

# Final Design of the INTT Ladder and Production Readiness Review (PRR)

## Stave Quality Verification Testing at BNL

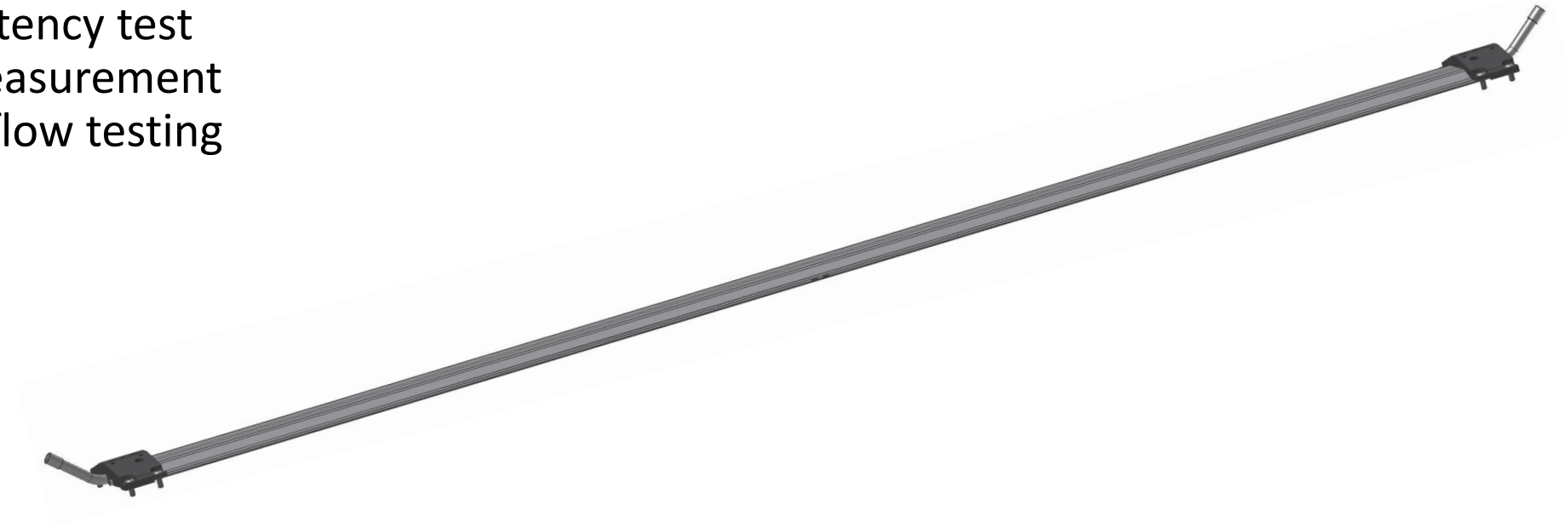


Robert Pisani, BNL

March 2<sup>nd</sup>, 2021

Each Stave goes through a multi-step testing and inspection process to ensure the staves are of high quality.

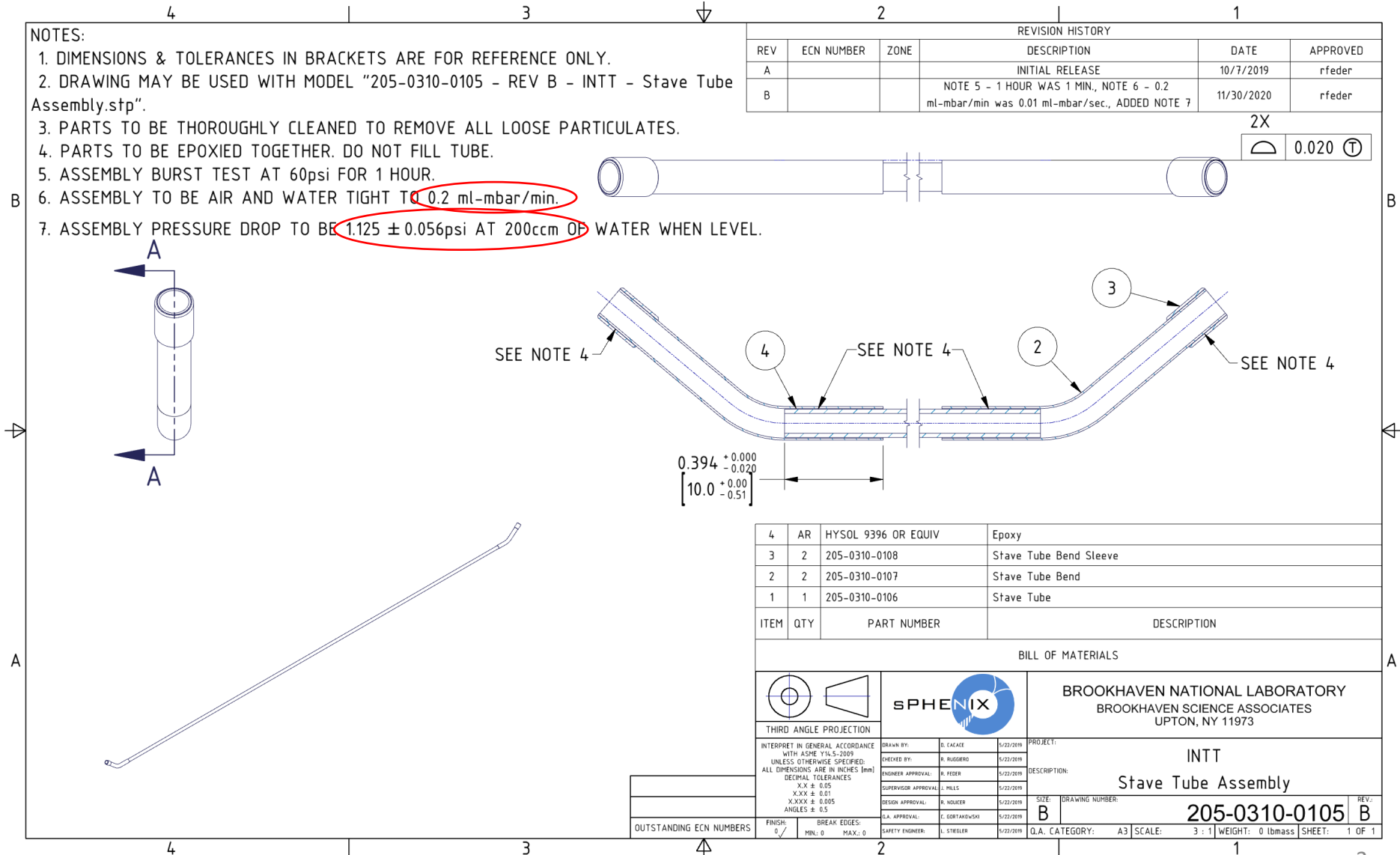
1. Inspection
2. Leak test
  - a) Pressurized test
  - b) Submersion test
3. Flow consistency test
4. Flatness measurement
5. Long Term flow testing



# Design from Dan's Talk



Specification stated on Drawings

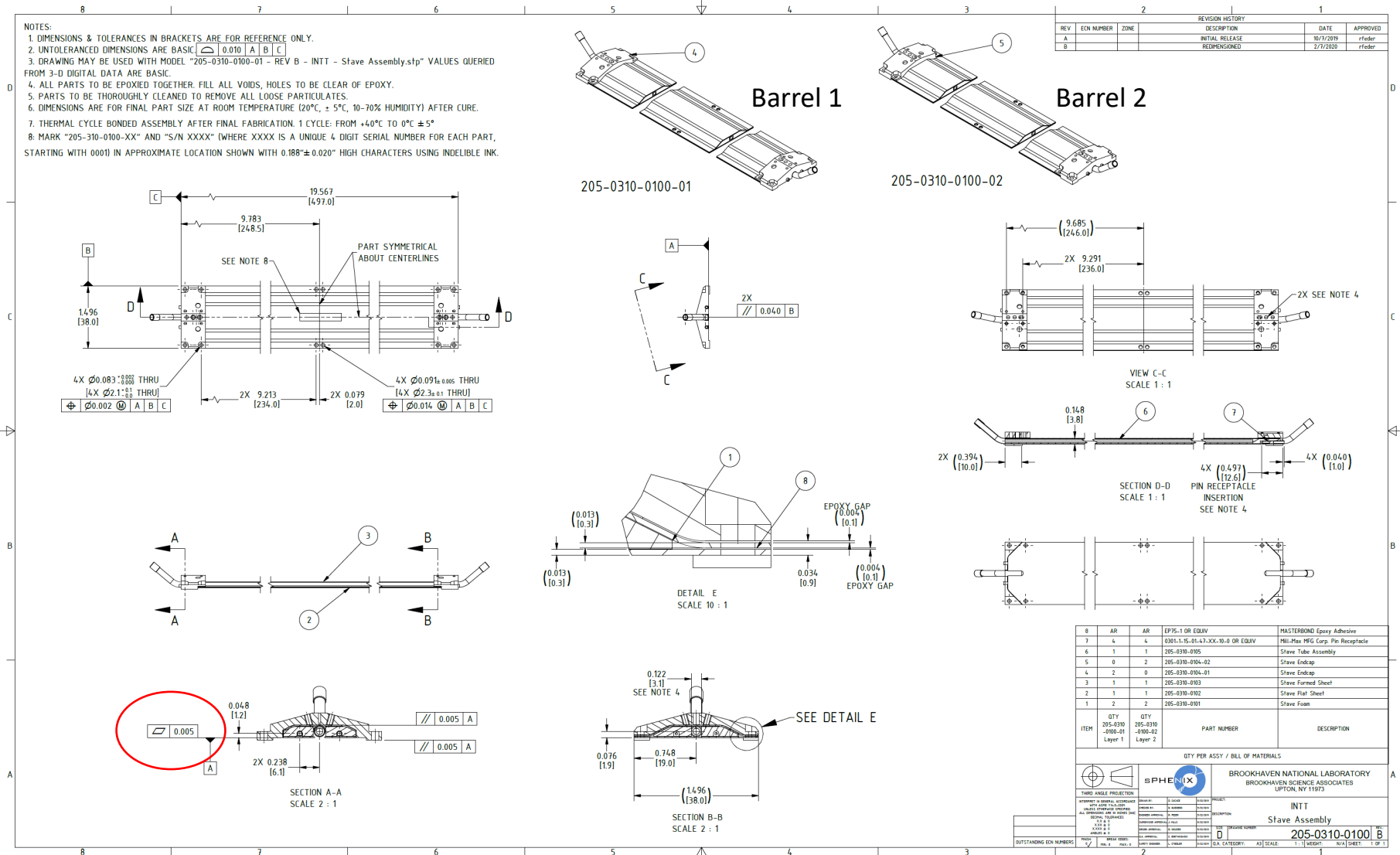


# Design from Dan's Talk



## Specification and tolerances stated on Drawings

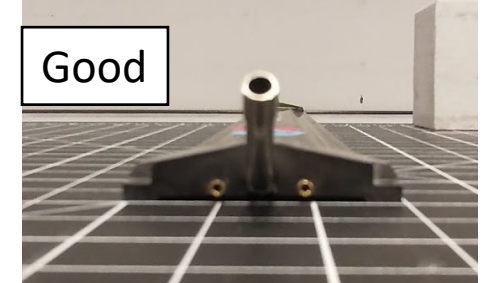
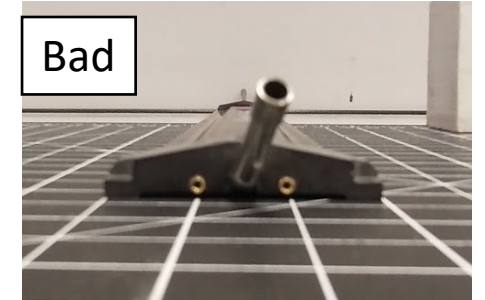
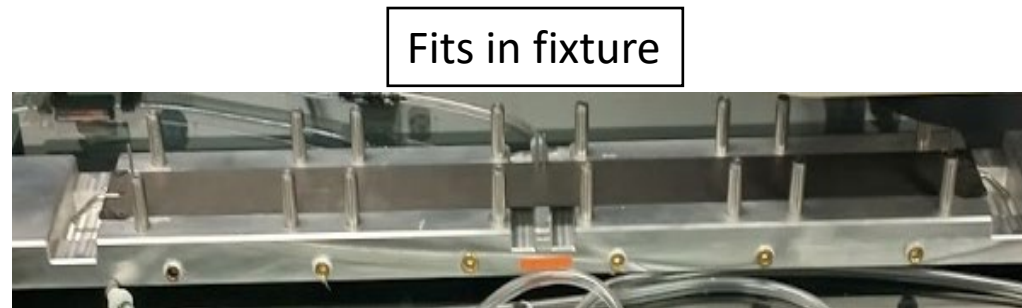
- NOTES:  
 1. DIMENSIONS & TOLERANCES IN BRACKETS ARE FOR REFERENCE ONLY.  
 2. UNTOLERANCED DIMENSIONS ARE BASIC (A B C).  
 3. DRAWING MAY BE USED WITH MODEL "205-0310-0100-01 - REV B - INTT - Slave Assembly.sfp" VALUES QUERIED FROM 3-D DIGITAL DATA ARE BASIC.  
 4. ALL PARTS TO BE EPOXIED TOGETHER. FILL ALL VOIDS, HOLES TO BE CLEAR OF EPOXY.  
 5. PARTS TO BE THOROUGHLY CLEANED TO REMOVE ALL LOOSE PARTICULATES.  
 6. DIMENSIONS ARE FOR FINAL PART SIZE AT ROOM TEMPERATURE (20°C, ± 5°C, 10-70% HUMIDITY) AFTER CURE.  
 7. THERMAL CYCLE BONDED ASSEMBLY AFTER FINAL FABRICATION. 1 CYCLE: FROM +40°C TO 0°C ± 5°  
 8. MARK "205-310-0100-XX" AND "S/N XXXX" (WHERE XXXX IS A UNIQUE 4 DIGIT SERIAL NUMBER FOR EACH PART, STARTING WITH 0001 IN APPROXIMATE LOCATION SHOWN WITH 0.188" ± 0.020" HIGH CHARACTERS USING INDELBLE INK.



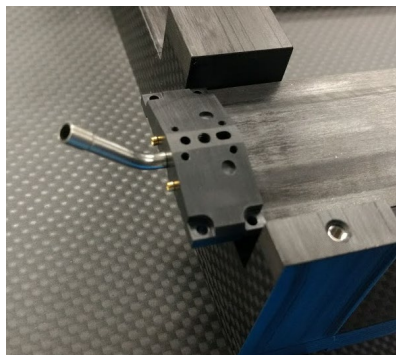


# Inspection

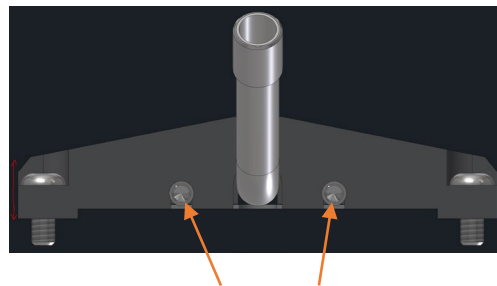
- Inspect tube for symmetry
- Inspect Endcaps for Barrel 1 and 2 ends.
- Test peek caps securely attached
- Inspect gaps and epoxy potting
- Check Conductivity



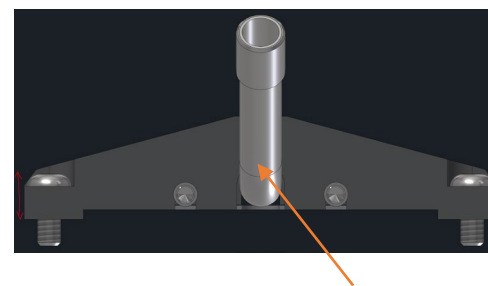
End Cap



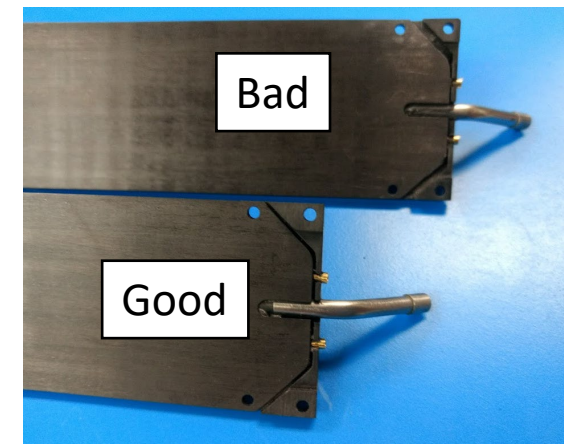
Barrel 2



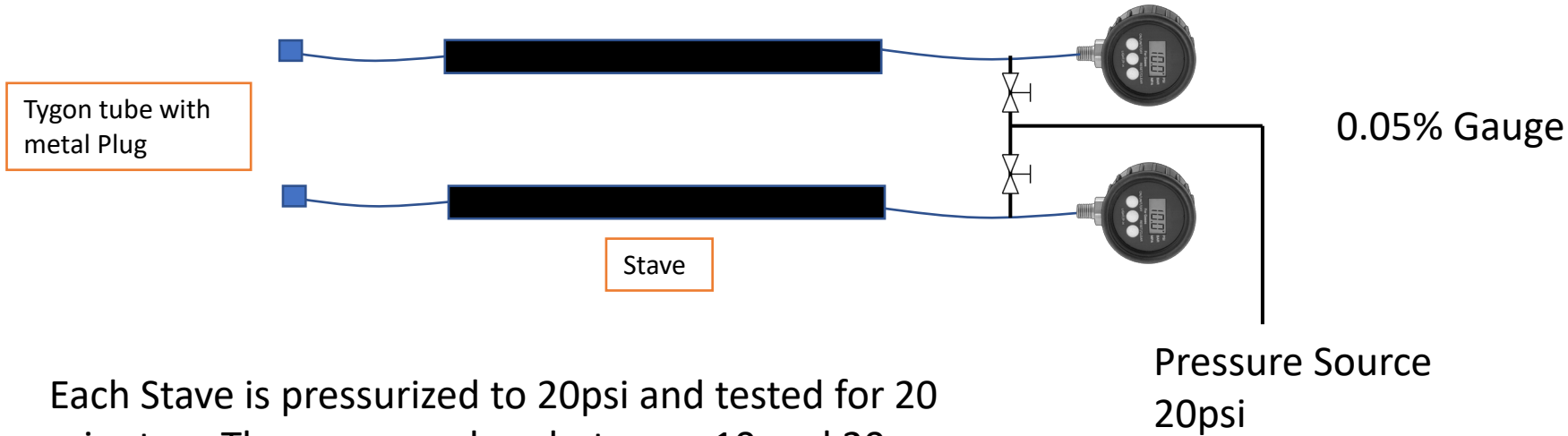
Barrel 1



Check Electrical Conductivity of Pins and Tube



# Pressure test of Stave



Specification given for production is **0.2 ml-mbar/min**  
**Volume of stave 1.87ml**

Setup has a max leak rate of 0.050psi for 10 min.

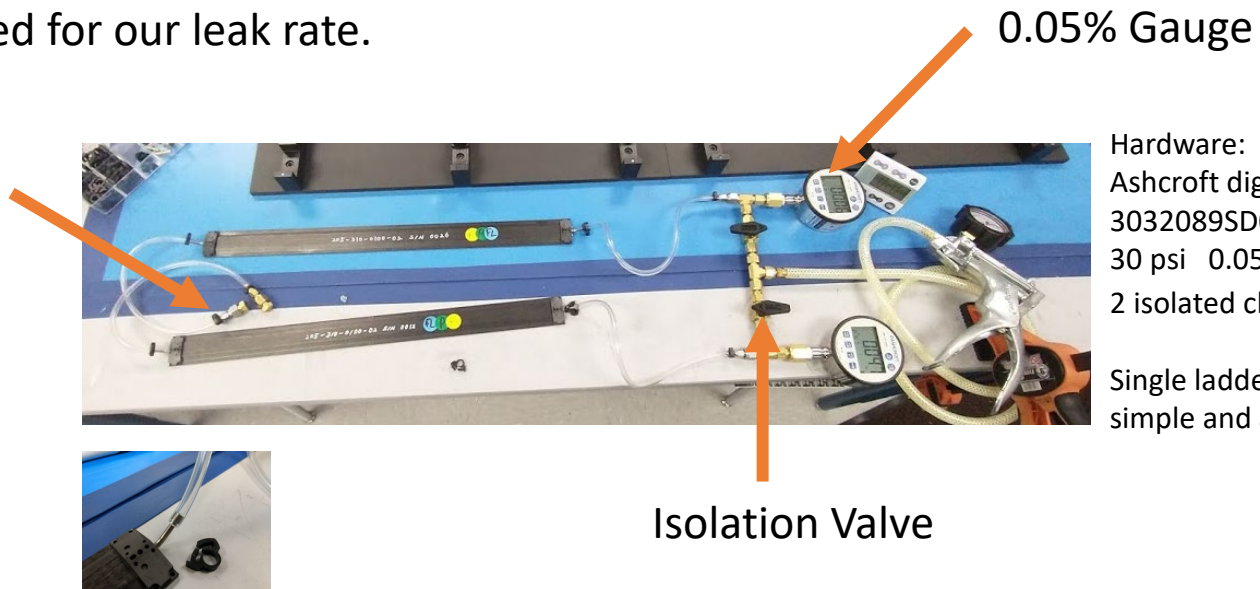
**With our set up, The leak of a good stave should be less than 0.090 psi drop in 10 minutes.**

Each Stave is pressurized to 20psi and tested for 20 minutes. The pressure drop between 10 and 20 minutes is recorded and used for our leak rate.

Tygon tube with metal Plug



Tygon connected directly to SS tube and clamped (0.25" OD 1/8" ID)

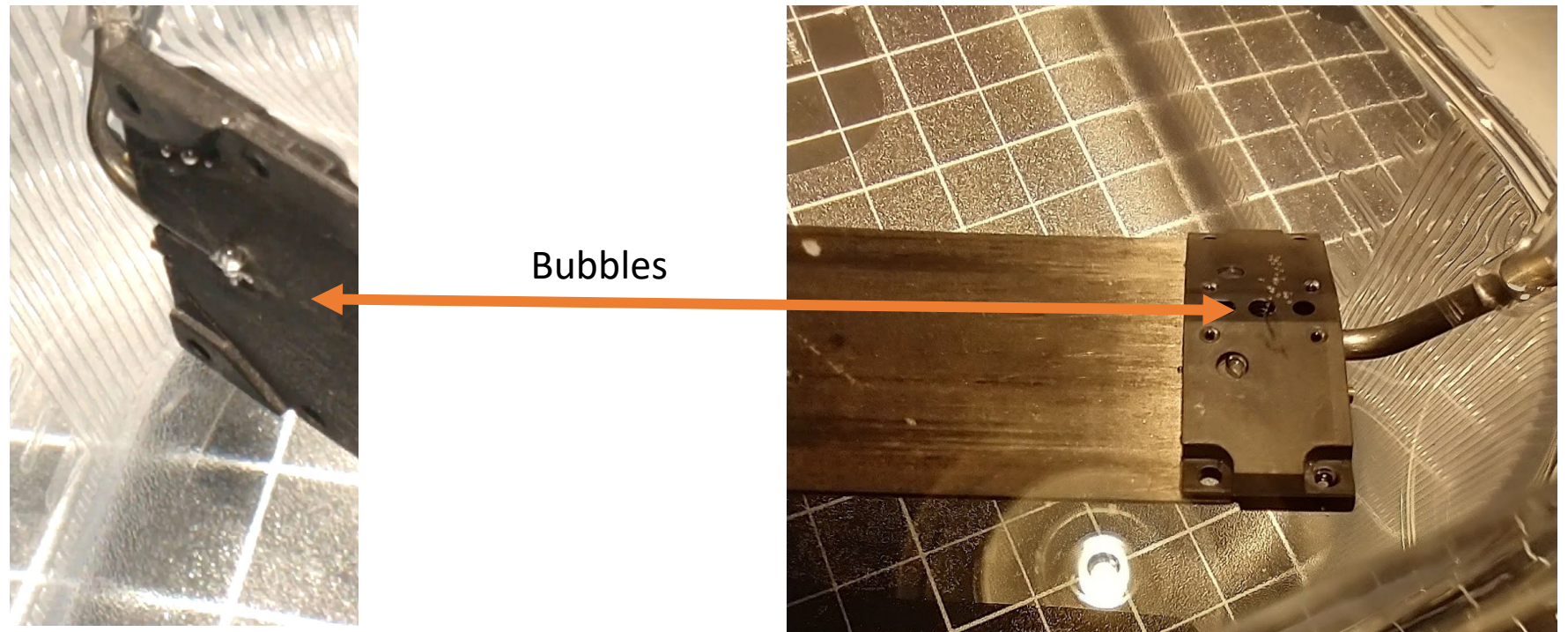


Hardware:  
Ashcroft digital High Precision Gauge 3032089SD02L30  
30 psi 0.05%  
2 isolated channels that are used independently.

Single ladder is tested at a time to keep system simple and accurate.

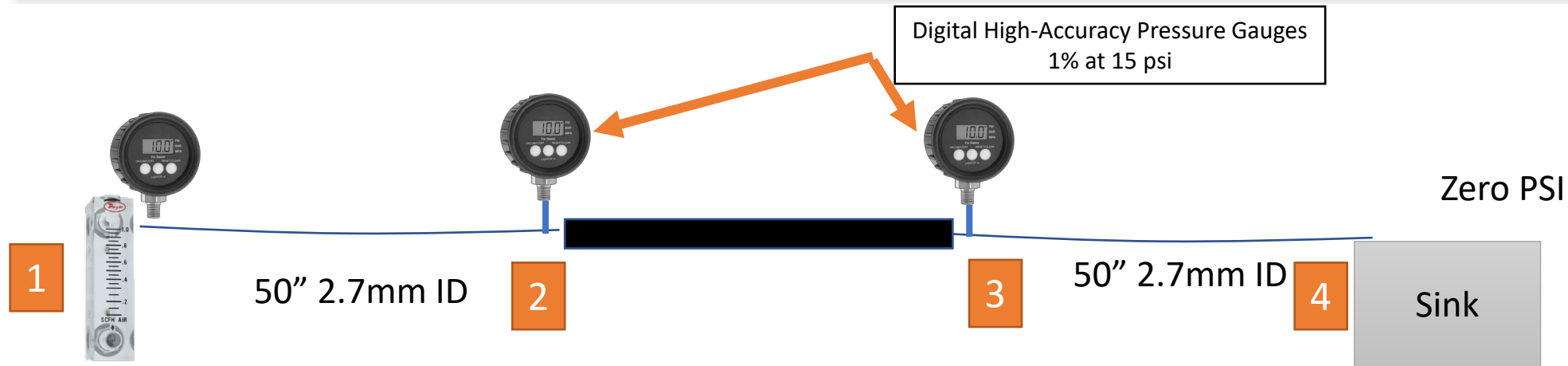
# Submersion test (Looking for Bubbles)

- In addition to the pressurized leak measurement, we have also been submerging staves in water to look for the location of leaks. We will continue this in production.
- Stave is pressurized to ~20 psi with air.
- Example of a leaking Staves below:





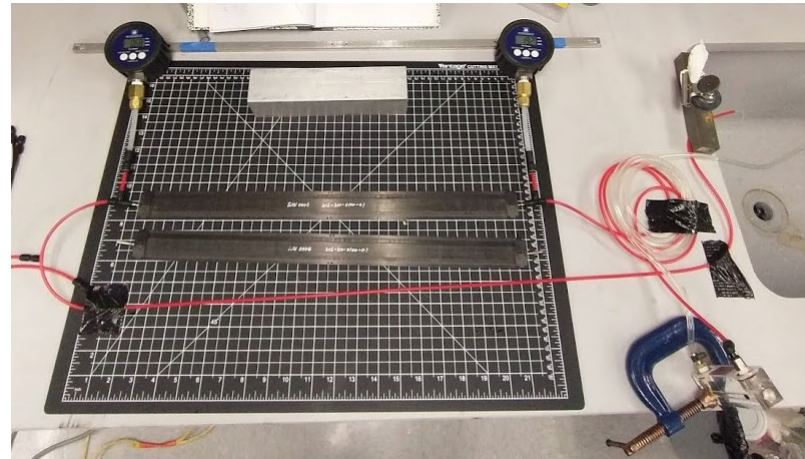
# Flow Test



200 ccm flow  
meter for water

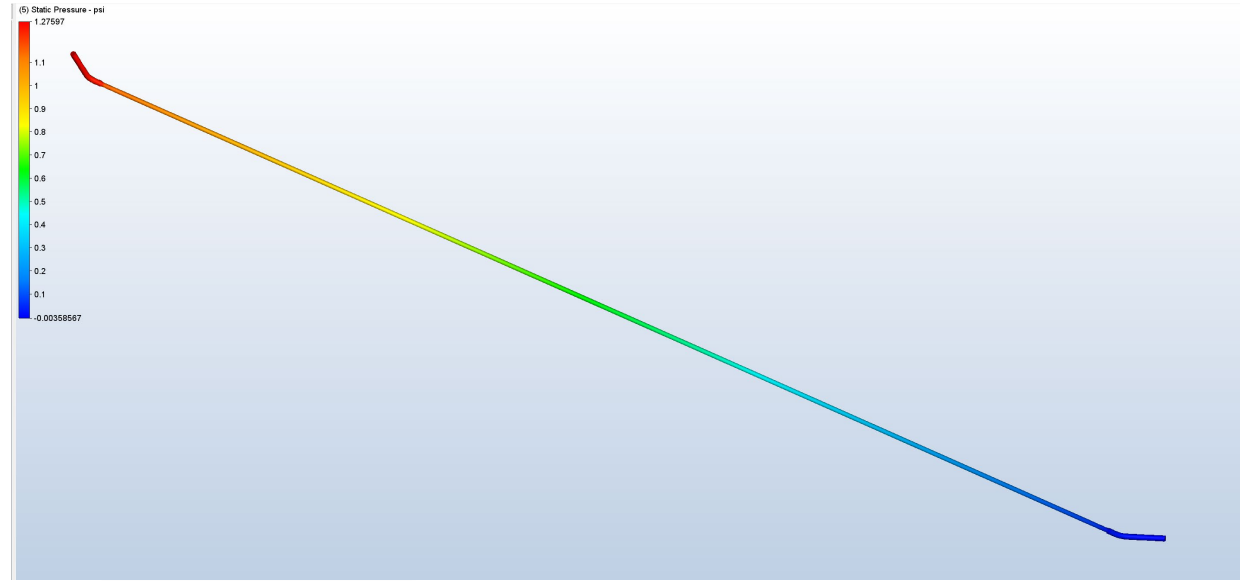
Specification:  
Pressure drop of stave at  
200ccm should be around  
 $1.125\text{psi} \pm 0.056\text{psi}$

Gauges, tube and stave must  
all be at the same level



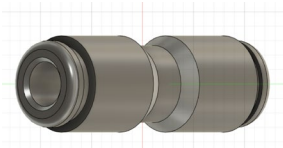
To ensure a balanced flow and stable temperature, each stave is being tested for flow and pressure drop at 200ccm with water. This test is also performed during tube production to ensure a constant pressure drop across staves.

# Pressures and flow analysis



Flow and pressure drop analysis was done with Autodesk CFD. From the analysis, 1.3psi is needed to flow of 120ccm through the ladder. Additional 1.8psi is needed for the 2.8m I.D. Poly Tubing.

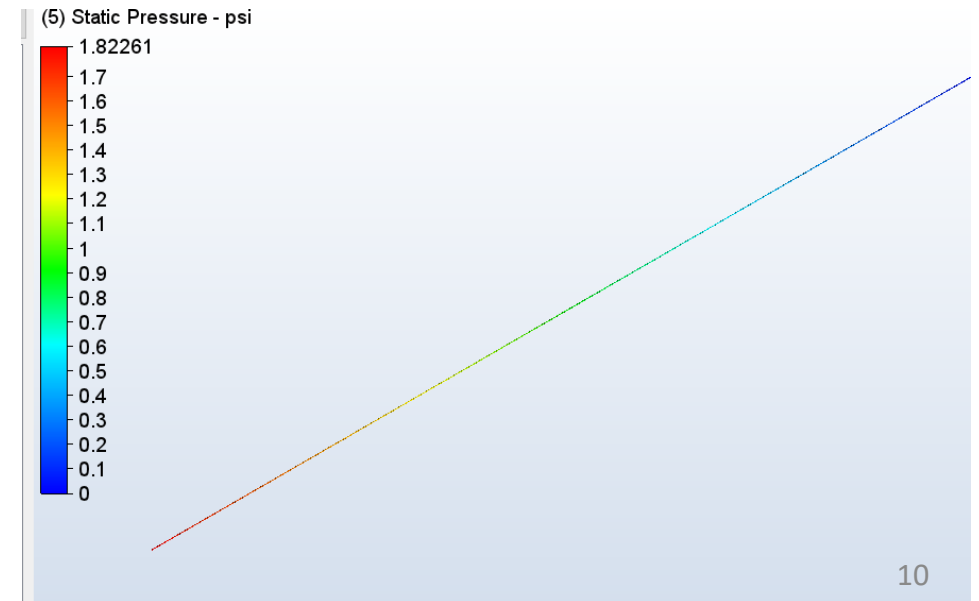
These calculations were confirmed with out from test setup.



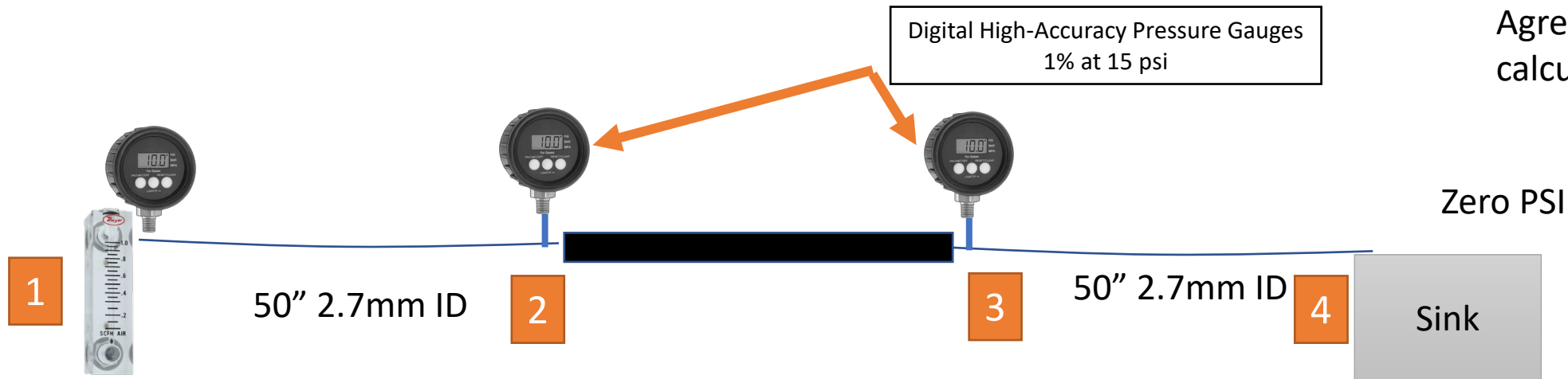
Coupling with 2.8mm bore



4mm OD  
2.8m ID Polyethylene  
Tubing



# Example Of Measurement



Agrees with analysis calculations

Location	Stave 1	Stave 2	Stave 3	Stave 4	Stave 5	Stave 6
1	2.5	2.95	2.9	2.75	2.85	2.8
2	1.75	2.16	2.15	1.97	1.95	2
3	1.01	1.11	1.08	1.04	1.05	1.02
4	0	0	0	0	0	0

4 points were used to confirm Calculations.

For stave testing, point 2 and 3 are used to measure pressure drop across stave at 200ccm.

Pressure in PSI Flow set to 200 CCM water  
 Tube ID 2.7  
 Stave ID 2.0mm

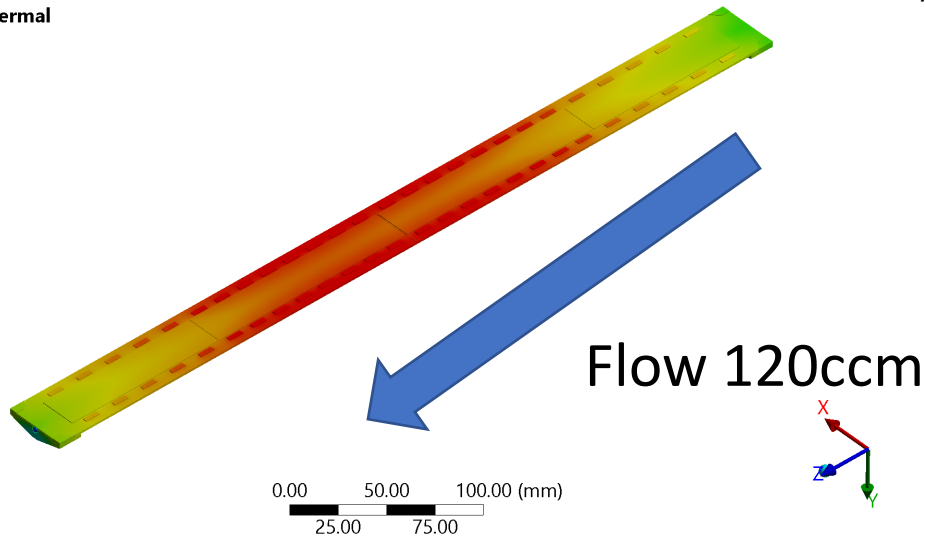
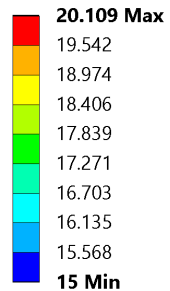
# Thermal Calculation from Dan- Temperatures



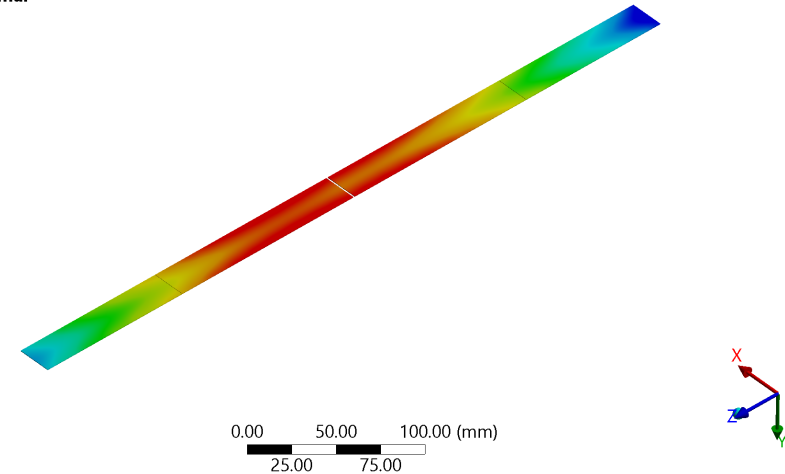
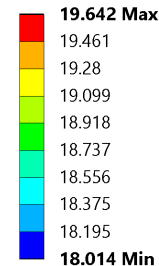
Stave  $\Delta T$  – 5.1 °C (9.2 °F)

Sensors  $\Delta T$  – 1.6 °C (2.9 °F)

D: Steady-State Thermal  
Temperature  
Type: Temperature  
Unit: °C  
Time: 1  
6/22/2020 10:23 AM



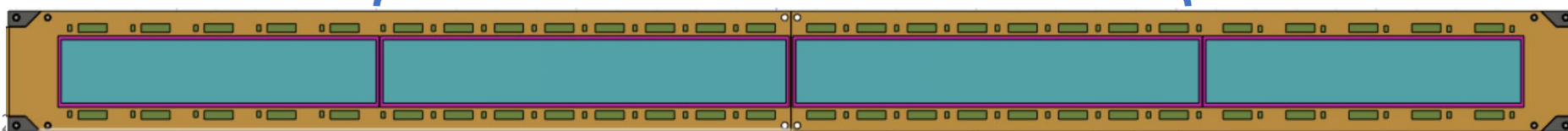
D: Steady-State Thermal  
Temperature 2  
Type: Temperature  
Unit: °C  
Time: 1  
6/22/2020 10:24 AM



52 Chips + HDI components → 2.6 Watts per ladder

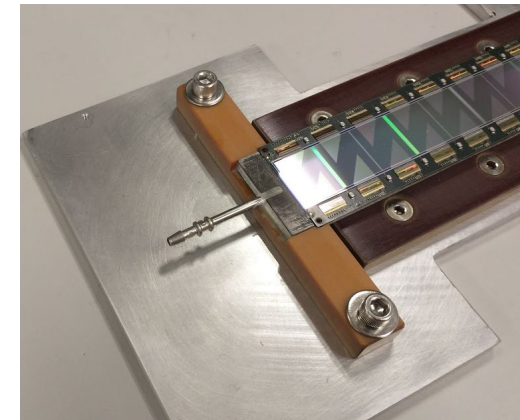
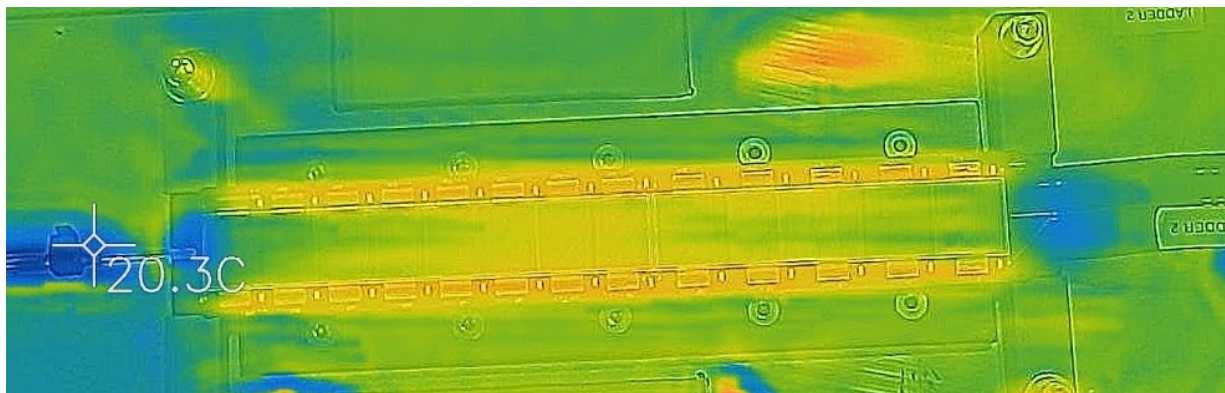
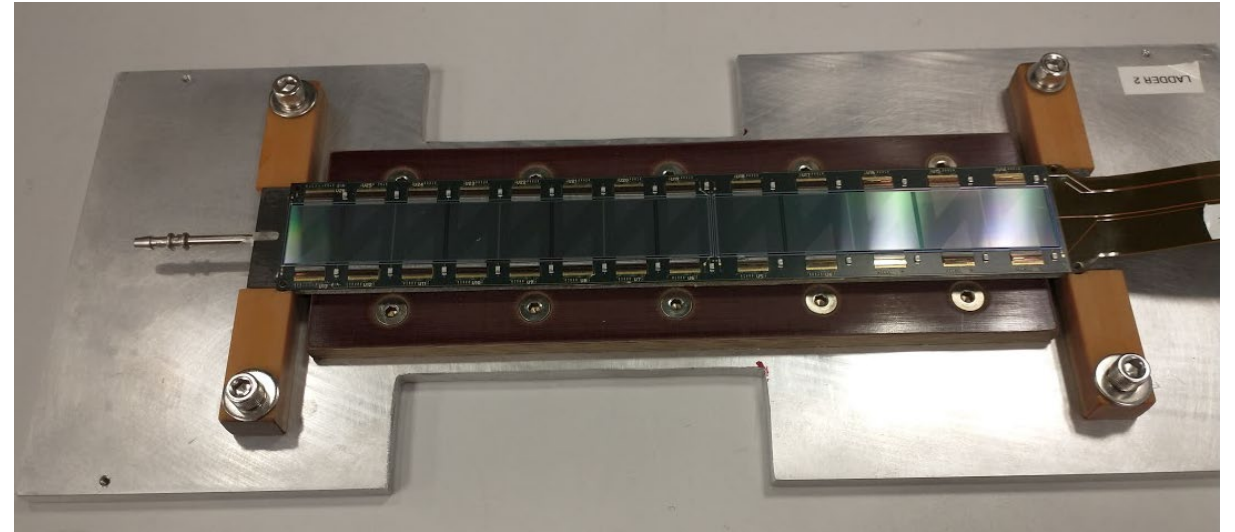
Higher Chip Density

Each FVTX chip → ~0.05W

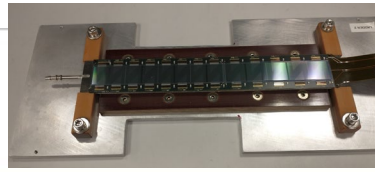


# 2019 Prototype Half Ladder

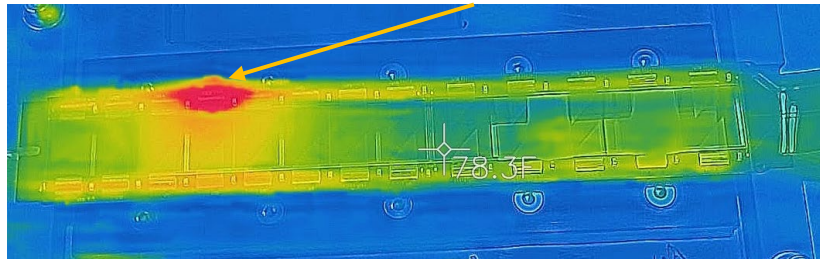
- 4 half ladders (2<sup>nd</sup> prototype) with cooling tube tested at FERMI Lab in 2019. Temperature was read out.
- Confirmed ANSYS calculations withing 10%
- Ladder temps were within 4C of input coolant temperature.
- Confirmed with thermal camera (next slide)



# Half Ladder

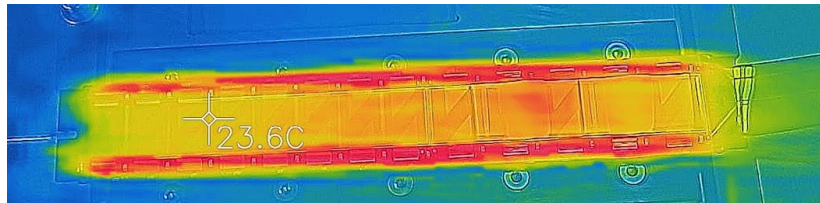


Start, not cooling, Bad Chip



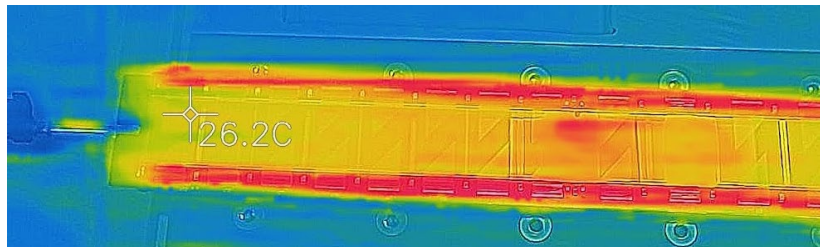
1

22C



2

23.6C



3

26.2C



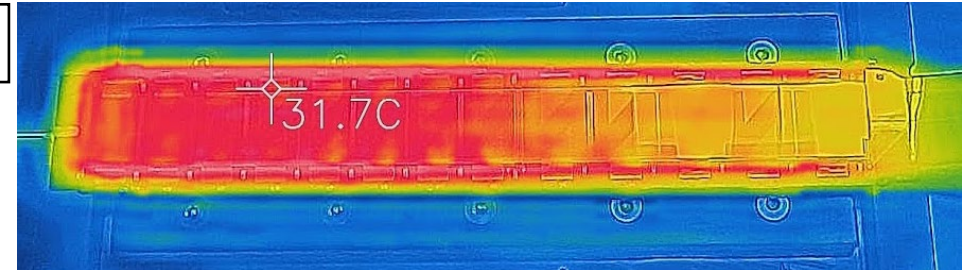
4

33.5C

March 2nd, 2021

Cooling ON, 120ccm 20C input

5



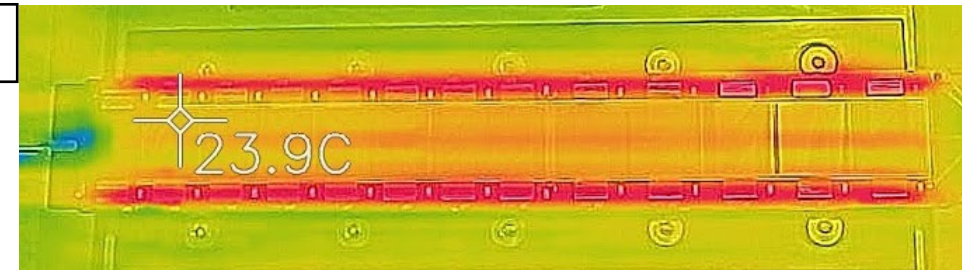
31.7C

6



25.4C

7



23.9C



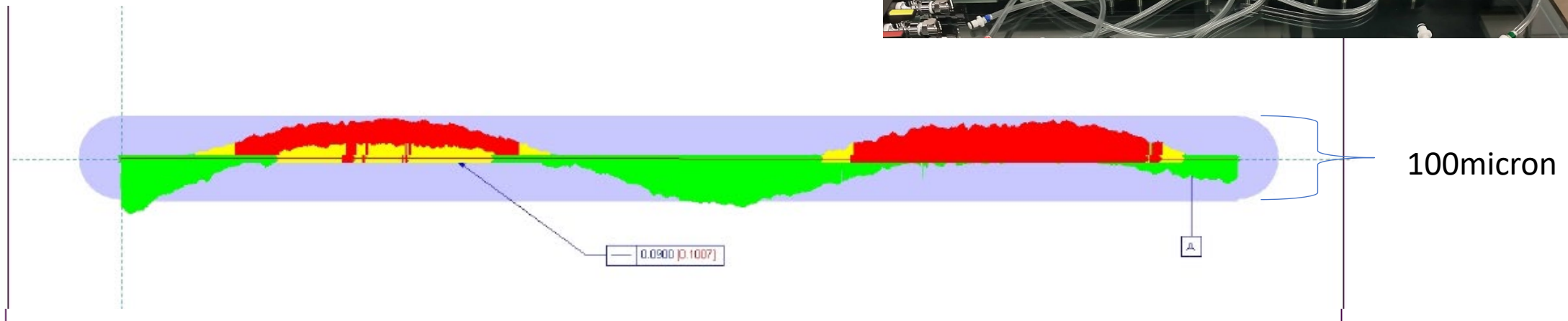
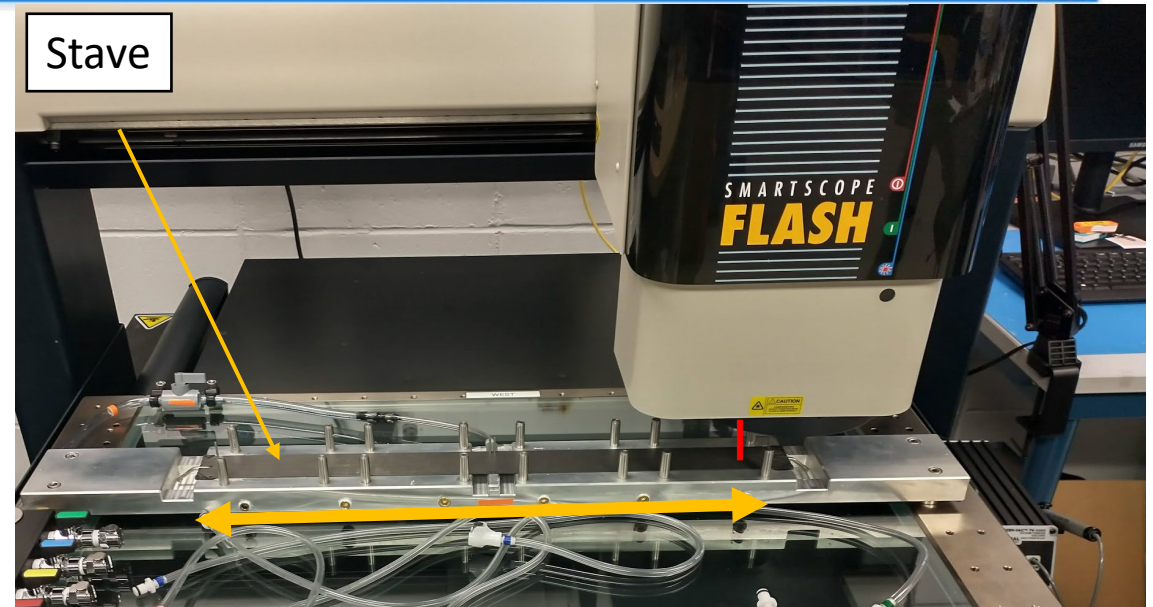
20.3C

From Analysis  
Stave  $\Delta T$  – 5.1 °C

Thermal images agree  
well with Model

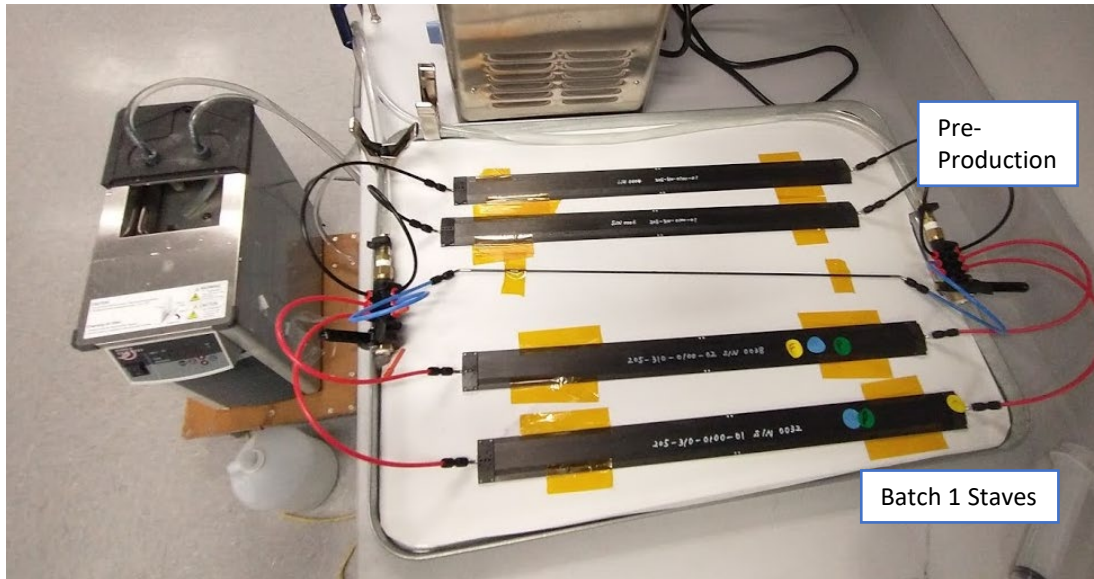
# Flatness measurement

- At BNL, we use a no contact **OGP SmartScope Multisensor Measurement Systems** to measure stave flatness. Fully Automated
- OGP takes measurements at several points across the whole stave.
- Measurement taken relative to plan made by mounting holes. Report gives us average deviation from the points made by the plan.
- Sample of a report below.



Dim	Dimension Label	Nominal	USL	LSL	Actual	Deviation	Status
1	Flatness	0.0000	0.0900		0.1007	0.1007	+ 0.0107

# Long Term Flow Testing



We are also conducting long term flow testing on the staves. We have placed 2 pre-production and 2 Batch 1 staves under circulation (cooling fluid is water plus a corrosion inhibitor). Recently we added 8 batch one staves to the loop. We will retest flow and pressure after 1-2 weeks.

The original pre-productions and Batch One staves will remain on the loop as long as possible. We will retest every few weeks to look for changes.





# Batch 1 (Pre-Production) Stave Testing Documentation



## Barrel Two Staves

- All Batch 1 (pre-production) staves being retested after shipping to BNL
- Flow rate, flatness and leak rated are tested for every stave.
- All testing is logged into an online database
- After testing, staves are given a Class number. Currently, only class 1 staves will be used.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	
	<b>Barrel 2</b>		<b>Barrel 2</b>	<b>Excellent</b>	<b>Class 1</b>	$X < 0.15$			<b>Barrel 2</b>		$X < 0.09$ psi Good	Range Good		
	Lot #-01 Layer 1			<b>Fair</b>	<b>Class 3</b>	$0.150 < X < 0.200$						$0.75 < X < 1.25$		
	Lot #-02 Layer 2			<b>Poor</b>	<b>Class 5</b>	$X > 0.201$		No Vacuum			$\geq 0.10$ Poor			
	Lot Number	Serial Number	Stave Type	Flatness	Operator	Date	Flatness no Vacuum mm	Vendor Flatness	Flow/Leak	Operator	Date	10 min leak in PSI start 20psi	Delta P of stave at 200 ccm (psi) PSI	Vendor Flow # PSI
Count				Name					Name				PSI	PSI
1	205-310-0100-02	0011	Batch 1	5	SA	12/16/2020	0.1037	0.0220	SA/RP	12/11/20	0.127	0.975	0.856	
2	205-310-0100-02	0012	Batch 1	1	SA	1/27/2021	0.0799	0.1140	SA	1/15/21	0.055	0.97	0.856	
3	205-310-0100-02	0014	Batch 1	1	SA	1/26/2021	0.1026	0.0670	SA	1/13/21	0.050	0.79	0.783	
4	205-310-0100-02	0015	Batch 1	4	SA	01/27/2021	0.1087	0.0340	SA	01/15/21	0.093	0.99	0.827	
5	205-310-0100-02	0017	Batch 1	1	RN	01/11/2021	0.1674	0.1450	SA	01/11/21	0.035	0.93	0.856	
6	205-310-0100-02	0020	Batch 1	1	SA	1/27/2021	0.0689	0.2560	SA	1/15/21	0.049	0.8	0.957	
7	205-310-0100-02	0021	Batch 1	5	SA	2/4/2021	0.0909	0.0660	SA	1/19/21	0.910	0.85	0.986	
8	205-310-0100-02	0023	Batch 1	5	RN	12/21/2020	0.0941	0.0820	SA	1/22/21	2.00	0.76	0.870	
9	205-310-0100-02	0024	Batch 1	4	RN	1/7/2021	0.1581	0.0980	SA/RP	12/23/20	0.103	1.18	0.812	
10	205-310-0100-02	0026	Batch 1	2	SA	1/27/2021	0.1698	0.0910	SA	1/15/21	0.065	1.005	0.740	
11	205-310-0100-02	0027	Batch 1	1	RN	1/11/2021	0.1584	0.2770	SA/RP	12/11/20	0.050	0.85	0.957	
12	205-310-0100-02	0029	Batch 1	1	RN	1/11/2021	0.1248	0.1450	SA	1/12/21	0.055	1.09	0.943	
13	205-310-0100-02	0030	Batch 1	1	RN	1/7/2021	0.0788	0.1330	SA/RP	12/23/20	0.043	1	1.044	
14	205-310-0100-02	0032	Batch 1	2	SA	1/26/2021	0.2212	0.0940	SA	1/13/21	0.070	0.975	0.783	
15	205-310-0100-02	0033	Batch 1	5	SA	2/4/2021	0.0679	0.1360	SA	1/28/21	0.190	0.59	0.841	
16	205-310-0100-02	0035	Batch 1	1	SA	1/25/2021	0.1328	0.2270	SA	1/14/21	0.047	0.925	0.928	
17	205-310-0100-02	0036	Batch 1	1	RN	12/21/2020	0.0906	0.1520	SA	02/04/21	0.055	0.575	0.812	
18	205-310-0100-02	0037	Batch 1	1	SA	1/27/2021	0.1090	0.2390	SA	1/15/21	0.065	1.025	0.740	
19	205-310-0100-02	0038	Batch 1	2	RN	1/7/2021	0.1768	0.0980	SA/SA	12/23/20	0.076	0.85	1.059	
20	205-310-0100-02	0041	Batch 1	5	SA	2/4/2021	0.1592	0.1210	SA	1/14/21	0.450	0.72	0.798	
21	205-310-0100-02	0042	Batch 1	1	SA	1/26/2021	0.1167	0.1450	SA	1/14/21	0.060	1.025	0.870	
22	205-310-0100-02	0044	Batch 1	2	SA	1/27/2021	0.1796	0.2240		1/13/21	0.055	0.8	0.754	
23	205-310-0100-02	0045	Batch 1	2	RN	1/7/2021	0.1838	0.2890	SA/SA	12/23/20	0.051	0.8	0.798	
24	205-310-0100-02	0047	Batch 1	2	SA	1/26/2021	0.1882	0.1380	SA	1/14/21	0.045	0.855	0.957	
25	205-310-0100-02	0048	Batch 1	1	RN	12/23/2020	0.1679	0.1720	SA	1/22/21	0.055	0.785	0.740	
26	205-310-0100-02	0050	Batch 1	2	SA	1/26/2021	0.2211	0.0910	SA	1/13/21	0.070	0.98	0.885	
27	205-310-0100-02	0051	Batch 1	5	RN	12/21/2020	0.1261	0.1760	SA	1/28/21	1.165	0.795	0.841	
28	205-310-0100-02	0053	Batch 1	1	SA	1/26/2021	0.1986	0.196	SA/RP	12/23/20	0.055	0.895	0.870	
29														

- All staves that are delivered to BNL will be tested as follows:

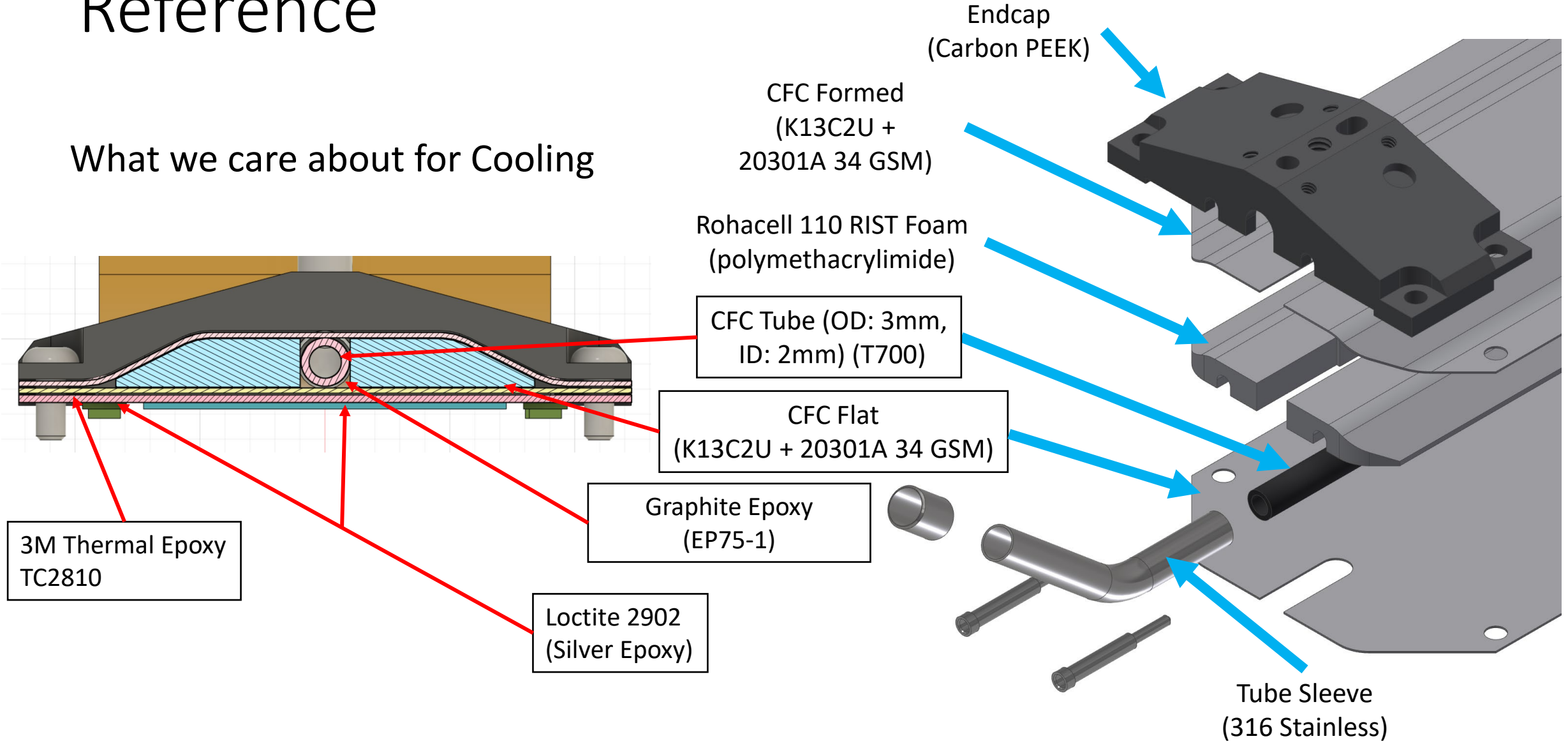
1. Inspection ✓
2. Leak test ✓
  - a) Pressurized test ✓
  - b) Submersion test ✓
3. Flow consistency test ✓
4. Flatness measurement ✓
5. Long term flow test ✓
6. Stave Classification ✓

The above testing ensures the highest quality ladders are built at BNL for INTT Ladders.

# Backup

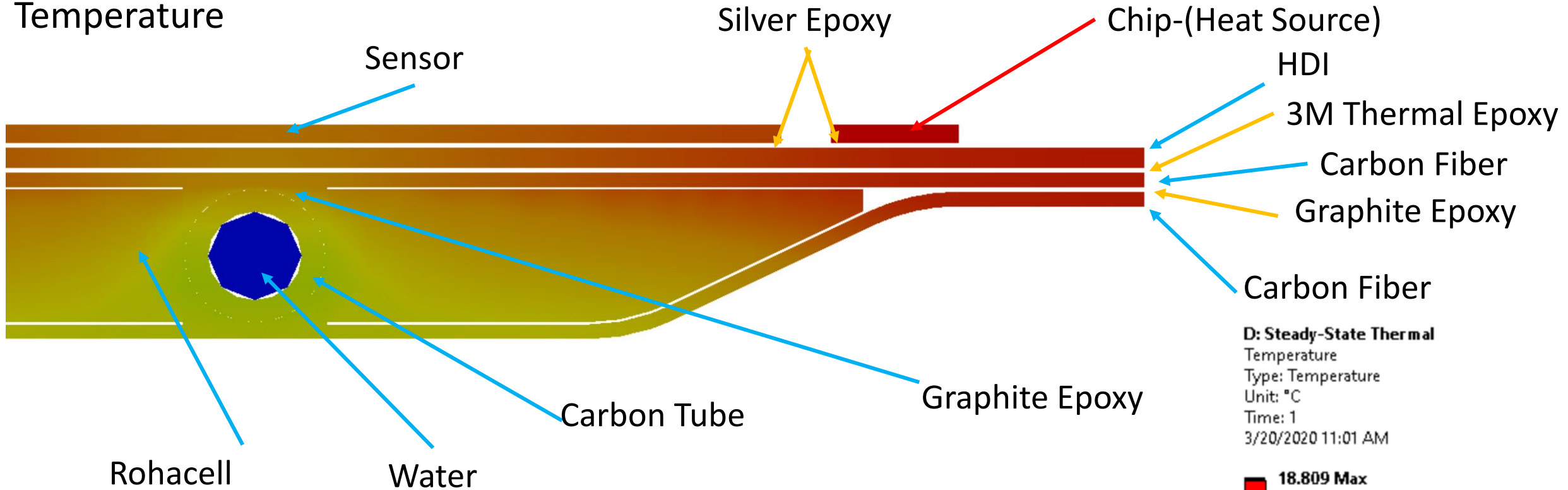
# Reference

## What we care about for Cooling

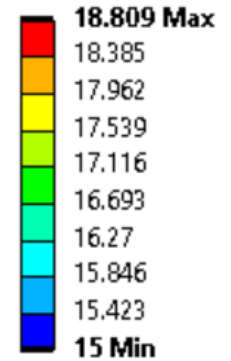


# Thermal – Midplane Cross Section

- Temperature



**D: Steady-State Thermal**  
 Temperature  
 Type: Temperature  
 Unit: °C  
 Time: 1  
 3/20/2020 11:01 AM



The heat is applied as a  $0.0055 \text{ W/mm}^3$ , which is about  $0.05 \text{ W}$  per chip, or  $2.6 \text{ W}$  total. There is also convection in the model, which adds about a  $0.4 \text{ W}$  load. Flow Rate is  $120 \text{ ccm}$  of water in the model.