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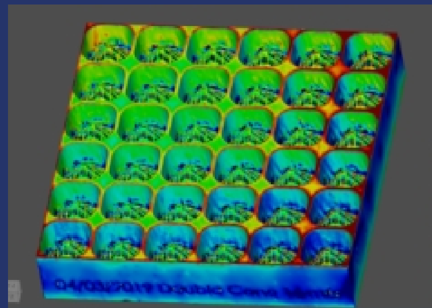


Westinghouse Design for Additive Manufacturing (AM) and Development Needs

Clinton Armstrong and David Huegel

Westinghouse

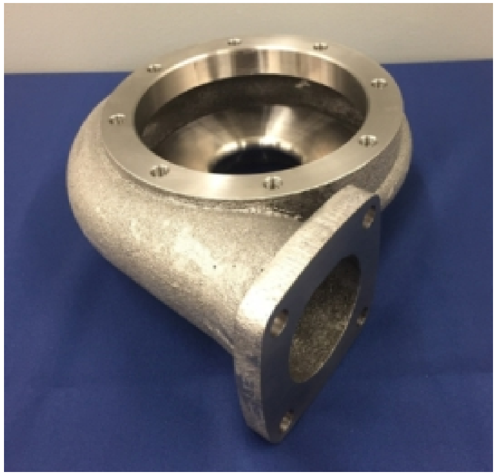
Outline

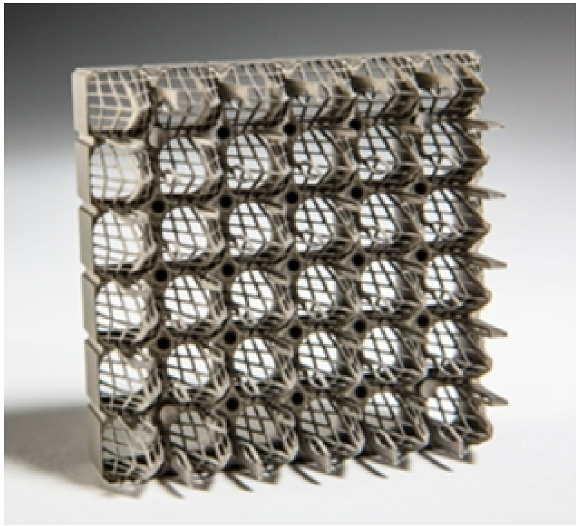
- Advance Manufacturing Objectives
- Additive Manufacturing (AM) Implementation
  - Irradiation Testing of AM Materials
  - Thimble Plugging Device (Reactor Ready Component Project)
- Design for AM (DfAM) Examples
  - Fuel Components
  - Tooling Applications
  - Advanced Reactor Components and Replacement Parts
- M&S Development Needs

Advanced Manufacturing Program Objectives

Improve industry competitiveness, through the development and implementation of advanced manufacturing technologies

- Drive cost reductions in component manufacturing
- Enable new products and services that provide innovative customer solutions
- Leverage collaborative development and external funding sources





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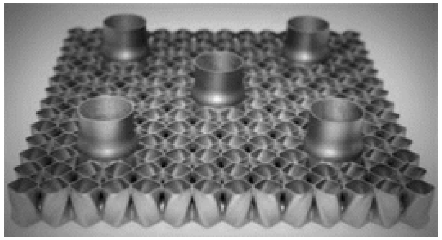
Additive Manufacturing Implementation

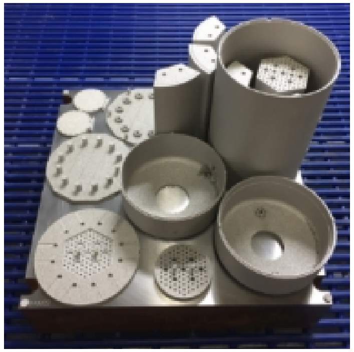
Exploiting the benefits of Additive Manufacturing

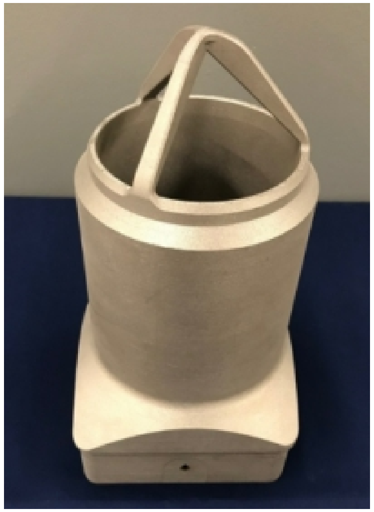
- Producing components with: Powder Bed Fusion, Binder Jetting, and Directed Energy Deposition AM technologies
- Complex components required for performance gains
- Obsolete and high value / lead-time components
- Advanced reactor components – eVinci™, LFR
- Prototypes, mockups, jigs / fixture, tooling

Enabling AM for Nuclear Component Manufacturing

- Leading material development & testing for in reactor use
- Supporting the development of ASTM and ASME codes and standards
- Submitted first ASME AM code case (August 2020)







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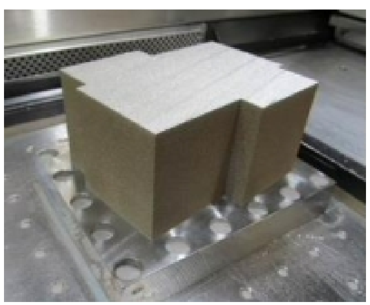
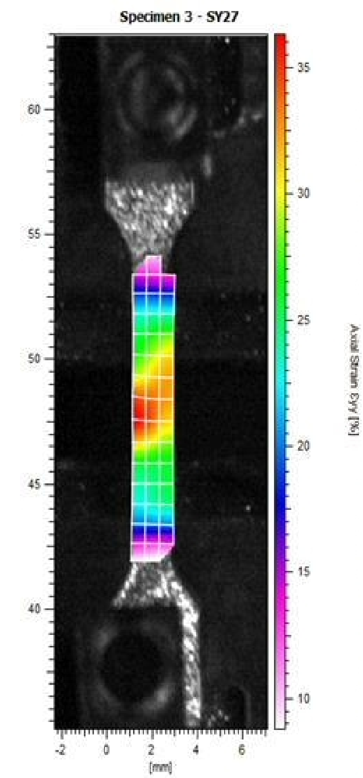
Irradiation Testing of AM Materials

AM Materials Development

Westinghouse has funded material development and irradiation performance testing for 316L SS, Ni Alloy 718 and Zr

- Produced AM block and micro-tensile test specimens
- Irradiating materials in MIT's test reactor (Oct. 2014 → 2018)
- Completing post-irradiation examination (PIE) at Westinghouse Churchill laboratory (316 and 718 completed, Zr PIE DOE funded)
- AM 316L irradiation performance consistent with wrought





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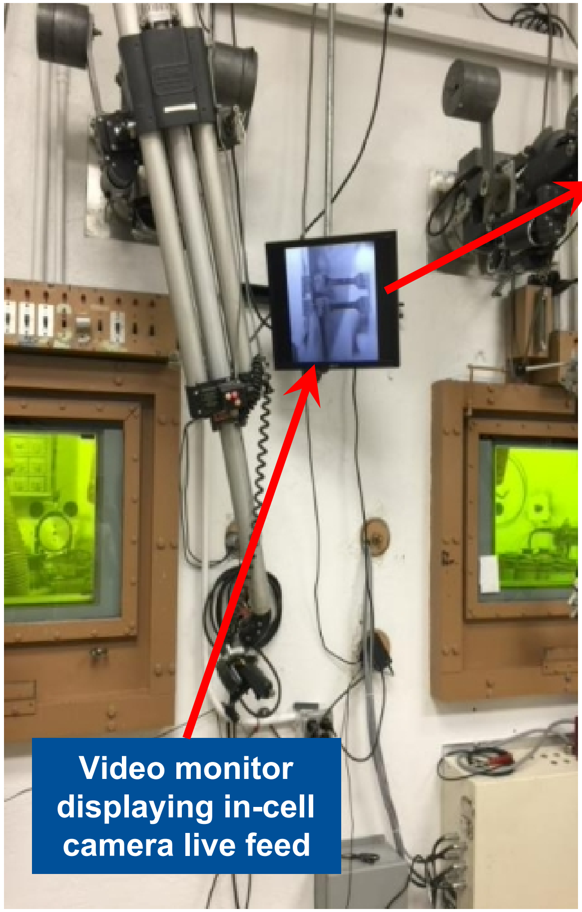
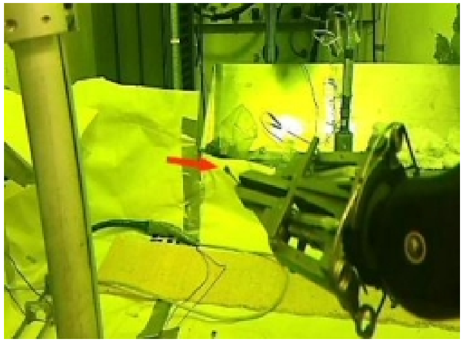
Mechanical Testing Irradiated AM Specimens

- Unirradiated and irradiated tensile testing of AM 316 SS and Alloy 718 materials inside WEC hot cell
- Room Temp and elevated Temp (i.e., 572°F) tensile testing of ~50 AM 316SS specimens and ~50 AM Alloy 718 specimens
- Extensive unirradiated and irradiated materials evaluations completed



Video monitor displaying in-cell camera live feed

Intact irradiated quad held with hot cell grips prior to separation into 4 individual miniature tensile specimens



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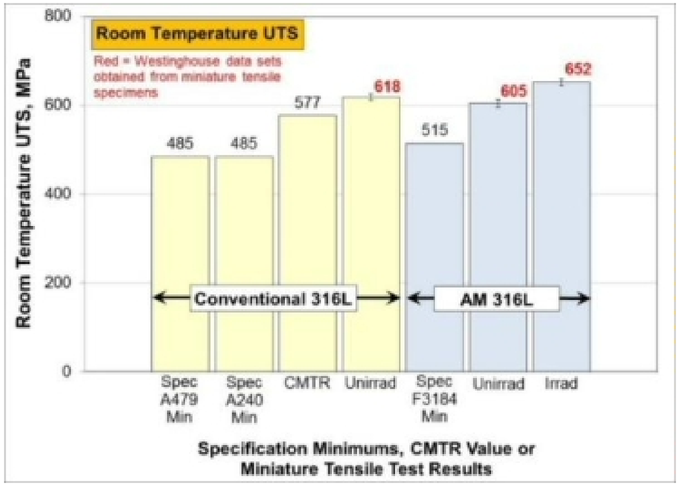
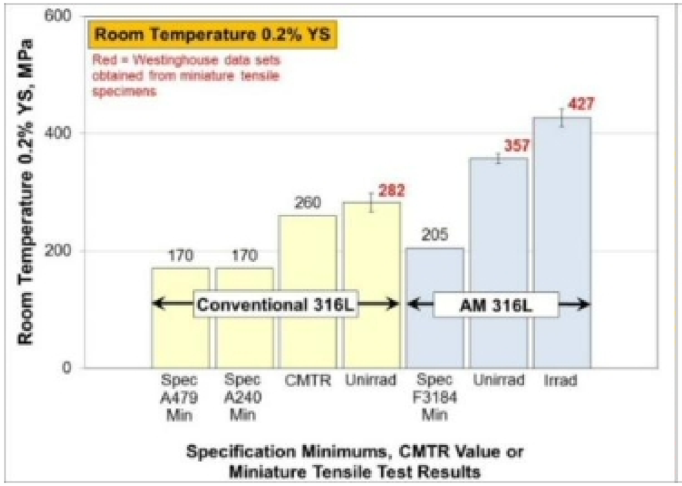
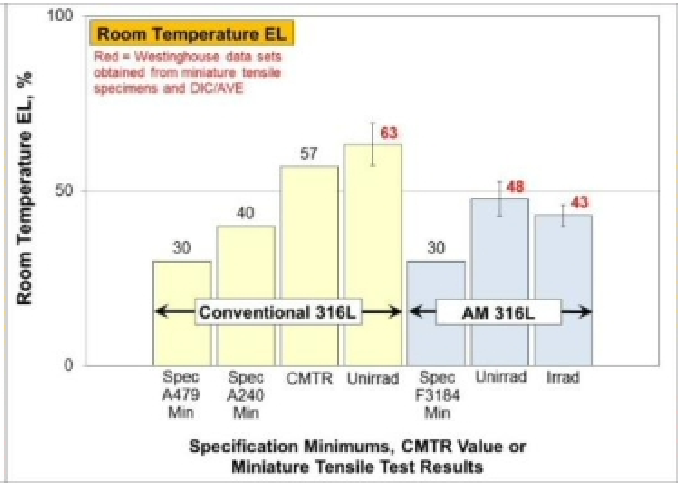
Mechanical Testing Irradiated AM Specimens

316L samples have been tested and evaluated for mechanical properties

- The absolute values for the AM material Ultimate Tensile Strength (UTS), 0.2% Offset Yield Strength (YS) and percent elongation (% EL) were as expected and consistent with conventional material
- Tensile strengths, both UTS and YS increased with irradiation as expected
- % EL went down with irradiation







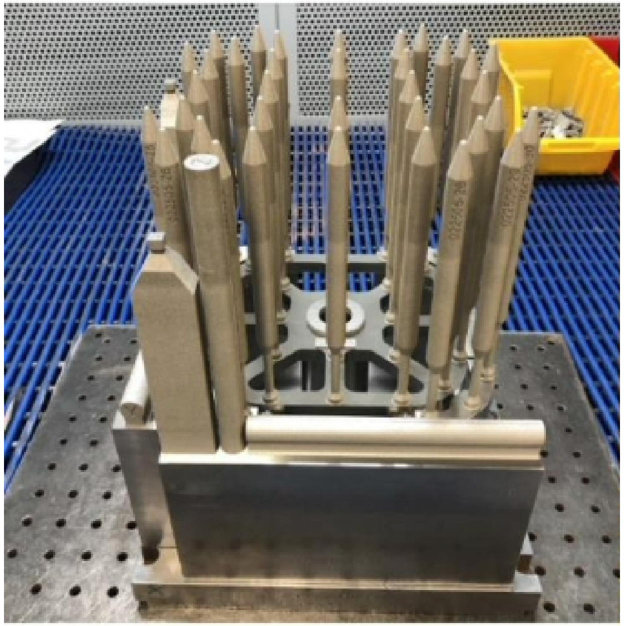
AM Thimble Plugging Device
(Reactor Ready Component Project)

Reactor Ready Component Project

Kaizen Event Held to Select Demonstration Component – Dec 2014

- Thimble Plugging Device (TPD) selected as the first AM Fuels component to be placed in a commercial reactor as a demonstration component
- Low risk component, moderate complexity, fully contained in guide thimble tubes.
- AM TPD is equivalent in Form, Fit and Function as existing TPD.

Completed testing, analysis, quality assurance, manufacturing qualification, licensing, etc. to support one production AM TPD



Working with Exelon, the AM TPD was delivered for the Byron Unit 1 Spring 2020 Outage via 10CFR50.59

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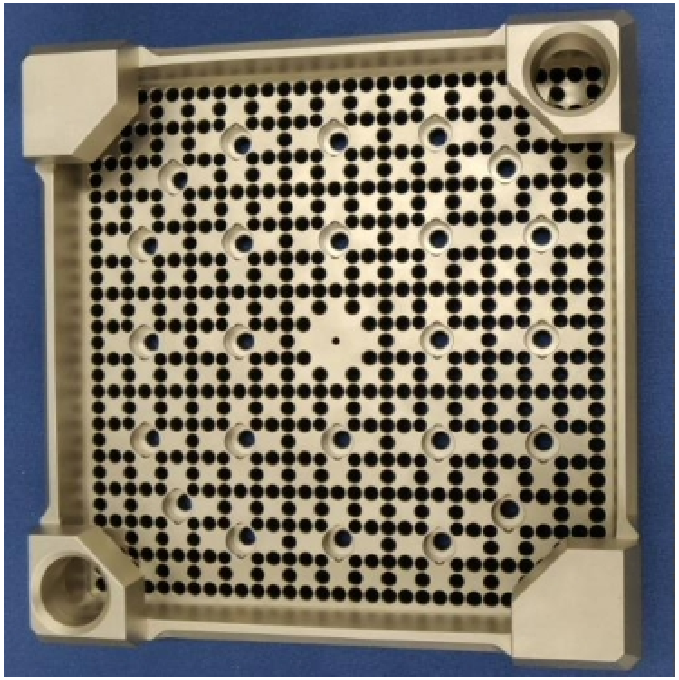
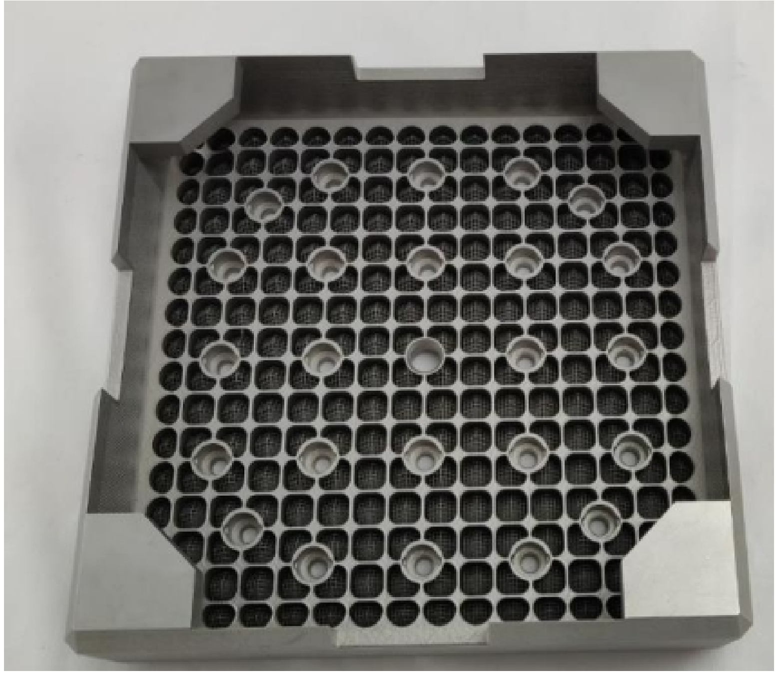
Fuel Components

PWR Debris Filtering Bottom Nozzle

AM Benefits

- Reduced pressure drop
- Improved debris filtration
- Multiple complex designs are enabled by AM, and prototypes can be built overnight





PWR Debris Filtering Bottom Nozzles

1. Single External Mesh
2. Single Internal Mesh
3. Double Internal Mesh
4. Optimized Double Internal Mesh
5. Optimized Double Internal Mesh with Inlet Features

AM allow for quick design iterations and performance testing

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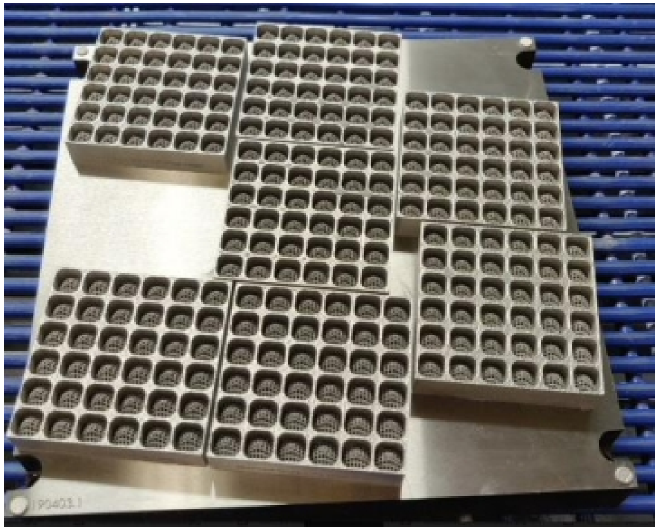
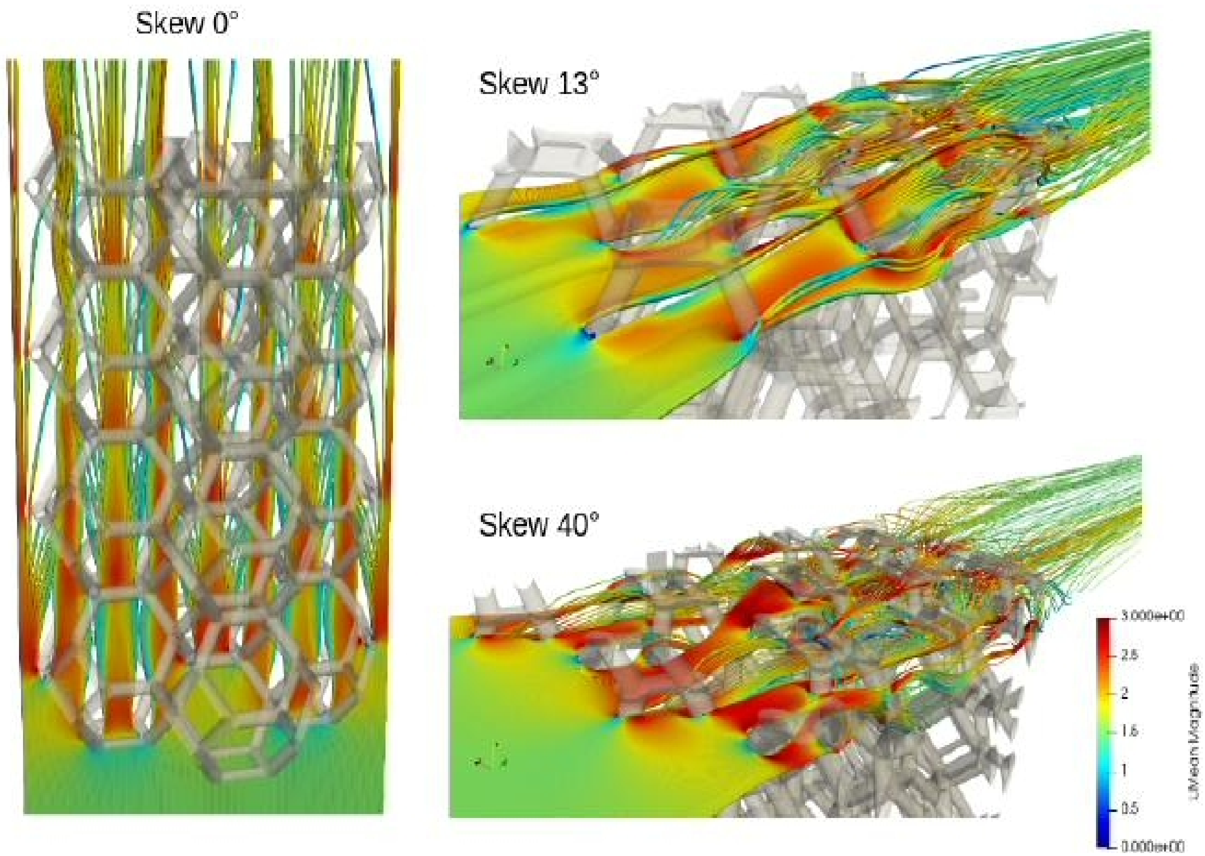


Testing of 7 Mesh Designs in 1 Build

PWR Bottom Nozzle – Multi-Physics Optimization

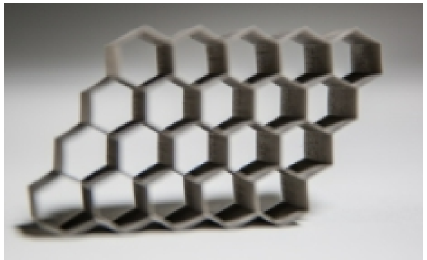
Pursuing advanced PWR Fuel Bottom Nozzle design through multi-physics topology optimization and DfAM to improving filtration and reduce pressure drop

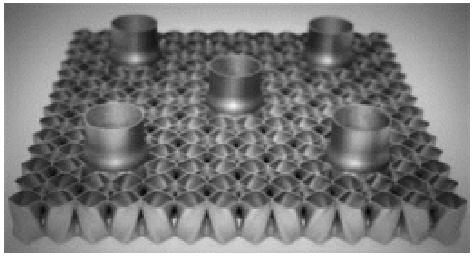


Fuel Spacer Grids

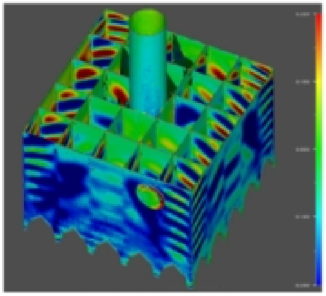
AM Benefits

- Stronger support of fuel rods
- Improved mixing characteristics

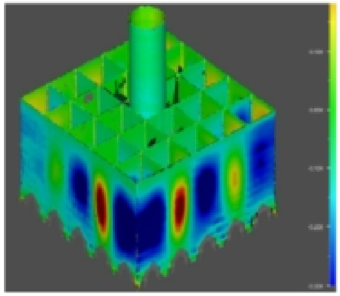




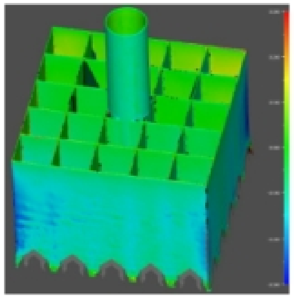
Designing AM thin-walled features to improve dimensional stability



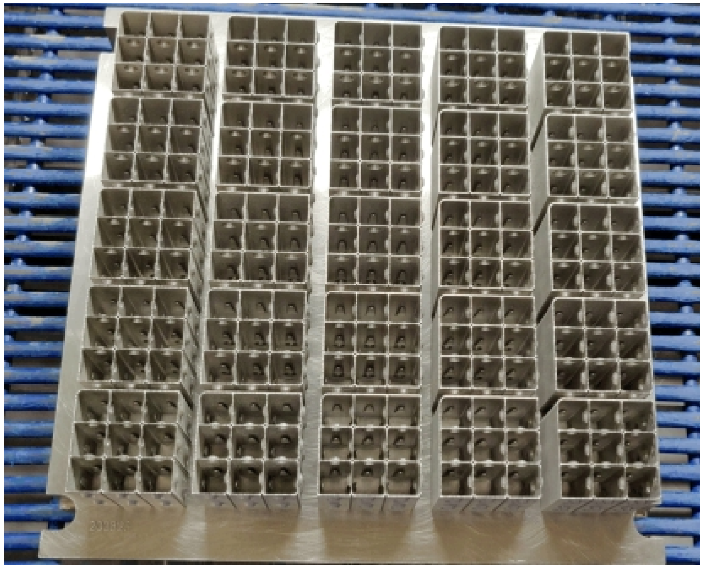
200 μm wall



300 μm wall

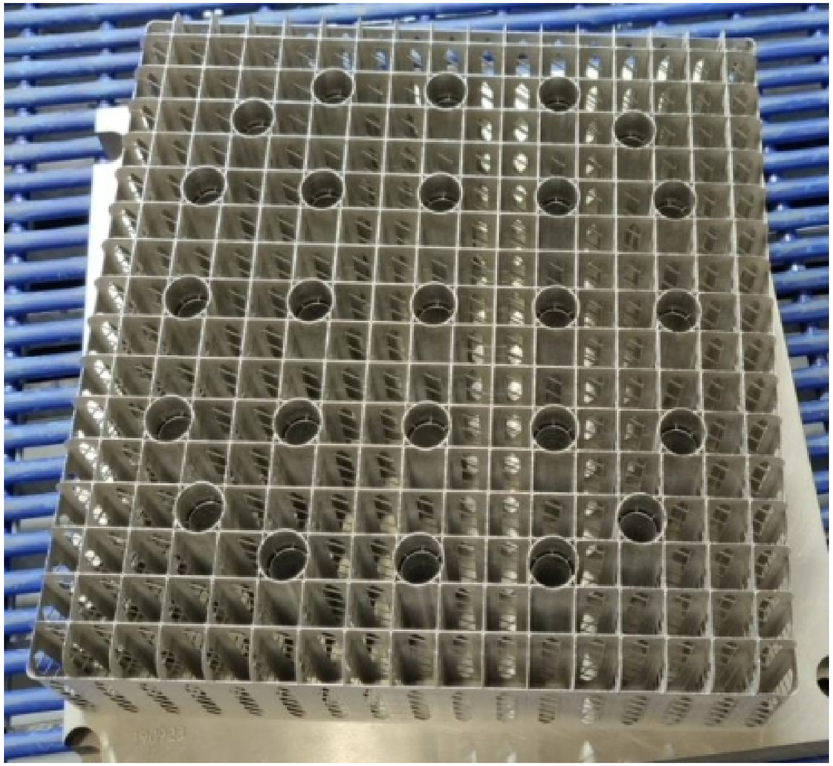


500 μm wall



Fuel Spacer Grids

Traditional stamped, assembled and welded grid versus 1-piece AM grid



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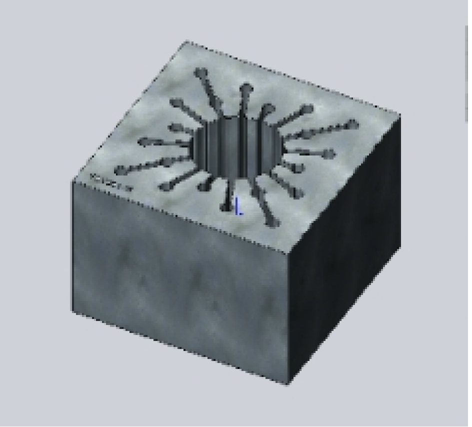
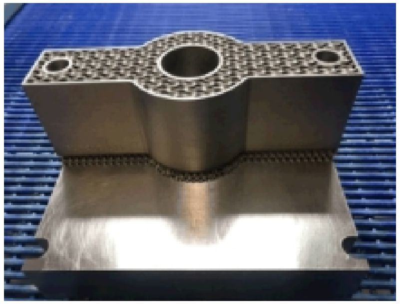
Tooling Applications

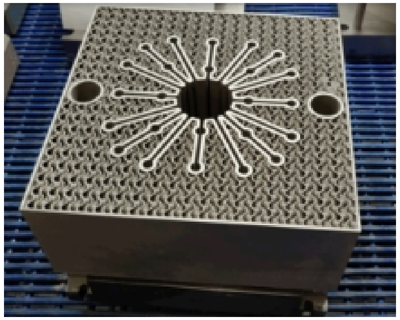
Control Rod Spider Gage

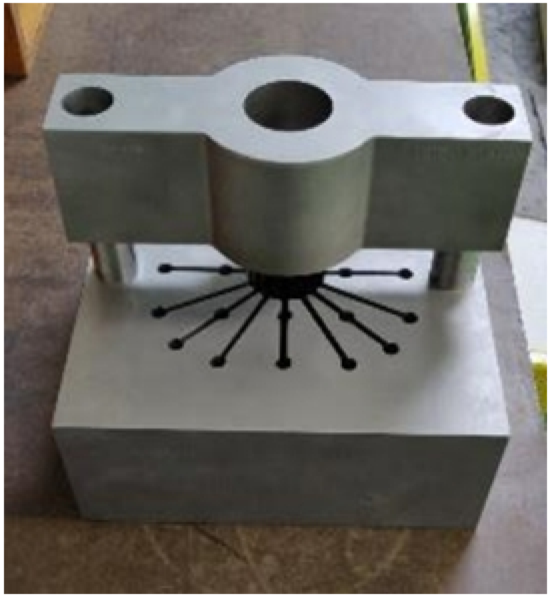


Gage used to measure the locations of the spider fingers after welding/brazing

- This gage weighs ~60 lbs, so inspectors are at risk of injury during gage movement
- Redesigned to a total weight of less than 35 lbs







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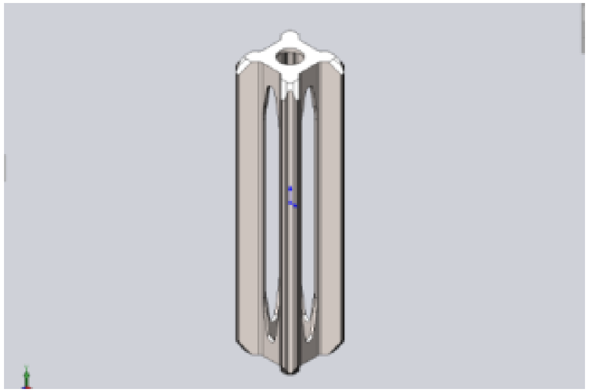
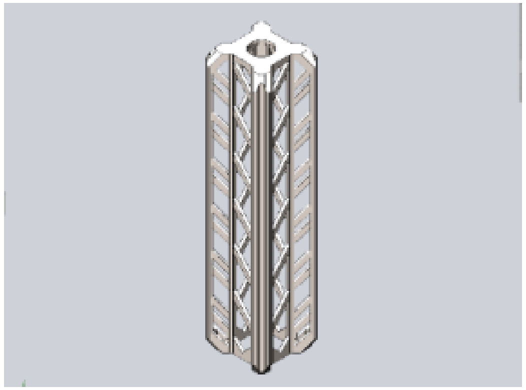
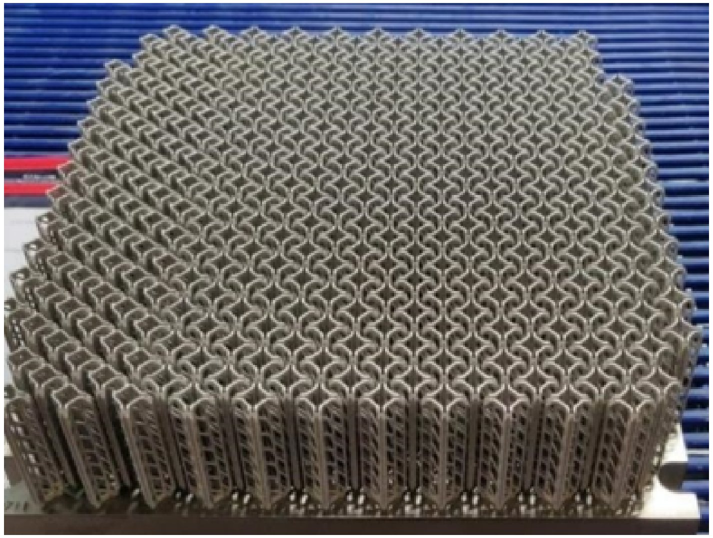
Fuel Grid Strap Alignment Pins

Completed multiple design iterations to reduce build times and material usage / weight and increase part life





Optimized build layout to maximize alignment pins per build and minimize cost per alignment pin



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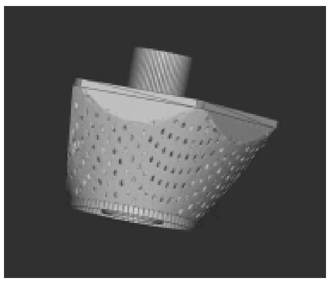
Advanced Reactor Components and Replacement Parts

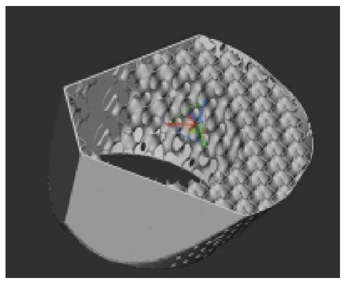
WAAP-12173

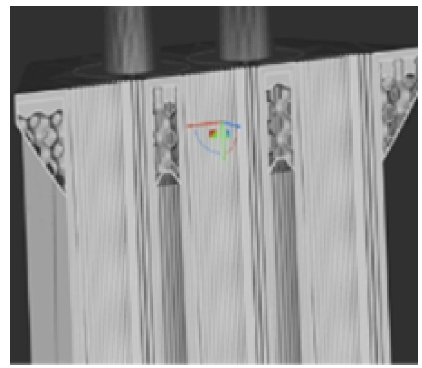
eVinci™ Microreactor Primary Heat Exchanger (PHX)

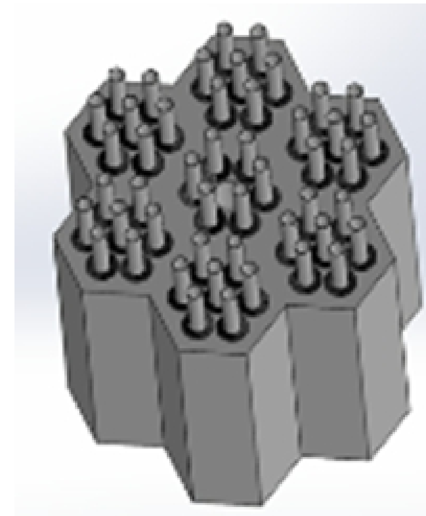
eVinci PHX AM Design / Concepts

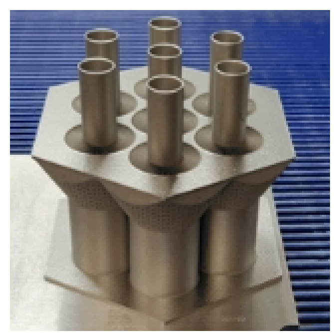
- Developed lattice support structure for HX header plates
- Flexible supports allow tube movement during thermal cycle











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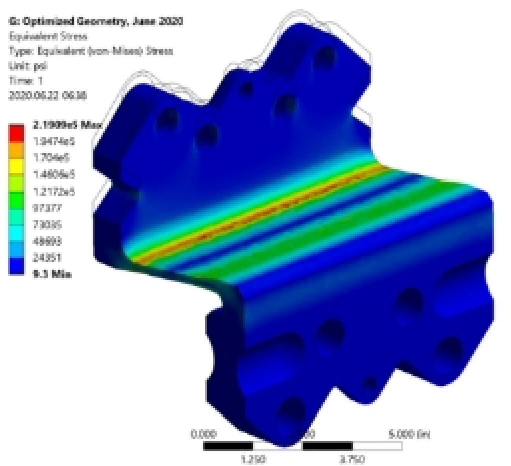
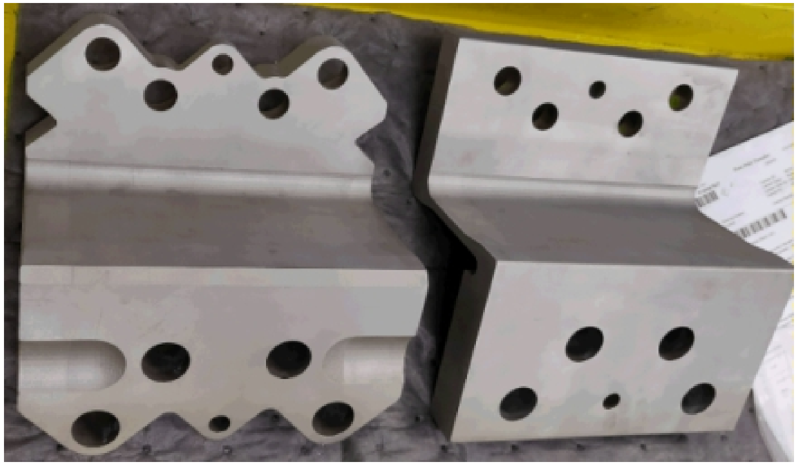
Thermal Shield Flexure

Topology Optimized AM Concept

- Completed topology optimization, FEA and DfAM
- Additively manufactured optimized and traditional designs
- Complete fatigue testing of traditional wrought flexure and AM flexures
  - All 3 flexure successfully met fatigue testing cycle requirement





Modeling and Simulation Development Needs

M&S Development Needs

- Multi-physics optimization / generative design for AM structural and flow components
  - Topology optimization / FEA, CFD and DfAM constraints
- High-resolution, high-speed distortion simulation with the ability to auto-adjust input model and/or optimize layer / region parameters
- AM process and material performance simulation
  - AM parameters > grain size & structure > mechanical properties
  - Ability to optimize for parameters to minimum build time
- Irradiation performance modeling for AM materials