Graphite Test Article and Heat Pipes

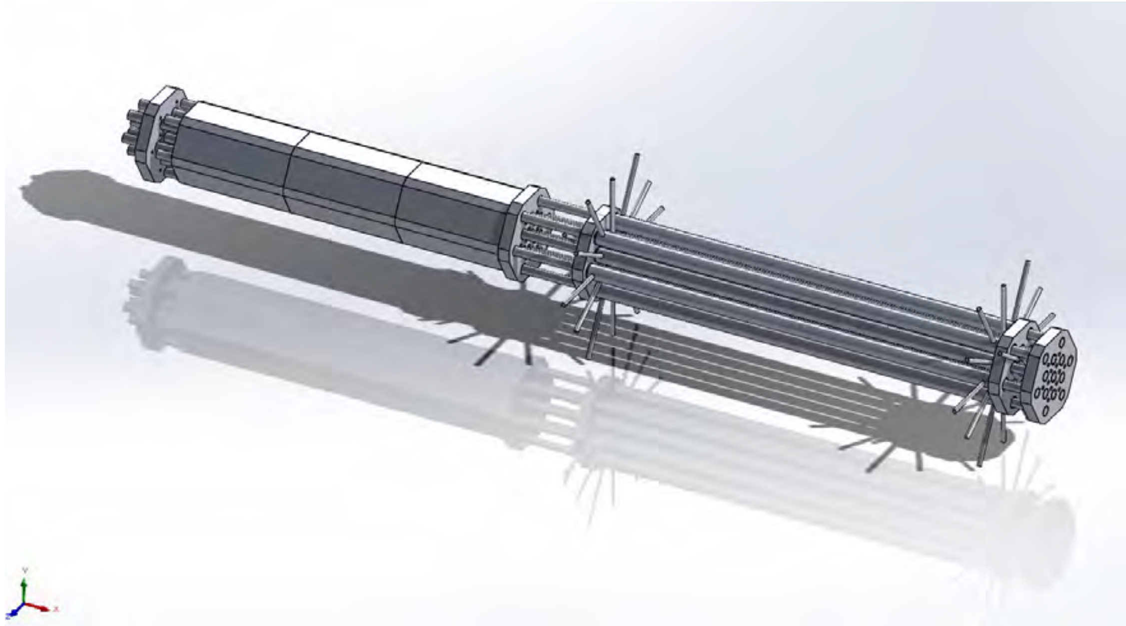
March 5, 2025

Martin Ward, Katrina Sweetland, Charles Onstead, and Holly Trellue

Microreactor Program

Outline

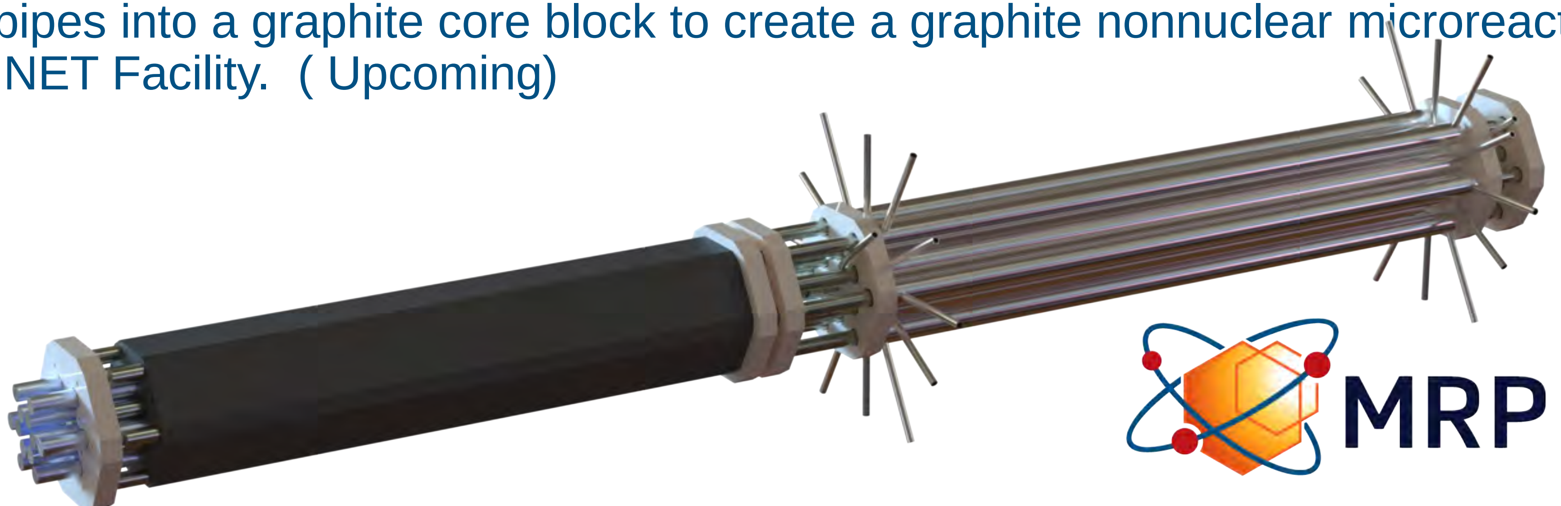
- Overall Goals
- Stainless Steel/Sodium Heat Pipe
  - Stainless Steel/Sodium Heat Pipe Fabrication
  - Stainless Steel/Sodium Heat Pipe Filling
  - Stainless Steel/Sodium Heat Pipe Test Stand
  - Stainless Steel/Sodium Heat Pipe Testing
- Graphite Core Block Status
- Heat Exchanger Status
- eFill37 Status
- Laser Welding in the eFill
  - Laser Weld Development Process
  - Status of Laser Welding
- Path Forward
- Milestone Status



Overall Goals

- Heat transfer in a microreactor overcomes unique challenges due to the compact footprint, radiation field, transportability, and high temperatures present. High temperature operation preferred to give higher power production efficiencies. Objectives for this work are as follows:

- Fill individual stainless steel heat pipes with sodium and provide them to SPHERE for testing. (Completed)
- Design and fabricate a heat exchanger for the heat pipe and graphite core block system. (Completed)
- Develop techniques for fabrication of individual high-capacity heat pipes with sodium using refractory metal (molybdenum) heat pipe tubes. (In Progress)
- Help with heat pipe characterization testing at SPHERE and university facilities. (In Progress)
- Incorporate the heat pipes into a graphite core block to create a graphite nonnuclear microreactor test article for at the MAGNET Facility. (Upcoming)

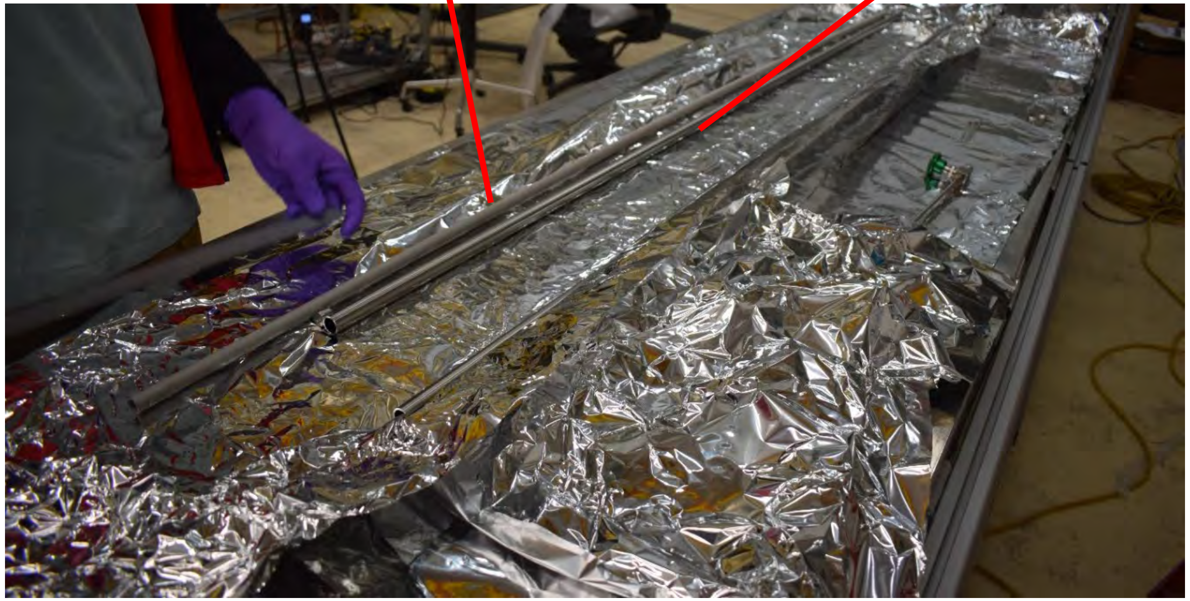


MRP Microreactor Program

Stainless Steel/Sodium Heat Pipe Fabrication

Heat Pipe Wick

Heat Pipe Tube

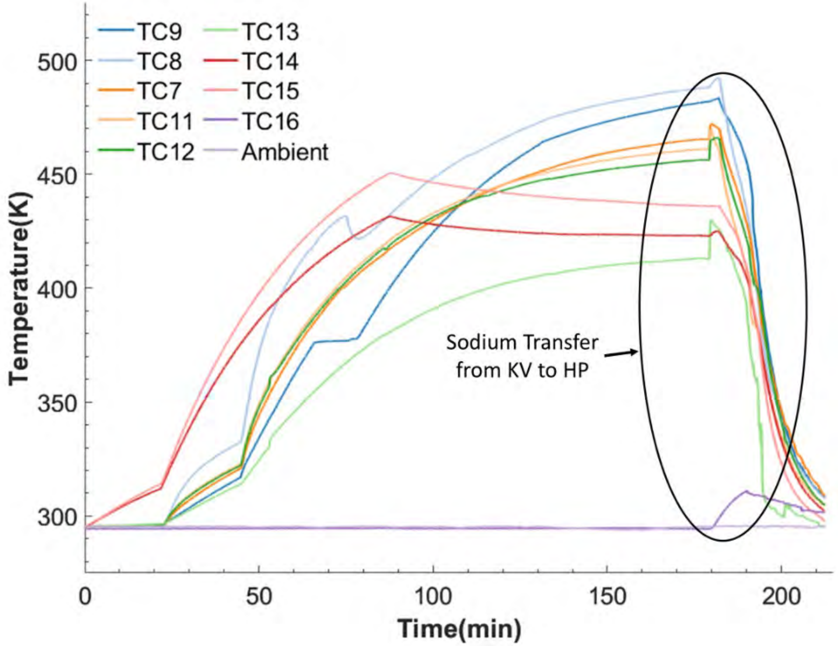


Heat Pipe Condenser Plug with Fill Stem Before Cleaning

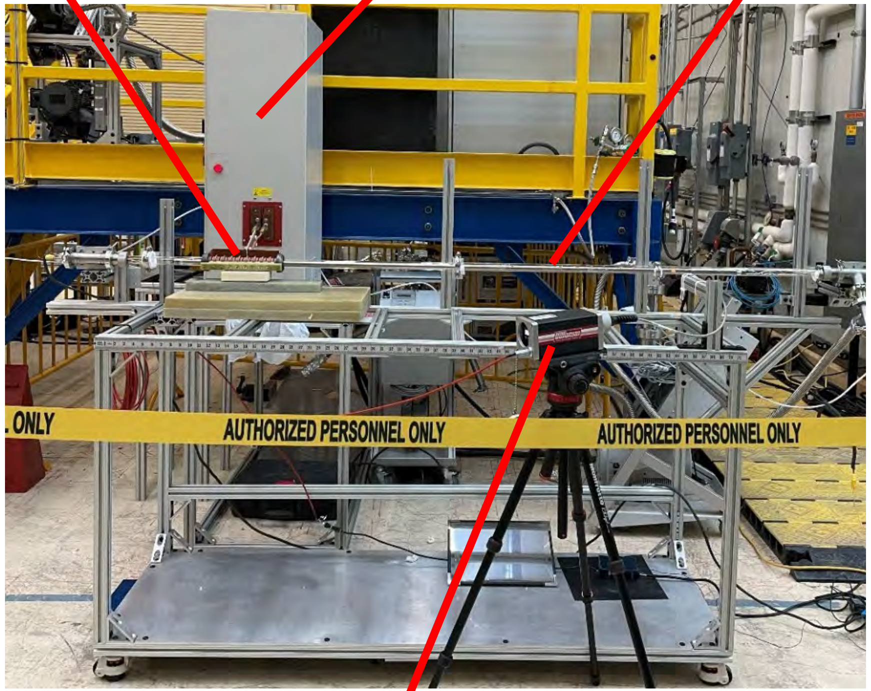
Heat Pipe Evaporator Plug Weld Process

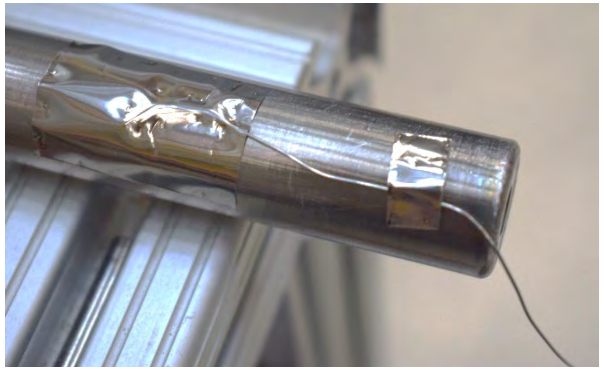
Stainless Steel/Sodium Heat Pipe Filling

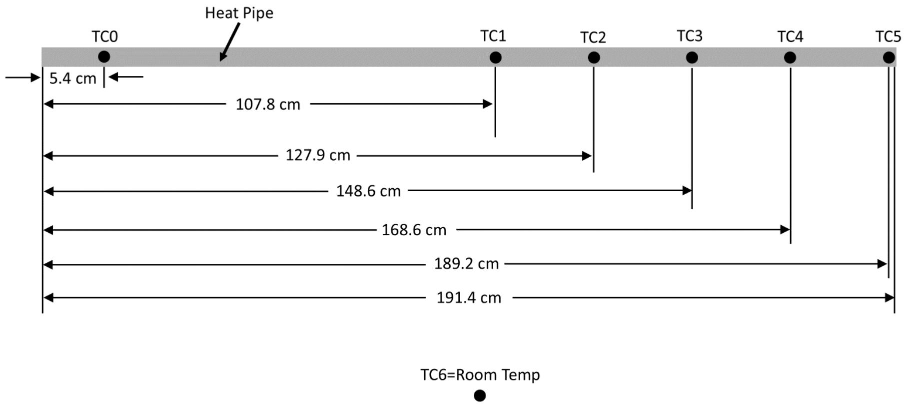
- 56.5 +/-1 g sodium transferred to the heat pipe



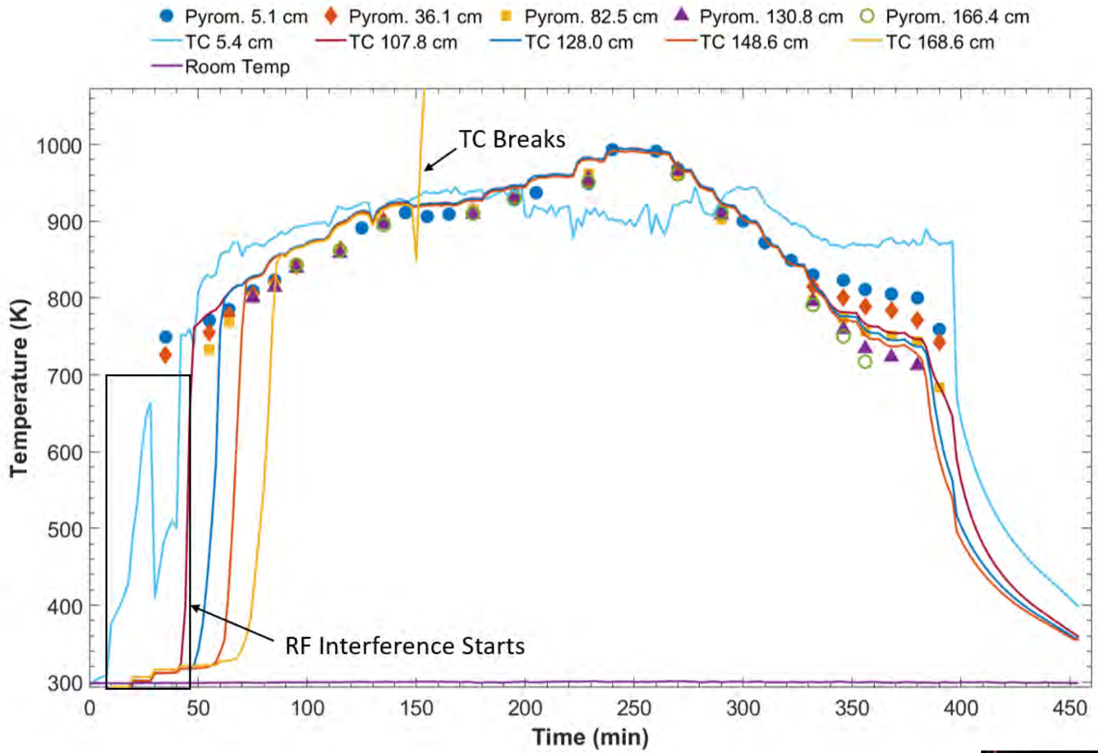
Stainless Steel/Sodium Heat Pipe Test Stand

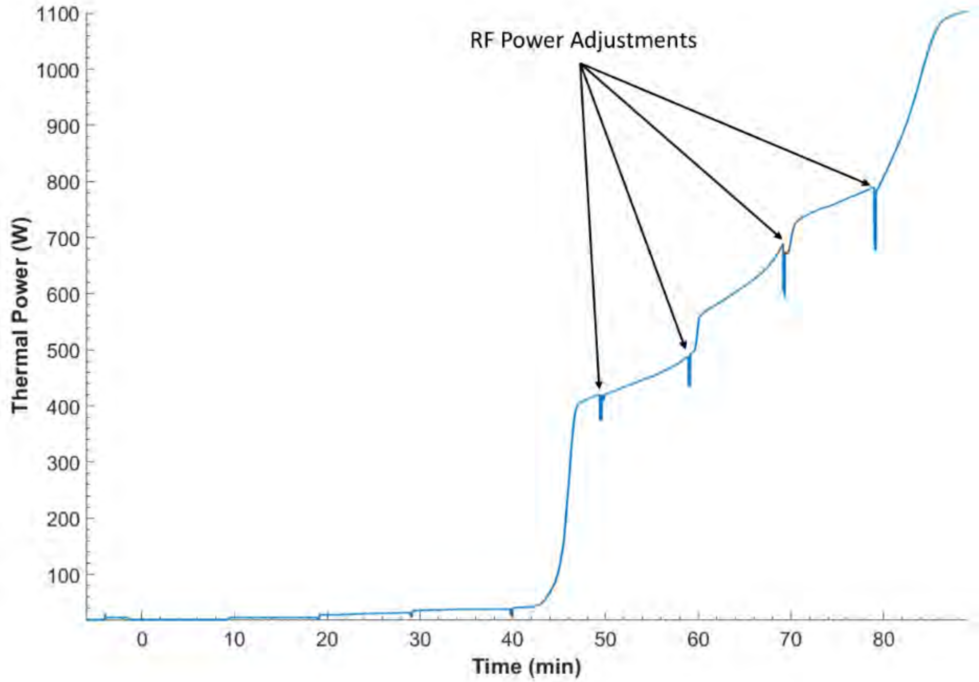


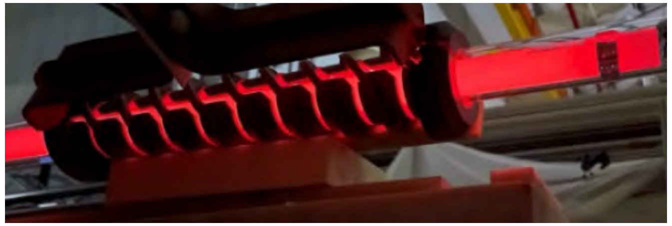


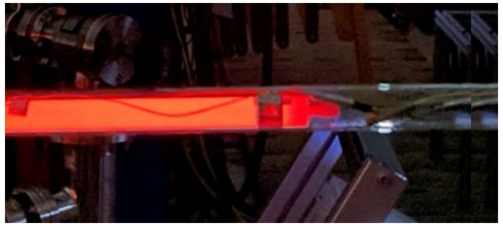


Stainless Steel/Sodium Heat Pipe Testing



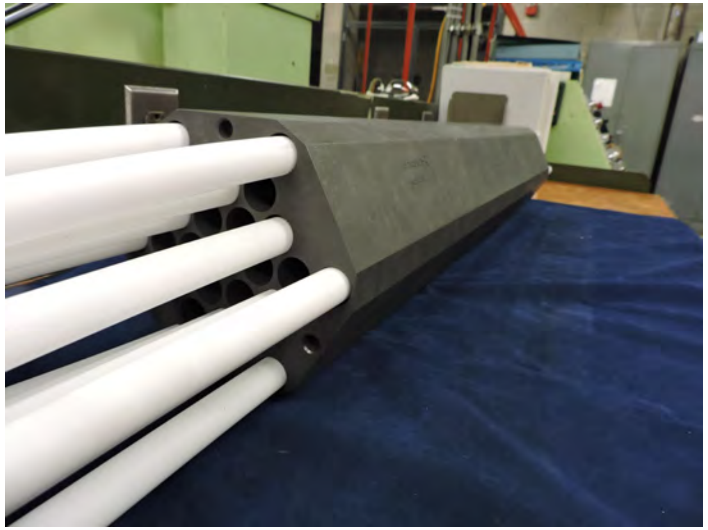






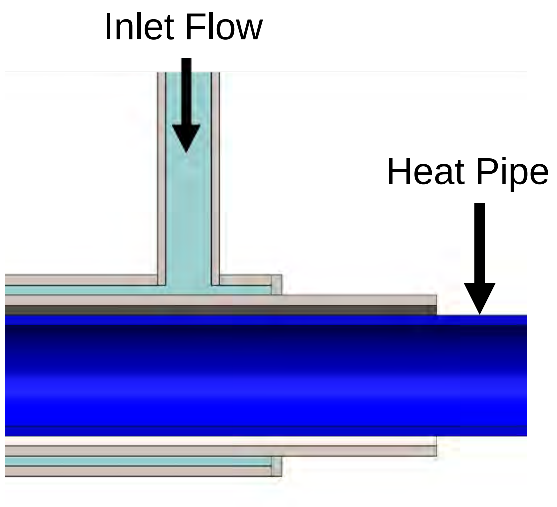
Graphite Core Status

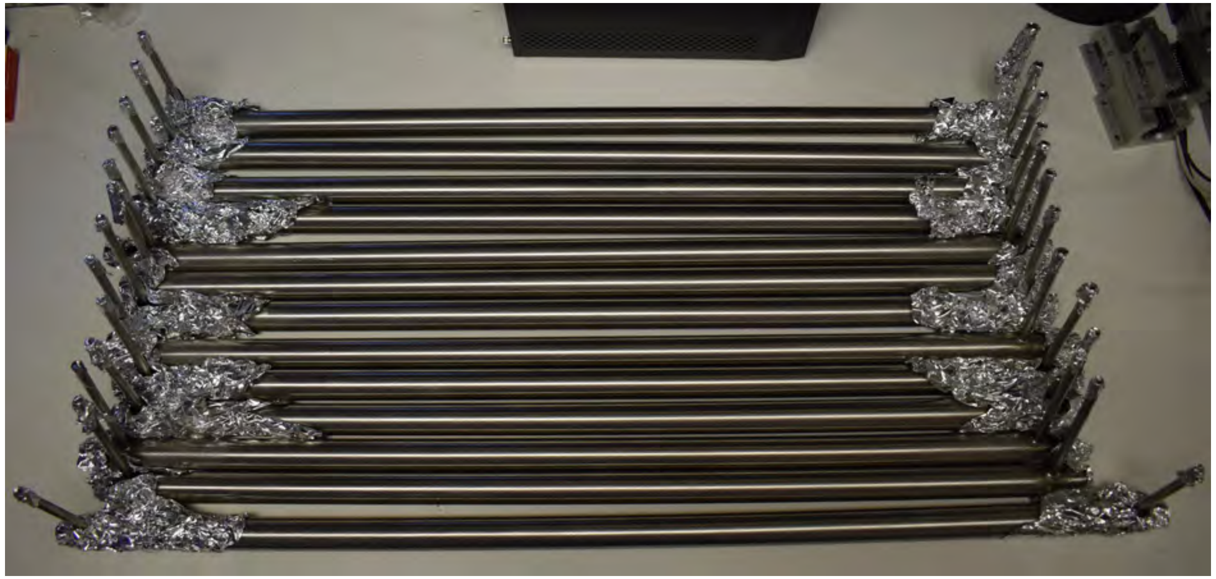
- Three graphite core sections.
- Fit tests with 19.1 cm diameter nylon rods performed; finding that there is interference between the core block sections where the heat pipes would hit.
- The graphite cores were machined to add a small chamfer at these locations to ensure the heat pipes can be installed.



Heat Exchanger Status

- Heat transfer analysis was used to design modular heat exchangers for all 13 heat pipes.
  - The modular heat exchanger was chosen as it minimizes stress on the graphite core block while allowing for the most information from each heat pipe to be collected.
- The heat exchangers were made from stainless steel tubes and allow for the performance of each region of heat pipes to be monitored.





eFill37 Status (filling heat pipes with sodium)

- The eFill37 charge sub-assembly has been prepared to fill the molybdenum tubes with sodium as soon as the tubed have been cleaned and had one end plug welding into place.
- Updated camera’s, plug placement verification system, and updated fill stem have been implemented.

Updated Charge Sub-Assembly

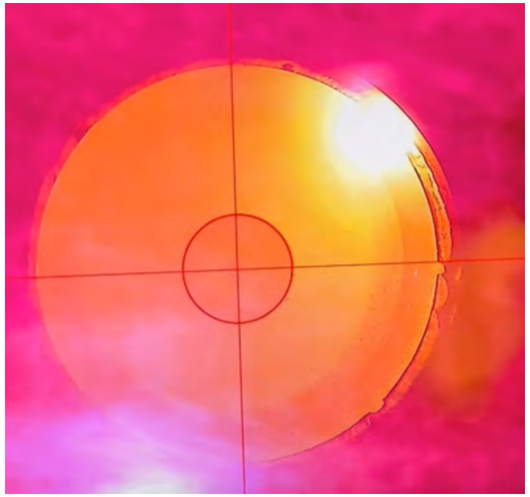
Light Tight Box Around Plug Placement Verification System

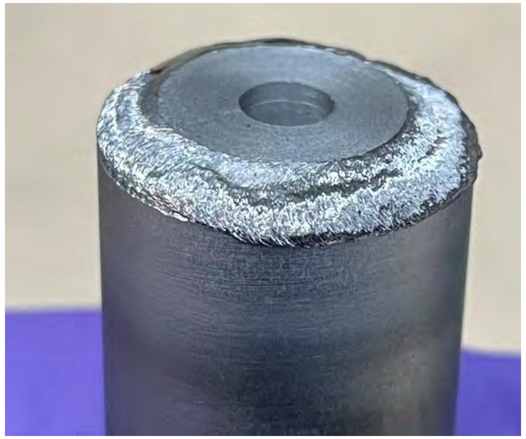
Updated Fill Stem

MRP Microreactor Program

Laser Welding in the eFill37

- System designed to allow for heat pipes to be filled and sealed in high-volume
- Designed for eBlock37 monolithic stainless-steel core
- Repurposed for filling individual heat pipes
- Weld process needed to be re-developed for molybdenum heat pipes





U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY | MRP Microreactor Program

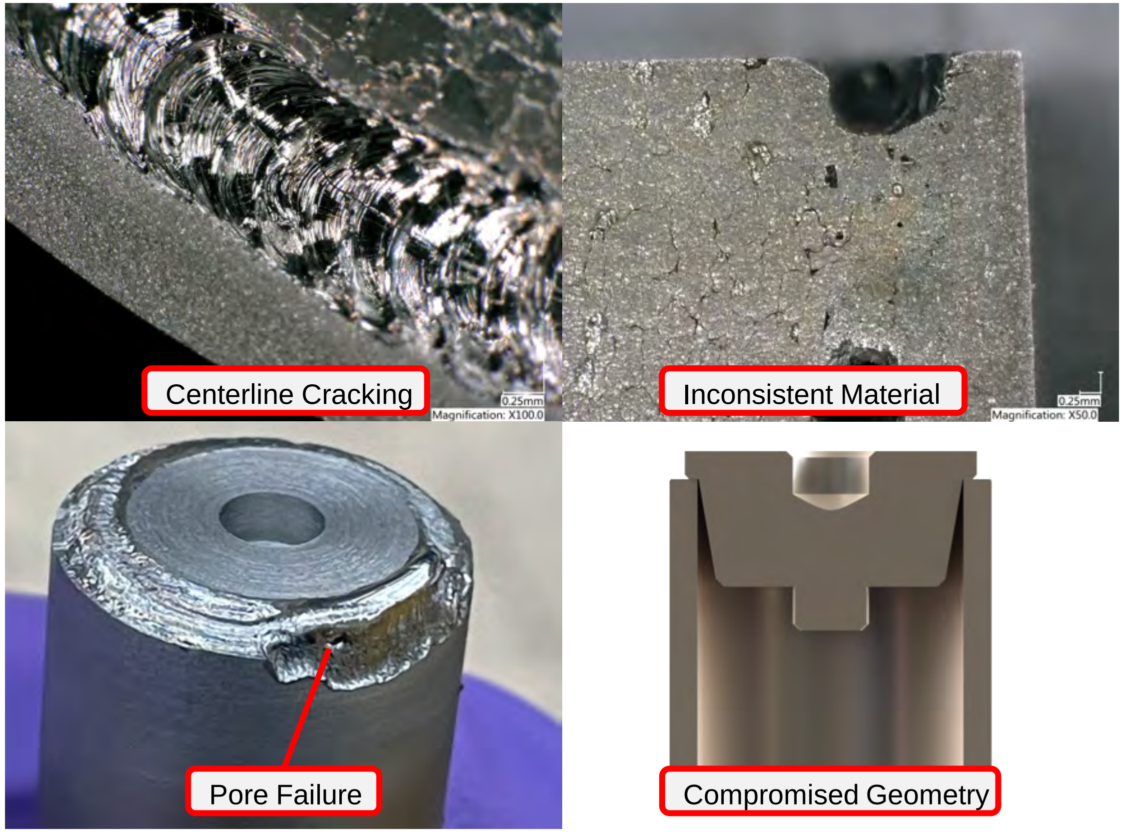
Laser Weld Development Process

- Procure materials (Expensive and lead times of 6-10 weeks for small parts, 6 months for long tubes)
- Machine tube and plug samples (Lead times of 6-8 weeks)
- Clean samples
  - Ultrasonic bath
  - Rinse with DI Water
  - Clean with Solvents
  - Vacuum fire at 750°C for ~2hr
- Install in eFill chamber
- Pump down the chamber to <20 mTorr
- Introduce a constant flow of helium to create 100 mTorr environment
- Test fire and adjust the crosshair to aim the laser
- Run weld program
- Let the part cool for about 45min
- Helium leak-check
- Microscope imaging
- Analyze results and document
- Propose adjusted parameters

Status of Molybdenum Welding

Challenges:
- Welding inside heat pipe filling chamber
- Difficult to change joint geometry
- Molybdenum availability
- Variability in composition and structure of materials
- Difficult to machine
- High cleanliness requirements
- Molybdenum recrystallization during weld

Solutions:
- Improve joint design as much as possible
- Switch to TZM plugs from a reputable vendor
- Improved welding process parameters from 38+ trials



Current parameters used with improved joint design and a TZM plug has resulted in a 100% leak test pass rate.

Path Forward

1. Identify laser welding parameters that can reliably seal a molybdenum heat pipe.

   -Initial TZM weld trial results are showing parameters that are sealing repeatable

2. Prepare molybdenum tubes and TZM or molybdenum plugs.

   -Consists of chemically cleaning and vacuum firing components at 750C.

1. Fill, seal, and wet-in one molybdenum tubed heat pipe to prove filling methodology.
2. Seal one end of the molybdenum tubes in batches of four.
3. Place the stainless-steel wick into the molybdenum tube.
4. Install the tube with the wick into the eFill.
5. Fill and seal the molybdenum tubes in batches of four using the eFill.
6. Wet-in the molybdenum heat pipes at a temperature of 750°C under 1 atm of helium for 24-48 hours in batches of 4.

Milestone Status

- M3AT-25LA0804021:Preform fill of heat pipe with Molybdenum tubing and sodium working fluid.
  - Will be completed by early March.
- M2AT-25LA0804022: Deliver graphite test article to INL to provide industry relevant analog to a core and heat extraction system.
  - On track for completion on time. Heat extraction system will be sent to INL this month in advance of the heat pipes and graphite core block.
- Activity AT-25LA0804023: Assist INL in initial test at MAGNET.
  - On track for completion on time.