Westinghouse **VISION & VALUES**

together

we advance technology & services to power a clean, carbon-free future.

- Customer Focus & Innovation
- Speed & Passion to Win
- Teamwork & Accountability

Safety • Quality • Integrity • Trust

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Additive Manufacturing at Westinghouse

2023 NRC Workshop on AMTs for Nuclear Applications

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Westinghouse

October 2023

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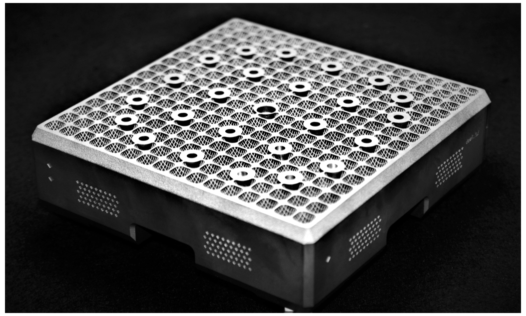
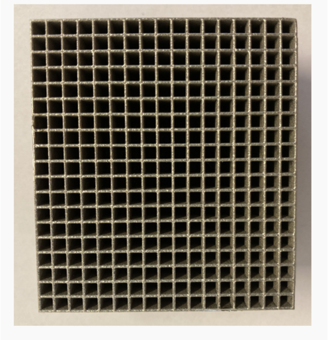
Advanced Manufacturing Objectives

- **Improve industry competitiveness, through the development and implementation of advanced manufacturing (AM) technologies**
  - Drive cost reductions in manufacturing
  - Enable new products and services that provide innovative customer solutions
  - Leverage external funding sources and collaborative development

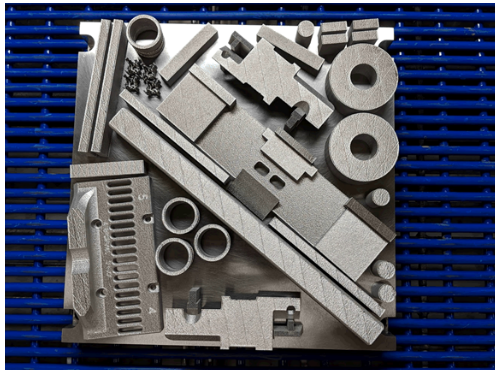
Thimble Plugging Device



Advanced AM PWR Bottom Nozzle



Advanced AM BWR Bottom Filter



Tooling - AM Laser Powder Bed Fusion

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Additive Manufacturing at Westinghouse

- Additive Manufacturing will have a big impact in Nuclear:
  - Cost Effect
  - Improve Performance and Reliability
  - Improve Delivery and Schedule
- Westinghouse is fully invested in the AM technology:
  - Continue to performed significant testing on 3D parts (with and without radiation effects)
  - Utilizing 3D printing for tooling for manufacturing
  - Implemented a 3D AM part in reactor to gain experience
  - Building/designing numerous parts with AM for eventual employment in a nuclear reactor (grids, nozzles, etc.)

Our Goal is for AM to Help Transform the Nuclear Industry

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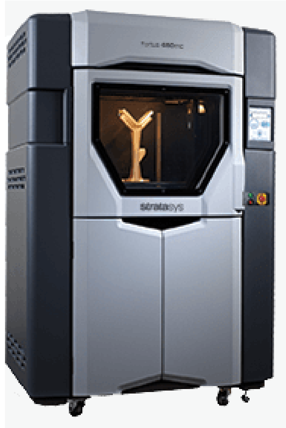
Additive Manufacturing – Westinghouse Equipment

- Westinghouse owns one (1) EOS M 290 machine for printing in metal with access to additional machines at the same facility
  - Currently printing in:
    - Alloy 718
    - SS Types: 316L, 304,17-4 PH and MS-1
    - Copper and Aluminum
  - Build volume 250mm x 250mm x 325mm (9.85 x 9.85 x 12.8 in)
- Additively Manufactured (3D Printed) Plastic Parts

- CFFF installed a high quality Fortus 450 polymer FDM printer.
- Build volume 406mm x 355mm x 406 mm (16 x 14 x 16in)
- Variety of ABS and Nylon materials



Westinghouse AM Equipment

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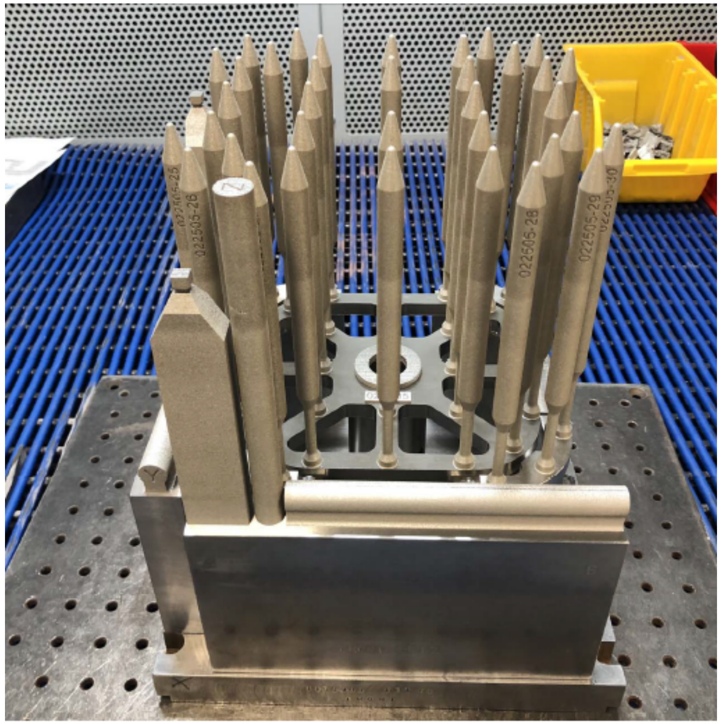
First AM Nuclear Fuel Component Installed in Commercial Reactor

First AM Component (TPD) Installed at Commercial Reactor

- AM Thimble Plugging Device (TPD) first AM fuels component successfully installed in a commercial reactor (Byron 1 March 2020)
  - Low Risk Component, moderate complexity
- Westinghouse met with NRC in May 2019 at the Westinghouse Rockville offices and discussed AM TPD in detail prior to installation.
  - Implemented using the 50.59 process



AM Component (TPD) Outage 25 Inspection Summary

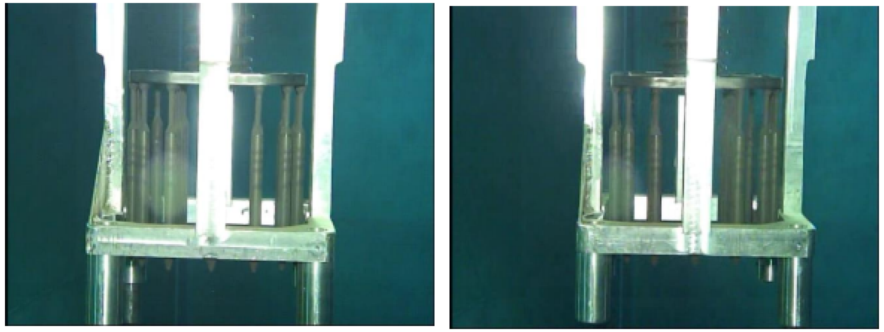


Figure 1: AM TPD Visual Rodlet Inspection Right and Left Side Alignment

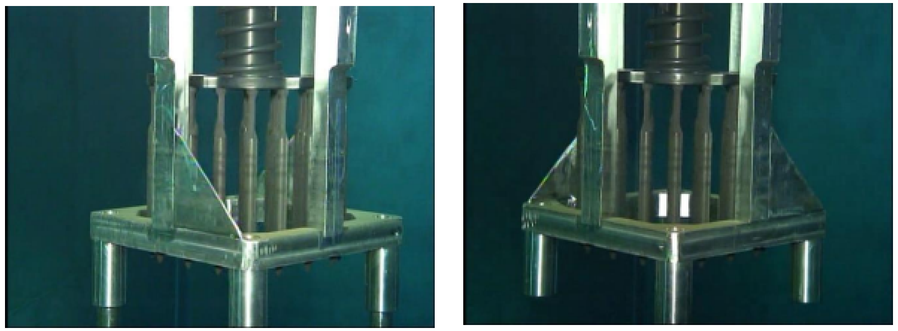
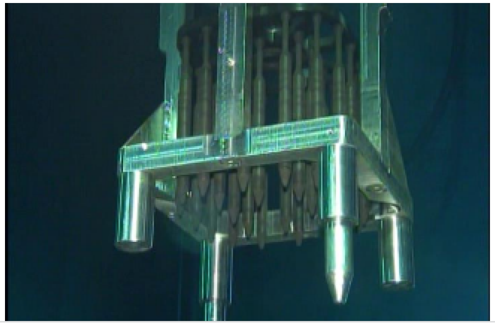


Figure 2: AM TPD Visual Rodlet Inspection 45° and 225°



AM Component (TPD) Inspection Following Removal

- Westinghouse is currently involved with discussions with EPRI and the customer to have the AM TPD (once removed from the Byron core) shipped to a national lab for the purposes of performing detailed analyses and testing.

- Westinghouse is in the process of performing detailed dose analyses to support the shipment of the AM TPD.

- Expected removal from the Byron Unit 1 Core following Cycle 27 operation.

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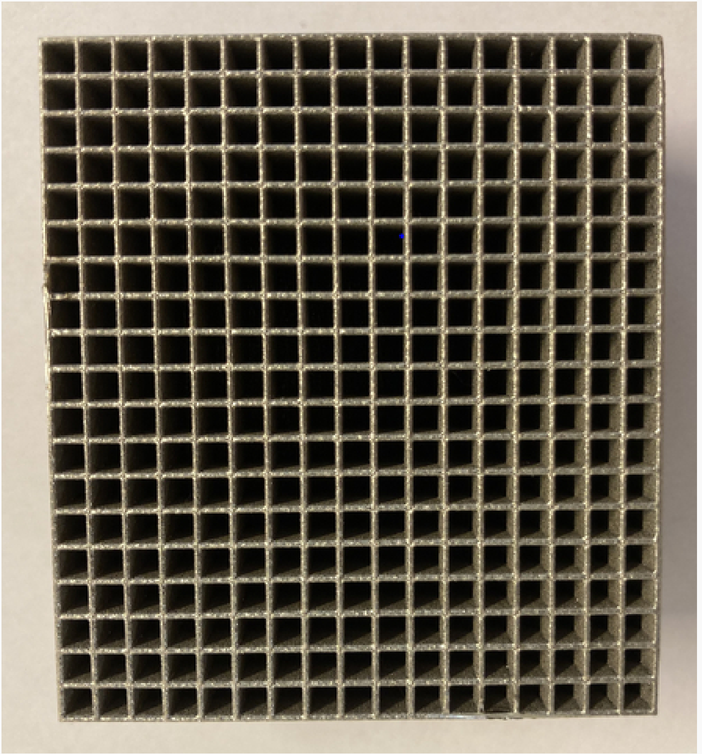
First AM BWR Bottom Filter Installed in Commercial Reactors

First AM BWR Bottom Filter Fuel Component Installed

- Westinghouse created the StrongHold AM filter in close cooperation with Teollisuuden Voima Oyj (TVO) and Oskarshamn (OKG)
- The StrongHold AM filter is a fully manufactured 3D printed bottom nozzle which offers enhanced capture features to prevent debris from entering the fuel assembly bundle region where it could potentially damage the fuel cladding.
- Debris testing demonstrated that the StrongHold filter performed better than the existing TripleWave+ bottom filter
- StrongHold AM filters were installed in Olkiluoto Unit 2 in Finland and Oskarshamn Unit 3 in Sweden



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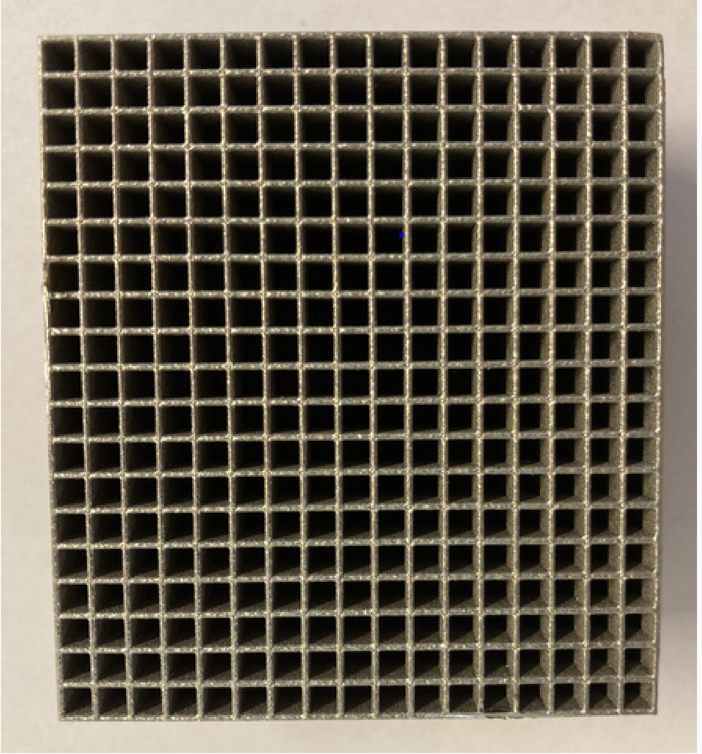
First AM BWR Bottom Filter Fuel Component Installed

- Internal debris capturing features added utilizing the reduced pressure
- Design incorporates a “tortuous pathway” with unique debris capturing features
- Testing demonstrated the effectiveness of the AM filter

Filter Version	100% Efficiency Threshold
Standard TripleWave+	> 10 mm
Conventional Stronghold	~ 7mm
Additive Stronghold	5 mm
Additive Triton 11	5 mm



Westinghouse Developed AM Nuclear Fuel Components

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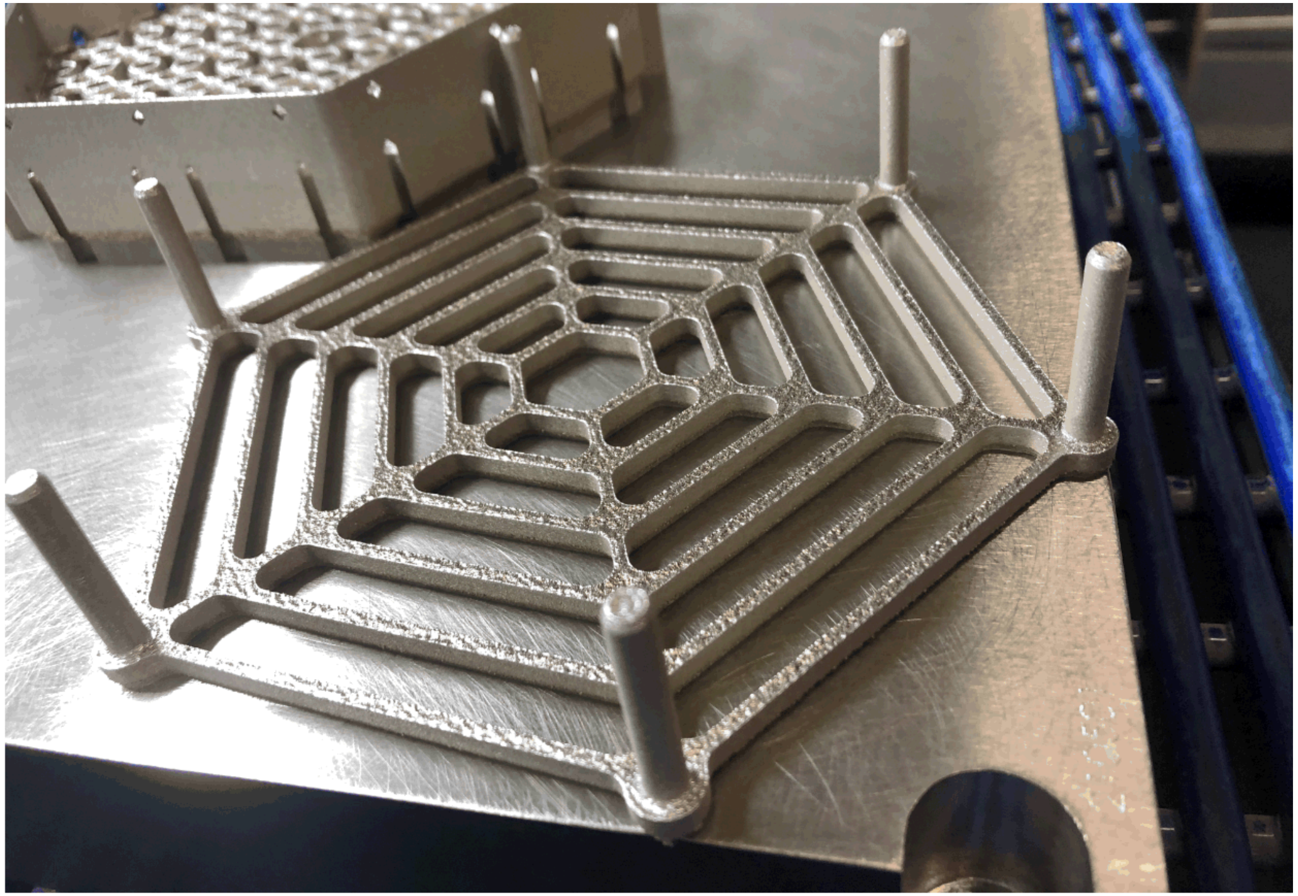
VVER-440 AM Top Flow Plate

- Hexagonal Russian fuel design
- Plate printed in 316L SS
- Eliminates need for welding of pins
- Combines 7 pieces into 1
- Retains fuel rods in accident scenario
- This AM top flow plate design was provided for implementation on a region basis to the Ukraine Rivne 2 plant in 2023.



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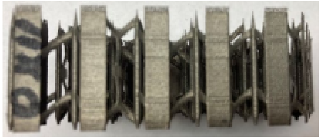
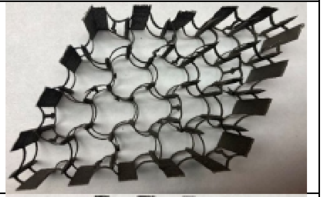
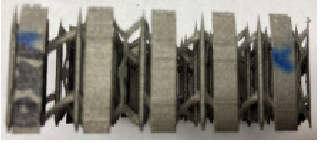
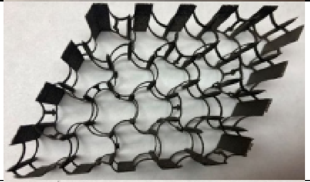
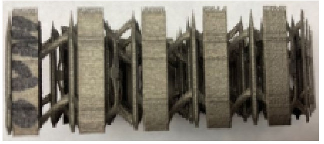
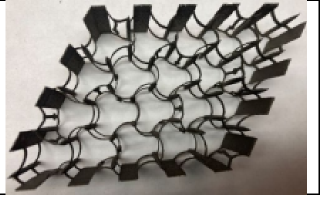
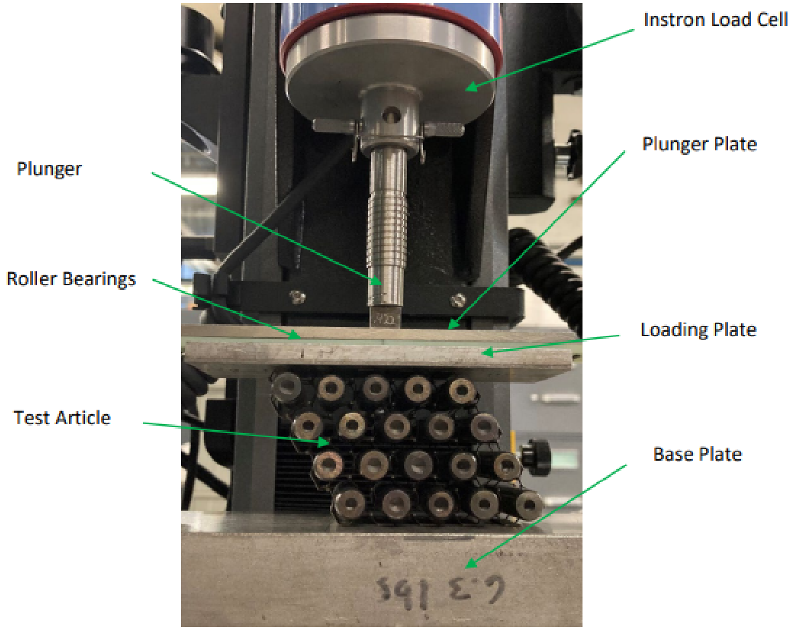
Additive Manufacturing Development Partnering with Industry/Academia

AM at Westinghouse - Partnering with Industry/Academia

- The Multiphysics Design Optimization and Additive Manufacturing of Nuclear Components project carried out under the U.S. DOE NE GAIN Voucher Program, in collaboration with Oak Ridge National Laboratory (ORNL), has established a generative design and optimization process to enable development of advanced nuclear component designs that are enabled by additive manufacturing strategies. The project is complete and a number of notable results were obtained regarding AM produced grids.

ID	Tube	Test Type	Sample Photo	
OXII	Yes	Load / Unload		
OXI	No	Cycling		
OVIII	Yes	Cycling		

The test setup is presented on Figure below.



Westinghouse Developed AM PWR Bottom Nozzle

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Westinghouse AM Bottom Nozzle

- AM development of the AM PWR bottom nozzle
- Debris Testing of AM PWR Bottom Nozzle
- GSI-191 Testing of AM PWR Bottom Nozzle
- Westinghouse Documentation of the AM Process (for PWR BN)
- Licensing of an AM PWR Bottom Nozzle

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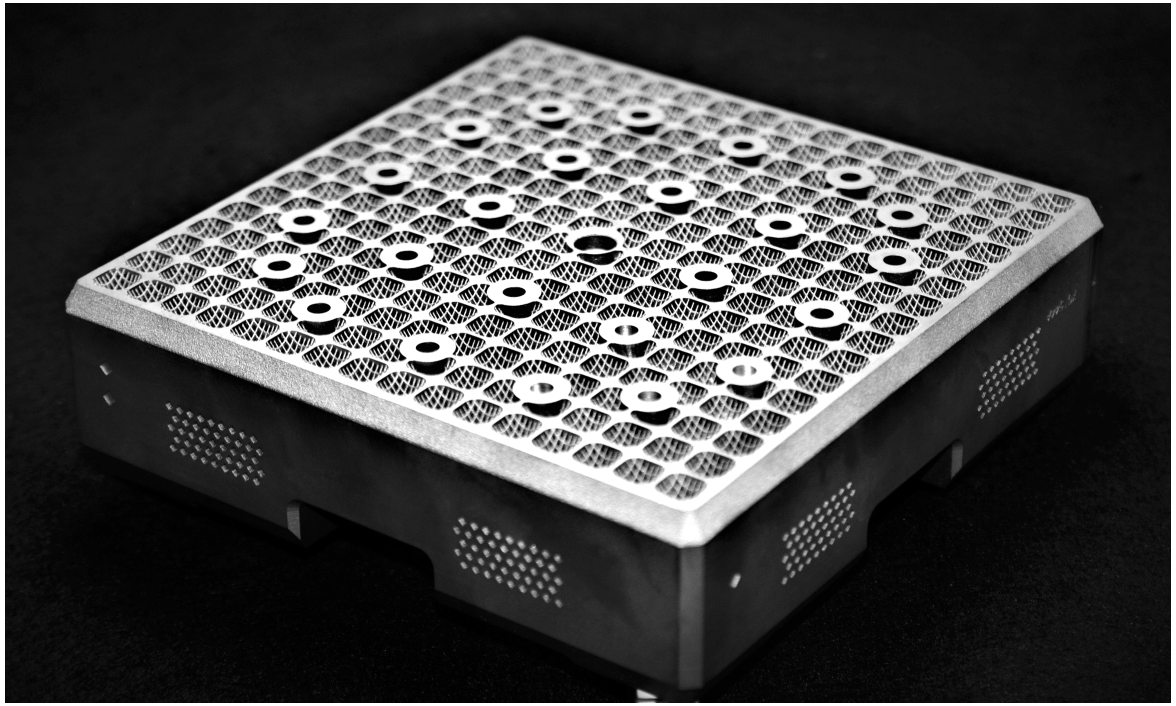
AM Fuel Bottom Nozzle

Full size AM produced Bottom Nozzle

- Equivalent pressure drop to existing bottom nozzle design
- All design and safety requirements satisfied
- Improved filtering ability
- All manufacturing interfaces satisfied
- No changes to basic BN envelop nor interfacing features



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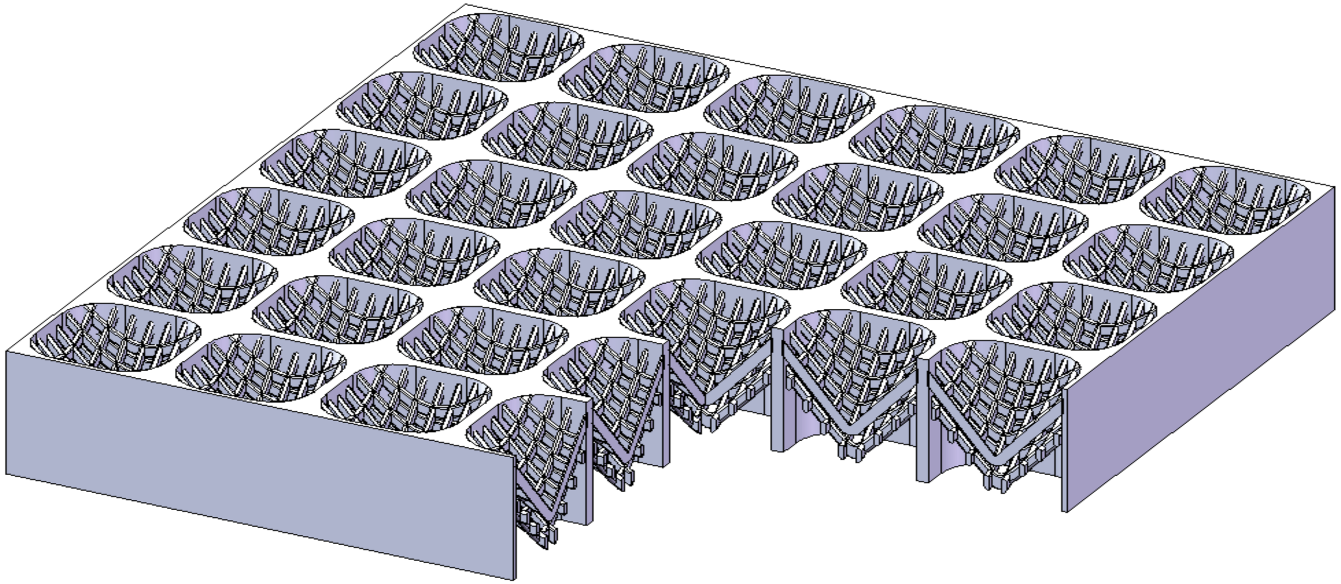
AM Fuel Bottom Nozzle – Debris Testing

- Debris testing of the Fine Mesh Filter (Spire) Structure Performed.
  - Double filter design (shown below) of the fine mesh filter structure achieves excellent debris capturing efficiencies exceeding the performance of existing current/advanced conventional bottom nozzle designs.



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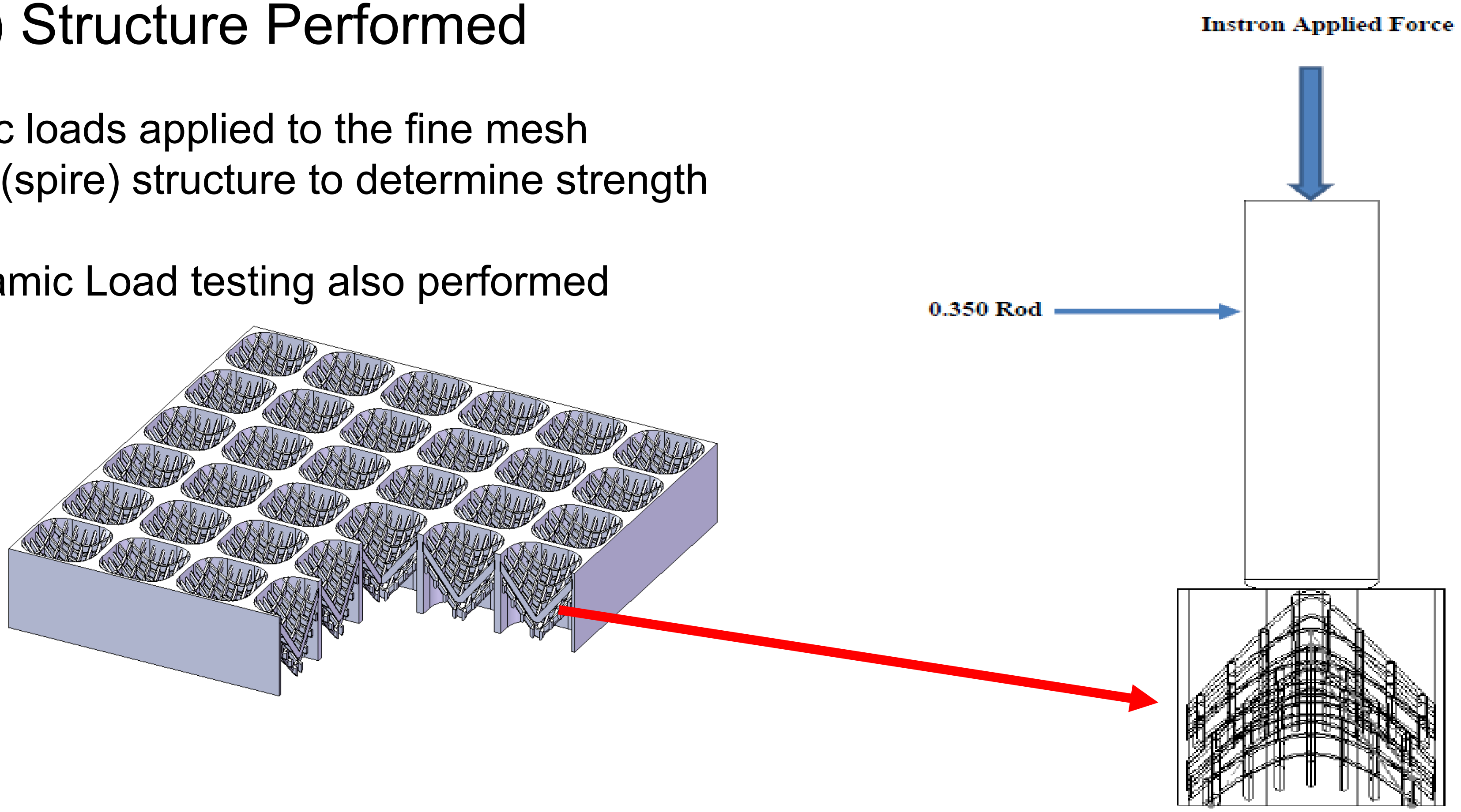
AM Fuel Bottom Nozzle - Mesh Structural Testing

- Detailed Mechanical (and T&H) Testing of Fine Mesh Filter (Spire) Structure Performed
  - Static loads applied to the fine mesh filter (spire) structure to determine strength
  - Dynamic Load testing also performed



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AM Fuel Bottom Nozzle - Mesh Structural Testing

- Detailed Mechanical and T&H Testing of Fine Mesh Filter.
- Mechanical tests performed to ensure that the fine mesh filter (spire) does not fail during operation and become debris.
  - Static load testing demonstrated significant fine mesh filter (spire) strength and margin to failure.
  - Ballistic testing performed - demonstrated "spire" will not fail when debris in flow field
- T&H testing:
  - Pressure drop - matches current bottom nozzle design
  - Debris filtering - significant improvement compared to current design

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AM Fuel Bottom Nozzle - GSI-191

- Subscale test loop results
  - GSI-191 testing demonstrated that the AM BN was acceptable with respect to the results presented in WCAP-17788 results (topical report for GSI-191)
  - AM bottom nozzle performed better than existing bottom nozzle

Q & A