

Review of Additive Manufacturing for Reactor Materials & Components

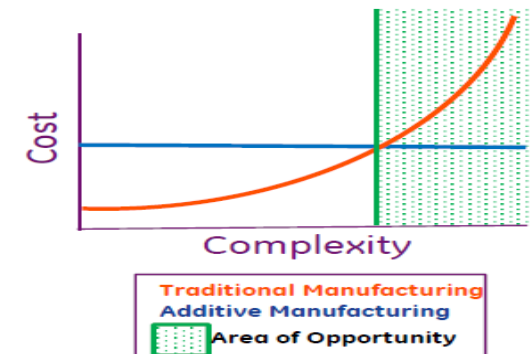
Office of Nuclear Regulatory Research
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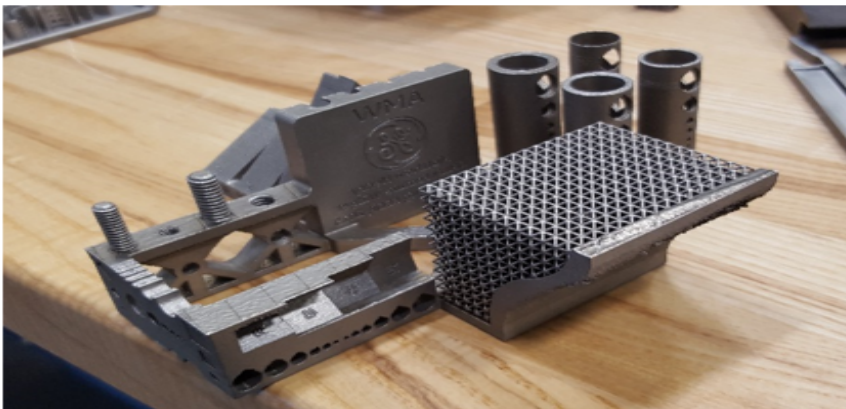
Introduction. Why Additive Manufacturing (AM) for Reactors?

Value and Benefits

- **Speed of Delivery**
 - Rapid Prototyping
 - On-Demand Parts → Reduced Inventory
 - Obsolete Parts → Scan, Model, Print
 - Emergent Parts → Outage Demand
- **Design for Performance**
 - Geometric Freedom → Performance Enhancements
 - Weight Reduction
- **Cost Reduction**
 - Low Volume Parts
 - Complex Multi-Component Assemblies
- **Enhanced Chemistry Control**
 - Alloy Control Favorable to Nuclear Environment

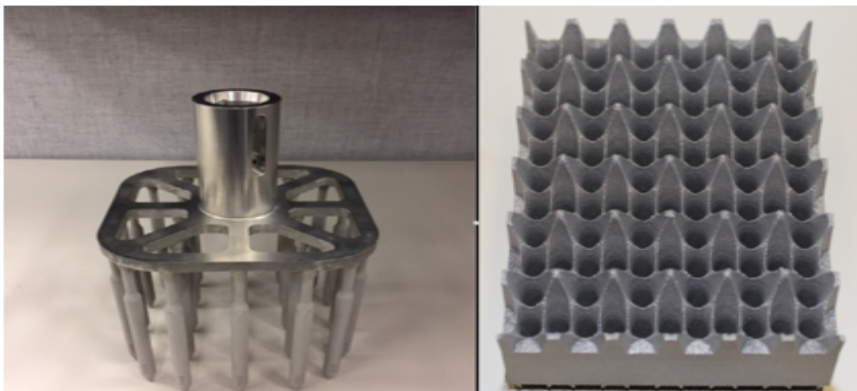


Regulatory Research Perspective



- RES Objective: Anticipatory review to allow NRC to be ready to assess adequacy of AM parts in NPPs – AM applications possible in 2018/2019.
- Driver/Applications: Provide critical ‘jump-start’ to ascertain NRC is ready for industry requests including direct metal laser melting (DMLM/AM).
- Prospective Collaboration: DOE, EPRI, NIST, ASTM, NASA, FAA, DOD

- *DMLM Process Demonstration Specimen at GE Power Advanced Manufacturing Works, Greenville, SC, C. Moyer, December 11, 2017.*
- *Westinghouse’s DMLM Examples: Thimble Plugging Device, Advanced Debris Filtering Bottom Nozzle, B. Cleary, November 28, 2017.*



Objective of NRC Engagement

- Become cognizant of relevant ongoing & emerging activities
 - Areva highlighting reverse engineering capability
 - BWXT's new DOE award for additive fabrication process for nuclear components and sub-components
 - Yielding acceptable material structure and strength
 - Acceptable to national code organizations and regulator.
- Engage with industry to understand potential implementation
- Engage with other organizations to understand expertise and resources
- Evaluate relevant codes & standards activities

Additive Manufacturing – Rapid Replacement of Safety-Related Parts

➤ Improving **SAFETY** with new equipment and advanced technology.

Why use additive manufacturing for replacement parts?

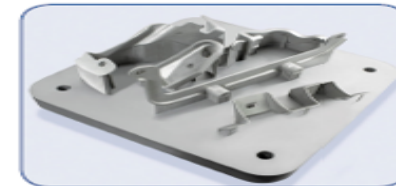
- Material test reports
- Isolate specimen fabricated with part
- CAD files provide permanent manufacturing record
- Fabrication technique and material specification change only requires an equivalency evaluation — no plant modification

Why use AREVA for additive manufacturing?

- 10CFR50, Appendix B program
- Reverse engineering capability
- Commercial dedication for safety-related applications

More Innovative Outage Solutions

- RCP pumps and motor shop services
- Engineering and analysis
- Chemistry lab services
- PWR & BWR refueling services
- Safety-related machining and coatings
- Outage management and OOC support



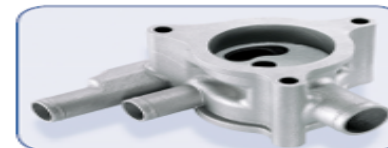
Ability to fabricate complex shapes with internal passages

Features

- 3-day manufacturing capabilities
- Selection of alloys
 - Stainless steel
 - Inconel
 - Ni-Cr
 - Aluminum
- Part sizes up to 12"

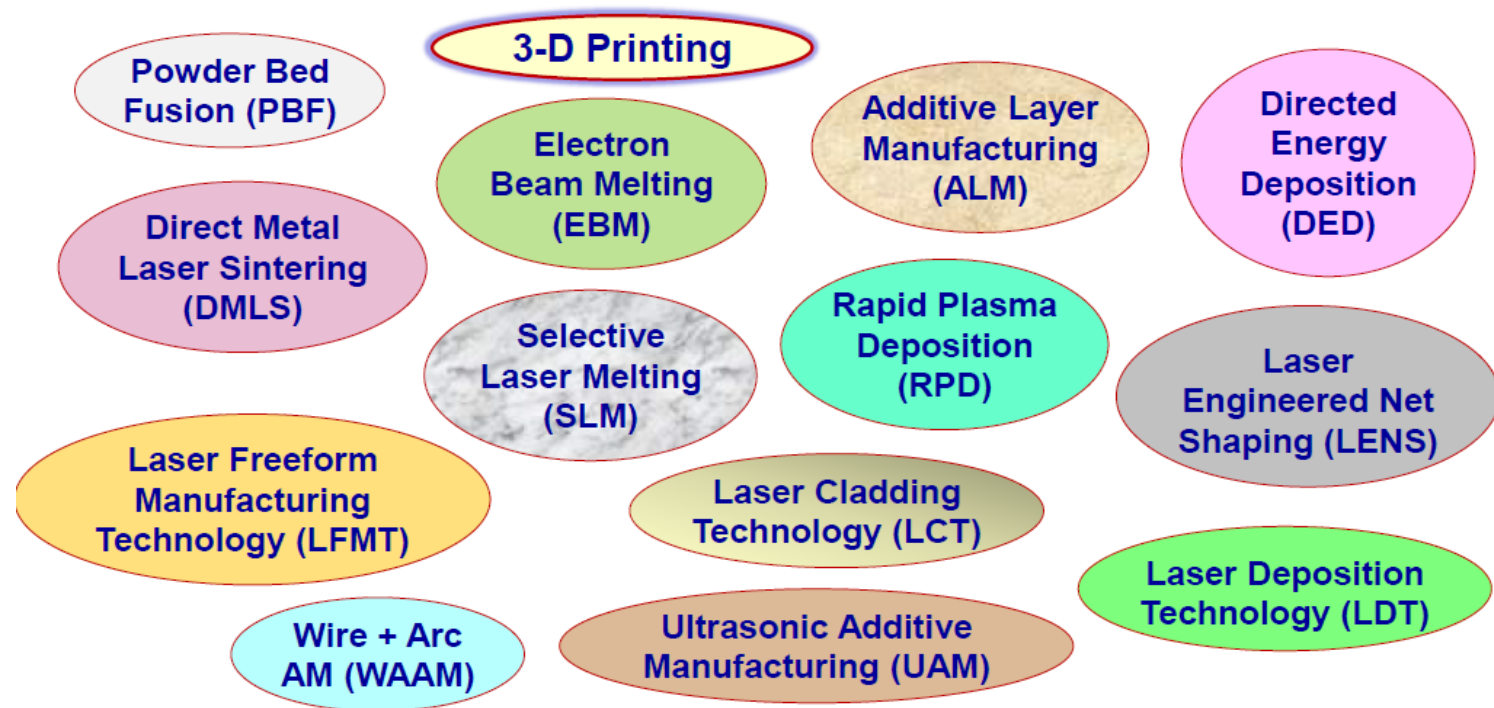
Benefits

- Reverse engineer obsolete parts with quick turn-around
- High quality safety-related parts with test specimens
- Cost-effective method for fabricating multiple parts
- Avoids need for component replacement and plant mods
- Rapid parts fabrication on-demand to reduce inventory



AM is Not a Single Process...

- A partial list of metal AM technologies
- Industry, agency, and society collaboration is needed to ensure safe introduction of AM in major industry sectors
 - M. Gorelik, *Regulatory Considerations for AM and Status of the FAA AM Roadmap*, Nov. 28, 2017





Overview

1. Stimulus of June 7, 2017 GE-H meeting with NRC
2. ANSI AMSC Activities & Phase II Meetings
3. Advanced Manufacturing & Supply Chain Innovation Nuclear Energy Leadership Summit & Industry Showcase and DOE-NE AMM Program Review (Oct 3-5 -- Idaho Falls)
4. Visit to WEC Churchill Laboratories to discuss direct metal laser melting (DMLM) irradiation and fabrication (Pittsburgh)
5. ASTM E08/F42 Symposium on Fatigue and Fracture of AM Materials & Components
6. NRC/Industry Additive Manufacturing Technical Information Exchange, Nov 28-29
7. Visits to Advanced Manufacturing facilities
8. Ongoing Activities
9. Path Forward

Engage with Other Organizations to Understand Expertise and Resources

Public meeting^α “Additive Materials for Reactor Materials and Components”

- Standardization activities
- AM research and applications in nuclear and other industry
- AM processes and capabilities
- Technical and regulatory challenges.

Presentations provided by:

- ASME, ASTM, ANSI
- NRC, DOE, NIST, FAA, NSWC, NAVSEA, NASA
- EPRI, NEI
- GEH, WEC, NuScale, RR, Additec, Novatech, CTC, EWI
- INL, ORNL, DRDC



 America Makes

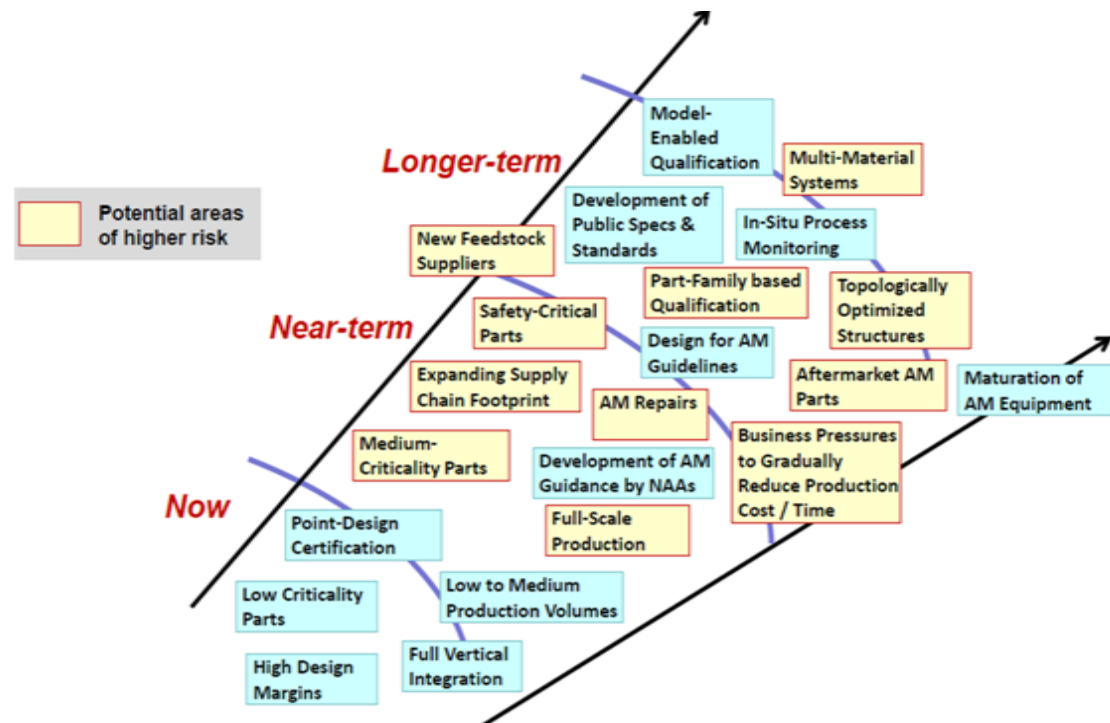
 **ANSI**
American National Standards Institute

^α Presentations archived at ADAMS - ML17338A880; from “Standards Development Organizations Involved with AM Standardization, J. McCabe, November 29, 2017

Coordinating with other regulators ...

NRC interest areas

- Reliability of AM processing and quality of AM parts
- Properties of AM parts
- Structural performance of AM parts, including their inspectability
- Service performance and aging degradation of AM parts
- Codes & standards development for AM



M. Gorelik, *Regulatory Considerations for AM and Status of the FAA AM Roadmap*, Nov. 28, 2017



NRC Action Plan

- Early stages of development
- To address preparation of NRC readiness for review of AM parts
- Provide for interoffice coordination - reactor side, waste management, research
- Address involvement in standards and codes organizations
- A subject of NRC “Innovation and Transformation” initiative



NRC Regulatory Information Summary

- RIS 2017-08 under revision to address AM

- ...plans and schedules for fabrication of large components and modules (Including nontraditional or advanced manufacturing methods, such as additive manufacturing, cryogenic machining, and Powder metallurgy-HIP)...
 - Are you considering using nontraditional or advanced methods of manufacturing (e.g., additive manufacturing (AM, 3-D printing), powder metallurgy-hot isostatic pressing, electron beam welding, etc.) for reactor internals, fuel, or component subject to the Appendix B Program at any stage of their lifecycle?
 - If so, what materials, components, and manufacturing technologies are you considering?
 - What is the estimated time frame for putting a component into service that used a nontraditional or advanced fabrication method?



Summary

- Advanced manufacturing has been identified as an area of potential future utilization by the nuclear industry – “when” and “how many” are the questions
- NRC interest areas
 - The reliability of AM processing and quality of AM parts
 - The properties of AM parts
 - The structural performance of AM parts, including their inspectability
 - The service performance and aging degradation of AM parts
 - Ongoing work in advanced methods for manufacturing.
- Codes and standards aspects of AM is a key to successful implementation
- Comparison of performance of parts from AM and conventional manufacturing process (benchmarking)
- NRC advanced manufacturing action plan under development
- Upcoming RIS may have questions pertaining to AMM