Additive Manufacturing for Nuclear Components

George Pabis
Craig Gramlich

December 5th, 2018

Acknowledgment and Disclaimer

Acknowledgment: This material is based upon work supported by the U.S. Department of Energy, Office of Science under Award Number DE-SC0015902.

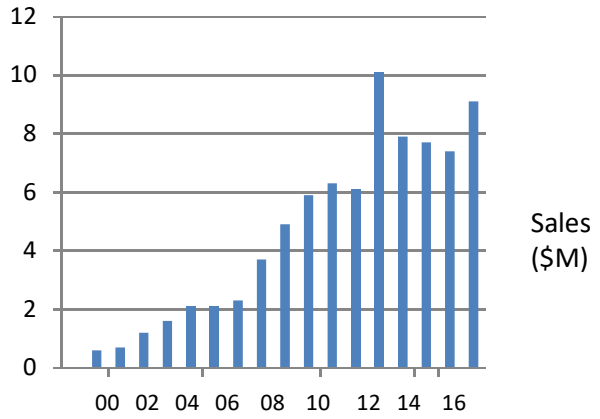
NOVATECH

Agenda

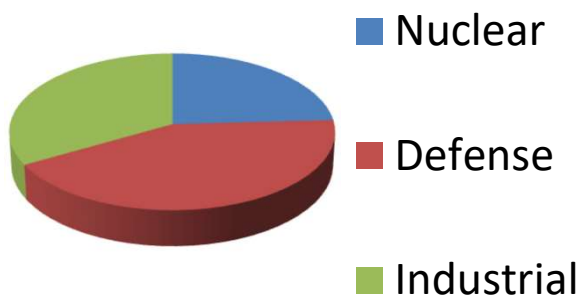
- NovaTech Overview
- AM Ideology
- Accomplishments
- Results
- Future Tasks

OVERVIEW – General Information

- **Founded in 1994, NovaTech is located in Lynchburg, Virginia**
- **35 Employees, 27,500 ft² Facility**
- **Sales of $9.3 M (2016), Small Business Classification, S-Corporation**
- **Quality Assurance Program Compliant with ASME NQA-1 and 10CFR50 App. B**
- **Registered with US Dept. of State (ITAR) and US/Canada Joint Certification Office**



Sales



NOVATECH

NUCLEAR – Engineering

SMALL MODULAR REACTOR SYSTEM DESIGN

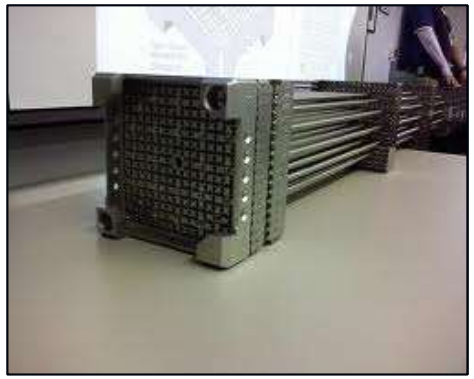
- Contract lasted 4 years
- Support the initial design studies beginning in 2008
  - Provided conceptual and preliminary design
  - Safety and support system design, analyses and documentation
  - Fuel mechanical design and testing
  - Fabrication and testing of fuel assembly and CRA prototypes
  - Component design and seismic analyses
  - Provided economic assessment for non-electric power applications
  - Provided design support for non-utility applications
  - NRC technical briefings during pre-application
  - Technical and topical reports
  - Drafting DCD sections
  - Review of specific licensing issues (10 CFR 50.62, 10 CFR 50.54(hh)(2), EA-12-049, etc)

NOVATECH

NUCLEAR – Engineering

FUEL DESIGN

- Contract lasted 2 years
- Varied from 5-10 engineers
- Work preformed remotely at NovaTech but travelled to support testing and meetings
- Work included
  - Design and analysis of skeleton
  - control rod assemblies
  - axial power shaping rods
  - burnable poison rods
  - primary and secondary neutron sources
- Generated and checked production drawings
- Supported the final design review.



NOVATECH

MAJOR CUSTOMER LIST

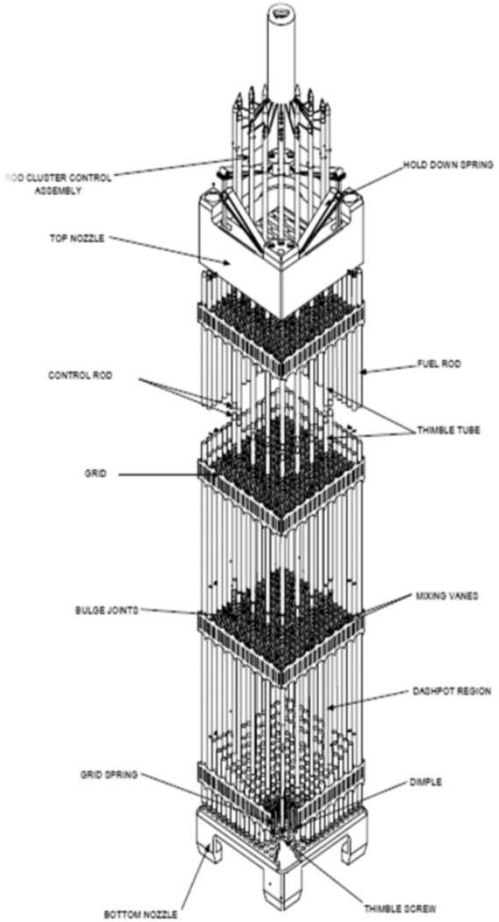
- Aerojet
- American Ordnance
- AREVA
- BWXT
- BAE Systems
- Battelle Memorial Lab.
- Cadence Medical
- Day & Zimmermann
- DE Technologies
- Department of Defense
- Department of Energy
- Dominion Power
- Duke Energy
- EPRI
- Flowserve
- TVA
- NASA
- Nuclear Fuel Services
- NuScale
- Sandia National Lab.
- Savannah River Company
- Siemens Energy
- Southern Company
- TerraPower
- US Army – ARDEC
- Vagts Engineering Inc.
- Westinghouse Electric

AM Ideology

- Use existing AM processes as if they were commonplace.
- Replace existing fuel assembly components.
- Add performance enhancing features.
- MUST ADD VALUE.

SBIR Methodology

- Start with components that have well established powder materials (Stainless Steel and Inconel)
  - Top & Bottom Nozzles
  - Holddown Springs
- Define design requirements
- Rapidly fabricate prototypes that show potential based on analysis
- Test designs
- Iterate



NOVATECH

DOE SBIR Awards

- Phase II Awards
  - Bottom Nozzles
  - Holddown Springs
  - Accident Tolerant Control Rods
- Phase I Awards
  - BWR Lower Tie Plates
  - Accident Tolerant Spacer Grids
  - NDT Techniques for TRISO Fuel

Bottom Nozzle

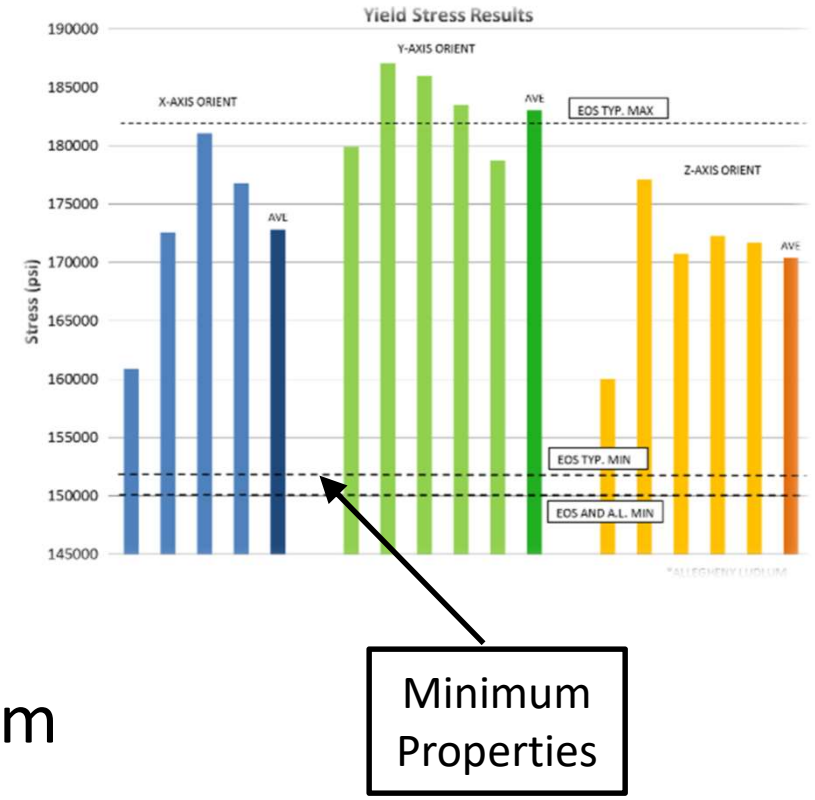
- Phase I Accomplishments
  - 3D printed eight bottom nozzle 5X5 prototypes out of Inconel-718
  - Age hardened and inspected Inconel-718 parts
  - Designed and fabricated a prototype fuel rod lower end cap
  - Successfully tested the fuel rod locking mechanism
  - Performed tensile tests, flow tests, and debris filtering tests
  - Submitted Technical report summarizing 2016 Phase I Research

Bottom Nozzle

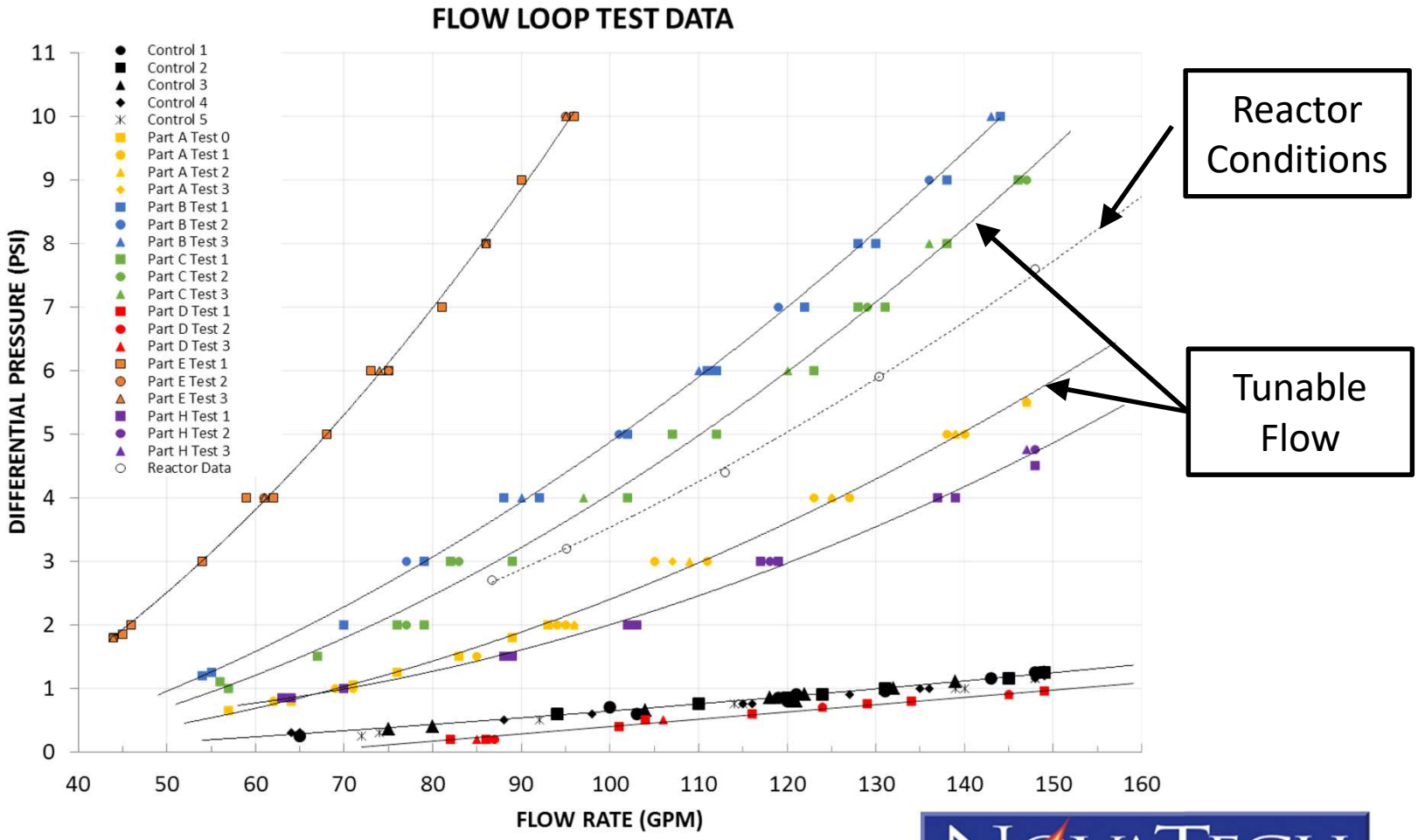
- Phase I – AM Build Example

Bottom Nozzle

- Tensile Testing
  - Yield Strength
  - Ultimate Strength
  - Elongation
  - Conclusion: Material properties of 3D printed Inconel-718 meet minimum material requirements.



Bottom Nozzle



Reactor Conditions

Tunable Flow

Bottom Nozzle

- Fuel Rod Locking
  - Designed to replace the lower end grid
    - Removes lower end grid and a fuel rod failure initiation point
  - Integral to the bottom nozzle grillage
    - Allows for longer fuel rod
      - Room for more fuel or plenum volume
  - Locks fuel rod axially
  - Provides anti-rotation feature
  - Reconstitutable
  - Designed for single setup machining
    - Lathe turning + wobble broaching
  - Successfully tested to 30 lb pull force

Bottom Nozzle

- Debris Filter Testing
  - Tested all filter designs twice for debris resistance
  - Small holes and torturous paths are the most effective filters
  - AM fabricated designs are highly effective at debris filtering

Bottom Nozzle

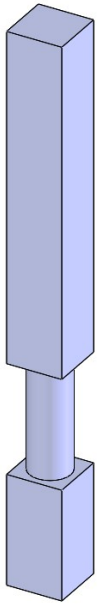
- Phase II Objectives
  - Full Scale Flow Loop Testing
    - Partnership with Framatome
  - Predictive CFD Modeling
  - HIFR irradiation testing
  - Further Hone Design Features
    - Debris Filtering
    - Fuel Rod Locking
    - Part consolidation

Bottom Nozzle

- Full Scale Flow Loop Testing
  - Verify Phase I testing
    - Pressure Drops
    - Debris Filtering
    - FA fit-up
    - Fuel Rod Locking
  - Measure Fuel Rod Wear

Bottom Nozzle

- Predictive CFD Analysis



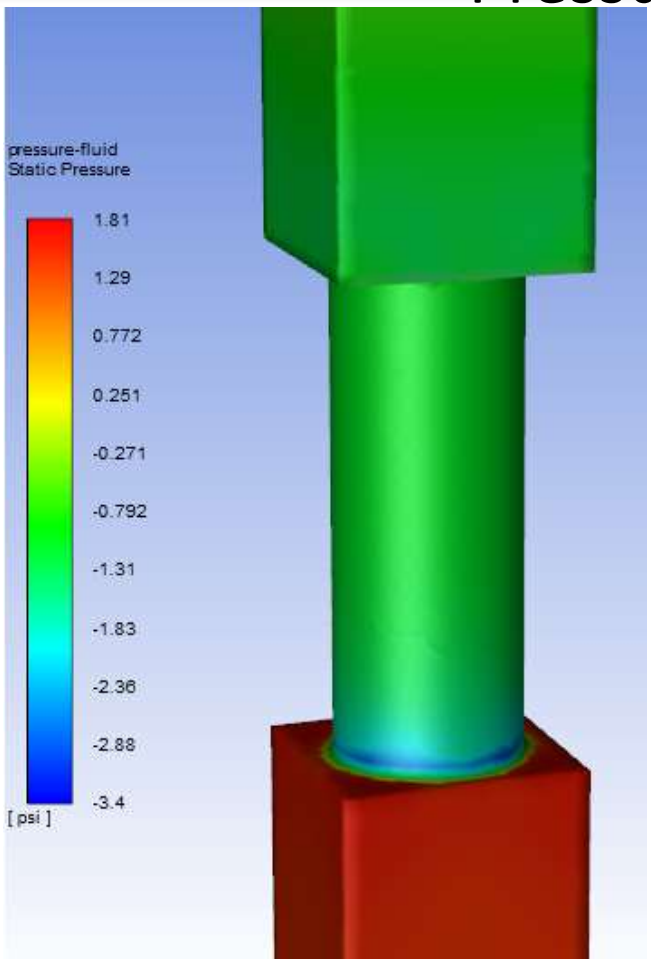
Standard Path

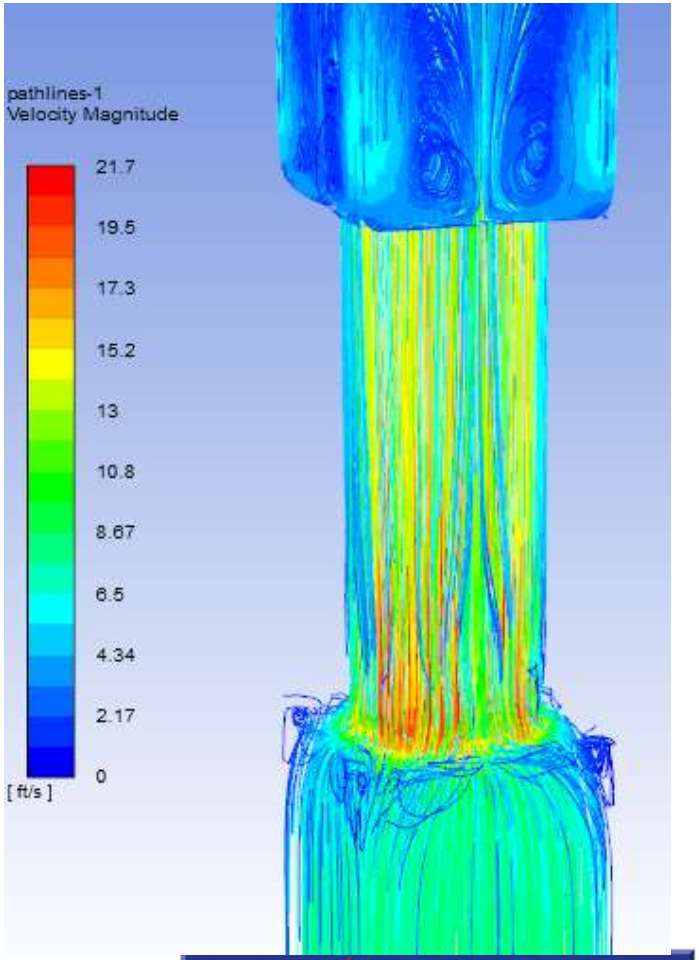
Part H

Part A

Standard Path – 150 GPM

Pressure Drop = 1.53 psi





Part H – 150 GPM

Pressure Drop = 4.75 psi

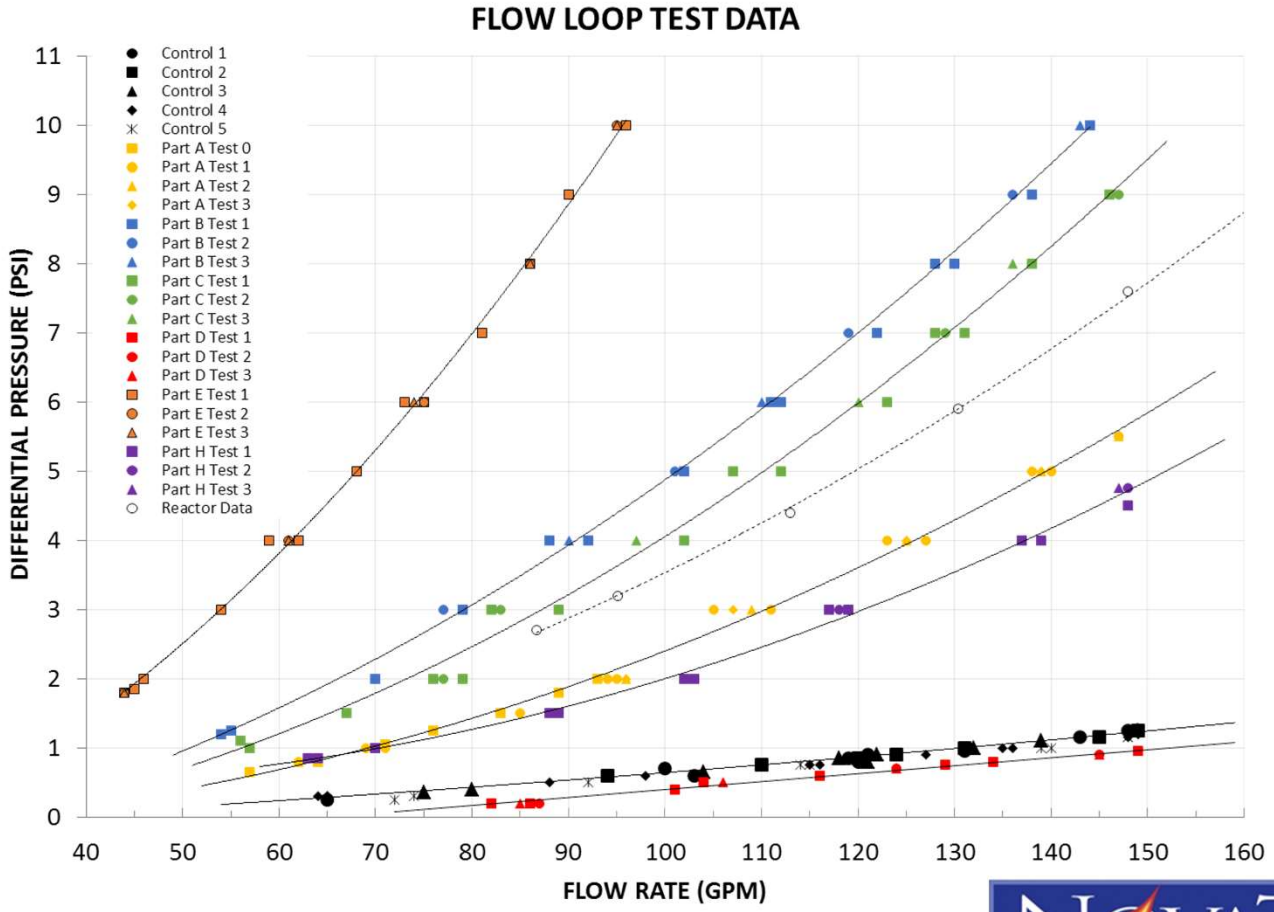
Part H – 60 GPM

Pressure Drop = 0.93 psi

Part B Path – 145 GPM

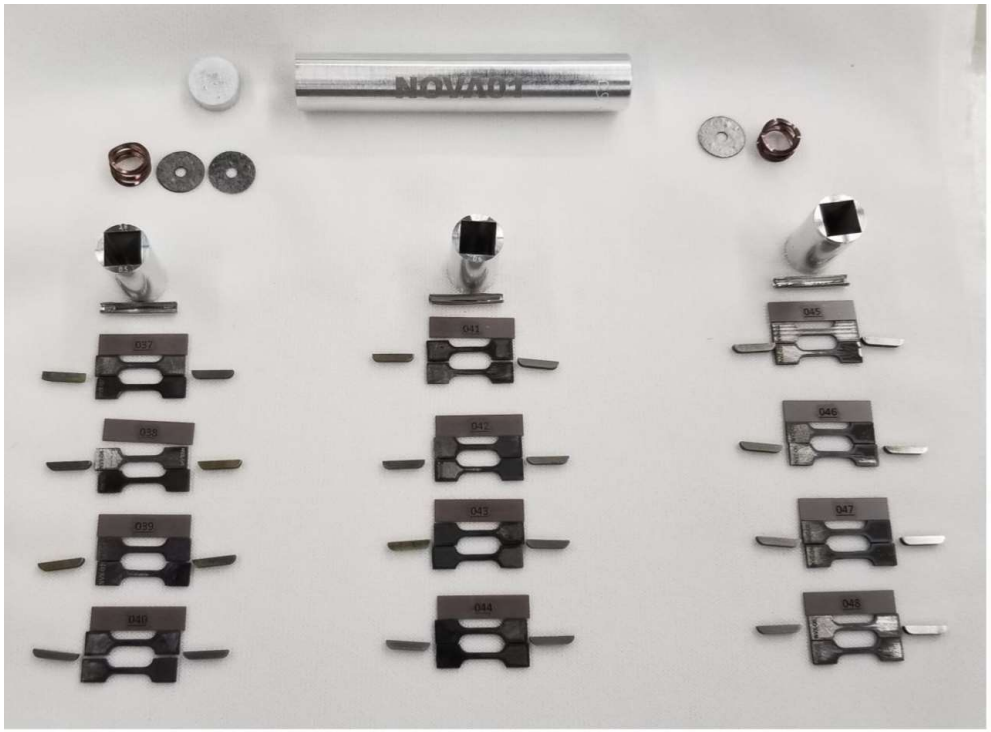
Pressure Drop = 9.36 psi

Bottom Nozzle



Bottom Nozzle

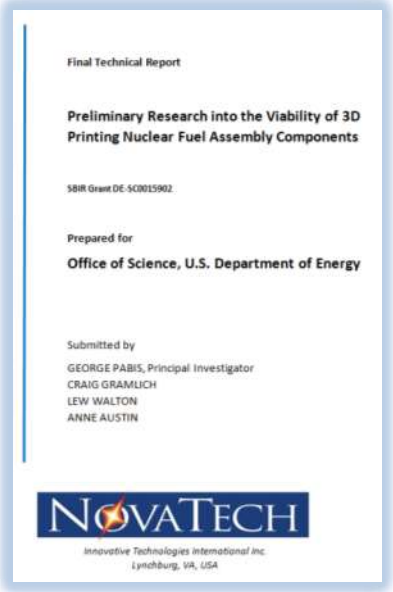
- HIFR Irradiation Testing
  - 24 specimens
  - Inconel-718
  - $60x10^{19}$ n/cm^2
    - ~6 dpa
  - 2020



Parts layout for NOVA01 capsule

Holddown Springs

- Phase I Accomplishments
  - FEA simulation of spring rates
  - 3D printed five different Holddown Spring Designs
  - Age hardened and inspected Inconel-718 parts
  - Performed load-deflection tests to failure
  - Submitted Technical report summarizing 2017 Phase I Research


Final Technical Report

Preliminary Research into the Viability of 3D Printing Nuclear Fuel Assembly Components

SBIR Grant DE-SC0015902

Prepared for

Office of Science, U.S. Department of Energy

Submitted by

GEORGE PABIS, Principal Investigator
CRAIG GRAMLICH
LEW WALTON
ANNE AUSTIN

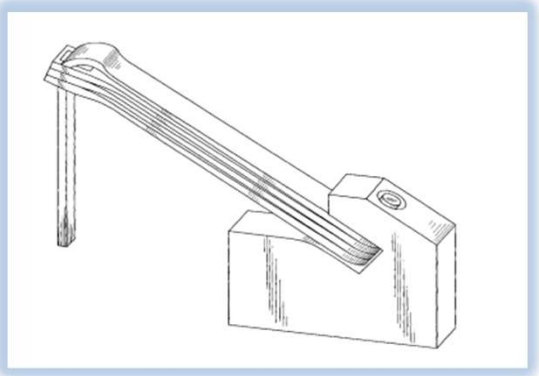
NOVATECH

Innovative Technologies International Inc.
Lynchburg, VA, USA

NOVATECH

Holddown Springs

- Design
  - 3-Leaf Westinghouse 17x17 spring replacement
  - Tunable to different fuel assembly and reactor designs
  - Minimize Upper Core Plate wear
  - Reduce rework
  - Evaluate potential Upper Nozzle / Holddown Spring Design Interface
  - Reduce number of parts



NovaTech

Holddown Springs

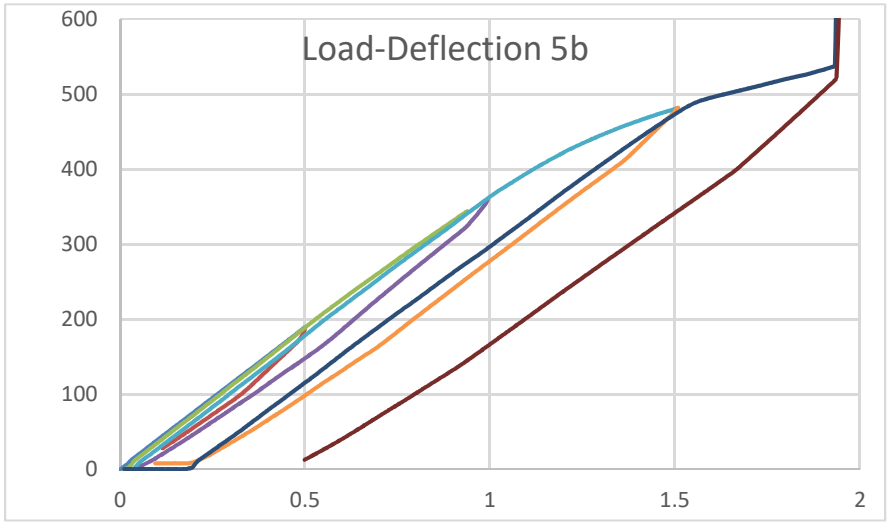
- Phase I – AM Build Example

Holddown Springs

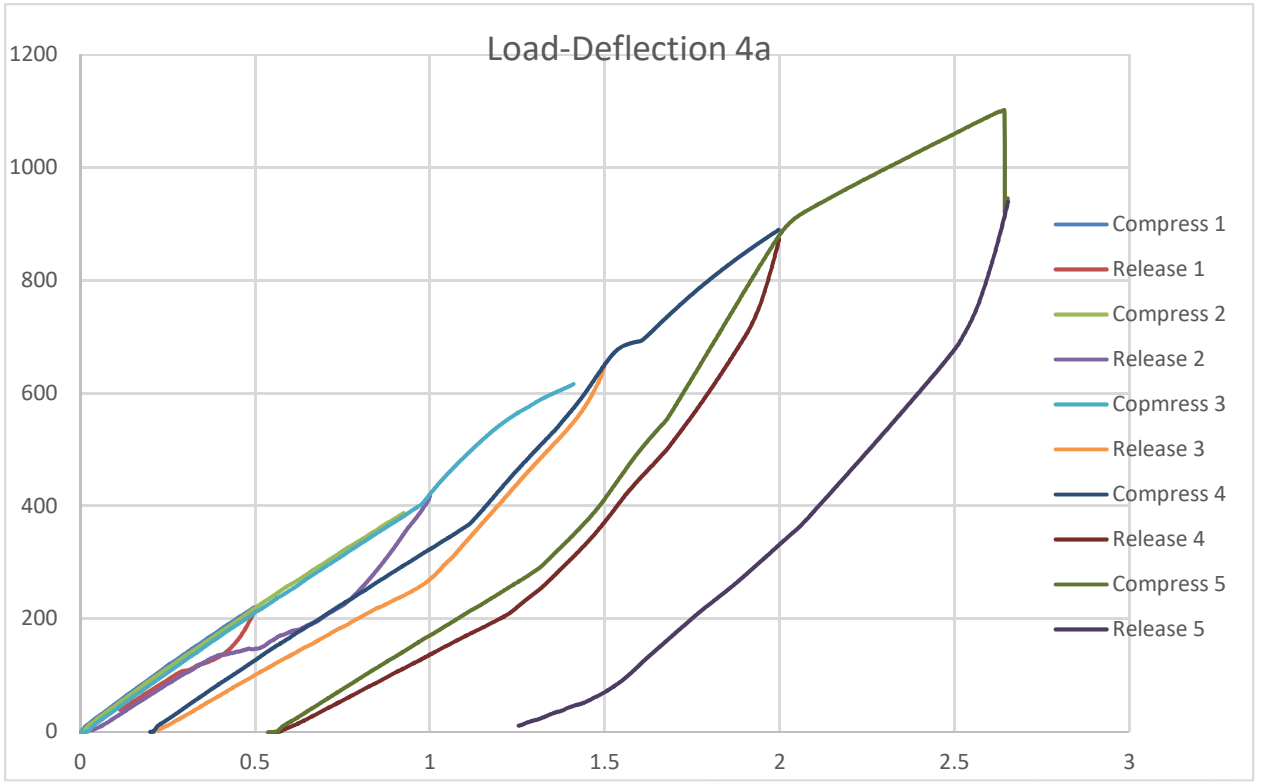
- FEA Simulation
  - Predict Spring Rates
  - Predict Deflection Shape
  - Guide design before manufacture
  - Stress states

Holddown Spring

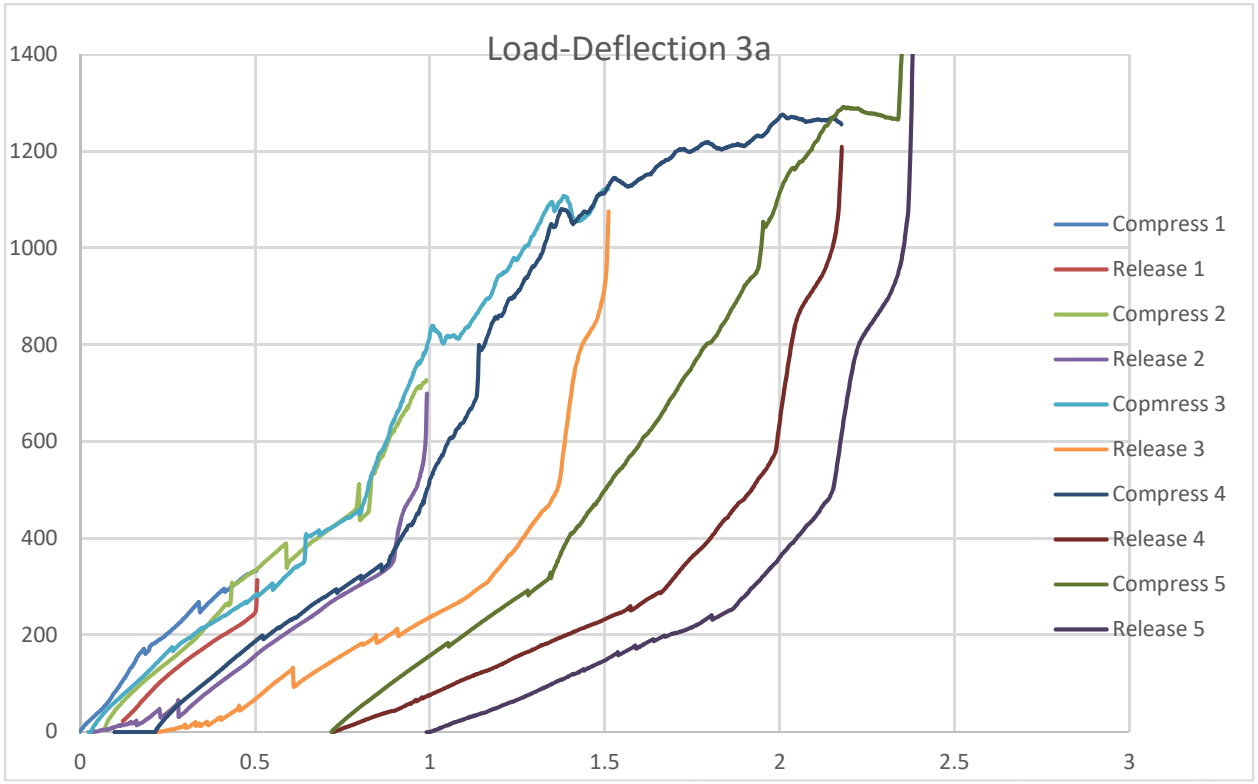
- Load-Deflection Testing
  - Failure Modes
  - Deflected Shape
  - Verify analytical models



Part 4a


Load-Deflection 4a
1200
1000
800
600
400
200
0
0
0.5
1
1.5
2
2.5
3
Compress 1
Release 1
Compress 2
Release 2
Copmress 3
Release 3
Compress 4
Release 4
Compress 5
Release 5

Part 3a


Load-Deflection 3a
1400
1200
1000
800
600
400
200
0
0
0.5
1
1.5
2
2.5
3
Compress 1
Release 1
Compress 2
Release 2
Copmress 3
Release 3
Compress 4
Release 4
Compress 5
Release 5

Holddown Springs

- Phase II Objectives
  - Top nozzle interface enhancement
  - Optimize successful Phase I designs
  - Fatigue Testing
  - SCC testing
  - Fuel Bundle Assembly

Summary

- NovaTech is excited to be involved with this transformative technology.
- We are using additive manufacturing to fabricate:
  - Bottom Nozzles
  - Holddown Springs
  - Top Nozzles
  - BWR Lower Tie Plates
- As we look to the future, we see:
  - More fuel assembly components being additively manufactured
  - Further Part consolidation
  - Faster fabrication times
  - Reduced costs