# 3D Metal Printing Application to Nuclear

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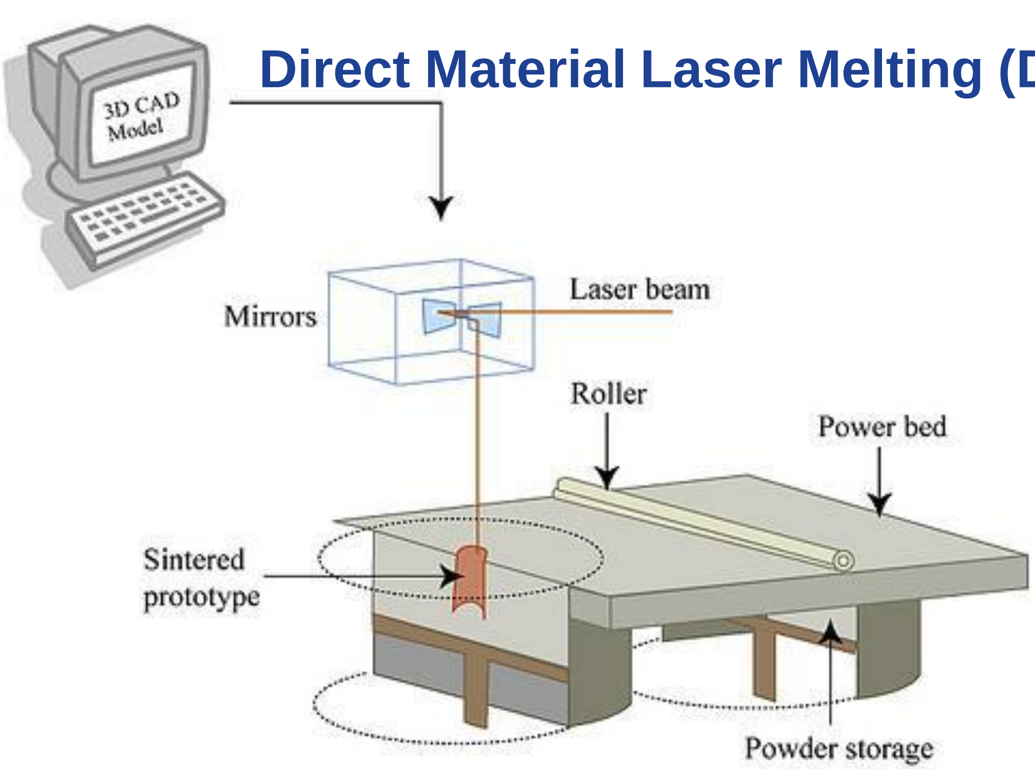
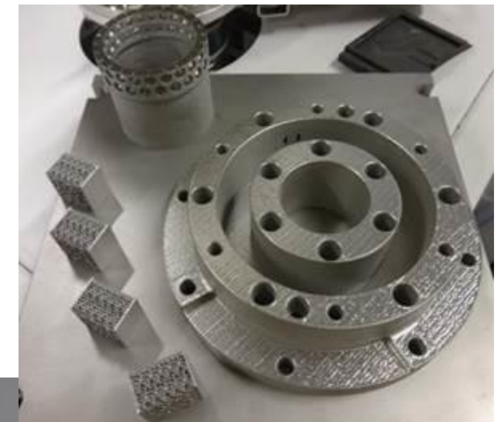
# Topics of Discussion

- 3D Metal Printing “Additive Manufacturing” Overview
- Materials Qualification
- Challenges

# Additive (3D Printing) Process

## Direct Material Laser Melting (DMLM)



**Post Processing (HIP, Heat Treat, Machining, etc.)**

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# Value of Additive/3D Metal Printing

Speed of Delivery: Condensed supply chain enables quick response to emergent needs

- No tooling required: fast turnaround time

Design for Performance: Fewer manufacturing limitations allow new designs

- Design-driven manufacturing as opposed to manufacturing-constrained design

Enhanced chemistry control: Powder atomization → Low Cobalt

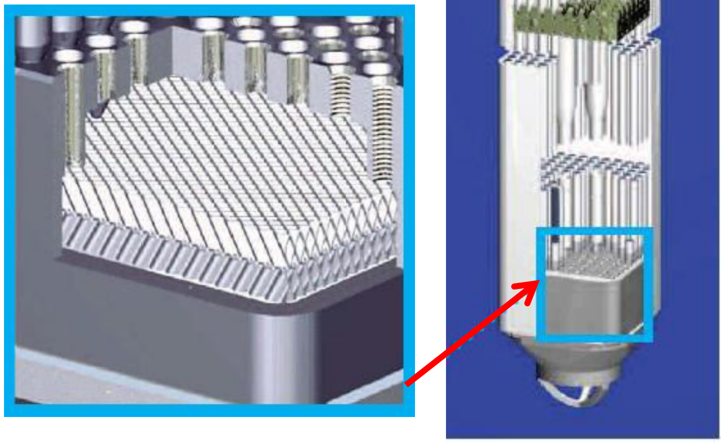
# When to Apply Additive

- Functional Prototypes
- Design for Performance Enhancement where conventional manufacturing is difficult or not possible
    - Weight Reduction
    - Geometric Features Enable Enhancements
- Cost reduction for complex multi-component assemblies
- High-value Products for low volume, specialized or unique components

# Unique Design Development Process

- Example: Enhanced Fuel debris filter: prevent fretting of fuel rods
  - 3D allows making a new design
  - Only way to make it
  - Can quickly make prototype for evaluation
  - Iterate on the design
  - Quickly build for actual in-plant trial

Key concern remains:
Can I use the materials to put a prototype into a plant?



# Additive Materials Qualification Program

# DOE Program - CFA-15-8309

## Environmental Cracking and Irradiation Resistant Stainless Steel by Additive Manufacturing

Objective: Evaluate the stress corrosion cracking susceptibility, corrosion fatigue, and irradiation resistance of the additively manufactured 316L stainless steel in nuclear environment.

Participants: GEGR (Lou - PI), ORNL (Muth), U of M (Was), GEH (Connor, Horn)

Activities: Study DMLM material nanostructure and optimize the material. Proton irradiation at 2 MeV to a dose in the range 5-10 dpa.

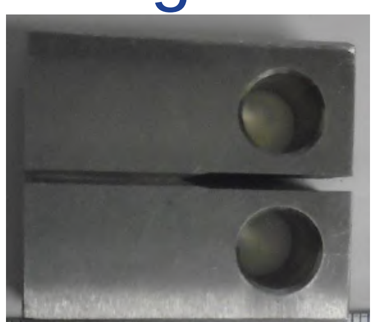
# DOE Program - CFA-16-10393

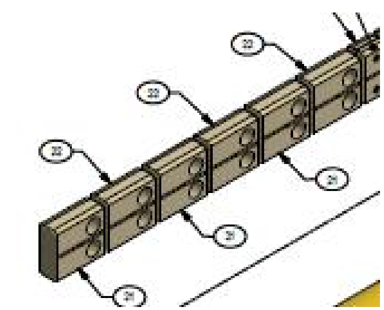
## Irradiation Testing of LWR Additively Manufactured Materials

<u>Objective</u>: Perform full irradiation / PIE on structural materials produced by DMLM

<u>Participants</u>: GEH (Horn - PI), INL (NSUF facility)

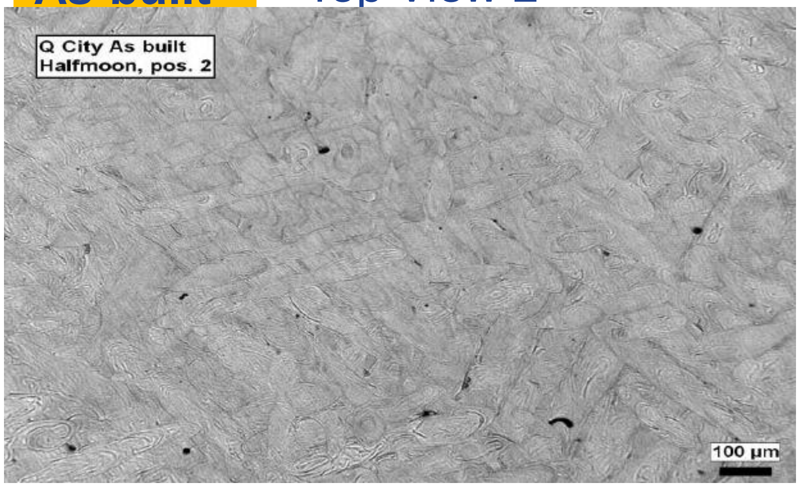
<u>Activities</u>: Obtain microstructural characterization, mechanical properties, stress corrosion crack growth data for un-irradiated **Type 316L and IN 718** (GEH) and corresponding irradiated data to 1 dpa (INL at the ATR)



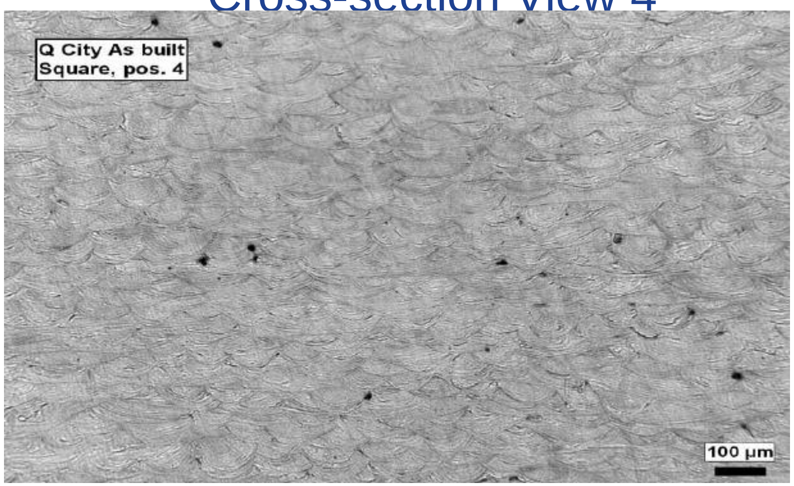



**As-built**

Top View 2



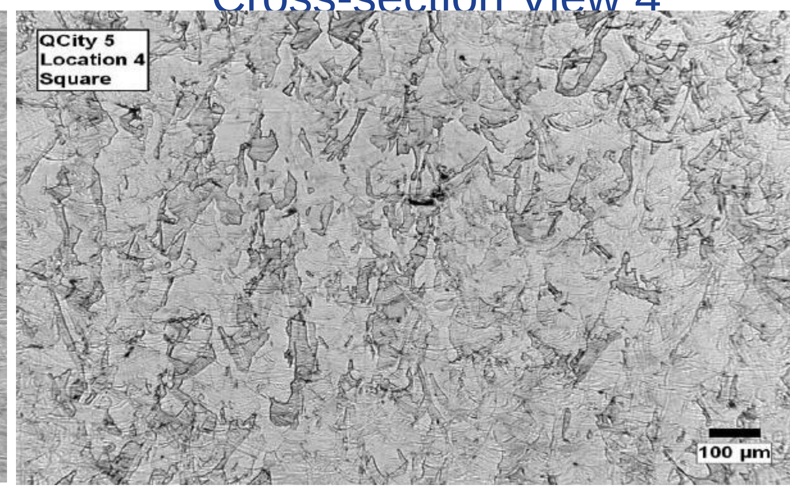

Cross-section View 4



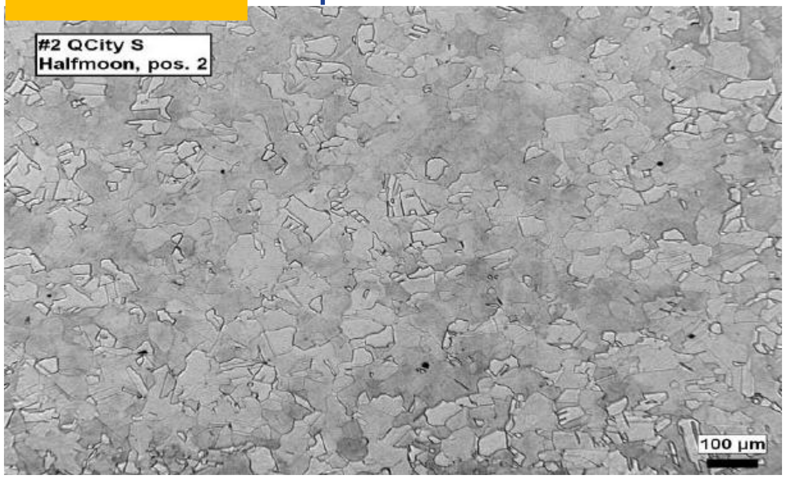

**Stress Relief**

Top View 2

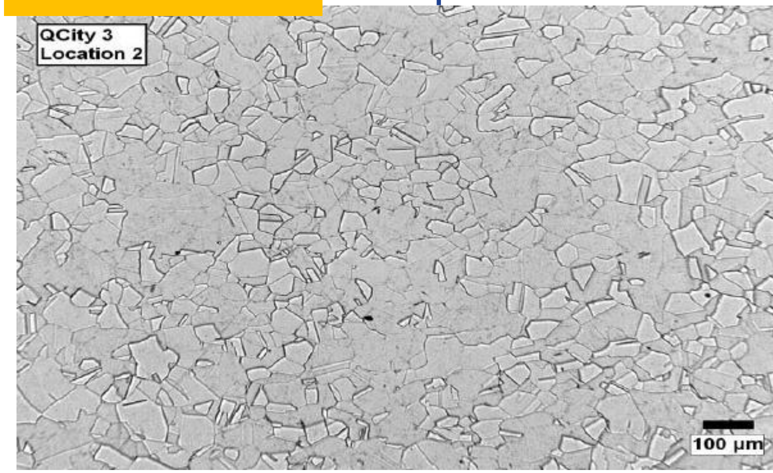

Cross-section View 4



**Anneal** Top View 2

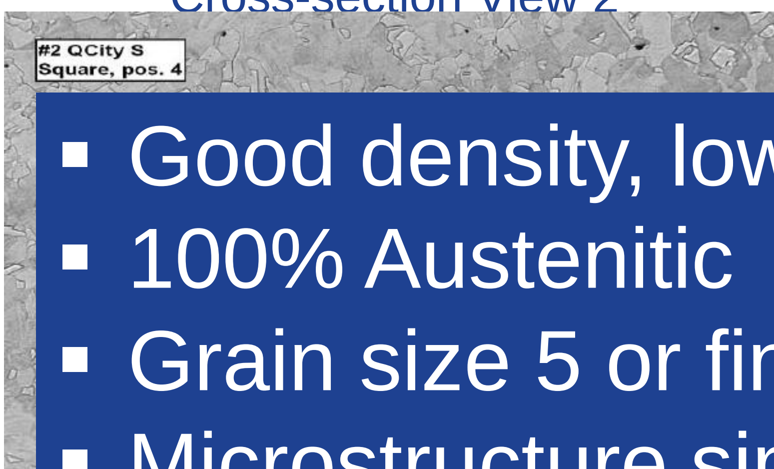



**HIP+Anneal** Top View 2

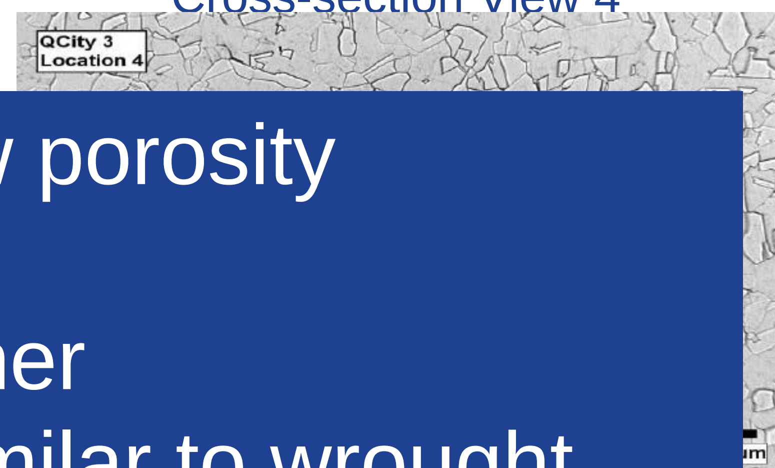




Cross-section View 2




Cross-section View 4




- Good density, low porosity
- 100% Austenitic
- Grain size 5 or finer
- Microstructure similar to wrought

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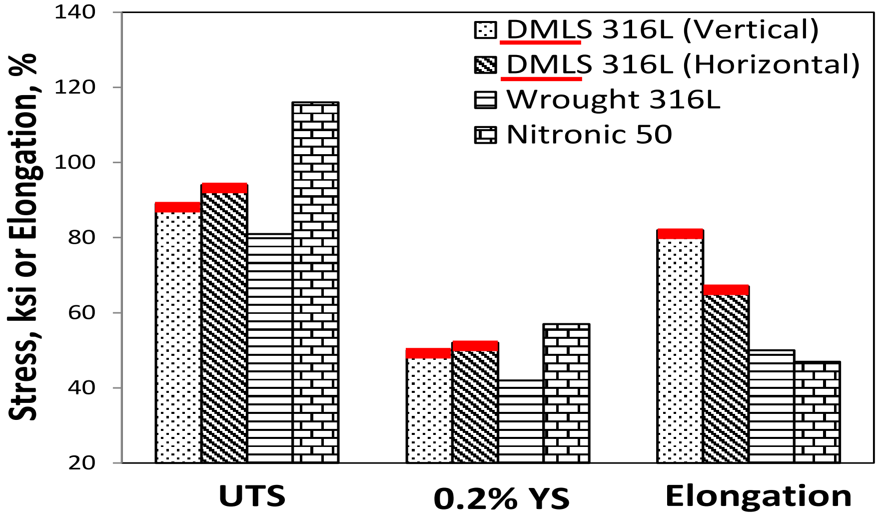
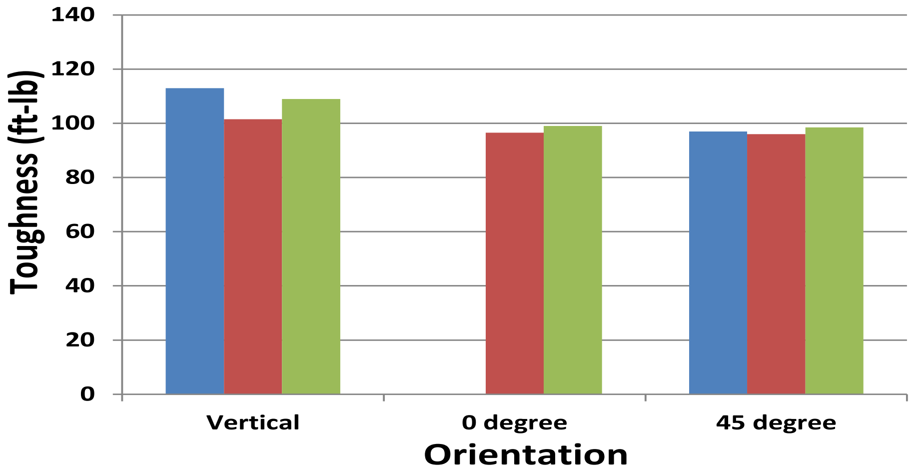
# Tensile and Charpy Properties

HIP+Anneal




HIP+Anneal




Good ductility (>40%El)
Good yield strength

Typical charpy toughness for annealed 316L @RT: 65~100 ft-lb

**AM 316L mechanical properties similar to Wrought 316L**

# Challenges

# Inspection Challenges

- Complex geometry = complex inspection
- Only simplest parts can be UT inspected
- Computed Tomography (CT) scan can be used for dimensional validation
- Produce test specimens as part of each build
  - ➢ Cut up, SEM, and mechanical testing of selected complete parts
- EPRI leading CFA-16-10169 team for In-situ monitor
  - ➢ Integrated Computational Materials Engineering (ICME) and In-situ Process Monitoring for Rapid Qualification of Components Made by Laser-Based Powder Bed Additive Manufacturing (AM) Processes for Nuclear Structural and Pressure Boundary Applications

# Standards & Regulatory Challenge

Approved ASTM Specifications

- Additive Manufacturing Stainless Steel Alloy (UNS S31603) with Powder Bed Fusion
- Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion

ASME Code Case – code application is not intended however this level of approval is generally accepted

BWRVIP-84 – EPRI BWR Vessel and Internals Program is working on guidelines for “Qualification of Advanced Processes”

# Part Performance Challenges

Although a multiplicity of features can be 3D printed, the performance must be tested or simulated

- Testing representative of nuclear operating conditions can be expensive
- CFD simulation is challenged for the areas of greatest opportunity
  - Steam separator for ΔP/efficiency optimization
  - Fuel spacer for CPR performance optimization

# Conclusions

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- DMLM process provides and excellent opportunity for nuclear metals application as has been shown for other industries
- Materials qualification is progressing well
- Challenges to inspection, standards, and performance optimization

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