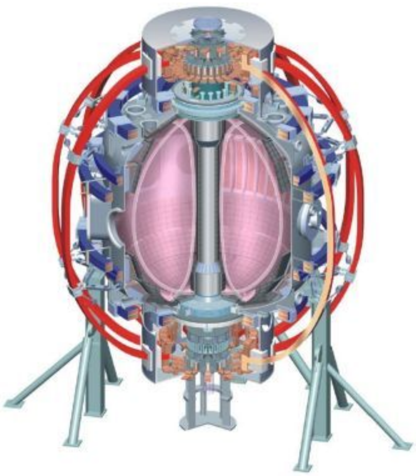
Center Stack/Magnet Systems

James H. Chrzanowski
and
NSTX Design Team

NSTX Upgrade Project
Conceptual Design Review
LSB, B318
October 28-29, 2009

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin



Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

Outline of Presentation

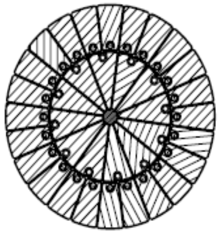
- **Conceptual Design of Inner TF Magnet**
- **Conceptual Design of OH Solenoid**
- **Conceptual Design of Vacuum Casing, bellows and Ceramic break**
- **Conceptual Design of Plasma Facing Components**
- **Conceptual Design of Inner PF Magnets**

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

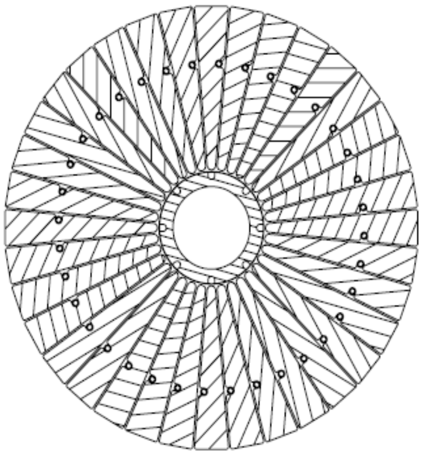
TF Design Parameters

	Base Design	Upgrade Design
Operating Voltage	1013 volts	1013 volts
Number of turns	36	36
Number of layers	2	1
Cooling	Water	Water
Operating current	71,168 amps	129,778 amps
Turn insulation	0.0324 in.	0.0324 in.
Dielectric strength- turn insulation		3.8 KV [3] half-lapped layer glass
Groundwall insulation	0.054 in.	0.090 in.
Copper mass	2260 lbs	10,900 lbs
Outside diameter	7.866 in.	15.752 in.
Insulation scheme	B-stage CTD-112	S-2 glass and VPI CTD-101K
Cooling hole size ID	0.186 in.	0.305 in.

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



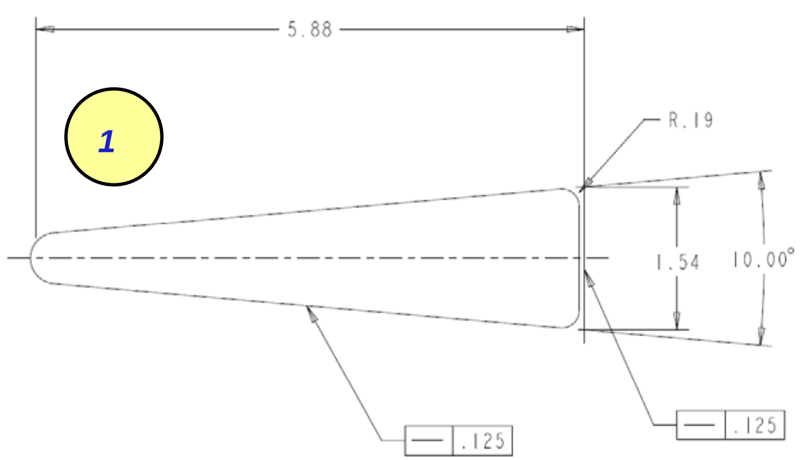
Current TF Bundle
7.9 inch diameter

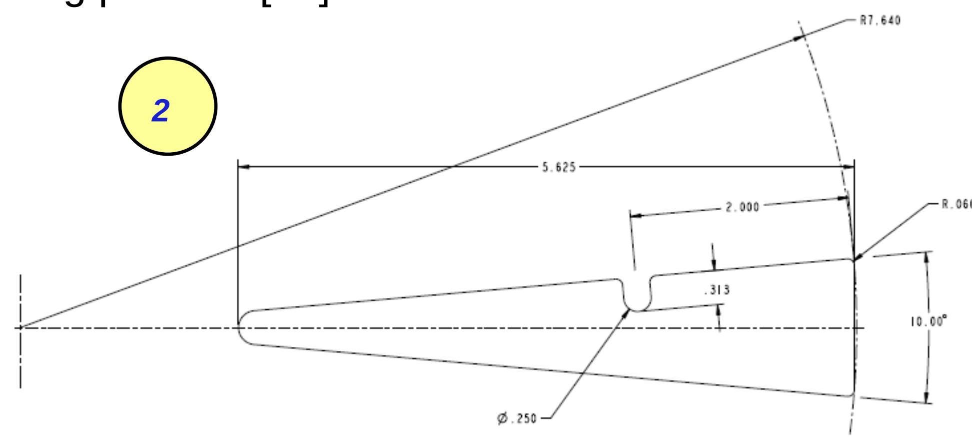


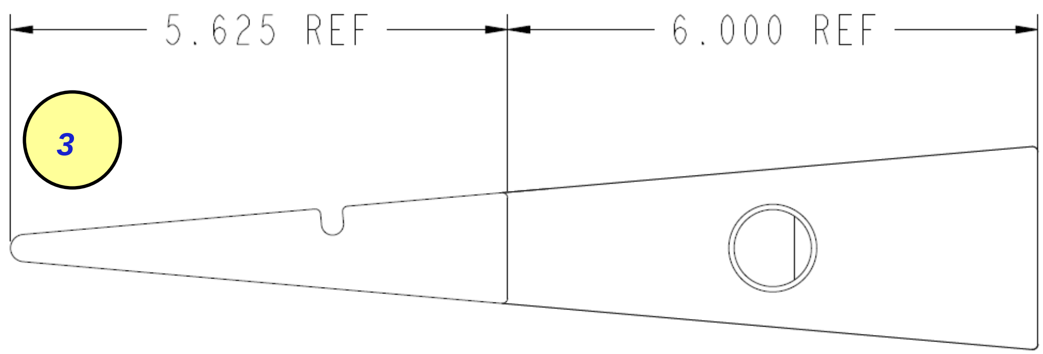
Upgraded TF Bundle
15.7 inch diameter

Inner TF Conductor

1. Inner bundle conductors will be procured as straight copper extrusions- 36 copper legs [80 will be purchased]- manufacturability has been confirmed with vendors
2. Machine conductor to final profile including cooling groove and relief for coil leads [40 will be machined]
3. Attach coil leads to using Friction stir welding process [40]

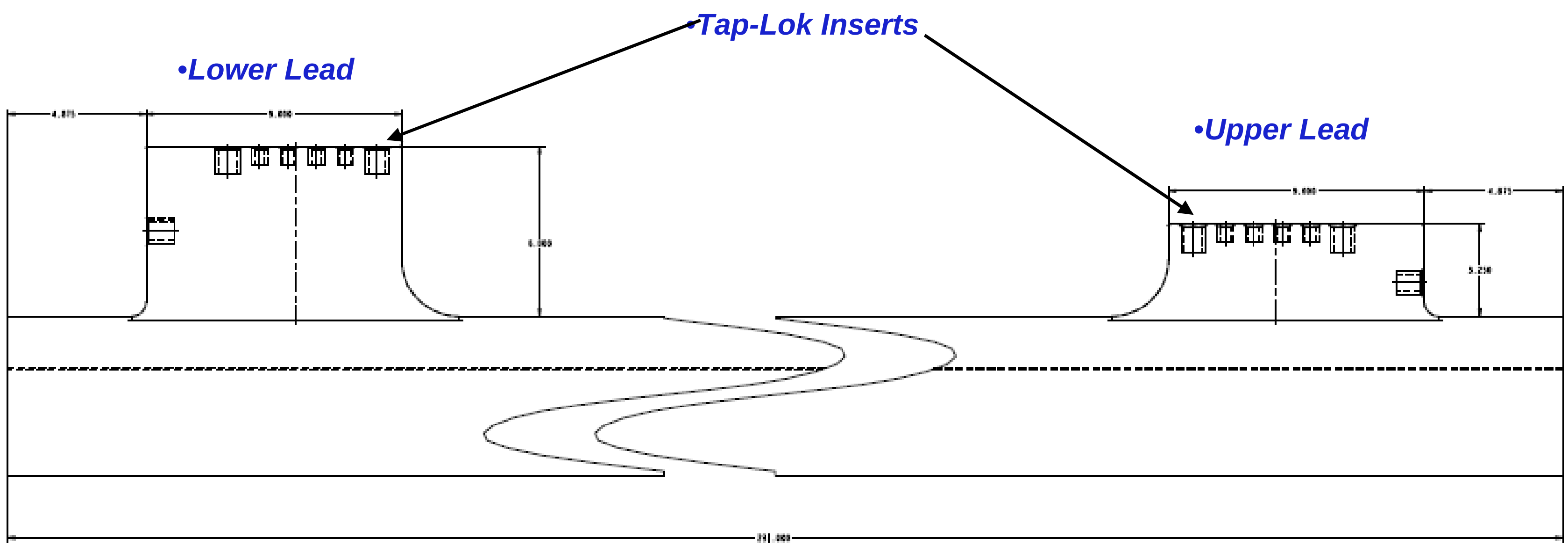




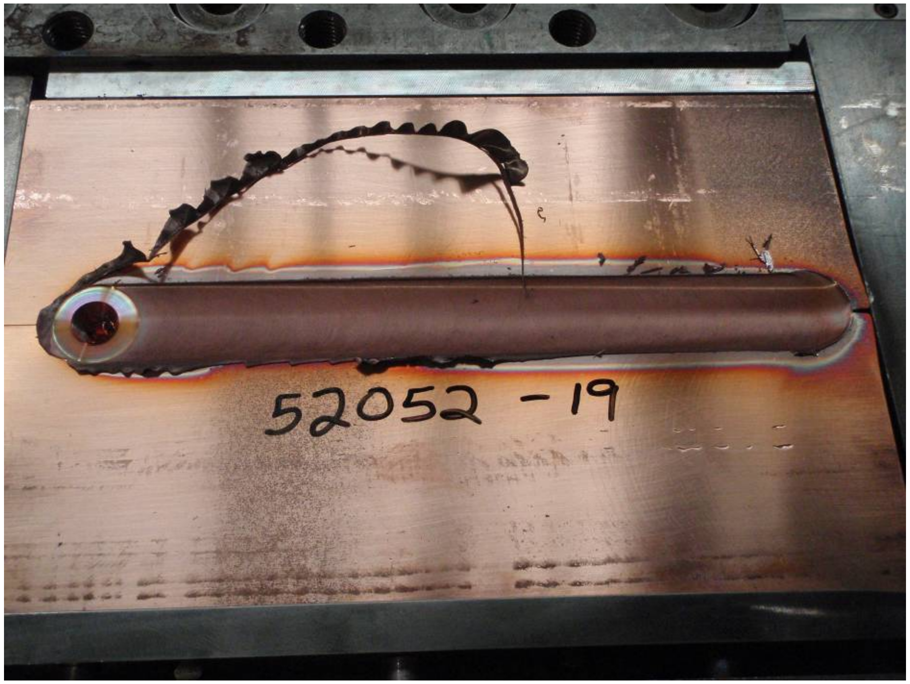


Conductor Lead Extensions

- 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]
- Tests were performed by Edison Welding Institute to qualify procedure [OFHC to OFHC]
- Additional tests using C18500 are being scheduled



Friction Stir Welding



What is Friction Stir Welding? [FSW]

• FSW is accomplished at temperatures below melting point of material/ no filler rod/no shielding gas.

• Metal working process using specially shaped rotating pin of hard alloy traversing along joint line.

• Rotation of pin and shoulder plasticize the material, move it across joint boundary and allow to cool and consolidate.

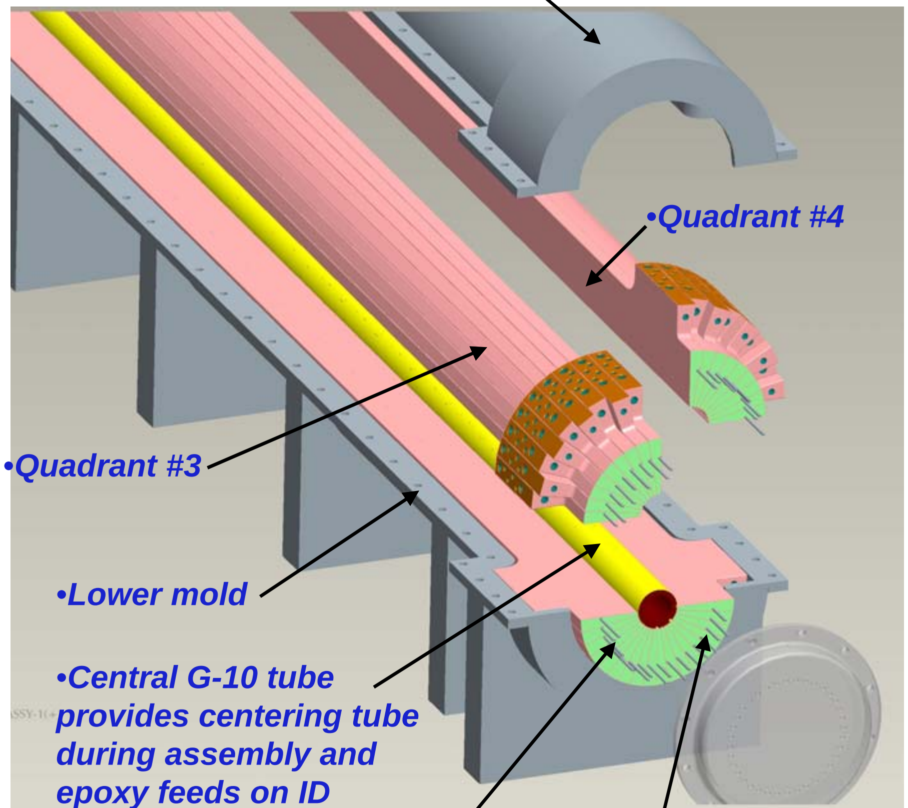
• Eliminates problems such as porosity, solidification cracking and shrinkage.

Selected Resin System- All Coils

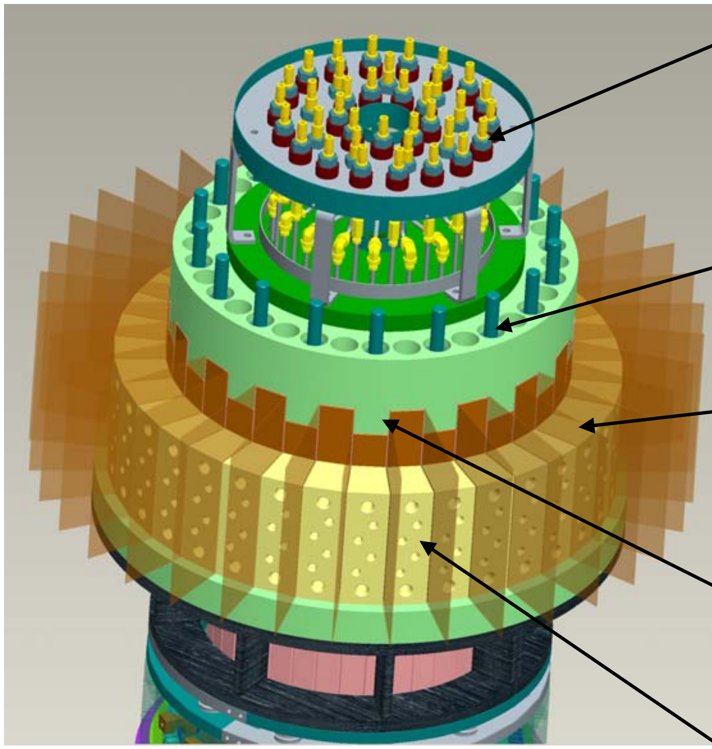
- **Resin System selected for the upgrade coils is CTD-101K**
  - ***Material has been well characterize for ITER & NCSX***
  - Product of *Composite Technology Dev. Inc.*
  - 3- Component epoxy system
  - Long pot life and low viscosity
- **Cure Cycle**
  - 5 hours @ 100 ° C (Cure)
  - 16 hours @ 125 ° 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

Inner TF Bundle Manufacturing Plan

- Due to schedule demands the plan is to procure the TF extrusions in early February 2010 following a Conductor Peer Review
- Present plans are to fabricate Inner TF bundle in-house
- Once TF conductor extrusions have been machined fabrication can begin
- Manufacturing Steps:
  - Solder cooling tubes
  - Apply T/T insulation [S2 glass]
  - Assemble conductors into quadrants and VPI [9 turns]
  - Assemble 4-quadrants together
  - Apply GW insulation [S2 glass]
  - VPI complete coil assembly
  - Perform final electrical and pressure tests
- Phase 2- Ready for OH solenoid [To be discussed later]

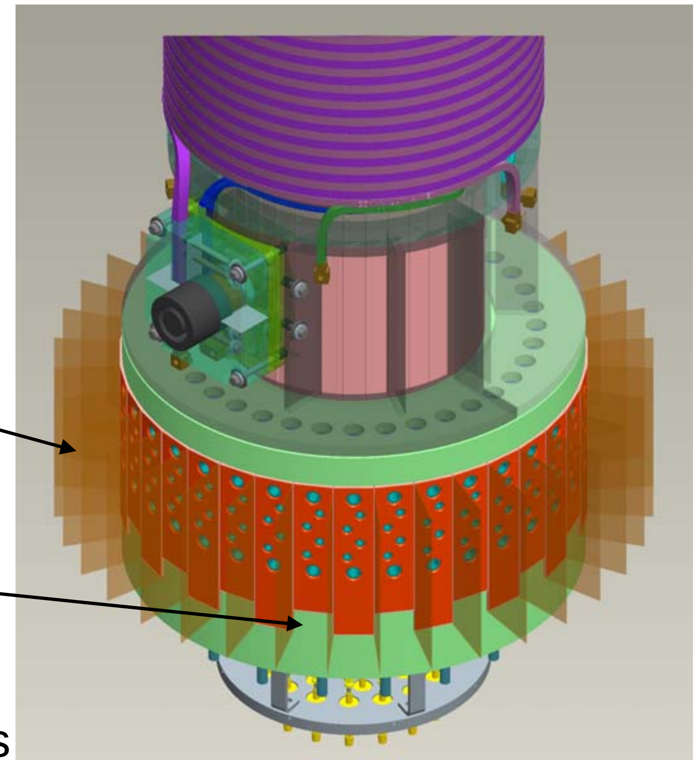


Inner TF Bundle End Details



•Upper TF Bundle

- Quick disconnect cooling tube connections
- Umbrella lid interface
- G-10/Kapton flash shield between lead areas
- G-10 Interlocking top plate
- Lead extensions [Upper only]



•Lower TF Bundle

•Tom Willard will present the design of the TF joint and Inner to Outer flex bus

Ohmic Heating Solenoid

•*Design Parameters*

	Base Design	Upgrade Design
Operating Voltage	6077 volts	8100 volts
Number of turns	964	1148
Number of layers	4	4
Cooling hole diameter	0.188 in	0.175 in
Operating current	24,000 amps	24,000 amps
Groundwall insulation	0.054 in.	0.090 in.
Turn insulation	0.0268 in	0.0480 in
Turn insulation dielectric strength		16.4 KV
Outside diameter	12.304 in	22.10 in
Copper mass	2340 lbs	6400 lbs
Cooling paths	8	8

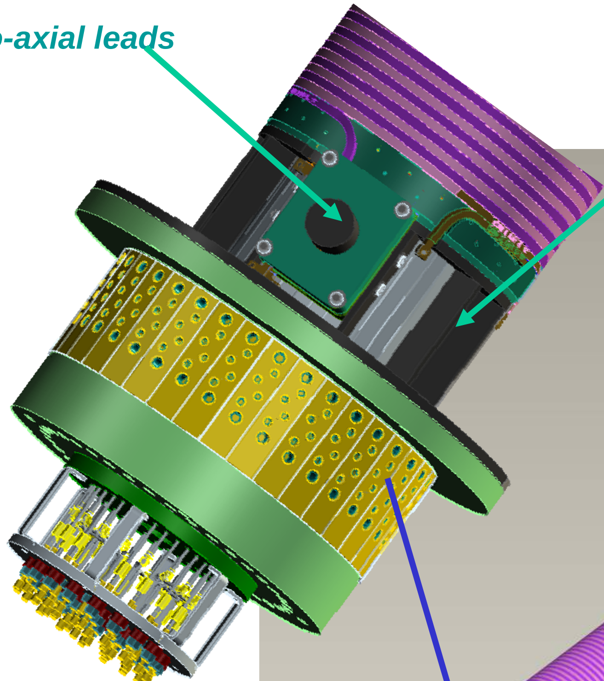
**** Reference: Per half-lapped layer- 7.6 KV [Kapton] and 1260 volts [VPI impregnated glass]***

OH Solenoid Design Features

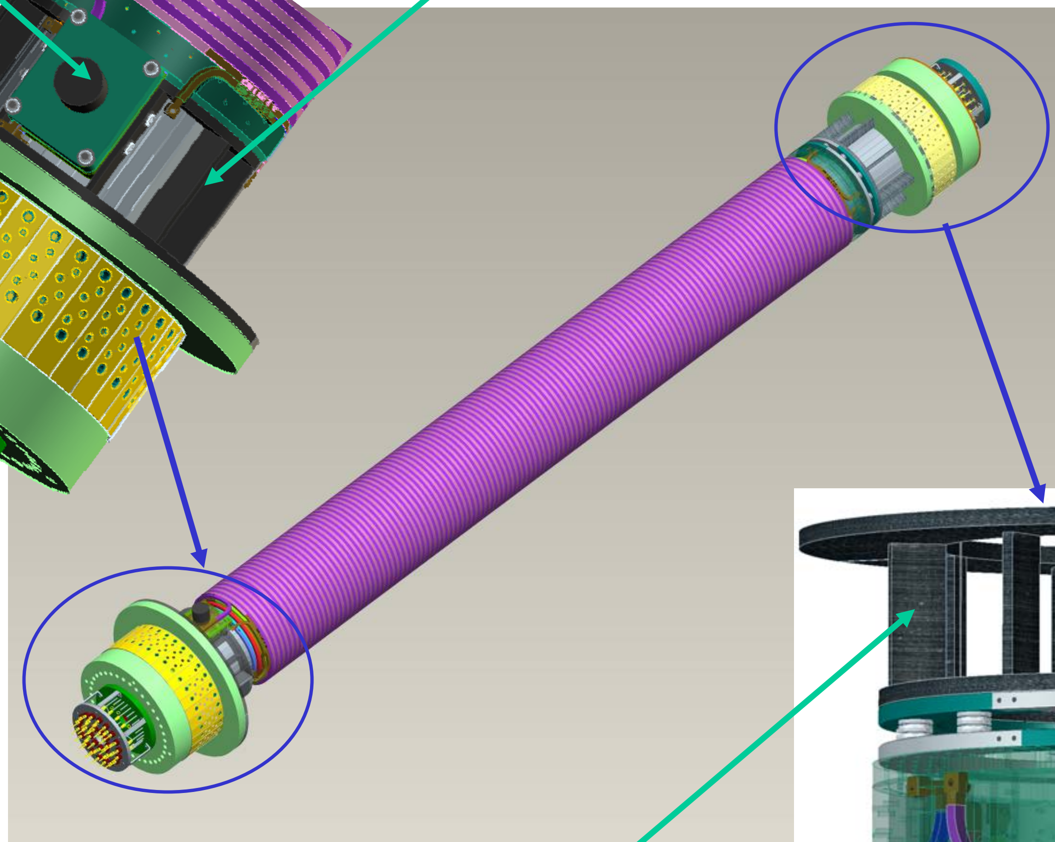
- Coil leads have been relocated to the bottom of machine
- Co-axial coil/bus lead design
- In line braze will be required due to conductor lengths
- Layer to Layer TIG-braze joints will be used
- Improved cooling fitting assemblies
- Coil will be wound directly onto the Inner TF bundle
- No tension tube
- Slip plane between TF and OH coil to allow for relative motion between components
- OH will have inner and outer electrical ground plane
  - Inner: Corona shield C215.51 tape [von-Rolla]
  - Outer: Conductive paint
- In case of a future OH solenoid failure the plan would be to remove [cut off] the existing coil from the TF bundle and rewound.

OH Solenoid End Details

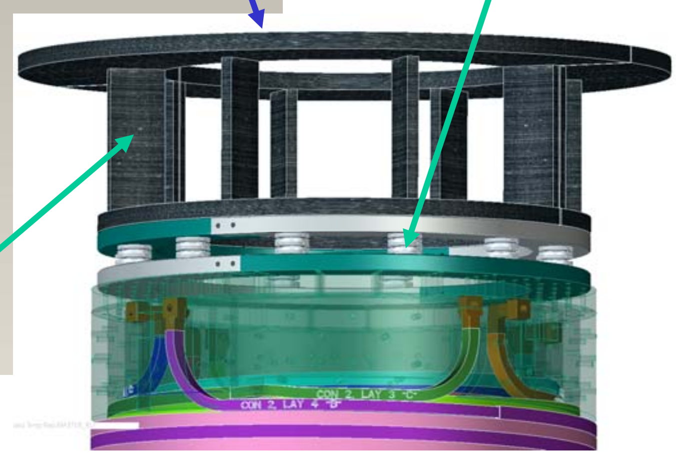
•Co-axial leads



•OH is supported between the upper and lower TF leads



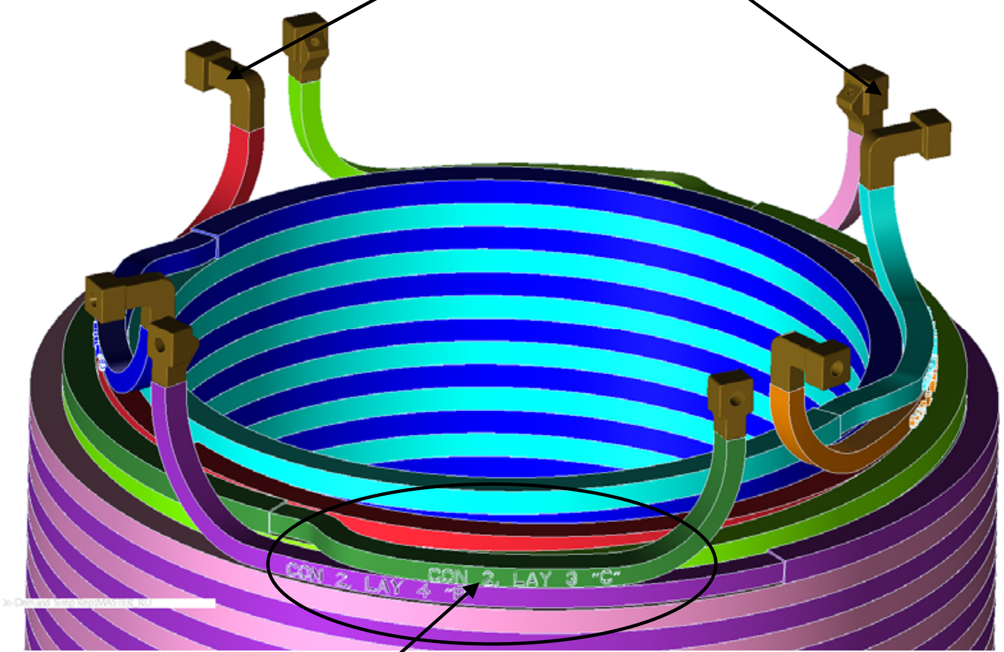
•Belleville washer package to maintain preload [Pre-load requirements presently being analyzed]



•OH is supported between the upper and lower TF leads

Layer to Layer Joints

•*OH Cooling fittings*



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

•*TIG-Brazing method minimizes annealing of conductors*

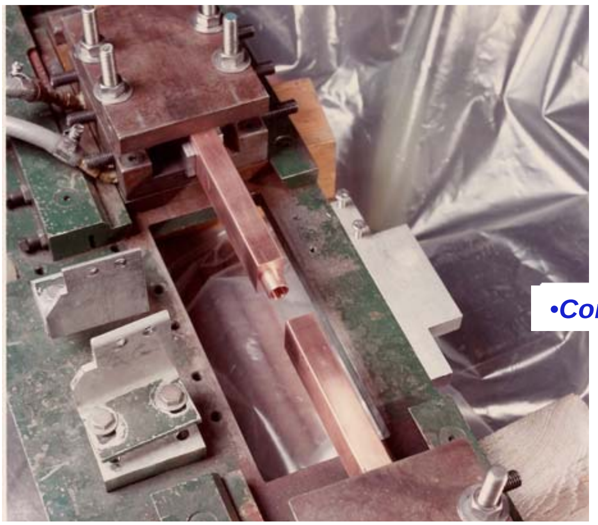
•*Provides adequate joint strength*

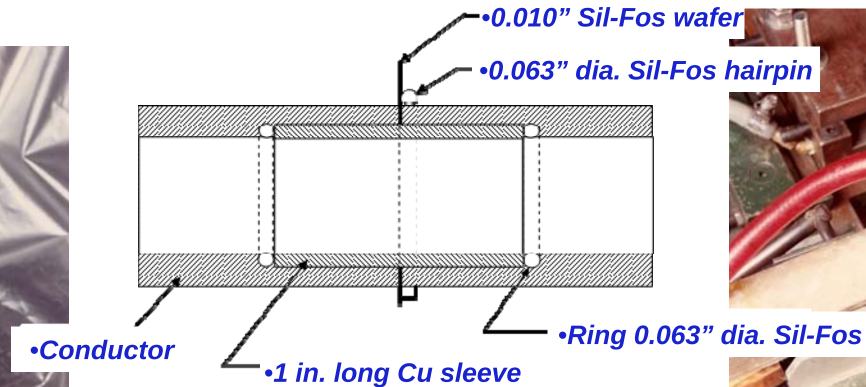
•*Proven method and procedures used in previous OH solenoids*

- 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 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.
- 4. Each lap joint shall be visually inspected for full flow and whetting of the braze material.
- 5. Remove the clamps from the previous operation. Apply flux to the pre-tinned joint and solder with 96%/ 4% Tin-Silver soft-solder with a melt temperature of 221°C (430°F) using pre-approved procedure and technique.

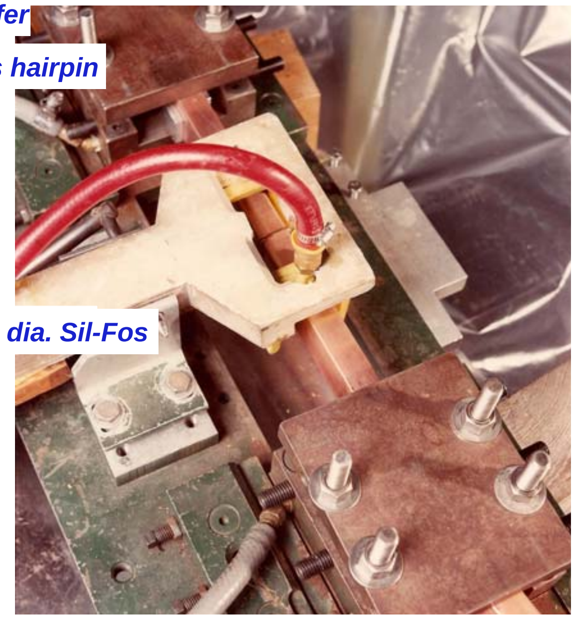
In-Line Braze Joint

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





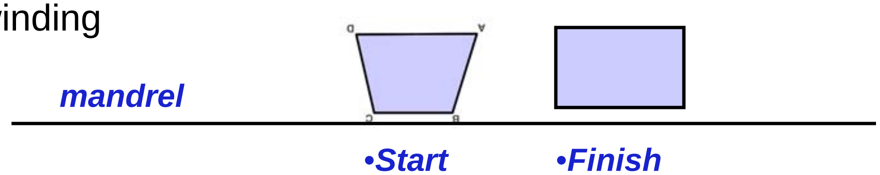
Typical Braze Joint



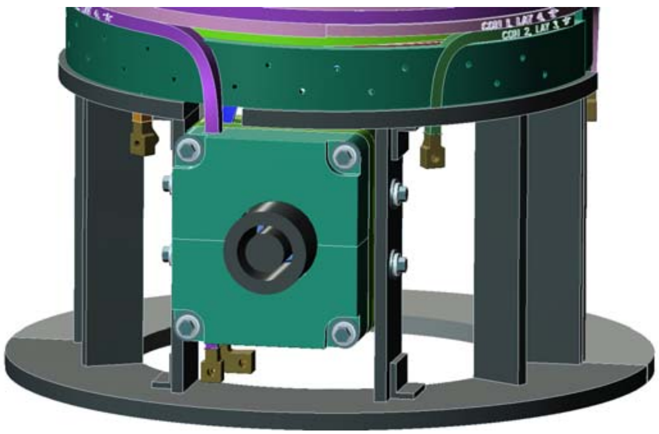
- Example of a Typical Brazed Joint
- Copper sleeve is used with “Sil-Fos” Wafer, hairpin and and 0.063” diameter rings to ensure full coverage and no voids
- Induction brazing strongly recommended
- Each joint would be hydraulically stretched and helium leak tested

OH Conductor

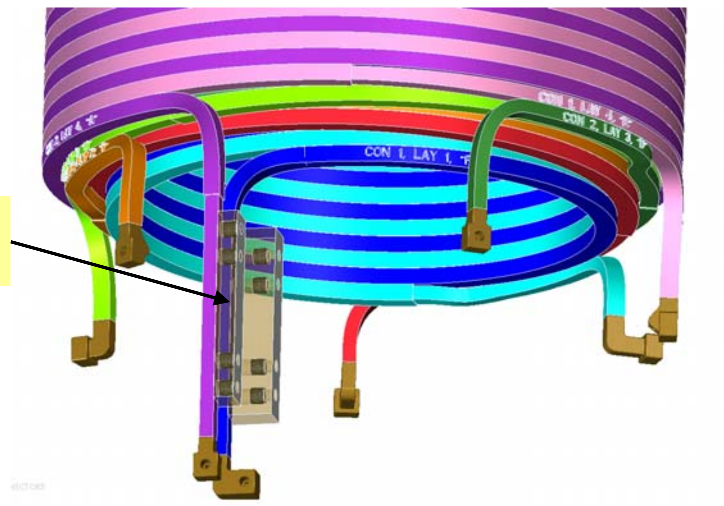
- Copper extruded conductor w/cooling hole [Procure by PPPL]
- Total Conductor length: 5025 feet [not based on final conductor design]
  - Layer 1: 555 feet each x 2
  - Layer 2: 603 feet each x 2
  - Layer 3: 653 feet each x 2
  - Layer 4: 702 feet each x 2
- Procure approximately 12,000 feet
- Material: C10700 [oxygen free w/silver] or equivilent
- Final conductor size: 0.650 in. x 0.485 in. w/0.175 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



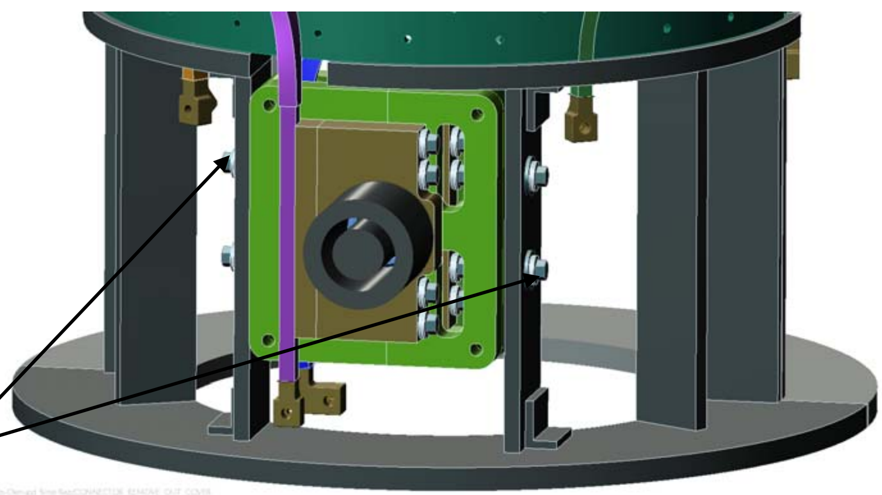
Co-axial bus leads



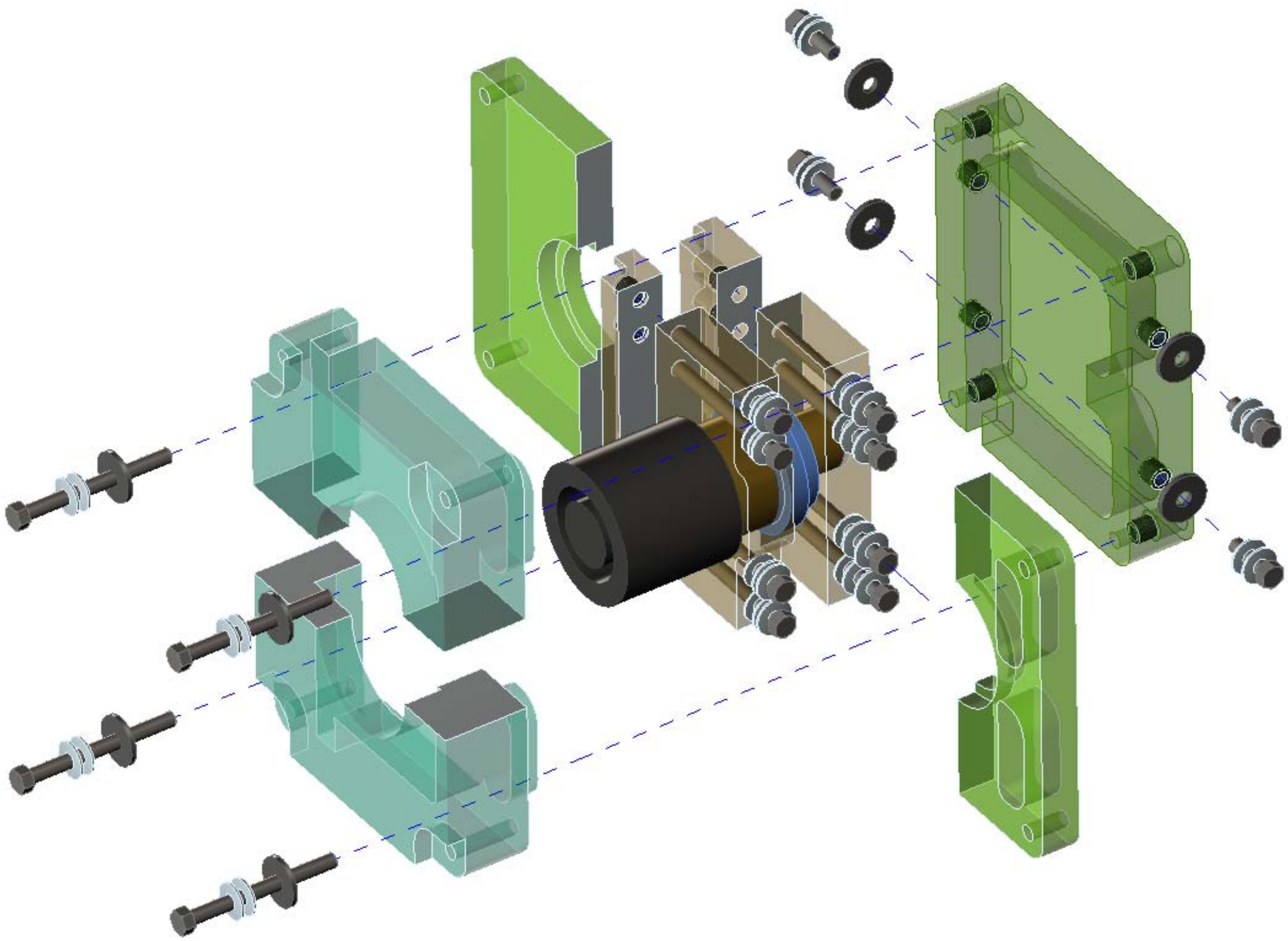
•*Leads will be brazed to coil conductors*



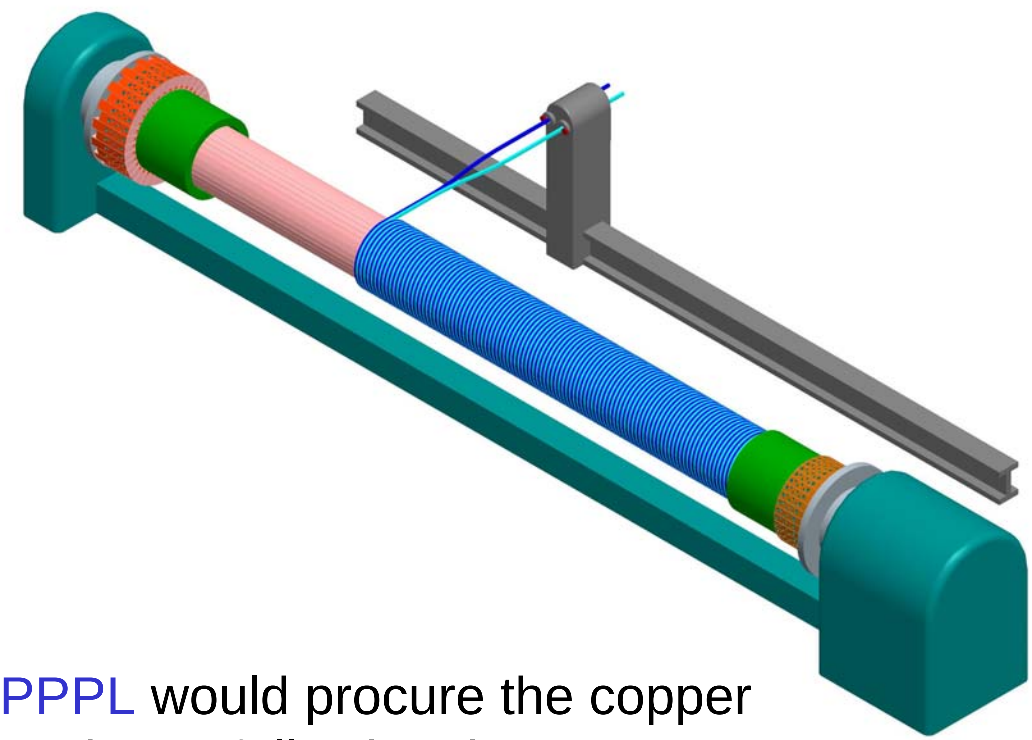
•*Leads will be supported via stainless steel structure that also provides vertical support for the OH solenoid*



Alignment of Coil Leads



OH Manufacturing Plan

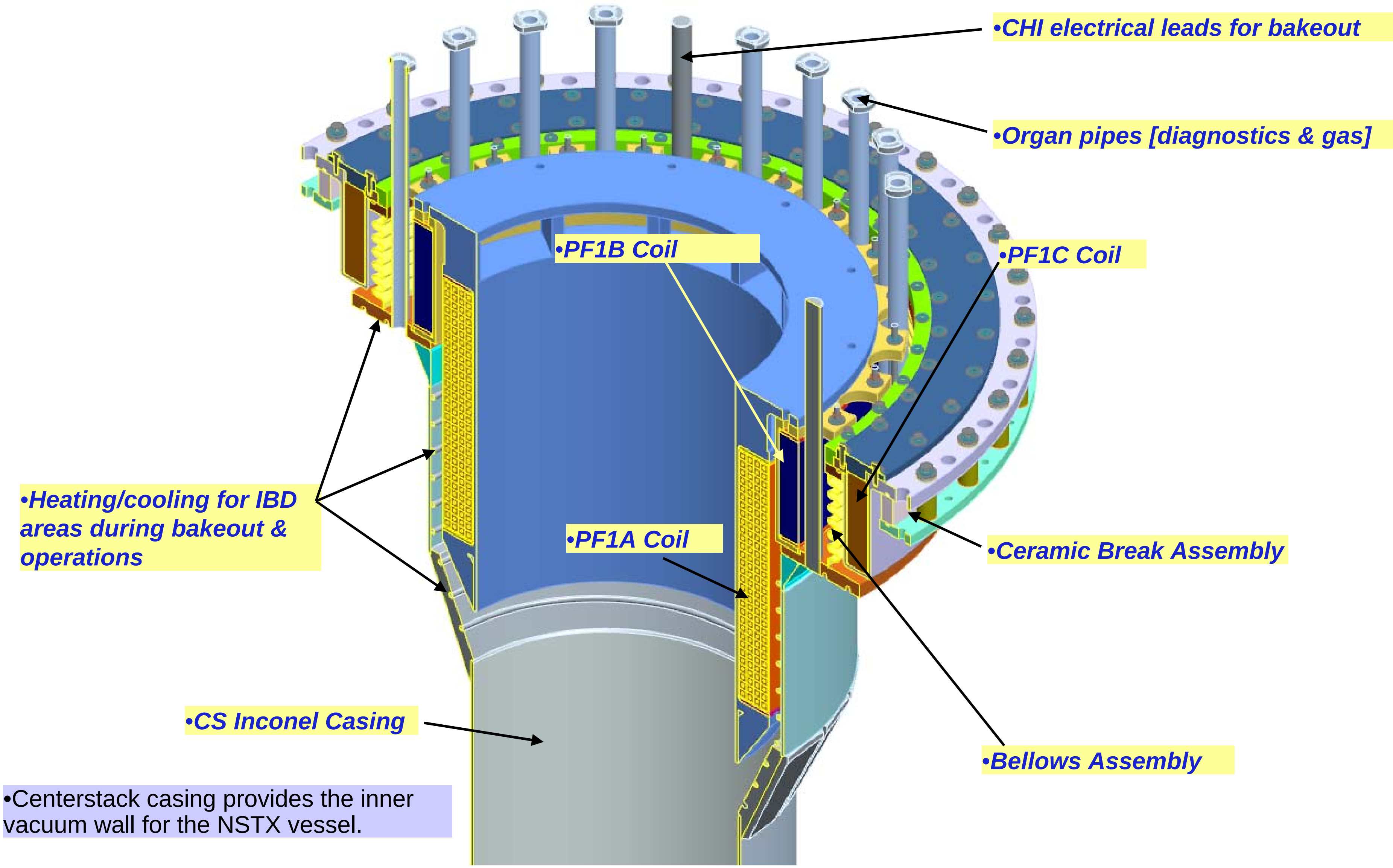


•PPPL would procure the copper conductor following the PDR

•Present plans are to build the OH/TF bundle in house in NCSX Test Cell

- TF would be mounted in turning fixture
- Teflon slip plane applied to OD of TF to allow vertical movement between OH/TF
- The OH solenoid is wound directly onto TF bundle
- 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 OH and TF bundle
- Apply outer ground plane
- Apply surface diagnostics
- Install "Micro-Therm" thermal blanket
- Ready for CS Assembly

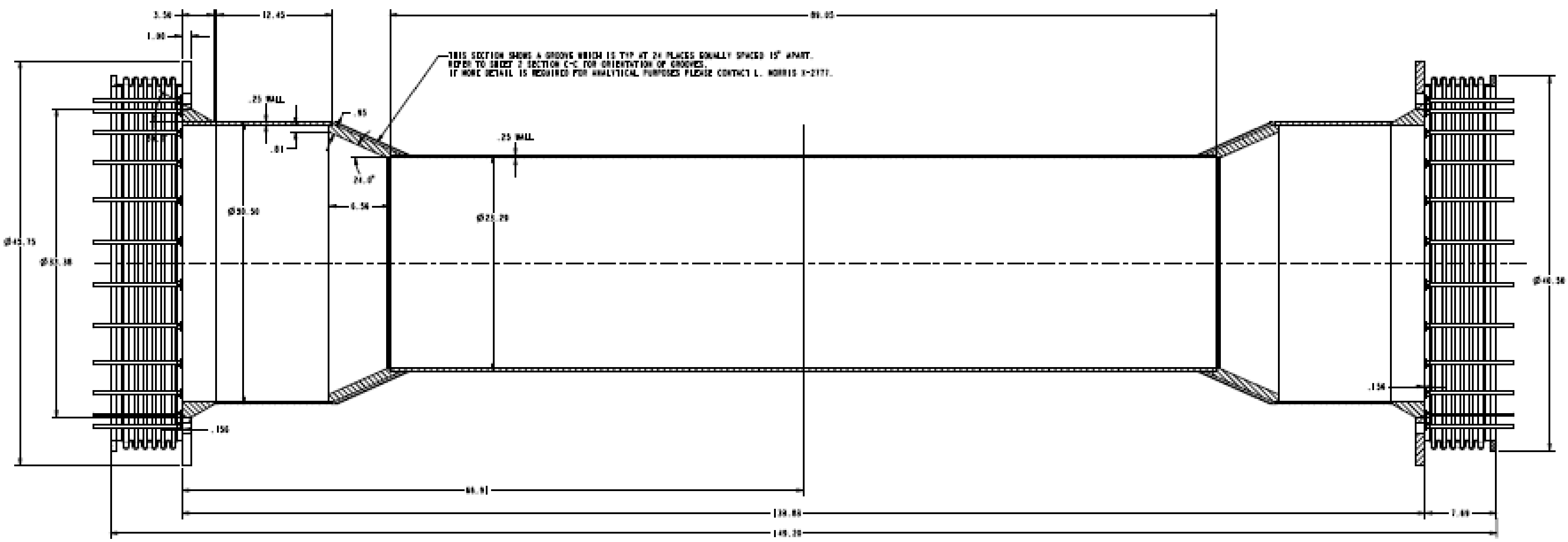
Center Stack Casing Components



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

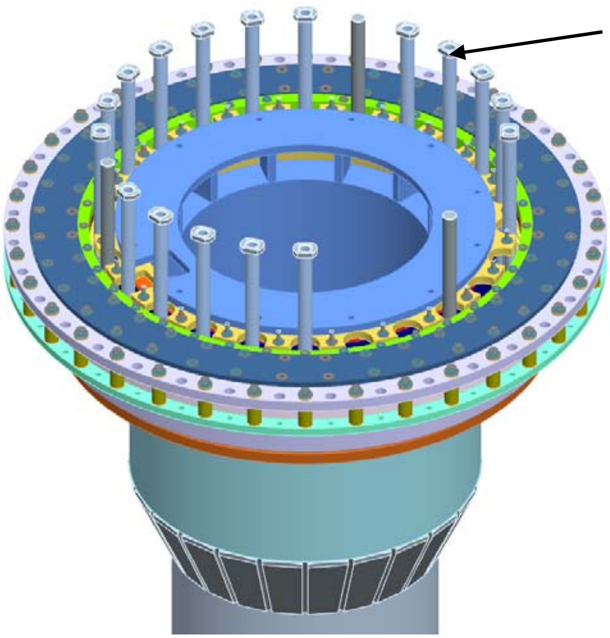
CS Case Design Features

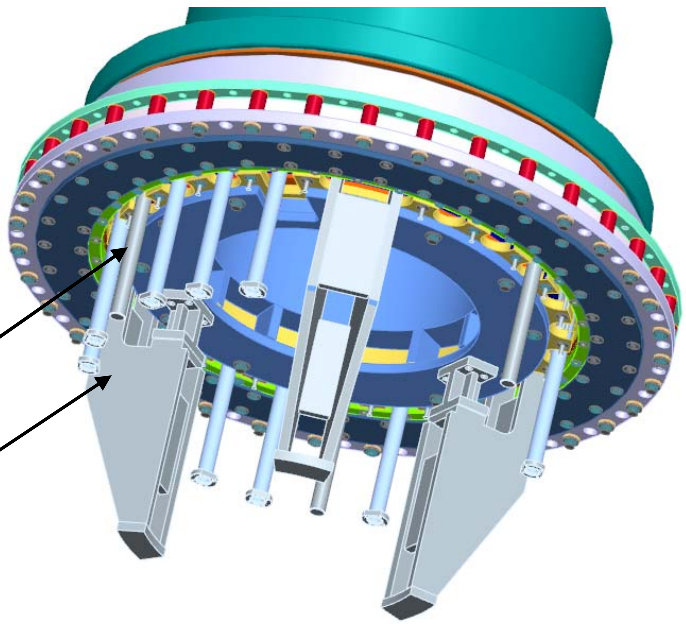
	Center section Dia. [In.]	Wall Thickness [in.]	Material	Length [in.]	Flange Diameter [in.]	Bellows	Organ Pipes
Original	13.162	0.157	Inconel 625	132.25	43.75	Inconel 625	Yes
Upgraded	23.29	0.25	Inconel 625	133.83	43.75	Inconel 625	Yes



SECTION A-A
(ORGAN PIPES NOT SHOWN)

Diagnostic Organ Pipes & CS Support Legs



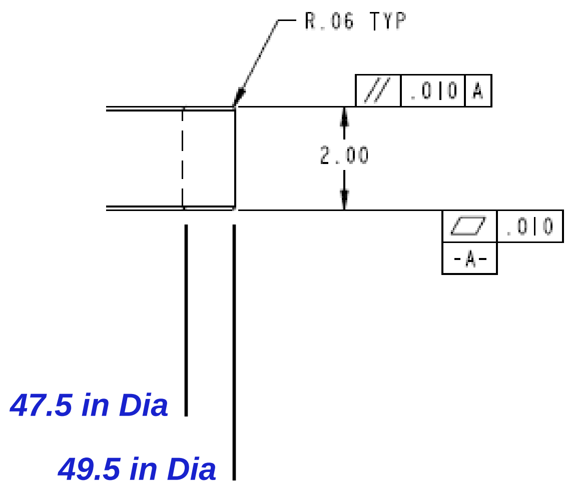


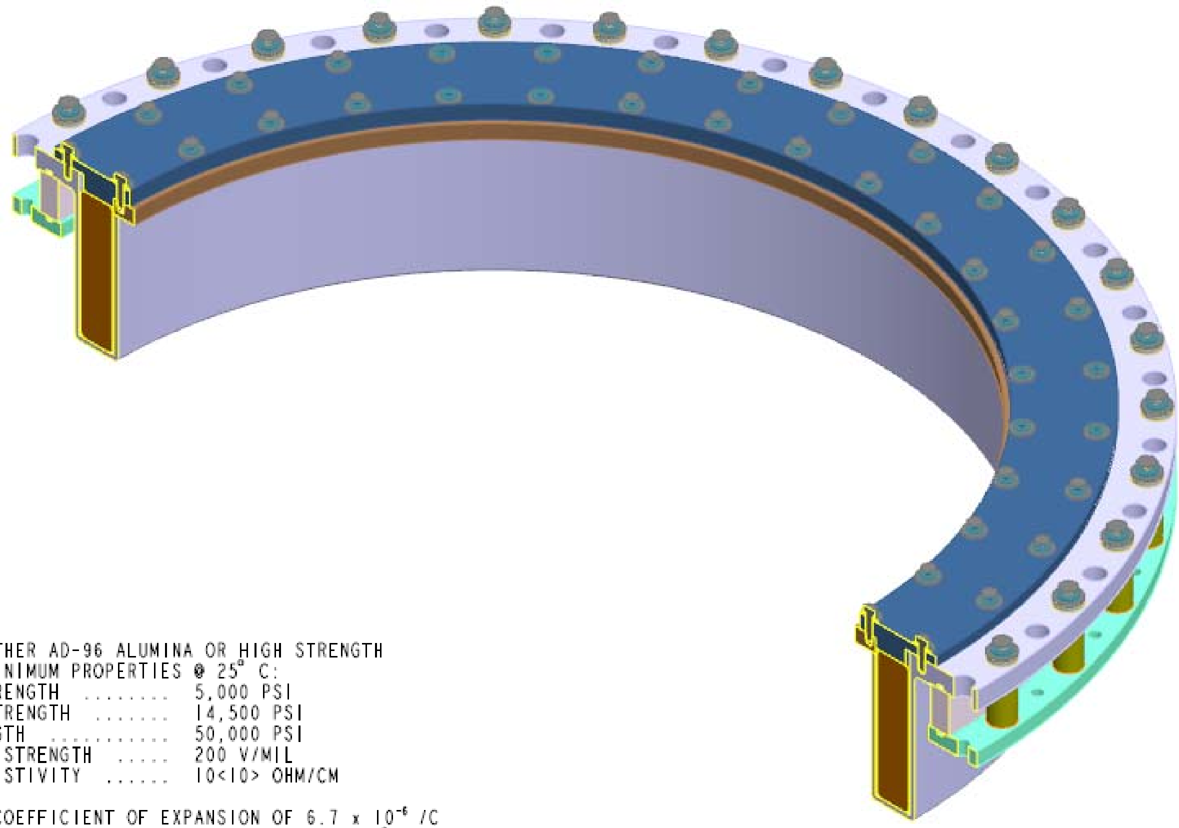
- •3-CHI leads [bakeout]
- •4- IBD cooling
- •2- Gas Injection
- •15- Diagnostics

- •3-CHI Leads [bakeout]
- •4- IBD cooling
- •6- CS supports
- •11- Diagnostics

- Organ pipes provide VV access for diagnostics, IBD cooling and gas injection
- 1.25 inch OD v 1.125 inch ID

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

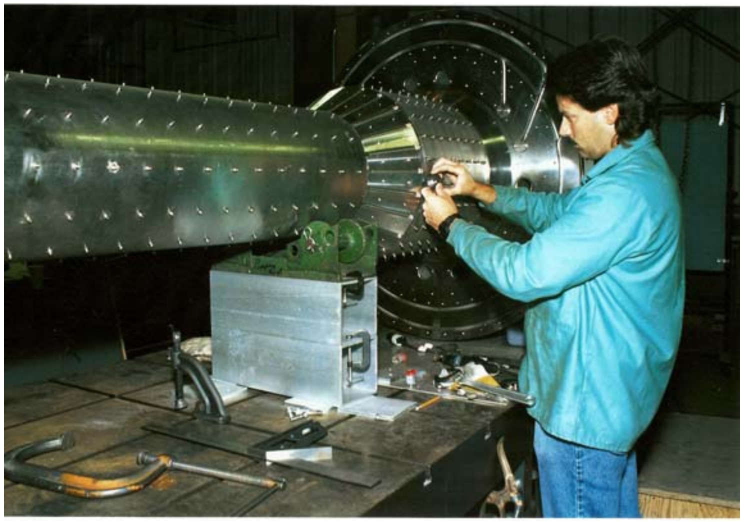
2. THE MATERIAL SHALL HAVE A MAXIMUM THERMAL COEFFICIENT OF EXPANSION OF 6.7×10^{-6} /C FROM 25° - 250° AND BE ABLE TO ABSORB A CUMULATIVE RADIATION DOSAGE OF 1×10^{8} RAD WITH NO DEGRADING EFFECT TO THE MATERIAL'S PROPERTIES.

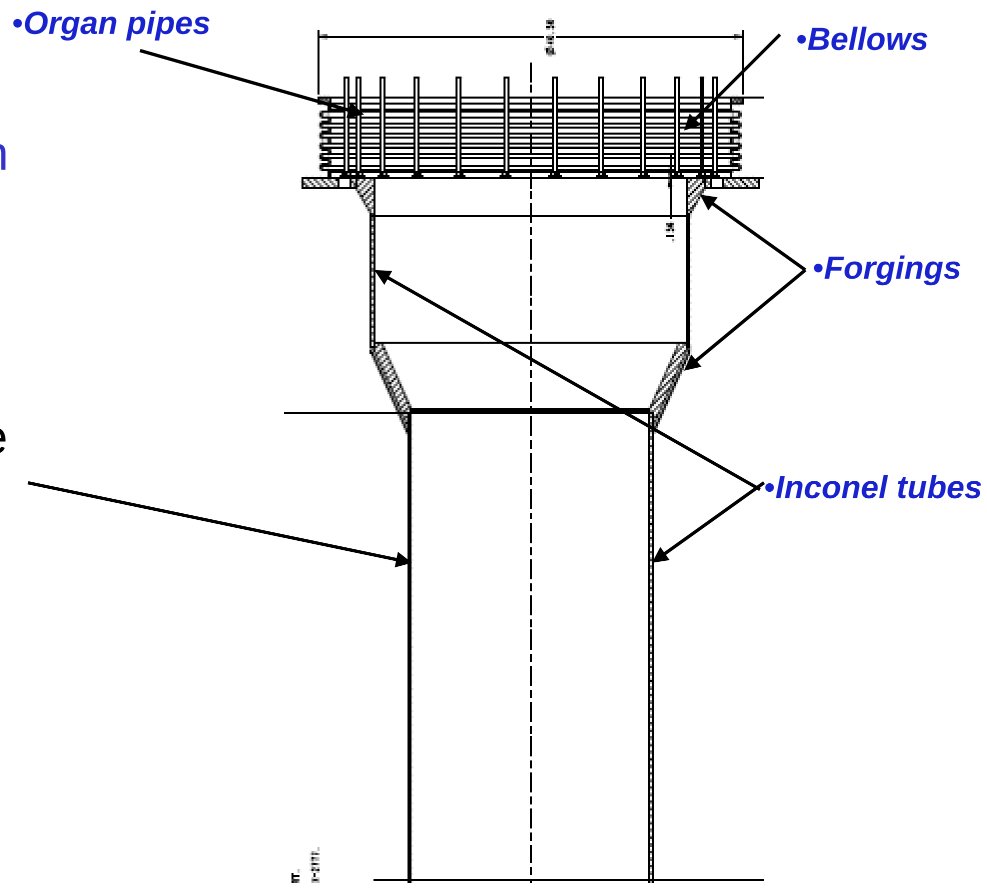
3. THE RING SHALL BE UNIFORM IN COLOR AND TEXTURE. CRACKS, BLISTERS, HOLES, POROUS AREAS, INCLUSIONS AND ADHERENT FOREIGN PARTICLES SHALL NOT BE PERMITTED.

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

CS Case Manufacturing Plan

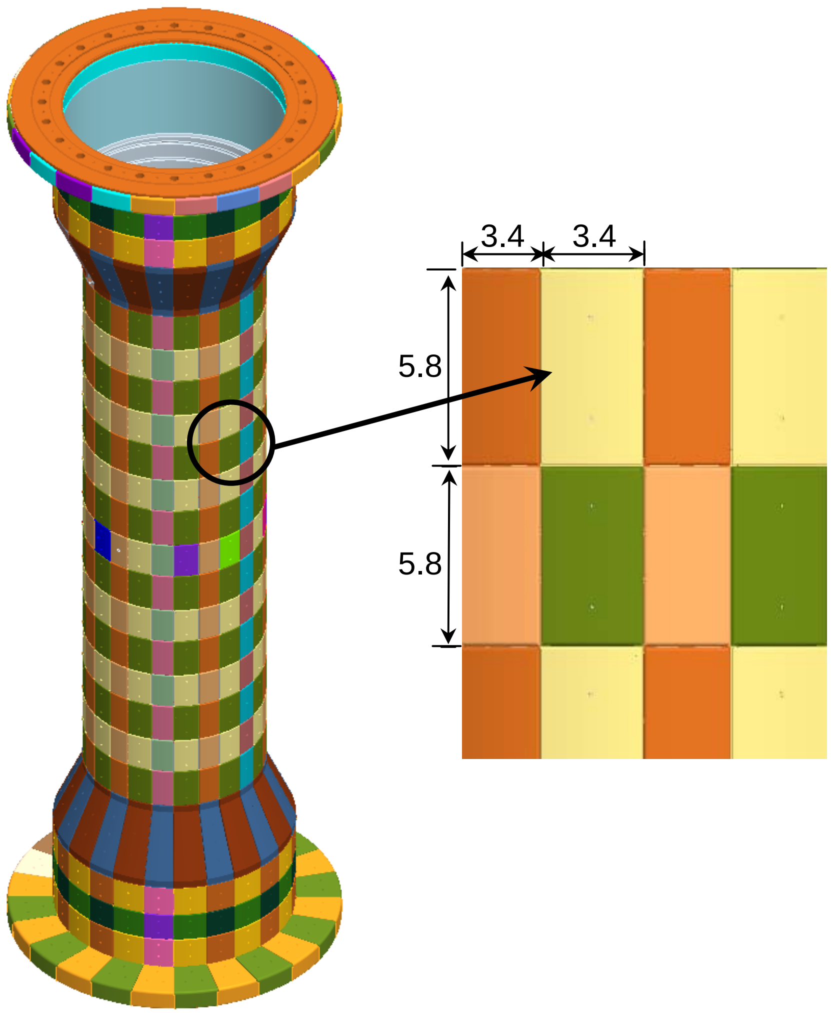
- Inconel components will be procured
  - Inconel tubes, bellows, organ pipes and forgings
- All welding will be performed in house
- Inconel studs will be added to case for mounting PFC hardware





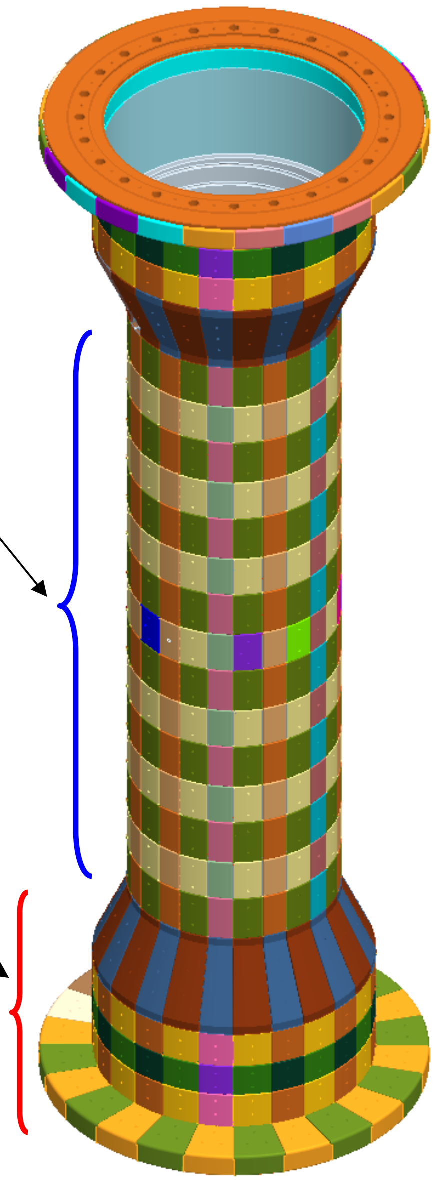
Centerstack Plasma Facing Component Upgrades

- Surfaces of Centerstack will be protected from the plasma with a layer of CFC tiles
- Larger CS Diameter but fewer, larger tiles
  - ~900 => ~600 tiles
- Diagnostics & gas injection incorporated into tile designs
  - Essentially same scheme as original, increased diagnostics where useful
  - New gas injection scheme
- Materials
  - Moving toward all CFC for better thermal and mechanical properties
- Fastening Scheme
  - Simplifying scheme where possible.
  - Rails & T-bars
  - Finding solutions to reoccurring issues such as stripped Allen keys, insufficient tolerances, plus ease-of-installation and removal.



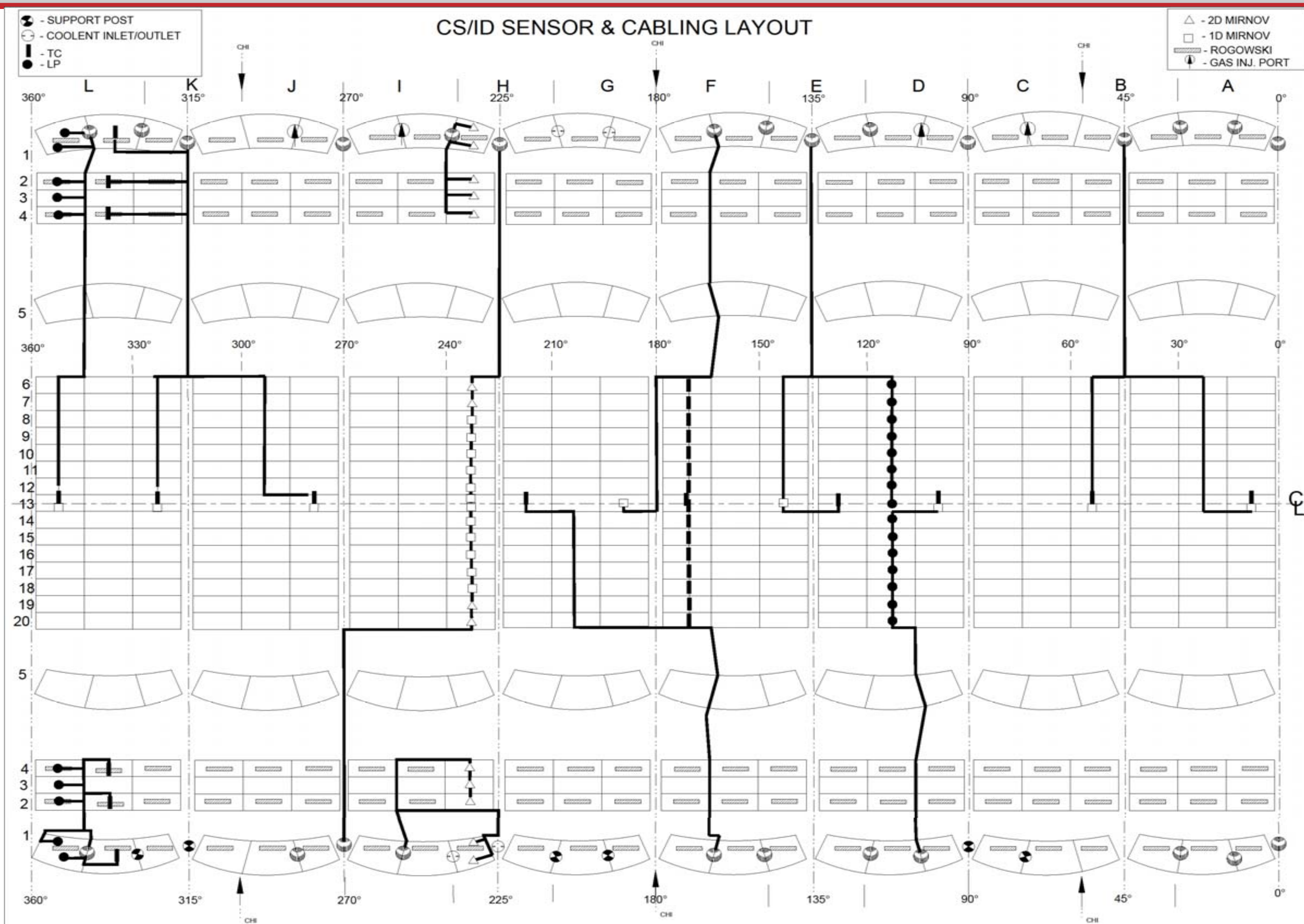
Tile Material: Carbon Fiber Composite

- Two zones to cover:
  - Vertical CS
    - Use low-k CFC
      - Limit heat load to CS casing
      - Tiles 0.75 in thick
  - Inboard Diverter
    - Use high-k CFC
      - Conduct heat to active cooling system
      - Vertical tiles- 1" thick tiles
      - Horizontal tiles- 2" thick

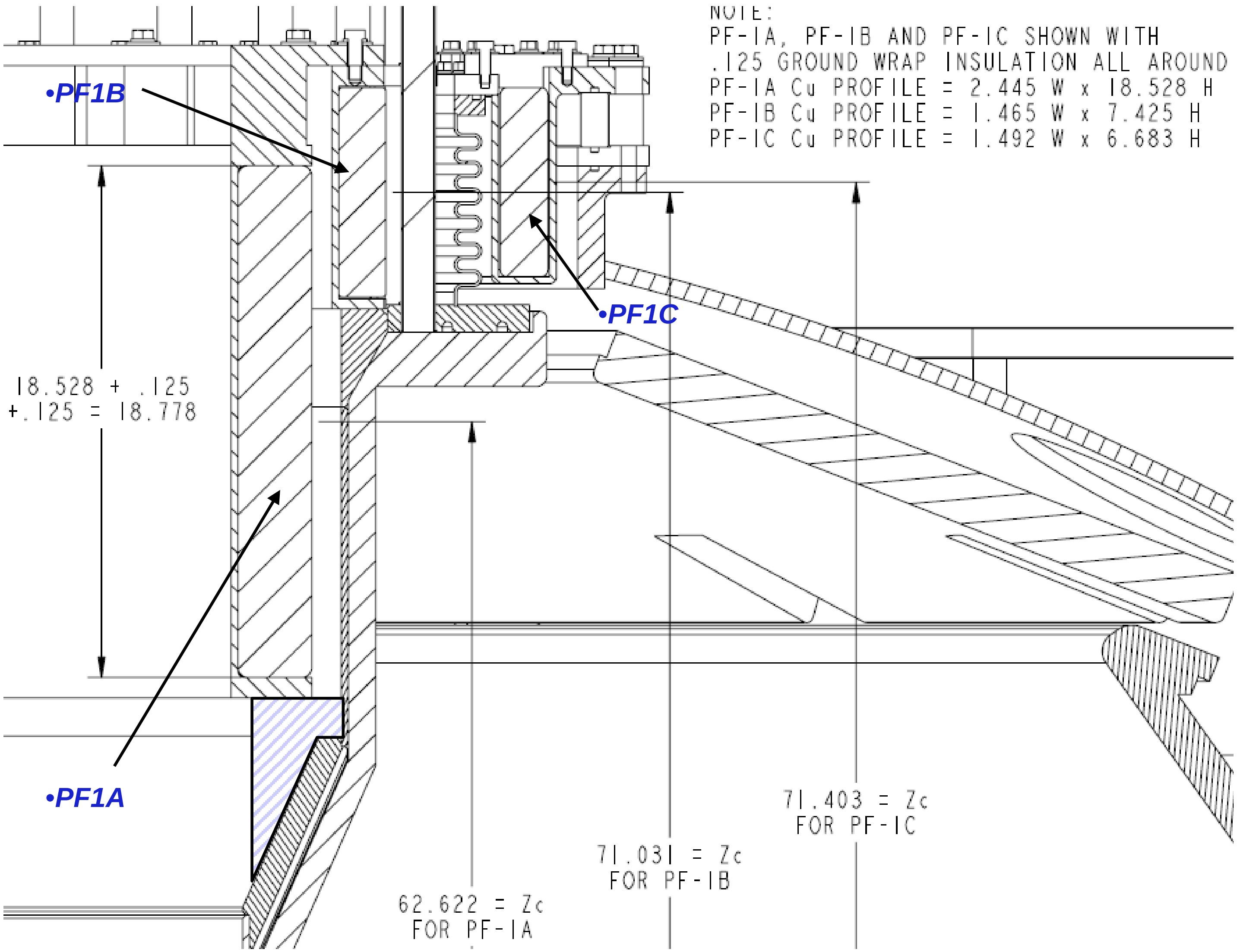


- Why Carbon Fiber Composite?
  - Wider range of thermal properties
    - Thermal shock
    - Oxidation thresholds.
  - Better mechanical properties for attachment
  - Exact specifications pending thermal analyses.
    - Analysis results will yield conclusive operating temperatures
      - These will define:
        - » Type of CFC
        - » Tile sizes
        - » Tolerances

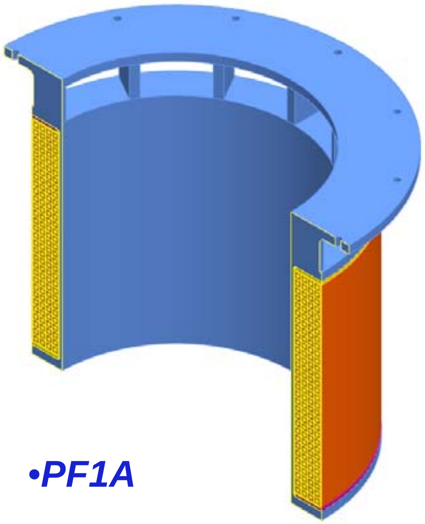
Diagnostics: New Layout

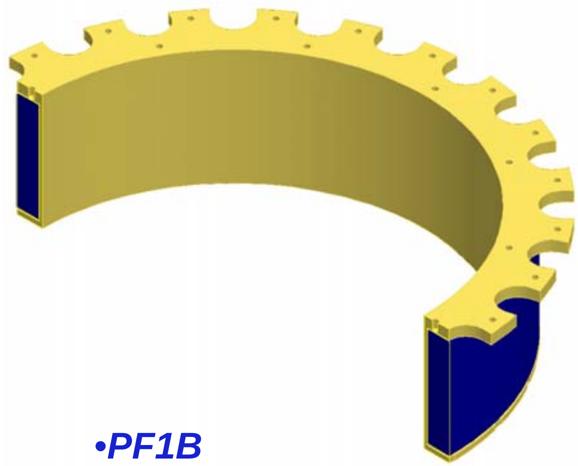


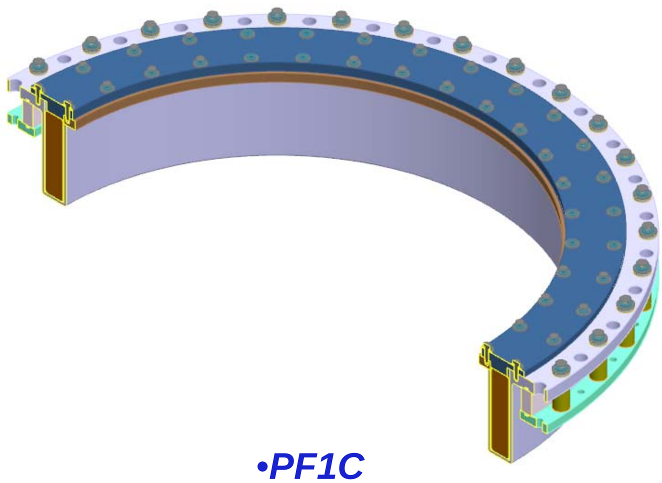
Inner Poloidal Field Coils



Inner Poloidal Field Coils







		PF1A	PF1B	PF1C
Voltage	Volts	1013	1013	1013
Current	Amps	1464	270	372.6
T/T Voltage	Volts	8.4	5.6	6.3
Number of Turns	n	120	180	162
ESW	sec	5.5	5.5	5.5
Conductor Width	In.	0.591	0.220	0.220
Conductor Height	In.	0.591	0.220	0.220
Cooling Hole Diameter	In.	0.217	0.098	0.098
Turn insulation thickness	In.	0.018	0.018	0.018
Ground insulation thickness	In.	0.108	0.108	0.108

Additional Planned R&D Activities

- Layer to layer TIG-Braze joint tests [OH]
  - Preliminary tests demonstrate good joint strength
- In-line braze joint tests [OH]
- Additional Friction Stir Welding [FSW] tests- OFHC to CU-Cr-Zr [TF leads]
- TF Joint tests
  - Build test stand
  - Mechanical & possibly full current tests