Heat Transfer/ eBlock37 Heat Pipe Test Article Update

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Objective

- 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.
- Novel concepts explored to transport heat and dampen transients affecting structural integrity and performance of core structures/components.
- Research/testing of nonnuclear components helps increase our understanding of system performance.
- Feasible heat pipe and gas-cooled components plus heat exchanger and power conversion units can be integrated for non-nuclear testing easier than in nuclear demonstrations.
- Techniques for fabricating test articles with these features will also be developed and demonstrated.

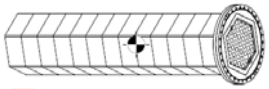
MRP Microreactor Program

eBlock37 Build

gCart37

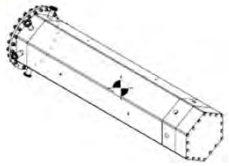
Handling Cart

Core37
US DOE S133,464

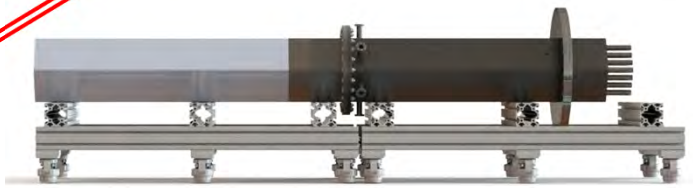


Monolithic
Reactor Core
Block

eXchanger37
US DOE S133,464

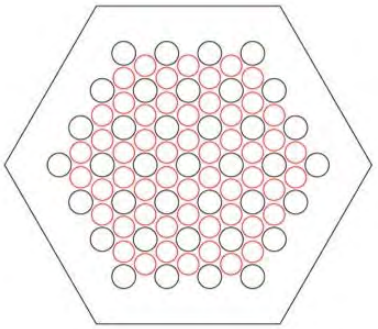


Monolithic
Heat Pipe to
Gas Heat Exchanger

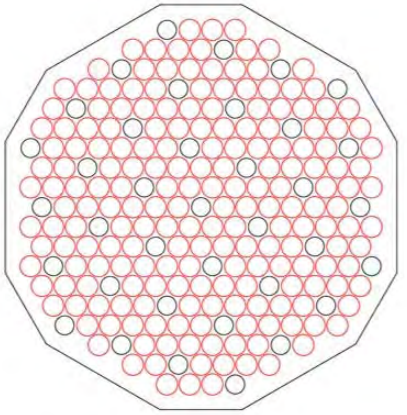


eWick37 (NQA-1)
US DOE S133,680

Mass Produced
NQA-1 Quality
High Capacity
Heat Pipe Wicks



Thermal Hydraulic
Similarity



Nuclear Similarity
(criticality)

eFill37
US DOE S133,662

Mass Produced
High Purity
Heat Pipe Fill
And Seal

MRP Microreactor Program

Presentation Outline

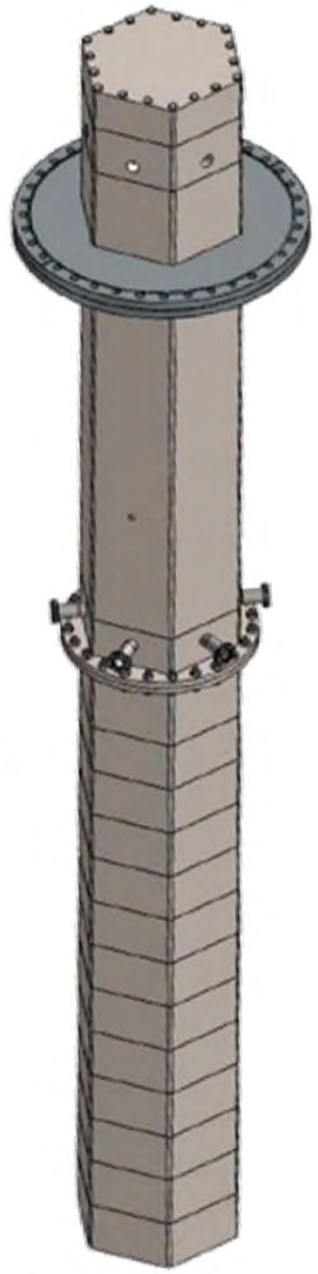
eBlock37 Assembly

- Core37 Subassembly
- eXchanger37 Subassembly
- eWick37 Subassembly

eFill37 Assembly

- eFill37 Charge Subassembly
- eFill37 Plug Loader Subassembly
- eFill37 Laser Weld Subassembly

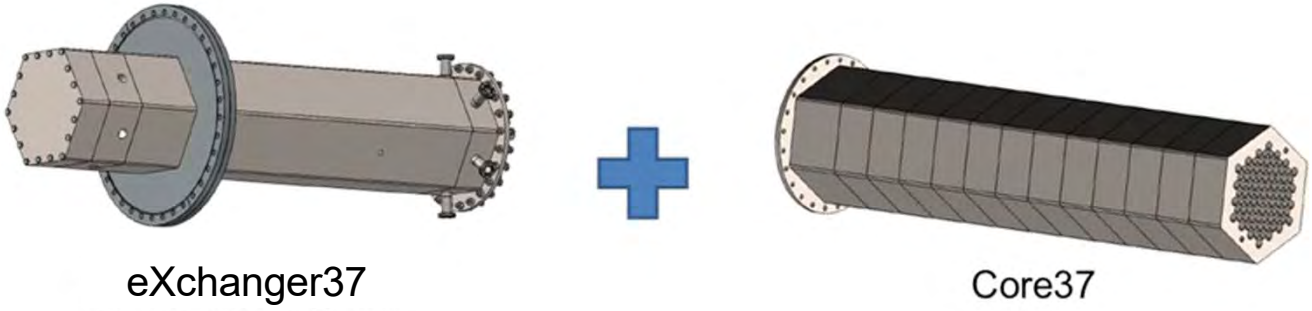
- Facility Upgrades

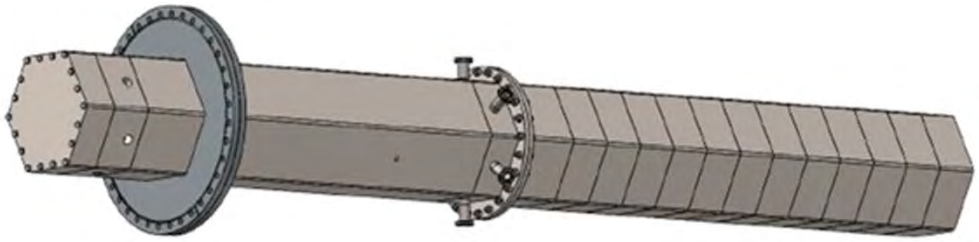


MRP Microreactor Program

eBlock37 System Assembly

- The eBlock37 is a sub-scale, electrically heated and heat-pipe cooled prototype of a fast spectrum microreactor.
- Comprised of a gas-cooled heat exchanger (eXchanger37) and electrically-heated and heat-pipe cooled core (Core37),
- Subassemblies built from stainless steel 316L and thermally linked by and array of 37 sodium heat pipes
- Heat pipes transfer nominal 100 kW from the core at 700°C





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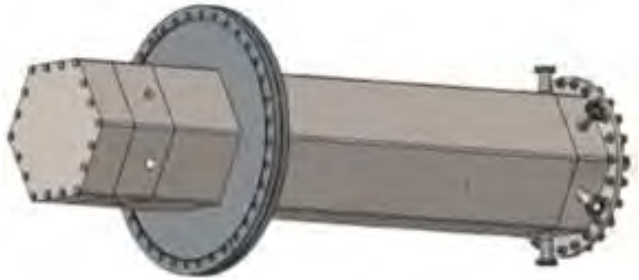
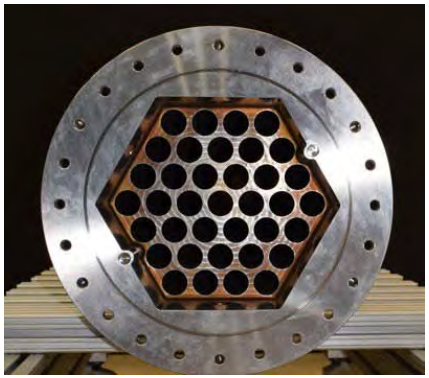
eXchanger37 Subassembly

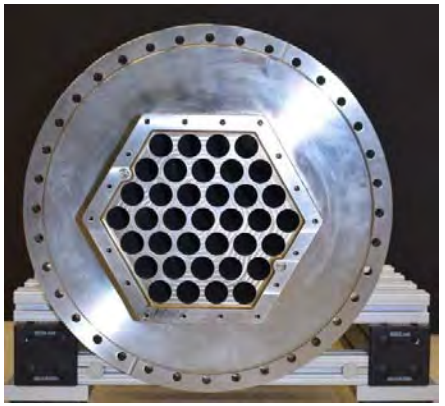


- Consists of a main body containing axial holes through which the heat-pipe array passes
- Flange on evaporator end links to Core37 Subassembly
- Flange on the condenser end links to the eFill37 and can be removed following heat-pipe fill operations



Evaporator End

eXchanger37 on gCart



Condenser End

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Path Forward

- Core37 Subassembly
  - Brazing repair of full-scale Core37 (Welds Complete, Inspection Pending)
  - Welding heat-pipe tubing to Core37 (Initial tests completed)
- eWick37 Subassembly (Complete)
- eFill37 Subassembly
  - Laser welding trial with IPG (Complete)
  - Plug loader awaits components (Fabricating final batch of plugs)
  - Final eFill37 test run on Mock Block (in Progress)
- Facility Upgrades
  - Mezzanine weld inspection (Complete)
  - Mezzanine insert anchors and bolts (Complete)
  - Electrical loads defined and on order (Complete)

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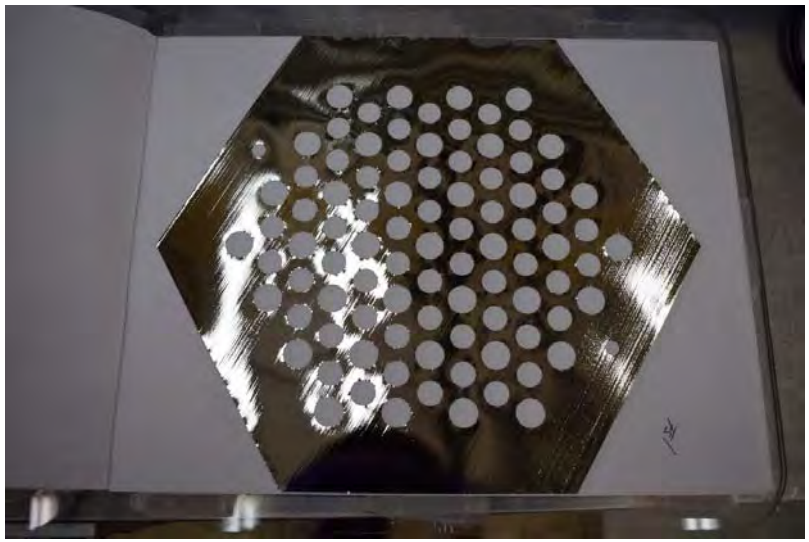
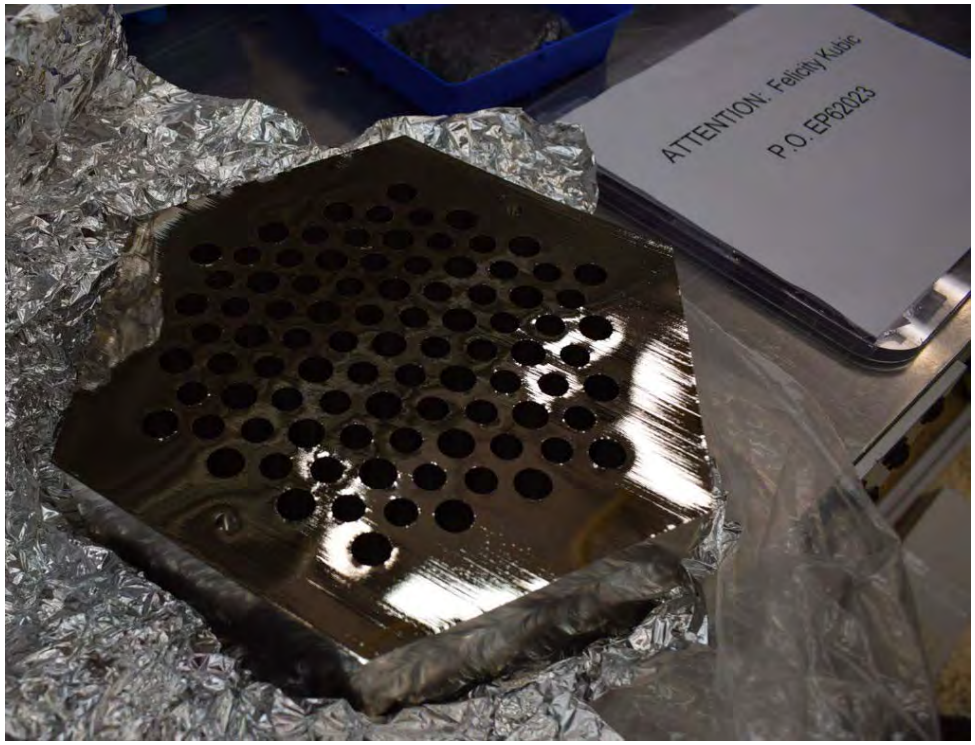
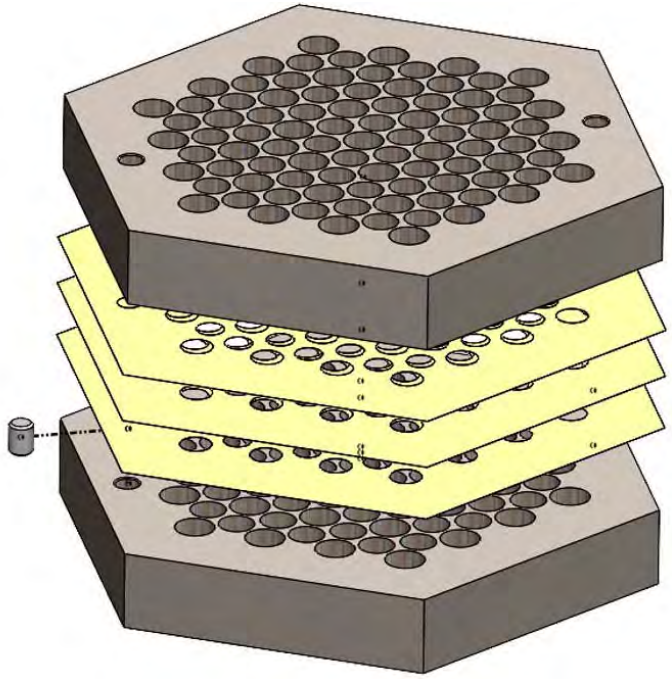
Core37 Subassembly – Braze Demonstration



Partial block unit for braze trials and braze witness coupons





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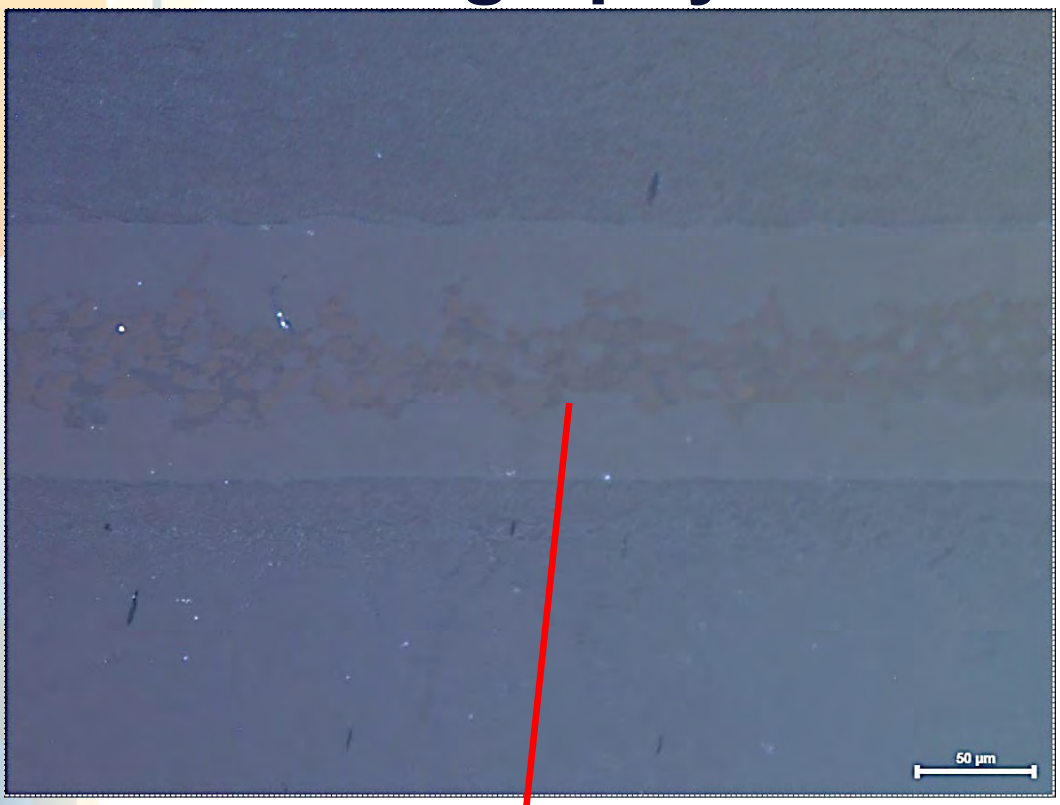
Core37 Subassembly – Braze Demo Metallography



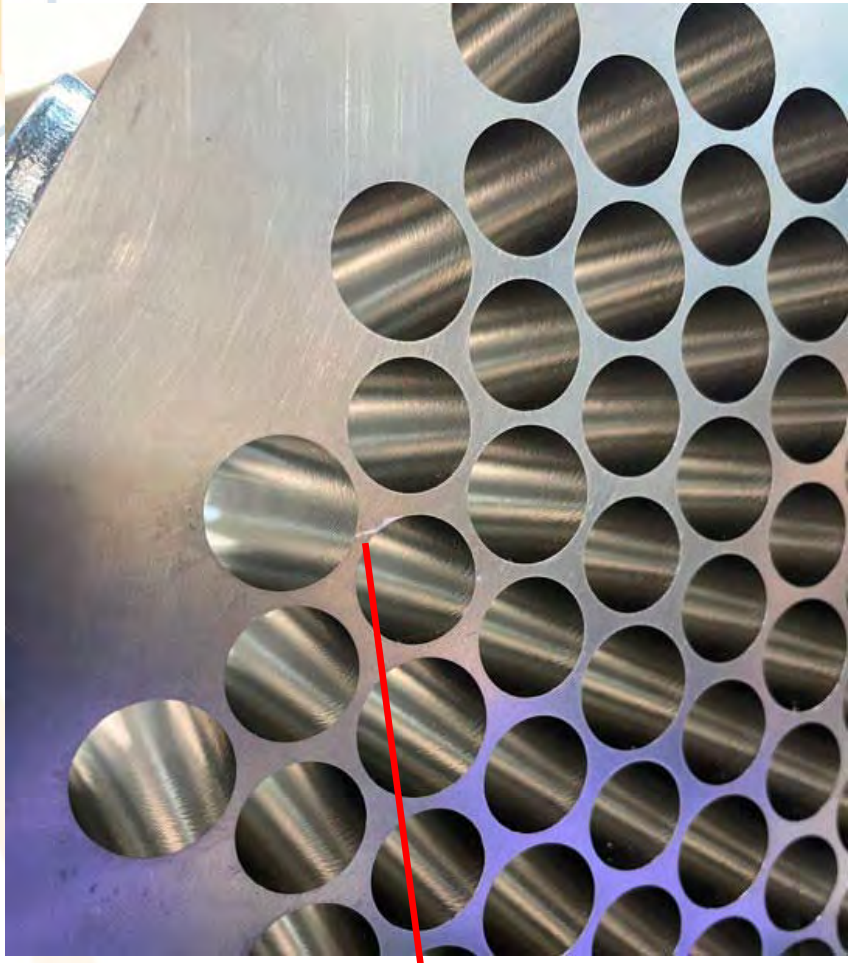
Dual foil bond line with B rich intermetallic interface

Core37 Subassembly – Braze Best Practices

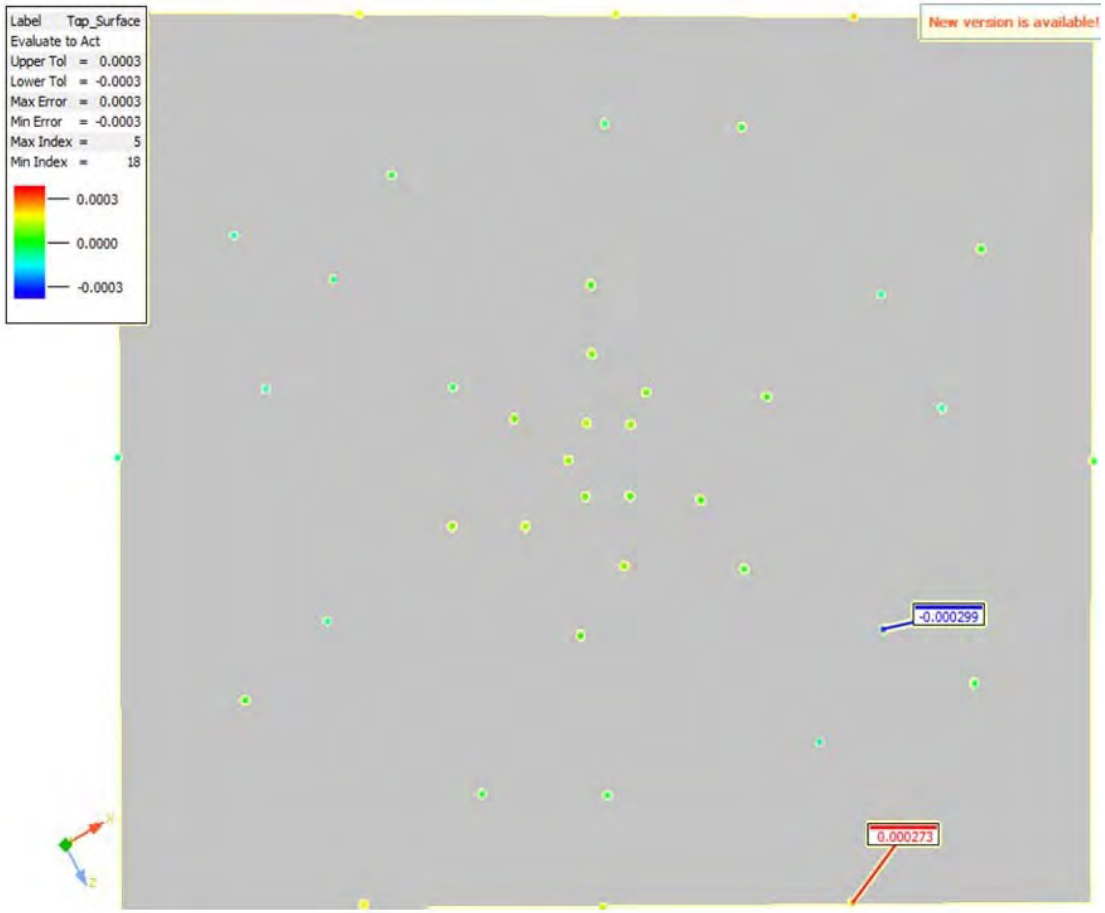
1. Machine Core37 bond surfaces flat <0.001 in to minimize joint gap clearance
2. Insert dowel pins between Core37 blocks to maintain alignment
3. Ensure dowel pins properly seat into adjacent alignment holes
4. Apply 2-micron nickel strike on Core37 bond surfaces to enhance wettability
5. Clean Core37 bond surfaces with acetone using lint free cloth
6. Place nickel braze foil layer at each Core37 bond line (spot weld to retain)
7. Perform a high temperature clean fire furnace burn out and vacuum leak up just prior to assembly of eBlock37 on grate
8. Place process control thermocouple in Core37 assembly cold spot
9. Inspect Core37 assembly to verify there are no fit-up issues that will cause blocks not to seat during the braze process
10. Tamp Core37 assembly if necessary to confirm line to line fit
11. Apply pressure to Core37 bond lines using block stack and weights
12. Perform a vacuum pump down and back fill furnace to atmospheric pressure with LAr boil off. Repeat three times before braze cycle
13. Hold Core37 assembly at recommended braze temperature. Heat the assembly slowly extending soak/hold times by a third
14. Vacuum cool Core37 assembly to intermediate hold temperature and then convective cool with LAr boil off

Core37 Subassembly - CMM Measurements

Sample CMM map of bond surface



High spot that required lapping



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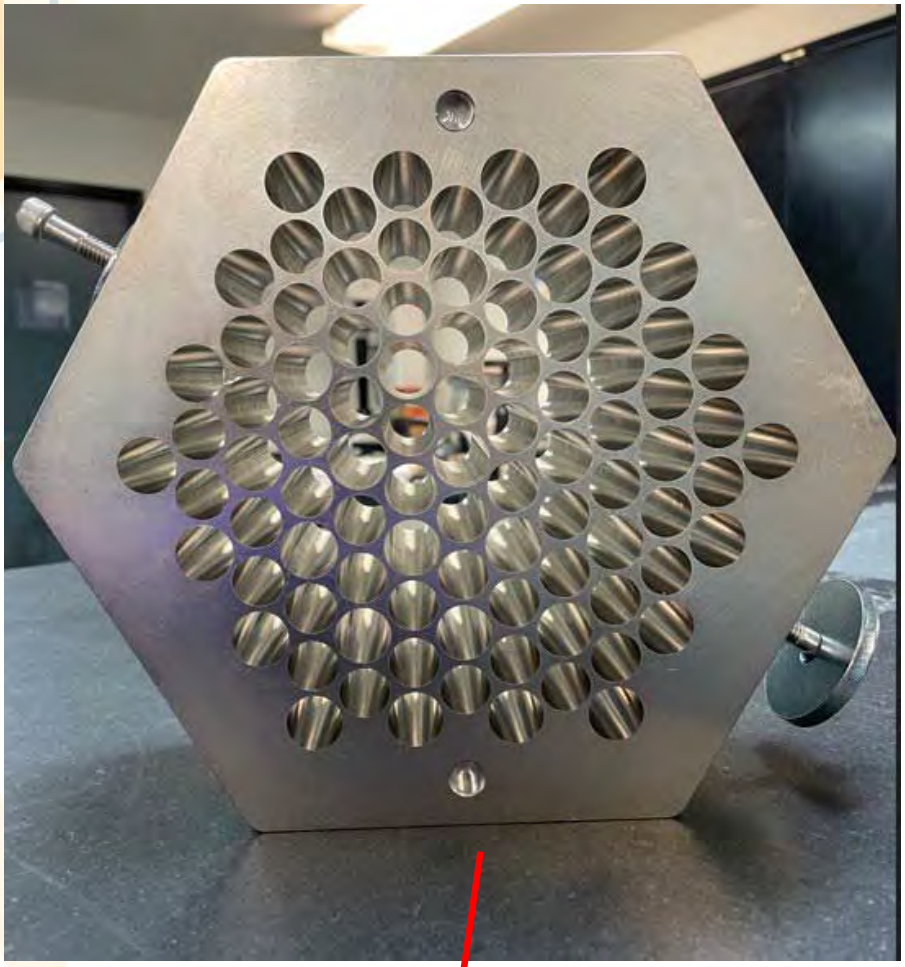
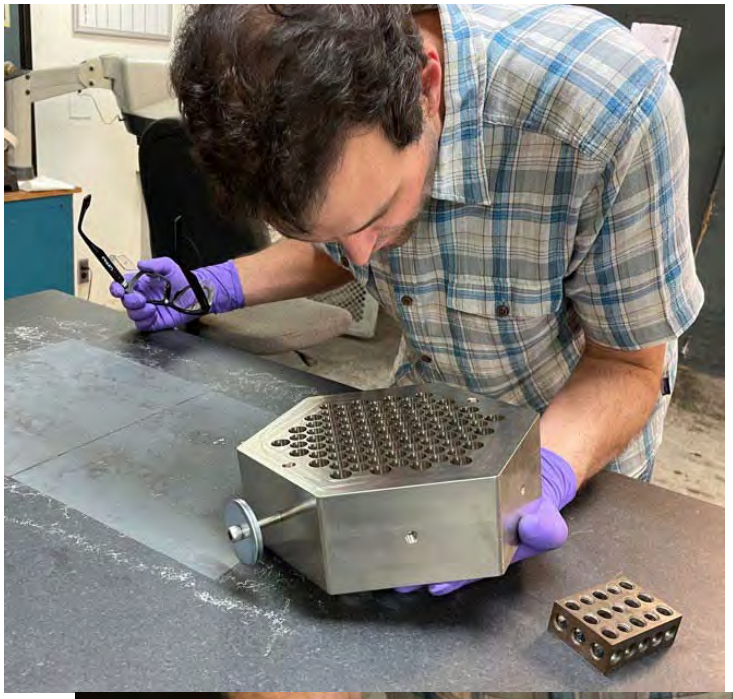
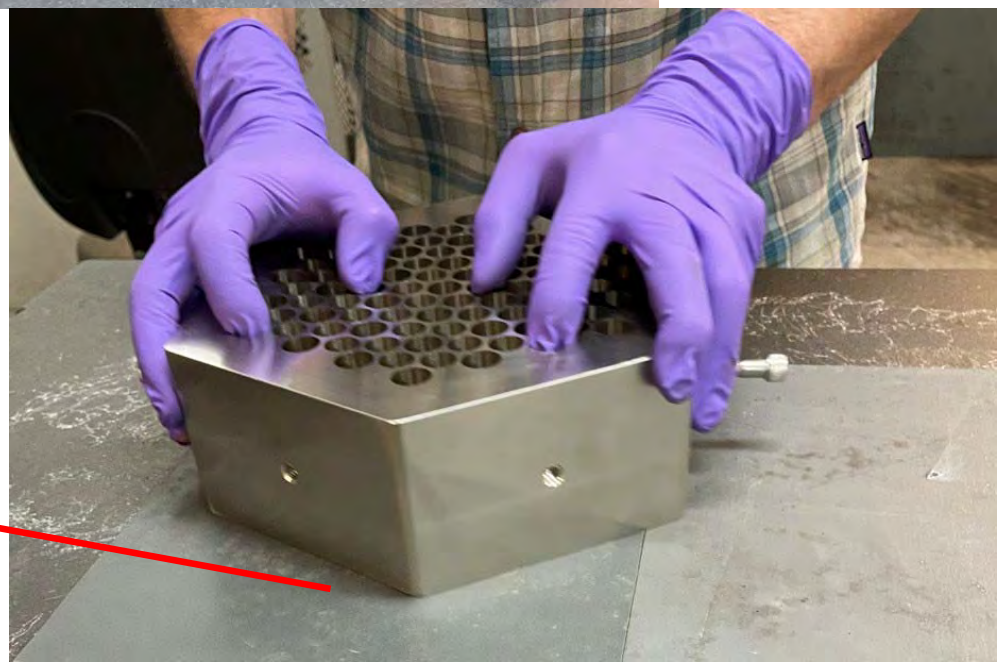
Core37 Subassembly – Lapping







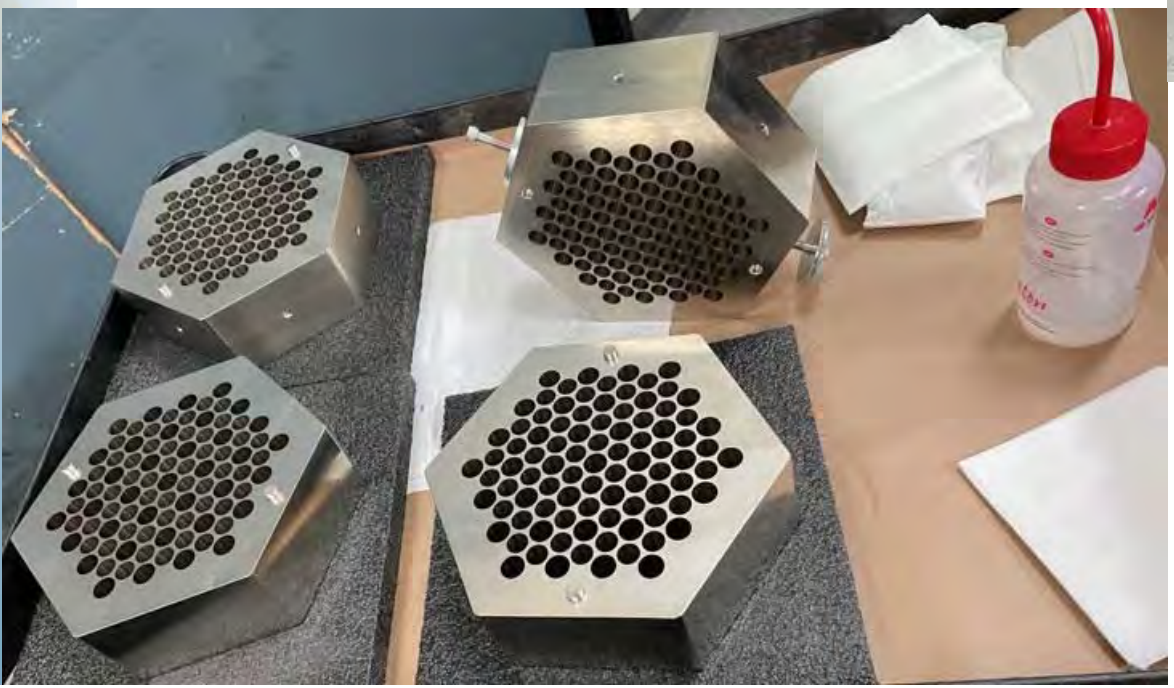
Core37 block on granite table

Core37 block being lapped

Core37 Subassembly – Chemical Cleaning

Isopropanol post-clean

Acetone wash



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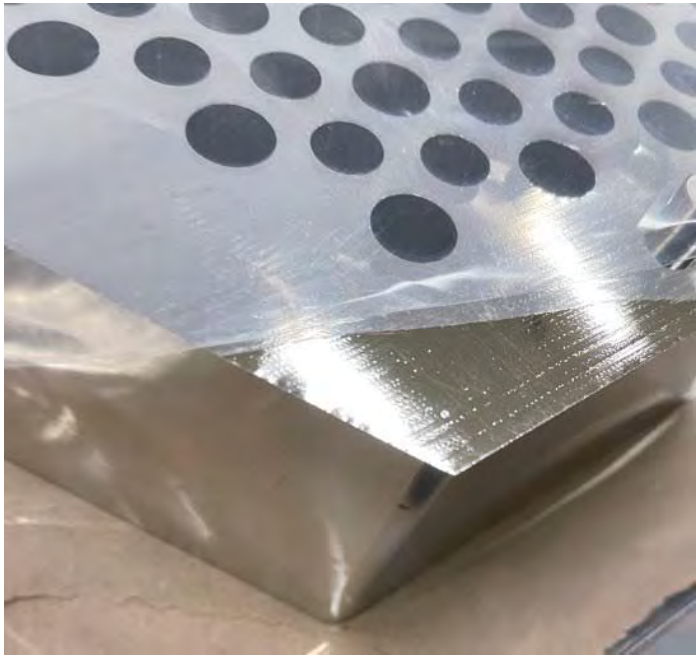
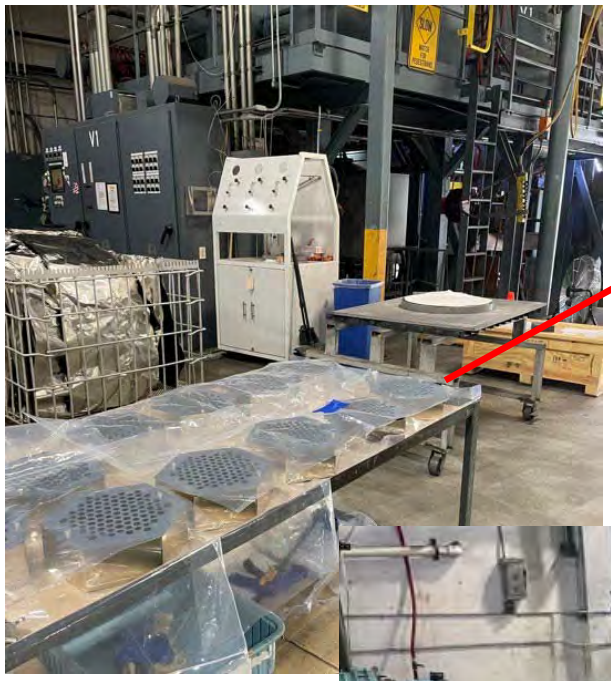
Core37 Subassembly – Braze Foil Placement



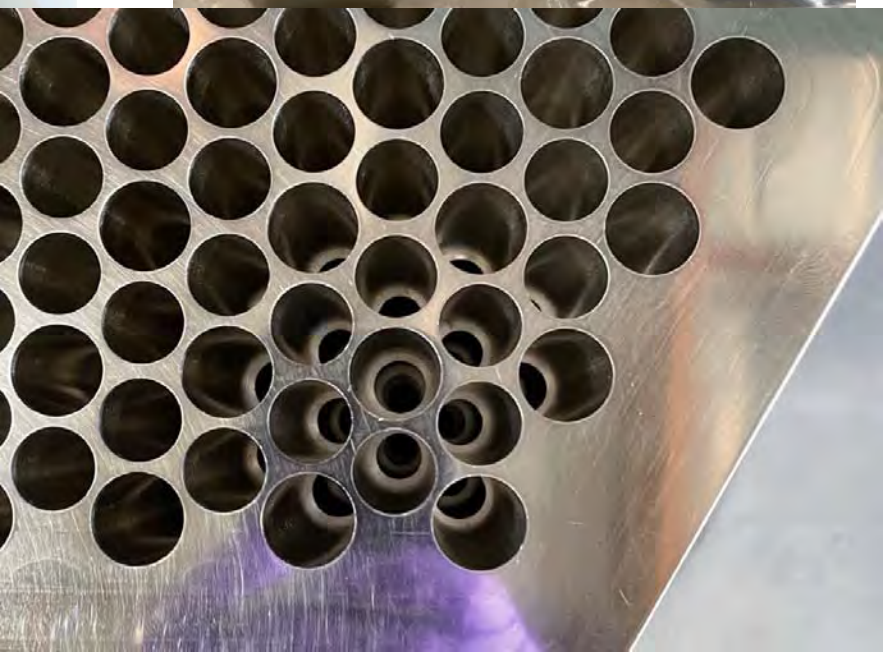
Braze foils applied to Core37 bonding surfaces

Core37 Subassembly – Furnace Loading

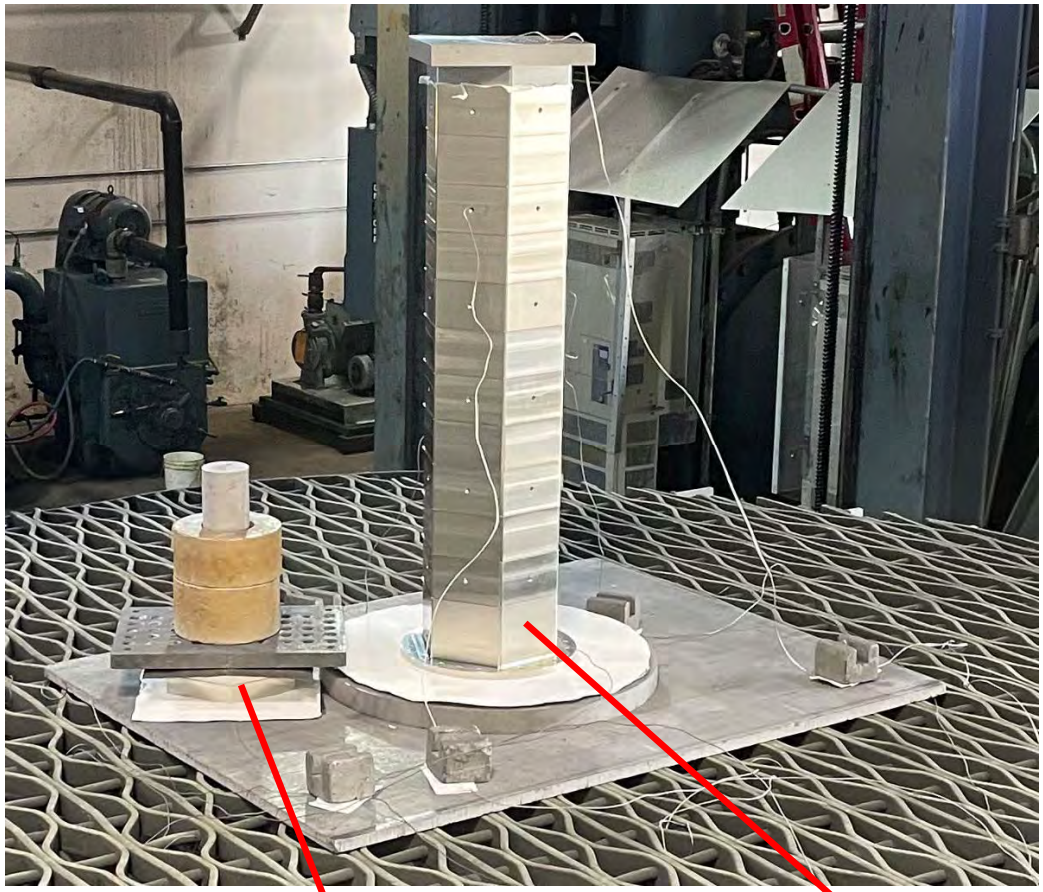


Completed Core37 blocks

Furnace grate



Core37 Subassembly – Furnace Loading



Witness Core37 block

Core37 Assembly

Core37 Stack

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Core37 Subassembly – Furnace Unloading

Core37 Assembly
Furnace Extraction

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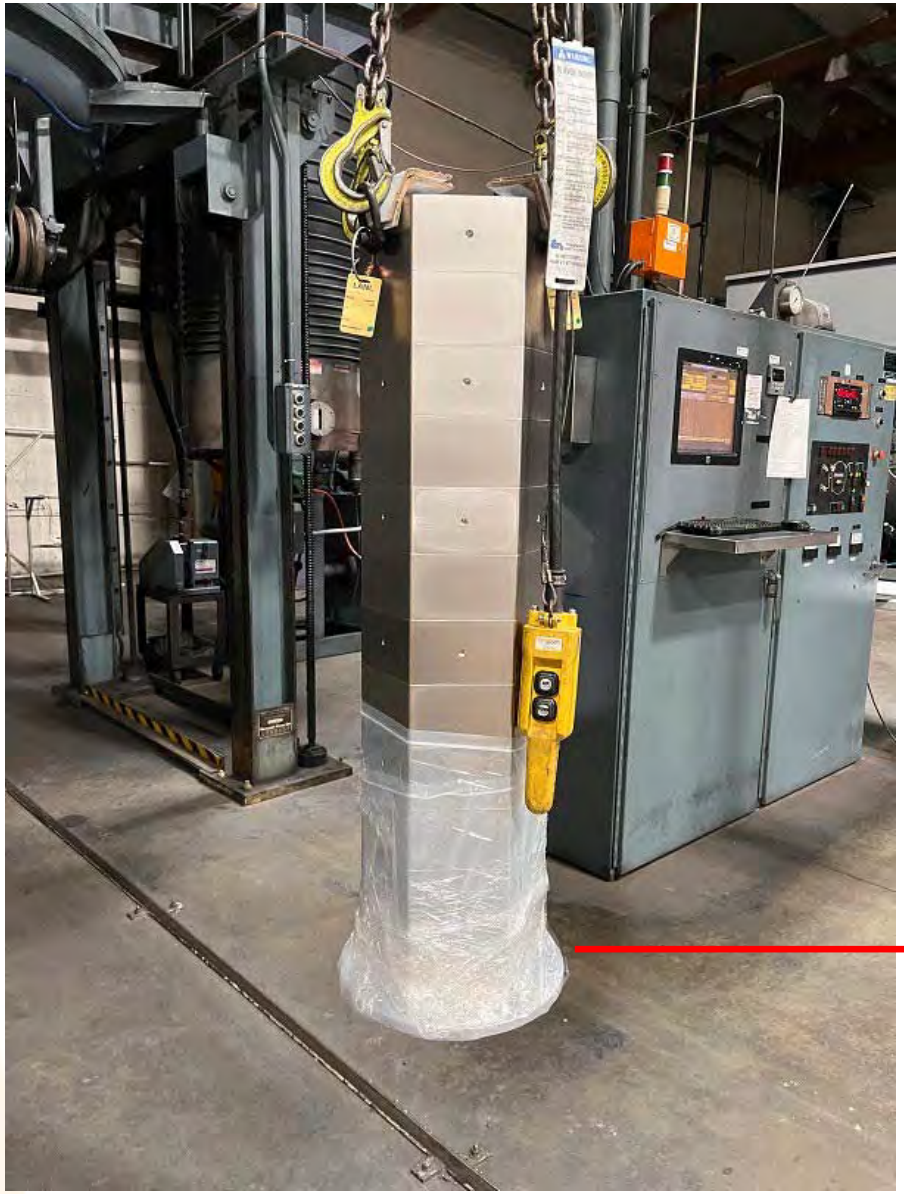
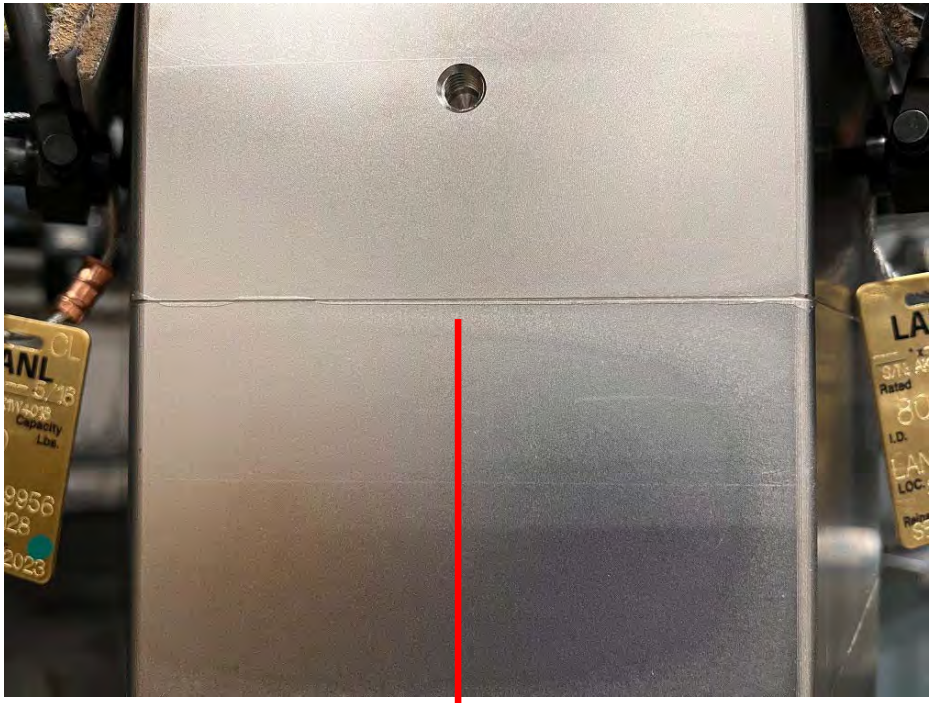
Core37 Subassembly – Post Fire Inspection





Sample bond line

Core37 Assembly removed from furnace grate

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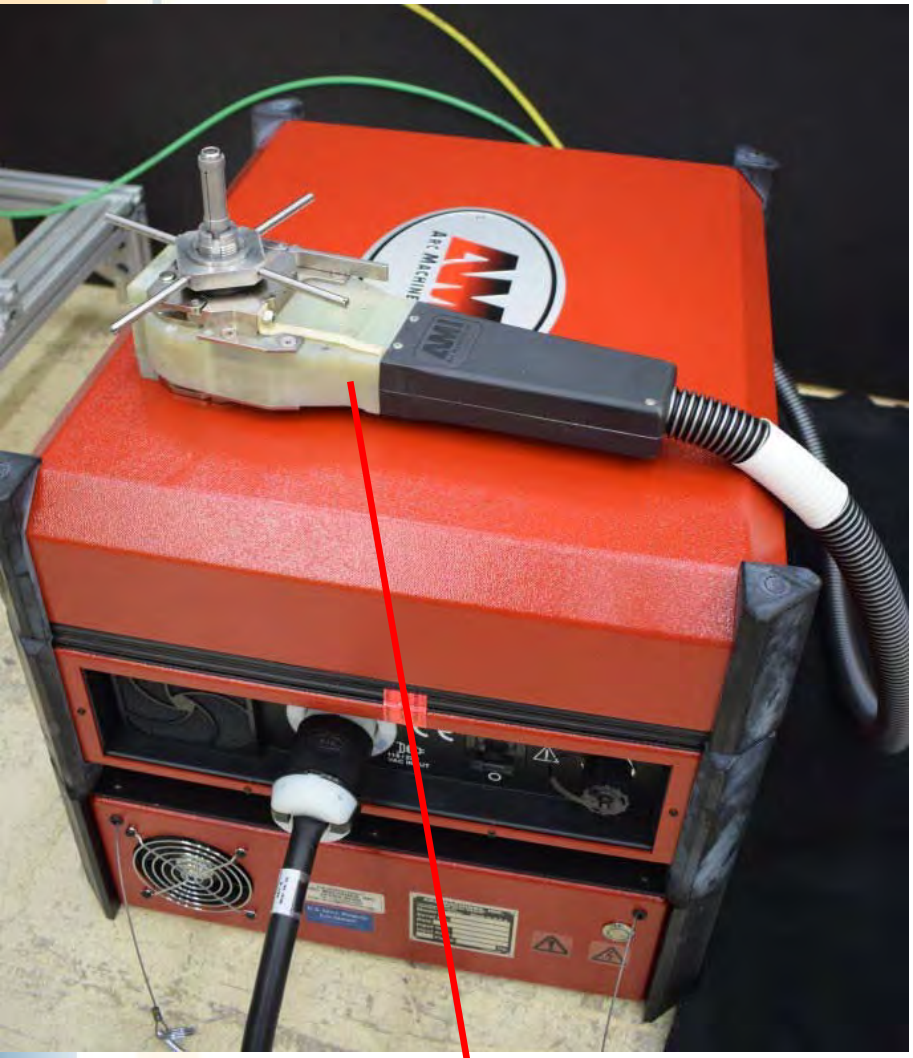
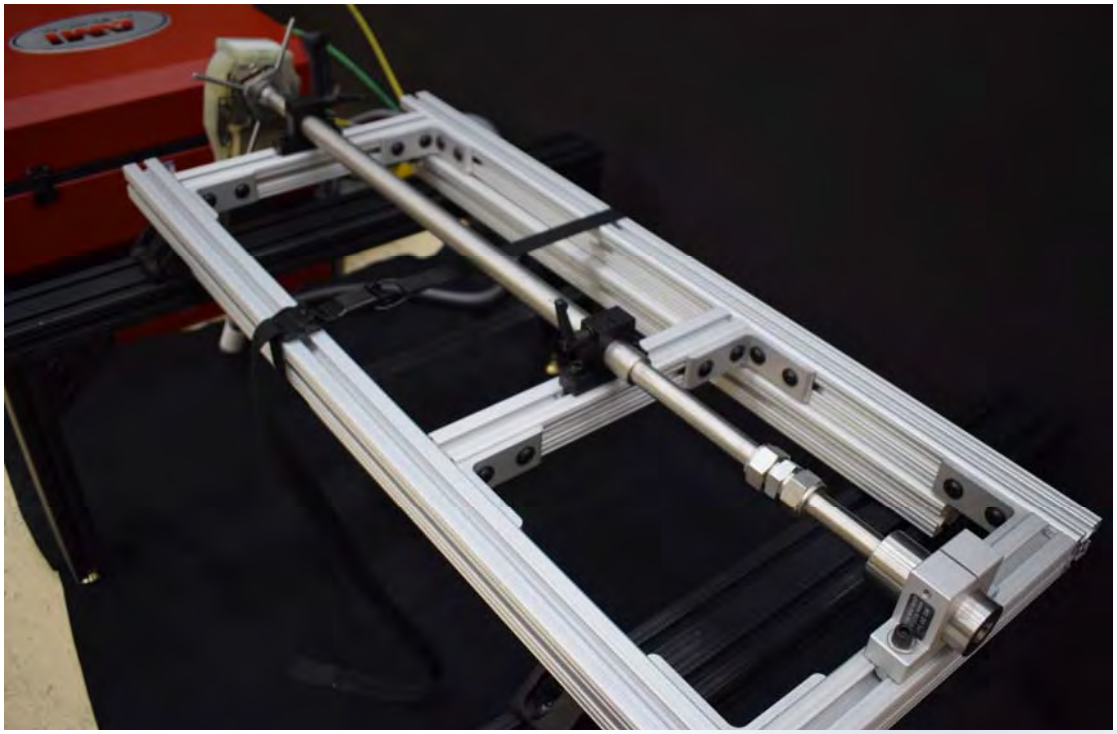
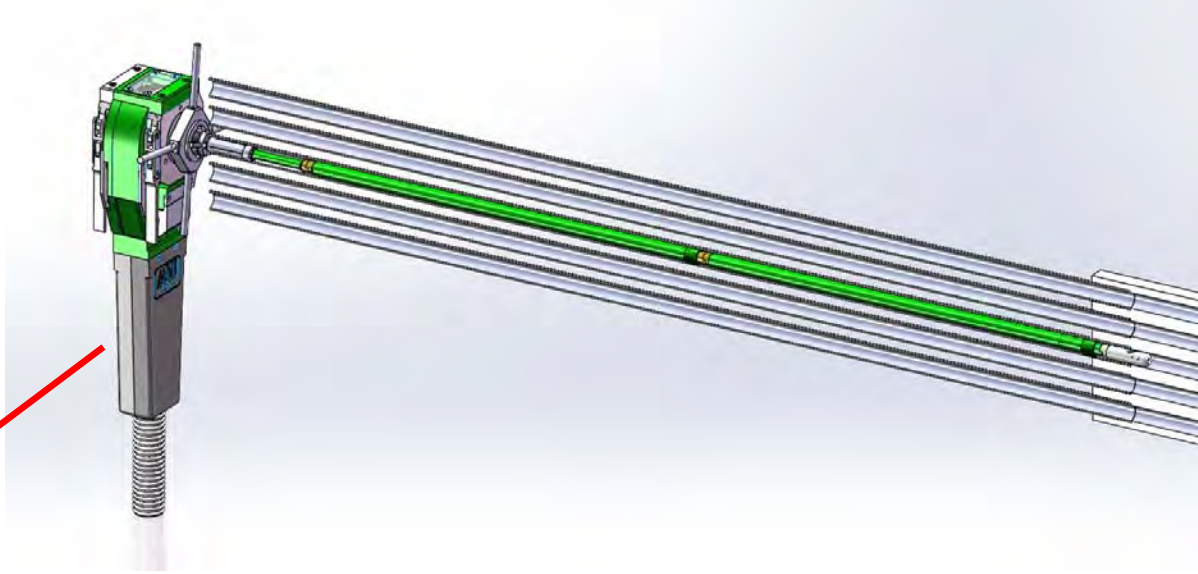
Core37 Subassembly – AMI OTW Torch

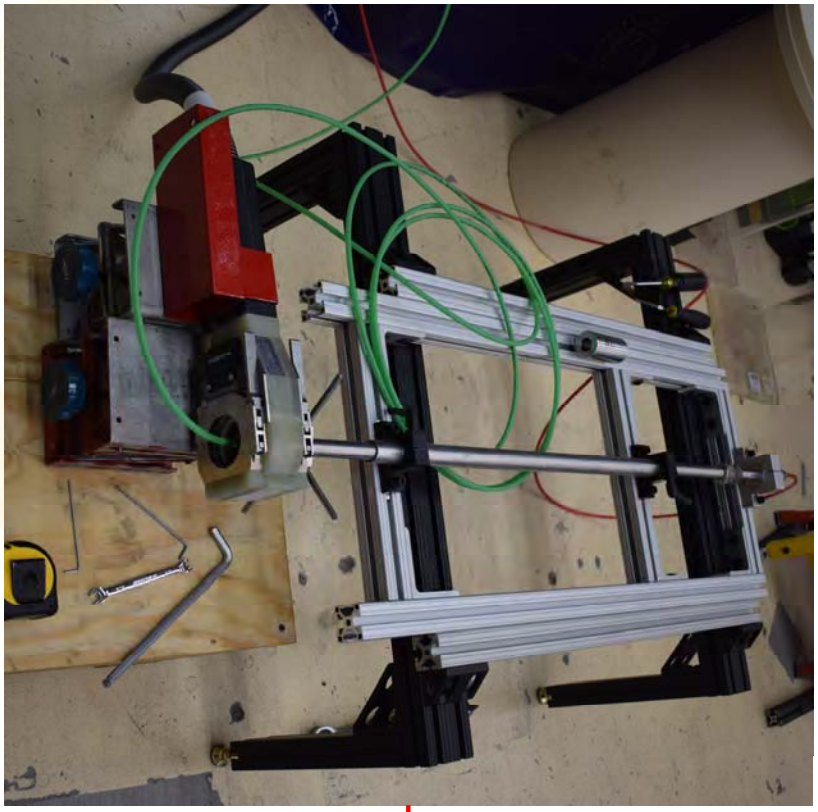




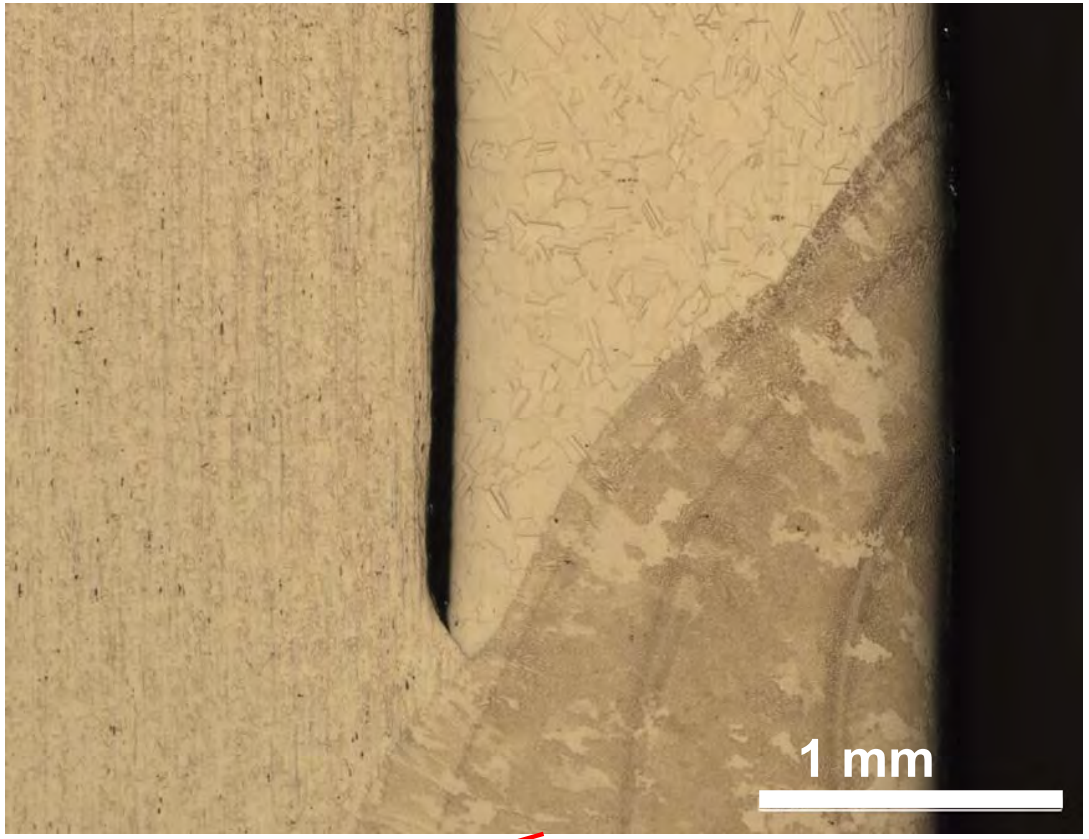


AMI Orbital Tube Weld Torch
Delivered 11/2/2022

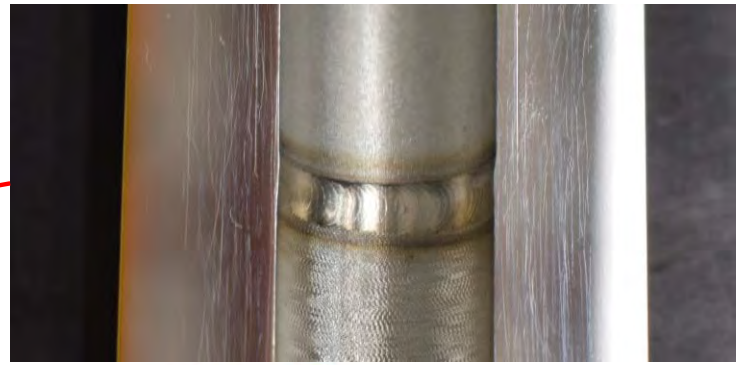
Core37 Subassembly-AMI OTW Heat Pipe Tubes



eXchanger37 tube weld set-up



Internal OTW test weld results



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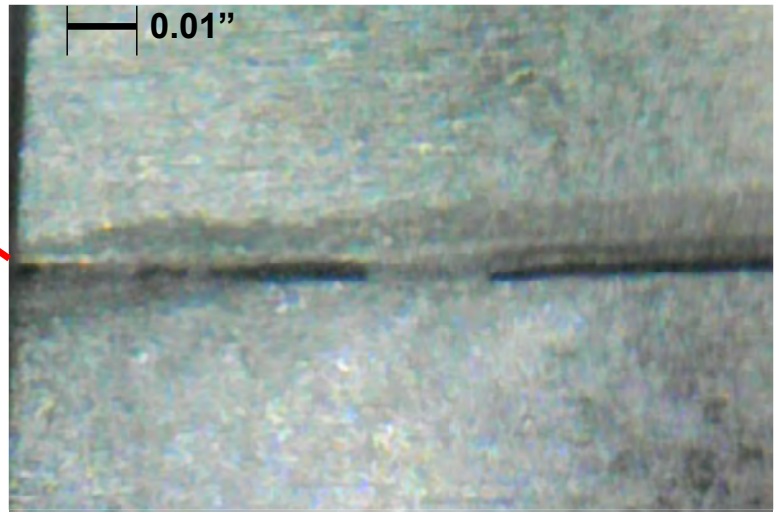
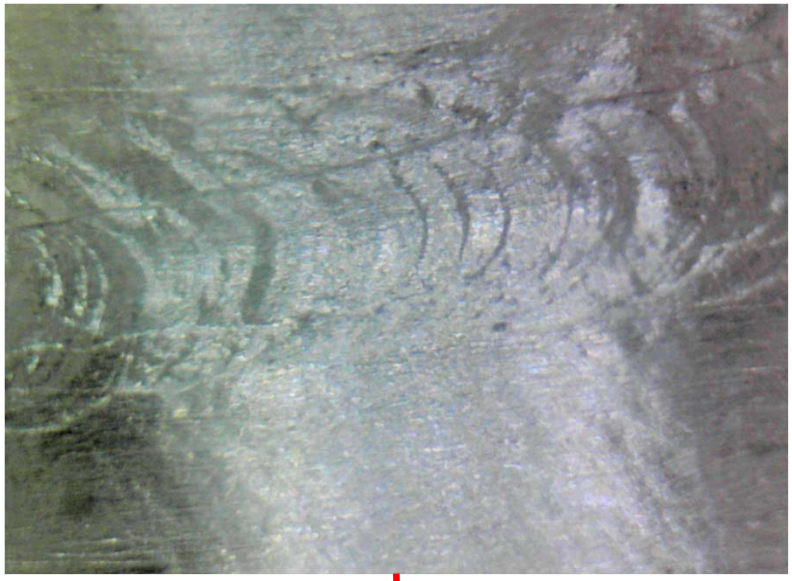
Core37 Subassembly-Braze Repair

0.002” Cracks at Bond Lines





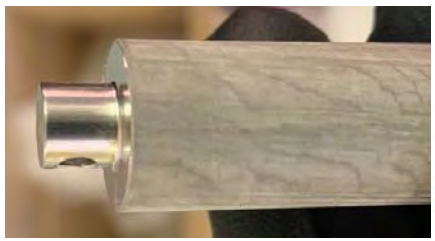
407 Bond Line Welds Completed

Example Repair Weld

MRP Microreactor Program

eWick37 Subassembly (NQA-1 Item Dedication)

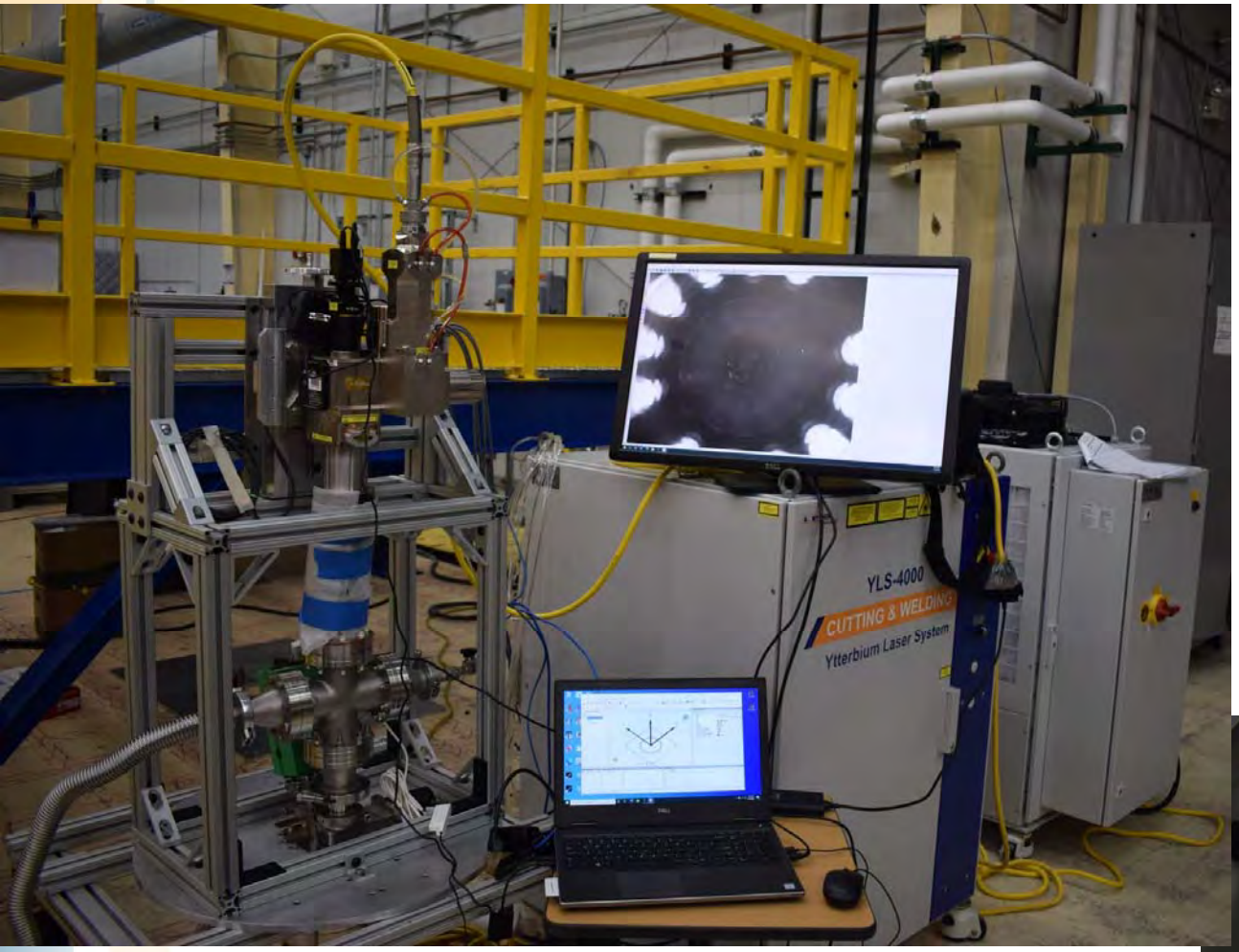
Serial Numb	Pressure At First Bubble (in H2O) - Test One	Pressure At First Bubble (in H2O) - Test Two	Total Number Of Bubbles At Cutoff Pressure - Test One	Total Number Of Bubbles At Cutoff Pressure - Test Two	Rmax(µm) - Test
2	13.0	12.5	103	97	13.9
3	12.0	15.5	180	35	15.1
4	12.0	12.0	125	25	15.1
5	12.5	11.0	198	31	14.5
6	12.0	10.0	175	21	15.1
7	13.0	15.0	293	27	13.9
8	15.0	16.3	24	28	12.0
9	13.0	14.0	41	23	13.9
10	14.0	15.0	62	8	12.9
11	14.0	15.0	101	41	12.9
12	13.0	13.5	55	92	13.9
13	14.0	13.5	37	62	12.9
14	14.0	14.0	174	41	12.9
15	15.0	13.0	34	67	12.0
16	17.5	16.0	10	47	10.3
17	16.5	15.0	17	21	10.9
18	14.5	16.0	40	9	12.5
19	14.0	14.0	44	20	12.9
20	15.0	15.5	30	30	12.0
21	15.5	15.0	47	34	11.7
22	15.5	14.0	55	24	11.7
23	16.0	16.0	33	93	11.3
24	13.5	14.5	22	37	13.4
25	15.5	15.0	15	19	11.7
26	16.5	16.5	22	24	10.9
27	15.5	16.0	19	173	11.7
28	14.5	14.0	27	129	12.5
29	15.0	14.0	53	103	12.0
30	12.0	16.0	23	65	15.1
31	14.5	11.5	34	132	12.5
32	15.0	11.0	57	202	12.0
33	15.0	14.0	91	89	12.0
34	12.0	15.5	21	28	15.1
35	18.0	18.0	1	2	10.0
36	15.0	17.0	22	23	12.0
40	15.0	17.5	5	10	12.0
42	19.0	15.0	4	23	9.5
43	17.0	17.0	2	21	10.6
44	20.5	19.0	2	2	8.8
45	17.0	15.0	22	20	10.6
46	19.5	19.0	2	3	9.3
48	16.0	15.0	4	9	11.3
49	17.5	19.5	1	3	10.3
50	16.0	16.5	36	16	11.3
51	18.0	17.0	1	1	10.0
52	17.5	16.0	2	13	10.3
53	17.5	17.5	7	3	10.3
54	15.0	15.0	47	21	12.0
55	15.5	16.0	40	37	11.7
56	17.5	18.5	3	1	10.3
57	18.0	19.0	1	1	10.0
58	19.0	19.5	1	3	9.5
59	13.0	14.0	19	20	13.9



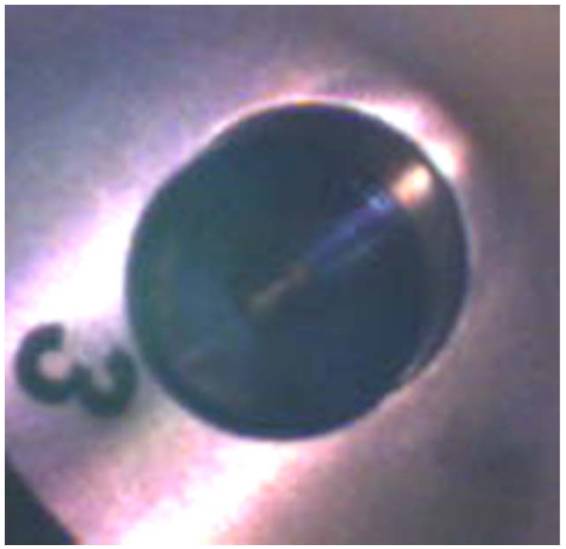
Rp,max ~ 15 microns!!

MRP Microreactor Program

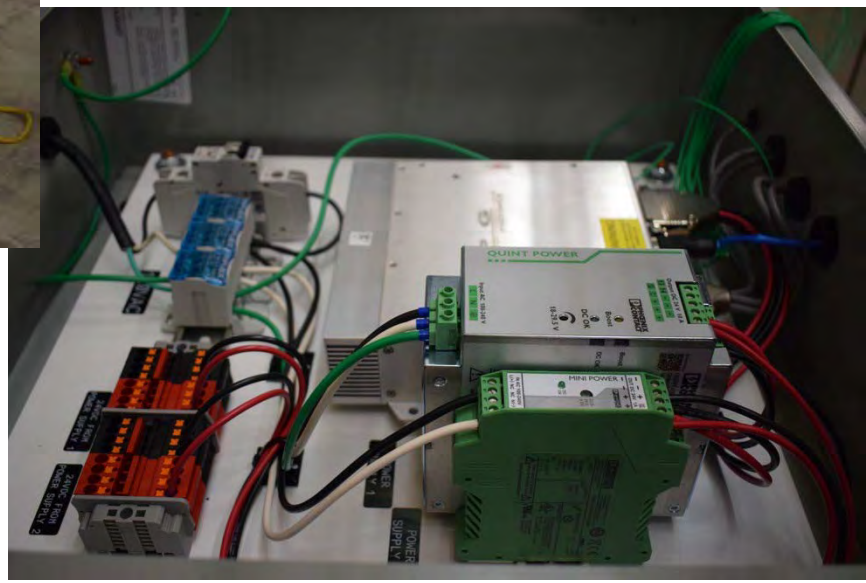
eFill37 Subassembly – Laser Closure System



YLS-4000
Laser Welding
System with
Wobble Head



Laser Weld Viewed
Through Window



Wobble Head
Power Supply

Facility Upgrades – Electrical & Instruments

Box	Circuit	Socket	Plug	Position	Location	Current	Load Description
LP2	CKT.1	1	1	3.5	W042	8	Booster pump(west wall)
LP2	CKT.1	1	2	3.5	W042	2	LC2000 Thompson motor
LP2	CKT.10	4	1	11	N240	12	3PN1010B Variac 5
LP2	CKT.10	4	2	11	N250	0	
LP2	CKT.10	3	1	9	N192	0	
LP2	CKT.10	3	2	9	N192	0	
LP2	CKT.10	2	1	6	N120	0	
LP2	CKT.10	2	2	6	N120	0	
LP2	CKT.10	1	1	3	N048	0	
LP2	CKT.10	1	2	3	N048	0	
LP2	CKT.12	4	1	10	N216	12	3PN1010B Variac 6
LP2	CKT.12	3	1	8	N168	1	Cameras
LP2	CKT.12	3	2	8	N168	1	Data acquisition
LP2	CKT.12	4	2	10	N216	0	
LP2	CKT.12	2	1	5	N096	0	
LP2	CKT.12	2	2	5	N096	0	
LP2	CKT.12	1	1	2	N024	0	
LP2	CKT.12	1	2	2	N024	0	
LP2	CKT.13	1	2	1	S000	20	Vacuum DPRP
LP2	CKT.13	2	1	4	S072	0	
LP2	CKT.13	2	2	4	S072	0	
LP2	CKT.13	1	1	1	S000	0	
LP2	CKT.15	1	1	3	S048	20	Vacuum Upper
LP2	CKT.15	1	2	3	S048	0	
LP2	CKT.17	2	1	5	S096	12	3PN1010B Variac 8
LP2	CKT.17	2	2	5	S096	0	
LP2	CKT.17	1	1	2	S024	0	
LP2	CKT.17	1	2	2	S024	0	
LP2	CKT.8	3	1	7	N144	12	3PN1010B Variac 7
LP2	CKT.8	3	2	7	N144	0	
LP2	CKT.8	2	1	4	N072	0	
LP2	CKT.8	2	2	4	N072	0	
LP2	CKT.8	1	1	1	N000	0	
LP2	CKT.8	1	2	1	N000	0	
pp3	pp3-14	1	1	2	W012	10	(IN USE)
pp3	pp3-14	1	2	2	W012	10	(IN USE)

Instrumentation, Heater, and Over Temperature Control Units
(to be used at LANL and at INL MAGNET)

Facility Upgrades-Mezzanine

MRP Microreactor Program

Path Forward

Worker safety comes first!!
Student labor is slower yet inexpensive conversely,
Staff labor is faster yet expensive

Leak check Core37

Connect Core37 to eXchanger37

Lift eBlock37 to mezzanine

OTW condenser array to Core37

TIG weld evaporator end plugs to Core37

Insert eWick37 array into eBlock37

Lift eBlock37 to mezzanine

Connect eFill37 to eBlock37 assembly

Perform eFill37 sodium transfer operation

Insert plugs into condenser tube array

Laser weld plugs to condenser tube array

Deliver eBlock37 to INL in DOT Crate

Most of eBlock37 work has been done with slower inexpensive student labor

To meet schedule in October tried faster & more expensive staff labor

Notable eBlock37 Accomplishments to Date

The eBlock37 program is not just a heat pipe reactor electrical demonstration unit for use in the INL MAGNET facility

The eBlock37 program also serves as a *basis for future mass production of reliable and affordable heat pipe reactors*

ASME B&PVC Analysis: The initial eBlock37 was informed by analysis conducted by ANL to address potential heat pipe reactor structural design issues

eWick37: a commercial NQA-1 qualified high temperature heat pipe wick manufacturing capability (a US national resource)

eFill61 fill: a high quality, rapid, affordable, and scalable high temperature heat pipe reactor alkali metal fill capability

eFill61 laser: a high quality, rapid, affordable, and scalable high temperature heat pipe reactor heat pipe closure capability

eBlock37: a fast spectrum reactor monolithic core block consisting of an array of high L/D close packed fuel and heat pipe cavities

OTW technology: an innovative internal welding technique that allows rapid integration of high temperature reactor heat pipes

Milestone status

- **M2 article**
  - Complete assembly of the 37 heat pipe microreactor test article
  - ***Assumed to be on schedule*** (fill of heat pipes should be completed and plugs added by April 12, 2023)
- **M3 shipment**
  - Ship 37 heat pipe test article to INL
  - ***May be delayed*** (currently scheduled for May 5, 2023)
- **M3 article**
  - Complete fabrication of graphite-blocked heat pipe test article
  - ***May be delayed*** but is in procurement process (currently scheduled for March 31, 2023)
- **M4 report: Transfer knowledge on advanced heat pipe manufacturing/testing and test article fabrication to nuclear industry**
  - Complete horizontal and vertical heat pipe testing (May 2023)
  - Transfer knowledge from advanced heat pipe testing to industry
  - ***On track to meet due date*** (September 22, 2023)

MRP Microreactor Program

End of Presentation