NSTX Liquid Lithium Divertor-1
Final Design Review for Mechanical Design

Presented by the LLD team at PPPL

April 22, 2008

Presentation Overview

- Mechanical Engineering Design and Analysis
  - R. Ellis, R. Nygren
- Cost and Schedule
  - R. Ellis
- Summary
- The scope of this review is the design and analysis of the mechanical components of the Liquid Lithium Divertor for NSTX. Controls and Diagnostic Interfaces will be addressed at a separate review.

Mechanical Engineering Design

- Design Requirements
- Design Overview
- Geometry Definition
- Design Description
- Thermal Analysis – R. Nygren
- Electromagnetic Analysis

Mechanical Design Requirements

- Location – outer divertor, ~5cm outboard of CHI gap, ~15-20cm wide
- The LLD is segmented into quadrants for ease of installation.
- The temperature must be maintained between 200C and 400C during operation.
  - Lithium will melt and wet surface at 200C, evaporate at 400C.
  - Heating and cooling systems will be required.
- The materials used must satisfy NSTX requirements.
- Loading and replenishing of lithium should be accomplished without breaking NSTX vacuum.
  - Initially fill by evaporating from LITERs.

Mechanical Design Overview

- The LLD is located on the outer divertor.
  - Replaces first two rows of tiles.
- Conical geometry follows the shape of the divertor.
- Thin layer of stainless steel bonded to a thick layer of copper, with a thin layer of Mo plasma sprayed on top of the stainless steel.
  - Copper provides thermal diffusivity.
  - Mo facilitates wetting by lithium.
- Heating and cooling systems required for divertor.
  - Maintain the desired temperature range for Li.
- Four quadrants comprise LLD.
  - Segmentation facilitates handling and installation.
- Supports use existing tapped holes on passive stabilizer plates.

Geometry Definition

- The LLD is to be located on the outer divertor.
  - ~5cm outside of CHI gap [inside radius is 65.51cm [25.790in].
  - Graphite tiles between CHI gap and LLD.
- The width is 20.00cm [7.874in] radially.
  - 23.10cm [8.463in] along top surface
  - Supplants first two rows of tiles on outer divertor.
  - Exact width was determined by location of available tapped holes for supports, interface with tile row 3.
- The top surface is 3.81cm [1.500in] above passive stabilizer surface.
  - Try to keep as close to original divertor profile as possible.
- Each quadrant covers 82.5degrees toroidally.
  - Double width [7.5degrees] tiles between each segment.

Design Description

- Basic Plate Geometry
- Heating System
- Instrumentation
- Wire Routing
- Cooling System
- Supports
- Replacement tiles
- Fabrication Process
- Assembly Sequence

Basic Plate Geometry

- Plate geometry follows outer divertor geometry.
  - 48 copper plates under outer divertor → each plate covers 7.5deg.
  - 2 graphite tiles toroidally per plate.
- Each quadrant of LLD covers 82.5 degrees.
  - Center of plate bisects a copper plate.
  - 2 graphite tiles toroidally between quadrants.

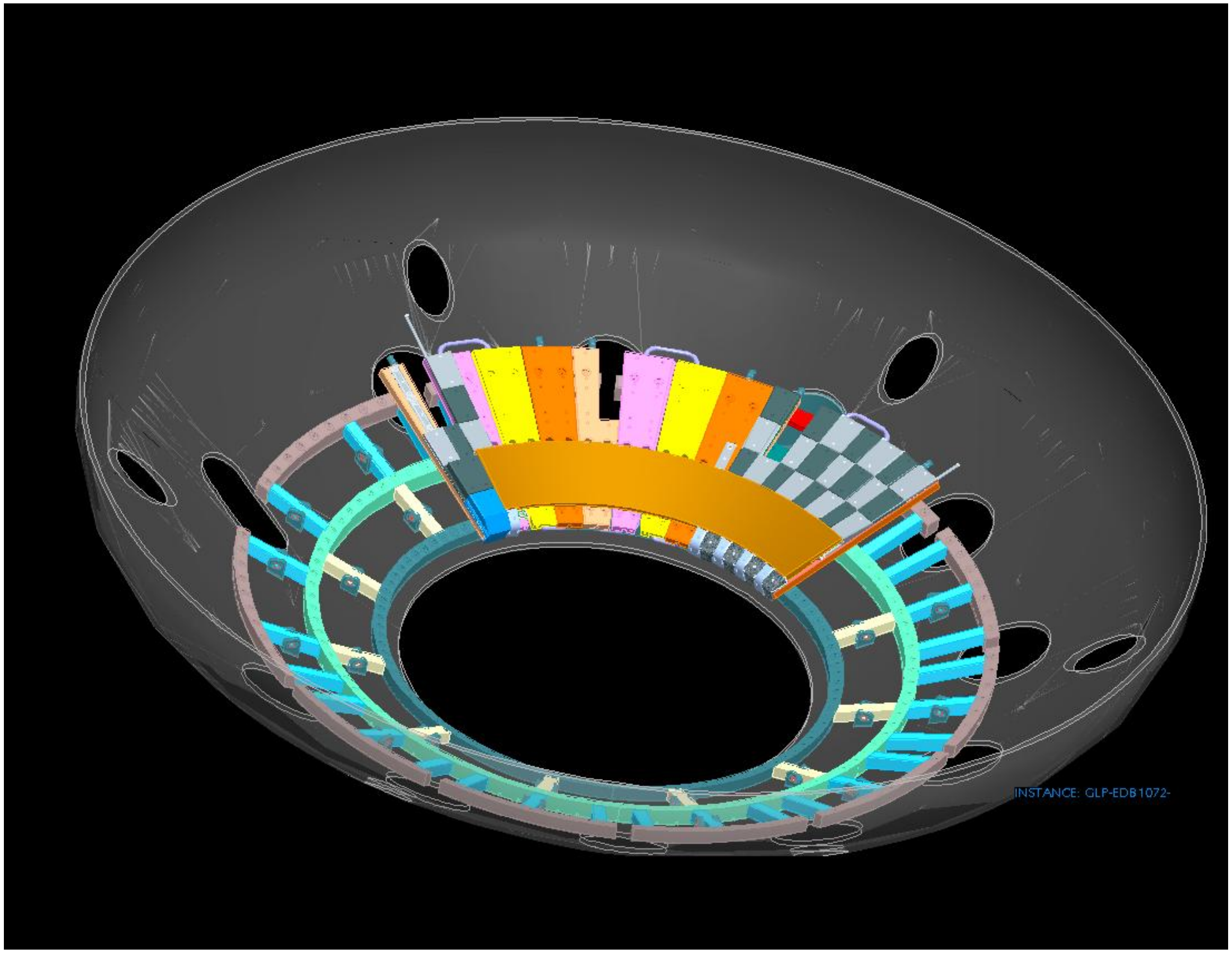
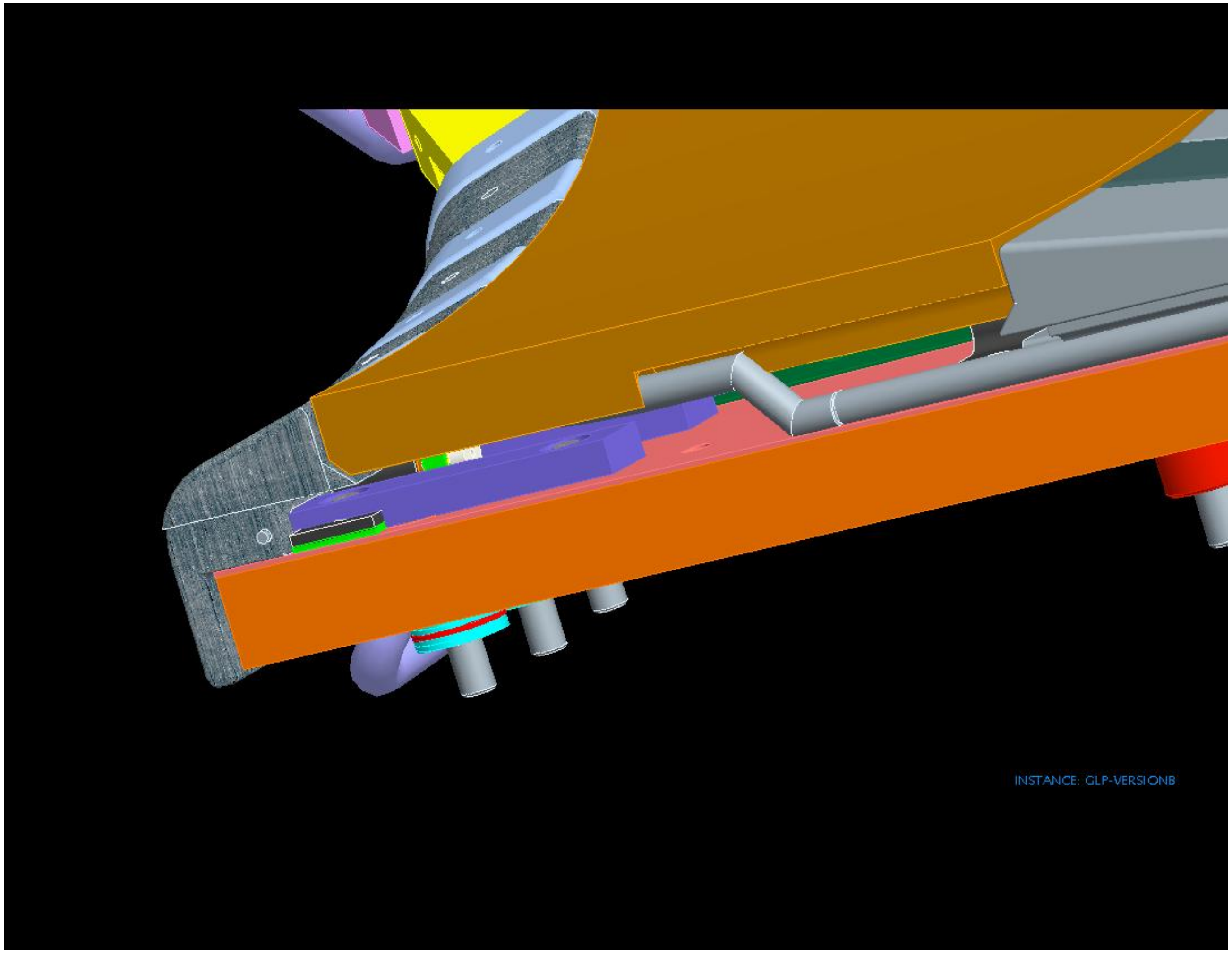


Plate Follows Outer Divertor Geometry

- Plate is .875" [2.22cm] thick.
- Inside corner is at R=25.790" [64.58cm].
- Plate is inclined at 21.5 degrees from horizontal.
- Top and bottom faces are 8.463" [21.50cm] long.
- Top surface is 1.5" [3.81cm] above copper stabilizer plates.
- Transition from 1" [2.54cm] required in row 3 tiles.



Basic Plate Geometry

- Inside corner is at R=25.790” [64.58cm].
- Top outside corner is at R=33.664” [85.51cm]
- Area of top surface = 362.3in^2 [2337cm^2]
- Area of bottom surface = 366.2in^2 [2362cm^2]
- Area of inside surface = 32.7in^2 [211cm^2]
- Area of outside surface = 42.7in^2 [275cm^2]
- Total surface area = 803.9in^2 [5185cm^2]
- Estimate volume of plate
  - Cross section area is 7.405in^2 [47.8cm^2]
  - Radius of centroid is 29.887in
- Volume is 318.7in^3 [5222cm^3]
  - Mass is ~96lbm [43kg]

A Heating System will Maintain the Temperature Above the Wetting Temperature [see Sandia analysis]

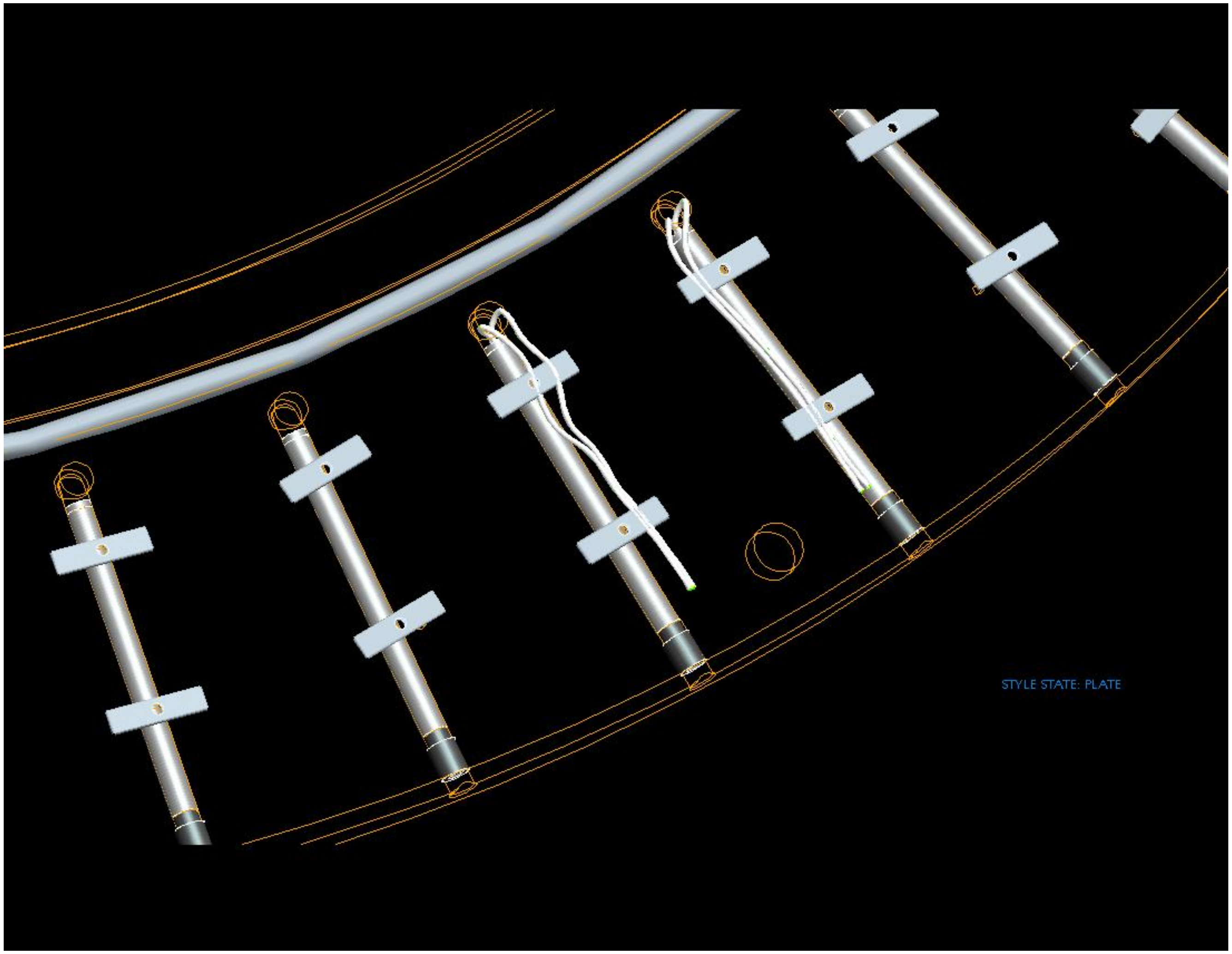
- For initial wetting, we want to be able to maintain the temperature of the plate at 350C [623K].
- Essentially all power loss from the plate is through radiation.
- Assume 20C [293K] sink temperature and blackbody radiation from all plate surfaces.
- Heat flux is .81W/cm^2, surface area is 5185cm^2 ➔ power is 4200W.
  - 1240W for 200C surface temperature
- Commercially available cartridge heaters will be used.
- We are using twelve 500W heaters per quadrant.
  - 6000W per quadrant.

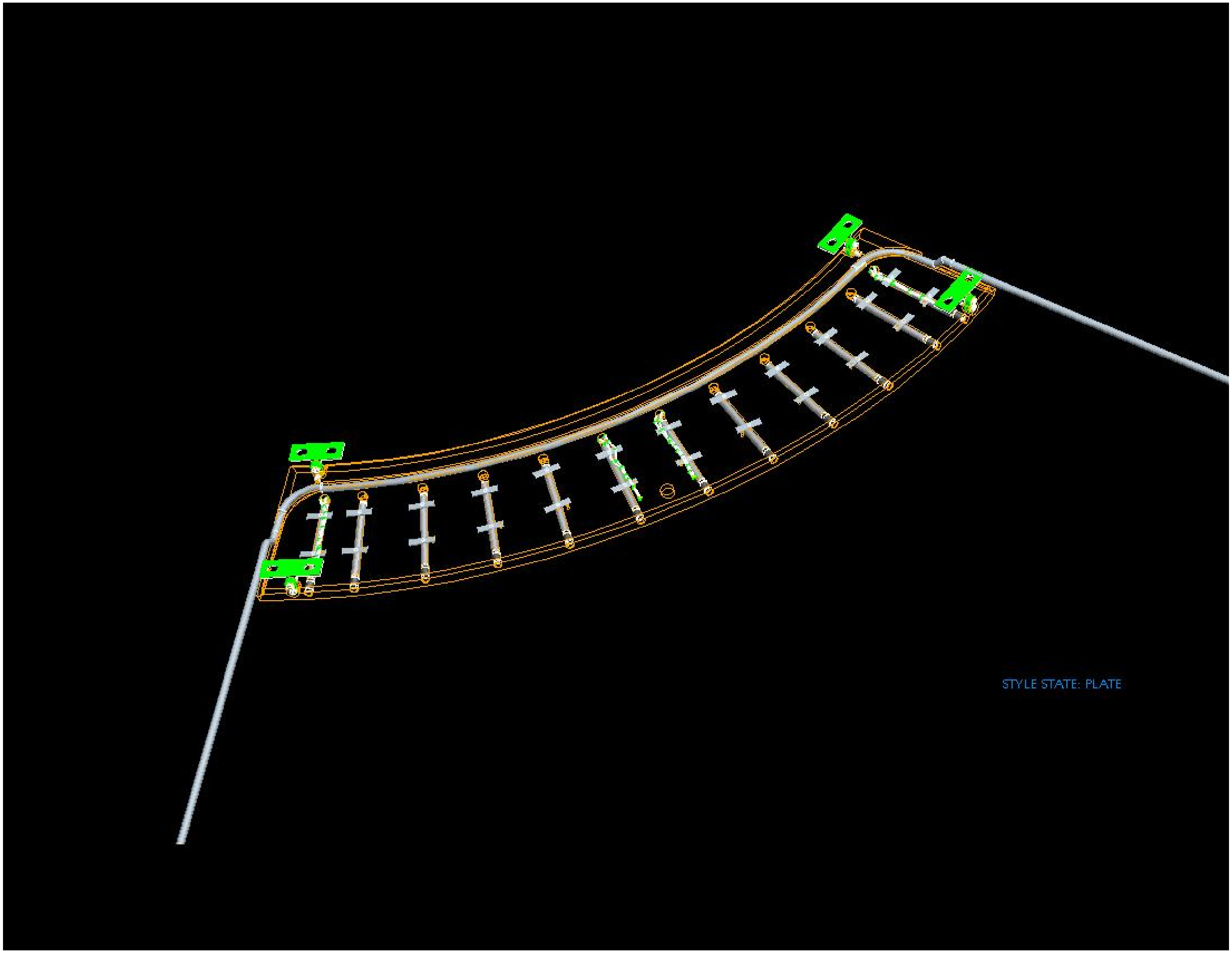
$$q'' = 5.669 * 10^{-12}\left(623^4 - 293^4\right) = .81W / cm^2$$

Commercially Available Cartridge Heaters will be Used

- Omega CSH-205500
  - 240V
  - .375”dia, 5” long
  - 500W each
  - 300SS sheath
  - Ceramic bead insulation allows 650C operating temperature.
  - Integral thermocouples
- All heaters will have integral thermocouples.
- The heater arrangement provides maximum protection for the wiring.
  - Heaters are installed into drilled and reamed holes leads first, wave spring and threaded plug retain heater, internal wire routing.

The Heater Arrangement Provides Maximum Protection for the Wiring



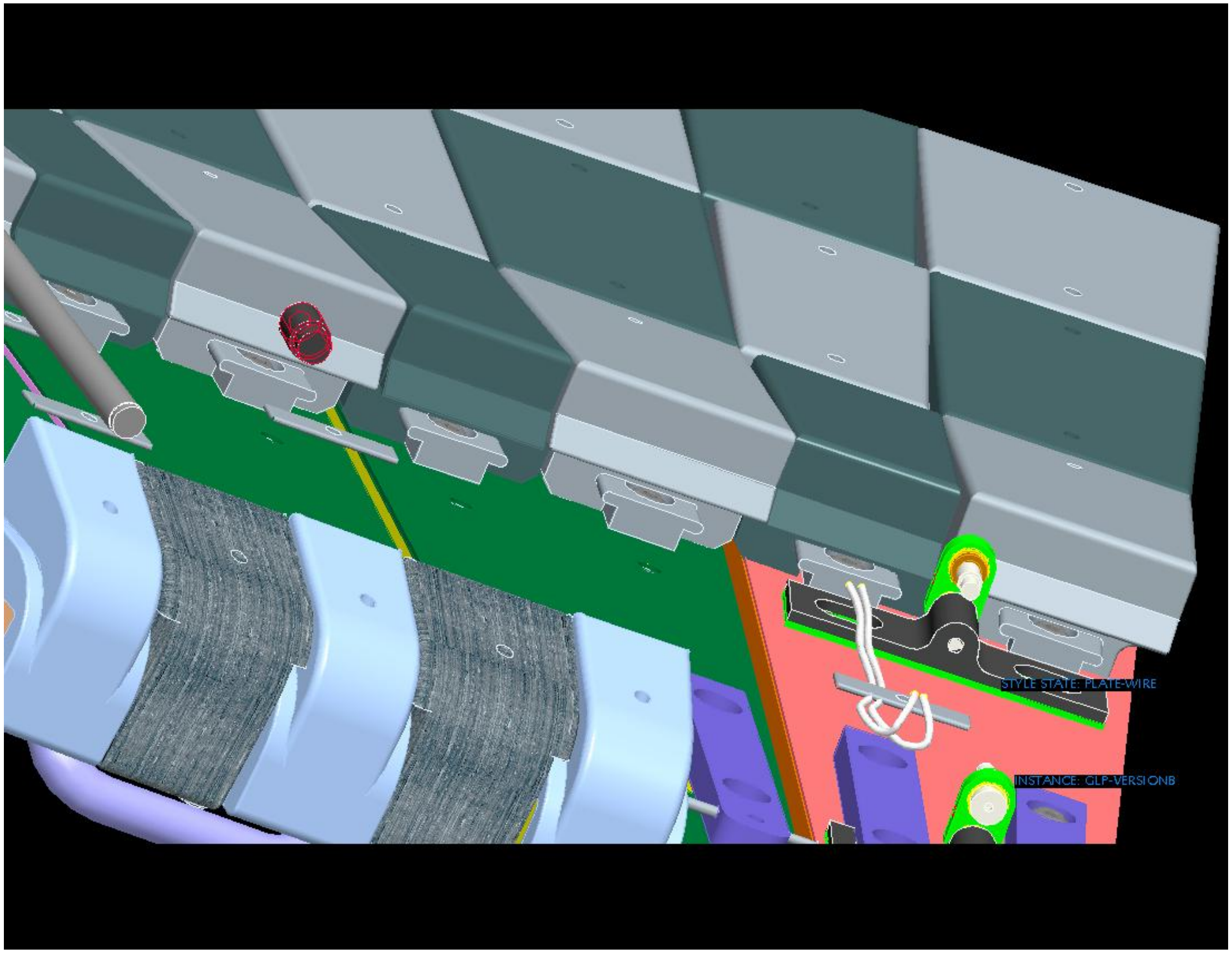

STYLE STATE: PLATE

Thermocouples, on LLD Plate and Inside some Heaters, Provide Temperature Measurement

- Twelve thermocouples in the plate.
  - ~.63cm [.25in] from each heater.
  - Used for temperature measurement and control.
- One thermocouple inside each heater [12 total].
  - Used for protection of heaters.

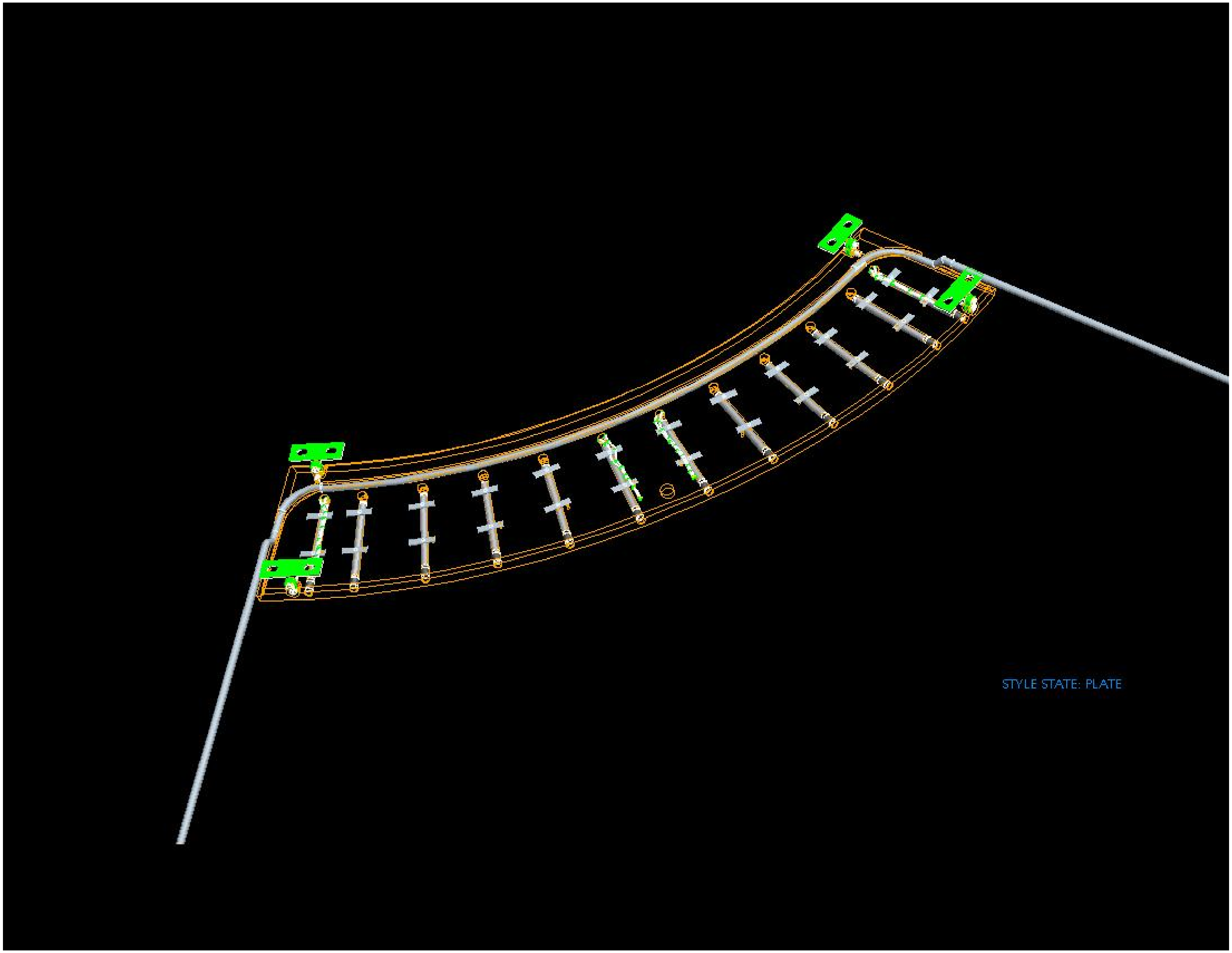
Wires are Routed Between LLD and Passive Stabilizer.

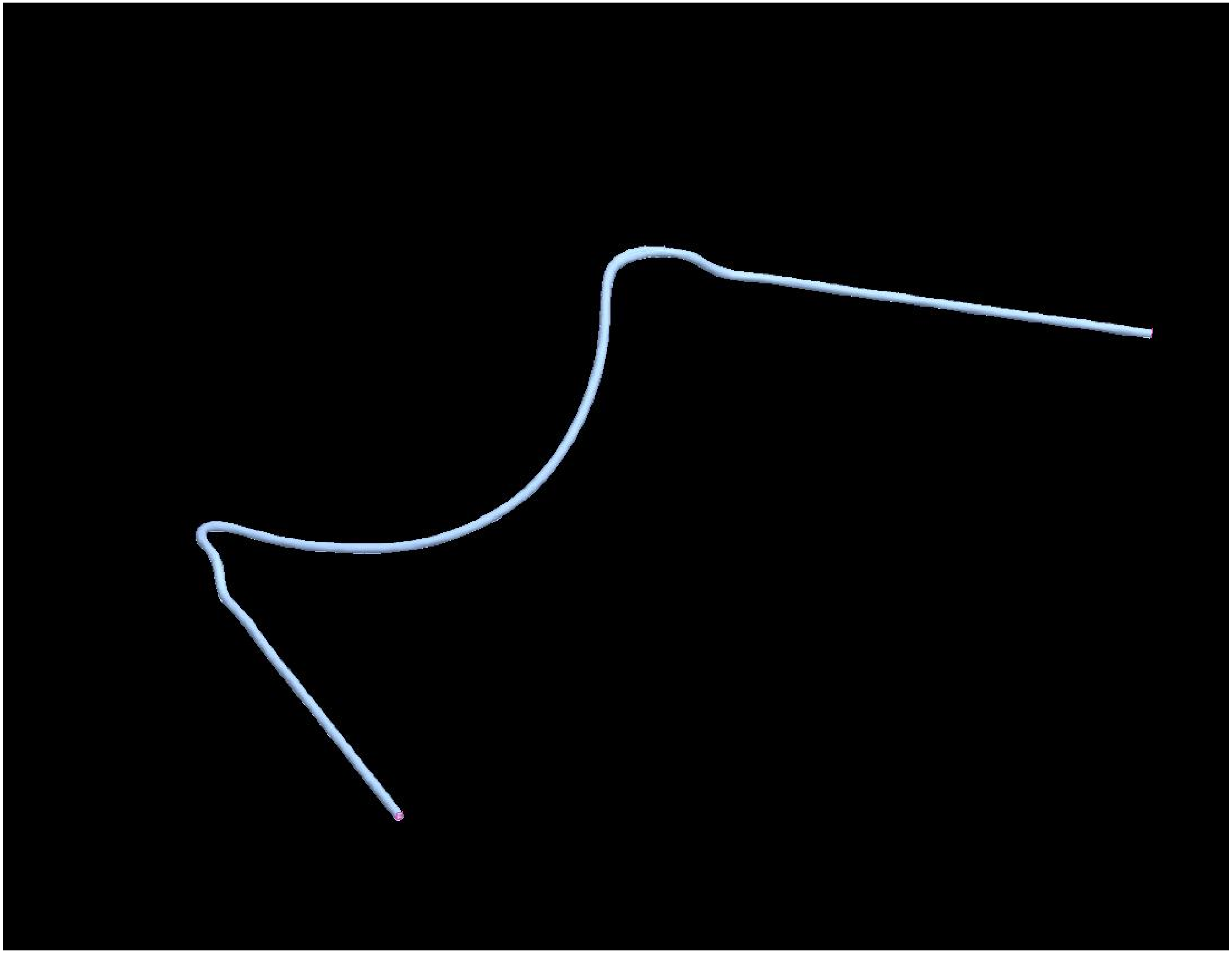
- 24 wires for thermocouples.
- 48 wires for heaters with integral thermocouples.
- 72 wires total per quadrant.
- Wires exit the outboard edge of the LLD at a toroidal location between tiles.



A Cooling System Assures that Temperature Returns to 200C Between Pulses [see Sandia analysis]

- Cooling by radiation is not adequate for operation at maximum duty cycle.
- Average heat flux across LLD surface is <100W/cm^2.
- Equivalent steady state flux for a 1.5sec/600sec duty cycle is .25W/cm^2 on plasma facing surface.
  - Equivalent steady state power for A=2337cm^2 is 584W per quadrant.
- Evaluate radiation from top and bottom surfaces to 50C sink with emissivity of 0.1:
  - Area = 2337+2362=4642cm^2
  - 200C→103W
  - 300C→255W
  - 400C→511W

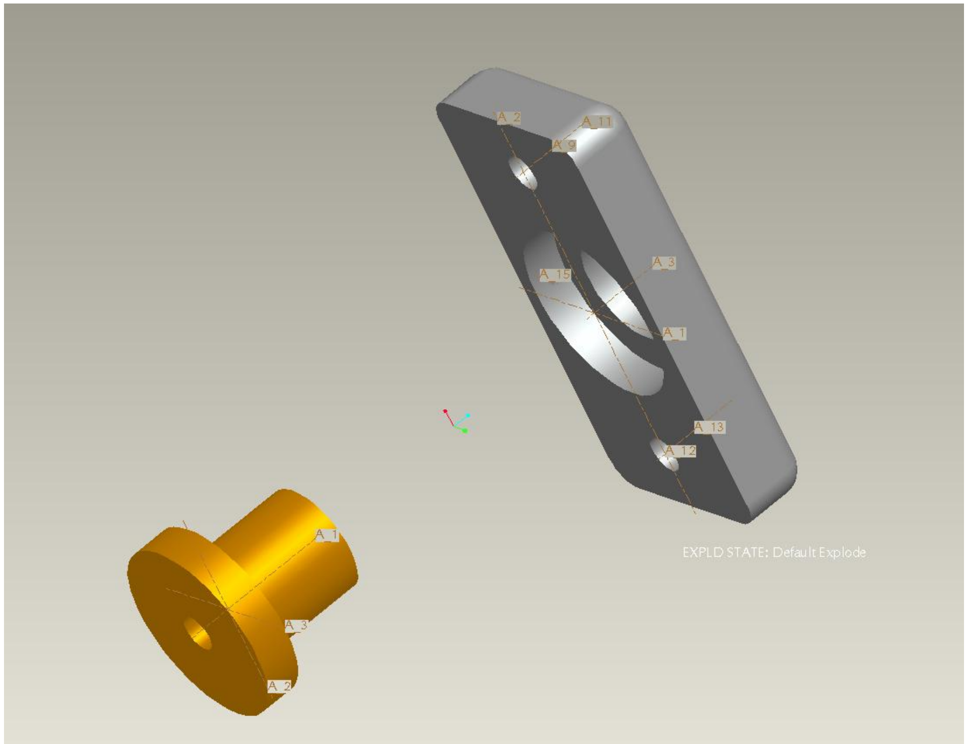

STYLE STATE: PLATE



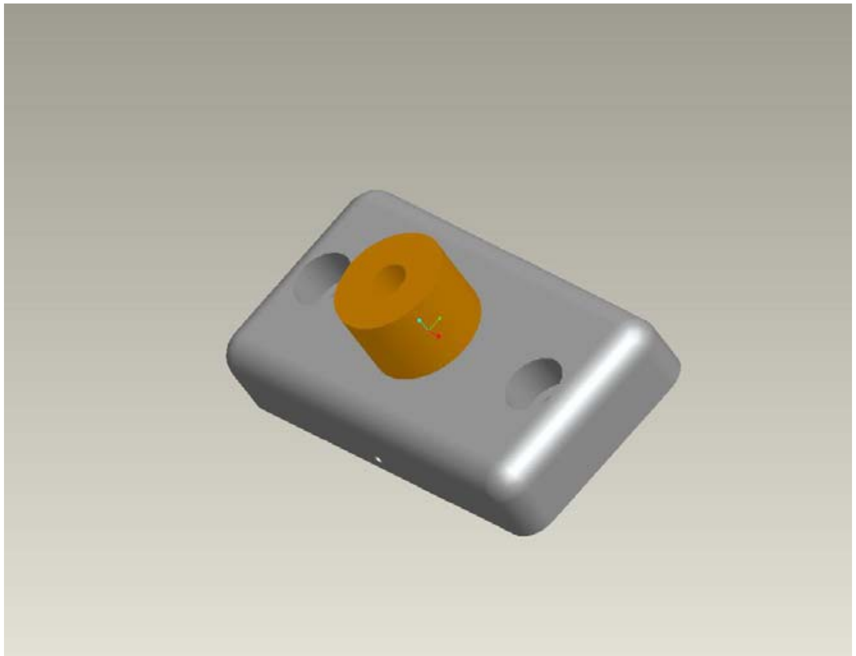
Supports Position the LLD, Accommodate Thermal Expansion, and Resist Electromagnetic Loads

- The LLD must not short out the passive stabilizer plates.
  - Single point ground to stabilizer plates.
  - Other support points are insulated.
- Plan for a 400C maximum temperature difference between LLD and stabilizer plates.
  - At R~33”, we have .211” expansion toroidally for one quadrant.
    - α~1.6*10^{-5}/K
- We will use five support points for each quadrant.
- A locating pin, near the outside edge, positions the LLD quadrant in the plane of the stabilizer plate.
  - Grounding strap from stabilizer plate to LLD near pin.
- Four insulating link supports at corners provide vertical positioning.
- The outer two supports provide radial positioning as well.

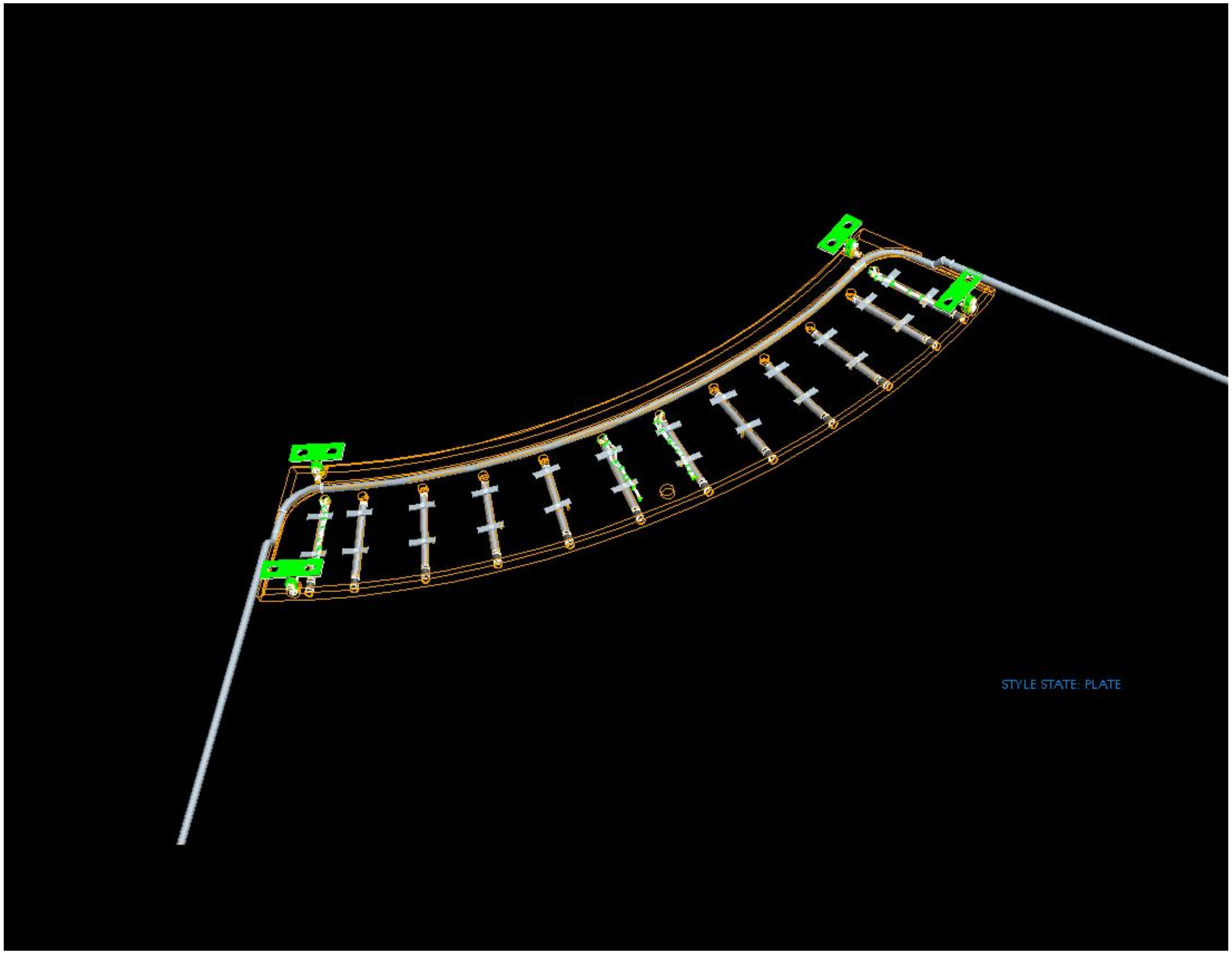
A Locating Pin Positions the LLD Quadrant in the Plane of the Stabilizer Plate



- 0.75" diameter plug
- Mounts to Passive Stabilizer with two ¼-20 screws

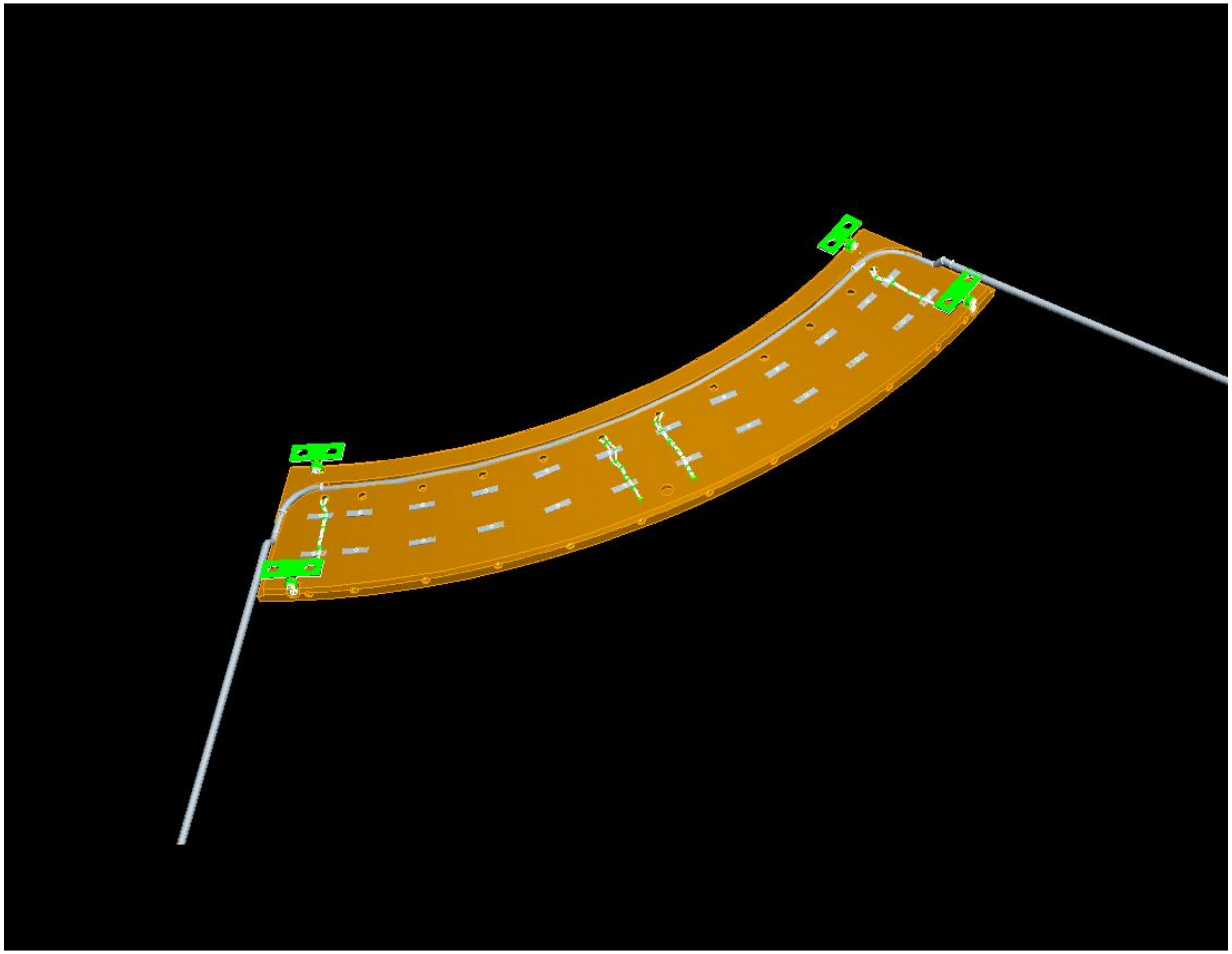


Locating Plug Mates to Hole in Bottom of LLD Plate



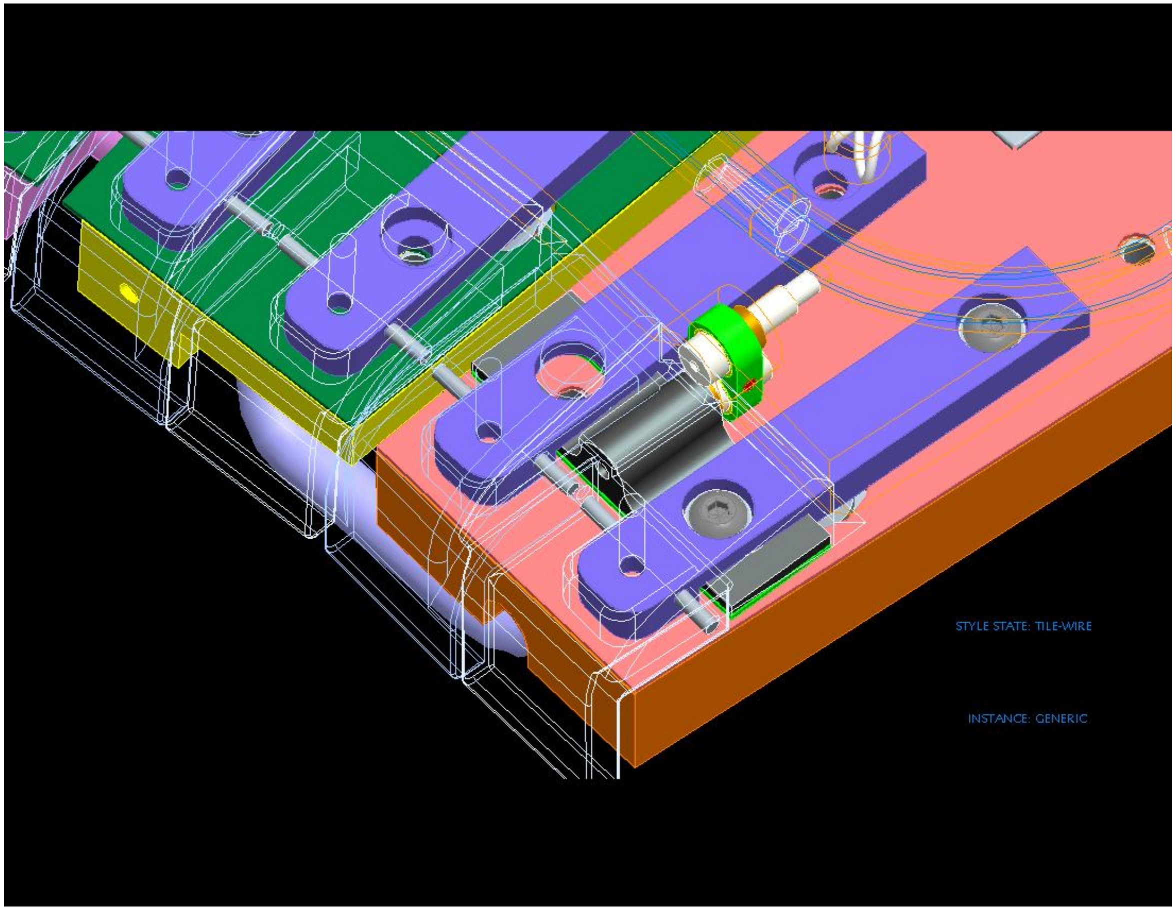
Four Insulating Link Supports at Corners Provide Vertical Positioning

- Links provide for .1” of toroidal motion with .01” drop towards passive stabilizers.
- Ceramic coated shoulder screws, aluminum bronze bushings and ceramic coated washers provide insulation.
  - Jet Lost α design



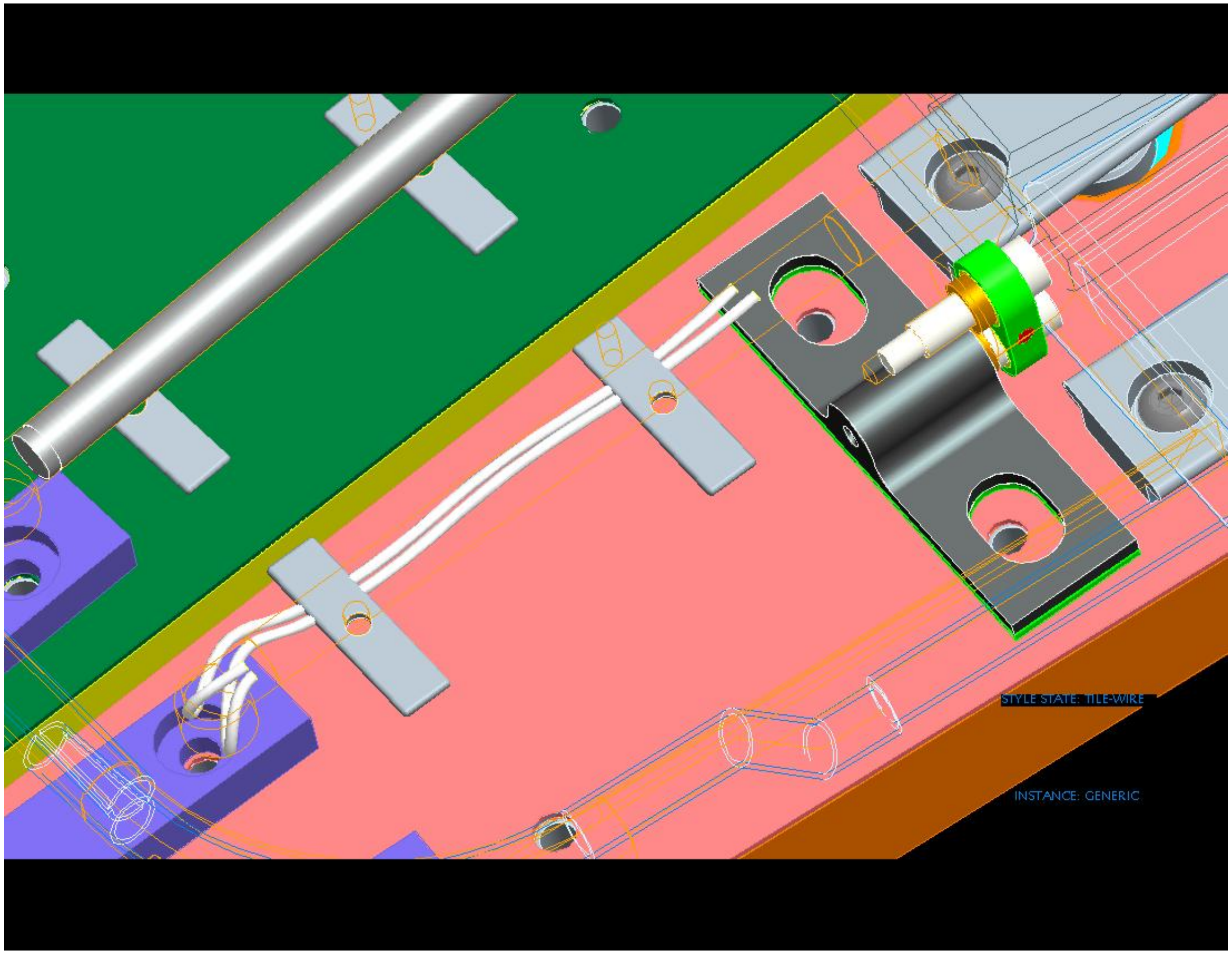
Ceramic Coated Screws and Washers Provide Insulation

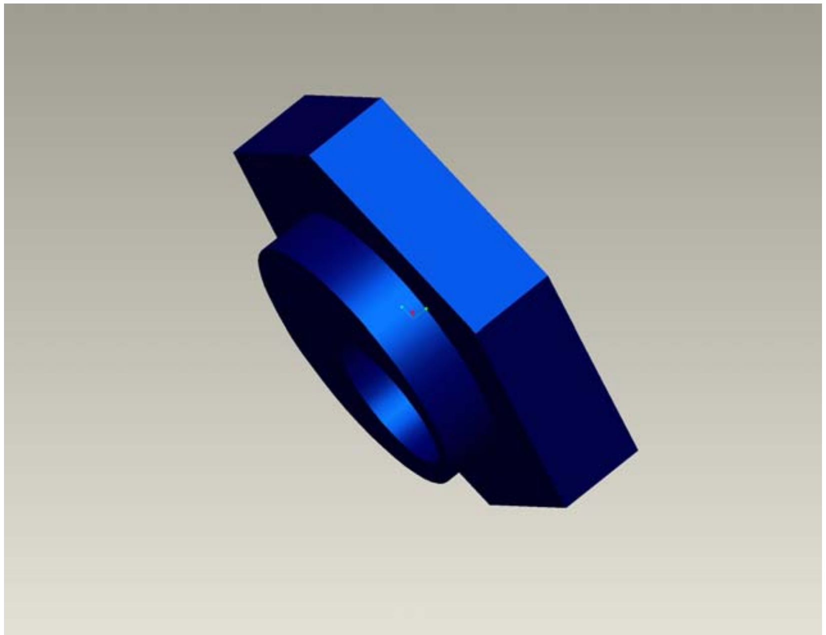
- Supports provide for .063” of nominal shim thickness, ±.19” horizontal travel.
  - Requirements come from Priniski measurements of passibe stabilizer plates summer 2007.
- One insulating break shown; insulation at both shoulder screws is easy.
- Shear strength of shoulder screw is 736lbf. [15ksi]

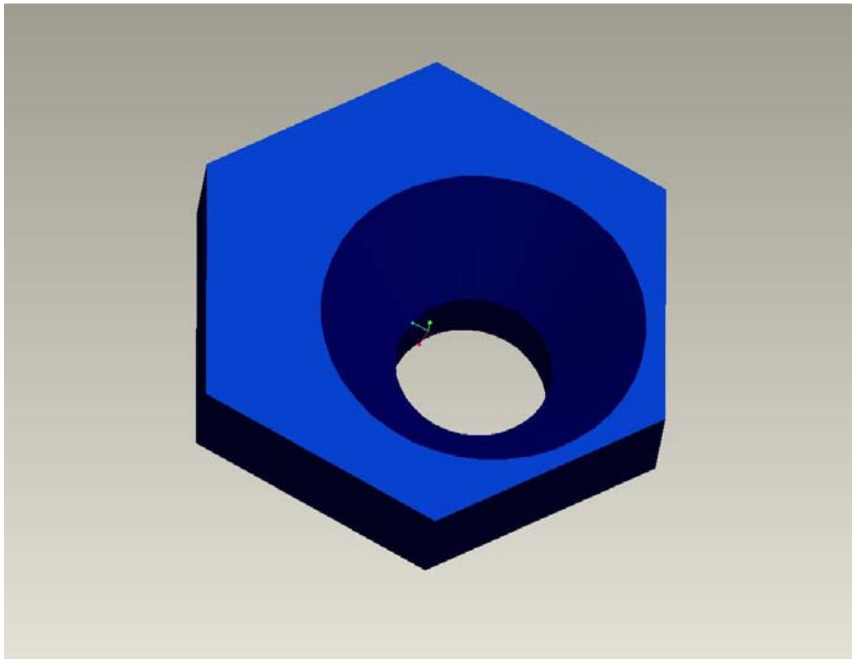


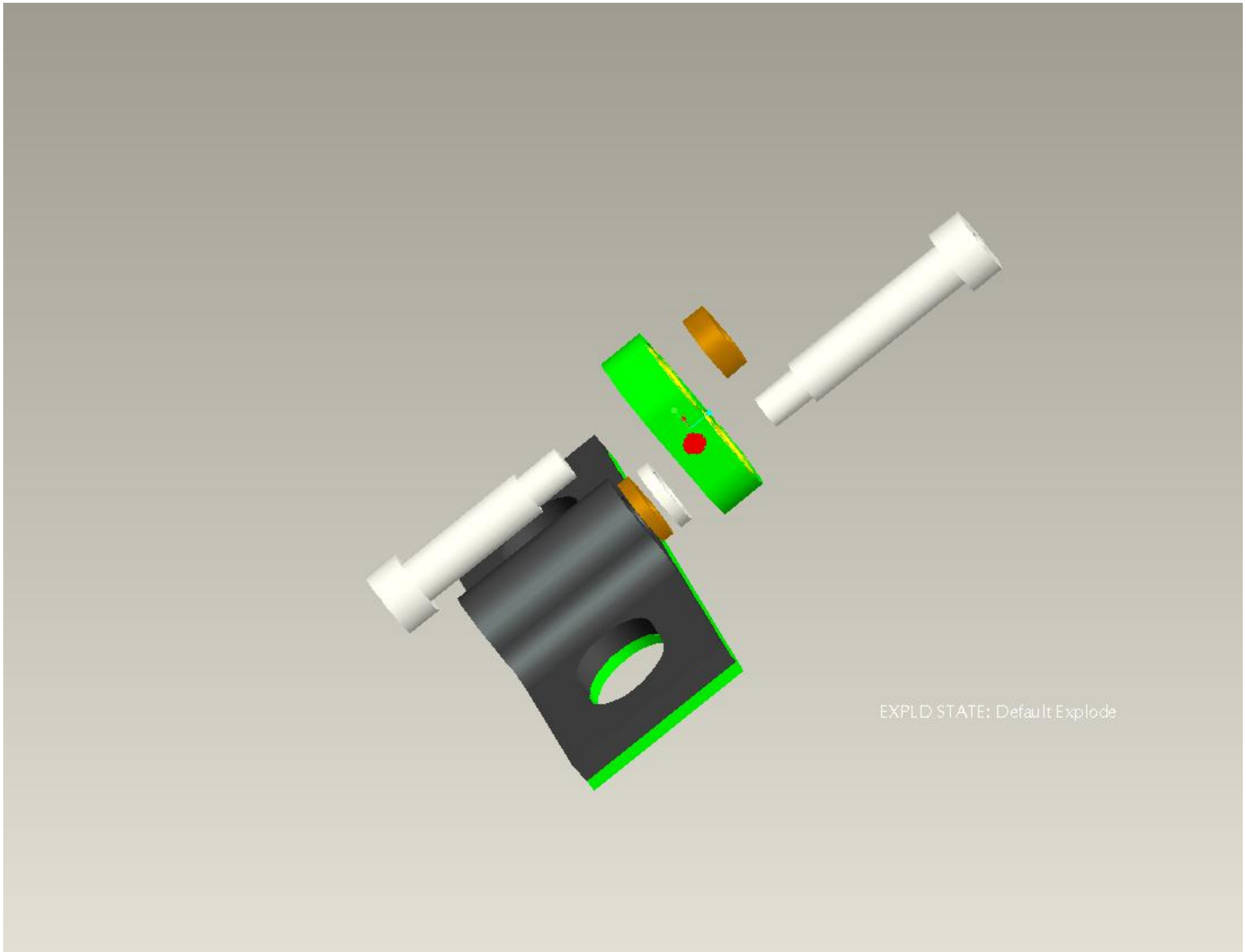
Slots and Eccentric Hex Bushing Provide Horizontal Adjustment

- Each support mounts to two existing ¼-20 tapped holes in passive stabilizer plate.
- A ¼-20 FHCS secures the eccentric hex bushing to the support and stabilizer plate.
- Set screws in bracket and LLD plate secure shoulder screws.





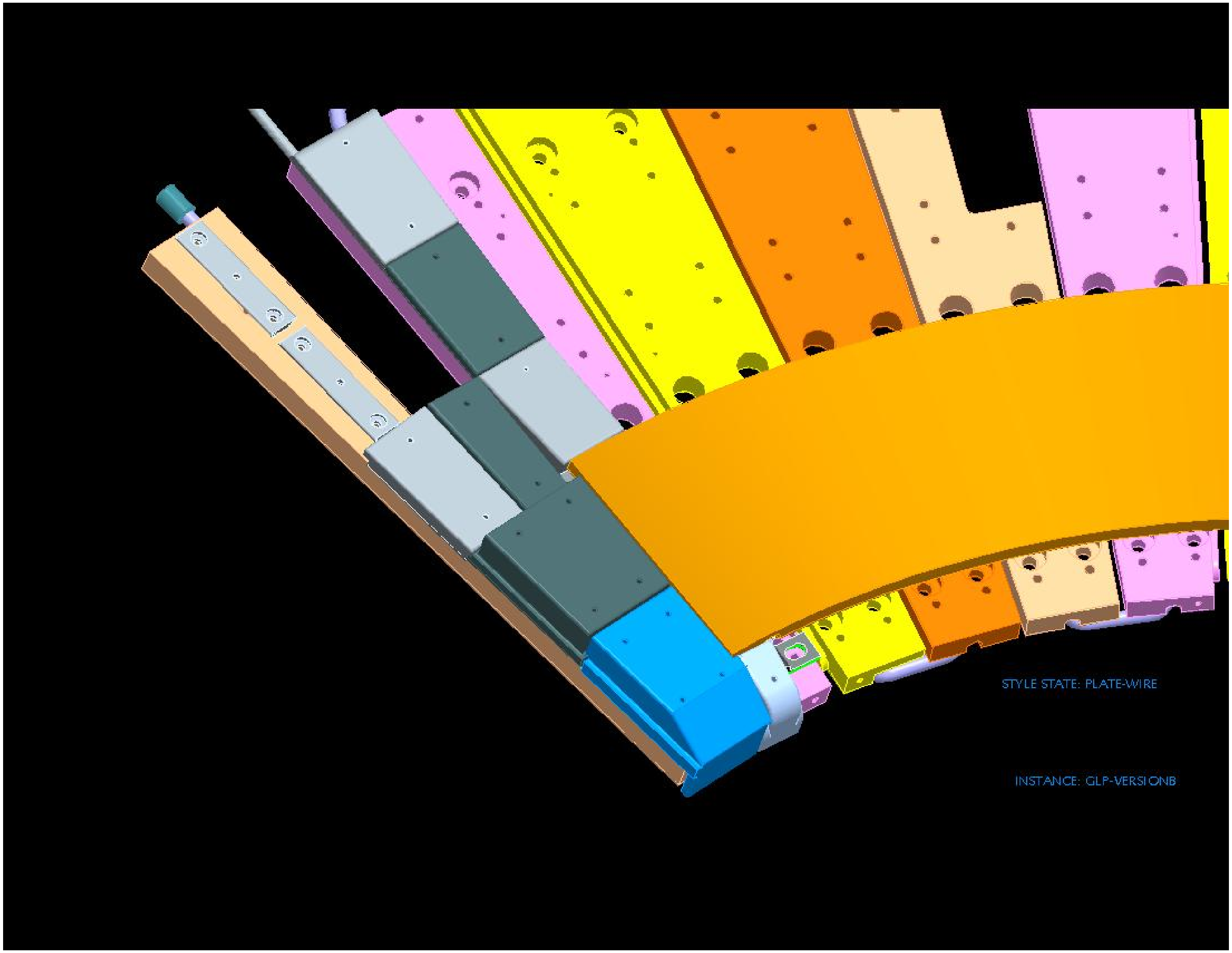


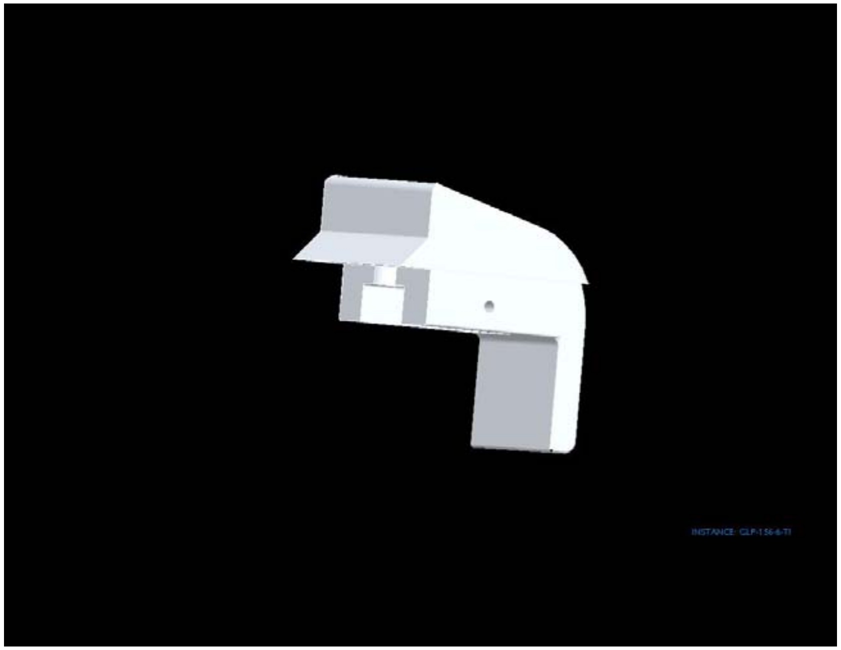


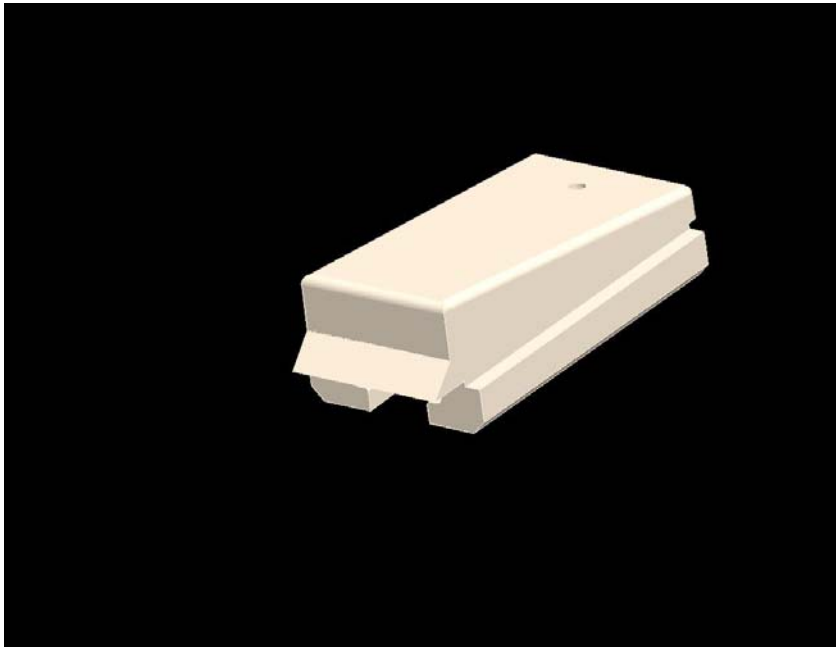
EXPLD STATE: Default Explode

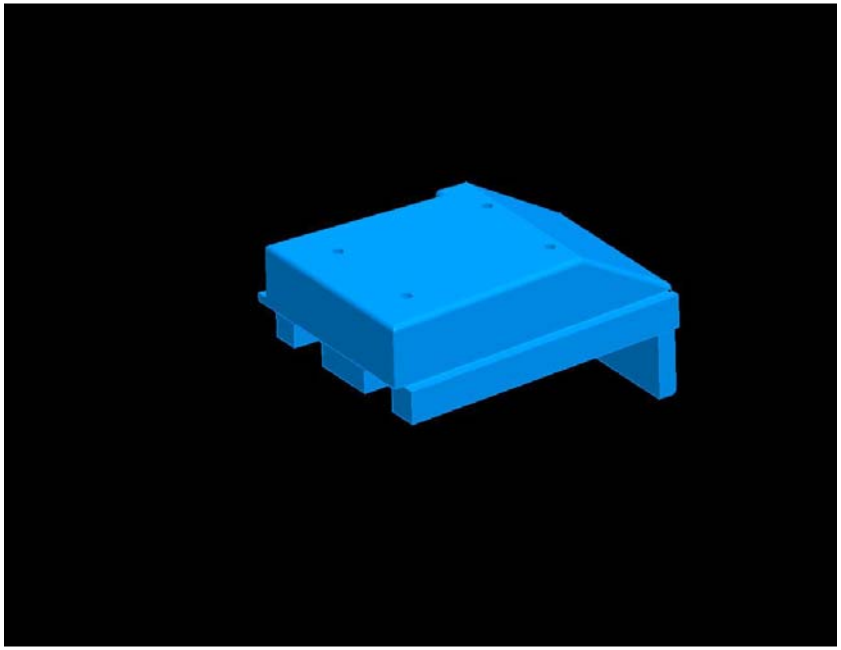
New Tiles are Required at LLD Boundaries

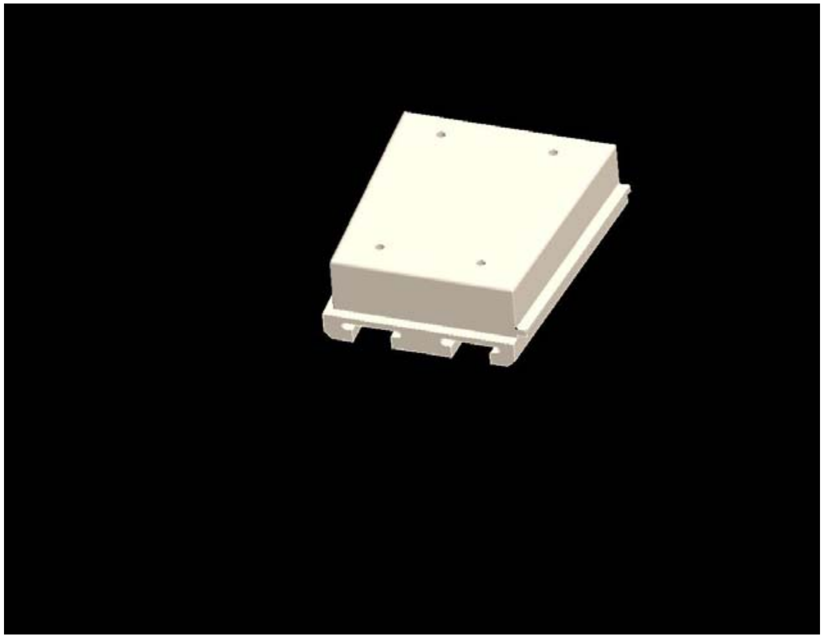
- Replacement tiles for row 1 and row 3 are required.
  - 192 total.
- Double width tiles at toroidal gap.
  - Eight total.
- Chamfered/rounded edges of tiles and LLD will be required.
- Relative thermal growth of LLD and passive stabilizer assembly must be accounted for.
  - ~0.30cm [.12in] gap toroidally.
- Row three tiles incorporate transition from 1.00in to 1.50in above passive stabilizer surface.


STYLE STATE: PLATE-WIRE
INSTANCE: GLP-VERSIONB


INSTANCE: GLP-156-6-T1







Fabrication

- Brazing is a feasible concept.
  – Lower temperature braze for cooling tube after plate bending and machining.
  – We have extensive experience brazing copper to stainless steel.
- HIP bonding of stainless steel to copper may also be a feasible technique, but further development is required.
- The curved plate presents the challenge.
- Supports are straightforward.

Initial Fabrication Step is Constructing a Cu/St.Stl. Flat Plate

- Brazing is a viable option that does not involve R&D.
  - Cu/SS brazing is a routine process.
  - Need to start with ~0.1” thick SS plate, machine off excess.
  - Requires a second braze for cooling tube.
- Developed view of 85degree segment fits into a 46” * 16” plate.
  - Within capabilities of numerous commercial brazing facilities.
  - Near limit of PPPL furnace.
- Hot Isostatic Pressing [HIP] may also be feasible.
  - Allows maximum temperature braze for cooling tube.
  - Cost of fixtures is an issue.
  - Further development is required.

Plates are Bent and Machined to Final Configuration

- Bend in steps to achieve conical geometry.
  - 3.75degree or 7.5degree intervals.
  - Bend angle is 1.3degrees or 2.6degrees.
  - Bend, anneal, measure, bend again if required.
- Machine to final configuration.
  - Holes, cooling tube channel, chamfers etc.
- Vendors such as Hollis, General Tool, Major Tool, Ranor are capable of these processes.

Assembly

- Once a quadrant is fabricated, the heaters, thermocouples, wires and supports are installed and tested.
- 2man-weeks per quadrant.
- In the vessel, the locator plug is first installed on the appropriate passive stabilizer plate.
- Using a locating jig, the quadrants are positioned in the vessel, one by one, using nominal shims.
- Position of each quadrant is measured, revised shim thicknesses are calculated.
- Each quadrant is then secured, and the routing of wires and cooling leads is finished.
- After final measurement, remaining tiles are installed.
- Assembly →2man - weeks per quadrant inside vacuum vessel.

Thermal Analysis

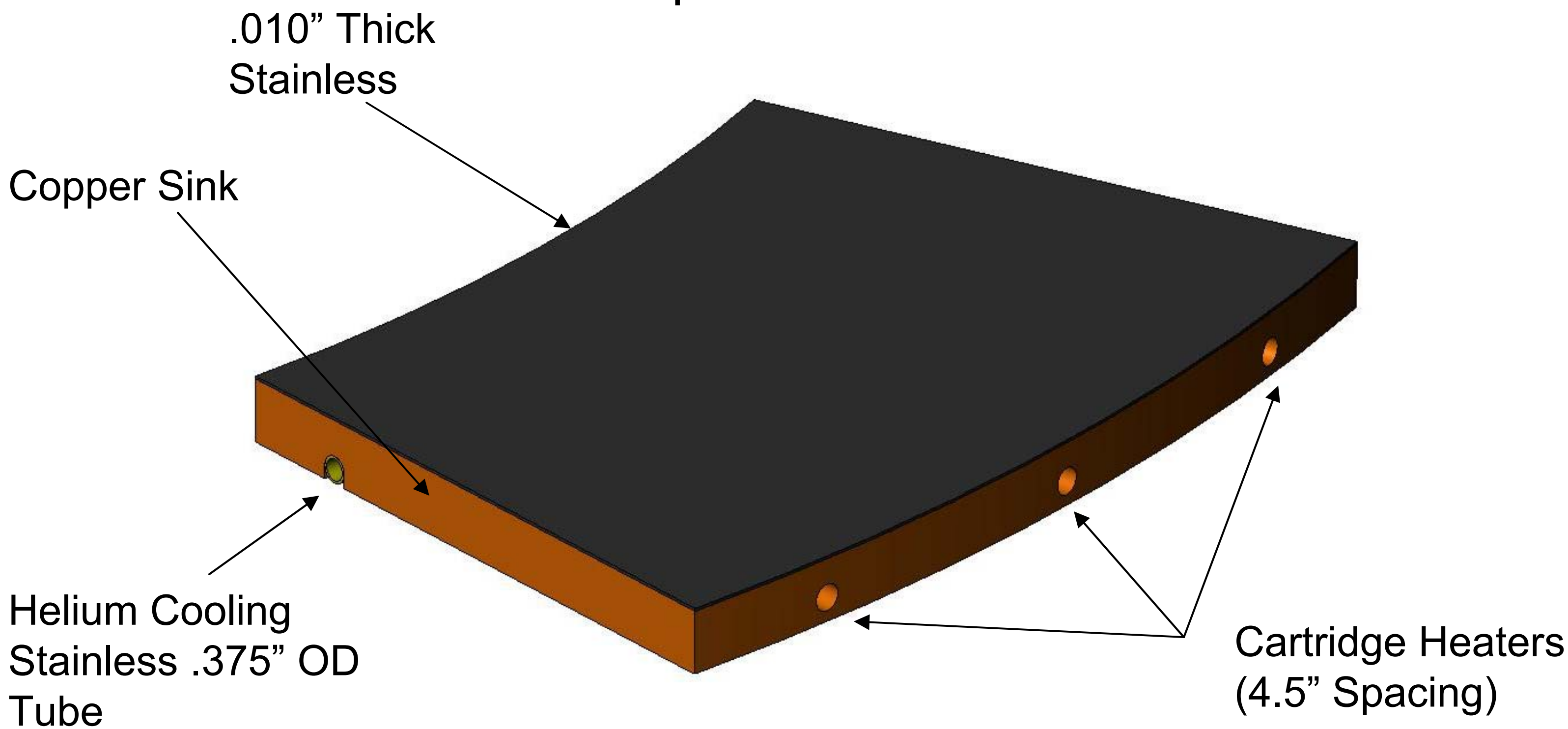
- Bounding calculations presented at CDR.
- 3-D finite element analysis performed by Sandia verifies initial calculations and provides more detailed results.
- Summary of CDR results:
  - Film coefficient > .06W/cm^{2}K can be obtained with He.
    - Verified by Sandia tests [.09W/cm^{2}K]
  - 12 * 500W heaters provide adequate power.
  - Acceptable front surface temperature rise for 200ms pulse.
  - Temperature drop between heaters is acceptable, even if one heater fails.
  - Equilibration and cool down times are reasonable.

3-D Finite Element Analysis Verifies CDR Calculations and Provides more Detail

- Summary of Sandia Results
  - Heating power is adequate.
  - Cooling system should be shut off during heating; it absorbs ~30% of heater power.
  - Front surface temperature rise is less than 200K for a strike point sweep rate of 50cm/sec.
  - Cool down time with Helium is adequate.
  - Radiation only gives ~1hour.
- <<Sandia analysis to be inserted here.>>

LLD Thermal Analysis

April 7th 2008



Material	Temp (K)	Density [Mg/mm^3]	Conductivity [mW/mmK]	Specific Heat [mJ/MgK]	emissivity
Copper	273	8.96E-09	401	3.90E+08	0.3 (slightly Oxidized)
Stainless Steel	273	7.968E-09	13.7	4.65E+08	
	923	7.693E-09	23	6.03E+08	0.2 (vapor deposited Moly)

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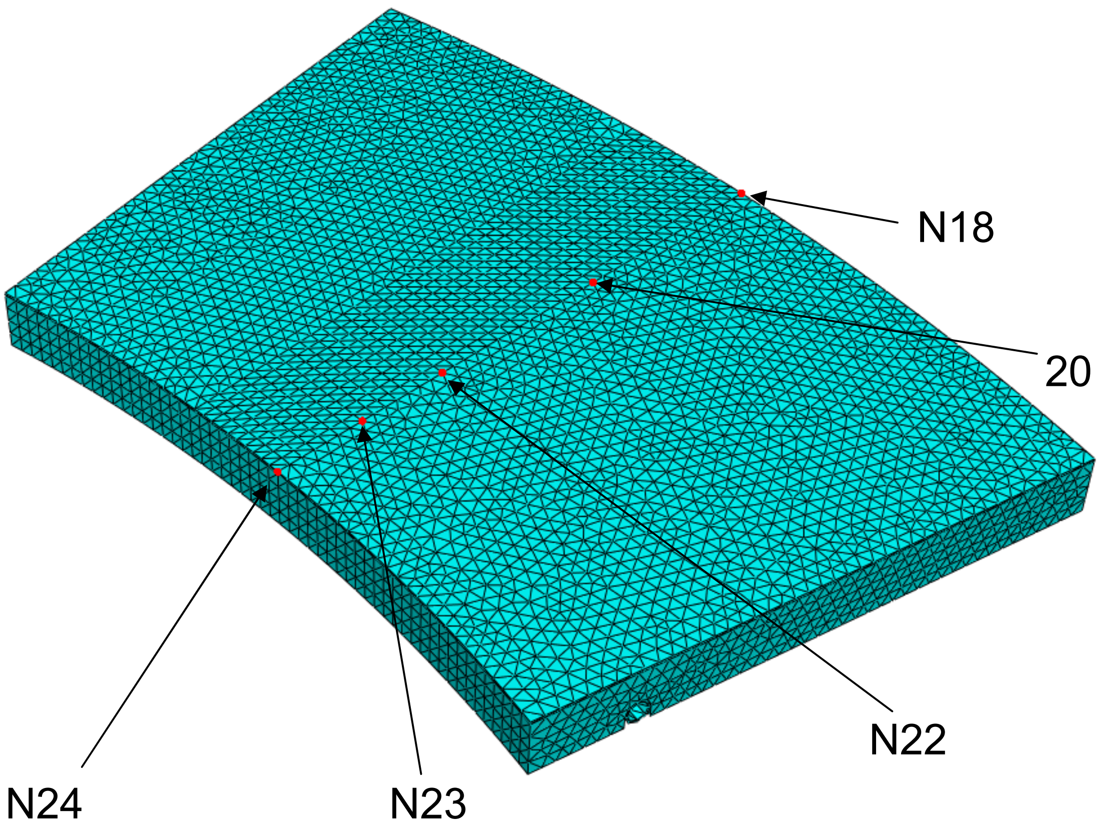
Node Locations for Temperature Response Plots



Volume Cu (mm^3)	Volume SS (mm^3)	
1.38E+06	6437	
Mass (Cu)	Mass (ss)	Mass (Kg)
0.0123	5.02E-05	12.39

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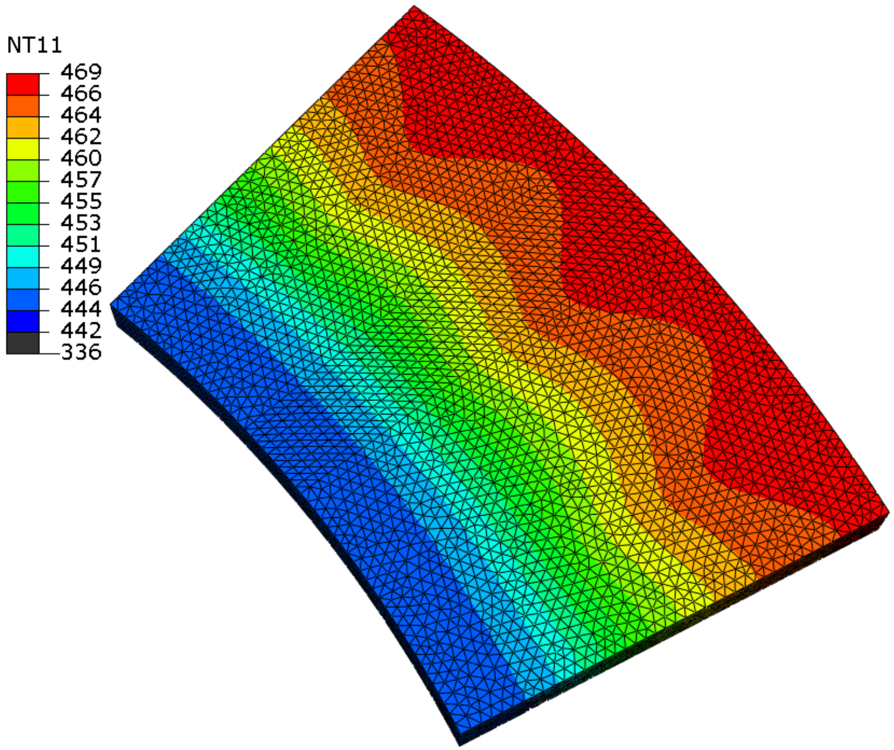
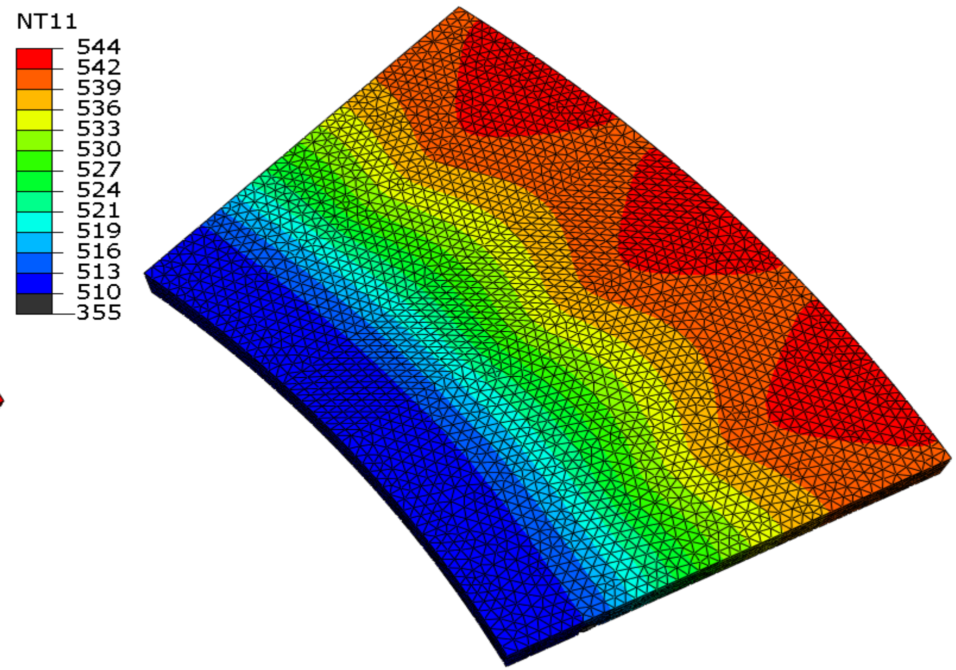
Temp Profile 3 Heater Simultaneous Heating and Cooling (900 W/M^{2}K He cooling).

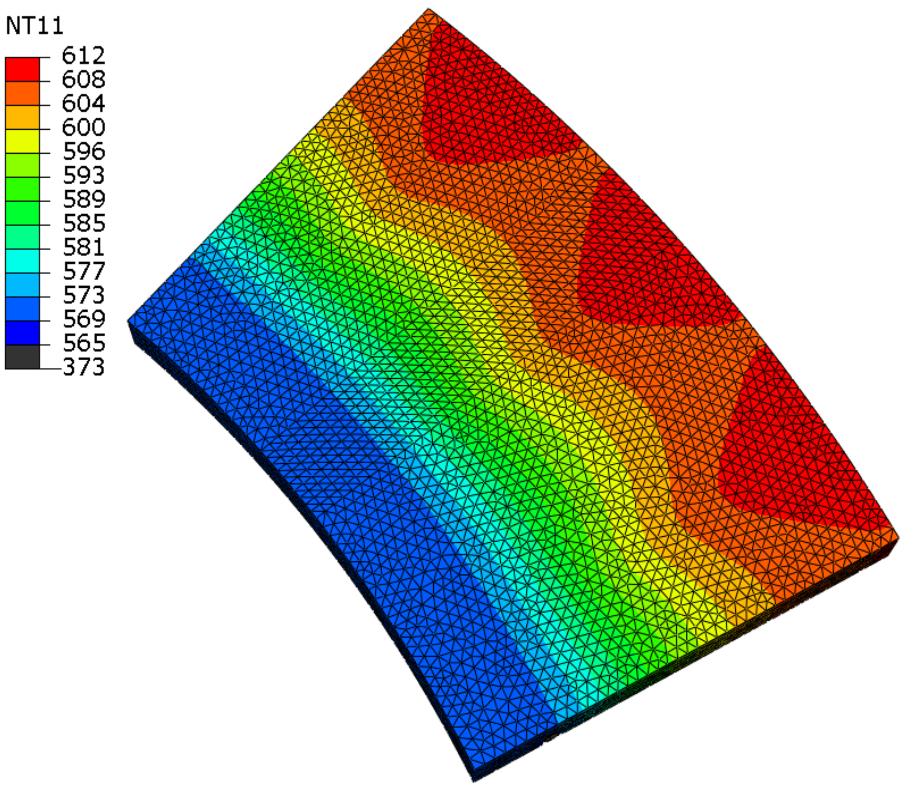


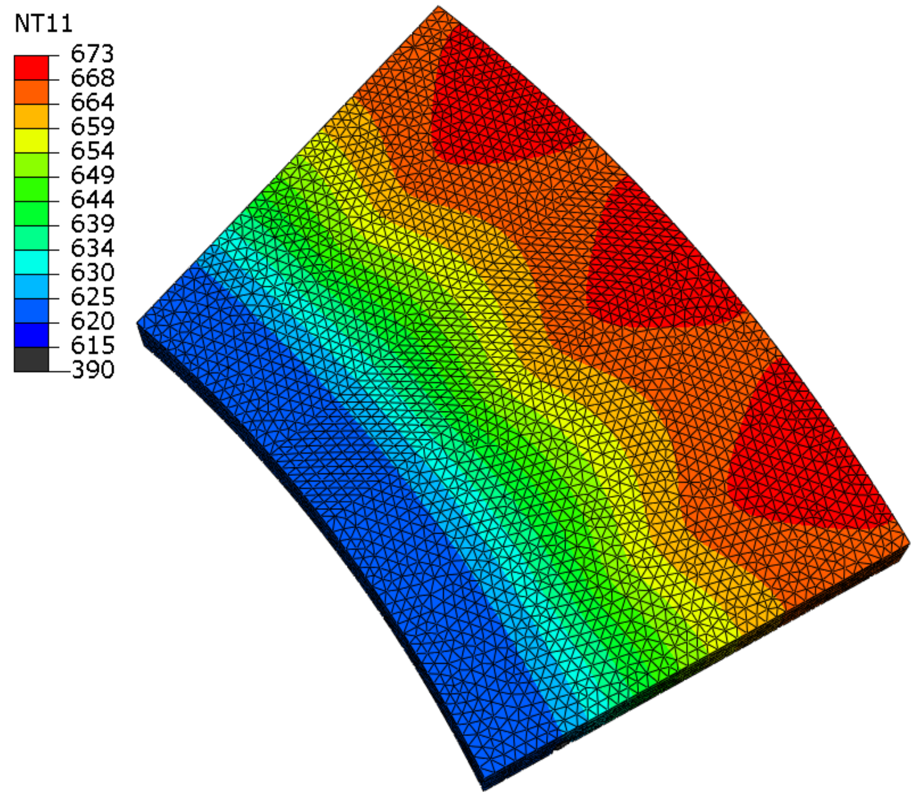


- Time Step 170 Minutes
- 200W Heating (53 mW/mm^2)

- Time Step 170 Minutes
- 300W Heating (79 mW/mm^2)

Temp Profile 3 Heater Simultaneous Heating and Cooling (900 W/M²K He cooling).





- Time Step 170 Minutes
- 400W Heating (105.25 mW/mm^2)

- Time step 170 Minutes
- 500W Heating (131.6 mW/mm^2)

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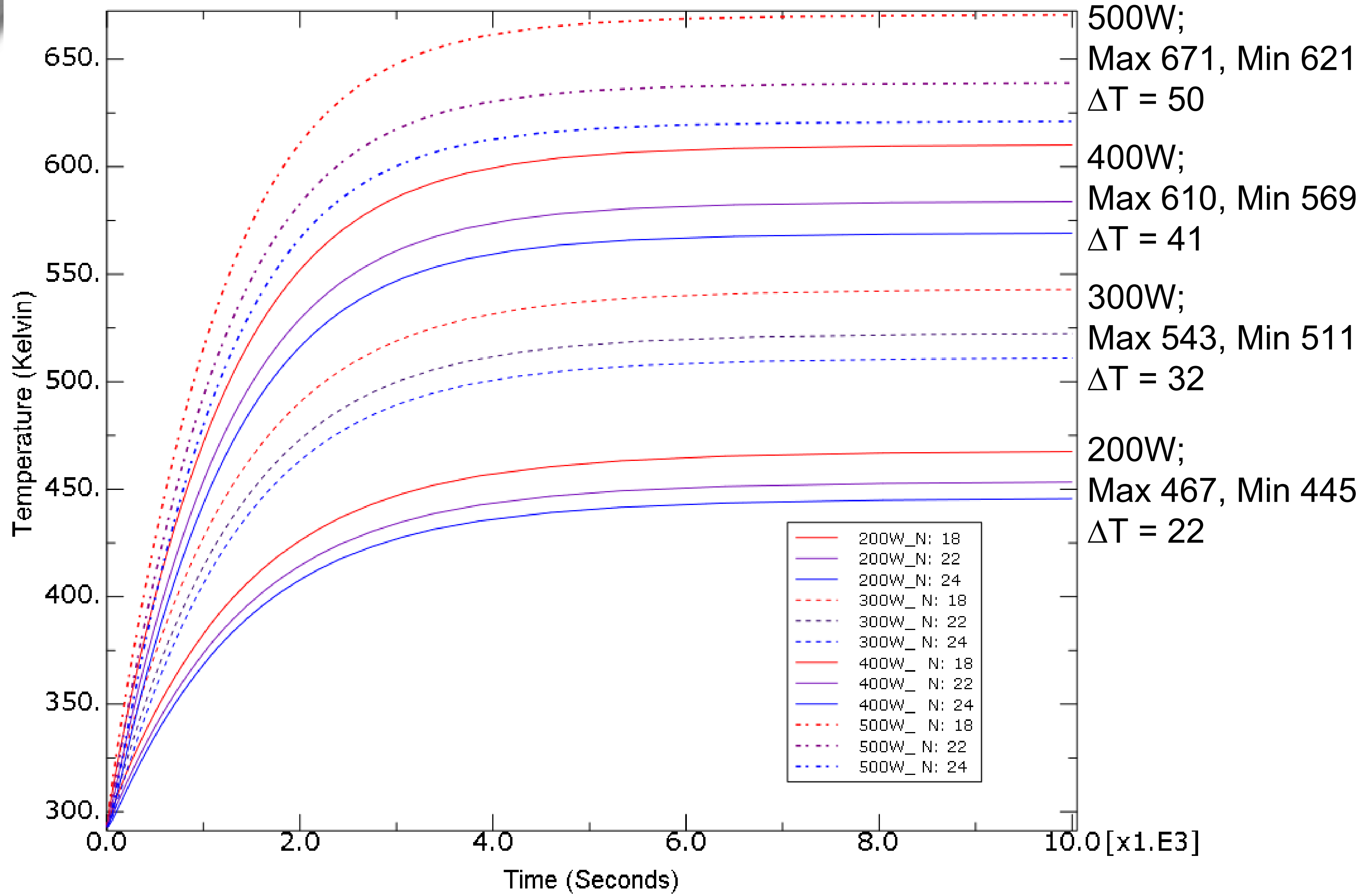
TEMPERATURE RESPONSE FOR 3 HEATERS WITH 900 W/M^2K He COOLING



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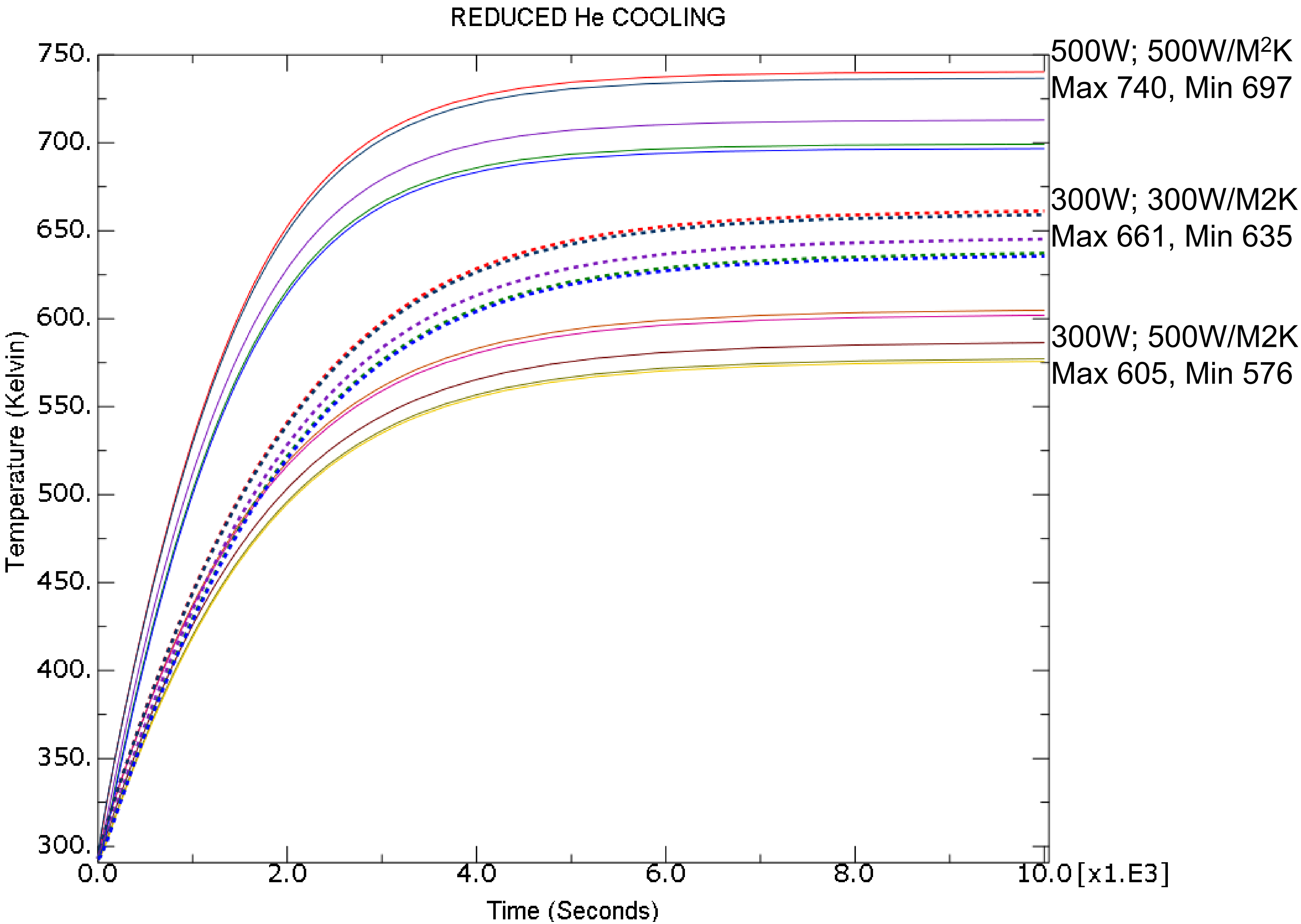

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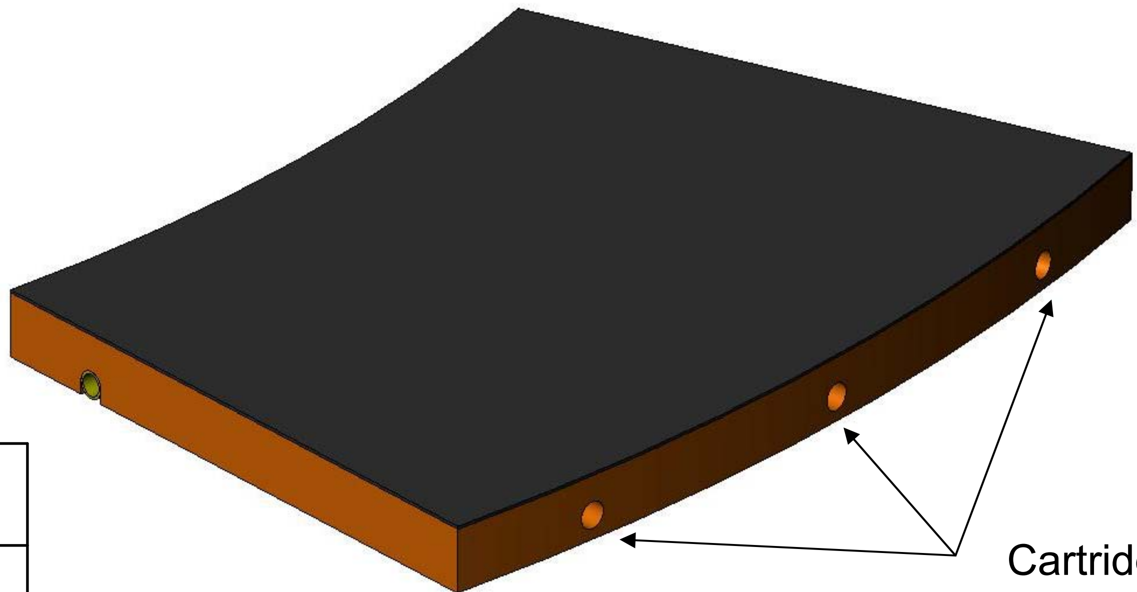
LLD Thermal Analysis
Heating with Radiation Only



Watts	Heat Flux (mW/mm^2)
100	26
200	53
300	79
400	105
500	132

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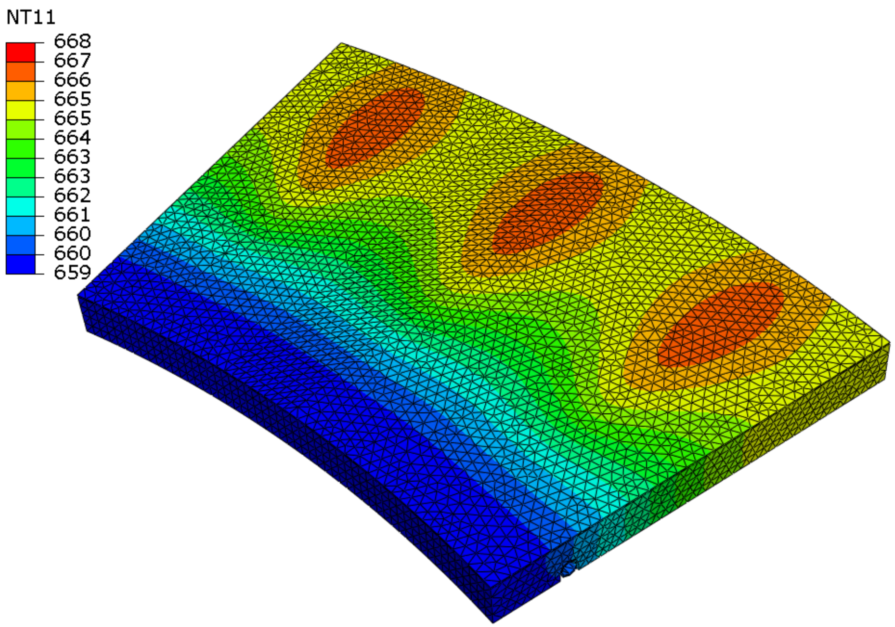
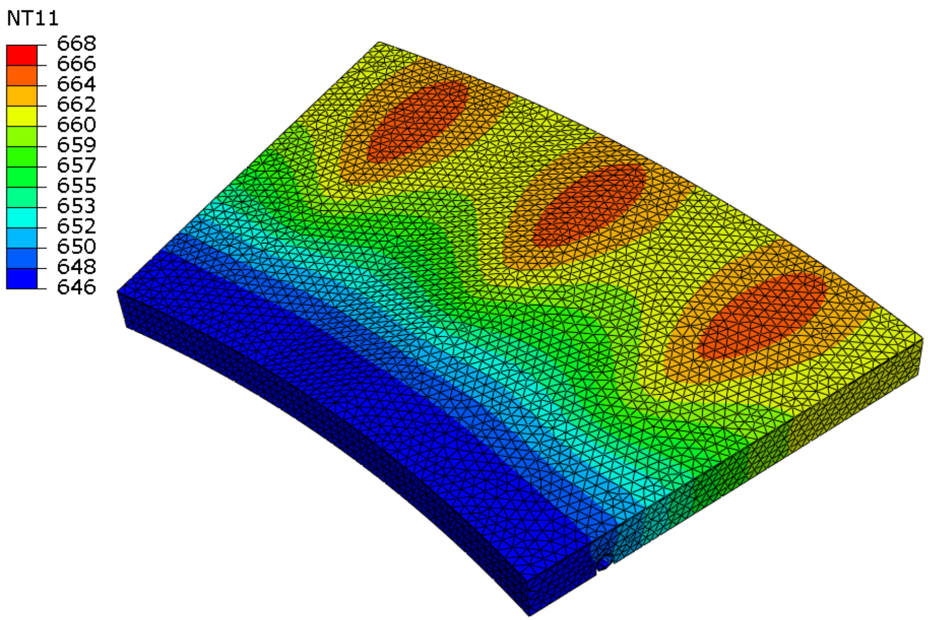
Temp Profile 3 Heater 200W Heating with Radiation only



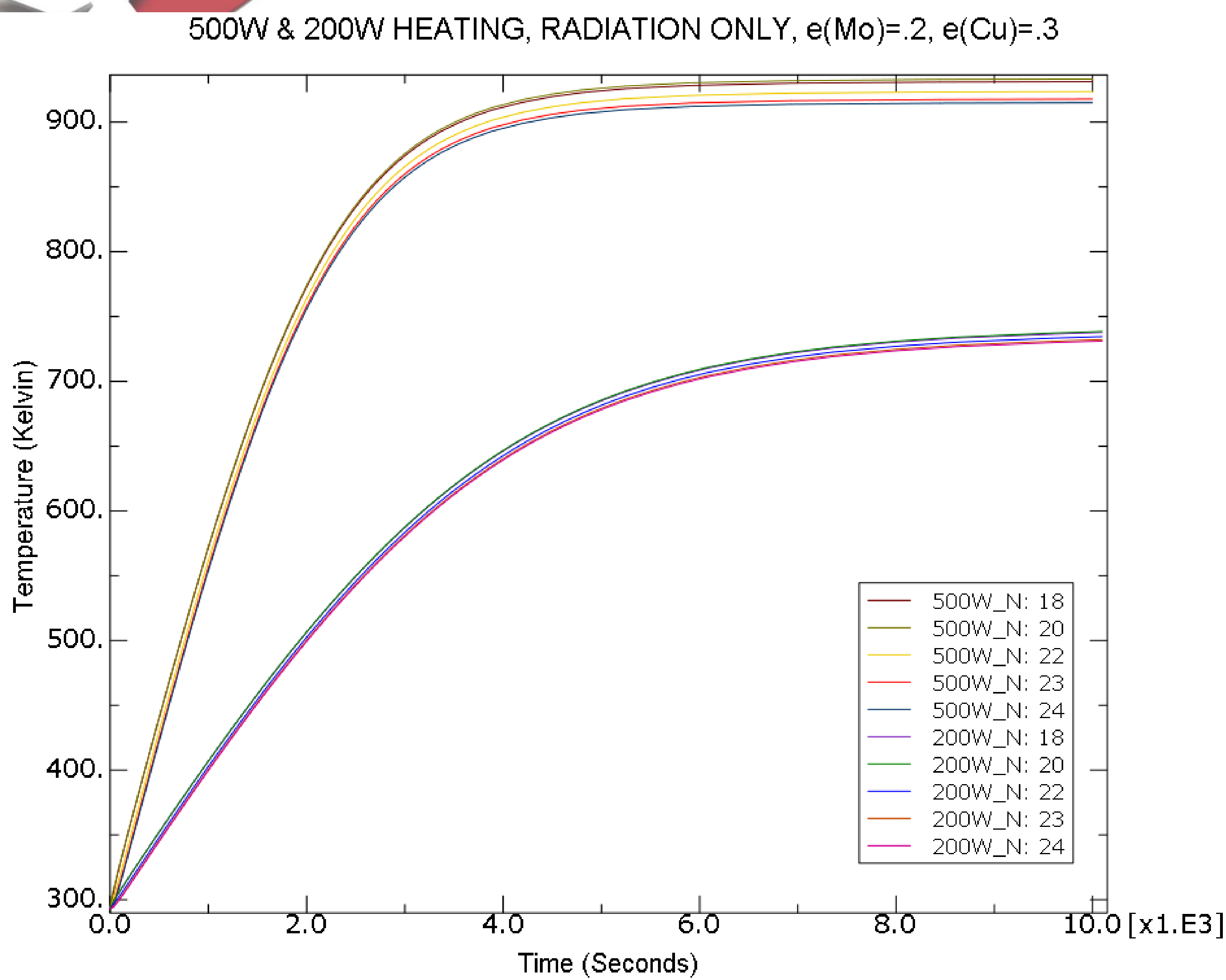
200W

Time Step 75 minutes

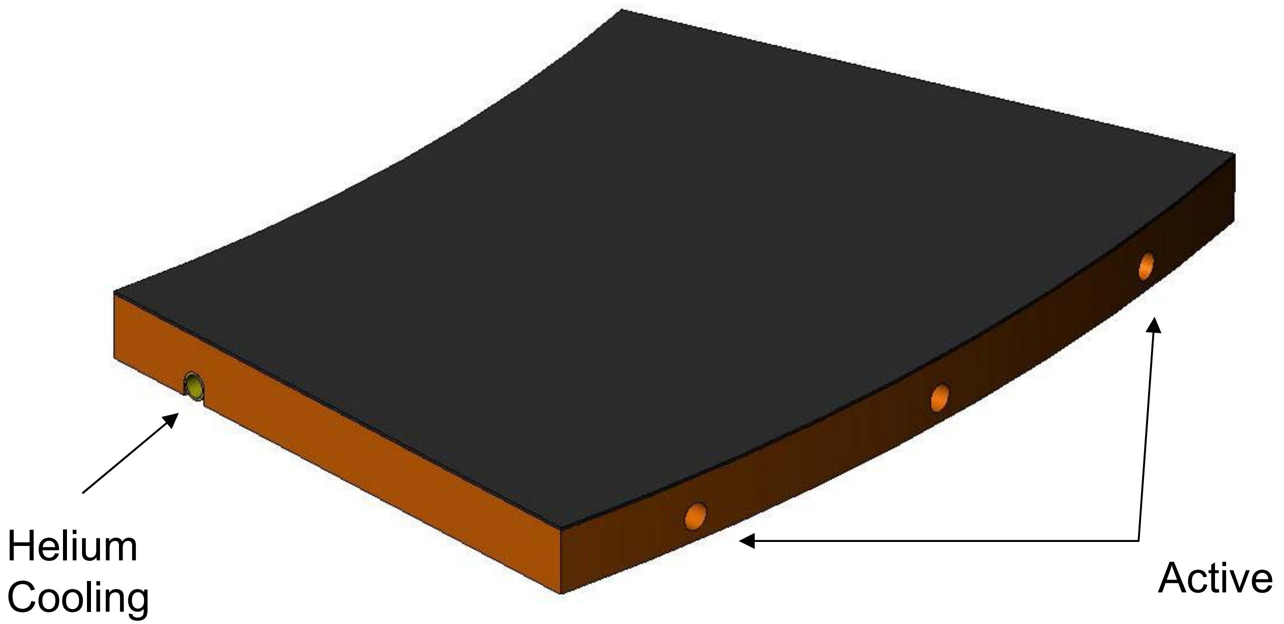


500W

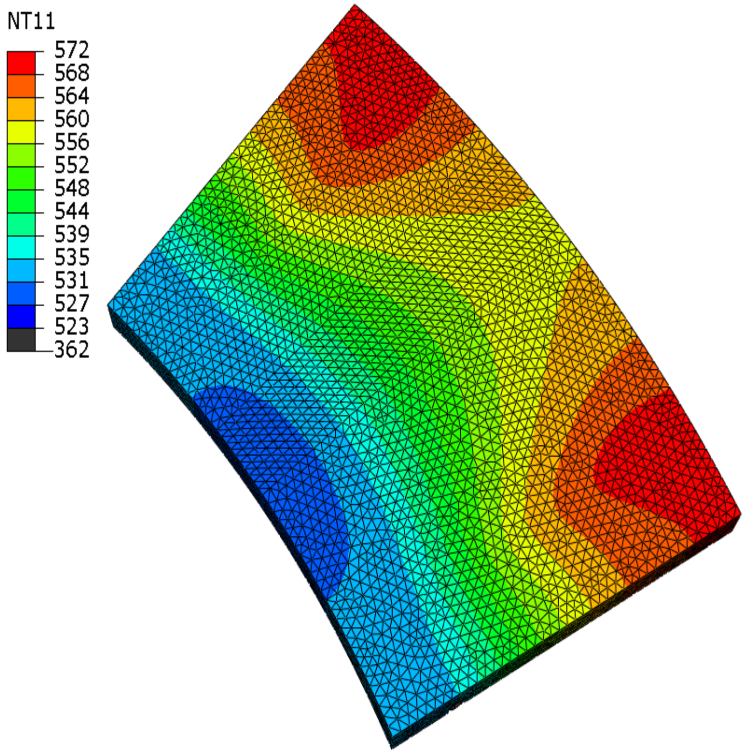
Time Step 25 minutes

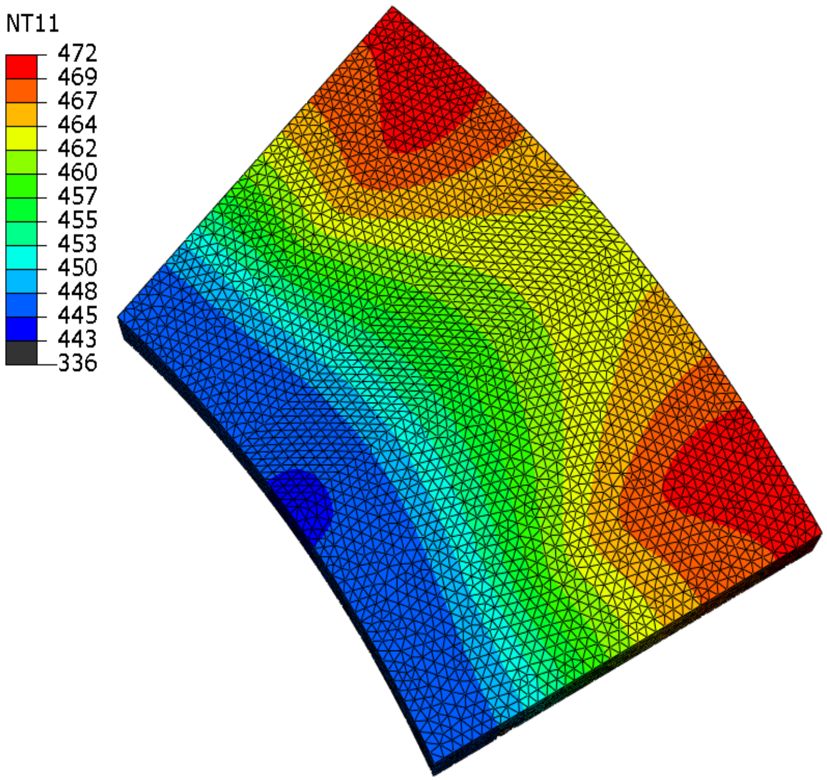

500W & 200W HEATING, RADIATION ONLY, e(Mo)=.2, e(Cu)=.3
Temperature (Kelvin)
900.
800.
700.
600.
500.
400.
300.
0.0
2.0
4.0
6.0
8.0
10.0 [x1.E3]
Time (Seconds)
500W_N: 18
500W_N: 20
500W_N: 22
500W_N: 23
500W_N: 24
200W_N: 18
200W_N: 20
200W_N: 22
200W_N: 23
200W_N: 24

LLD Thermal Analysis
Simultaneous Heating and Cooling
2 Heater Steady State.



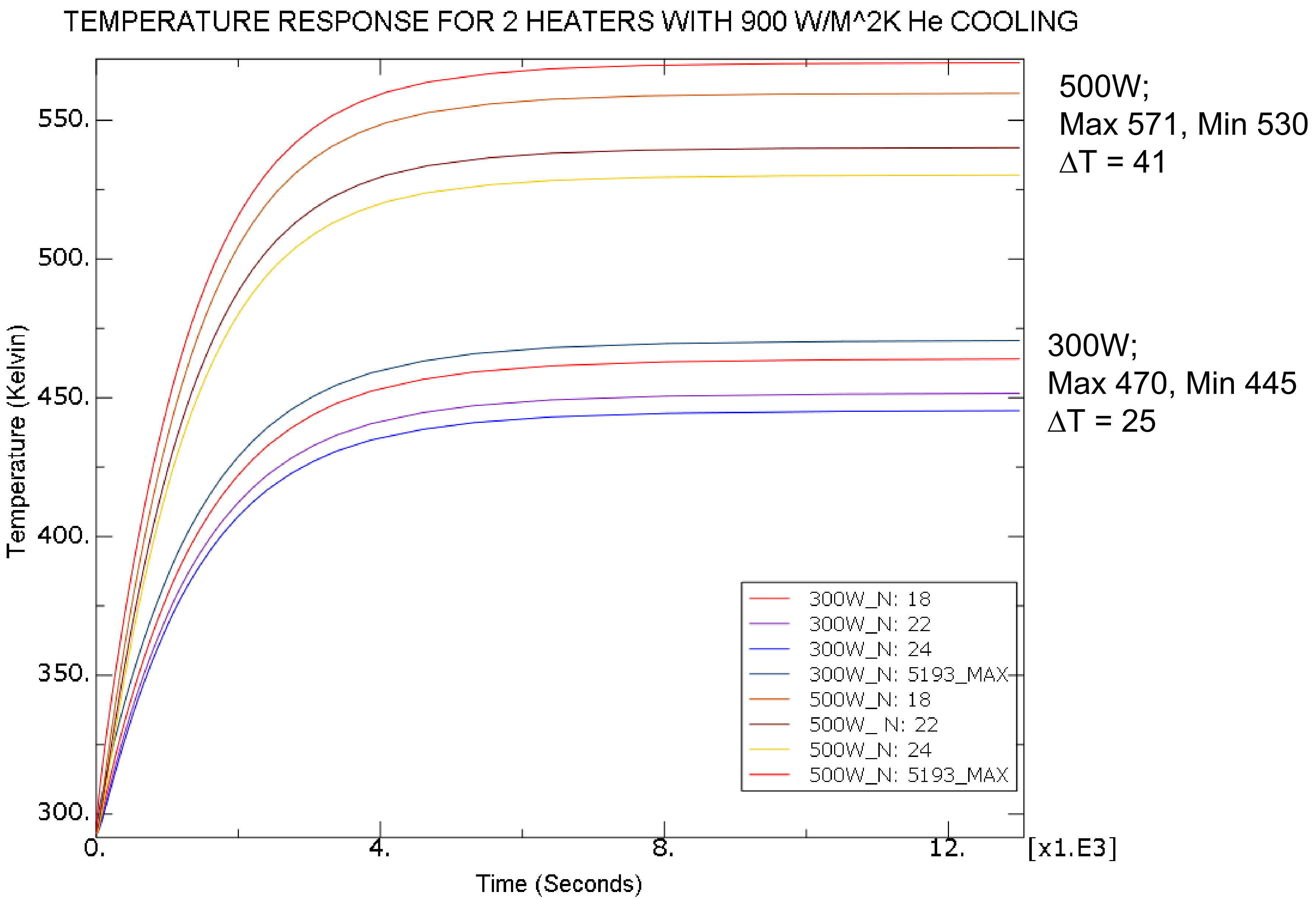
Temp Profile 2 Heater Simultaneous Heating and Cooling



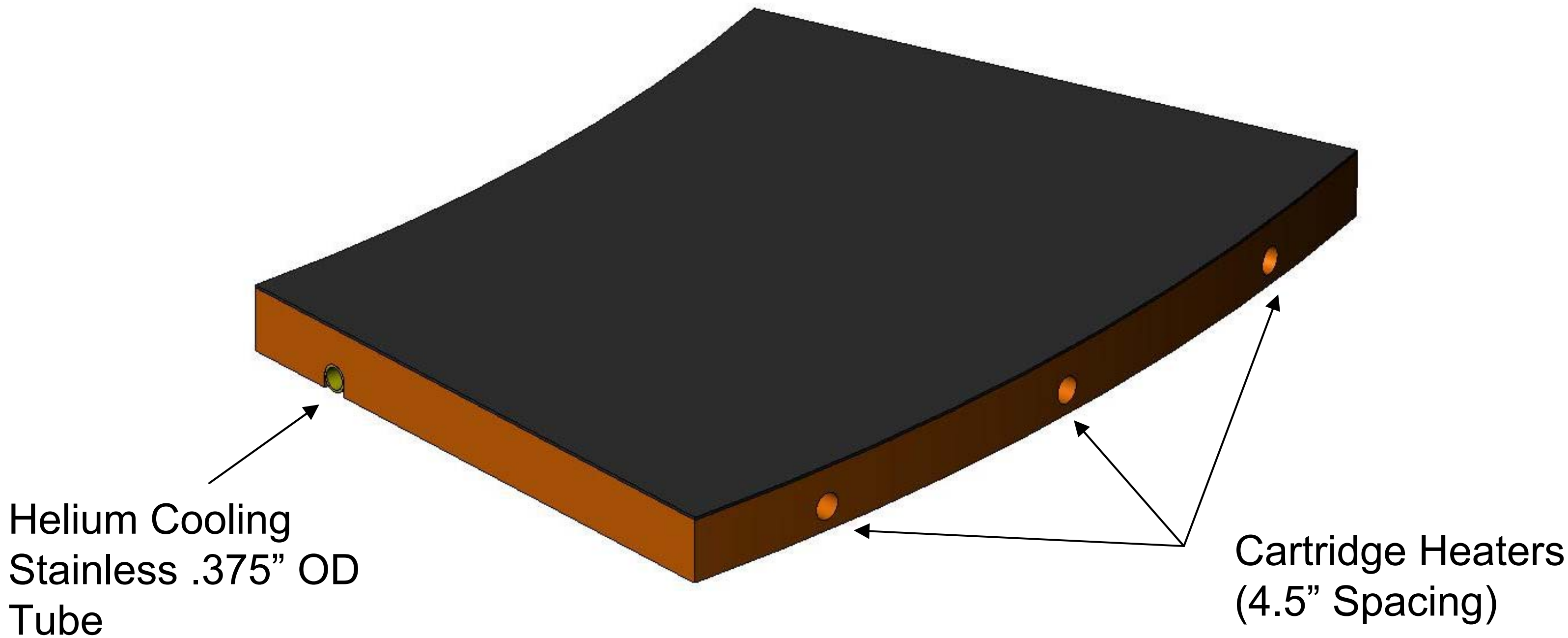


- Time Step 220 Minutes
- 500W Heating (131.6 mW/mm^2)

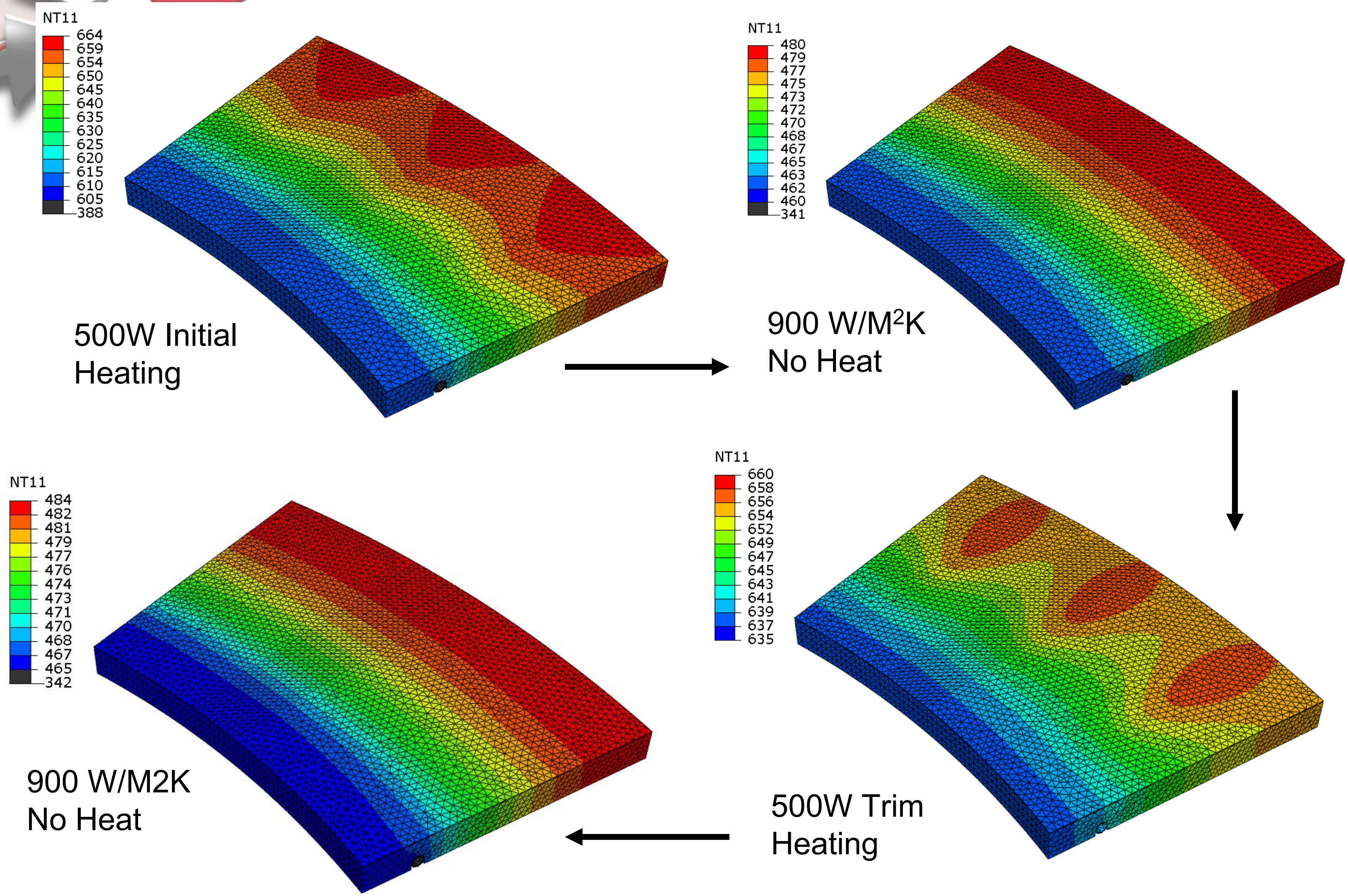
- Time Step 220 Minutes
- 300W Heating (131.6 mW/mm^2)


TEMPERATURE RESPONSE FOR 2 HEATERS WITH 900 W/M^2K He COOLING
Temperature (Kelvin)
550.
500.
450.
400.
350.
300.
0.
4.
8.
12.
[x1.E3]
Time (Seconds)
300W_N: 18
300W_N: 22
300W_N: 24
300W_N: 5193_MAX
500W_N: 18
500W_ N: 22
500W_N: 24
500W_N: 5193_MAX
500W;
Max 571, Min 530
ΔT = 41
300W;
Max 470, Min 445
ΔT = 25

LLD Thermal Analysis
Heating, Cooling and Trim Heating for Operational Cycle time of 10 minutes.



- 673K max allowable temperature for heat up
- 473 is target temperature for cool down.
- Cycle Time approximately 10 minutes between heat up and cool down.



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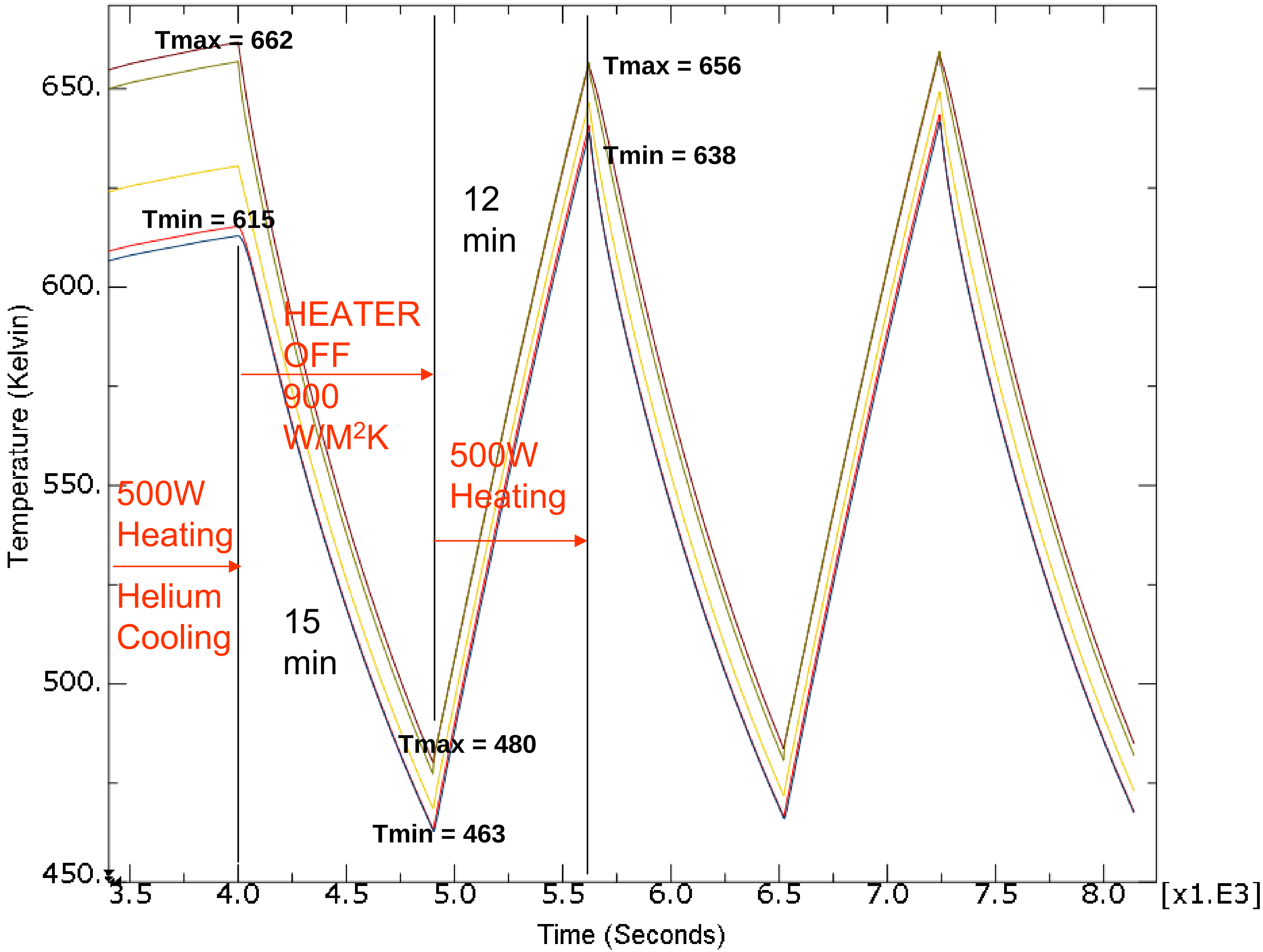
500W HEATING; He COOLDOWN NO HEAT; 500W TRIM HEATING



NNSA National Nuclear Security Administration

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Sandia National Laboratories

Cycle time Calculations for Heating and Cooling of LLD
Time to heat and Cool Mass

Cooling Tube Loss (Watts)	*Area Cooling tube (M^2)*	*Heat Transfer Coeffecient W/M^2K*	*delta T*	
1186	*0.006591*	*900*	*200*	
Black Body	*mW/mm^2*	*Temp max*	*Temp min*	
Ω	*5.669E-11*	*673*	*293*	
ε(Mo)	*0.2*			
ε(Cu)	*0.3*			
	Mo mW/mm^2	*Cu mW/mm^2*	**Total Power out (W)**	
Rad Loss Cylce	*1.76*	*2.64*	**319**	
Mass (Cu)	*Mass (ss)*	*Mass (Kg)*		
0.01	*5.02E-05*	*12.39*		
Cooling Rate	*Cp(Cu) (J/MgK)*	*ΔT*	*Power loss (Watts)*	**Time (Sec)**
	3.90E+05	*200*	*1505*	**639**
Heating Rate (Seconds)	**815**			
Actual Power (W)	*1181*			
Required Mass to Cool in 5 minutes		**5.79**	Kg	
Heat Up Rate @ this mass		**6.37**	Minutes	

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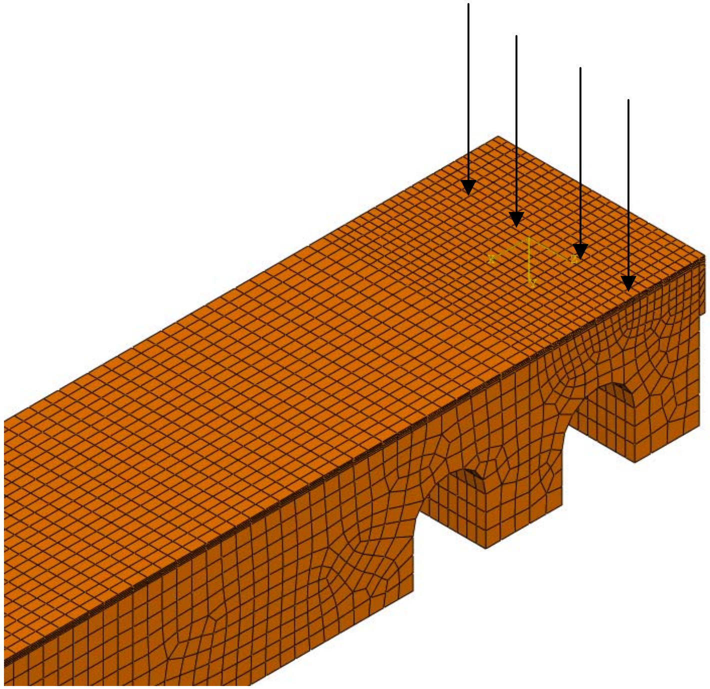
Heating at Strike Point

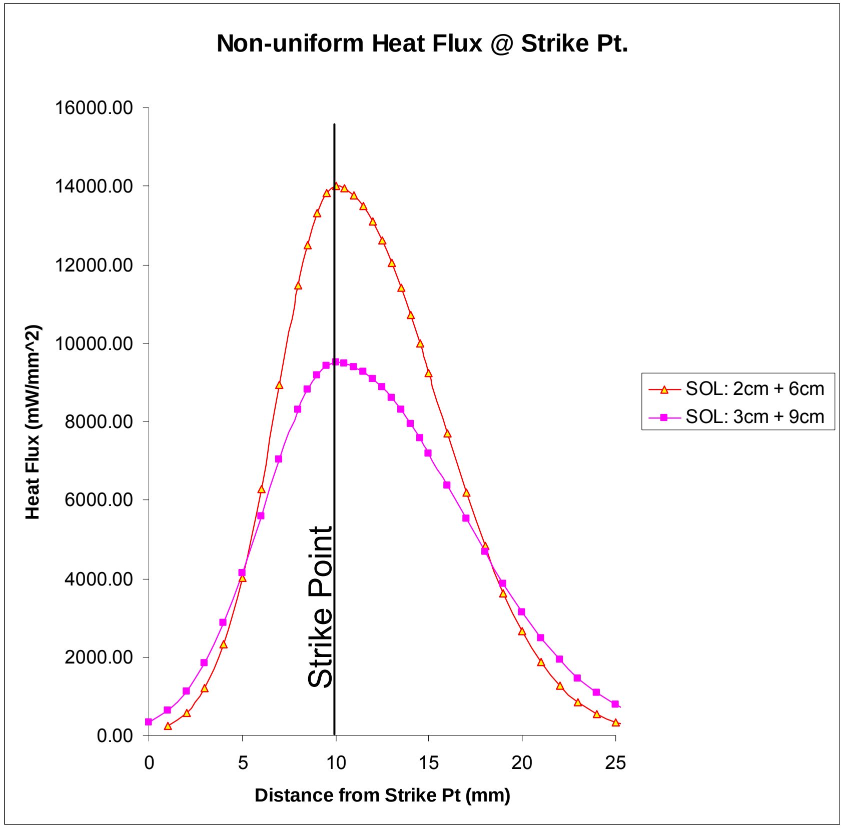


$$q_o \times \exp\left[-(x-x_o)^2/\lambda_q\right]$$

Where λ_q = a (x>0) and b (x<0)

SOL: 2cm + 6cm; a=60 and b=20

SOL: 3cm + 9cm; a=90 and b=30



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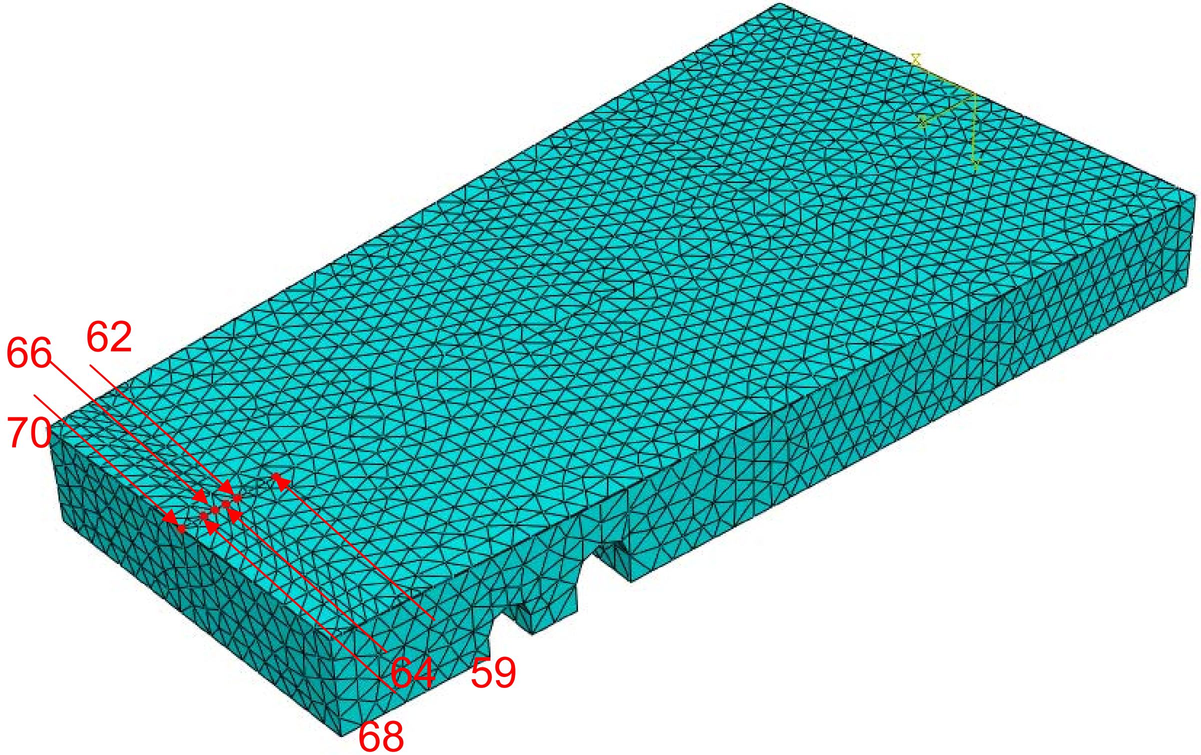
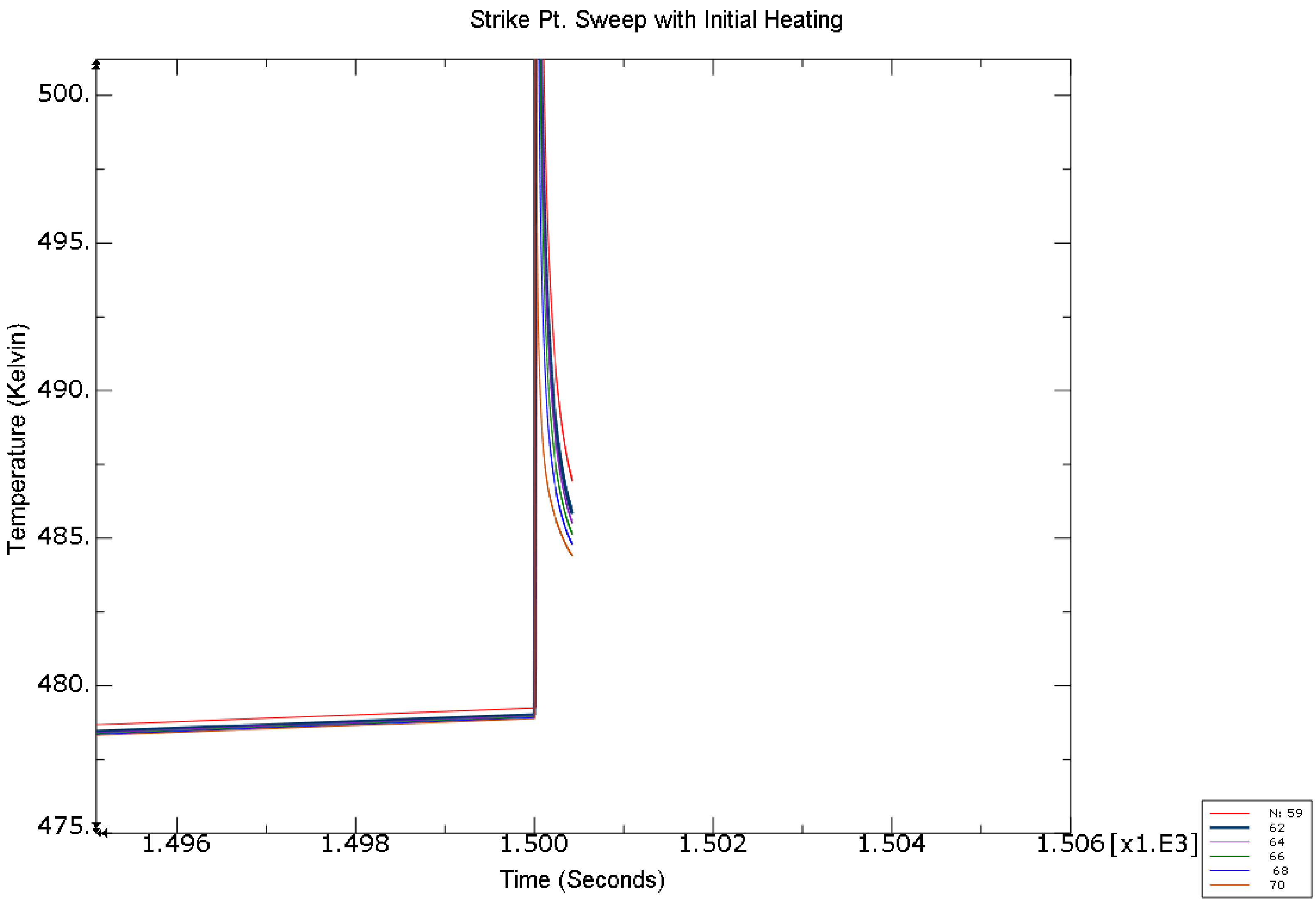
Strike Point Sweep Analysis
Velocity Calculation to Keep Strike Point temp below 675 K



Node	Kelvin (max)
59	645
62	662
64	630
66	639
68	638
70	578

- Initial heating from 200W heater for 25 minutes
- Initial temperature at strike pt. 475 K
- Duration at strike pts. = .005 seconds Total time for sweep = .020 seconds
- Δx = 2.5 mm for a .43 second sweep across entire area.
- Total distance of sweep 215mm
- 500 mm/s

Strike Point Heating and Cooling by Radiation Only.



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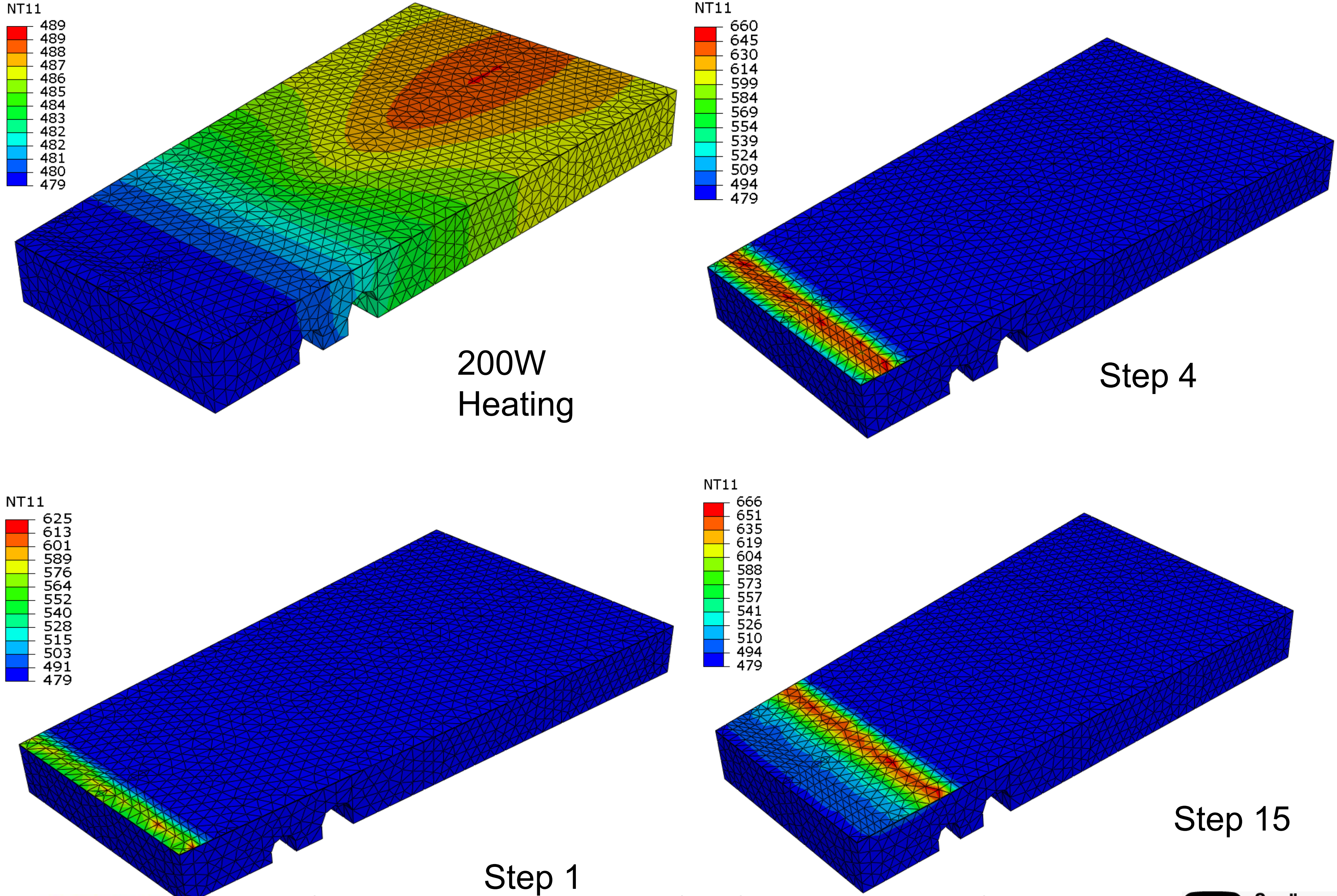
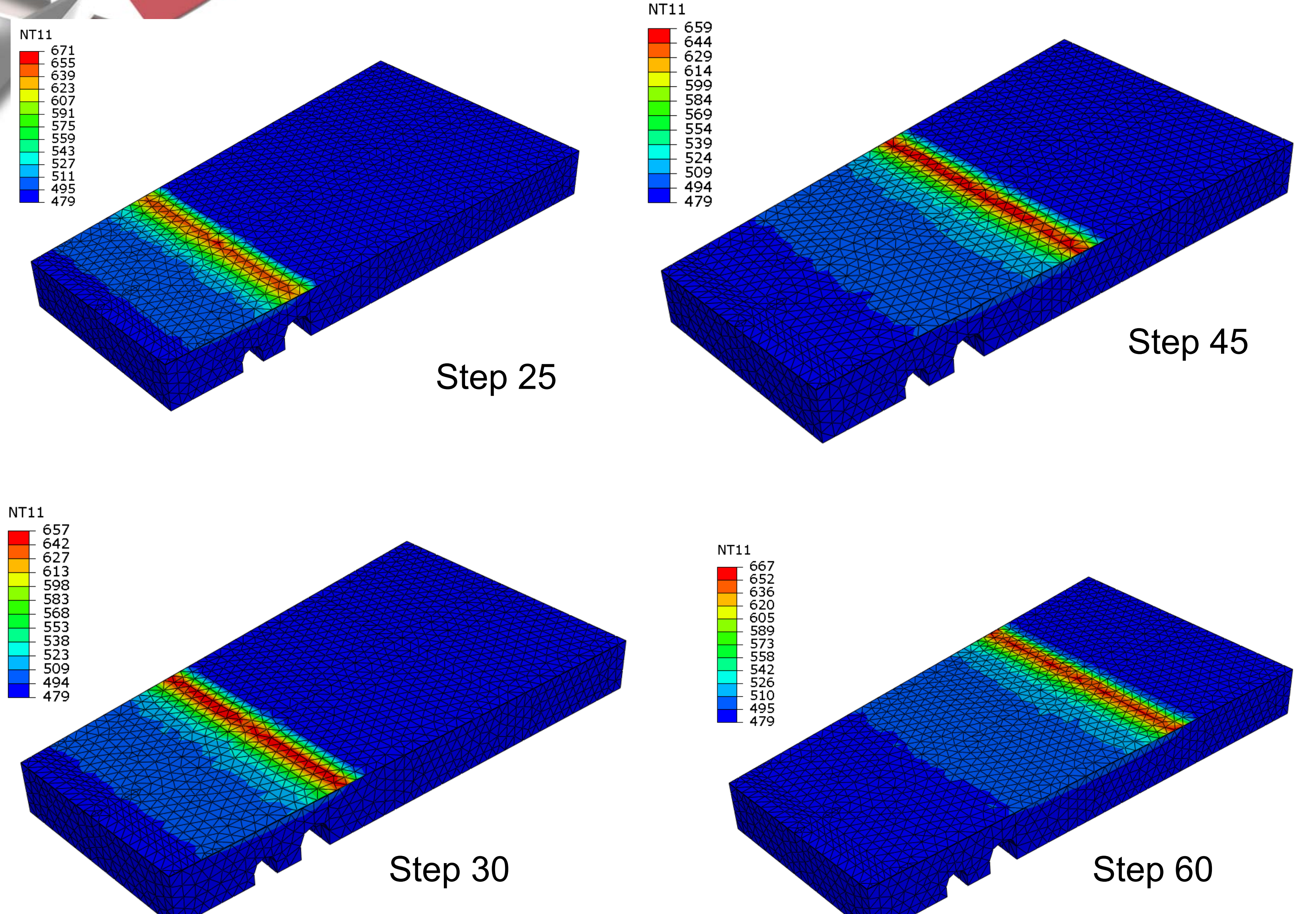

NT11
489
489
488
487
486
485
484
483
482
482
481
480
479
200W
Heating
NT11
660
645
630
614
599
584
569
554
539
524
509
494
479
Step 4
NT11
625
613
601
589
576
564
552
540
528
515
503
491
479
Step 1
NT11
666
651
635
619
604
588
573
557
541
526
510
494
479
Step 15



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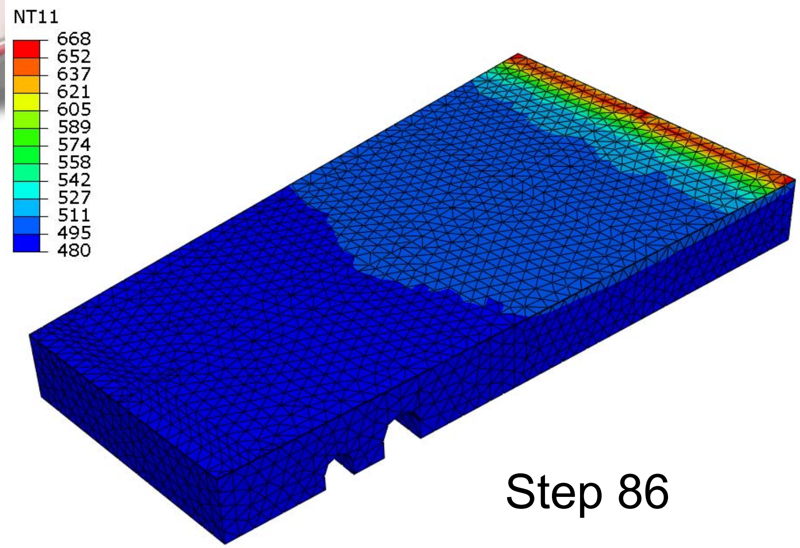
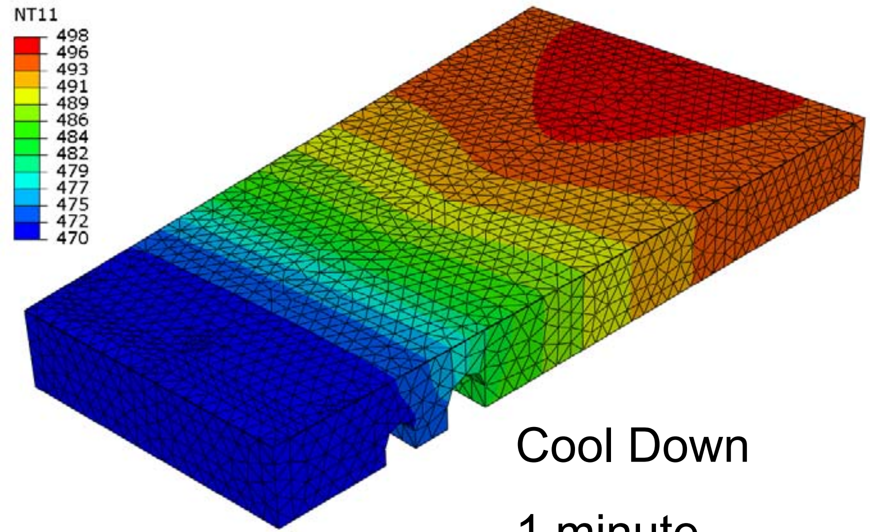
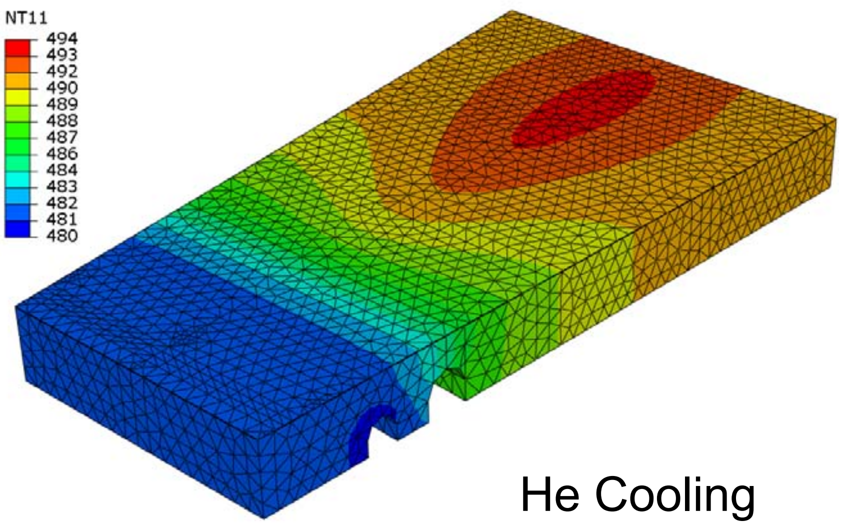


Step 86



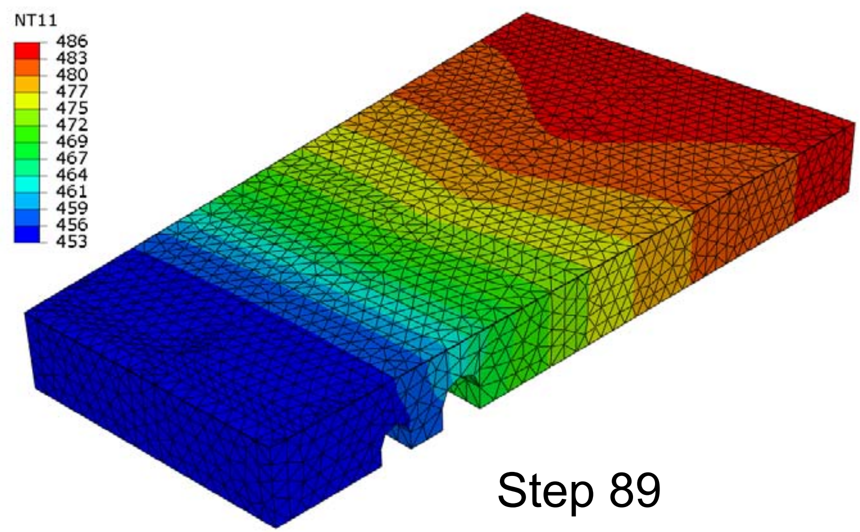
Cool Down

1 minute



He Cooling

5 seconds



Step 89

60 minutes

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Electromagnetic Considerations

- CDR: Based on scale-up of Brooks analysis.
  - Now that we are more certain of the LLD geometry, calculations can be revisited.
- Z-forces are reacted by supports.
- CDR: Scale original Brooks loads by factor of ~2
  - Roughly double radial width of LLD
  - Fz on each curved edge is ~600lbf
  - Fz on each straight edge is ~700lbf
- New results from Brooks [next four slides]:
  - Fz on each curved edge is ~281lbf
  - Fz on each straight edge is ~490lbf
- Shoulder screws are the weakest part of support.
  - 736lbf shear (15ksi allowable)
  - Can make shoulder screws from Inconel 718 if necessary (~2x allowable)

Liquid Lithium Divertor
Eddy Current and Force Estimates Update [A. Brooks]

- 4 Toroidal Segments modeled
  - LLD Geometry updated – Conical Shape
  - Repeat of analysis with VV, PP & CS
  - LLD assumed electrically floating (no loops with VV)
- Eddy Currents and Forces calculated for Shot 116066
  - Self consistent PF distribution extracted from shot data
- Normal Flux change thru LLD from Plasma Model estimated to be ~60 T/s for 3 ms
  - This compares to Stefan Gerhardt measurements of 25 T/s Normal and 200 T/s Tangent Field

Fields at LLD [A. Brooks]

Field at Lithium Divertor Before and after disruption							
	Re: Shot#116066, time=.325s						
	from pfcalcx.f routine						
PF Coils Only							
	r	z	br	bz	Bnet	phi	
	0.65910	-1.60820	0.05151	-0.19314	0.19989	-0.47367	
	0.85910	-1.52940	0.04327	-0.20737	0.21184	-0.68190	-0.20823
Plasma Only							
	r	z	br	bz	Bnet	phi	
	0.65910	-1.60820	-0.12801	0.18773	0.22722	0.31104	
	0.85910	-1.52940	-0.17009	0.14686	0.22471	0.52896	0.21791
PF Coils+Plasma							
	r	z	br	bz	Bnet	phi	
	0.65910	-1.60820	-0.07650	-0.00541	0.07669	-0.16263	
	0.85910	-1.52940	-0.12682	-0.06052	0.14052	-0.15294	0.00968
TF							
cur	-52752.4	amps					
Nturns/coil	3						
Ncoils	12						
Nturns	36						
NI	-1899086.4	amp-turns					
Rin	0.65913	m					
Rout	0.85913	m					
Bth in	-0.58	T					
Bth out	-0.44	T					

Force Estimates [A. Brooks]

Force Estimates

Based on LLD Only without VV/PP/CS effects

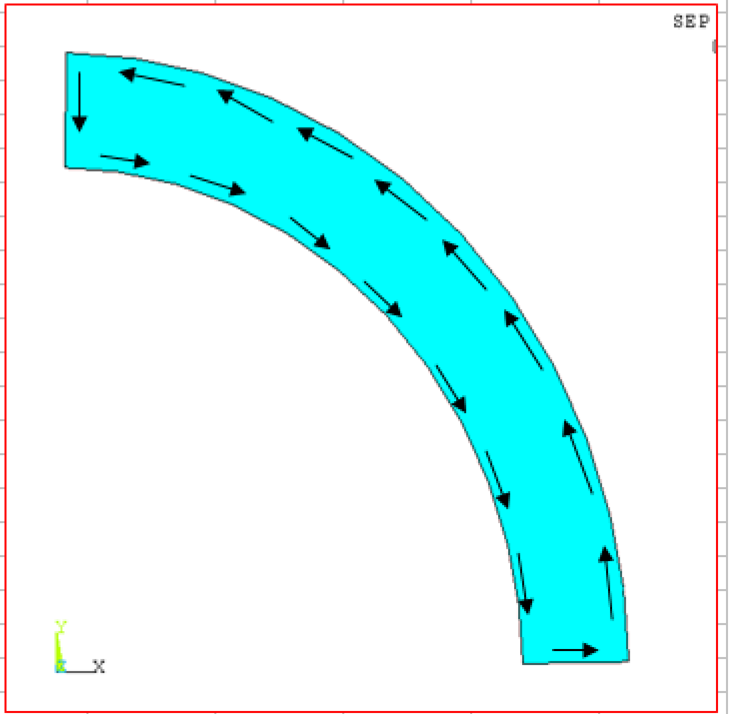
Imax 21405 amps — Spark .9 MA Plasma Model with effective dB/dt~60 T/s for 3 ms

Running Load, lb/in

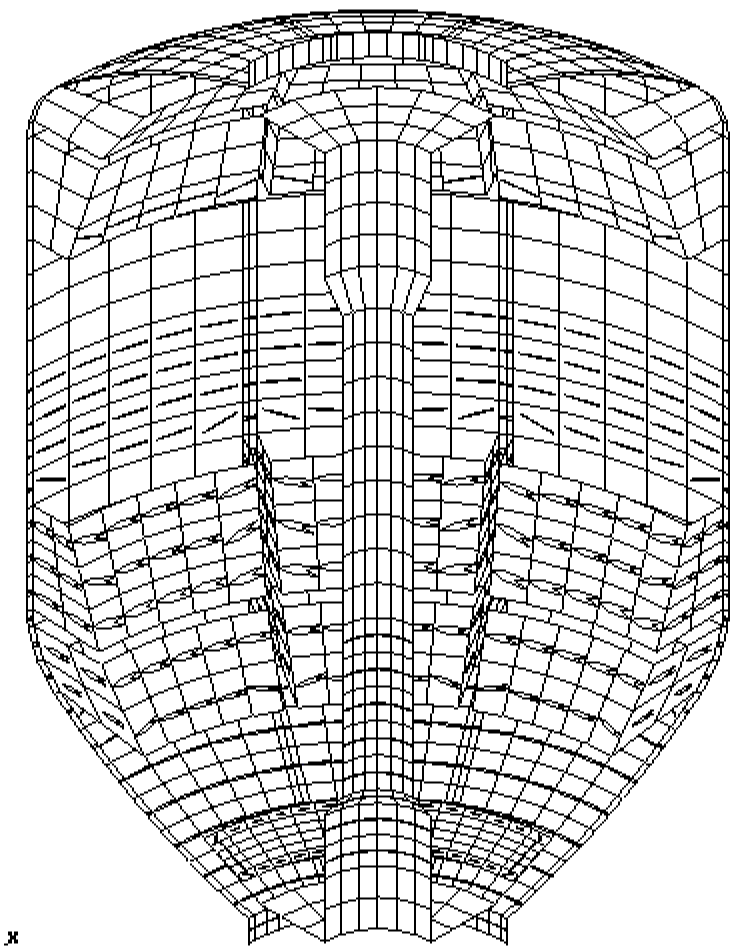
	Fr/l	Fth/l	Fz/l
IR	23.6	0.0	6.3
OR	-25.3	0.0	-5.3
0 deg	0.0	-24.5	-62.2
90 deg	0.0	24.5	62.2

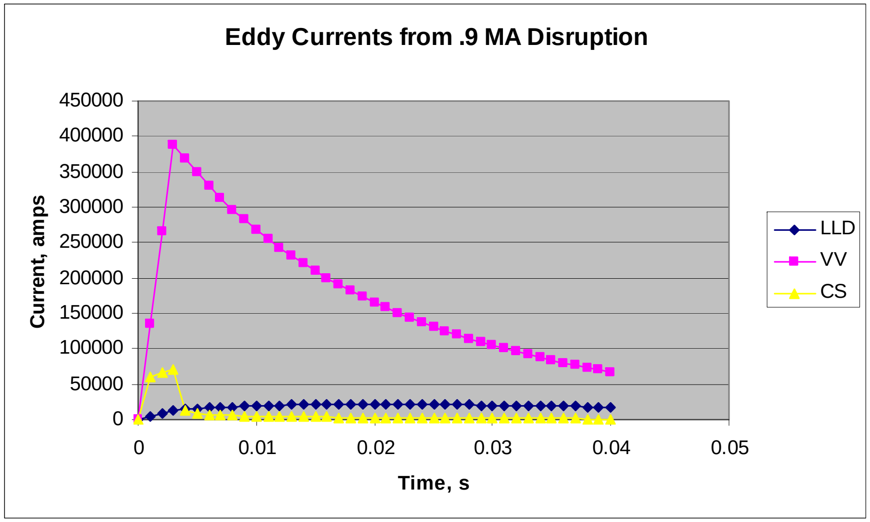
Net Load on Edges, lbs

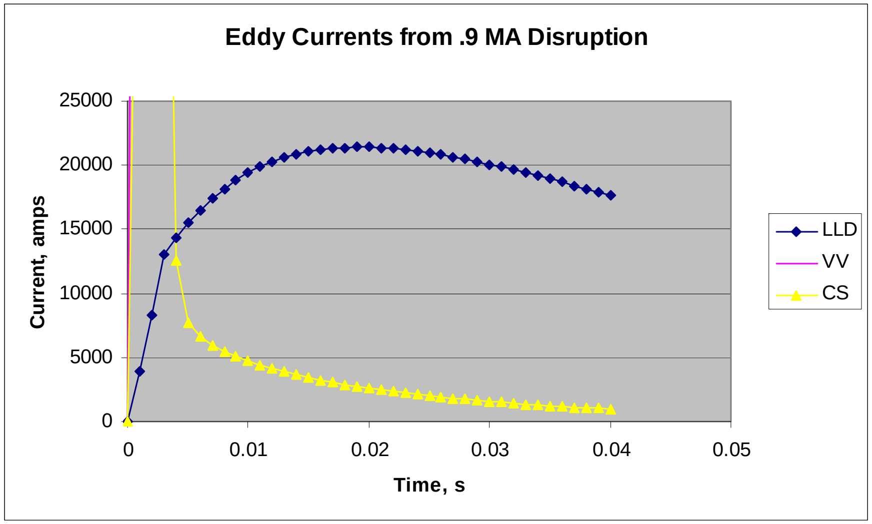
	Fr	Fth	Fz
IR	962	0	257
OR	-1347	0	-281
0 deg	0	-193	-490
90 deg	0	193	490
~Total	-384	0	-24



Spark Transient Eddy Currents [A. Brooks]







Time = 3 ms

Current Buildup in LLD driven by VV/PP

CS decays rapidly **Peak Current 21405 amps**

Cost and Schedule

- We want to install the LLD this outage.
- Major fabrication steps are:
  - Order copper and stainless steel plates.
  - Braze copper/stainless plates.
  - Flatten and machine plates to final thickness.
  - Bend and machine plates.
  - Braze cooling tubes into plates.
  - Plasma spray Mo on plates
  - Install heaters/thermocouples/wires/supports and vacuum prep.
- 200 replacement tiles need to be procured.
- Much of the hardware cost is in Sandia scope.
- Cost estimate spreadsheet shows $870K total, $370k Component Fabrication
  - ➔$500k PPPL cost

	Activity Name	Start Date	Finish Date	2008 April	May	June	July	August	September	October	November	December
1	Finalize drawings	4/23/08	5/6/08									
2	Establish vendor lists for braze & fab	4/23/08	5/6/08									
3	Order large SS/Cu plates	5/7/08	5/30/08									
4	RFQs for plate brazing	5/7/08	5/30/08									
5	Plate brazing	6/2/08	6/27/08									
6	RFQs for plate bending/machining	6/2/08	6/27/08									
7	Plate bending/machining	6/30/08	8/15/08									
8	Cooling tube brazing	8/18/08	8/29/08									
9	Mo plasma spraying	9/1/08	9/26/08									
10	Install heaters etc. & vacuum prep	9/29/08	10/31/08									
11	RFQ tiles	5/26/08	6/13/08									
12	Order tiles	6/16/08	9/12/08									
13	Vacuum bake tiles	9/15/08	10/31/08									
14	Order Misc. Hardware	6/16/08	9/12/08									
15	Install LLD segments	11/3/08	11/28/08									
16	Install tiles	12/1/08	12/5/08									
				April	May	June	July	August	September	October	November	December

NSTX LLD-1

FY08 RATES-9/13/07

	EREM	EEEM	ECEM	EAEM	ERSB	EESB	ERTB	EETB	EADM	EMSB	TRAVEL	STKRM	M&S	Unloaded	Loaded
Conceptual Design	0	0	0	300	0	0	0	0	0	0	$0	$0	$0	$29,379	$58,213
Prepare Conceptual Design				300										$29,379	$58,213
Task #2														$0	$0
Task #3														$0	$0
Task #4														$0	$0
Task #5														$0	$0
Task #6														$0	$0
Task #7														$0	$0
Task #8														$0	$0

	EREM	EEEM	ECEM	EAEM	ERSB	EESB	ERTB	EETB	EADM	EMSB	TRAVEL	STKRM	M&S	Unloaded	Loaded
L-245 Wetting Tests	0	0	0	0	0	0	0	200	0	200	$0	$0	$0	$21,118	$40,610
Chamber setup / initial tests								200		200				$21,118	$40,610
Task #2														$0	$0
Task #3														$0	$0
Task #4														$0	$0
Task #5														$0	$0
Task #6														$0	$0
Task #7														$0	$0
Task #8														$0	$0

	EREM	EEEM	ECEM	EAEM	ERSB	EESB	ERTB	EETB	EADM	EMSB	TRAVEL	STKRM	M&S	Unloaded	Loaded
Design Prototyping and testing	0	0	0	60	0	0	0	40	0	120	$0	$300	$2,000	$17,203	$32,021
Design and fab prototypes				40						80		$300	$2,000	$11,021	$20,018
PPPL Prototype Tests				20				40		40				$6,182	$12,003
Task #3														$0	$0
Task #4														$0	$0
Task #5														$0	$0
Task #6														$0	$0
Task #7														$0	$0
Task #8														$0	$0

	EREM	EEEM	ECEM	EAEM	ERSB	EESB	ERTB	EETB	EADM	EMSB	TRAVEL	STKRM	M&S	Unloaded	Loaded
Final Design	0	40	0	160	0	0	0	0	320	0	$0	$0	$0	$43,683	$86,257
Mechanical Engineering Design				160					320					$39,874	$79,007
Controls Interface Engineering		40												$3,809	$7,250
Task #3														$0	$0
Task #4														$0	$0
Task #5														$0	$0
Task #6														$0	$0
Task #7														$0	$0
Task #8														$0	$0

NSTX LLD-1

FY08 RATES-9/13/07

Misc. Hardware Purchases	EREM	EEEM	ECEM	EAEM	ERSB	EESB	ERTB	EETB	EADM	EMSB	TRAVEL	STKRM	M&S	Unloaded	Loaded
Misc. Hardware Purchases	0	0	0	0	0	0	0	0	0	0	$0	$0	$23,000	$23,000	$29,463
Misc. hardware													$4,000	$4,000	$5,124
Electrical Feedthroughs (16 20-pin)													$8,000	$8,000	$10,248
Gas Feedghroughs (8 single tube mini cf)													$1,000	$1,000	$1,281
Ceramic Breaks (16 mini cf)													$4,000	$4,000	$5,124
Ceramic coating for washers & misc. components													$4,000	$4,000	$5,124
2.75" cross													$2,000	$2,000	$2,562
Task #7														$0	$0
Task #8														$0	$0

Assembly and Installation	EREM	EEEM	ECEM	EAEM	ERSB	EESB	ERTB	EETB	EADM	EMSB	TRAVEL	STKRM	M&S	Unloaded	Loaded
Assembly and Installation	0	0	0	200	0	520	0	0	0	360	$0	$0	$0	$73,933	$142,994
Engineering Support				80										$7,834	$15,523
ssembly Prep [includes brazing and welding at PPPL]				40						240				$18,329	$35,692
Installation				80										$7,834	$15,523
Install 2 racks						360								$22,658	$43,124
Install feedthroughs										120				$7,206	$13,965
Install cables						160								$10,070	$19,166
Task #7														$0	$0
Task #8														$0	$0

Component Fabrication (Sandia)	EREM	EEEM	ECEM	EAEM	ERSB	EESB	ERTB	EETB	EADM	EMSB	TRAVEL	STKRM	M&S	Unloaded	Loaded
Component Fabrication (Sandia)	0	0	0	0	0	0	0	0	0	0	$0	$0	$288,000	$288,000	$368,928
Order raw material for six plates													$19,000	$19,000	$24,339
Order heaters and thermocouples													$4,000	$4,000	$5,124
Brazing/HIP bonding of six plates													$30,000	$30,000	$38,430
Bending/machining of six plates													$50,000	$50,000	$64,050
Fab cooling tubes (six sets)													$10,000	$10,000	$12,810
Braze plates / cooling tubes													$5,000	$5,000	$6,405
Plasma spray Mo													$70,000	$70,000	$89,670
Fabricate supports													$20,000	$20,000	$25,620
Fabricate graphite tiles													$80,000	$80,000	$102,480

PPPL Mech. Fab. and Elect. Support	EREM	EEEM	ECEM	EAEM	ERSB	EESB	ERTB	EETB	EADM	EMSB	TRAVEL	STKRM	M&S	Unloaded	Loaded
PPPL Mech. Fab. and Elect. Support	0	480	0	200	0	0	0	0	48	0	$0	$0	$0	$68,927	$132,999
Control Interface Engineering		480												$45,710	$86,997
Procurement tracking - mechanical components				200					48					$23,217	$46,002
Task #3														$0	$0
Task #4														$0	$0
Task #5														$0	$0
Task #6														$0	$0
Task #7														$0	$0
Task #8														$0	$0

FY08 RATES-9/13/07

	EREM	EEEM	ECEM	EAEM	ERSB	EESB	ERTB	EETB	EADM	EMSB	TRAVEL	STKRM	M&S	Unloaded	Loaded
Total PPPL Resources	0	520	0	920	0	520	0	240	368	680	$0	$300	$313,000	$565,243	$891,484

FY08 RATES-9/13/07	**DEMOG	**Base	**Loaded	DEMOG
E A Div Engineer	EAEM	$97.93	$194.04	LEAEM
Computer Div Engineer	ECEM	$80.24	$155.50	LECEM
Computer Div SL&S(B)	ECSB	$51.88	$100.54	LECSM
Computer DivTech	ECTB	$39.30	$76.16	LECTB
EE Div Engineer	EEEM	$95.23	$181.24	LEEEM
EE Div SL&S(B)	EESB	$62.94	$119.79	LEESM
EE DivTech	EETB	$45.54	$86.67	LEETB
RF Engineer	EREM	$95.23	$181.24	LEREM
RF SL&S(B)	ERSB	$62.94	$119.79	LERSM
RF Tech	ERTB	$45.54	$86.67	LERTB
ME Engineer	EMEM	$86.66	$167.95	LEMEM
ME Machinist	EMNB	$60.05	$116.38	LEMNB
ME SL&S(B)	EMSB	$60.05	$116.38	LEMSM
ME Tech	EMTB	$43.37	$84.05	LEMTB
Drafting SL&S(B)	EADM	$75.64	$149.88	LEADM
M&S Purchases	MS(41)	M&S $$	1.281	MSGA
Stockroom Withdrawals	STKR(37)	STKR$$	1.281	SRGA
Travel	TVL(35)	TVL$$	1.209	TVLGA
EA Mechanical Div Burden	EABUR	14.00%		
EC Comp Sys Div Burden	ECBUR	11.50%		
EE Electrical Eng Div Burden	EEBUR	9.50%		
EM Fab, Ops & Maint Div Burden	EMBUR	11.50%		
Operating G&A	G_A	73.81%	(site burden x G&A)	
Operating G&A: M&S	G_A_M	28.13%	(no G&A if $=>$**250**k)	
Escalation Multiplier from FY08	ESC	1.0000	**OK 9/13/07**	

**

note that all SM demographics are costed at S(B) labor rates

Benefits rates:
33% for regular employees
15% for hourly employees

MHX	2007	28.13	%
Site	2007	73.81	%
Offsite	2007	26.00	%

Summary

- We have a design for a practical LLD.
- Detailed analyses indicate that performance will be adequate.
- We need to work towards having major procurements in place.