PPPL Calculation Form

Calculation # NSTXU-CALC-133-19 Revision # 0 WP #, if any (ENG-032) ________

Purpose of Calculation: (Define why the calculation is being performed.)

This calculation qualifies that reorienting the NSTX-U CS Casing from Horizontal to Vertical, or visa versa, will not overstress the Tiles due to imposed displacements from net beam bending behavior of the Casing.

(This calculation does not qualify the lift itself, which was done as part of the Lift Package for L-D-NSTX-1035 and its associated documents.)

References (List any source of design information including computer program titles and revision levels.)

See Attached

Assumptions (Identify all assumptions made as part of this calculation.)

See Attached

Calculation (Calculation is either documented here or attached)

See Attached

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)

Inboard Divertor Horizontal Section Tiles are assumed to be removed to install the Casing Lift Fixtures.

Upending the CS Casing with the other CS PFCs installed is safe.

Although practical issues are not addressed in this calculation, adequate care must be taken to ensure that temporary supports and rigging (e.g. when the Casing is in the horizontal position) do not apply local contact forces to the Tiles. Previously qualified Procedures and Fixtures must be used for Lifting.

Cognizant Engineer (or designee) printed name, signature, and date

Michael Mardenfeld

Digitally signed by Michael Mardenfeld
DN: cn=Michael Mardenfeld, o=PPPL, ou=Mechanical Engineering, email=mmarden@pppl.gov, c=US
Date: 2016.11.16 16:08:59 -05'00'

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

Checker's printed name, signature, and date

Art Brooks

Digitally signed by Art Brooks
DN: cn=Art Brooks, o=PPPL, ou=Engineering, email=abrooks@pppl.gov, c=US
Date: 2016.11.18 13:31:58 -05'00'

1. Assure that inputs were correctly selected and incorporated into the design.

2. Calculation considers, as appropriate:

   - Performance Requirements (capacity, rating, system output)
   - Design Conditions (pressure, temperature, voltage, etc.)
   - Load Conditions (seismic, wind, thermal, dynamic)
   - Environmental Conditions (radiation zone, hazardous material, etc.)
   - Material Requirements
   - Structural Requirements (foundations, pipe supports, etc.)
   - Hydraulic Requirements (NPSH, pressure drops, etc.)
   - Chemistry Requirements
   - Electrical Requirements (power source, volts, raceway, and insulation)
   - Equipment Reliability (FMEA)
   - Failure Effects on Surrounding Equipment
   - Tolerance Buildup

3. Assumptions necessary to perform the design activity are adequately described and reasonable.

4. An appropriate calculation method was used.

5. The results are reasonable compared to the inputs.

NOTE: IT IS THE RESPONSIBILITY OF THE CHECKER TO USE METHODS THAT WILL SUBSTANTIATE TO HIS/HER PROFESSIONAL SATISFACTION THAT THE CALCULATION IS CORRECT.

BY SIGNING CALCULATION, CHECKER ACKNOWLEDGES THAT THE CALCULATION HAS BEEN APPROPRIATELY CHECKED AND THAT THE APPLICABLE ITEMS LISTED ABOVE HAVE BEEN INCLUDED AS PART OF THE CHECK.

Summary

During the original fabrication of the NSTX-U Centerstack (CS) various assembly steps required reorienting the CS Casing from Vertical to Horizontal, and from Horizontal to "Upside Down" Vertical. Previously this upending was qualified and performed without the Plasma Facing Components (PFCs or Tiles) installed. This calculation qualifies that these same hoisting operations may be performed with the PFCs installed, and that the beam bending deflection during the lift will not overstressing them. It is assumed that appropriate techniques are used during rigging and supporting the Casing in the horizontal position to avoid local contact stresses with the Tiles – for example removing any Tiles which would bear load when the Casing is supported on cradles in the Horizontal position. Specific details of these practical matters are beyond the scope of this document.

General Assumptions

- Linear Elastic
- Small Displacement Theory
- Casing Stiffness dominates global response
    - This justifies separate sub-models of the Casing and a representative PFCs assembly
    - Casing only model determines overall deflections
    - PFCs assembly sub-model with imposed displacements bounds stresses within the Tiles
- Inboard Divertor Horizontal Section Tiles are removed before the lift
- Inboard Divertor Vertical Section and Angled Section Tiles have Grafoil shims behind them

References

1. Drawing E-ED1312 and child assemblies: Highest level CS Assembly Drawing
2. NSTXU-CALC-133-05-01: Halo Current Analysis of Center Stack
3. NSTXU-CALC-11-03-01: Stress Analysis of ATJ Centerstack Tiles and Fasteners
4. Lift Procedure L-C-NSTX-1035
5. NSTX-CRIT-0001-02: NSTX-U Structural Design Criteria
6. Installation Procedure D-NSTX-IP-3360, NSTX-U CS PFC Preassembly and Installation

Attachments

1. Drawing E-ED1312 "Center Case Tile Assembly and Row Orientation"
2. Drawing E-ED1261 "Centerstack Upgrade ... Tile ... Style 1 Assembly"
3. Drawing E-ED1262 "Centerstack Upgrade ... Tile ... Style 2 Assembly"
4. Excerpt from report NASA CR-66933: Typical POCO Graphite Elastic Properties (various grades)
5. Certified Material Test Report from Req#411529
6. Excerpt from Special Metals Inconel 626 Datasheet showing Elastic Properties
7. L-D-NSTX-1035 LDS run copy dated 10/9/2014 showing measured weights of Casing with 2x PF1B and PFCs installed.

Assumptions for Casing Sub-Model

- Casing material is Inconel 625

- Casing is modeled as monolithic solid
  - No additional joint compliance due to welds
  - Casing and Welds structural integrity have already been qualified by design basis (NSTXU-CALC-133-05-01) and previous Lifting Procedures (L-C-NSTX-1035).

- Boundary Conditions
  - Quarter Symmetry model
  - Casing is supported through a single bolt hole on each end flange
    - "Compression Only Support" allows end rotation
    - Support holes are above part centerline

- Loading
  - Total Weight supported by Casing is 5000 lbf (Casing + PFCs + 2x PF1B Coils)
  - Load is distributed uniformly over CS Casing

Assumptions for Tile Sub Model

- Materials
  - Tile Material is POCO Graphite, per attached CMTRs
  - Mounting Hardware (Backing Plate, Locating Pin) are Inconel 626

- Tile Assembly is simplified into two parts
  - Tile is a single part
  - Mounting Bracket and Pin are considered as a monolithic part with conformal mesh

- Clearances
  - No clearance between Bracket and Pin
  - .004" clearance between Pin OD and Tile Hole ID
  - .005" clearance all around between Tile and Bracket (gap assumed not to close)

- Boundary Conditions
  - Quarter Symmetry model
  - Bracket has imposed displacement under Bolt Head to simulate preload
  - Bracket edge has imposed displacement to simulate effect of Casing deflection
  - Frictionless Contact between Pins and Tiles

- Other Geometric Considerations
  - Pin is initially positioned to make contact at the bottom of the Tile's Hole (b/c the Pin is drawing the Tile downwards to seat on the Casing)
  - Pin is stepped so that contact with Tile only occurs locally towards the center of the Tile
  - Note that there are no Bellevilles Washers or Grafoil for the CS Vertical Section Tiles assemblies, so all of the compliance must come from deformation of the Bracket

Discussion: Casing Sub Model

The Casing is effectively a simply supported beam. However there were two conditions which could deviate from simple beam theory. First, the t/r ratio is sufficiently small that shear deflections and/or warping and/or ovalization may be significant. Second, the Casing will likely not be supported through the neutral axis. By modeling the actual geometry in FEA these effects, as well as the added stiffening due to the end flanges and locally increased thickness at the frustums regions, could be considered.

Since the overall structural integrity of the Casing has already been qualified the goal of this portion of the calculation is to determine the deflection imposed on the tile assemblies by the beam bending behavior of the Casing. Note that the key parameter for this is not the deflection of the Casing from its original position, but rather the "chordal tolerance" – the distance between the local curvature of the beam and a secant line which is the length of a single tile (approximately 5.5").

This "chordal tolerance" is more than an order of magnitude smaller than the global displacement of the beam. It was calculated by plotting the global displacement of the Casing along a path at the outermost fiber and outputting the value of these displacements to an excel spreadsheet. The length along the casing was split into 12 "buckets" with each bucket of approximately 5.5" representing the span of a single tile. For each tile span a secant line was fit such that it intersected the beam deflection curve at each endpoint of the corresponding span, and then the distance between the secant line and the beam deflection curve calculated.

The maximum value of this chordal deviation is a good approximation of the deflection imposed on the tile by the casing bending under load. This imposed deflection can these be used as a boundary condition for the tile submodel. The peak magnitude of this deviation was computed to be about .0001".

Discussion: Regarding Various Tile Types

The Inboard Divertor Horizontal Section Tiles need to be removed to install the CS Casing Lifting Fixtures (LF#330 and #331) and therefore do not need to be qualified. According procedure D-NSTX-IP-3360, the Inboard Divertor Vertical Section and Inboard Divertor Angled Section Tiles have Grafoil installed behind them. It is clear that this Grafoil will have sufficient compliance to absorb deformations on the order of .0001" without impacting the Tile Loading. Therefore, the Tile Sub Model is only required for qualification of the CS Vertical Section Tiles to show that there is sufficient compliance in the Inconel Bracket to serve the same function. Since the load path for the "Underlap Tiles" is also through the Inconel Bracket mounting their neighboring "Overlap Tile" (through the cantilevered pins), they will have similar compliance as the Overlap Tiles. Therefore it is assumed that showing adequacy of the Overlap Tiles is sufficient to qualify the Underlap Tiles without explicitly modeling them.

Discussion: Tile Sub Model

There are two primary scenarios of concern which could endanger the PFCs due to the loading during Upending. First, the deflection of the Casing could cause Tiles edges to touch. Second the deflection of the Casing could impose strain controlled loads onto the PFCs. Both of these scenarios are driven by displacements imposed on the Tiles by the Casing deformation, which has been bounded to be less than about .0001".

Since the Tile to Tile nominal horizontal gaps are at least .010", the differential displacement between the Tile and the Casing is .0001", and the horizontal displacement which tends to close the gap between tiles will be a fraction of the differential displacement, it is clear that the first scenario will not be an issue for any of the Tile types.

The second scenario is only applicable to the CS Vertical Section Tiles because the other sections will either be removed, have Grafoil installed to provide sufficient compliance, or do not use an Over/Underlap alternating fastening scheme. An FEA simulation was used to quantify the incremental change in stresses in the Tiles due to imposed casing deformations. This model includes several simplifying assumptions which require explanation.

Note that there are many variants of Tiles, with two primary types: Overlap and Underlap tiles. The overlap tiles are housed within an Inconel Bracket, fastened to the Bracket with pins, and the Bracket is mounted on the Casing using "nut caps" and studs welded to the Casing. The Underlap tiles do not have any fasteners themselves; rather the edges of the Overlap tiles' pins extend on top of the Underlap tiles and bear down on them. This provides a clamping load which retains the Underlap Tiles in place. There is no Grafoil or Belleville washers to provide compliance. Only a single representative Overlap Tile Assembly was modeled: the Casing, fasteners, and Underlap tiles were not explicitly modeled.

The end edge of the Inconel Bracket is assumed to make contact with the Casing. The region of the bracket underneath the nut cap had an imposed downward displacement to simulate the preload in the fasteners. Consider that in a physical part the curvature of the of the Bracket will never exactly match the curvature of the Casing and therefore as preload is applied to the Stud joint some local deformation occurs until the gap is closed. Before this gap is closed the stud preload causes reaction forces at the contact between the pins and edges of the Underlap Tile and this clamping force secures the Underlap Tile. However, once this gap is closed the remainder of the preload is reacted directly by compressive forces at the contact between the Bracket and the Casing at the region immediately near the nut cap. Therefore, only a small portion of the Stud Preload is actually applied as a Clamping force to the Underlap tiles. For this model, three assumptions were made regarding this phenomenon. First, it is implicitly assumed that the outer edges of the Bracket make contact with the Casing and that before preload some gap exists immediately near the Nut Cap. This is the most adverse scenario because it maximizes the bending moment in the bracket. Second, the magnitude of the downward deflection required to close this local gap near the Nut Cap was assumed to be .003”. This somewhat arbitrary deflection was chosen to provide some modest preload (approximately 175 lbf per tile) between the Tiles and their retaining pin while keeping the Tile stresses in a reasonable range.

Since the tiles have already been qualified and successfully operated with the as installed preload, the intention of the analysis is simply to show that the incremental change due to the displacements imposed by the Casing is small. Therefore the exactly modeling conditions regarding the preload and contact between the Tile and Casing are not important. In order to show this, the model was run three times. First, the edge of the bracket was held fixed (with the downward displacement near the bolt) to simulate preload with the Casing in an un-deflected configuration (the Casing standing vertically). In the second iteration, the edge of the Bracket was deflected upwards by .0001” to simulate the imposed displacements for a Tile on the concave side of the Casing during bending. Lastly, the model was rerun with the edge of the Bracket deflected downwards by .0001” to represent a Tile on the convex side of the Casing during Bending. The change in preload and Tile stress can be compared between the first case and the second two cases the imposed displacements from the Casing beam bending deflection have small effects.

Material Properties

Properties of Outline Row 4: POCO Graphite

	A	B	C	D	E
1	Property	Value	Unit		
2	Isotropic Elasticity				
3	Derive from	Young's Modulus and Poisson's Ratio			
4	Young's Modulus	1.5229E+06	psi		
5	Poisson's Ratio	0.262			
6	Bulk Modulus	7.3529E+09	Pa		
7	Shear Modulus	4.1601E+09	Pa		

	A	B	C	D	E
1	Property	Value	Unit		
2	Isotropic Elasticity				
3	Derive from	Young's Modulus and Poisson's Ratio			
4	Young's Modulus	3E+07	psi		
5	Poisson's Ratio	0.28			
6	Bulk Modulus	1.567E+11	Pa		
7	Shear Modulus	8.0798E+10	Pa		

Figure 1: Assumed Material Properties for POCO and Inconel 625

POCO

This specification defines the material characteristics for TM and TM-1 grades of graphite furnished by Poco Graphite, Inc. (POCO).

2.1.1	PROPERTY	UNIT	MIN.	MAX.
	Flexural Strength	psi	6,000**	--
	Compressive Strength	psi	11,600	--
	Electrical Resistivity	μ-Ω-in.	410	745
	Shore Hardness	Unitless	59	76
	Apparent Density (A.D.)	g/cm^3	1.70	1.88
	C.T.E.	x10^{-6}/°C	7.2	9.4
	Ash (TM)	ppm	300	3,000
	Ash (TM-1)	ppm	0	5

** Set at -1 SD

Figure 2: CMTRs from Req#411529

This appears, but has not been confirmed, to be the actual material for the CS Tiles

Casing Model

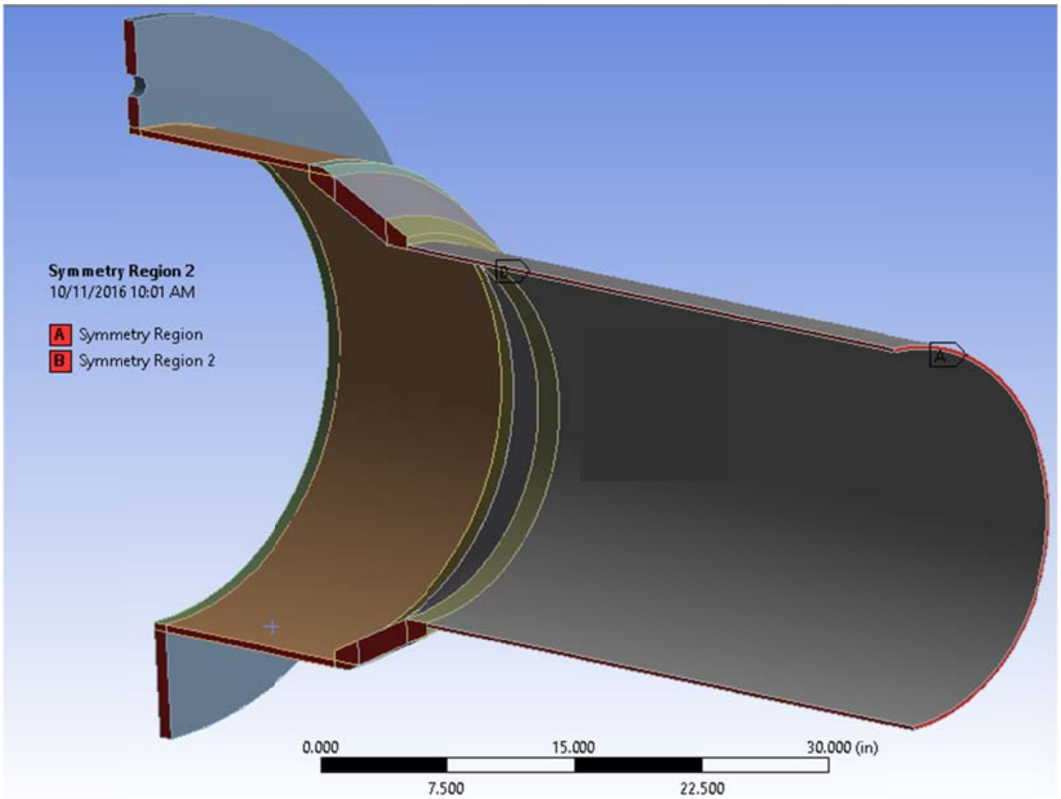


Figure 3: Quarter Symmetry Boundary Conditions

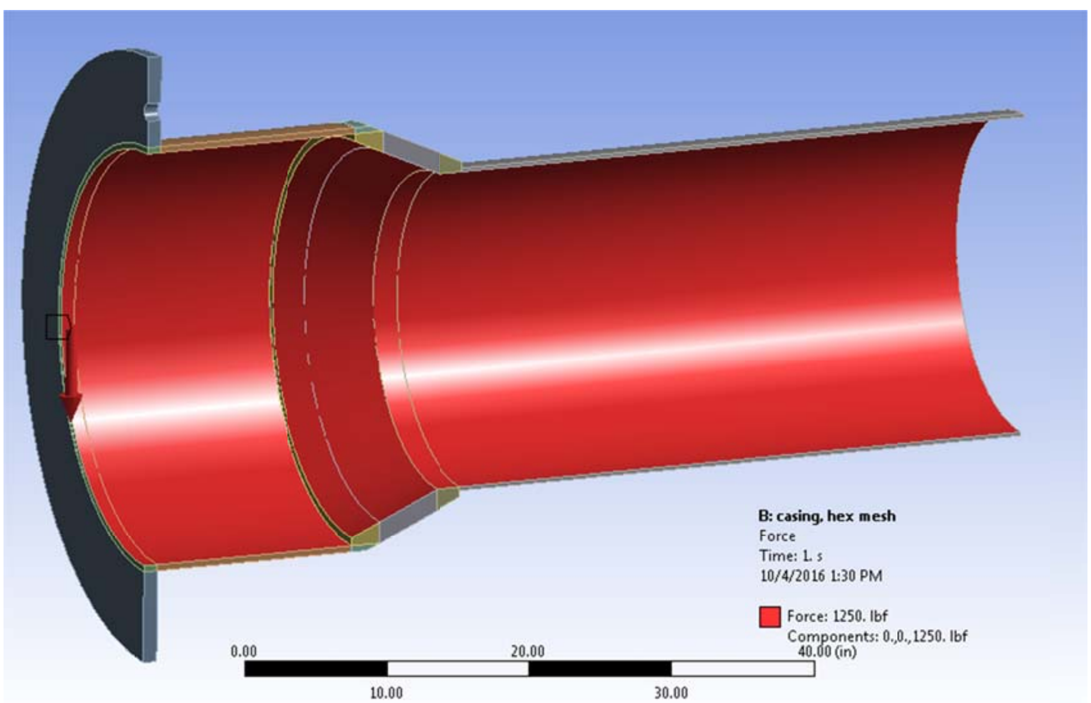


Figure 4: Gravity Loads from Casing, PF1B Coils, and Tiles applied uniformly to the Casing.

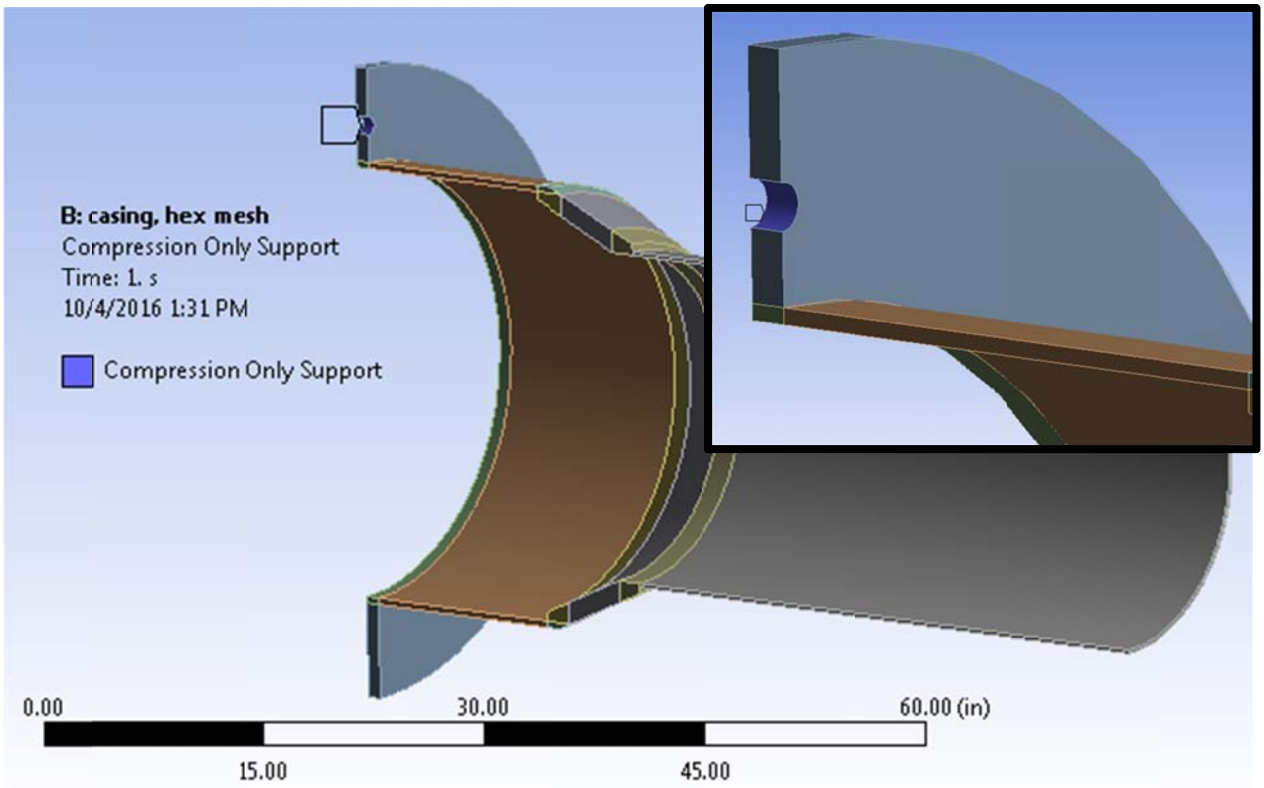


Figure 5: Compression Only Support Condition

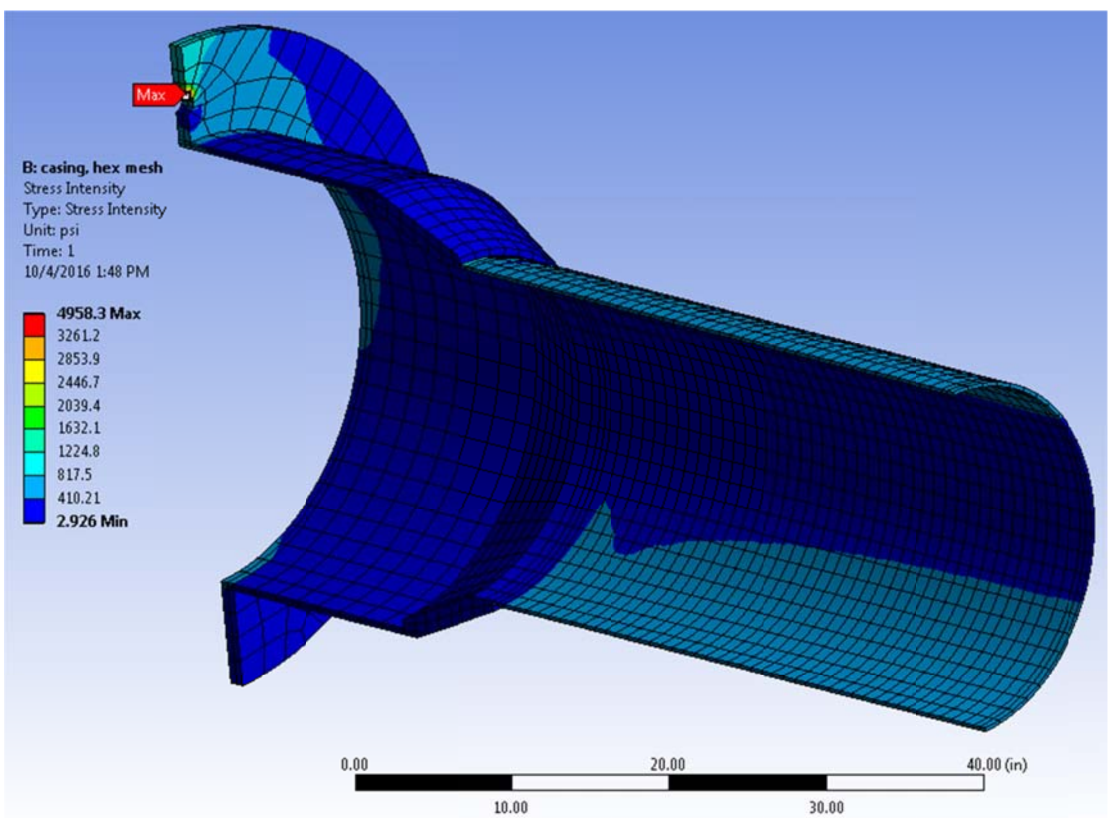


Figure 6: Stress Intensity in CS Casing

(Casing Stress already qualified by NSTXU-CALC-133-05-01)

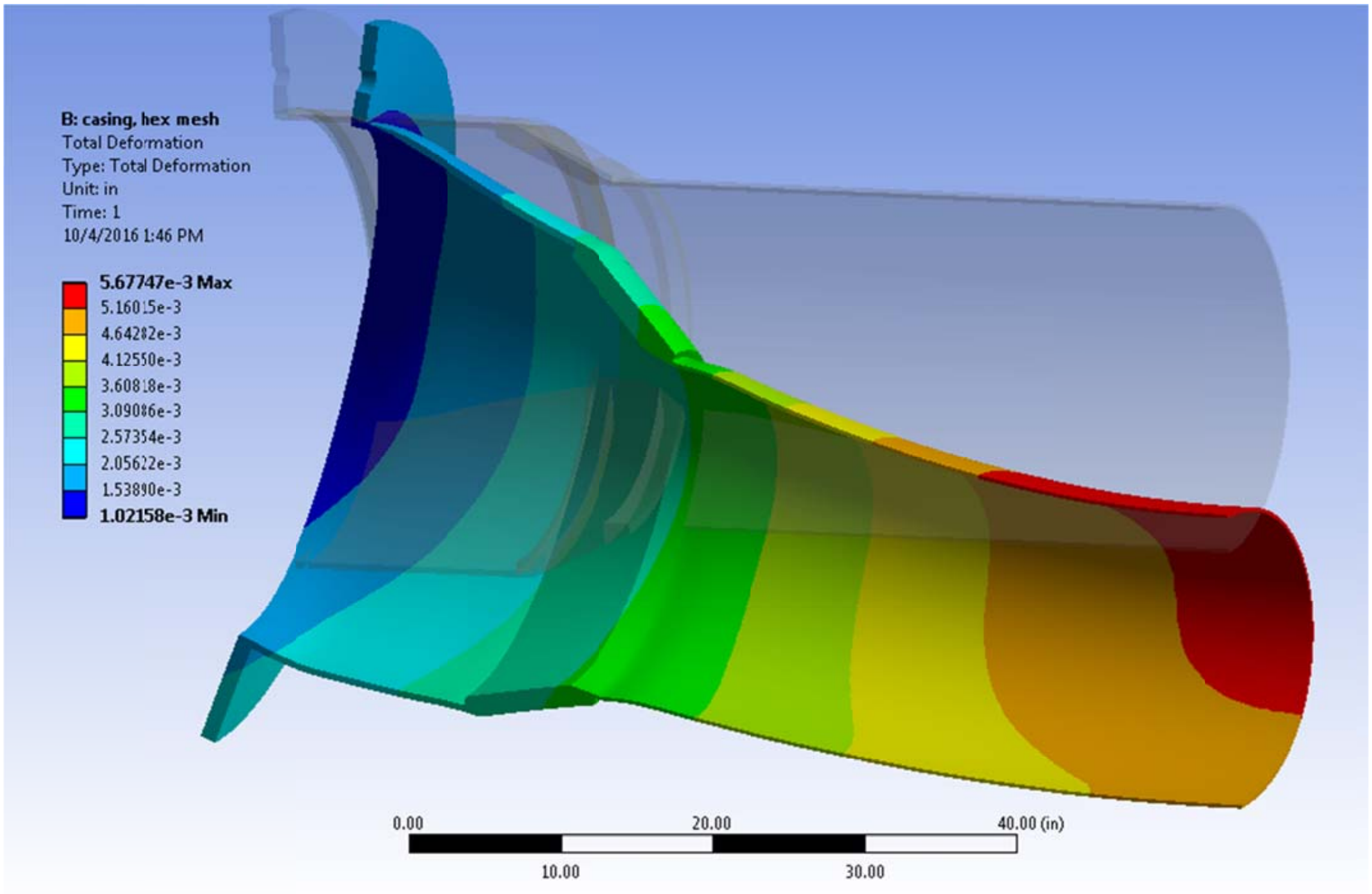


Figure 7: Global "Beam Bending" Deflection of Casing

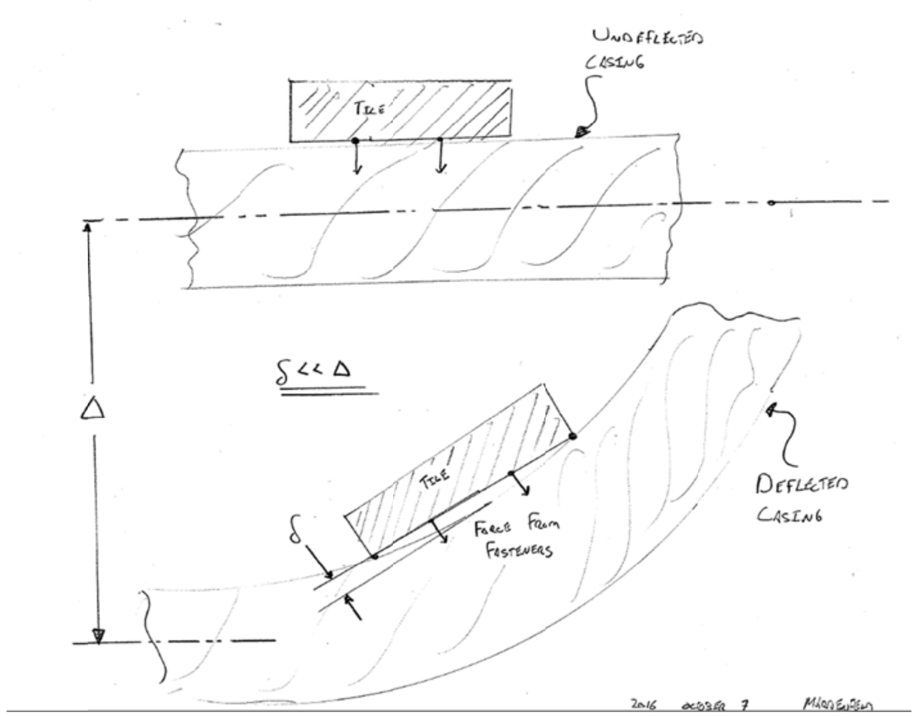


Figure 8: "Chordal Deviation" is key deflection parameter

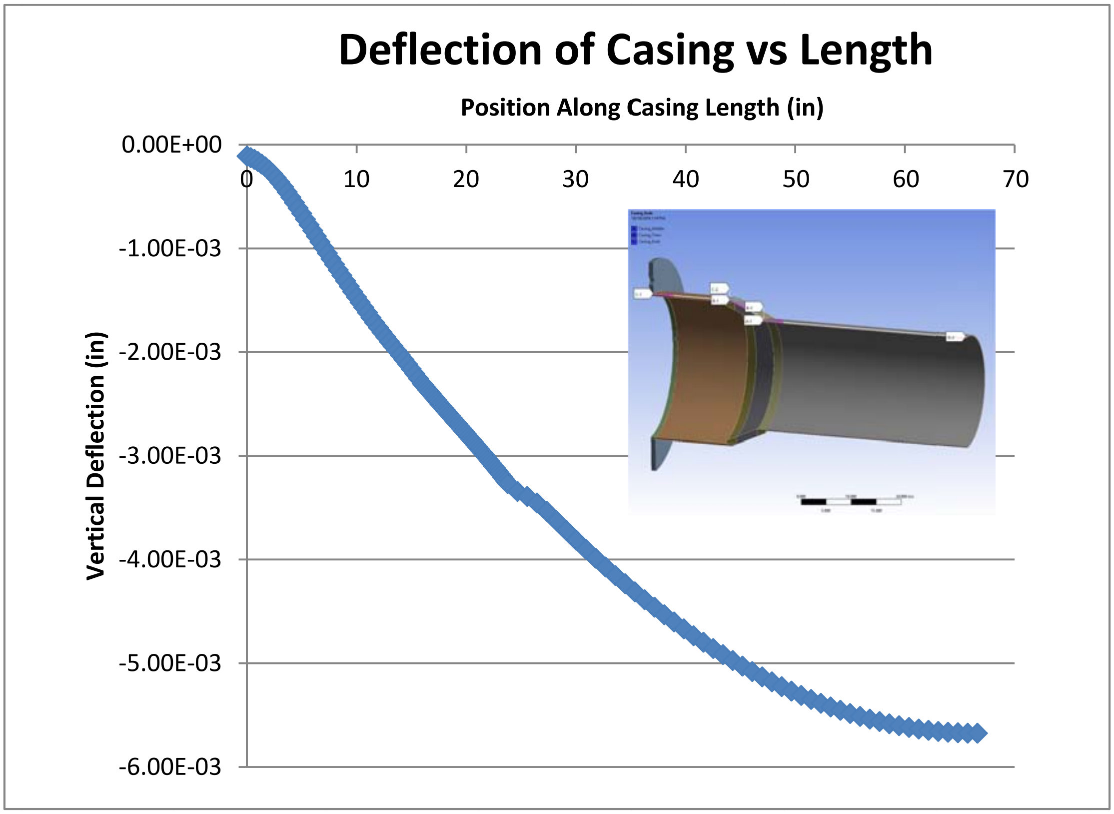


Figure 9: Casing Vertical Displacement plotted along top outermost fiber

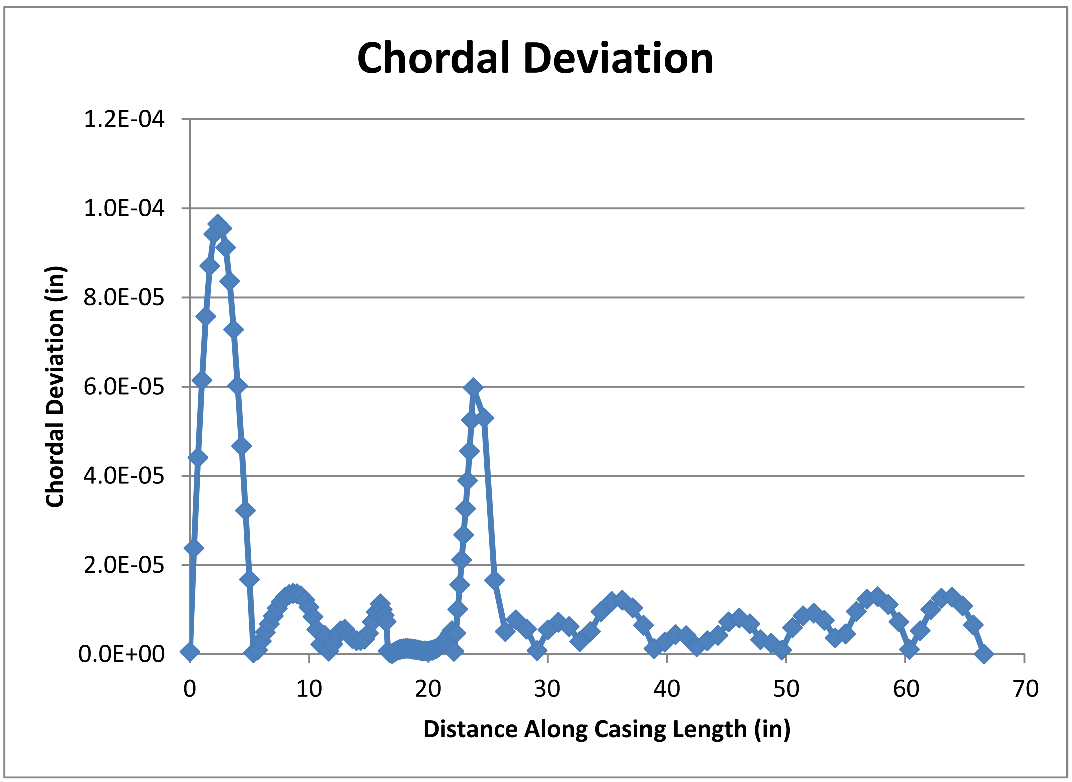


Figure 10: "Chordal Deviation" plotted along length of Casing (top outermost fiber)

Casing was split into 12 "buckets" each of which approximately span the length of a single tile. A secant chord was fit to the enpoints of each span and the deviation shown in Figure 8 calculated algebraically.

Tile Submodel

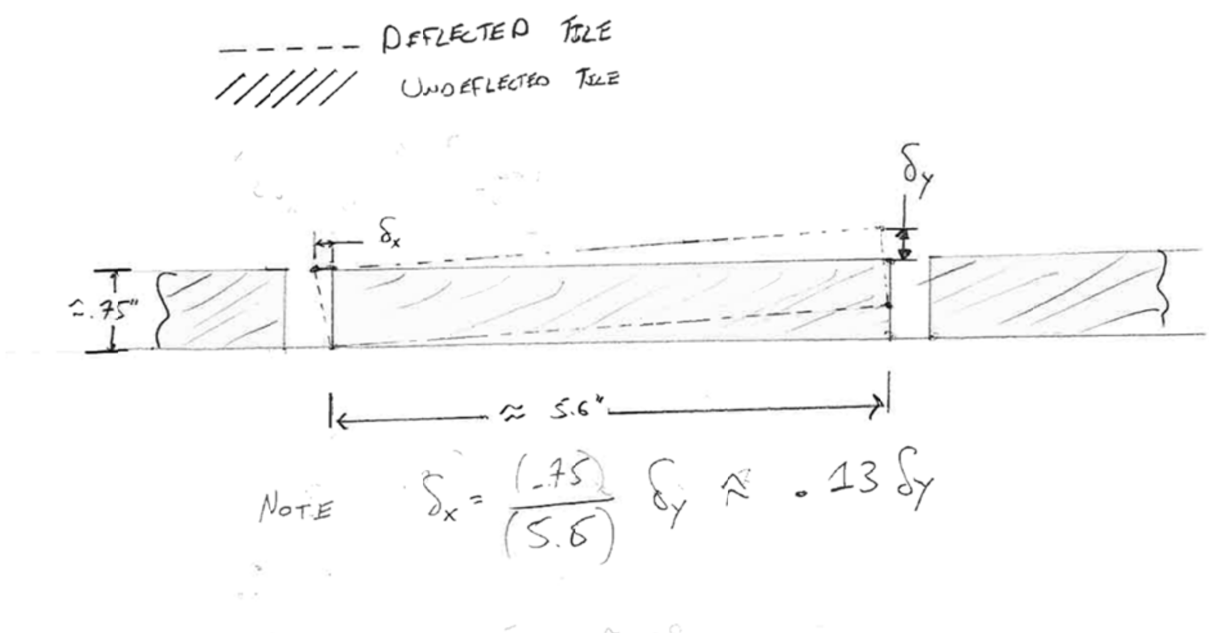


Figure 11: Horizontal "Gap" Closing Displacement

Since the chordal deviation is of order .0001" and the tile to tile gap is of order .010", Tiles will not touch.

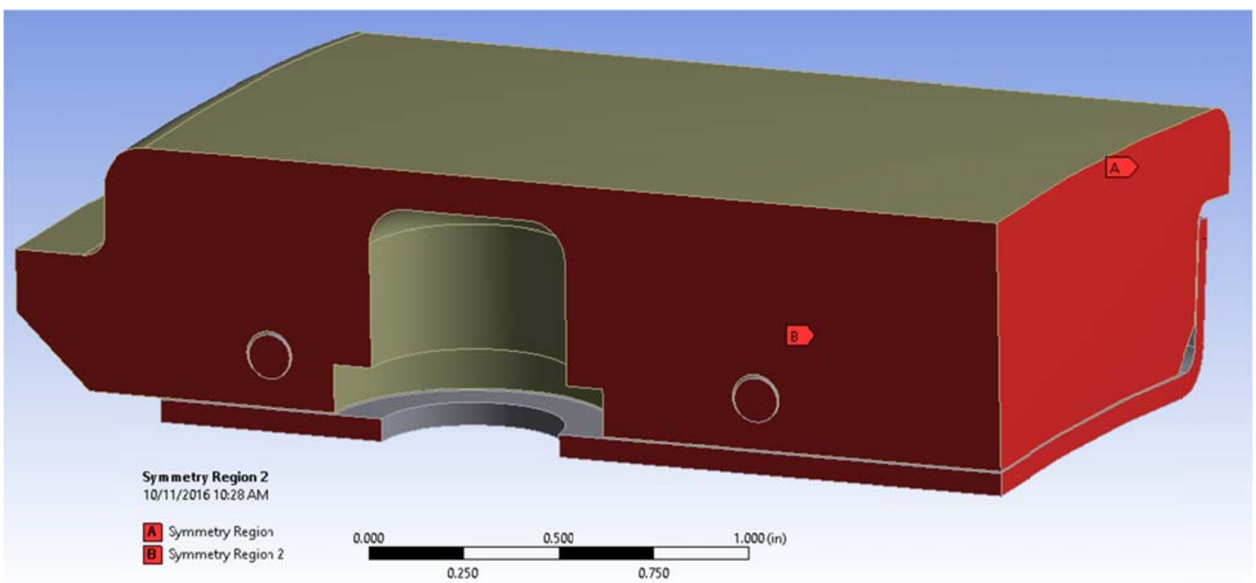


Figure 12: Quarter Symmetry Boundary Conditions

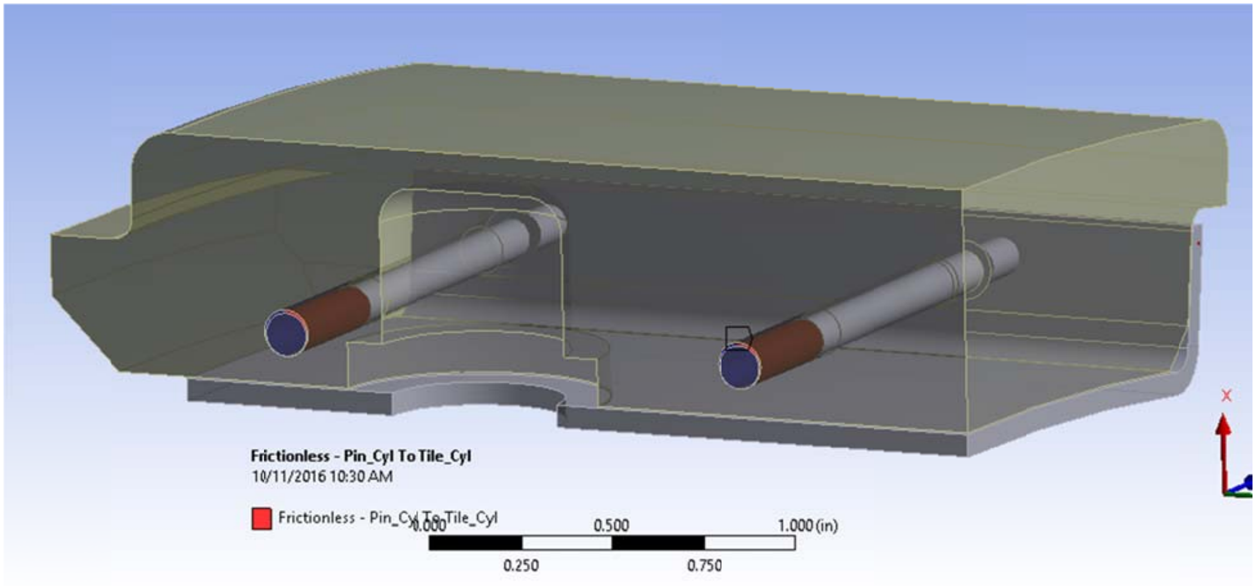


Figure 13: Frictionless Contact between Pins and Tiles

Note that the pin makes initial contact with the bottom of the Tile's through hole, and that contact only occurs at a centralized region because the Pin is stepped. There is no contact between the Pin and Bracket because they are assumed to be a monolithic part.

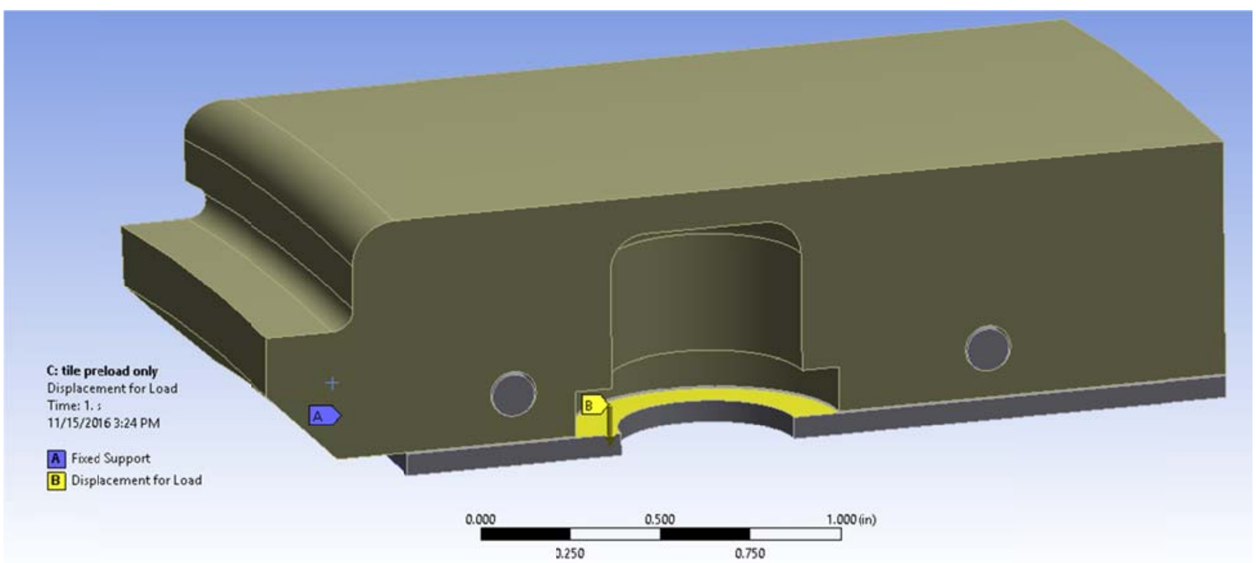


Figure 14: Supports and Imposed Displacements

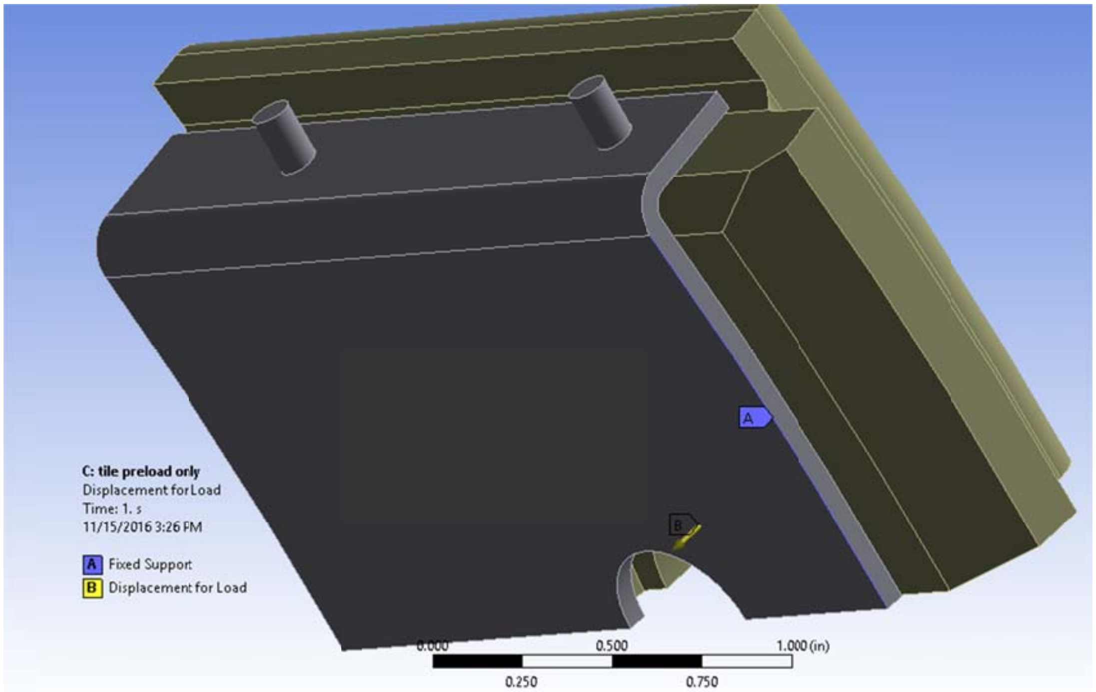


Figure 15: Supports and Imposed Displacements, Second View

A: Fixed Support

This represents the edge of the Bracket contacting the Casing. In a real part, the curvature of the Bracket will not exactly match the curvature of the Casing and some raised point will make contact first. This simulation was rerun with three different assumptions at this boundary condition. First it was modeled as a fixed support, then an upwards displacement of .0001", and finally a downward displacement of .0001". These respectively simulate the undeflected casing, tiles on the compressive side of the Casing during bending, and tiles on the tensile side of the Casing during bending. They are denoted in the screenshots as "Preload Only", "Tile Up", and "Tile Down", respectively.

B: Displacement for Load

This downward displacement of .003" represents a preload applied by the stud joint which provides the clamping force to hold the Underlap Tile in place. It is assumed that after .003" the bracket makes contact with the Casing in a region closer to the Nut Cap, the gap closes, and further tensioning of the Nut Cap results in direct compressive forces between the Bracket and the Casing without providing additional clamping load on the Underlap Tile.

Figure 16: Explanation of Support Conditions and Imposed Displacements shown in Figures 13 and 14

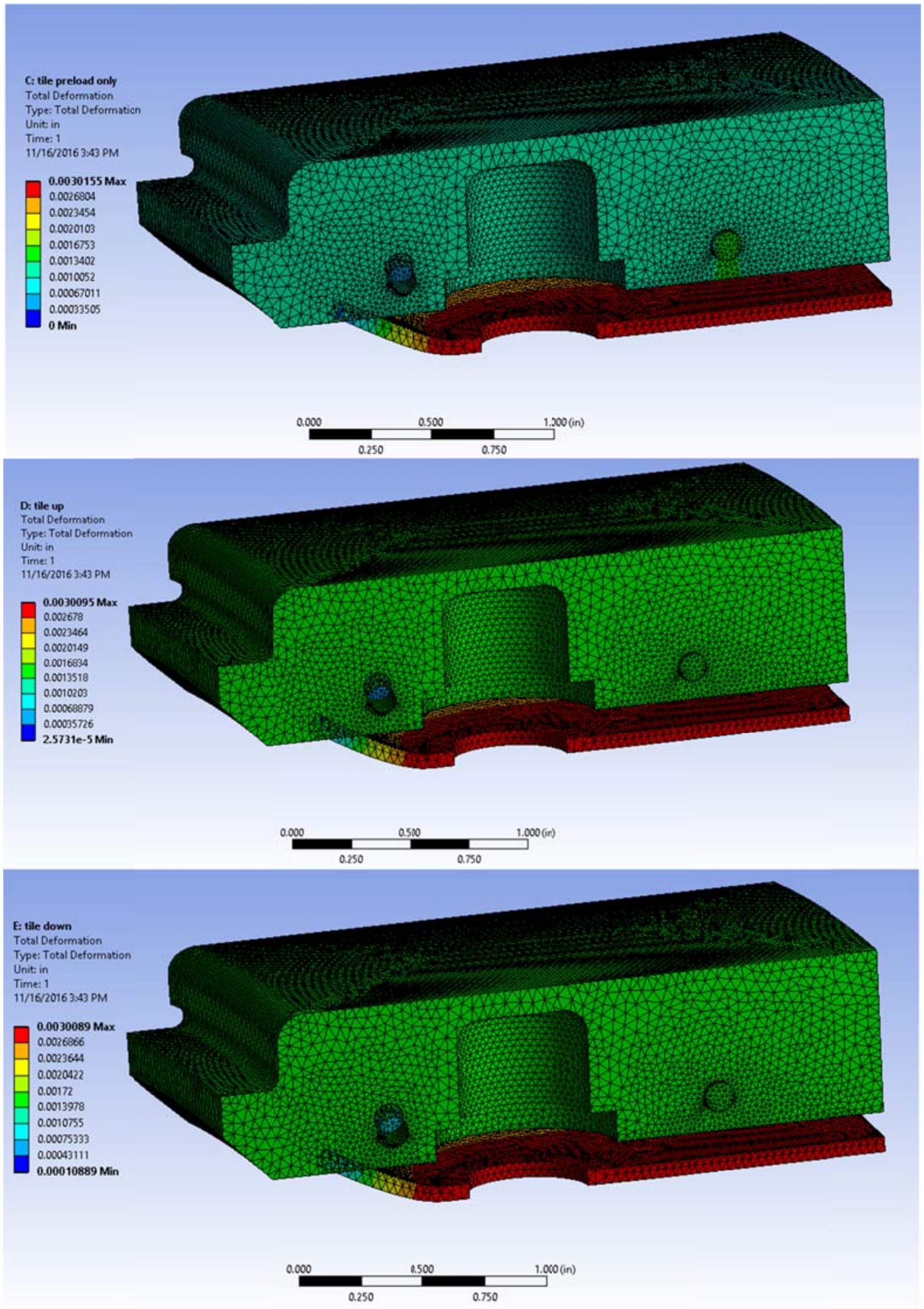


Figure 17: Tile Assembly Deflected Shape

The deflected shape of the assembly is driven by the deflection of the bracket during initial preload of the stud joint fastening it to the Casing. The differential displacement due to the reorientation of the Casing is extremely small.

The figures show the Casing with just stud preload and then with stud preload + imposed displacement from the Casing's deflection under load. The upwards displacement represents a tile on the concave (compressive) side of the Casing and the downwards displacement a tile on the convex (tensile) side of the Casing.

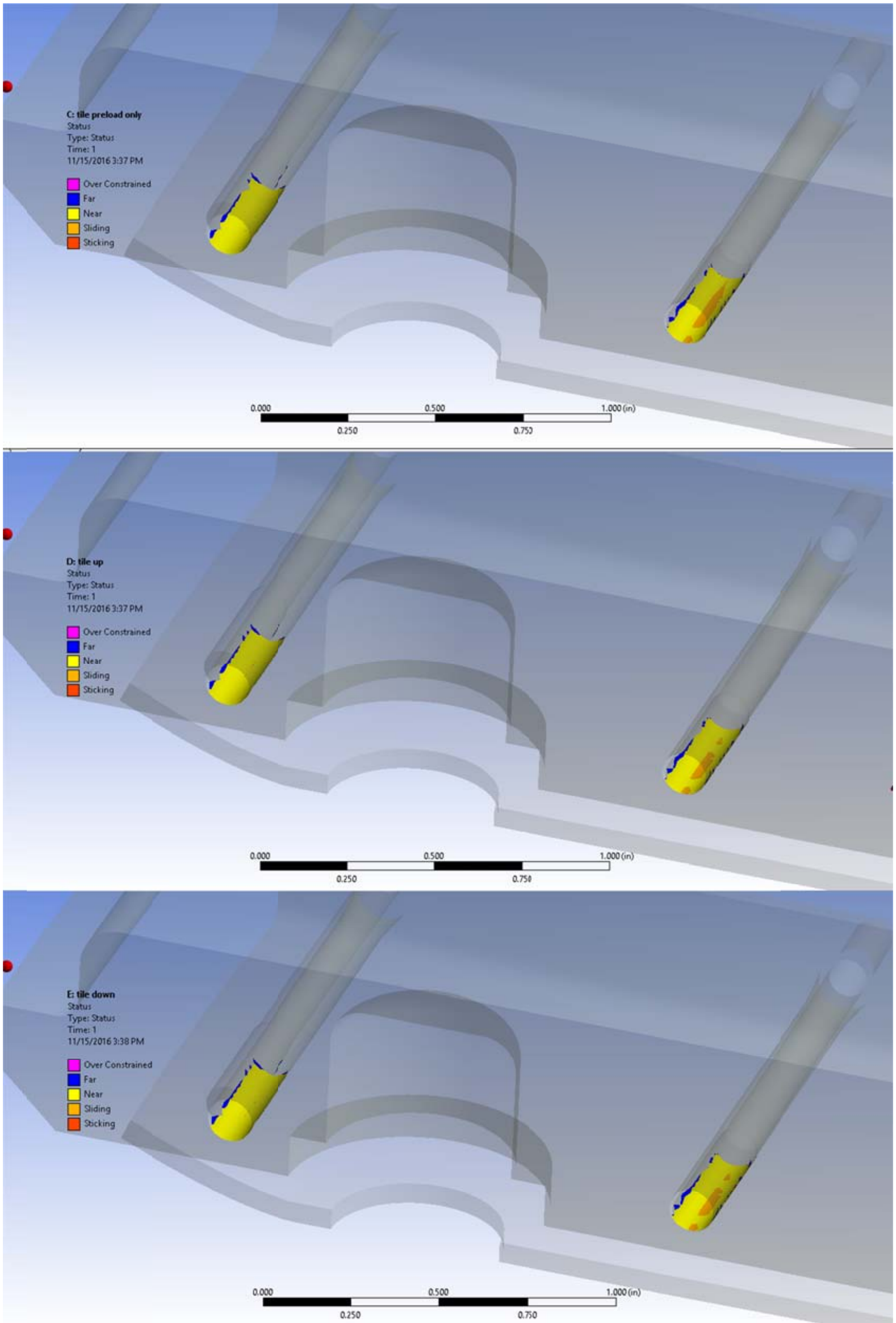


Figure 18: Tile Assembly Contact Conditions

The three figures illustrate the contact behavior of the pins inside of the Tile. Note that there is little change between the scenario with only preload and the scenarios with imposed deflections from the Casing.

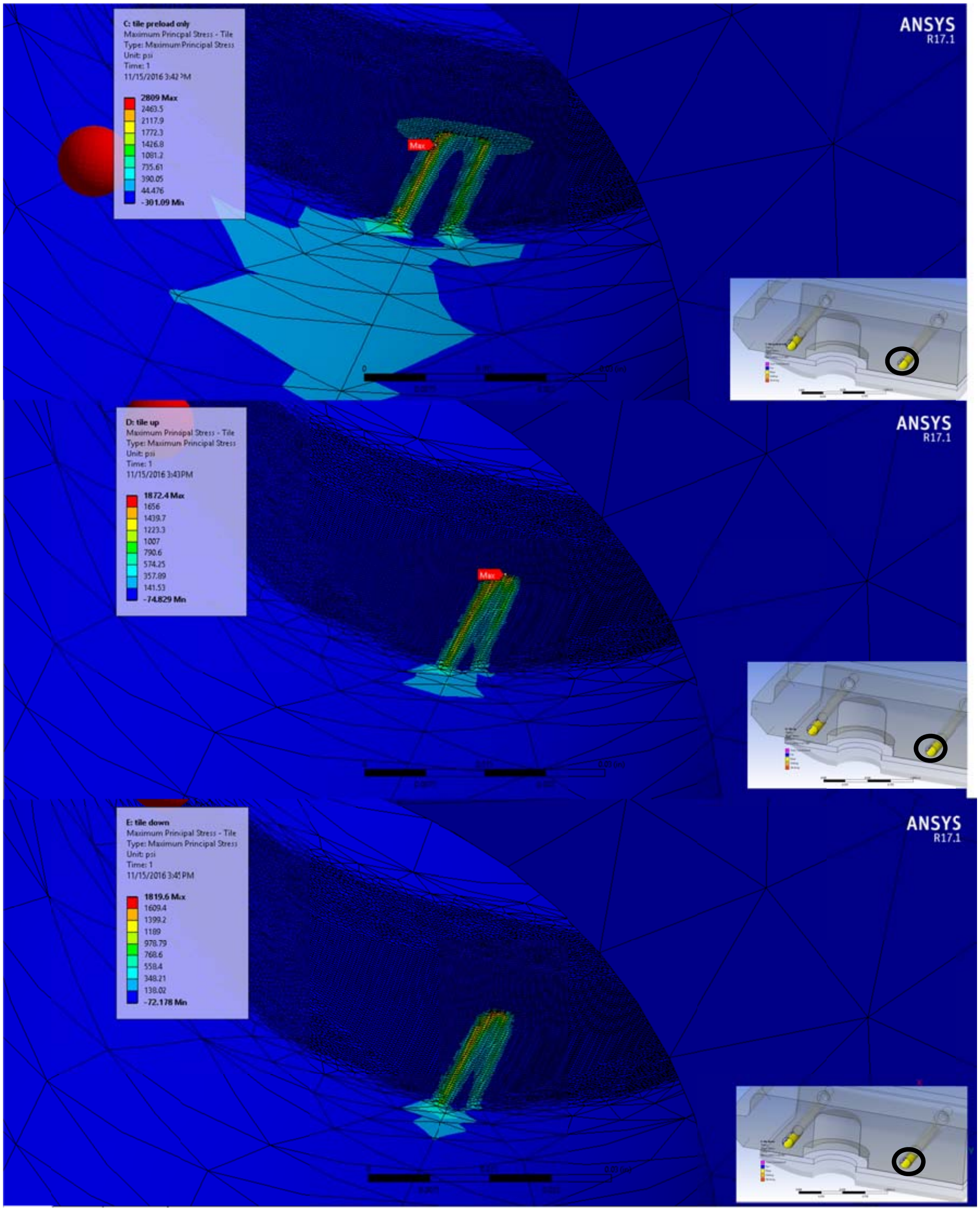


Figure 19: Local Max Principal Stress at Pin/Tile Contact

The only stresses of interest occur at the local contact between the Pin and Tile. Note that the S1 stress is relatively benign compared to POCO Material flexural strength of 6000 PSI. Again, there is only a small change between the deflected and deflected cases.

(The NSTX-U Structural Design Criteria allowable is ½ to ¾ Ultimate Strength depending on application.)

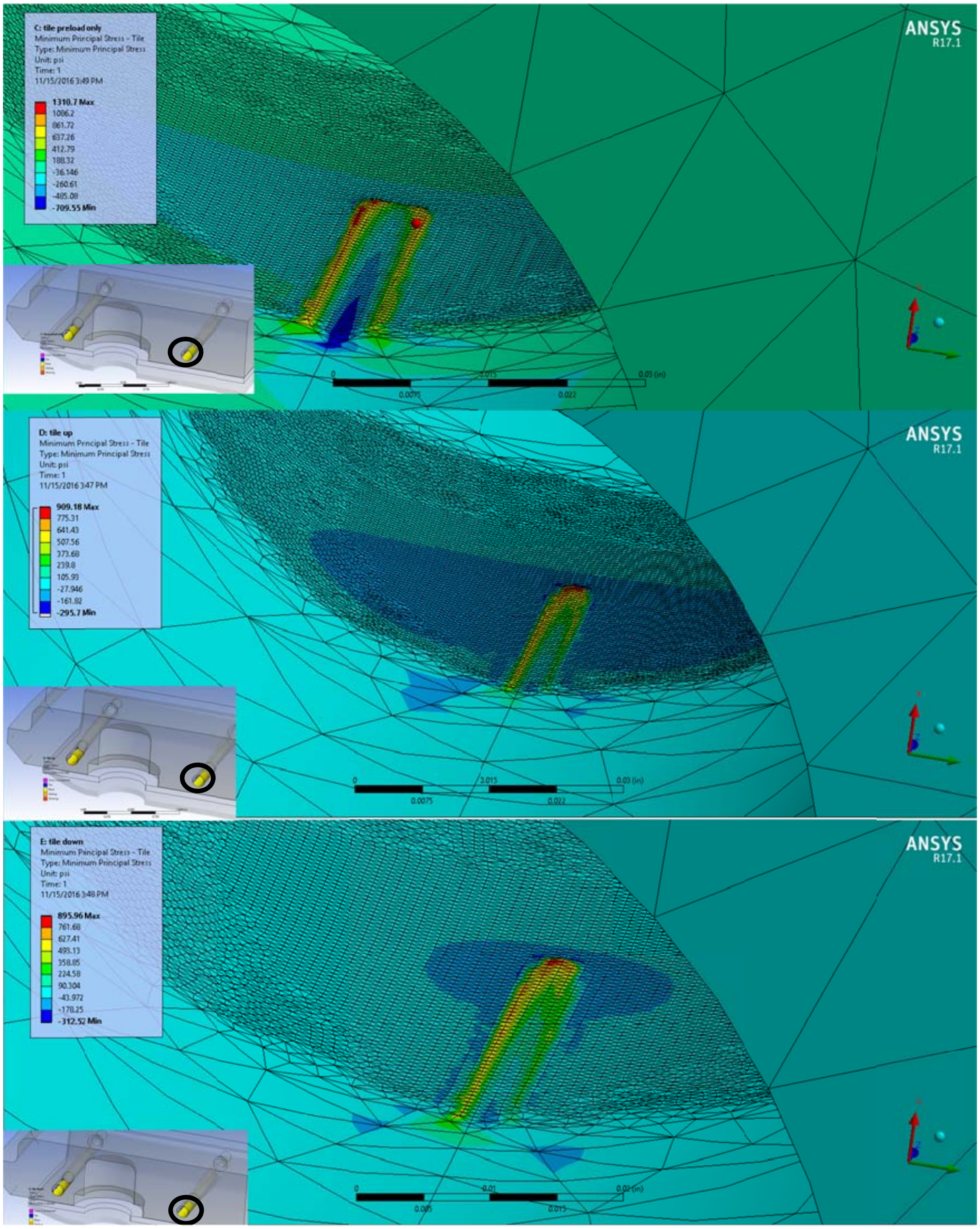


Figure 20: Local Minimum Principal Stress at Pin/Tile Contact

The only stresses of interest occur at the local contact between the Pin and Tile. Note that POCO Graphite compressive strength is 11600 PSI and the Structural Design Criteria allows ½ to ¾ of this depending on application. Again, there is only a small change between the deflected and deflected cases, which is more important than the absolute value given the simplified boundary assumptions for preload application.

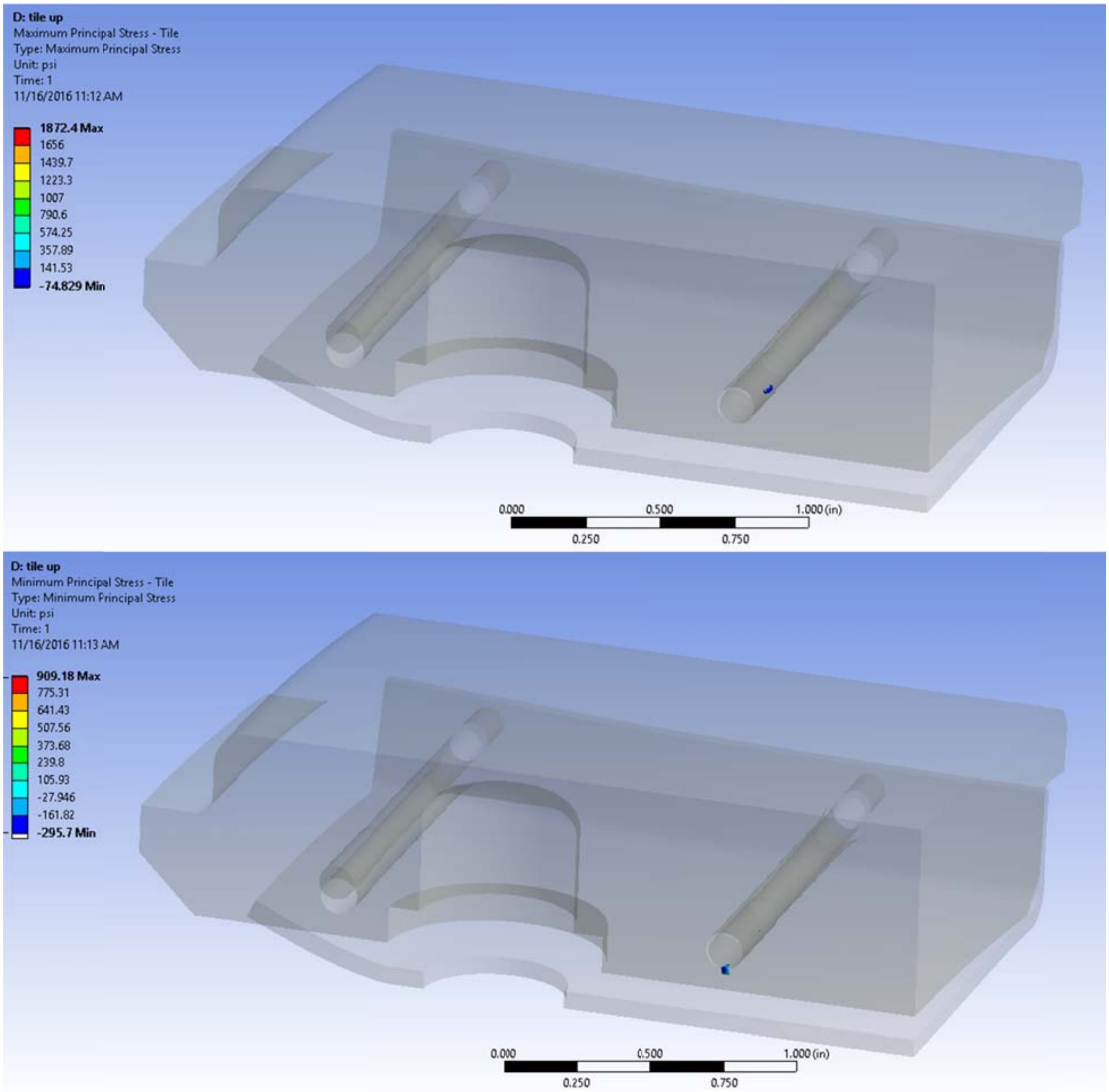


Figure 21: Tile Stresses are Low Except Near Pin/Tile Contact

These figures illustrate that stresses of interest for the Tile only occur near the Pin contact regions. The S1 plot only shows stresses which are above 100 PSI and the S3 plot only shows stresses which are below -100 PSI. Both plots show the load scenario "Tile Up", but the circumstances are similar for the other two load cases.

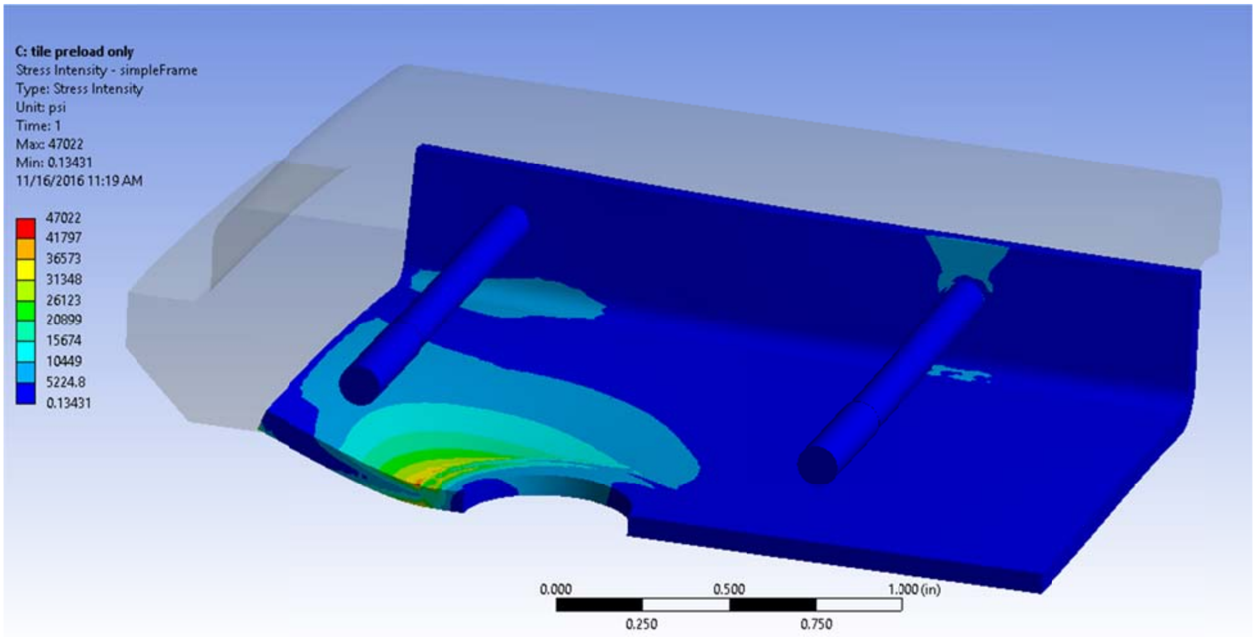
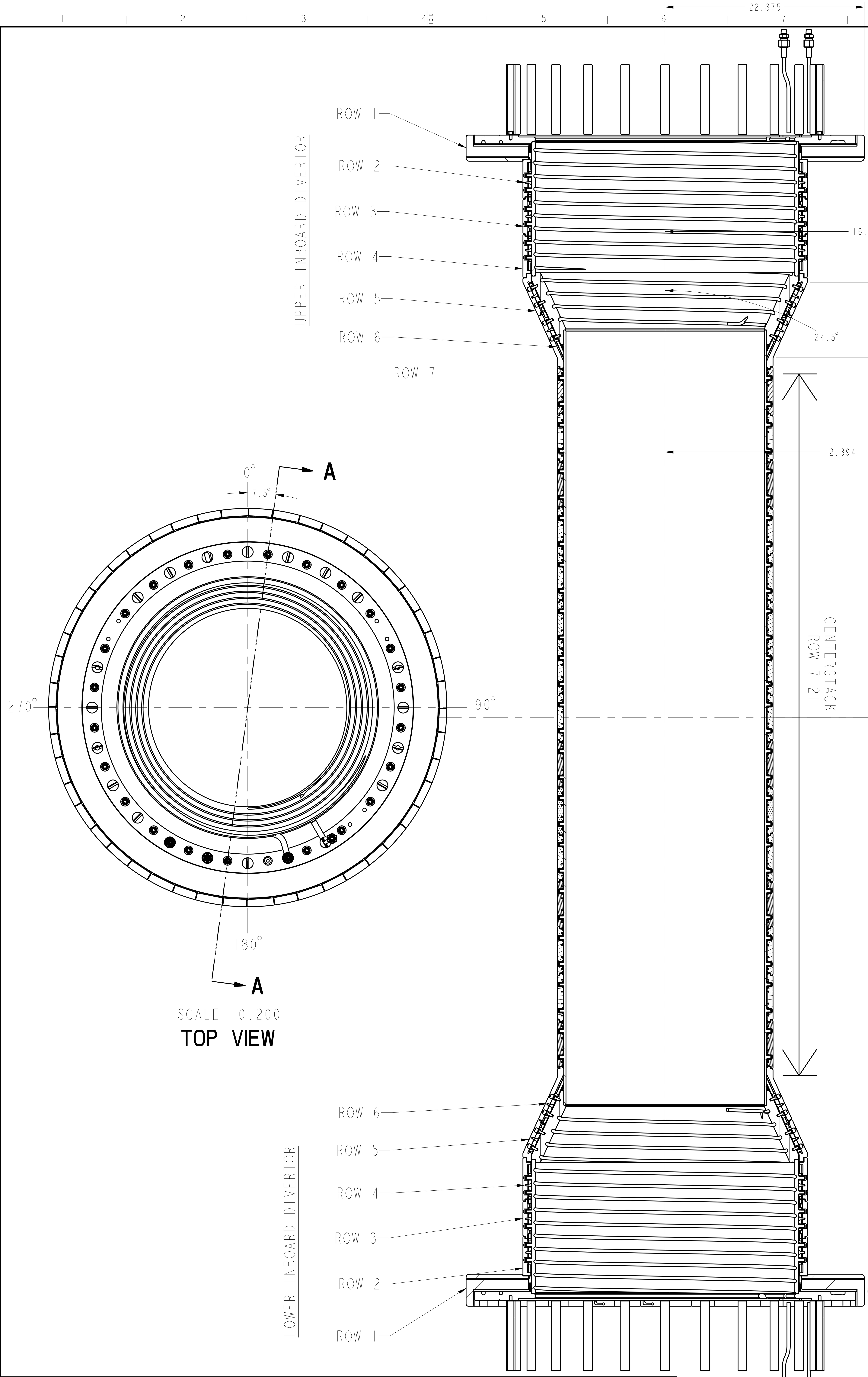


Figure 22: Stress Intensity in Bracket

This figure indicates that the Stress Intensity in the Bracket and Pins is relatively benign. The local peak is at a discontinuity at the edge of an applied boundary condition (imposed displacement).

Inconel 625 has a yield stress of approximately 60+ KSI. This shows the scenario "Preload Only", but stresses are equally benign or slightly lower for "Tile Up" and "Tile Down".

NO.	REVISION	BY	CH	SUP	APPROVED	DATE
1	REVISED PER ECN 7057	JW	LM	LM	K.TRESEMER	6/5/13
2	REVISED PER ECN 7138	JW	KT	LM	K. TRESEMER	11/4/13
3	REVISED PER ECN 7214	JW	KT	LM	K. TRESEMER	4/3/14



NOTES:
1. REFER TO DRAWINGS E-ED1324 & E-ED1342 FOR TILE AND DIAGNOSTIC LAYOUT.

PARTS LIST CONTINUED IN ZONE J-8 THRU J-11

ITEM NO.	DRAWING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	QTY REQD
62	E-ED1329-08	TILE ROW 1 -MGI/SPECTROSCOPY STYLE 2 ASSEMBLY-BOTTOM		4
61	E-ED1329-07	TILE ROW 1 - COOLANT IN/OUT -R- STYLE 2 ASSEMBLY-BOTTOM		4
60	E-ED1329-06	TILE ROW 1 - 3 LANGMUIR PROBE STYLE 2 ASSEMBLY-BOTTOM		1
59	E-ED1329-05	TILE ROW 1 - CHI THERMOCOUPLE STYLE 2 ASSEMBLY-BOTTOM		2
58	E-ED1329-04	TILE ROW 1 - LANGMUIR PROBE/SPECTROSCOPY STYLE 2 ASSEMBLY-BOTTOM		1
57	E-ED1329-03	TILE ROW 1 - MIRNOV STYLE 2 ASSEMBLY-BOTTOM		2
56	E-ED1329-02	TILE ROW 1 - THEROMCOUPLE STYLE 2 ASSEMBLY-BOTTOM		2
55	E-ED1329-01	TILE ROW 1 - STYLE 2 ASSEMBLY-BOTTOM		8
54	E-ED1328-07	TILE ROW 1 - MGI/SPECTORSCOPY STYLE 1 ASSEMBLY-BOTTOM		4
53	E-ED1328-06	TILE ROW 1 - FAST TC STYLE 1 ASSEMBLY-BOTTOM		1
52	E-ED1328-05	TILE ROW 1 - COOLANT IN/OUT -L- STYLE 1 ASSEMBLY-BOTTOM		4
51	E-ED1328-04	TILE ROW 1 - CHI THERMOCOUPLE STYLE 1 ASSEMBLY-BOTTOM		1
50	E-ED1328-03	TILE ROW 1 - LANGMUIR PROBE STYLE 1 ASSEMBLY-BOTTOM		1
49	E-ED1328-02	TILE ROW 1 - MIRNOV/SPECTROSCOPY STYLE 1 ASSEMBLY-BOTTOM		1
48	E-ED1328-01	TILE ROW 1 - STYLE 1 ASSEMBLY-BOTTOM		12
47	E-ED1300-09	TILE ROW 1 - CHI THERMOCOUPLE STYLE 2 ASSEMBLY-TOP		1
46	E-ED1299-10	TILE ROW 1 - MGI DIAGNOSTIC STYLE 1 ASSEMBLY-TOP		1
45	E-ED1299-09	TILE ROW 1 - CHI THERMOCOUPLE STYLE 1 ASSEMBLY-TOP		2
44	E-ED1310-05	TILE ROW 2-4 -1 MIRNOV STYLE 1 ASSEMBLY		2
43	E-ED1310-04	TILE ROW 2-4 - LANGMUIR PROBE STYLE 1 ASSEMBLY		3
42	E-ED1310-03	TILE ROW 2-4 - MIRNOV STYLE 1 ASSEMBLY		2
41	E-ED1310-02	TILE ROW 2-4 - THERMOCOUPLE STYLE 1 ASSEMBLY		2
40	E-ED1310-01	TILE ROW 2-4 - 1 MIRNOV STYLE 1 ASSEMBLY		15
39	E-ED1309-02	TILE ROW 2-4 - THERMOCOUPLE STYLE 2 ASSEMBLY		2
38	E-ED1309-01	TILE ROW 2-4 - STYLE 2 ASSEMBLY		22
~~37~~	~~E-ED1300-08~~	~~TILE ROW 1 - 3 LANGMUIR PROBE STYLE 2 ASSEMBLY~~		~~1~~
~~36~~	~~E-ED1300-07~~	~~TILE ROW 1 - COOLANT IN/OUT -R- STYLE 2 ASSEMBLY~~		~~4~~
35	E-ED1300-06	TILE ROW 1 - GAS INJECTION STYLE 2 ASSEMBLY-TOP		4
34	E-ED1300-05	TILE ROW 1 - COOLANT IN/OUT -L- STYLE 2 ASSEMBLY-TOP		4
33	E-ED1300-04	TILE ROW 1 - LANGMUIR PROBE/MGI STYLE 2 ASSEMBLY-TOP		1
32	E-ED1300-03	TILE ROW 1 - MIRNOV STYLE 2 ASSEMBLY-TOP		2
31	E-ED1300-02	TILE ROW 1 - THEROMCOUPLE STYLE 2 ASSEMBLY-TOP		2
30	E-ED1300-01	TILE ROW 1 - STYLE 2 ASSEMBLY-TOP		10
29	E-ED1299-08	TILE ROW 1 - FAST TC STYLE 1 ASSEMBLY-TOP		1
~~28~~	~~E-ED1299-07~~	~~TILE ROW 1 - NO ROGOWSKI STYLE 1 ASSEMBLY~~		~~1~~
27	E-ED1299-06	TILE ROW 1 - GAS INJECTION STYLE 1 ASSEMBLY-TOP		4
~~26~~	~~E-ED1299-05~~	~~TILE ROW 1 - COOLANT IN/OUT -L- STYLE 1 ASSEMBLY~~		~~4~~
25	E-ED1299-04	TILE ROW 1 - COOLANT IN/OUT -R- STYLE 1 ASSEMBLY-TOP		4
24	E-ED1299-03	TILE ROW 1 - LANGMUIR PROBE STYLE 1 ASSEMBLY-TOP		1
23	E-ED1299-02	TILE ROW 1 - MIRNOV STYLE 1 ASSEMBLY-TOP		1
22	E-ED1299-01	TILE ROW 1 - STYLE 1 ASSEMBLY-TOP		10
21	E-ED1270-04	TILE ROW 6 - GAS INJ MID PLANE STYLE 2 ASSEMBLY		2
20	E-ED1270-03	TILE ROW 6 - GAS INJ SHLDR STYLE 2 ASSEMBLY		2
19	E-ED1270-02	TILE ROW 6 - THERMOCOUPLE STYLE 2 ASSEMBLY		2
18	E-ED1270-01	TILE ROW 6 - STYLE 2 ASSEMBLY	--	18
17	E-ED1269-03	TILE ROW 5 - GAS INJECTION STYLE 2 ASSEMBLY		4
16	E-ED1269-02	TILE ROW 5 - THERMOCOUPLE STYLE 2 ASSEMBLY		2
15	E-ED1269-01	TILE ROW 5 - STYLE 2 ASSEMBLY		18
14	E-ED1268-02	TILE ROW 6 - THERMOCOUPLE STYLE 1 ASSEMBLY		2
13	E-ED1268-01	TILE ROW 6 - STYLE 1 ASSEMBLY		22
12	E-ED1267-02	TILE ROW 5 - THERMOCOUPLE STYLE 1 ASSEMBLY		2
11	E-ED1267-01	TILE ROW 5 - STYLE 1 ASSEMBLY	--	22
~~10~~	~~E-ED1266-02~~	~~VERT RAIL TILE ROW 7-21 -TC STYLE 1-2~~		~~4~~
9	E-ED1266-01	VERT RAIL TILE ROW 7-21 -STYLE 1-2		2
8	E-ED1265-07	VERT RAIL TILE ROW 7-21 -GAS INJ, SHUNT STYLE 3-4		1
7	E-ED1265-06	VERT RAIL TILE ROW 7-21 -2 MIRNOV STYLE 3-4		2
6	E-ED1265-05	VERT RAIL TILE ROW 7-21-GAS INJ ROT.MIRNOV,SHUNT STYLE 3-4		1
5	E-ED1265-04	VERT RAIL TILE ROW 7-21 -LPROBE STYLE 3-4		1
4	E-ED1265-03	VERT RAIL TILE ROW 7-21 -MIRNOV STYLE 3-4		2
3	E-ED1265-02	VERT RAIL TILE ROW 7-21 -2 TC,MIRNOV STYLE 3-4		1
2	E-ED1265-01	VERT RAIL TILE ROW 7-21 -TC,MIRNOV, SHUNT STYLE 3-4		2
1	E-DC1435-01	CENTER CASE ASSEMBLY	--	1
X	E-ED1312-01	CENTER CASE TILE ASSEMBLY	-	-

PARTS LIST

PARTS LIST CONTINUED FROM ZONE A-12 THRU A-15

67	E-ED1266-05	VERT RAIL TILE ROW 7-21 -SHUNT STYLE 1-2		1
66	E-ED1266-04	VERT RAIL TILE ROW 7-21 -SHUNT STYLE 1-2		3
65	E-ED1266-03	VERT RAIL TILE ROW 7-21 -SHUNT STYLE 1-2		6
64	E-ED1265-09	VERT RAIL TILE ROW 7-21 -MIRNOV,SHUNT (1) STYLE 3-4		1
63	E-ED1265-08	VERT RAIL TILE ROW 7-21 -MIRNOV,SHUNT (2) STYLE 3-4		1

GENERAL NOTES

1. PPPL APPROVED DRAWINGS TAKE PRECEDENCE OVER MODEL DIMENSIONS.
2. WHEN MODELS ARE PROVIDED, VENDOR MUST VERIFY THAT MODEL DIMENSIONS CONFORM WITH PPPL APPROVED DRAWINGS PRIOR TO FABRICATION.

MAGNETIC PERMEABILITY REQUIREMENT (SEE NOTES)

YES | NO

RELEASED FOR FABRICATION / INSTALLATION
PPPL Drafting:

RELEASE LEVEL: Fabrication
DWG VERSION NO: 3.1

WELDING ENGINEER APPVD: N/A DATE:

COMPUTER GENERATED DRAWING MANUAL CHANGES NOT PERMITTED
Pro E
DO NOT VERIFY INFORMATION BY SCALING DRAWING
SCALE: 0.05x & AS NOTED
NEXT ASSEMBLY

CENTRAL FILES:
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
MACHINE SURFACES 125
BREAK SHARP EDGES .005/.020
TOLERANCES NON-CUMULATIVE

DECIMAL-INCH		FRACTIONS	
.X	±.100	0"-12"	±1/16
.XX	±.030	12"-72"	±1/8
.XXX	±.010	72"-120"	±1/4
ANGULAR	±0°-15'	OVER 120"	±1/2

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT

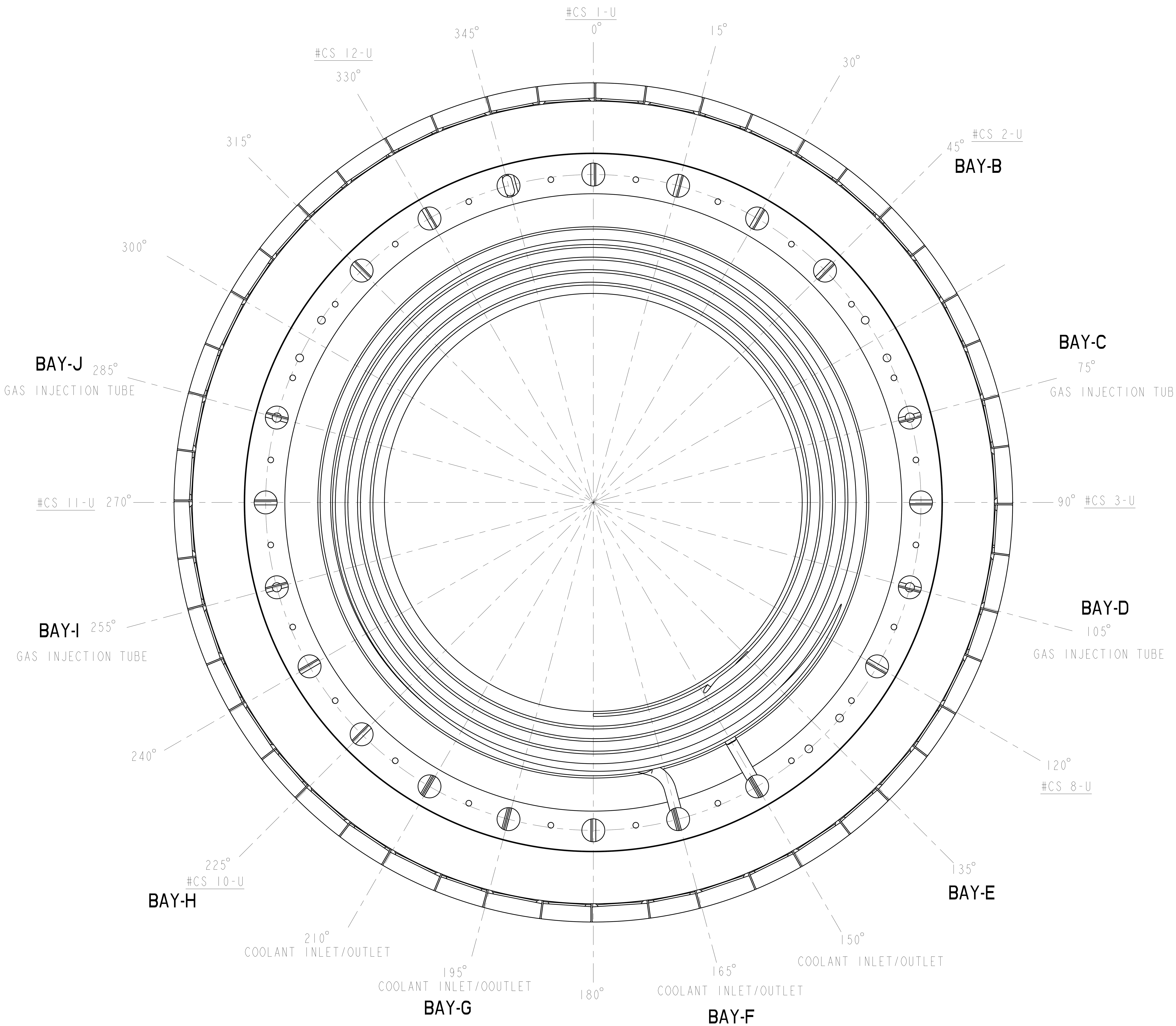
CENTERSTACK UPGRADE
CENTER CASE TILE ASSEMBLY
AND ROW ORIENTATION

DIV: MECH. ENG. | DATE: 04/18/2012
ENG: K.TRESEMER | APPROVED K.TRESEMER
DSN: A.JARIWALA
CHK: L.MORRIS | CHK LM | SUPV LM

E-ED1312

SHEET 1 OF 3 | REV 3

NSTX-E-ED1312



SCALE 0.500

TOP VIEW

GENERAL NOTES

1. PPPL APPROVED DRAWINGS TAKE PRECEDENCE OVER MODEL DIMENSIONS.
2. WHEN MODELS ARE PROVIDED, VENDOR MUST VERIFY THAT MODEL DIMENSIONS CONFORM WITH PPPL APPROVED DRAWINGS PRIOR TO FABRICATION.

MAGNETIC PERMEABILITY REQUIREMENT (SEE NOTES)			
YES			NO

RELEASE LEVEL: Fabrication
DWG VERSION NO: 3.1

RELEASED FOR FABRICATION / INSTALLATION
PPPL Drafting:

WELDING ENGINEER
APPVD: N/A DATE:

NO	REVISION	BY	CH	SUP	APPROVED	DATE

COMPUTER GENERATED DRAWING MANUAL CHANGES NOT PERMITTED

Pro E

DO NOT VERIFY INFORMATION BY SCALING DRAWING

SCALE: 0.05x & AS NOTED

NEXT ASSEMBLY

CENTRAL FILES:

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES
MACHINE SURFACES 125

BREAK SHARP EDGES .005/.020

TOLERANCES NON-CUMULATIVE

DECIMAL-INCH		FRACTIONS	
.X	±.100	0"-12"	±1/16
.XX	±.030	12"-72"	±1/8
.XXX	±.010	72"-120"	±1/4
ANGULAR	±0°-15′	OVER 120"	±1/2

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT

CENTERSTACK UPGRADE
CENTER CASE TILE ASSEMBLY
AND ROW ORIENTATION

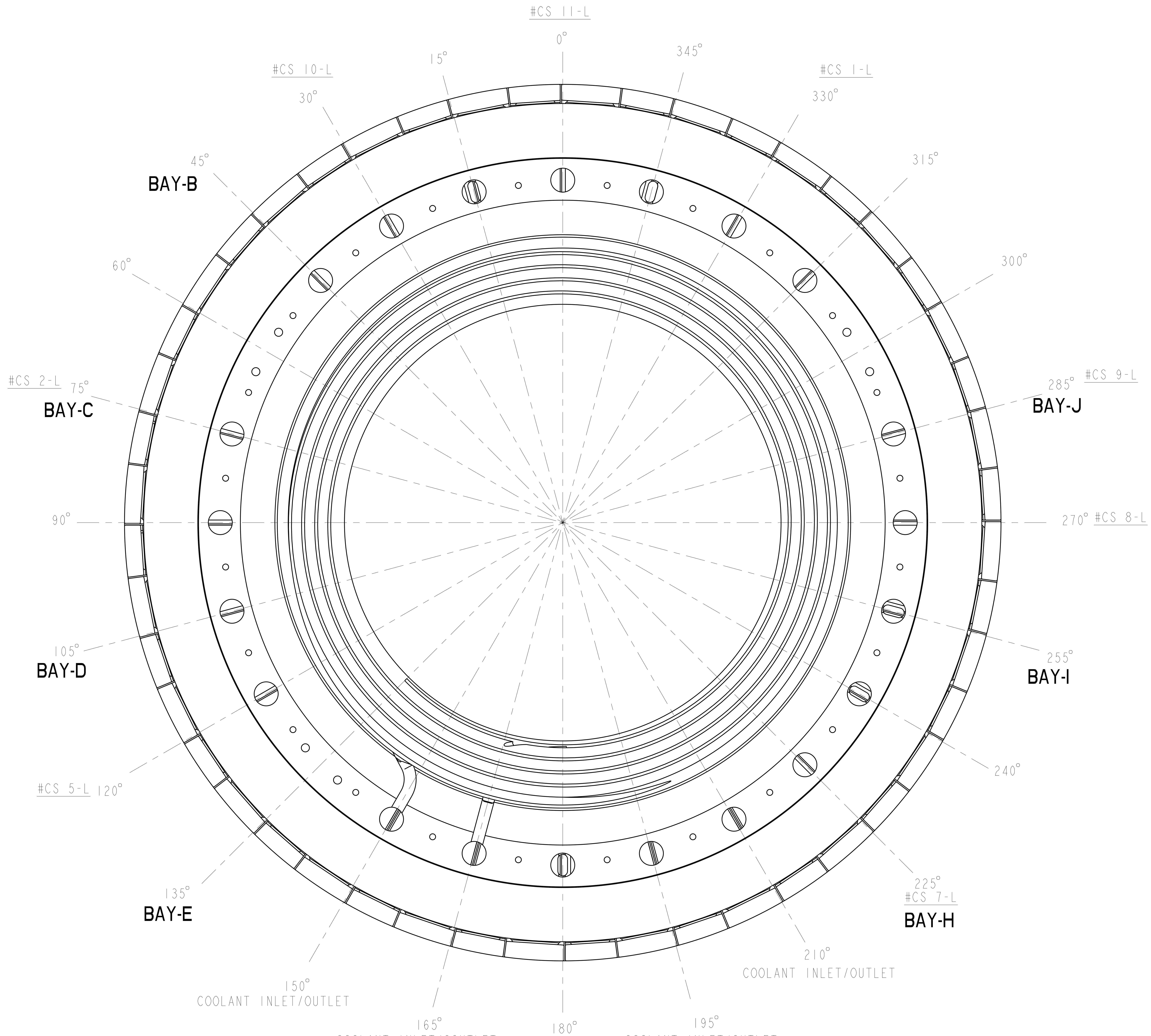
DIV: MECH. ENG. DATE: 04/18/2012
ENG: K.TRESEMER APPROVED
DSN: A.JARIWALA K.TRESEMER
CHK: L.MORRIS CHK LM SUPV LM

E-ED1312

SHEET 2 OF 3 REV 3

EMI

NSTX-E-ED1312



SCALE 0.500

BOTTOM VIEW

GENERAL NOTES

1. PPPL APPROVED DRAWINGS TAKE PRECEDENCE OVER MODEL DIMENSIONS.
2. WHEN MODELS ARE PROVIDED, VENDOR MUST VERIFY THAT MODEL DIMENSIONS CONFORM WITH PPPL APPROVED DRAWINGS PRIOR TO FABRICATION.

MAGNETIC PERMEABILITY REQUIREMENT (SEE NOTES)

YES		NO	X

RELEASE LEVEL: Fabrication
DWG VERSION NO: 3.1

RELEASED FOR FABRICATION / INSTALLATION
PPPL Drafting:

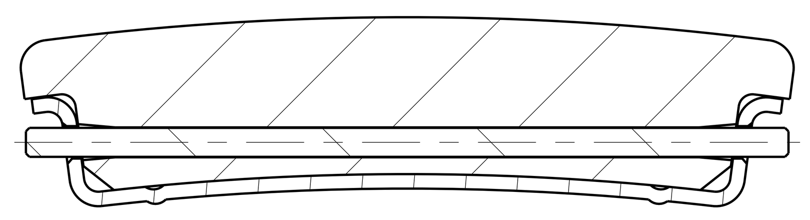
WELDING ENGINEER
APPVD: N/A DATE:

COMPUTER GENERATED DRAWING MANUAL CHANGES NOT PERMITTED	CENTRAL FILES:	PRINCETON PLASMA PHYSICS LABORATORY PRINCETON UNIVERSITY NATIONAL SPHERICAL TORUS EXPERIMENT
Pro E	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES MACHINE SURFACES 125	CENTERSTACK UPGRADE CENTER CASE TILE ASSEMBLY AND ROW ORIENTATION
DO NOT VERIFY INFORMATION BY SCALING DRAWING	BREAK SHARP EDGES .005/.020	
SCALE:	TOLERANCES NON-CUMULATIVE	DIV: MECH. ENG. / DATE: 04/18/2012
NEXT ASSEMBLY	DECIMAL-INCH: .X ±.100; .XX ±.030; .XXX ±.010; ANGULAR ±0°-15′ / FRACTIONS: 0"-12" ±1/16; 12"-72" ±1/8; 72"-120" ±1/4; OVER 120" ±1/2	ENG: K. TRESEMER / APPROVED K. TRESEMER; DSN: A. JARIWALA; CHK: L. MORRIS / CHK LM / SUPV LM; E-ED1312; SHEET 3 OF 3; REV 3

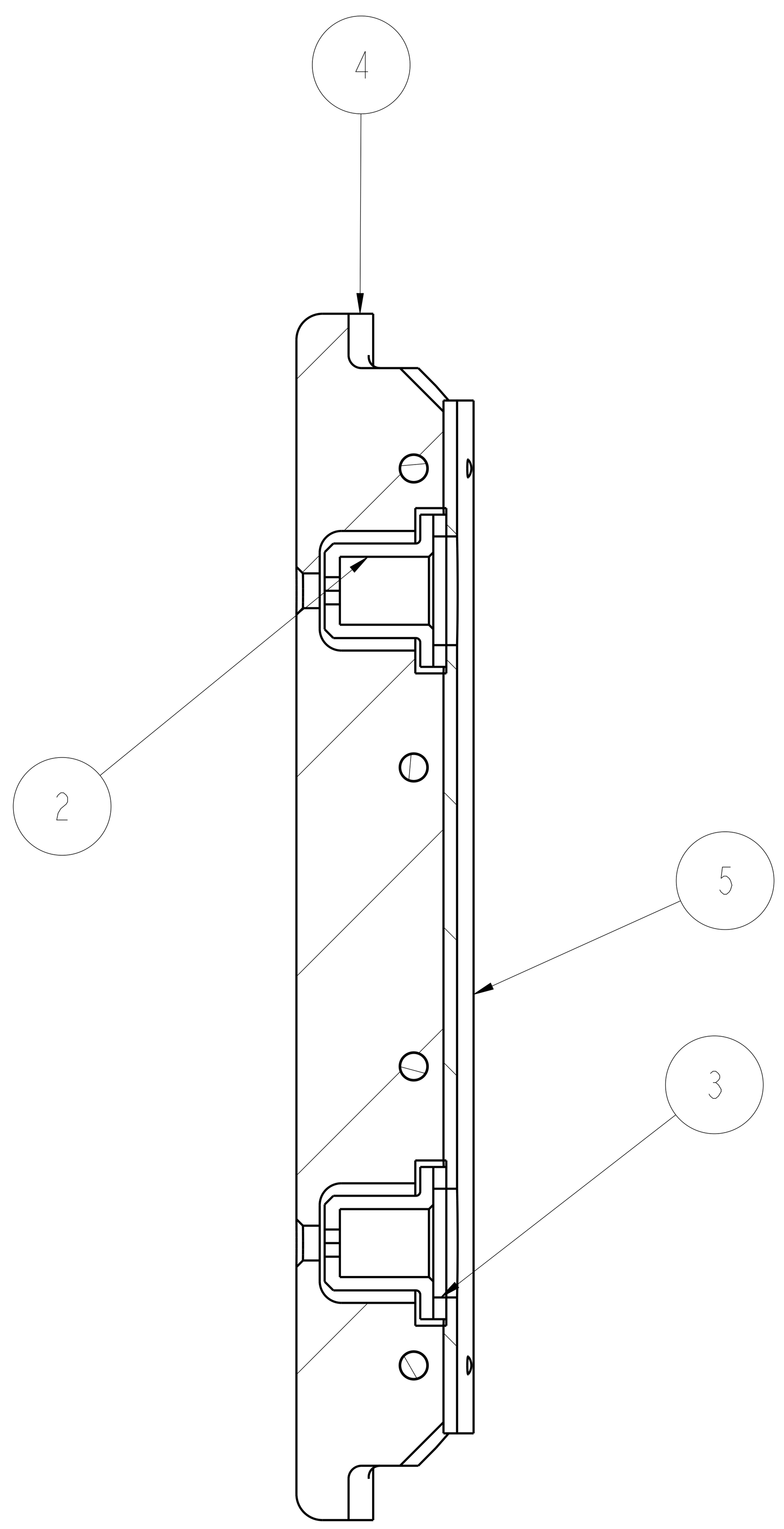
EMI

NSTX-E-ED1312

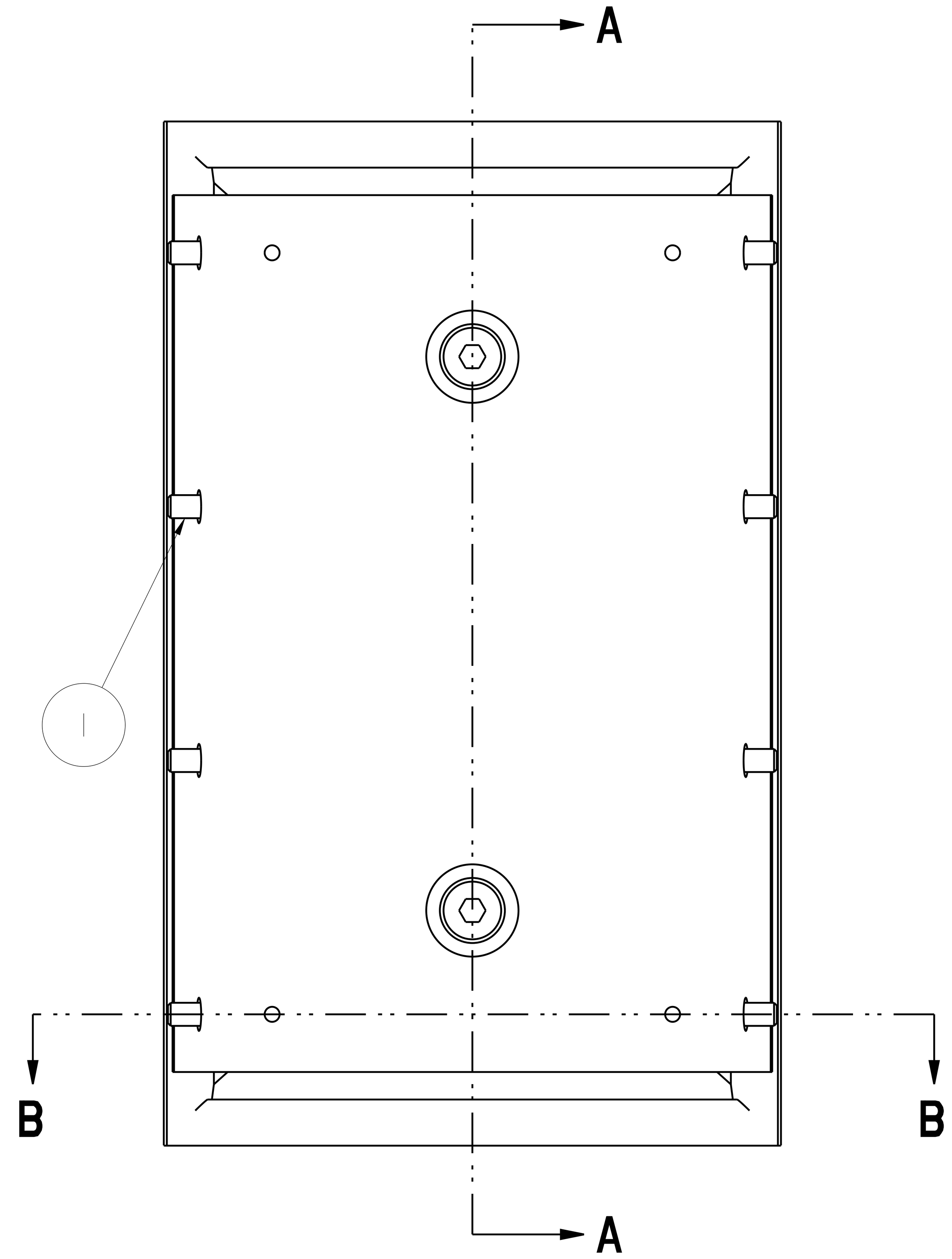
NO	REVISION	BY	CH	SUP	APPROVED	DATE

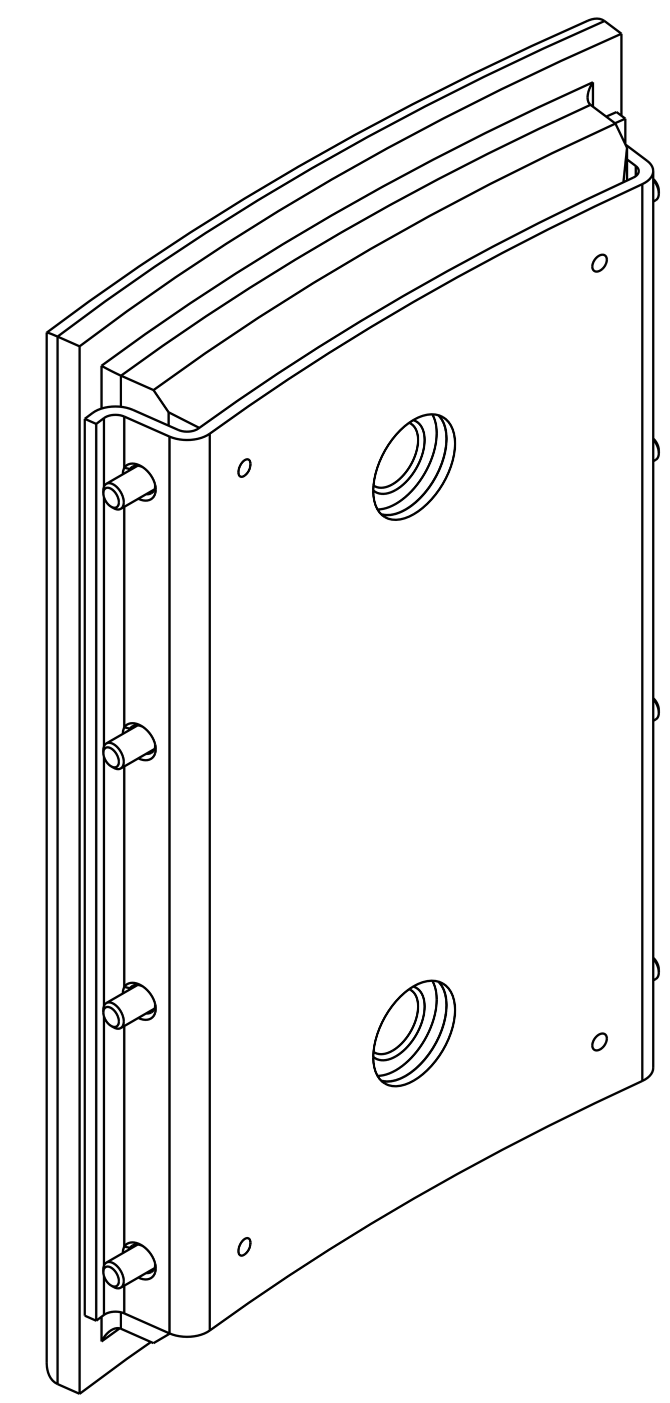


SECTION B-B



SECTION A-A





REFERENCE ISOMETRIC VIEW

NO	REVISION	BY	CH	SUP	APPROVED	DATE

TILE ASSEMBLY (E-ED1261-01) - 96 REQD.

ITEM NO.	DRAWING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	QTY REQD
5	E-ED1260-1	BACKING PLATE ROW 7-21	INCONEL 625	1
4	E-ED1258-1	TILE ROW 7-21 STYLE 1	POCO GRAPHITE	1
3	C-ED1303-1	WASHER- 0.5 I.D. X 0.7" O.D.X .06"THK	316 SS	2
2	C-ED1302-1	HEX ALLEN NUT	A286	2
1	C-ED1215	LOCATING PIN	INCONEL 625	4
X	E-ED1261-01	TILE ROW 7-21 STYLE 1 ASSEMBLY	--	-

PARTS LIST

NSTX-E-ED1261

GENERAL NOTES

1. PPPL APPROVED DRAWINGS TAKE PRECEDENCE OVER MODEL DIMENSIONS.
2. WHEN MODELS ARE PROVIDED, VENDOR MUST VERIFY THAT MODEL DIMENSIONS CONFORM WITH PPPL APPROVED DRAWINGS PRIOR TO FABRICATION.

RELEASE LEVEL: Fabrication
DWG VERSION NO: 0.24

WELDING ENGINEER
APPVD: N/A DATE:

RELEASED FOR FABRICATION / INSTALLATION
PPPL Drafting:

COMPUTER GENERATED DRAWING MANUAL CHANGES NOT PERMITTED

Pro E

DO NOT VERIFY INFORMATION BY SCALING DRAWING

SCALE: 2X

NEXT ASSEMBLY

CENTRAL FILES:

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES
MACHINE SURFACES 125

BREAK SHARP EDGES .005/.020

TOLERANCES NON-CUMULATIVE

DECIMAL-INCH		FRACTIONS	
.X	±.100	0"-12"	±1/16
.XX	±.030	12"-72"	±1/8
.XXX	±.005	72"-120"	±1/4
ANGULAR	±0°-15′	OVER 120"	±1/2

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT

CENTERSTACK UPGRADE
CENTERCASE SECTION
TILE ROW 7-21 STYLE 1 ASSEMBLY

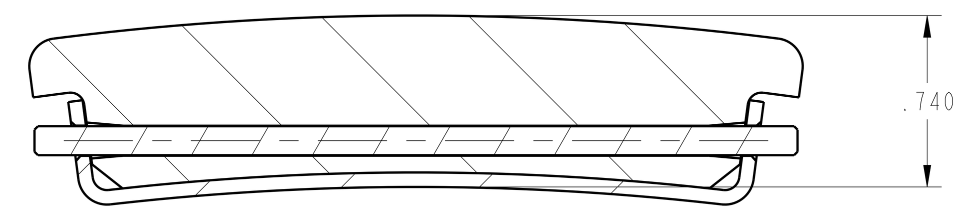
DIV: MECH. ENG. DATE: 04/12/2012
ENG: K.TRESEMER APPROVED K.TRESEMER
DSN: A. JARIWALA
CHK: L.MORRIS CHK LM SUPV LM

E-ED1261

SHEET 1 OF 1 REV 0

EMI

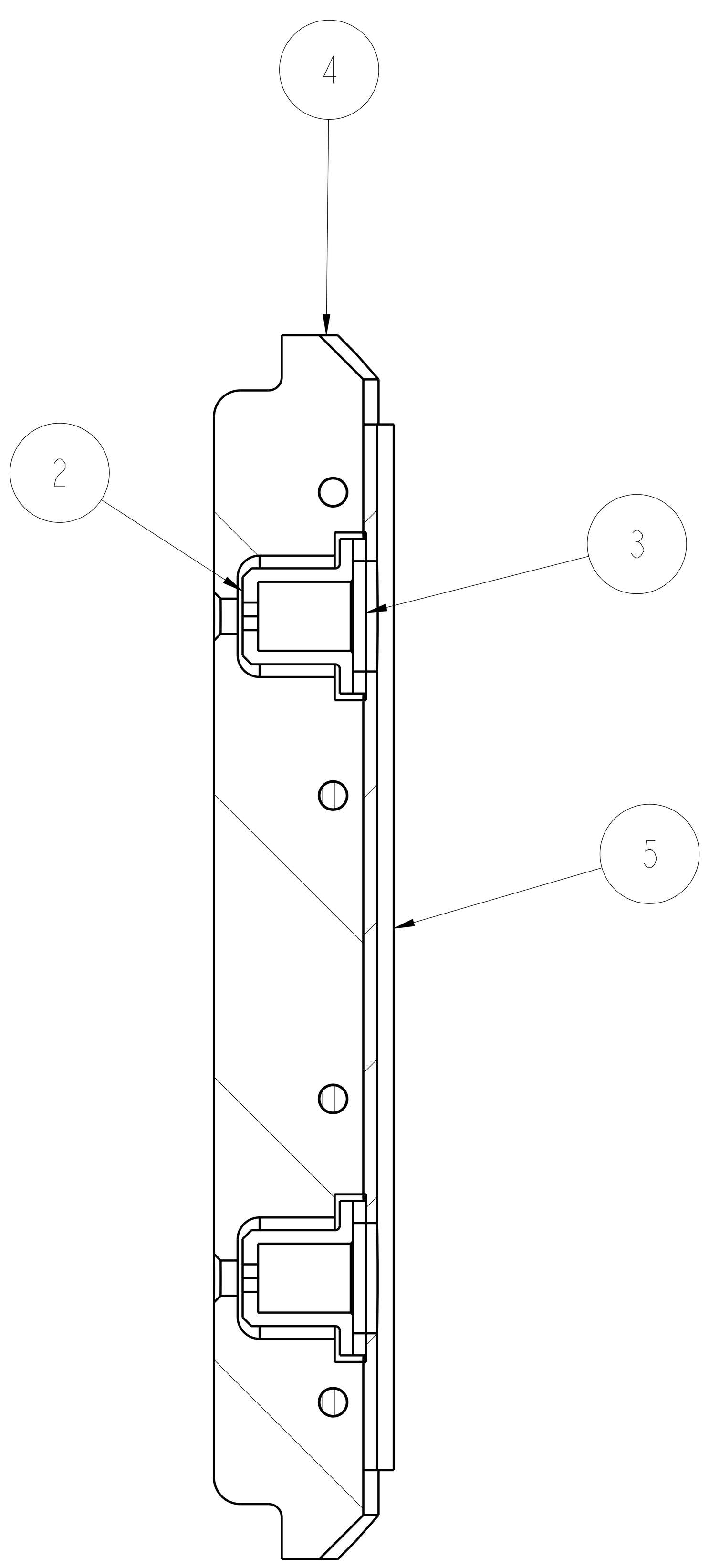
NO.	REVISION	BY	CH	SUP	APPROVED	DATE
1	REVISED PER ECN 7138	JW	KT	LM	K. TRESEMER	10/31/13
2	REVISED PER ECN 7214	JW	KT	LM	K. TRESEMER	4/2/14



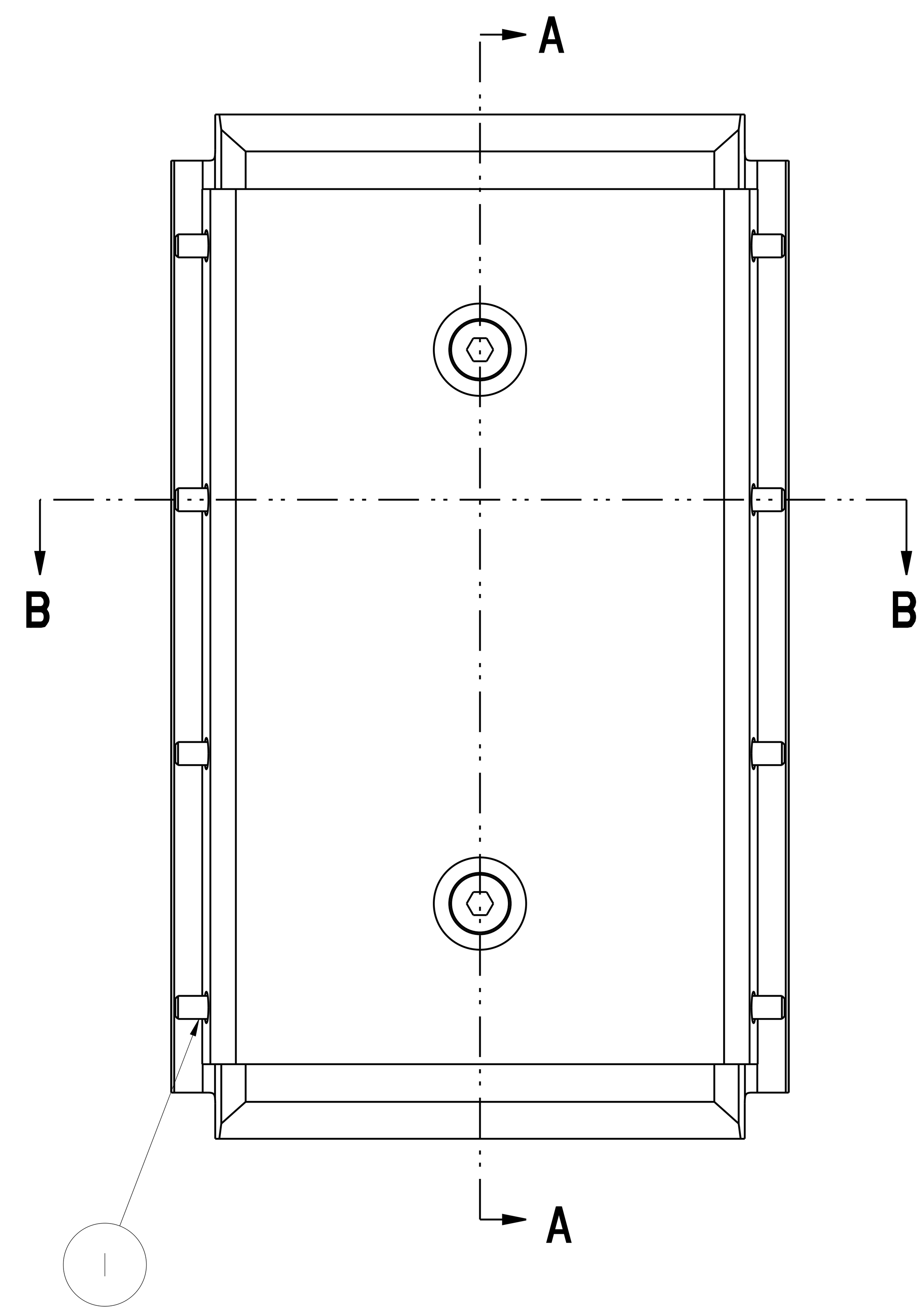
SECTION **B-B**

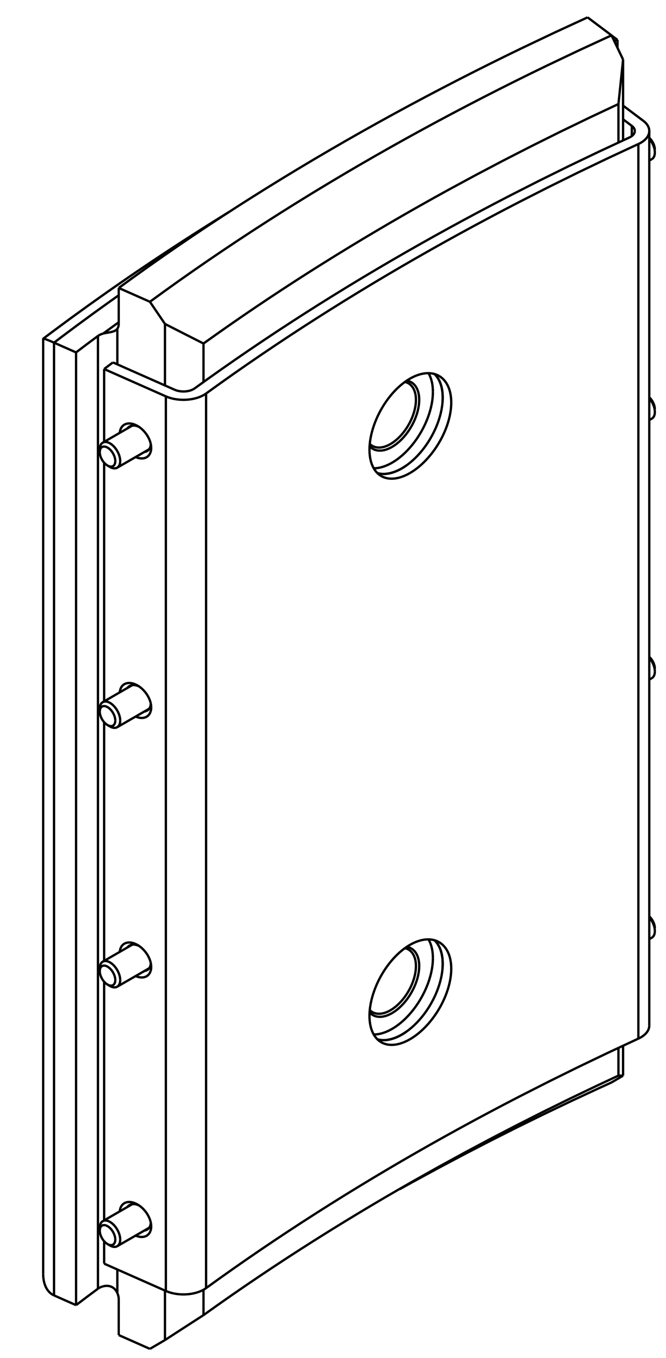
NOTE:

1. FOR THERMOCOUPLE TILE ASSEMBLY (E-ED1262-02) SEE SHEET 2.



SECTION **A-A**





REFERENCE ISOMETRIC VIEW

TILE ASSEMBLY (E-ED1262-01) - 46 REQD.

NSTX-E-ED1262

ITEM NO.	DRAWING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	QTY REQD
5	E-ED1260-1	BACKING PLATE ROW 7-21	INCONEL 625	1
4	E-ED1259-1	TILE ROW 7-21 STYLE 2	POCO GRAPHITE	1
3	C-ED1303-1	WASHER- 0.5 I.D. X 0.7" O.D.X .06"THK	316 SS	2
2	C-ED1302-1	HEX ALLEN NUT TILE ROW 7-21	A286	2
1	C-ED1215-1	LOCATING PIN	INCONEL 625	4
X	E-ED1262-01	TILE ROW 7-21 STYLE 2 ASSEMBLY	--	-

PARTS LIST

RELEASED FOR FABRICATION / INSTALLATION
PPPL Drafting:

GENERAL NOTES

1. PPPL APPROVED DRAWINGS TAKE PRECEDENCE OVER MODEL DIMENSIONS.
2. WHEN MODELS ARE PROVIDED, VENDOR MUST VERIFY THAT MODEL DIMENSIONS CONFORM WITH PPPL APPROVED DRAWINGS PRIOR TO FABRICATION.

MAGNETIC PERMEABILITY REQUIREMENT (SEE NOTES)			
YES		NO	X

RELEASE LEVEL: Fabrication
DWG VERSION NO: 2.0

WELDING ENGINEER
APPVD: N/A DATE:

COMPUTER GENERATED DRAWING MANUAL CHANGES NOT PERMITTED
Pro E
DO NOT VERIFY INFORMATION BY SCALING DRAWING
SCALE: 2X & AS NOTED
NEXT ASSEMBLY

CENTRAL FILES:
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
MACHINE SURFACES 125√
BREAK SHARP EDGES .005/.020
TOLERANCES NON-CUMULATIVE

DECIMAL-INCH		FRACTIONS	
.X	±.100	0"-12"	±1/16
.XX	±.030	12"-72"	±1/8
.XXX	±.010	72"-120"	±1/4
ANGULAR	±0°-15′	OVER 120"	±1/2

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT

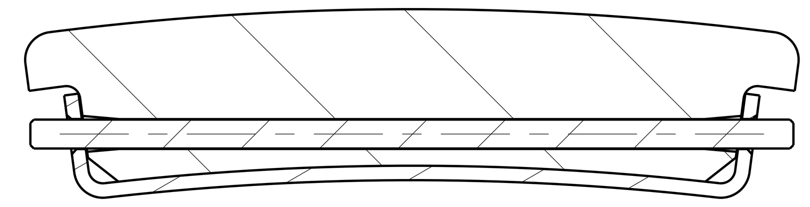
CENTERSTACK UPGRADE
CENTERCASE SECTION
TILE ROW 7-21 STYLE 2 ASSEMBLY

DIV: MECH. ENG. DATE: 04/12/2012
ENG: K.TRESEMER APPROVED K.TRESEMER
DSN: A.JARIWALA
CHK: L.MORRIS CHK LM SUPV LM

E-ED1262

SHEET 1 OF 3 REV 2

EMI



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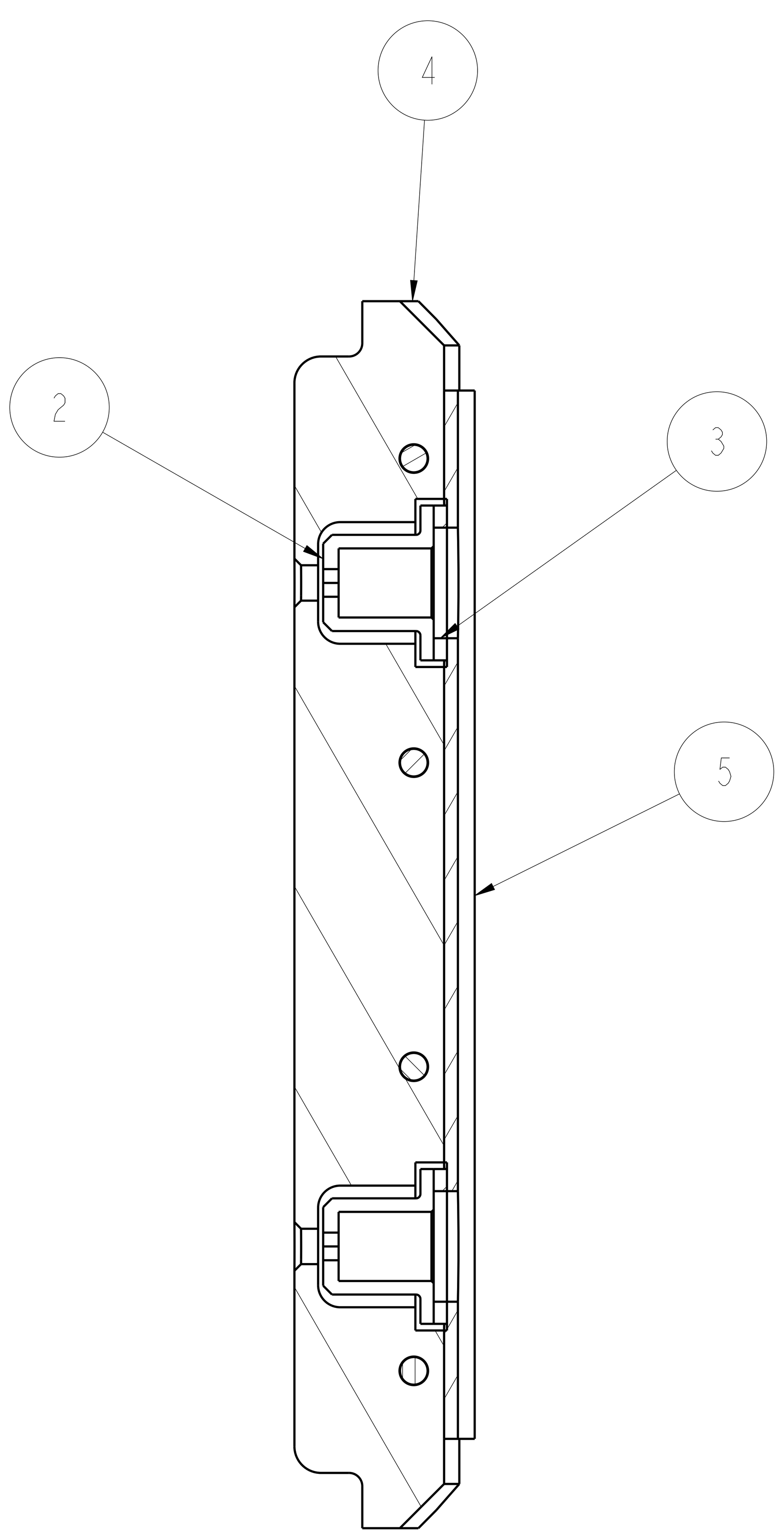
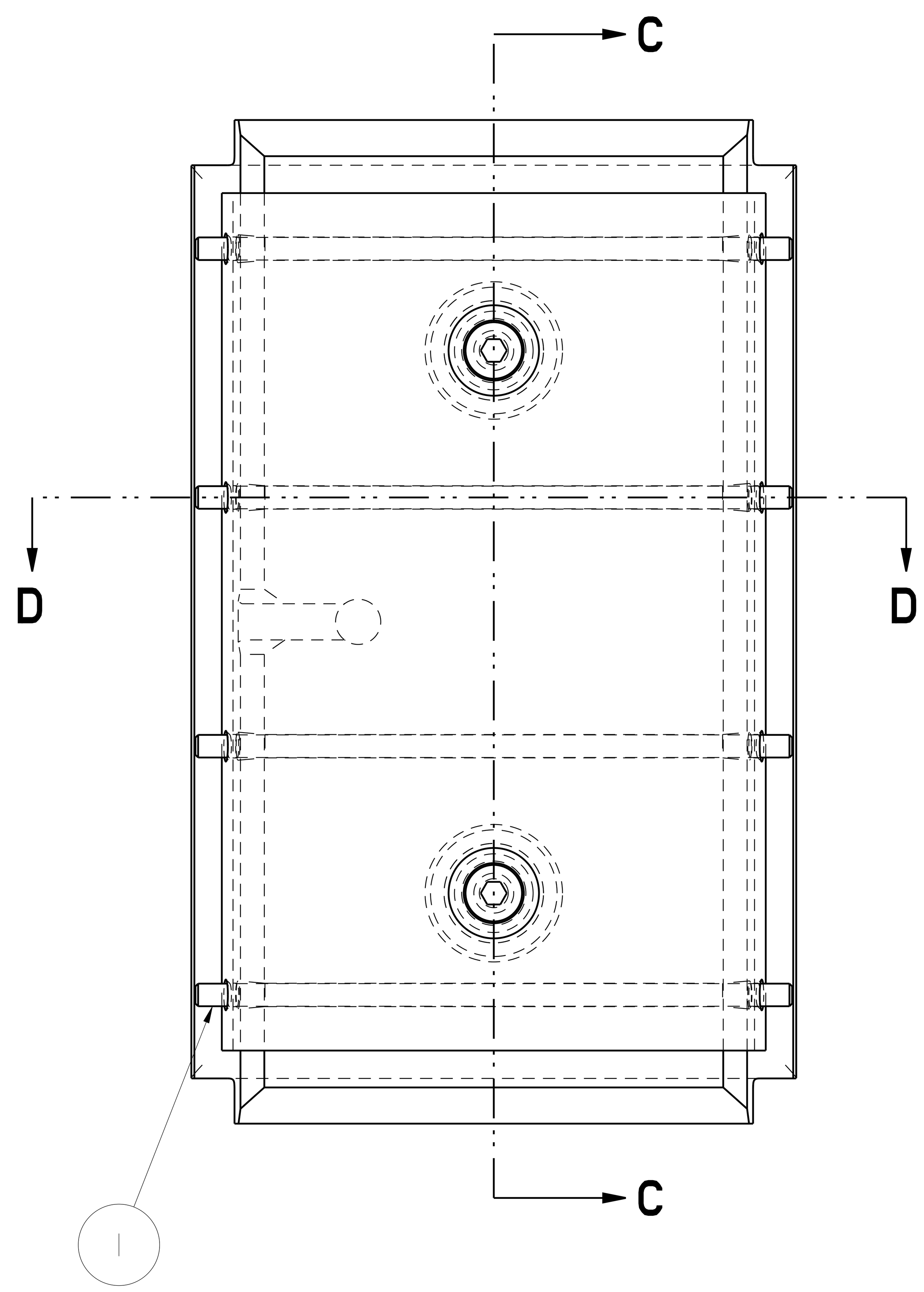
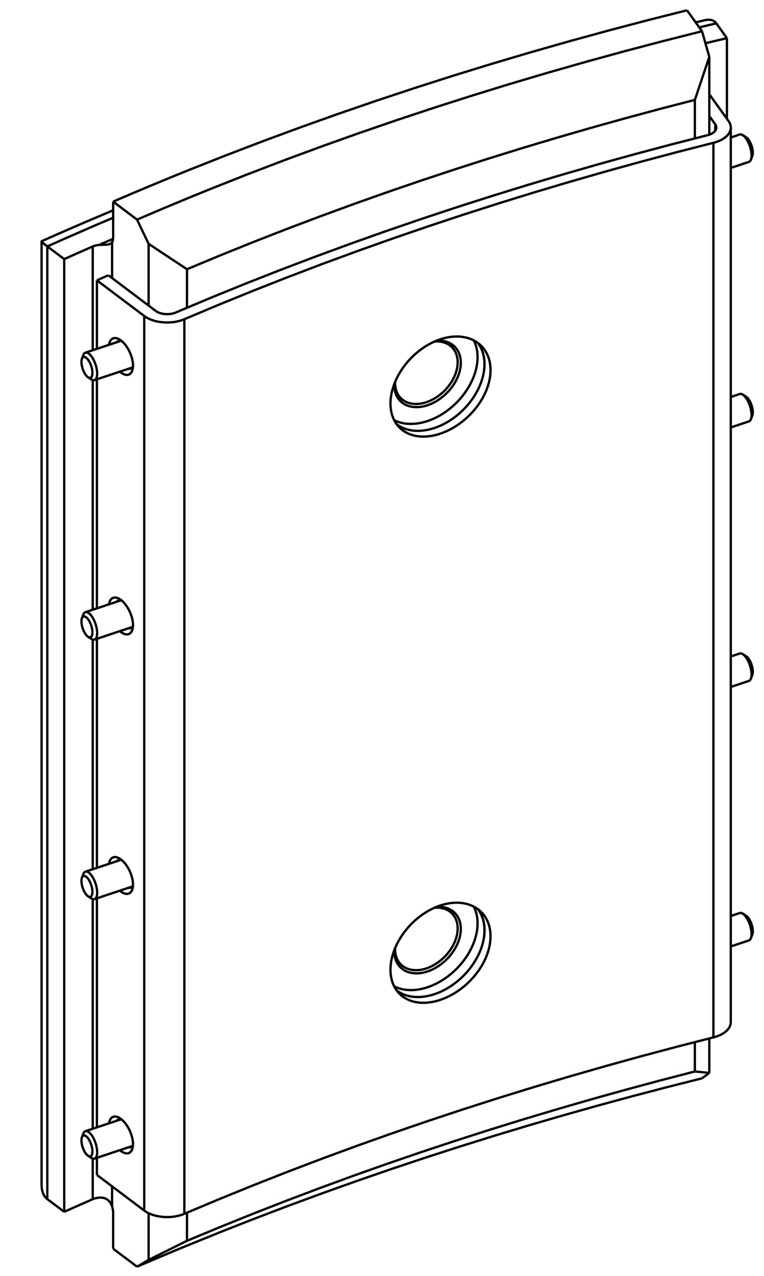


SECTION C-C





REFERENCE ISOMETRIC VIEW

NO	REVISION	BY	CH	SUP	APPROVED	DATE

THERMOCOUPLE TILE ASSEMBLY (E-ED1262-02) - 4 REQD.

ITEM NO.	DRAWING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	QTY REQD
5	E-ED1260-1	BACKING PLATE ROW 7-21	INCONEL 625	1
4	E-ED1259-2	TILE ROW 7-21 - TC STYLE 2	POCO GRAPHITE	1
3	C-ED1303-1	WASHER- 0.5 I.D. X 0.7" O.D.X .06"THK	316 SS	2
2	C-ED1302-1	HEX ALLEN NUT TILE ROW 7-21	A286	2
1	C-ED1215-1	LOCATING PIN	INCONEL 625	4
X	E-ED1262-02	TILE ROW 7-21 - TC STYLE 2 ASSEMBLY	--	-

PARTS LIST

GENERAL NOTES

1. PPPL APPROVED DRAWINGS TAKE PRECEDENCE OVER MODEL DIMENSIONS.
2. WHEN MODELS ARE PROVIDED, VENDOR MUST VERIFY THAT MODEL DIMENSIONS CONFORM WITH PPPL APPROVED DRAWINGS PRIOR TO FABRICATION.

MAGNETIC PERMEABILITY REQUIREMENT (SEE NOTES)

YES | NO X

RELEASE LEVEL: Fabrication
DWG VERSION NO: 2.0

RELEASED FOR FABRICATION / INSTALLATION
PPPL Drafting:

WELDING ENGINEER
APPVD: N/A DATE:

COMPUTER GENERATED DRAWING MANUAL CHANGES NOT PERMITTED
Pro E
DO NOT VERIFY INFORMATION BY SCALING DRAWING
SCALE: 2X & AS NOTED
NEXT ASSEMBLY

CENTRAL FILES:
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
MACHINE SURFACES 125
BREAK SHARP EDGES .005/.020
TOLERANCES NON-CUMULATIVE

DECIMAL-INCH		FRACTIONS	
.X	±.100	0"-12"	±1/16
.XX	±.030	12"-72"	±1/8
.XXX	±.010	72"-120"	±1/4
ANGULAR	±0°-15′	OVER 120"	±1/2

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT

CENTERSTACK UPGRADE
CENTERCASE SECTION
TILE ROW 7-21 TC STYLE 2 ASSEMBLY

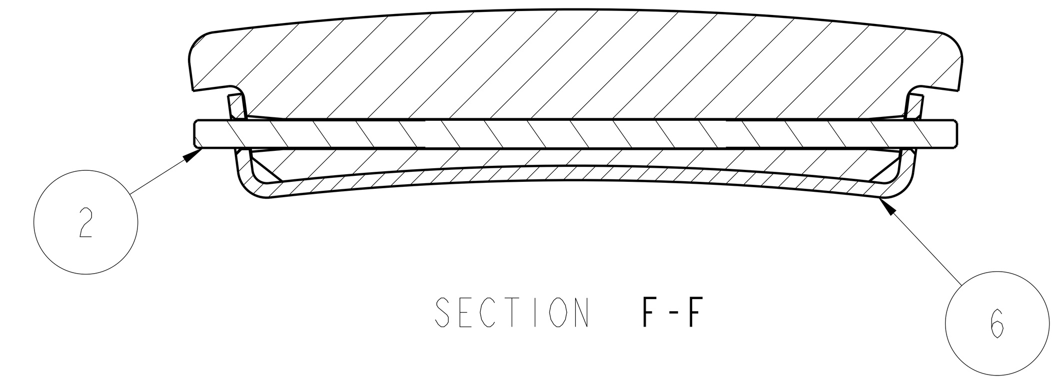
DIV: MECH. ENG. DATE: 04/12/2012
ENG: K.TRESEMER
DSN: A.JARIWALA
CHK: L.MORRIS
APPROVED K.TRESEMER
CHK LM SUPV LM

E-ED1262

SHEET 2 OF 3 REV 2

NSTX-E-ED1262

EMI



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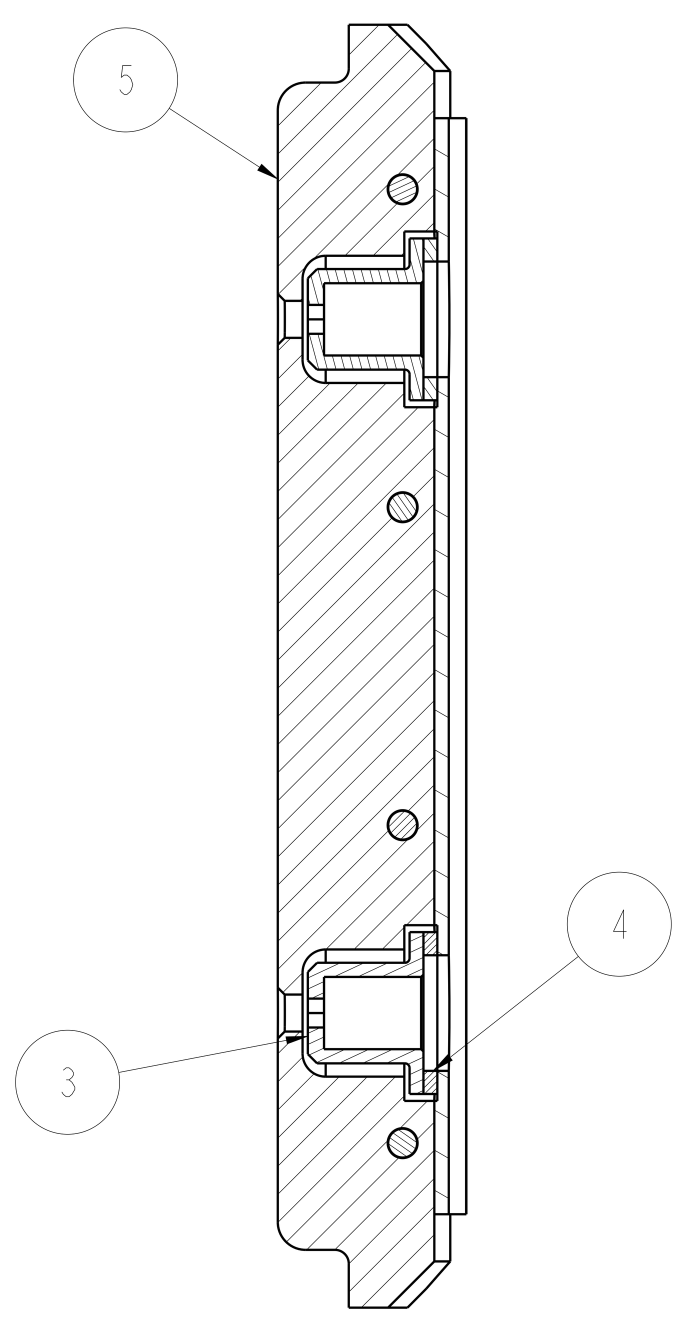
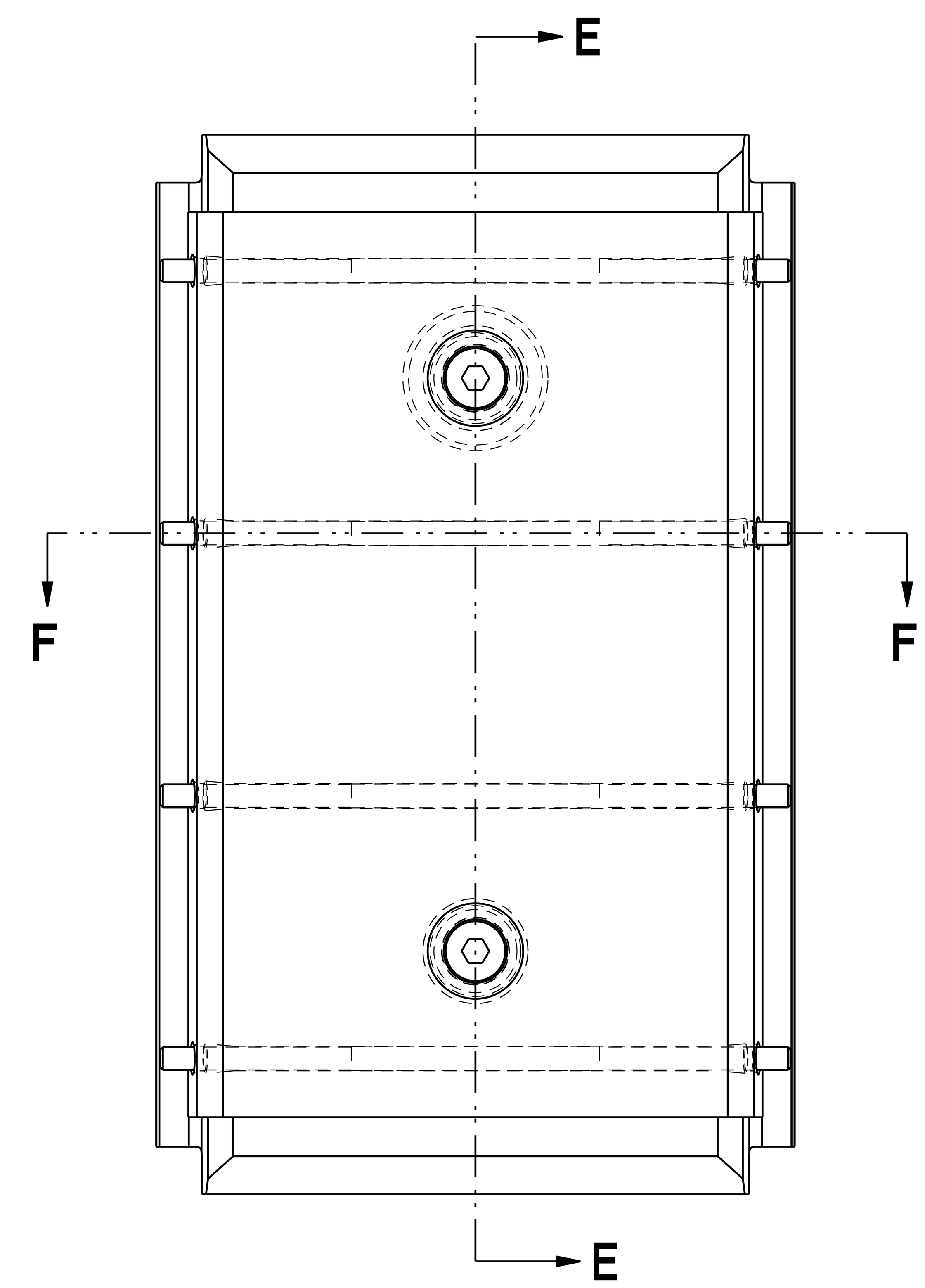
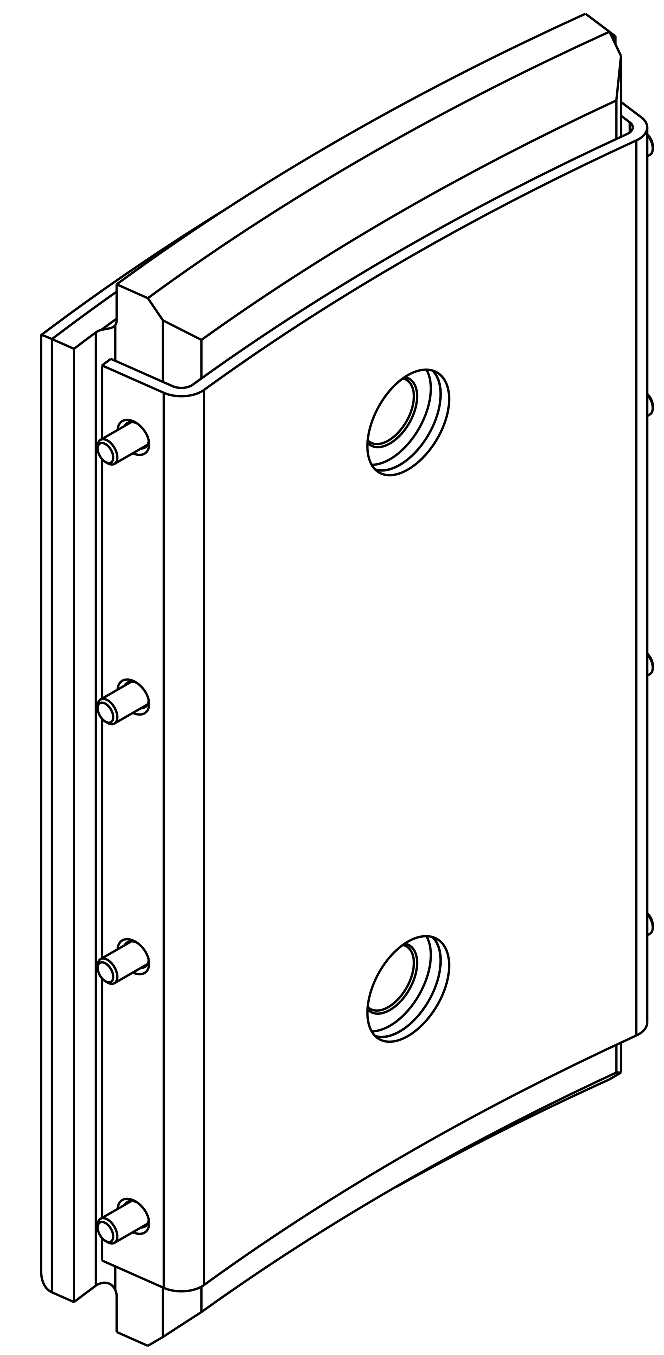


SECTION E-E





NO	REVISION	BY	CH	SUP	APPROVED	DATE

SHUNT TILE ASSEMBLY (E-ED1262-03) - 32 REQD.

ITEM NO.	DRAWING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	QTY REQD
6	E-ED1260-1	BACKING PLATE ROW 7-21	INCONEL 625	1
5	E-ED1259-1	TILE ROW 7-21 STYLE 2	POCO GRAPHITE	1
4	C-ED1303-1	WASHER- 0.5 I.D. X 0.7" O.D.X .06"THK	316 SS	2
3	C-ED1302-1	HEX ALLEN NUT TILE ROW 7-21	A286	2
2	C-ED1215-2	LOCATING PIN, COATED	INCONEL 625	4
1	E-ED1262-03	TILE ROW 7-21 -SHUNT STYLE 2 ASMBLY	--	1

PARTS LIST

GENERAL NOTES

1. PPPL APPROVED DRAWINGS TAKE PRECEDENCE OVER MODEL DIMENSIONS.
2. WHEN MODELS ARE PROVIDED, VENDOR MUST VERIFY THAT MODEL DIMENSIONS CONFORM WITH PPPL APPROVED DRAWINGS PRIOR TO FABRICATION.

MAGNETIC PERMEABILITY REQUIREMENT (SEE NOTES)			
YES		NO	X

RELEASE LEVEL: Fabrication
DWG VERSION NO: 2.0

WELDING ENGINEER
APPVD: DATE:

RELEASED FOR FABRICATION / INSTALLATION
PPPL Drafting:

COMPUTER GENERATED DRAWING
MANUAL CHANGES NOT PERMITTED
Pro E
DO NOT VERIFY INFORMATION BY SCALING DRAWING
SCALE: 2X
NEXT ASSEMBLY

CENTRAL FILES:
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
MACHINE SURFACES 125
BREAK SHARP EDGES .005/.020
TOLERANCES NON-CUMULATIVE

DECIMAL-INCH		FRACTIONS	
.X	±.100	0"-12"	±1/16
.XX	±.030	12"-72"	±1/8
.XXX	±.010	72"-120"	±1/4
ANGULAR	±0°-15′	OVER 120"	±1/2

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT

CENTERSTACK UPGRADE
CENTERCASE SECTION
TILE ROW 7-21 SHUNT STYLE 2 ASSEMBLY

DIV: MECH. ENG. | DATE: 10/30/13
ENG: K. TRESEMER | APPROVED
DSN: A. JARIWALA | K. TRESEMER
CHK: K. TRESEMER | CHK KT | SUPV LM

E-ED1262

SHEET 3 OF 3 | REV 2

NSTX-E-ED1262

EMI

NASA CR-66933

ELASTIC PROPERTIES OF THREE GRADES OF FINE GRAINED GRAPHITE TO 2000°C

M. O. MARLOWE

NASA Contract NAS1-9852
June 25, 1970

NUCLEONICS LABORATORY • GENERAL ELECTRIC COMPANY
VALLECITOS NUCLEAR CENTER, PLEASANTON, CALIFORNIA, 94566

GENERAL ELECTRIC

TABLE 3. SUMMARY OF ROOM TEMPERATURE ELASTICITY RESULTS*

Specimen Number	Young's Modulus (10^6 psi)	Shear Modulus (10^6 psi)	Poisson's Ratio
POCO 5Q-1	1.844 ± 0.004	0.724	0.273 ± 0.003
POCO 5Q-2	1.880 ± 0.001	0.734 ± 0.002	0.280 ± 0.001
POCO 5Q-3	1.811 ± 0.003	0.713	0.269 ± 0.002
POCO 5Q-4	1.831 ± 0.004	0.719	0.275 ± 0.003
POCO 5Q-5	1.859 ± 0.031	0.733 ± 0.001	0.258 ± 0.025
POCO 5Q-6	1.859 ± 0.001	0.729 ± 0.002	0.274
POCO 5Q-AVG.	1.847 ± 0.024	0.725 ± 0.008	0.272 ± 0.008
POCO 9Q-1	1.741 ± 0.005	0.685	0.274 ± 0.002
POCO 9Q-2	1.630 ± 0.002	0.656 ± 0.001	0.242
POCO 9Q-3	1.571 ± 0.005	0.637	0.235 ± 0.005
POCO 9Q-4	1.680 ± 0.005	0.668	0.258
POCO 9Q-5	1.530 ± 0.005	0.622	0.230 ± 0.005
POCO 9Q-6	1.723 ± 0.003	0.682	0.265 ± 0.003
POCO 9Q-AVG.	1.646 ± 0.084	0.658 ± 0.025	0.251 ± 0.018
ATJS-1	1.730 ± 0.006	0.742 ± 0.002	0.164 ± 0.004
ATJS-2	1.805 ± 0.005	0.730	0.235 ± 0.005
ATJS-3	1.604 ± 0.006	0.676	0.191 ± 0.002
ATJS-4	1.764 ± 0.004	0.723 ± 0.001	0.221 ± 0.002
ATJS-5	1.692 ± 0.004	0.699 ± 0.001	0.211 ± 0.003
ATJS-6	1.777 ± 0.004	0.722 ± 0.001	0.230 ± 0.003
ATJS-AVG.	1.729 ± 0.073	0.715 ± 0.024	0.209 ± 0.027

*The ± values shown are one standard deviation; if none is shown the standard deviation was less than one in the third decimal phase for the listed value.

TITLE: TM and TM-1

PREPARER:	R.G. Sheppard Manager, R & D	19 Jan 05 Date	APPROVED:	[signature] General Manager, TD	2005 JAN 19 Date
APPROVED:	[signature] Supervisor, Analytical Services	1/19/05 Date	APPROVED:	Scott [signature] General Sales Manager, SIP	1/20/05 Date
APPROVED:	[signature] Supervisor, Customer Service	1/24/05 Date	FINAL APPROVAL:	John D. [signature] President	1/24/05 Date

ISSUE DATE	REV.I.D.	BRIEF DESCRIPTION OF CHANGES
01/94	A	Initial Issuance of Document.
01/98	B	Updated Section 4.1.
01/05	C	Revised to New Format

1.0 SCOPE

This specification defines the material characteristics for TM and TM-1 grades of graphite furnished by Poco Graphite, Inc. (POCO).

2.0 MATERIAL CHARACTERISTICS

2.1 Material Properties **Note: Test Level Definitions Given at Bottom of Page**

2.1.1

PROPERTY	UNIT	MIN.	MAX.	TEST LEVEL*
Flexural Strength	psi	6,000**	--	II
Compressive Strength	psi	11,600	--	II
Electrical Resistivity	μ-Ω-in.	410	745	II
Shore Hardness	Unitless	59	76	II
Apparent Density (A.D.)	g/cm^3	1.70	1.88	I
C.T.E.	$x10^{-6}/°C$	7.2	9.4	III
Ash (TM)	ppm	300	3,000	IV
Ash (TM-1)	ppm	0	5	II

** Set at -1 SD

* TEST LEVEL	TESTING FREQUENCY
I	The whole billet (a single block of graphite) is tested for the property in question. The values shown are the acceptance limits.
II	Each batch (a group of billets from a single, identifiable blend of raw materials) or process lot (a collection of billets handled as a single units through an identifiable process step) is sampled. The values shown are two standard deviations from the mean of all tests done.
III	Every batch or process lot is not tested. However, statistical analyses have been made and the values shown are two standard deviations from the mean of those tests that have been done. POCO does not certify that these values apply to each or any process lot, batch, billet, or piece of material that it supplies.
IV	Every batch or process lot is not tested. These values are the extremes that have been detected in the testing that has been done. POCO does not certify that these values apply to each or any process lot, batch, billet, or piece of material that it supplies.

2.2 Material Composition

2.2.1 Physical Composition

TM and TM-1 are isotropic graphites with a typical particle size of 10 microns. The typical pore size is 1.5 microns and the typical open porosity is 85% (both by mercury porosimetry). No specification limits are set for these properties.

2.2.2 Chemical Composition Characteristics

2.2.2.1 Standard Material Purity

TM is at least ≥ 99.7% carbon with ≤ 0.3% impurities.

2.2.2.2 Specialty Purified Materials (Optional at higher cost.)

Purified TM is given the grade designation TM-1 and has a 5 ppm or less impurity level by ash analysis.

3.0 DISCLAIMER OF EXPRESS OR IMPLIED WARRANTIES

EXCEPT AS EXPRESSLY SET FORTH HEREIN, POCO GRAPHITE, INC. ("POCO") EXPRESSLY DISCLAIMS AND BUYER EXPRESSLY WAIVES ALL WARRANTIES, EXPRESS OR IMPLIED, including any implied warranty of *MERCHANTABILITY* under section 2.314 of the Texas Business and Commerce Code and any implied warranty of ***FITNESS FOR A PARTICULAR PURPOSE*** under section 2.315 of the Texas Business and Commerce Code and any other warranty pursuant to section 2.313 of the Texas Business and Commerce Code.

4.0 TRACEABILITY OF MATERIALS

At appropriate times throughout the manufacturing process, POCO identifies its product to ensure that traceability is maintained throughout the production process. Various levels of traceability may be provided as an agreed upon requirement by the customer's purchase order.

5.0 CERTIFICATION

POCO will certify only that TM and TM-1 materials are manufactured in accordance with internal specifications and controls that produce material having the properties as defined in Section 2.0. No other data, samples, or records will be provided. Historical data on material will be maintained by POCO strictly at its own discretion and for its own purposes. Data on processes, controls and other proprietary items will not be made available.

INCONEL® nickel-chromium alloy 625 (UNS N06625/W.Nr. 2.4856) is used for its high strength, excellent fabricability (including joining), and outstanding corrosion resistance. Service temperatures range from cryogenic to 1800°F (982°C). Composition is shown in Table 1.

Strength of INCONEL alloy 625 is derived from the stiffening effect of molybdenum and niobium on its nickel-chromium matrix; thus precipitation-hardening treatments are not required. This combination of elements also is responsible for superior resistance to a wide range of corrosive environments of unusual severity as well as to high-temperature effects such as oxidation and carburization.

The properties of INCONEL alloy 625 that make it an excellent choice for sea-water applications are freedom from local attack (pitting and crevice corrosion), high corrosion-fatigue strength, high tensile strength, and resistance to chloride-ion stress-corrosion cracking. It is used as wire rope for mooring cables, propeller blades for motor patrol gunboats, submarine auxiliary propulsion motors, submarine quick-disconnect fittings, exhaust ducts for Navy utility boats, sheathing for undersea communication cables, submarine transducer controls, and steam-line bellows. Potential applications are springs, seals, bellows for submerged controls, electrical cable connectors, fasteners, flexure devices, and oceanographic instrument components.

High tensile, creep, and rupture strength; outstanding fatigue and thermal-fatigue strength; oxidation resistance; and excellent weldability and brazeability are the properties of INCONEL alloy 625 that make it interesting to the aerospace field. It is being used in such applications as aircraft ducting systems, engine exhaust systems, thrust-reverser systems, resistance-welded honeycomb structures for housing engine controls, fuel and hydraulic line tubing, spray bars, bellows, turbine shroud rings, and heat-exchanger tubing in environmental control systems. It is also suitable for combustion system transition liners, turbine seals, compressor vanes, and thrust-chamber tubing for rocket

The outstanding and versatile corrosion resistance of INCONEL alloy 625 under a wide range of temperatures and pressures is a primary reason for its wide acceptance in the chemical processing field. Because of its ease of fabrication, it is made into a variety of components for plant equipment. Its high strength enables it to be used, for example, in thinner-walled vessels or tubing than possible with other materials, thus improving heat transfer and saving weight. Some applications requiring the combination of strength and corrosion resistance offered by INCONEL alloy 625 are bubble caps, tubing, reaction vessels, distillation columns, heat exchangers, transfer piping, and valves.

In the nuclear field, INCONEL alloy 625 may be used for reactor-core and control-rod components in nuclear water reactors. The material can be selected because of its high strength, excellent uniform corrosion resistance, resistance to stress cracking and excellent pitting resistance in 500°-600°F (260-316°C) water. Alloy 625 is also being considered in advanced reactor concepts because of its high allowable design strength at elevated temperatures, especially between 1200°-1400°F (649-760°C).

The properties given in this bulletin, results of extensive testing, are typical of the alloy but should not be used for specification purposes. Applicable specifications appear in the last section of this publication.

Table 1 – Limiting Chemical Composition, %

Nickel	58.0 min.
Chromium	20.0-23.0
Iron	5.0 max.
Molybdenum	8.0-10.0
Niobium (plus Tantalum)	3.15-4.15
Carbon	0.10 max.
Manganese	0.50 max.
Silicon	0.50 max.
Phosphorus	0.015 max.
Sulfur	0.015 max.
Aluminum	0.40 max.
Titanium	0.40 max.
Cobalt[a]	1.0 max.

[a]If determined

INCONEL® alloy 625

Table 4 – Modulus at Elevated Temperatures[a]

Temp. °F	Modulus of Elasticity, 10^3 ksi				Poisson's Ratio		Temp. °C	Modulus of Elasticity, GPa			
	Tension		Shear					Tension		Shear	
	Annealed	Solution-Treated	Annealed	Solution-Treated	Annealed	Solution-Treated		Annealed	Solution-Treated	Annealed	Solution-Treated
70	30.1	29.7	11.8	11.3	0.278	0.312	21	207.5	204.8	81.4	78.0
200	29.6	29.1	11.6	11.1	0.280	0.311	93	204.1	200.6	80.0	76.5
400	28.7	28.1	11.1	10.8	0.286	0.303	204	197.9	193.7	76.5	74.5
600	27.8	27.2	10.8	10.4	0.290	0.300	316	191.7	187.5	74.5	71.7
800	26.9	26.2	10.4	10.0	0.295	0.302	427	185.5	180.6	71.7	68.9
1000	25.9	25.1	9.9	9.6	0.305	0.312	538	178.6	173.1	68.3	66.2
1200	24.7	24.0	9.4	9.2	0.321	0.314	649	170.3	165.5	64.8	63.4
1400	23.3	22.8	8.7	8.8	0.340	0.305	760	160.6	157.2	60.0	60.7
1600	21.4	21.5	8.0	8.3	0.336	0.289	871	147.5	148.2	55.2	57.2

[a]Determined dynamically on samples from ¾ -in. hot-rolled rod.

Mechanical Properties

Nominal room-temperature mechanical properties of INCONEL alloy 625 are shown in Table 5.

For service at 1200°F and below, hot-finished, cold-finished, and annealed conditions (depending on requirements involved) are recommended.

For service above 1200°F, either annealed or solution-treated material will give best service. The solution-treated condition is recommended for components that require optimum resistance to creep or rupture. Fine-grained (annealed) material may be advantageous at temperatures up to 1500°F with respect to fatigue strength, hardness, and tensile and yield strength.

MacGregor's two-load was used for determination of the true stress-strain curve for alloy 625 at room temperature. The two-load test requires no strain measurement during the test, and only the maximum and fracture loads are recorded. Data for both annealed and solution-treated material are shown in Figure 2.

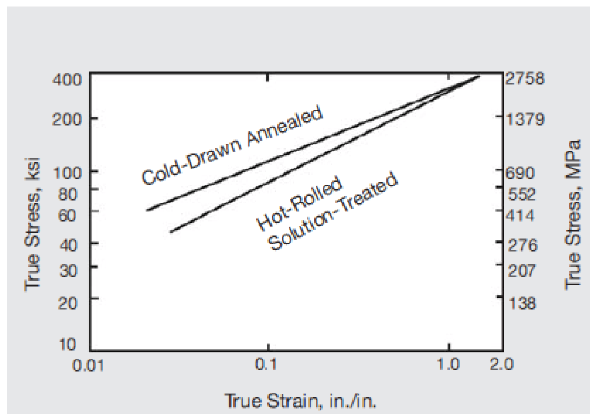


Figure 2 – True stress-true strain of round.

Table 5 – Nominal Room-Temperature Mechanical Properties[a]

Form And Condition	Tensile Strength		Yield Strength (0.2% Offset)		Elongation	Reduction Of Area	Hardness, Brinell
	ksi	MPa	ksi	MPa	%	%	
ROD, BAR, PLATE							
As-Rolled	120-160	827-1103	60-110	414-758	60-30	60-40	175-240
Annealed	120-150	827-1034	60-95	414-655	60-30	60-40	145-220
Solution-Treated	105-130	724-896	42-60	290-414	65-40	90-60	116-194
SHEET and STRIP							
Annealed	120-150	827-1034	60-90	414-621	55-30	-	145-240
TUBE and PIPE, COLD-DRAWN							
Annealed	120-140	827-965	60-75	414-517	55-30	-	-
Solution-Treated	100-120	689-827	40-60	276-414	60-40	-	-

[a]Values shown are composites for various product sizes up to 4 in. They are not suitable for specification purposes. For properties of larger-sized products, consult Special Metals Corporation.

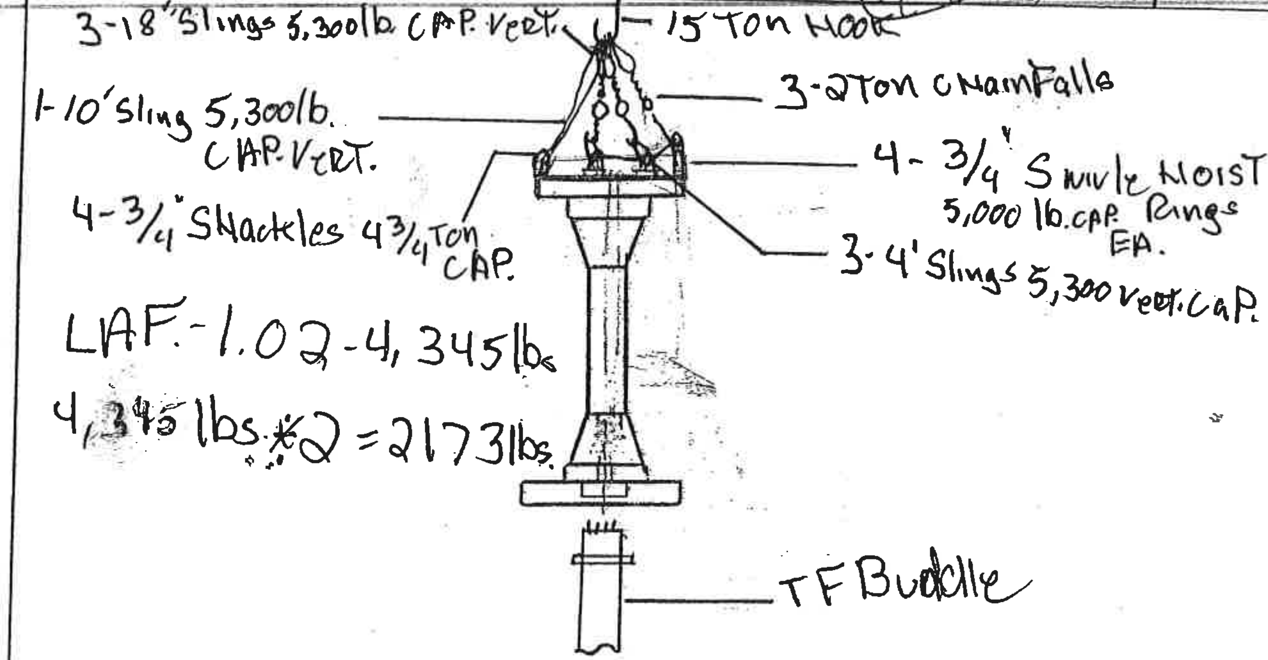
TCR-ES-MECH-007, R1-002

4.0 LIFT DATA SHEET BLANK

LIFT AREA: NSTX South High Bay TITLE:	Effective Date: 10/8/14	Repetitive Lift Expiration Date: 10/9/15
LIFT PROCEDURE NO. L-D-NSTX 1035 Sheet No (if applicable) LDS:	Approved: [signature] LIFT MANAGER	Repetitive Lift: [signature] Approved LIFT MANAGER

ITEM PREPARATION VERIFIED AND READY TO BE LIFTED PIC: S. Raftopoulos [signature] 10/9/2014
(Print and Initial)

PROCEDURE PREREQUISITES COMPLETED QC: J. T. Smith / [initials] N/A [initials] 10/9/2014
(Print and Initial-QRS for repetitive lifts)



DESCRIPTION: WEIGHT: 4,260 lbs DETERMINED BY: WeigHeD + CAL.
Sketch of rigging shall include: Crane Capacity, Hook Load, All Rigging, Load Angles
Sketch of equipment shall include: Dimensions, Allowable Tilt, Approx. CG

(Print & Initial) CLCO(s) or QRS(s): Kris Gilton KG, M. FERNANDEZ MF, F. SIMMONS FS

Rigging Team: A. Carpe, M. Anderson, S. Gifford, D. Stevens

APPROVED: (Print and Initial) 10-9-14
Fred Simmons FS — QRS (Rigged to sketch)
Manny Fernandez MF — CLCO
S. Raftop. [initials] 10/9/2014 — PIC (Equipment ready to lift)
N/A [initials] 10/9/2014 — LIFT ENGINEER (Qualification/Inspection complete) N/A for repetitive lift

. . . PERFORM LIFT. . . PERFORM LIFT . . . PERFORM LIFT . . .

Equipment is secure and rigging may be removed: PIC: ______________ Date Performed: ______________

PIC SHALL SEND/RETURN COMPLETED ORIGINAL DATA SHEETS TO PPPL OPERATIONS CENTER.