document are available online at https://quicksearch.dla.mil.)

1-4.1.2 Other Government Documents. The following other Government documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

NAVAL SEA SYSTEMS COMMAND (NAVSEA) LETTERS

4870 Ser 05T/2018-024 - Guidance on the Use of Additive Manufacturing

9070 Ser 05Z/191 - Guidance on Identification and Installation of Low Risk Additively Manufactured Metal Components

(Copies of these documents are available by request from Command Standards at usn.ncr.comnavseasyscomdc.mbx.command-standards@us.navy.mil.)

NAVSEA TECHNICAL PUBLICATIONS

S9074-AQ-GIB-010/248 - Requirements for Welding and Brazing Procedure and Performance Qualification

S9074-AR-GIB-010/278 - Requirements for Fabrication Welding and Inspection, and Casting Inspection and Repair for Machinery, Piping, and Pressure Vessels

T9074-AS-GIB-010/271 - Requirements for Nondestructive Testing Methods

(Copies of these documents are available online via Model Based Product Support (MBPS) at https://mbps.navseaplm.navy.mil/Windchill/app/. To gain access to MBPS, obtain an account with National Help Desk Service Management (NHDSM) at https://nhdsm.navair.navy.mil (a valid CAC is required to access this website) and submit a SAAR-N Request. Refer questions, inquiries, or problems to (888) 292-5919. These documents are available for ordering (hard copy) via the Naval Logistics Library (NLL) at https://nll.navsup.navy.mil. For questions regarding the NLL, contact the NLL Customer Service at nllhelpdesk@navy.mil, (866) 817-3130, or (215) 697-2626/DSN 442-2626.)

1-4.2 NON-GOVERNMENT DOCUMENTS. The following documents form a part of this document to the extent specified. Unless otherwise specified, the issues of the documents are those cited in the solicitation or contract.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

Boiler Pressure and Vessel Code (BPVC), Section V, Nondestructive Examination

(Copies of this document are available online at www.asme.org.)

AMERICAN WELDING SOCIETY (AWS)

AWS A2.4 - Standard Symbols for Welding, Brazing, and Nondestructive Examination

(Copies of this document are available online at www.aws.org.)

ASTM INTERNATIONAL

ASTM B214	-	Standard Test Method for Sieve Analysis of Metal Powders
ASTM B215	-	Standard Practices for Sampling Metal Powders
ASTM B243	-	Standard Terminology of Powder Metallurgy
ASTM B822	-	Standard Test Method for Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering
ASTM E3	-	Standard Guide for Preparation of Metallographic Specimens
ASTM E8/E8M	-	Standard Methods for Tension Testing of Metallic Materials
ASTM E10	-	Standard Test Method for Brinell Hardness of Metallic Materials
ASTM E18	-	Standard Test Methods for Rockwell Hardness of Metallic Materials
ASTM E23	-	Standard Test Methods for Notched Bar Impact Testing of Metallic Materials
ASTM E92	-	Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials
ASTM E112	-	Standard Test Methods for Determining Average Grain Size
ASTM E407	-	Standard Practice for Microetching Metals and Alloys
ASTM E1820	-	Standard Test Method for Measurement of Fracture Toughness
ASTM E2651	-	Standard Guide for Powder Particle Size Analysis
ASTM F3049	-	Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes

(Copies of these documents are available online at www.astm.org.)

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

ISO/ASTM 52900	-	Additive manufacturing – General principles – Fundamentals and vocabulary
ISO/ASTM 52921	-	Additive manufacturing – General principles – Part positioning, coordinates and orientation

(Copies of these documents are available online at www.iso.org.)

SAE INTERNATIONAL

SAE AMS2772	-	Heat Treatment of Aluminum Alloy Raw Materials
SAE AMS-H-6875	-	Heat Treatment of Steel Raw Materials
SAE AMS-H-81200	-	Heat Treatment of Titanium and Titanium Alloys

(Copies of these documents are available online at www.sae.org.)

1-4.3 ORDER OF PRECEDENCE. In the event of a conflict between the text of this document and the references cited herein, the text of this document shall take precedence. In the event of a conflict between the base document and the appendix, the appendix takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been made.

1-5 DEFINITIONS.

a. Except as noted herein, terms related to AM shall be as specified in ISO/ASTM 52900.

b. Except as noted herein, terms related to powder shall be as specified in ASTM B243.

c. Except as noted herein, nondestructive testing (NDT) nomenclature and definitions shall be as specified in T9074-AS-GIB-010/271, Requirements for Nondestructive Testing Methods.

d. Except as noted herein, terms related to coordinate systems for AM shall be as specified in ISO/ASTM 52921.

1-5.1 ACCEPTABLE. An item is acceptable when it complies with or conforms to the applicable standard or specification.

1-5.2 ACTIVITY. All sites of an organization under the same quality assurance management and using the same quality assurance and Process Control Plans performing work to which this document is applicable.

1-5.3 ADDITIVE MANUFACTURING (AM). The process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies (in accordance with ISO/ASTM 52900).

1-5.4 AM AUTHORIZED REPRESENTATIVE. An AM authorized representative is specifically authorized to approve equipment, material, or procedures within the scope of this document for NAVSEA. AM authorized representatives are Naval Surface Warfare Center Carderock Division, NAVSEA, or individuals explicitly approved by NAVSEA.

1-5.5 APPROVAL (APPROVED). Approval means the item under consideration requires acceptance by NAVSEA or its AM authorized representative. “Approval” or “approved,” as used herein, is granted by the NAVSEA AM authorized representative unless NAVSEA approval is specified. “NAVSEA approval” means approval by the Naval Sea Systems Command headquarters.

1-5.6 AS-BUILT. The state of parts made by a PBF process before any surface post-processing (machining, peening, etc.), not including the removal from the build plate or removal of supports and/or unprocessed feedstock.

1-5.7 BUILD. The physical part(s) built from a single complete operation (a “build cycle” in accordance with ISO/ASTM 52900) of the AM process.

1-5.8 COUPON. Walls, cylinders, or other geometries from which test specimens are extracted.

1-5.9 DIGITAL FILES. All files, including dependent files, necessary to control the AM system during part fabrication. These files include file formats for communicating the surface model of the part (e.g., STL, STEP, or other computer aided design [CAD] formats), part orientation, slice files, build files, etc. The set of files will be specific to the PBF system software and ancillary software used for preparing the build.

1-5.10 ELECTRON BEAM POWDER BED FUSION. A PBF process that uses an electron beam as the energy source.

1-5.11 ENERGY SOURCE. The source of thermal energy delivered by a PBF machine.

1-5.12 ESSENTIAL ELEMENTS. Elements, either material or process, that are important in establishing an AM procedure. These elements shall be defined as part of an AM procedure. Changes in these elements after a procedure has been qualified require a change in the written procedure and may require requalification depending on the element being changed and the magnitude of the change.

1-5.13 FABRICATION DOCUMENT. The document invoked by the contract, purchase order, or requirements governing the work being accomplished.

1-5.14 FAMILY OF PARTS. A set of parts with similar geometric features that can be made using the same procedure and qualification data.

1-5.15 FUSION. The process of melting and fusing a layer of powder to the previous layer by the energy source.

1-5.16 HEAT TREATMENT. A post-processing procedure that consists of any of the following processes: homogenization/normalization, annealing, solution treating, precipitation hardening, austenitizing, tempering, quenching (in any medium), stress relieving, hydrogen soaking, or hot isostatic pressing (HIP).

1-5.17 INSPECTOR. Any contractor, Naval shipyard, or other Government agency employee, or American Bureau of Shipping Surveyor, qualified as required by this document to accept or reject materials or workmanship on the basis of specified test results.

1-5.18 LASER POWDER BED FUSION. A PBF process that uses a laser or lasers as the energy source.

1-5.19 LAYER HEIGHT. The nominal value used by the machine to define the vertical spacing between applications of powder and scans.

1-5.20 MACHINE. The section of the system including hardware, machine control software, required set-up software, and peripheral accessories necessary to produce a build.

1-5.21 MANUFACTURING LOT. A set of manufactured parts having commonality between feedstock, production run, AM system, and post-processing steps (if required) as recorded on a single manufacturing work order.

1-5.22 OPERATOR. The user of an AM machine.

1-5.23 PART. The final physical product fabricated using AM, after all post-processing.

1-5.24 PART VERIFICATION. A procedure in which a pre-production build is fabricated using final production procedures.

1-5.25 PART VERIFICATION BUILD. A pre-production build fabricated using final production procedures that serves as a model for pre-production testing and approval.

1-5.26 POST-HEAT. The process after the fusion process in which heat is applied to the build or build layer in order to maintain the required powder bed temperature.

1-5.27 POWDER BED FUSION (PBF). An AM process in which thermal energy selectively fuses regions of a powder bed (in accordance with ISO/ASTM 52900).

1-5.28 POWDER BLEND. A quantity of powder made by thoroughly intermingling powders originating from one or several powder lots of the same nominal composition (in accordance with ISO/ASTM 52900).

1-5.29 POWDER LOT. A quantity of powder produced of the same composition or composition blend and the same particle size distribution, manufactured during a single manufacturing process cycle from batches of base materials by the same manufacturing process, and submitted for the vendor's inspection at the same time.

1-5.30 POWDER REMOVAL SYSTEM. A system by which used powder is removed from the PBF system and from around the build and processed for re-use.

1-5.31 PREHEAT. The process used to heat the build plate before the start of the PBF process.

1-5.32 PRESINTER. To heat a layer of powder by electron beam before the fusion process in order to lightly sinter the powder together, increase powder conductivity, and prevent smoke events during the fusion process. This process is performed on each layer of powder during the electron beam PBF process.

1-5.33 PROCEDURE. A written fabrication instruction that contains all the applicable essential elements listed in this document.

1-5.34 PROCEDURE QUALIFICATION. An action by which test assemblies are prepared in accordance with a proposed procedure and evaluated by destructive tests or NDT, or both. Also included are requirements for qualification record keeping.

1-5.35 PROCEDURE QUALIFICATION BUILD. A build containing test specimens for procedure qualification.

1-5.36 PRODUCTION LOT. All builds produced on one machine using the same procedure, digital files, and time-defined or other events in a production run. Where multiple parts or parts in a different orientation are produced in a single build, all parts of the same design in the same vertical orientation will be considered the same lot, while parts in a different vertical orientation or of a different design shall be considered a separate lot, unless otherwise approved. Unless otherwise specified, witness coupons built separately on the same build as the part(s) they represent comprise all parts in the build.

1-5.37 RECOATER. A device that applies a layer of powder on a build plate, on a substrate, or over previously applied powder layers.

1-5.38 RECYCLED POWDER. Used powder recovered from inside the AM machine that has been processed (such as by sieving) for reuse.

1-5.39 REVIEW FOR ADEQUACY. A review determining whether a submission contains all relevant controls and procedures defined in the applicable standard or specification that is actionable but does not require approval.

1-5.40 SCAN STRATEGY. A pattern defined by geometric, speed, and time delay parameters that the energy source follows over a layer or multiple layers of material during the AM process with the purpose of joining or fusing the layer or layers (in accordance with ISO/ASTM 52900).

1-5.41 SPECIAL PBF APPLICATIONS/PARTS. Parts or applications that require additional testing and approvals outside of the requirements of this document in accordance with NAVSEA's Guidance on the Use of AM. This includes, but is not limited to, parts covered by any NAVSEA fabrication documents not listed in this document and parts in the Submarine Safety Program (SUBSAFE), Critical Ship Systems, Pressure Hull Boundaries, and Material Identification and Control level I parts.

1-5.42 SYSTEM. The AM equipment, machine, and auxiliary equipment used for producing PBF parts.

1-5.43 TP 248 AUTHORIZED REPRESENTATIVE. The authorized representative as defined by S9074-AQ-GIB-010/248, Requirements for Welding and Brazing Procedure and Performance Qualification.

1-5.44 USED POWDER. Powder moved over the build plate. This includes powder removed from parts after a build is complete and powder located in powder overflow regions of the system.

1-5.45 VIRGIN POWDER. Unused powder from a single powder lot (in accordance with ISO/ASTM 52900).

1-5.46 WAIVER. A document submitted for approval that allows for deviation from some or all of the requirements in the procedure qualification.

1-5.47 WITNESS COUPON. Material built along with a part verification build or production build for reference or testing purposes from which test specimens can be obtained.

1-6 CLASSIFICATION.

1-6.1 INCLUDED CLASSIFICATION. The following classifications are contained in this document:

a. Machinery, class M-PBF. S9074-AR-GIB-010/278, Requirements for Fabrication Welding and Inspection, and Casting Inspection and Repair for Machinery, Piping, and Pressure Vessels, shall be the governing document for any requirements for this class outside of those listed in this document.

(1) Class M-PBF-1. Class M-PBF-1 machinery includes moving parts, such as gears, rotors, impellers, and shafting (excluding propulsion shafting and rudder stocks) that transmit torque or thrust.

(2) Class M-PBF-2. Class M-PBF-2 machinery includes stationary non-pressurized parts or structures, such as sub-bases for turbines, engines, motors, and pumps. Stationary pressurized parts (other than turbines) that cannot be classified as pressure vessels or piping may be classified as M-PBF-2, if approved.

Each of these sub-classes shall be further categorized as to criticality in accordance with the following:

(a) Category A. Safety and mission of the ship.

1. Safety. Machinery forming part of, or directly supporting, watertight integrity or machinery whose failure would cause loss of ship control, propulsion, or weight handling equipment.

2. Mission. Machinery essential to the mission of the ship, such as weapon and fire control systems, navigation communication systems, and major auxiliary support systems.

(b) Category B. Normal operation of the ship. Machinery essential to the normal operation of the ship.

(c) Category C. Non-essential items. Includes parts of components in categories A and B that do not transmit the principal operating load or support any type of pressure boundary.

b. Piping, class P-PBF. Class P-PBF piping includes all PBF piping, tubing, and fittings for conveying fluids. S9074-AR-GIB-010/278 shall be the governing document for any requirements for this class outside of those listed in this document.

(1) Class P-PBF-1. Class P-PBF-1 includes production parts for design pressures exceeding 300 pounds per square inch (lb/in^2) or design temperatures exceeding 650 °F, or both, such as steam lines, hydraulic systems, boiler generating tubes, superheater and economizer elements, other pressure retaining tubes and piping (excluding nozzles to pressure vessels, which are covered under the appropriate classification), and all piping systems for conveying oxygen, gasoline, and lethal gases or liquids regardless of pressure and temperature. This class also includes production parts in piping systems that transmit oxygen, helium, mixed gases, air, water, and exhaust of diving life support systems. Specifically excluded are pipe joints meeting the classification criteria of class P-PBF-LT.

(2) Class P-PBF-2. Class P-PBF-2 includes production parts for design pressures not exceeding 300 lb/in^2 or 650 °F. Also included are fabrication parts of all open-ended vent, drain, and steam escape piping that has no isolation capability from its origin to its terminus regardless of the design temperature or pressure. Specifically excluded are pipe joints meeting the classification criteria of class P-PBF-LT.

(3) Class P-PBF-LT. Class P-PBF-LT includes production parts for all piping of design pressures greater than 50 lb/in^2 and service temperatures of -20 °F or below.

c. Pressure vessels and tanks, class A-PBF. Class A-PBF pressure vessels and tanks include production parts for parts of drums, tanks, or closed receptacles (including nozzles) and valves that are designed to contain gases or liquids. This includes all feed tanks, lubricating oil storage tanks, and similar vessels that contain only the static head of the obtained liquid. It does not include tubing or piping that joins to the pressure vessel, which are subject to the requirements of class P piping. Valves to be installed in class P-1 piping systems shall be fabricated and inspected in accordance with class A-PBF-2 pressure vessel requirements. Valves to be installed in other classes of piping systems shall be fabricated and inspected in accordance with the appropriate pressure vessel category as determined by design temperatures and pressures. S9074-AR-GIB-010/278 shall be the governing document for any requirements for this class outside of those listed in this document.

(1) Class A-PBF-F. Class A-PBF-F includes production parts for fired and unfired pressure vessels for all pressures and temperatures that are specifically designed for a finite fatigue life and are consequently required to undergo low cycle fatigue evaluations. Also included are any structural parts made for the internal or external surfaces of a fluid boundary that are subject to the system pressure of the adjacent A-PBF-F pressure vessel, but which do not form a part of the fluid boundary. Examples of pressure vessels in this class are all submergence pressure sea water cooled submarine heat exchangers and catapult steam receivers.

(2) Class A-PBF-1. Class A-PBF-1 includes production parts for fired pressure vessels, drums, and headers in which steam is generated by the application of heat resulting from the combustion of fuel. It includes economizer and superheater headers. Specifically excluded are parts for pressure vessels meeting the classification criteria of classes A-PBF-2, A-PBF-3, A-PBF-4, or A-PBF-LT.

(3) Class A-PBF-2. Class A-PBF-2 consists of production parts of unfired pressure vessels with design pressures or design temperatures exceeding 400 lb/in^2 or 600 °F, respectively; for liquids at 300 °F or higher; and for lethal gases and liquids at any temperature or pressure. Class A-PBF-2 also includes valves to be installed in class P-1 piping systems. Specifically excluded are parts for pressure vessels meeting the classification criteria of classes A-PBF-3, A-PBF-4, or A-PBF-LT.

(4) Class A-PBF-3. Class A-PBF-3 consists of production parts of unfired pressure vessels with design pressures and design temperatures less than 400 lb/in^2 and 600 °F. Specifically excluded are parts for pressure vessels meeting the classification criteria of classes A-PBF-4 or A-PBF-LT.

(5) Class A-PBF-4. Class A-PBF-4 consists of production parts of unfired pressure vessels with design pressures or design temperatures less than 150 lb/in^2 and 450 °F, including tanks subject only to the static head of the liquid contained. Specifically excluded are parts for pressure vessels meeting the classification criteria of class A-PBF-LT.

(6) Class A-PBF-LT. Class A-PBF-LT consists of production parts of pressure vessels with design pressures greater than 50 lb/in^2 and service temperatures of -20 °F and below.

1-6.2 OTHER CLASSIFICATIONS. Any part covered by any NAVSEA fabrication or other governing document that is not included in this section (e.g., class T turbines in S9074-AR-GIB-010/278) shall be considered a special PBF part. The document in which these classes are described shall be the governing document for any requirements for this class outside of those listed in this document.

CHAPTER 2
GENERAL REQUIREMENTS AND TEST REPORTS

2-1 SCOPE.

This chapter provides general requirements for the qualification of a PBF Procedure, qualification of a part-specific Part Verification Test Plan, and use of these procedures during production. Part review in accordance with NAVSEA's Guidance on the Use of AM may require changes to the requirements of this document, which may include testing and acceptance criteria.

2-2 GENERAL REQUIREMENTS AND TEST REPORTS.

2-2.1 RESPONSIBILITY. Each activity qualifying procedures under the requirements of this document shall prepare written procedures and perform the required tests to qualify these procedures.

2-2.1.1 Qualification Builds. Personnel performing procedure qualification builds and part verification builds shall be regular employees of the activity (i.e., not subcontractors or temporary specialists) and under the full supervision and control of the activity. Execution of procedure qualification builds and part verification builds should be accomplished at one of the activity's sites with the activity's PBF equipment or equipment similar to that being acquired by the activity; if builds are performed at a site other than the activity's site, the activity's employee(s) responsible for developing the procedure being qualified and ensuring that it is correctly implemented shall also be present and directing the activity's operator during all builds.

2-2.2 CERTIFICATION OF QUALIFICATION TESTING. After testing, the responsible official of the activity shall certify that the tests and the test results meet all the requirements of this document and that the PBF Procedure meets all requirements of this document and, if applicable, the fabrication document. Qualification tests and data containing deviations from requirements may be submitted for approval if such deviations are specifically identified as deviations and the technical justification for each deviation is provided. Deviations shall not be used for production pieces until written approval is received from NAVSEA.

2-2.2.1 Approval of Other Procedure Qualifications. Procedure qualifications previously prepared for other Government agencies or other established regulatory codes may be submitted for approval to the AM authorized representative if the qualification testing and approval (to the other Government agencies' or regulatory bodies' requirements) occurred prior to an activity's invitation for bid or request for proposal. NDT requirements, as specified in this document but not required by other agencies, shall be accomplished on additional test samples or, if approved by the AM authorized representative, on a production application. Such data shall be submitted for approval as required in 2-2.3.

2-2.3 SUBMITTAL OF PROCEDURES, TEST PLANS, AND TEST REPORTS. Procedures are the responsibility of the activity. Prior to the production application of the PBF Procedure, the activity shall obtain approval of all documents required by 2-2.3.2, and shall submit for review for adequacy all documents required by 2-2.3.1. The activity shall submit all documents to the TP 248 authorized representative and the AM authorized representative for concurrent review. When required, or otherwise at their discretion, the AM authorized representative shall submit documents to NAVSEA for approval or review for adequacy. Once all requirements are met, the AM authorized representative shall be given notice of a minimum of 15 business days prior to the start of production to provide the opportunity to conduct an initial production audit. During production, the activity shall submit all documents required by 2-2.3.3 for part acceptance.

2-2.3.1 Review for Adequacy. The review for adequacy does not eliminate the need for waivers from the requirements herein. The activity shall submit the following documents for review for adequacy:

a. PBF Procedure in accordance with 3-2.
b. Part Manufacturing Plan in accordance with 4-2.
c. Quality Assurance Plan in accordance with 6-2.
d. Process Control Plan in accordance with 6-3.
e. The activity may submit the draft PBF Test Plan in accordance with 3-3 for review for adequacy.

If any submitted documents are found to not be adequate during the review for adequacy, appropriate controls shall be implemented and revised documentation shall be submitted prior to fabrication of any additional builds.

2-2.3.2 Procedure Approval. The activity shall submit the following for approval:

a. Procedure Qualification Test Report in accordance with 3-4.
b. Part Verification Test Plan in accordance with Chapter 4.
c. Part Verification Test Report in accordance with 4-4.
d. Production Conformance Evaluation Plan in accordance with Chapter 5, unless already approved per 5-2.7.
e. New PBF Procedure and Procedure Qualification Test Report when level 1 changes are made to the PBF Procedure in accordance with 3-5, or when level 2 changes are made to the PBF Procedure in accordance with 3-6.
f. New Part Verification Test Plan and Part Verification Test Report when part level changes are made to the PBF Procedure in accordance with 4-5.

2-2.3.3 Part Acceptance. During production, the activity shall provide the following for part acceptance:

a. Production Conformance Test Report in accordance with 5-6.
b. Certificate of Conformance in accordance with 5-7.1.

2-2.3.4 Approval by Audit. The activity shall identify the cases for which on-site audits shall be used to meet requirements for approval, review for adequacy, and part acceptance. Procedure Qualification Test Reports, Part Verification Test Reports, and all NDT and destructive testing data and procedures shall not be eligible for approval by audit. The activity shall submit a list of the items proposed to be approved by audit to NAVSEA for approval prior to submission of any other documents.

2-2.3.5 AM Authorized Representative Advance Notification. The activity shall notify the AM authorized representative and the TP 248 authorized representative no less than 5 business days prior to the production of any PBF qualification builds. The applicable authorized representatives shall be afforded the opportunity to observe the building of the procedure qualification build(s), the part verification build, and the performance of the required NDT and destructive testing. Notifications shall be in writing. Observations shall be at the discretion of the AM authorized representative.

2-2.4 VENDOR PROCEDURE QUALIFICATION. It shall be the responsibility of each activity to ensure that its subcontractors have qualified procedures based on approved qualification data.

2-2.5 WAIVER OF QUALIFICATION. Procedure qualification testing may be waived if deemed appropriate in accordance with NAVSEA's Guidance on the Use of AM or if otherwise approved by NAVSEA. A PBF Procedure, including all required essential elements and acceptance criteria, shall be required even when procedure qualification testing is waived.

2-2.6 APPROVAL OF CRITICAL APPLICATIONS. NAVSEA approval of procedure qualification and part verification data shall be obtained for parts with service condition level severities of levels 1 through 5 in accordance with NAVSEA's Guidance on the Use of AM. AM authorized representative approval shall be obtained for parts with service condition level severities of level 6 in accordance with NAVSEA's Guidance on the Use of AM.

2-2.7 APPROVAL OF SPECIAL PARTS AND APPLICATIONS. NAVSEA approval of the procedure qualification and part verification data shall be obtained for special parts and applications (e.g., SUBSAFE, Critical Ship Systems, Pressure Hull Boundaries). The submittal shall include evaluation methods and proposed performance qualification tests in accordance with 3-2.3.

2-2.7.1 Approval of Special PBF Systems. NAVSEA approval of procedure qualification and part verification data shall be obtained for PBF systems with processing capabilities not captured by this document, such as multi-laser systems.

2-2.8 QUALIFICATION LEVEL. When this document is specified in contracting documents, procedure qualification is required. The essential elements for the PBF process shall be incorporated into the PBF Procedures in accordance with the requirements of this document and the applicable fabrication document.

2-2.8.1 Level 1. This qualification level covers the initial qualification of PBF Procedures for the fabrication of material by any activity, or requalification of PBF Procedures due to variations specified in 3-5. Changes that require level 1 requalification are expected to have a significant impact on material properties.

2-2.8.2 Level 2. This qualification level is intended to permit qualification for a variation in a procedure of that has already been qualified by qualification level 1 due to variations specified in 3-6. These are changes where material properties can be expected to not change significantly. Level 2 requalification requires qualification of one procedure build for any or all level 2 variations made to the procedure at one time. Unless otherwise stated herein, the procedure qualification build shall use the nominal values of all other essential variables.

2-2.8.3 Part Level. This qualification level is intended to qualify specific procedures and files used to produce a specific build. Changes that require part requalification invalidate the specific Part Verification Test Report. Changes that require part requalification do not invalidate the associated Procedure Qualification Test Report. Changes to a new part do not invalidate previous Part Verification Test Reports.

2-2.9 REPAIR OF PROCEDURE QUALIFICATION BUILDS AND PART VERIFICATION BUILDS. Repair of procedure qualification builds shall not be permitted. Unless otherwise approved by NAVSEA, repair of part verification builds shall not be permitted. Repair of production parts shall be in accordance with S9074-AR-GIB-010/278 and the special welds paragraph in S9074-AQ-GIB-010/248 with approval from NAVSEA prior to repair.

2-2.9.1 Insufficient Procedure Qualification and Part Verification. If a procedure qualification or part verification build fails to meet the destructive testing or NDT requirements, the procedure qualification or part verification build shall be rejected by the performing activity, and the AM authorized representative shall be notified of all rejections in writing.

2-2.10 TRANSFER OF PROCEDURE QUALIFICATION. Transfer of qualified PBF Procedures from one activity to another shall not be permitted unless qualification testing is performed and approved for the new activity.

2-2.10.1 Transfer of Qualified Procedures Between Sites of an Activity. Transfer of qualified PBF Procedures between sites of an activity shall be governed by the requirements stated in the activity's quality assurance manual (see 6-2) and shall require approval by the AM authorized representative.

CHAPTER 3
POWDER BED FUSION PROCEDURE QUALIFICATION

3-1 SCOPE.

This chapter provides general requirements for the qualification of PBF Procedures for general applications. The purpose of the qualification of the PBF Procedure is to verify the process and material performance.

3-2 PBF PROCEDURE.

3-2.1 SCOPE. A PBF Procedure shall be developed. The PBF Procedure shall be used in conjunction with the Process Control Plan and Quality Assurance Plan to control all PBF operations.

3-2.2 ESSENTIAL ELEMENTS. Unless otherwise specified in the fabrication document, if applicable, the PBF Procedure shall include, at a minimum, the essential elements listed in Table A-1.

3-2.3 MATERIAL ACCEPTANCE CRITERIA. The PBF Procedure shall specify the acceptance criteria for the powder feedstock material and for NDT and destructive testing of the PBF material. Powder testing acceptance criteria shall include, at a minimum, the powder chemistry, particle size distribution, apparent density, and tap density. NDT acceptance criteria shall be developed from MIL-STD-2035, class 1 unless otherwise specified or approved by NAVSEA. Destructive testing acceptance criteria shall include, at a minimum, the following:

a. Yield and ultimate tensile strength.
b. Strain and elongation to failure.
c. Impact toughness and fracture toughness.
d. Hardness.
e. Metallographic requirements, including microstructural phases and porosity shape, size, and distribution.
f. Any other testing identified via the review conducted in accordance with NAVSEA's Guidance on the Use of AM.

3-2.3.1 Existing Acceptance Criteria. The use of material acceptance criteria established by NAVSEA or other Government agencies shall be permitted. The use of material acceptance criteria established by commercial standard organizations for metal PBF AM shall be permitted with approval from the AM authorized representative.

3-2.3.2 Original Equipment Manufacturer (OEM) Properties. The use of metal PBF AM OEM material properties shall be permitted, with approval, only when the powder feedstock and processing parameters submitted for approval are those defined by the OEM.

3-2.3.3 New Acceptance Criteria. Where acceptance criteria from 3-2.3.1 and 3-2.3.2 are not applicable, alternative material property requirements for PBF shall be generated.

a. Where tensile properties are not specified, minimum property requirements shall be proposed for NAVSEA approval. Guidance may be sought by considering industry data and specifications for product forms other than metal PBF AM (e.g., casting, welding)
b. Where toughness properties are not specified, individual and average toughness results shall be reported to NAVSEA for approval. In the absence of other requirements, testing shall be performed at the minimum design temperature or as approved by NAVSEA.
c. For any other acceptance criteria, the test plan and test report approved by NAVSEA shall detail the method used for determining the alternative material property requirements and tolerances.

3-2.4 POWDER FEEDSTOCK. Powder feedstock shall conform to the applicable powder specification and the acceptance criteria established in accordance with 3-2.3. The PBF Procedure shall establish the frequency of evaluating used, recycled, or blended powders. Supporting data shall be provided to establish the evaluation frequency. Supporting data demonstrating the adequacy of powder processed in accordance with the Process Control Plan (see 6-3.6.c) shall be provided, if necessary.

3-2.5 HEAT TREATMENT. Heat treatment shall be performed in accordance with the requirements of Government or commercial specifications or standards or as approved. Where base material (e.g., other product form or process) heat treatment specifications or standards are used, the base material shall be the same nominal chemistry as the PBF material, except as approved. Heat treatment furnaces, temperature recording and other equipment, and working zone temperature surveys shall be in accordance with SAE AMS-H-6875, SAE AMS2772, SAE AMS-H-81200, or similar, as approved. The heat treatment schedule shall be provided and approved. At a minimum, a stress relieving heat treatment is required unless other heat treatment is performed.

3-2.6 REVIEW FOR ADEQUACY. The PBF Procedure shall be submitted concurrently with the PBF Test Report for review for adequacy.

3-3 PBF TEST PLAN.

3-3.1 SCOPE. The activity shall develop a test plan for qualifying the PBF Procedure.

3-3.2 PROCEDURE QUALIFICATION BUILDS. The PBF Procedure shall be used to make procedure qualification builds that meet the requirements specified in Table A-3 (Table A-4 provides a reference list of examples of the specimens shown in Figure B-1 and Figure B-2) unless otherwise specified, if applicable, in the fabrication document.

3-3.2.1 Procedure Qualification Powder Feedstock. Powder feedstock shall be procured to Government or commercial specifications or as approved. The powder used to make the procedure qualification builds shall be tested as specified in Table A-2. Powder shall be evaluated in accordance with 7-3 before each build. A certificate of conformance from the powder OEM that shows the powder meets the acceptance criteria in 3-2.3 can fulfill the powder testing requirement for virgin powder for the relevant test(s).

3-3.2.1.1 Procedure Qualification Powder Feedstock Condition. Unless only virgin powder shall be used for production PBF builds, virgin powder shall be used for no more than two procedure qualification builds.

3-3.2.2 Procedure Qualification Build Quantities. A minimum of three procedure qualification builds shall be produced to meet the specimen quantity requirements in accordance with Table A-3.

3-3.2.3 Procedure Qualification Build Specimen and Coupon Locations. The layout of specimens on the build plate shall be consistent across the three procedure qualification builds. The orientation and location of the procedure qualification build specimens shall be varied across the build plate. The procedure qualification build specimens and coupons shall be located across the entire area of the build plate that will be used to make production PBF builds.

3-3.2.4 Procedure Qualification Build Metallographic Specimens. Each procedure qualification build shall contain a minimum of five coupons with minimum dimensions of 0.5 inch by 0.5 inch by H, where H is equivalent to the height of the tallest coupon on the build. These coupons shall be in multiple locations across the build plate (e.g., corners, center). These coupons shall be used to meet the metallographic testing requirements listed in Table A-3 and 3-3.4.1. Sectioning for metallographic imaging shall be in two orientations, one parallel to the build plate and one perpendicular to the build plate, with both sections falling within ½ inch of the middle of the build. Extra coupons may be used as spares in accordance with 7-2.

3-3.2.5 Build Layout. The PBF Test Plan shall contain figures of CAD drawings that show the build layouts in three dimensions. The figures shall provide the following, at a minimum:

a. Build plate layout of all specimens.
b. Scaling and orientation information, including orientation of the recoater and gas flow direction.
c. Extraction locations for destructive tests.
d. If applicable, markings on the part(s), including identification scheme.
e. Exposure order, if controlled by the machine software or operator.

3-3.2.6 Procedure Qualification Build Interruptions. If process interruptions and restart procedures are included in the Process Control Plan, at least one procedure qualification build shall be subjected to a simulated interruption and restart in accordance with the Process Control Plan (see 6-3.7.c) to evaluate the impact of an interruption on the PBF Procedure. The interruption and restart shall occur within the gage section of the procedure qualification build specimens and coupons (i.e., halfway through the build; an example is shown in Figure B-3). In an electron beam PBF Procedure, this shall be accomplished through a simulated arc fault. If a build interruption is not evaluated, all future builds with any pauses shall be rejected unless a level 2 qualification is performed using a simulated process interruption in accordance with this section and approved. Different types of build interruptions (e.g., power outage, addition of powder feedstock) shall be qualified separately unless otherwise approved by NAVSEA.

3-3.2.6.1 Process Interruption Build Metallographic Specimens. For Process Interruption Builds, a minimum of five coupons shall be used for metallographic imaging such that the interruption and restart are contained in a specimen perpendicular to the build plate.

3-3.2.7 Procedure Qualification Post-Processing.

3-3.2.7.1 Surface Finish. No specimens from procedure qualification builds shall be tested in the as-built surface condition.

3-3.2.7.2 Heat Treatment. The activity shall maintain a complete record of all heat treatments, including stress relief, to be included in the Procedure Qualification Test Report.

3-3.3 NONDESTRUCTIVE TESTING (NDT). The use of NDT methods in addition to destructive testing for procedure qualification builds shall not be required unless specified by NAVSEA, except that visual inspection of titanium builds shall be performed in accordance with 7-4.1 and 7-4.1.1. NDT, if approved, shall be performed in accordance with 7-4.

3-3.4 DESTRUCTIVE TESTING. Destructive tests shall be evaluated in accordance with 7-5.

3-3.4.1 Metallographic Specimens. Metallographic specimens shall be selected such that, across the multiple Procedure Qualification builds, each metallographic specimen location in the build layout is evaluated at least once. Metallographic specimens prepared in accordance with 3-3.2.6.1 shall not contribute to this requirement.

3-4 PROCEDURE QUALIFICATION TEST REPORT.

The Procedure Qualification Test Report shall include the required and measured values for each of the essential elements of the procedure as specified in Table A-1 (an example is shown in Table A-10) and the NDT and destructive test results in sufficient detail to ensure compliance with the requirements of Table A-3. The Procedure Qualification Test Report shall include all metallographic photos and any work instructions referenced in the procedure or test report that contain the required essential element information. The report shall contain a certification statement in accordance with 2-2.2. The report shall include build layout figures in accordance with 3-3.2.5.

3-5 CHANGES REQUIRING LEVEL 1 REQUALIFICATION OF PROCEDURE.

Changes other than those listed in this section, those listed in 3-6 for level 2 qualification, and those listed in 4-4 for part qualification may be made in the PBF Procedure without the necessity for requalification; however, the revised procedure with all changes identified shall be submitted to the AM authorized representative. If the AM authorized representative or NAVSEA has a concern with the revised procedure, requalification using the revised procedure may be required. The changes specified in 3-5.1 through 3-5.14 require requalification of the PBF Procedure for qualification level 1. The changes listed in 3-5.1 through 3-5.14 refer only to programmed changes. Changes due to process drift that are corrected through routine maintenance shall not trigger requalification.

3-5.1 POWDER FEEDSTOCK.

a. A change in powder chemistry outside the limits specified in 3-2.3.
b. A change from one size distribution (D10, D50, D90), as specified in 3-2.3, to another.

3-5.2 POWDER FEEDSTOCK PRODUCTION PROCESS.

a. A change from one powder production process to another powder production process.
b. A change in gas used during powder production to another gas.
c. A change in gas used to package the powder to another gas.

3-5.3 BUILD PLATE. A change from one build plate alloy to another build plate alloy.

3-5.4 MACHINE.

a. A change in manufacturer, manufacturer model number, or machine serial number from that recorded on the qualification test report.
b. A change in machine software version from that recorded on the qualification test report unless otherwise allowed per the Process Control Plan.
c. A change in build file processing software and version from that recorded on the test report unless otherwise allowed per the Process Control Plan.
d. A change in any of the machine subsystems that is not a direct replacement.
e. A change in physical location of a machine to a new location.

3-5.5 RECOATER. A change in the recoater material to a different material.

3-5.6 PREHEAT TEMPERATURE. A change in preheat temperature outside the temperature range specified in the PBF Procedure or, if applicable, the fabrication document.

3-5.7 ENERGY SOURCE PARAMETERS (LASER).

a. Any change in programmed power.
b. A change in focus position by more than 5 percent.
c. A change from one laser control method (pulsing, waveform) to a different control method.
d. A change in beam orientation by more than 5 percent.
e. A change in the number of lasers used.
f. A change in the scan pattern within the region of overlap if more than one laser is used.
g. A change in the minimum distance between laser spots if more than one laser is used.

3-5.8 ENERGY SOURCE PARAMETERS (ELECTRON BEAM).

a. A change in maximum beam current.
b. A change in minimum beam current.
c. A change in accelerating voltage by more than 5 percent.
d. A change in presintering average beam current by more than 5 percent.

3-5.9 SHIELDING.

a. Any change in the composition of the shielding gas.
b. A change in the nominal percentage of any non-inert gas in a gas mixture.
c. A change in the nominal flow rate.
d. The addition or deletion of a shielding gas.
e. The elimination of purge gas.
f. A change in entry location of the shielding gas.
g. A change in chamber vacuum pressure that exceeds 3.5×10^{-3} millibars.

3-5.10 POST-BUILD PROCESSING.

a. The addition or omission of stress relief heat treatment.
b. A change in the heat treatment temperature and time range from that recorded in the test report. A change in temperature that is within the range specified by the fabrication document does not require requalification.
c. The addition or removal of a hot isostatic pressing procedure.
d. For parts that are hot isostatically pressed, a change to the pressure, temperature, and time range from that recorded in the test report. A change in pressure or temperature that is within the range specified by the fabrication document does not require requalification.

3-5.11 CONTOUR SCAN PARAMETERS.

a. A change in the programmed contour pattern or strategy from that recorded on the test report, including the programmed travel speed and hatch spacing.
b. A change in the number of contours from that recorded on the test report.
c. A change in beam offset by more than 5 percent.

3-5.12 FILL SCAN PARAMETERS.

a. A change in the programmed build parameters from that recorded on the test report, including the travel speed, hatch spacing, and scan strategy.

b. A change in beam offset by more than 5 percent.

3-5.13 SCAN PARAMETERS (ELECTRON BEAM). A change in the presintering beam offset to part by more than 5 percent.

3-5.14 LAYER HEIGHT. A change in programmed layer height to another programmed layer height.

3-6 CHANGES REQUIRING LEVEL 2 REQUALIFICATION OF PROCEDURE.

One additional procedure qualification build as specified in 2-2.8.2 shall be fabricated for changes to an essential element specified in 3-6.1 through 3-6.8 from that recorded in the procedure previously qualified under level 1. This build shall undergo NDT and destructive testing.

3-6.1 POWDER FEEDSTOCK.

a. A change from one powder supplier to another powder supplier.

b. A change to the recycled powder limit from that set in the Process Control Plan.

c. A change from one powder lot to another (if not established in the Process Control Plan).

3-6.2 BUILD PLATE.

a. For a specific alloy, a change in temper from that reported in the test report.

b. For a specific alloy, a change from one build plate specification to another build plate specification.

c. A change from one build plate reconditioning method to another method.

d. A change in build plate thickness lower than the minimum set in the Process Control Plan.

3-6.3 RECOATER. A change in spreading method (e.g., blade to roller).

3-6.4 POWDER DEPOSITION.

a. A change in the programmed powder dosage parameters.

b. A change in the programmed recoater speed.

3-6.5 FILL SCAN PARAMETERS.

a. A change in programmed acceleration set points from that recorded on the test report.

b. A change in edge settings from that recorded on the test report.

3-6.6 ENERGY SOURCE PARAMETERS (LASER). A change in pulse frequency to another pulse frequency.

3-6.7 SCAN PARAMETERS (ELECTRON BEAM).

a. Any change in speed function.

b. A change in the presintering beam speed by more than 5 percent.

c. A change in presintering raster pattern from that recorded on the test report.

3-6.8 POST PROCESSING. The addition of, deletion of, or change in any chemical post-processing method from that in the test report.

CHAPTER 4
PART VERIFICATION

4-1 SCOPE.

This chapter provides general requirements for Part Verification Testing for general applications. The purpose of the Part Verification Testing is to verify that geometry- and orientation-dependent pre-production parts meet material and nondestructive testing and evaluation performance requirements.

4-2 PART MANUFACTURING PLAN.

This section provides the requirements for the Part Manufacturing Plan. The Part Manufacturing Plan shall be used to manufacture a specific part for Part Verification Testing and production.

4-2.1 ESSENTIAL ELEMENTS. Part verification builds shall be made using the same essential elements qualified in the PBF Procedure in accordance with 3-2.2. Part verification build essential elements shall be controlled using the same Quality Assurance and Process Control Plans as in the PBF Procedure.

4-2.1.1 Presintering Parameters. If the presintering parameters (beam speed, raster pattern, number of passes, etc.) used in the Part Verification Test Plan are different from those used for the procedure qualification builds, the updated presintering procedure shall be included as part of the Part Verification Test Plan, along with the technical justification for the changes.

4-2.2 MATERIAL ACCEPTANCE CRITERIA. Part verification builds and production builds shall meet application-specific requirements and the acceptance criteria in the qualified PBF Procedure. Unless otherwise specified, application-specific requirements shall take precedence in the event of a conflict.

4-2.3 BUILD LAYOUT FIGURES. The Part Manufacturing Plan shall contain figures that show all the part verification builds in three dimensions. The figures shall provide the following, at a minimum:

a. Build plate layout, including part(s), specimens, and witness coupons.
b. If applicable, markings on the part(s), specimens, and witness coupons, including identification scheme.
c. Scaling and orientation information, including orientation of the recoater and gas flow direction.
d. Exposure order, if controlled by the machine software or operator.
e. Orientation of the recoater.
f. Gas flow direction.
g. Extraction locations for destructive tests.
h. Locations for NDT.

4-2.3.1 Witness Coupons. Part verification builds and production builds shall contain at least four witness coupons. Where possible, the geometry of the witness coupons shall be similar in thickness to the part. Witness coupons shall be dispersed across the build plate (an example is shown in Figure B-4). Witness coupons shall be evaluated in accordance with 7-4 and 7-5. Witness coupons shall receive the same post-processing heat treatments as the parts.

4-2.3.2 Post-Processing. Builds shall be made using the same heat treatment post-processing methods as the procedure qualification builds. Additional post-processing steps (e.g., machining, chemical processing) and all relevant details describing these post-processing steps shall be included in the Part Manufacturing Plan.

4-2.3.3 Process Interruptions. Interruptions occurring during the part verification builds and production builds shall not be greater than the time occurring for the PBF procedure qualification build interruption in accordance with 3-3.2.6, unless the pause during the procedure qualification build interruption was long enough that it can be assumed to have reached a steady-state temperature. Builds shall be restarted in accordance with the Process Control Plan.

4-2.3.4 Family of Parts Changes Not Requiring Part Requalification. Where applicable, for family of parts applications, the Part Manufacturing Plan shall identify features (i.e., geometric, dimensional) where changes do not require part requalification when the digital files (i.e., CAD) are changed. Supporting evidence for allowing the feature changes shall be provided to NAVSEA for approval.

4-2.3.5 Part Manufacturing Plans Containing Multiple Parts. Part Manufacturing Plans may contain multiple parts produced in one build. Part verification testing shall be performed independently for each part build in a different orientation or with a different geometry unless the different geometries are the same family of parts per 4-2.3.4 or otherwise approved by NAVSEA.

4-2.4 REVIEW FOR ADEQUACY. The Part Manufacturing Plan shall be submitted concurrently with the Part Verification Test Plan for review for adequacy. The Part Manufacturing Plan shall not be used for production builds until after the Part Verification Test Plan is approved.

4-3 PART VERIFICATION TEST PLAN.

This section provides the requirements for testing part verification builds.

4-3.1 NDT. Part verification builds shall be evaluated in accordance with 7-4. One-hundred percent of the volume of builds shall be inspected. If builds cannot be inspected to 100 percent coverage, then the builds shall be inspected to the maximum extent possible. Any deviation from 100 percent volumetric inspection shall be approved by NAVSEA. Unless the activity's level III examiner is performing the inspection, the activity's level III examiner shall be on-site with the level II examiner performing the inspection of the part verification builds. NDT acceptance criteria shall be specified in the Part Manufacturing Plan per 4-2.2.

4-3.2 DESTRUCTIVE TESTING. Destructive testing shall be evaluated in accordance with 7-5 to the acceptance criteria approved as specified in 3-2.3. Destructive testing types, numbers, locations, and orientations shall be determined in accordance with NAVSEA's Guidance on the Use of AM. At a minimum, witness coupons shall be tested in accordance with Table A-8.

4-3.2.1 Metallographic Specimens. Specimens shall be evaluated in accordance with 7-5.4. Sectioning plans for witness coupons shall be included in the Part Verification Test Plan.

4-3.3 APPLICATION-SPECIFIC REQUIREMENTS. If necessary, the Part Verification Test Plan shall include additional build(s) to be produced that contain specimens of a type and quantity that reflect application-specific requirements (e.g., fatigue). When a part is designed with an as-built surface as the final surface condition, additional as-built specimens shall be produced as part of the additional build(s). All additional application-specific testing shall occur prior to production PBF. Where existing data shows that the material produced by the PBF Procedure meets the application-specific requirements, that data shall be provided to NAVSEA for approval in lieu of additional testing. Documentation shall be provided showing that the same PBF procedure was used.

4-4 PART VERIFICATION TEST REPORT.

The Part Verification Test Report shall include the values employed for each of the essential elements of the procedure in accordance with 4-2.1 and all results of NDT and destructive testing. Metallographic photos and any work instructions referenced in the procedure or test report that contain the required essential element information shall be submitted with the test report. If applicable, the report shall contain supporting evidence for allowing a family of part feature changes in accordance with 4-2.3.4. The report shall contain a certification statement in accordance with 2-2.2. The build layout figures in accordance with 4-2.3 shall be included in the Part Verification Test Report.

4-4.1 WORK INSTRUCTIONS. All work instructions or other documents referenced in the submitted test reports, plan, or procedures that contain essential element information shall be made available upon request.

4-4.2 POWDER FEEDSTOCK TESTING. Where powder testing was performed during the part verification process, the results shall be included in the Part Verification Test Report.

4-5 CHANGES REQUIRING PART REQUALIFICATION.

Changes other than those listed in this section may be made to a qualified Part Verification Procedure without the necessity for requalification; however, the revised procedure, with all changes identified, shall be submitted to the AM authorized representative. If the AM authorized representative or NAVSEA has a concern with the revised procedure, requalification using the revised procedure may be required. The changes specified in 4-5.1 through 4-5.4 require re-execution of the Part Verification Test Plan for part qualification. Any changes to the previously approved Part Verification Test Plan, including the omission of any application-specific testing, shall require NAVSEA approval.

4-5.1 LEVEL 1 QUALIFICATION CHANGES. Any change requiring level 1 requalification per 3-5.

4-5.2 DIGITAL FILES.

a. Any change to the digital CAD files used to make the part verification build.

b. Any change to the digital files used to make the part verification build except as approved in 4-2.3.4.

4-5.3 ENERGY SOURCE PARAMETERS (ELECTRON BEAM). Any change in the number of presintering passes.

4-5.4 POST-PROCESSING.

a. The addition of, removal of, or change to any post-build surface treatment (e.g., peening).

b. The addition of, removal of, or any change to any post-build surface finishing method or a change in the method used. A change in the machining order shall not trigger requalification.

c. The addition of, removal of, or any change to any chemical post-processing method from that in the Part Verification Test Report.

CHAPTER 5
PRODUCTION CONFORMANCE EVALUATION PLAN

5-1 SCOPE.

This chapter provides general requirements for the Production Conformance Evaluation Plan for general applications. The purpose of the Production Conformance Evaluation Plan is to identify conformance testing requirements during production.

5-2 GENERAL REQUIREMENTS.

5-2.1 PRODUCTION BUILDS. Production builds shall be performed in accordance with the Part Manufacturing Plan qualified by the Part Verification Test Plan.

5-2.2 PRODUCTION CONFORMANCE TESTING. The Production Conformance Evaluation Plan shall include destructive testing and NDT requirements. The Production Conformance Evaluation Plan shall include application-specific production testing requirements. Testing shall be performed at a minimum in accordance with Table A-8. The frequency, type, and quantity of specimens to be tested shall be identified.

5-2.3 BUILD LAYOUT FIGURES. The Production Conformance Evaluation Plan shall contain figures that show the following, at a minimum:

a. Build plate layout, including part(s).
b. Markings on the part(s), specimens, and witness coupons.
c. Orientation of the recoater.
d. Gas flow direction.
e. Extraction locations for destructive tests.
f. Locations for NDT.

5-2.4 PART VERIFICATION MATERIAL CHANGE. If a different alloy has been loaded into the system between part verification and production, or between production builds, the activity shall provide objective qualifying evidence that potential contamination from the material change is not a concern. If the risk of contamination is a concern, the activity shall provide objective qualifying evidence that cleaning procedures have been sufficient to eliminate the risk of contamination.

5-2.5 WITNESS COUPONS. Witness coupons shall be stored as a record of each build. Specimens used for conformance testing shall be extracted from witness coupons from different locations on the build plate throughout production.

5-2.6 PROCESS INTERRUPTIONS. Any and all process interruptions occurring during production builds shall be reported and require dispensation prior to part acceptance. Parts that experience process interruptions that have not been qualified in accordance with 3-3.2.6 shall be rejected.

5-2.7 USE OF PART VERIFICATION TEST PLAN AS PRODUCTION CONFORMANCE EVALUATION PLAN. Where a previously approved Part Verification Test Plan meets all requirements of the Production Conformance Evaluation Plan, the activity may use the previously approved Part Verification Test Plan for production conformance evaluation without additional approval required by 2-2.3.2.d. When this section is invoked, it shall be referenced in the Part Verification Test Plan.

5-3 POWDER FEEDSTOCK TESTING.

Powder feedstock shall be evaluated in accordance with 7-3 to the acceptance criteria specified in 3-2.3. Powder testing shall be as specified in the Production Conformance Evaluation Plan. Certificate of Conformance data from the powder OEM that meets the acceptance criteria in 3-2.3 can fulfill the powder test requirement for virgin powder for the relevant test.

5-4 NDT AND REPAIRS.

Production builds shall undergo NDT based on the relevant classification in accordance with 1-6. NDT shall be performed in accordance with 7-4. NDT shall be described in the Production Conformance Evaluation Plan. The extent of NDT coverage for each part on a build requiring the listed NDT shall be as follows:

a. Visual testing (VT) shall be conducted on all accessible surfaces that comprise the finished part.

b. Magnetic particle testing (MT) and/or liquid penetrant testing (PT) shall be conducted on all accessible surfaces that comprise the finished part.

c. Pressure tests shall be applied to all areas containing pressure.

d. Radiographic testing (RT) coverage shall be 100 percent except that, insofar as part configurations and thickness variations prevent attainment of the required film density in some locations and for the purpose of defining coverage required, a part is considered to contain the following areas:

   (1) 75 percent minimum radiographic coverage areas. These include areas containing pressure, areas designed for dynamic loads, and areas stressed to ⅔ or more of the yield strength under high-impact shock.

   (2) 50 percent minimum radiographic coverage areas and any remaining areas in the part.

The 75 or 50 percent minimum coverages are defined as part areas in the film that are within the specified density limits and are interpretable. It is not the intent that only 75 or 50 percent of part surfaces be radiographed and that any specific area be excluded. Areas that will not be interpretable shall be identified in the Production Conformance Evaluation Plan and subject to approval. In submitting for approval, the criticality of the areas not to be covered by RT and whether the area can be inspected by ultrasonic testing (UT) shall be described.

5-4.1 NON-PRESSURIZED MACHINERY. Non-pressurized machinery parts shall be inspected in accordance with Table A-5.

5-4.2 PRESSURIZED MACHINERY AND PRESSURE VESSELS. Pressurized machinery and pressure vessel parts shall be inspected in accordance with Table A-6.

5-4.3 PIPING. Piping parts shall be inspected in accordance with Table A-7.

5-4.4 OTHER PARTS. Parts that do not fall under one of these classifications shall be inspected as approved by NAVSEA.

5-4.5 ACCEPTANCE CRITERIA. The minimum acceptance criteria shall be the same as the acceptance criteria used in accordance with 4-3.1.

5-4.6 REPAIR OF PRODUCTION BUILDS. In-process and post-build repair methods, including NDT requirements for excavations prior to repair and completed repairs, shall be described in a written procedure in accordance with 6-3.7.

5-4.6.1 Post-Build Repair. Post-build rejectable defects may be removed and repaired with approval from the AM authorized representative. Completed repairs shall be inspected in the same manner as that required for the build. Where MT/PT is required for the build, completed excavation surfaces shall be subject to MT/PT or VT at 5X magnification prior to deposition of repair metal to ensure the absence of linear indications greater than 1/16 inch. Where repair depth does not exceed 3/16 inch or 20 percent of the build or part thickness in an area previously subject to satisfactory RT/UT, MT/PT may be used in lieu of RT/UT.

5-4.6.1.1 Post-Build Repair NDT Records. NDT results, including NDT of excavations prior to further repair, shall be recorded and included along with other build NDT records.

5-5 DESTRUCTIVE TESTING.

Destructive testing shall be evaluated in accordance with 7-5.

5-6 PRODUCTION CONFORMANCE TEST REPORT.

The Production Conformance Test Report shall include the results from the evaluation performed in accordance with the Production Conformance Evaluation Plan. Metallographic photos and any work instructions referenced in the test report that contain the required essential element information shall be included with the test report. The report shall contain a certification statement in accordance with 2-2.2. Conformance testing results shall be maintained in accordance with 6-2.2 and available for audit in accordance with 2-2.3.4.

5-7 RESPONSIBILITY FOR PRODUCTION CONFORMANCE.

All production parts must meet the requirements in this document. The absence of any requirements in this document shall not relieve the activity of the responsibility of ensuring that all parts submitted for acceptance comply with all the requirements of the contract or purchase order. Sampling for conformance neither authorizes submission of known defective parts, either indicated or actual, nor requires acceptance of defective parts.

5-7.1 CERTIFICATE OF PRODUCTION CONFORMANCE. A certificate of production conformance shall be prepared for each part offered for acceptance. The certificate shall state that the part has been made in accordance with the Production Conformance Evaluation Plan and that quality assurance practices ensure the part meets requirements. The certificate shall include the revisions of the Production Conformance Evaluation Plan, Quality Assurance Plan, and Process Control Plan used and the date of the most recent approval or recertification.

CHAPTER 6
QUALITY ASSURANCE AND PROCESS CONTROL PLAN

6-1 SCOPE.

This chapter provides general requirements for the Quality Assurance Plan and Process Control Plan for general applications. The purpose of the Quality Assurance Plan is to maintain the quality of the qualified procedures and production parts. The purpose of the Process Control Plan is to ensure quality processes throughout manufacturing and evaluation.

6-2 QUALITY ASSURANCE PLAN.

The activity shall maintain a quality assurance system adequate to assure the AM authorized representative that all the requirements of this document have been met and are continuously being met. The Quality Assurance Plan shall detail the elements of the quality assurance system. Written procedures shall be prepared to assign responsibility and provide accountability for performing work and inspections.

6-2.1 MATERIAL CONTROL. The activity is responsible for inspecting and evaluating the powder, build plate, and other materials upon receipt to ensure that material and chemical requirements are met. Receipt inspection shall consist of, but not be restricted to, comparing the activity's data with the specified requirements and sampling of the activity's data.

6-2.1.1 Identification System. An identification system shall be established and maintained that enables powder, build plates, and completed builds and coupons to be tracked. The powder lot number, material type, and whether the material is virgin or used shall be maintained in the identification system. Specimens shall be labeled to be traceable to the build and their location on the build plate. Periodic internal audits of the inventories, stocking facilities, and shops shall be performed in accordance with the Quality Assurance Plan to ensure that materials are correctly identified.

6-2.1.2 Visual Verification of Materials Prior to Use. A system shall be established that requires visual verification of any procedure qualification build, part verification build, or production run to ensure that the identification of the material corresponds to that specified by the applicable document.

6-2.2 RECORDS. The quality control system shall include the preparing and maintaining of written or digital records of all of the following: PBF system operation including maintenance and usage, destructive testing and NDT, powder testing, build plate material, and post-processing operations. Records shall be labeled and be traceable to the operation where they were generated.

6-2.2.1 Record Form. A record form shall be prepared prior to the commencement of the operation which it covers. Operations shall be recorded prior to the commencement of the next operation. The records shall be signed and dated by the applicable personnel performing the operation.

6-2.2.2 Maintenance of Records. Unless otherwise specified, all required records shall be maintained by the activity and shall be available to the AM authorized representative in accordance with the contract. At the expiration of the record retention period, the AM authorized representative shall be given a written notification. Disposition of records shall be as agreed upon by NAVSEA and the contractor.

6-2.2.3 Maintenance of Procedure Test Reports. The approved procedure test reports shall be retained by the activity as long as the procedure is applicable. Each qualifying activity shall retain the pertinent test data, destructive test specimens, and NDT result reports, including radiographs, until written approval of the data is obtained.

6-2.3 NONCONFORMANCE. If the AM authorized representative has evidence that the requirements of this document are not being met, they can suspend, upon written notification, the use of any questionable materials, equipment, procedures, personnel, or work covered by this document until conformance with the requirements of this document is judged satisfactory by NAVSEA.

6-3 PROCESS CONTROL PLAN.

The activity shall demonstrate an adequate Process Control Plan that outlines process control for all aspects of the manufacturing and evaluation process. The activity shall ensure the employees responsible for manufacturing and testing the approved product(s) understand the appropriate procedures in the plan. The activity shall ensure that an up-to-date copy of the Process Control Plan, including any amendments, is readily available in the plant for use by auditors when evaluating compliance with procedures approved by part verification testing. The plan must indicate problems that have been identified by the activity, customers, or the AM authorized representative with their product, including receipt inspection, fabrication, or in-service and how these problems were resolved and whether the necessary changes were made in the manufacturing procedures to ensure that these problems will not occur in the future. The Process Control Plan shall include the following:

a. Change control plan (see 6-3.1)
b. Personnel training plan (see 6-3.2)
c. Maintenance control plan (see 6-3.4)
d. Digital file handling plan (see 6-3.5)
e. Powder feedstock plan (see 6-3.6)
f. Build procedure (see 6-3.7)
g. Post-processing procedure (see 6-3.8)
h. In-process monitoring plan (if applicable, see 6-3.9)

6-3.1 CHANGE CONTROL PLAN. The change control plan shall specify the criteria and plan to verify the adequacy of any change in the Process Control Plan. The change control plan shall specify how it is determined whether a change requires approval. The change control plan shall require approval. If NAVSEA has a concern with the new procedure, NAVSEA may require requalification using the revised procedure.

6-3.2 PERSONNEL TRAINING PLAN. The activity shall maintain a personnel training plan that covers training and qualification of personnel involved in the PBF operations and testing. The plan shall detail training required, initial qualification requirements, and requalification timeframes. Personnel shall include, but not be limited to, PBF operators, nondestructive evaluation personnel, the various inspectors responsible for work performance, and materials and other engineers in production or support positions. The plan shall include personnel responsible for work performance of the procedure qualification builds, part verification builds, and production builds. Records of personnel training and training test results shall be maintained with appropriate review to keep qualification current. Written procedures shall be prepared to assign responsibility and provide accountability for performing work and inspections. NDT personnel shall meet the requirements of T9074-AS-GIB-010/271 and shall have additional training specific to NDT of PBF parts.

6-3.3 VISION TEST REQUIREMENTS. Each additive manufacturing operator shall be required to pass an annual vision test. Vision tests shall be conducted using standard test methods for determining visual acuity. In addition, vision tests for operators of titanium and titanium alloys shall include a color perception test on workmanship samples displaying the colors and shades expected in titanium builds. At a minimum, these colors and shades shall include silver, straw, light blue, dark blue, purple, and gray. The standard of acceptance for vision tests shall be natural or corrected near distance acuity such that the individual can read J1 letters on the standard Jaeger-type chart for near vision. Other equivalent visual tests, such as the Snellen chart, may be substituted for the Jaeger chart. When corrective aids are used for the vision test, equivalent aids shall be employed in production work. Additive manufacturing operators who do not pass the color perception part of the vision test shall not be permitted to work with titanium or titanium alloys.

6-3.4 MAINTENANCE CONTROL PLAN. The Maintenance Control Plan shall include maintenance and calibration plans and schedules for all components that control essential machine elements provided in Table A-1 and that are essential for ensuring quality. The plan shall include the calibration metrics identified by the PBF machine manufacturer to declare the equipment fit for service. The plan shall include maintenance schedules of equipment used to prepare used powder for reuse, such as sieve equipment. The plan shall also include the tests or machine checks that will be performed following maintenance, component replacement, or repair. The plan shall include procedures for when the tests or machine checks are failed. The Maintenance Control Plan shall include the method and schedule for calibrating, maintaining, and verifying the performance of the following:

a. Energy source power
b. Beam profile and spot size
c. Energy source start and stop time
d. Energy source position controls
e. Build plate motion, alignment, and levelness
f. Recoater motion, alignment, and condition
g. Platform heating
h. Atmospheric sensors (e.g., oxygen, pressure)
i. Consumables (e.g., filters, seals)

6-3.5 DIGITAL FILE HANDLING PLAN. The Digital File Handling Plan shall provide the tracking and handling method of the digital files necessary to make the procedure qualification builds and part verification builds (e.g., CAD files, slice files, build files). The plan shall provide naming and revision conventions for the files. The plan shall detail control measures as necessary to ensure the build files and any dependent files called by the build files (e.g., program files, subroutines, procedural files) are not compromised. The plan shall contain a verification plan to demonstrate the build files have not changed during digital transfer. The plan shall detail continuous active computer security on all computer systems and associated devices, including storage devices used to transfer files that are associated with any aspect of the build file design and build process. The Digital File Handling plan shall include the following, at a minimum:

a. The method for verifying that transferred files have not been modified during transfer.
b. Relevant Government or commercial digital specifications used.

6-3.6 POWDER FEEDSTOCK PLAN. The Powder Feedstock Plan shall include the following, at a minimum:

a. Details of the powder recycling process, if applicable.

b. Details of the methods for blending and recycling, if applicable.

c. Number of times that powder can be used, blended, or recycled prior to evaluation.

d. Powder feedstock storage conditions and labeling procedures, including the maximum length of time that powder can be stored outside a sealed container (i.e., in a PBF system).

e. Details of the methods for demonstrating equivalency between different material lots.

6-3.7 BUILD PROCEDURE. The Build Procedure shall contain details that ensure a consistent, repeatable process. The Build Procedure shall include the following, at a minimum:

a. System cleaning methods for the following circumstances:

(1) Between builds of the same alloy.

(2) Between builds using different alloys in the same alloy system (e.g., from 304 stainless steel to 316 stainless steel).

(3) Between builds of different alloy systems.

b. Powder loading, handling, and removal processes that prevent contamination. Specify potential sources of contamination.

c. Anticipated interruption types (e.g., power outage), resulting faults to the system, and restart procedure including the maximum acceptable time for restarting the system, pre-heating passes with the energy source (if applicable), etc.

d. Build plate storage, handling, and reconditioning (via mechanical method, heat treatment, and chemical processing) methods.

e. Build plate minimum thickness.

6-3.8 POST-PROCESSING PROCEDURE. The Process Control Plan shall contain details ensuring the post-processing procedures (e.g., powder removal, heat treatment, surface finishing, chemical processing) in accordance with 3-3.2.7 are performed in a consistent and repeatable manner.

6-3.9 IN-PROCESS MONITORING PLAN. If necessary, the Process Control Plan shall contain an in-process monitoring plan. For essential elements, the in-process monitoring plan shall include the step-by-step procedure for conducting continuous in-process monitoring and electronic data collection, recording, and storage to demonstrate adequate process controls and compliance with the qualification limits. The in-process monitoring plan shall include the monitoring method (e.g., human monitoring, data acquisition, infrared cameras, sensors), frequency, sampling rate, and step-by-step procedures used for monitoring. If applicable, the data shall be traceable to locations on the build plate.

6-3.10 DATA COLLECTION SYSTEM. Where the PBF system is equipped with a data collection system, the following shall be identified:

a. The data available to be recorded.

b. The procedure for collecting the data.

c. The method of how the data will be used.

d. The method for verifying the collected data.

Monitored data shall be logged and retained as supporting data until all destructive testing and NDT for the parts made corresponding to the data have been completed and validated against the monitored data. Data shall be retained in accordance with 6-2.2.2.

CHAPTER 7
EVALUATION

7-1 SCOPE.

This chapter provides evaluation requirements. The purpose of evaluation is to ensure appropriate methods and acceptance criteria for required testing. The requirements are classified as follows:

a. Powder feedstock testing (see 7-3)

b. NDT (see 7-4)

c. Destructive testing (see 7-5)

7-2 GENERAL EVALUATION REQUIREMENTS.

7-2.1 REJECTION AND RETESTS. When a test specimen fails to meet the requirements, the build shall be rejected. The activity may rework or retest the material as provided herein. Only one retest of a nonconforming original test is permitted, and the test specimen shall be taken in the vicinity of the initial location of the failed specimen(s) or from a witness coupon. If any retest specimen fails, the build shall be rejected with no further testing permitted. All test results including failures shall be reported, unless otherwise approved in part verification to accommodate automated data reporting systems. In all cases, all test results including failures shall be available for review upon request.

7-2.2 REHEAT TREATMENT. The activity shall be permitted to reheat-treat material that fails to meet the requirements if approved by NAVSEA. If material is reheat-treated, the witness coupons from the associated build shall also be reheat-treated. Required tests originally performed on the failed material shall be repeated, except for powder feedstock testing. If material is reheat-treated, it shall be fully reheat-treated; no partial reheat treatments are permitted.

7-2.3 DEFECTIVE SPECIMEN/REPLACEMENT OF TEST SPECIMENS. The test specimen shall be discarded and a replacement specimen extracted from the same build under the following conditions:

a. When the specimen is incorrectly machined.

b. When the test procedure is incorrect.

c. When there is a malfunction of the testing equipment.

d. When a flaw that is not indicative of an inferior or defective lot of material develops during the test. However, internal flaws such as cracks, ruptures, and porosity are not reasons for the selection of a replacement test specimen.

In the event that there is insufficient material to extract a specimen from the same build, additional builds using the same process parameters may be used to produce additional test specimens.

7-3 POWDER FEEDSTOCK TESTING.

Powder feedstock shall be tested in accordance with Table A-2. For acceptance, powder feedstock tests shall meet the requirements established in 3-2.3.

7-3.1 SAMPLING. All powder feedstock shall be sampled in accordance with ASTM B215 or ASTM E2651.

7-3.2 CHEMISTRY. Chemistry shall be evaluated in accordance with ASTM F3049.

7-3.3 SIZE DISTRIBUTION. Powder size distribution shall be evaluated in accordance with ASTM B822 or ASTM B214. Powder size distribution values of D10, D50, and D90 shall be reported (a sample form is provided in Table A-11).

7-3.4 APPARENT DENSITY. Powder apparent density shall be evaluated in accordance with ASTM F3049. Apparent density shall be reported (a sample form is provided in Table A-12).

7-3.5 TAP DENSITY. Powder tap density shall be evaluated in accordance with ASTM F3049. Tap density shall be reported (a sample form is provided in Table A-12).

7-4 NDT.

7-4.1 VISUAL TESTING (VT). VT using 5X magnification shall be performed in the final surface condition in accordance with T9074-AS-GIB-010/271.

7-4.1.1 Titanium and Titanium Alloys. Titanium and titanium alloy specimens shall meet the following criteria:

a. All as-built surfaces shall exhibit a dull silvery luster. Other conditions are unacceptable and shall be removed unless otherwise approved by NAVSEA. In all cases, the shielding deficiencies shall be corrected prior to fabrication of further builds.

b. All machined surfaces shall exhibit a bright, shiny silvery luster. Other conditions are unacceptable and shall be removed unless otherwise approved by NAVSEA. In all cases, the shielding deficiencies shall be corrected prior to fabrication of further builds.

7-4.2 DIMENSIONAL EXAMINATION. Dimensional examination shall be performed in accordance with a standardized method approved by the AM authorized representative. Dimensional examination shall be performed in the final part condition.

7-4.3 MAGNETIC PARTICLE TESTING (MT) AND LIQUID PENETRANT TESTING (PT). MT and/or PT inspection shall be performed in accordance with T9074-AS-GIB-010/271 for weld inspection, with any modifications as approved by the AM authorized representative. MT and/or PT shall be performed in the final part condition. Where the final surface condition is as-built, testing methods shall be as approved by NAVSEA.

7-4.3.1 MT and PT Suitability. In general, MT shall be used on ferrous materials and PT on nonferrous materials and austenitic corrosion-resisting steels. Where applicable, PT may be substituted for MT on ferrous materials where both procedures have been qualified on an approved PBF Procedure. Production builds shall use the same testing method as the relevant part verification build.

7-4.4 RADIOGRAPHIC TESTING (RT) AND INSPECTION. RT shall be performed in accordance with T9074-AS-GIB-010/271 for castings and forgings, with any modifications as approved by the AM authorized representative. Where the final surface condition is as-built, testing methods shall be as approved by NAVSEA. Where specifically approved by NAVSEA, UT of the entire build may be substituted for RT.

7-4.4.1 Radiographic Shooting Sketch. In accordance with AWS A2.4, the activity shall select and identify areas requiring radiography on the engineering drawing. The activity performing the inspection shall prepare the radiographic shooting sketch that shows film placements and radiation directions to ensure adequate radiographic coverage as specified by the engineering drawing. The radiographic shooting sketch shall be validated by the signature of a certified radiographic inspector. The requirements specified in T9074-AS-GIB-010/271 in the paragraph regarding interpretation of radiographs provide specific detailed requirements that shall be contained on the radiographic shooting sketch. The sketches shall ensure that coverage is obtained in two perpendicular directions.

7-4.5 ULTRASONIC TESTING (UT). UT inspection shall be performed prior to the machining of features (such as corners and other details) that render areas un-inspectable to the degree practicable. A combination of shear wave and longitudinal wave scanning (as applicable) shall be employed so as to scan the entire build or part volume for defects oriented parallel and perpendicular to the recoater direction and in the plane between layers. Inspection shall be in accordance with T9074-AS-GIB-010/271 for weld inspection for shear wave and forged material for longitudinal wave, with any modifications necessary as approved by the AM authorized representative.

7-4.5.1 Calibration Reference Standard Acoustic Similarity. Sound paths used for calibration shall be validated to be acoustically similar to the sound paths used for inspection. Results for acoustic similarity are restricted to the wave mode, refracted angle used, and frequency used. If it is determined that sound paths between the reference calibration standard differ by greater than required by T9074-AS-GIB-010/271, gain compensation shall be used and impacts to material velocity variations shall be documented in the procedure qualification.

7-4.6 ALTERNATE NDT METHODS. Alternate NDT methods, such as phased array UT, full matrix capture, and in-situ monitoring techniques, shall be as approved by NAVSEA. Calibrations and procedures shall follow a commercial standard, such as ASME Boiler Pressure and Vessel Code (BPVC), Section V, with additional requirements from NAVSEA. This shall include where alternate NDT methods are used to replace or supplement traditional NDT methods.

7-4.6.1 X-Ray Computed Tomography (XCT). Where specifically approved by NAVSEA, XCT may be substituted for UT and/or RT.

7-5 DESTRUCTIVE TESTING.

7-5.1 TENSION TESTS. Where tensile specimen testing is required, specimen preparation dimensions and mechanical testing shall be prepared and evaluated in accordance with ASTM E8/E8M (a sample form is provided in Table A-13). For acceptance, tension test specimens with post-processed and machined surfaces shall have ultimate tensile strength, yield strength, and percent elongation that are not less than the minimum requirements established in accordance with 3-2.3 and, if applicable, the fabrication document. All results shall be reported regardless of the failure location.

7-5.2 CHARPY V-NOTCH (CVN). Where CVN testing is required, specimens shall be prepared and evaluated in accordance with ASTM E23 (a sample form is provided in Table A-14). The testing temperature shall be in accordance with 3-2.3. For acceptance, CVN testing shall meet the minimum requirements established in 3-2.3. Specimen thickness shall be the full size (0.394 inch [10 millimeters]) unless sufficient material is not available. In the case where sufficient material is not available, reduced thickness specimens shall be used of as large a size as possible with proportionally small energy requirements. Impact testing using reduced specimen sizes shall require NAVSEA approval. Submissions shall include data and technical justification supporting an appropriated reduction in the minimum energy requirements.

7-5.3 FRACTURE TOUGHNESS. Where fracture toughness testing is required, specimen preparation dimensions and mechanical testing shall be prepared and evaluated in accordance with ASTM E1820. For acceptance, fracture toughness testing shall meet the minimum requirements established in 3-2.3. Specimen thickness shall be 1 inch unless otherwise approved by NAVSEA.

7-5.4 METALLOGRAPHIC SPECIMENS. Metallographic specimens shall be sectioned in the Z and XY orientations relative to the build layers in accordance with ASTM E3 and ASTM E407 (a sample form is provided in Table A-15). The specimen face of each metallographic specimen shall be polished, etched, and examined at a length scale capable of identifying macro level defects, with a magnification between 5× and 10×, and a length scale capable of identifying microstructural attributes, with a 50× minimum magnification. Image size shall be the appropriate field of view for the magnification in use. For acceptance, metallographic specimens shall be free of any cracks and meet the minimum requirements established in accordance with 3-2.3. Test reports shall include all of the information analyzed in 7-5.4.1.

7-5.4.1 Metallographic Features. Metallographic specimens shall be evaluated for the following features:

a. For porosity: maximum size, average size, size distribution, quantity, locational distribution, shape(s), and type(s) (e.g., lack of fusion, keyhole porosity, gas porosity).
b. Cracking.
c. Microstructural phases.
d. Grain structure and grain size, where applicable (see ASTM E112).
e. Any other discontinuities present.

7-5.5 HARDNESS TEST. Hardness specimens shall be prepared and evaluated in accordance with ASTM E10, ASTM E18, or ASTM E92 (a sample form is provided in Table A-16). Hardness testing shall be performed in the Z and XY planes. A minimum of ten indentations shall be made per specimen. For acceptance, hardness testing shall meet the minimum requirements established in accordance with 3-2.3.

7-5.6 CHEMISTRY. For acceptance, the chemical composition of an as-built specimen shall be tested and meet the requirements established in accordance with 3-2.3. Specimens shall be analyzed in accordance with a standard ASTM method or a method shall be provided that will ensure equally accurate results for conformance to the chemistry requirements. The range over which the chemical analysis test methods can be shown to be accurate for the particular element shall be reported. The accuracy and precision of the chemical analysis method(s) used for each element being analyzed shall be provided.

7-5.7 SPECIAL TESTS. When tests, such as explosion-bulge, dynamic tear, and other tests not detailed in this document are required in part verification testing, these tests will be specified by NAVSEA and information as to methods and guidance for performance of the required test and acceptance criteria will be provided at that time.

CHAPTER 8
ACQUISITION

8-1 SCOPE.

This chapter is intended to provide the general requirements for acquisition of PBF parts.

8-2 ACQUISITION REQUIREMENTS.

Acquisition documents shall specify the following, in addition to any additional requirements listed in the fabrication document, if applicable:

a. Title, number, and date of this document.
b. When part verification testing is not required in accordance with approval received by NAVSEA.
c. If virgin material is required.
d. Dimensions of non-standard tensile test specimens.
e. Any special packaging requirements.

8-3 PART VERIFICATION.

The contracting officer shall include specific instructions in acquisition documents regarding arrangements for examinations and disposition of part verification builds. Invitations for bids should provide that the Government reserves the right to waive the requirement for samples for first inspection to those bidders offering a product that has been previously acquired or tested by the Government, and that bidders offering such products who wish to rely on production or test must furnish evidence with the bid that prior Government approval is presently appropriate for the pending contract.

8-3.1 NEW VENDORS. Prior to delivery, the contracting officer shall ensure that activities that have not previously supplied products as described in this manual demonstrate to NAVSEA that their facilities produce products conforming to the requirements of this manual.

8-4 PREPARATION FOR PACKAGING AND PACKING.

Preparation for packaging and packing shall be as follows:

a. Part(s) shall be clean and free of foreign matter.
b. Part(s) shall be segregated as to composition.

8-4.1 PACKAGING, PACKING, AND MARKING FOR SHIPMENT. Unless additional requirements are specified by the purchaser, part(s) shall be prepared for shipment in accordance with commercial practice to ensure delivery of part(s) in full compliance with this manual. The level of packaging and marking for shipment shall meet the requirements of carrier rules and regulations applicable to the mode of transportation.

8-4.2 PACKAGING BY DOD PERSONNEL. When actual packaging of parts is to be performed by DoD personnel, these personnel need to contact the responsible packaging activity to ascertain requisite packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activity within the Military Department of Defense Agency, or within the Military Department's System Command. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

APPENDIX A
ASSOCIATED TABLES

Table A-1. Essential Elements of the PBF Procedure

Element	Laser	Electron Beam
Powder feedstock: Chemistry, size distribution	X	X
Powder feedstock production process: Powder production process (e.g., atomization, plasma rotating electrode), gas used during process (e.g., argon, nitrogen), gas used during packaging	X	X
Build plate material: Specification, chemistry, temper, minimum thickness	X	X
Build plate reconditioning	X	X
Machine: Manufacturer, model, machine serial number, energy source, machine software version, build file processing software and version, machine subsystems	X	X
Recoater: Material and type	X	X
Preheat temperature	X	--
Start temperature	--	X
Powder deposition parameters: Recoater speed, powder dosage parameters	X	X
Laser parameters: Programmed power, focus position, pulse characteristics, spot shape, spot size, beam waist, power-spot size distribution	X	--
Electron beam parameters: Accelerating voltage, beam current, focus position, deflection profile, amplitude, frequency, spot shape, spot size	--	X

Table A-1. Essential Elements of the PBF Procedure – Continued

Element	Laser	Electron Beam
Digital files: CAD files, slice files, build files	X	X
Environment, purge shielding, and in-process shielding: Composition, pressure, purity, dew point, flow rate, oxygen concentration, mixture	X	X
Post-build processing: Heat treatment, hot isostatic pressing, chemical processing, surface finishing	X	X
Fill scan parameters: Type (e.g., hexagonal, collinear), overlap or width, speed, hatch distance, beam offset	X	X
Edge scan parameters: Type (e.g., hexagonal, collinear), overlap or width, speed, hatch distance, beam offset	X	X
Scan parameters (electron beam): Speed function, multi-spot parameters (number of spots, spot time, current)	--	X
Presintering parameters (electron beam): Presintering temperature, beam speed, beam offset, scan strategy, number of presintering passes	--	X
Layer height	X	X

Table A-2. Powder Testing for PBF Procedure Qualification

Test Type	Number of Tests
Chemistry	1
Size distribution	3
Apparent density	3
Tap density	3

Table A-3. Destructive Testing for PBF Procedure Qualification

Printed Coupon Thickness	Surface Finish	Type	Quantity			
			Specimen Longitudinal Orientation			Total
			Z	X or Y	40 to 55 degrees	
Min ¼ inch	Machined	Tensile	24	24	12	60
		Charpy V-notch	12	12	--	24
		Fracture toughness	9	9	--	18
		Metallographic	6	6	--	12
		Hardness	--			6
		Chemistry	--			3

Table A-4. Destructive Testing Figure Reference

Specimen Type	Surface Finish	Figure	Notes
Tensile	Machined	Figure B-1	Shows examples of specimen orientations and acceptable extractions from coupons
Charpy V-notch	Machined	Figure B-2	Shows examples of specimen orientations and acceptable extractions from coupons

Table A-5. Non-Pressure Containing Parts in Machinery [4/]

Category	Application Rules	Stress Due to	Stress Level, Percent of Yield	NDT Requirements			Sub-Category
				Volumetric [3/]	MT/PT	VT	
A [1/]	Parts that, by failure of any one build, would prevent steering, diving, or propulsion with no standby capability	Dynamic loads [2/]	All	X [1/]	X [1/]	X	A1
		High-impact shock grade A	>⅔	X	X	X	A2
			≤⅔	--	X	X	A3
B	Parts that, by failure of any one build, would reduce the capability of the ship to launch, land, or transfer aircraft between flight and hangar decks	Dynamic loads [2/]	All	X	X	X	B1
		High-impact shock grade A	>⅔	X	X	X	B2
			≤⅔	--	X	X	B3
C	Parts for weapons handling systems that, by failure of any build, would result in dropping or damaging a weapon or result in reduction of weapons service to any space, launcher, or aircraft by 50% or more	Dynamic loads [2/]	All	X	X	X	C1
		High-impact shock grade A	>⅔	X	X	X	C2
			≤⅔	--	X	X	C3
The following requirements apply to all builds not covered in categories A, B, or C above:							
Machinery Classification	**Category**	**Stress Due to**	**Stress Level, Percent of Yield**	**NDT Requirements**			**Sub-Category**
				Volumetric [3/]	**MT/PT**	**VT**	
M-PBF-1	A	All	All	Each build, 100%	X	X	E1
	B	All	All	Each build, 100%	X	X	E2
	C	All	All	--	--	X	E3
M-PBF-2	A	All	All	Each build, 100%	X	X	F1
	B	All	All	--	X	X	F2
	C	All	All	--	--	X	F3

Table A-5. Non-Pressure Containing Parts in Machinery – Continued

NOTES:

1/ Ship propellers shall be subjected to VT with PT used only as an aid in locating discontinuities as specified in MIL-STD-2035. RT shall be performed on practicably inspectable areas in accordance with a plan approved by NAVSEA. Critical areas not inspectable by RT shall be subject to UT in accordance with 7-4.5 with coverage to be approved by NAVSEA.

2/ For purposes of clarification, parts stressed by dynamic loads are parts with areas that are designed for normal-service dynamic loads of a degree and frequency. Such loads are used in the strength equations that determine dimensions of the area (note that high-impact shock is not a dynamic load for purposes of this rule).

3/ RT shall be performed in a minimum of two perpendicular directions. UT, where approved by NAVSEA, shall be in accordance with 7-4.5.

4/ In the event of a conflict in NDT requirements between this table, the ship specifications, the part specification, or other document, the more stringent NDT requirements shall be invoked.

Table A-6. Inspection for Pressurized Machinery and Pressure Vessels

Application	Pressure [1/] (lb/in^2)	Size [2/] (inches)	NDT Requirements					Sub-Category
			Volumetric [6/]	Extent	MT/PT	Pressure [3/]	VT	
Lethal or gasoline service	All	All	X	Each part, 100%	X	X	X	A
Oxygen or hydrogen service	All	All	X	Each part, 100%	X	X	X	B
Steam service	≥300	≥½	X	Each part, 100%	X	X	X	C1
	<300	≥2½	X	--	X	X	X	C2
		½ to 2½	X	--	X	X	X	C3
		<½	X	--	X	X	X	C4
Gas (other than lethal, oxygen, or hydrogen) [5/] Water or hydraulic service [5/]	≥1,000	≥2½ [4/]	X	Each part, 100%	X	X	X	D
	300 to 1,000	≥2½ [4/]	X	Each part, 100%	X	X	X	E
Special shipboard systems: Weapon service – all ships: Parts for weapons handling systems	All	All	X	Each part, 100%	X	X	X	F
Submarine service: a. Parts associated with hull boundary and subject to submergence pressure	All	All	X	Each part, 100%	X	X	X	G1
b. Parts in sea-connected systems from the inboard flange of the backup valve outboard to the hull	All	All	X	Each part, 100%	X	X	X	G2

Table A-6. Inspection for Pressurized Machinery and Pressure Vessels – Continued

Application	Pressure [1/] (lb/in^2)	Size [2/] (inches)	NDT Requirements					Sub-Category
			Volumetric [6/]	Extent	MT/PT	Pressure [3/]	VT	
c. Parts in sea-connected systems inboard of the backup valve that are open to the sea below 200 ft submergence depth during any mode of operation	All	For sizes ≥4, see [7/]. For sizes <4 not RT inspected in accordance with [7/], see [8/].	X	Each part, 100%	X	X	X	G3
Aircraft carrier service: Parts, the failure of which would reduce the capability to launch, land, or transfer aircraft between the flight and hangar decks	All	≥2½	X	Each part, 100%	X	X	X	H
Parts for normal steering systems	All	≥2½	X	Each part, 100%	X	X	X	I
Class A-PBF-F, A-PBF-1, A-PBF-2, A-PBF-LT, and A-PBF-3 parts, excluding parts in categories A through I	Temperature and pressure in accordance with class definitions	≥2½	X	Each part, 100%	X	X	X	J1
		½ to <2½	X	--	X	X	X	J2
		<½	X	--	--	X	X	J3
For parts not covered by categories A through J, including parts in surface ship sea-connected systems below the V lines not isolatable from the sea and all refrigerant systems of 50-lb/in^2 design pressure and greater	All	≥2½	X	--	--	X	X	K
Parts not covered above (e.g., generic class A-PBF-4 <2.5)	All	All	X	--	--	X	X	L

Table A-6. Inspection for Pressurized Machinery and Pressure Vessels – Continued

FOOTNOTES:

1/ "Pressure" is the design pressure of the system in which the part is used.

2/ For machinery and pressure vessel parts, the size shown is the inside diameter (or an equivalent cross-sectional area).

3/ Refer to the applicable system or part specifications for pressure test requirements. Pressure tests shall be conducted on uncoated parts.

4/ For hydraulic parts with cylindrical datum features, the size is the largest diameter subject to normal operating pressure. For parts with non-cylindrical datum features, the size shall be the largest dimension of the largest cross-sectional area subject to normal operation pressure.

5/ Also excluding special shipboard system categories.

6/ RT shall be performed in a minimum of two perpendicular directions. UT, where approved by NAVSEA, shall be in accordance with 7-4.5.

7/ Parts of sizes less than 4 inches shall be RT inspected where their failure would result in the loss of propulsion power due to lack of cooling water necessitated by the closing of the hull and back-up valves in the main seawater system for the purpose of isolating defective parts.

8/ Parts of sizes less than 4 inches that are not RT inspected in accordance with footnote 7 shall be inspected in accordance with category J1, J2, J3, K, or L, as applicable.

NOTE:

1. In the event of a conflict in NDT requirements within this table or between this table, the ship specifications, the part specification, or other document, the more stringent NDT requirements shall be invoked.

Table A-7. Class P Piping Part Inspection Requirements

Piping Class	Design Pressure (lb/in^2) [1/]	Pipe Size, (inches nps) [2/]	Required Examinations and Tests [3/]					Category
			VT	MT/PT	Volumetric [4/]		Pressure	
			Final Part	Final Part [5/]	Final Part	Extent		
Lethal or gasoline	All	All	X	X	X	Every part, 100%	X	A
Oxygen or hydrogen service	≥100 [6/]	≥½ [7/]	X	X	X	Every part, 100%	X	B
Steam service	≥300	≥½ [7/]	X	X	X	Every part, 100%	X	C
Submarine service: [8/] a. Parts associated with pressure hull boundary and subject to submergence pressure	All	All	X	X	X	Every part, 100%	X	D1
b. Parts in sea-connected systems from the inboard flange of the backup valve outboard to the hull	All	All	X	X	X	Every part, 100%	X	D2
c. Parts in sea-connected systems inboard of the backup valve that are open to the sea below 200 ft submergence depth during any mode of operation	All	For sizes ≥4, see [9/]. For sizes not RT inspected in accordance with [9/], see [10/]	X	X	X	Every part, 100%	X	D3

Table A-7. Class P Piping Part Inspection Requirements - Continued

Piping Class	Design Pressure (lb/in^2) [1/]	Pipe Size, (inches nps) [2/]	Required Examinations and Tests [3/]					Category
			VT	MT/PT	Volumetric [4/]		Pressure	
			Final Part	Final Part [5/]	Final Part	Extent		
P-PBF-1, other than categories A through D-3	>3,400	1 and > [11/]	X	X	X	Every part, 100%	X	E1
	300 through 3,400, and all if T >650 °F	≥2½	X	X	X	Every part, 100%	X	E2
	300 through 3,400, and all if T >650 °F	½ to 2½	X	X	X	[12/]	X	E3
	300 through 3,400, and all if T >650 °F	<½	X	X	X	--	X	E4
Class P-PBF-2 and P-PBF-3: a. Steam service	All, excluding drains	≥2½	X	--	X	--	X	F1
		½ to 2½	X	--	X	--	--	F2
		<½	X	--	--	--	X	F3
b. Surface ship sea-connected piping parts below the V lines not isolatable from the sea	All	≥2½	X	--	X	--	X	F4

Table A-7. Class P Piping Part Inspection Requirements - Continued

Piping Class	Design Pressure (lb/in^2) [1/]	Pipe Size, (inches nps) [2/]	Required Examinations and Tests [3/]					Category
			VT	MT/PT	Volumetric [4/]		Pressure	
			Final Part	Final Part [5/]	Final Part	Extent		
c. Refrigerant	50 and above	≥2½	X	--	X	--	X	F5
d. P-PBF-2 and P-PBF-3 other than listed above	All	All	X	--	X	--	X	F6
P-PBF-LT	All	[13/]	[13]	[13]	[13]	[13]	[13]	G

FOOTNOTES:

[1/] "Pressure" is the design pressure of the system in which the part is used.

[2/] The size shown is nominal pipe size (nps).

[3/] In the event of a conflict in NDT requirements within this table or between this table, the ship specifications, the part specification, or other document, the more stringent NDT requirements shall be invoked.

[4/] RT shall be performed in a minimum of two perpendicular directions. Where approved by NAVSEA, UT shall be in accordance with 7-4.5.

[5/] The outer surface and, when accessible, the inner surface shall be MT/PT inspected, and the inspection shall be performed after machining operations. When post-weld heat treatment or stress relief is performed, this inspection shall be accomplished after heat treatment or stress relief.

[6/] For lower maximum design pressures, inspect in accordance with category E3 for all sizes ½ inch and greater.

[7/] For smaller sizes, inspect in accordance with category E4.

[8/] RT of PBF valve discs and balls that form a part of the hull boundary where failure could permit direct flooding inside the ship shall be the same as for other parts of the category involved; for discs and balls not meeting this criteria, RT shall be in accordance with footnotes 17 and 4 and, when specifically approved by NAVSEA, footnote 4 RT may be omitted for identified sizes and applications.

[9/] Parts of sizes less than 4 inches shall be RT inspected where their failure would result in the loss of propulsion power due to lack of cooling water necessitated by the closing of the hull and back-up valves in the main seawater system for the purpose of isolating defective parts.

[10/] For sizes less than 4, inspection shall be in accordance with category E1, E2, E3, or E4, as applicable, except for pressures and temperatures less than 300 lb/in^2 and less than 650 °F (that are not P-PBF-LT) where inspection shall be the same as F1, F2, or F3 for equivalent sizes.

[11/] For smaller sizes, inspection shall be in accordance with category E3 or E4, as applicable.

(Footnotes continued on next page.)

Table A-7. Class P Piping Part Inspection Requirements – Continued

FOOTNOTES (continued):

12/ (a) Refer to the applicable system or part specifications for testing requirements. Testing shall be conducted on uncoated parts after final machining and thermomechanical processing. Where the part specification does not explicitly address parts produced by AM and where each part is planned to not receive the pressure test for time and pressure generally specified, prior NAVSEA approval of full pressure testing details shall be obtained.
(b) For repairs to builds that have passed a hydrostatic test, hydrostatic re-testing is not required where repairs do not exceed $\frac{3}{16}$ inch or 20 percent of the thickness at the repair location, whichever is less. This exception does not apply if the repair weld is subjected to post-weld heat treatment.

13/ Inspection for class P-PBF-LT shall be the same as categories E2, E3, or E4 based on equivalent sizes.

NOTES:

1. An "X" indicates that the test is required.
2. For hydraulic systems and water systems with a maximum design temperature of 120 °F, RT is required only when the design pressure exceeds 600 lb/in^2.

Table A-8. Production Conformance Testing

Specimen Type	Quantity	Frequency
Tensile	2	Every production build
Metallographic	1	Every production build
Chemistry	1	Every production build

Table A-9. Sample Form: PBF Procedure

General

PBF Procedure ID _____

Activity _____ Site _____

Approver Name _____

Approver Signature _____ Date _____

Quality Assurance Plan ID _____ Revision _____

Process Control Plan ID _____ Revision _____

Material Acceptance

(check one)

_____Existing Design

Specification _____ Alloy _____ Product Form _____

Other Information _____

_____New Design

Other Information _____

_____OEM Properties

Table A-9. Sample Form: PBF Procedure – Continued

OEM _____ Relevant Equipment Make/Model _____

Specification _____ Alloy _____

Other Information _____

Build Layout A

Procedure Qualification Build ID: _____ Build File ID: _____

Planned Interruption?: _____ Slice File ID: _____

View 1	View 2	View 3

Specimen List for Build Layout A

Specimen ID	CAD File Name	Test Type	Post-Processing ID

Table A-9. Sample Form: PBF Procedure – Continued

Build Layout B

Procedure Qualification Build Supplemental ID: _____ Build File ID: _____

Planned Interruption?: _____ Slice File ID: _____

View 1	View 2	View 3

Specimen List for Build Layout B

Specimen ID	CAD File Name	Test Type	Post-Processing ID

Table A-9. Sample Form: PBF Procedure – Continued

Build Plate and Powder Feedstock

Build Plate Chemistry and Temper _____ Build Plate Thickness _____

Build Plate Specification _____

Build Plate Cleaning _____

Powder Feedstock Specification _____ Powder Lot _____

Powder Manufacturer _____

Powder Production Process _____

Gas Used During Production _____ Gas Used for Packaging _____

Machine and Software

Manufacturer _____ Model _____

Machine Serial Number _____

Machine Operation Software Name _____ Version _____

Build File Processing Software Name _____ Version _____

Other Name _____ Version _____

Table A-9. Sample Form: PBF Procedure – Continued

Recoater Type and Material _____

Energy Source (Laser(s))

Laser Manufacturer and Model _____ Date of Last Laser Calibration _____

Laser Serial Number _____

Laser Power _____ Laser Fiber Diameter _____

Laser Pulse Characteristics _____ Laser Current _____

Laser Beam Offset _____

Energy Source (Electron Beam)

Electron Gun Manufacturer and Model _____ Date of Last Electron Beam Calibration _____

Electron Gun Serial Number _____ Beam Spot Size at Last Calibration _____

Electron Beam Power _____

Table A-9. Sample Form: PBF Procedure – Continued

Electron Beam Accelerating Voltage _____

Electron Beam Current _____

Electron Beam Deflection Profile _____

Electron Beam Amplitude _____

Electron Beam Frequency _____

Electron Beam Focus Position _____

Shielding

Purge Shielding Gas Type and Grade _____

Purge Shielding Gas Dew Point _____

Build Chamber Oxygen Concentration Set Point _____

Recirculation Gas Flow Rate _____

Continuous Recirculation? _____

Supplemental Gas Type and Grade _____

Supplemental Gas Flow Rate _____

Table A-9. Sample Form: PBF Procedure – Continued

Laser PBF Build Parameters (complete separately for parameters specific to fill, edge, etc.)

Parameter Set ID _____ Description (fill ,edge, etc.) _____

Parameter Set Material _____

Layer Height _____

Recoater Travel Speed _____

Laser Power _____ Build Plate Preheat Temperature _____

Beam Spot Size _____ Raster Pattern Type _____

Beam Offset _____ Overlap Distance _____

Beam Travel Speed _____ Beam Profile _____

Focal Length _____ Beam Orientation _____

Table A-9. Sample Form: PBF Procedure – Continued

Electron Beam PBF Presintering Parameters (complete separately for parameters specific to different presintering processes)

Parameter Set ID _____ Description (Preheat 1, 2, etc.) _____

Parameter Set Material _____

Layer Height _____

Recoater Travel Speed _____

Start Temperature _____

Size of Scale _____ Focus Offset _____

Average Current _____ Max Current _____

Beam Speed _____ Number of Repetitions _____

Offset to Part _____

Table A-9. Sample Form: PBF Procedure – Continued

Electron Beam PBF Build Parameters (complete separately for parameters specific to fill, edge, etc.)

Parameter Set ID _____

Description (fill, edge, etc.)
_____

Parameter Set Material _____

Layer Height _____

Recoater Travel Speed _____

Start Temperature _____

Number of Contours _____

Multispot Parameters:

Speed Function _____

Number of Spots
_____

Max Current _____

Spot Time
_____

Focus Offset _____

Beam Current
_____

Hatch Distance _____

Table A-9. Sample Form: PBF Procedure – Continued

Post Processing

Post-Processing ID _____

Powder Removal System (PRS) _____

Heat Treatment Time and Temperature _____

Heat Treatment Atmosphere _____

Hot Isostatic Pressing (HIP) Time, Temperature, and Pressure _____

HIP Atmosphere _____

Surface Finish Method _____

Other Post-Processing _____

Table A-10. Sample Form: Powder Size Distribution and Morphology Results

Powder Lot:					
Testing Standard:					
Sample Extraction Date and Time	**Test Date and Time**	**D10**	**D50**	**D90**	**Notes**

Table A-11. Sample Form: Powder Density Testing Results

Powder Lot:			
Testing Standard:			
Sample Extraction Date and Time	**Test Date and Time**	**Results**	**Notes**

Table A-12. Sample Form: Tensile Test Results

Test Date:											
Testing Standard:											
Specimen ID	**Specimen Orientation**	**Specimen Location**	**Width**	**Thickness**	**Area**	**Yield Strength**	**Ultimate Strength**	**Strain at Failure**	**Failure Type**	**Failure Location**	**%Elongation**

Table A-13. Sample Form: Charpy V-Notch Test Results

Test Date:					
Testing Standard:					
Specimen ID	**Specimen Orientation**	**Specimen Location**	**Test Temperature**	**Absorbed Energy**	**Notes**

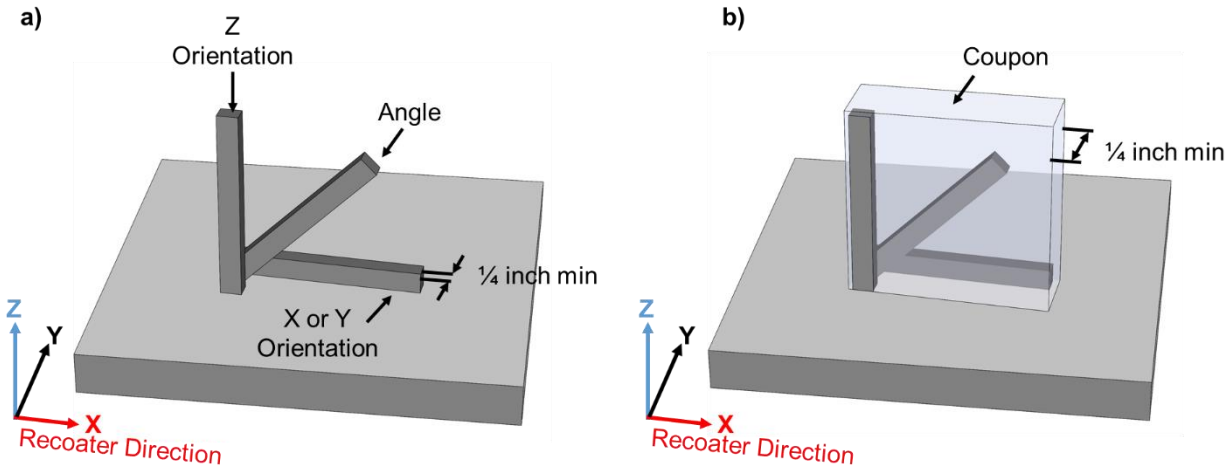
Table A-14. Sample Form: Metallographic Test Results

Test Date:				
Testing Standard:				
Specimen ID	**Specimen Orientation**	**Specimen Location**	**Results**	**Notes**

Table A-15. Sample Form: Hardness Test Results

Test Date:				
Testing Standard:				
Specimen ID	**Specimen Orientation**	**Specimen Location**	**Hardness**	**Notes**

APPENDIX B
ASSOCIATED ILLUSTRATIONS

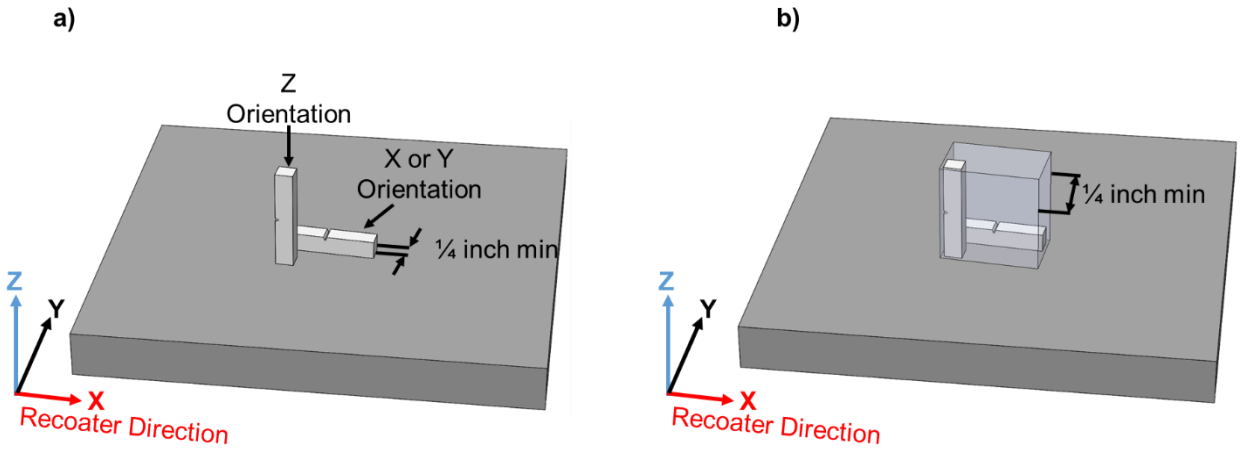


NOTES:

a) ¼-inch minimum thickness coupons in each specimen orientation.

b) ¼-inch minimum thickness wall coupon showing specimen extraction orientations.

Figure B-1. Tensile Specimen Orientations and Extraction for Machining (Examples)



NOTES:

a) ¼-inch minimum thickness coupons in each specimen orientation.

b) ¼-inch minimum thickness wall coupon showing specimen extraction orientations.

Figure B-2. Charpy V-Notch Specimen Orientations and Extraction for Machining (Examples)

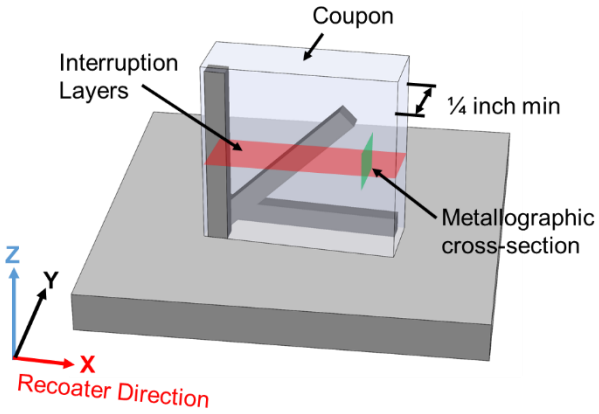
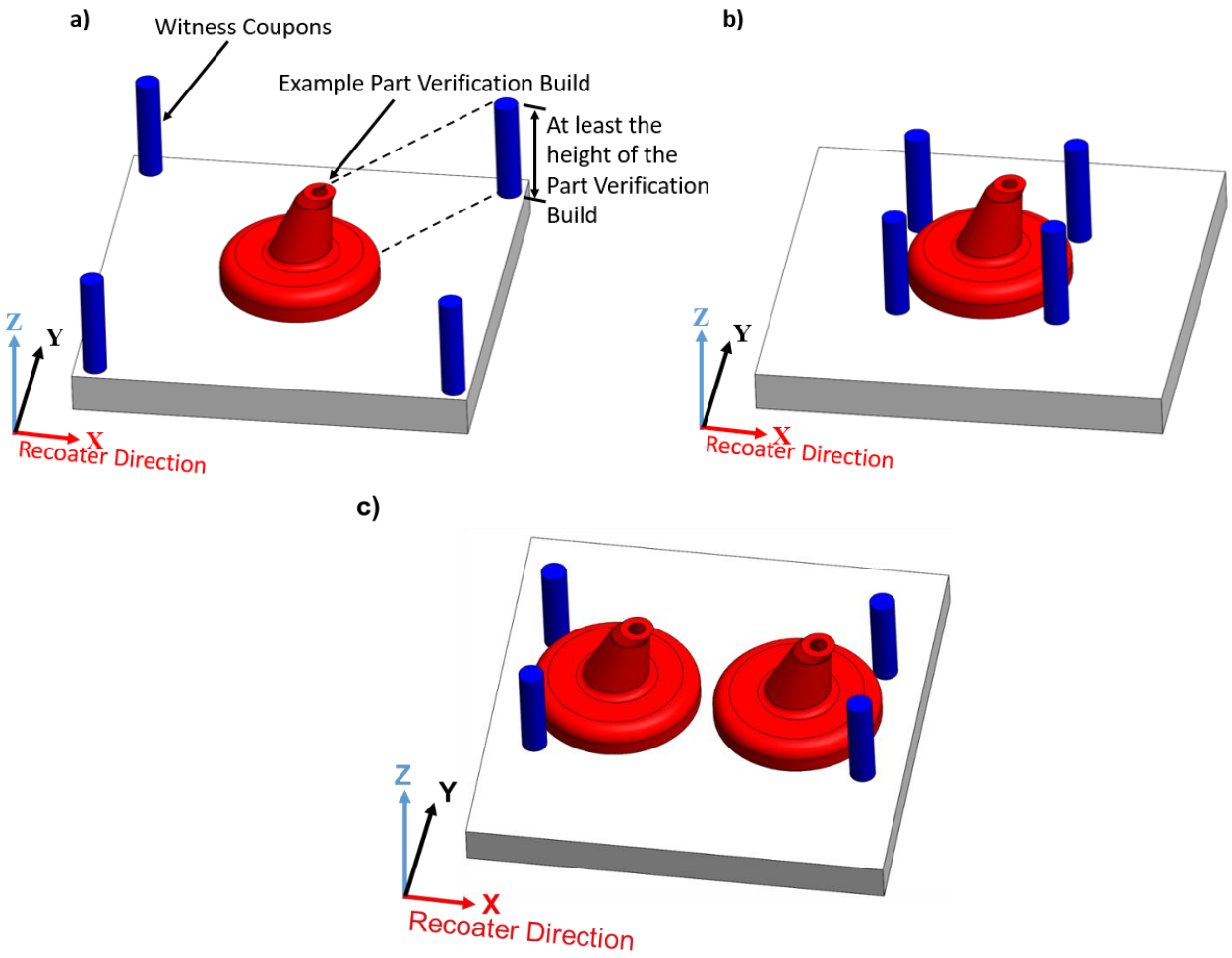


Figure B-3. Example of Destructive Testing Orientations in Build Interruption (Example)



NOTES:

a) Witness coupons at extreme edges of build plate.

b) Witness coupons near parts.

c) Witness coupons near parts.

Figure B-4. Witness Coupon Locations on Part Verification Builds (Examples)

Ref: NAVSEAINST 4160.3 NAVSEA S0005-AA-PRO-010/TMMP

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