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Center Stack and Magnet Systems

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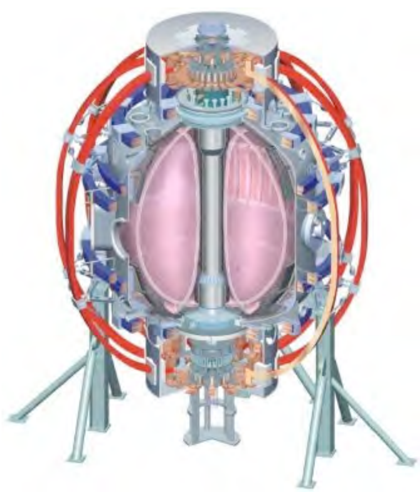
James H. Chrzanowski

and

NSTX Design Team

NSTX Upgrade PDR
LSB, B318
June 23-24, 2010



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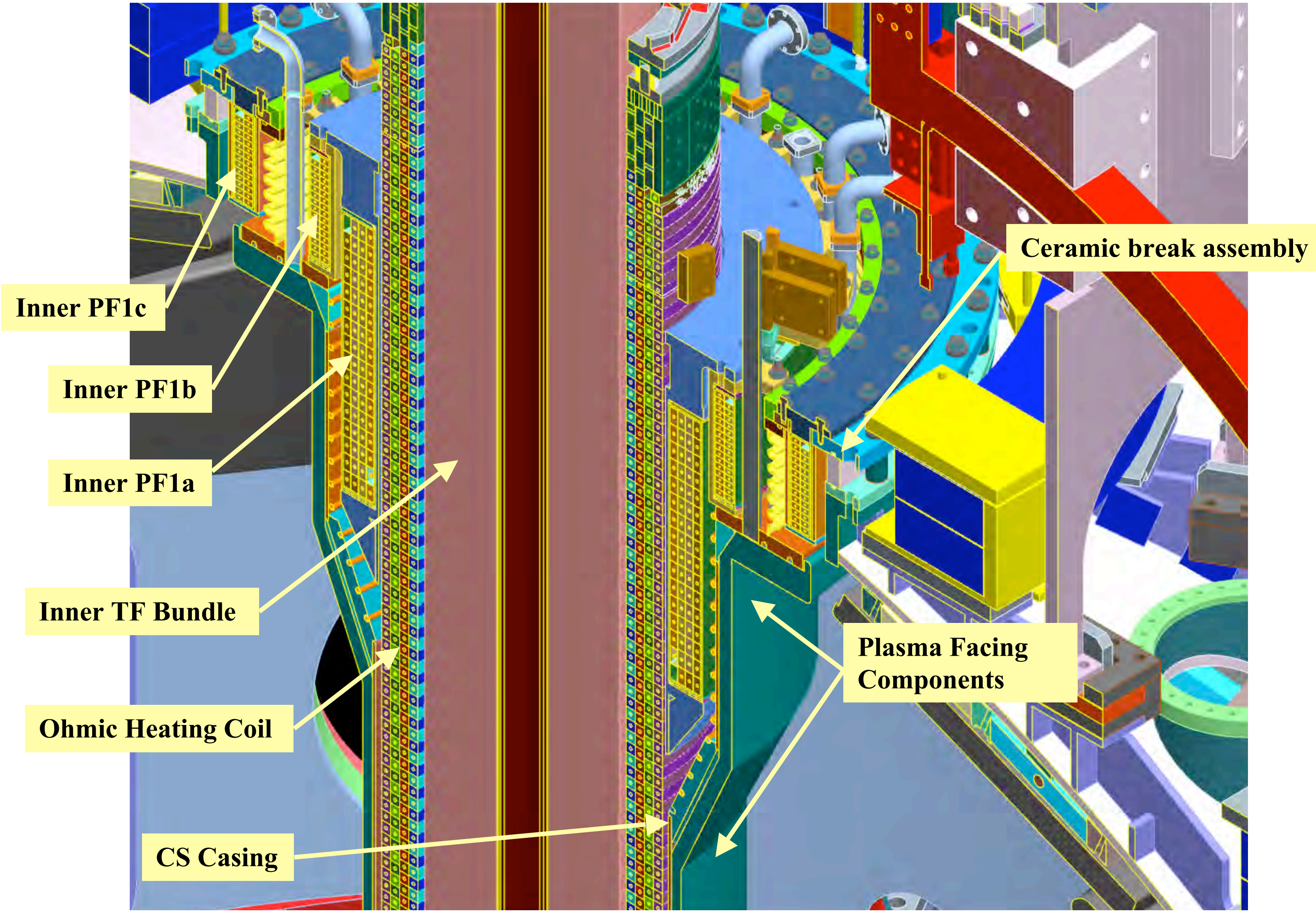
Outline of Presentation

- **Inner TF Magnet**
- **OH Solenoid**
- **Vacuum Casing and Ceramic break Assembly**
- **Inner PF Magnets**
- **TF Joint and flex bus will be presented by Tom Willard at 10:00 AM**
- **Plasma Facing Components will be discussed by Kelsey Tresemer 10:50 AM**

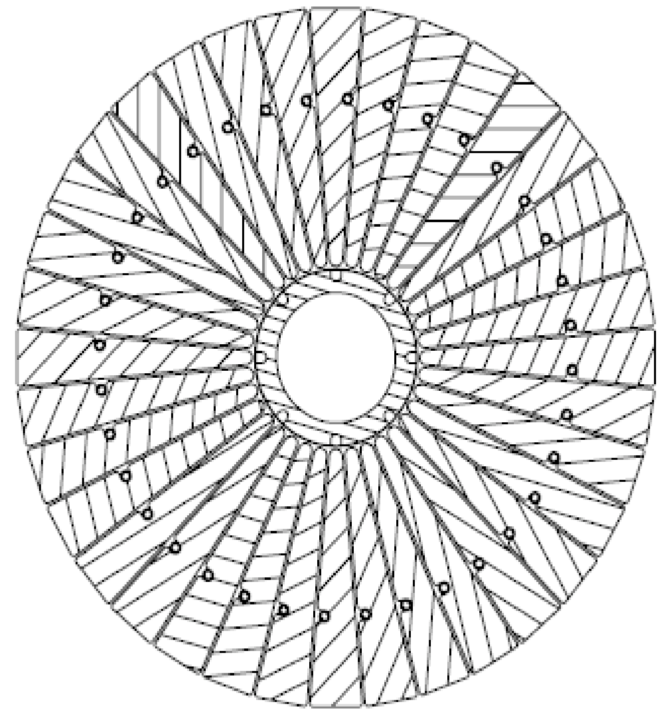
Note: Input for this presentation provided by Lew Morris, Bruce Paul, Richard Upcavage and Tom Meighan

Upgraded Centerstack Components



Inner TF Design Parameters

	Upgrade Design
Operating Voltage	1013 volts
Number of turns	36
Number of layers	1
Cooling	Water
Operating current	129,778 amps
Turn insulation	0.0324 in.
Dielectric strength- turn insulation	3.8 KV [3] half-lapped layer glass
Groundwall insulation	0.1080 in.
Copper mass	10,900 lbs
Outside diameter	15.752 in.
Insulation scheme	S-2 glass and VPI CTD-101K
Cooling hole size ID	0.305 in.

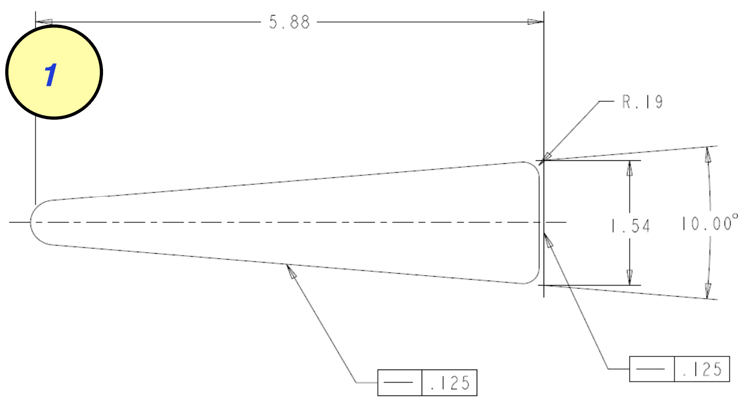


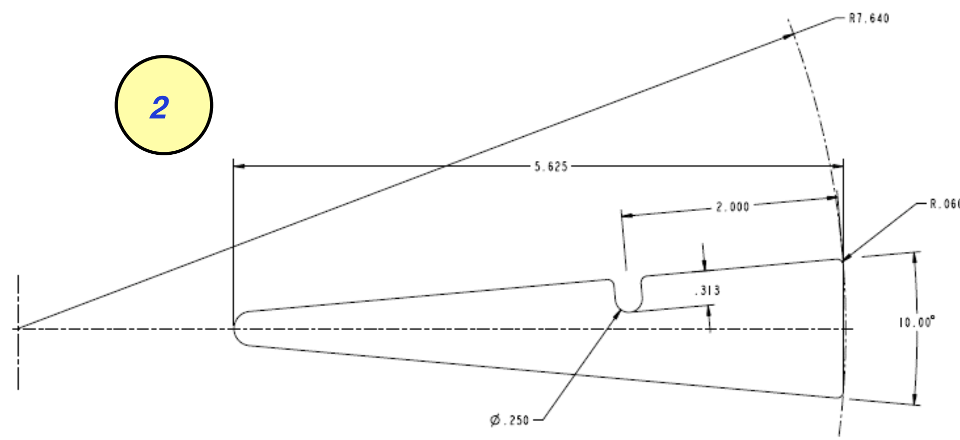
Upgraded TF Bundle
15.7 inch diameter

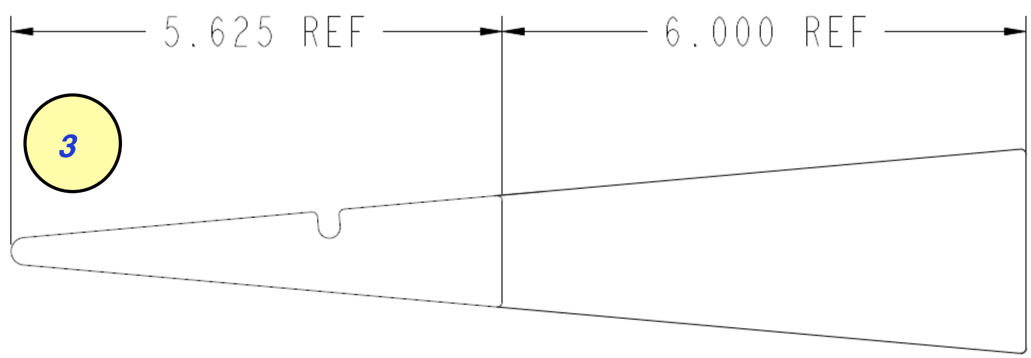
**** Reference: Per half-lapped layer- 1260 volts [VPI impregnated glass]***

Inner TF Conductor Fabrication-1

- Inner bundle conductors will be procured as straight copper extrusions- 36 copper legs [80 will be purchased]- manufacturability has been confirmed with vendors
- Machine conductor to final profile including cooling groove and relief for coil leads [45 conductors will be machined]
- Leads will be attached using Friction Stir Welding process (FSW) [45 bars]





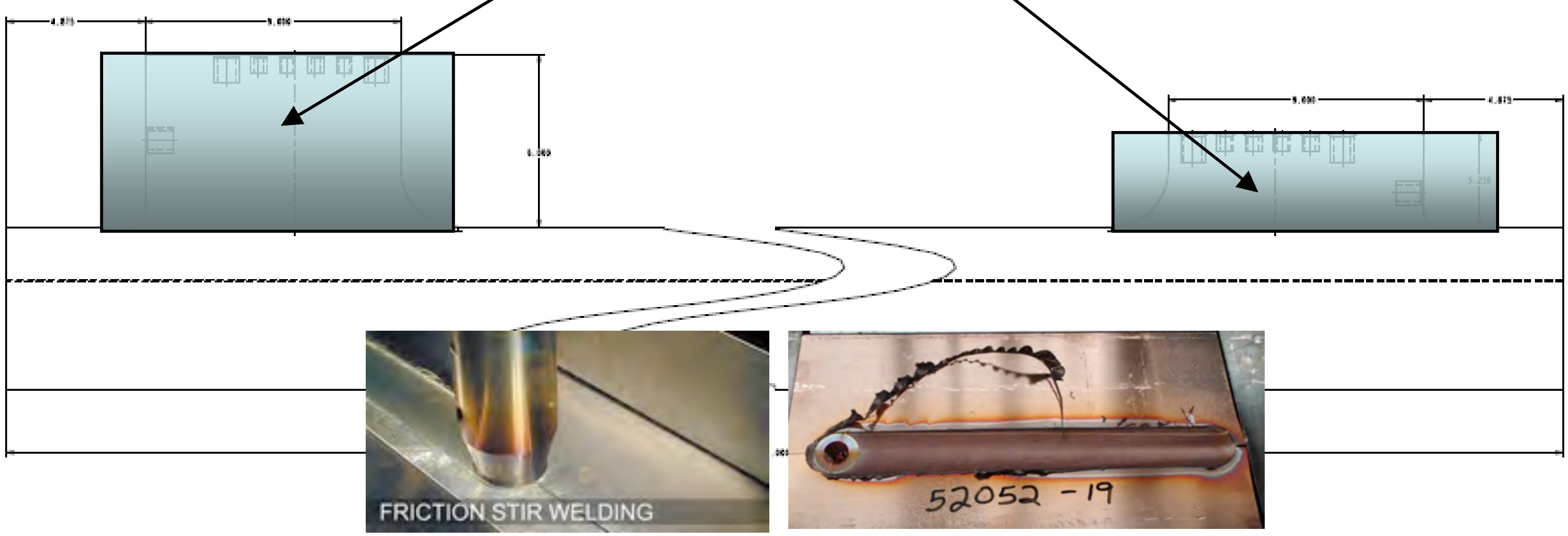


Inner TF Conductor Fabrication-2

- Lead extensions will be added to the TF bundle via Friction Stir Welding [FSW]
- The upper coil lead is shorter in height than the lower to allow for installation of the PF1A coils and Center stack casing
- Lead extensions will be fabricated using higher strength copper [Cu-Cr-Zr]
- R&D Phase 1: Tests were successfully completed by Edison Welding Institute to qualify FSW procedure [OFHC to OFHC]
- R&D Phase 2: Additional tests using C18150 for the leads are presently being performed by Edison Welding Institute

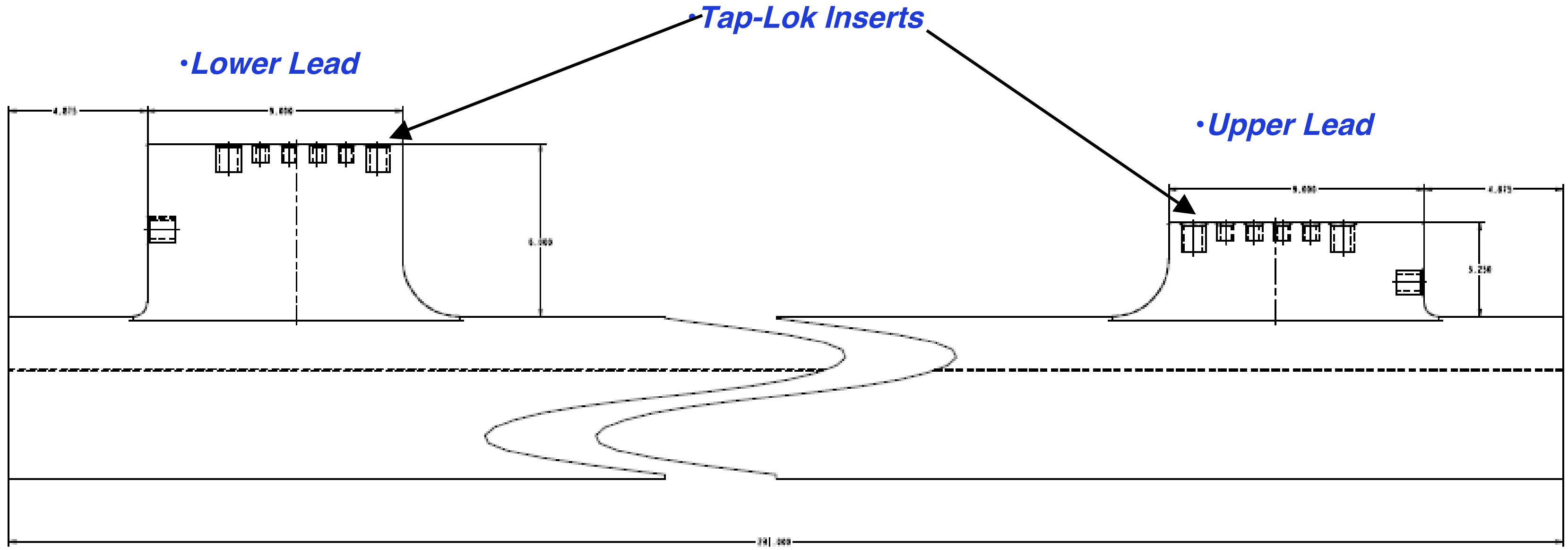
PPPL will provide lead extensions with additional material to support FSW operation. [CDR Chit #12]

- ***Lower Lead***



Inner TF Conductor Fabrication-3

- **Following FSW operations, the conductor lead area will be final machined to remove extra material from the FSW process and preparing electrical lead surfaces. [Includes installation of inserts]**

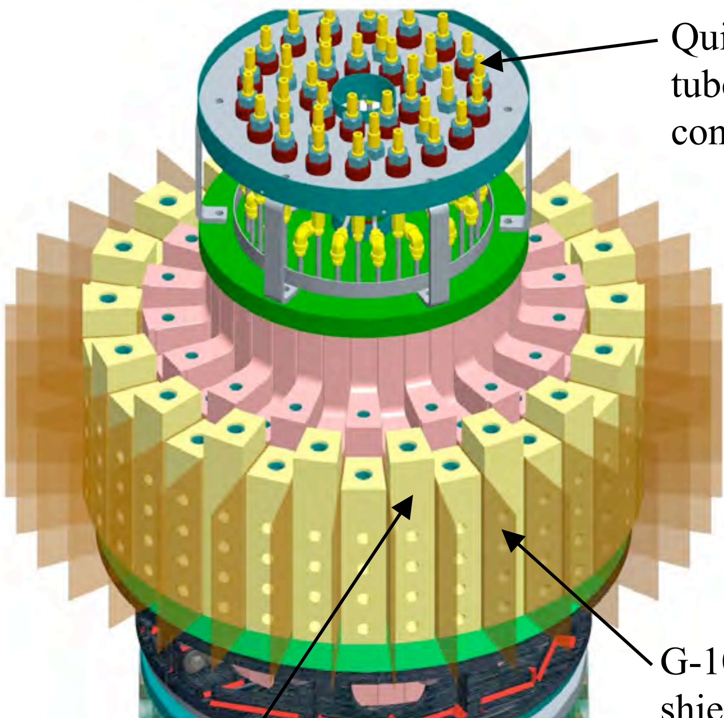


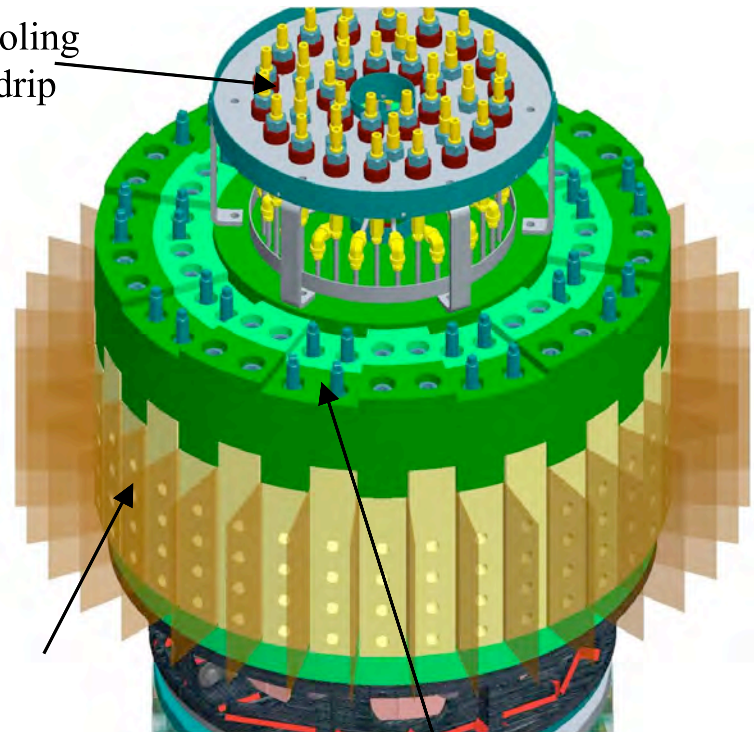
Resin System for all CS Upgrade Coils

- **All of the new CS Upgrade coils will be vacuum pressure impregnated.**
- **Resin System is CTD-101K** *[Product of Composite Technology Dev. Inc.]*
  - ***Material has been well characterized for ITER & NCSX projects***
  - 3- Component epoxy system
  - Long pot life and low viscosity
- **Cure Cycle**
  - 5 hours @ 100 ° C (Cure)
  - 16 hours @ 125 ° C (Post cure)
- **Pot Life:**
  - 145 hours @ 25° C……… 1300 Cp viscosity
  - 60 hours @ 40° C……. 400 Cp viscosity *
  - 20 hours @ 60° C……… 100 Cp viscosity

- **Shear Bond Strength:** [data obtained from CTD] [CDR Chit #3 & 4]
  - 40 Mpa @ 373 K
  - **[Allowable SBS= 22 MPA]**

Details- Inner TF Bundle Upper End





Quick Disconnect cooling tube connections w/ drip containment

G-10/Kapton flash shield between lead areas

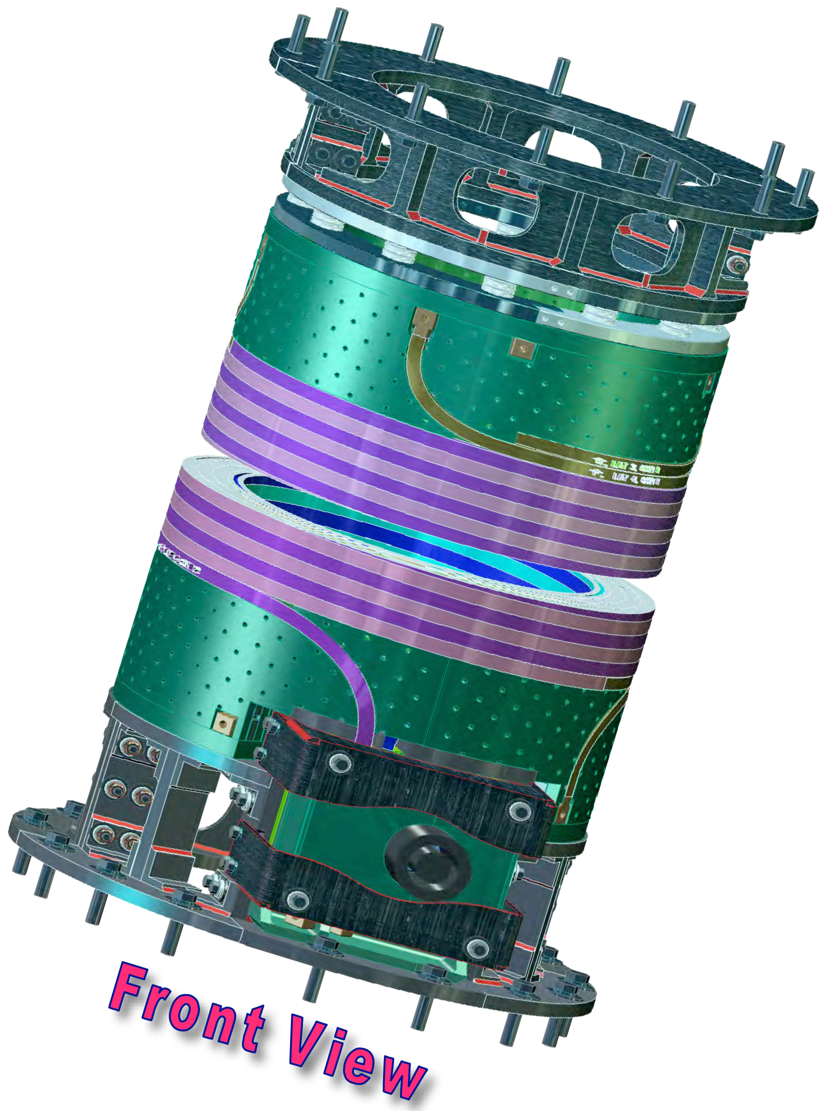
Lead extensions [Upper only]

Umbrella Lid Interface

* Preliminary analysis results show that the double crown G-10 support interface will adequately provide torque transfer capabilities to the umbrella without generating stress concentrations due to transient loads. [CDR Chit #3]

Ohmic Heating Solenoid- Design parameters

	Upgrade Design
Operating Voltage	6077 volts
Number of turns	884
Number of layers	4
Cooling hole diameter	0.2250 in
Operating current	24,000 amps
Groundwall insulation	0.1080 in.
Turn insulation	0.0480 in
Turn-Turn Voltage Stress	57 Volt/mil
Outside diameter	22.10 in
Copper mass	6184 lbs
Cooling paths	8



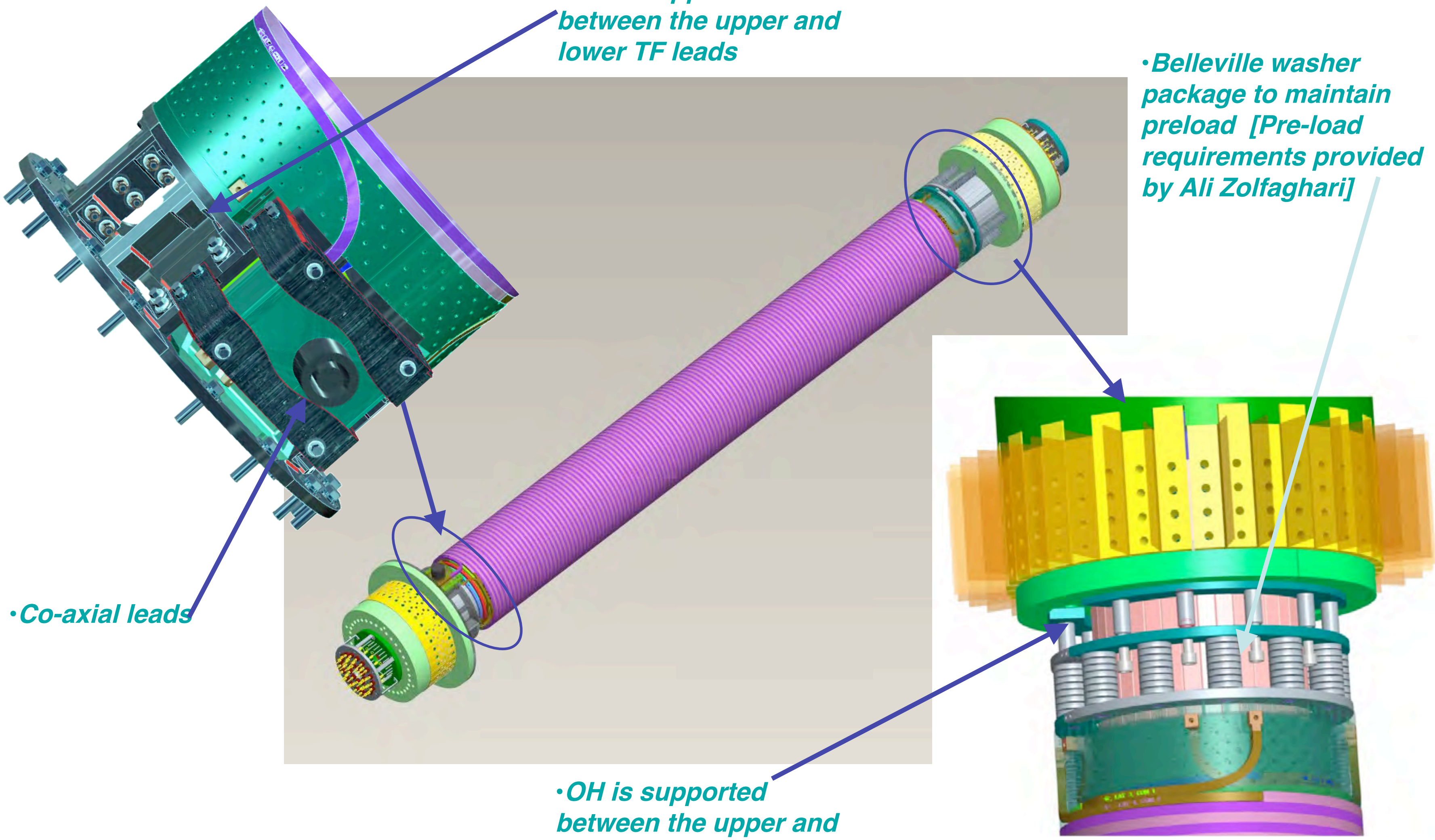
OH Solenoid Design Features

- Located Coil leads on the bottom of machine [minimize motion]
- Co-axial coil/bus lead design
- In line braze may be required if full conductor lengths are not available
  - "Conform" extrusions will be investigated when placing conductor order [CDR- Chit #2]
- Layer to Layer TIG-braze joints may be used [similar to existing joints]
- Improved cooling fitting assemblies
- Coil will be wound around the Inner TF bundle
- No tension tube
- 0.100 inch clearance will be maintained between TF and OH coil to allow for thermal growth and motion between coils
- OH will have inner and outer electrical ground plane
  - Inner: Corona shield C215.51 tape [von-Rolla]
  - Outer: Conductive paint

- *If OH solenoid fails during lifetime, the plan would be to surgically remove the existing coil from the TF bundle and rewind new OH.*

OH Solenoid End Details

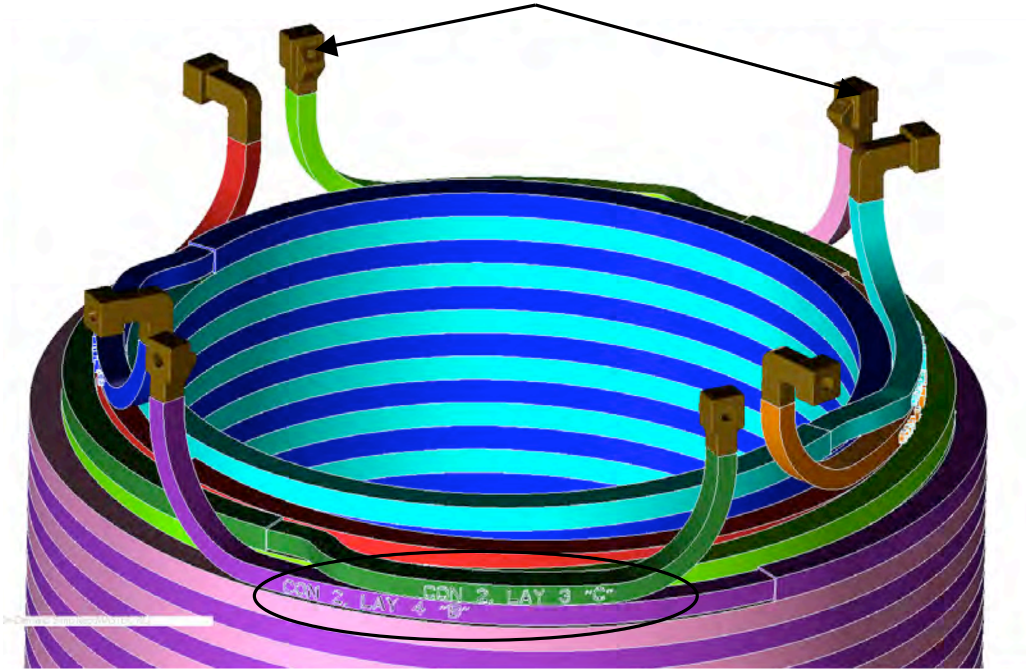
- OH is supported between the upper and lower TF leads
- Belleville washer package to maintain preload [Pre-load requirements provided by Ali Zolfaghari]



- Co-axial leads
- OH is supported between the upper and lower TF leads

OH Layer to Layer Joints

•*OH Cooling fittings*



•*Layer to layer TIG-Braze joint [Typical]*

•***TIG-Brazing method minimizes annealing of conductors***

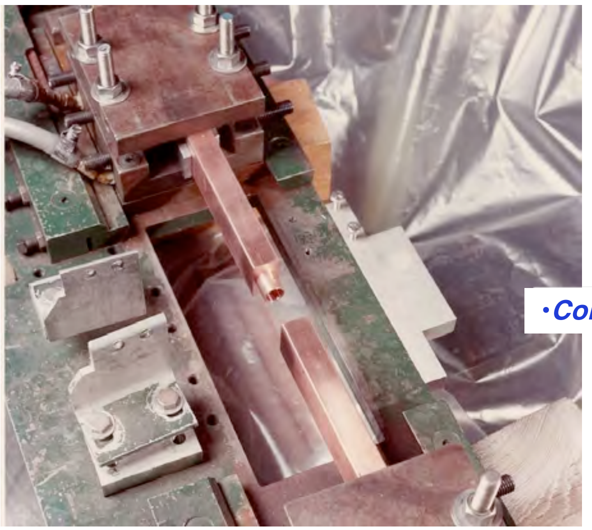
•***Provides adequate joint strength***

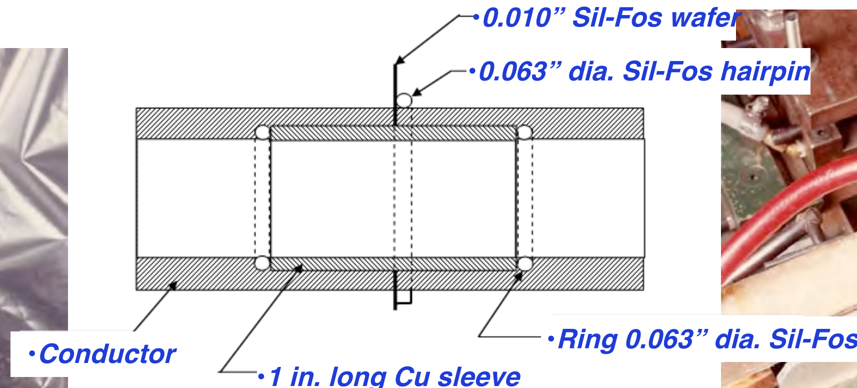
•***Proven method and procedures used in previous OH solenoids***

- 1. Pre-tin the overlapping joint surfaces using the 96%/4% tin-silver soft-solder. The conductors shall not be heated above 260 °C [500°F].
- 2. Each end of the conductors shall be TIG brazed, by a qualified operator, using Sil-Fos braze material with helium or argon shield gas. (12-18 seconds at 135 amps per end)
- **Note: TIG brazing heat input MUST be carefully controlled to minimize annealing of the copper conductor.**
- 3. The maximum joint temperature and the time required to complete the TIG operation must be monitored and documented.

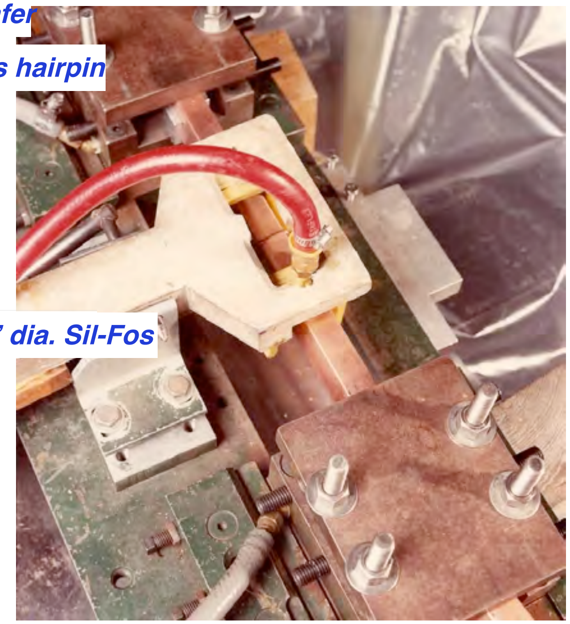
In-Line Braze Joint

- During winding, conductor lengths may be joined together using induction brazing [Years of in-house experience]





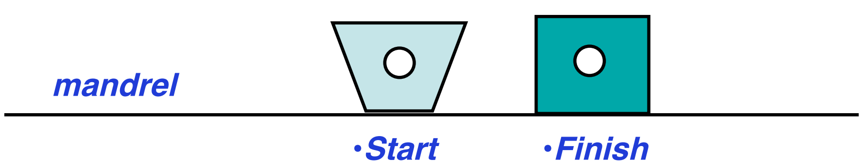
Typical Braze Joint



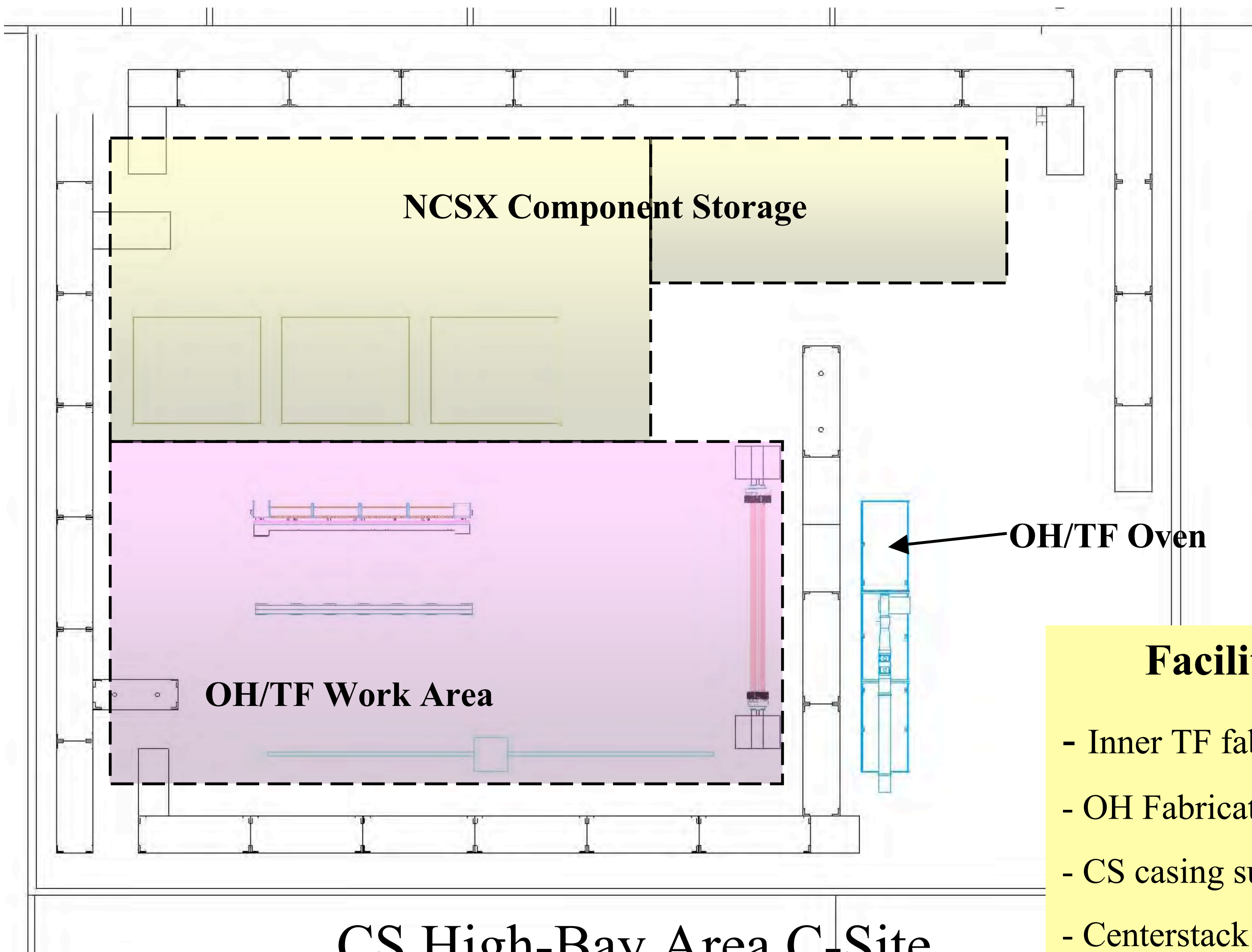
- Example of a Typical Brazed Joint
- Copper sleeve is used with “Sil-Fos” Wafer, hairpin and and 0.063” diameter rings to ensure full coverage and no voids
- Induction brazing strongly recommended
- Each joint would be hydraulically stretched and helium leak tested

OH Coil Conductor

- Copper extruded conductor w/cooling hole
- Total Conductor length: 5025 feet [2 x plus 20% overage]
  - Layer 1: 505 feet each x 2
  - Layer 2: 541 feet each x 2
  - Layer 3: 580 feet each x 2
  - Layer 4: 614 feet each x 2
- Procure approximately 11,000 feet of conductor
- Material: C10700 [oxygen free w/silver] or equivalent
- Final conductor size: 0.6105 in. x 0.6598 in. w/0.225 in. diameter cooling hole
- Due to tight radial tolerances tests to determine keystone dimensions of conductor are being performed
- Conductor will be procured as trapezoidal [keystone] shape
- Keystone shaped conductor will be wound as shown in lower figure and will return to required dimensions after winding



OH/TF Manufacturing Area



CS High-Bay Area C-Site

Facility Uses

- Inner TF fabrication
- OH Fabrication
- CS casing sub-assembly
- Centerstack Assembly

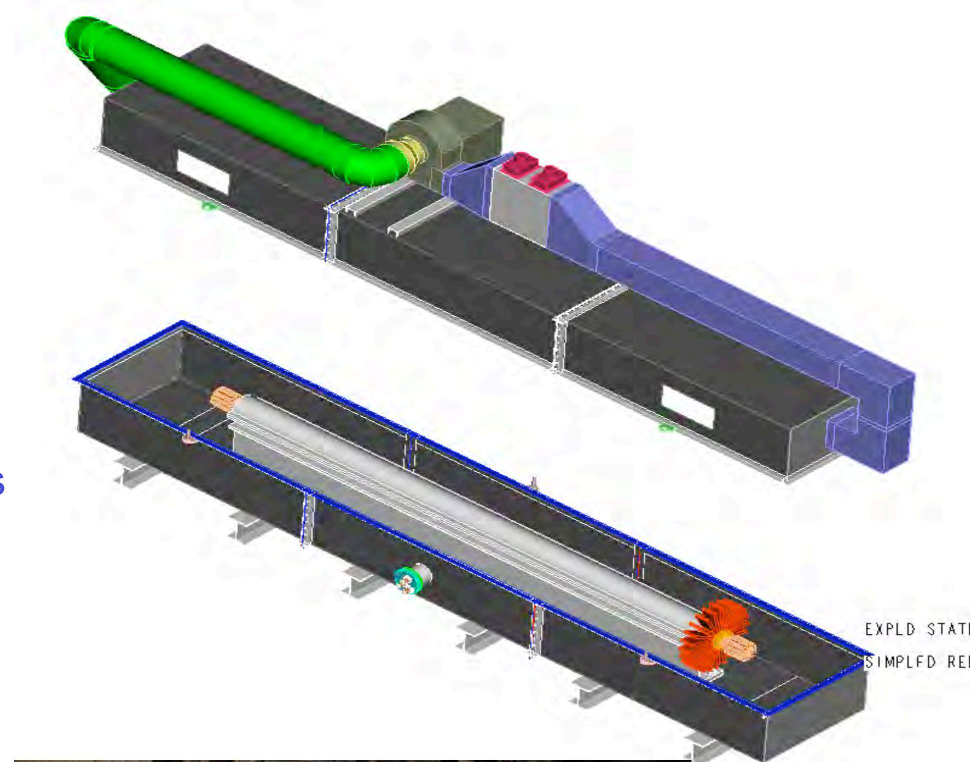
To Support Manufacturing Plan

- ***In order to meet the project milestones the are a number of activities that need to begin prior to or immediately following the FDR***
- ***Procure TF conductor- October 2010***
- ***Procure long lead items such as equipment and tooling. – Beginning January 2011***

Long Lead Items	**Order Date**	**Weeks Delivery**
TF Quadrant Mold [TF]	**3/24/11**	**16**
TF Full Mold [TF]	**5/9/11**	**16**
Coil Winding machine [OH]	**1/10/11**	**12**
Induction braze unit [OH]	**1/10/11**	**10**
OH Mold [OH]	**8/1/11**	**16**
Additional Equipment Needs		
VPI Delivery system [TF & OH]		
Lifting beam- [TF @ OH]		
Sandblast unit [TF Bundle]		
TF tube soldering station [TF Bundle]		
TF conductor insulation station [TF]		
Taping machine [OH Solenoid]		
Tension unit [OH Solenoid]		

Inner TF Bundle Manufacturing Plan-1

- *Inner TF bundle will be fabricated in-house @ PPPL*
- **Manufacturing Steps:**
  - Conductor: -after machining
    - Solder cooling tubes into conductor
    - Sandblast and apply CTD primer to conductor surface
    - Apply T/T insulation [S2 glass]
  - Assemble conductors into quadrants and VPI [9 turns] use existing PPPL oven
  - Assemble 4-quadrants together
  - Apply GW insulation [S2 glass]
  - VPI complete coil assembly
  - Perform final electrical and pressure tests
- **Phase 2- Transfer to OH winding station** [To be discussed later]



Inner TF Manufacturing Plan-2

- Assemble conductors into 9 turn quadrants and VPI [Figure 1]
- Assemble 4-quadrants together [Figure 2]
  - Apply GW insulation [S2 glass]
- VPI complete coil assembly
- Perform final electrical and pressure tests

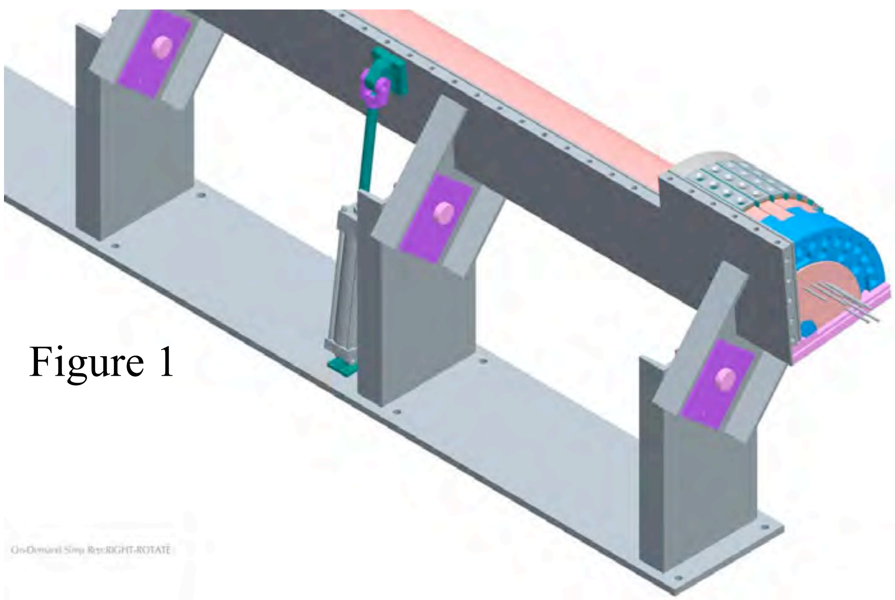
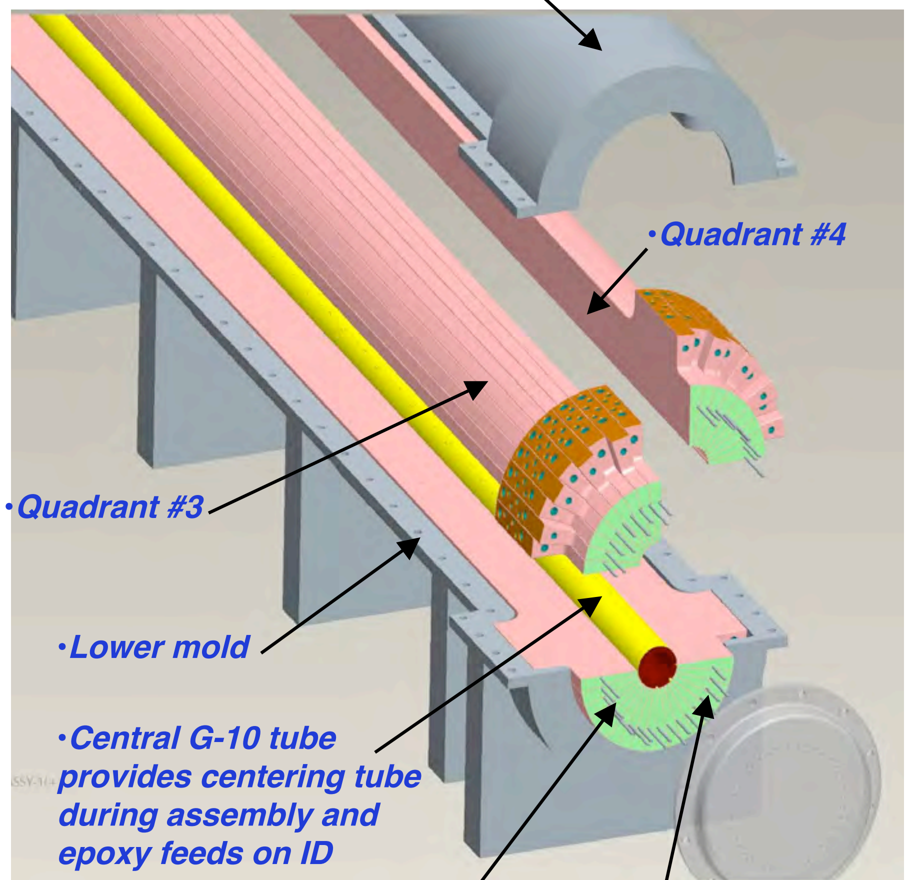


Figure 1

Figure 2



•Phase 2- Ready for OH solenoid [To be discussed later]

OH Coil Manufacturing Plan-1

- *Present plans are to build the OH/TF bundle in house in the CS High Bay Area- C-Site*

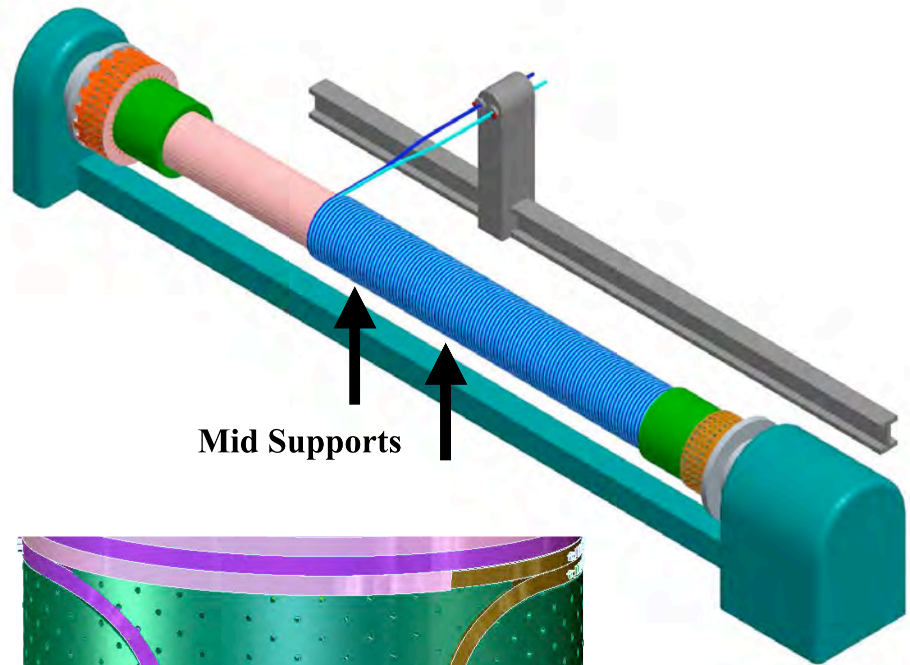
- PPPL will procure the copper conductor in continuous lengths. If unavailable induction brazing of conductors will be performed.

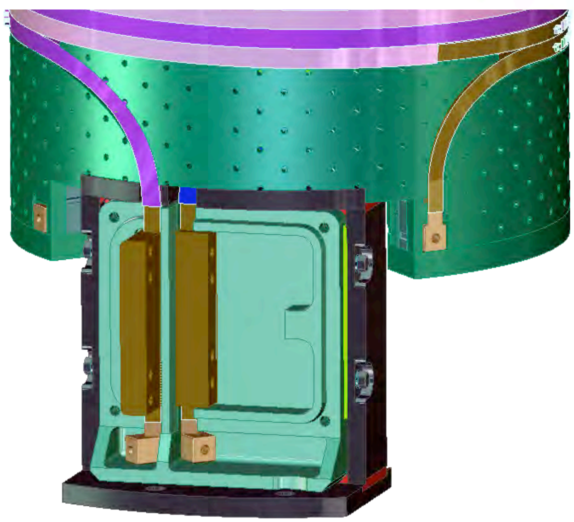
- The OH solenoid will be wound onto the TF bundle with a 0.100 gap between coils.

- A temporary mandrel using a product “Aquapour” will be used as a base for winding the OH solenoid.
  - In-house tests are presently being performed on this material
  - The material is easily removed with water once the coils have been completed to provide the necessary gap between coils.
  - An epoxy/glass layer will be applied over the cured mandrel, upon which the coil will be wound
  - Once the OH has be VPI’d the Aquapour will be removed

OH Manufacturing Plan-2

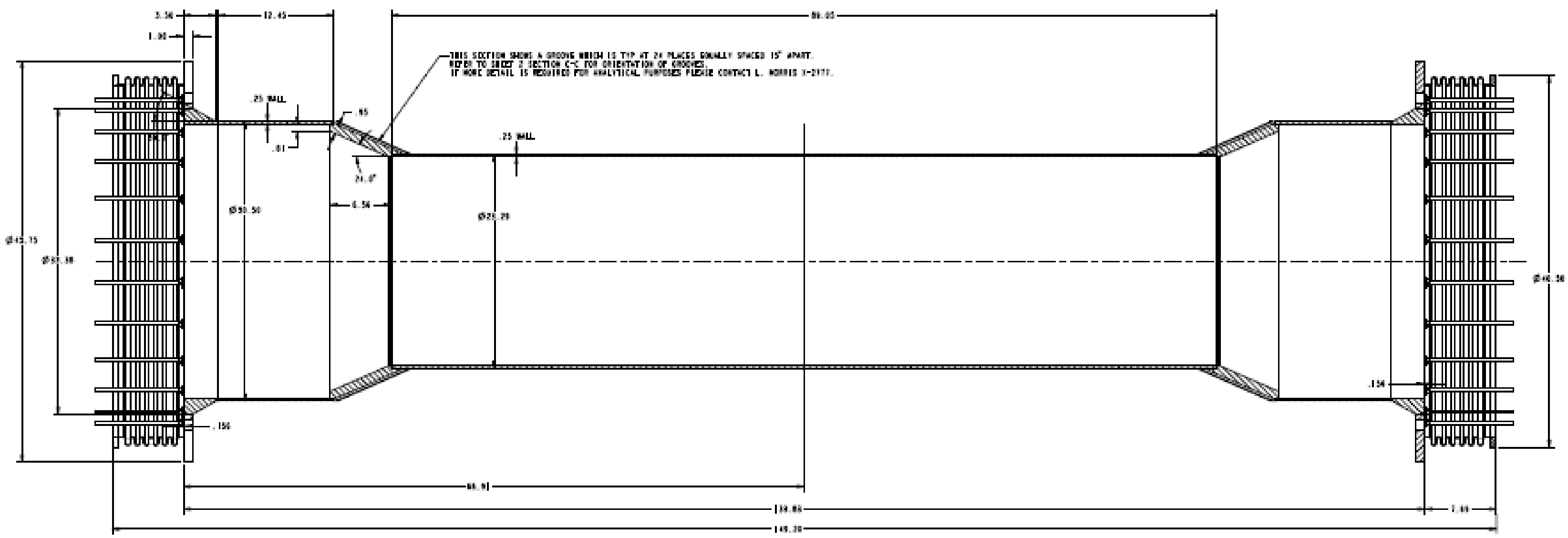
- Manufacturing Steps:
  - The TF with "Aquapour" mandrel would be mounted into a turning fixture
  - The OH conductor will be wound under tension
  - Finalize lead area
  - Install outer groundwrap insulation
  - Install mold around coil assembly
  - VPI OH coil- full cure cycle both coils
    - Discussions with Composite Technical Development has verified that this process [double epoxy full cure- TF and OH] would work.
  - Perform final electrical and pressure tests on both OH and TF bundles
  - Apply outer ground plane
  - Mount surface diagnostics
  - Install "Micro-Therm" insulation
  - Ready for Centerstack Assembly.





Center Stack VV Case Design Features

	Center section Dia. [In.]	Wall Thickness [in.]	Material	Length [in.]	Flange Diameter [in.]	Bellows	Organ Pipes
	23.29	0.25	Inconel 625	133.83	43.75	Inconel 625	Yes

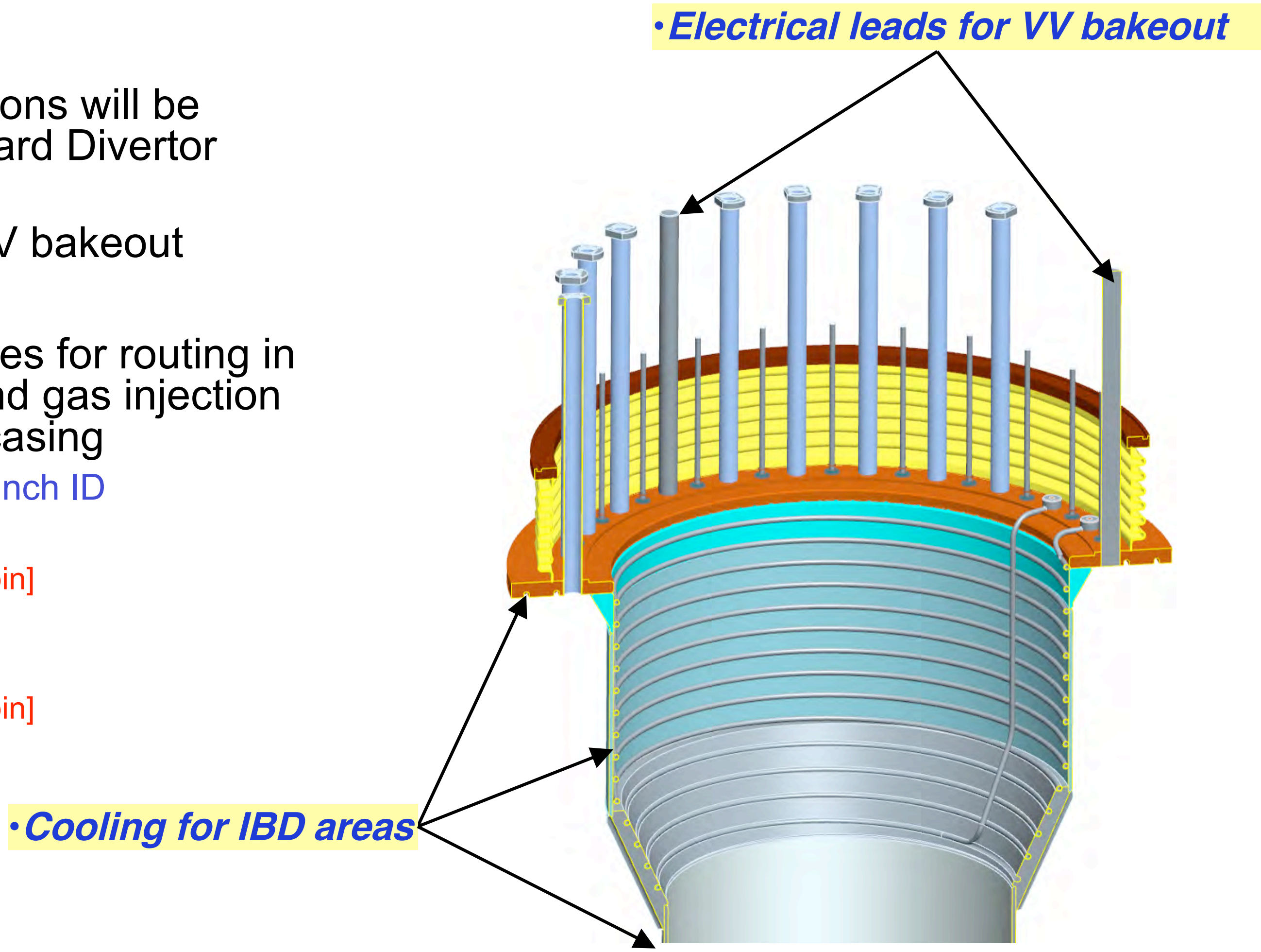


SECTION A-A
(ORGAN PIPES NOT SHOWN)

•Centerstack casing provides the inner vacuum wall for the NSTX vessel.

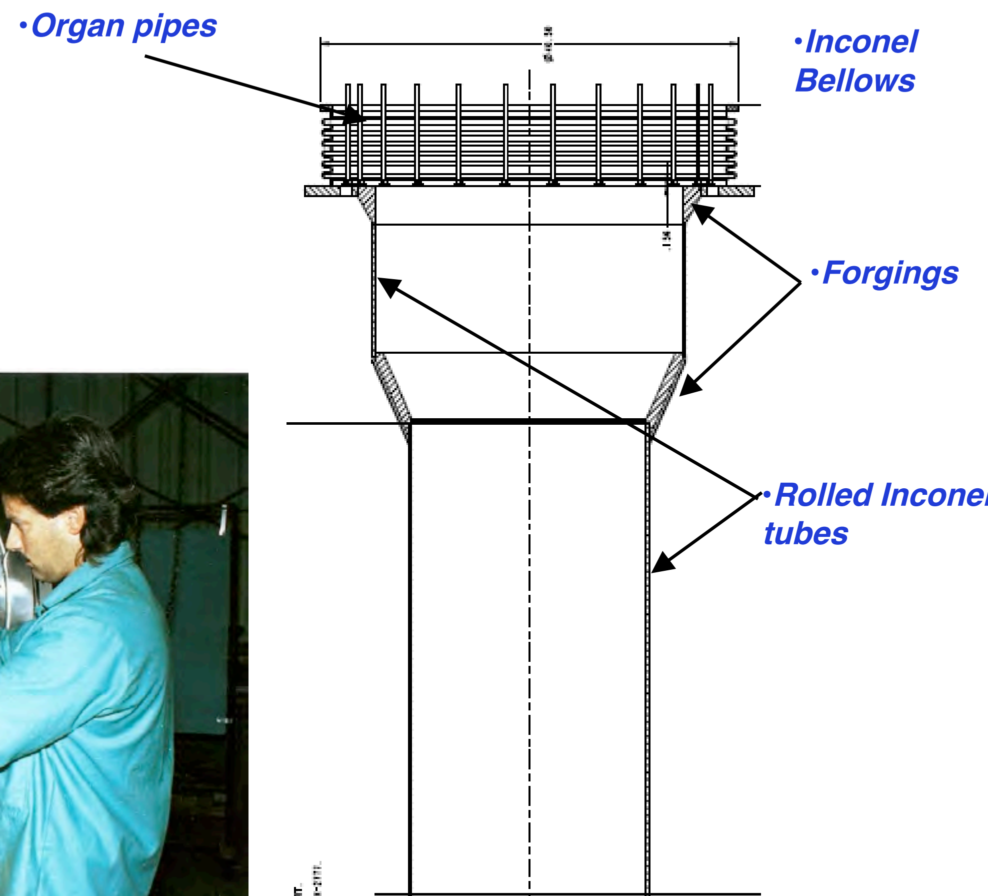
Features of Center Stack Vacuum Case

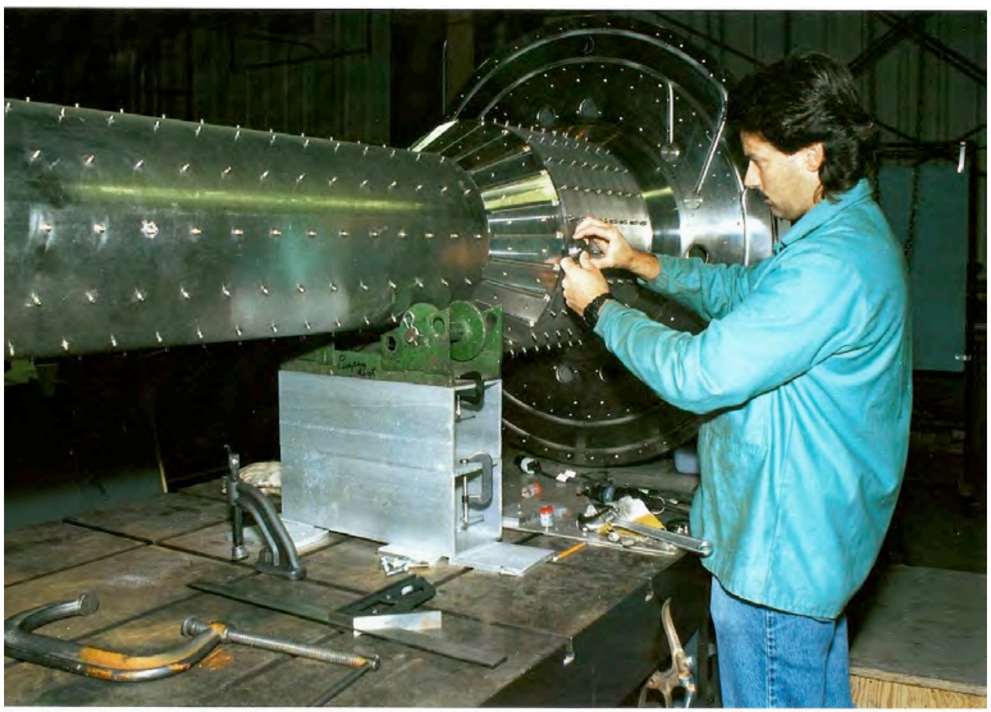
- Active cooling provisions will be provided for the Inboard Divertor regions
- Electrical leads for VV bakeout
- Inconel 625 bellows
- Diagnostic Organ pipes for routing in vessel diagnostics and gas injection on either end of the casing
  - 1.25 inch OD x 1.125 inch ID
  - Upper Flange:
    - (15) diagnostics [19 pin]
    - (2) Gas injection
  - Lower Flange
    - (17) diagnostics [19 pin]



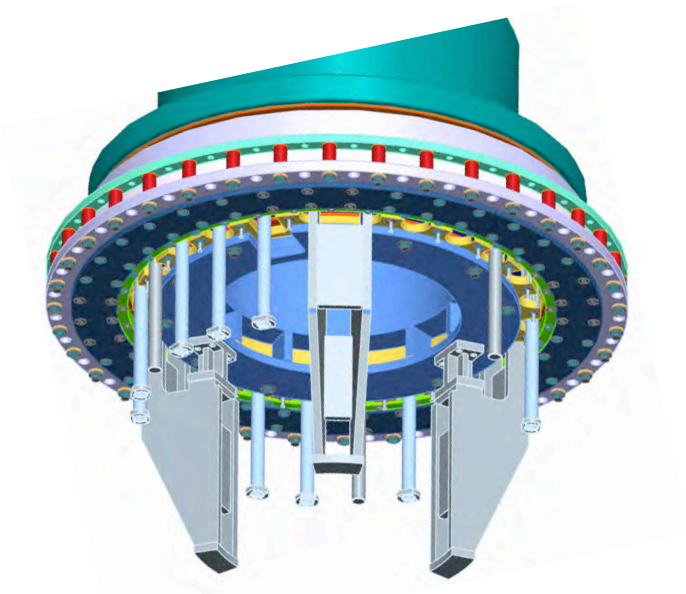
Center Stack Case Manufacturing Plan

- The CS casing will be fabricated by an outside vendor.
- Inconel studs for mounting the PFC tiles will be installed at PPPL
- Bellows: Inconel 625

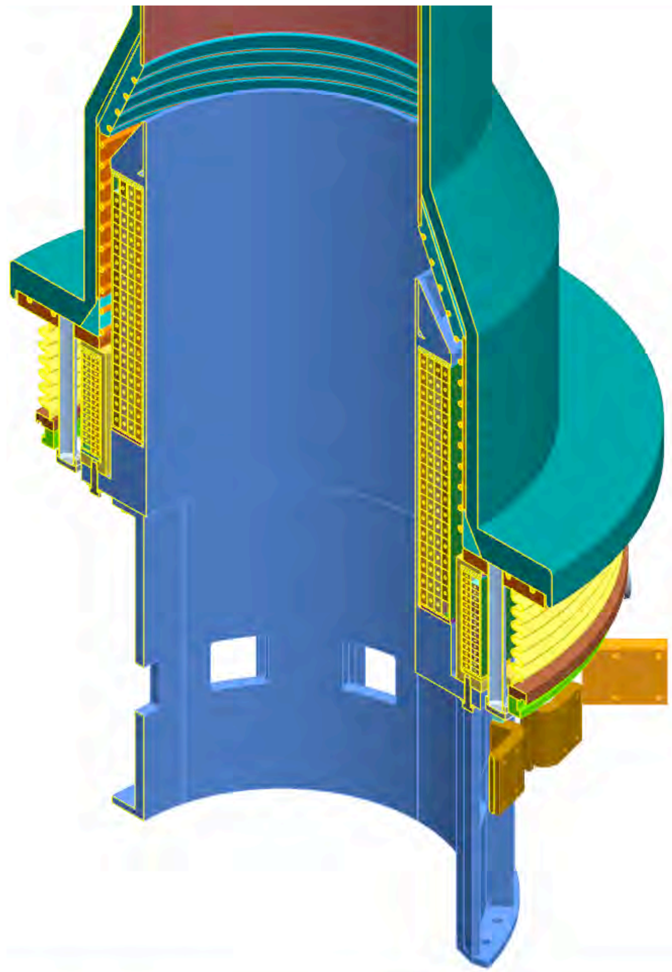


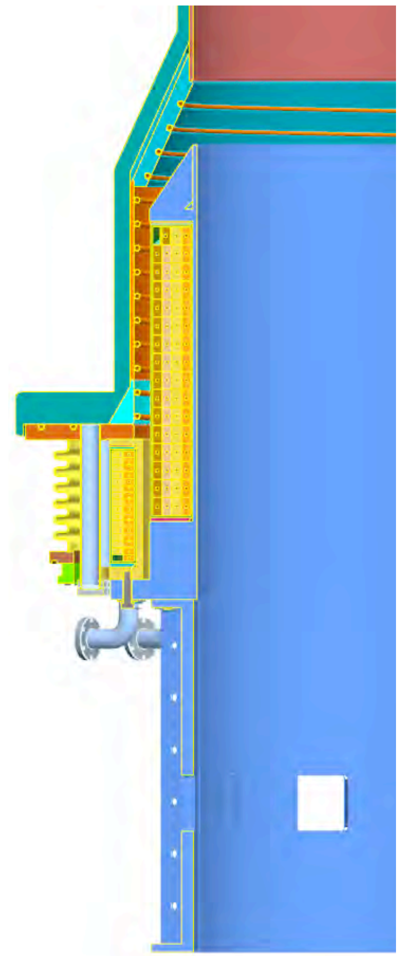


Center Stack Casing Support



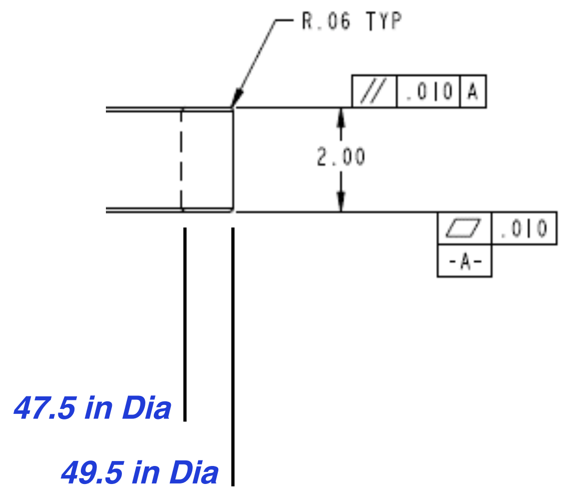
- CDR Proposed CS Casing support structure

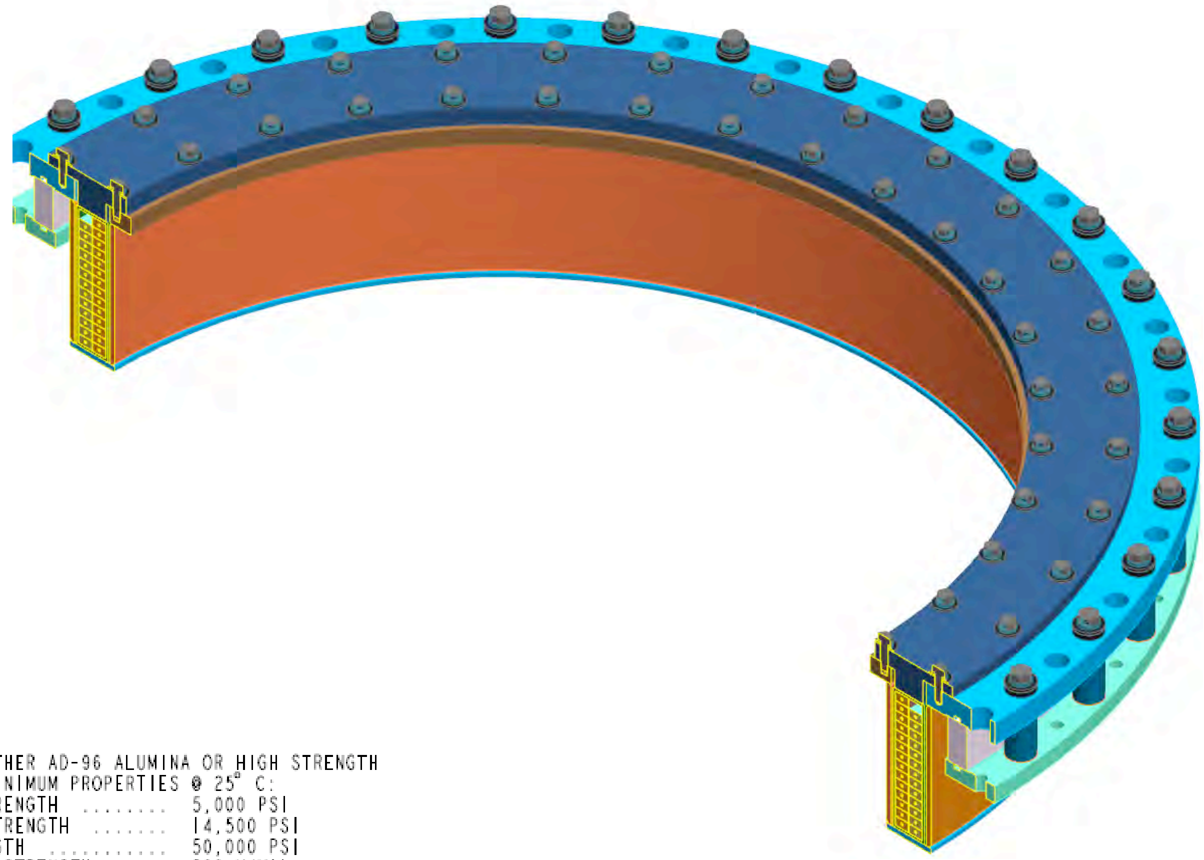




- PDR Proposed CS Casing support structure

Ceramic Break Assembly





NOTES:

1. MATERIAL: RING CAN BE MANUFACTURED FROM EITHER AD-96 ALUMINA OR HIGH STRENGTH PORCELAIN HAVING THE FOLLOWING MINIMUM PROPERTIES @ 25° C:
   - TENSILE STRENGTH .... 5,000 PSI
   - FLEXURAL STRENGTH .... 14,500 PSI
   - COMPR STRNGTH .... 50,000 PSI
   - DIELECTRIC STRENGTH ..... 200 V/MIL
   - VOLUME RESISTIVITY ...... 10<10> OHM/CM

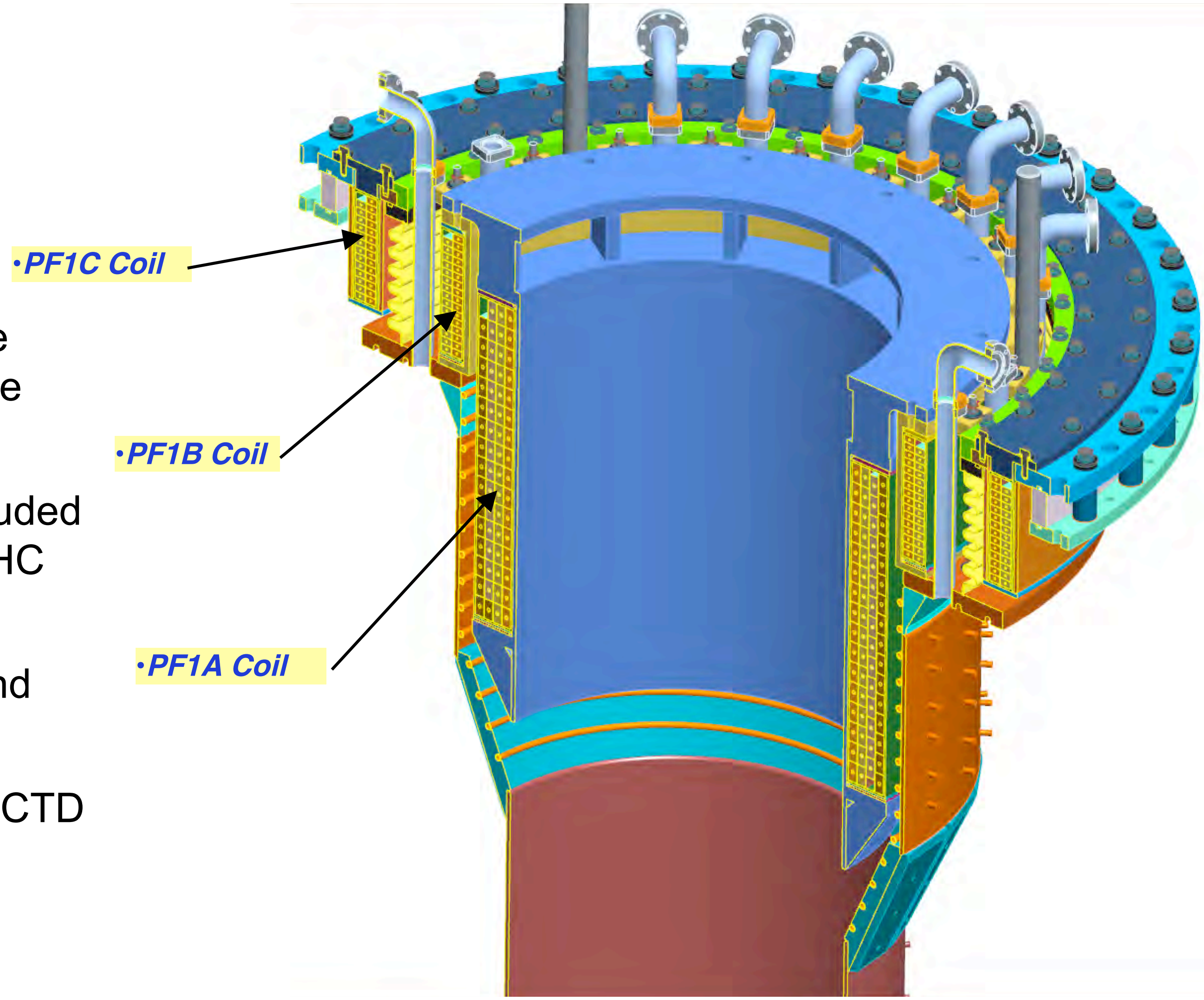
2. THE MATERIAL SHALL HAVE A MAXIMUM THERMAL COEFFICIENT OF EXPANSION OF 6.7 x 10^{-6} /C FROM 25° - 250° AND BE ABLE TO ABSORB A CUMULATIVE RADIATION DOSAGE OF 1 x 10^{8} RAD WITH NO DEGRADING EFFECT TO THE MATERIAL'S PROPERTIES.

3. THE RING SHALL BE UNIFORM IN COLOR AND TEXTURE. CRACKS, BLISTERS, HOLES, POROUS AREAS, INCLUSIONS AND ADHERENT FOREIGN PARTICLES SHALL NOT BE PERMITTED.

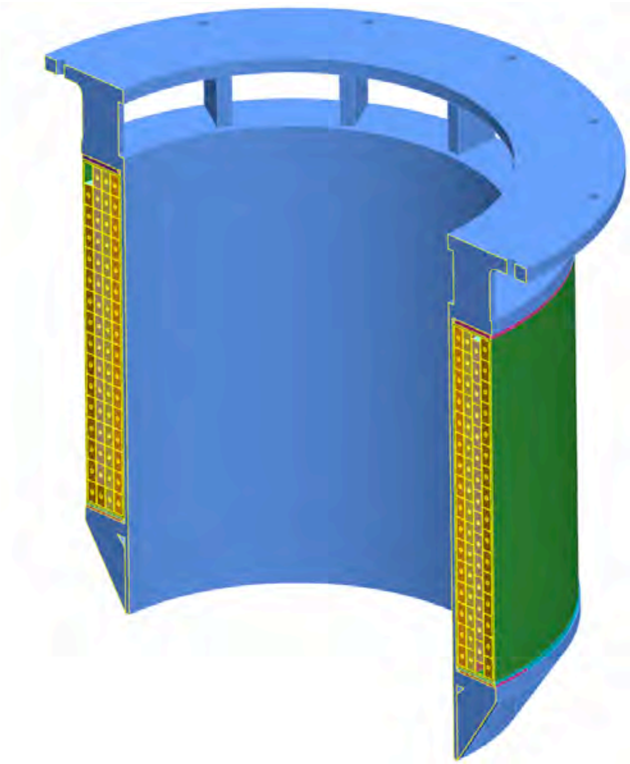
4. FABRICATE RING FROM ONE PIECE. NO JOINTS OR SEAMS PERMITTED.

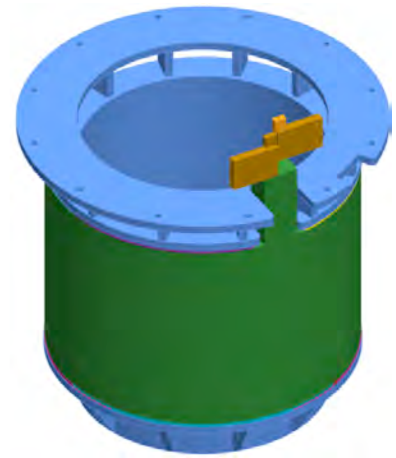
Inner Poloidal Field Coils

- The inner PF coils will be manufactured by an outside vendor.
- Conductor material: extruded C10700 silver-bearing OFHC copper
- Turn insulation: Co-wound Kapton and S-2 glass tape
- Coils will be VPI'd using CTD 101k resin system



Inner PF1A

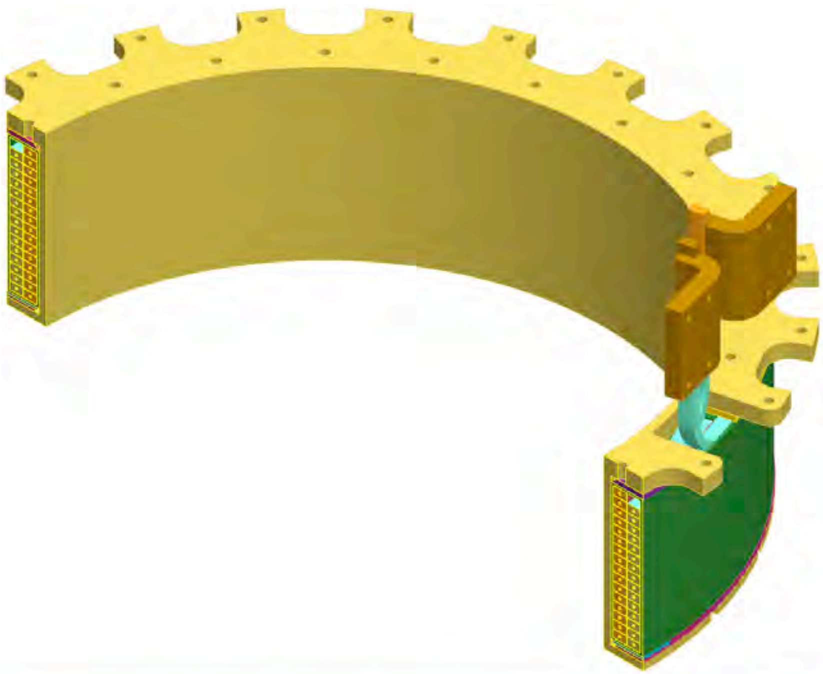


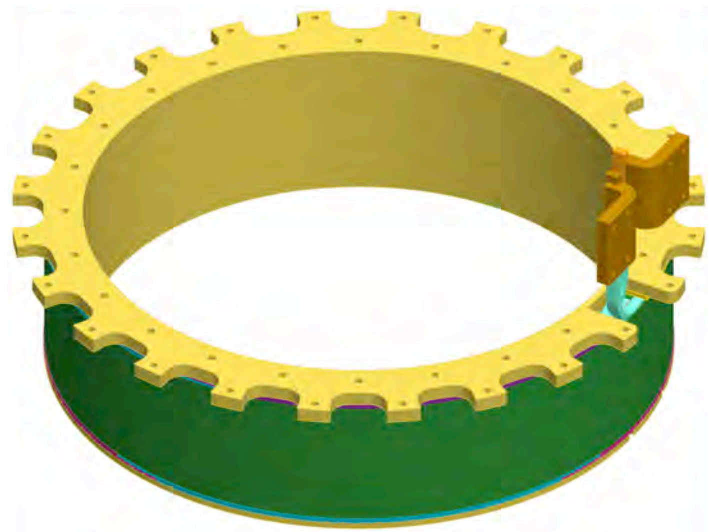


PF1A		
Number of coils	na	2
Voltage	Volts	2026
Current	KA	18.3
T/T Voltage	Volts	31.7
Number of Turns	n	64
ESW	sec	4.6
Conductor Width	In.	0.551
Conductor Height	In.	1.100
Cooling Hole Diameter	In.	0.205
Turn insulation thickness	In.	0.022
Ground insulation thickness	In.	0.144

- The coil will be wound directly onto the and support structure.
- VPI the coil on the support structure
- Use CTD101K resin system
- PF1A will be mounted to the CS casing and PF1B structure

Inner PF1B

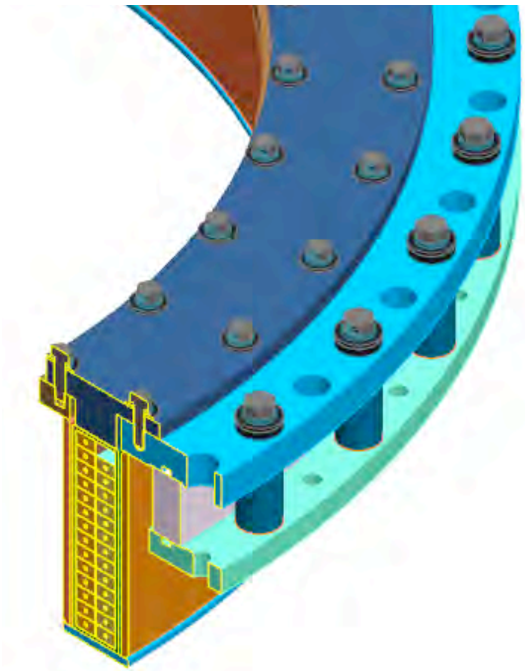


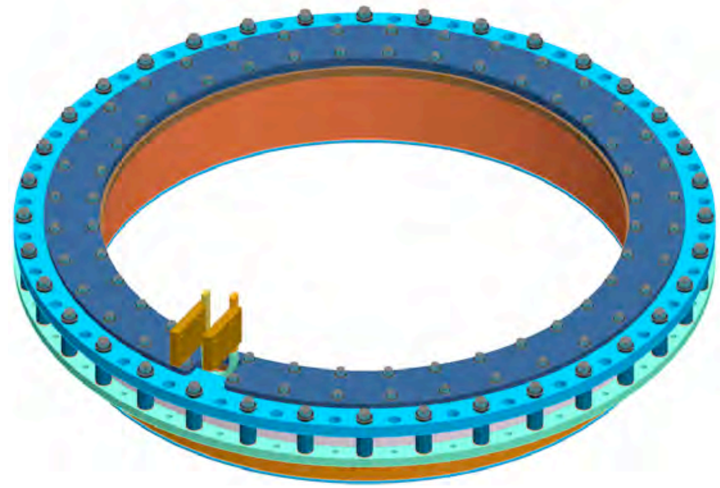


- The coil will be wound directly onto the and stainless steel support structure.
- VPI the coil on the support structure
- Use CTD101K resin system
- Coil and support structure will be welded to the CS case flange

PF1B		
Number of coils	na	2
Voltage	Volts	2026
Current	KA	13.0
T/T Voltage	Volts	5.6
Number of Turns	n	32
ESW	sec	5.5
Conductor Width	In.	0.633
Conductor Height	In.	0.392
Cooling Hole Diameter	In.	0.126
Turn insulation thickness	In.	0.029
Ground insulation thickness	In.	0.144

Inner PF1C



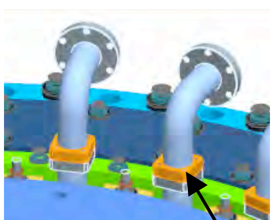


PF1C		
Number of coils	na	2
Voltage	Volts	2026
Current	KA	15.9
T/T Voltage	Volts	5.6
Number of Turns	n	20
ESW	sec	5.5
Conductor Width	In.	0.705
Conductor Height	In.	0.603
Cooling Hole Diameter	In.	0.126
Turn insulation thickness	In.	0.029
Ground insulation thickness	In.	0.072

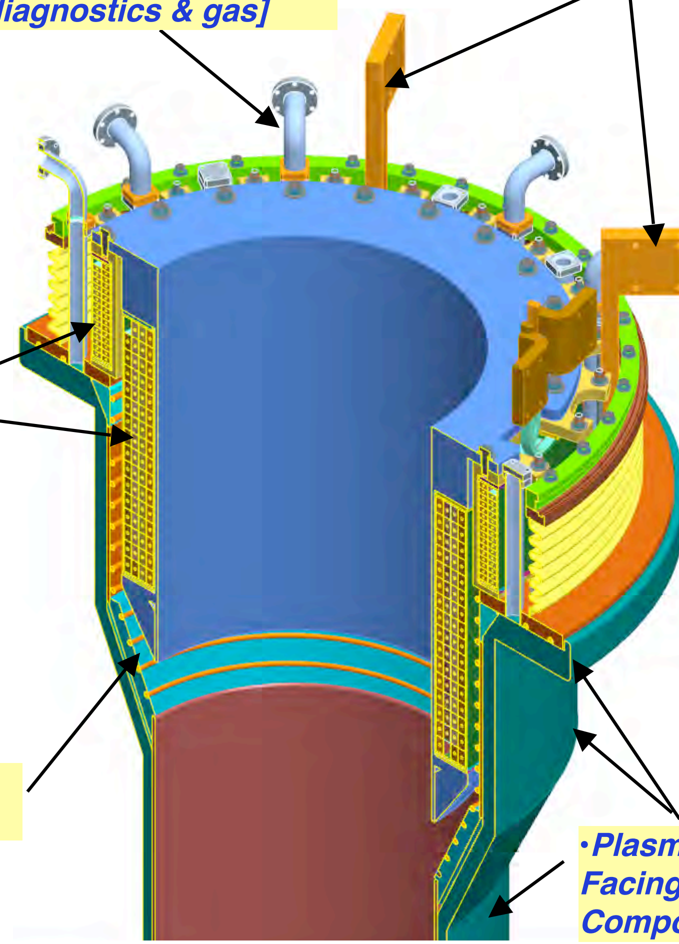
- The coil will be wound on a mandrel then installed into it's stainless steel support structure. [Part of ceramic break system]
- VPI the coil in the support structure
- Use CTD101K resin system

Assembly of Centerstack Components

- The final assembly of the Centerstack components will be completed in the NCSX Test Cell area
- CS Assembly components include:
  - OH/TF Assembly
  - Casing
  - Inner PF coils
  - PFC Tiles
  - Organ pipes
  - CHI [Bakeout] leads



"Viton" O-rings will be used for 90º organ pipe extensions [April Peer Review Chit #5]



Assembly of Centerstack Components

- The completed Center Stack Assembly will be transported to the NSTX Test Cell and installed into the vacuum vessel.

R&D and Testing Activities

- R&D for the TF joint and flexible bus will be discussed by Tom Willard in his talk
- Fabricate full size mock up of the umbrella TF and flex bus to evaluate assembly tools and procedures [In process]
- Phase 2- Friction Stir Welding [FSW] trials
  - Repeat trials using OFHC 107 and C18150
  - Contract with Edison Welding Institute in process
  - Work is scheduled to be completed this summer
- Additional Layer to layer TIG-Braze joint tests [OH]
  - Initial tests were successfully completed. Once OH conductor has been received additional tests will be repeated
- In-line braze joint tests [OH] qualification
  - Tests will be performed once induction braze equipment has been procured and OH conductor received