THE NRC STAFF HAS PREPARED THIS DRAFT DOCUMENT AND IS RELEASING IT TO SUPPORT THE SEPTEMBER 8, 2021, PUBLIC WEBINAR ON DRAFT GUIDELINES FOR ADVANCED MANUFACTURING TECHNOLOGIES. THIS DRAFT DOCUMENT IS SUBJECT TO CHANGE AND ITS CONTENT SHOULD NOT BE INTERPRETED AS OFFICIAL AGENCY POSITIONS. SUBSEQUENT TO THE PUBLIC WEBINAR, THE NRC STAFF PLANS TO CONTINUE WORKING ON THIS DOCUMENT AND COULD INCORPORATE STAKEHOLDER FEEDBACK RECEIVED AT THE PUBLIC WEBINAR.

Draft Guidelines Document for Additive Manufacturing—Laser Powder Bed Fusion

1. Introduction and Purpose

When finalized, this draft guidelines document (DGD) will provide U.S. Nuclear Regulatory Commission (NRC) staff with guidelines for conducting reviews of submittals that include components manufactured using additive manufacturing—laser powder bed fusion (LPBF). These guidelines are based on the NRC assessment of the safety significance of the identified differences between LPBF and traditional manufacturing methods as documented in "NRC Technical Assessment of Additive Manufacturing—Laser Powder Bed Fusion," (Agencywide Documents Access and Management System (ADAMS) Accession No. ML20351A204) (hereafter, "NRC technical assessment"), which builds on the Oak Ridge National Laboratory's (ORNL's) technical information and gap analysis, "Review of Advanced Manufacturing Techniques and Qualification Processes for Light Water Reactors—Laser Powder Bed Fusion Additive Manufacturing," (ADAMS Accession No. ML20351A217). This document provides LPBF-specific draft guidelines under Subtask 2C, "Action Plan for Advanced Manufacturing Technologies (AMTs)," Revision 1, dated June 23, 2020 (ADAMS Accession No. ML19333B973), as a supplement to the AMT generic guidelines document, "Draft AMT Review Guidelines" (ADAMS Accession No. ML21074A037) (hereafter, "generic guidelines").

When reviewing an AMT submittal, the NRC staff can refer to the generic guidelines once finalized, which can assist the NRC staff's review of a submittal requesting the use of an AMT. The finalized generic guidelines along with this DGD will identify the generic and LPBF-specific information that could be necessary in a submittal in order to provide a timely and efficient review. The NRC technical assessment is also available for additional background and technical information to support the review of a submittal.

2. Brief Description of the NRC Technical Assessment of Laser Powder Bed Fusion

The purpose of this section is to describe the NRC technical assessment of LPBF, which provides the technical basis for the technical review guidelines described in this DGD. The primary objective of the NRC technical assessment is to describe the differences between an LPBF-fabricated component and a traditionally manufactured component, assess the safety significance of the identified differences, and identify relevant technical information pertaining to these differences for LPBF-fabricated components. This DGD is intended to build on the NRC technical assessment and provide guidelines, when finalized, to the NRC staff by identifying important considerations when reviewing a submittal requesting the use of LPBF.

An important note should be made with regard to discussions of safety significance in both the NRC technical assessment and this LPBF DGD. The safety significance of each identified difference in the context of these documents refers to the impact on component performance. The overall impact to plant safety is a function of component performance and the specific component application (e.g., its intended safety function). These reports do not address the impact on plant safety, as such an assessment would not be possible without considering a specific component application. In addition to the technical review guidelines in this document, the NRC staff should consider the specific component application and the potential for secondary consequences, such as debris generation and associated impacts, when assessing the impact to overall plant safety.

As discussed in the NRC technical assessment, the NRC staff identified the differences between AMT and traditional manufacturing processes by reviewing the information and gap analysis rankings from the ORNL report, as well as other relevant technical information (e.g., NRC regulatory and research experience, technical meetings and conferences, codes and standards activities, Electric Power Research Institute and U.S. Department of Energy products and activities).

3. NRC Generic Guidelines for Advanced Manufacturing Technologies and Laser Powder Bed Fusion-Specific Guidelines

The finalized generic guidelines will identify the information that could be necessary in a submittal to ensure a timely and efficient review. Appendix A to the generic guidelines identifies the five primary topics to be addressed in a submittal:

(1) Quality Assurance (QA): process followed during the manufacture and implementation of AMTs to ensure adherence to QA requirements (e.g., Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic licensing of production and utilization facilities," Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants"), established methods (e.g., commercial-grade dedication), or both

(2) Process Qualification: steps taken to demonstrate that the component will be produced with characteristics that will meet the intended design requirements

(3) Supplemental Testing: testing conducted to demonstrate that those material and component properties required to meet the design requirements are acceptable in the applicable service environmental conditions, and thus the performance of the component in service will be acceptable

(4) Production Process Control and Verification: steps taken to ensure that each component will be produced in accordance with the qualified process and, if the production process fails to meet the qualification essential variables, the steps taken to reestablish the qualified process

(5) Performance Monitoring: actions taken to provide assurance that the component will continue to meet its design requirements until the end of its intended service life

Table 1 includes the identified differences between LPBF and traditional manufacturing outlined in the NRC technical assessment (both generic and 316L material specific) and identifies those primary elements from Appendix A to the generic guidelines that are expected to be most commonly applicable to each of the differences. However, the applicable primary elements may vary on a case-by-case basis, depending on the licensee's approach to demonstrating quality and safety. Therefore, this table provides an example of applicable elements and reflects that not every element in Appendix A to the generic guidelines is applicable to every difference listed in Table 1.

QA comprises all those planned and systematic actions necessary to provide adequate confidence that a system or component will perform satisfactorily in service. QA processes implemented during the manufacture and implementation of AMTs ensure that QA requirements (e.g., 10 CFR Part 50, Appendix B), established methods (e.g., commercial-grade dedication), or both, have been satisfied. For AMTs, a QA program will specifically address novel or unique aspects of manufacturing or implementation specific to the AMT. Therefore, Table 1 does not explicitly include QA as a distinct column, but QA is applicable to each of the differences between traditional manufacturing and LPBF processes identified in the table and achieved through successful performance of the other four Appendix A items: process qualification, supplemental testing, production process control and verification, and performance monitoring.

Tables 2A and 2B provide the technical review guidelines. Table 2A lists the generic differences between traditional manufacturing and LPBF. Table 2B lists the material-specific differences between traditional manufacturing and LPBF 316L stainless steel. 316L is the alloy relevant to LPBF-fabricated nuclear applications with the most information currently available in the open literature. While Table 2B is also based on the available information in the open literature for 316L, the differences identified in Table 2B involving material-specific properties and performance would likely need to be considered for any newly fabricated material using LPBF. In general, material-specific data for the proposed processing and post-processing parameters are important for any nuclear LPBF-fabricated component to ensure adequate component performance in the applicable environment, including properties (e.g., fracture toughness, tensile strength) and resistance to aging mechanisms (e.g., thermal aging, irradiation effects, and stress corrosion cracking (SCC)).

Tables 2A and 2B provide technical review guidelines related to the differences for the LPBF process and component performance through the following columns:

- Difference: identifies the differences between LPBF and traditional manufacturing outlined in the NRC technical assessment

- Key Technical Information: summarizes the key technical information documented in the NRC technical assessment for easy reference

- Technical Review Guidelines: provides additional guidelines related to the differences between LPBF and traditional manufacturing that the staff should consider when evaluating how a licensee's or applicant's submittal addresses the differences between LPBF and traditional manufacturing

Table 1. Relevant Elements from Appendix A to the Generic Guidelines

Difference	Process Qualification	Supplemental Testing	Production Process Control and Verification	Performance Monitoring
LPBF machine process control	X		X	
Powder quality	X		X	
LPBF build process management and control	X		X	
Witness specimens	X		X	
Post-processing	X		X	
Local geometry impacts on component properties and performance	X	X		
Heterogeneity and anisotropy in properties	X	X		
Residual stress	X	X		
Porosity	X	X		
Surface finish	X	X		
Tensile properties	X	X		
Initial fracture toughness	X	X		
Thermal aging		X		X
SCC		X		X
Fatigue		X		X
Irradiation effects		X		X
High Temperature Time-Dependent Aging Effects (e.g., Creep and Creep-Fatigue)		X		X

Weld integrity		X		X
Weldability/joining	X		X	

Table 2A. Technical Information and Review Guidelines—LPBF Generic

Difference	Key Technical Information	Technical Review Guidelines
LPBF machine process control	• Careful control of LPBF file preparation is needed to ensure process control. Improper file control can significantly impact final component properties and performance and affect fabrication replication. • Machine calibration is vital for fabrication replication, particularly contamination minimization when recycling powder, ensuring correct laser power and beam shape, and ensuring atmospheric quality control in addition to geometric tolerances.	**Process Qualification** • The applicant should identify the essential variables related to LPBF machine process control and demonstrate that controlling these variables within identified ranges will ensure reliable, adequate, and repeatable component properties and performance. • At a minimum, the process qualification should consider the following essential variables: o software file preparation (e.g., LPBF software version, and LPBF software settings) o calibration of LPBF machine and subsystems (e.g., build stage, powder hopper, laser optics, atmosphere control) • The applicant should identify additional specific essential variables and their ranges as appropriate. **Production Process Control and Verification** • During production, the applicant should demonstrate that process control and verification will maintain the production process within the qualified essential variable ranges. • One possible approach for machine process control that the applicant can use to demonstrate process control and verification is periodic machine calibration verification.
Powder quality	• Powder contamination is a critical issue that may adversely affect material properties and process by introducing oxides and changing chemical composition. • Powder should always be sieved before using because unsieved powder may not be representative of composition, as elemental composition and phases may	**Process Qualification** • Through process qualification, the applicant should provide sufficient data to identify the essential variables related to powder quality and demonstrate that controlling these variables within identified ranges will ensure reliable and adequate component properties and performance. • At a minimum, the process qualification should consider the following essential variables for powder quality: o chemical composition, including trace elements o powder size and morphology distribution o powder flowability

Difference	Key Technical Information	Technical Review Guidelines
	not be uniformly distributed across the powder size range. • Powder reuse acceptance/rejection depends on routinely sampling and characterizing powder after sieving. The LPBF system, sieving system, and maintenance of inert environment are all important factors that influence the amount of powder reuse that can be done without affecting component performance. • For example, in 316L, silicon and manganese content in the powder can create oxides that have adverse effects on SCC growth rates. Consideration should be given to oxide content in powder acceptance (virgin and recycled) criteria.	o acceptance criteria or limits for powder reuse • The applicant should identify additional specific essential variables and their ranges as appropriate. **Production Process Control and Verification** • During production, the applicant should demonstrate that process control and verification will maintain the production process within the qualified essential variable ranges. • The applicant can use a variety of powder quality approaches to demonstrate process control and verification, including, but not limited to, the following: o testing final components on a sampling basis (e.g., witness specimens with demonstration of applicability) o characterizing essential variables by routine sampling after sieving powders before initial use and reuse o implementing procedures to minimize powder contamination during production
LPBF build process management and control	• Build interruptions (planned and unplanned) can have a very significant impact on the quality of the component and should be avoided. • In situ monitoring without feedback control can be used to identify issues in the build process in real time and may be used alone or in conjunction with other approaches to demonstrate process control. • In situ monitoring with feedback control (e.g., reapplying a powder layer, adjusting laser/environmental parameters) is still a developing area of research and should be carefully managed. • While artificial intelligence (AI) is commonly used to flag defects for human review, lack of AI-flagged	**Process Qualification** • The applicant should identify the essential variables related to LPBF build process management and control and demonstrate that controlling these variables will ensure reliable, adequate, and repeatable component properties and performance. • At a minimum, the process qualification should consider defining essential variables with demonstration for the following: o build interruption (e.g., duration, frequency, component location, and geometry) o loss of environmental control (e.g., event time, degree of air ingress). • The applicant should identify additional specific essential variables as appropriate. **Production Process Control and Verification** • The applicant should identify the process control and verification approaches (e.g., in situ monitoring, AI) used during the build process and demonstrate during process qualification how these approaches will ensure that a quality component will be produced. o Due to the lack of maturity of the approach, in situ monitoring with feedback control should be adequately supported with a strong basis on the effectiveness of the approach.

Difference	Key Technical Information	Technical Review Guidelines
	defects should not be interpreted as no existing defects. • One limitation of all build chamber surface monitoring methods is that only the top surface is observed.	• One possible approach the applicant can use to demonstrate build process management and control is to scrap any builds that deviate from the qualified essential variable ranges.

Witness specimens	• The most highly representative test specimens are obtained from end-use component geometries.
	  ○ Geometry impacts, particularly thickness, on witness specimen microstructure and properties should be considered and addressed.
	• Optimal witness specimen parameters (geometry, size, location, spatial orientation, and frequency) depend highly on the end-use component geometry and the goal of the witness testing approach (e.g., monitoring build issues as part of process control or generating representative material properties data as part of process qualification).
	• When sectioning end-use geometries is not feasible, functional evaluations of end-use geometries such as burst tests are recommended in conjunction with simplified witness specimen geometries.
		Process Qualification
		• The applicant should identify the component properties and characteristics for which witness testing will be used to demonstrate process qualification.
		  ○ Component properties and characteristics for which witness testing could be used include various microstructure and material properties (e.g., composition, density, hardness, microstructure, tensile, fatigue, fracture toughness, corrosion testing).
		• The applicant should demonstrate that witness specimens are representative of the end-use component in terms of microstructure and material properties. At a minimum, the applicant should address how the witness specimens consider geometry, size, location, and spatial orientation.
		  ○ One acceptable approach would be to benchmark witness specimen results to end-use component results.
		• The applicant should discuss the witness testing methodology with regard to evaluation technique and frequency.
		Production Process Control and Verification
		• The applicant should discuss how witness testing will be used for process control and verification such that essential variables will be maintained within the qualified ranges during the production process.
		• The applicant can use a variety of witness specimen approaches to demonstrate process control and verification, including, but not limited to, the following:
		  ○ monitoring build issues (e.g., incomplete spreading, delamination, or other events that may result in component rejection)
		  ○ confirming build parameters, such as chemical composition and contamination (e.g., oxides)
		  ○ for location-specific measurements, measuring of materials properties (e.g., strength, hardness), appropriately demonstrating how they are representative of geometry, size, location, and spatial orientation
		  ○ confirming of expected material microstructure and characteristics (e.g., residual stress, porosity, surface finish)

<table>
<tr><th>Difference</th><th>Key Technical Information</th><th>Technical Review Guidelines</th></tr>
<tr><td rowspan="2">Post-processing</td><td rowspan="2">Post-processing heat treatments without HIP generally are designed to provide two benefits—stress relief and annealing—but likely have little impact on porosity or flaws.
Stress-relief heat treatments will primarily reduce residual stresses from the as-built part without otherwise affecting the microstructure or properties.
Annealing heat treatments should greatly reduce or eliminate residual stress as well as coarsen the microstructure (to improve toughness) and reduce heterogeneity in microstructure and properties.
HIP may be beneficial for reducing residual stress, porosity, heterogeneity, and internal cracks, while also coarsening the microstructure (to improve toughness).
For all post-processing approaches, material-specific demonstration is important to identify adequate heat treatment or HIP parameters to achieve desired improvements in microstructure, properties, heterogeneity, porosity, and fabrication flaws.
Other types of post-processing techniques (e.g., machining, shot peening, chemical treatments) can be used to address or improve component performance.
Post-processing may significantly impact considerations related to the other LPBF-specific topics identified in lower rows in the table.</td><td>Process Qualification
For process qualification, the applicant should identify appropriate post-processing techniques for the fabricated component and demonstrate the intended effects of post-processing on the final component.
The applicant should provide sufficient data to identify the essential variables related to post-processing and demonstrate that controlling these variables within identified ranges will ensure reliable and adequate component properties and performance.
At a minimum, the process qualification for post-processing heat treatments should consider the following essential variables for post-processing:
for heat treatment: temperature profile over time, including heating rate, cooling rate, hold time at temperature, and environment during heat treatment
for HIP: temperature and pressure profile over time, including heating rate, cooling rate, hold time at temperature, and environment during heat treatment
The applicant should identify additional specific essential variables as appropriate.</td></tr>
<tr><td>Production Process Control and Verification
During production, the applicant should demonstrate that process control and verification will maintain the production process within the qualified essential variable ranges for post-processing.
The applicant can use a variety of approaches to demonstrate process control and verification, including, but not limited to, the following:
testing final components on a sampling basis (e.g., witness specimens with demonstration of applicability)
validated monitoring of post-processing parameters during heat treatment or HIP process.</td></tr>
</table>

Difference	Key Technical Information	Technical Review Guidelines

Local geometry impacts on component properties and performance	• The role of geometry on local microstructure and properties is one of the key differences between LPBF-produced components and conventionally produced components.
	• Local geometry significantly impacts thermal profiles during fabrication, which affects the local microstructure and properties.
	    ○ For example, a thin section with relatively rapid cooling rates will likely have a much finer microstructure than a thicker section with a slower cooling rate due to more surrounding material being melted.
	    ○ As a result, local material properties such as strength, ductility, and toughness will be affected by the variation in microstructure as a function of geometry.
	• Witness specimens can be used to assess local geometry impacts but should be carefully demonstrated to be applicable to the end-use geometry.
	• Post-processing and scan strategy refinement can potentially minimize the local geometry impacts; however, they can vary significantly based on the geometry and materials used.
	• Varying processing parameters is potentially another method to compensate for the effect of geometry and minimize local geometry impacts. This is a less mature approach.
		Process Qualification
		• Through process qualification, the applicant should provide sufficient data to demonstrate that local geometry impacts on material properties and microstructure will be addressed to ensure reliable and adequate component properties and performance.
		• In the absence of demonstrated post-processing or build scan strategy to minimize or eliminate the local geometry impacts, the applicant needs to use an appropriate sampling methodology during process qualification to quantify the variability in materials properties and ensure adequate performance.
		• The applicant should consider the following key factors affecting local geometry impacts by changing cooling rates and the resulting microstructure and properties:
		    ○ local thickness variation
		    ○ local size or shape
		• The applicant should identify additional specific key factors as appropriate.
		Supplemental Testing
		• The applicant should demonstrate that the local geometry impacts in an LPBF-fabricated component will not unacceptably degrade material properties and performance due to in-service aging.
		    ○ This demonstration should be performed on a sample that is representative of, or bounds, the component's qualified pre-service condition, including post-processing.

Difference	Key Technical Information	Technical Review Guidelines
Heterogeneity and anisotropy in properties	• Heterogeneity generally manifests with different properties in the build direction relative to the other two directions due to the nature of the layer-by-layer build process. This impacts the microstructure and fabrication defect structure and generally creates poorer properties between build layers. • Post-processing with appropriate parameters would be expected to make material properties and performance more homogeneous and similar to conventional forged materials. • For example, in as-fabricated and stress-relieved 316L, the variation in microstructure due to geometry also causes fatigue and SCC cracks to preferentially travel in the build direction should they initiate.	**Process Qualification** • Through process qualification, the applicant should provide sufficient data to demonstrate that heterogeneity and anisotropy in the LPBF build process will be addressed to ensure reliable and adequate component properties and performance. • In the absence of demonstrated post-processing to minimize or eliminate the heterogeneity, the applicant needs to use an appropriate sampling methodology during process qualification to quantify the variability in materials properties and ensure adequate performance. **Supplemental Testing** • The applicant should demonstrate that the heterogeneity and anisotropy in an LPBF-fabricated component will not unacceptably degrade material properties and performance due to in-service aging. o This demonstration should be performed on a sample that is representative of, or bounds, the component's qualified pre-service condition, including post-processing.
Residual stress	• High residual stress may result in warping, cracking, and delamination; however, these events typically can be detected visually. • In addition, residual stress can make the component susceptible to future degradation such as SCC or fatigue from the presence of high tensile residual stress on the surface. • Post-processing with appropriate parameters would be expected to relieve residual stress.	**Process Qualification** • Through process qualification, the applicant should provide sufficient data to demonstrate that residual stress will be addressed to ensure reliable and adequate component properties and performance and prevent unacceptable warping, cracking, and delamination. • Post-processing through heat treatment, HIP, or both, would be expected to address residual stress but should be demonstrated. **Supplemental Testing** • The applicant should address, by testing if necessary, that the residual stresses in an LPBF-fabricated component will not significantly increase the susceptibility to in-service degradation mechanisms, such as SCC or fatigue. o This demonstration should be performed on a sample that is representative of, or bounds, the component's qualified pre-service condition, including post-processing.
Porosity	• Porosity is known to adversely affect fatigue life, SCC, and irradiation-assisted SCC, though the precise quantitative impact depends on	**Process Qualification** • Through process qualification, the applicant should provide sufficient data to demonstrate that porosity will be managed sufficiently to ensure reliable and adequate component properties and performance.

Difference	Key Technical Information	Technical Review Guidelines
	the material and porosity characteristics (e.g., pore density/distribution, pore size, pore morphology, and total void fraction). • Machine parameters and scan strategy refinement have the potential to address porosity concerns; however, they may vary significantly based on the geometry and materials used. • For post-processing, HIP (with appropriate parameters) has been demonstrated to reduce porosity and produce properties more similar to conventionally forged materials.	• Post-processing through heat treatment, HIP, or both, may significantly reduce porosity; the applicant should demonstrate this. • The applicant should consider the following key characteristics of porosity when assessing porosity: o pore density o pore distribution (e.g., location relative to the surface) o pore size o pore morphology o total void fraction • The applicant should identify additional specific characteristics as appropriate.
		Supplemental Testing • The applicant should demonstrate that the porosity in an LPBF-fabricated component will not unacceptably degrade material properties and performance due to in-service aging. o This demonstration should be performed on a sample that is representative of, or bounds, the component's qualified pre-service condition, including post-processing.
Surface finish	• Surface roughness is generally greater in as-built LPBF parts compared to similar forged materials. • Higher surface roughness can lead to reduced fatigue life and reduced corrosion resistance. • Surface finish can be improved by post-processing such as precision machining, or other surface treatment.	Process Qualification • Through process qualification, the applicant should provide sufficient data to demonstrate that surface roughness will be managed sufficiently to ensure reliable and adequate component properties and performance. • Post-processing through precision machining, shot peening, or other surface treatment may be able to significantly reduce surface roughness but should be demonstrated.
		Supplemental Testing • The applicant should demonstrate that the surface finish in an LPBF-fabricated component will not unacceptably degrade material properties and performance due to in-service aging. o This demonstration should be performed on a sample that is representative of, or bounds, the component's qualified pre-service condition, including post-processing.

Table 2B. Technical Information and Review Guidelines—LPBF 316L Material Specific

Difference	Key Technical Information	Technical Review Guidelines

Tensile properties	• Tensile properties for LPBF 316L are generally equal or superior to those of conventional 316L, even in the weaker direction in the as-built condition.
	• High porosity could degrade tensile performance but would likely have a greater impact on other material properties.
		Process Qualification/Supplemental Testing
		• For process qualification and supplemental testing, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments, to show adequate tensile properties for the design of the component.
		  o The corresponding analysis can demonstrate acceptable safety margins using approaches such as the following:
		    ▪ demonstrating equal or superior performance by comparison to tensile properties for conventionally manufactured materials
		    ▪ analyzing design requirements to demonstrate sufficient tensile properties for the component

Initial fracture toughness	• Data in representative environments are important to demonstrate that fracture toughness will be adequate to meet component design assumptions.
	• Post-processing with appropriate parameters would be expected to improve fracture toughness.
		Process Qualification/Supplemental Testing
		• For process qualification and supplemental testing, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments, to show adequate fracture toughness for the intended function of the component.
		  o The corresponding analysis can demonstrate acceptable safety margins using approaches such as the following:
		    ▪ demonstrating equal or superior performance by comparison to fracture toughness for conventionally manufactured materials
		    ▪ analyzing design requirements to demonstrate sufficient fracture toughness for design and flaw evaluation purposes

Thermal aging	• Data in representative environments are important to demonstrate that fracture toughness does not degrade excessively from thermal aging and will be adequate to meet component design assumptions.
	• Post-processing with appropriate parameters would be expected to make material properties and performance more similar to conventional, forged materials.
		Supplemental Testing/Performance Monitoring
		• Through supplemental testing and performance monitoring, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments, to show adequate fracture toughness after thermal aging throughout the service life of the component.
		  o The corresponding analysis can demonstrate acceptable safety margins using approaches such as the following:
		    ▪ demonstrating equal or superior performance by comparison to fracture toughness after thermal aging for conventionally manufactured materials
		    ▪ addressing uncertainties in the data on fracture toughness after thermal aging and the implications to in-service performance through conservative design assumptions, additional margins in analyses, surveillance programs, or additional performance monitoring

Difference	Key Technical Information	Technical Review Guidelines
SCC	• Data in representative environments are important to demonstrate that changes in material performance due to SCC will not be degraded to a greater degree in LPBF materials than forged materials. • Post-processing with appropriate parameters would be expected to make material properties and performance more similar to conventional, forged materials.	**Supplemental Testing/Performance Monitoring** • Through supplemental testing and performance monitoring, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments, to show adequate SCC resistance for the intended function of the component. o The corresponding analysis can demonstrate acceptable safety margins by using approaches such as the following: ▪ demonstrating equal or superior performance by comparison to SCC performance for conventionally manufactured materials ▪ addressing uncertainties in the data on SCC and the implications to in-service performance through additional performance monitoring as appropriate
Fatigue	• Surface roughness is known to be a greater issue with LPBF materials, which can reduce fatigue life. • Fatigue properties are strongly dependent on post-processing heat treatment and component porosity. • Data in representative environments are important to support fatigue calculations, including environmentally assisted fatigue (EAF), in LPBF materials.	**Supplemental Testing/Performance Monitoring** • Through supplemental testing and performance monitoring, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments and loading conditions, to show adequate fatigue performance throughout the service life of the component. o The applicant can use current fatigue management approaches supported by sufficient data for LPBF 316L to manage metal fatigue (e.g., cumulative usage factors, cycle counting, EAF penalty factors). o The corresponding analysis can demonstrate acceptable safety margins by using approaches such as the following: ▪ demonstrating equal or superior performance by comparison to fatigue testing for conventionally manufactured materials ▪ addressing uncertainties in the data on fatigue and the implications to in-service performance through conservative design assumptions, additional margins in analyses, surveillance programs, or additional performance monitoring

Difference	Key Technical Information	Technical Review Guidelines
Irradiation effects	• Data in representative environments are important to demonstrate that irradiation effects in LPBF materials will be equivalent to or acceptable when compared to forged materials. • Post-processing with appropriate parameters would be expected to make material properties and performance more similar to conventional forged materials.	**Supplemental Testing/Performance Monitoring** • Through supplemental testing and performance monitoring, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments, to show adequate performance after irradiation (including irradiation-assisted SCC and loss of toughness) for the intended function of the component throughout its service life. o The corresponding analysis can demonstrate acceptable safety margins by using approaches such as the following: ▪ demonstrating equal or superior performance by comparison to irradiation effects for conventionally manufactured materials ▪ addressing uncertainties in the data on irradiation effects and the implications to in-service performance through conservative design assumptions, additional margins in analyses, surveillance programs, or additional performance monitoring
High Temperature Time-Dependent Aging Effects (e.g., Creep and Creep-Fatigue)	• For high temperature operating environments (as discussed in ASME Code Section III), data in representative environments are important to demonstrate that high temperature time-dependent aging effects in LPBF materials will be equivalent to or acceptable when compared to forged materials. • Post-processing with appropriate parameters would be expected to make material properties and performance more similar to conventional forged materials.	**Supplemental Testing/Performance Monitoring** • Through supplemental testing and performance monitoring, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments, to show adequate performance after high temperature time-dependent aging effects (including creep and creep-fatigue) for the intended function of the component throughout its service life. o The corresponding analysis can demonstrate acceptable safety margins by using approaches such as the following: ▪ demonstrating equal or superior performance by comparison to high temperature time-dependent aging effects for conventionally manufactured materials ▪ addressing uncertainties in the data on high temperature time-dependent aging effects and the implications to in-service performance through conservative design assumptions, additional margins in analyses, surveillance programs, or additional performance monitoring

Difference	Key Technical Information	Technical Review Guidelines
Weld integrity	• Data in representative environments are important to demonstrate that welds with LPBF base materials will perform similarly to those with conventionally manufactured base materials.	**Supplemental Testing/Performance Monitoring** • Through supplemental testing and performance monitoring, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments, to show adequate performance of the weld throughout the service life of the component. o This analysis can be informed by relevant experience and knowledge of performance of welds of conventional materials along with potential limited-scope testing on welds of LPBF materials. o The corresponding analysis can demonstrate acceptable safety margins by using approaches such as the following: ▪ demonstrating equal or superior performance by comparison to weld performance for conventionally manufactured materials ▪ addressing uncertainties in the data on weld performance and the implications to in-service performance through conservative design assumptions, additional margins in analyses, or additional performance monitoring
Weldability/ joining	• Limited data show a narrower weld parameter range may be appropriate for LPBF 316L.	**Process Qualification/Production Process Control and Verification** • Through process qualification and production process control and verification, the applicant should provide sufficient data to demonstrate that weldability using traditional arc welding or other joining processes that may be required for component installation in service can be performed consistently and reliably with sufficient quality to meet Code acceptance criteria. o This should include careful consideration of unique aspects of LPBF-fabricated materials compared to traditional manufacturing methods, including local geometry impacts on material properties (e.g. fracture toughness) and heterogeneity/anisotropy, which are described in greater detail previously in this document.