Oak Ridge National Laboratory

Cold Plate Upgrade at the SNS

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POCPA7

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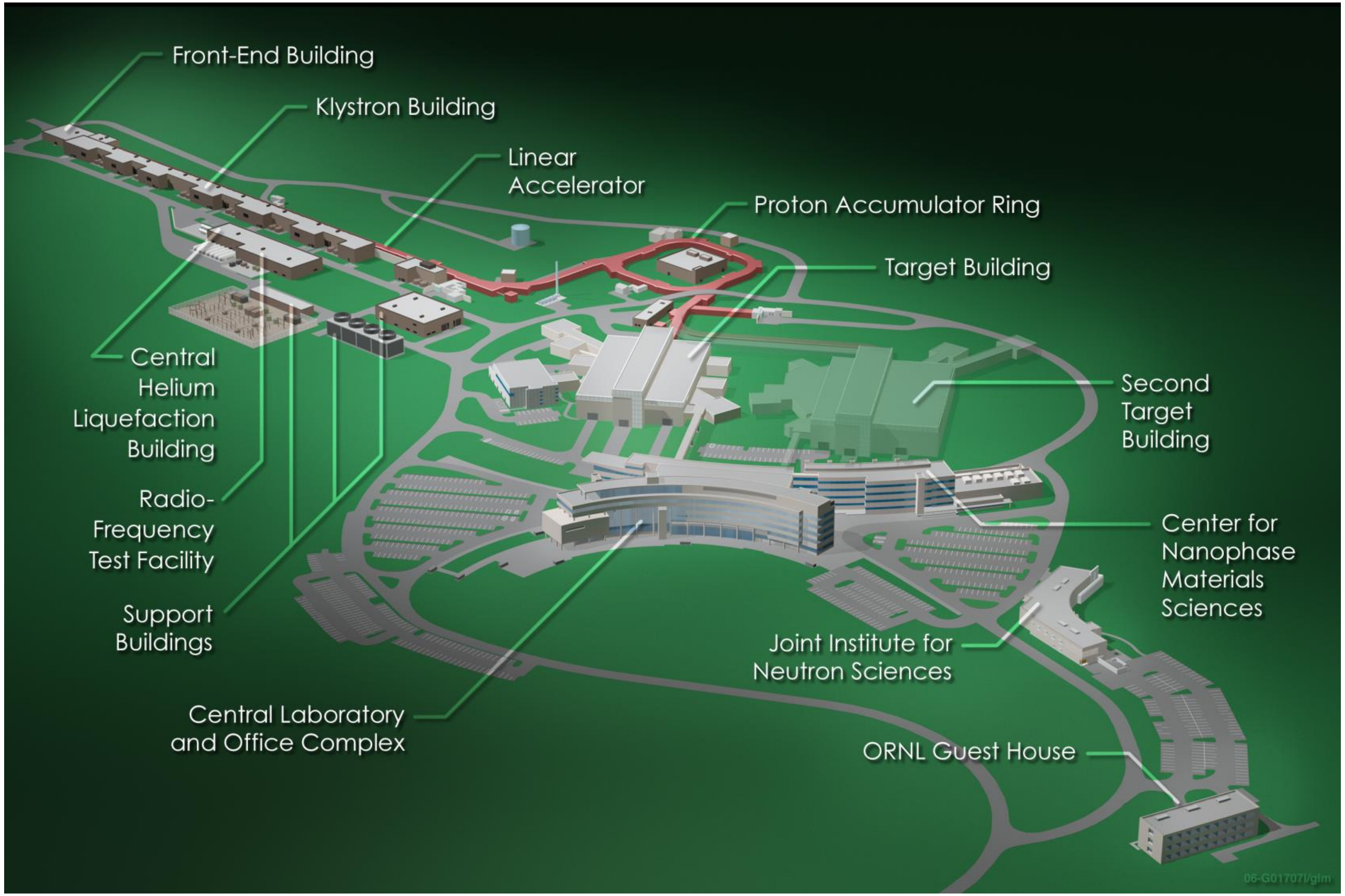
- Summary

SNS

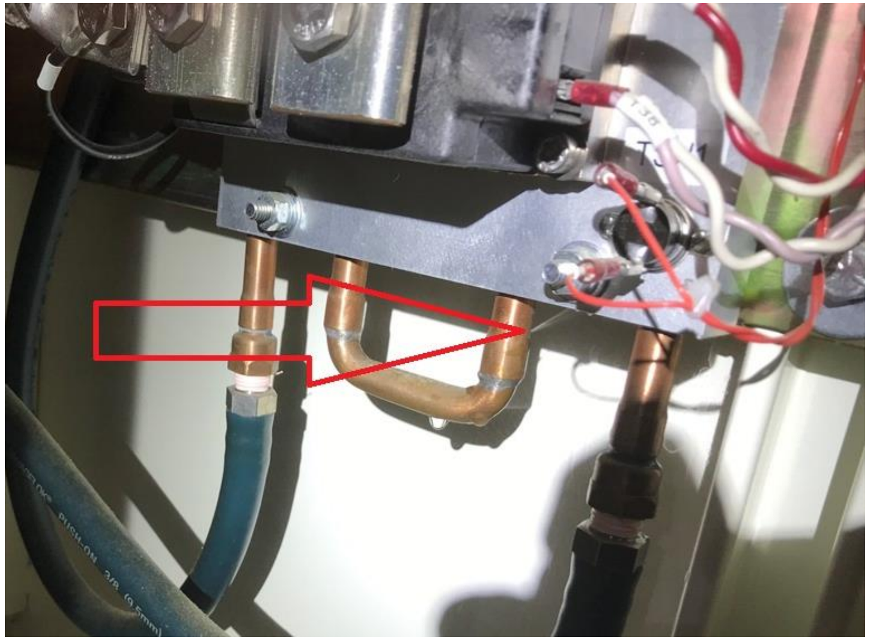
- Produces high intensity pulsed neutrons for scientific research and industrial development.
- Operations began in 2006. Availability goal 90%.

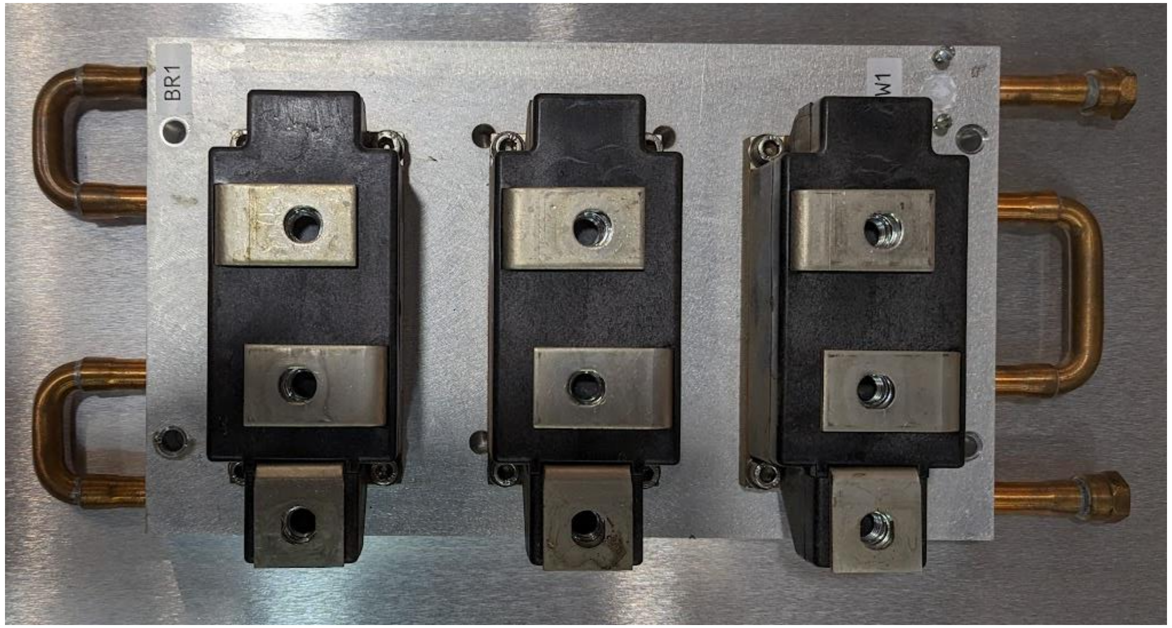


SNS Beam Animation

Cold Plate Water Leak

- A cold plate is used to cool power semiconductor devices and made of an aluminum plate with copper tube.
- Deionized (DI) water corrodes copper, causing pin hole leak.
- Corrosion rate could be 50μm/Year*.





Cold Plate with SCRs

Pin Hole Leak

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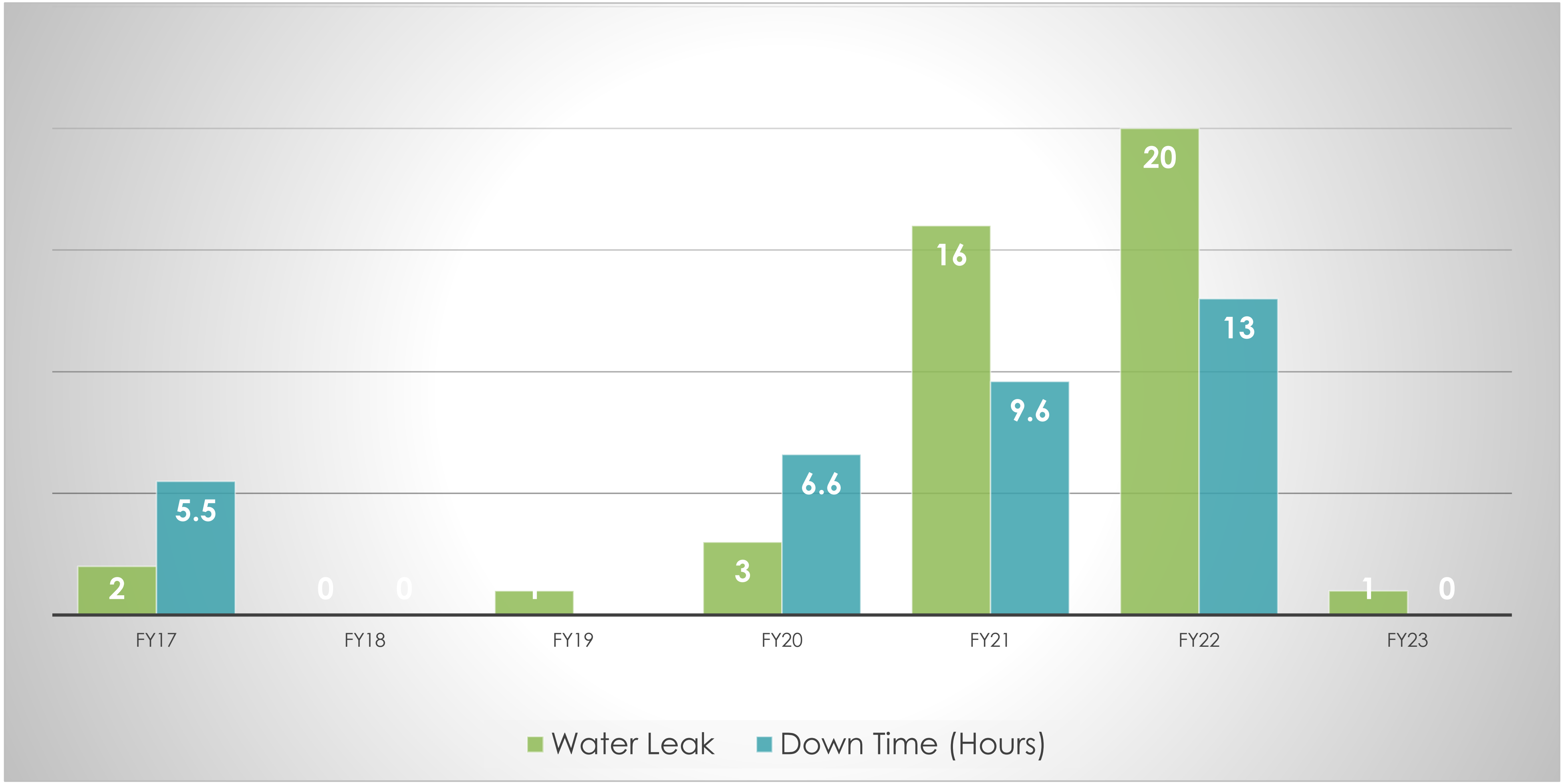
* Corrosion of Copper by Deionized Cooling Water, H Scholer, etc, EPAC, 1988

Water Leaks in Recent Years

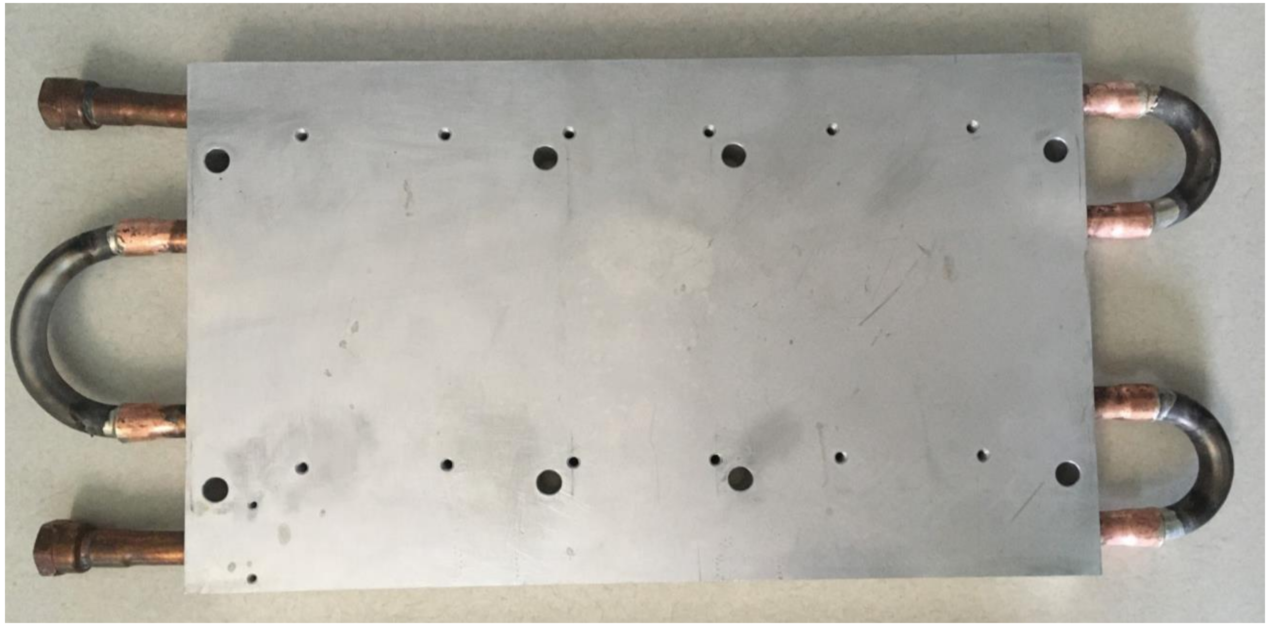
- Cold plate water leak caused many hours of downtime, especially in FY 21 and FY22.



Repair : A Temporary Solution

- It is more than pin hole damage.
- Repair is a temporary remedy.

The corrosion is severe. The wall is too thin to be braizing sealed.



A repaired cold plate with stainless steel U-bends.

New Design: Permanent Solution

Use Stainless Steel (SS) as cooling tube.

Advantage: SS304 is rated excellent in DI compatibility.

Disadvantage: SS304 doesn't conduct heat as well as copper. The cold plates with SS tube may operate at a higher temperature than ones with copper tube.

Material	Thermal Conductivity (W/m*K)
Copper	386
SS 304	16.3

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Chemical Compatibility Database

CHEMICAL SELECTED : Water, Deionized

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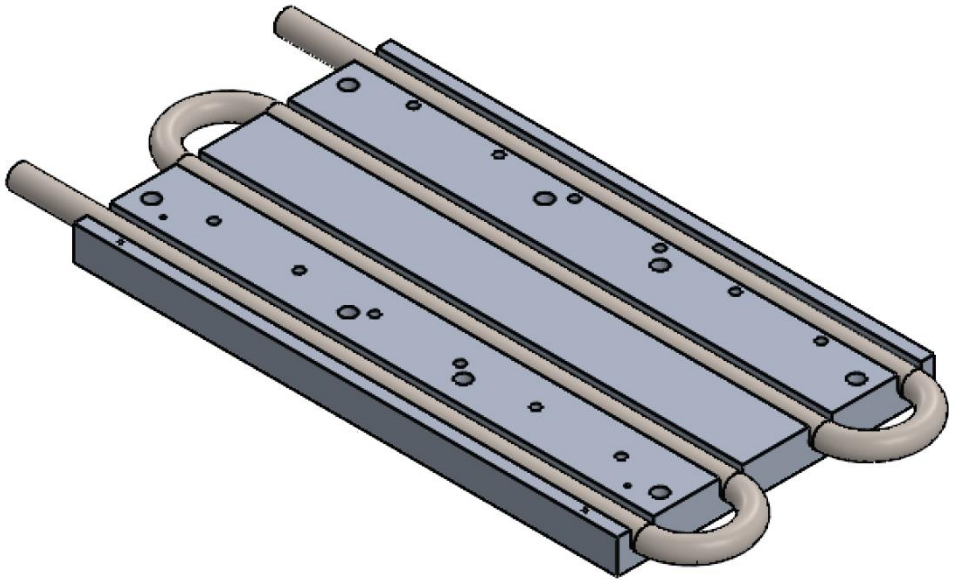
MATERIAL	COMPATIBILITY
stainless steel - 304	A[1] - Excellent

Ratings - Chemical Effect
A - Excellent
B - Good: Minor Effect, slight corrosion, or discoloration.
C - Fair: Moderate Effect, not recommended for continuous use. Softening or loss of strength, and swelling may occur.
D - Severe Effect: Not recommended for any use.
E - Information not available.

Explanation of Footnotes
1-Satisfactory to 72°F (22°C)
2-Satisfactory to 120°F (48°C)

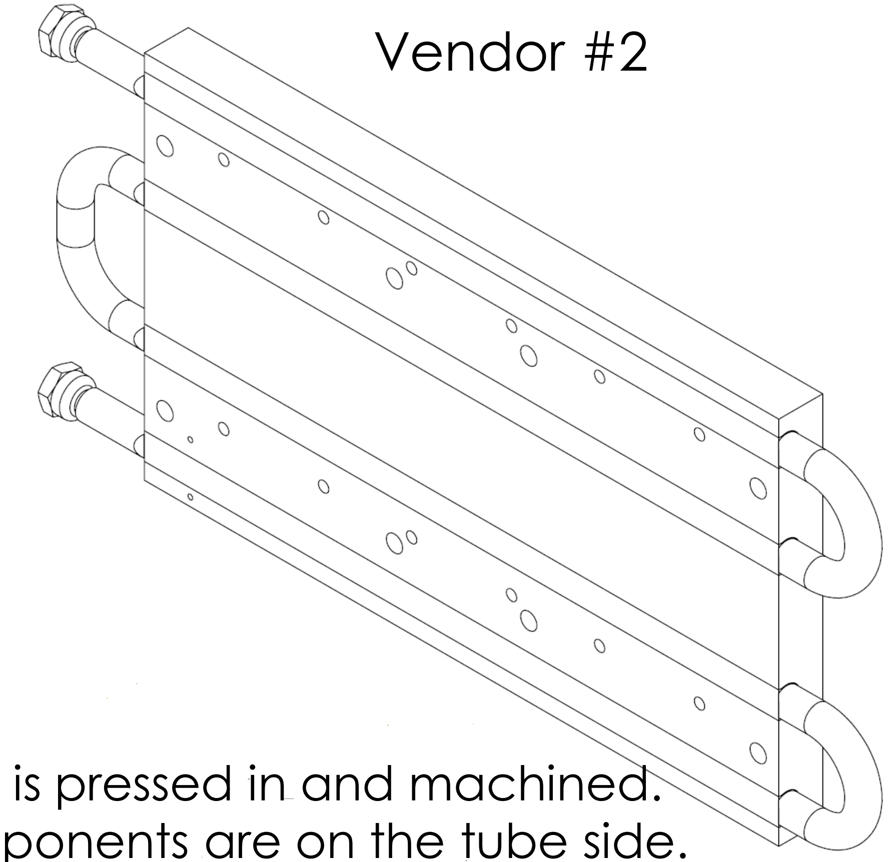
Two Vendors, Different Designs

Vendor #1



Tube is in the channel and epoxied. Components are on the non-tube side. Epoxy is thin but has high thermal resistance.

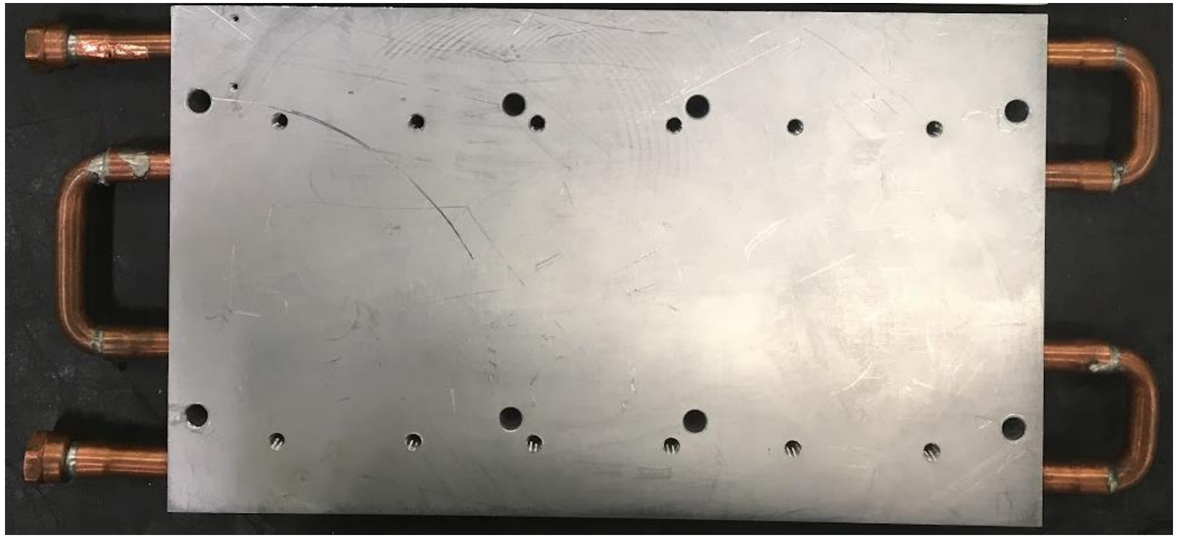
Vendor #2



Tube is pressed in and machined. Components are on the tube side. This is a good design because components make direct contact with tube.

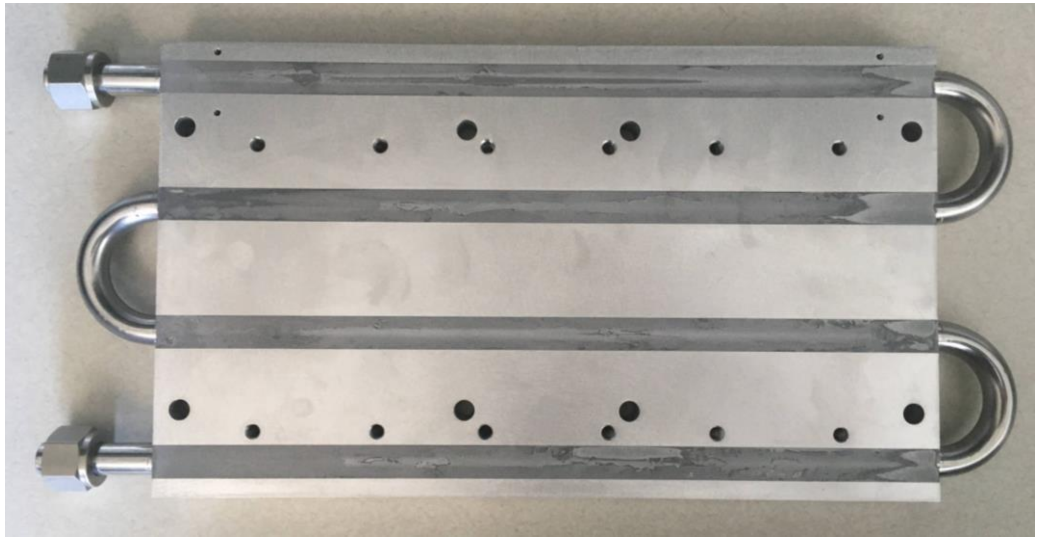
10 cold plates were ordered each for evaluation.

Vendor #1 and #2's Cold Plates



Existing Cold Plate Copper Tube OD=0.45"

Multiple copper pieces brazed together. Tube in the middle of cold plate.

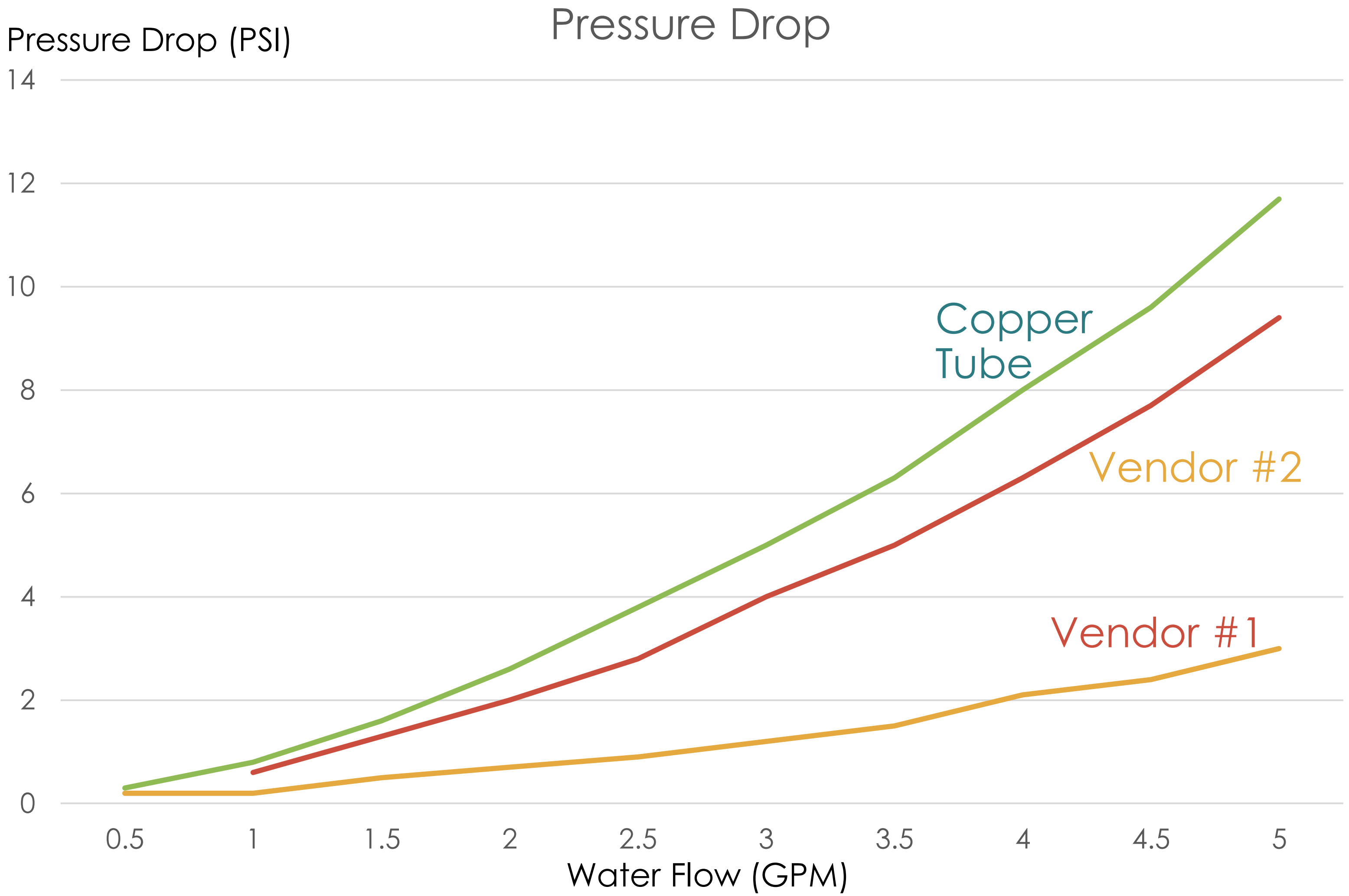


Vendor#1 Cold Plate with 1/2" SS Tube

Vendor#2 Cold Plate 1/2" SS Tube

Pressure Drop Test

Flow (GPM)	ΔP (PSI) Copper	ΔP (PSI) #1 1/2" SS Tube	ΔP (PSI) #2 1/2" SS Tube
0.5	0.3	0.2	
1	0.8	0.2	0.6
1.5	1.6	0.5	1.3
2	2.6	0.7	2
2.5	3.8	0.9	2.8
3	5.0	1.2	4
3.5	6.3	1.5	5
4	8.0	2.1	6.3
4.5	9.6	2.4	7.7
5	11.7	3	9.4

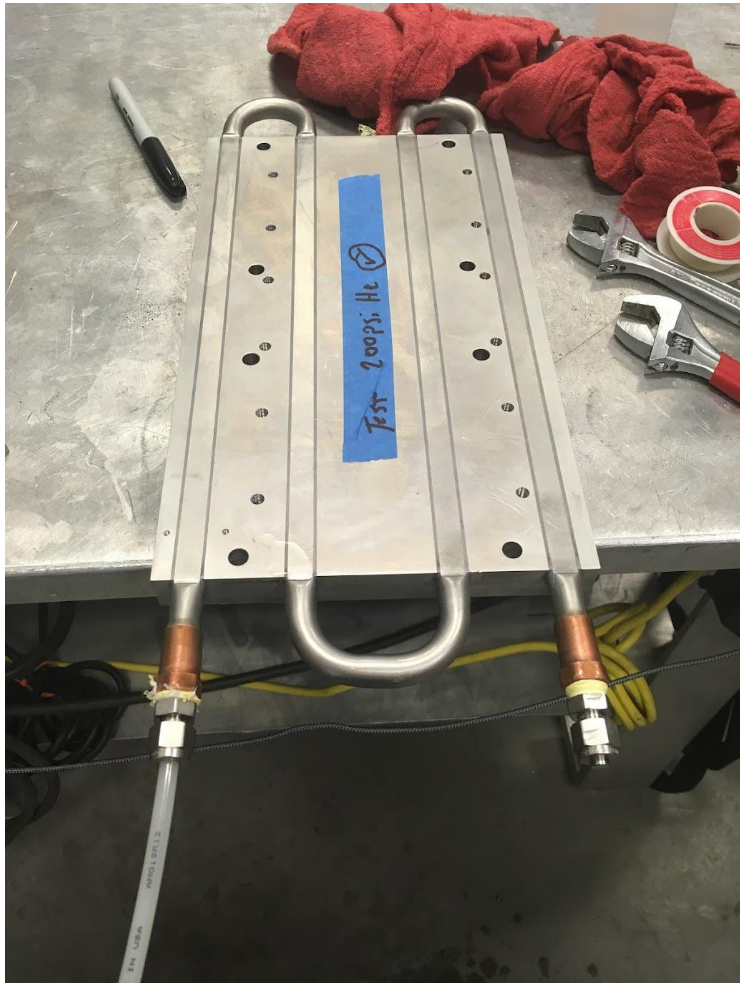


Copper Tube OD=0.45" ID=0.38"
Vendor#1 Tube SS304 OD=0.5" Wall=0.028" ID=0.444"
Vendor#2 Tube SS304 OD=0.5" Wall=0.049" ID=0.402"

Vendor#1 and Vendor #2 cold plates have less pressure drop than the copper tube cold plate.

Pressure Hold-off Test

Operating pressure=80 PSI.
Both cold plates passed 200PSI, 1 hour test, 2.5 times of the operating pressure.



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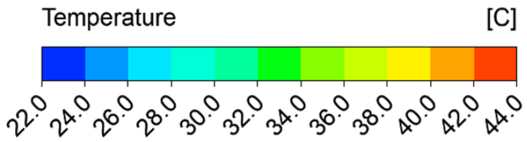
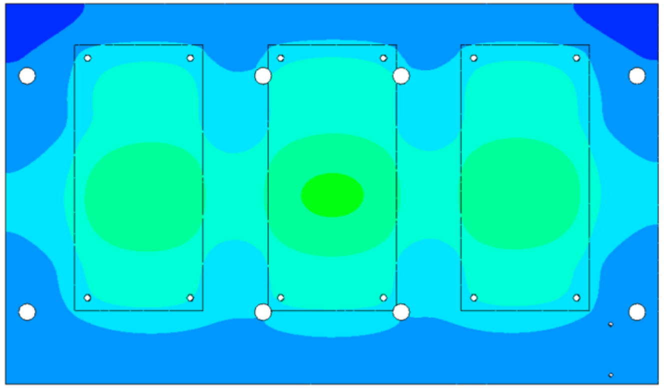
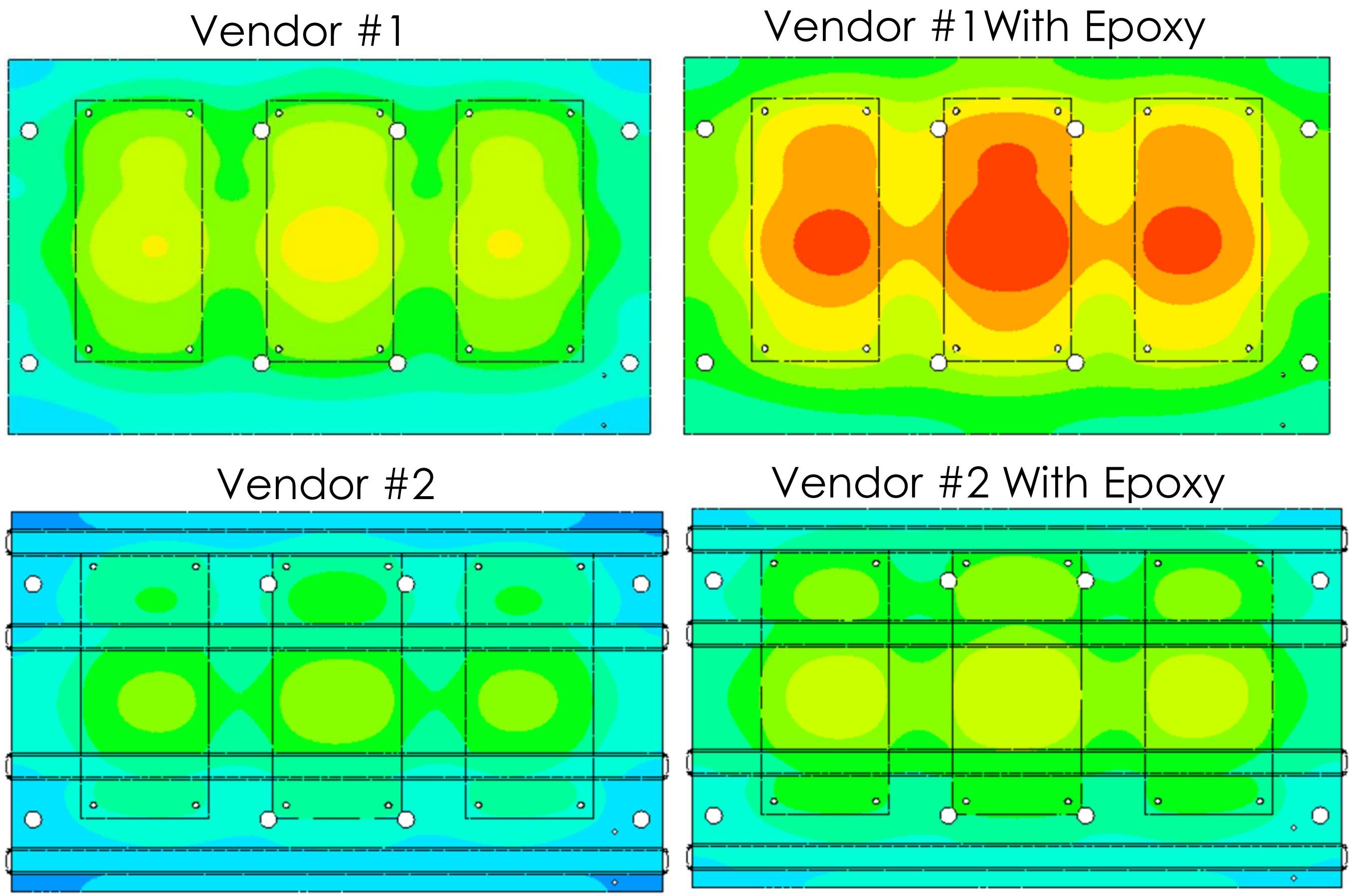
Simulation

- Vendor #1 cold plate is hotter than vendor #2 under same conditions.
- Epoxy plays an important role.



Copper Tube



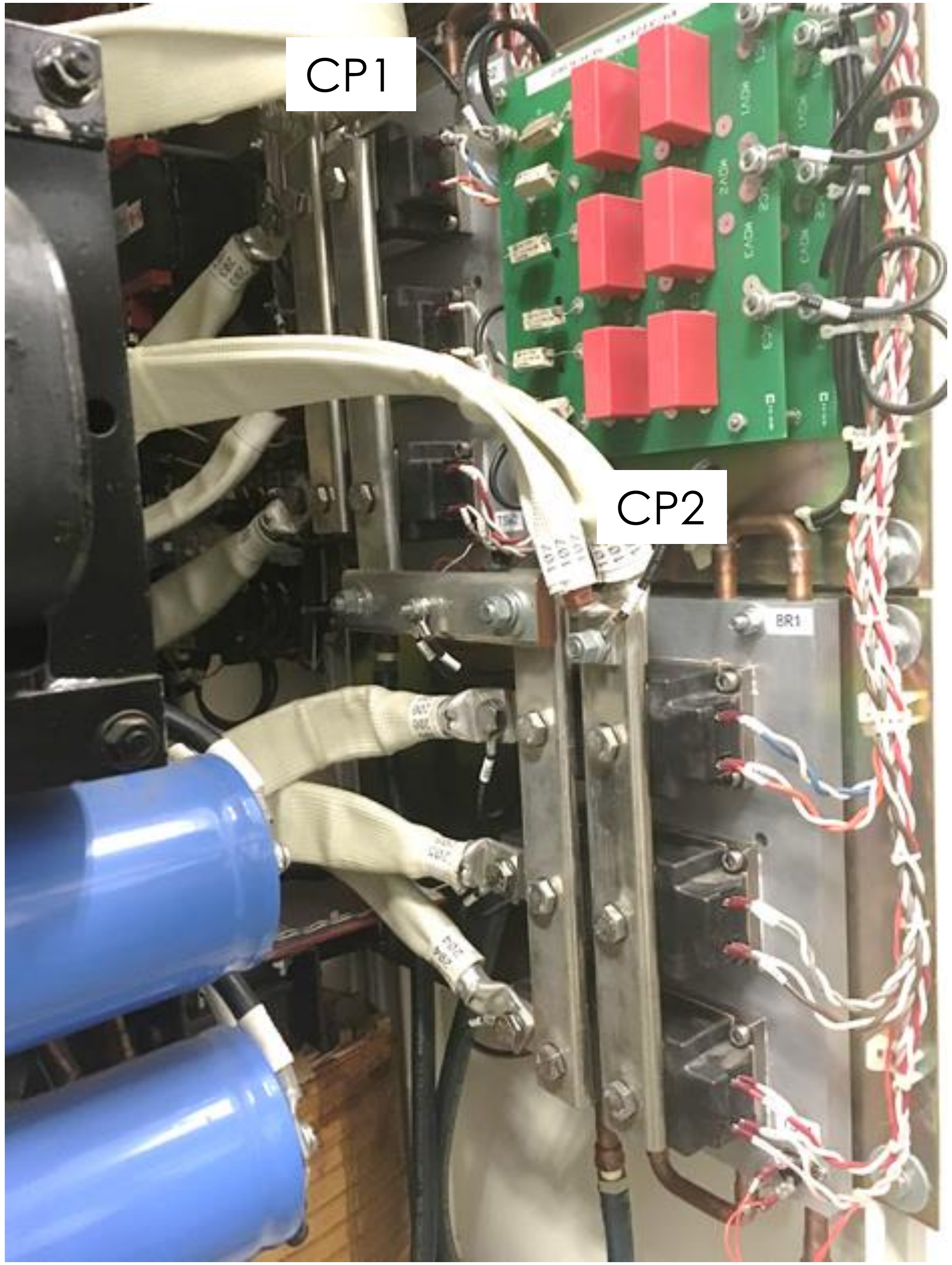


Heat Flow =1 kW Water Flow=2.1GPM	Copper Tube	Vendor #1	Vendor #2	Vendor #1 w/Epoxy	Vendor #2 w/Epoxy
Thermal Contact Resistance (m^2K/W)	0	0	0	0.0001*	0.0001*
ΔT Probe Temp on CP to Inlet (°C)	6.9	13.2	9.9	18.1	12.6
ΔT Max Temp on CP to Inlet(°C)	10.3	17.3	13.3	22.0	15.9

* Thermal Contact Resistance of Various Carbon Nanomaterial-based Epoxy Composites Developed for Thermal Interface Applications, Mohsin Ali Raza, Aidan Westwood, Journal of Materials Science: Materials in Electronics, 2019

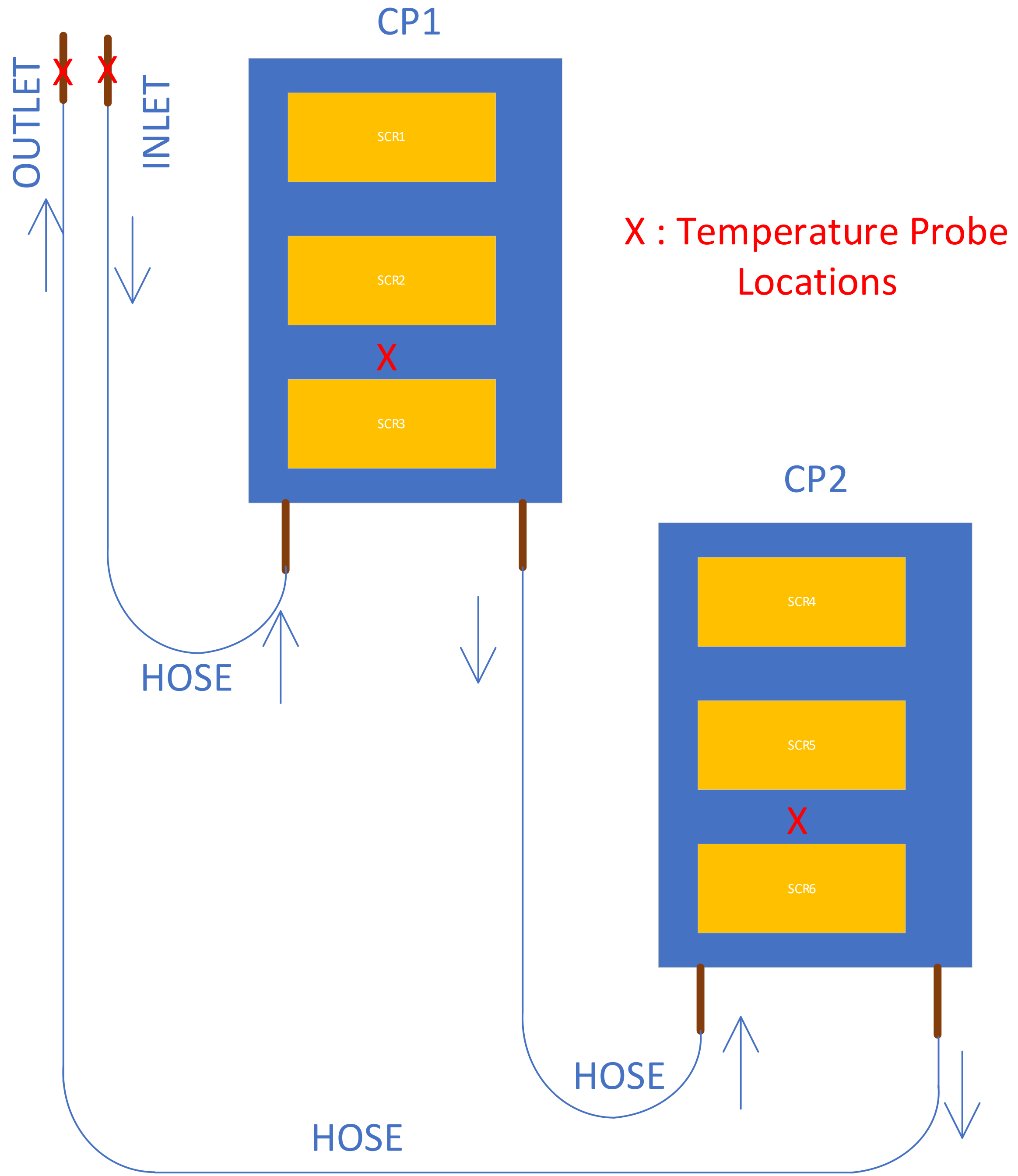
Cold Plate Thermal Test

- The test was conducted on a spare power supply in the power supply test stand so we could acquire data quickly.
- Two cold plates (CP1 and CP2) are in use.



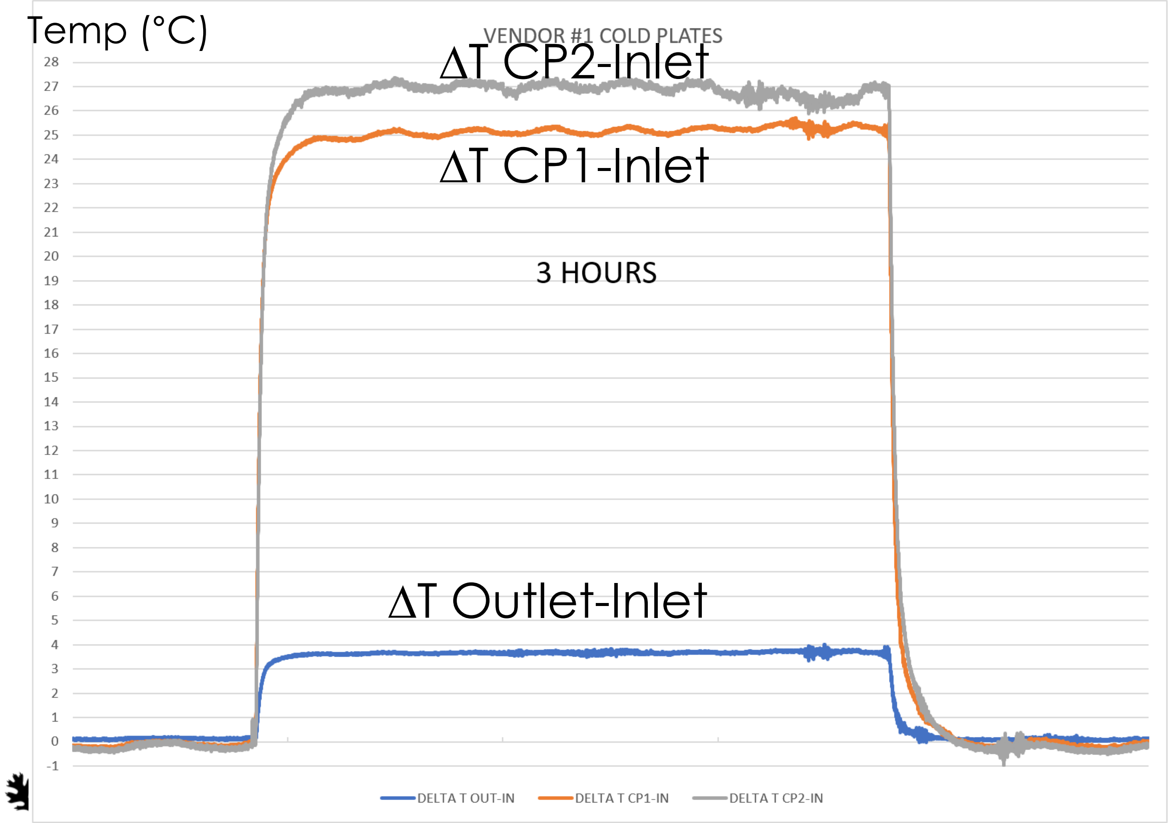
Cold Plate Test

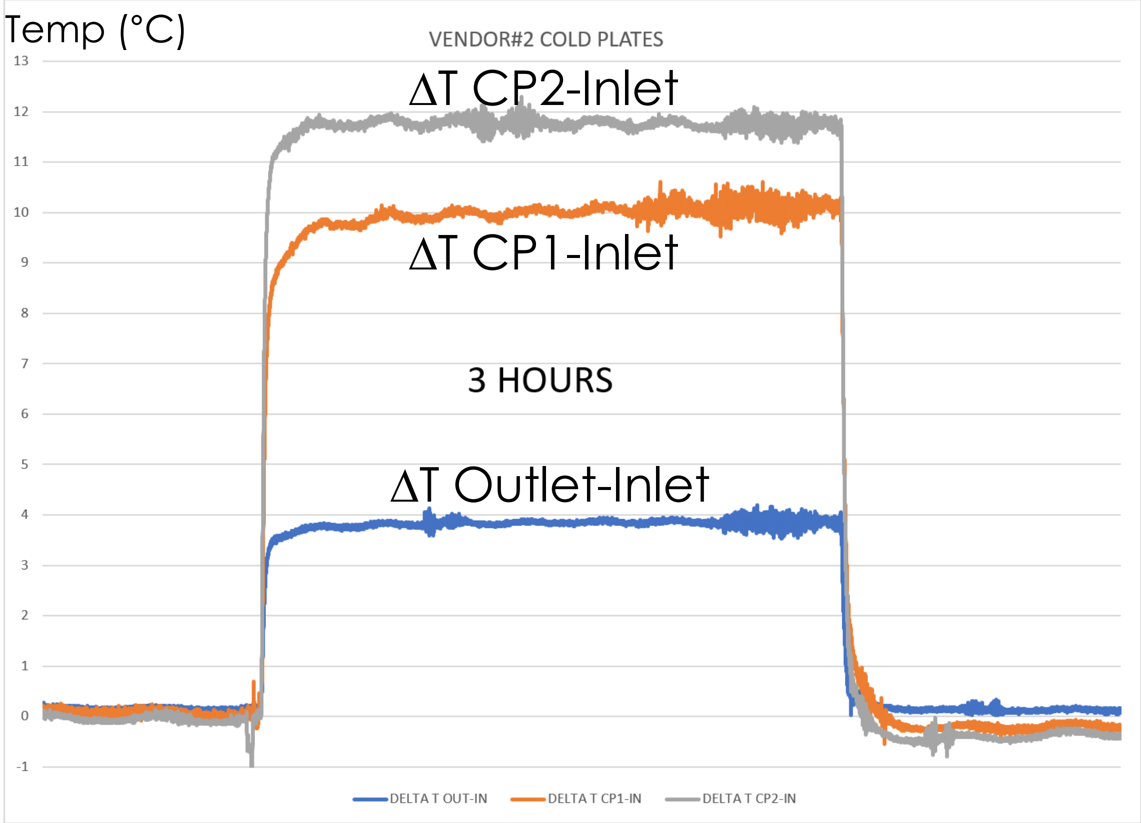
- Power supply output 500A/18V.
- A Keyence flow meter was used to measure the flow, ensuring the flow remained same ~2.1GPM.
- Four temperatures were taken: inlet, outlet, CP1 and CP2.
- ΔT
  - Outlet to inlet : For calculation of heat flow removed by water = 264*Flow(GPM)* ΔT(C) (Watt)
  - CP1 to inlet & CP2 to inlet: related to the cold plate thermal resistance.



Test Data

Flow=2.1GPM PS Output 500A 18V	Cold Plate with Copper Tube	Vendor #1 Cold Plate with 1/2” SS Tube	Vendor #2 Cold Plate with 1/2” SS Tube
ΔT Outlet-Inlet (°C)	4.2	3.7	3.9
ΔT CP1-Inlet (°C)	8	25	10
ΔT CP2-Inlet (°C)	10	27	12





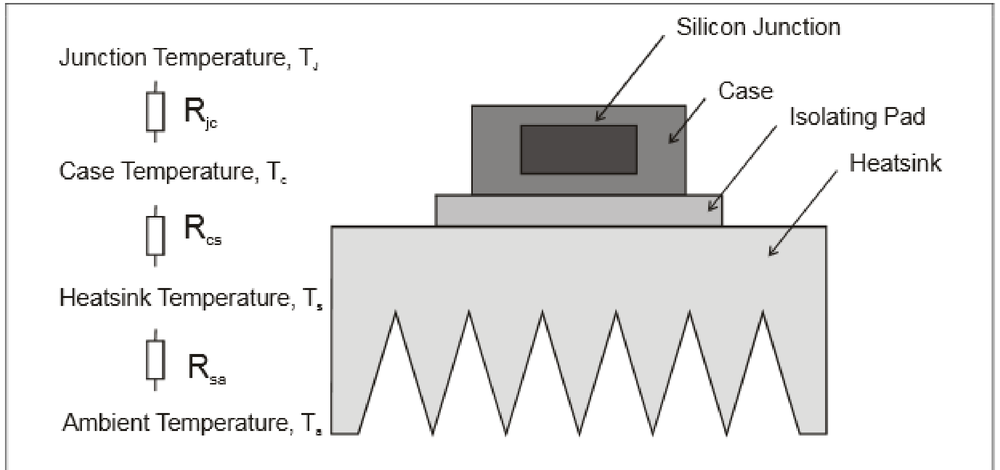
Junction Temperature

Junction temperature, is the highest operating temperature of the actual semiconductor in an electronic device.
Exceeding a junction temperature for an extended period can result in device failure.

Solid State Devices	Ratings	Operating Temperature T_J(C)
Powerex CM800DU-12H	800A/600V	-40 to 150
Powerex LD430850NA	500A/800V	-40 to 130
Powerex LD430825NA	250A/800V	-40 to 130

Junction Temperature Calculations

Heat removed by water P=264*Flow *ΔT ~2160 Watts
Two Cold Plates, each 1080 Watts



$T_j = P_d(R_{jc}+R_{cs}+R_{sa}) + T_a$

Thermal Characteristics

Characteristics	Symbol				Max.	Units
Thermal Resistance, Junction to Case	$R_{\Theta J\text{-}C}$	Per Module, both conducting			0.0325	°C/W
		Per Junction, both conducting			0.0650	°C/W
Thermal Impedance Coefficients	$Z_{\Theta J\text{-}C}$	$Z_{\Theta J\text{-}C} = K_1 (1-\exp(-t/\tau_1))$	K_1 = 8.03E-04	τ_1 = 3.39E-04		
		$+ K_2 (1-\exp(-t/\tau_2))$	K_2 = 1.03E-02	τ_2 = 3.15E-03		
		$+ K_3 (1-\exp(-t/\tau_3))$	K_3 = 1.64E-02	τ_3 = 0.106		
		$+ K_4 (1-\exp(-t/\tau_4))$	K_4 = 3.75E-02	τ_4 = 2.066		
Thermal Resistance, Case to Sink Lubricated	$R_{\Theta C\text{-}S}$	Per Module			0.01	°C/W

Thermal Resistance Junction to Case Rjc=0.0325 C/W
Thermal Resistance Case to Sink Rcs=0.01 C/W
Thermal Resistance Junction to Sink = 0.0325+0.01=0.0425 C/W
Three SCRs on each cold plates
Power Dissipation of Each SCR=360 Watts
Delta T Junction to Sink= 360*0.0425=15 C
Inlet Temperature = 33C

Vendor #1
Cold Plate Probe Temperature Ts=33+27 =60 C
Max Temperature =60+3=63C
Junction Temperature Tj=15+63=78 C

Vendor #2
Cold Plate Probe Temperature Ts=33+12 =45 C
Max Temperature =45+3=48C
Junction Temperature Tj=15+48=63 C

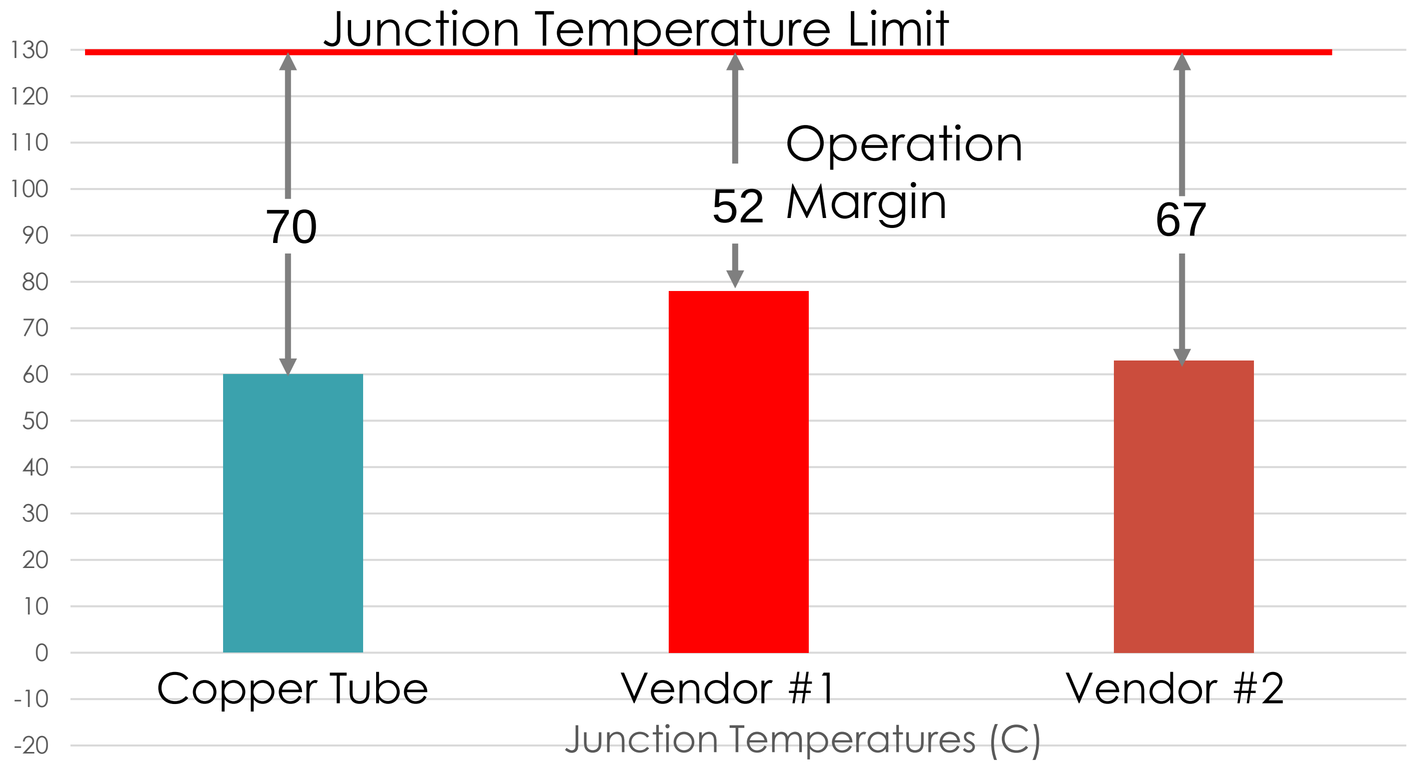
Test Results

- Both Vendor #1 and Vendor #2 cold plates have sufficient design margin under normal operating conditions.
- Vendor #2 cold plate has better thermal performance than Vendor #1 cold plate.
- Vendor #2 cold plate runs slightly hotter than existing cold plate under same conditions.

After the test, 5 Vendor #2 cold were installed in operational power supplies and ran for over 6 months with no issues.

Vendor#2 has been selected as the path forward.

Flow Q=2.1GPM I=500A V=18V	Copper Tube Cold Plate	Vendor #1 Cold Plate	Vendor #2 Cold Plate
Inlet Temperature (°C)	33	33	33
ΔT CP2-Inlet (°C)	9	27	12
CP2 Probe Temperature (°C)	42	60	45
CP2 Maximum Temperature (°C)	45	63	48
SCR Junction Temperature (°C)	60	78	63



Cold Plate Count

Power Supply	Ratings	Cold Plate						
		Large 12"X7"X0.83"					Small 7.875"X5"X0.83"	
		Type 1A: SCR	Type 1B: SCR	Type 2: IGBT	Type 3: Resistor	Type 4: IGBT&Diode	Type 1: SCR	Type 2: Diode
Injection Kicker (8)	1400A 800V	8		96	8			8
Medium 185A (4+1)	185A 27V						10	
Type 3 (5+3)	375A 80V					8		
Medium 390A (16+1)	390A 24V						34	
Type 2 (7+1)	400A 24V					8		
Medium 700A (13)	700A 18V		26					
Medium 700A (1+1)	700A 25V		4					
Medium 900A (9)	900A 51V	18						
Medium 900A (3+1)	900A 80V	8						
Sub-Total		34	30	96	8	16	44	8
Total		236						

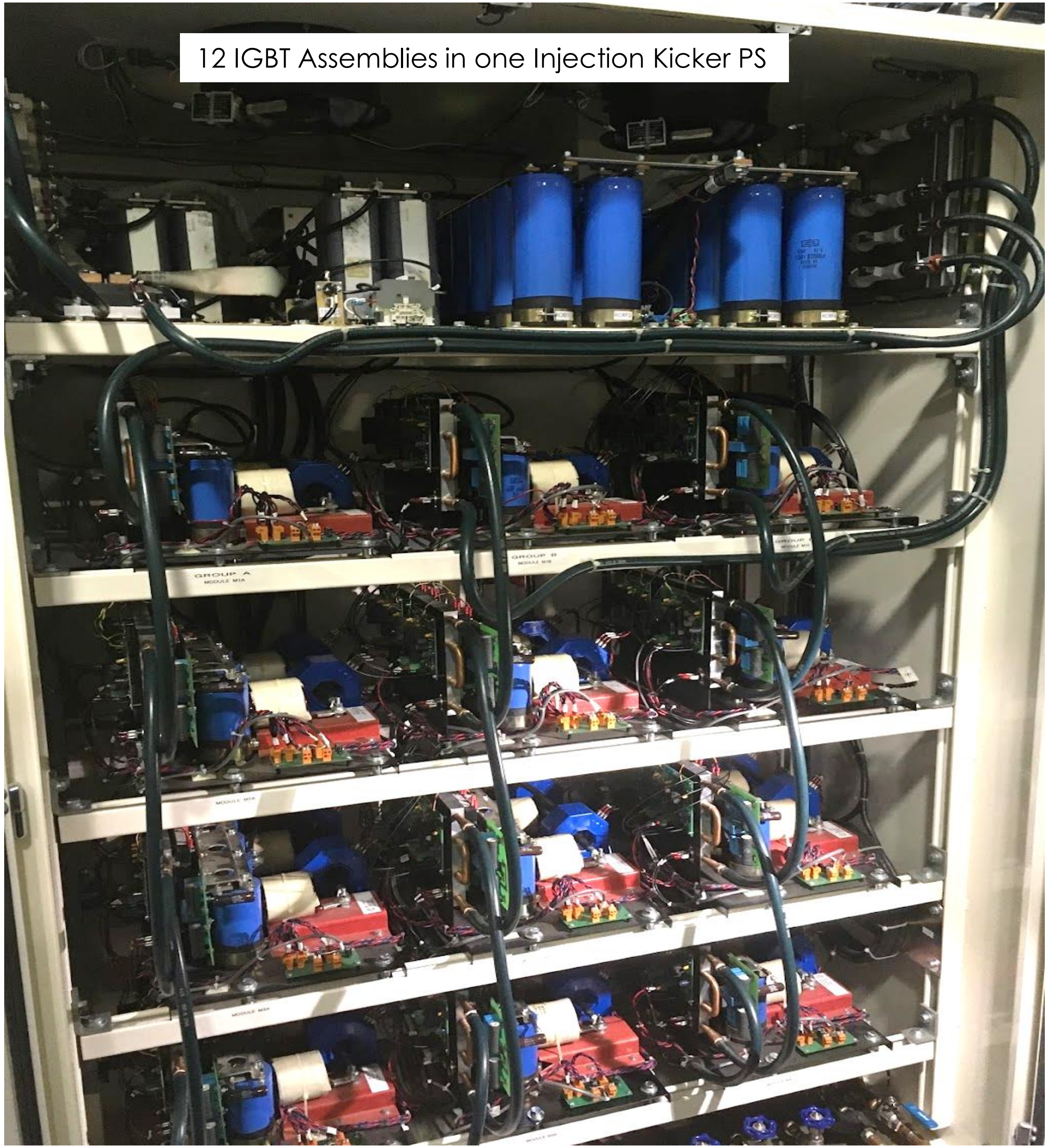
Installation Plan

Facts

- All leaks happen in Ring Service Building (RSB).
- Most occur in Injection Kicker power supplies because each injection kicker power supply has 15 cold plates while other IE power supplies have two cold plates each.

Plan

- Complete RSB first, then RTBT service building, HEBT service building, Klystron building.
- Most installation will be done in FY23B outage.


12 IGBT Assemblies in one Injection Kicker PS

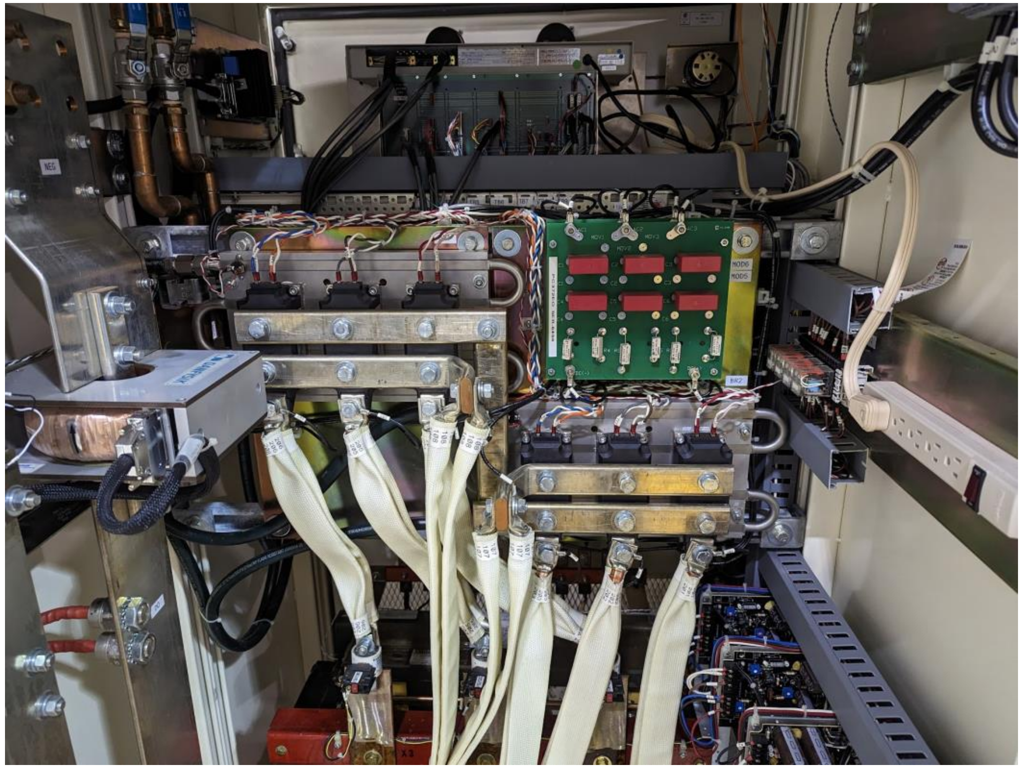
Detailed Upgrade Plan

Week	From	To	Systems
1	2/28/2023	3/3/2023	Injection Kicker H01 (15 Cold Plates)
2	3/6/2023	3/10/2023	Injection Kicker V01 (15 Cold Plates)
3	3/13/2023	3/17/2023	Injection Kicker H02 (15 Cold Plates)
4	3/20/2023	3/24/2023	Injection Kicker V02 (15 Cold Plates)
5	3/27/2023	3/31/2023	Injection Kicker H03 (15 Cold Plates)
6	4/3/2023	4/7/2023	Injection Kicker V03 (15 Cold Plates)
7	4/10/2023	4/14/2023	Injection Kicker H04 (15 Cold Plates)
8	4/17/2023	4/21/2023	Injection Kicker V04 (15 Cold Plates)
9	4/24/2023	4/28/2023	Power Supplies in Ring Service Building (28 Cold Plates)
10	5/1/2023	5/5/2023	Power Supplies in RTBT Service Building (22 Cold Plates)
11	5/8/2023	5/12/2023	Power Supplies in HEBT Service Building #1 (22 Cold Plates)
12	5/15/2023	5/19/2023	Power Supplies in HEBT Service Building #2 (22 Cold Plates)

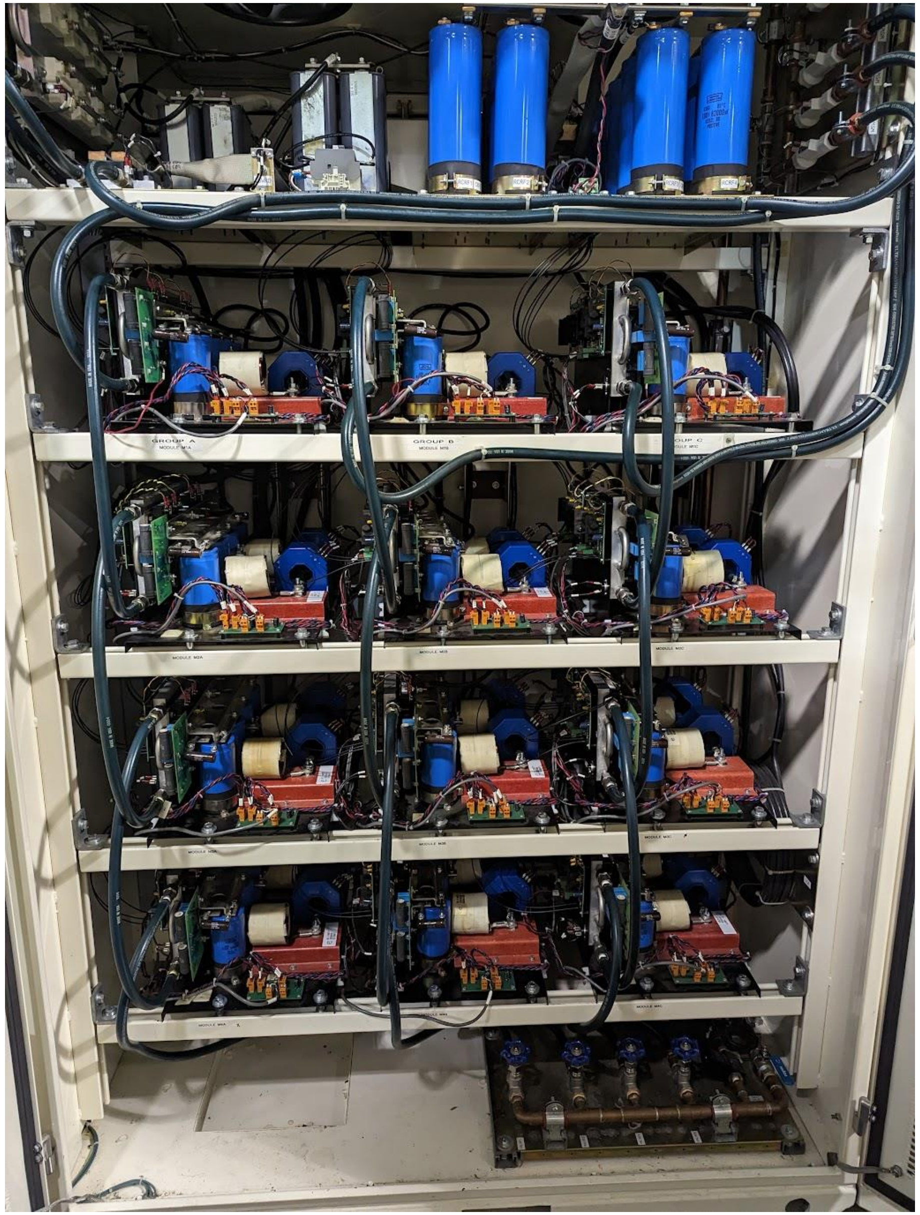
Klystron building power supplies can be swapped out on maintenance days.

Replacement Campaign

- Long lead time due to Covid but eventually we received new cold plates in January 2023.
- The campaign started March 1, 2023.
- All the cold plates were replaced as planned.
- PSs turned on 5/26/2023. A few had issues on connections.



New Cold Plates in a 900A Quad PS



Injection Kicker PS with New Cold Plates

Summary

- Deionized (DI) water corrodes copper, causing pin hole leak and long hours of downtime.
- Stainless-Steel is compatible with DI water. Two vendors’ cold plates were evaluated, and the one with better thermal performance was selected as the replacement unit.
- We completed a campaign to replace more than 95% of copper tube cold plates in service.

- Questions/ Comments?