3D Printing of Components and Coating Applications at Westinghouse

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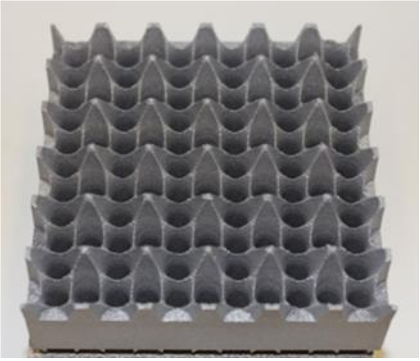
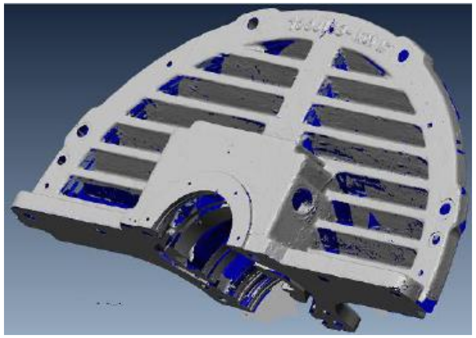
Outline

- Additive Manufacturing (AM) / 3D Printing
- Metals Additive Manufacturing Technologies
- Westinghouse Fuel Manufactured Products
- Status of Nuclear Fuel Development Efforts
- Development in Support of Advanced Reactors
- Coated Cladding – Key Requirements
- CHF Testing With and Without CRUD Deposit, Oxide and Coatings
- Summary

Additive Manufacturing (AM) / 3D Printing

- Develop and test critical nuclear materials: 316L, Alloy 718, and Zirconium
- Produce a reactor ready test component
- Exploit the benefits of Additive Manufacturing
  - Producing components with: Powder Bed Fusion, Binder Jetting, and Directed Energy Deposition AM technologies
  - Obsolete and high value / lead time components
  - Next gen plant components - SMR, LFR, …
  - Prototypes, mockups, jigs / fixture, tooling, etc.
- Support the development of codes and standards
  - Participating on ASTM F42 subcommittees
  - DOE funded project: Qualification of AM for Nuclear
- Development Needs:
  - Additional material development and testing to support the development of code & standards
  - Cost effective, large scale equipment
  - AM suppliers with Nuclear programs





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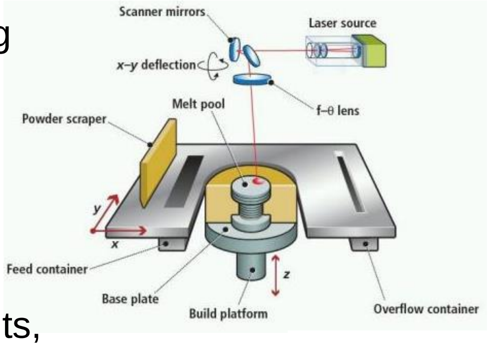
Metals Additive Manufacturing Technologies

- Direct Energy Deposition (Sciaky, Optomec)
  - Automated welding systems using electron beam (EB) or laser energy sources
  - **Opportunities:** Component repairs, cladding, weld buildup

- Powder Bed Fusion (EOS, etc.)
  - Powder bed systems using laser or EB melting
  - **Opportunities:** Small, complex components



- Binder Jetting (ExOne)
  - Metals, ceramics or casting sand molds
  - **Opportunities:** Large replacement components, castings and prototypes at low cost / lead-time

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Westinghouse Fuel Manufactured Products

Pressurized Water Reactors (PWRs)

W-PWR

14x14
15x15
16x16
17x17

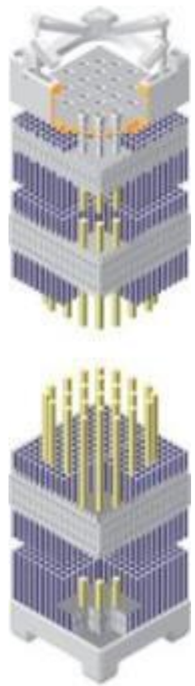
CE-PWR

14x14
16x16

KWU/Siemens PWR

14x14
16x16
18x18

NFI PWR



14x14
15x15
17x17
MOX

Boiling Water Reactors (BWRs)

W-BWR

Optima2
Optima3

NFI BWR

9x9
MOX

VVER (PWR)

VVER-1000
VVER-440

Advanced Gas Reactors (AGRs)

AGR Fuel

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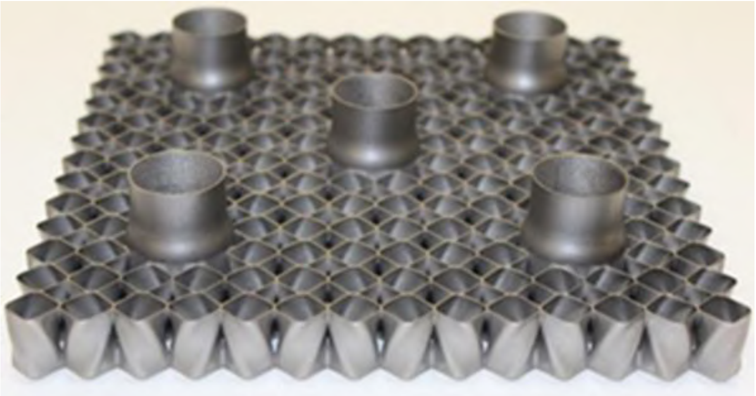
Status of Nuclear Fuel Development Efforts

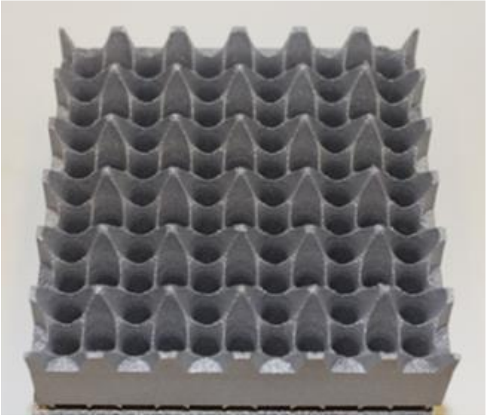
OVERVIEW

- Design of Advanced Debris Filtering Bottom Nozzle
- Spacer grids optimized utilizing design freedom
- Advanced tubular grid ("Flower Grid")
- Evaluating available AM metal powders for use in fuel components
- Radiation exposure testing of two alloy systems



BENEFITS

- Better fuel margins
  - Lower fuel assembly pressure drop
  - Better flow mixing and greater heat transfer ability
- Extended fuel cycles
- Customizable fuel assemblies
- Reduced time from concept to market



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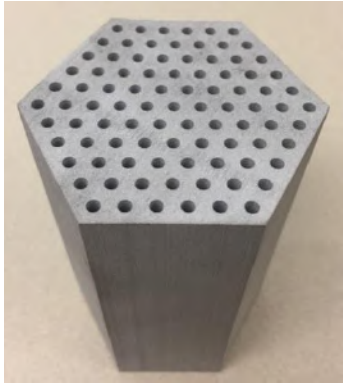
Development in Support of Advanced Reactors

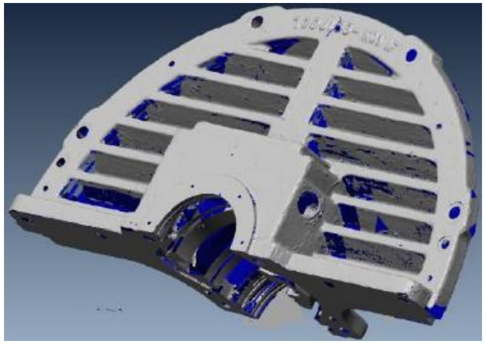
OVERVIEW

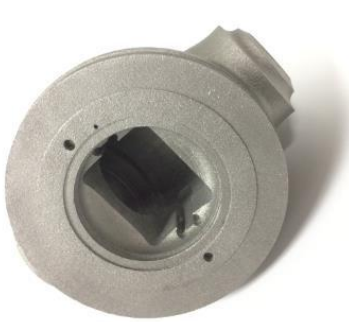
- Prototype components for SMR, advanced reactors and AM manufacturing / design demonstration
- Material development for next generation applications
- Support the development of codes and standards (ASTM & ASME)

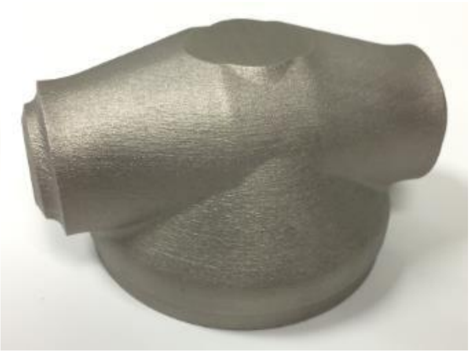


BENEFITS

- Design freedom: complex geometries, internal passageways, etc.
- Reduced design time: fast prototyping & mold production
  - Little to no tooling required
  - Design complexity at minimal cost
- Near net shape: reduced material, machining & welding
- Reduced lead-time / reduced supply chain







Development of Accident Tolerant Fuel

- Accident tolerant fuel being developed to improve safety for severe accidents and economics
- Exploring cladding concepts
  - Coated cladding concepts can deliver significant loss of coolant accident (LOCA) margins as well as modest improvements in accident tolerance

Coated Cladding – Key Requirements

- Reduced oxidation and hydrogen pickup in the base material during normal operation (250 to 350°C)
- Resistance to high temperature steam and air corrosion during LOCA and beyond design basis conditions (>1200°C)
- Reasonably low absorption of thermal neutrons (<5 barns)
- No cracking or spalling when strained
  - No cracking during normal operation
  - No spalling during transients
- Cost effective manufacturing at an industrial scale
- Crud deposition comparable to current fuel
- Enhanced resistance to wear (debris, grid-to-rod or rod-to-grid)
- Possible improvement in Critical Heat Flux

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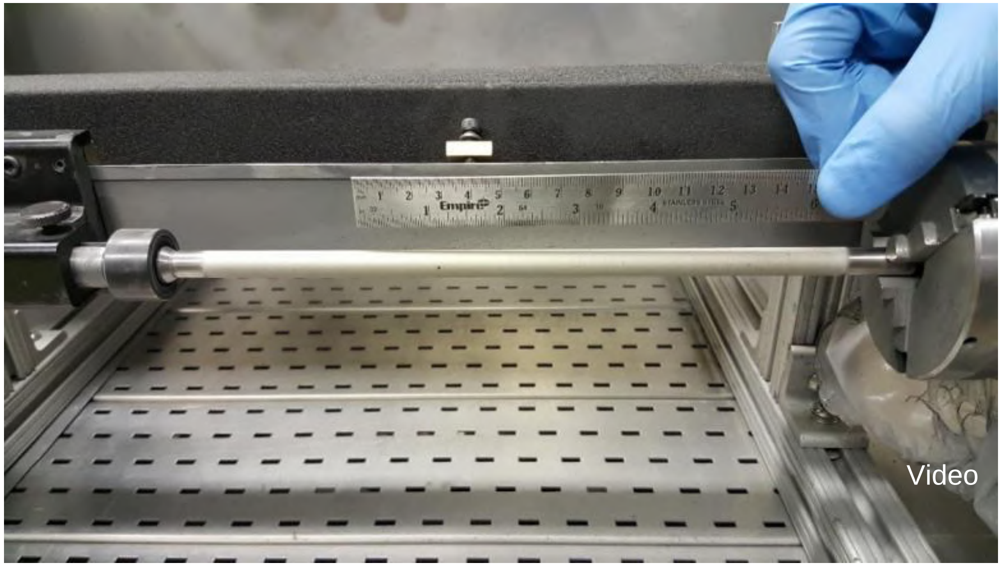
Cold Spray Coating Process



- Cr, FeCrAl and Mo deposited on Zirconium Cladding

CHF Testing With and Without CRUD Deposit, Oxide and Coatings

Single Heater Rod WALT Loop Test Facility – at reactor conditions

Rod	Condition	CHF (W/cm^2)	Coolant T (°C)	Pressure (MPa)	Flow Velocity (m/s)
167	No Deposit	459	338.0	15.44	2.4
170	No Deposit	460	333.8	15.66	2.4
171	No Deposit	455	338.9	15.49	2.3
171	Deposit, 21 microns	451	338.6	15.60	2.4
165	Thermal Oxide Layer applied by MIT	503	334.5	15.58	2.4
177	TiO_2 coating applied by MIT	510	337.5	15.58	2.4

CHF Impact due to CRUD Deposit appeared to be within repeatability of clean rod tests, thermal oxide layer showed a noticeable difference and TiO_2 showed an increase over the oxide layer

Summary

- Westinghouse is working to develop additive manufacturing technologies and associated materials, for use in the nuclear industry.
- This R&D is enabling new complex designs, for both the WSMR, next generation reactor designs and for current fuel
- These technologies are also being used to reduce component manufacturing lead-time and cost for prototype and demonstration components, as well as existing critical and obsolete components.
- Coatings can help make fuel more accident tolerant and improve fuel performance (CHF, reduced corrosion and fretting, etc)