Opportunities in additive manufacturing for advanced nuclear energy systems

Molten Salt Reactor Workshop 2020

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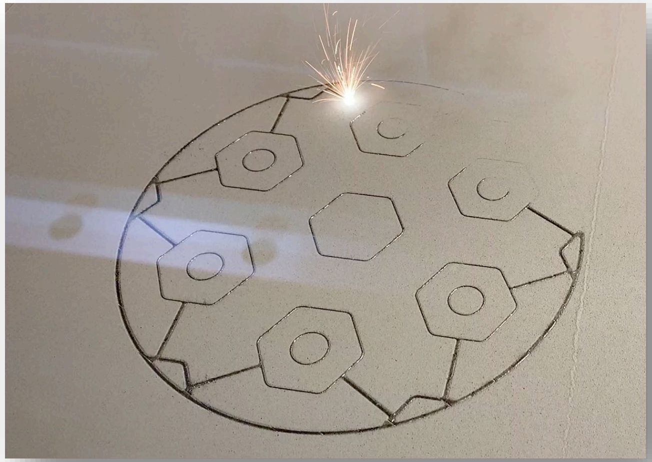
Outline

- Myriad additive manufacturing methods and advanced hybrids
- Enabling opportunities in AM/AI being pursued by the Transformational Challenge Reactor program
  - Improved design for enhanced operation
  - Advanced materials enabled by additive manufacturing
  - Integrated sensing for enhance health monitoring and autonomy
  - Rapid (on-the-fly) quality assessment and certification
- Immediate opportunities

Myriad additive manufacturing methods span a vast dimensional scale across a range of material systems

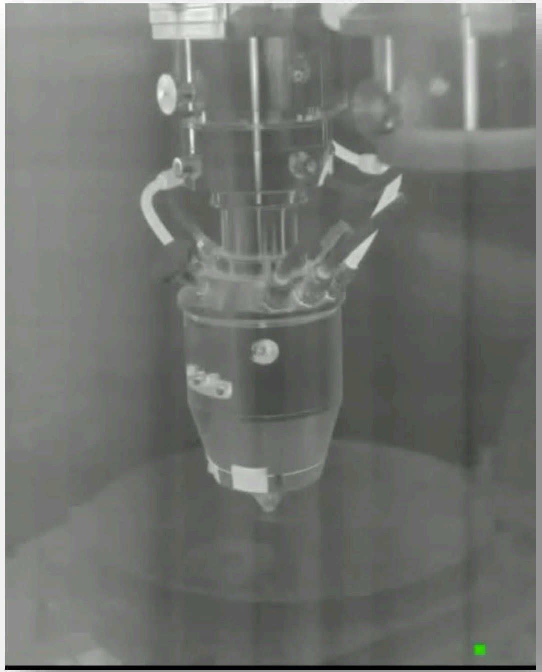
Powder bed techniques

- Metal or ceramic powder or slurry sequentially spread and fused in 2D layers
- Fusion achieved via melting (e.g. laser or e-beam source) or binding (via binder jet or lithography)
- Ability to accommodate most complex geometry with best spatial resolution
- Limited to a single material system
- Build volumes usually < 0.05 m^3 with some extending up to 0.3 m^3



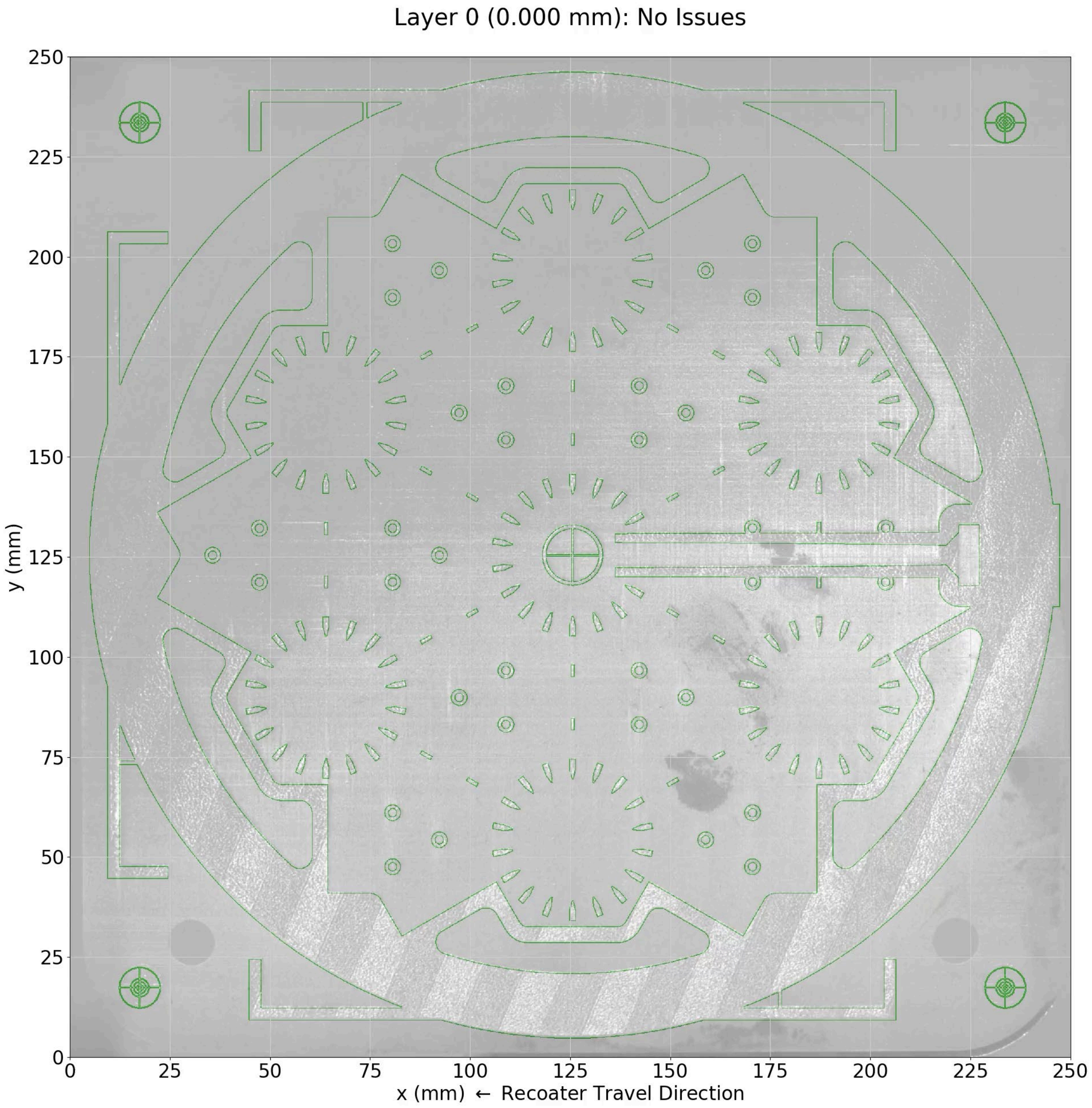
Direct deposition techniques

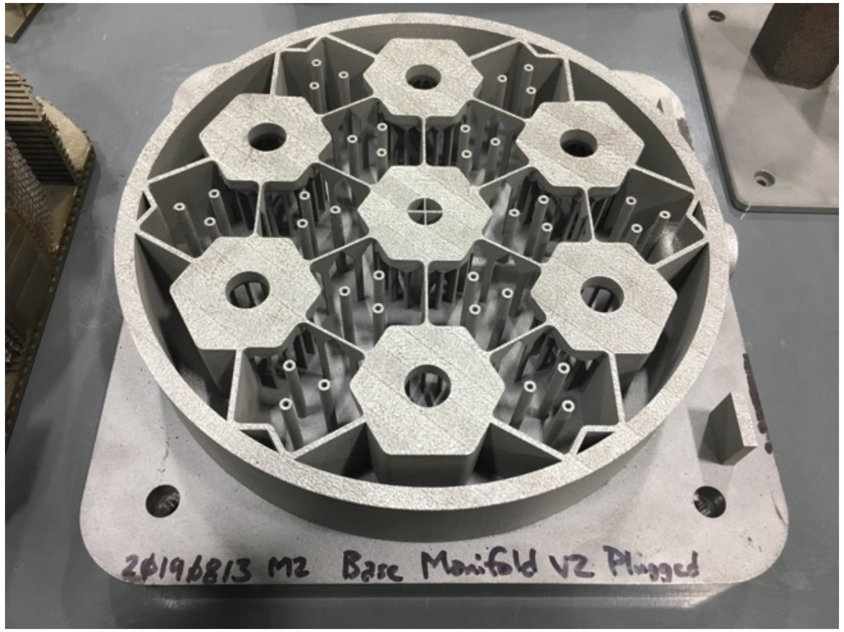
- Metal powder or wire or ceramic slurry directly deposited as continuous point on substrate
- Deposition via melting (e.g. laser or arc welding), drying, or curing
- Complex tool path design is needed, and less geometric complexity is accommodated
- Flexibility to accommodate multiple material systems

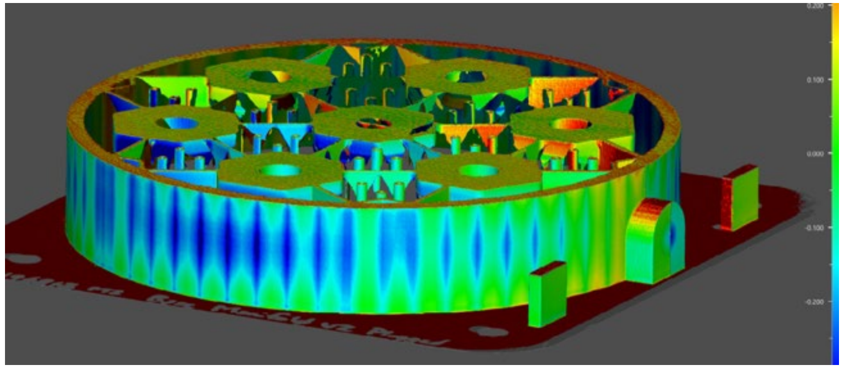


- Build volumes usually < 0.5 m^3 with some extending up to 7 m^3

Example of powder bed system: 3D printing of stainless steel via laser powder bed fusion technique

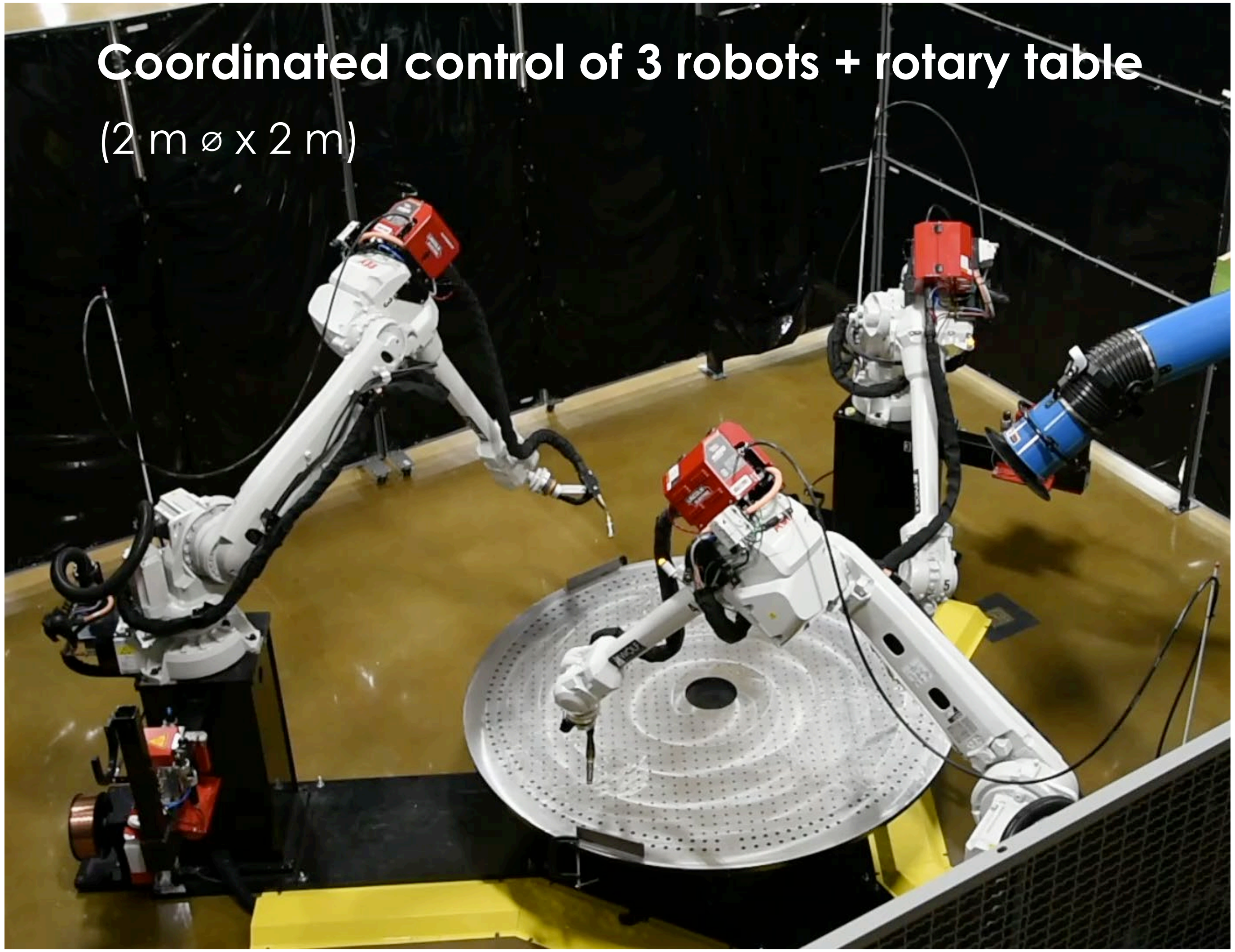


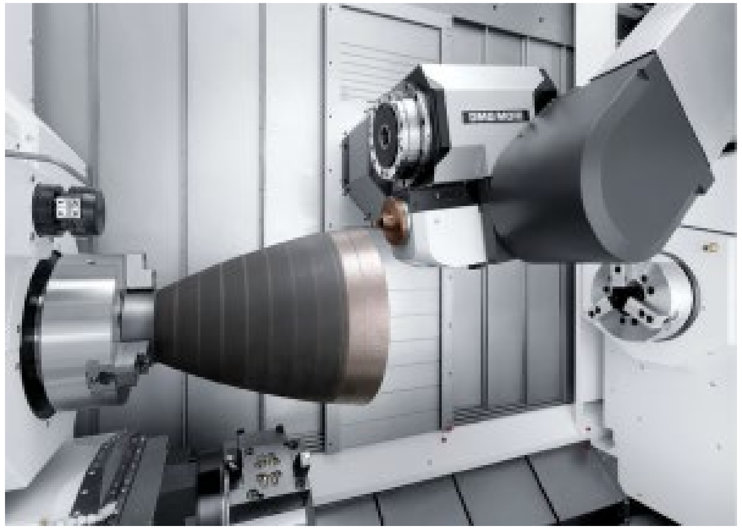


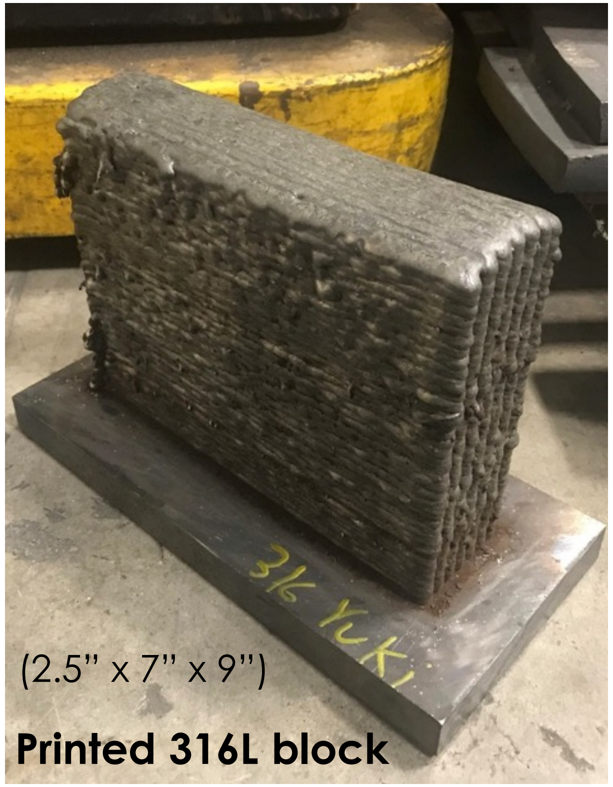


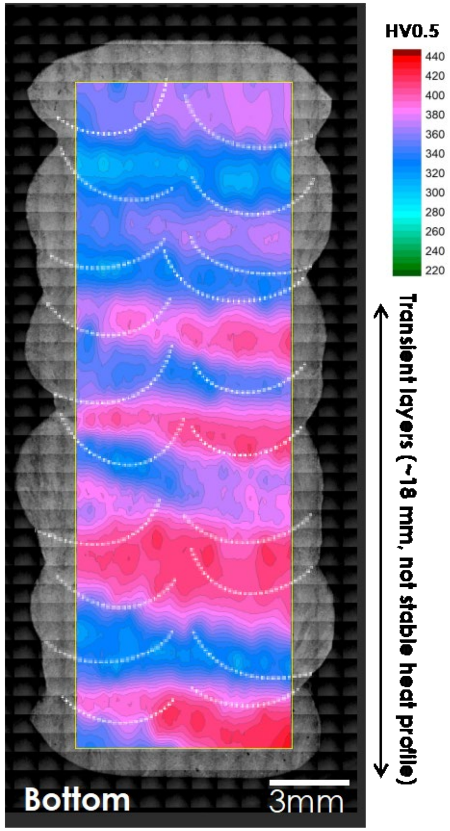
L. Scime, V. Paquit (ORNL)

Example of large direct deposition system: Medusa wire arc additive









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L. Love, M. Noaks, Y. Yamamoto, A. Nycz (ORNL)

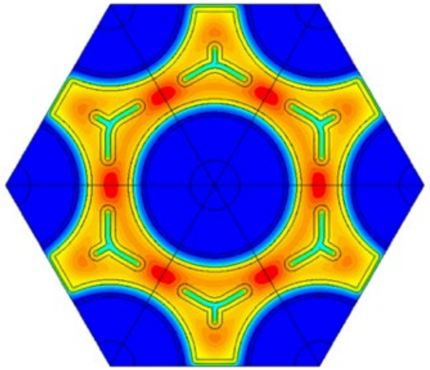
TCR is bringing to bear additive manufacturing (AM) and artificial intelligence (AI) to deliver a new approach

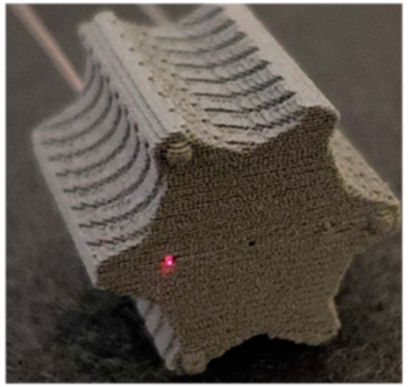
Using AI to navigate an unconstrained design space and realize superior performance

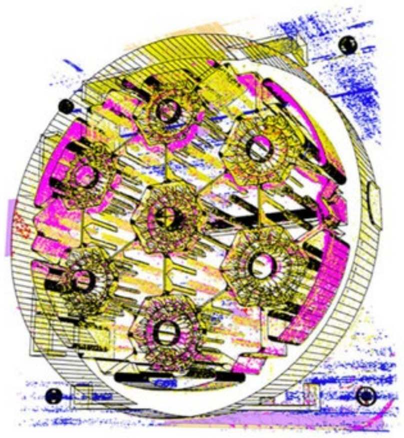
Leveraging AM to arrive at high-performance materials in complex geometries

Exploiting AM to incorporate integrated and distributed sensing in critical locations

Using AI to assess critical component quality using in situ manufacturing signatures



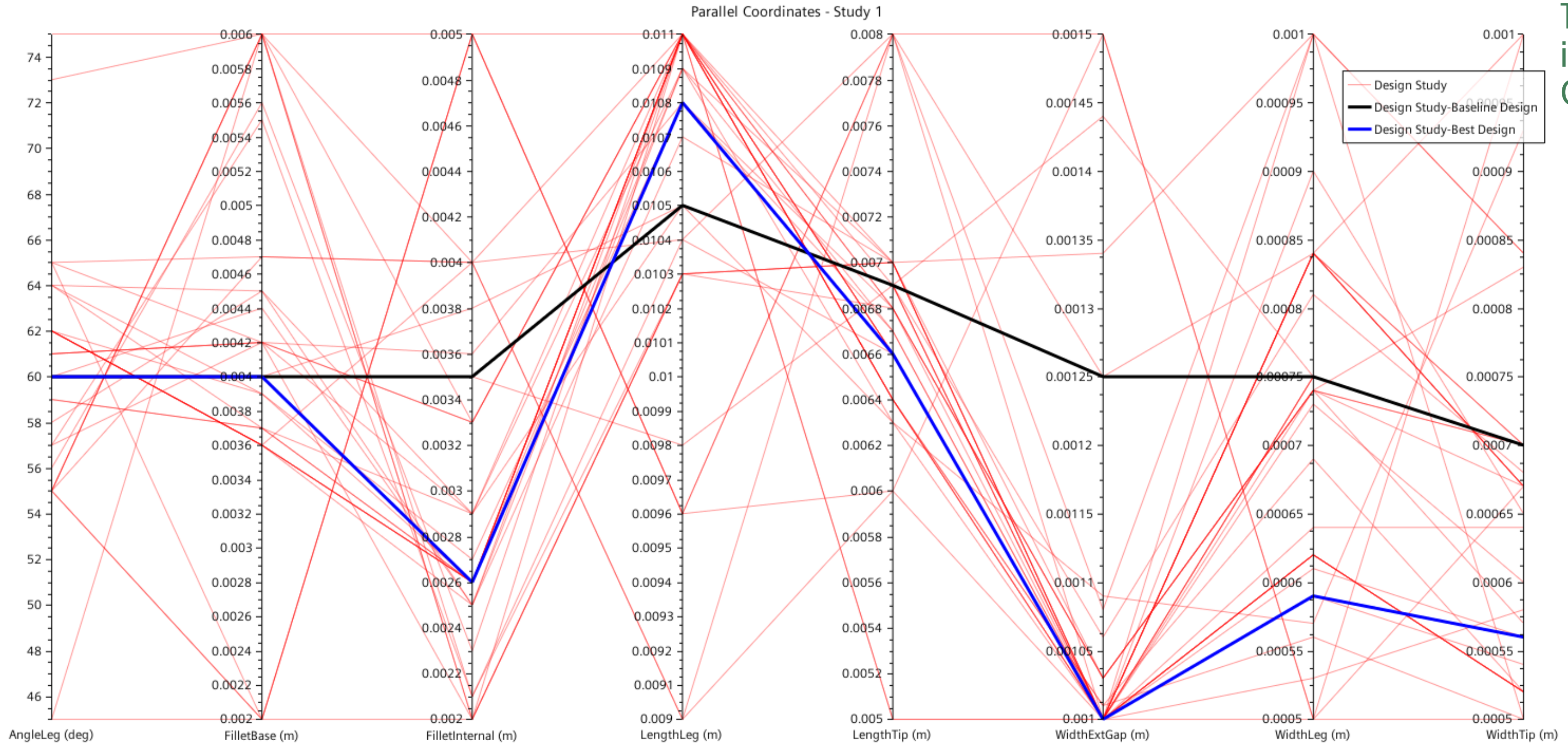




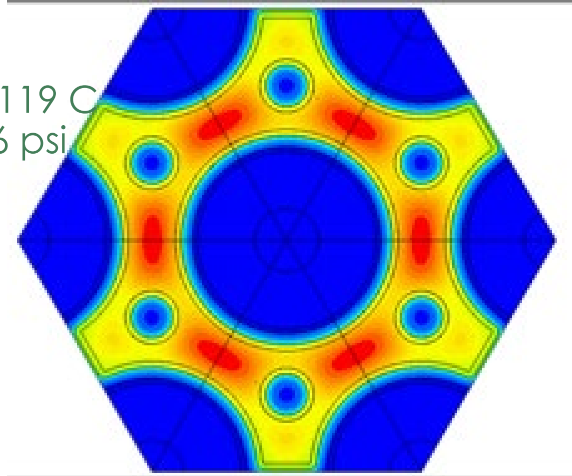
tcr.ornl.gov

Exploring an unconstrained design space to realize superior performance: Coolant channel shape optimization in fuel elements

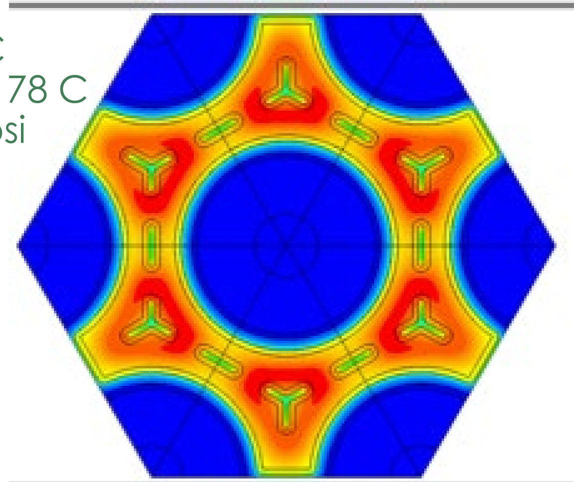
parameter space search to find optimized cooling channel design



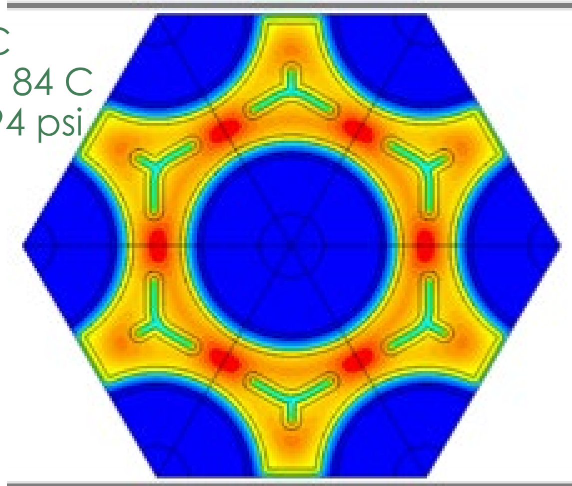
Tmax = 687 C
in−plane ΔT = 119 C
Core ΔP = 0.56 psi



Tmax = 622 C
in−plane ΔT = 78 C
Core ΔP = 1 psi

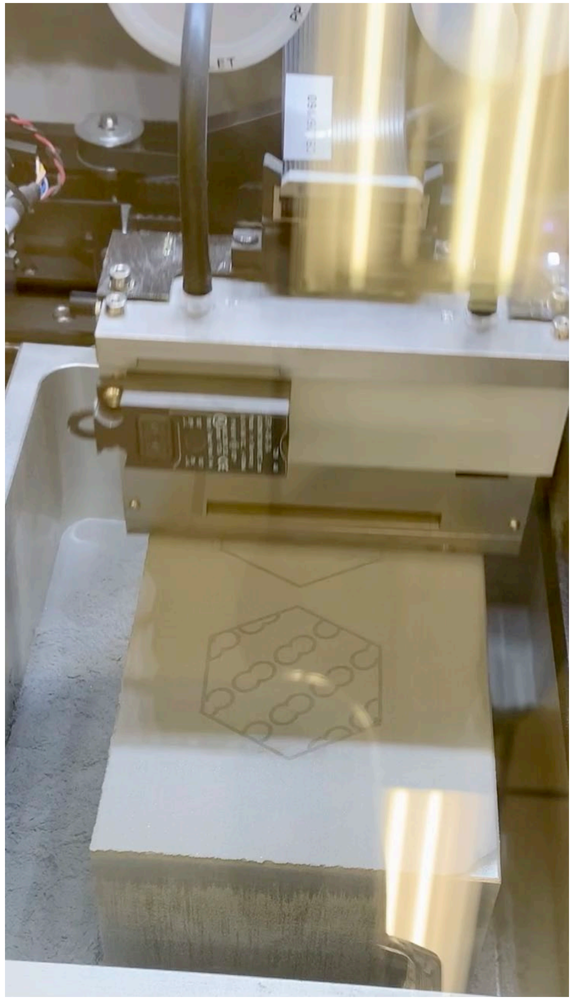


Tmax = 624 C
in−plane ΔT = 84 C
Core ΔP = 0.94 psi

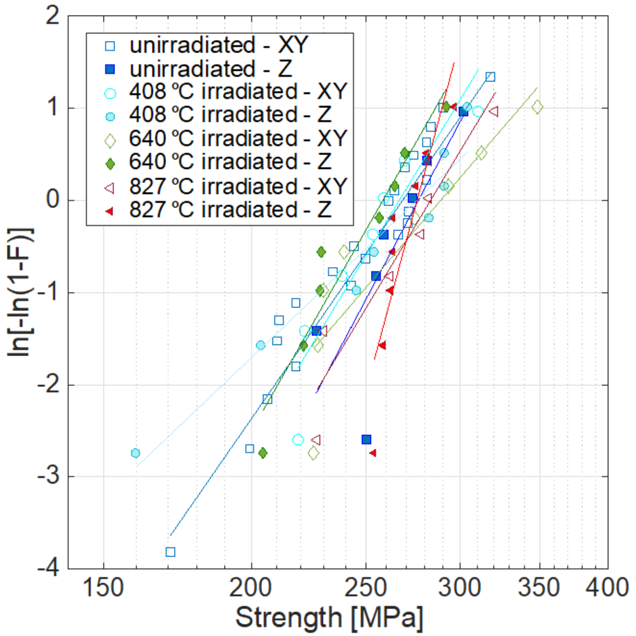


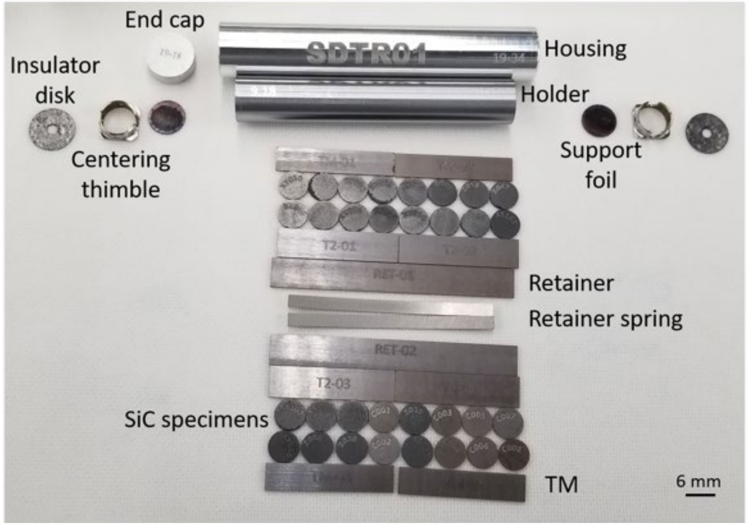
J. Weinmeister, P. Jain, B. Betzler (ORNL)

Leveraging AM to arrive at high-performance materials in complex geometries: 3D printing and neutron irradiation of silicon carbide as matrix for advanced fuel elements



No degradation in strength after neutron irradiation





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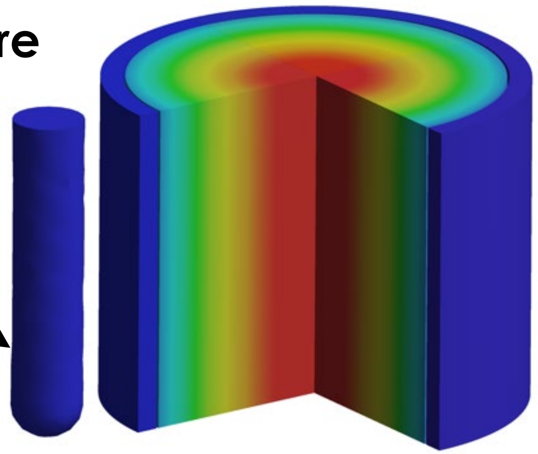
Exploiting AM to incorporate integrated and distributed sensing in critical locations: incorporation of sensors in 3D printed structures

Conventional sensing

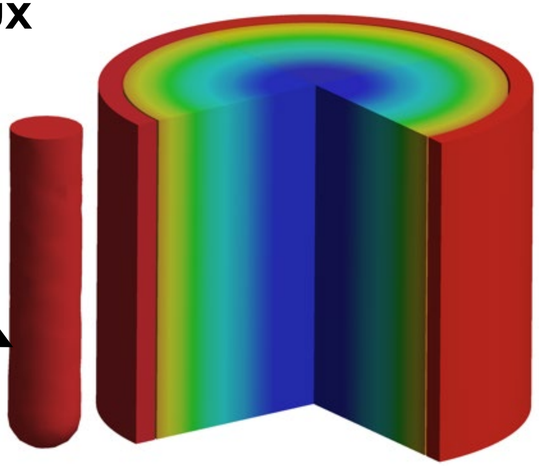
Temperature

Coolant temperature sensor



Neutron flux

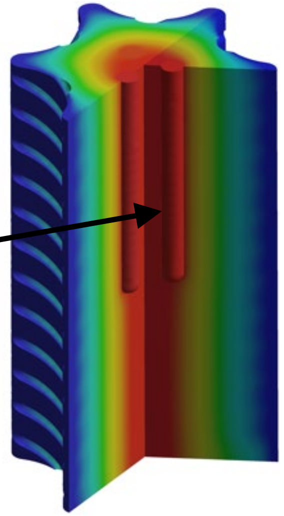
Local power monitor in coolant



Integrated sensing

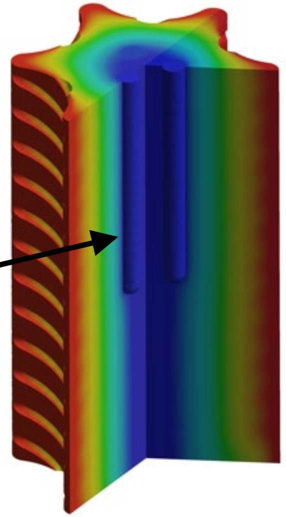
Temperature

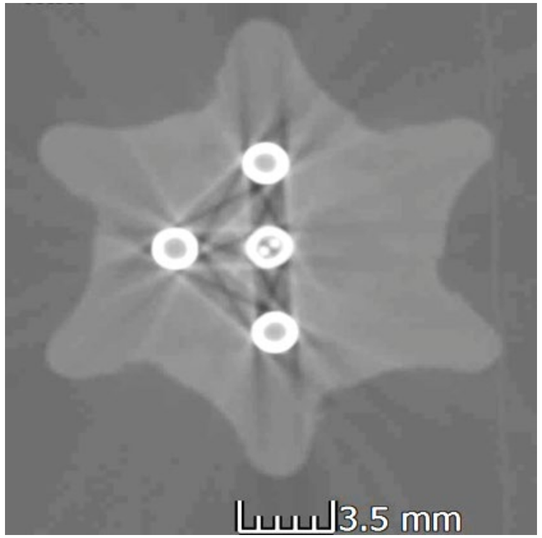
Temperature sensors embedded in fuel



Neutron flux

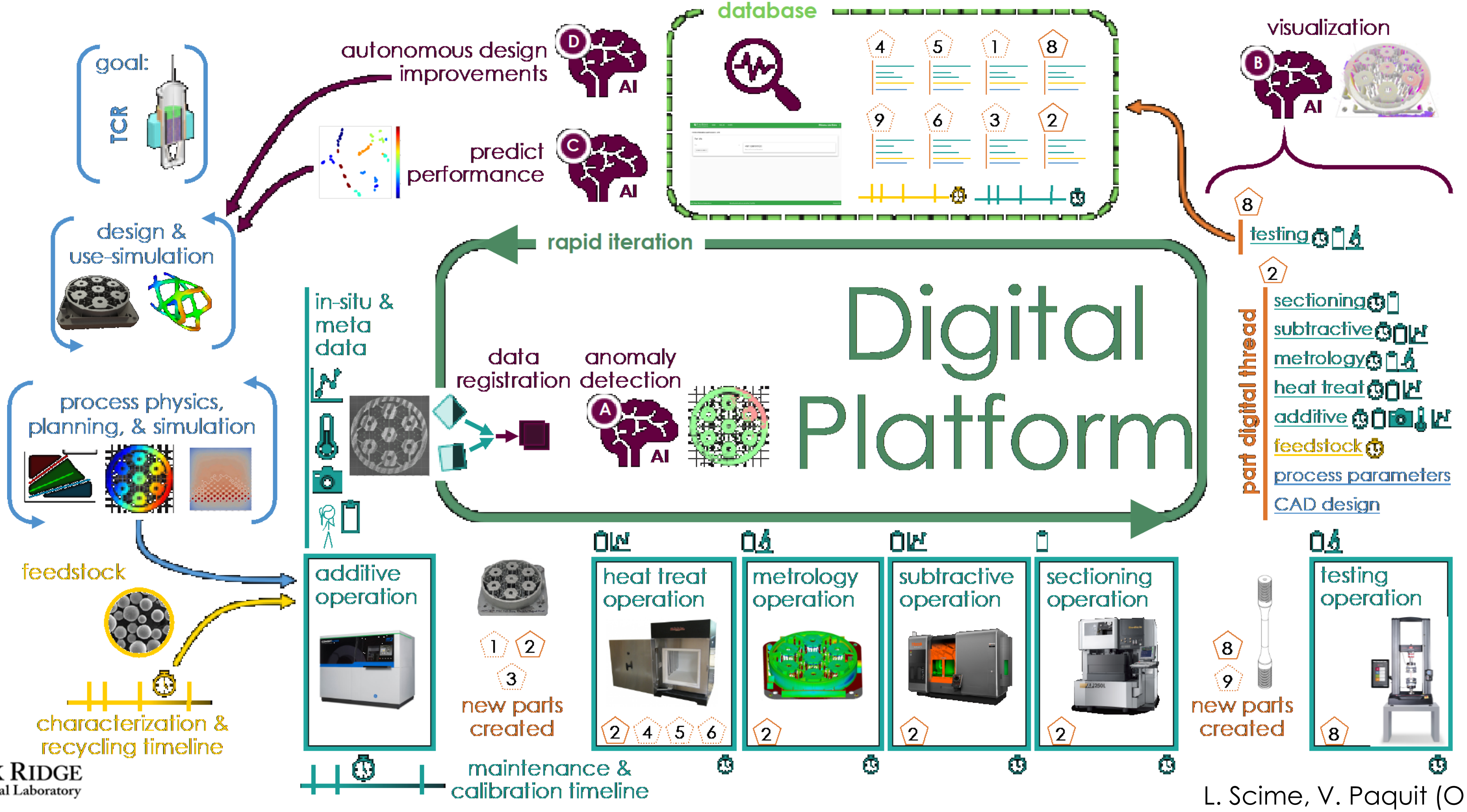
Neutron detectors embedded in fuel





C. Petrie (ORNL)

Using AI to assess critical component quality using in situ manufacturing signatures: Digital Platform for quality assurance



L. Scime, V. Paquit (ORNL)

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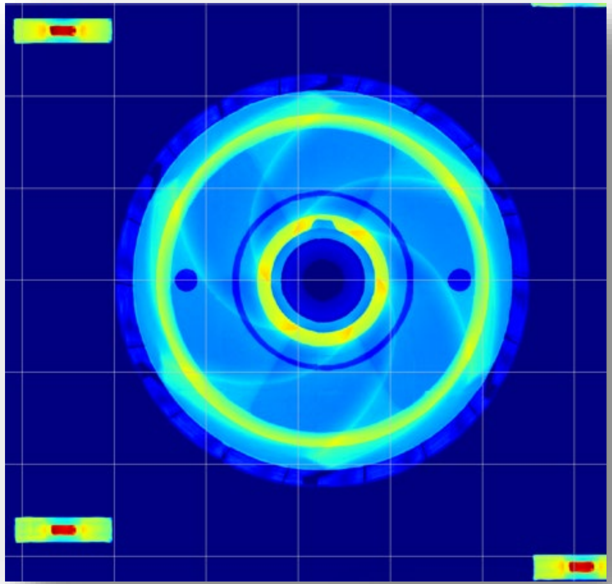
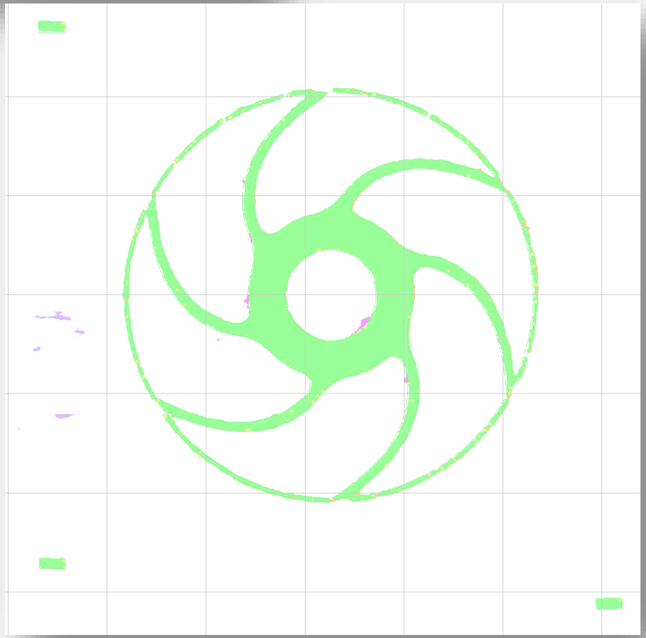
Additive manufacturing of salt pump impeller for Kairos Power

As ORNL builds novel reactor, nuclear industry benefits from technology

At the Department of Energy Manufacturing Demonstration Facility at ORNL, this part for a scaled-down prototype of a reactor was produced for industry partner Kairos Power. Credit: Kairos Power



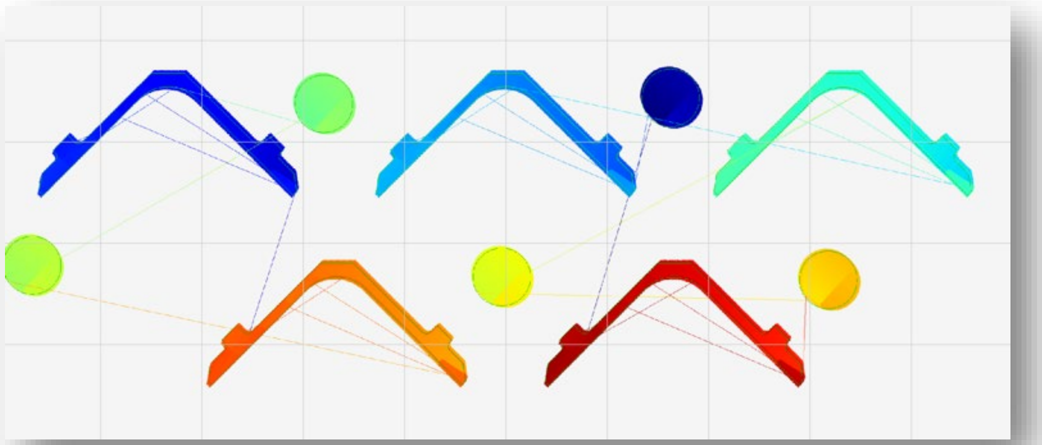


Reconstruction of in situ manufacturing data

Kairos Power

Additive manufacturing of fuel assembly components for Tennessee Valley Authority

Reconstruction of in situ manufacturing data



3D printed fuel assembly brackets as first ever safety-related components to be inserted into a nuclear power plant. The digital signatures collected during additive manufacturing and processed using artificial intelligence techniques lay the ground for an improved, accelerated, and cost-effective approach for nuclear quality certification.