Review of Additive Manufacturing for Reactor Materials & Components

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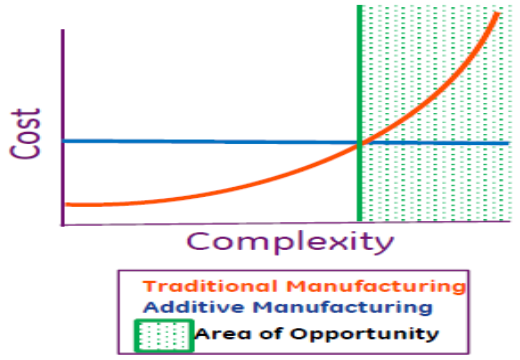
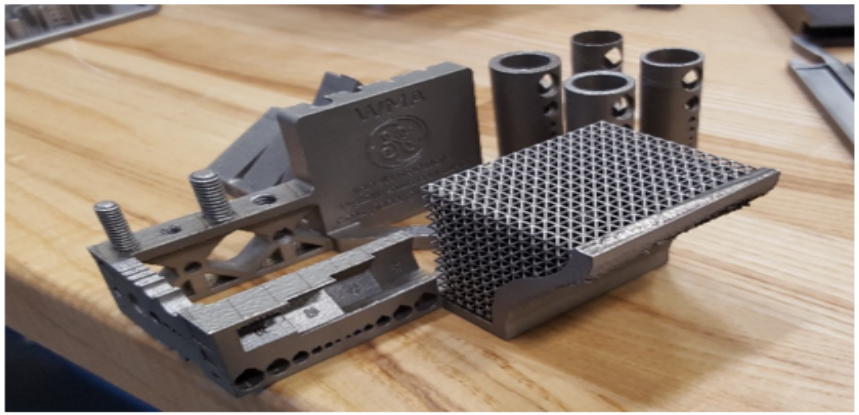
Introduction. Why Additive Manufacturing (AM) for Reactors?

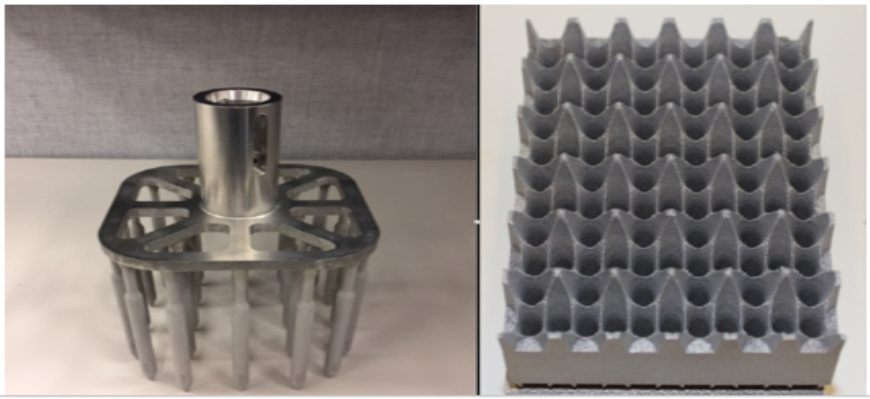
Value and Benefits

- **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
- Tensile 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 OCC 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

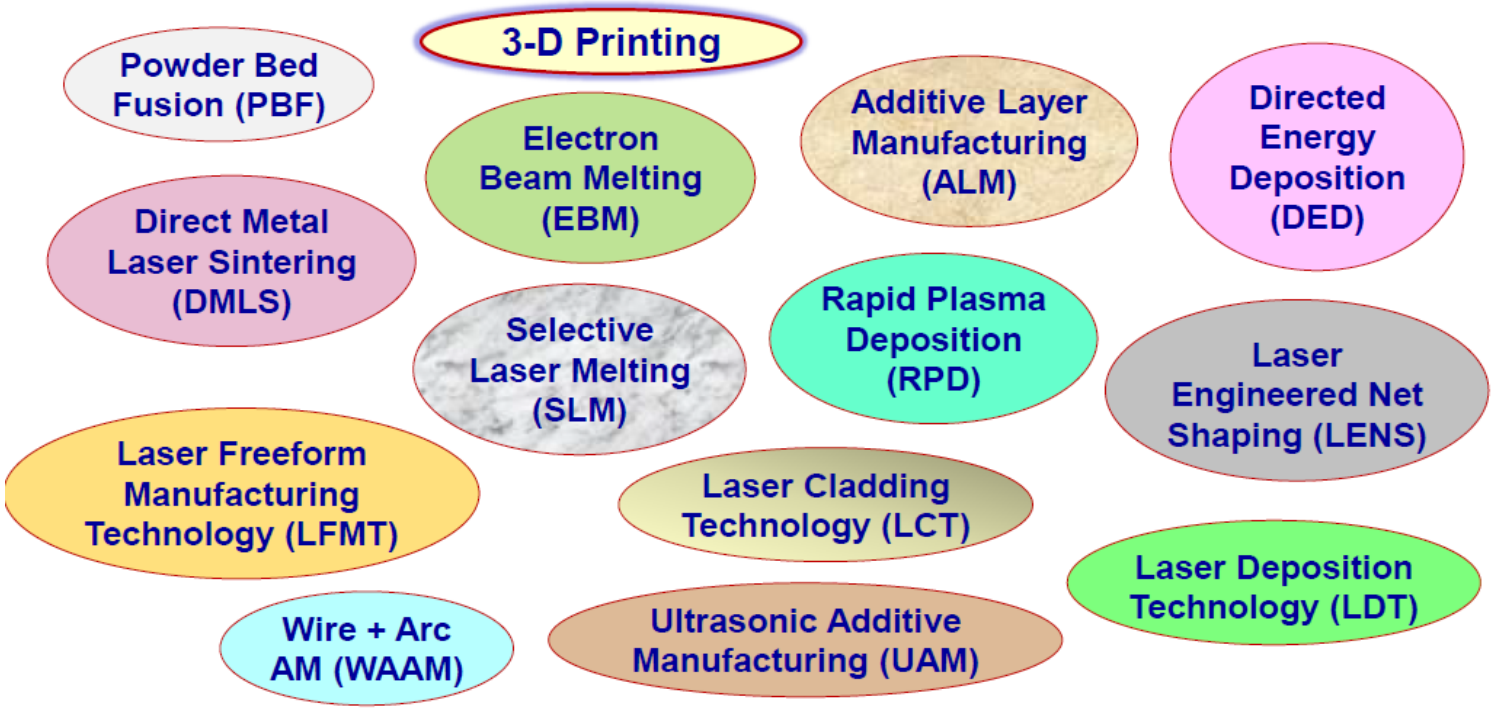
AREVA

forward-looking energy

http://us.areva.com/home/liblocal/docs/Catalog/PWR/ANP_U_481_V1_14_ENG_Additive%20MfgRapidReplacementSafetyRelatedParts.pdf

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

[α] *Presentations archived at* ADAMS - ML17338A880; *from "Standards Development Organizations Involved with AM Standardization, J. McCabe, November 29, 2017*

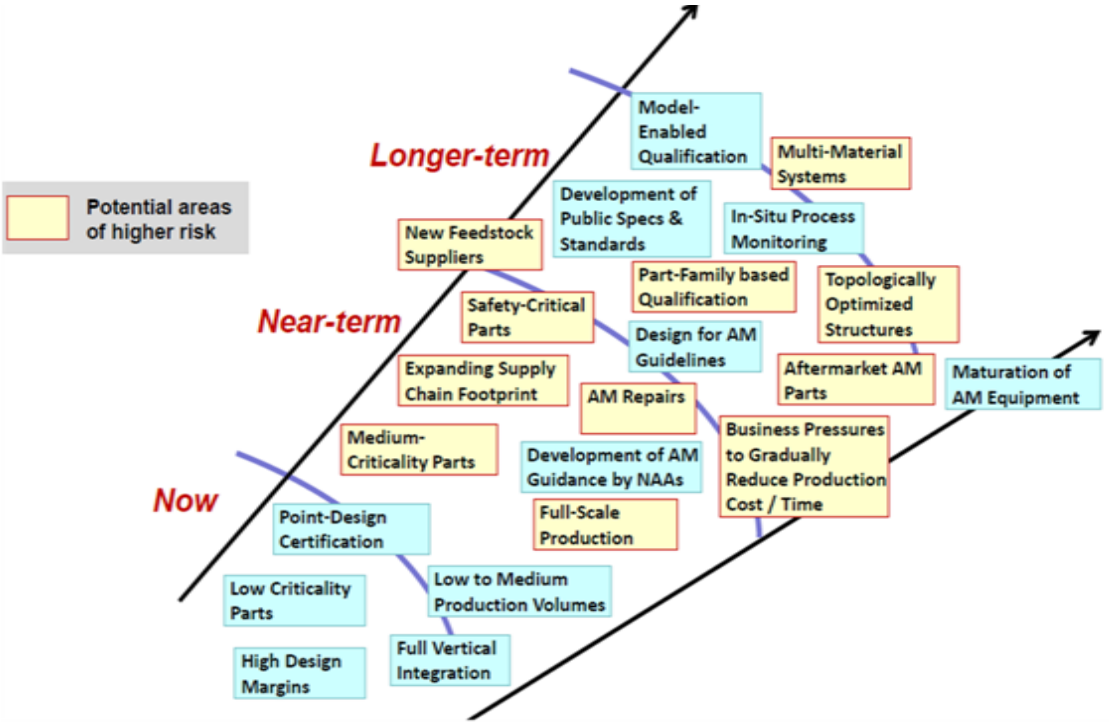
Technical Areas of Additive Manufacturing Presentations at November Public Workshop on AM-RMC

Organization/Speaker	State of Art of AM Processes	Industry Activities	Irradiation Testing & Effects	AM qualification	Standards for AM	NDE	Degradation in AM components	American/ international context	Cyber-security	Regulatory Perspectives	Computer Modeling	Nuclear Fuel
NEI (Mark Richter)		■										
EPRI (Dave Gandy)	■					■					■	
FAA (Michael Gorelik)				■	■					■		
CTC (Scott Zimmerman)									■			
EWI (Bill Mohr)				■	■		■					
EWI (Frank Medina)	■	■										
GEH (Myles Connor)			■				■					
WEC (Zeses Karoutas)		■										
WEC (Bill Cleary)		■										■
WEC (Paula Freyer)		■	■				■					
Novatech (C. Gramlich)		■	■									■
NuScalePower (S. Wolbert)		■										
DRDC (Shannon Farrell)						■	■	■				
RollsRoyce (Dave Poole)								■				
DOE (Alison Hahn)	■											
ORNL (Andrew Worrall)		■										
INL (Isabella van Rooyen)				■								■
NSWC (Sam Pratt)	■											
NAVSEA (Justin Rettaliata)				■								
NIST (Paul Witherell)				■								
ORNL/UTK (Suresh Babu)				■								
NASA/MSFC (Doug Wells)	■											
NASA/WSTF (Jess Waller)						■						
NIST (Kevin Jurrens)				■	■	■						
ANSI (Jim McCabe)					■							
ASME (Kate Hyam)					■							
ASTM (Mohsen Seifi)					■							
NRC/NRR (Dave Rudland)					■							
NRC/NRR (Allen Hiser)										■		

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