3-D PRINTING OF NUCLEAR FUEL ASSEMBLY NOZZLES AND END SPACER GRIDS

AMM Technical Review Meeting Webinar
December 17-18, 2019

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Funded By:
DOE SBIR Phase II Grant, DE-SC0015902

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Acknowledgement 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.

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Agenda

- NovaTech Overview
- Project Team
- Objectives
- Project Plan
- Project Status
- Publications
- Future Tasks
- Q&A

Who is NovaTech?

- Founded in 1994
- Located in Lynchburg, VA
- Quality Assurance Program Compliant with:
  - ASME NQA-1
  - 10CFR50 Appendix B
- Business Segments
  - Aerospace
  - Defense
  - **Nuclear**
  - Industrial

Project Team

- George Pabis – Principal Investigator (PI)
- Anne Austin – Engineering Manager
- Lauren Gramlich – Senior Engineer
- Lew Walton – Consulting Engineer
- John Malloy – Consulting Engineer
- Sean Routon – Consulting Engineer

Project Objectives

- Additively Manufacture (AM) a monolithic Pressurized Water Reactor (PWR) Bottom Nozzle that will be ready for implementation on lead assemblies at the conclusion of Phase II.
  - Reduce part count
    - combine the bottom nozzle, filter plates, and the bottom end grid into one part.
  - Improve performance
    - debris capture, pressure drop, and fuel handling
  - Utilize geometries that were previously not manufacturable
    - torturous path designs and internal fuel rod locking features.

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Bottom Nozzle Engineering Requirements Document

Summary of Key Engineering Requirements (NT-TDR-16-016 Rev 0):

1. Normal Operations	➢ Bottom Nozzle shall fit existing envelope ➢ Shipping and handling loads ➢ Shall operate in all reactor thermal & hydraulic conditions ➢ SCRAM loads
2. Performance	➢ Pressure Drop of existing Bottom Nozzle shall be used as baseline ➢ FME filtering shall meet or exceed current capabilities ➢ Maintain Fuel geometry
3. Interfaces	➢ Reactor Alignment Pins ➢ Guide Tubes ➢ Fuel Rods ➢ Incore Detector ➢ Adjacent Fuel ➢ Shipping and Handling Equipment
4. Cost/Part count	➢ Bottom Nozzles shall be designed with the fewest parts possible
5. Manufacturing	➢ Compatible with existing fuel assembly fabrication techniques
6. Bottom Nozzle Material	➢ Bottom Nozzle material shall be Low-cobalt Inconel 718 (with heat treat) or Stainless Steel.

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Phase I – Accomplishments

- Additive Manufactured (AM) eight bottom nozzle 5X5 prototypes out of Inconel-718
- Age hardened (no HIP) 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

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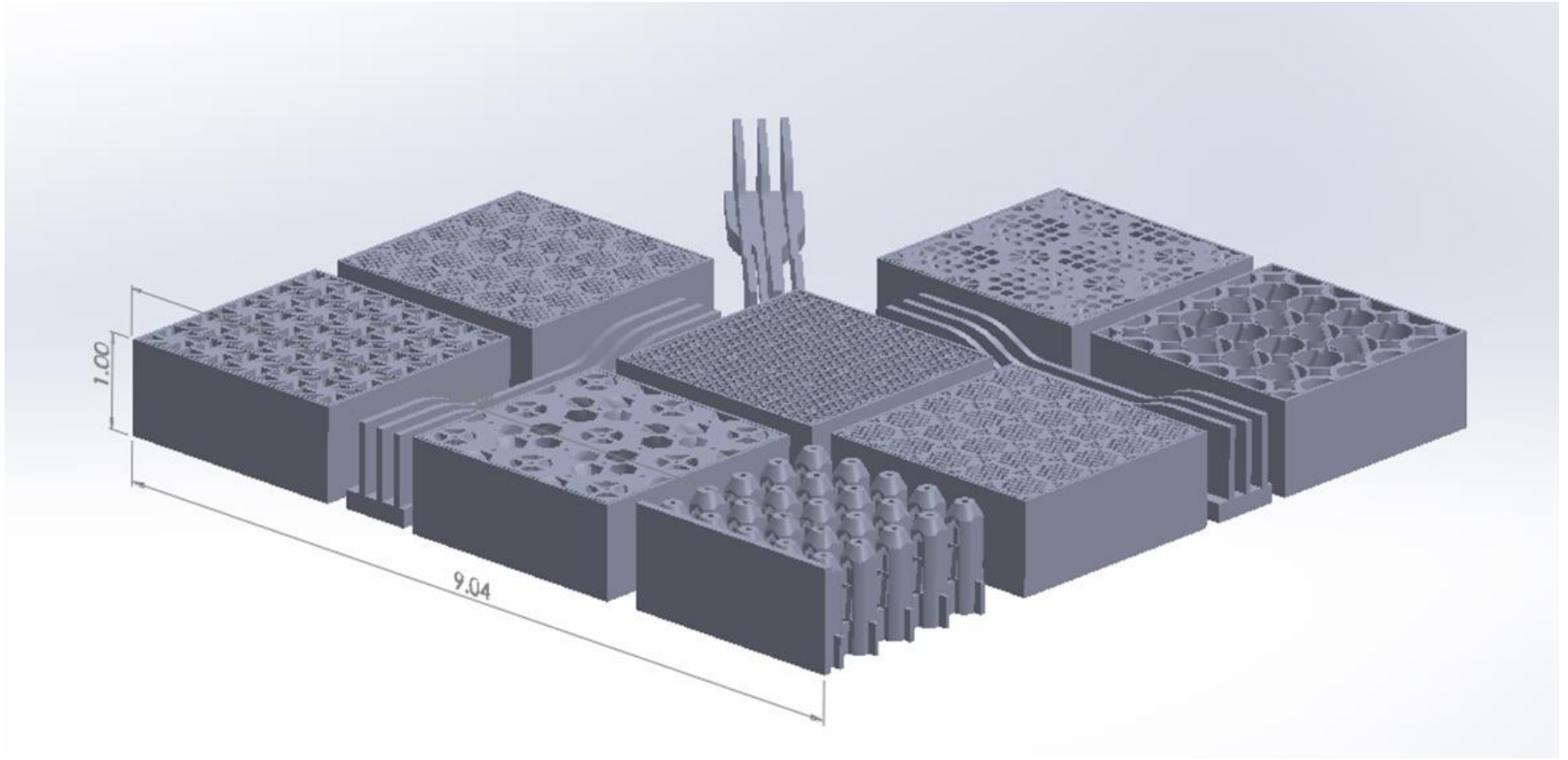
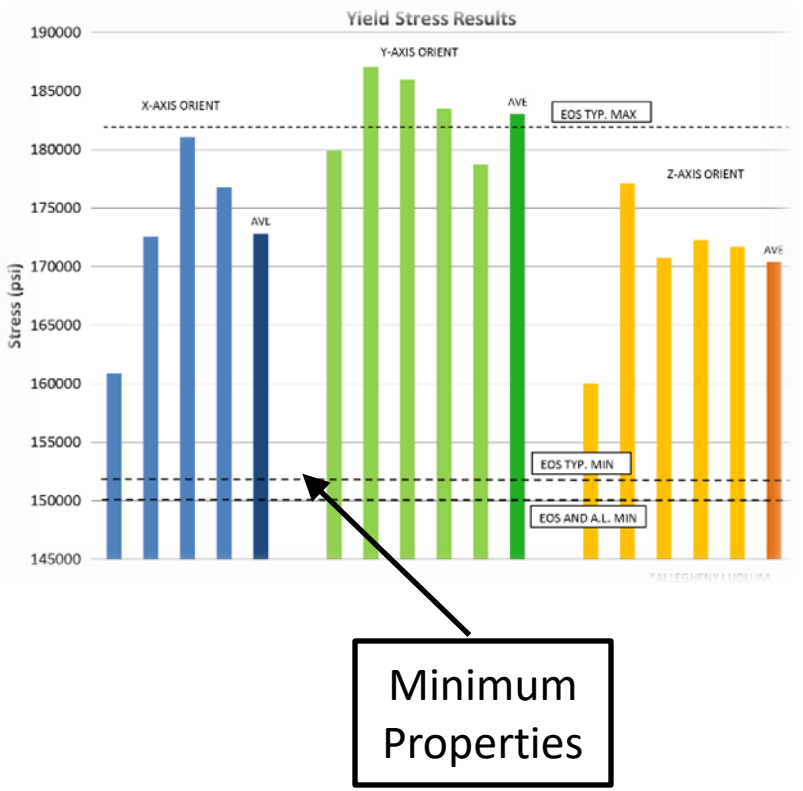
Phase I – AM Build Example



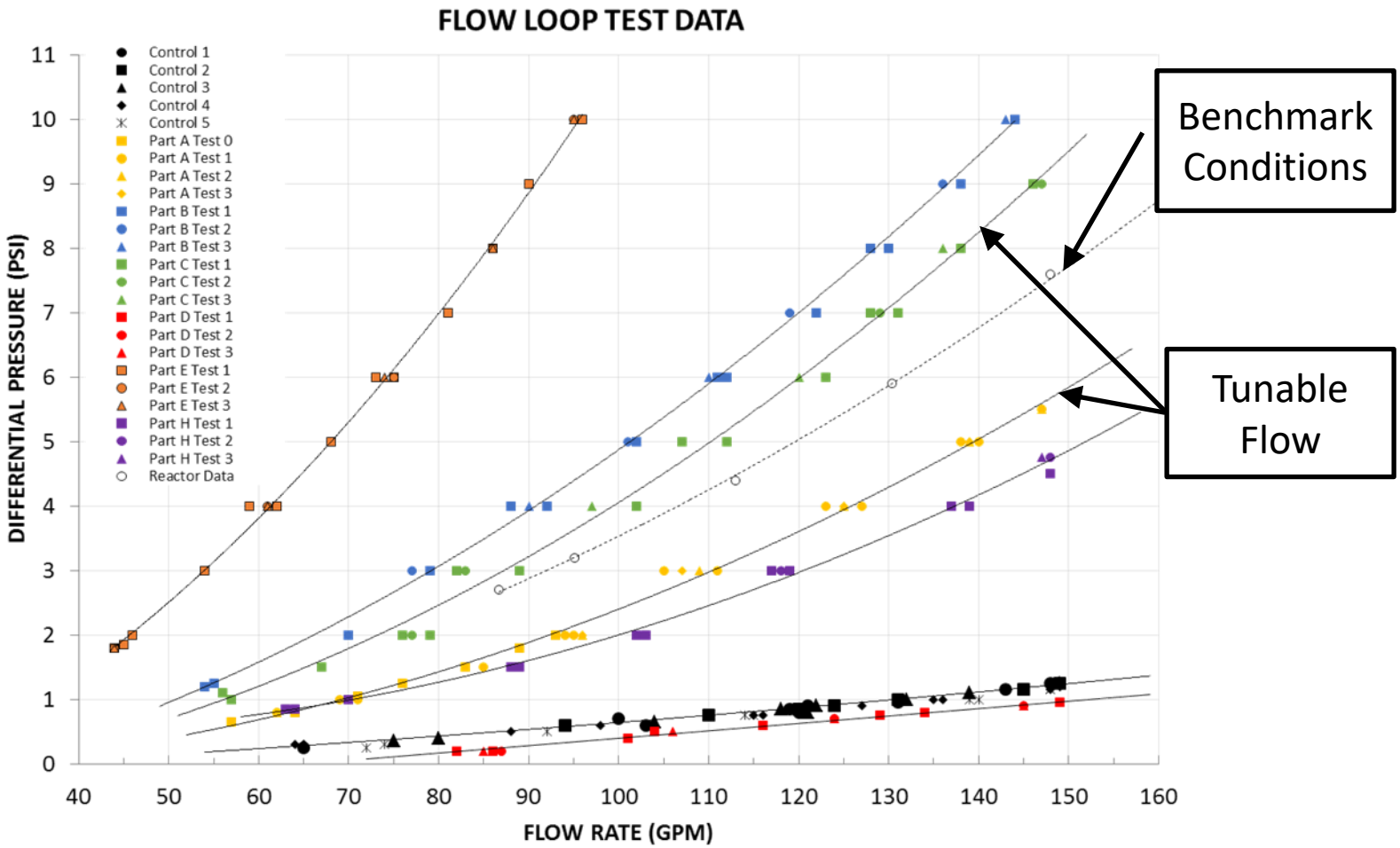
Phase I – Tensile Testing

Tensile Testing

- Yield Strength
- Ultimate Strength
- Elongation
- Conclusion: Material properties of AM Inconel-718 meet minimum material requirements.



Phase I – Flow Loop Testing



Phase I – 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

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Phase I – Fuel Rod Locking Tests

- 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

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Phase II – Objectives

- Predictive CFD Modeling
- HFIR (High Flux Isotope Reactor) Irradiation Testing
- Fuel Rod Vibration Testing
  - Small scale flow loop at NovaTech
- Design Full Nozzle
  - Merged debris filtering with fuel rod locking
  - Incorporated Guide Tube and ICD Tubes
  - Incorporated Core Pin Holes
  - Added lead-in features for handling
- Full Scale Flow Loop Testing
  - Built a full scale flow loop at NovaTech

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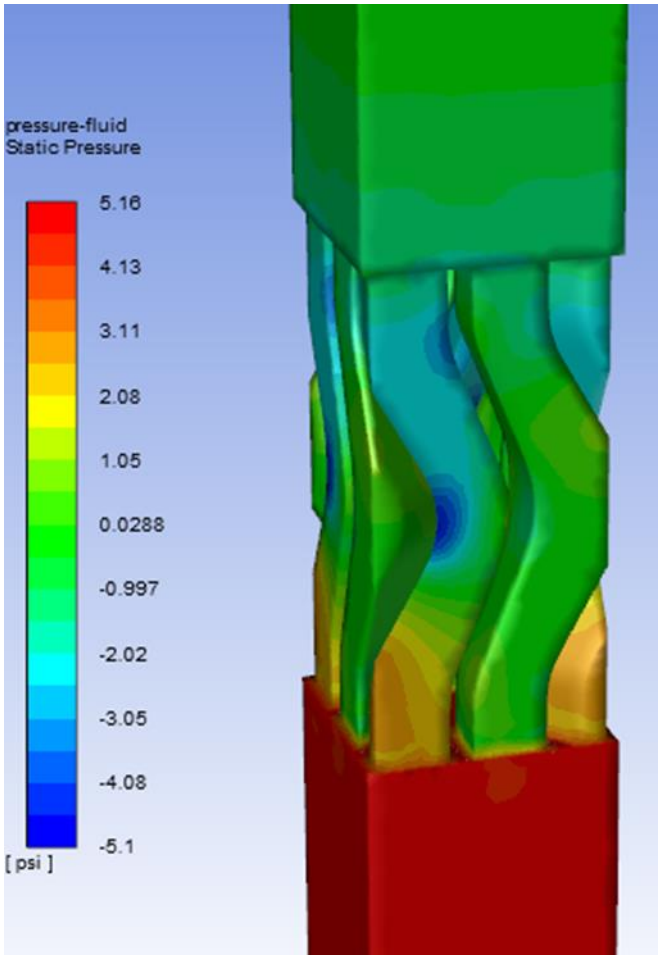
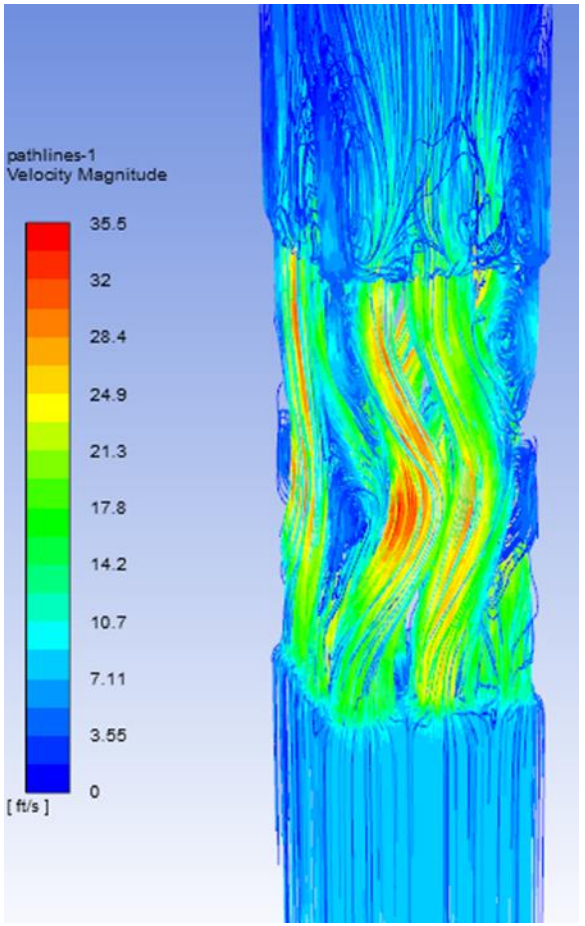
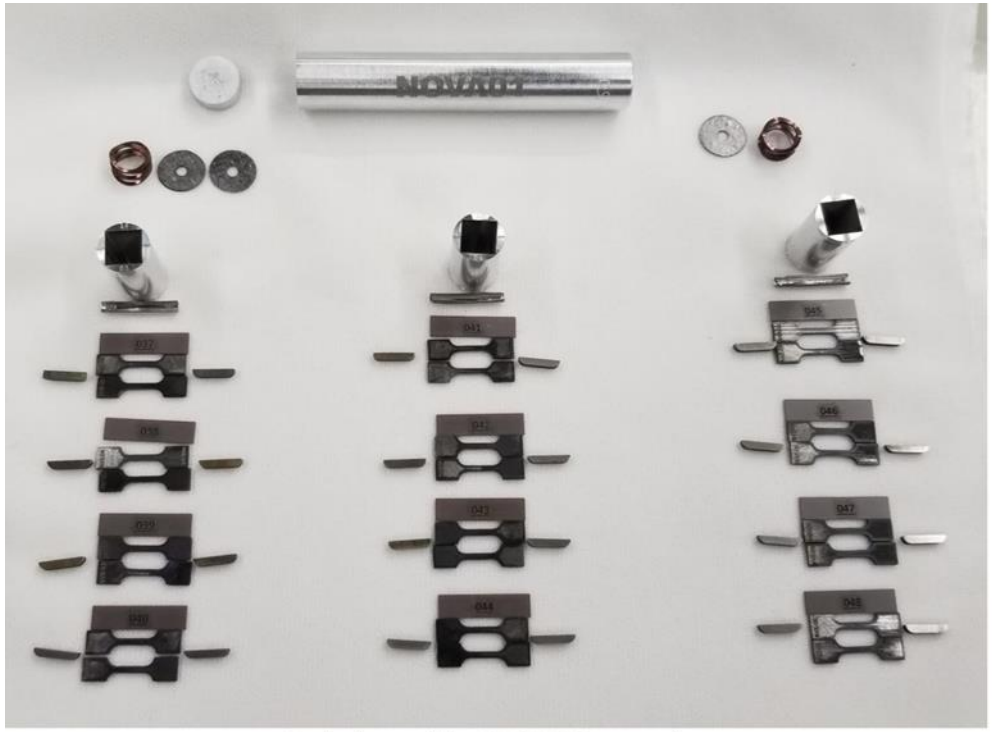
Phase II – CFD Benchmarking





Phase II – HFIR Irradiation Testing

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



Parts layout for NOVA01 capsule

Phase II – Fuel Rod Vibration Testing

- Testing Performed in the small flow loop at NovaTech
  - 5X5 Test Bundle representing a standard 17X17 bundle – Baseline.
  - Production-grade fuel rod components with copper tungsten ballast
  - Production-grade guide tube in center of bundle
  - Production-grade grid segments
  - Axial flow up to ~150 gpm
  - Cross flow up to ~2 fps focused at grid mid-span
  - Fuel rod vibrations measured with strain gages and Keyence laser displacement sensors

PWR Bottom Nozzle

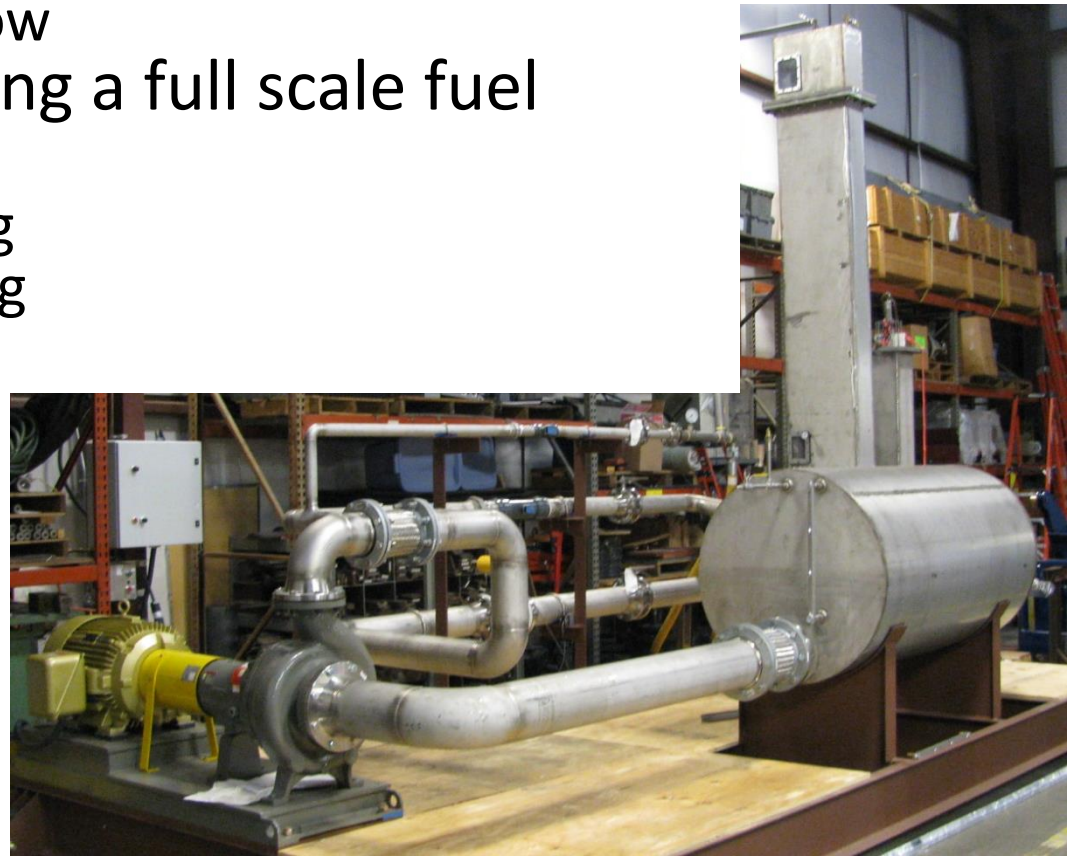
Phase II – Full Bottom Nozzle Design

[Redacted]

Patent Pending

Phase II – Full Scale Flow Testing

- Full Scale flow loop fabricated
  - Up to ~2000 gpm flow
- Capable of flow testing a full scale fuel bundle
  - Life and wear testing
  - Pressure drop testing



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Phase II – Project Risks

- Time
  - Funding ends at the end of January 2020
  - As presented, many tasks left to complete
- Implementation on a production fuel assembly
  - NovaTech is not a fuel vendor
  - Fuel users (utilities) are not willing to buy an individual fuel assembly component and modify a purchased fuel assembly
    - Liability issues
  - Need fuel vendors (Framatome and/or Westinghouse) to work with NovaTech to get an AM Bottom Nozzle on a production fuel assembly
    - Liability issues
    - Intellectual Property (IP) issues

Publications/Presentations

- Phase I Final Report
  - "Preliminary Research into the Viability of Additive Manufacturing of Nuclear Fuel Assembly Components"
  - DOE-NOVATECH-15902-1
  - Submitted to: Office of Science, U.S. DOE
- NRC Presentation at the Public Meeting on Additive Manufacturing for Reactor Materials & Components
  - November 28, 2017
- AMM Program Review
  - INL, October 4, 2017
  - ORNL, December 5, 2018
- Meeting with DOE Program Manager, Tansel Selekler
  - July 17, 2018

Publications/Presentations (Cont.)

- AMM Newsletter article
  - March 2016
  - September 2019
- Fuel Vendor Presentations
  - Framatome
  - Westinghouse
- Customer Presentations
  - Dominion
- Provisional Patent
  - In process

Next Activities

- HFIR Irradiation Testing
  - Late 2020
  - Waiting for HFIR availability
- Fuel Rod Vibration Testing
  - Ongoing
  - 5X5 Assembly in Small Flow Loop
- Full Size Bottom Nozzle Fabrication
  - Getting quotes now
- Full Scale Testing
  - January 2020
- Final DOE Report
  - January 2020
- Phase IIB Funding Proposal?

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Questions?