Strategy/Approach for Qualification of Nuclear Components Produced Via AM

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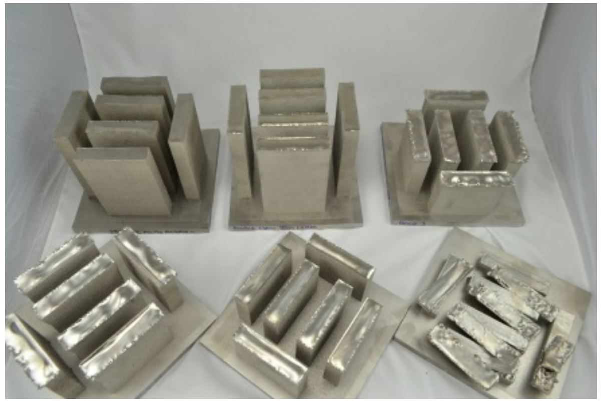
Introduction



- ASME, NRC, and industry are struggling to identify strategy/approach for nuclear quality components manufactured by AM.
- Current approach requires manufacture of multiple parts followed by destructive testing of several parts
  - Properties (microstructural and mechanical) are still difficult to predict
- ORNL/EPRI have been working on an approach that incorporates *Integrated Computational Materials Engineering (ICME)* and *in-situ process control* aimed at properties reproducibility.

There has to be a better way to qualify AM parts for nuclear applications…..

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EPRI Perspective & Expected Benefits

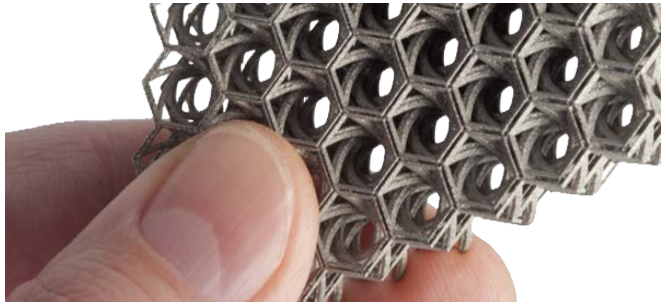
Perspective

- Laser Powder Bed Additive Manufacturing (LPB-AM) will be used for small internals (<100lbs) and for fuel assemblies/ handling equipment
- PM-HIP will be used for large equipment
- Long road to gain acceptance, but achievable
- LPB-AM must be used in combination with HIP to assure densification

Expected Benefits

- Manufacture of obsolete parts; Just-in-time manufacturing
- Great way to produce intricate parts, while minimizing machining

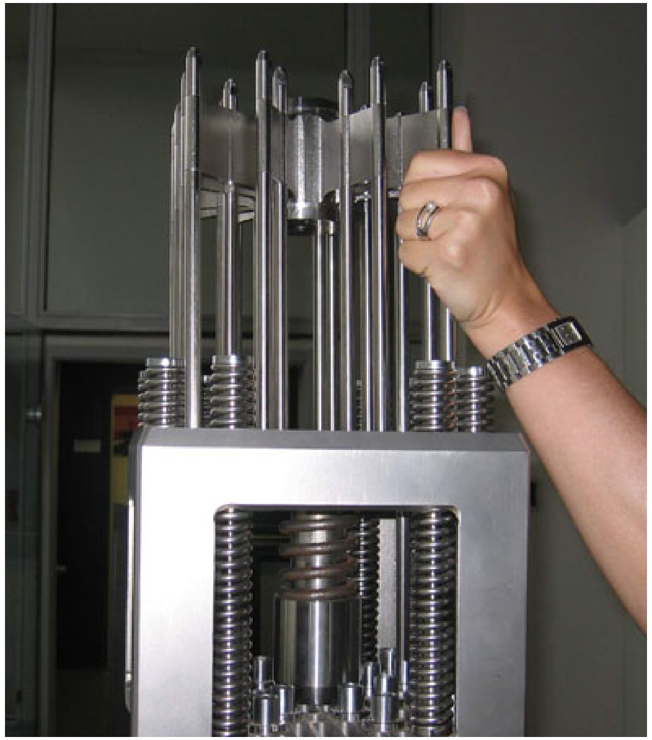
Nuclear Applications for Additive Manufacturing --Reactor Internals and Fuel Assemblies



- Again, for smaller parts (<100 lbs)

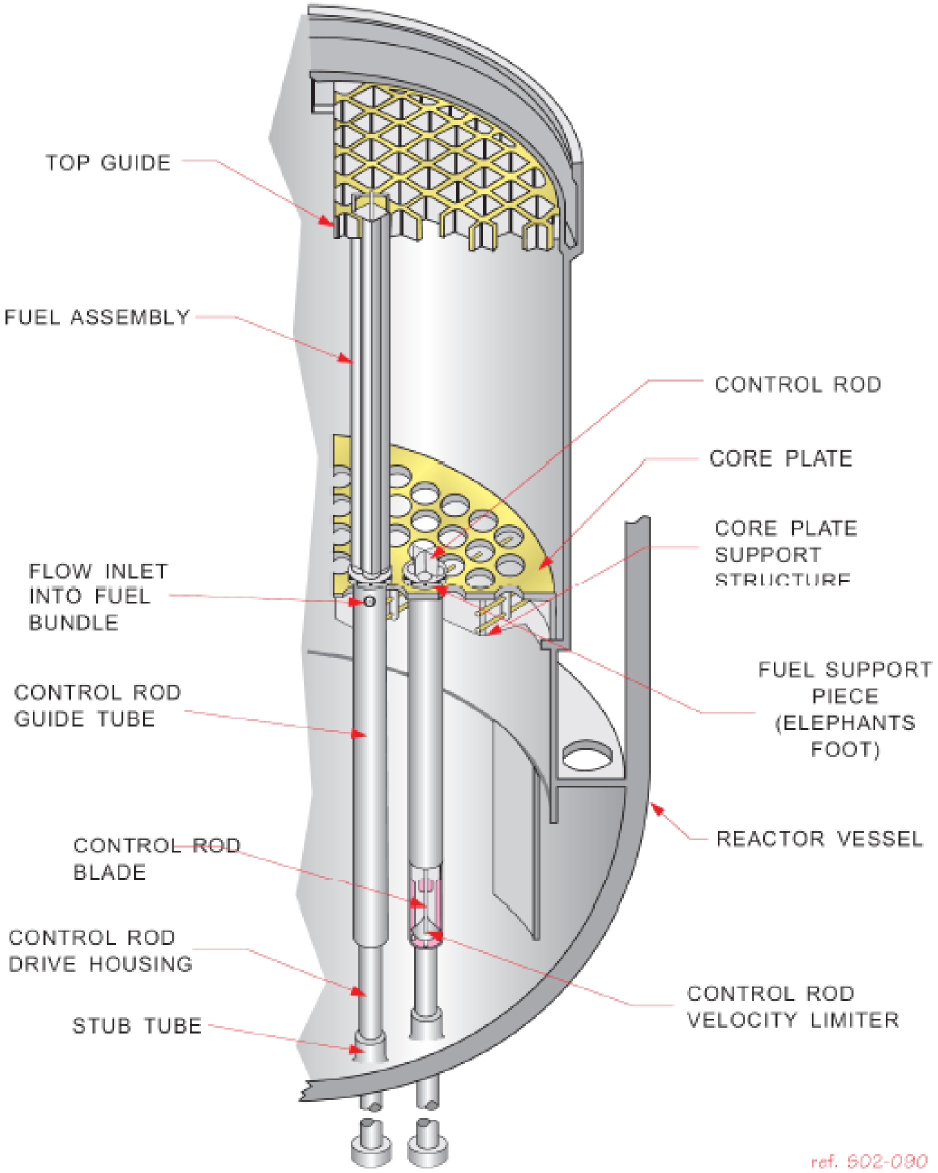
Potential Reactor Internals

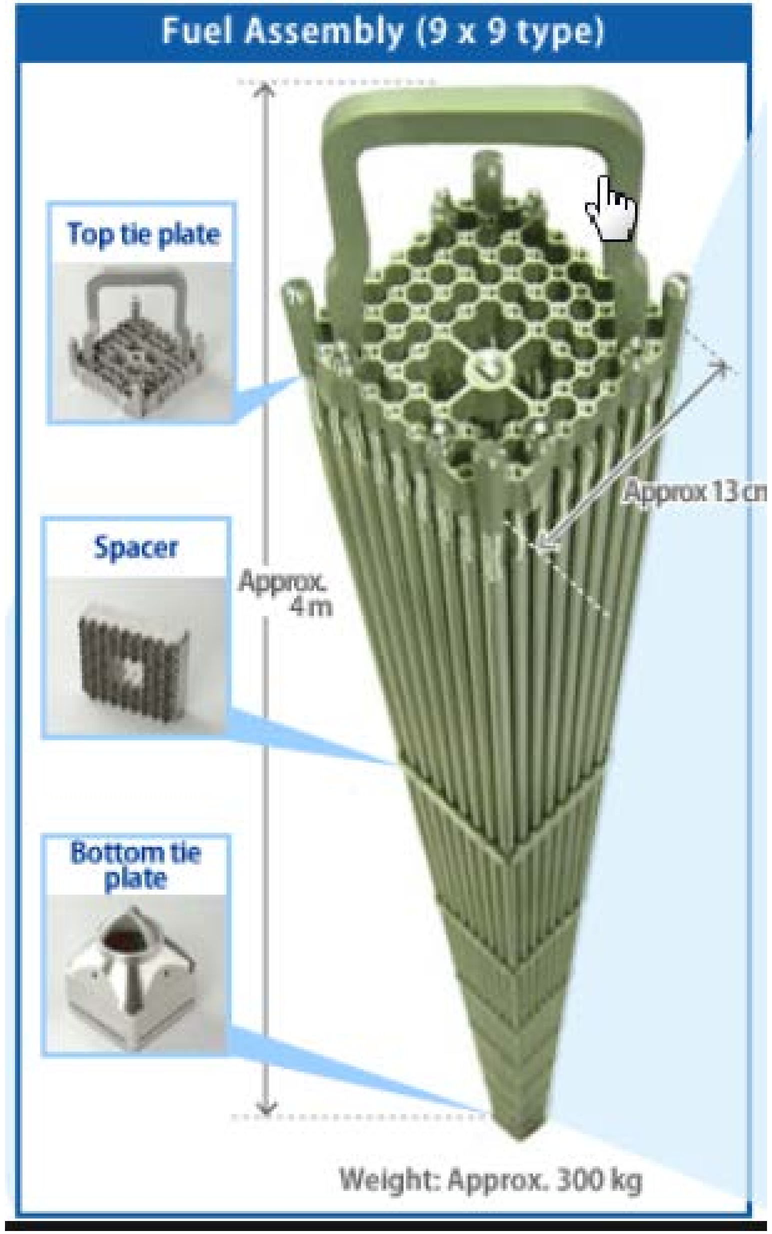
- Fuel assemblies (next slides)
- Control rod drive internals
- Alignment pins (bi-metallic)
- Small spray nozzles
- Instrumentation brackets
- Stub-tube/housing
- Steam separator inlet swirler
- Flow deflectors
- GEN IV—cooling channels

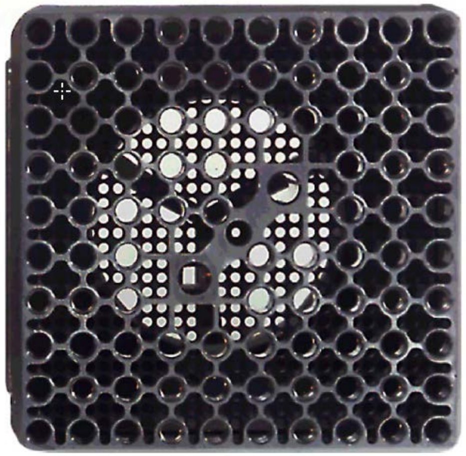


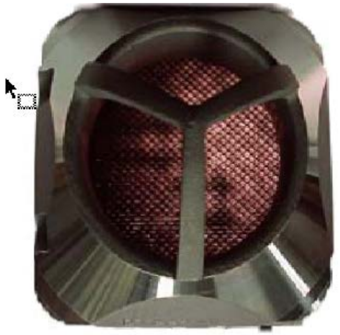
PWR Control Rod Assembly

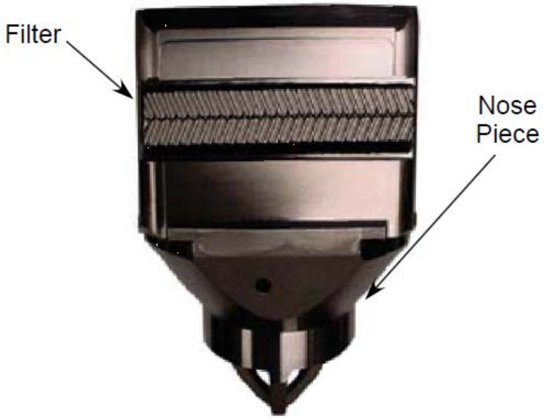
Fuel Assemblies



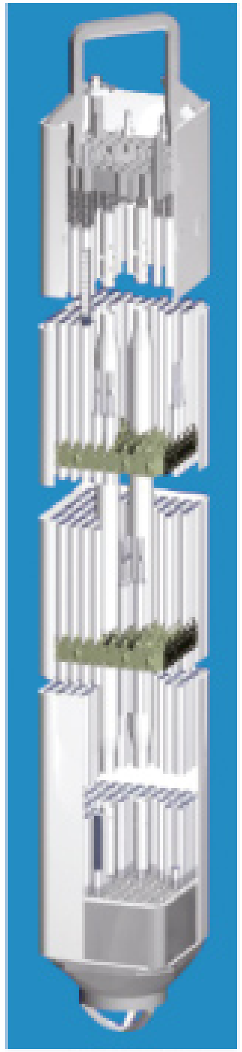




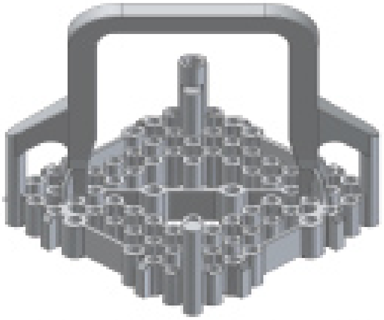




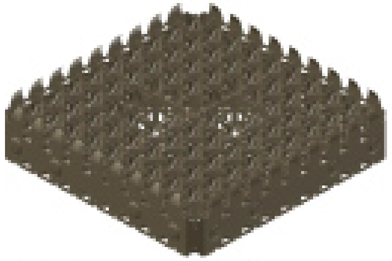
ABWR Fuel Assembly (another view)



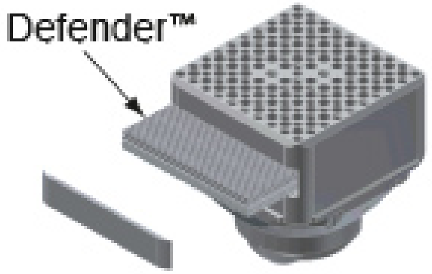
GNF2



GNF2 Low Pressure Drop UTP



GNF2 High Performance Spacer



GE14 & GNF2 Defender™ LTP
Improved Debris Protection

Courtesy of Hitachi

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EPRI Perspective & Expected Benefits

- Even after project is complete, considerable work will be necessary to:
  - Push technology through ASME or other Codes
  - Work with NRC toward acceptance
  - Incorporate irradiation information from DOE/GEH project
  - Perform CGR (SCC) testing

Why Is Industry Interested in Laser Powder Bed-AM?

- Make replacement parts (for often obsolete parts—remember some units are over 40 years old) for the existing fleet with a very short turn around
- Make new parts for the new fleet of ALWRs, SMRs and Gen IV applications
- Design to include improved flow characteristics or special features that they couldn't do through casting/forging/machining in the past.
- Introduce favorable properties through unique microstructures
- Design for performance

Project Tasks

1. Demonstrate Artifact Design and Baseline Properties
2. Process Design, Processing and In-situ Monitoring & Validation
3. Deploy and Validate High Performance Computational Models
4. Ex-situ Non Destructive Microstructure Characterization
5. Scale up to Full Size Components
6. Develop ASME and Regulatory Acceptance

Task 1: Demo Artifact Design and Baseline Properties

- Three complex demonstration components (e.g. fuel casting assembly or other) are to be identified
- The baseline static (yield strength, tensile strength, elongation) and dynamic (Charpy toughness and fatigue) properties will be measured and documented.
- W and RR will provide components using existing technologies (forging, casting, etc0 for comparison

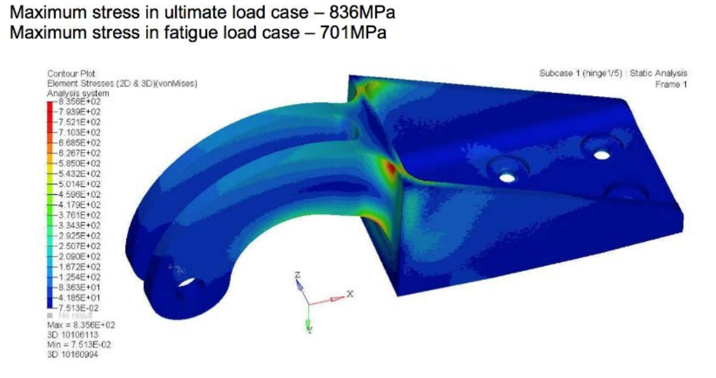
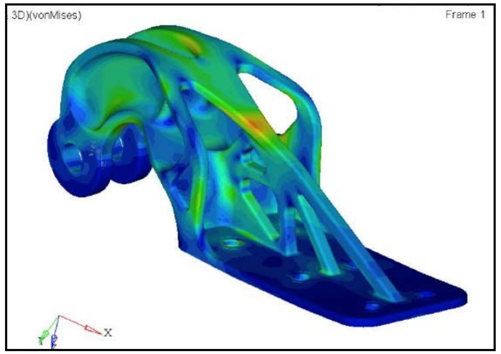


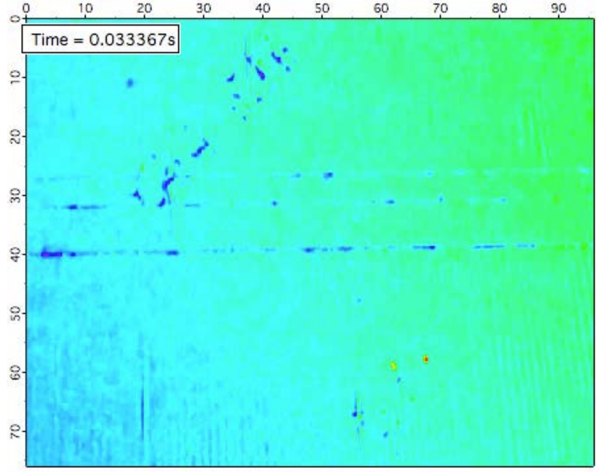
Figure 5: FEA analysis of original part

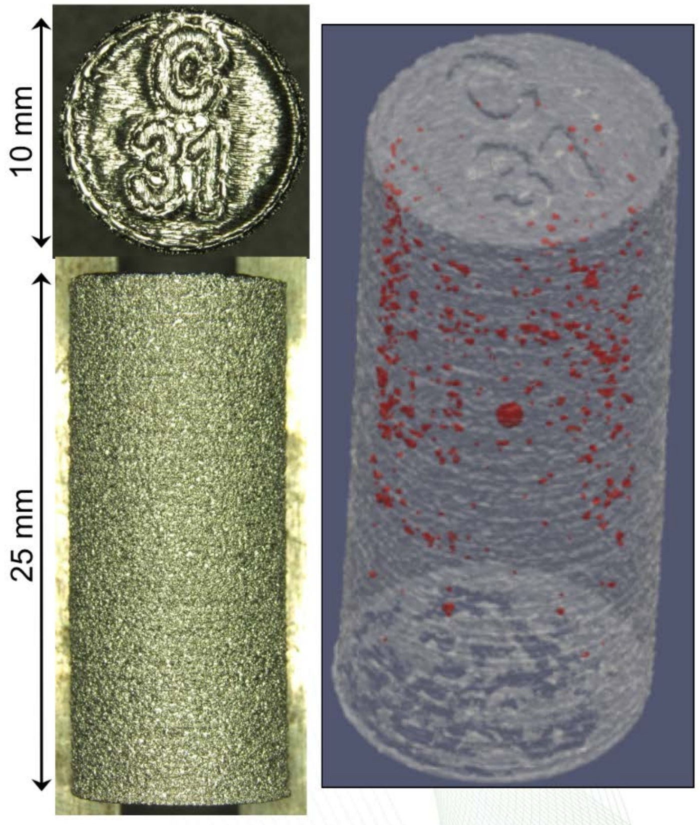


Application of Topology, Sizing and Shape Optimization Methods to Optimal Design of Aircraft Components

Task 2: Process Design

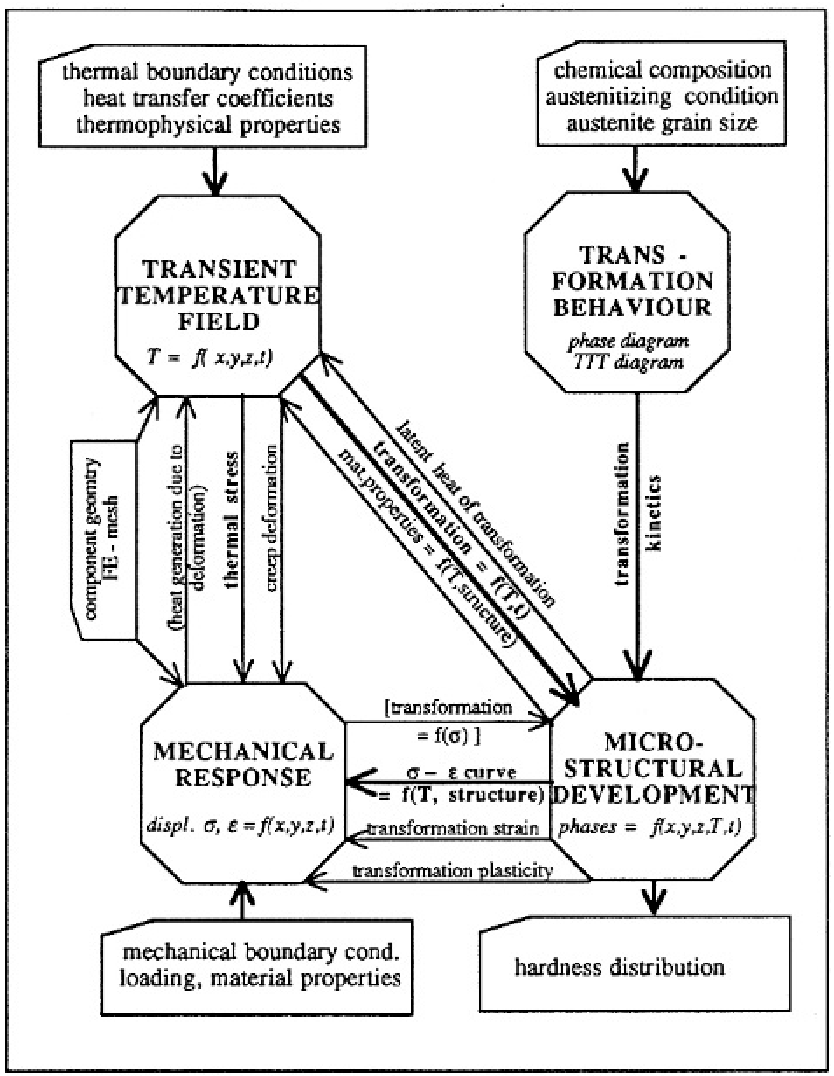
- Parts will be manufactured using Renishaw® laser powder bed processing machine.
- The complex geometry from Task 1 will be scaled and appended
  – includes support structures to address overhangs.
- The process variables including laser power, scanning speed, scanning strategy (continuous, island or chess) preheat temperature, and powder characteristics will be recorded and documented within Dream 3D architecture.
- Three different qualities of build: poor, medium and high quality (intentionally) and compared.





Task 3: Deploy and Validate High Performance ICME Computational Models (1)

- Process parameter data and boundary conditions will be used as input for ICME models for heat transfer and mass transfer
- Models will be used to predict spatial variations of temperature, liquid metal flow, and liquid solid interface velocity.

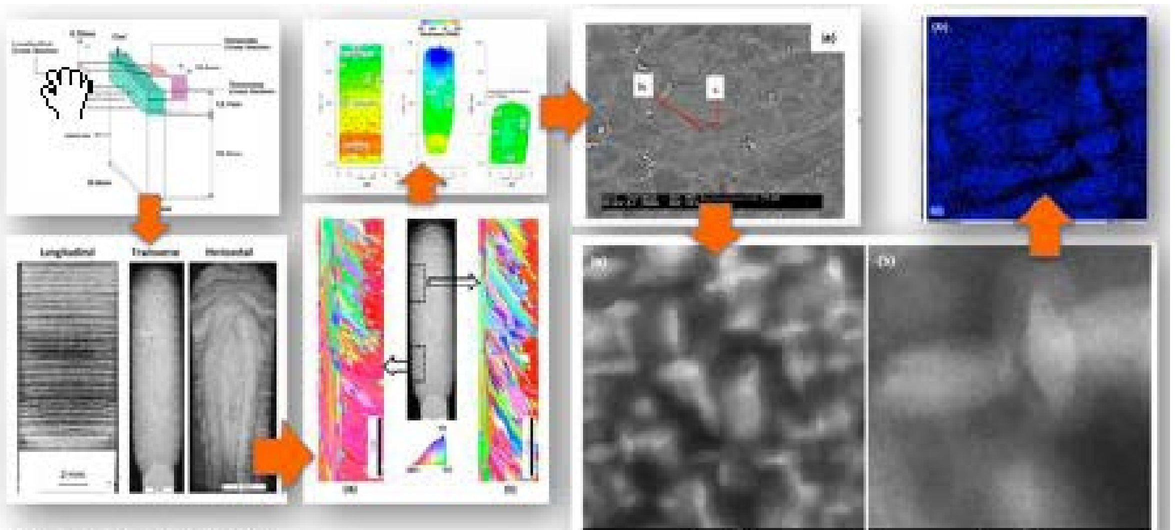


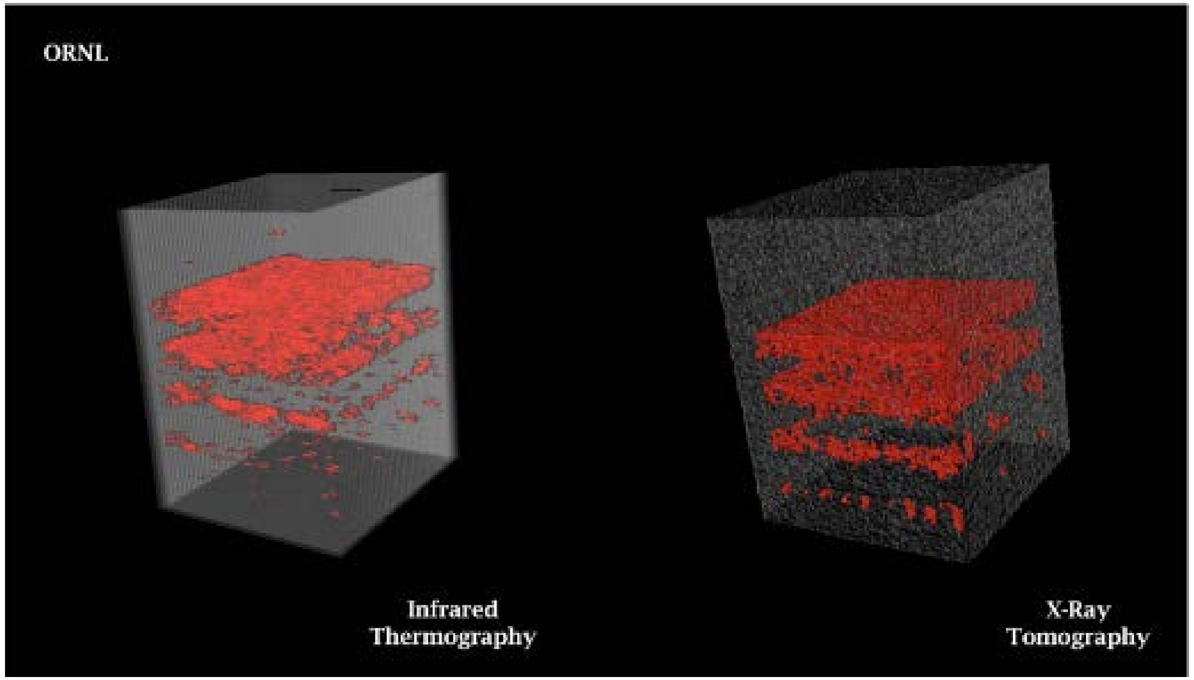
Task 3: Deploy and Validate High Performance ICME Computational Models (2)

- From these characteristics, models will be used to predict:
  - Defect formation
  - Columnar vs equiaxed grain deformation

- Predicted results will be validated from in-situ monitoring (Task 2)
- Data in turn will be loaded into 3D framework
- ICME models will be used to predict the debit of static, dynamic, corrosion properties

Task 4. Ex-situ NDE and Microstructural Characterization

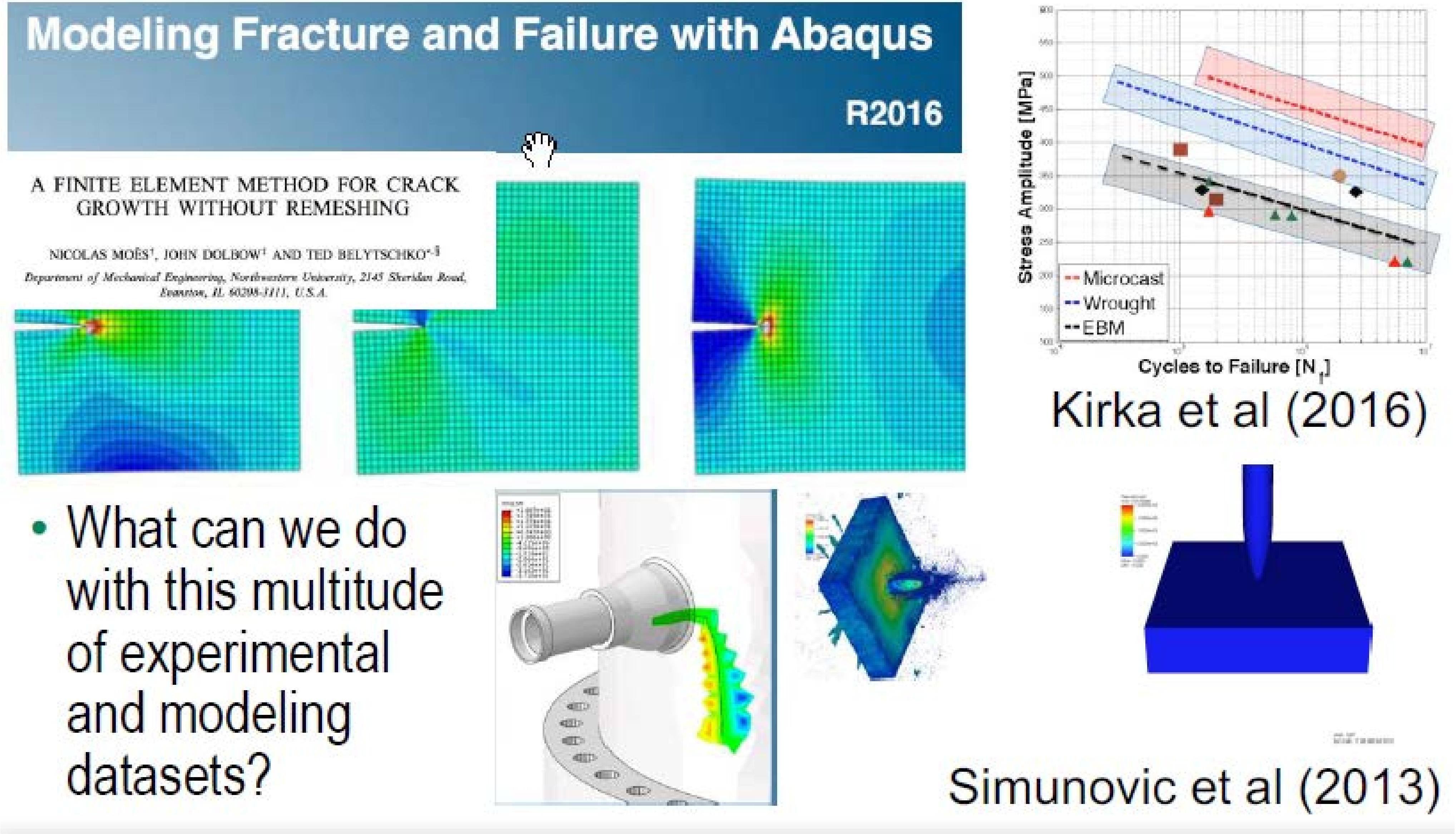

Tian et al (2014)



Multi-scale Characterization Methods (Optical, SEM, EBSD, TEM, etc

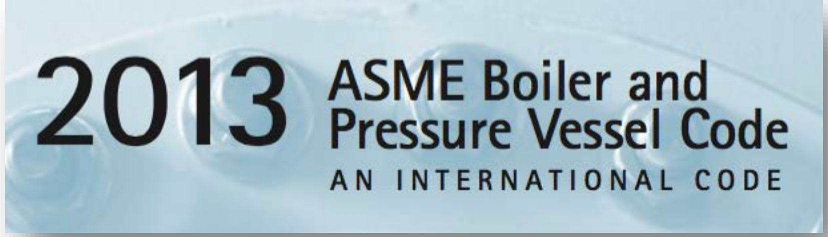
Comparison of Infrared Thermography and X-Ray Tomography Results

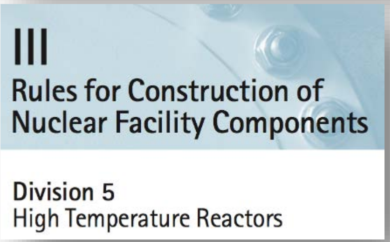
Task 5: Scale Up To Full Size Components

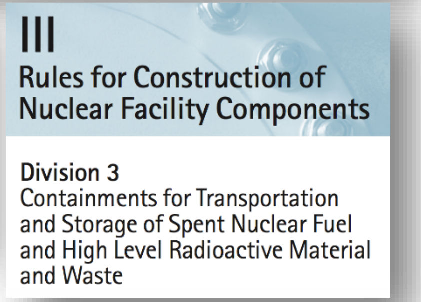


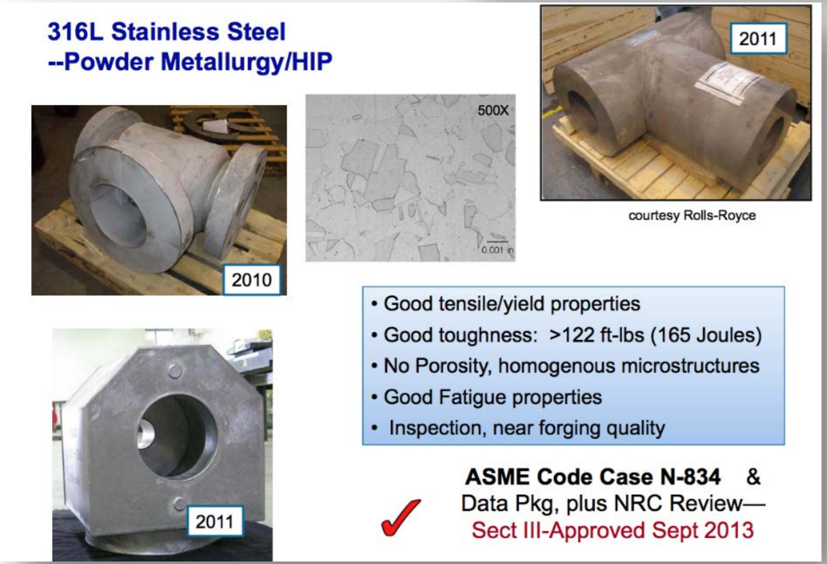
Task 6: Develop ASME Code Acceptance & Project Management

- Drawings and Images
- Chemical Composition
- Grain Size
- Microstructure
- Density and Inclusion Content
- Tensile/Yield Properties
  - Stress-Strain Diagram
- Toughness
- Fatigue
- Weldment Properties









Is this methodology applicable to additive manufacturing?

Major Deliverables Anticipated from the Project

- Designs that will allow for LPB-AM of complex components
- Fabrication of 3 components by AM, as well as, a traditional manufacturing processes
- ICME process analytical methods to fuse the modeling, process, *in-situ* and *ex-situ* characterization data through Dream3d architecture
- Data and ICME and *in-situ* process monitoring qualification methodology package to support ASME & regulatory qualification/acceptance.

Together…Shaping the Future of Electricity