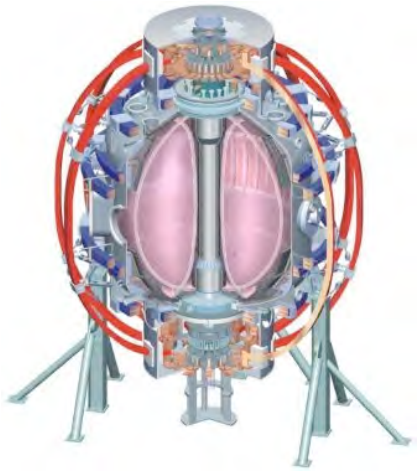
Center Stack/Magnet Systems

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

James H. Chrzanowski
and
NSTX Design Team

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

NSTX Center Stack Upgrade Peer Review
LSB, B318
August 13, 2009

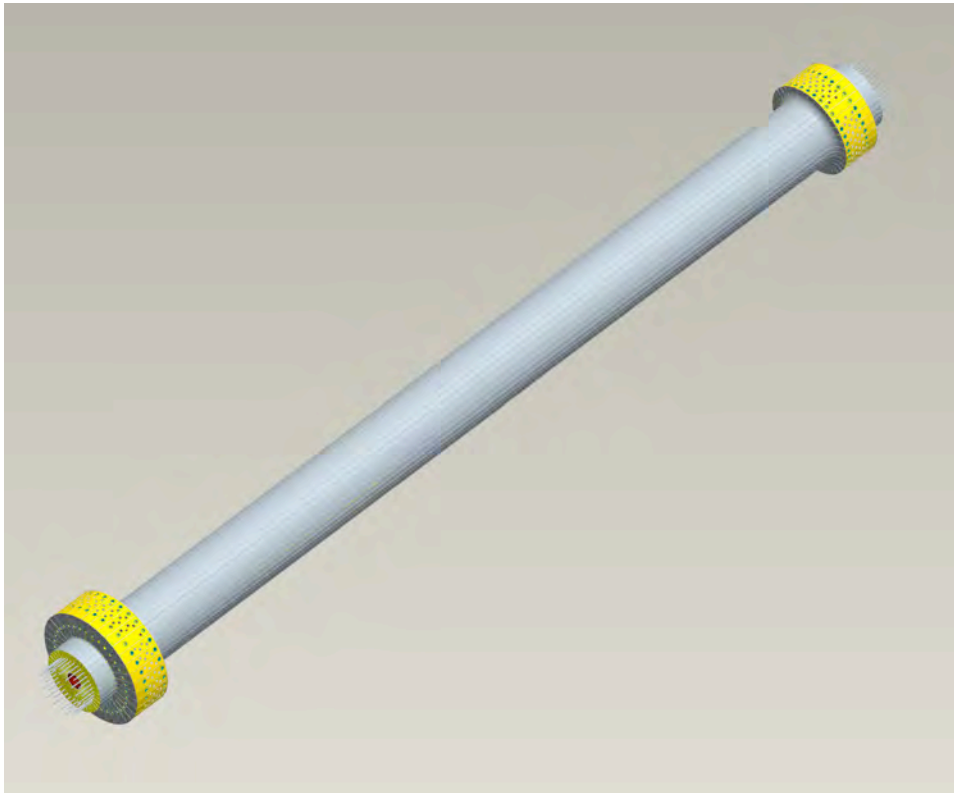


Outline of Presentation

- **TF Magnets Conceptual Design [9:20AM]**
  - Design features
  - Manufacturing Plan
  - Outer TF coil leak mitigation plan
- **Design of OH Solenoid [11:25 AM]**
  - Design features
  - Manufacturing Plan
- **Design of Inner PF Magnets, Casing, Ceramic break & Bellows 1:05 PM]**
  - Design features
  - Manufacturing Plan

Inner TF Design Features

- Conductors- 36 straight copper legs
- Water cooled conductors
- Friction Stir Welded lead extensions
- Larger joint surface area
- Weight approximately 11,000 pounds
- Insulation scheme: S-2 glass tape w/ CTD101K VPI epoxy system

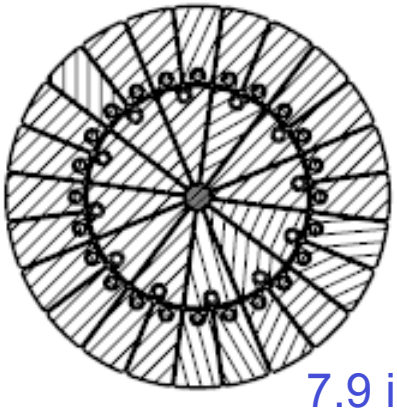


TF Design Parameters

	Base Design	Upgrade Design
Operating Voltage	1013 volts	1013 volts
Number of turns	36	36
Number of layers	2	1
Operating current	71,168 amps	129,778 amps
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.

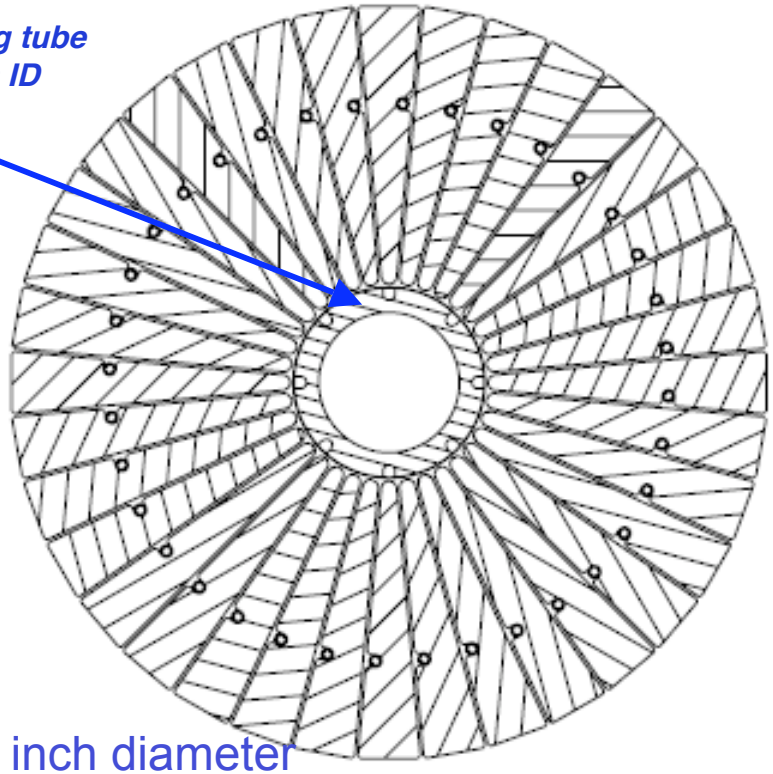
Inner TF Cross-Section

- *Central G-10 tube provides centering tube during assembly and epoxy feeds on ID*



7.9 inch diameter

CURRENT DESIGN

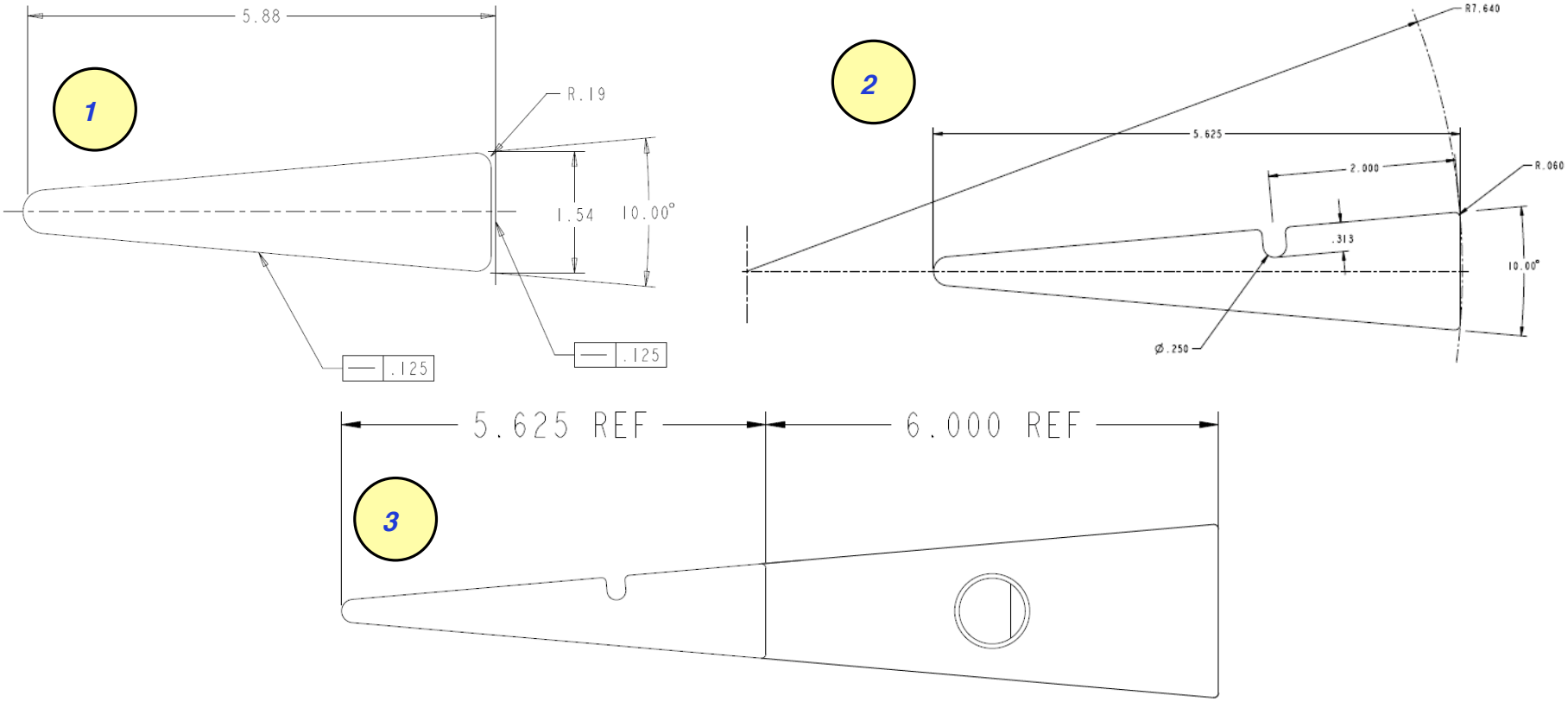


15.7 inch diameter

PROPOSED UPGRADE DESIGN

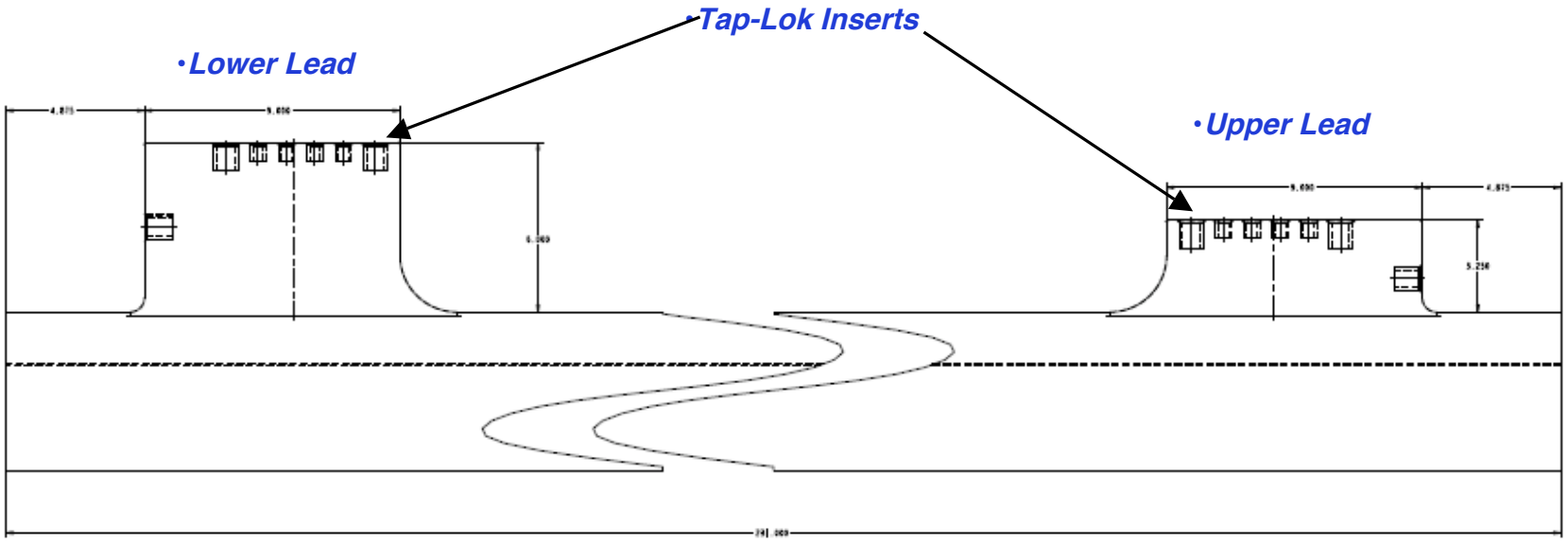
Inner TF Conductor

1. Inner bundle conductors would be procured as copper extrusions- 36 straight 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
3. Attach coil leads to using Friction stir welding process

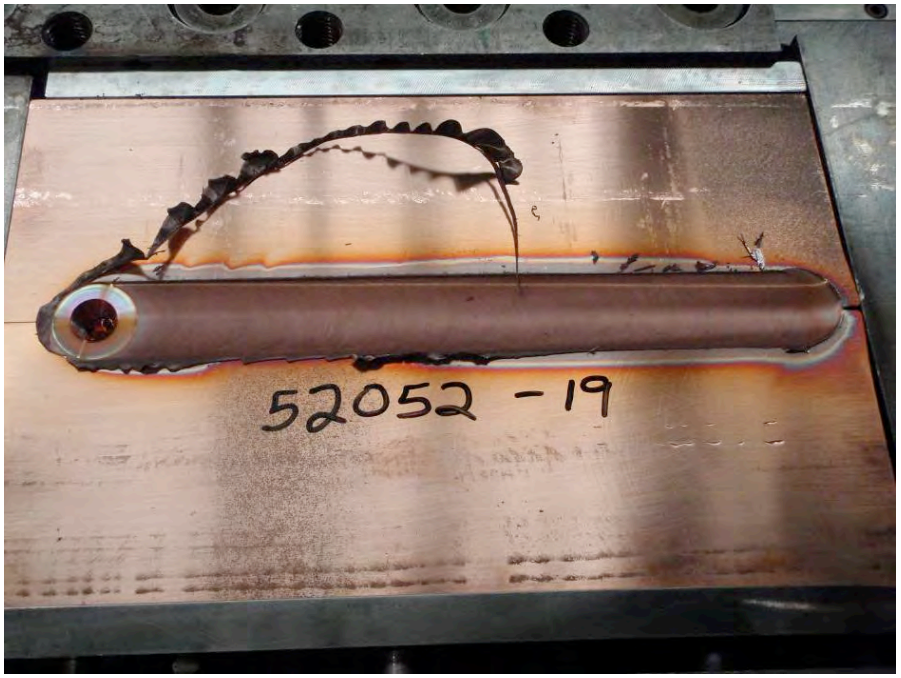


Conductor Lead Extensions

- Lead extensions on the TF bundle will be added via Friction Stir Welding
- The upper lead is shorter the lower to allow for installation of the PF1A coil and the Center stack casing
- Lead extensions may be fabricated with CDA 107 or higher strength copper [CuCrZr]



Friction Stir Welding



What is Friction Stir Welding? [FSW]

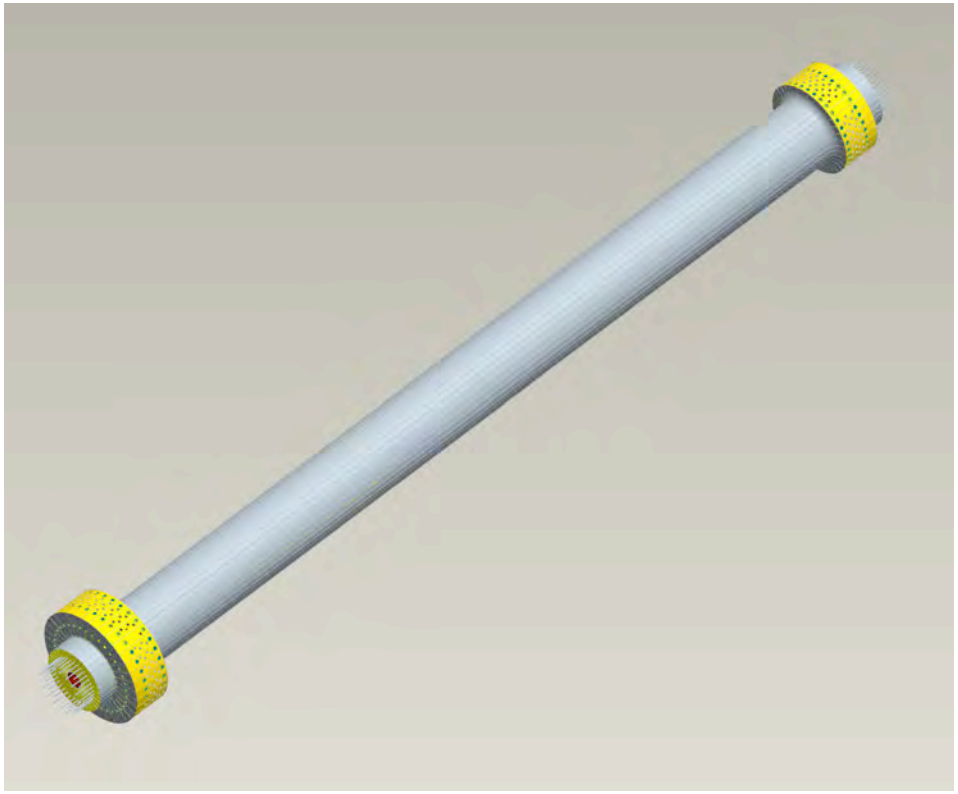
- FSW is accomplished at temperatures below melting point of material/ no filler rod/no shielding gas.
- Metal working process using specially shaped rotating pin of hard alloy traversing along joint line.
- Rotation of pin and shoulder plasticize the material, move it across joint boundary and allow to cool and consolidate.
- Eliminates problems such as porosity, solidification cracking and shrinkage.
- Tests are presently being performed by Edison Welding Institute

Selected Resin System- All Coils

- **Resin System selected- CTD-101K** ***(Well characterized for ITER & NCSX)***
  - Product of *Composite Technology Dev. Inc.*
  - 3- Component epoxy system
  - Excellent performance at cryogenic temperatures with a 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

TF Bundle Manufacturing Plan

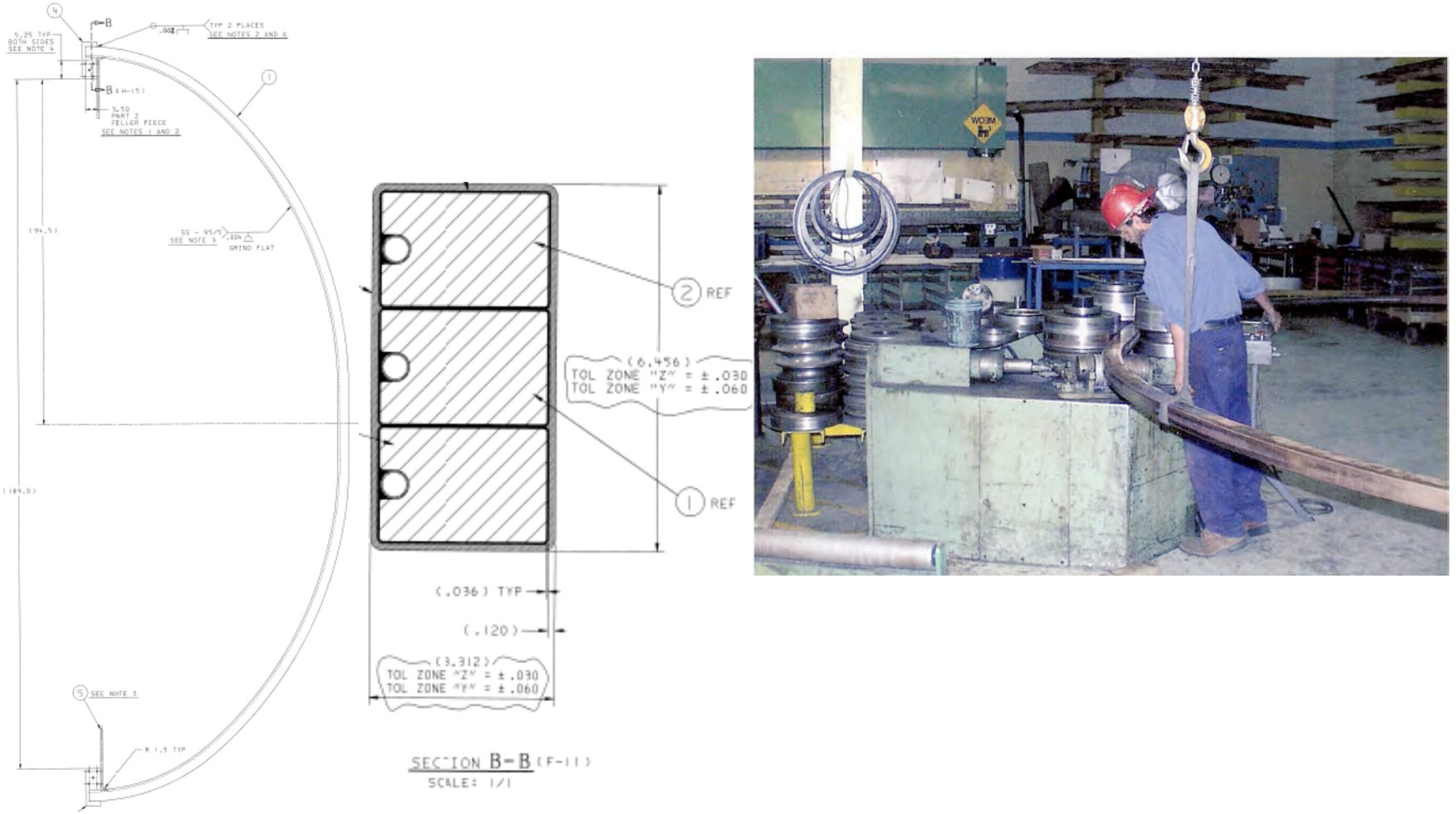
- PPPL will procure TF conductor extrusions with machining and lead extensions
- Outside vendor will fabricate TF bundle
- Vendor: solder cooling tubes
- Apply T/T insulation [S2 glass]
- Assemble conductors together
- Apply GW insulation [S2 glass]
- VPI'd coil assembly
- Phase 2- Ready for OH solenoid [To be discussed later]



Outer TF Coil Leak

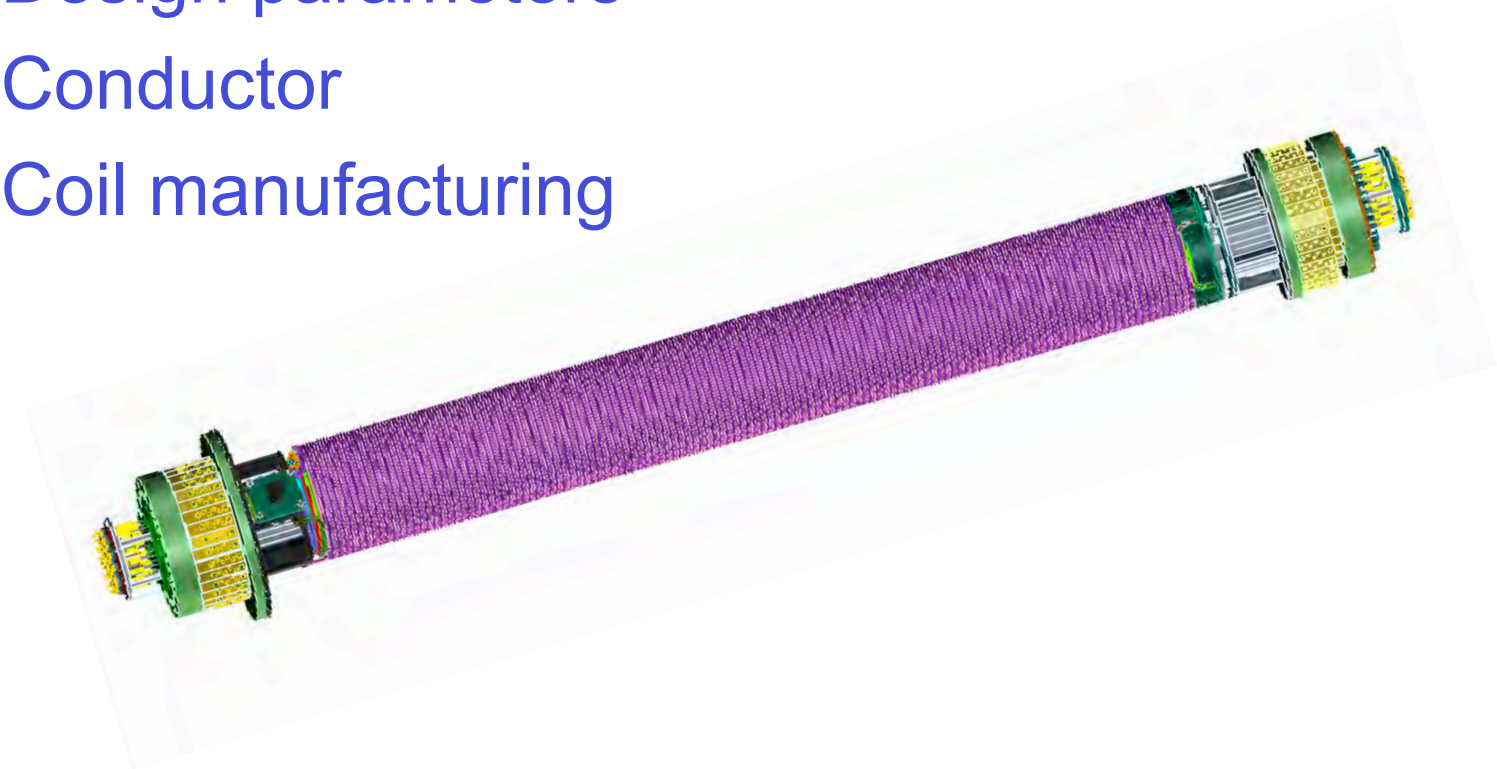
- The Outer TF Coil Assembly number 7 has a known internal cooling path leak that prohibits active cooling of the coil.
- In line with the proposed Centerstack upgrades, it will be necessary to restore active cooling to the Outer TF coils [OTF].
- Initial efforts to obtain a vendor [Ace Duraflo] to seal the leak internally have failed.
- **PROPOSAL:**
  - The plan would be to replace the existing OTF#7 assembly with a newly fabricated OTF assembly.
  - Copper bar conductors would be procured, machined and rolled
  - Tooling from original OTF are stored in Receiving 3 warehouse
  - The removed OTF7 would be repaired and stored as spare for future needs
  - Fabrication of new OTF would occur over the next 1.5 years. [PPPL or outside vendor fabrication]
  - The replacement would occur during the upgrade activities outage that is presently planned for FY12.

Outer TF Coil Fabrication



OH Solenoid

- OH Solenoid
  - Design parameters
  - Conductor
  - Coil manufacturing



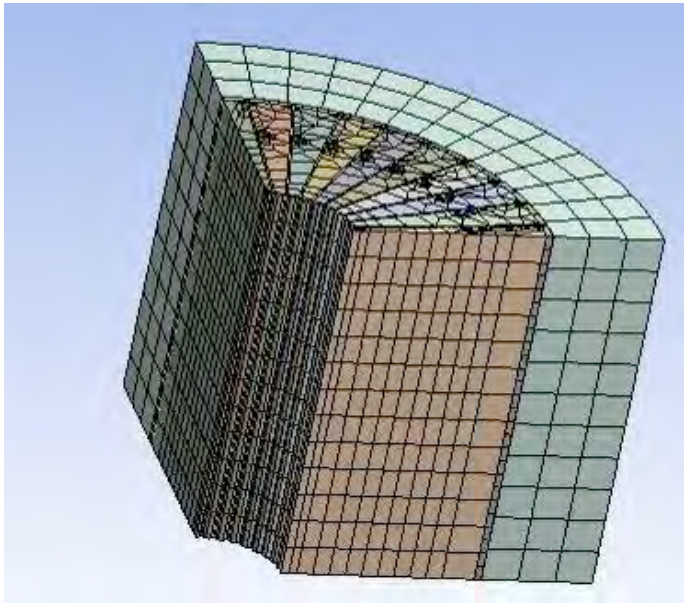
OH Solenoid Design Parameters

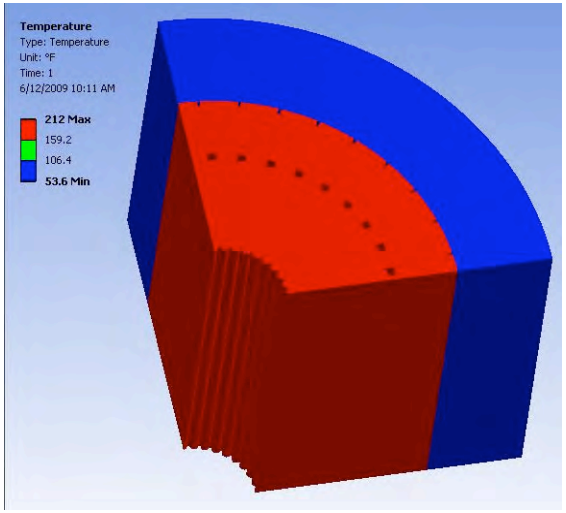
	Base Design	Upgrade Design
Operating Voltage	6077 volts	8100 volts
Number of turns	964	1148
Number of layers	4	4
Cooling hole diameter	0.188 in	0.175 in
Operating current	24,000 amps	24,000 amps
Groundwall insulation	0.054 in.	0.090 in.
Turn insulation	0.0268 in	0.0480 in
Outside diameter	12.304 in	22.10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

OH Solenoid Design Features

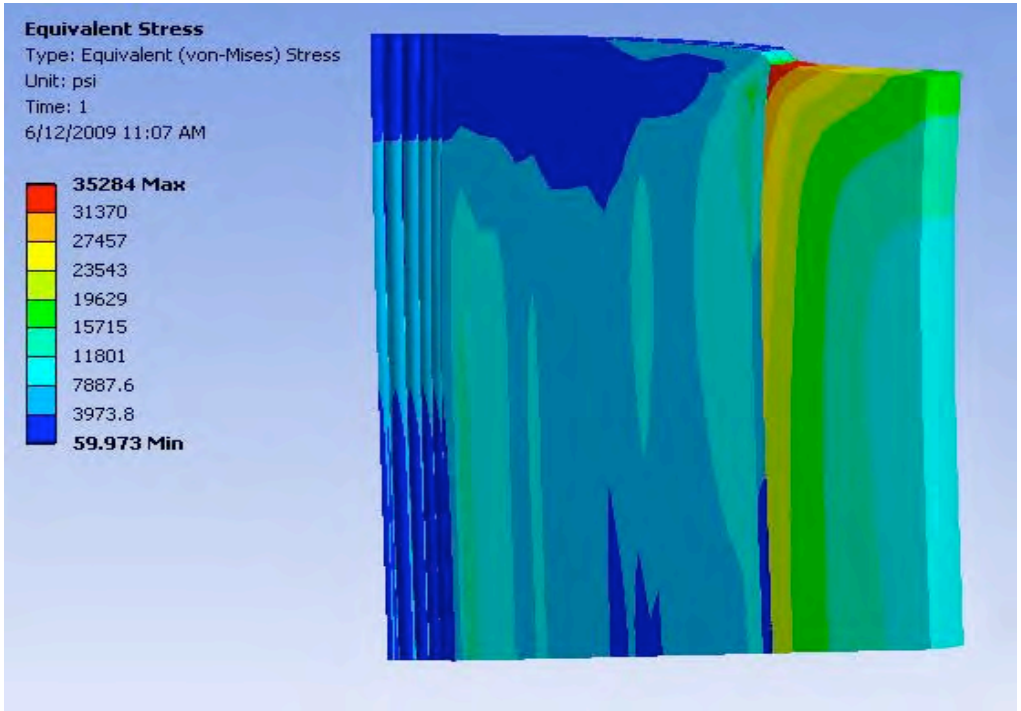
- Coil leads relocated to bottom of machine
- Co-axial coil/bus leads
- In line braze will be required
- Layer to Layer TIG-braze joints will be used
- Improved cooling fitting assemblies
- Coil will be wound directly onto the Inner TF bundle
- No tension tube
- Trapped coil- Cannot be removed as separate component
- Slip plane between TF and OH coil
- OH will have inner and outer electrical ground plane

•Hot TF Cold OH Produces Acceptable Stresses



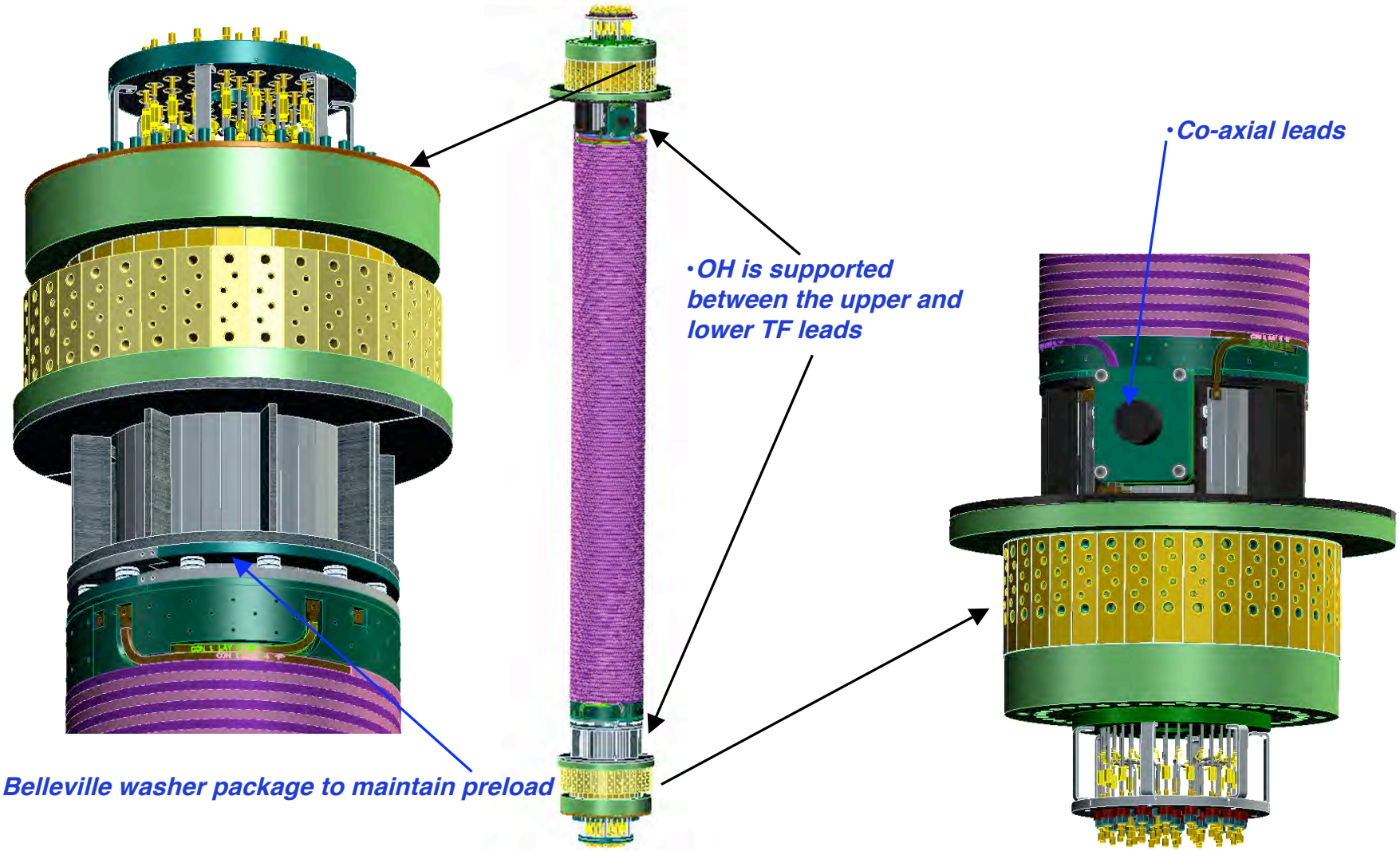


It Allows Winding the OH on the TF



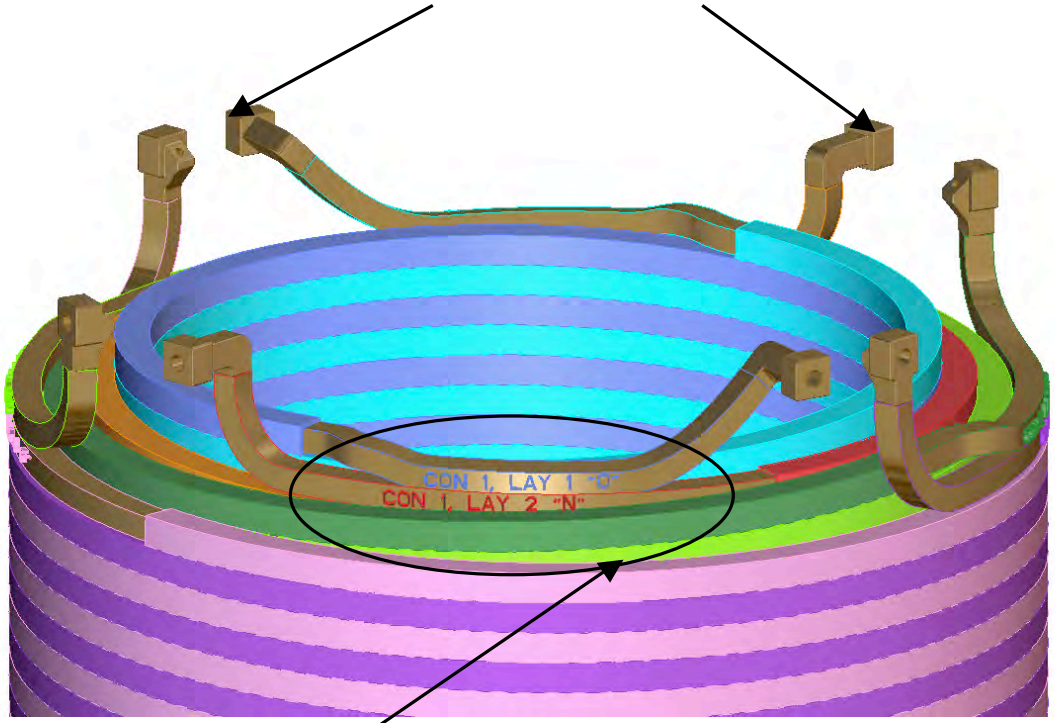
22 ksi is 152 MPa, or 219 MPa with Correction for .69 OH Packing Fraction

OH Solenoid End Details



Layer to Layer Joints

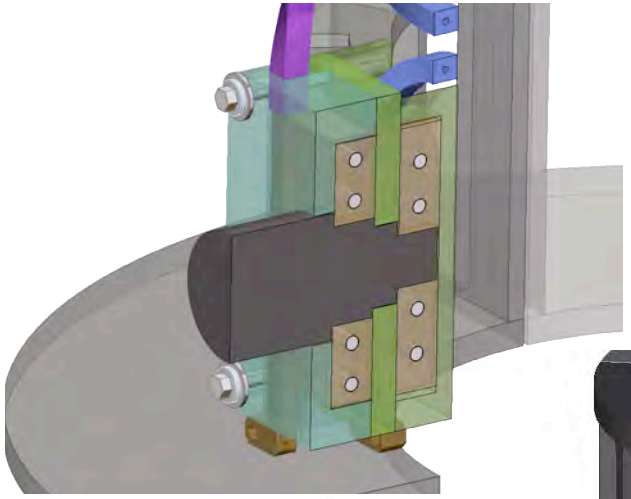
- *OH Cooling fittings*

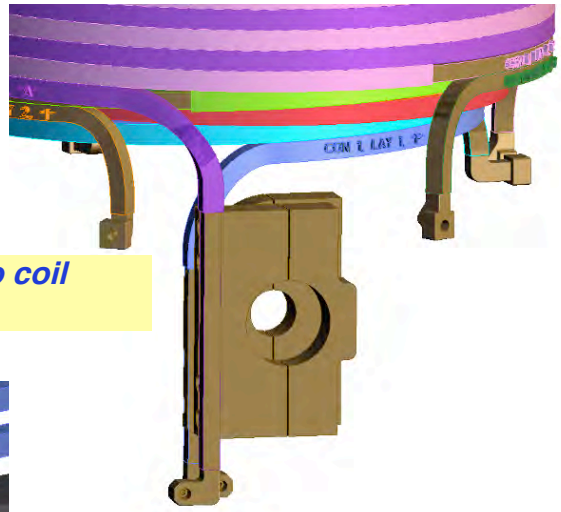


- *Layer to layer TIG-Braze joint [Typical]*
- *TIG-Brazing method minimizes annealing of conductors*
- *Provides adequate joint strength*
- *Proven method and procedures used in previous OH solenoids*
- *Present design being tested*

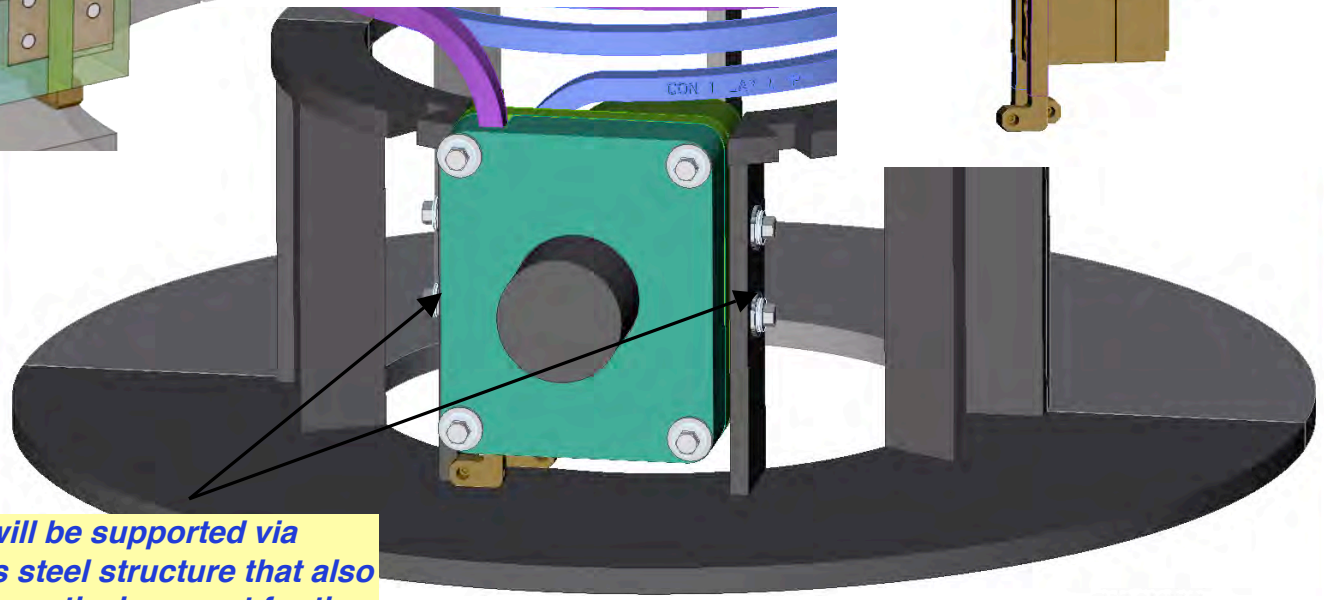
- 1. Pre-tin the overlapping joint surfaces using the 96%/4 % tin-silver soft-solder. The conductors shall not be heated above 260 °C [500°F].
- 2. Each end of the conductors shall be TIG brazed, by a qualified operator, using Sil-Fos braze material with helium shield gas. (12-18 seconds at 135 amps 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.
- 6. Carefully clean the joint with hot water, assuring that no water gets into the surrounding insulation, and remove excess solder using a file and hand sanding.
- 7. A visual inspection of the finished joint shall be made to ascertain complete flow of solder/braze material into the joint area and joint quality.

Co-axial bus leads



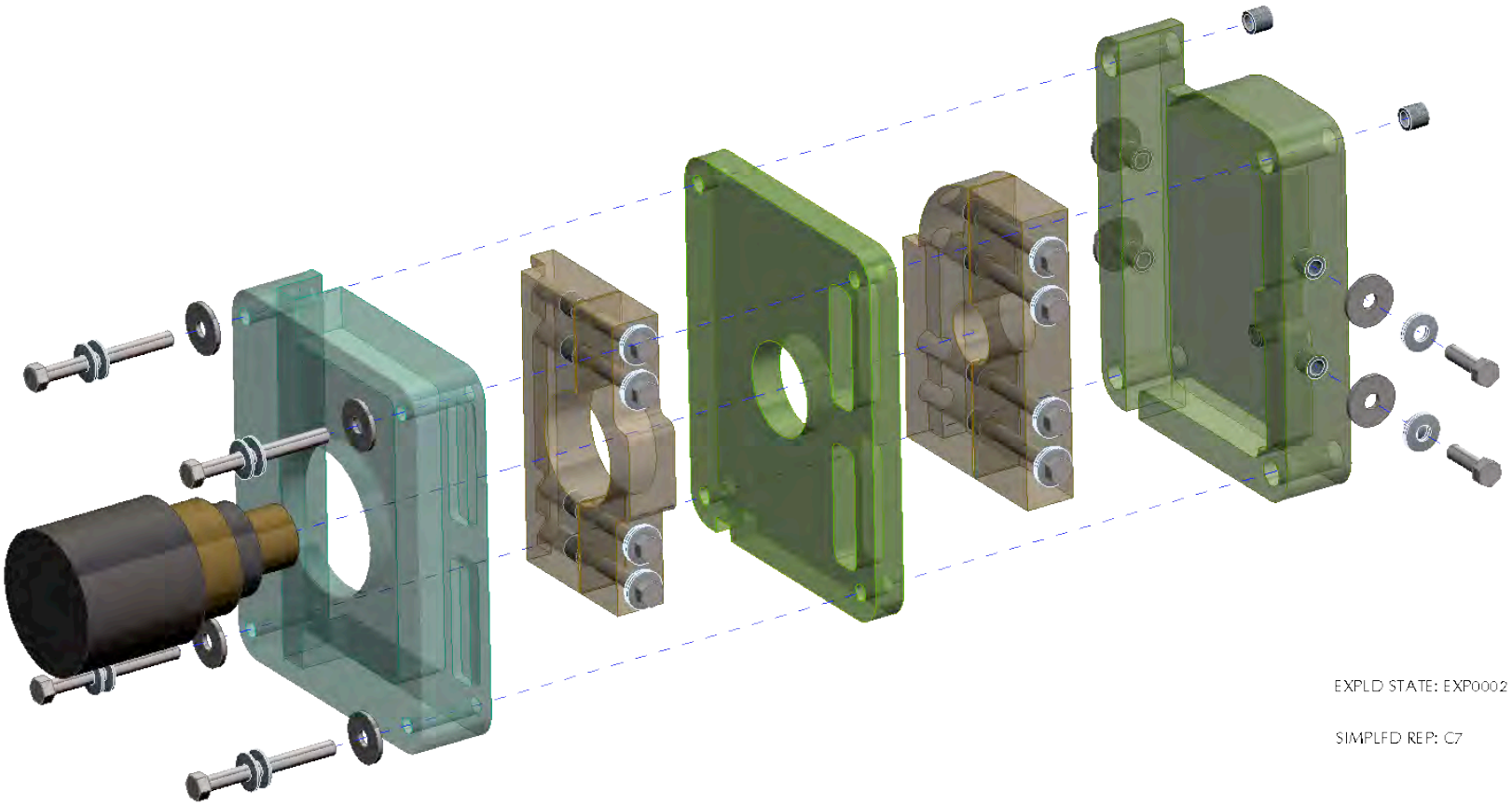


- *Leads will be brazed to coil conductors*



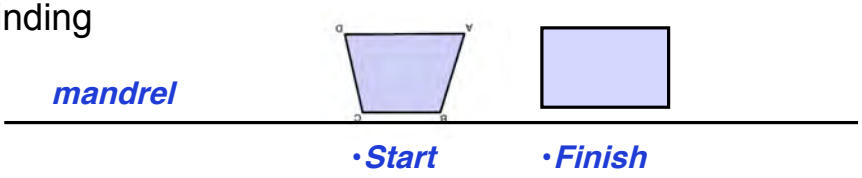
- *Leads will be supported via stainless steel structure that also provides vertical support for the OH solenoid*

Alignment of Coil Leads



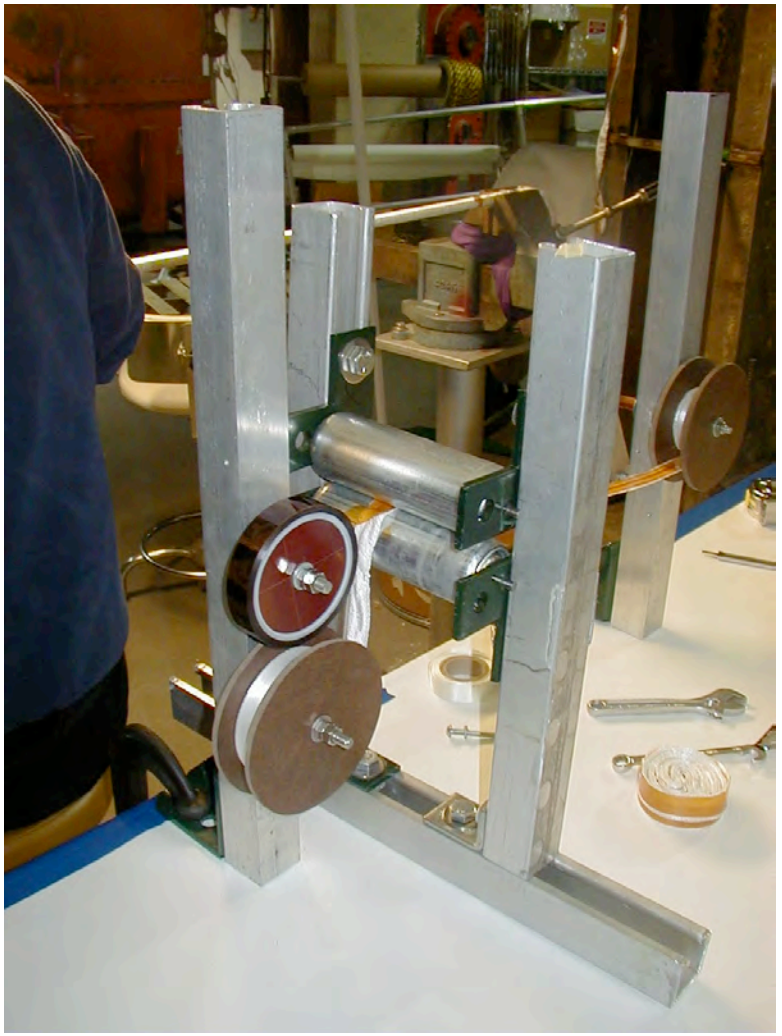
OH Conductor

- 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 12,000 feet
- Material: C10700 [oxygen free w/silver]
- Final conductor size: 0.649 in. x 0.4859 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



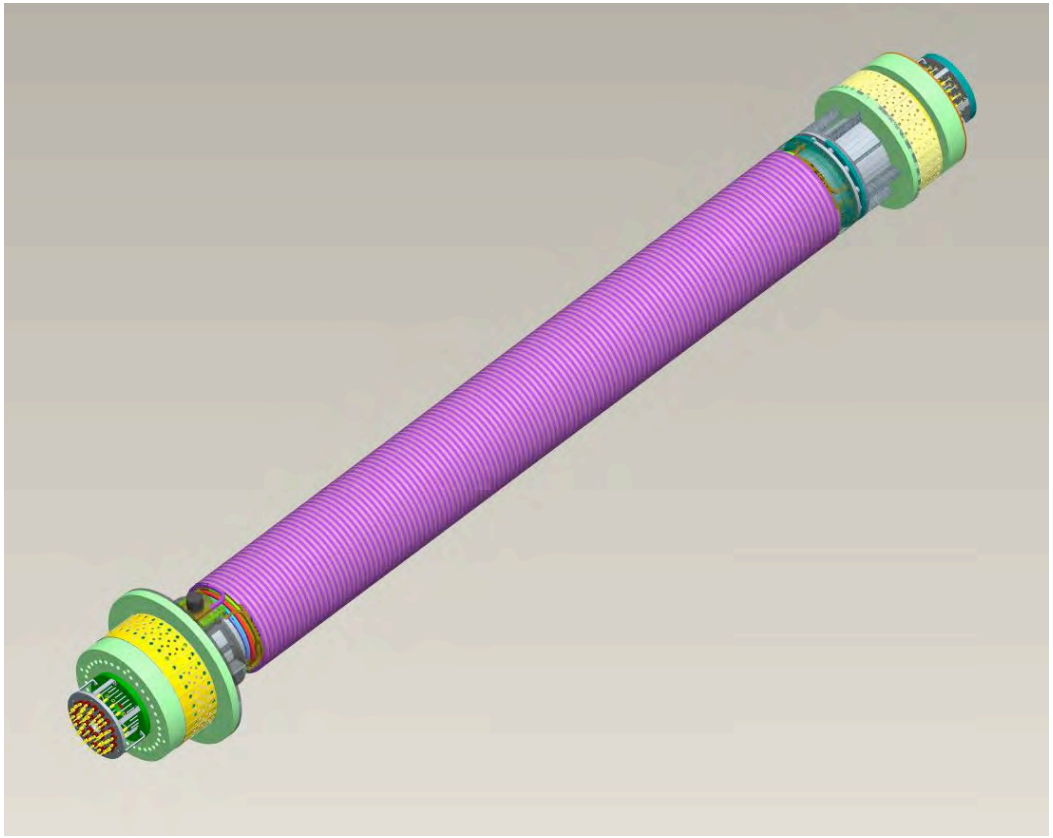
OH Insulation Scheme

- Turn to turn insulation: (3) half-lapped layers co-wound Kapton and S-2 glass
- Ground wall insulation: S-2 glass [0.090 inch thick]
- VPI Epoxy system: CTD-101K
  [see description on slide 9]

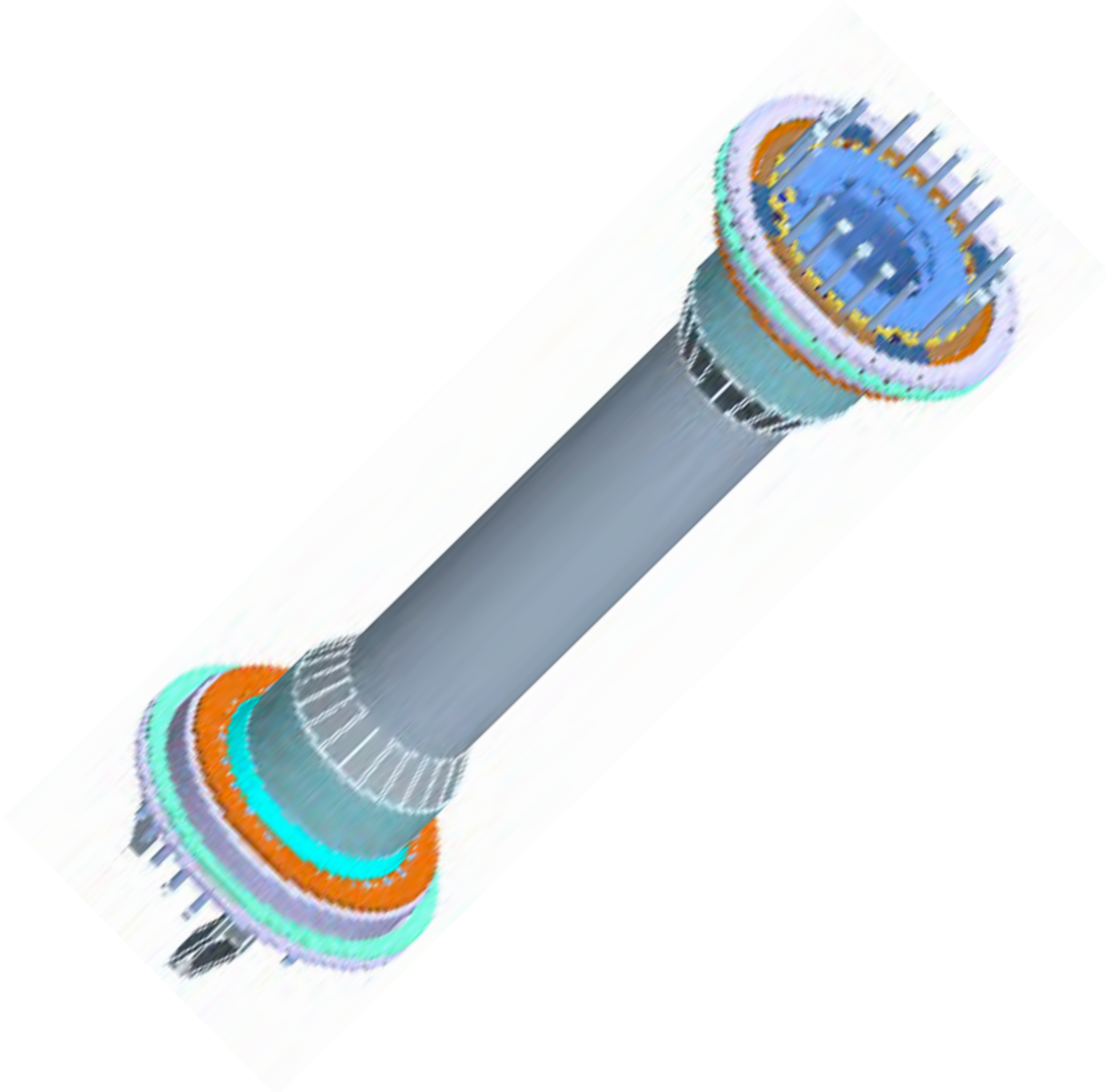


OH Manufacturing Plan

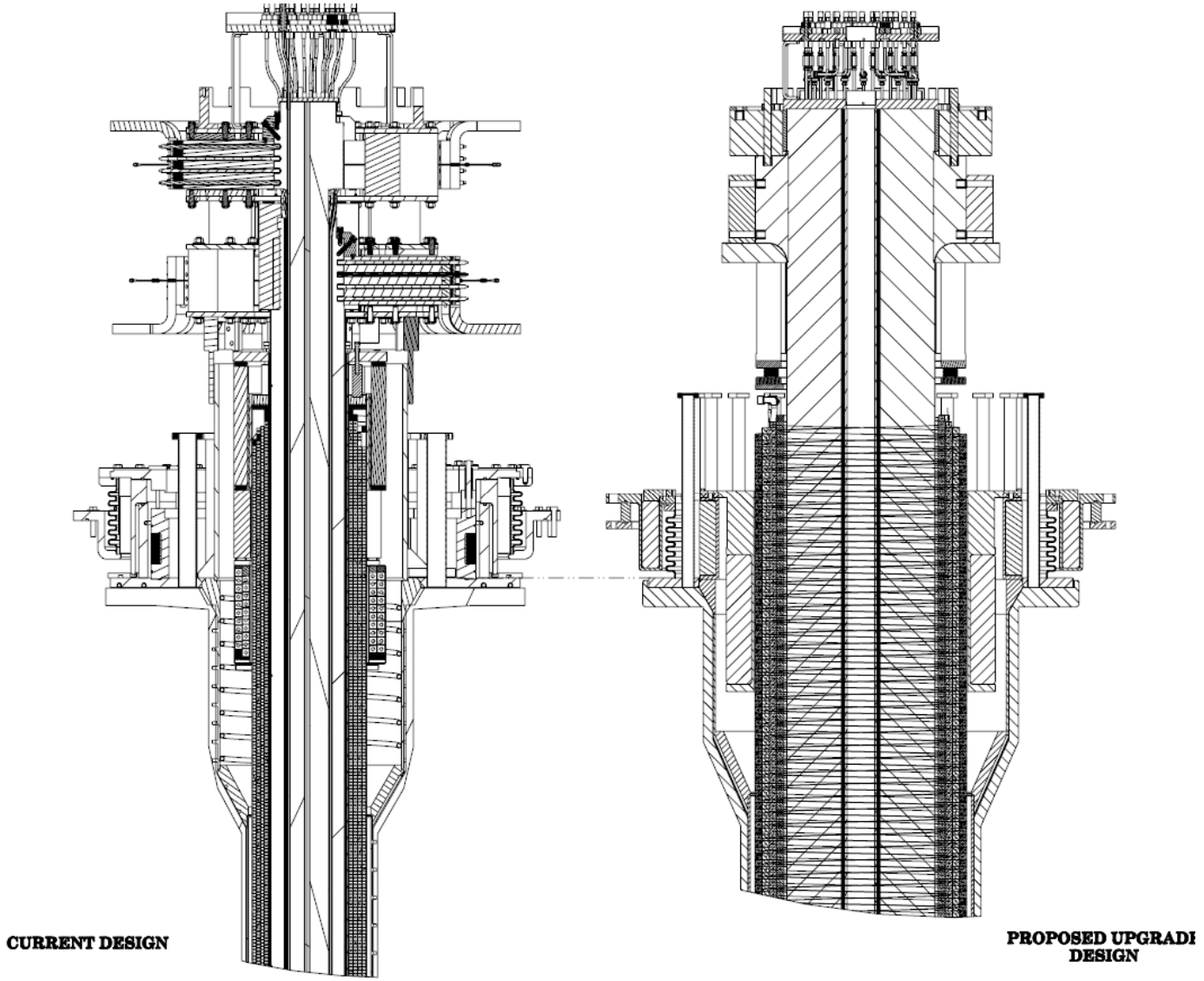
- **PPPL** would procure copper conductor
- **Select vendor: Note: vendor may or may not be same as TF vendor**
- Apply Teflon slip plane to TF OD to allow movement between OH/TF
- **Vendor** winds the OH solenoid directly onto TF bundle
- VPI OH coil- full cure cycle both coils
- Discussions with Composite Technical Development has verified that this process [double epoxy full cure- TF and OH] would work.
- Apply ground plane
- Apply surface diagnostics
- Apply thermal blanket



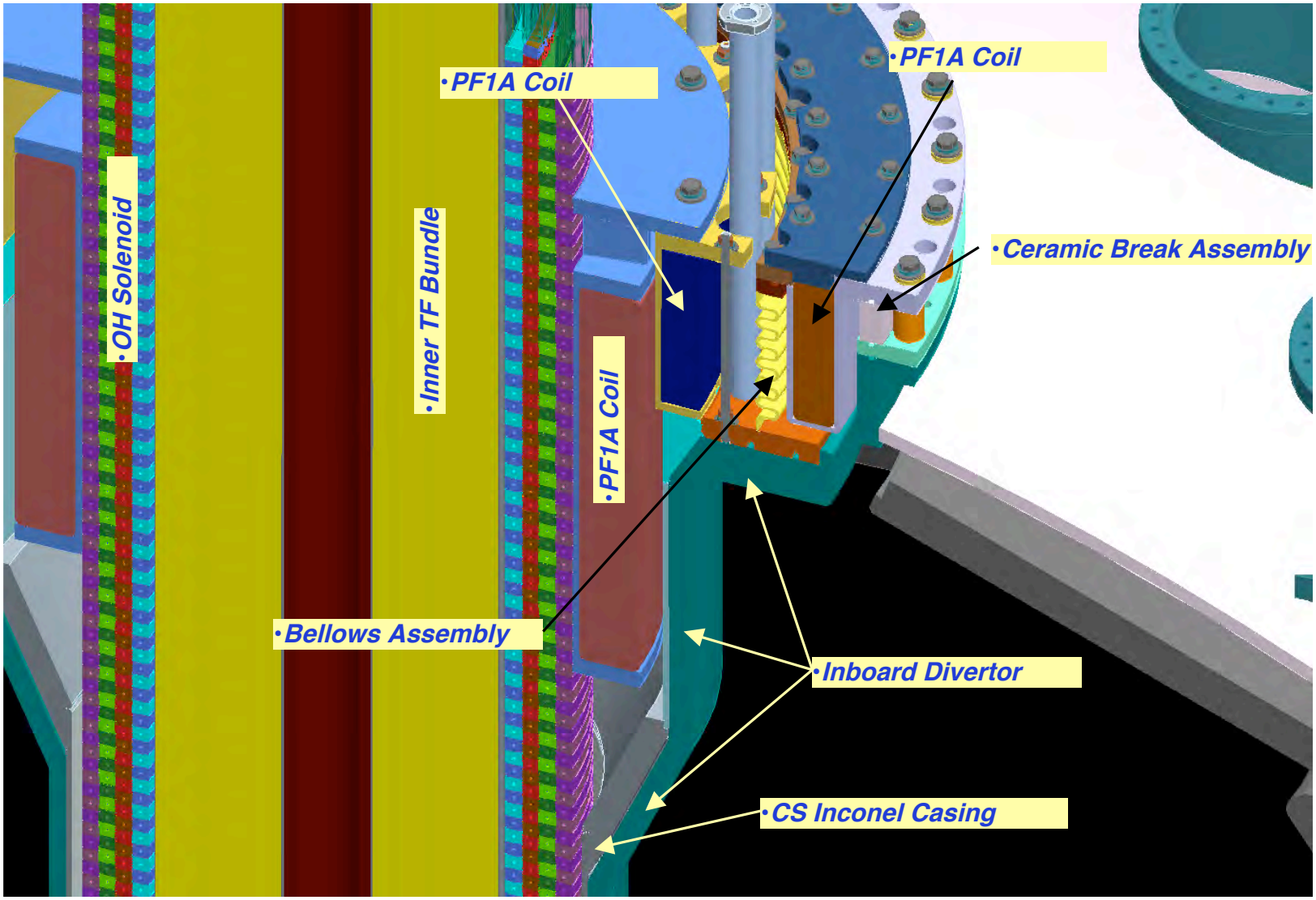
Design of Inner PF Magnets, Casing, Ceramic break & Bellows



Centerstack Comparison



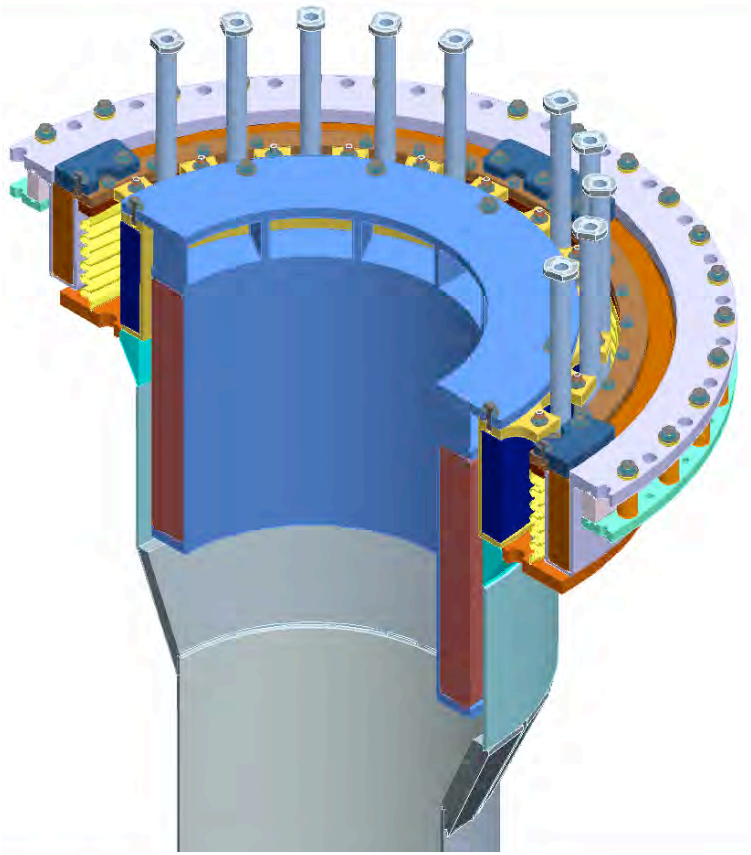
Center Stack Assembly Components



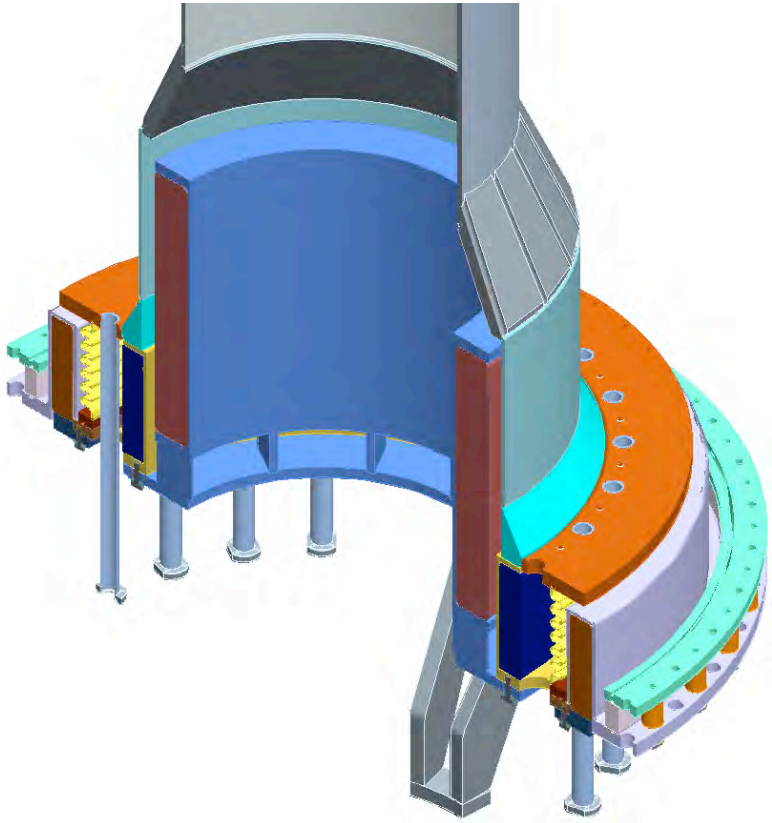
Center Stack Casing

- Centerstack casing provides the inner vacuum wall for the NSTX vessel.
- Included Components:
  - Inconel wall
  - Diagnostic organ pipes
  - Inconel Bellows
  - Provisions for PFC tiles
  - CHI electrical leads- bakeout
  - Heating/cooling for IBD areas during bakeout
  - Vespel “O” rings

Upgraded Centerstack Casing



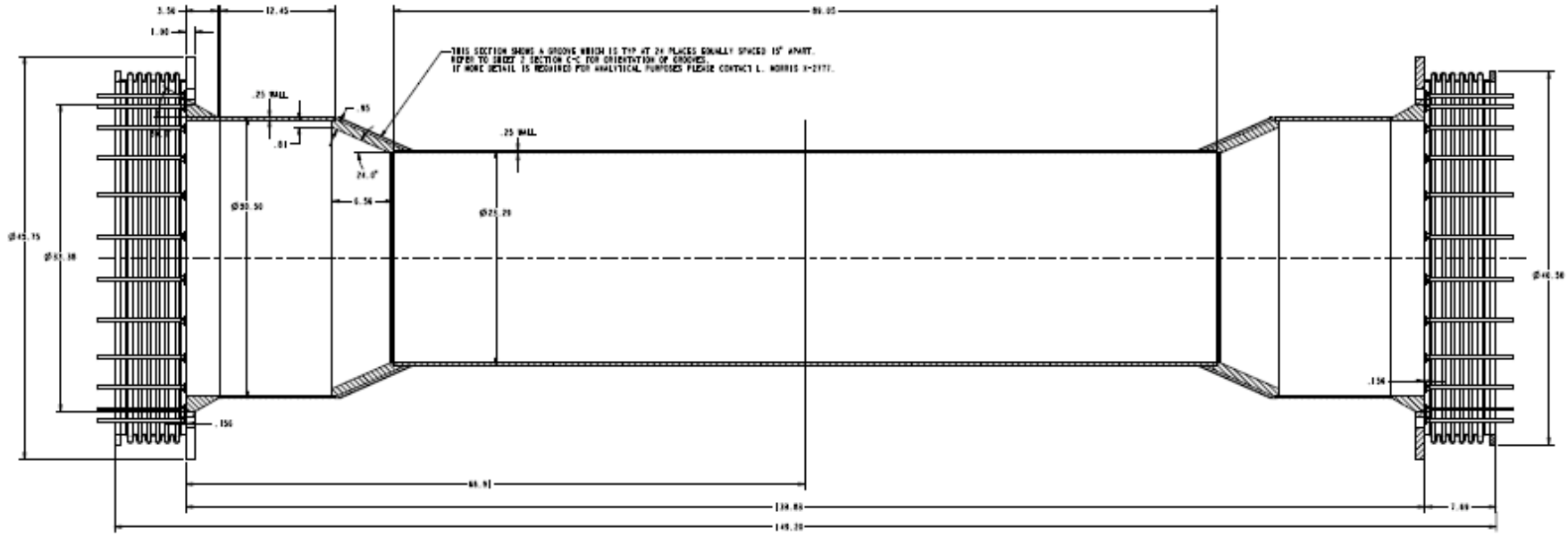
SECTION THRU TOP OF CENTERSTACK ASSEMBLY



SECTION THRU BOTTOM OF CENTERSTACK ASSEMBLY

CS Case Design Features

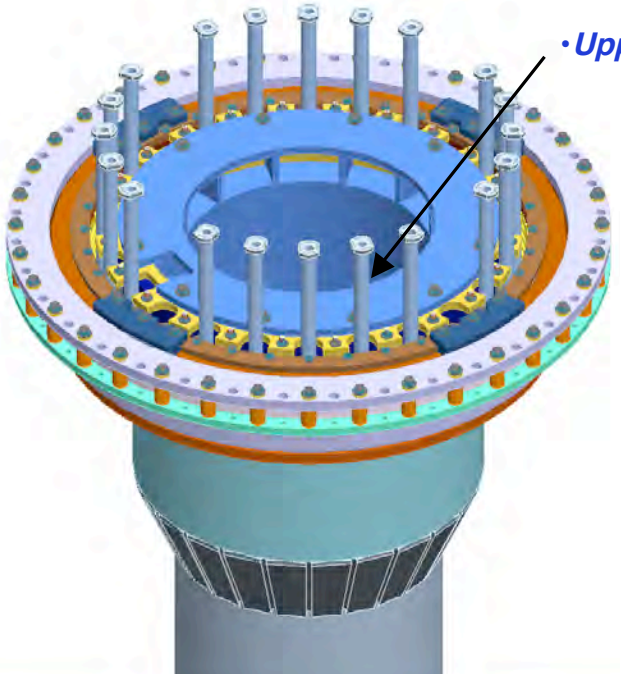
	Center section Dia. [In.]	Wall Thickness [in.]	Material	Length [in.]	Flange Diameter [in.]	Bellows	Organ Pipes
Original	13.162	0.157	Inconel 625	132.25	43.75	Inconel 625	Yes
Upgraded	23.29	0.25	Inconel 625	133.83	43.75	Inconel 625	Yes



SECTION A-A

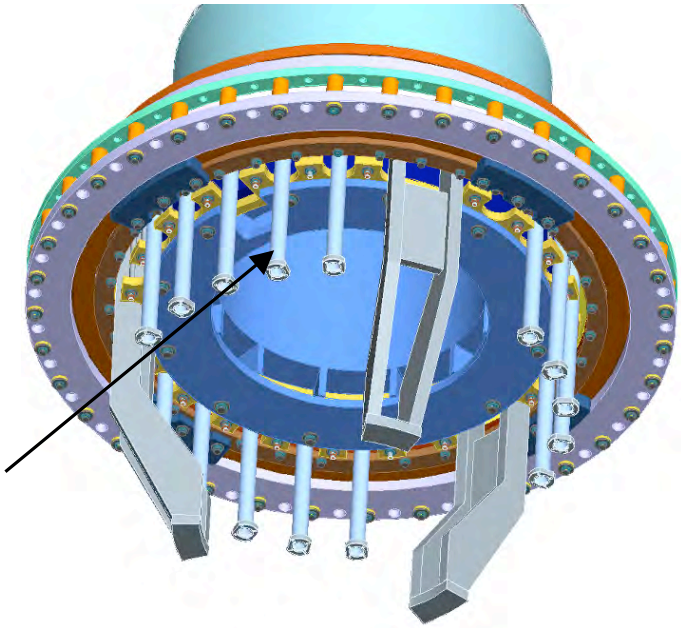
(ORGAN PIPES NOT SHOWN)

Diagnostic Organ Pipes



- *Upper Organ Pipes*

- *3-CHI*
- *4- IBD cooling*
- *2- Gas Injection*
- *15- Diagnostics*

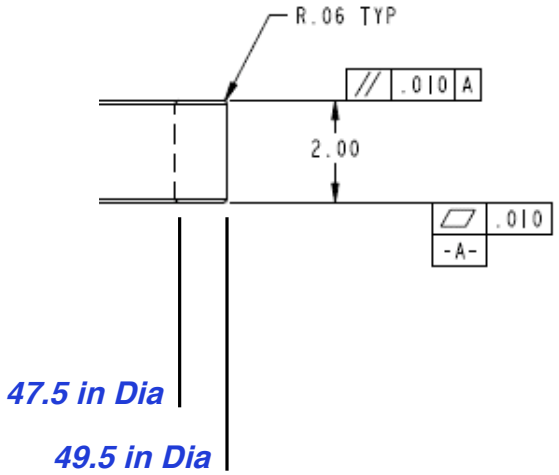


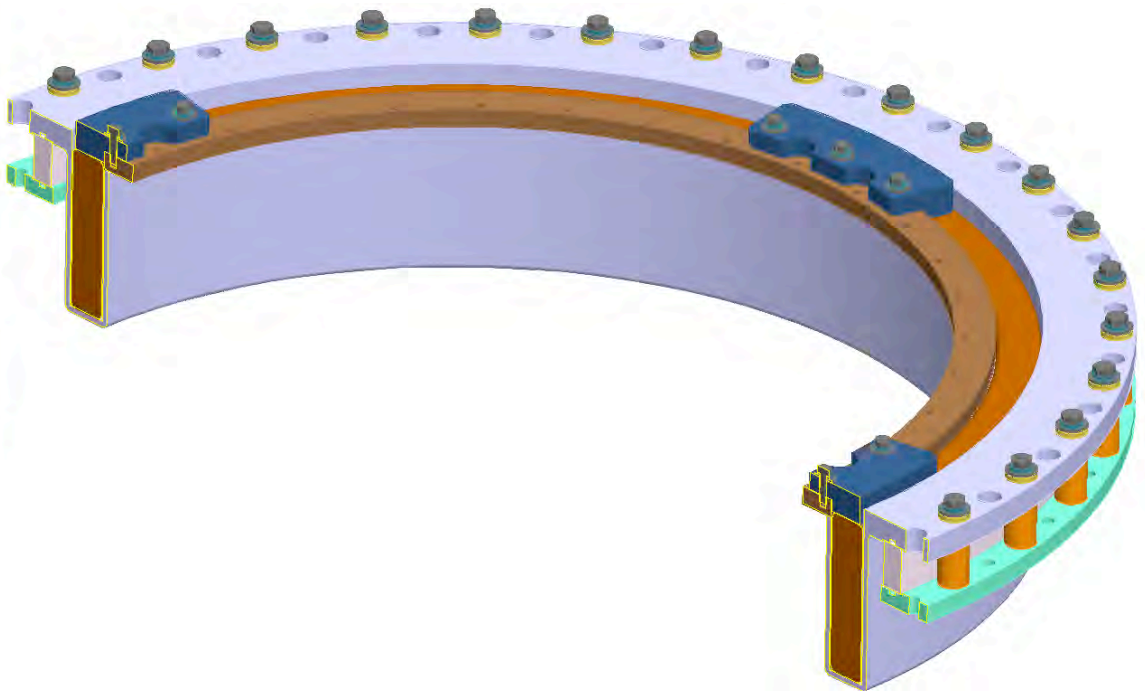
- *Lower Organ Pipes*

- *3-CHI*
- *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

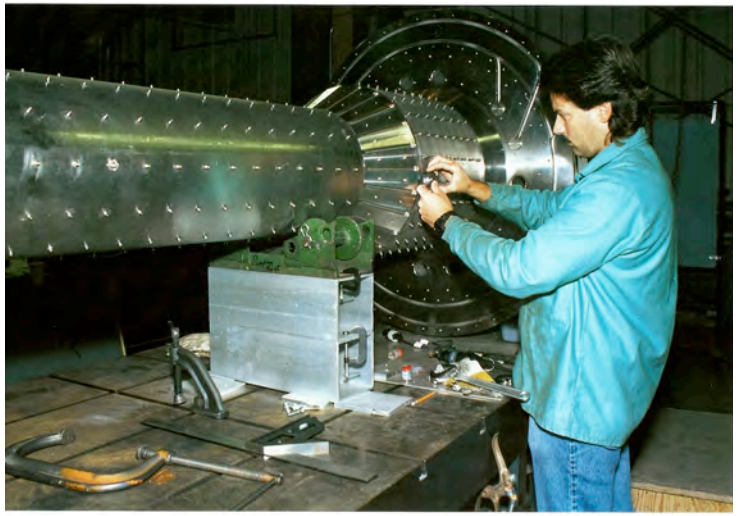
2. THE MATERIAL SHALL HAVE A MAXIMUM THERMAL COEFFICIENT OF EXPANSION OF 6.7×10^{-6} /C FROM 25° - 250° AND BE ABLE TO ABSORB A CUMULATIVE RADIATION DOSAGE OF 1×10^{8} RAD WITH NO DEGRADING EFFECT TO THE MATERIAL'S PROPERTIES.

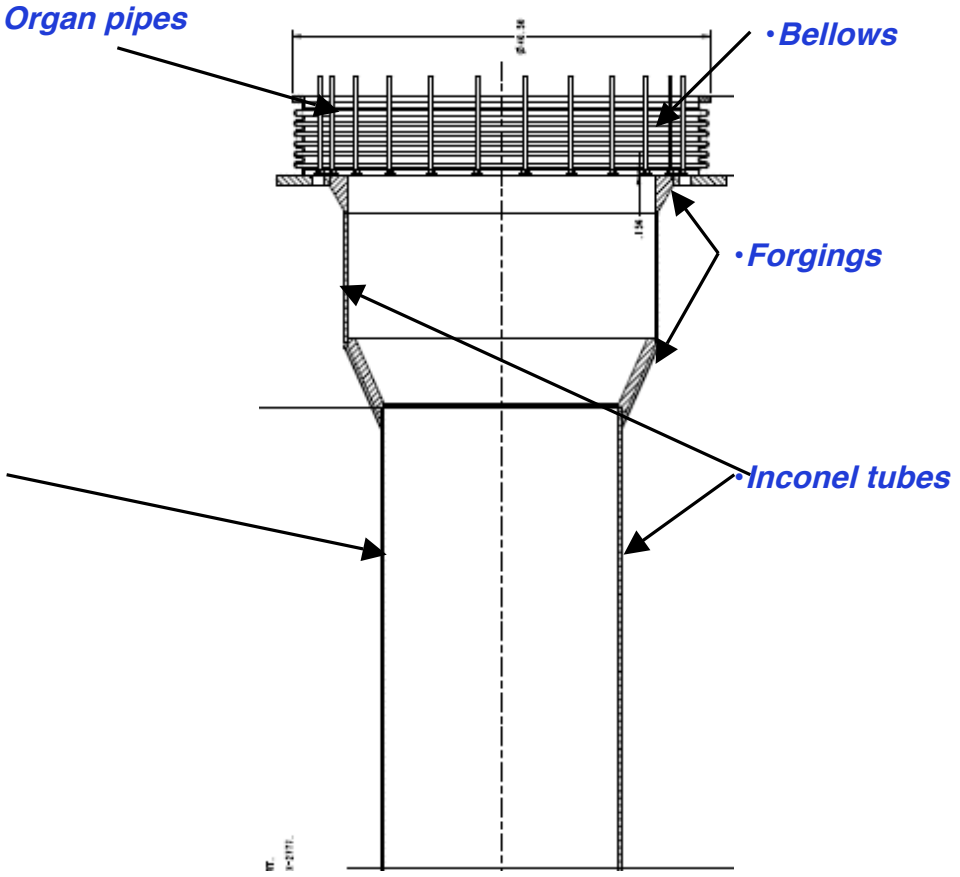
3. THE RING SHALL BE UNIFORM IN COLOR AND TEXTURE. CRACKS, BLISTERS, HOLES, POROUS AREAS, INCLUSIONS AND ADHERENT FOREIGN PARTICLES SHALL NOT BE PERMITTED.

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

CS Case Manufacturing Plan

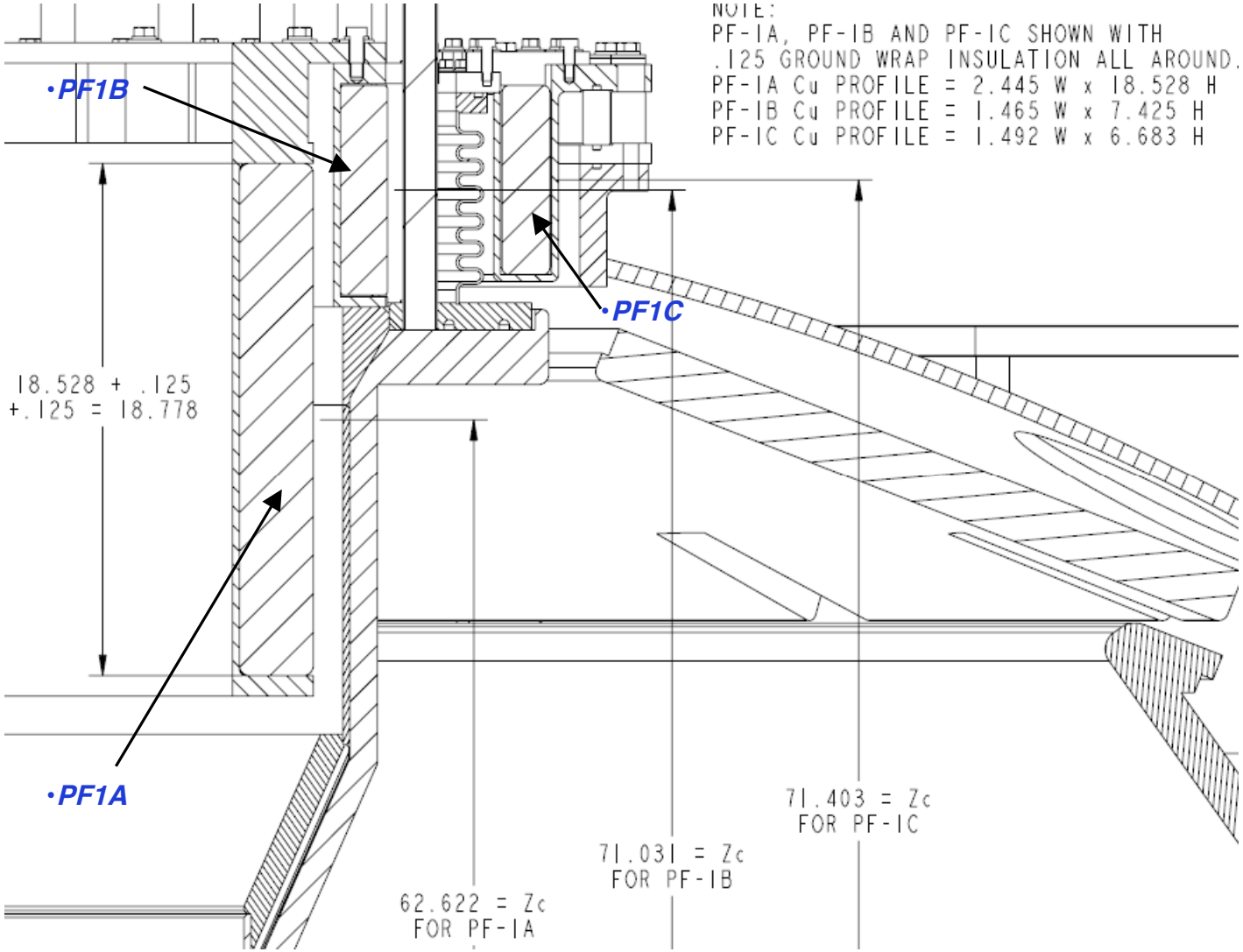
- Inconel components will be procured
  - Inconel tubes, bellows, organ pipes and forgings
- All welding will be performed in house
- Inconel studs will be added to case for mounting PFC hardware



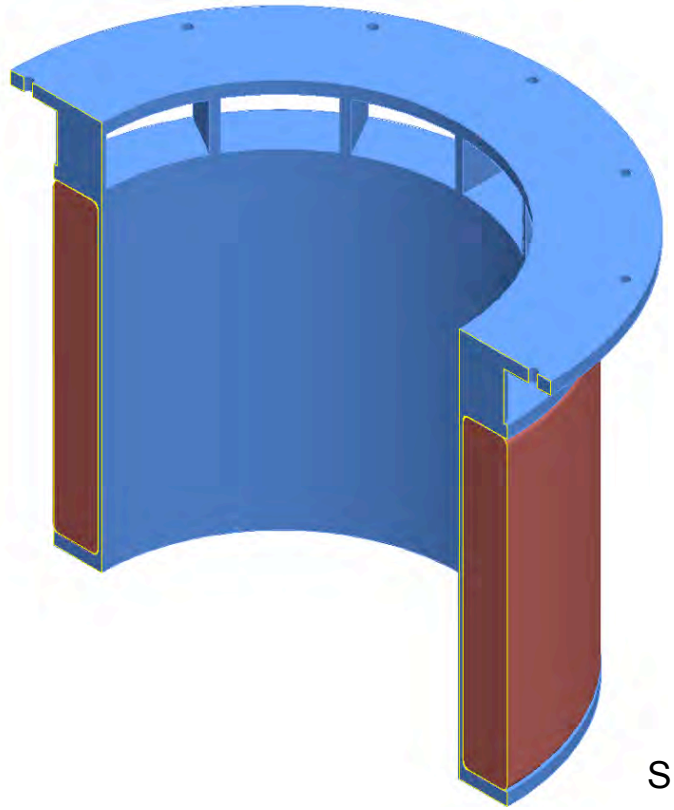


•PFC's for CS and IBD to be presented by K. Tresemer

Inner PF Coils



Inner PF 1A



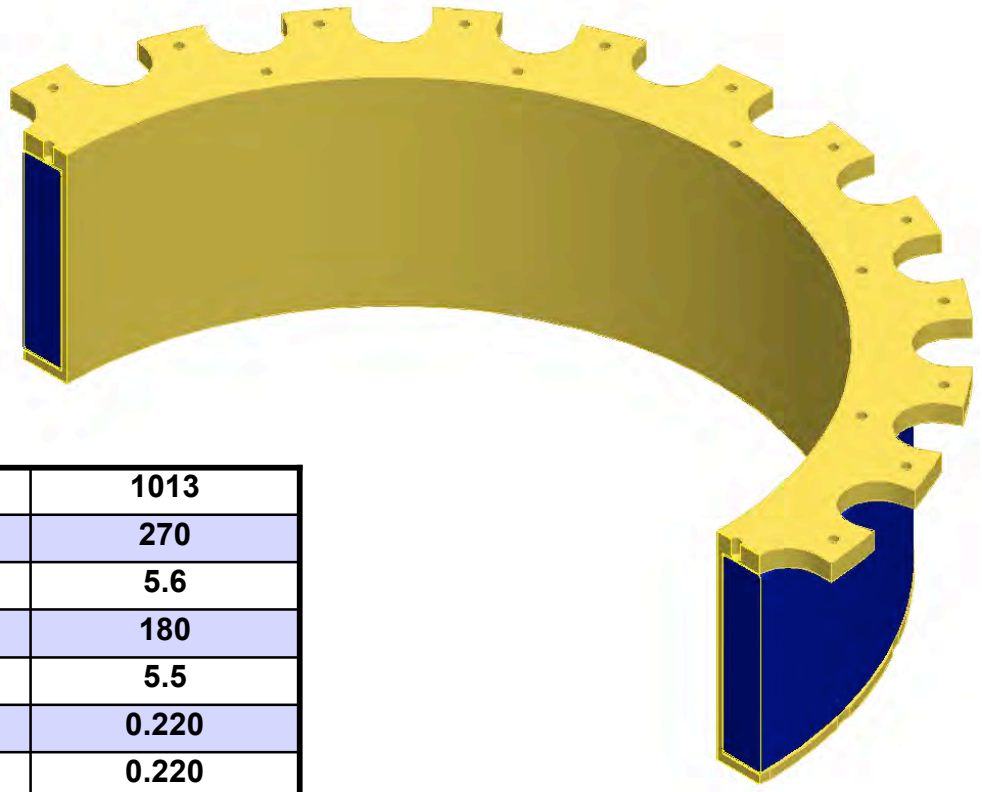
Voltage	Volts	1013
Current	Amps	1464
T/T Voltage	Volts	8.4
Number of Turns		120
ESW	sec	5.5
Conductor Width	In.	0.591
Conductor Height	In.	0.591
Cooling Hole Diameter	In.	0.217
Turn insulation thickness	In.	0.011
Ground insulation thickness	In.	0.108

SECTION THRU PF-1A COIL ASSEMBLY

- *Supported from Centerstack casing*
- *Kapton/glass turn insulation*
- *VPI- CTD-101k*

Inner PF 1B

- *Mounted directly onto Centerstack casing*
- *Kapton/glass turn insulation*
- *VPI- CTD-101k*

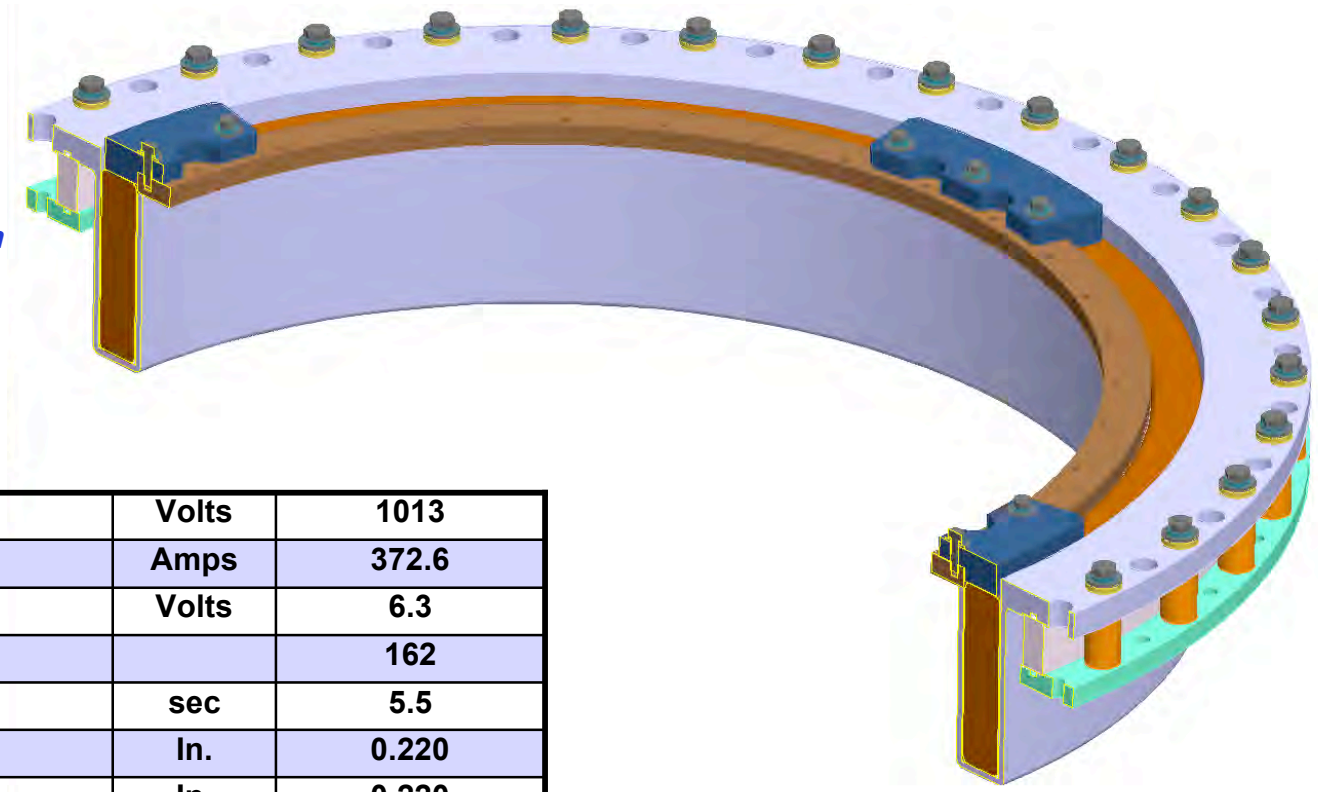


SECTION THRU PF-1B COIL ASSEMBLY

Voltage	Volts	1013
Current	Amps	270
T/T Voltage	Volts	5.6
Number of Turns		180
ESW	sec	5.5
Conductor Width	In.	0.220
Conductor Height	In.	0.220
Cooling Hole Diameter	In.	0.098
Turn insulation thickness	In.	0.011
Ground insulation thickness	In.	0.108

Inner PF 1C

- *Supported from vacuum Vessel and part of ceramic break sub assembly*
- *Kapton/glass turn insulation*
- *VPI- CTD-101k*



SECTION THRU PF-1C COIL ASSEMBLY

Voltage	Volts	1013
Current	Amps	372.6
T/T Voltage	Volts	6.3
Number of Turns		162
ESW	sec	5.5
Conductor Width	In.	0.220
Conductor Height	In.	0.220
Cooling Hole Diameter	In.	0.098
Turn insulation thickness	In.	0.011
Ground insulation thickness	In.	0.108