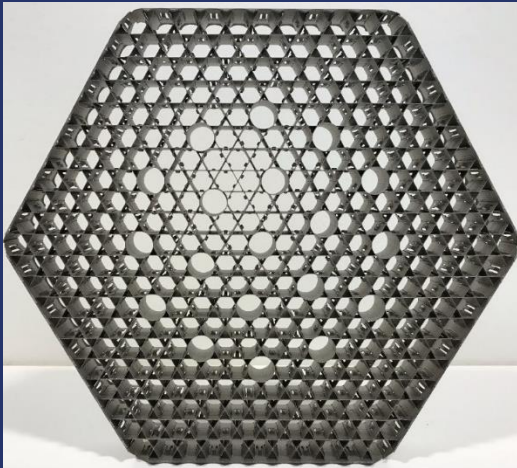
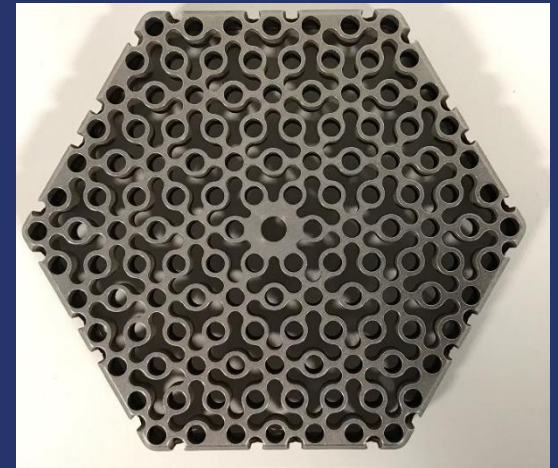


Additive Manufacturing Design and Process



August 2022

Uffe Bergmann & William Cleary



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Outline

- Introduction to Additive Manufacturing (AM)
 - Powder Bed Fusion
- Current AM Projects for Westinghouse Fuel
- AM Process Development

Introduction to Additive Manufacturing

What is Additive Manufacturing?

According to ASME:
Any process that
creates objects by
adding material
instead of removing it



There are 7 types of AM, we focus on one of them

7 Families of Additive Manufacturing

According to ISO/ASTM52900-15 (formerly ASTM F2792)



VAT PHOTOPOLYMERIZATION	POWDER BED FUSION (PBF)	BINDER JETTING	MATERIAL JETTING	SHEET LAMINATION	MATERIAL EXTRUSION	DIRECTED ENERGY DEPOSITION (DED)	HYBRID
<p>Alternative Names: SLA™ - Stereolithography Apparatus DLP™ - Digital Light Processing 3SP™ - Scan, Spin, and Selectively Photocure CLIP™ - Continuous Liquid Interface Production</p> <p>Description: A vat of liquid photopolymer resin is cured through selective exposure to light (via a laser or projector) which then initiates polymerization and converts the exposed areas to a solid part.</p> <p>Strengths:</p> <ul style="list-style-type: none"> • High level of accuracy and complexity • Smooth surface finish • Accommodates large build areas <p>Typical Materials UV-Curable Photopolymer Resins</p>	<p>Alternative Names: SLS™ - Selective Laser Sintering; DMLS™ - Direct Metal Laser Sintering; SLM™ - Selective Laser Melting; EBM™ - Electron Beam Melting; SHS™ - Selective Heat Sintering; MJF™ - Multi-Jet Fusion</p> <p>Description: Powdered materials are selectively consolidated by melting it together using a heat source such as a laser or electron beam. The powder surrounding the consolidated part acts as support material for overhanging features.</p> <p>Strengths:</p> <ul style="list-style-type: none"> • High level of complexity • Powder acts as support material • Wide range of materials <p>Typical Materials Plastics, Metal and Ceramic Powders, and Sand</p>	<p>Alternative Names: 3DP™ - 3D Printing ExOne Voxeljet</p> <p>Description: Liquid bonding agents are selectively applied onto thin layers of powdered material to build up parts layer by layer. The binders include organic and inorganic materials. Metal or ceramic powdered parts are typically fired in a furnace after they are printed.</p> <p>Strengths:</p> <ul style="list-style-type: none"> • Allows for full color printing • High productivity • Uses a wide range of materials <p>Typical Materials Powdered Plastic, Metal, Ceramics, Glass, and Sand.</p>	<p>Alternative Names: PolyJet™ SCP™ - Smooth Curvatures Printing MJM - Multi-Jet Modeling ProJet™</p> <p>Description: Droplets of material are deposited layer by layer to make parts. Common varieties include jetting a photocurable resin and curing it with UV light, as well as jetting thermally molten materials that then solidify in ambient temperatures.</p> <p>Strengths:</p> <ul style="list-style-type: none"> • High level of accuracy • Allows for full color parts • Enables multiple materials in a single part <p>Typical Materials Photopolymers, Polymers, Waxes</p>	<p>Alternative Names: LOM - Laminated Object Manufacture SDL - Selective Deposition Lamination UAM - Ultrasonic Additive Manufacturing</p> <p>Description: Sheets of material are stacked and laminated together to form an object. The lamination method can be adhesives or chemical (paper/plastics), ultrasonic welding, or brazing (metals). Unneeded regions are cut out layer by layer and removed after the object is built.</p> <p>Strengths:</p> <ul style="list-style-type: none"> • High volumetric build rates • Relatively low cost (non-metals) • Allows for combinations of metal foils, including embedding components. <p>Typical Materials Paper, Plastic Sheets, and Metal Foils/Tapes</p>	<p>Alternative Names: FFF - Fused Filament Fabrication FDM™ - Fused Deposition Modeling</p> <p>Description: Material is extruded through a nozzle or orifice in tracks or beads, which are then combined into multi-layer models. Common varieties include heated thermoplastic extrusion (similar to a hot glue gun) and syringe dispensing.</p> <p>Strengths:</p> <ul style="list-style-type: none"> • Inexpensive and economical • Allows for multiple colors • Can be used in an office environment • Parts have good structural properties <p>Typical Materials Thermoplastic Filaments and Pellets (FFF); Liquids, and Slurries (Syringe Types)</p>	<p>Alternative Names: LMD - Laser Metal Deposition LENS™ - Laser Engineered Net Shaping</p> <p>Description: Powder or wire is fed into a melt pool which has been generated on the surface of the part where it adheres to the underlying part or layers by using an energy source such as a laser or electron beam. This is essentially a form of automated build-up welding.</p> <p>Strengths:</p> <ul style="list-style-type: none"> • Not limited by direction or axis • Effective for repairs and adding features • Multiple materials in a single part • Highest single-point deposition rates <p>Typical Materials Metal Wire and Powder, with Ceramics</p>	<p>Alternative Names: AMBIT™ - Created by Hybrid Manufacturing Technologies</p> <p>Description: Laser metal deposition (a form of DED) is combined with CNC machining, which allows additive manufacturing and 'subtractive' machining to be performed in a single machine so that parts can utilize the strengths of both processes.</p> <p>Strengths:</p> <ul style="list-style-type: none"> • Smooth surface finish AND High Productivity • Geometrical and material freedoms of DED • Automated in-process support removal, finishing, and inspection <p>Typical Materials Metal Powder and Wire, with Ceramics</p>

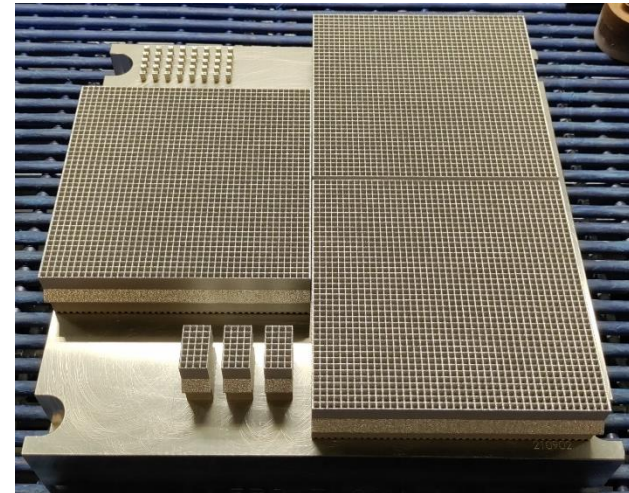
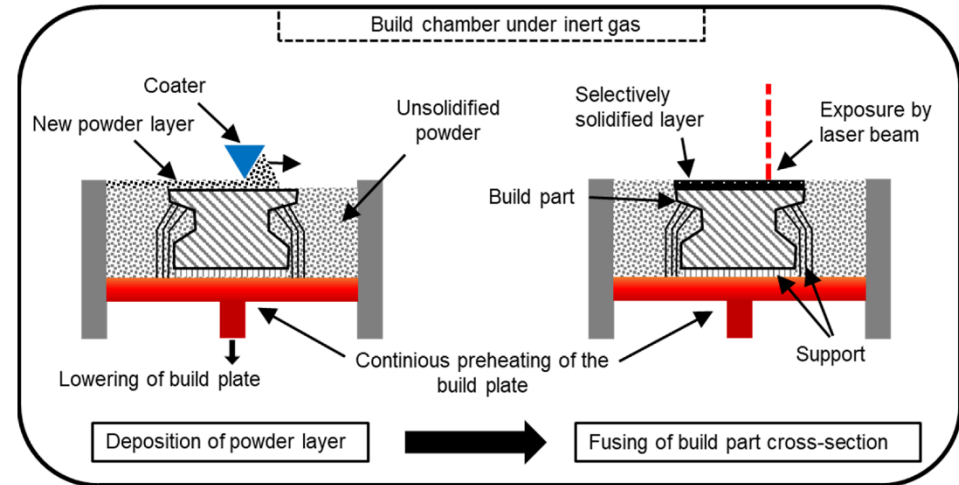
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Powder Bed Fusion



Overview of Powder Bed Fusion

1. A layer of powdered material between 20-80 μ m is spread across a build platform
2. Laser fuses 1st layer cross-section geometry to build platform
3. New layer of powder is spread on top of the previous layer using the recoater blade
4. Further layers/cross sections are fused and added
5. The process repeats until the entire model is created
6. Unmelted powder remains in position until printing ends and is removed and recovered during post processing



Westinghouse Machine

- EOS M290
- Year purchased: 2018
- Location: Penn United, Cabot, PA
- 250 x 250 x 325 mm
- 400W Yb fibre laser



Penn United - AM Facility



- Operates three EOS M290s and one EOS M400-4
- EOS M290s are process development machines
- EOS M440-4 is for larger production volumes
 - Large building volume of 400 x 400 x 400 mm with four 400 W lasers operating independently



Powder Bed Fusion - EOS M290 in Operation



Powder Material Availabilities

- Currently Printing
 - Stainless Steels
 - 304
 - 316L
 - Nickel Alloys
 - A625
 - A718
 - Tool Steels
 - MS-1
 - H230
 - 17-4 PH
- Low cobalt powder available
- Investigating zircaloy development
- Multiple suppliers
 - Promotes security of supply

Example Commercial Powder Suppliers

<https://www.oerlikon.com/am/en/offerings/metal-powders/>

<http://www.praxairsurfacetechologies.com/en/components-materials-and-equipment/materials/additive-manufacturing-powders/?tab=cobalt-iron-and-nickel-powders>

<https://www.additive.sandvik/en/products-services-am/metal-powder/>

Opportunities for AM

- Better performance
 - Printing complex shapes
 - Enabling geometry that cannot be machined or cast
- Cheaper manufacturing of components
 - Printing near net shapes
- Faster lead time (considering manufacturing & material)
 - Printing in hours or days
- Combining assemblies into single part

Current AM Projects for Westinghouse Fuel

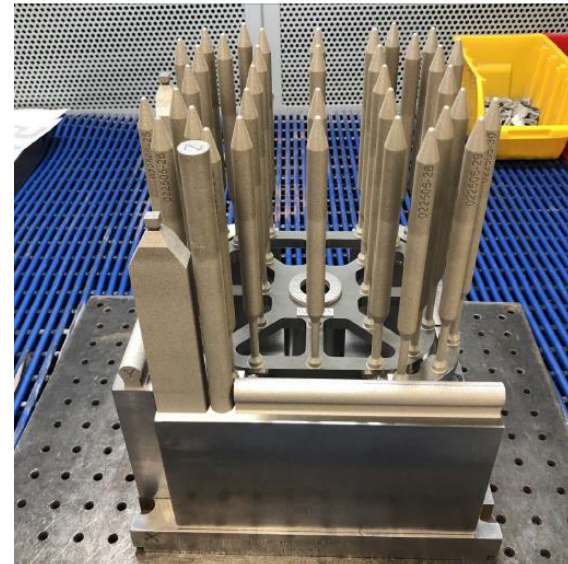
Current AM Projects for Westinghouse Fuel

- PWR Thimble Plugging Device (WEC)
- PWR Additively Manufactured Bottom Nozzle (WEC)
- BWR **StrongHold**[®] Debris Filter (WSE)
- VVER-1000 Prototype Grids (WSE)
- VVER-440 Top and Bottom Flow Plates (WSE)

PWR Thimble Plugging Device

- 316L Material

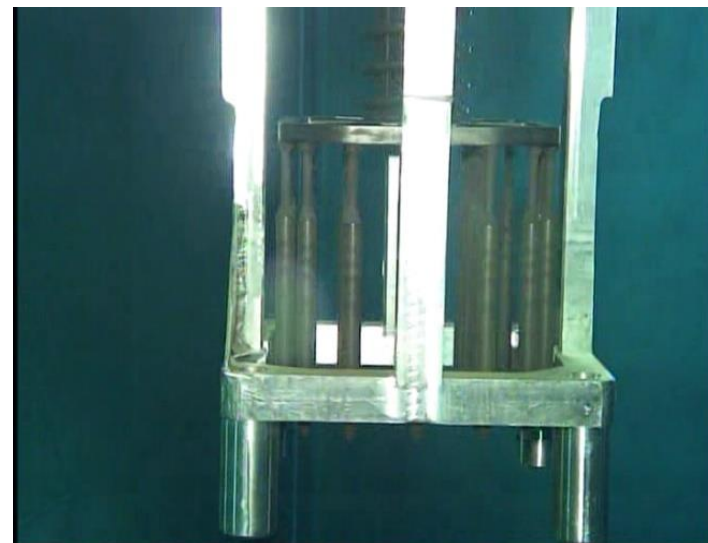
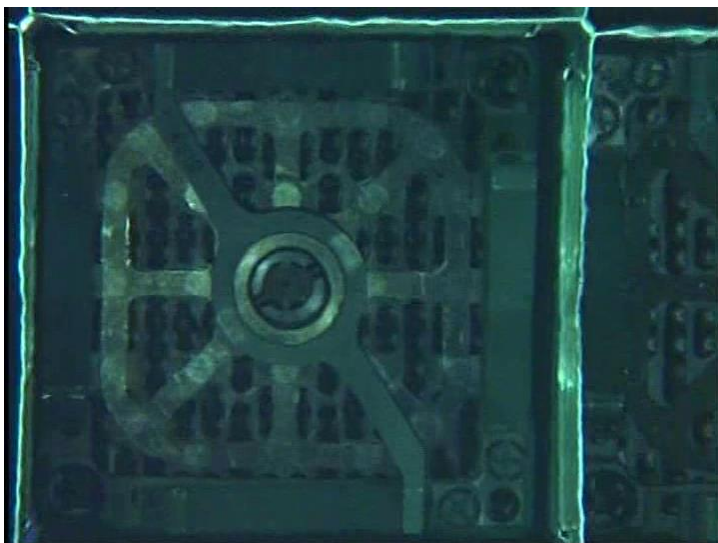
- Selected as first AM demonstration component in commercial reactor
 - Low risk component, moderate complexity
 - **Inserted in U.S. PWR in Spring 2020**



PWR Thimble Plugging Device

- 316L Material

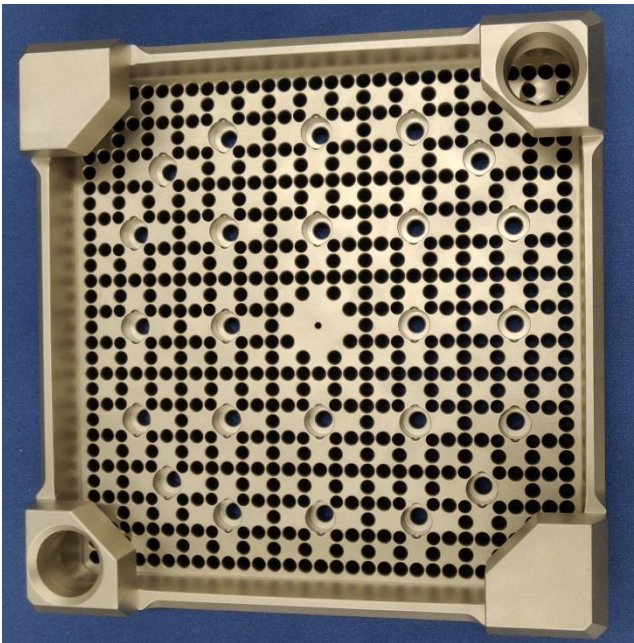
- First inspection (after one 18-month cycle) in Sept 2021
 - No visual distortion
 - Normal drag forces during removal and reinsertion
- Component placed back in core for further irradiation



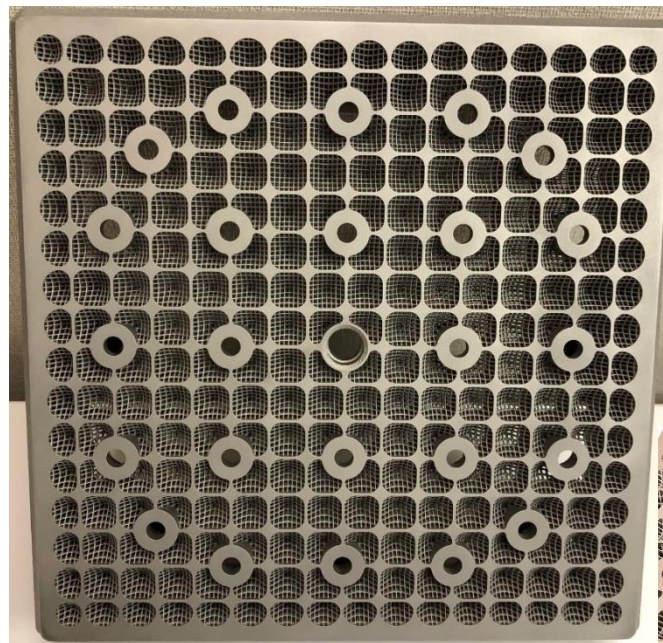
PWR Additively Manufactured Bottom Nozzle - A718 Material

- Improved debris filtration with same pressure drop
- Larger flow holes enabled by utilizing strength of A718 material
- Double spire with several mesh thicknesses evaluated

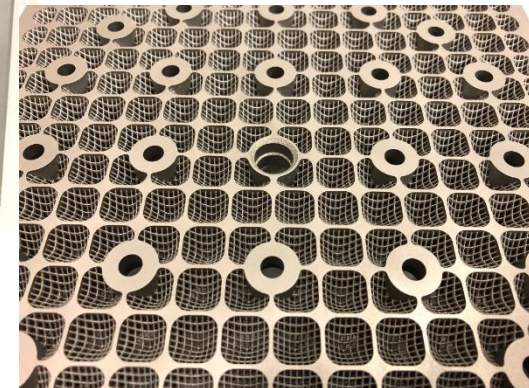
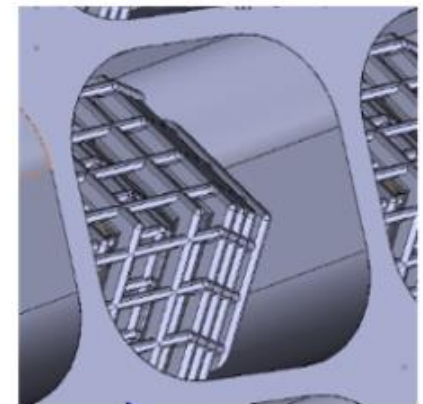
Conventional Design



AM Design



Double spire mesh



BWR StrongHold® Debris Filter

- 316L Material

- Outstanding debris capture performance thanks to internal design features only possible with AM
- First AM component to be inserted in reactor core for improved performance (intended for final use)



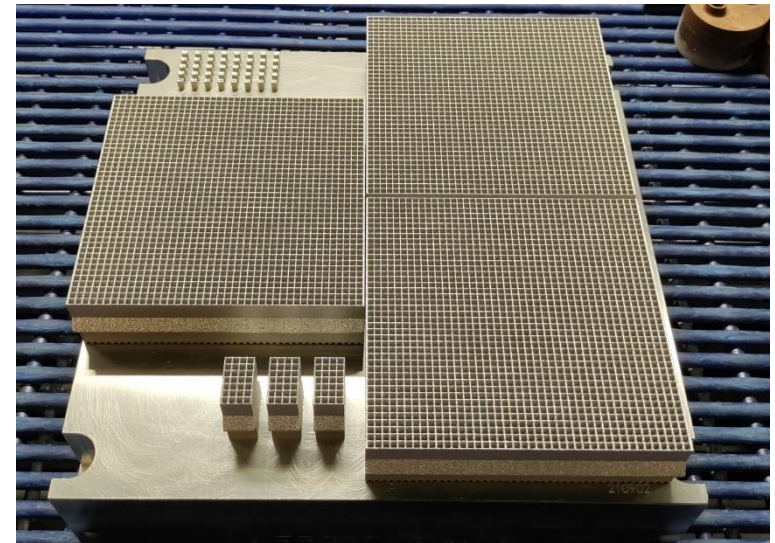
Energy & Environment | New Nuclear | Regulation & Safety | Nuclear Policies | [Corporate](#) | Uranium &

First use of 3D-printed nuclear fuel debris filters

14 June 2022



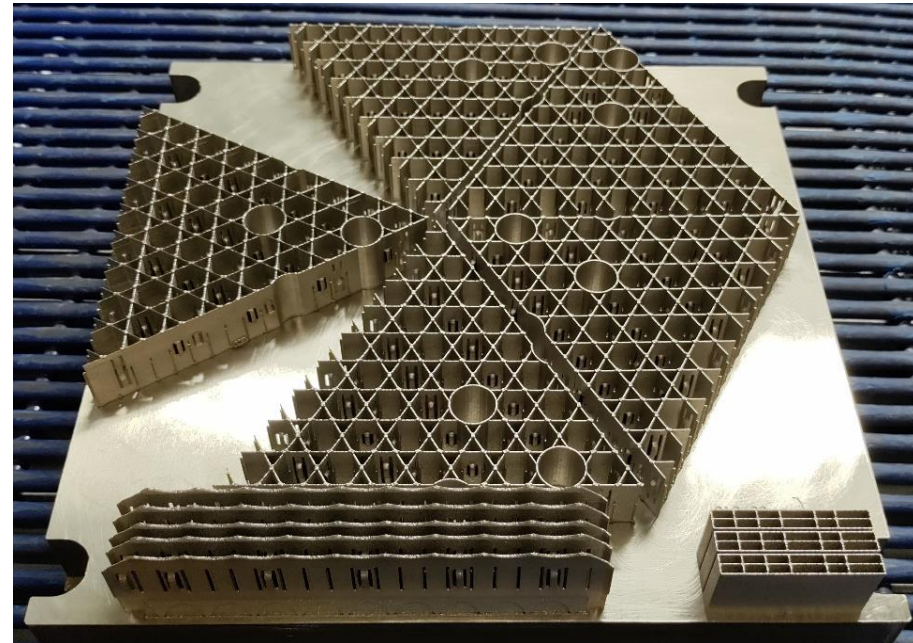
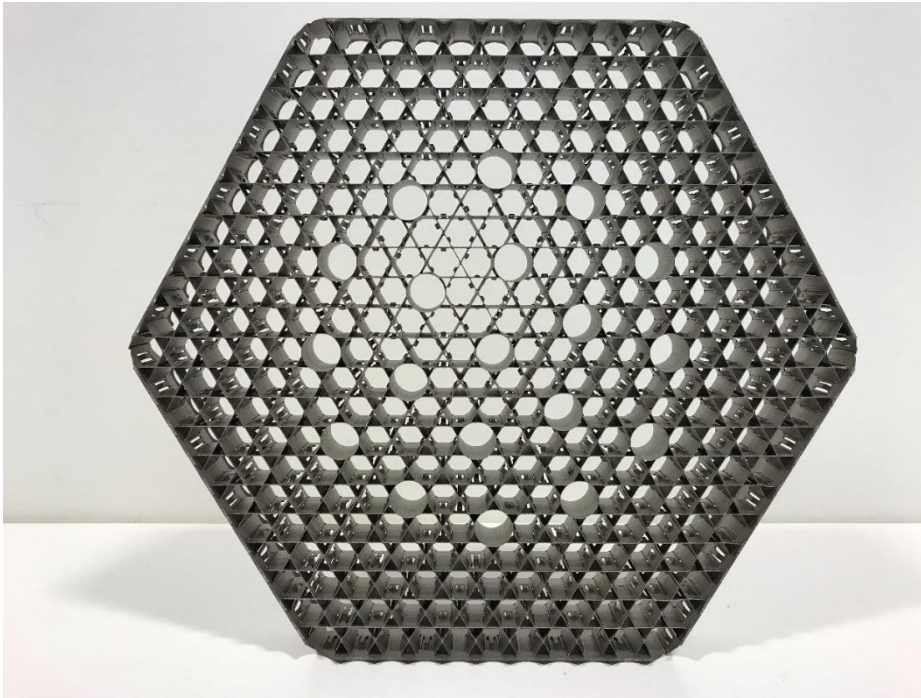
Nuclear fuel debris filters manufactured by Westinghouse Electric Sweden AB using 3D printing technology have been installed at unit 2 of the Olkiluoto nuclear power plant in Finland and unit 3 of the Oskarshamn plant in Sweden.



Lead Test StrongHold filters operating in Oskarshamn 3 and Olkiluoto 2 BWR units since May 2022

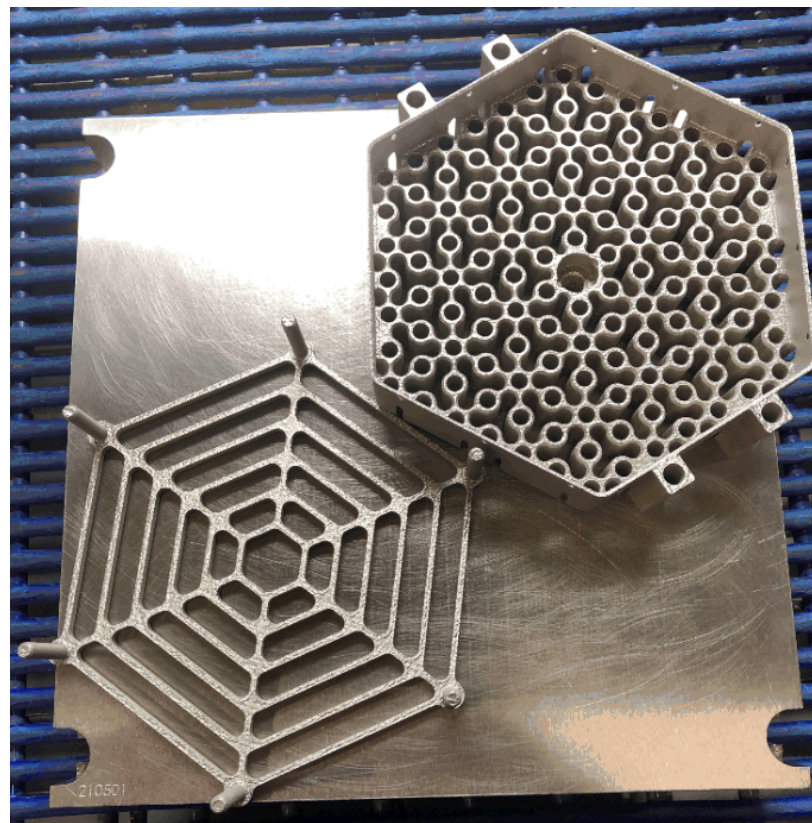
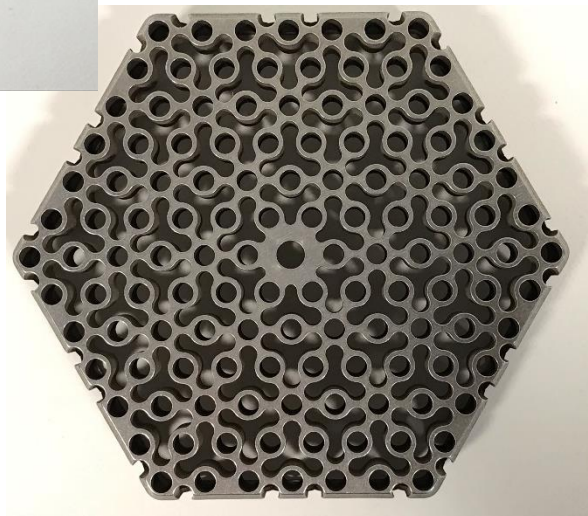
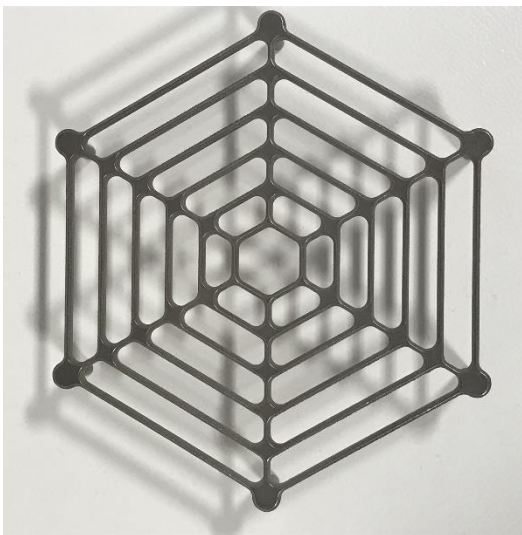
VVER-1000 Prototype Grids - A718 Material

- Full-size grids in A718 material made for scoping tests of new grid design concepts and existing RWFA grid as reference



VVER-440 Flow Plates - 316L Material

- AM process used for top and bottom flow plates



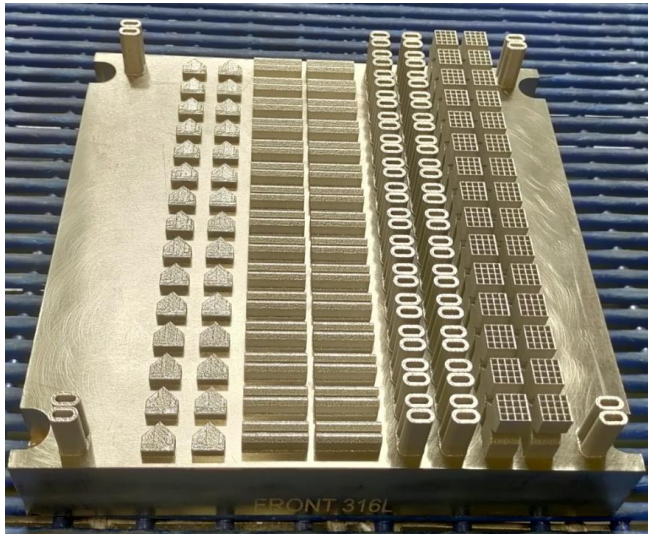
AM Process Development

AM Process Development Steps

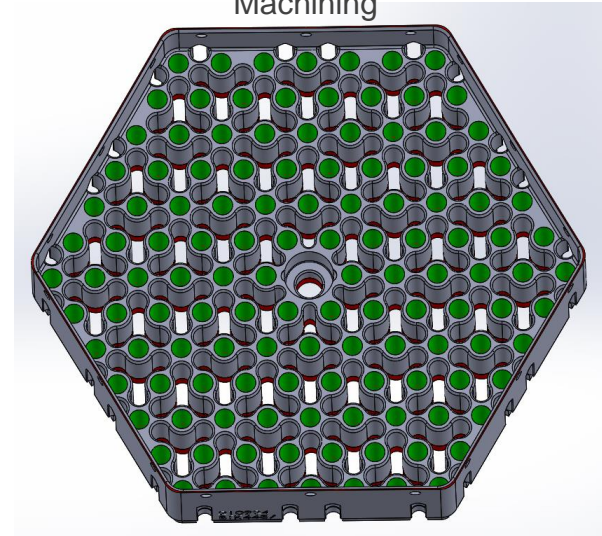
- Design for AM (CAD to as-printed model)
- Optimize machine parameters for geometry, mechanical properties and surface finish
- Build part
- Cleaning / powder removal
- Heat treatment (on build plate)
- Post machining
- Surface treatment
- Dimensional inspection
- Mechanical / material testing

AM Process Development Steps

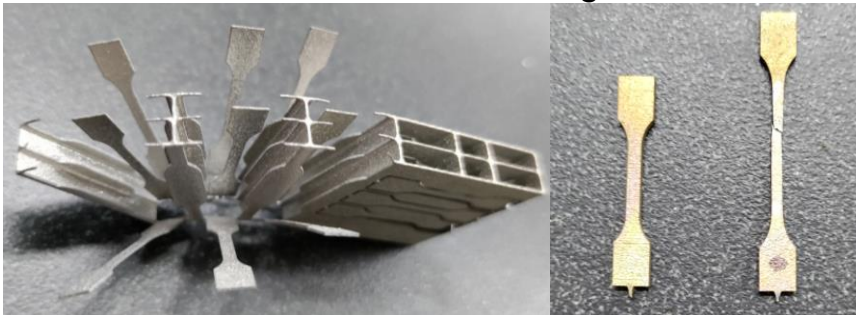
30/60 μ m parameter optimization build



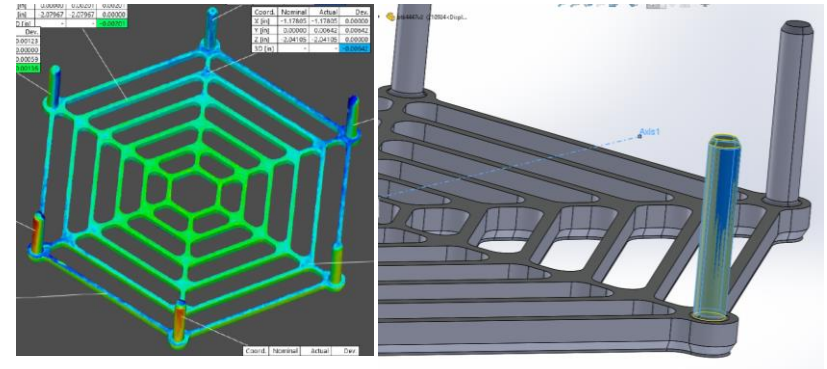
Machining

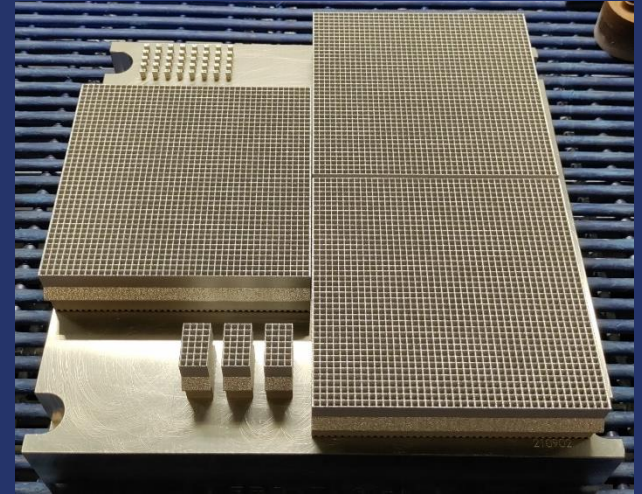
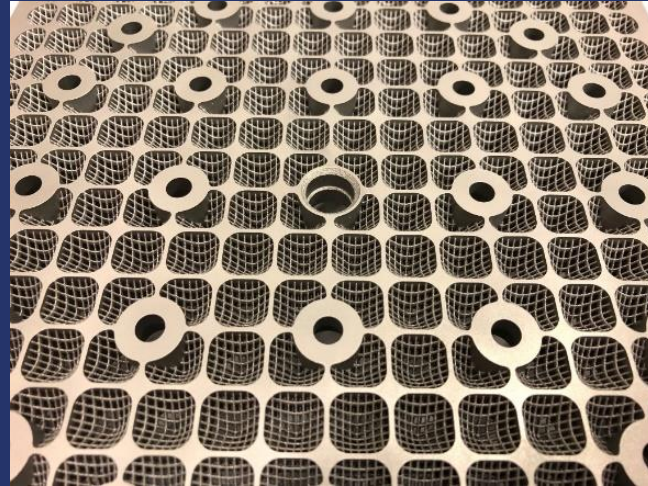
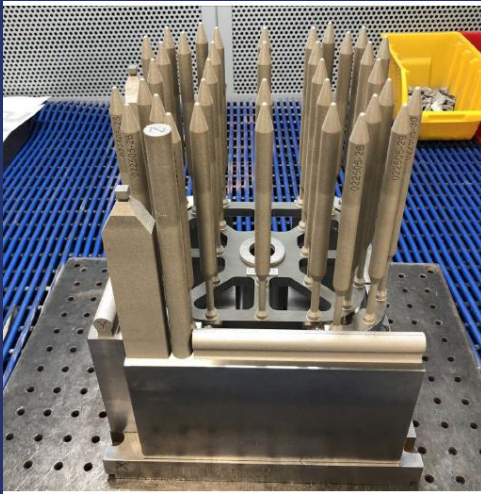


Mechanical Testing



Inspection - "warp" as-printed model





Thank you for your time and attention!

