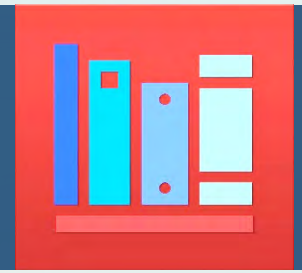
Advanced Manufacturing



- **Moderator**: Matthew Hiser, Materials Engineer, RES/DE/MEB

- **Panelists/Speakers:**
  - Robert Davis (NRC)
  - David Gandy (EPRI)
  - Daniel Mann (ASME)
  - George Rawls (SRNL) and David Gandy (EPRI)

NRC Regulatory Approach for Advanced Manufacturing Technologies

Bob Davis
Senior Materials Engineer
Office of Nuclear Reactor Regulation

NRC Standards Forum
September 15, 2021

NRC Focus

- Advanced Manufacturing Technologies (AMTs) are techniques and material processing methods
  - Not traditionally used in the U.S. nuclear industry
  - Not formally standardized/codified by the nuclear industry
- Initial AMTs based on industry interest:
  - Laser Powder Bed Fusion (LPBF)
  - Direct Energy Deposition (DED)
  - Cold Spray
  - Electron Beam Welding (Already Permitted by ASME Code Section III)
  - Powder Metallurgy - Hot Isostatic Pressing (PM-HIP) (Code Case N-834)

AMT Action Plan

In June 2020, the NRC drafted Revision 1 of its advanced manufacturing technologies action plan ADAMS Accession No. ML19333B980:

- Assess the need for guidance updates
- Ensure NRC staff preparedness to review AMT applications for the Nuclear Industry

- The AMT Action Plan
  - Task 1: Technical preparedness
  - Task 2: Regulatory preparedness
  - Task 3: Communications and knowledge management

Task 1 Technical Preparedness Activities

- Subtask 1A: AMT Processes under Consideration
  - Perform a technical assessment of multiple selected AMTs of interest
  - Gap assessment for each selected AMTs vs traditional manufacturing techniques
  - Technical context document for each report developed by AMT team: LPBF - ML20351A292

- Subtask 1B: NDE Gap Assessment
  - Literature survey of the current state of the art of non-destructive examination (NDE) of components made using advanced manufactured technologies (AMTs) (ML20349A012).

- Subtask 1C: Microstructural and Modeling
  - Evaluate modeling and simulation tools used to predict the initial microstructure, material properties and component integrity of AMT components
  - Identify existing gaps and challenges that are unique to AMT compared to conventional manufacturing processes:
    - Predicting Initial Microstructures (ML20269A301); Predicting Material Performance (ML20350B550)

Task 2 - Regulatory Preparedness Activities

- Subtask 2A: Implementation using the 10 CFR 50.59 Process
  - Provide guidance and support to regional inspectors regarding AMTs implemented under quality assurance and 50.59 programs. Complete: ML21155A043

- Subtask 2B: Assessment of Regulatory Guidance
  - Assess whether any regulatory guidance needs to be updated or created to clarify the process for reviewing submittals with AMT components. Complete: ML20233A693

- Subtask 2C: AMT Guidelines Document
  - Develop a report which describes the generic technical information to be addressed in AMT submissions. Technology specific guidelines are also being developed.
  - Public meeting scheduled for September 16, 2021 to discuss Draft AMT Review Guidelines ML21074A037 and Draft Guidelines Document for AM –LPBF ML21074A040

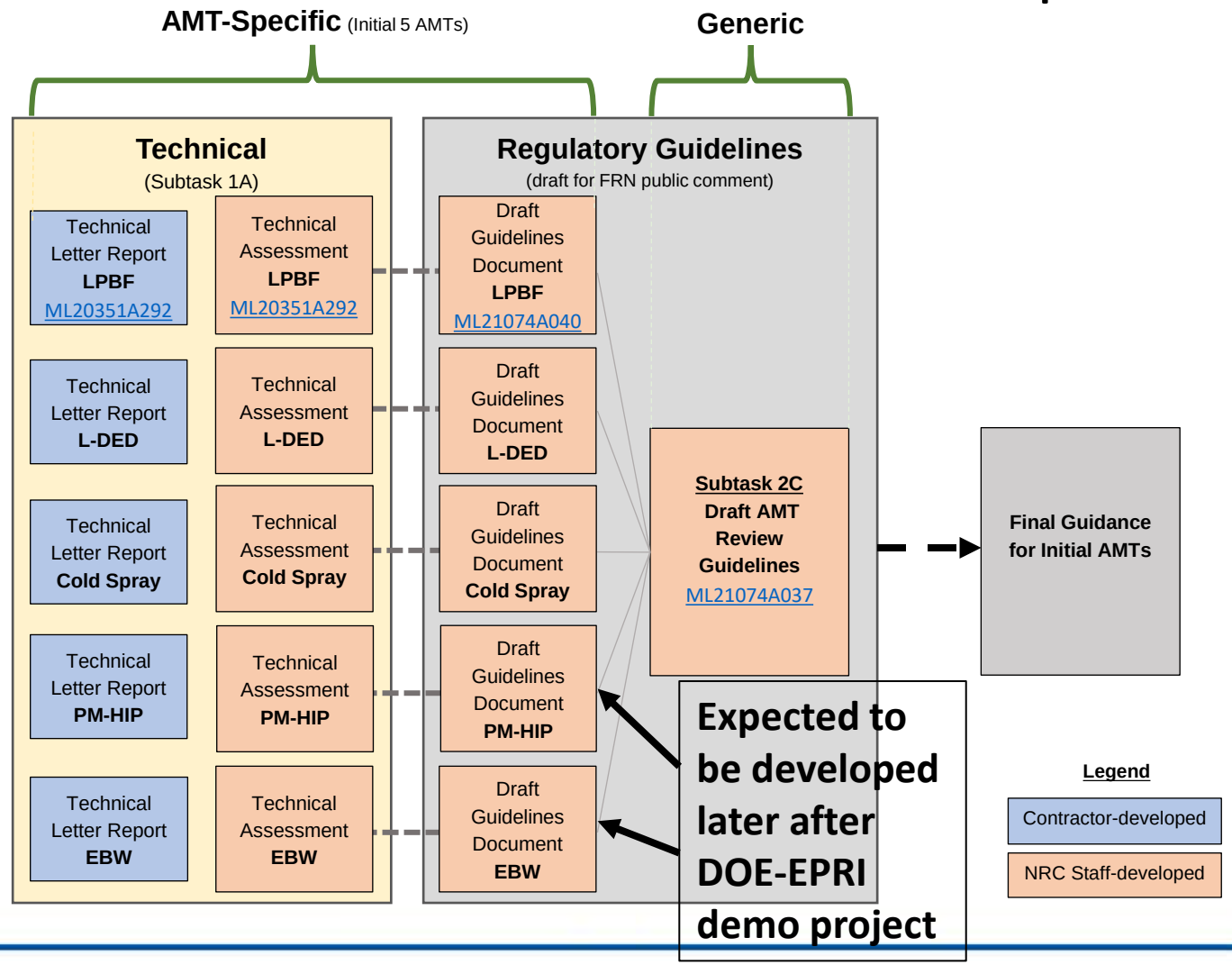
NRC Guidelines for AMT

- A Technical Letter Report (TLR) will be generated for each of the initial five AMTs (e.g., LPBF, DED, Cold Spray, Electron Beam Welding, PM-HIP)
  - Provides technical basis information and gap analysis
  - Written by NRC contractor (National Labs)

- A Technical Assessment (TA) will be generated for each TLR by NRC staff which will provide the staff technical assessment

- A Draft Guidelines Document (DGD), informed by the TA and TLR, will be generated by the NRC staff for each AMT.
  - DGDs to accompany the **Advanced Manufacturing Technologies Review Guidelines**

NRC AMT Guidelines Development



U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Communications and KM Activities

- Subtask 3A: Internal Interactions
  - Internal coordination with NRC staff in other areas (e.g., advanced reactors, dry storage, fuels)
- Subtask 3B: External Interactions
  - Engagement with codes and standards, industry, research, international
- Subtask 3C: Knowledge Management
  - Seminars, public meetings, training, knowledge capture tools
- Subtask 3D: Public Workshop
  - RIL 2021-03: Part 1 Part 2
- Subtask 3E: AMT Materials Information Course
  - Internal NRC staff training
  - Five seminars to date on a variety of topics

Regulatory Pathways

Several Regulatory Pathways exist to implement an AMT

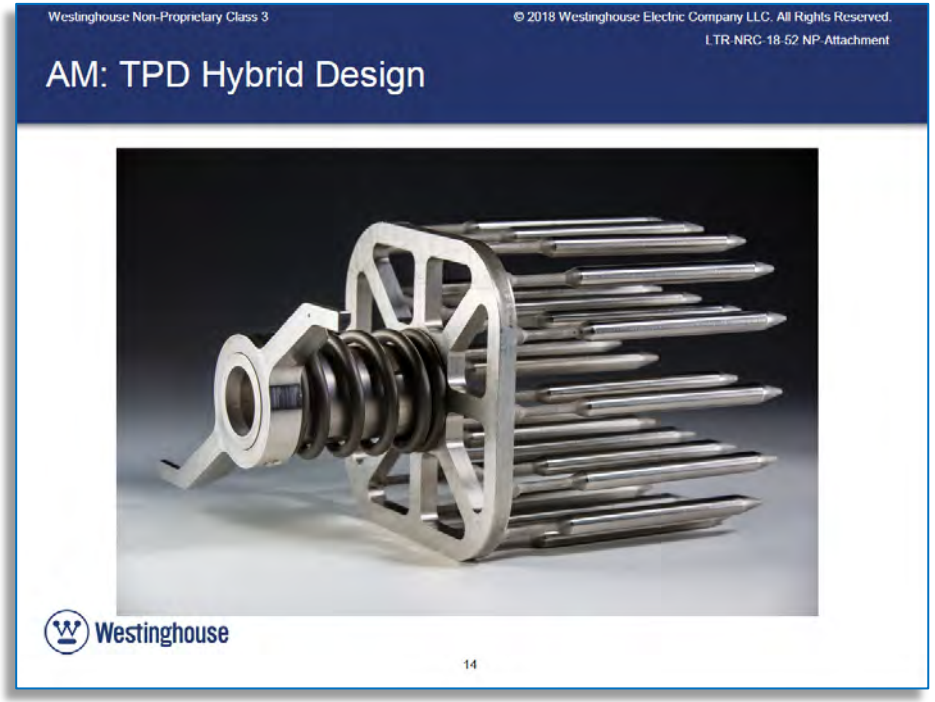
- Title 10 of the *Code of Federal Regulations* (10 CFR) 50.59, “Changes, tests and experiments”
- License amendment (e.g., technical specification change) 10 CFR 50.90
- Alternative to a regulatory requirement (e.g., using 10 CFR 50.55a(z)(1) or (2))
- Change in regulations through the rulemaking process
- ASME Code Cases

10 CFR 50.59 and AMTs

- 10 CFR 50.59 is a change process that involves using screening questions to determine if a change can be made without NRC approval.
- The staff prepared a paper to document the staff's generic review of how a change to use an AMT component for a safety-related application could be implemented at a plant in accordance with
  - QA requirements in Appendix B to 10 CFR Part 50
  - 10 CFR 50.59
- The paper is available under the NRC Agencywide Documents Access and Management System (ADAMS) Accession No. ML21155A043
  - Two AMT components have been installed using the 50.59 process.
    - Byron Unit 1 thimble plugging device
    - Browns Ferry Unit 2 channel fasteners

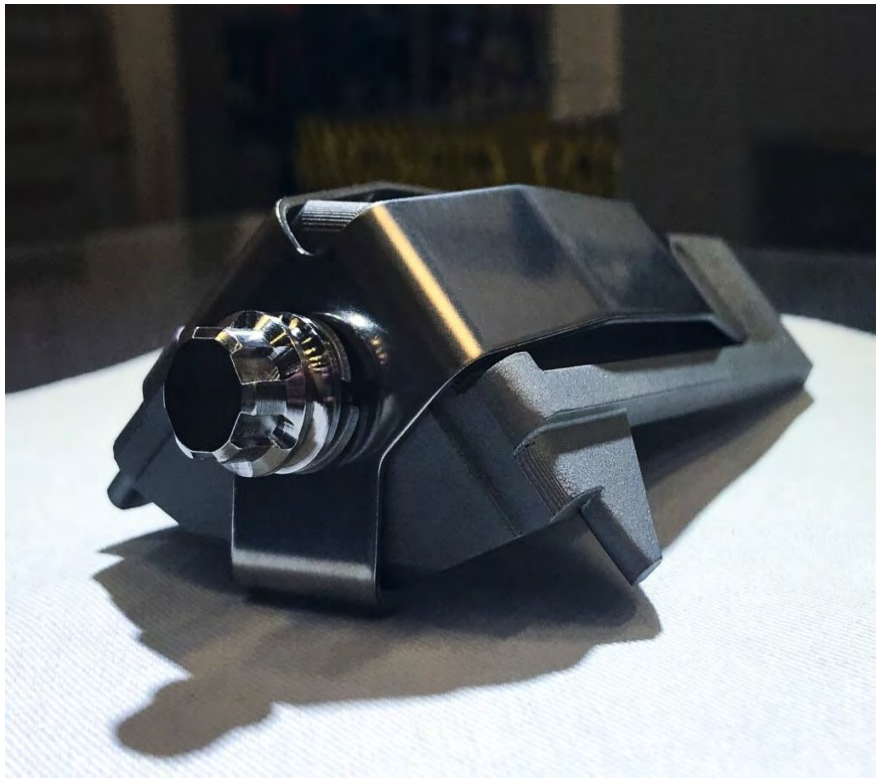
First US Application of Additive Manufacturing

- Thimble Plugging Device
  - Installed in March 2020 in Byron Unit 1
  - 316L stainless steel -LPBF
  - Very low safety significant component (Non ASME B&PV Code class)
  - PWR environment with irradiation
  - Installation done without prior NRC approval under 10 CFR 50.59



Second US Application of Additive Manufacturing

- Channel Fastener
  - Installed in April 2021 at Browns Ferry Unit 2
  - 316L stainless steel - LPBF
  - Non ASME B&PV Code Class
  - BWR environment with irradiation
  - Installation done without prior NRC approval under 10 CFR 50.59



https://www.powermag.com/nuclear-first-3d-printed-safety-related-components-installed-at-browns-ferry/
Credit: Framatome

Regulatory Pathways
ASME Components

- NRC approved *Alternatives to codes and standards requirements.*
  - 10 CFR 50.55a(z)(1)
  - 10 CFR 50.55a(z)(2)

- ASME Code Cases
  - ASME Code Section III Code Cases (When listed in Regulatory Guide (RG) 1.84 *Design, Fabrication, and Material Code Case Acceptability, ASME Section III*)
  - ASME Code Section XI Code Cases (When listed in Regulatory Guide 1.147 Inservice Inspection Code Case Acceptability, ASME Code Section XI, Division 1.)

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Regulatory Pathways
ASME Components

- 10 CFR 50.55a(z) Alternatives to codes and standards requirements may be granted by the Director, Office of Nuclear Reactor Regulation. The applicant or licensee must demonstrate that:
  - 10 CFR 50.55a(z)(1) *Acceptable level of quality and safety.* The proposed alternative would provide an acceptable level of quality and safety; or
  - 10 CFR 50.55a(z)(2) *Hardship without a compensating increase in quality and safety.* Compliance with the specified requirements would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety
- ASME Code Cases
  - When listed in Regulatory Guide 1.84 or 1.147 a code case can be used without requesting NRC approval
  - Code cases not yet listed in RGs 1.84 or 1.147, may be requested for use as part of a proposed alternative by a licensee or applicant in accordance with (z)(1) or (z)(2) above

NRC AMT Action Plan Deliverables Currently Publicly Available

- Task 1A Laser Powder Bed Fusion TLR and TA ML20351A292
- Task 1B NDE Gap analysis ML20349A012
- Task 1C Modeling and Simulation of Microstructure
  - Gap analysis to predict microstructure ML20269A301
  - Gap analysis to predict material performance ML20350B550
- Task 2A 10 CFR 50.59 process ML21200A222
- Task 2B Assessment of regulatory guidance ML20233A693
- Task 2C Guidance Document
  - Draft AMT Review Guidelines ML21074A037
  - Draft Guidelines Document for AM –LPBF ML21074A040
- Task 3D NRC Workshop on AMTs for Nuclear Applications
  - RIL 2021-03: Part 1 Part 2

Questions ?????

EPRI Advanced Manufacturing Methods (AMM) Roadmap

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Marc Albert,
Sr. Technical Leader
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NRC Standards Forum
September 15, 2021

AMM Roadmap Background

- Considerable industry interest in applying AMMs to production of nuclear system components
  - Repair/ maintenance of operating plants
  - Extends to new plants (ALWRs, SMRs, ARs)
- Deployment is complicated by multiple candidate processes, lack of standards, ASME acceptance
- Technology Drivers:
  - Production of near net shapes (reduced machining, waste)
  - Flexible production of obsolete parts
  - Improved inspection characteristics
  - Shorter lead times
  - Reduced costs

Advanced Manufacturing

GOAL & VALUE

Identify, develop, qualify and implement more economical manufacturing technologies that enable:

Higher Quality Components | Reduced Lead Times | Alternative Supply Chains | Cost Competitiveness

Additive Manufacturing

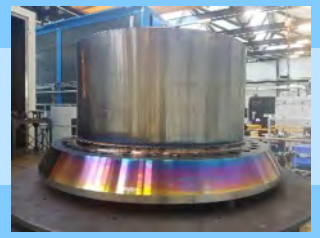
316L LPBF AM Data Package & Code Case

DED-AM Component Demonstration

Advanced Manufacturing Demonstration Project

PM-HIP

EB Welding



Diode Laser Cladding

Heat Treatment

Advanced Welding Techniques

Adaptive Feedback Welding

Modular In-Chamber EBW

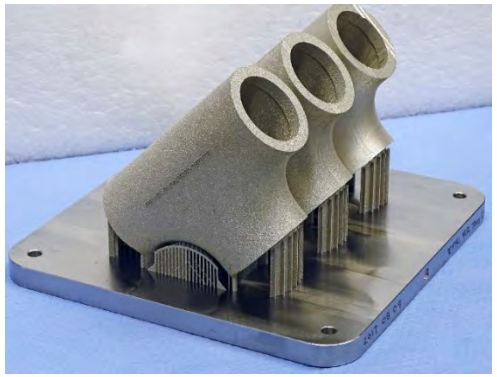
EPRI Research on AMMs…

- Understanding AMMs and Applicability of Each
  - Advanced Manufacturing Methods Roadmap, Including ALWR and SMR Primary System Candidate Components (3002021059)
  - Review of LWR Component Opportunities for Powder Metallurgy-HIP (3002005432)
  - Additive Manufacturing Roadmap (3002018276)
  - Easily extends to advanced plants (SMRs, non-LWR ARs)
- Demonstration of AMMs at Scale
- Development of Data Packages and Code Cases
- Development/Compilation of Environmental Effects for Regulatory Approval

Candidate AMM Processes for Nuclear Components

AMM Processes	Sizes
Powder Metallurgy-Hot Isostatic Pressing	~4ft (1.2m) diameter
Directed Energy Deposition-AM	< 500 lb. (227kg) max.
Laser Powder Bed Fusion-AM	~75 lb. (34kg) max.
Electron Beam Welding	up to 10ft diameter
Advanced Cladding Processes (diode laser cladding, cold-spray & laser assisted cold-spray friction additive stir, diffusion bonding)	NA
Other Processes (advanced welding techniques, machining techniques, surfacing technologies	NA

Size Often Dictates Advanced Manufacturing Process



Laser Powder Bed Fusion Additive Manufacturing:
<75 lbs (35 kg)

Direct Energy Deposition Additive Manufacturing:
<500 lbs (225 kg)

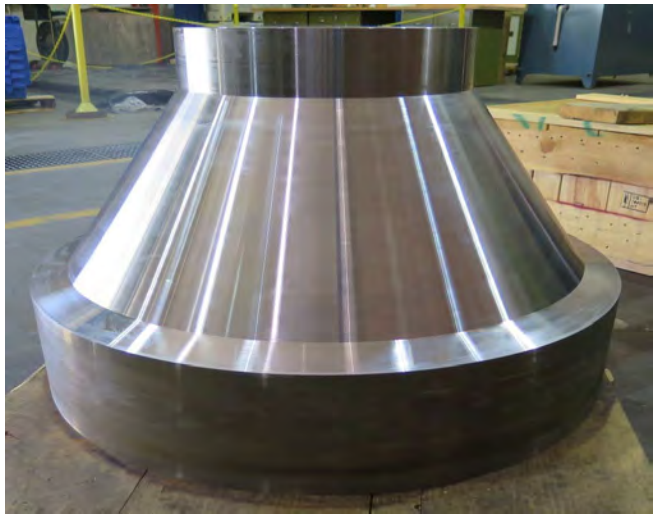
Powder Metallurgy-HIP:
100-10,000 lbs (45-4500 kg)

Roadmap Development --Overview

- Roadmap development generated based on component size/materials
  - This distinction avoids complications associated with addressing components on individual basis

- **Three Roadmaps** considered:
  1. **Primary pressure boundary (Class 1) components**
  2. **Reactor internals**
  3. **Other components (Obsolete parts, Classes 2 &3, etc.)**

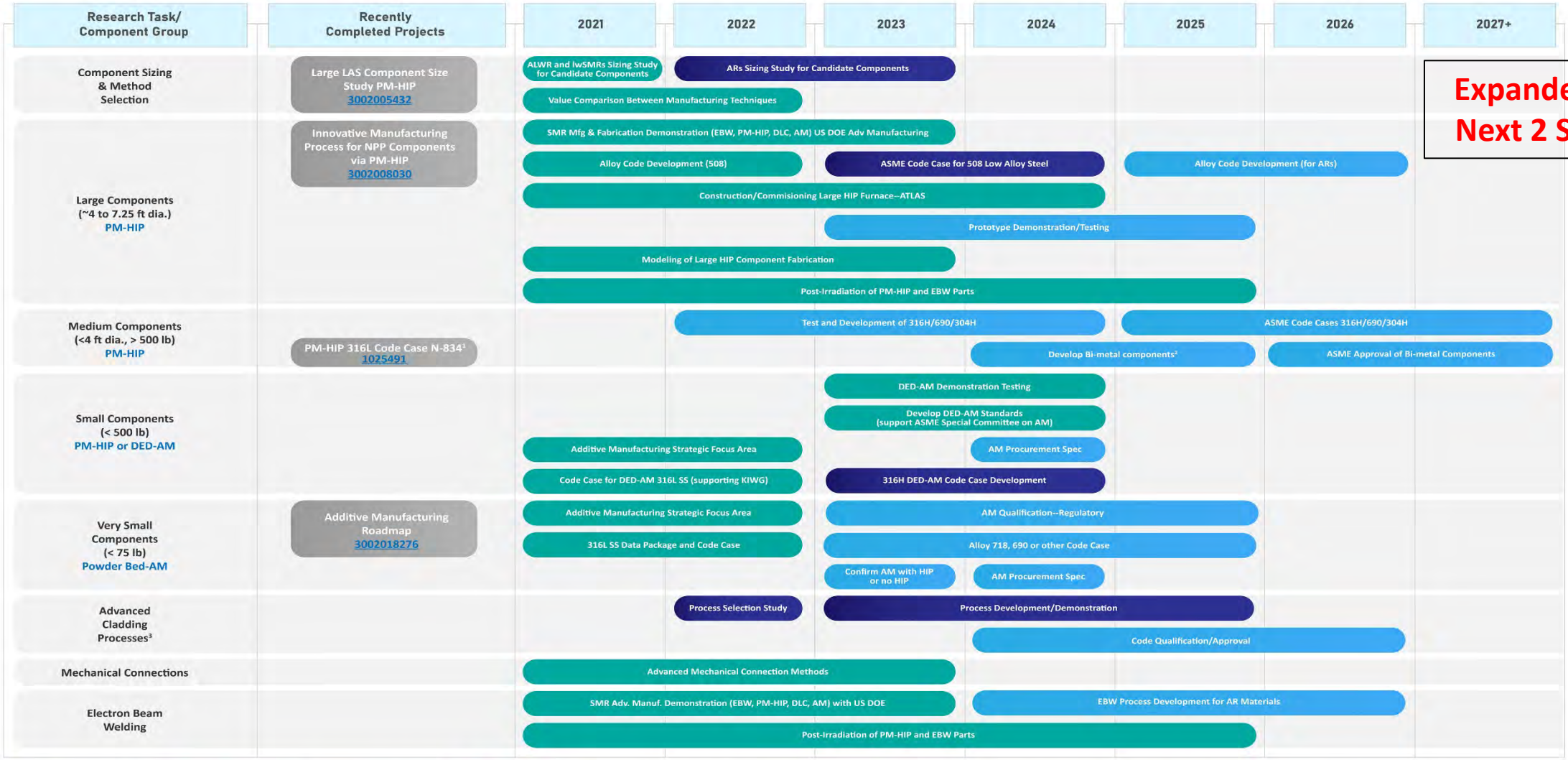
1. Primary Pressure Boundary (Class 1) Roadmap



16” BWR Feedwater Inlet Nozzle (LAS)

- Roadmap includes an initial sizing study to identify candidate components
  - Many large LWR Class 1 components exceed limitations of certain AMTs.
- Developments identified are specific to: size groups/processes/materials
  - **Larger Class 1 components** can be manufacture **using PM-HIP**
    - Demonstration pieces of LWR components already produced
    - 316L already accepted by ASME, but other alloys require qualification testing and ASME approval
  - **Smaller Class 1 components** may be produced **by DED-AM or Powder Bed-AM**
    - Process development, qualification testing, ASME approval shown
    - Few Class 1 components candidates for Powder Bed AM (size limitation)

Advanced Manufacturing Methods – Class 1 Pressure Boundary

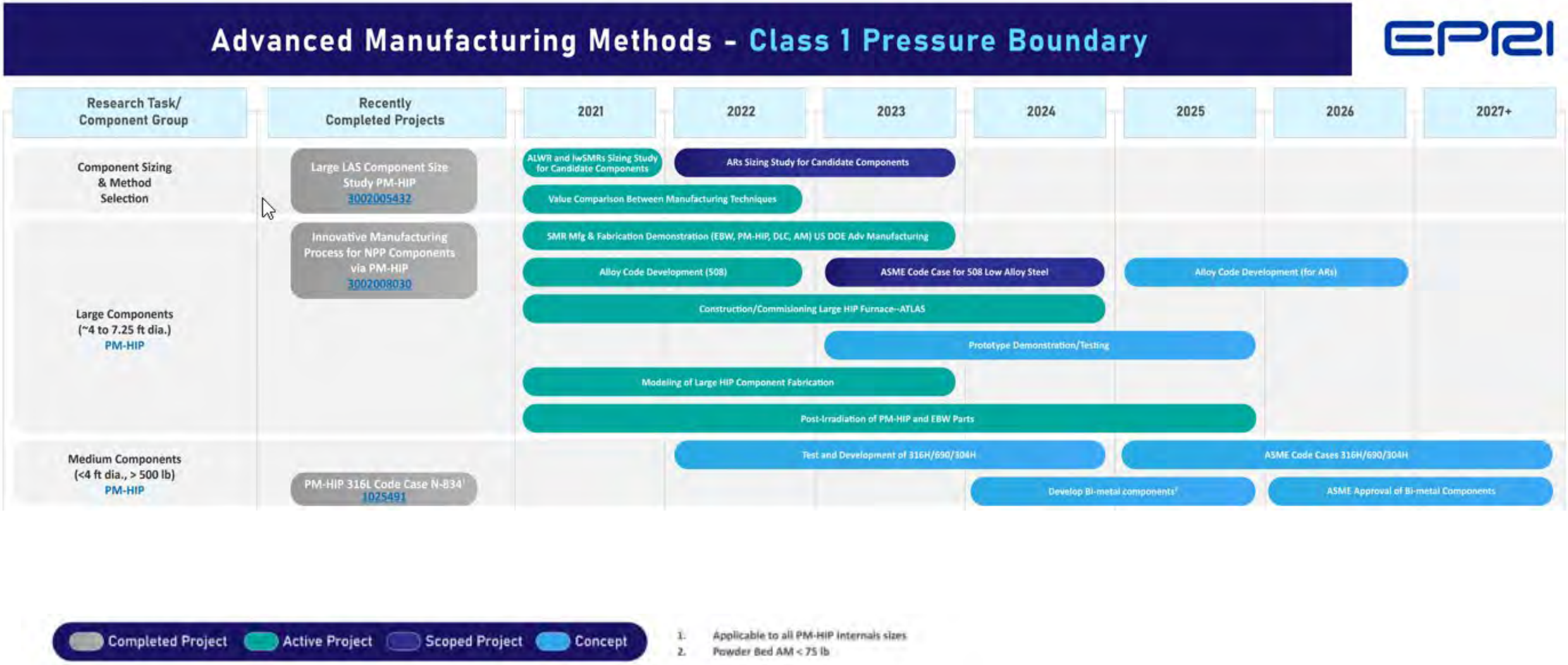


Expanded on Next 2 Slides

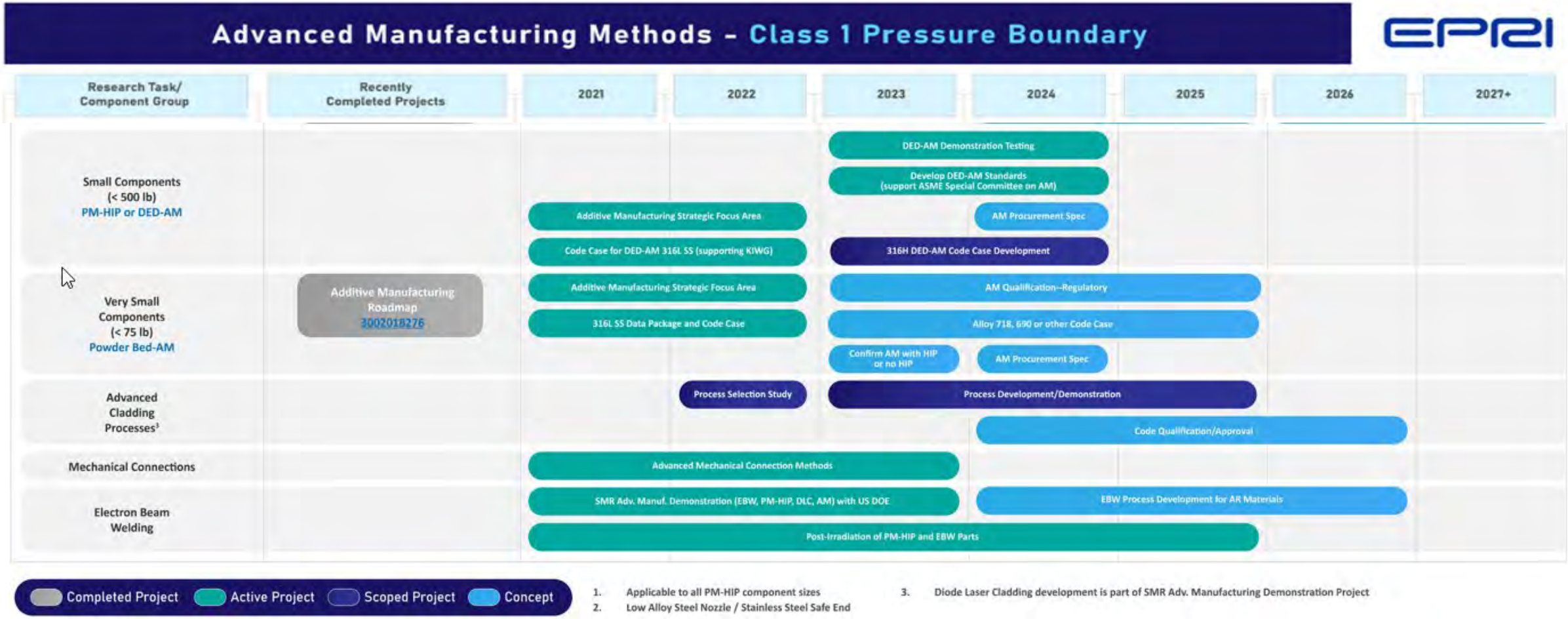
Completed Project | Active Project | Scoped Project | Concept

1. Applicable to all PM-HIP component sizes
2. Low Alloy Steel Nozzle / Stainless Steel Safe End
3. Diode Laser Cladding development is part of SMR Adv. Manufacturing Demonstration Project

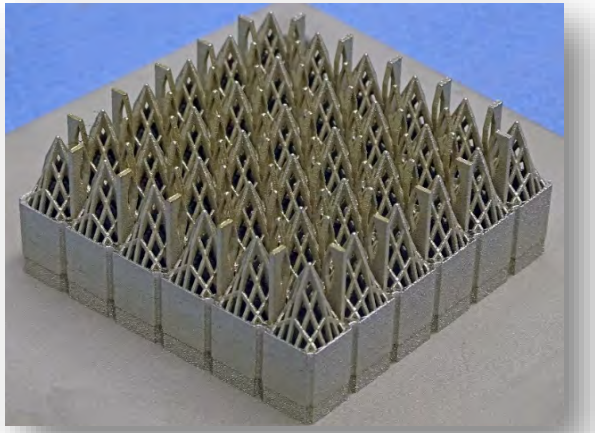
Class 1 Pressure Boundary Components (1/2)



Class 1 Pressure Boundary Components (2/2)

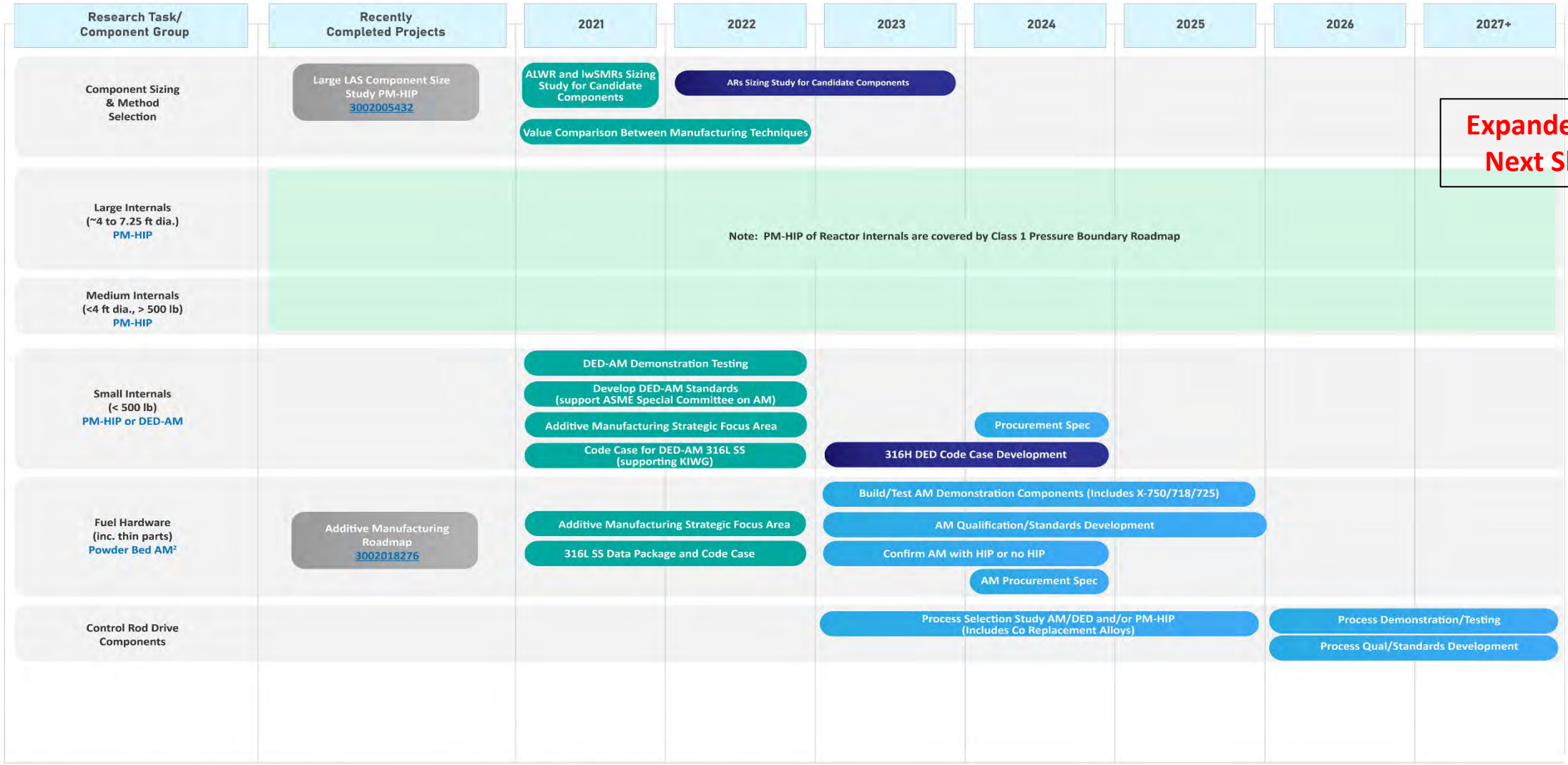


2. Reactor Internals Roadmap



- Internals Roadmap generally follows similar pattern set for Class 1
  - Up front sizing study
- Some significant differences:
  - No low alloy steel components
  - Fuel Hardware and Control Rod Drive components (unique shapes and materials)
  - High strength Ni-base alloys and cobalt-free alloys
- **Interaction with ASME is limited** for Internals Roadmap
  - Only core support structures require ASME approval
  - Interaction with NRC may be required for some Safety Related Internals
  - Other internals: free to use ASTM, AMS, etc. or no standard at all (a potential case for fuel hardware or control rod drive components)

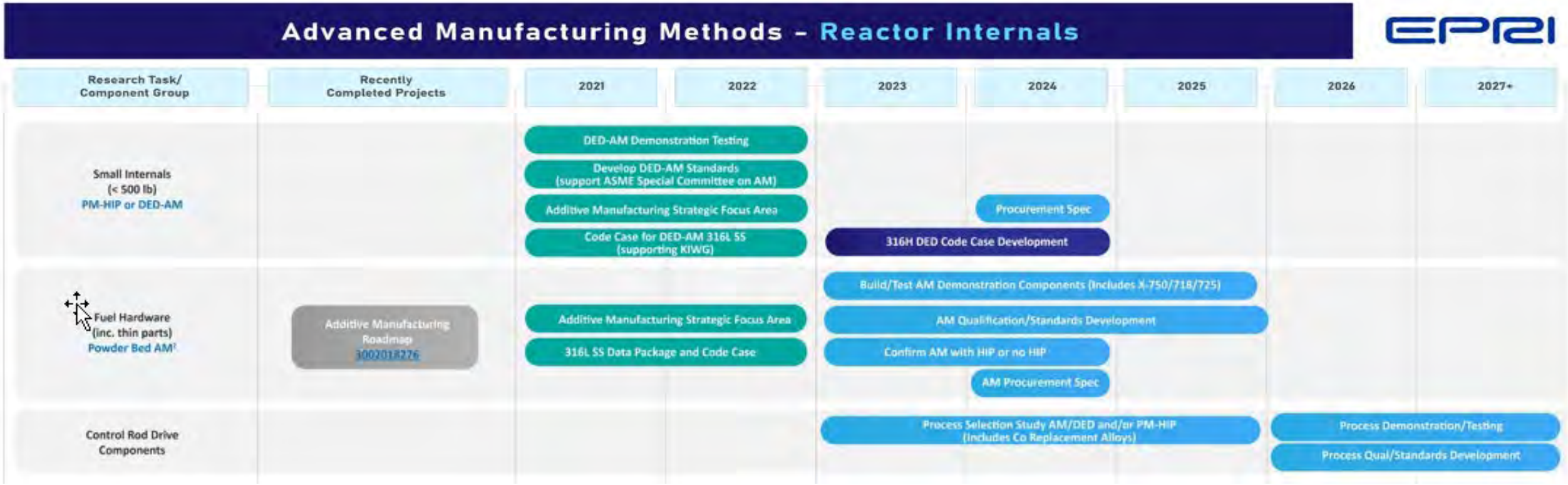
Advanced Manufacturing Methods – Reactor Internals



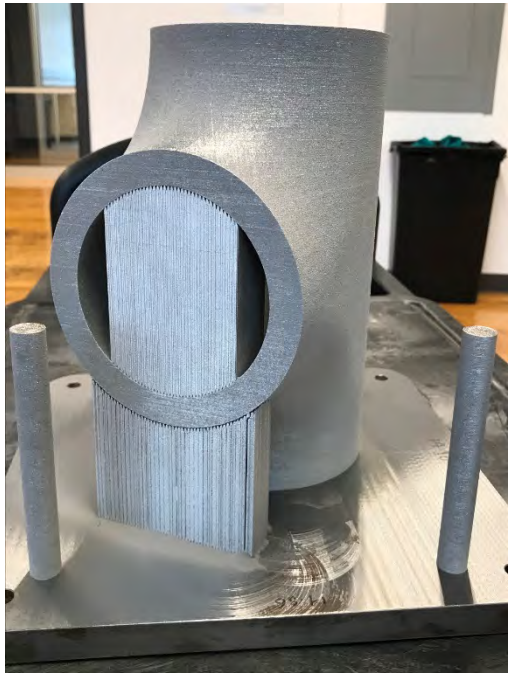
Expanded on Next Slide

1. Applicable to all PM-HIP Internals sizes
2. Powder Bed AM < 75 lb

Reactor Internals (expanded)

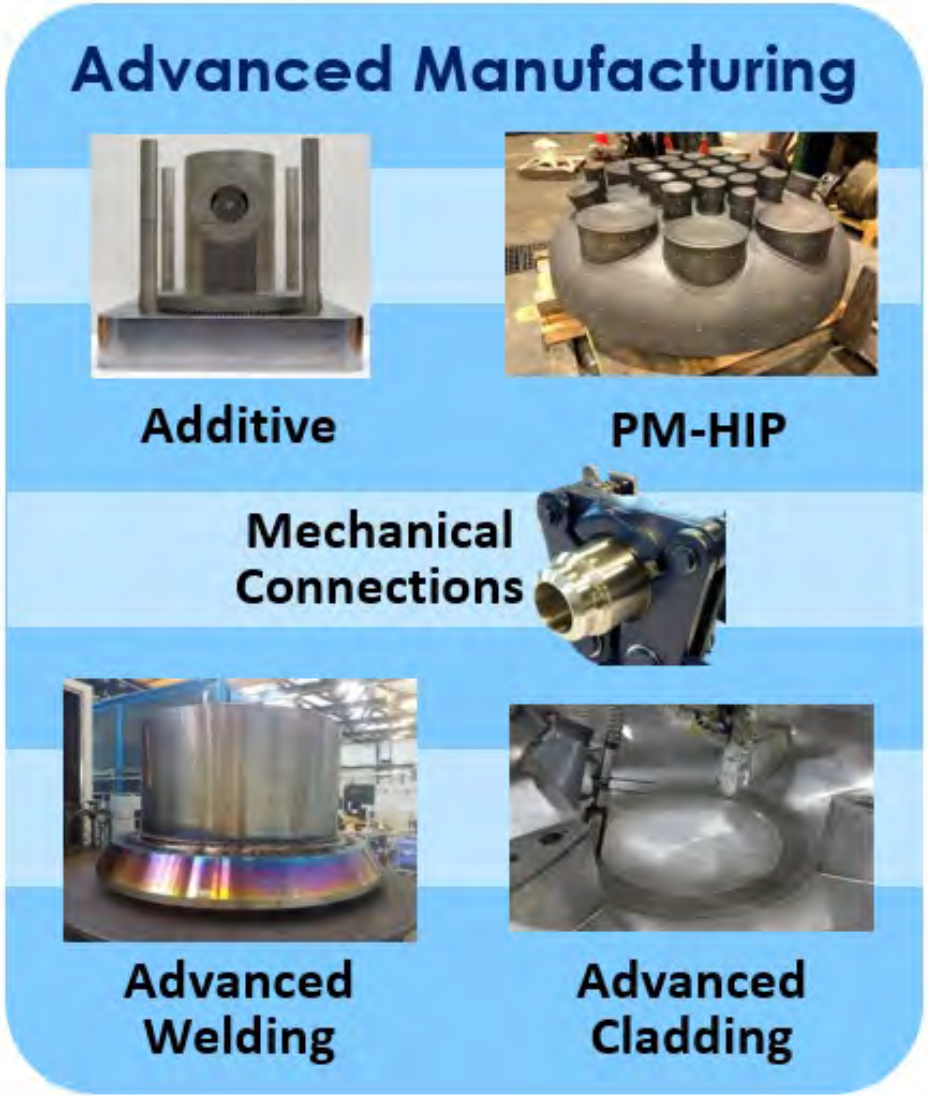


3. All Other Components Roadmap --Obsolete Parts, Class 2 & 3, etc.



- Primary Pressure Boundary and Reactor Internals Roadmaps fully address needs of “Other Components” category
  - e.g., ASME acceptance of a process/material for Class 1 immediately applicable to Class 2 & 3
  - **Other “Components Roadmap” is not required**

Example List of Components



Reactor Internals	Current Product Form	AMM Material	AMM Process
Core Barrel (stacked rings)	Forging	304/304L	PM/HIP
Reflector Blocks	Forging	304/304L	PM/HIP
Reflector Alignment Pins	Bar	304/304L	LPBF
Lower Core Plate	Forging or Plate	304/304L	PM/HIP
Lower Core Support Blocks	Plate	304/304L	PM/HIP
Upper Core Support Blocks	Bar or Plate	304/304L	PM/HIP
Upper Riser Shell Sections	Plate	304/304L	PM/HIP
Upper Riser Transition Section	Plate	304/304L	PM/HIP
Upper Riser CRD Supports	Plate	304/304L	PM/HIP
Upper Riser Hanger Ring and Hanger Braces	Plate	304/304L	PM/HIP, DED
Pressurizer Spray Nozzles	Bar	304/304L	LPBF
Lower Riser Transition Cone	Plate	304/304	PM/HIP
In Core Guide Tube Support	Plate	304/304L	PM/HIP
Lower Riser Shell	Plate	304/304L	PM/HIP
CRA Guide Tube Support Plates	Plate	304/304L	PM/HIP
CVCS Piping Supports	Plate	304/304L	DED
CVCS Piping Fittings (Elbows/Caps)	Forging	304/304L	DED/LPBF
Upper Core Plate	Plate	304/304L	PM/HIP
Lower Riser Trunnions	Plate	304/304L	PM/HIP,DED
ICI Guide Tube Supports	Plate	304/304L	DED/LPBF
CRD Guide Cones, Guide Cards, and Lower Flanges	Plate	304/304L	LPBF/DED

Summary—AMM Roadmap

- Two Roadmaps cover majority of component needs
  - Primary Pressure Boundary (Class 1)
  - Reactor Internals
- AMMs are described based on component size
  - Large – PM-HIP
  - Medium – PM-HIP & DED-AM
  - Small – PM-HIP & DED-AM
  - Very small – PBF
- Other technologies included:
  - EBW, advanced cladding processes, fuel hardware, mechanical connections, CRDs

ASME Section III, SubGroup-MF&E. Materials, Fabrication and Examination, TG-AM Task Group Advanced Mfg.

Public Meeting NRC Standards Forum:
Advanced Manufacturing Technologies
September 15, 2021.
Virtual Meeting

Daniel Mann - FLOWSERVE
Task Group Chair, TG on AM

Task Group Goal

- Write rules for the adoption of Advanced Manufacturing processes by Section III, Div. 1 for incorporation into the 2023 and future Editions of Section III

Formal ASME Task Group Charter

- *The Task Group on Advanced Manufacturing is responsible for developing, clarifying, and prescribing rules for the fabrication and stamping of items manufactured by techniques including: Powder Metallurgy / Hot Isostatic Pressing; Powder Bed-Additive Manufacturing; Direct Energy Deposition-Additive Manufacturing / Wire; Cold Spray Deposition/Cladding; and Diode Laser Cladding.*

ASME
SETTING THE STANDARD

1st formal TG meeting 1-27-2021

- Meeting Cadence: during the 2 weeks prior to each ASME Code Week (Quarterly)
- Process Specific Focus Groups meeting monthly
  - Quality Assurance
  - PM/HIP
  - DED-GMAAM
- Members of TG include representation from ASME Section II (Materials), Section III (MF&E), and Section IX (Welding) as well as representatives of Industry

TG Charter

- TG determined Process specific Advanced Manufacturing (AM) methods should be limited to a selected scope achievable for 2023.
- TG did not want to miss the next publication cycle due to an excessive scope which was not supportable by current resources.

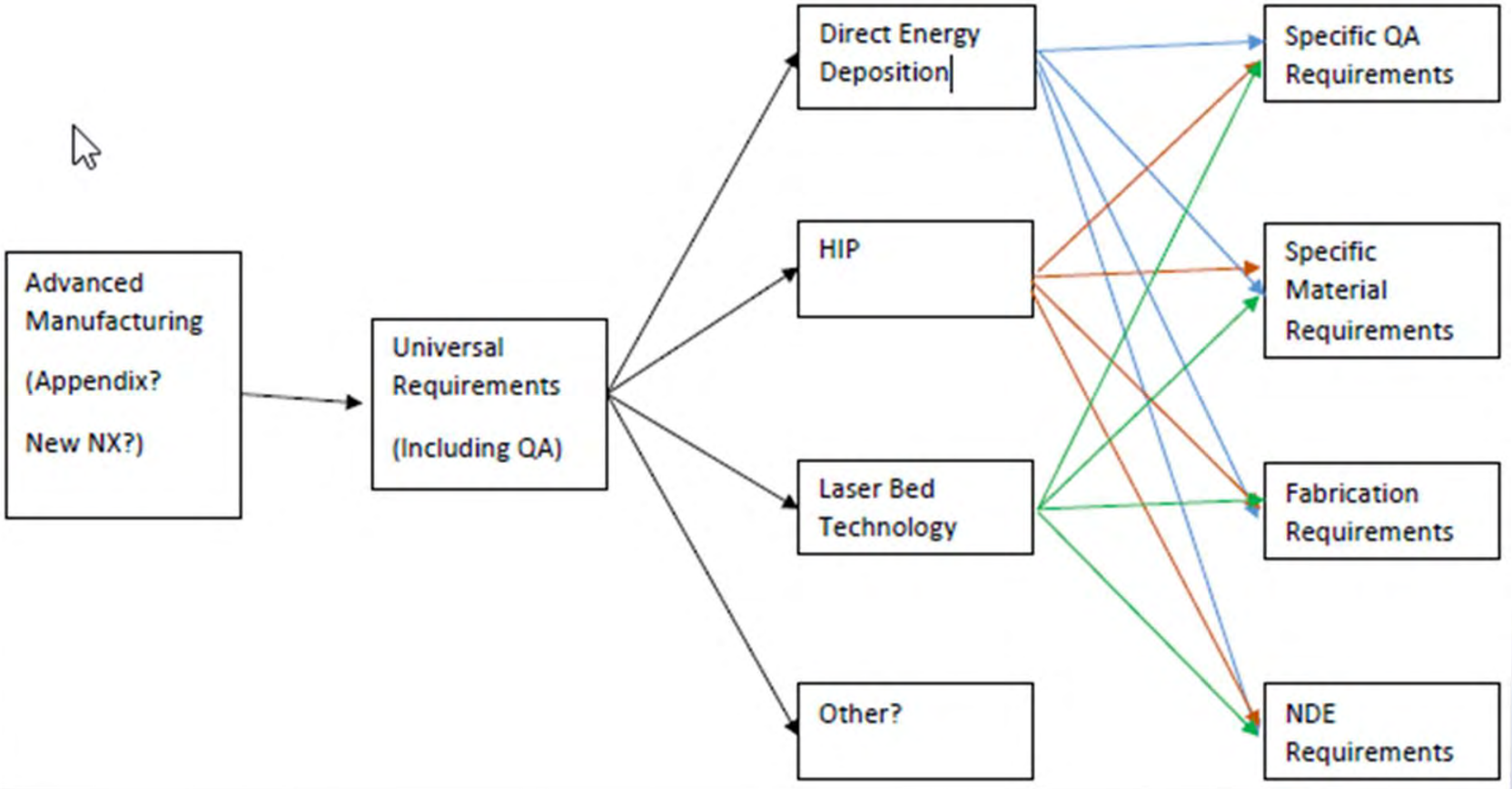
AM Specific Methods

- TG Identified and evaluated the status of current Code actions, supporting AM, to identify the specific methods for the TG to address for 2023.
  - Powdered Metal/Hot Isostatic Pressing (PM/HIP)
  - Direct Energy Deposition Gas Metal Arc Additive Manufacturing (DED-GMAAM)
  - Laser Powdered Bed Fusion (LPBF) – Evaluated and held for the 2025 Edition

Topics required to be addressed by the TG to address for incorporation of AM into BPV III

- Where to place the requirements in Section III, (New Article, New Section, Appendix)
- How to handle the AM items as a new “Product Form(s)”
- Evaluate the use of existing product form data as support of AM product form
- Appendix to Address Specific: QA Requirements, Material Requirements, Fabrication Requirements, NDE Requirements

Philosophy for AM Incorporation into Section III: Section III, Article 2000 to support AM Product Form and reference Mandatory Appendix for AM rules:



PM/HIP

- Structure incorporation of PM/HIP based upon approved Code Case N-834 ASTM A988/A988M-11 UNS S31603
- We are Currently focused on alloy 316L as represented in CC N-834 supporting utilization in Section III
- Expanding scope to include additional alloys in the initial release of this Appendix would likely negatively impact incorporation into 2023 due to scope creep
- The Appendix will be expanded to incorporate additional alloys following current Code rules for new materials
- Industry to drive the prioritization of which alloys are incorporated

Directed Energy Deposition - DED

- Selected DED-GMAAM as the 1st DED Process to be incorporated
- Structure incorporation of GMAAM based upon approved Section IX Code Case 3020
- GMAAM selected as it is an extension of current industry experience. Welds and weld metal build up technology with decades of demonstrated in-service experience.

Quality Assurance

- Intend to incorporate NCA-4200/-4300 (Material Organization) quality requirements as criteria as these standards have already been accepted for other product forms and processes.

Section III, Div.1 AM

Questions/Comments?

Savannah River National Laboratory®

We put science to work.™

ASME Criteria for Powder Bed Fusion Additive Manufacturing

ASME Special Committee on Additive Manufacturing

George Rawls

Advisory Engineer SRNL

David Gandy

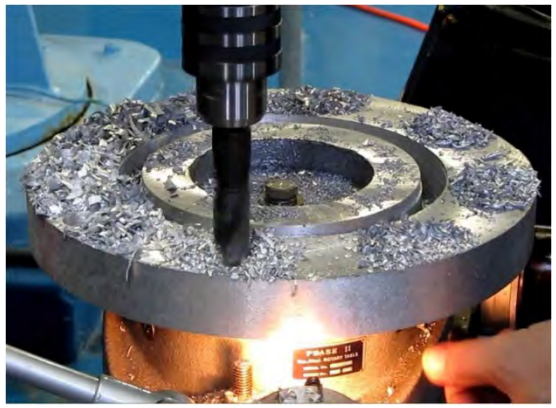
EPRI

NRC Standards Forum

September 15,2021

ASME Criteria for Powder Bed Fusion Additive Manufacturing

- What is Additive Manufacturing
- Additive Manufacturing (AM) - a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.
- Subtractive Manufacturing - making objects by removing material (for example, milling, drilling, grinding, etc.) from a bulk solid to leave a desired shape.



Subtractive

Additive

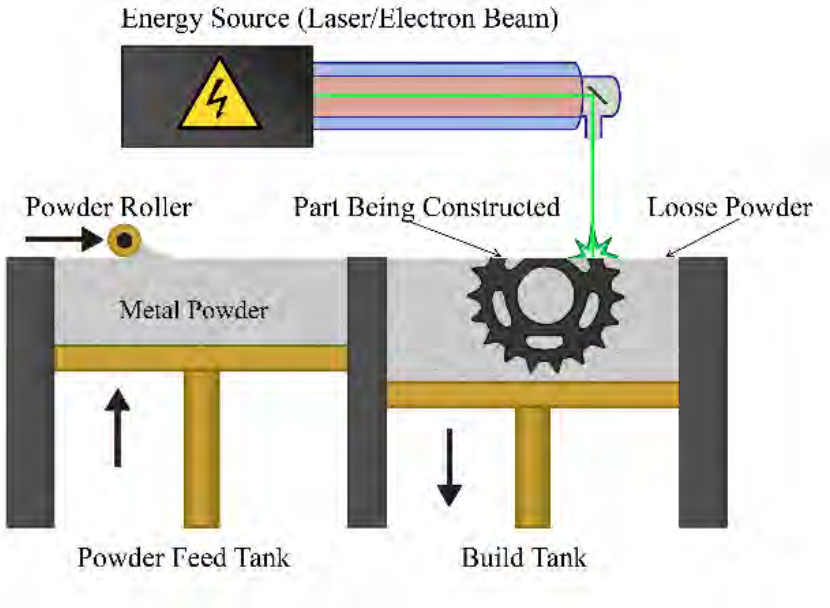
Additive + Subtractive

Application will require additive joined to non-additive

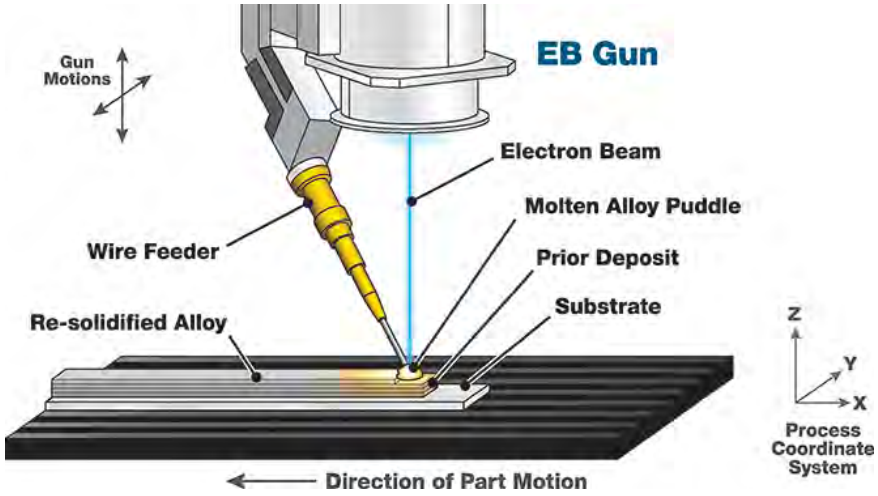
ASME Criteria for Additive Manufacturing

- Additive Manufacturing (AM) Technologies

Powder Bed Fusion



Direct Energy Deposition



- The ASME AM Committee has completed the initial work on the Powder Bed Fusion (PBF) criteria document.

- Work has commenced on AM criteria for Direct Energy Deposition (DED) for metal inert gas and electron beam processes.

ASME Criteria for Powder Bed Fusion Additive Manufacturing

- The PBF work is published In ASME PTB -13 -2021 “Criteria for Pressure Retaining Metallic components using Additive Manufacturing
- The document provides criteria on the materials, design, fabrication, examination, inspection, testing and quality control essential to be addressed in any proposed standard for the construction of metallic pressure retaining equipment using powder bed fusion additive manufacturing.

- The additive manufacturing criteria document addresses the follow areas.

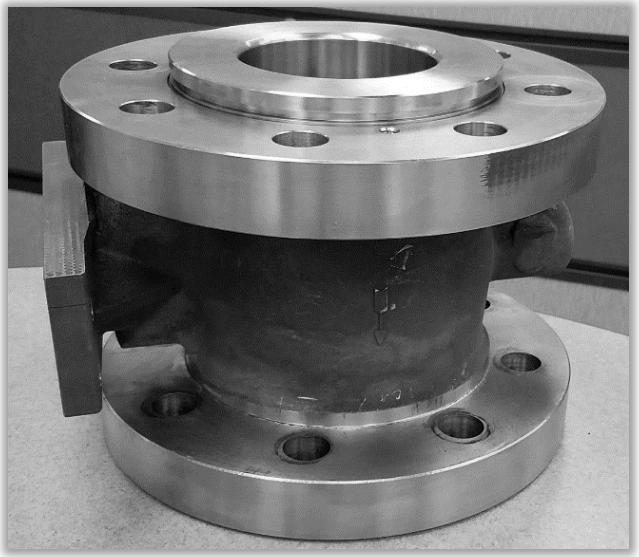
- Scope
- Additive Manufacturing Specification
- Materials
- Thermal Treatment
- Powder Requirements
- Additive Manufacturing Design Requirements
- Additive Manufacturing Procedure
- Additive Manufacturing Procedure Qualification
- Qualification Testing of Additive Manufactured Components
- Production Builds
- Chemistry Testing
- Mechanical Property Testing
- Metallographic Evaluation
- Referenced Standards
- Definitions
- Records
- Quality Program

ASME Criteria for Powder Bed Fusion Additive Manufacturing

- Scope
  - These criteria address the construction of pressure retaining equipment using the Additive Manufacturing (AM) Powder Bed Fusion process using both Laser and Electron Beam energy sources.
  - Hybrid construction incorporating AM components joined (Welded or Brazed) to non-AM components is acceptable. Additive manufactured components joined to other AM components or non-AM components shall follow the requirements for the applicable ASME Construction Code or Standard.
  - The pressure design for components shall follow the requirements of the applicable ASME Construction Code or Standard.
  - The maximum design temperature shall be at least 50°F (25° C) colder than the temperature where time-dependent material properties begin to govern for the equivalent wrought ASME material specification, as indicated in ASME Section II, Part D [15.1].
  - The minimum design temperature shall follow the requirements for the applicable ASME Construction Code or Standard.
  - The materials are limited to austenitic stainless-steel alloys and nonferrous alloys.

ASME Criteria for Powder Bed Fusion Additive Manufacturing

- Materials
  - Material for the purpose of this specification is defined as the additively manufactured component in its final heat-treated condition.
  - The Additive Manufacturer shall select a listed wrought ASME material specification from ASME Section II for the component material.
  - The requirements for chemical composition, grain size, hardness, final heat treatment and mechanical properties shall be identical to the requirement of the ASME material specification.

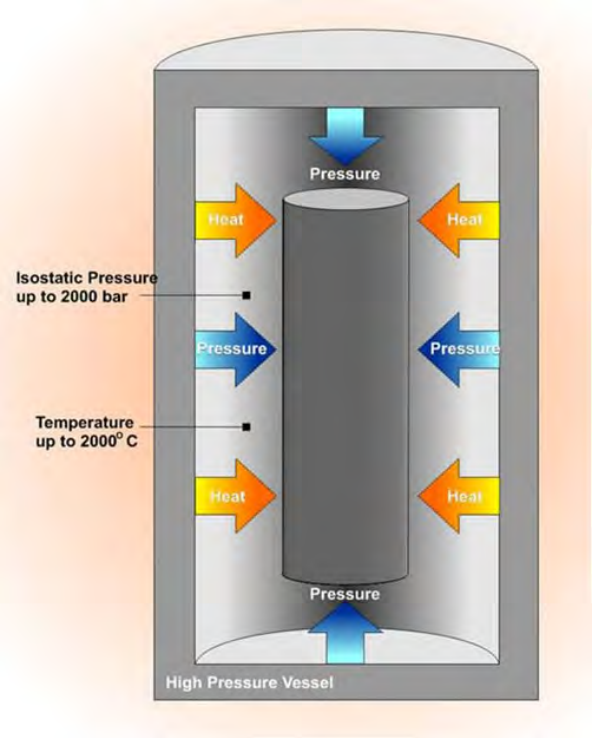


Valve Body Fabricated Using Powder Bed Fusion AM
Courtesy of Emerson

- The AM Committee basically followed the same criteria for materials that was used in the codification of component fabricated using the powder metallurgy

ASME Criteria for Powder Bed Fusion Additive Manufacturing

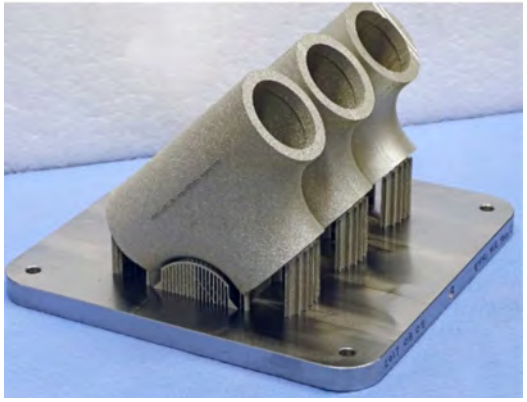
- Thermal Treatment
  - The final heat treatment requirements applied to the AM material shall be identical to those applied to the ASME material specification.
  - Additional intermediate thermal treatment is acceptable. Intermediate thermal treatment may include stress relief, hot isostatic pressing or other thermal processing.
  - When intermediate thermal treatment is performed ASTM F3301 [15.2] may be used as guidance.
  - When hot isostatic pressing is performed ASTM A988 [15.3] or ASTM A1080 [15.4] may be used as guidance.
  - All material testing shall be performed on material specimens in the final heat-treated condition ASME material specification.



Schematic of the Hot Isostatic Pressing Process

ASME Criteria for Powder Bed Fusion Additive Manufacturing

- Design
  - In addition to the design requirements of the ASME Construction Code or Standard the following design requirements apply for components produced using the powder bed fusion AM process.
  - Any material produced during the AM build that is specified as cosmetic material shall not be credited as load bearing material in the stress analysis.
  - Fatigue critical surfaces shall be designed to be accessible for liquid penetrant examination.
  - Surfaces interfacing with sacrificial supports shall be fully accessible for removal of supports and for liquid penetrant examination.
  - The effect of any support that will not be removed following the AM build shall be included in the stress analysis.

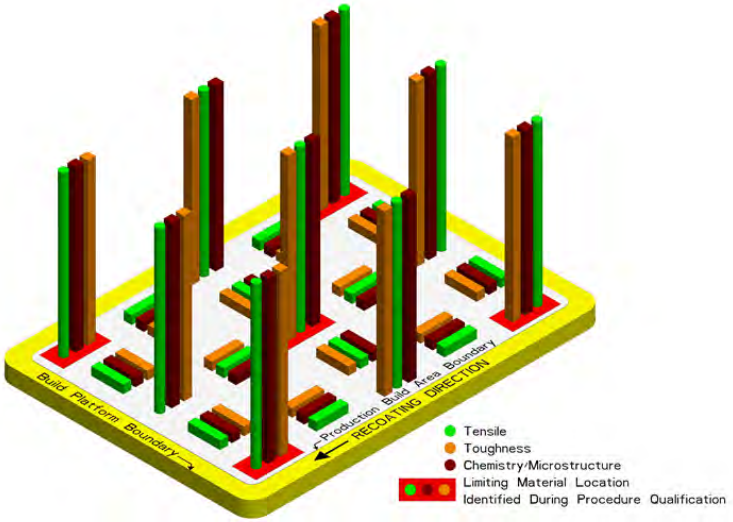


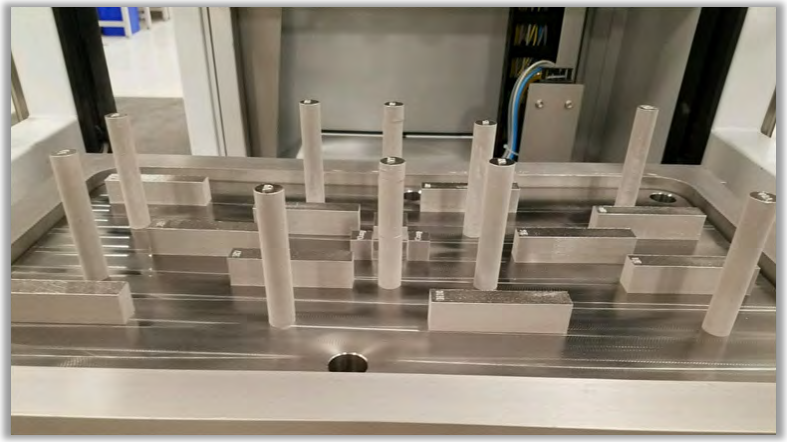
Sacrificial Supports
Courtesy of Rolls- Royce

Permanent Supports

ASME Criteria for Powder Bed Fusion Additive Manufacturing

- Additive Manufacturing Procedure
  - Additive Manufacturing Procedure
    - The Additive Manufacturer shall prepare an Additive Manufacturing Procedure.
    - The AM Procedure shall address applicable process variables.
    - The Additive Manufacturer shall complete sufficient qualification builds and produce sufficient material qualification specimens to support a 95% confidence that 99% of the produced material is in accordance the ASME material specification.
    - The Additive Manufacturer shall identify the locations of limiting material conditions for each energy source.

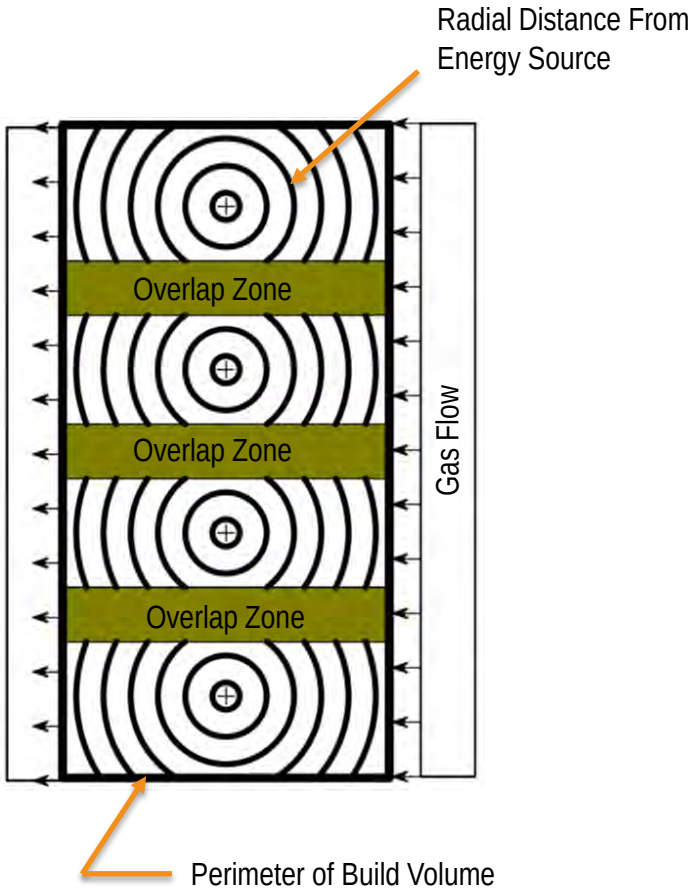


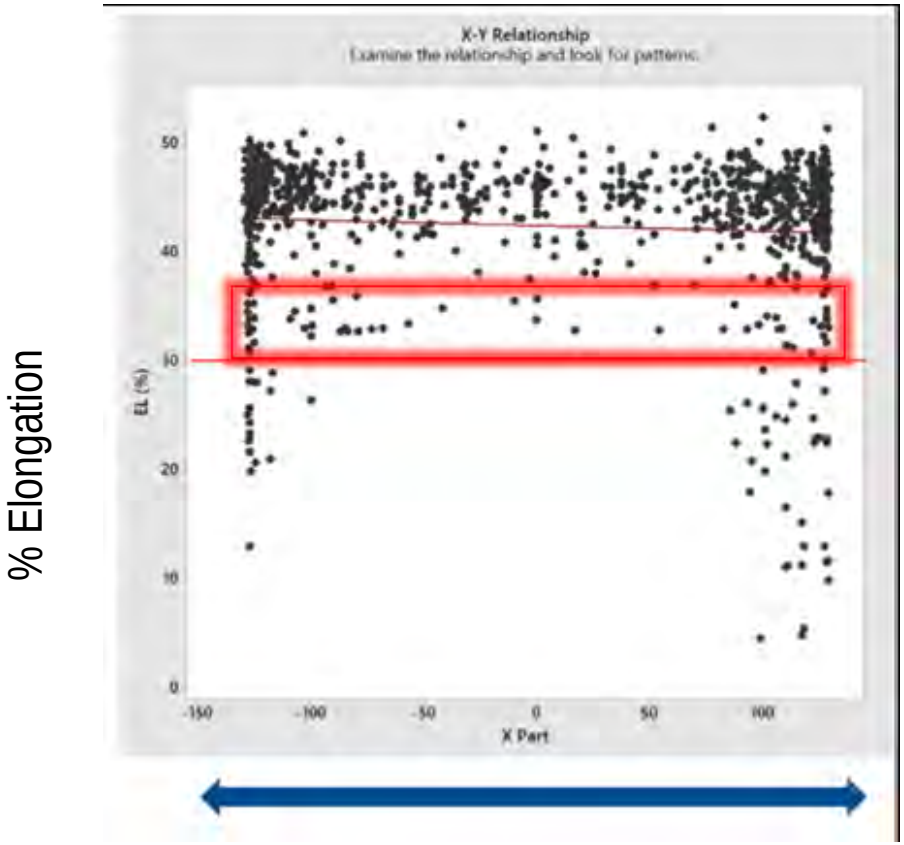


Material Qualification Specimens for Additive Manufacturing Procedure Qualification
Courtesy of Emerson

ASME Criteria for Powder Bed Fusion Additive Manufacturing

- Additive Manufacturing Procedure Qualification
  - Limiting material conditions for each energy source.





Radial Distance From Energy Source
Courtesy of Emerson

ASME Criteria for Powder Bed Fusion Additive Manufacturing

- Qualification Testing of Additive Manufactured Components
  - Fabricated components shall be subjected to qualification testing.
  - Correlation between the samples and the actual component.
- Prototype Testing Requirements

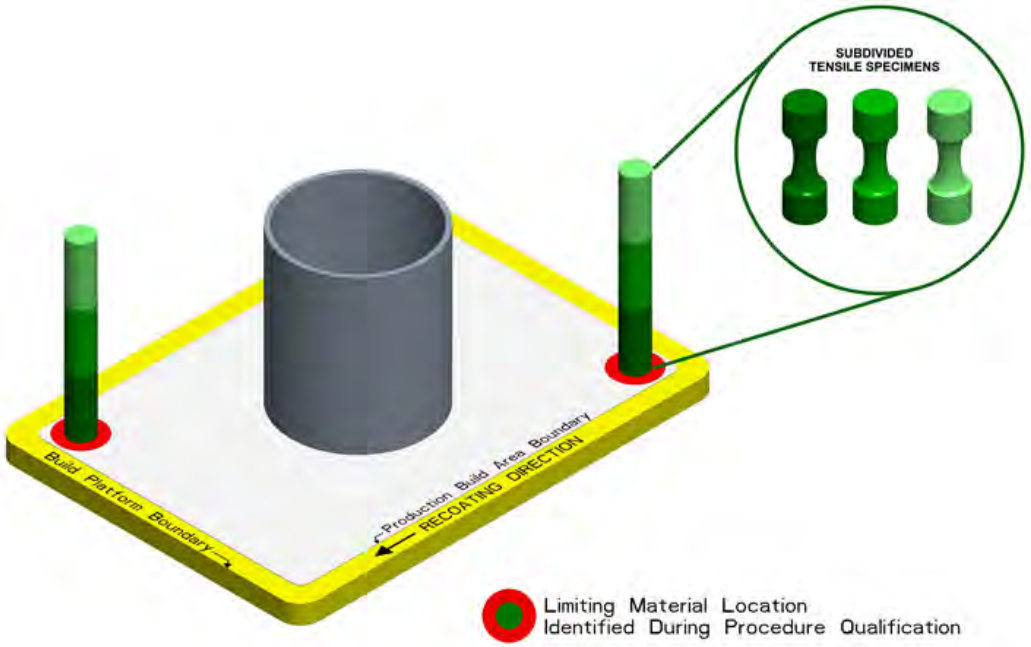
Prototype Test	Number of Prototypes	Test Criteria
Proof	1	Section 9.12
Fatigue	2 to 5	Section 9.13
Material Properties	1	Sections 12-14
Toughness	1	Construction Code

- Locations for Material Qualification Specimens for Component Qualification Build

Location	Description	Minimum Samples
CQ1	Locations of limiting material conditions identified during the procedure qualification.	2 per Energy Source
CQ2	Thinnest pressure retaining feature in the component	1
CQ3	Highest stressed location in the component	1

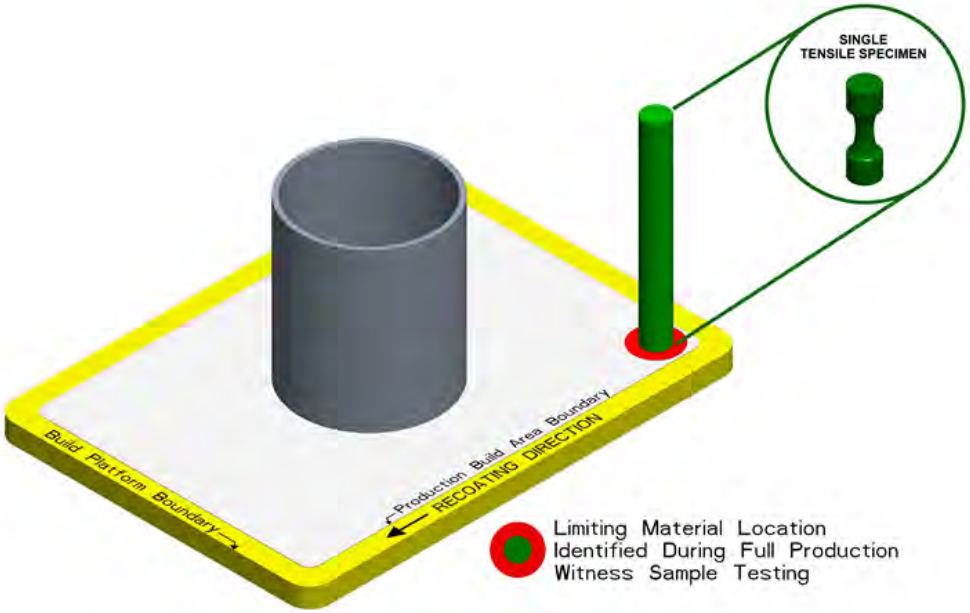
ASME Criteria for Powder Bed Fusion Additive Manufacturing

- Production Builds
  - First 10 Production Builds
  - A vertically oriented witness specimen shall be constructed over the total height of the build volume at a minimum of 2 locations of limiting material conditions determined during procedure qualification for each energy source.
  - Witness specimens shall be subdivided when required to meet the requirement of ASTM E8.
  - All tensile specimens from each energy source shall be tested.



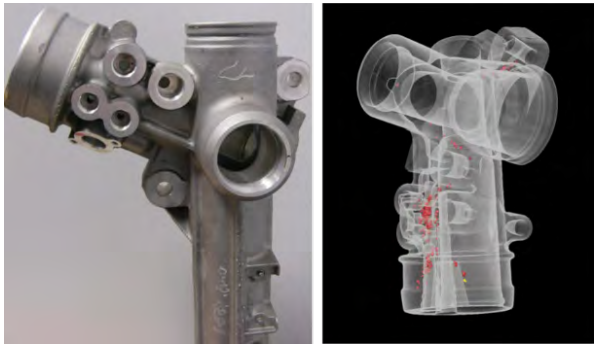
ASME Criteria for Powder Bed Fusion Additive Manufacturing

- Production Builds
  - Production builds greater than 10 with all tensile samples conforming.
  - One vertically oriented witness specimen for each energy source shall be constructed to the height required to capture the limiting material location determined from the data for the first 10 production build cycles for each energy source.
  - The location of the single tensile specimen shall be at the limiting location within the witness sample identified during the first 10 production build cycles.
  - The single tensile specimen from each energy source shall be tested.



ASME Criteria for Powder Bed Fusion Additive Manufacturing

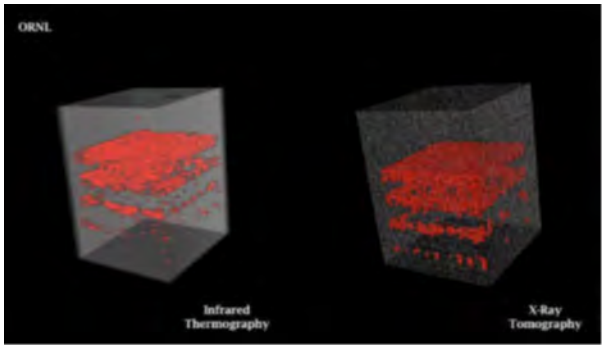
- Examination Requirements for AM Components
  - Follow current ASME Construction Codes examination Requirements.
  - It is recognized that the additional examination may be needed for AM pressure parts, These requirements should be identified in the AM Manufacturing Specification.
- Computed Tomography
  - Computed tomography is needed to provide full volumetric examination of AM Components.
  - Section V has completed Article 20 Computed Tomography Examination that can be used for AM Examination.



CT Pipe Scan EMS Corp

ASME Criteria for Powder Bed Fusion Additive Manufacturing

- Future Work
  - PTB-13 will serve as the baseline for future development of an ASME AM PBF Code Cases and Standards Development.
    - *A Code Case for Section III is being developed for 316 L material using the AM PBF Process.*
  - Complete the criteria document for DED AM Processes.
  - Defect acceptance criteria for load-bearing AM parts and fatigue analysis of AM parts (Current DOE Project).
  - Move to real time monitoring of flaws during an AM build.
  - The current PBF criteria document addresses the manufacturing of multiple duplicate parts. Additional work in needed for manufacturing single AM part using PBF.



Comparison of Infrared Thermography and Computed Tomography Results

THANK YOU

QUESTIONS