Final Design- CS Magnets and Components

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James H. Chrzanowski
and the NSTX Upgrade Team

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ASCR, Czech Rep
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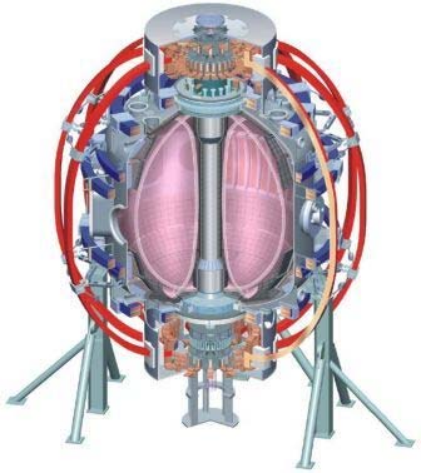
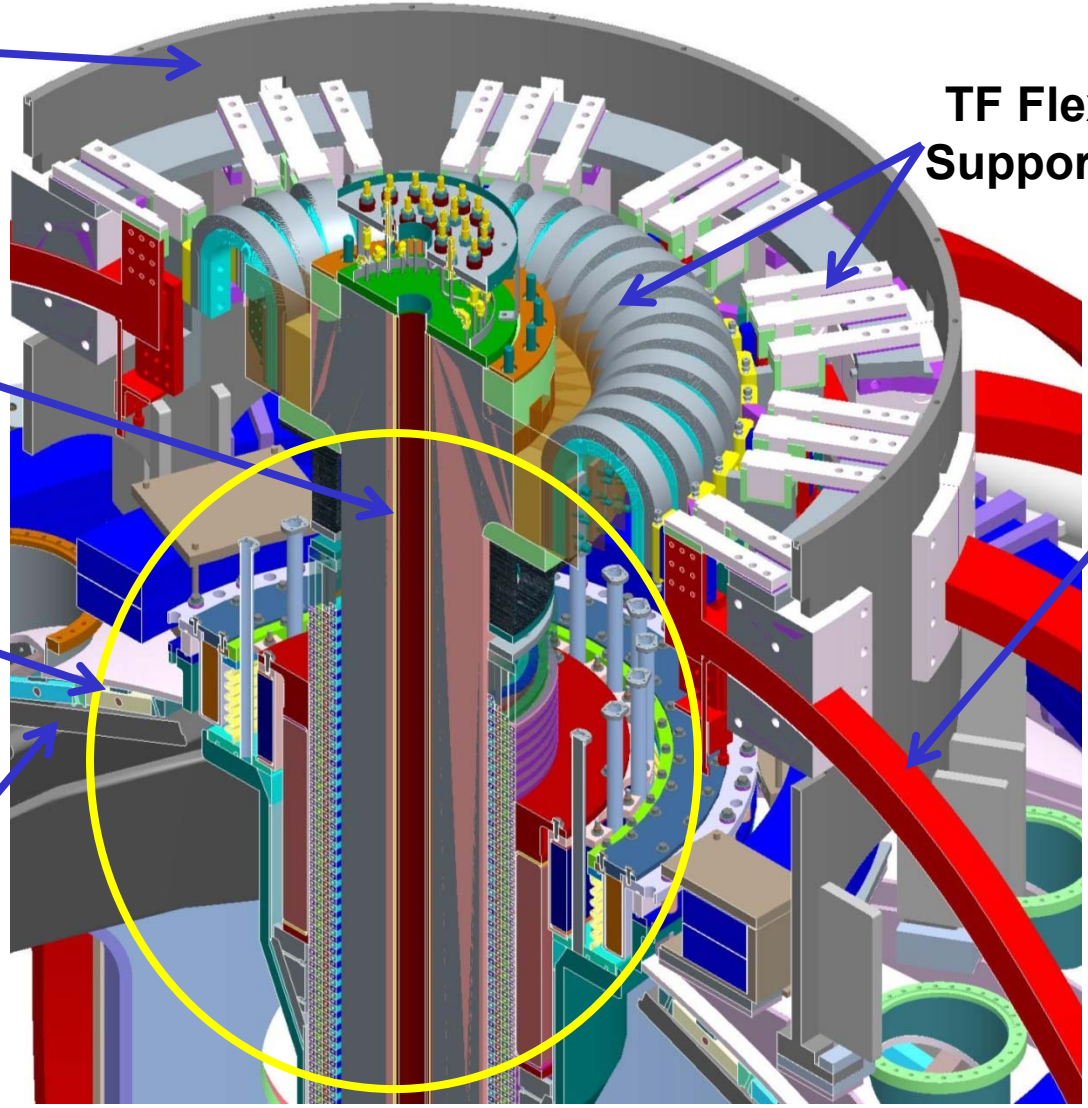
NSTX Upgrade Project
Peer Review
LSB, B318
May 18, 2011



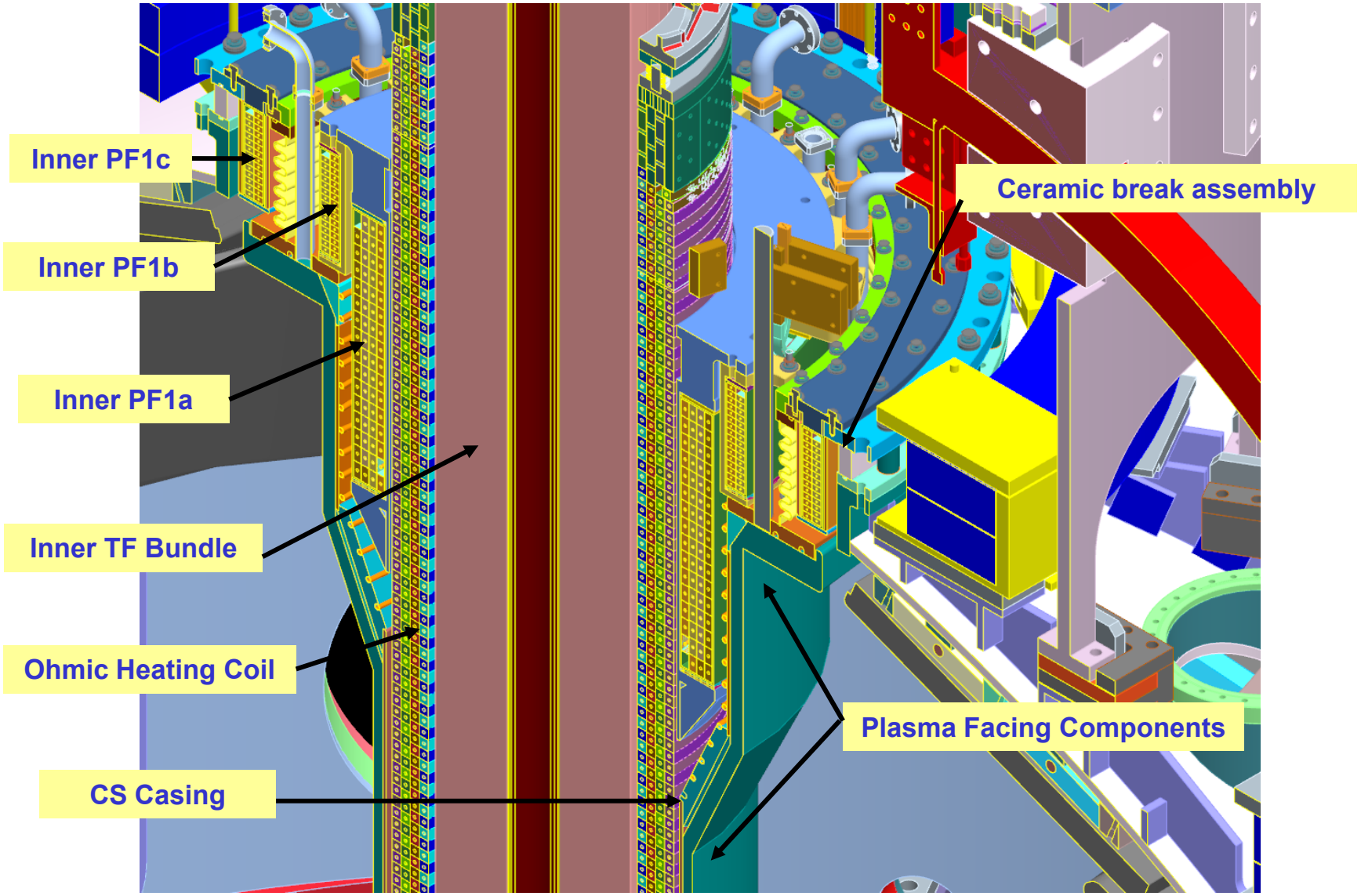
Outline of Presentation

- Inner TF Coil Assembly
- OH Solenoid
- Center Stack Inconel Casing
- Inner PF Magnets
- TF Flex Bus Joint
- Outer TF Coil
- R&D Activities
- Drawings and documents
- Summary

General Arrangement

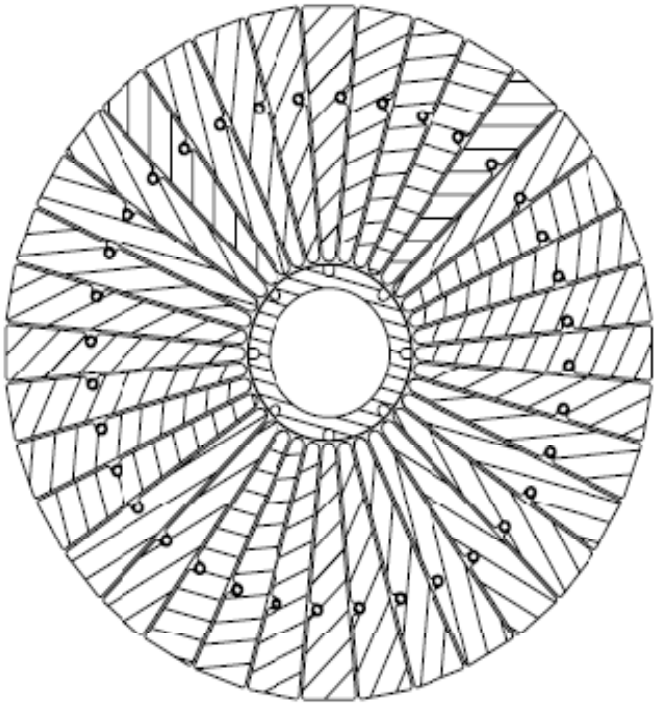


Upgraded Centerstack Components



Inner TF Design Parameters

Description	Parameters
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 layers resin/ glass
Groundwall insulation	0.1080 in.
Copper mass	10,900 lbs
Outside diameter	15.752 in.
Insulation scheme	S-2 glass and VPI (CTD-425)
Cooling hole size ID	0.305 in.

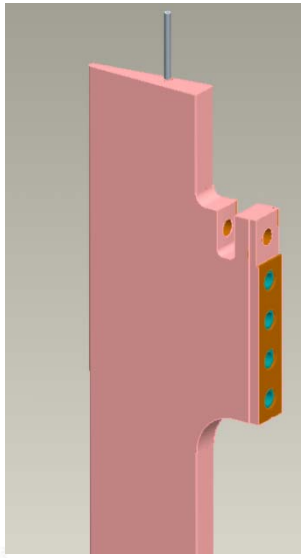


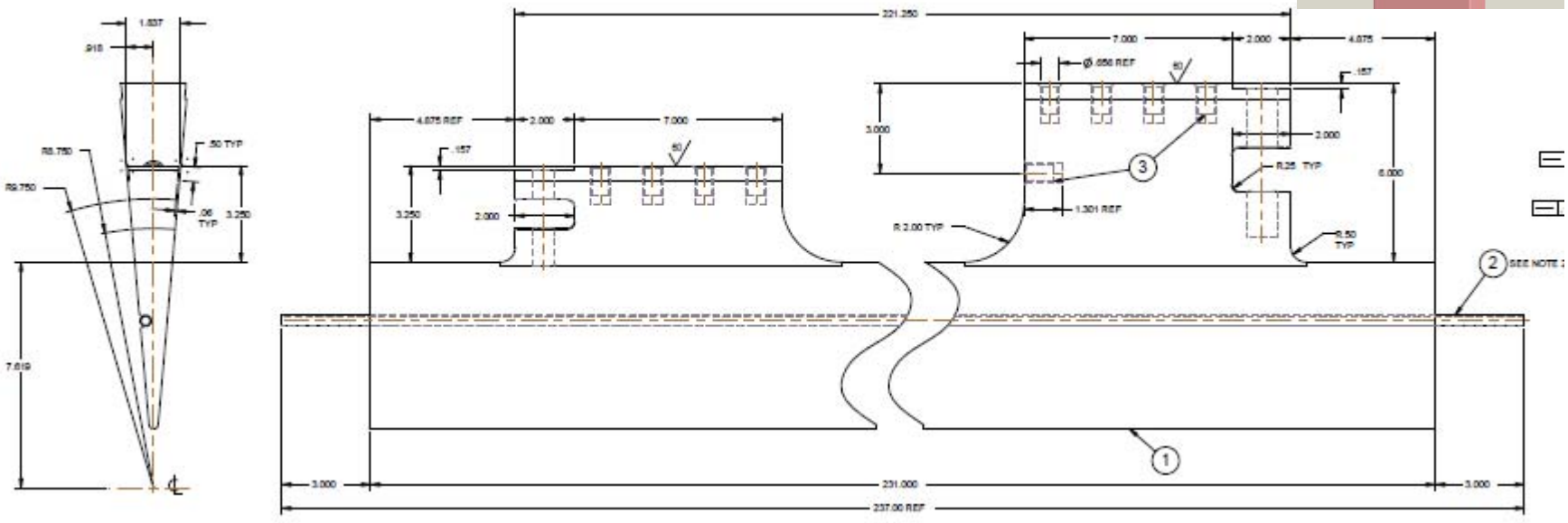
Inner TF Bundle

(15.7 inch diameter)

INNER TF CONDUCTOR ASSEMBLY

- **Material:** C10700 –Oxygen free-silver bearing copper conductor
  Extrusions: Purchased from “Luvata” delivery in May
- **Lead Extensions:** Material- Copper-Chromium-Zirconium
- **Inner TF Conductor Assy.:** Will be handled with a single contract (issued in the May-June 2011) DOE approval has been received
  - Preliminary machining of conductors
  - Friction Stir Weld (FSW) Cu-Cr-Zr lead extensions to copper extrusions
  - Final machine conductors



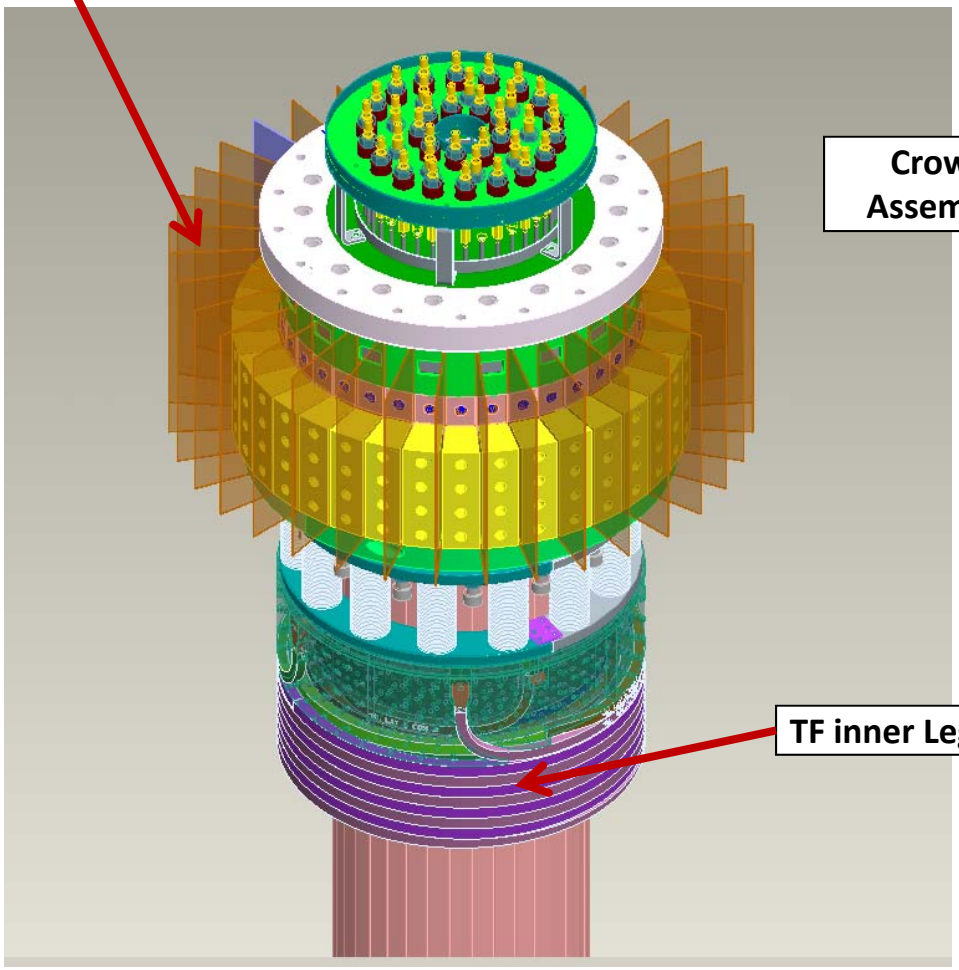


INNER TF INSULATION and VPI DESCRIPTION

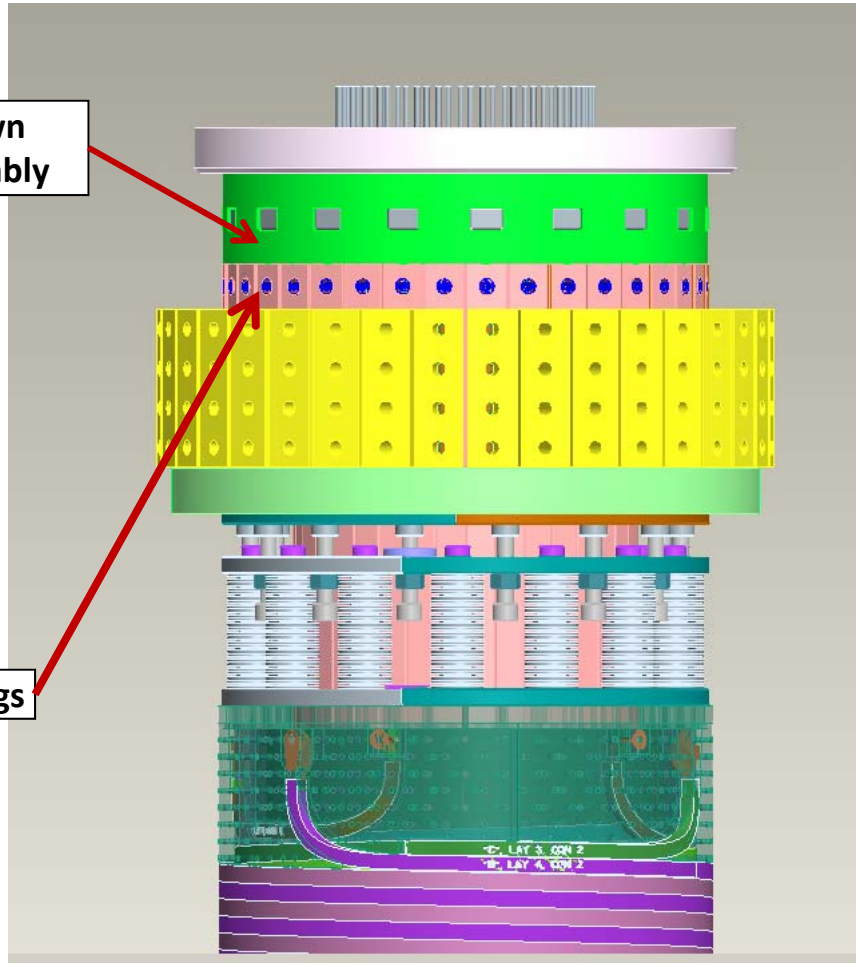
- **Conductor Preparation:** To enhance the shear strength of the insulation to the copper surface pre-requisite steps will be taken.
  - Grit blast conductor surfaces
  - Apply primer to surfaces (CTD-450 Cyanate Ester Primer)
    - **Cure cycle:** 8 hours @ 110 degrees C
    - **Post Cure Cycle:** 4 hours @ 150 degrees C
- **Insulation:** (3-half-lapped layers) 0.006 inch thick S-2 (satin weave) standard silane finish glass tape- (Temperature class- 180 degrees C)
- **Ground wrap Insulation:** Half-lapped layers of S-2 glass
- **VPI System-** CTD-425 Cyanate-Ester Hybrid
  - **Cure cycle:** 22 hours @ 110 degrees C
  - **Post Cure Cycle:** 24 hours @ 170 degrees C

Upper & Lower Crown Assemblies

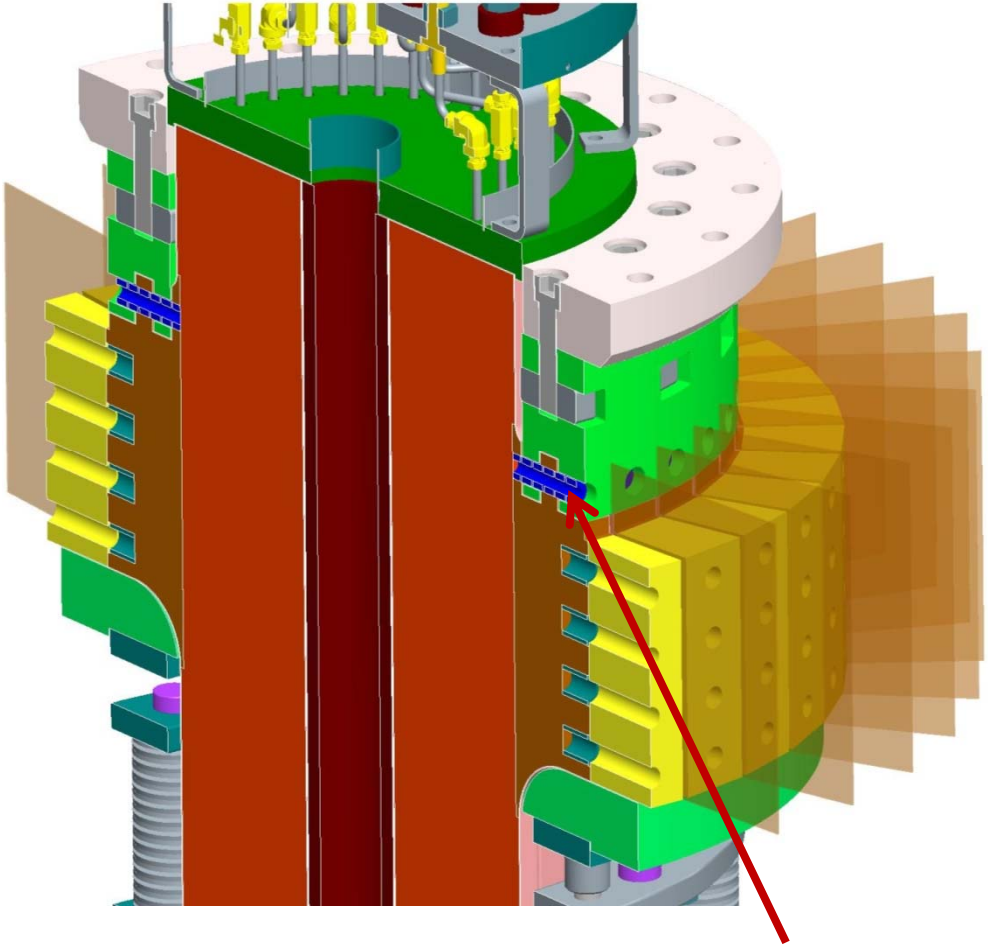
Kapton/G-10 Flash shields between adjacent joint areas



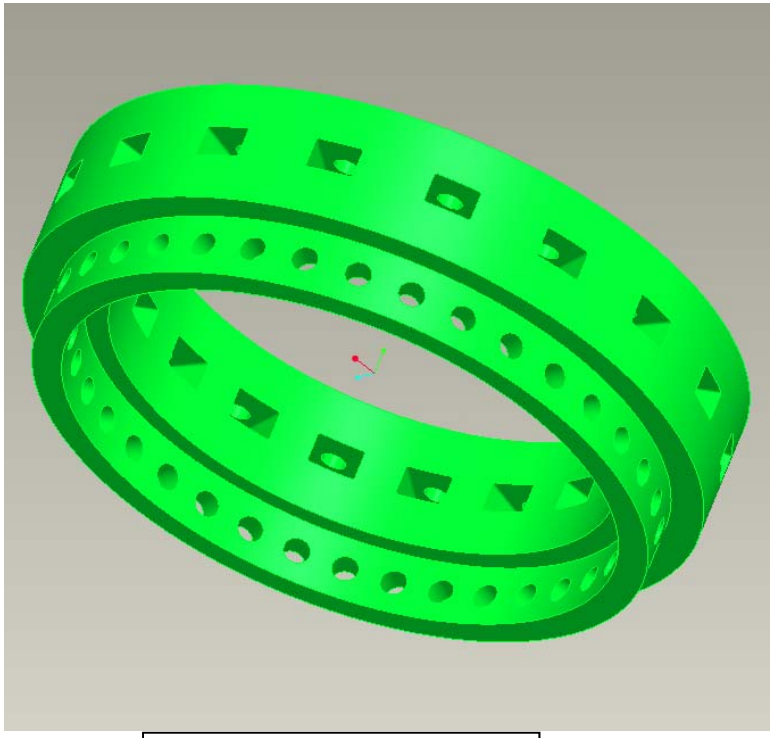
Purpose: Lock conductors together & help transfer load from TF bundle through lid structure to umbrella



Upper & Lower Crown Assemblies-cont'd



Pinned to Inner TF Conductors



Laminate Crown

Epoxy/S-2 glass construction

OH Solenoid Parameters

Description	OH Parameters
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 Materials

- **Conductor :** C10700 –Oxygen free-silver bearing copper conductor
  Insulation:
  - **Turn Insulation:** Co-wound Kapton/S2 glass tape
  - **Ground wrap Insulation:** Half-lapped layers- 0.006 inch thick S-2 (satin weave) standard silane finish glass tape- (Temperature class- 180 degrees C)
- **Fillers:** All G-10
- **Cooling Fittings:** Custom cast copper components C10200
- **VPI System-** CTD-101k 3-part epoxy system
  - **Cure cycle:** 5 hours @ 110 degrees C
  - **Post Cure Cycle:** 25 hours @ 125 degrees C

OH Solenoid Design Features

- The Coil leads are located on the bottom of machine to minimize motion on the leads and bus connections.
- Co-axial coil/bus lead design to minimize field errors
- In line braze may be required if full conductor lengths are not available
  - "Conform" extrusions will be investigated when placing conductor order
- Layer to Layer TIG-braze joints will be used [similar to existing joints]- qualified
- Improved cooling fitting assemblies- more stable and resilient

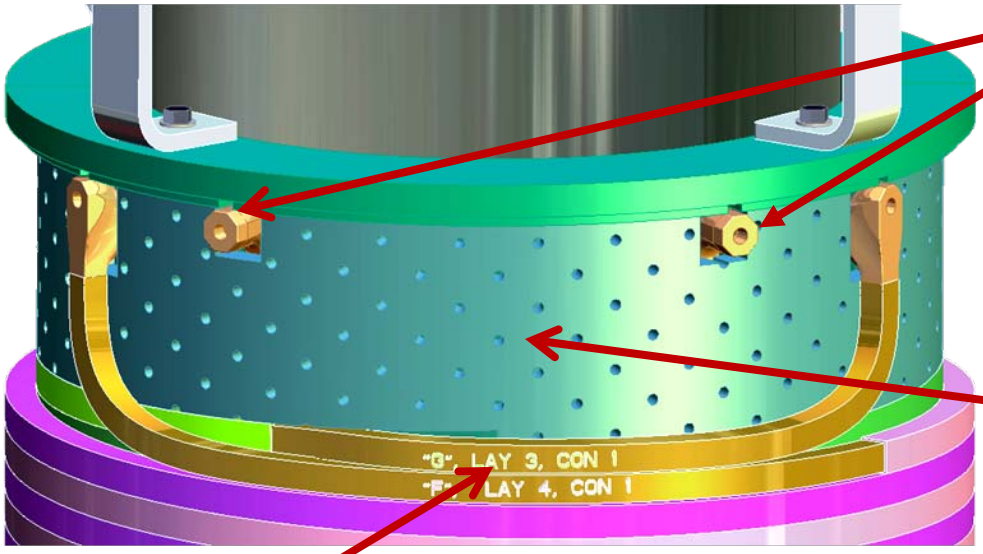
OH Solenoid Design Features-cont'd

- **Coil will be wound 2 conductors in-hand 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 an outer electrical ground plane, identical to existing design.**
  - **Outer: Conductive paint**
- ***If OH solenoid fails during lifetime, the plan would be to remove [cut off] the existing coil from the TF bundle and rewind new OH.***

OH Solenoid VPI System

- **OH solenoid will be vacuum pressure impregnated using resin system CTD-101k** *[Product of Composite Technology Dev. Inc.]- system used on NCSX Modular and TF coils*
  - 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

OH Layer to Layer Joints



OH Cooling fittings- torch brazed to copper conductors

- **G-10 fillers between layers supports turns**
- **S-2 glass between G-10 fillers**
- **Perforations in G-10 will enhance epoxy flow during VPI**

•Layer to layer TIG-Braze joint [Typical]

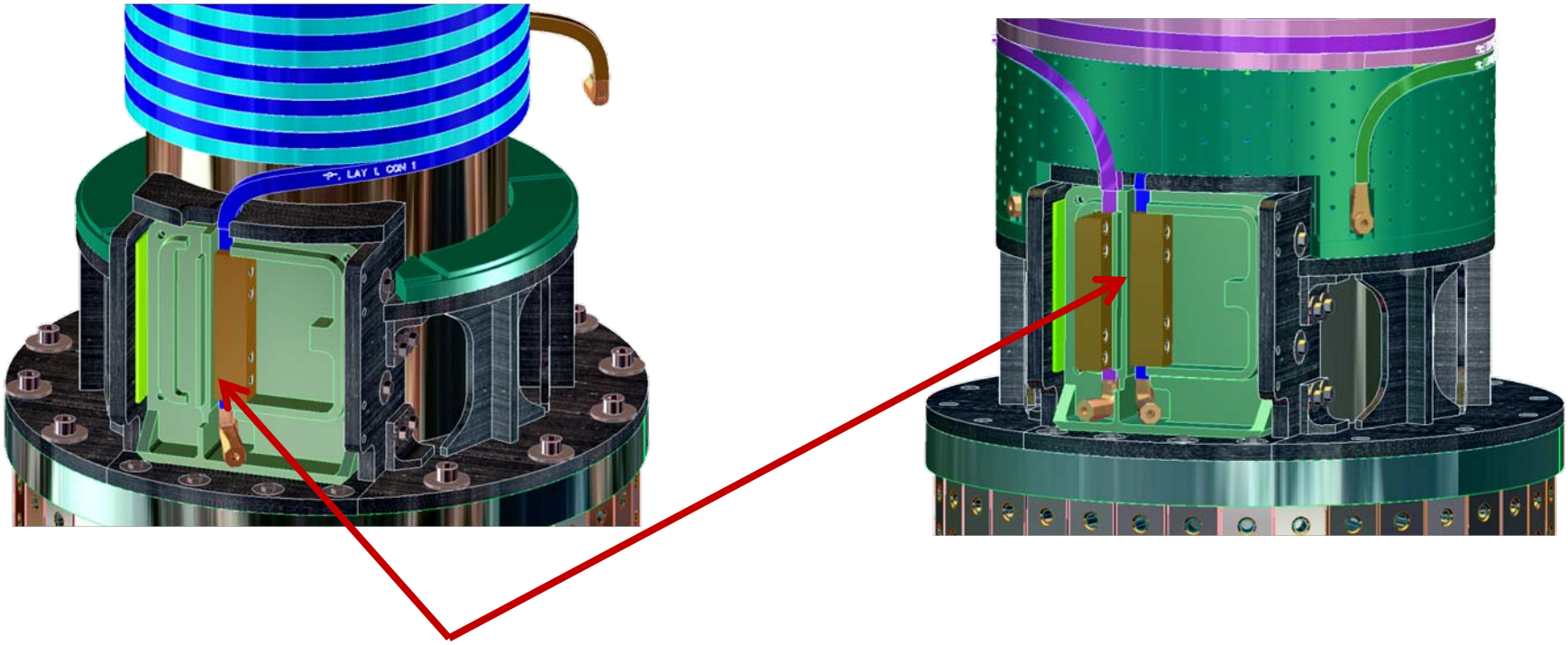
"TIG-Braze"

•TIG-Brazing method minimizes annealing of conductors (use Sil-Fos)

•Provides adequate joint strength

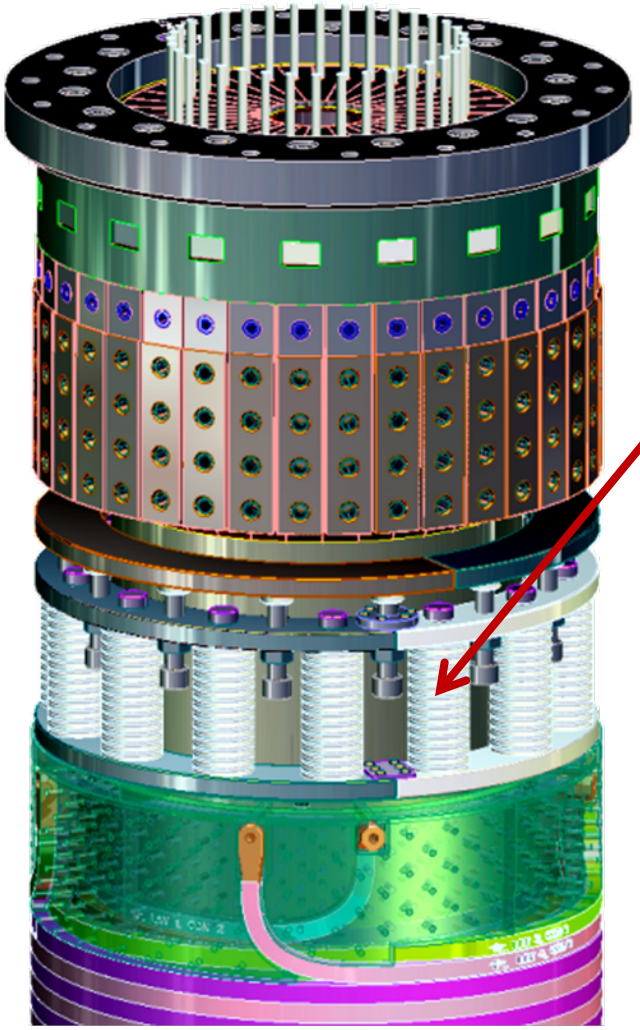
•Qualified method and procedures used in previous OH solenoids

OH Solenoid Lead Area



- Coil leads are brazed to copper conductor
- Well supported in structure
  - Stainless 316 and G-10 insulating materials

OH Solenoid End Conditions

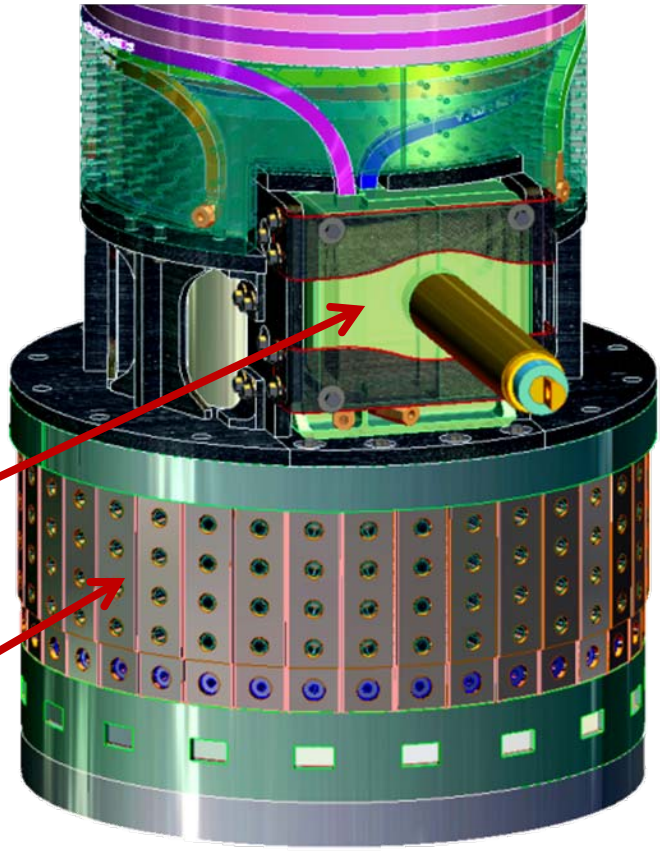


Upper OH Coil

Belleville washer assembly
- designed to maintain vertical pre-load on the OH solenoid at all times

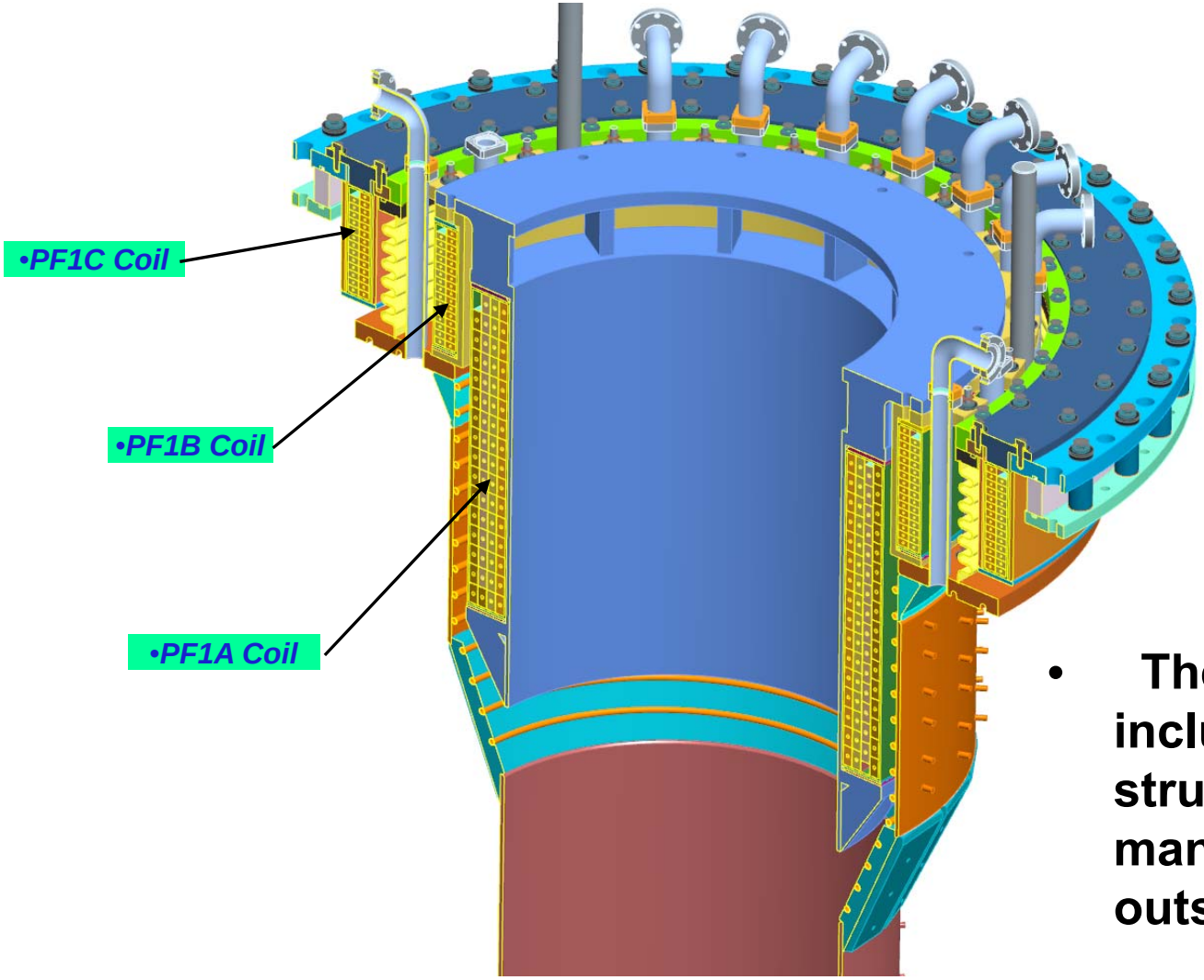
Coaxial bus lead connection

Lower Inner TF leads



Lower OH Coil

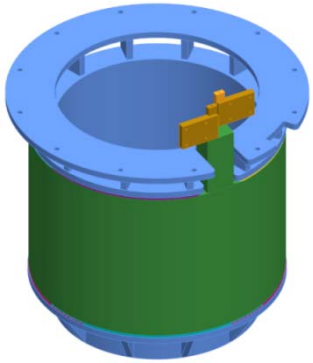
Inner Poloidal Field Coils

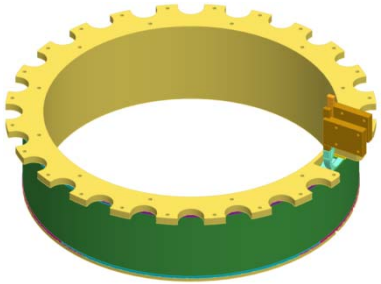


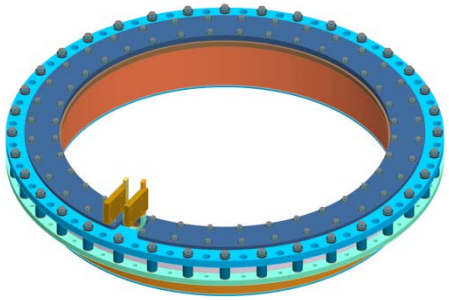
- The inner PF coils including support structure will be manufactured by an outside vendor.

Inner PF Coil Parameters

- 3-Sets of inner PF coils
- PF1a & 1b wound directly onto support
- PF1c wound on mandrel & install into can and VPI



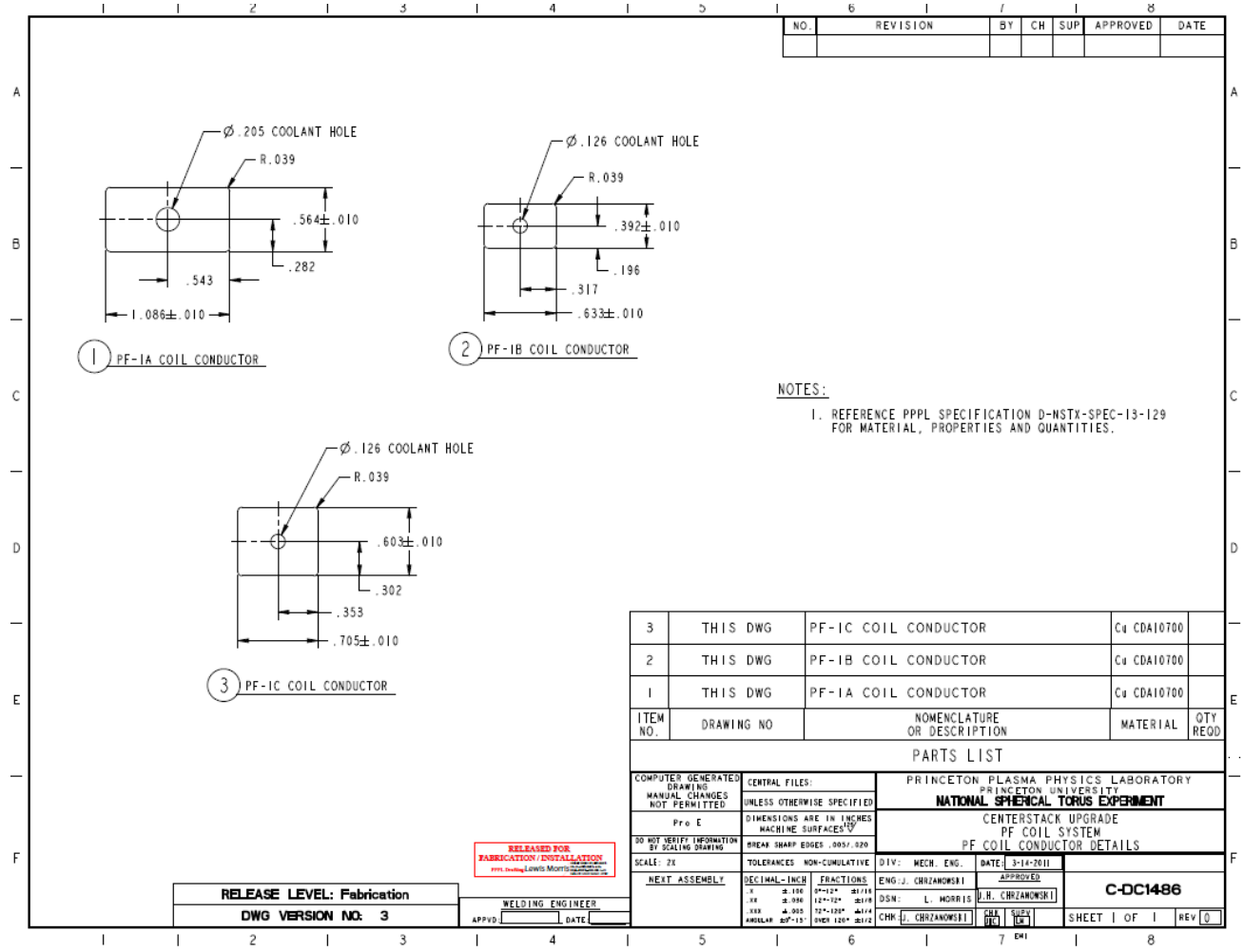




	PF1a	PF1b	PF1c
Number of coils	2	2	2
Voltage	2026	2026	2026
Current	1380	252	356
T/T Voltage	31.7	5.6	5.6
Number of Turns	64	32	180
ESW	4.6	5.5	5.5
Conductor Width	0.551	0.633	0.705
Conductor Height	1.100	0.392	0.603
Cooling Hole Diameter	0.205	0.126	0.126
Turn insulation thickness	0.022	0.029	0.029
Ground insulation thickness	0.144	0.144	0.072

Inner PF Coil Materials & Construction

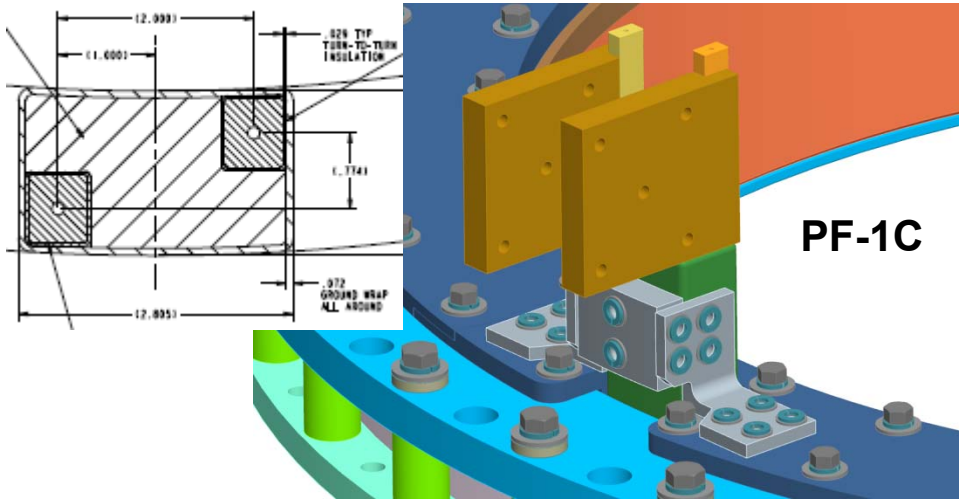
- **Conductor:**
  - **10700 (ASTM 187) Oxygen free-silver bearing copper conductor w/ cooling hole.**

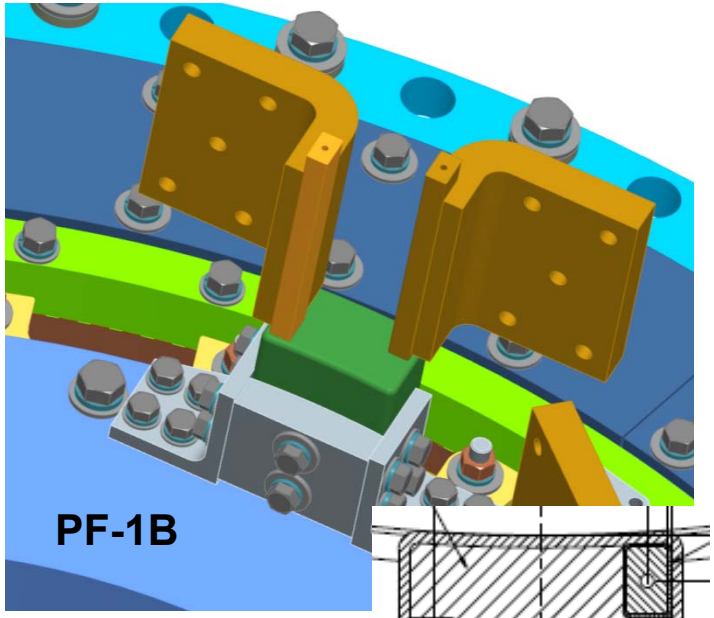


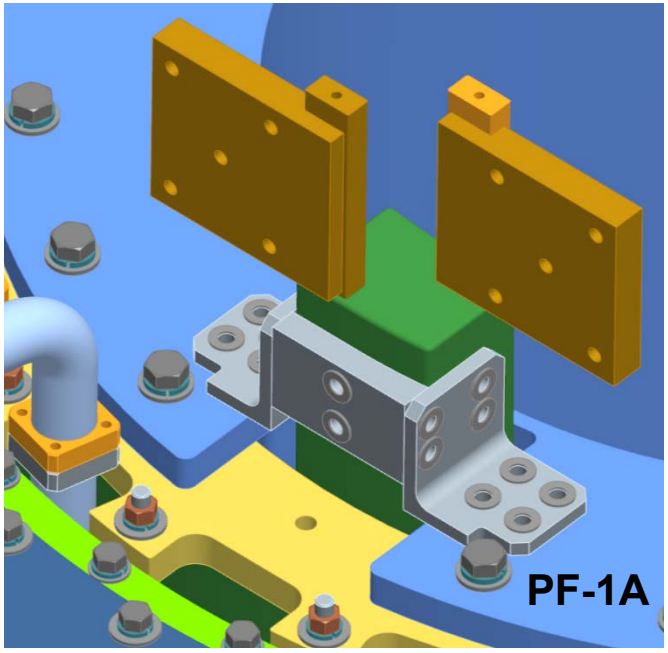
Inner PF Coil Conductor

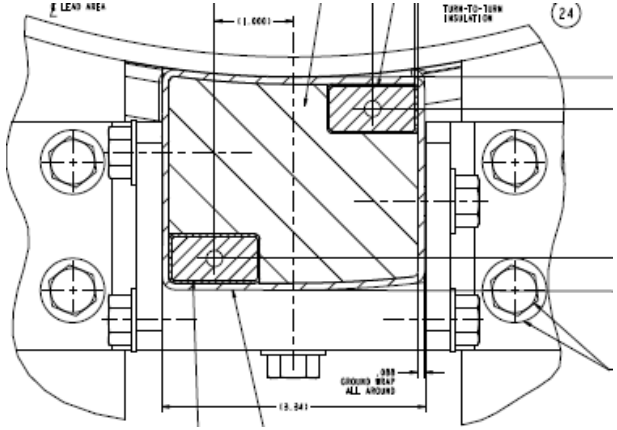
- **Insulation Scheme:**
  - Co-wound Kapton w/ S-2 glass tape
- **VPI System:**
  - CTD-101K 3-part epoxy system
- **Coil Fillers:**
  - G-10
- **Structures:**
  - Stainless steel 316
- **Construction:**
  - Standard copper tension wound coils
  - No in line brazes required
  - Torch braze lead terminals
  - Outside vendor procurement- includes PF supports, copper conductor and VPI materials

Inner PF Coil Leads



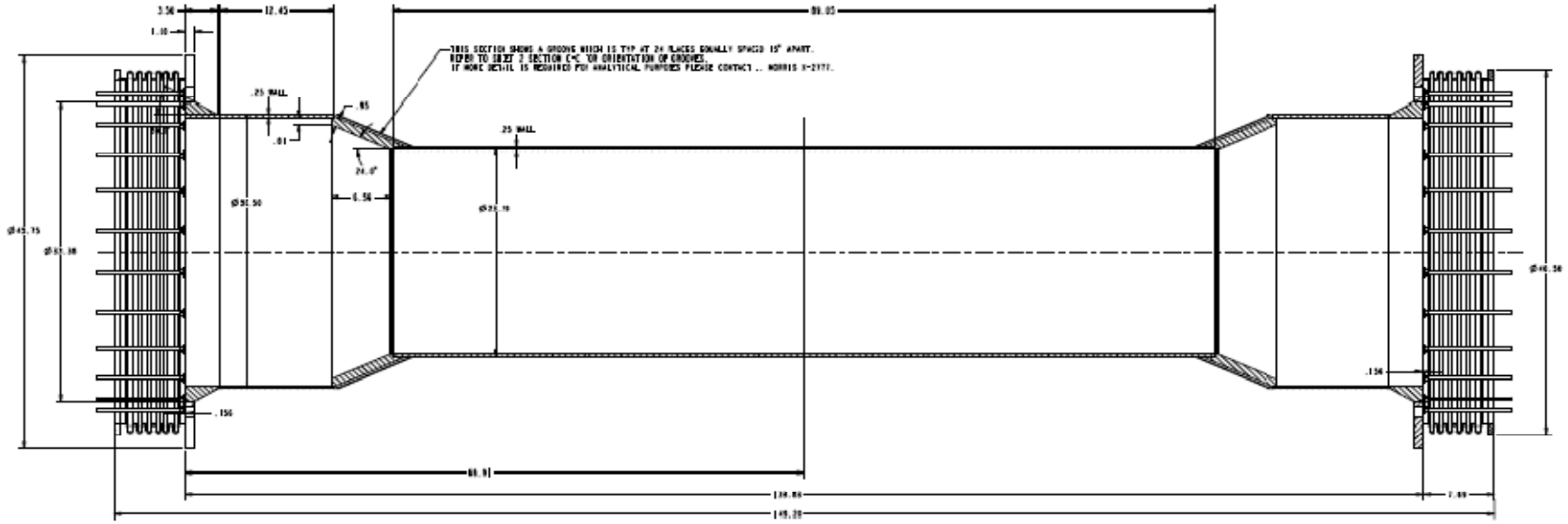






Center Stack VV Case Design Features

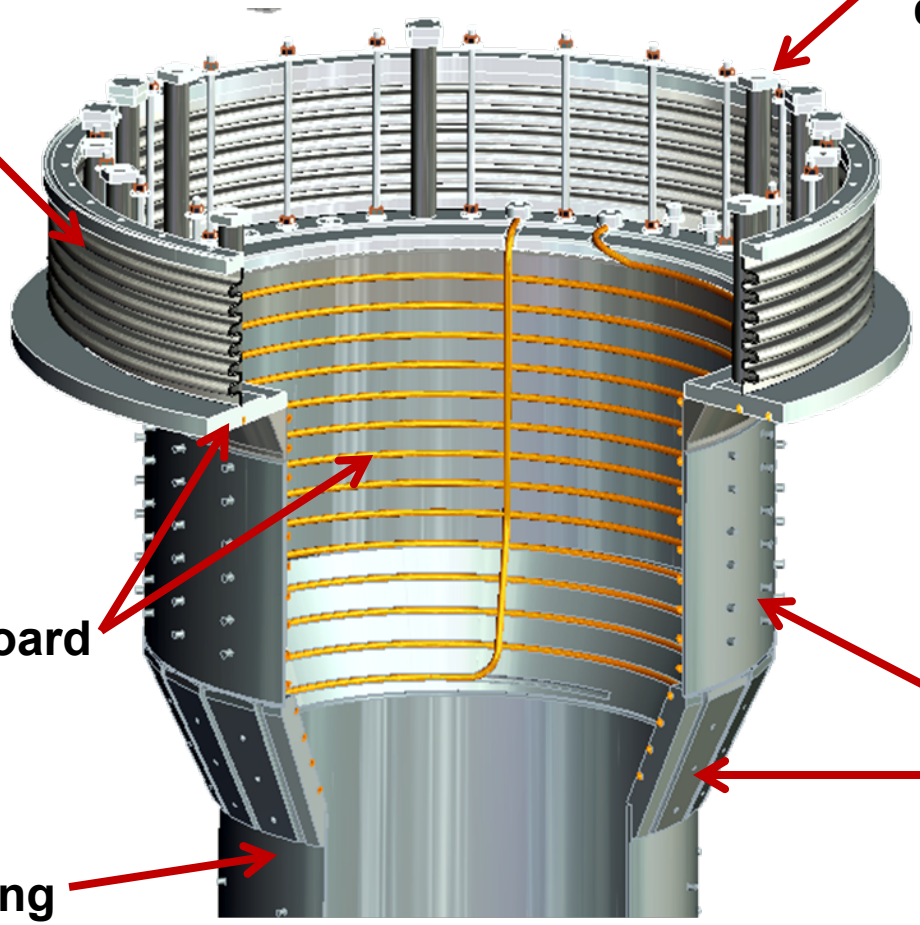
	Center section Dia. [In.]	Wall Thickness [in.]	Material	Length [in.]	Flange Diameter [in.]	Bellows	Organ Pipes
	23.29	0.25	Inconel 625	133.83	43.75	Inconel 625	Yes



SECTION A-A
(ORGAN PIPES NOT SHOWN)

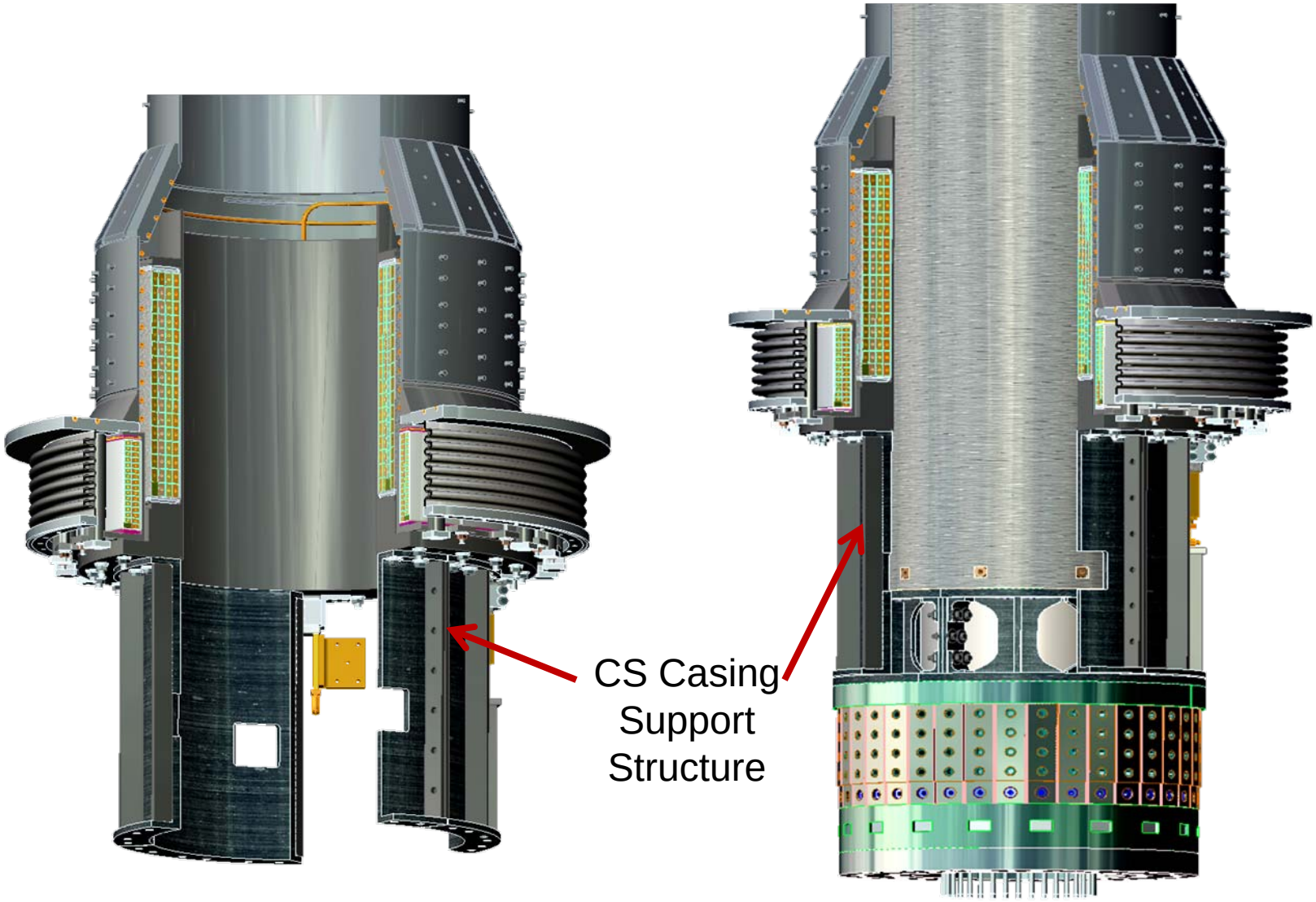
•Centerstack casing provides the inner vacuum wall for the NSTX vessel and mounting surface for PFC's.

Center Stack Casing Components

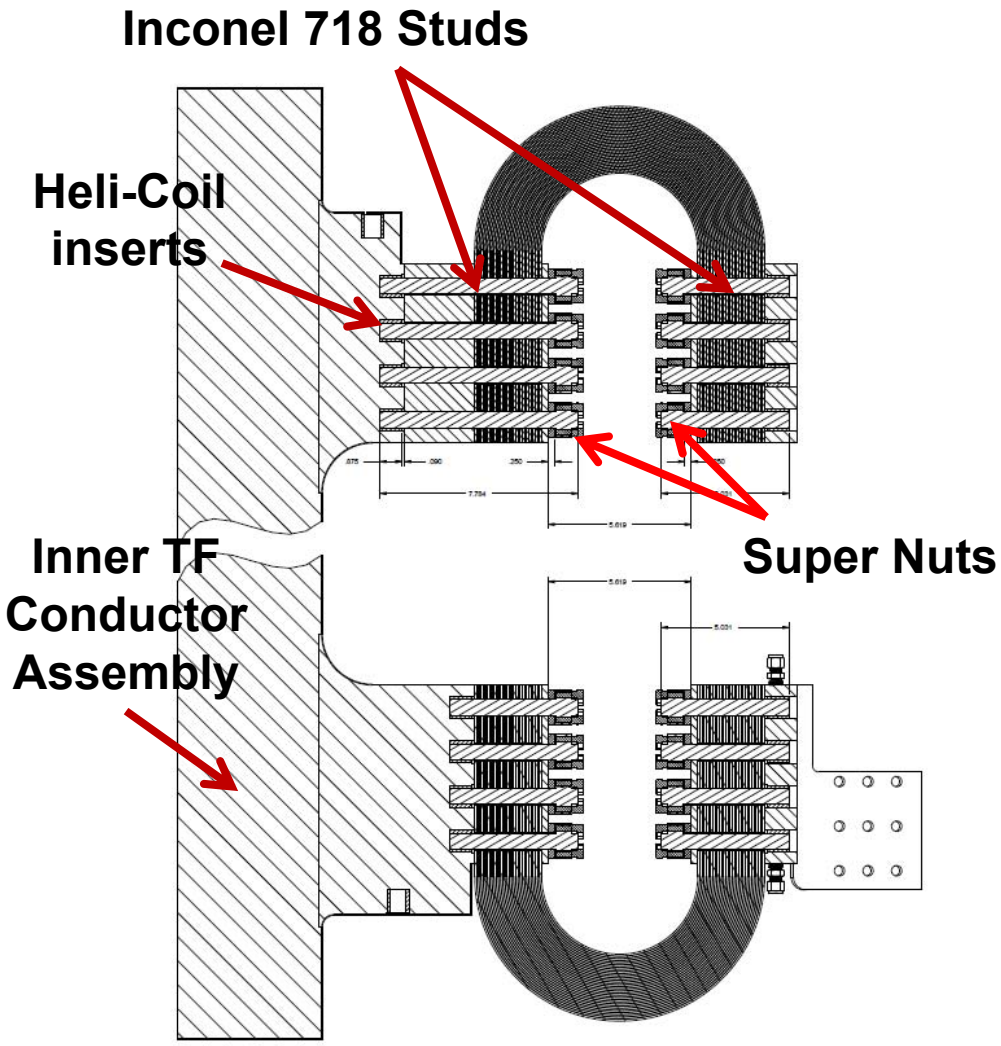


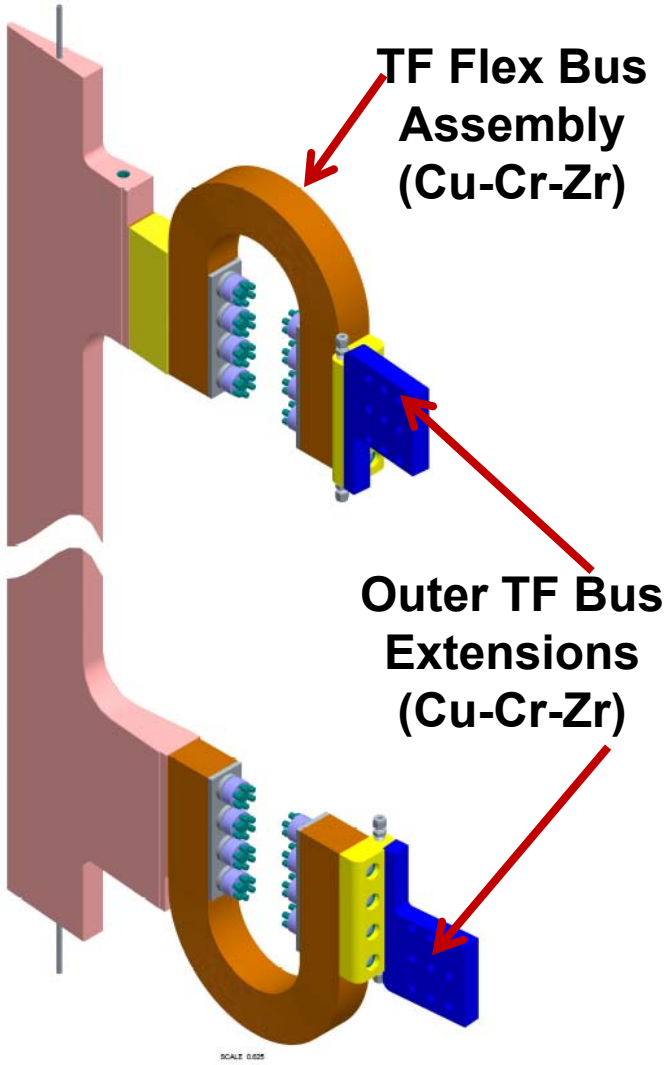
* Outside vendor procurement

CS Casing Support Structure

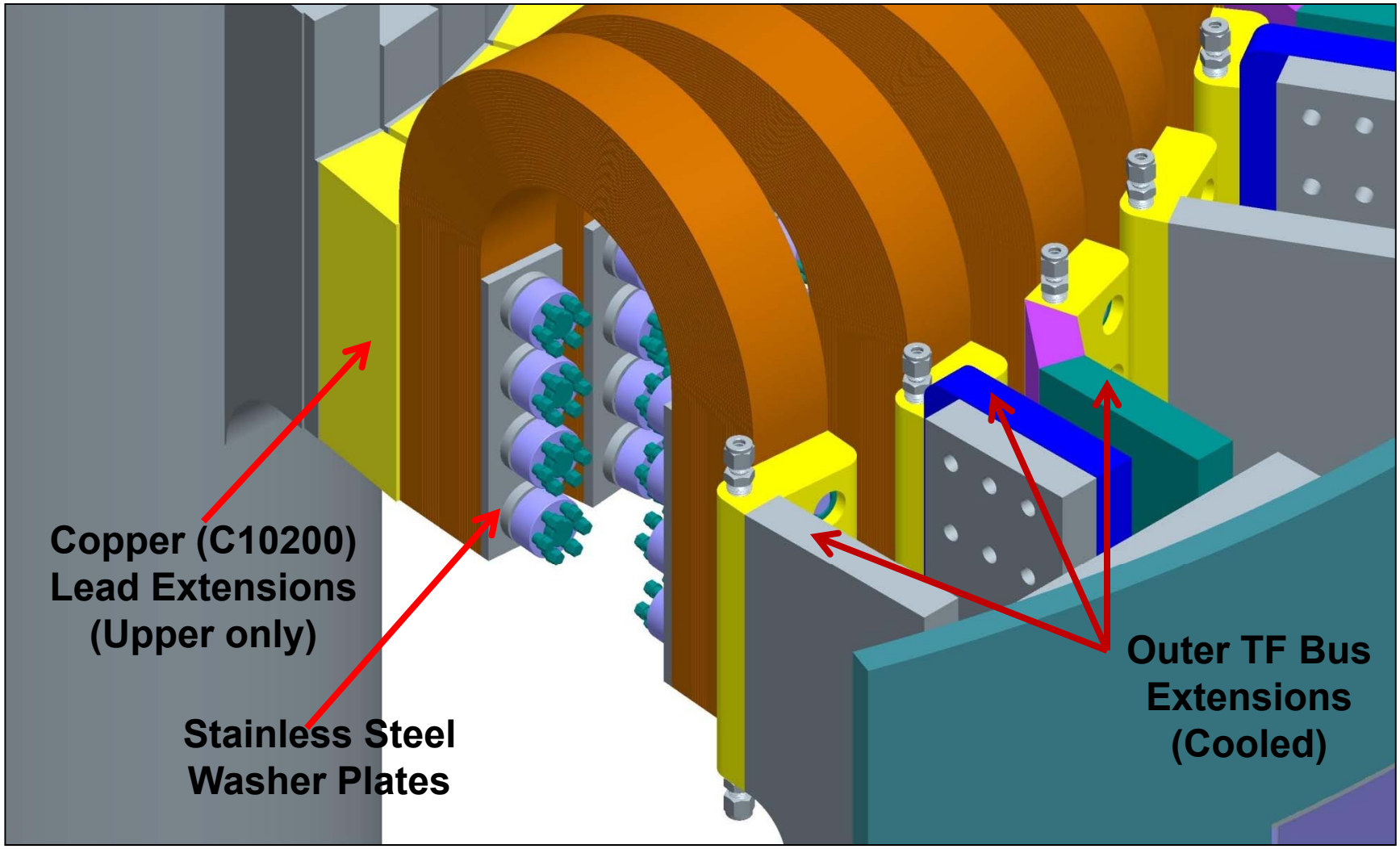


Inner TF Flex Bus Joint





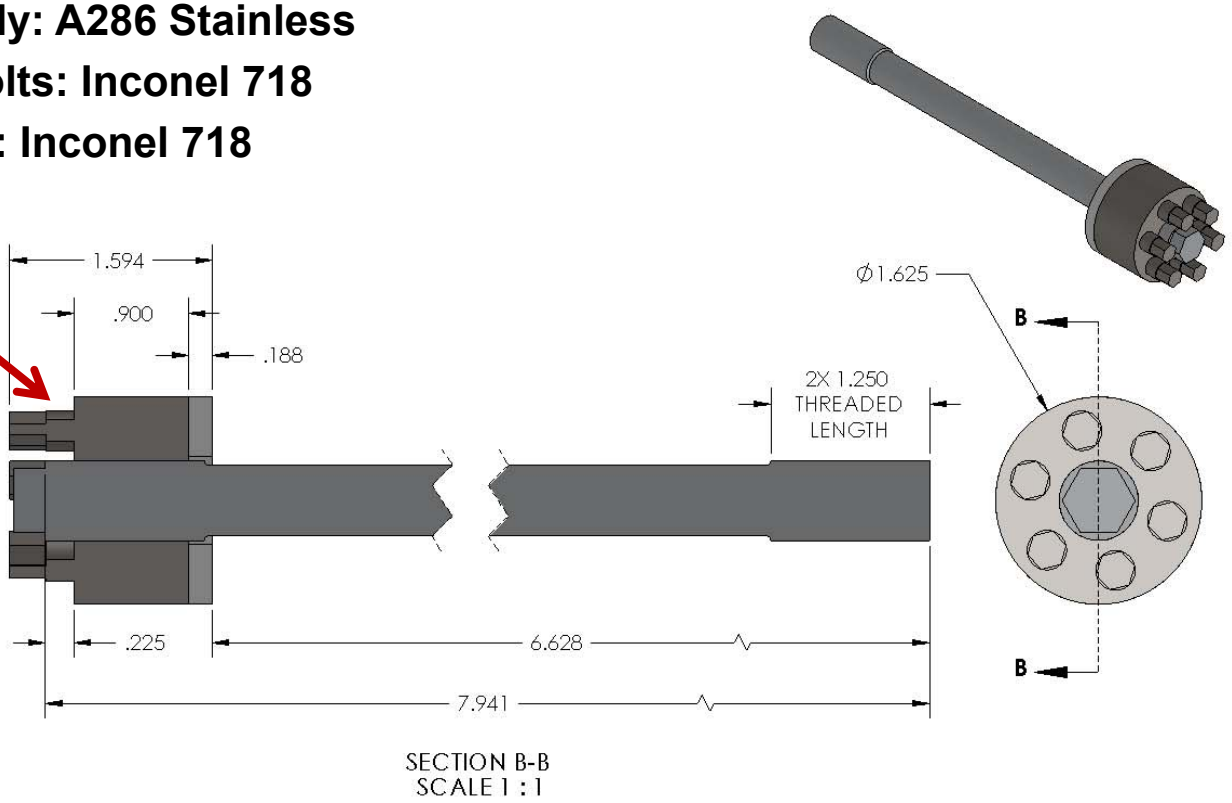
Inner TF Flex Bus Joint



TF Flex Bus Hardware

"Super Bolt" Materials:

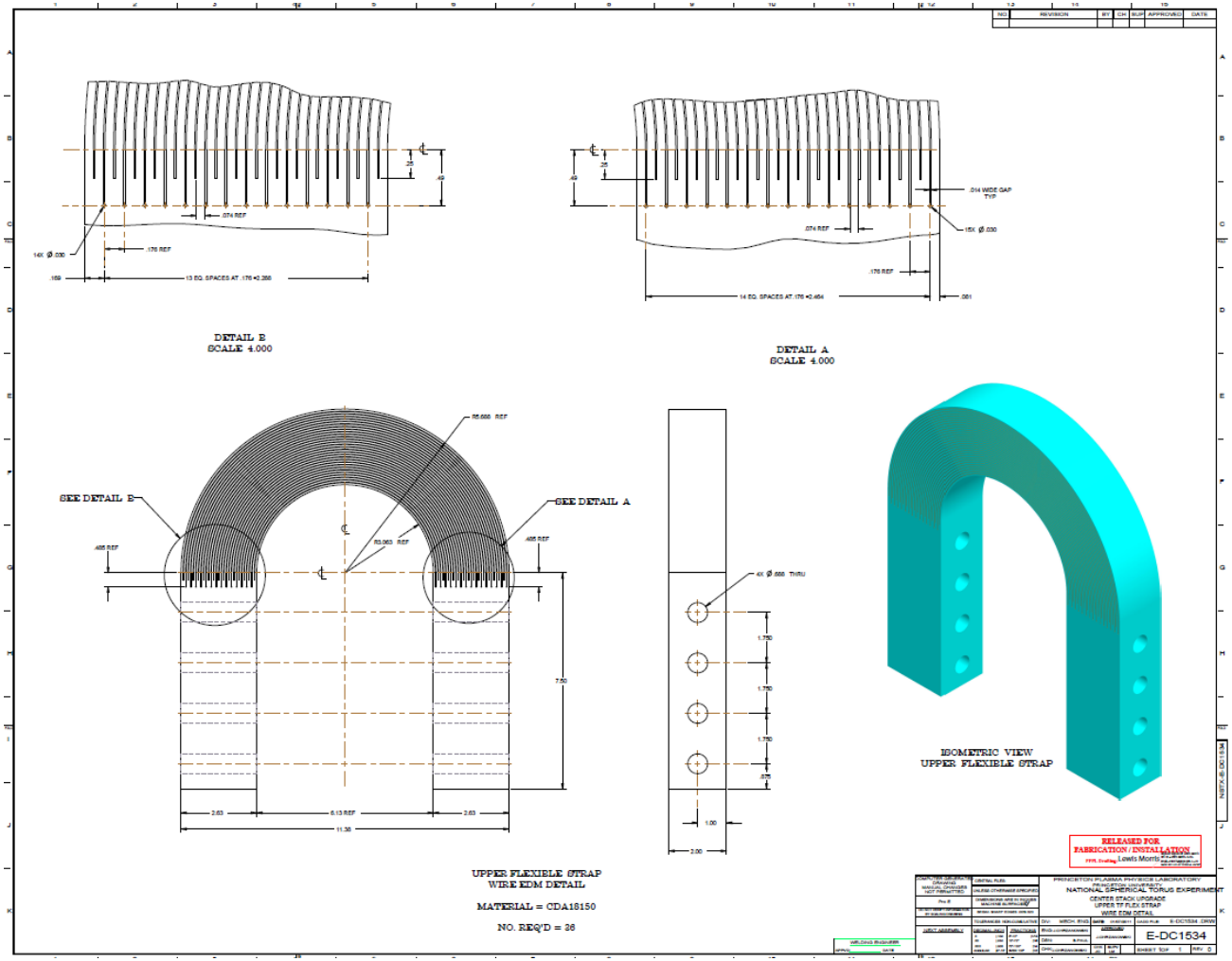
- **Nut Body: A286 Stainless**
- **Jack Bolts: Inconel 718**
- **Washer: Inconel 718**



LONG SUPERNUT AND STUD ASSEMBLY

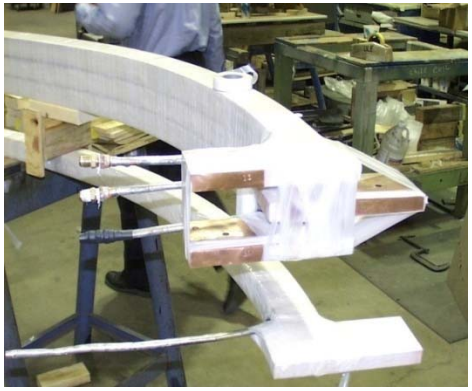
TF Flex Bus Assembly

- **Material:** Cu-Cr-Zr
- **Manufacturing Process:** EDM from sheet material (preferred method)



Outer TF Coil

- One Outer TF coil assemblies will be replaced during the upgrade shutdown. (Coil #OTF-7)
- No change in the physical design is being planned
- Insulation scheme will change.
  - **Existing insulation scheme:** B-stage insulation (CTD-112) is no longer available
  - **New OTF assembly scheme:** CTD-425 the Cyanate Ester hybrid will be used. Sandblasting and priming w/ CTD-450 will be used to prepare the copper conductors.
- The aluminum support blocks and stainless steel clamps will be reclaimed from the existing OTF and reused on the new coil.
- The coil will be built by an outside vendor
- PPPL will mount (in-house) the aluminum support blocks and SS clamps



Center Stack Assembly

- The assembly of the center stack components will be completed at PPPL.

- The next talk will describe in detail the plans and assembly sequence for the center stack.

R&D Activities

- ***R&D Activities to support the design of the upgraded center stack are complete***
  - **Selection of VPI system for Inner TF bundle- tests performed by CTD √ complete**
  - **Friction Stir Welding (FSW) development for TF conductors- development & tests completed by Edison Welding √ complete**
  - **TIG-Braze for OH solenoid Layer to Layer joints- in house √ complete**
  - **"Aquapour" qualification program for use during winding OH solenoid- in house √ complete**
  - **TF Joint Insert Pull out tests- in house √ complete**
  - **TF Flex bus tests- in house √ complete**

Drawing & Document Progress

- **Inner PF Coil:** 65 drawing approved (100%)
- **Inner TF Bundle:** 28 drawings approved (95%)
- **OH Solenoid:** 39 drawings are ready for approval (100%)
- **Center Stack casing:** drawings in progress
- **Inner TF Conductor:**
  - Completed conductor Specification (D-NSTX-SPEC-13-128)
  - Completed Inner TF Conductor Assembly SOW (D-NSTX-SOW-13-133)
  - Procurement process has started
- **Manufacturing Plan:** generated manufacturing plan for the CS components (NSTX-PLAN-MFG-1300-00)

SUMMARY

- *The design for the Center Stack components have been completed*
- *R&D activities have been completed*
- *In process of approving drawings for CS components*
- *Procured Inner TF copper extrusions*
- *In process of placing purchase order for completing Inner TF coil conductor assemblies.*
- *Inner TF flex bus and joint have been designed and has been supported with R&D tests.*
- *One Outer TF Leg assembly will be fabricated to replace the damaged OTF-7*