



Graphite Test Article and Heat Transfer

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Martin Ward, Katrina Sweetland

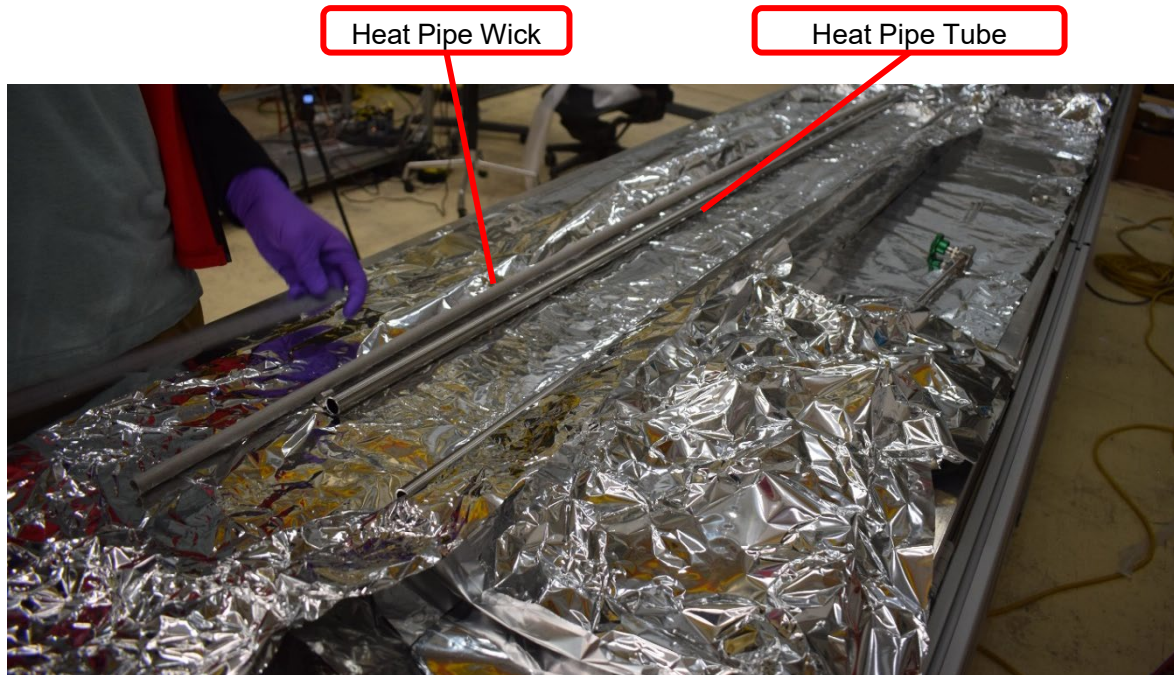
Outline

- Bottom Line Up Front on Status
- eFill37 Sodium Filling
- Laser Welding in the eFill
 - Laser Weld Development Process
 - Laser Welding
- Heat Exchanger
- Graphite Core Block

Bottom Line Up Front on Status

- 2 stainless steel walled/SS wicked/sodium individual heat pipes shipped to INL for SPHERE testing.
- 15 molybdenum walled/SS wicked/sodium heat pipes have been shipped to INL for both SPHERE and MAGNET graphite article testing!

Stainless Steel/Sodium Heat Pipe Fabrication



Heat Pipe Condenser Plug with Fill Stem Before Cleaning



Heat Pipe Evaporator Plug Weld Process



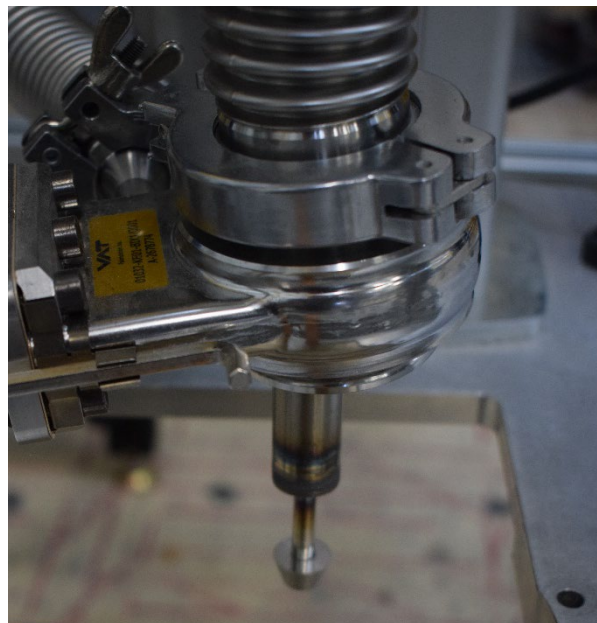
eFill37 (filling heat pipes with sodium)

- The eFill37 charge sub-assembly has been prepared to fill the molybdenum tubes with sodium as soon as the tubes 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.

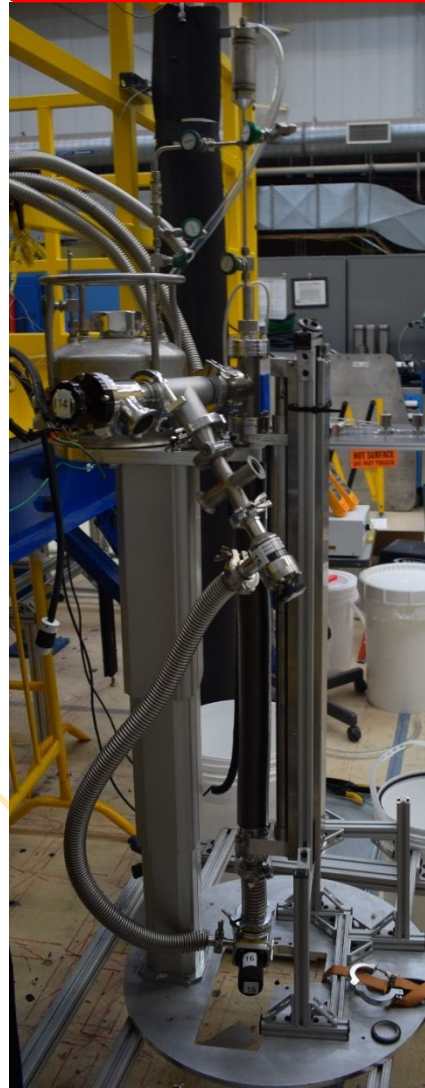
Light Tight Box Around Plug Placement Verification System



Updated Fill Stem

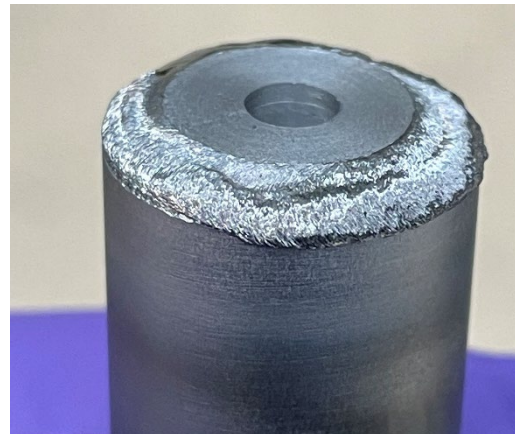
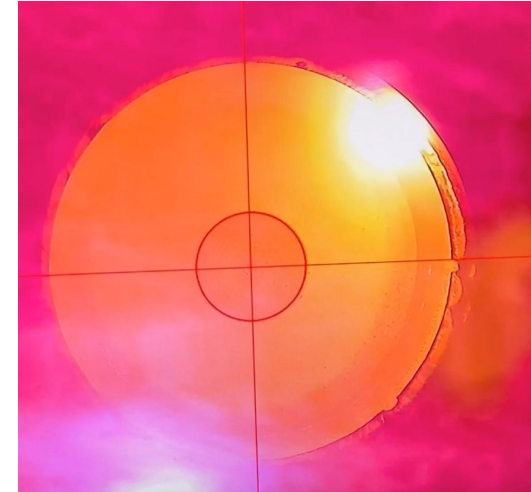


Updated Charge Sub-Assembly



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



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
 - Degreaser in ultrasonic bath
 - Rinse, DI water, acetone, and methanol
 - 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 reticle 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

Laser Welding Progression

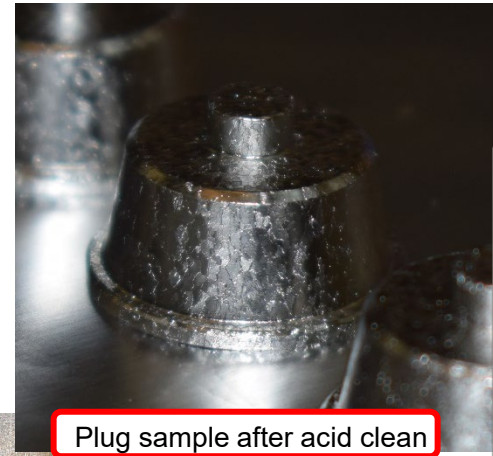
- **Procure sample materials**
 - Sample weld tubes were high-quality drawn powder metallurgy
 - Sample plugs were lower quality powder metallurgy rod. (quick lead time, intended for practice)

- **Cleaning solution**

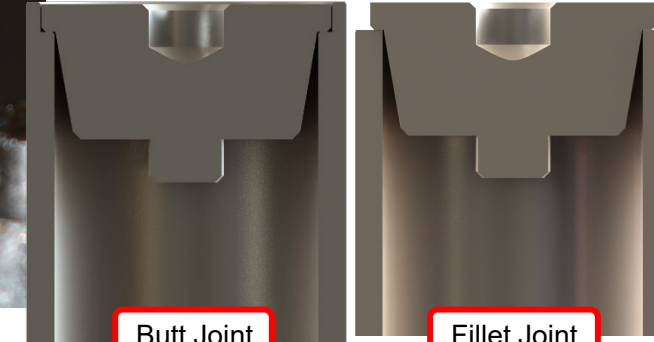
- Acid cleaning process from literature
 - Results were inconclusive
 - Process could not be scaled within time or budget
- Switch to more available ultrasonic solutions
 - Branson MC2 (basic)
 - Citranox (acidic)
- In parallel start building ultrasonic bath to fit 2m heat pipes.

- **Solutions to centerline cracking**

- Change to fillet joint
 - Reduce sinking action
 - Machining socket in 2m long heat pipe bodies challenging and risky
- TZM plugs
 - TZM has improved weld qualities
 - Ordered from reputable supplier
 - Change geometry slightly (constrained by eFill)

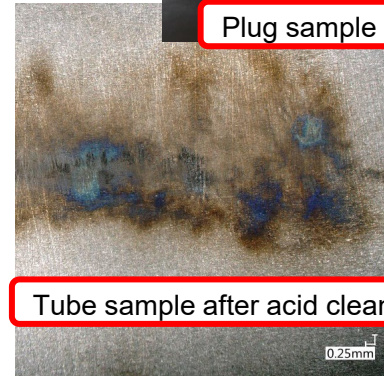


Plug sample after acid clean

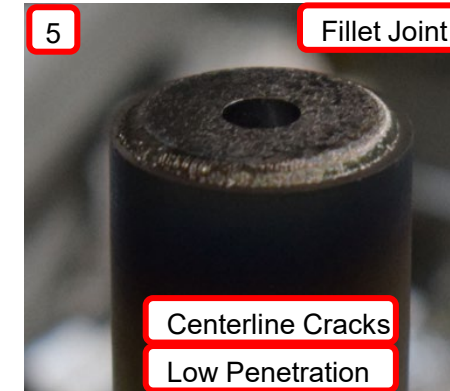


Butt Joint

Fillet Joint



Tube sample after acid clean



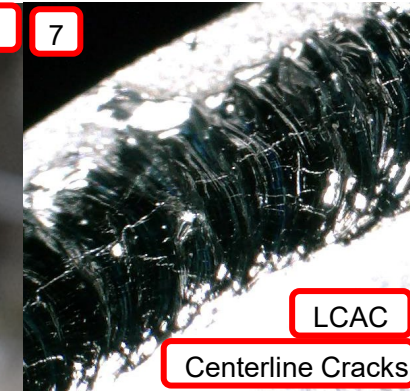
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Fillet Joint

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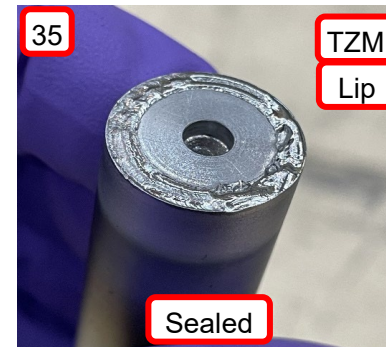
Centerline Cracks

Low Penetration



LCAC

Centerline Cracks

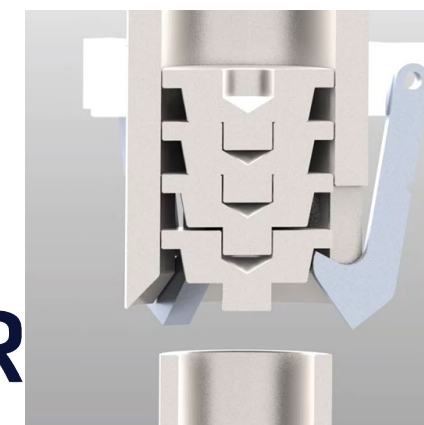


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TZM

Lip

Sealed



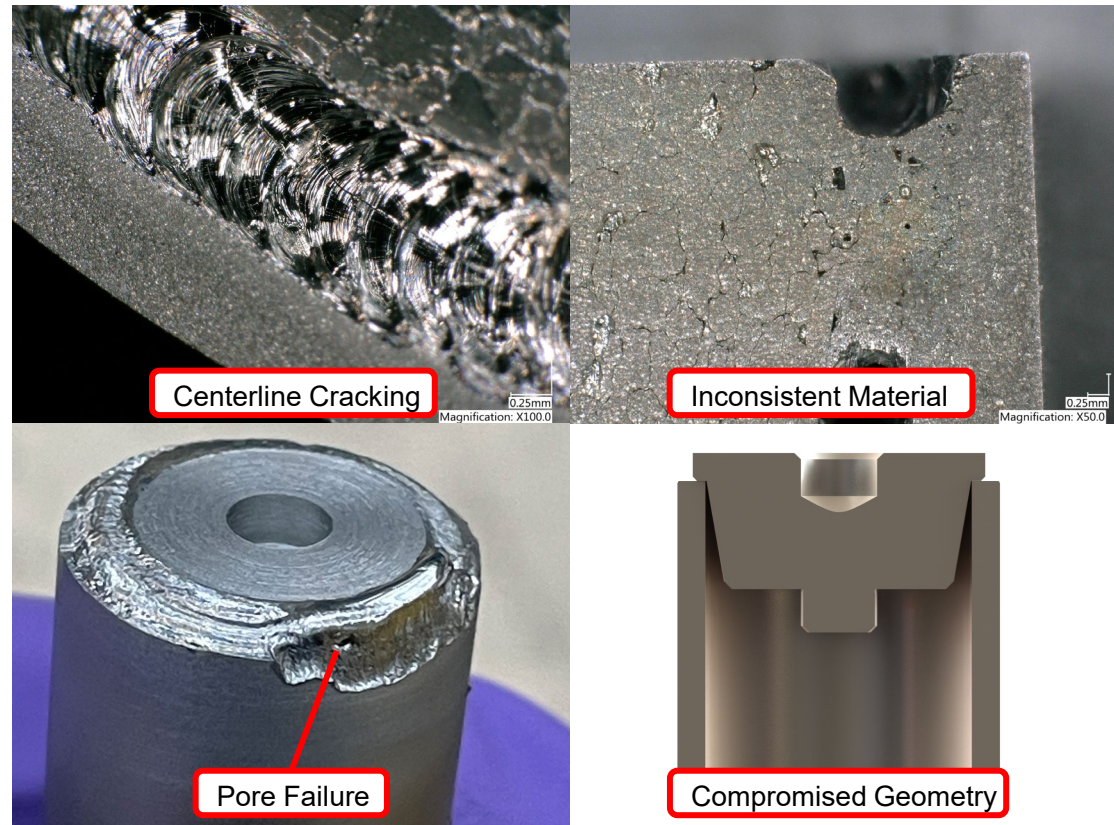
Molybdenum Tube Welding

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

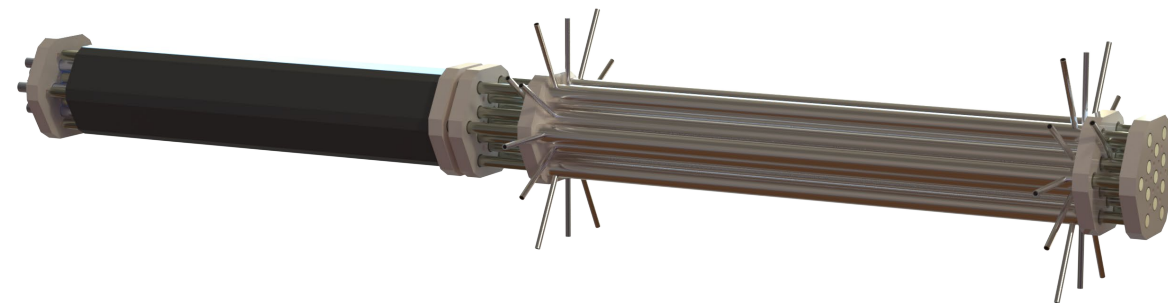
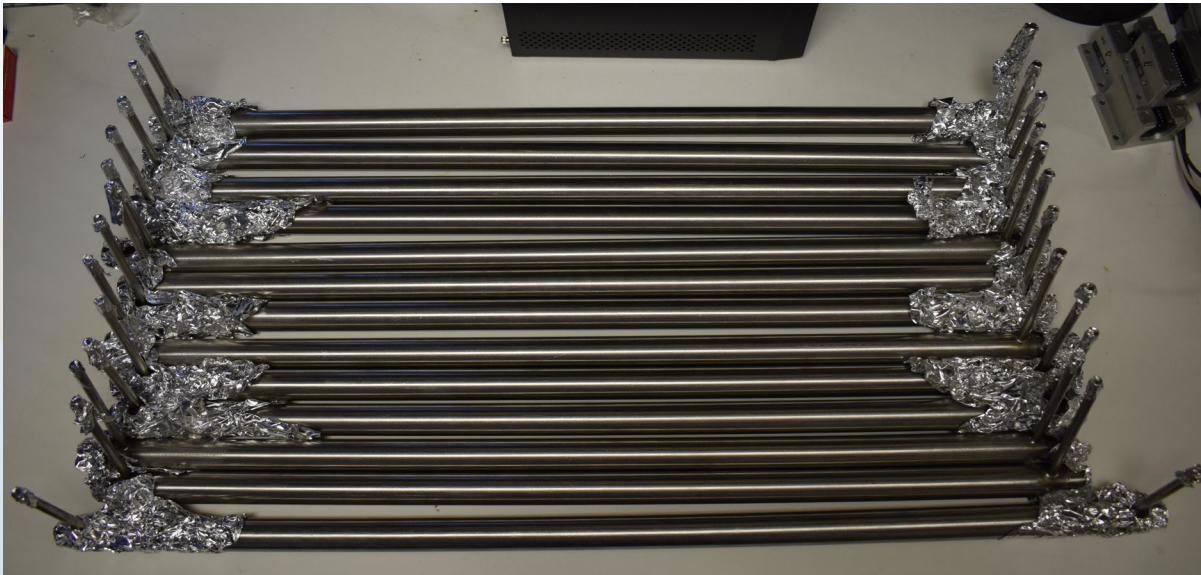
Solutions:

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



Heat Exchanger

- 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.



Graphite Core

- 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.

