OAK RIDGE National Laboratory

Accelerating Quality Certification of Critical Components with Additive Manufacturing

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TCR Lead – Digital/Manufacturing/Testing

Workshop on Advanced Manufacturing Technologies for Nuclear Applications
Session 4 – Approaches to Component Qualification and Aging Management

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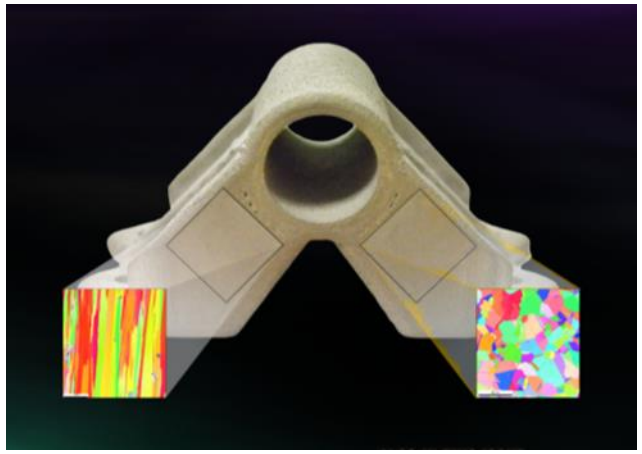
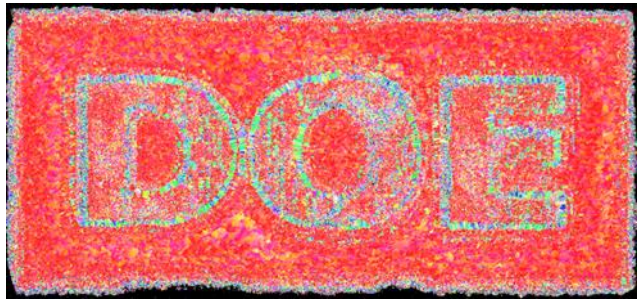
U.S. DEPARTMENT OF ENERGY

Scientific drivers

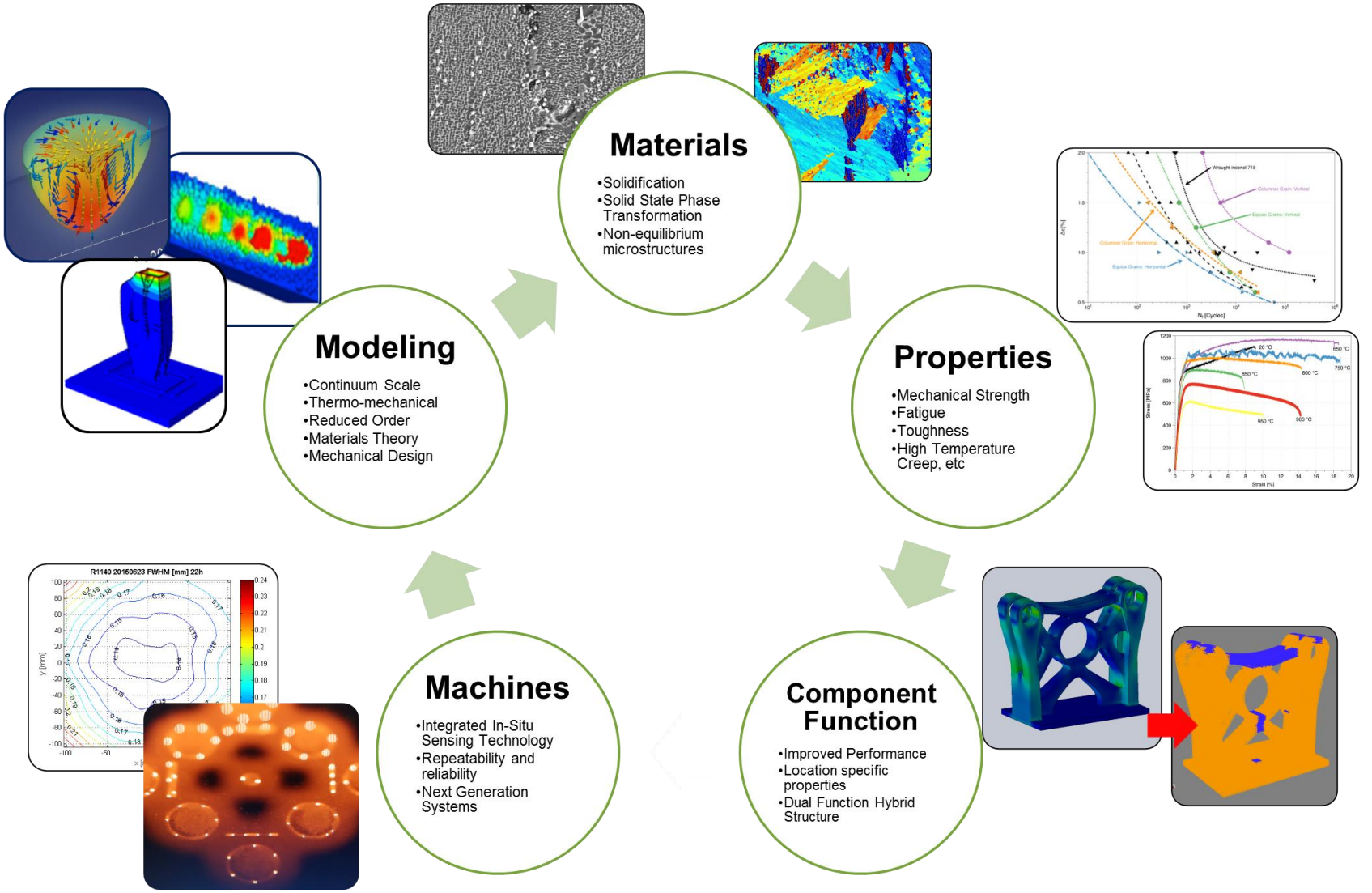




- Certification of AM components by conventional methods eliminates the business case for AM components
- Limited understanding of local and global processing state for additive manufacturing

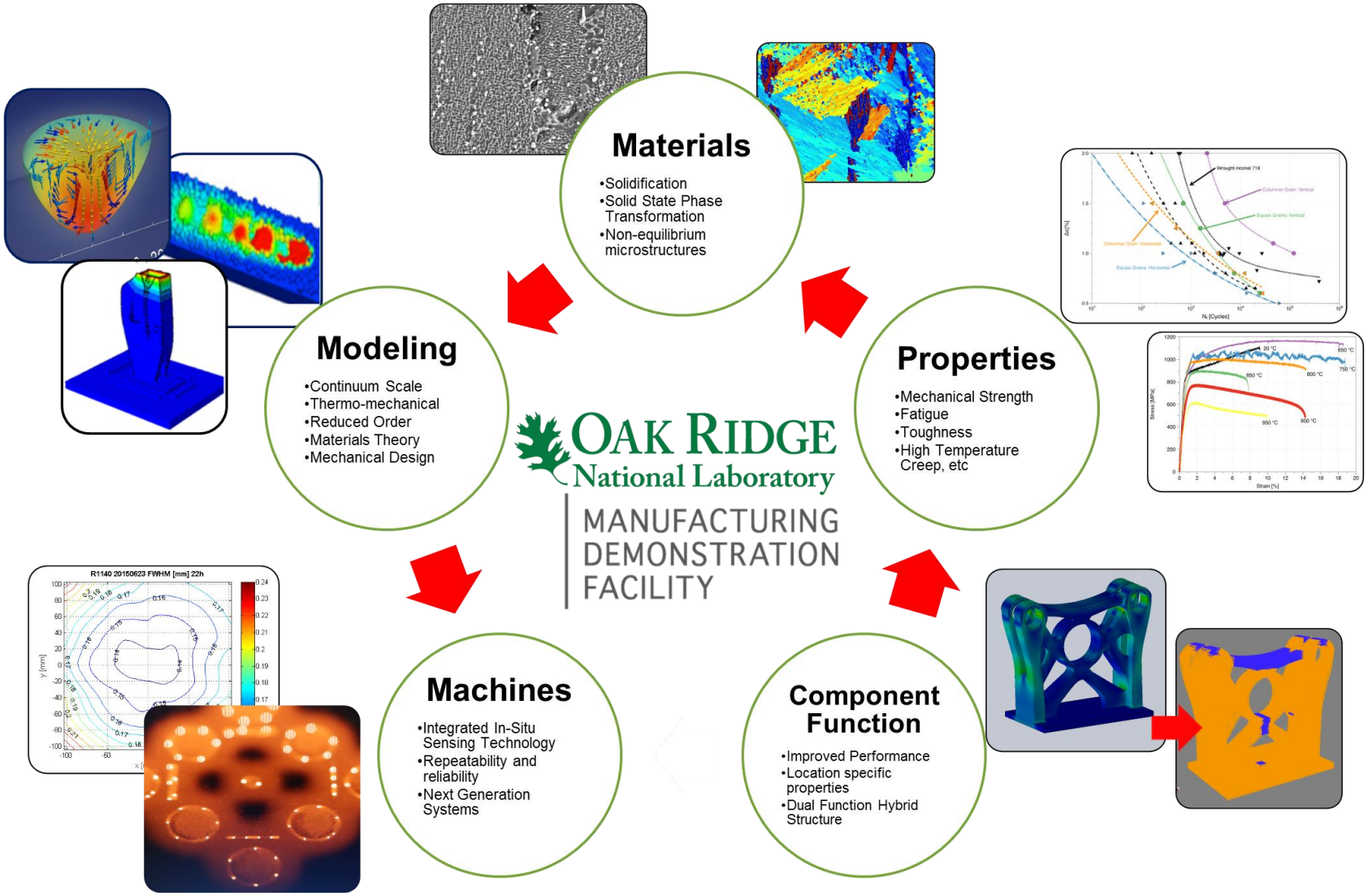
Develop new certification methodologies for manufacturing technologies

Conventional Approach



Path to Certification

Use data analytics and machine learning to intentionally design components with location specific control of microstructure



Smart Manufacturing Approach

ORNL has developed a technology agnostic data analytics framework for manufacturing.

A four-steps data driven approach toward processes optimization, and qualification, and certification of manufactured parts

Step 1: Understanding the process

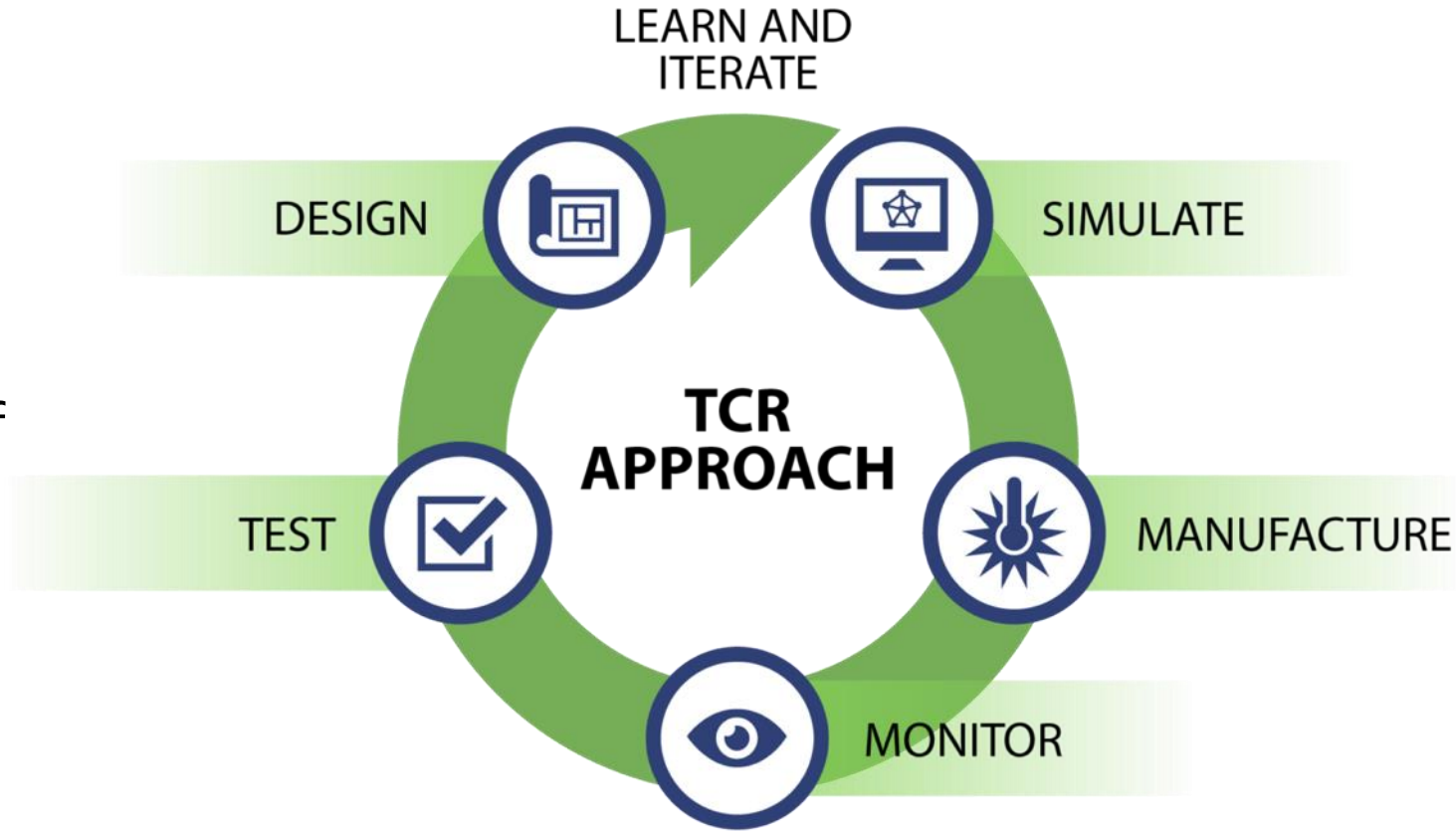
Step 2: Optimizing the process

Step 3: Feedback loop for self-optimization/correction

Step 4: Certifying and qualifying components

TCR will demonstrate that an agile development approach can be applied to accelerate deployment.

- An agile approach breaks with traditional linear development models to exercise an iterative, dynamic development process.
- The approach lends itself to complex projects in which a large, multidisciplinary team works together closely to complete a product.



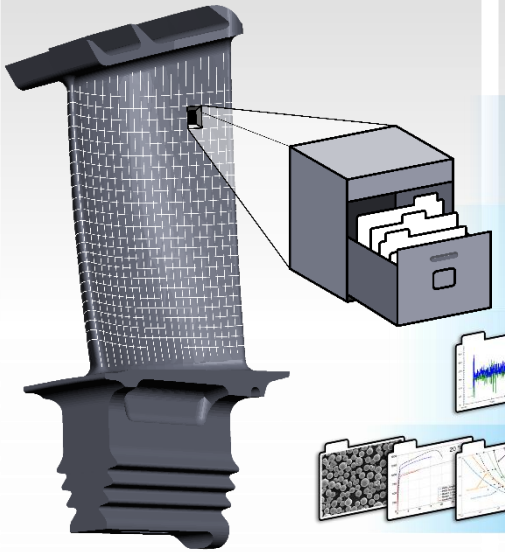
Digital Platform for Manufacturing

Advanced manufacturing technologies produce valuable datasets at every stage of the manufacturing workflow. Collecting, structuring, and analysis such data is paramount to understanding, optimizing and validating the manufacturing process.

IT Infrastructure

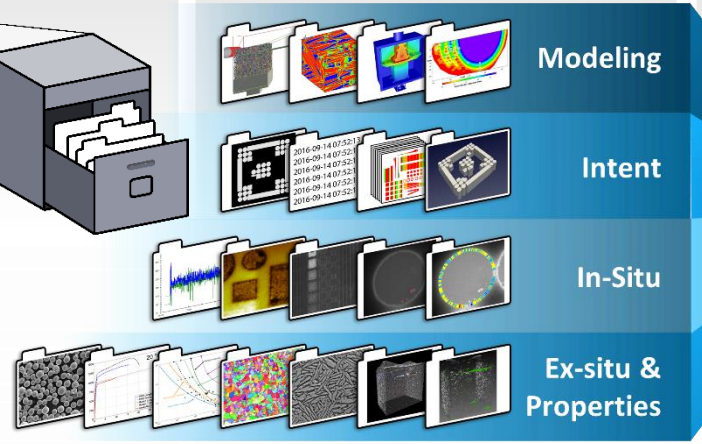
- Wired network
- WiFi network
- IoT
- Storage systems
- HPC systems
- Embedded Systems

Voxelized Parts



Data Producers

Sensor data



Digital Clone

Unified Data Architecture

DREAM.3D
Open Source Edition

Data Workflow

- Data Management & Tracking
- Signal Processing
- Computer Vision & Image Processing
- n-D Data Visualization
- Modeling & Simulation
- Data Analytics & Machine Learning
- Process Optimization
- Certification, Verification & Validation

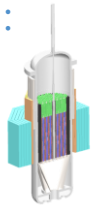
Cybersecurity

Digital Thread

Digital Thread

goal:

TCR

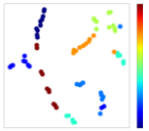


autonomous design improvements

D AI

predict performance

C AI



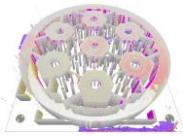
database

4 5 1 8

9 6 3 2

visualization

B AI



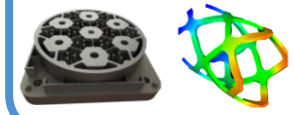
8 testing

2 part digital thread

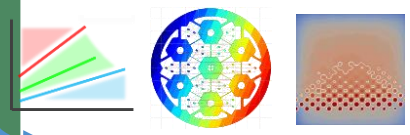
- sectioning
- subtractive
- metrology
- heat treat
- additive
- feedstock
- process parameters
- CAD design

rapid iteration

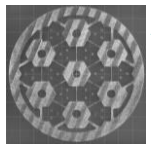
design & use-simulation



process physics, planning, & simulation



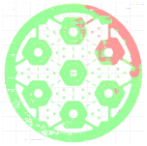
in-situ & meta data



data registration

anomaly detection

A AI



feedstock

characterization & recycling timeline

additive operation

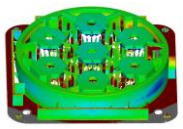
1 2 3

new parts created

heat treat operation

2 4 5 6

metrology operation



2

subtractive operation

2

sectioning operation

2

8 9

new parts created

testing operation

8

maintenance & calibration timeline

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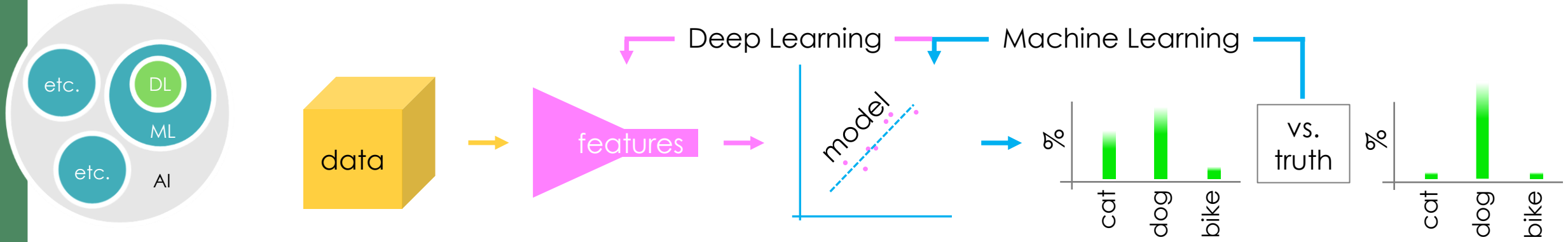
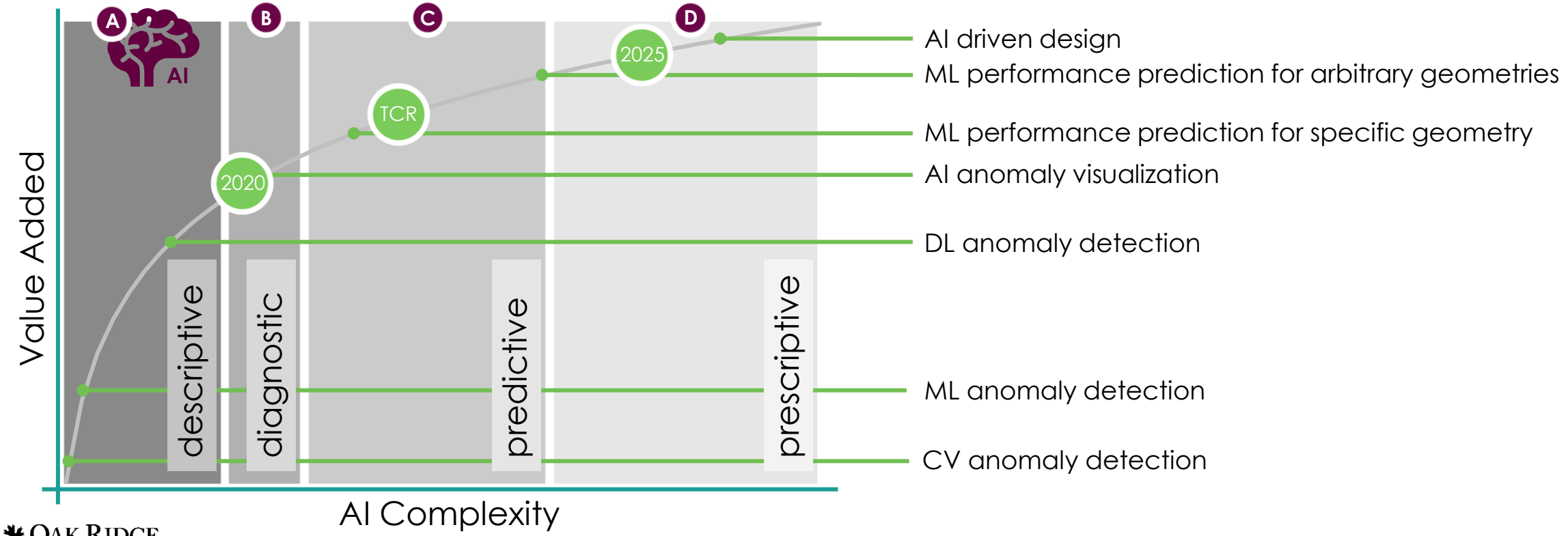
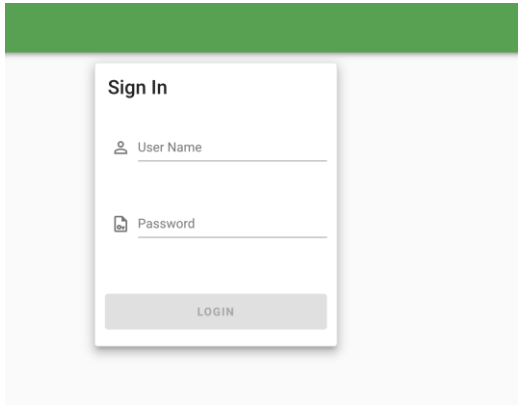
Augmented Intelligence for Advanced Manufacturing



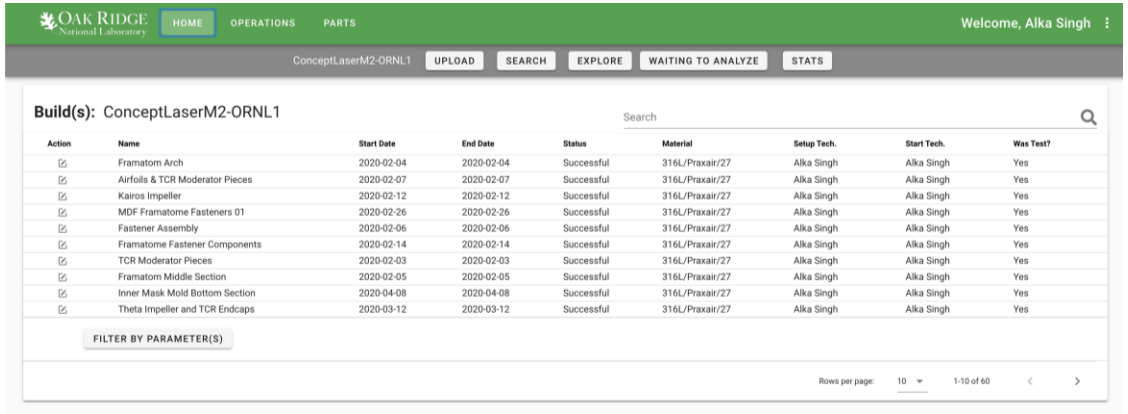


Web-Based Interface and API Makes Data Accessible

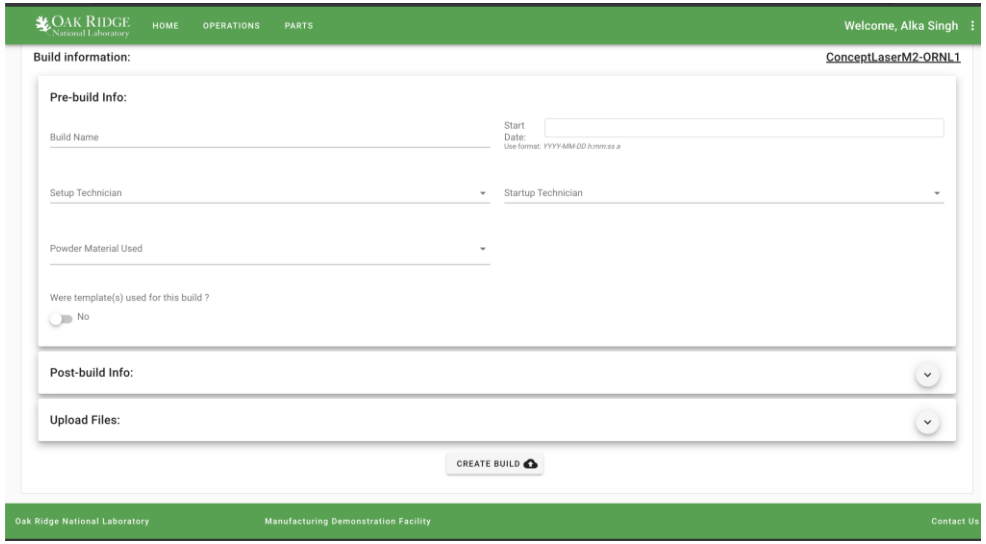
LDAP authentication



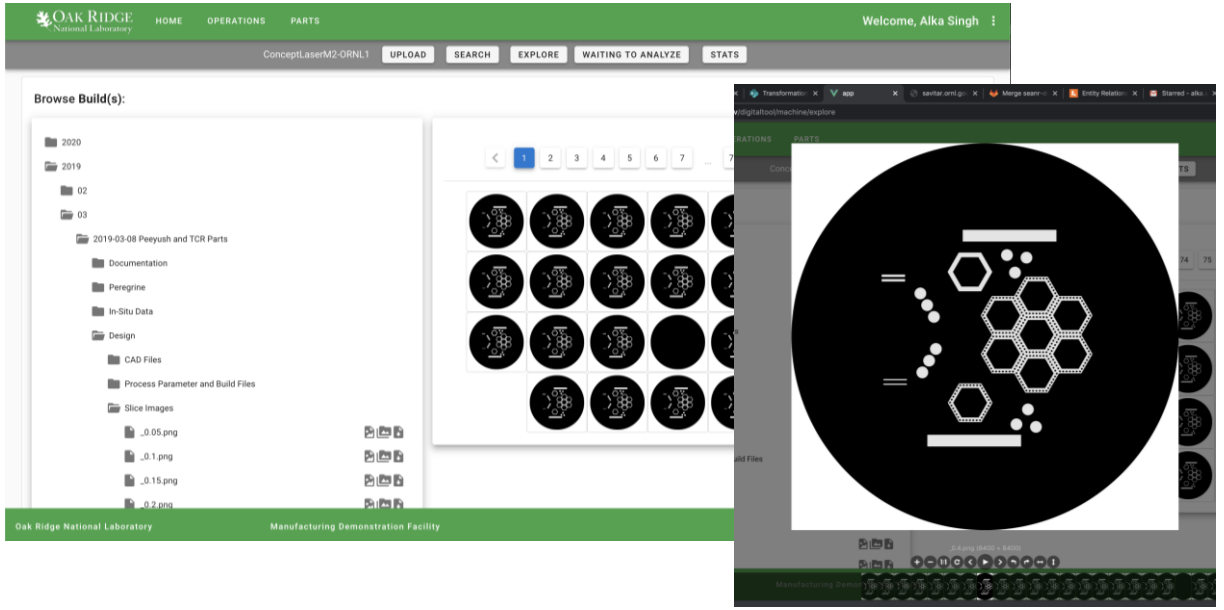
Metadata search



Upload form



Data viewer



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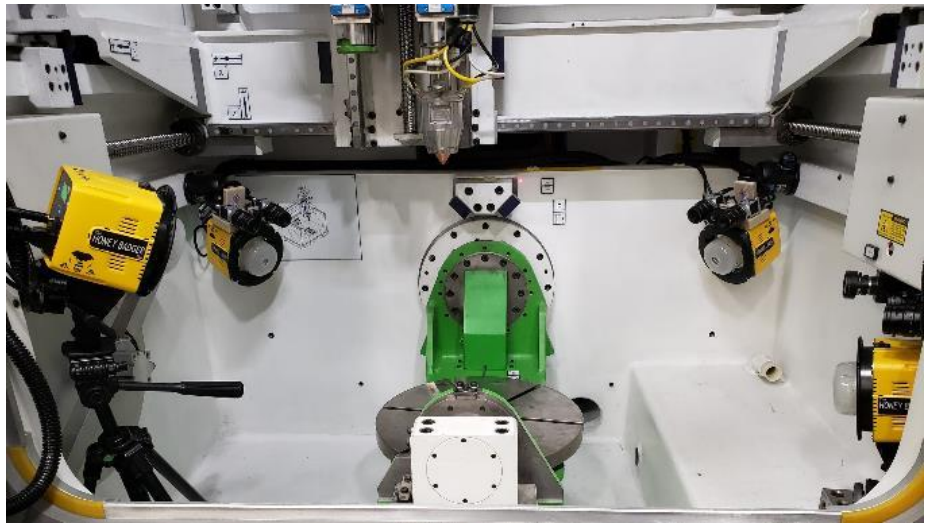
Additive Technologies & Parts

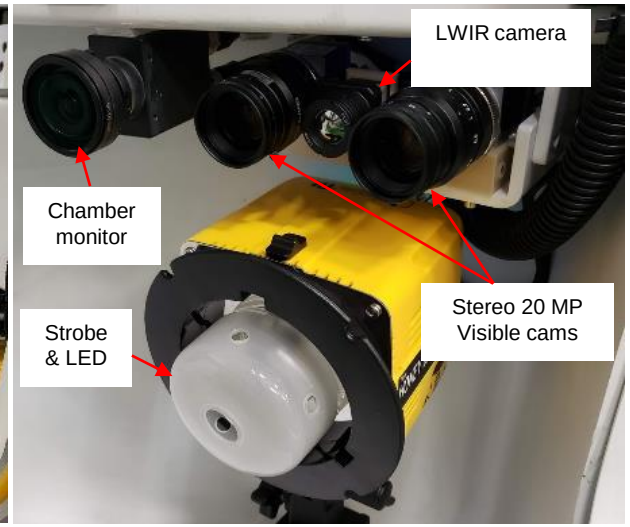
Laser Powder Bed

Blown Powder

Binder Jet

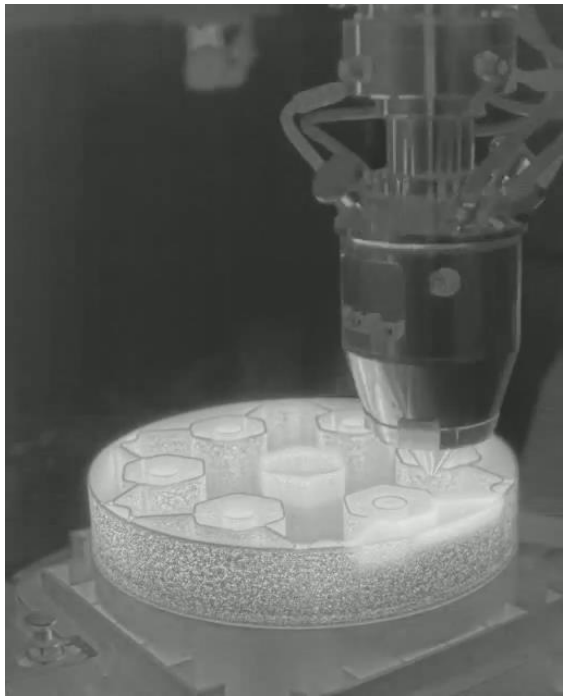
BeAM – Blown Powder

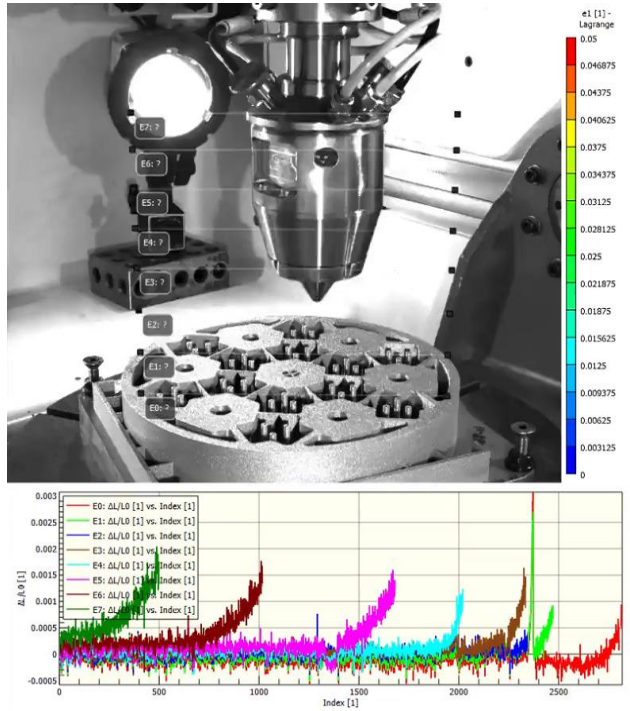


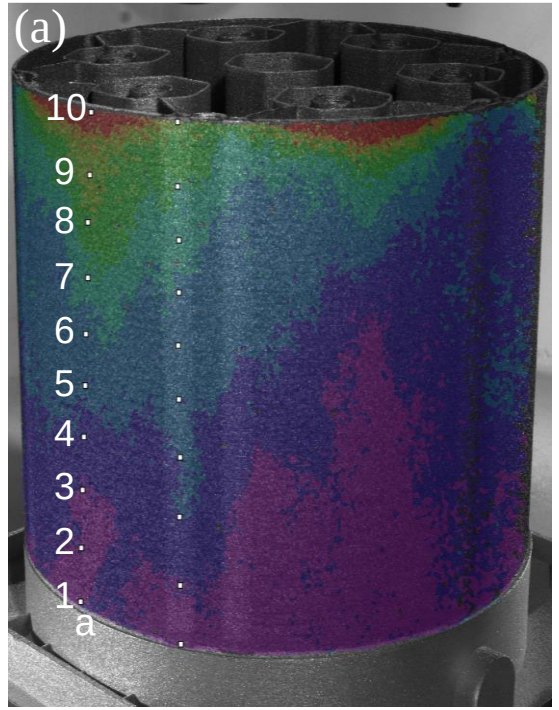


Imaging system provides:

- real time 360 measurement
- 3D geometry dimensions
- 3D strain measurement,
- thermal measurement







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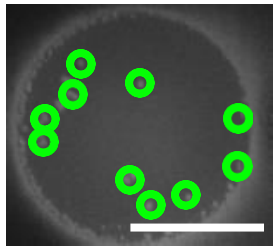
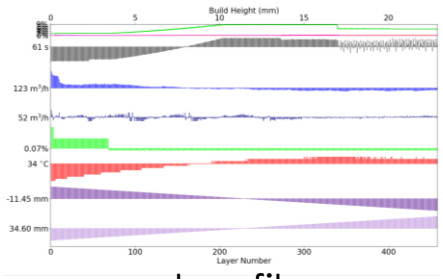
Anomaly Detection

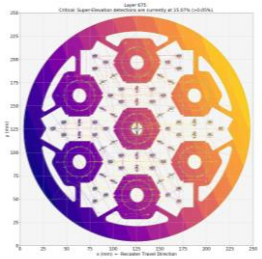
1. Detect and **classify** any anomalies
2. **Localize** anomaly detections



3. **Register** sensing modalities

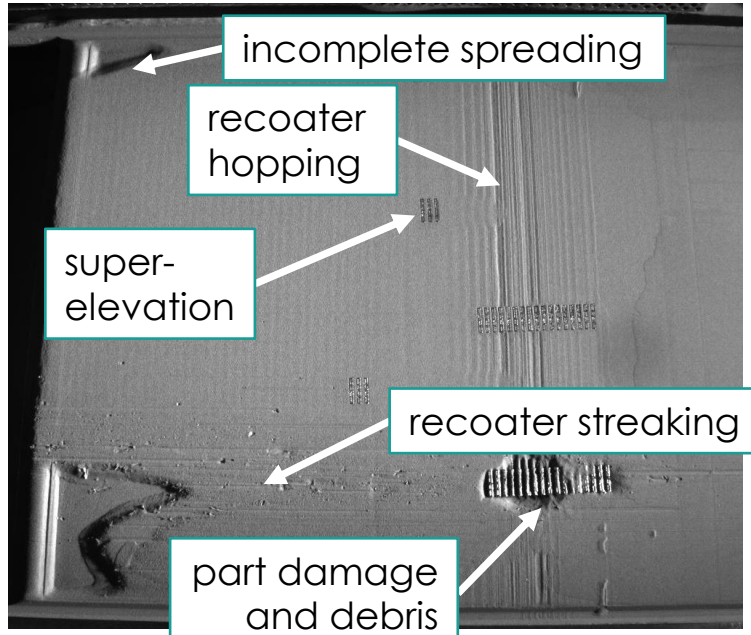


log file



scan path

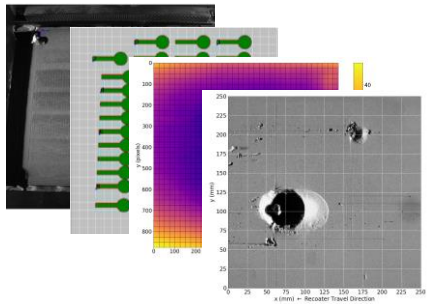
4. Perform **process interventions**
5. Fully **machine agnostic** solution



"Critical layer"
"Attempt to re-spread the powder"

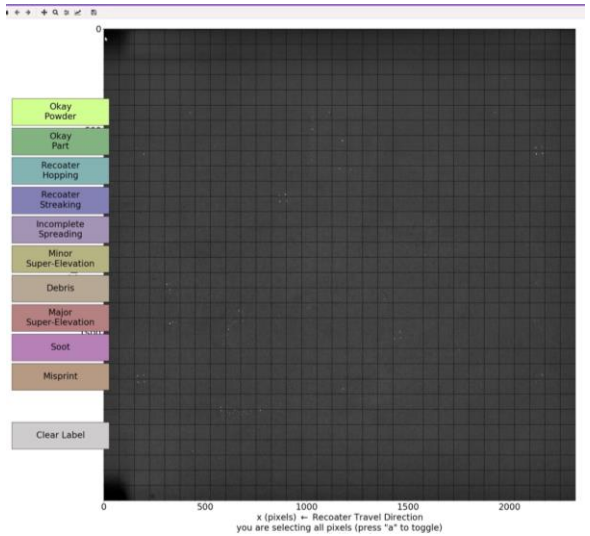
AI workflow and transfer learning

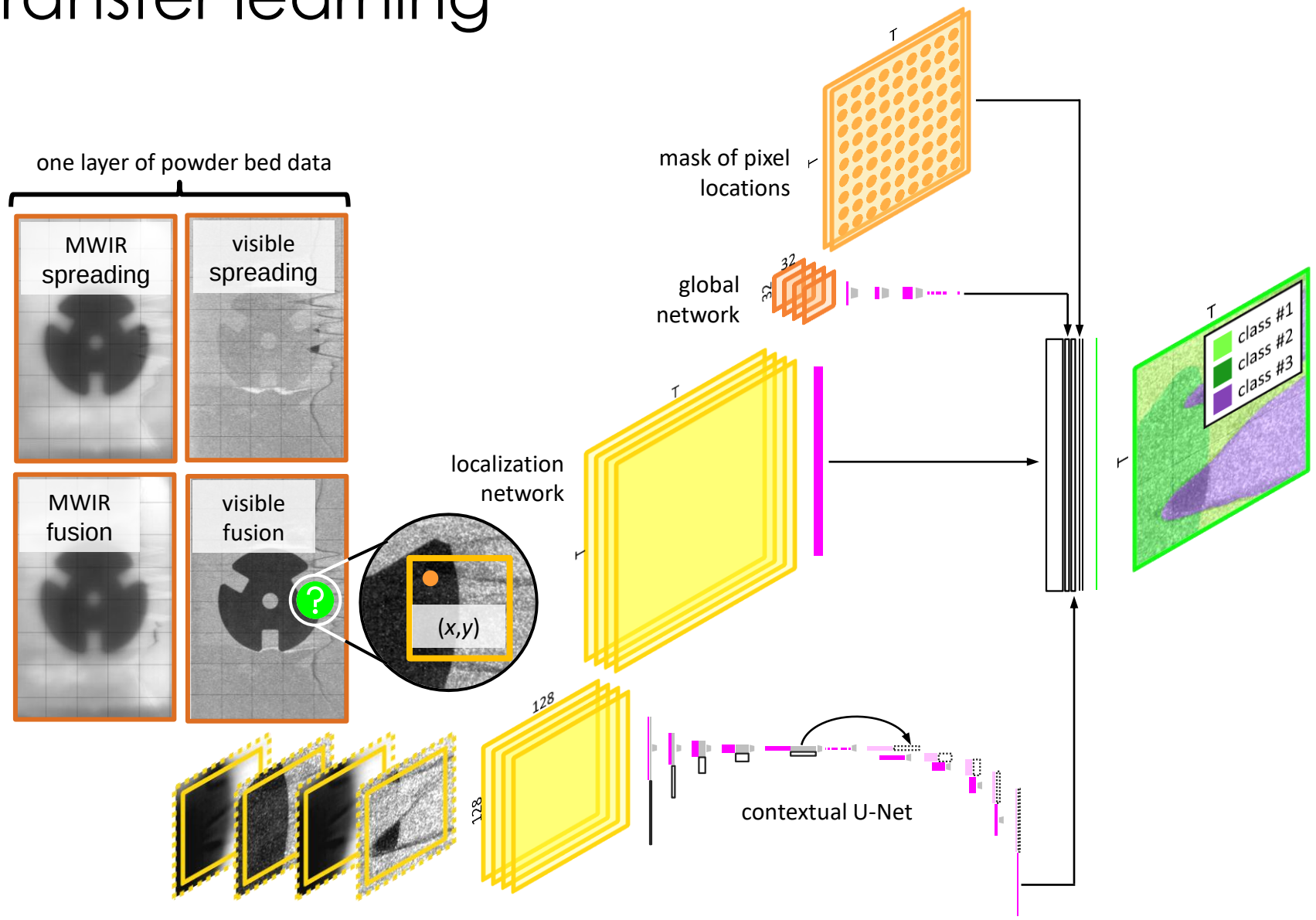
data curation



Manual data annotation

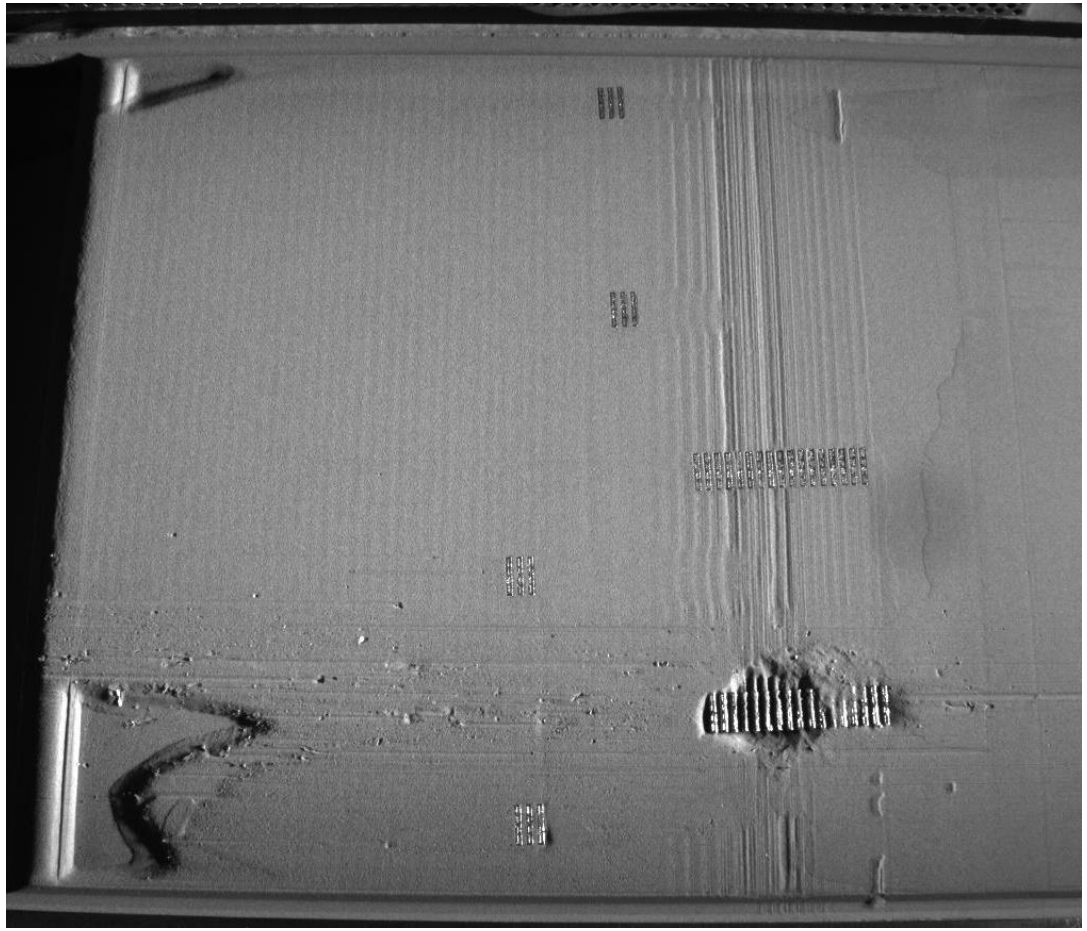
- Training the machine learning algorithm from scratch
  - 100,000,000+ labeled pixels



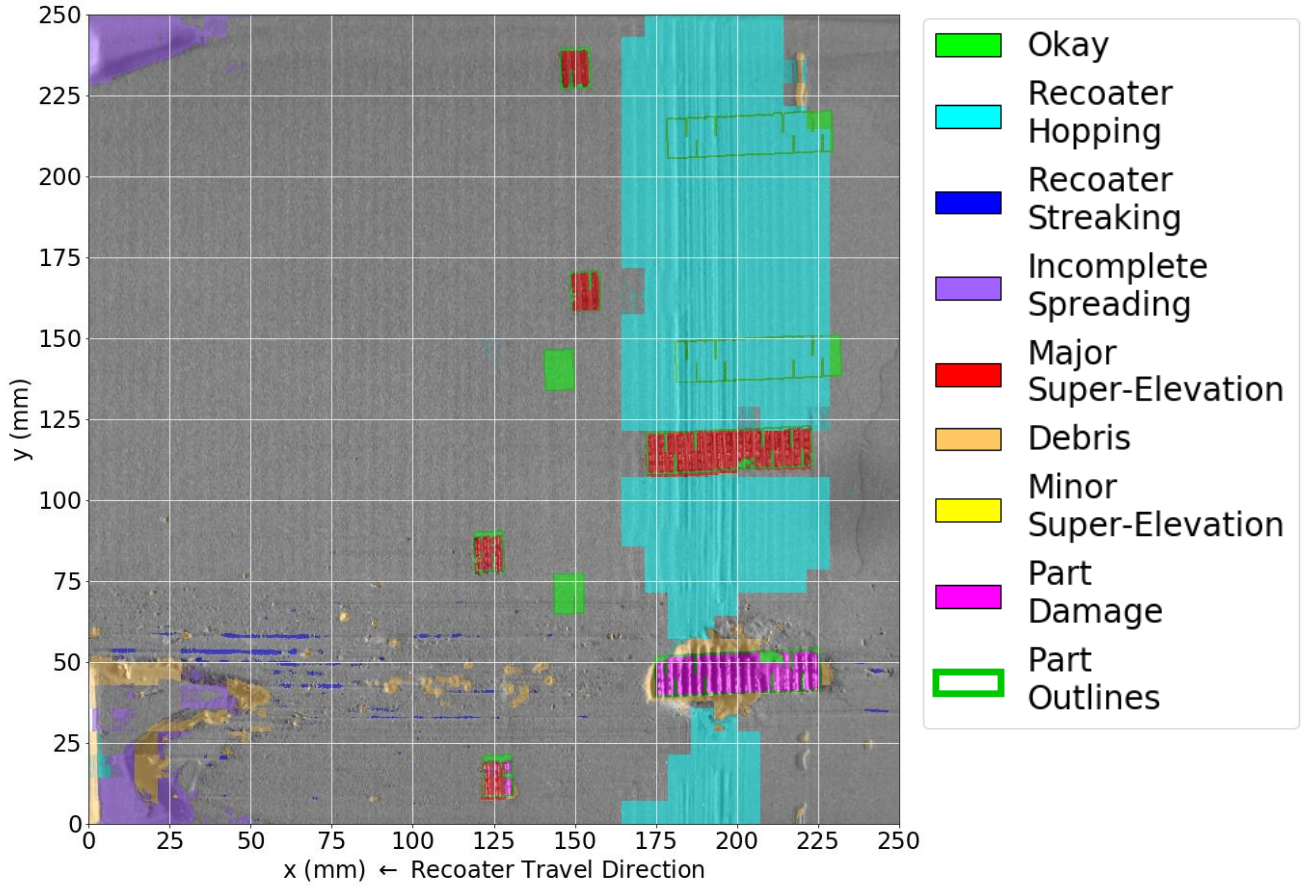


Dynamic Segmentation Convolutional Neural Network

Approach: classification results

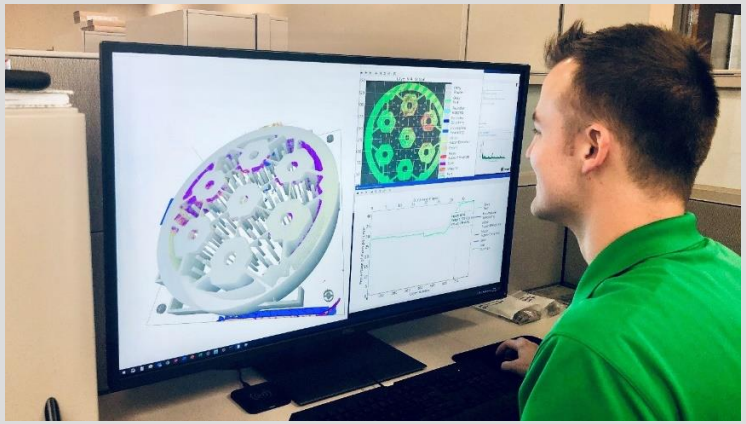


Input image

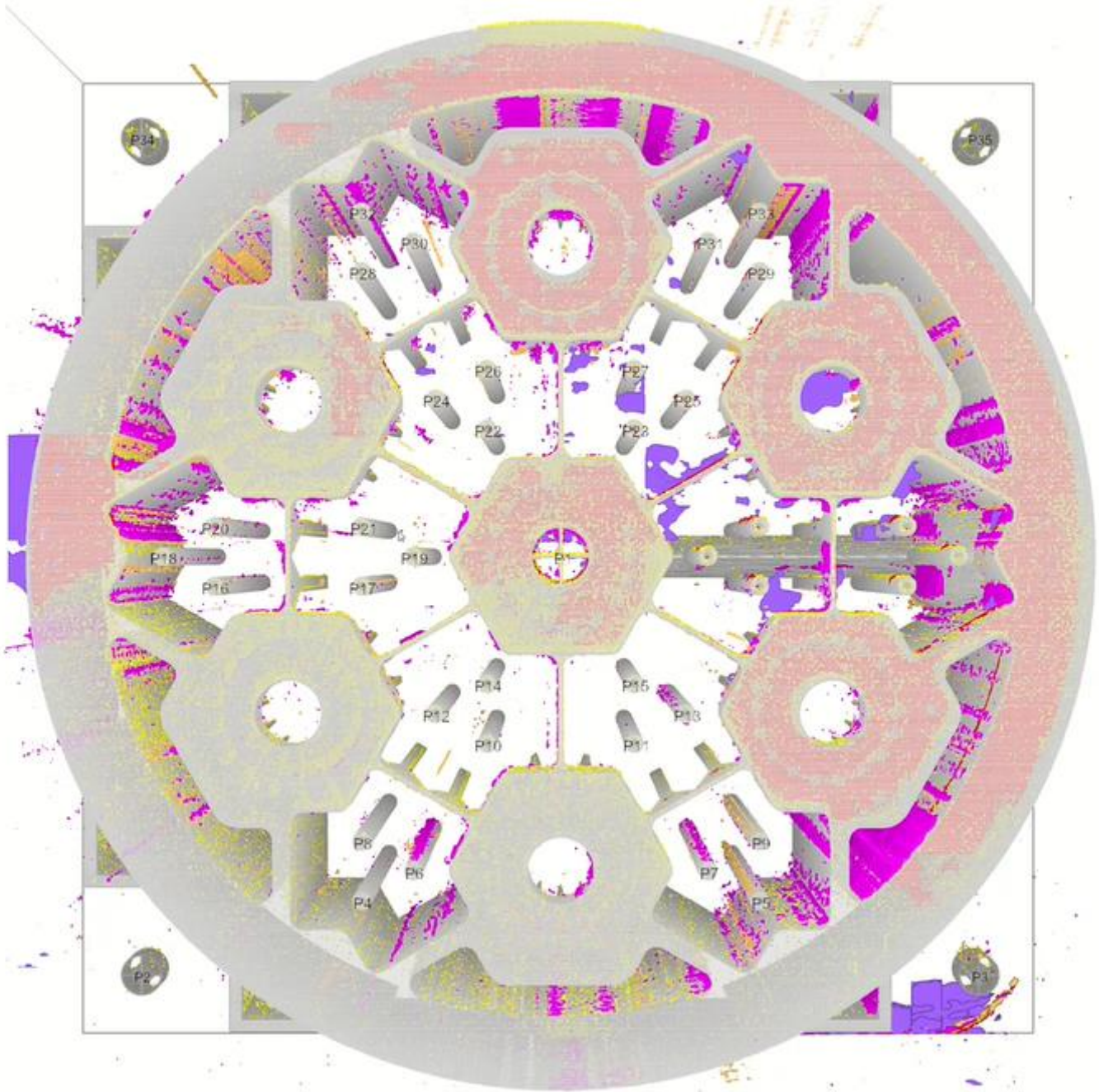


Classification results

Peregrine

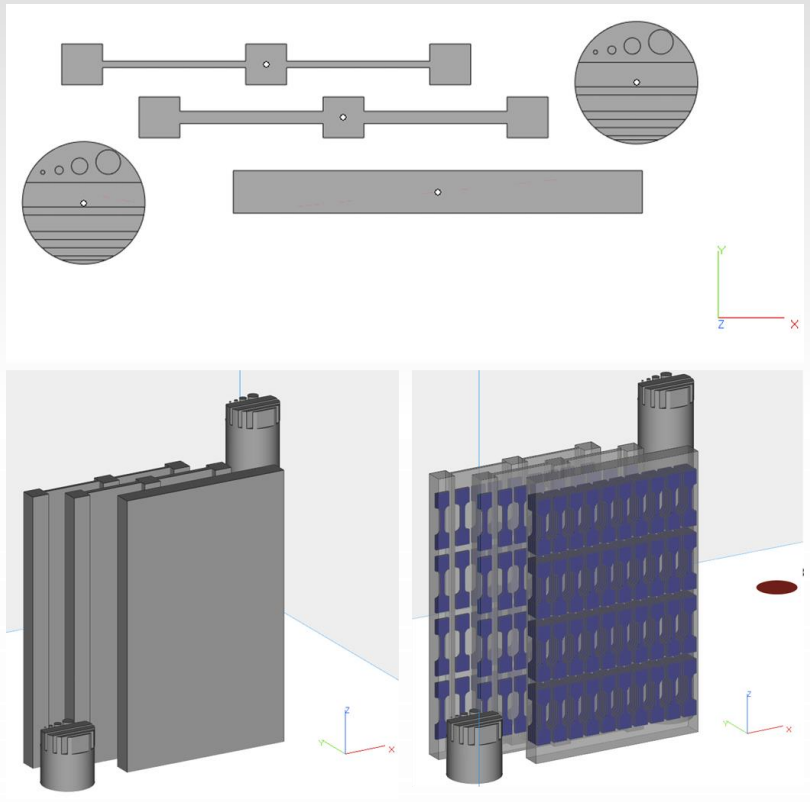


- AI software for real-time 3D print monitoring
- Main platform for most of the TCR data analytics activities
- Commercial copyright license available
- Publication DOI: 10.1016/j.addma.2020.101453



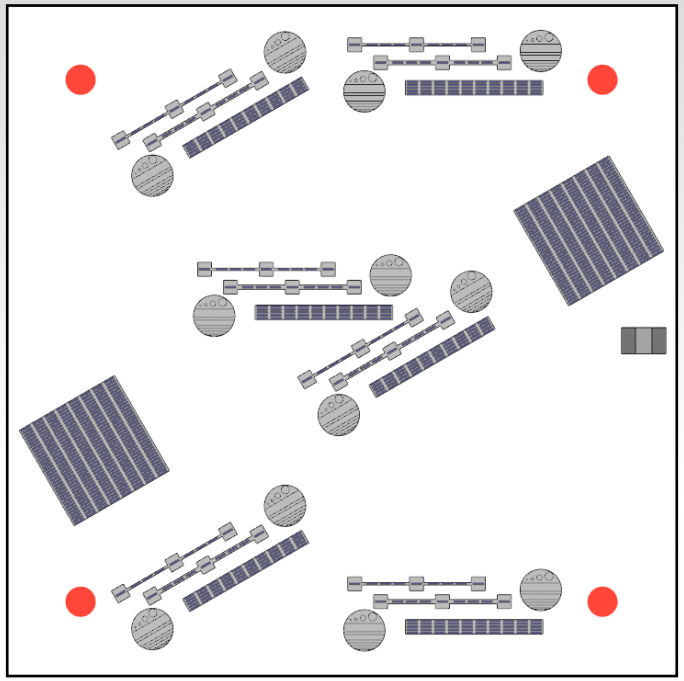
Process Correlation Campaign For Properties Predictions

Standard Cluster



Location Specific Sample Extraction

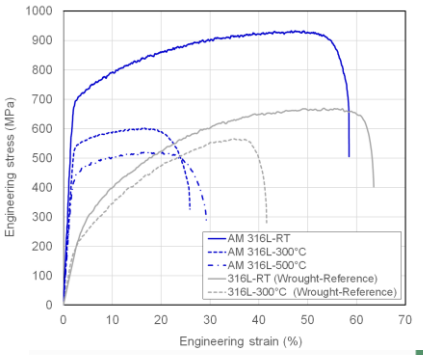
Build 0.1 Layout



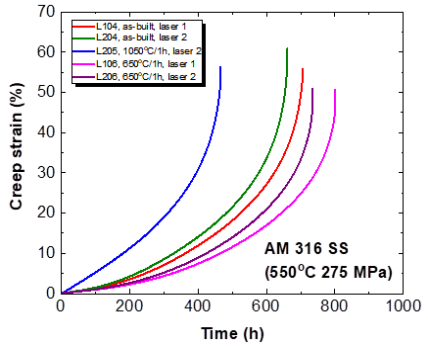
2,784 SS-J3 specimens

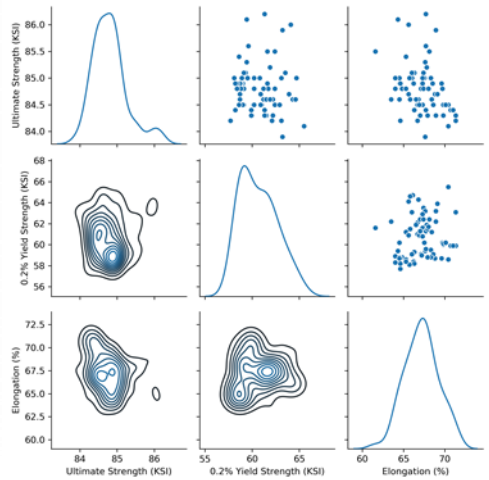
Data Correlation

Mechanical properties

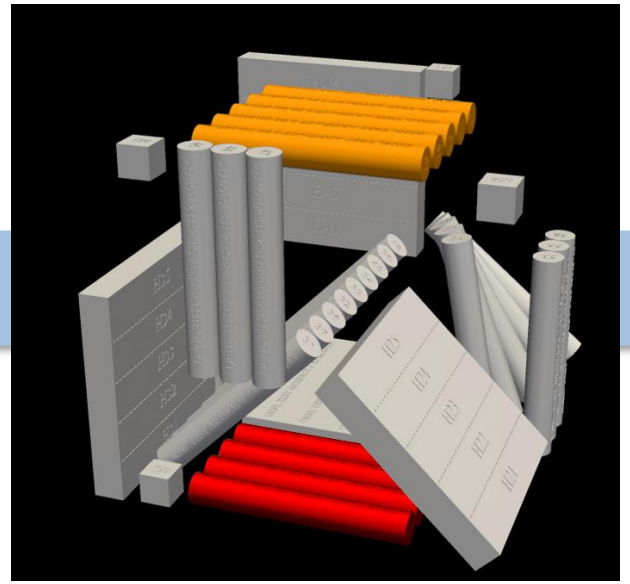


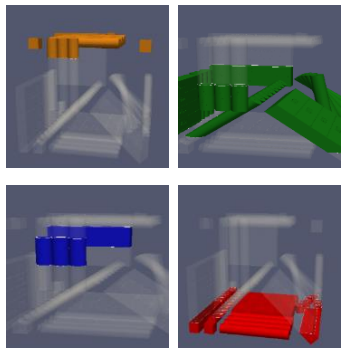
Creep properties

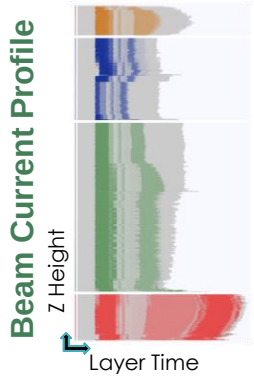




Achieving Uniform Material Properties through Data Analytics and AI

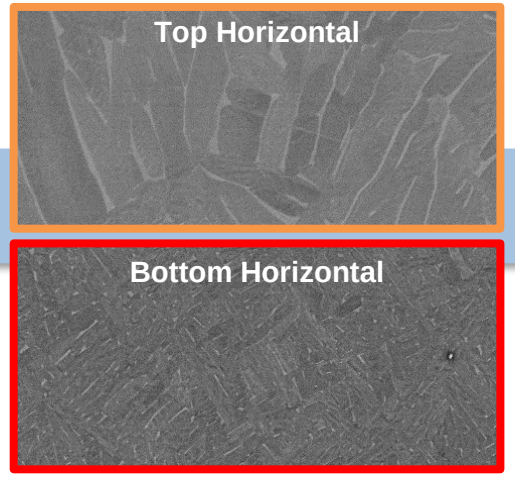


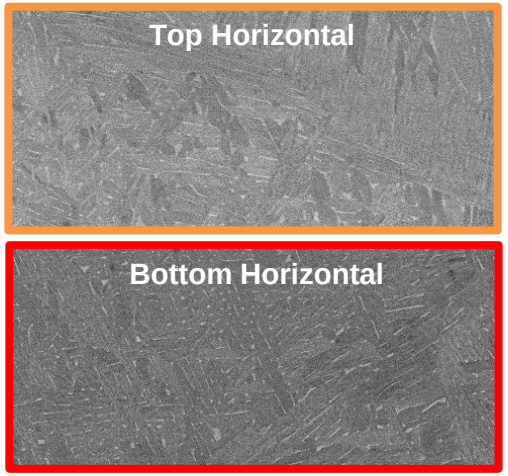




Geometry with varying cross section and printing time per layer

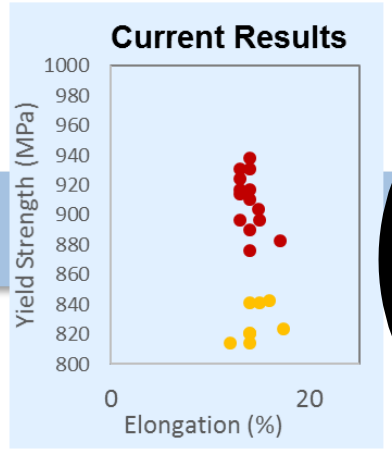
Micrographs Base Melt Theme

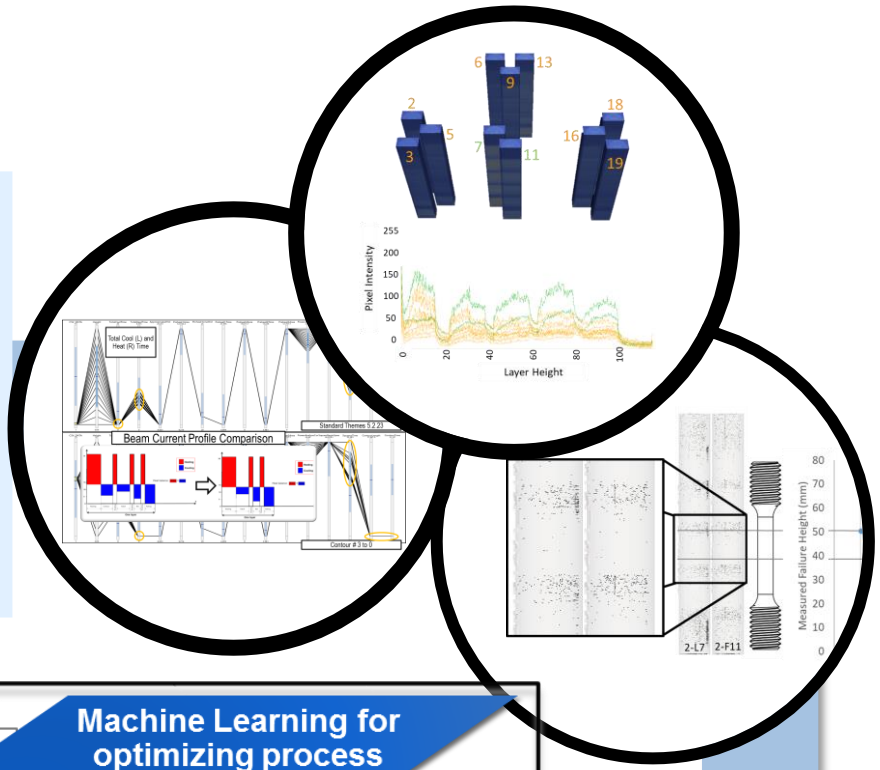


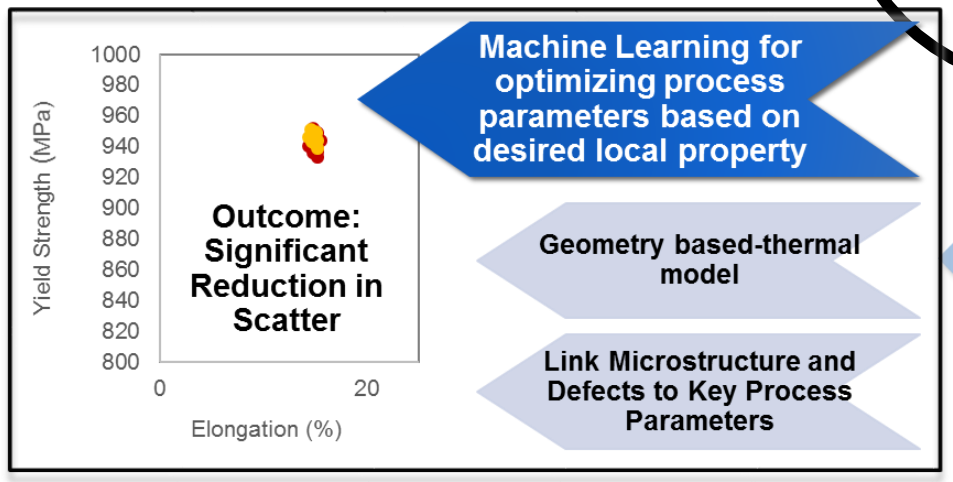


Micrographs Modified Melt Theme

Scattered mechanical testing results







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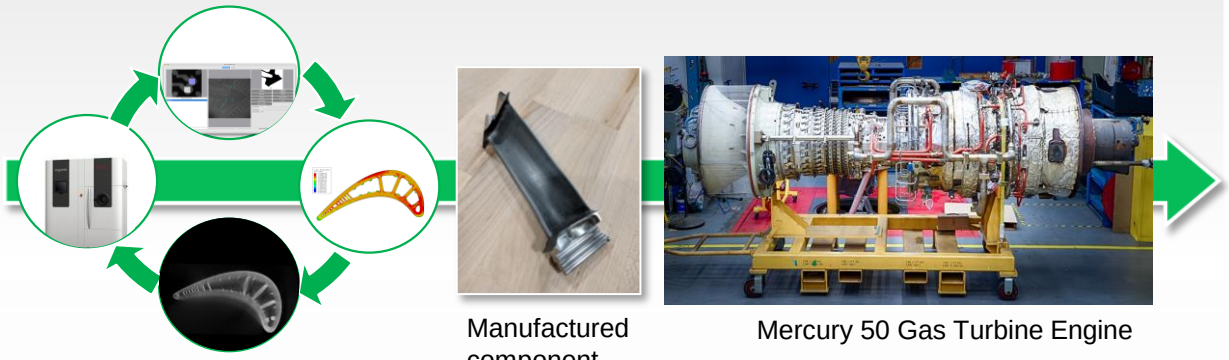
Relevance and impact

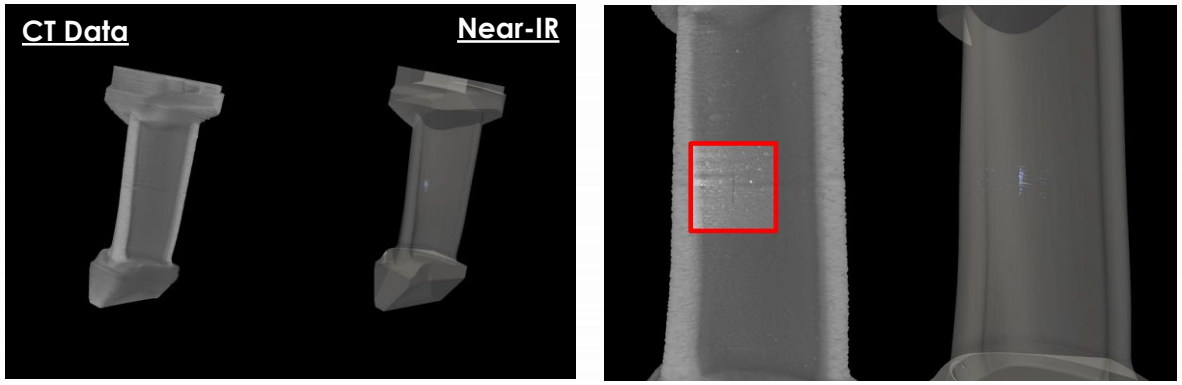
Solar Turbines

- **Objective:** Fabricate near net-shaped SGT5-400F airfoil with no surface breaking cracks from a high gamma prime Ni-base superalloy
- **Successfully tested on August 25th 2020**



Manufactured component

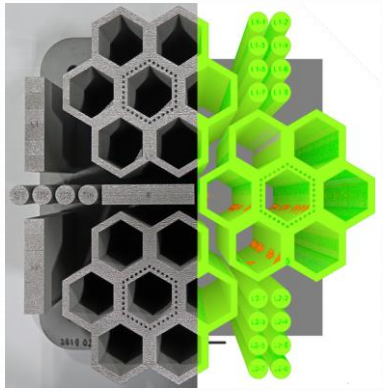
Mercury 50 Gas Turbine Engine



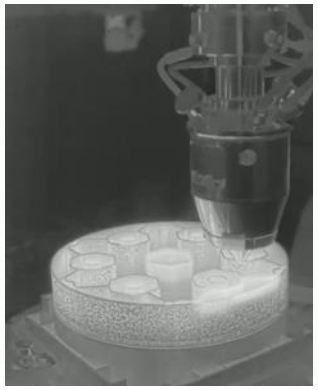
AI for CT reconstruction and defect detection

TCR

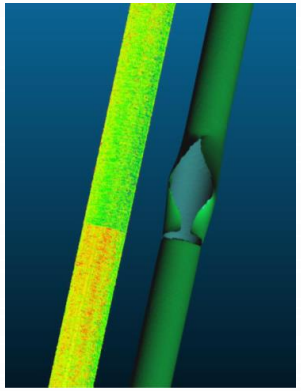
- **Objective:** Develop a digital platform and associated processes to couple data analytics with design and manufacturing data for use in rapid prototyping and quality evaluations of manufactured products.



In-situ & AI



Sensor development

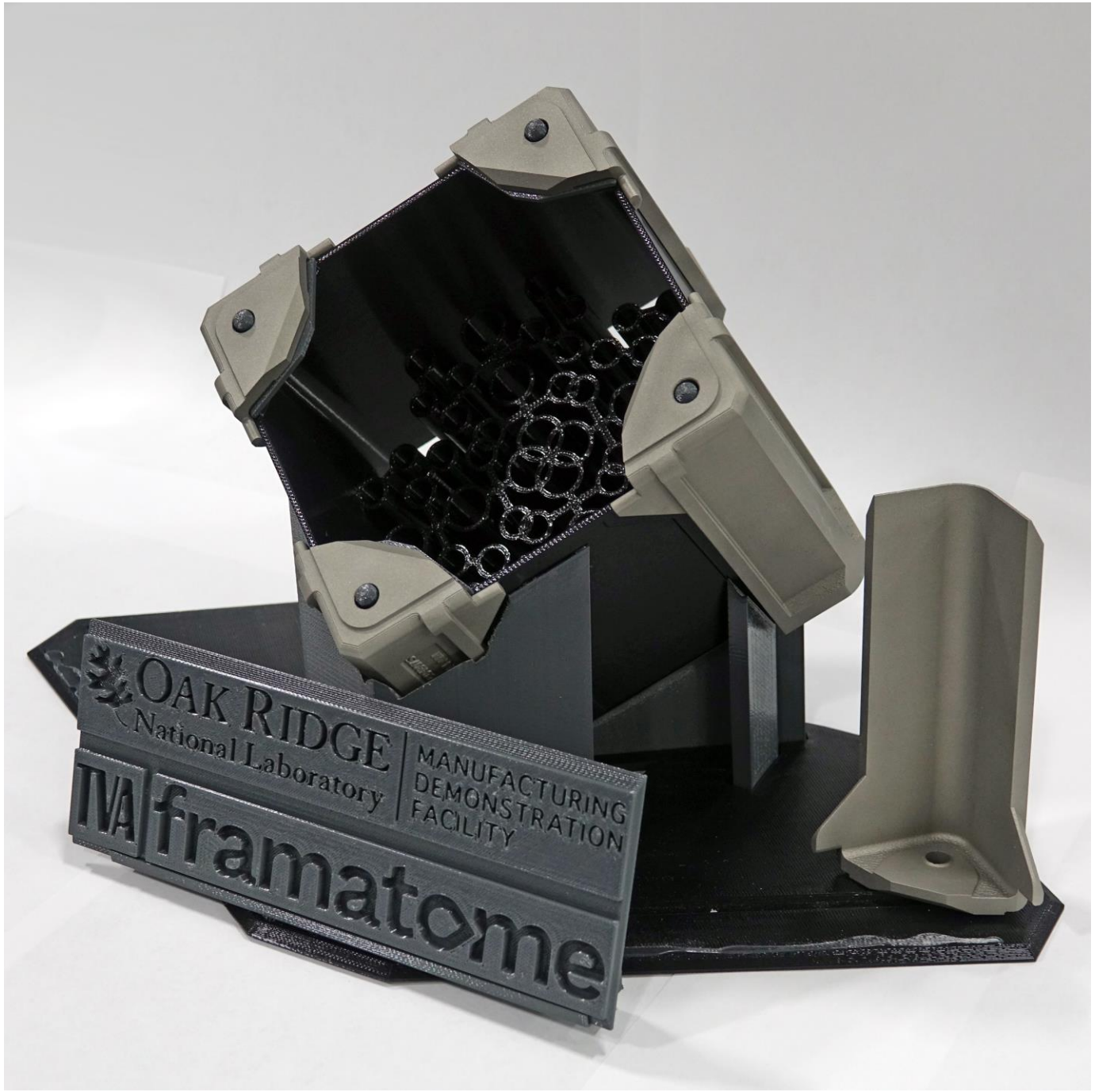


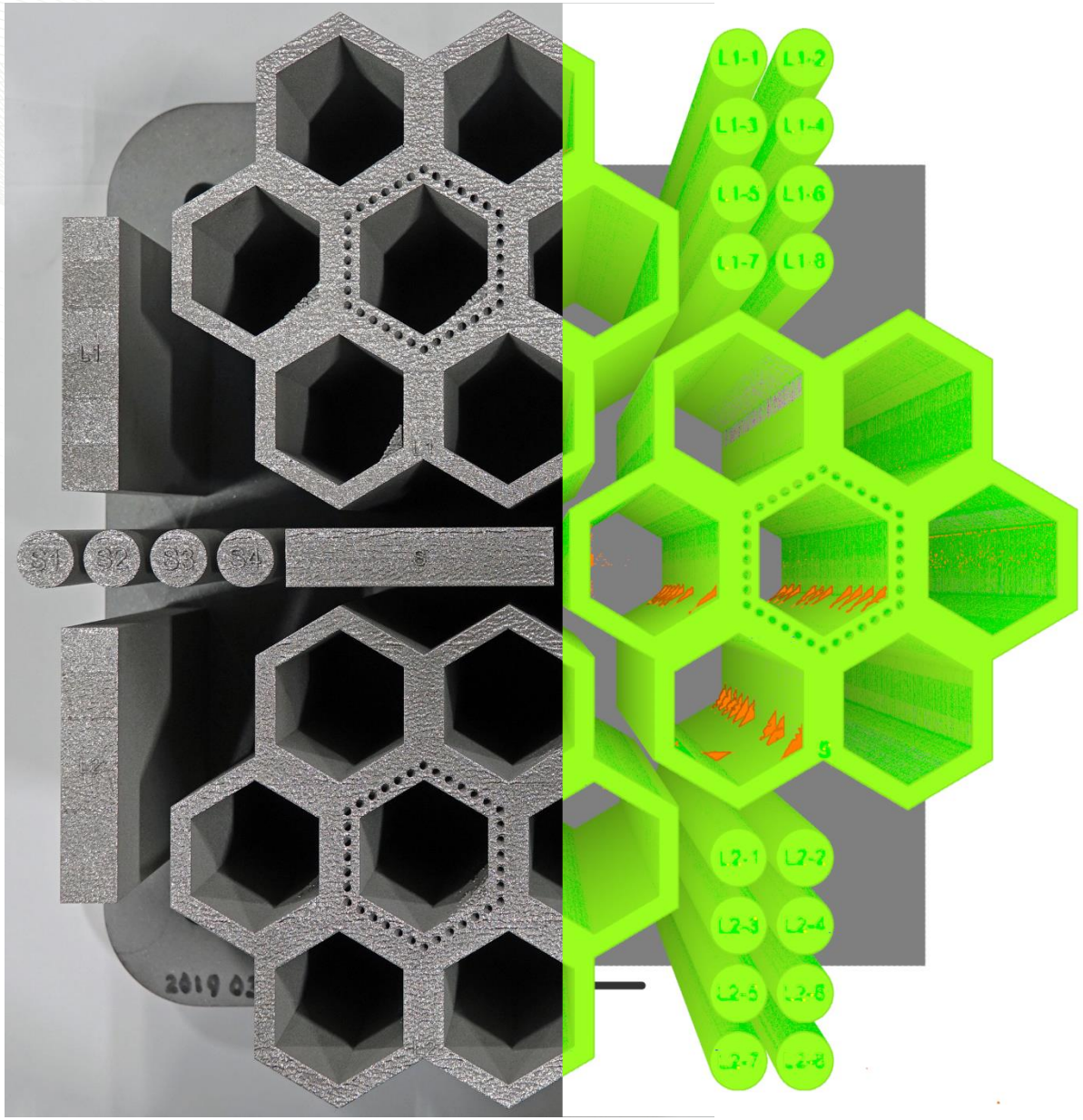
In-situ and Ex-situ correlation

Framatome, TVA, Oak Ridge National Laboratory to load first 3D-printed component in commercial reactor

"The fuel assembly channel fasteners were printed at ORNL using additive-manufacturing techniques, also known as 3D printing, as part of the lab's Transformational Challenge Reactor Program and installed on ATRIUM 10XM fuel assemblies at Framatome's nuclear fuel manufacturing facility in Richland, Washington."

Framatome website (Dec 2020)





Questions?

Contact: paquitvc@ornl.gov