NCSX Field Period Assy Overview

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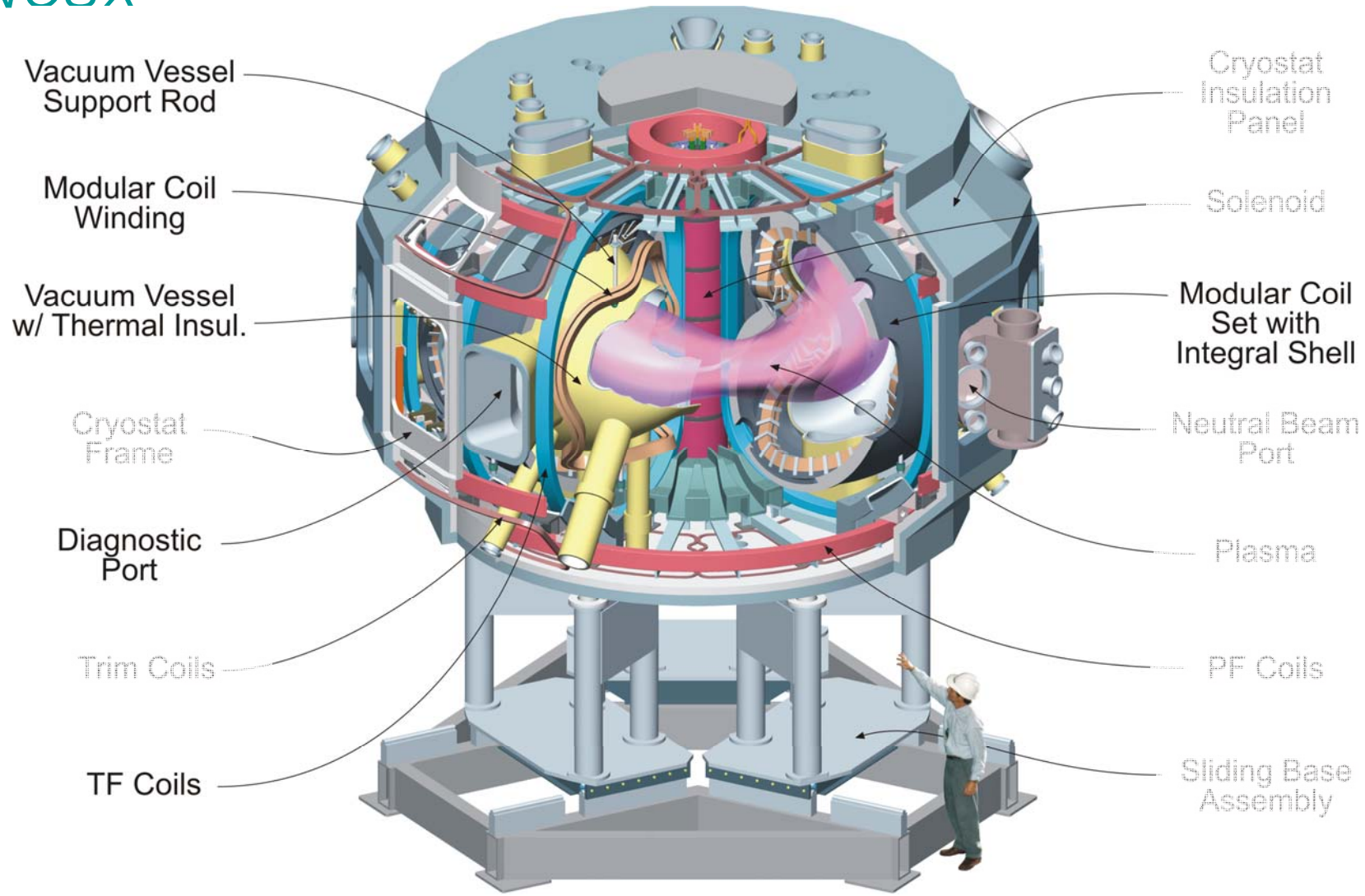
NCSX FPA Peer Review
October 11-12, 2006
PPPL

Presentation Outline

- **Overview of the Stellarator Core**
- **Field Period Assy**
  - **Components**
  - **Assembly Steps**
- **Summary**

Cutaway View of Stellarator Core



Vacuum Vessel design overview

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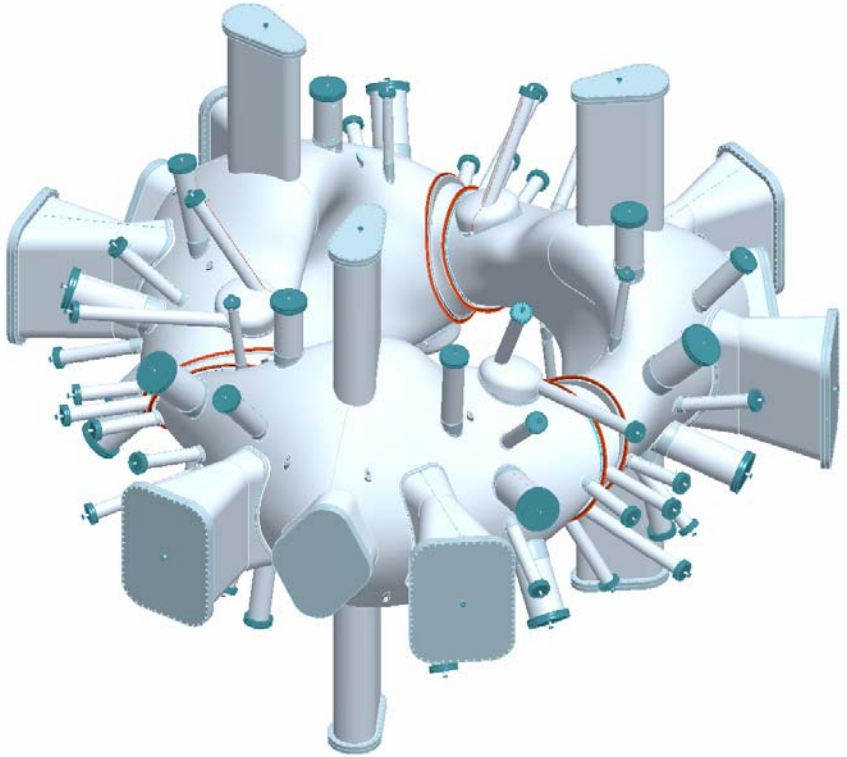
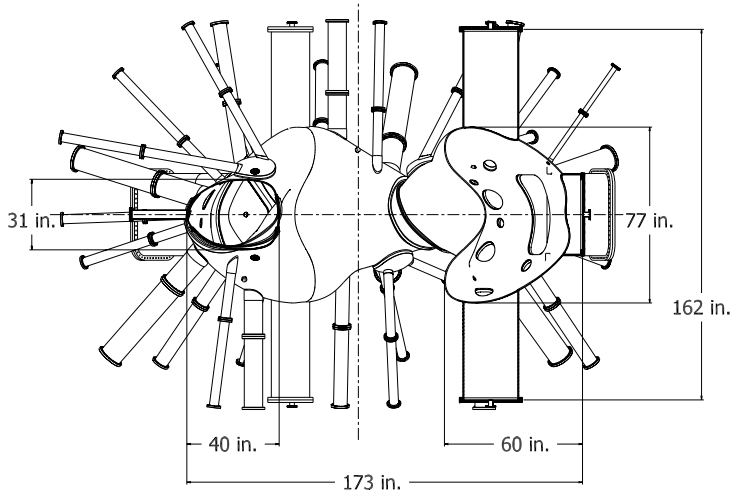
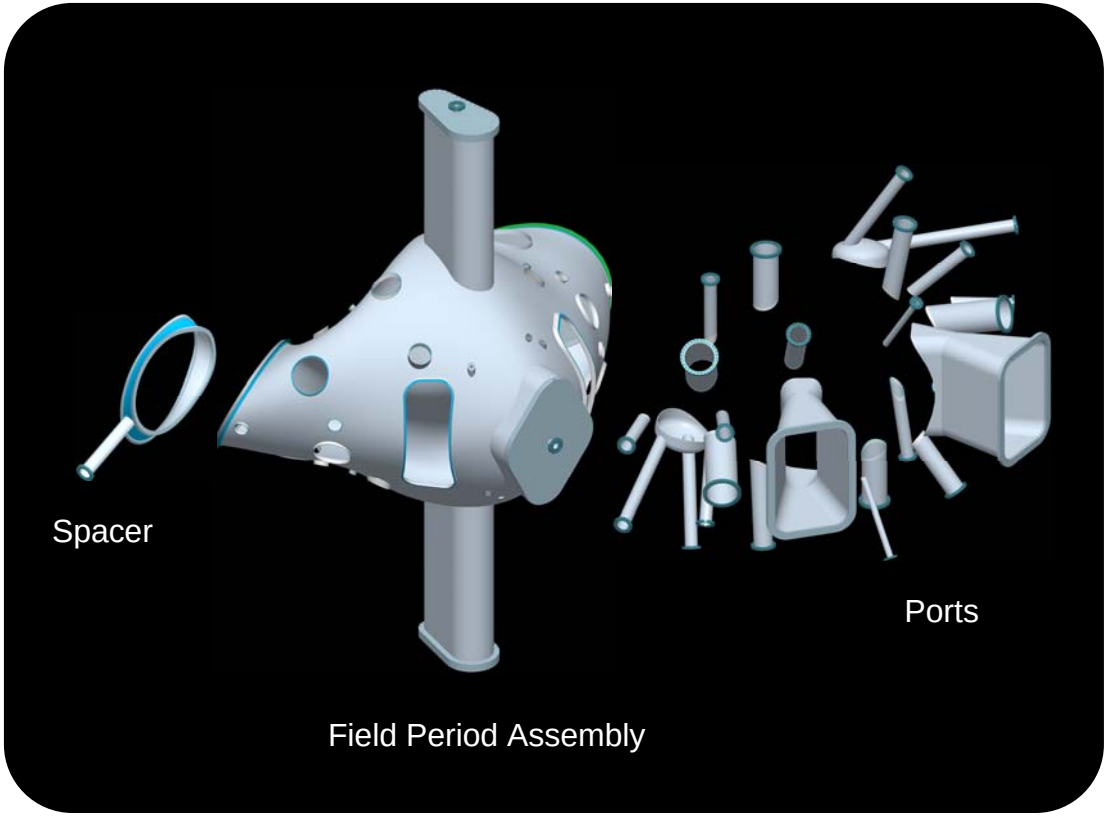
- **Shell material - - - - - - -Inconel 625**
- **Thickness - - - - - - - -- - .375 inch**
- **Time constant - - - - - - -5.3 ms**
- **Total wt w/ports - - --~ 20,000 lbs**
- **Welded joints connect field periods**
- **Traced with He gas lines for heating (to 350C) and cooling**
- **Nanogel insulation between VV and cold mass**





Vacuum Vessel Subassembly (VVSA)

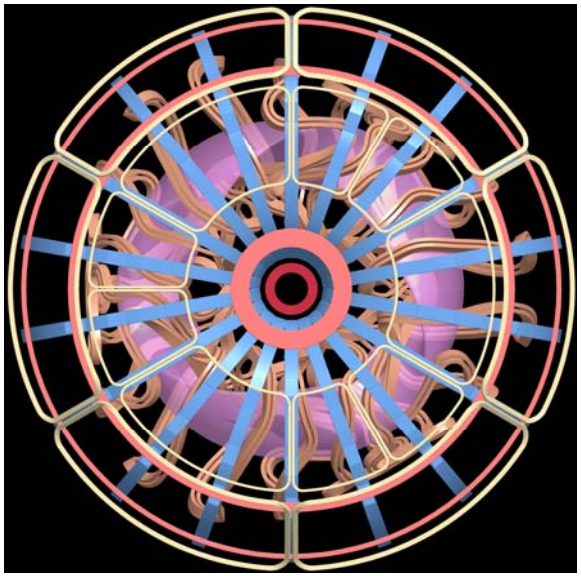
- **120 degree vessel shell with holes, port stubs, vertical ports, NB port**
- **Port extensions with backing rings, leak check tubes, all hardware**
- **Spacer with port extension**

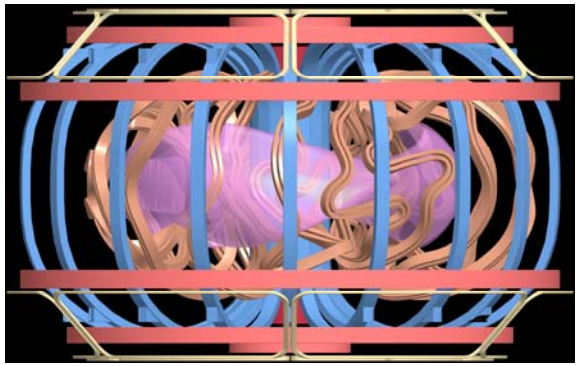


3 complete VVSAs have been procured

Four coil systems are required

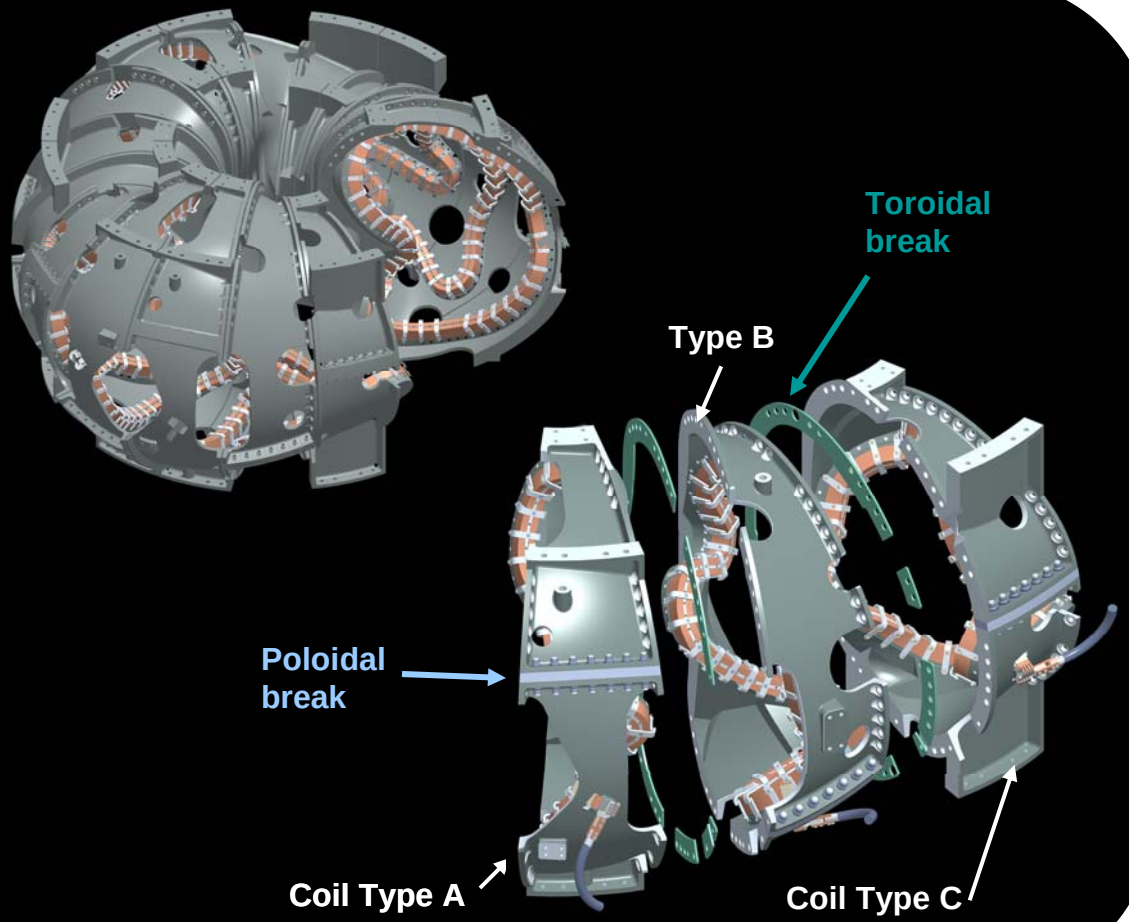
Coil Set	Function: Coil Set Provides
Modular Coils	Basic quasi-axisymmetric magnetic configuration
Poloidal Field Coils	Inductive current drive, plasma position control, plasma shaping
Toroidal Field Coils	Addition or subtraction of toroidal field for control of magnetic transform
Trim Coils	Control of magnetic flux surface quality



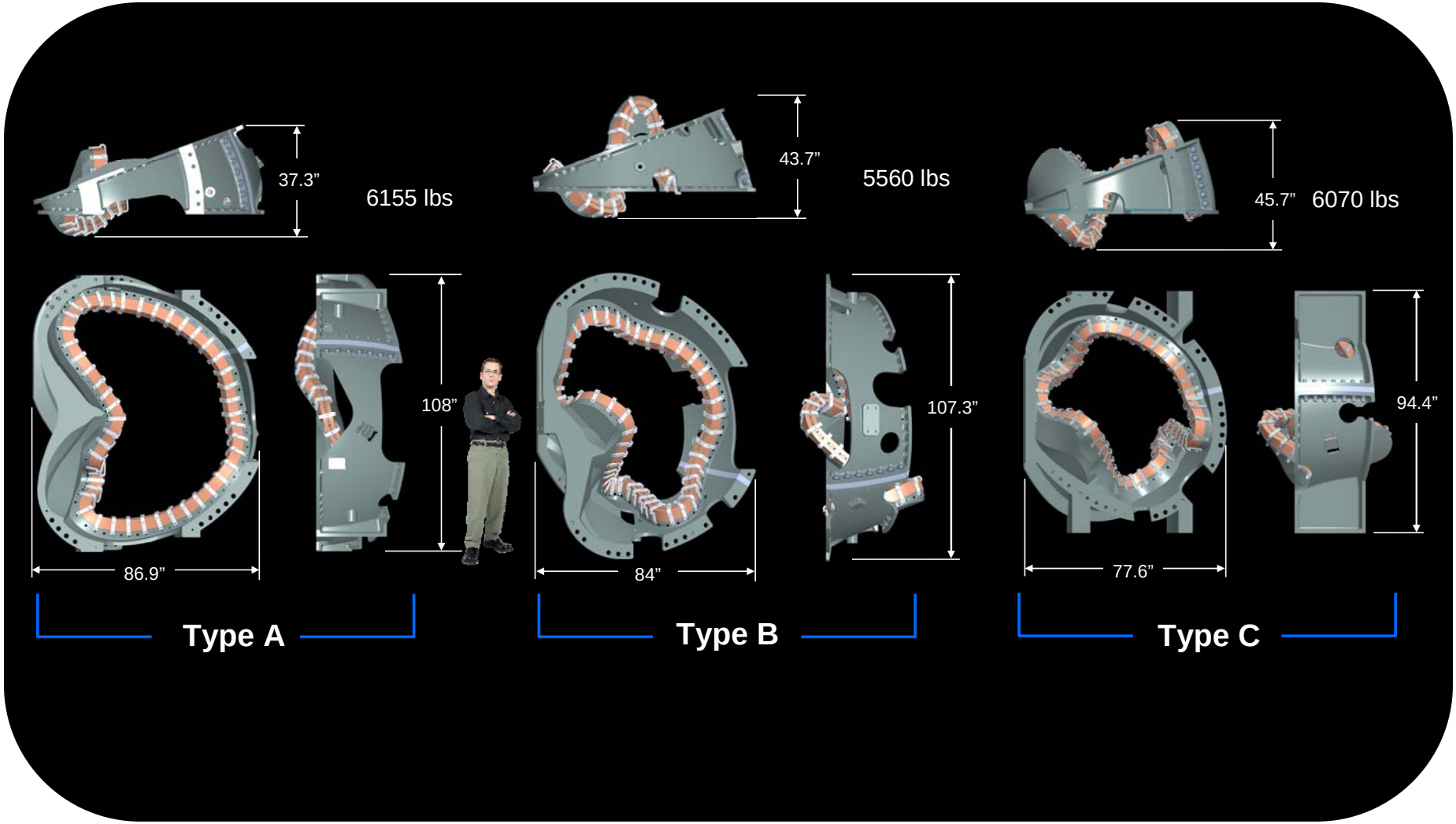


Modular Coils

- Shell consists of individual modular coil winding forms that are bolted together
- Penetrations have been provided where needed
- Provides “machine base” for all other components
- Stellarator symmetry preserved
- toroidal and poloidal electrical breaks to limit eddy currents



Three types of modular coil assemblies



Coil fabrication based on winding form

- Continuous support for strength and accuracy of winding
- Single machined part provides winding form and assembly features
- Winding never removed from winding form

Casting:

- Casting poured
- Casting from mold and upgraded

Poloidal Break:

- Poloidal break cut
- Poloidal break hardware is installed,

Machining:

- All machining is completed
- Port openings cut

Winding:

- Studs attached
- Conductor wound
- Chill plates & coolant tubing installed

VPI and Testing:

- VPI
- Cryogenic and electrical tests
- Final geometry measurement

TF Coils and Structure

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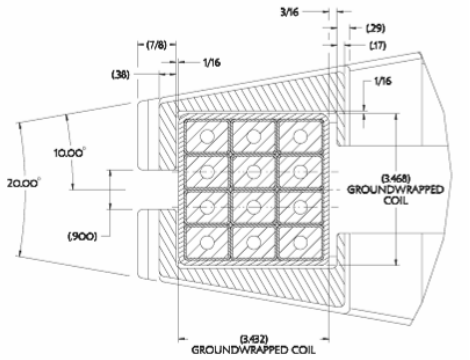
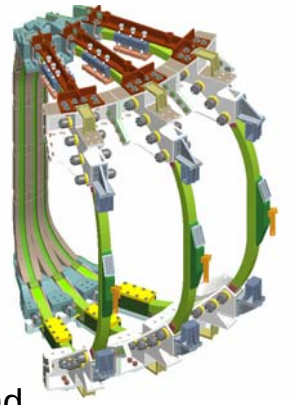
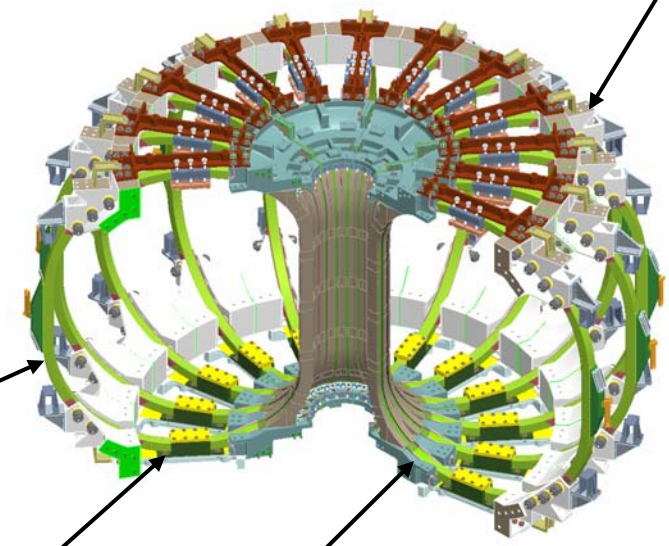
- **18 coils provide up to +/- 0.5 T for flexibility beyond reference scenarios**
- **Wound from hollow copper conductor and vacuum pressure impregnated with epoxy**
- **Supported from external coil support structure , Centering load supported by wedging**
- **Pre-cooled to LN2 temperature, temp rise < 5K**





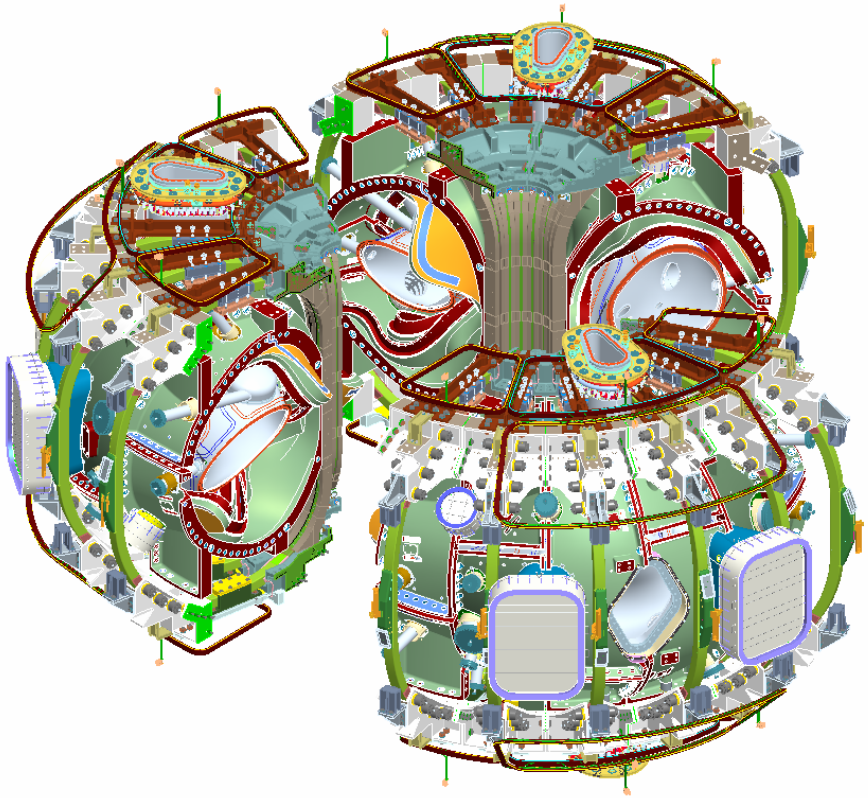
• Wedge structures and winding

• 3-Coil module



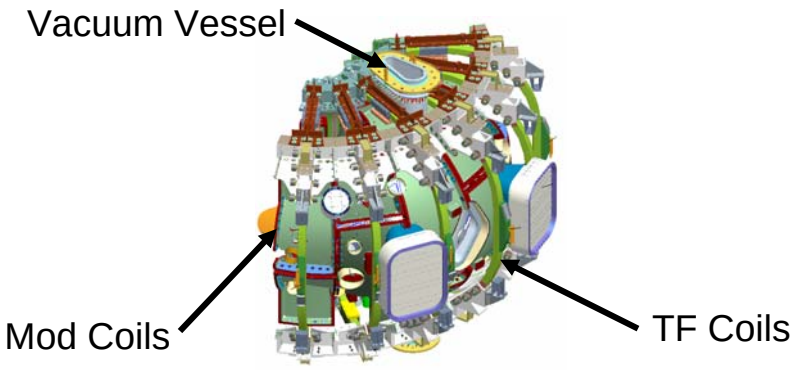
What is a Field Period?

The Stellarator Core consist of 3 Field period assembles

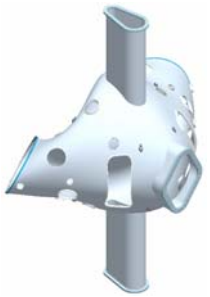


Each Field Period Assy has the following major components:

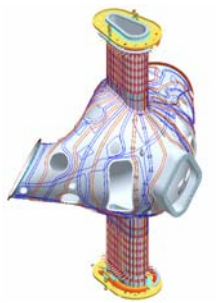
- 1 Vacuum Vessel Segment
- Six MC segments
- Six TF Coil segments



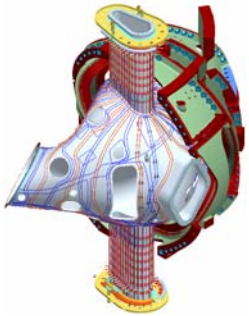
Field Period Assembly



Receive VVSA from vendor

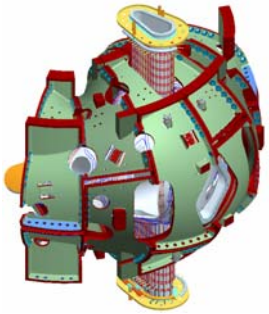


Add coolant tracing



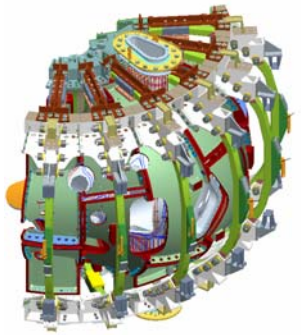
Add first 3-mod-coil set

Add 2nd 3-mod-coil set

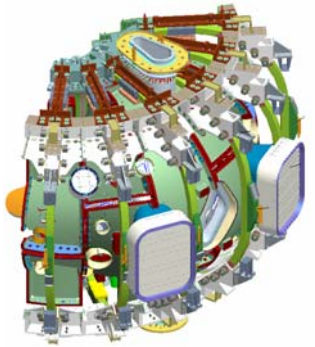


Add VV supports

Add first 3-TF-coil set



Add 2nd TF-mod-coil set



Add port extensions

VACUUM VESSEL HEATING AND COOLING & INST

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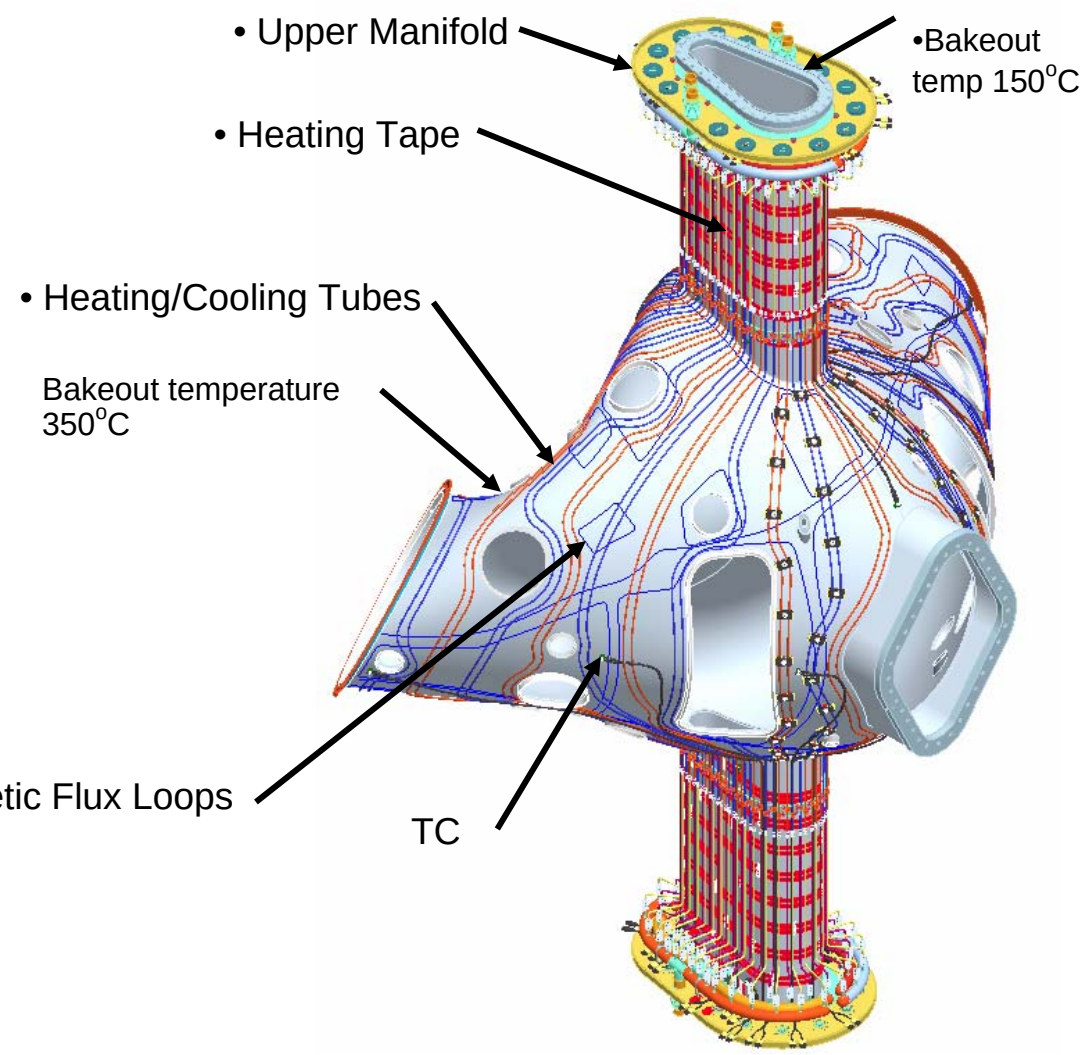
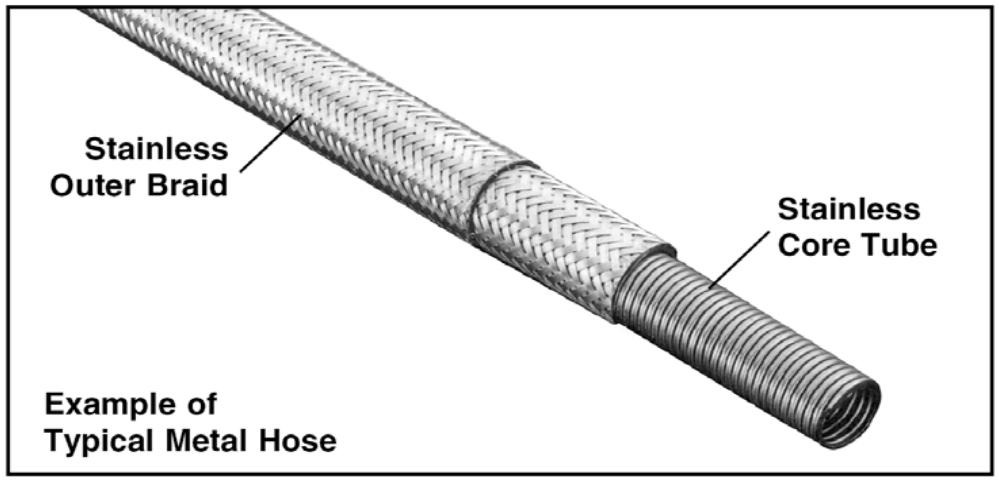
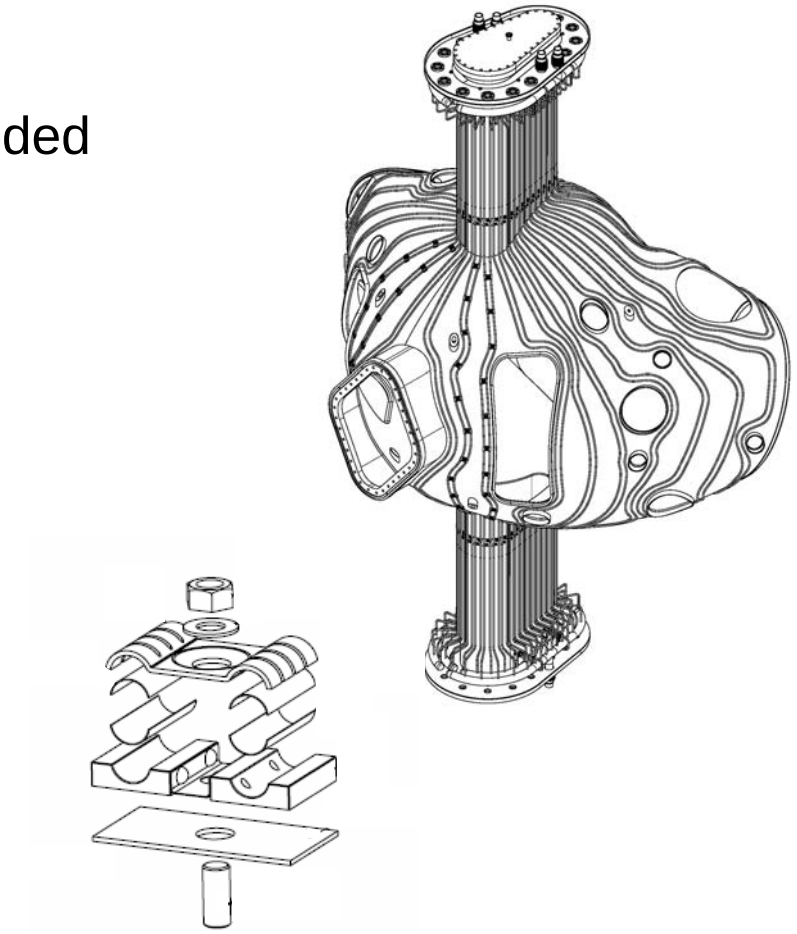
- Magnetic Flux Loops - ~70
- Heating/cooling tubes - 32
- Heating tapes on vertical ports - 16
- Upper and lower manifolds
- Instrumentation – TC - 58



Cooling tube design modified to aid fabrication

- Design uses welded bellows with braided reinforcement
- Standard product, easy to install





Cross section at typical clamp

Assy Requirements

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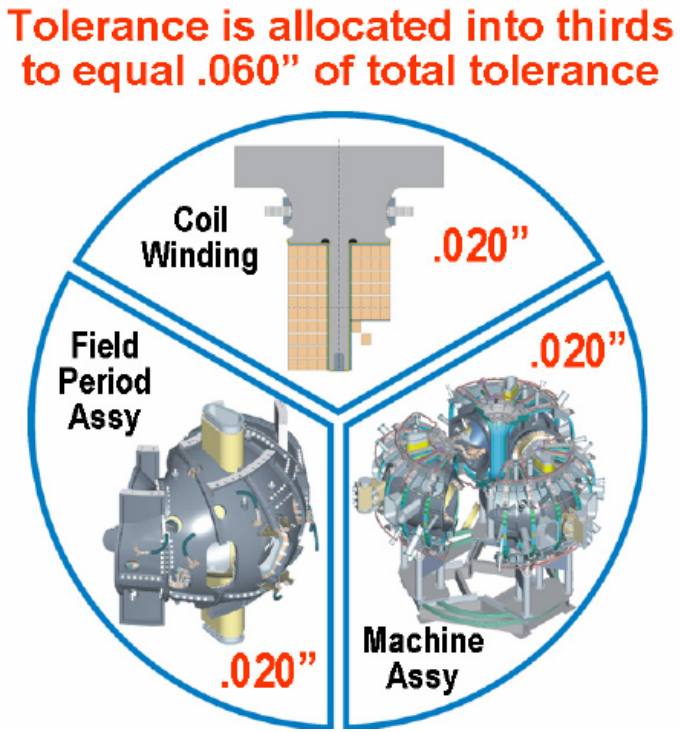
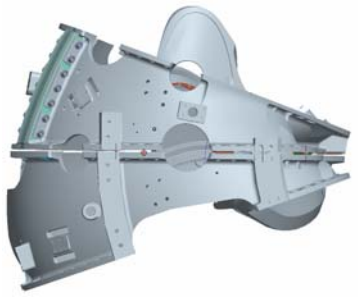
Requirements

- Position Winding Center within a TP of .020 inch.

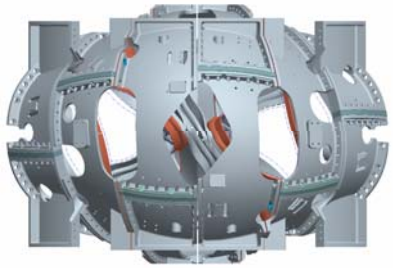


FPA tol distribution



Tol for coil to coil
.010

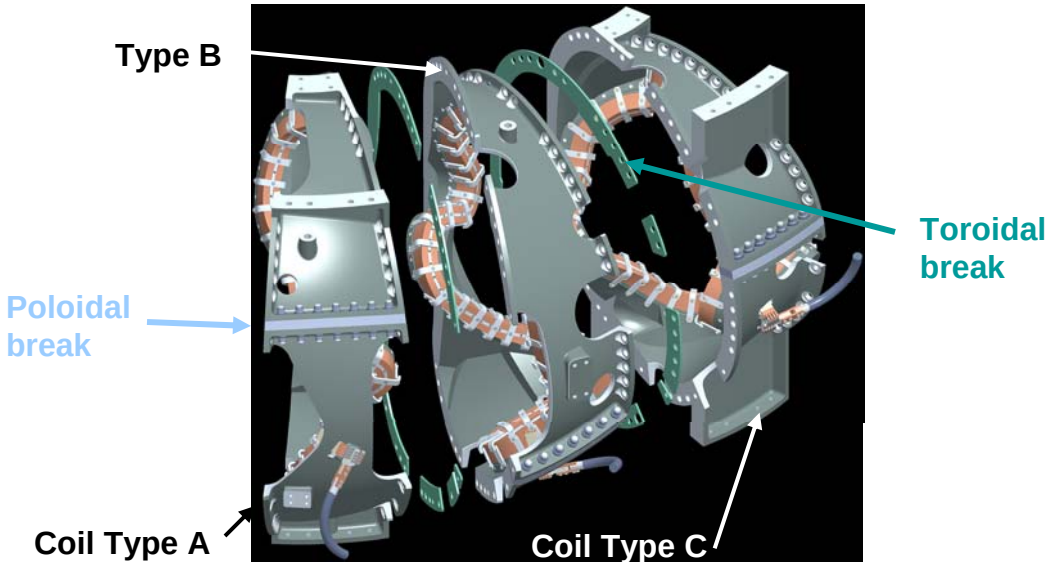
Tol for HP assy
.010



Mod Coil Half Period (HP) Assembly

Several steps are necessary to assemble mod coil segments

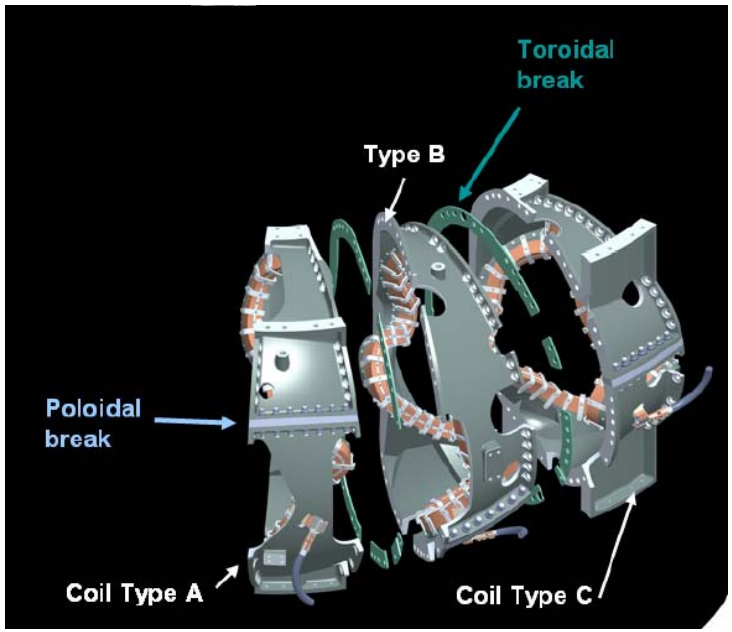
- Coils are positioned relative to each other using a 3 point system to adjust coil location to achieve a +/- .010 in. tolerance
- Shims are installed between coils for electrical isolation and shear/compressive load carrying capacity
- Bladders are installed between wings and winding form to limit deflection to < .120 in.
- Bushings and bolts are installed to clamp the coils together to provide electrical isolation and provide clamping and shear force



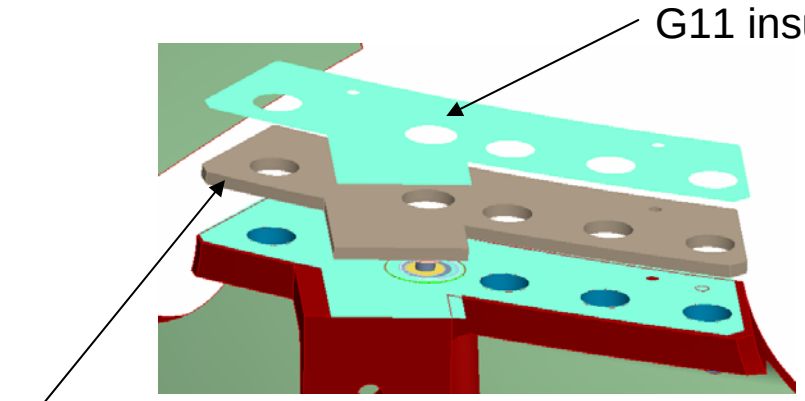
Shims between coil to coil assy

The shims provide the following functions

- Insulate between the coils
- Path for compressive and shear loads
- Adjust coil position during assy



Shims consist of a composite of sstl and G11 insulation



sstl shims machined from data obtained during dimensional inspection of flange surface

Shims between coil to coil assy

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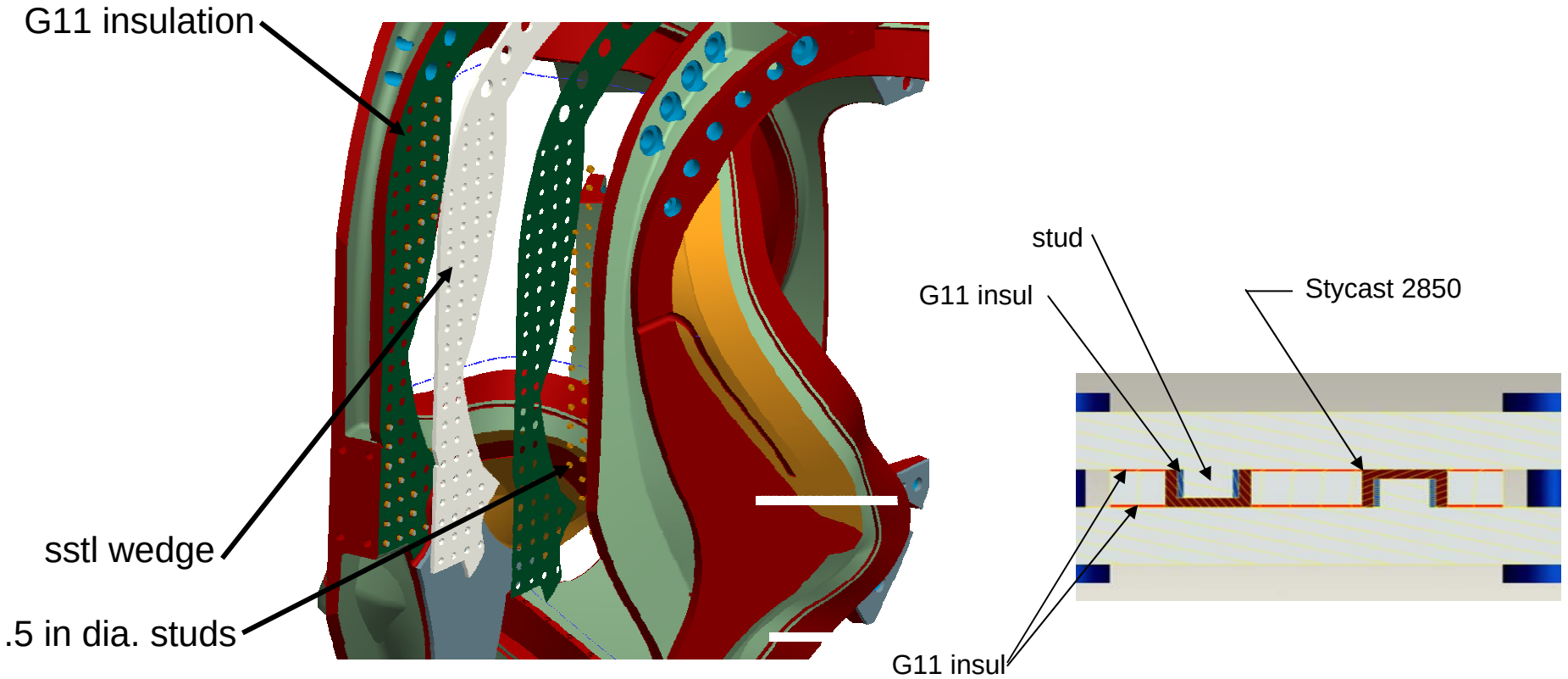
Shims provide shear path for loads on the inside coil flange where bolting is not practical.



Bladder Installation

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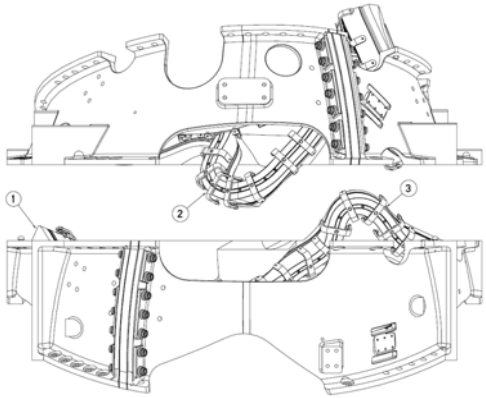
Requirement for bladders - deflections under load

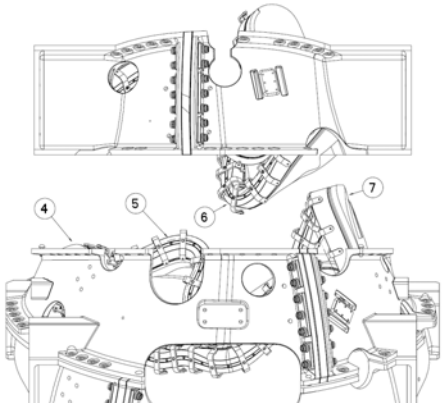
- Modular coils shall be designed such that deflections due to thermal growth and due to electromagnetic loads preserve stellarator symmetry
- Deflection of the nominal current centroid due to electromagnetic loads shall not exceed .120 in.

Bladder installation is needed for:

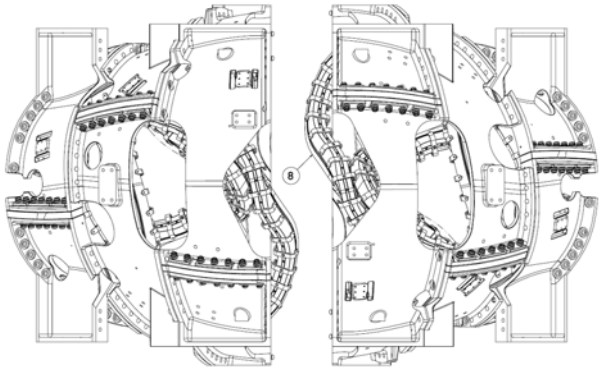
Coil to coil interface A-B



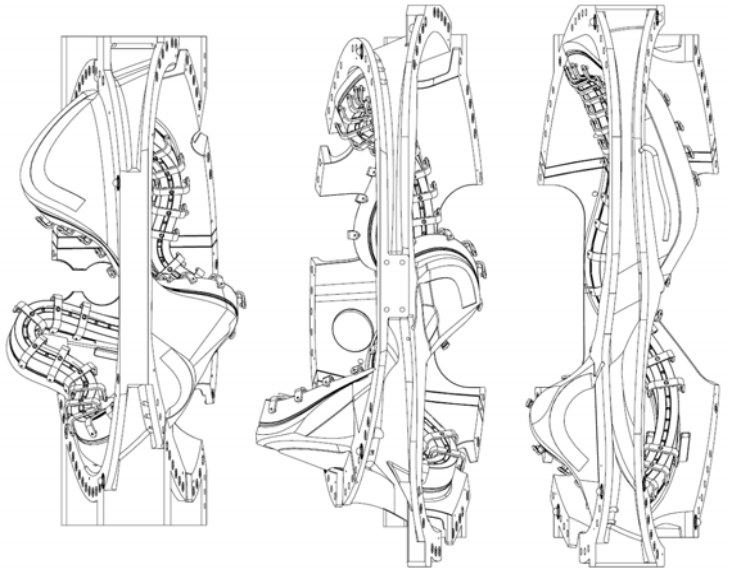
Coil to coil interface B-C



Coil to coil interface A-A

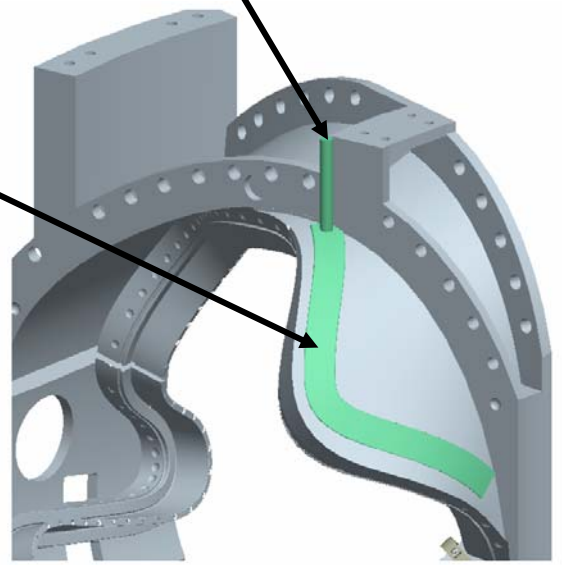


Bladder Installation

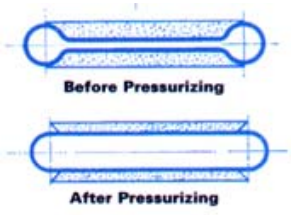


Fill access for expanding bladder

Expandable sstl can installed in machined grove of wing



Exploring option for using commercially available configuration and/or similar to this design

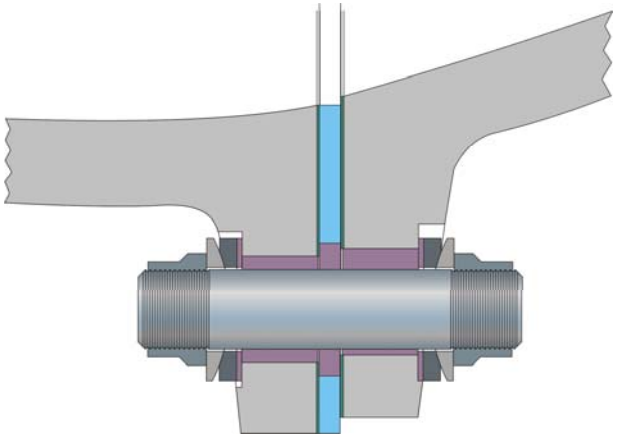


Commercial steel capsule jack or “flat jack”

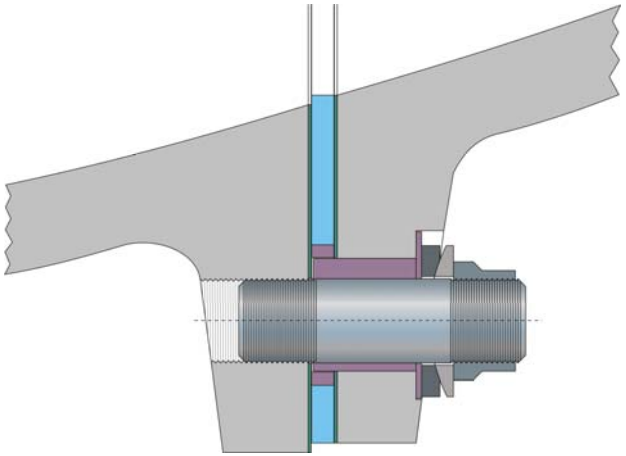
Bushings, Bolts and Reaming

- The coils are bolted together using 1.375 in. dia. high strength bolts
- G11 bushings are installed in the flange of each coil type for isolation
- Two configurations thru bolts and tapped holes are used

Thru bolting configuration



Tapped bolting configuration



Reaming operation for thru bolt configuration

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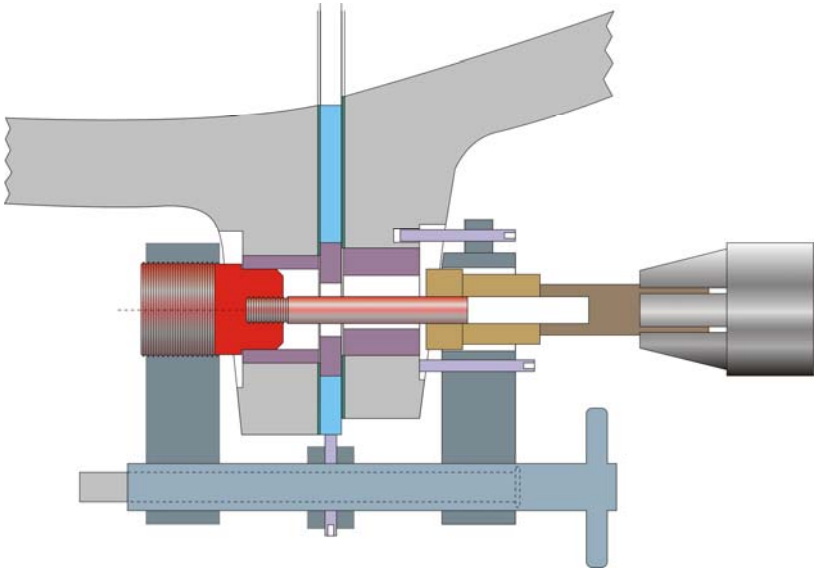
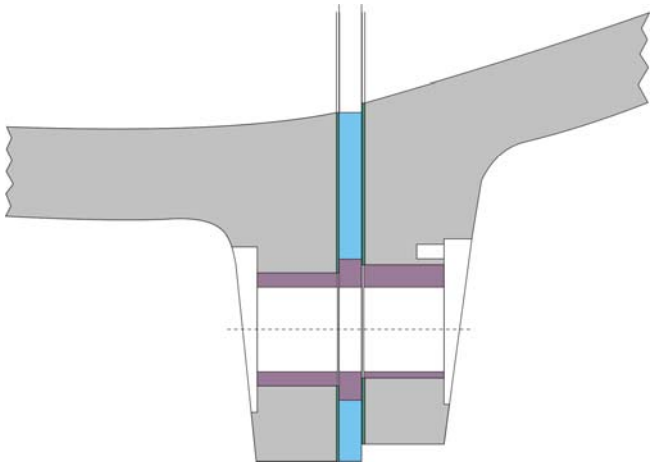
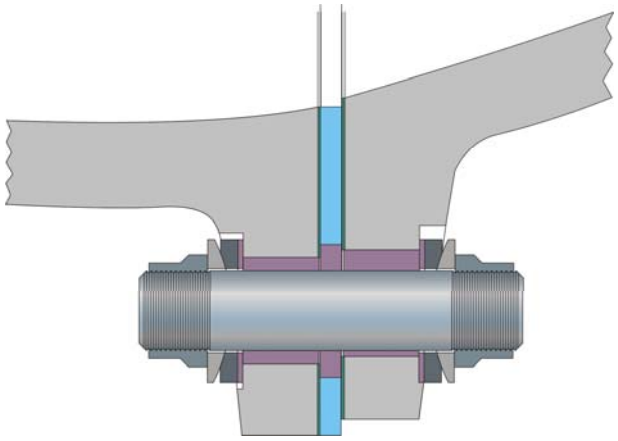
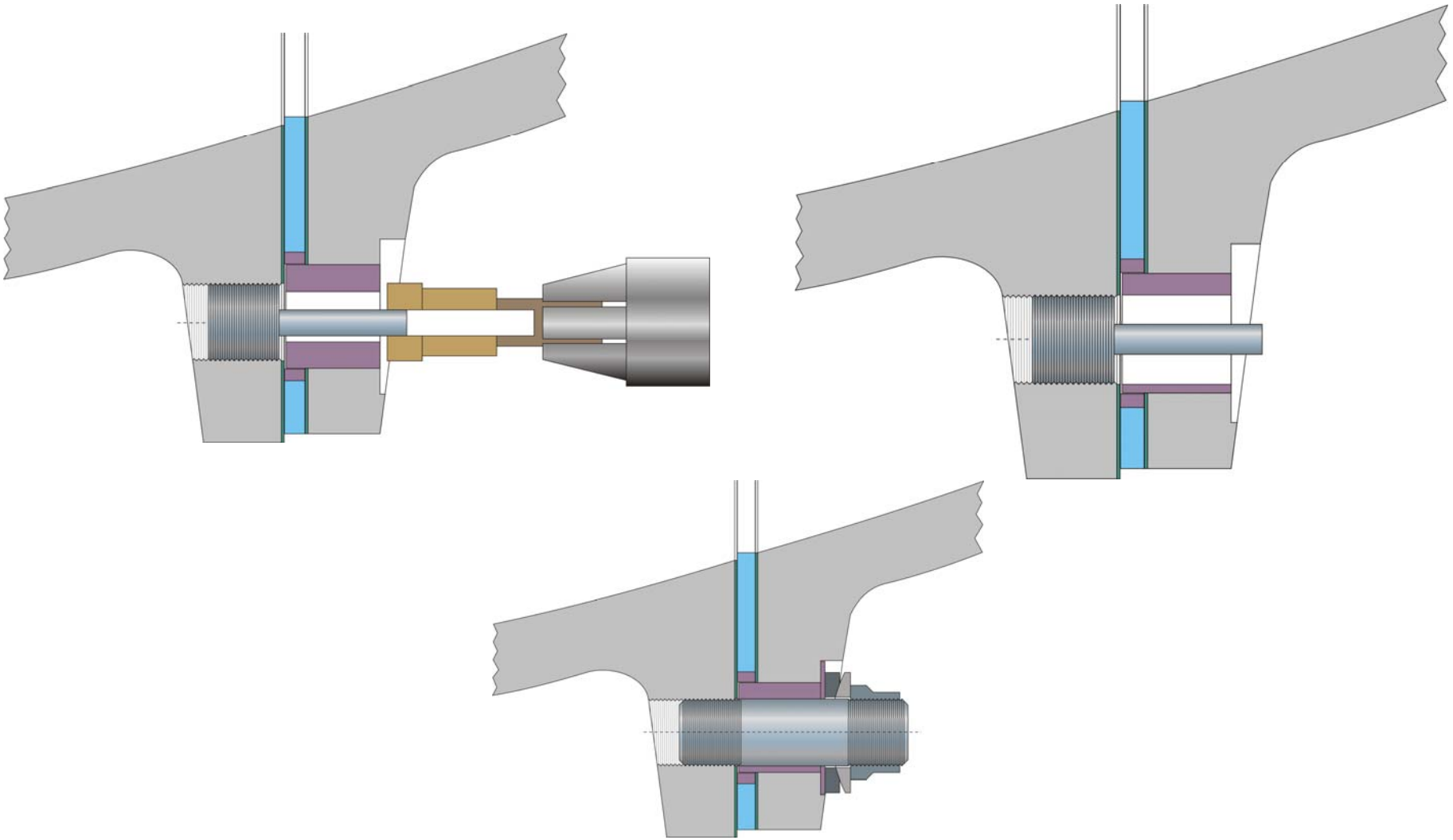






Reaming operation for tapped hole configuration



Access for reaming

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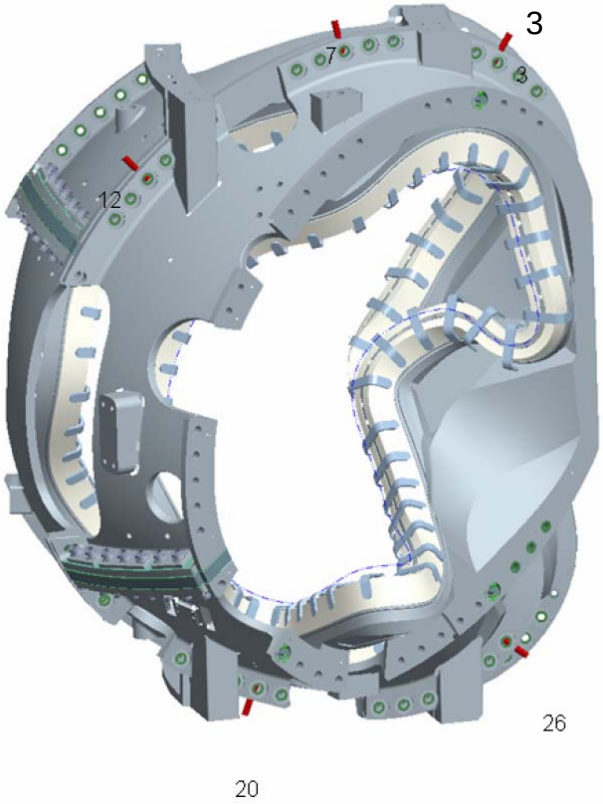
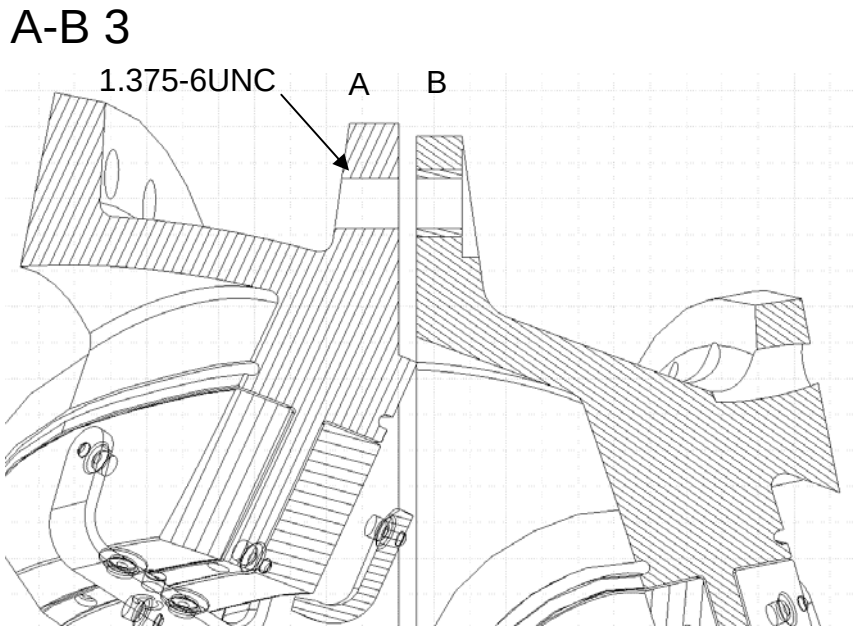
Access for reaming is very important. We are currently reviewing the configuration to assure adequate access is available.



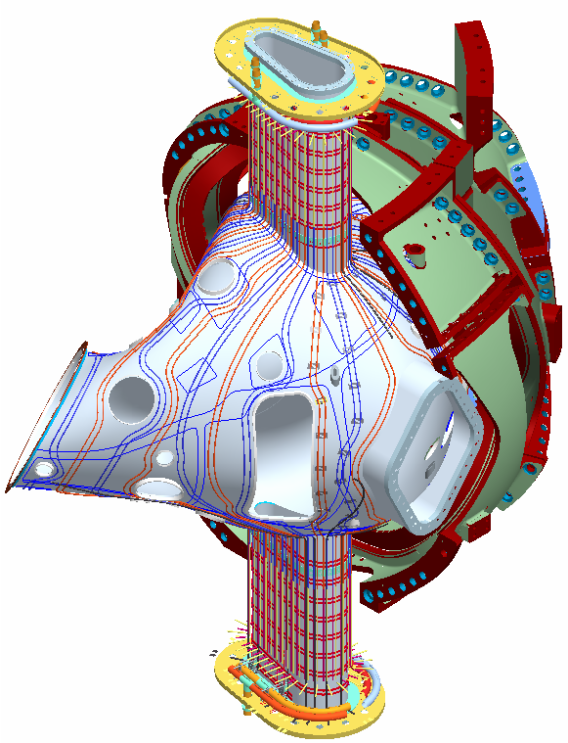


Installation of first HP over Vessel

Special tooling is required for assy of the HP coil over the vessel.

Fiducials mounted on the mod coils will be used during assy to monitor position and to position mod coils

Additional details will be presented in the next talk



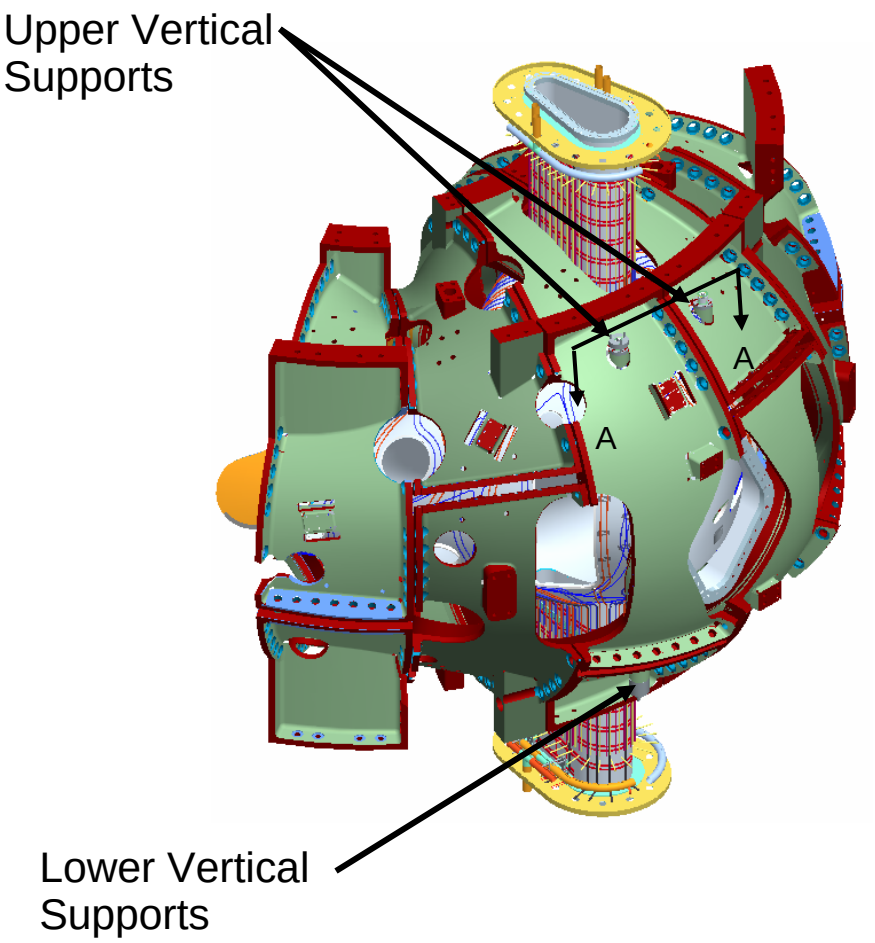
Vacuum Vessel vertical support location

The vacuum vessel vertical supports are located above and below the NB port

The supports above the NB port carry the weight of the vessel.

The supports below the NB resist vertical loads during a disruption

Temporary supports are located on the inside area of the vessel during FPA. These supports are removed during machine assy.



Vacuum Vessel Vertical supports

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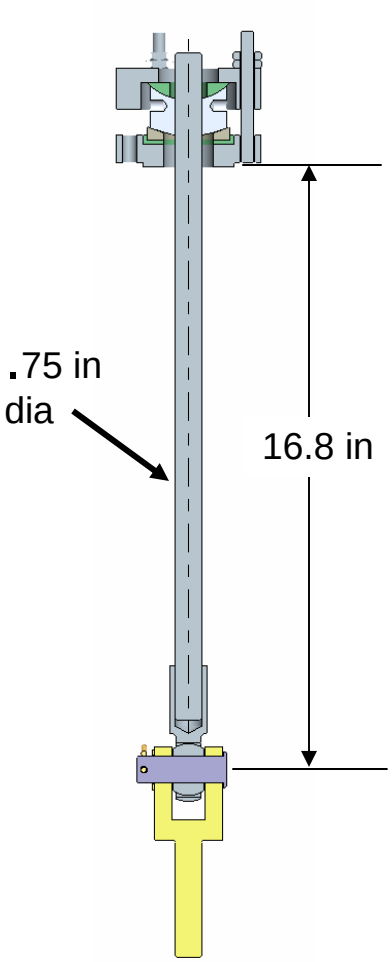
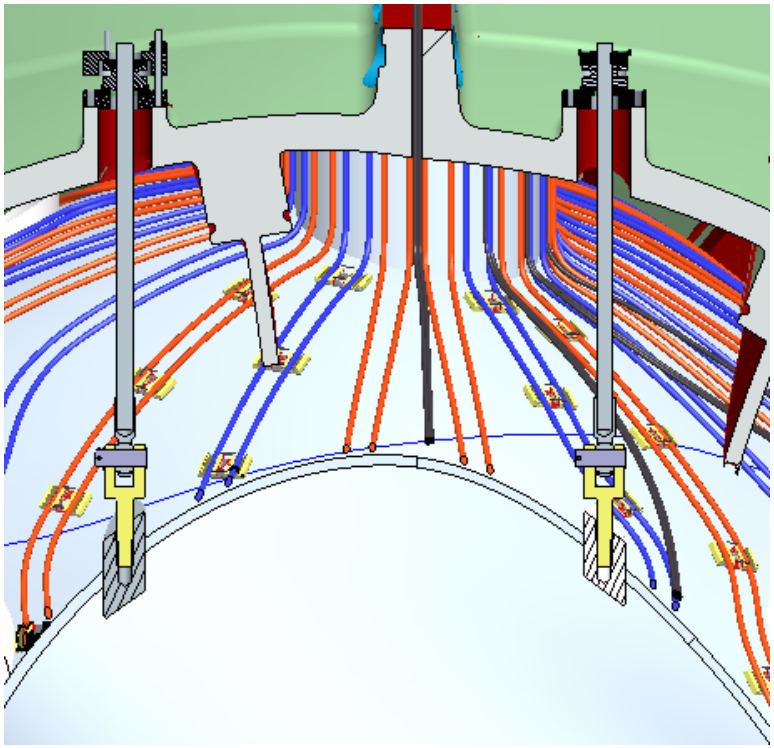
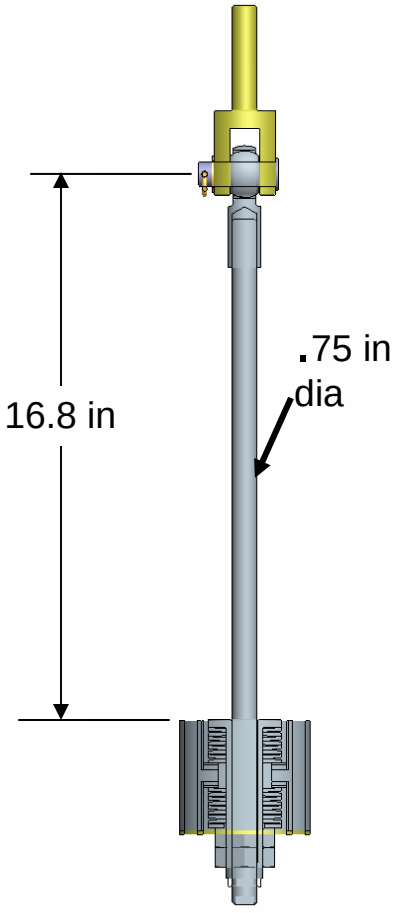
Upper Vertical Support



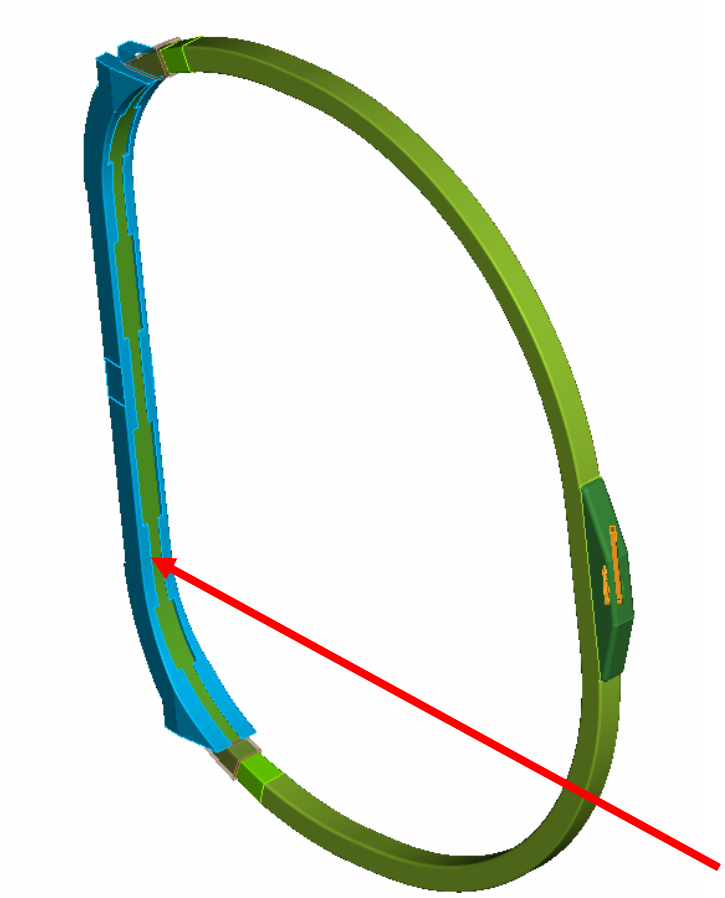


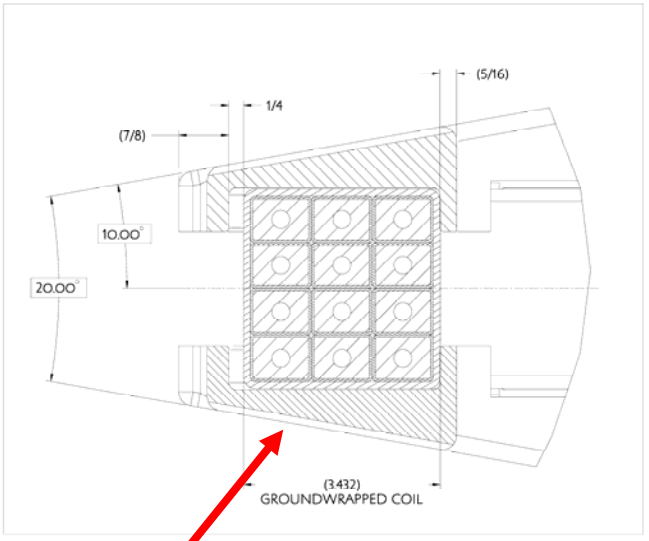
Section A-A

Lower Vertical Support



Wedge casting and TF coil



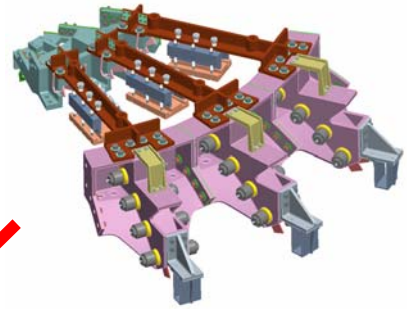


Wedge Casting Assembled to front face of Coil

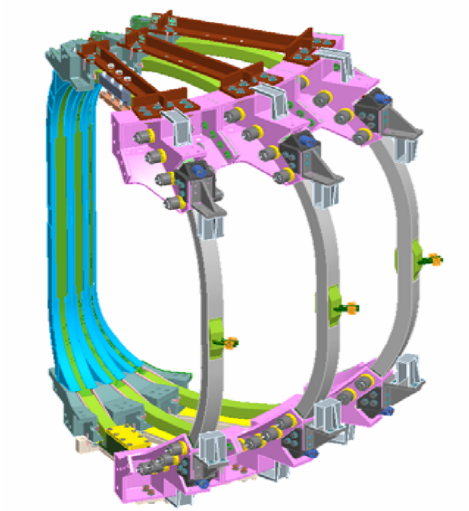
HP TF Coil Assy

The HP TF coil consist of the following components

TF coil and wedge casting

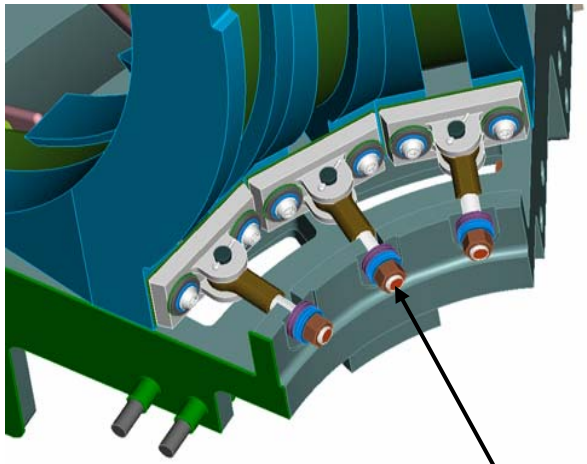


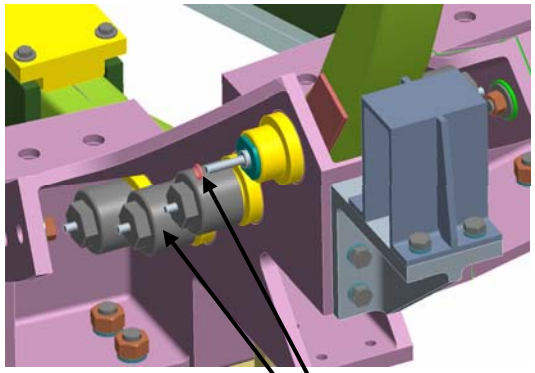
Support Structure

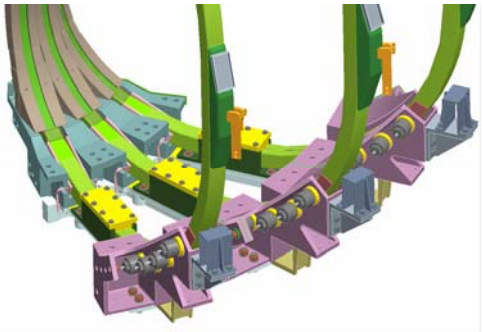


TF coil HP assy

Fine adjustment of TF coil is achieved using the radial and the lateral adjustment systems.







TF coils are nominally positioned at the FPA.

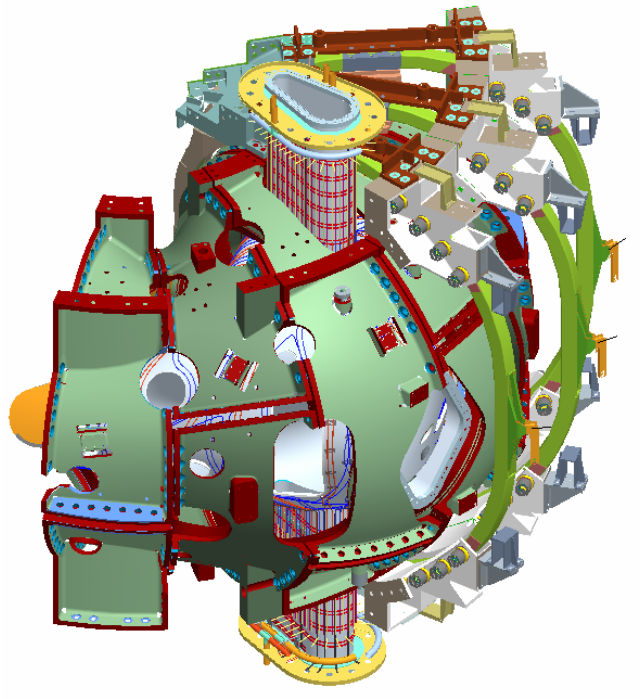
During machine assy the TF coils are wedged together

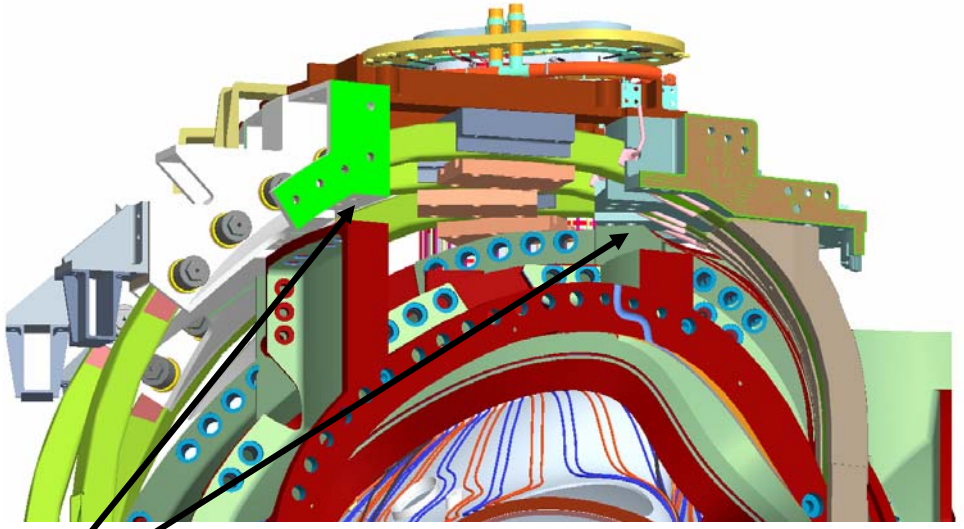
Adjustment in the toroidal direction is achieved using the Belleville washers & adjusting nut. Typ both sides

TF coil assy to mod coils

The TF coil is assembled over the mod coils using a fixture that simply supports the coil configuration until it is attached to the mod coils

Fiducials located on the mod coils and the TF coil will be used to temporarily position the coils. Final positioning will be accomplished in the test cell where the coils will be wedge together.





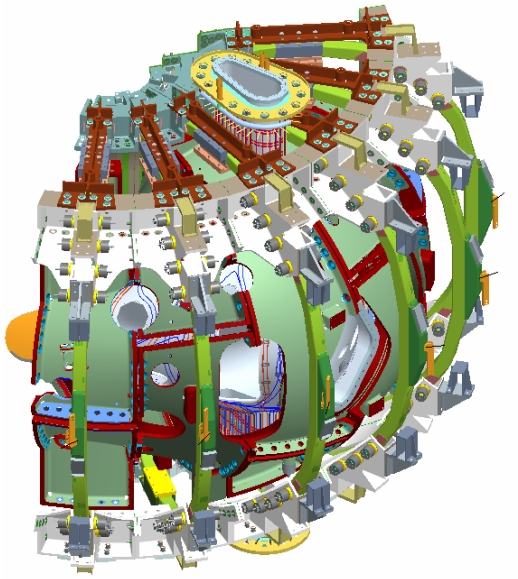
TF coils to be shimmed and bolted to mod coils supports in this region

Addition of Ports to vessel

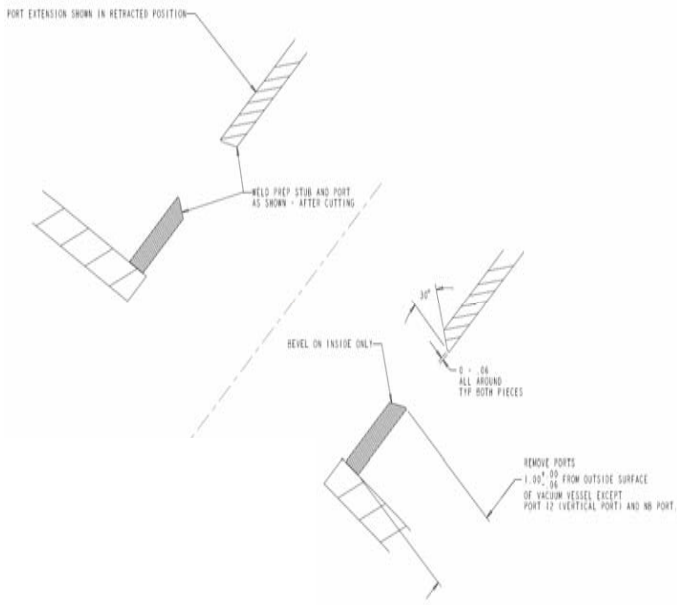
After installing the mod coils the ports can be welded to the vacuum vessel

Ports require heater tapes and insulation added to the outside surface before attaching to the vessel

The large hour glass ports will be tacked into place at the FPA. Final welding will be performed after the vessel has been fully assembled in the test cell to minimize warping during the welding operation.



Typical port welding detail

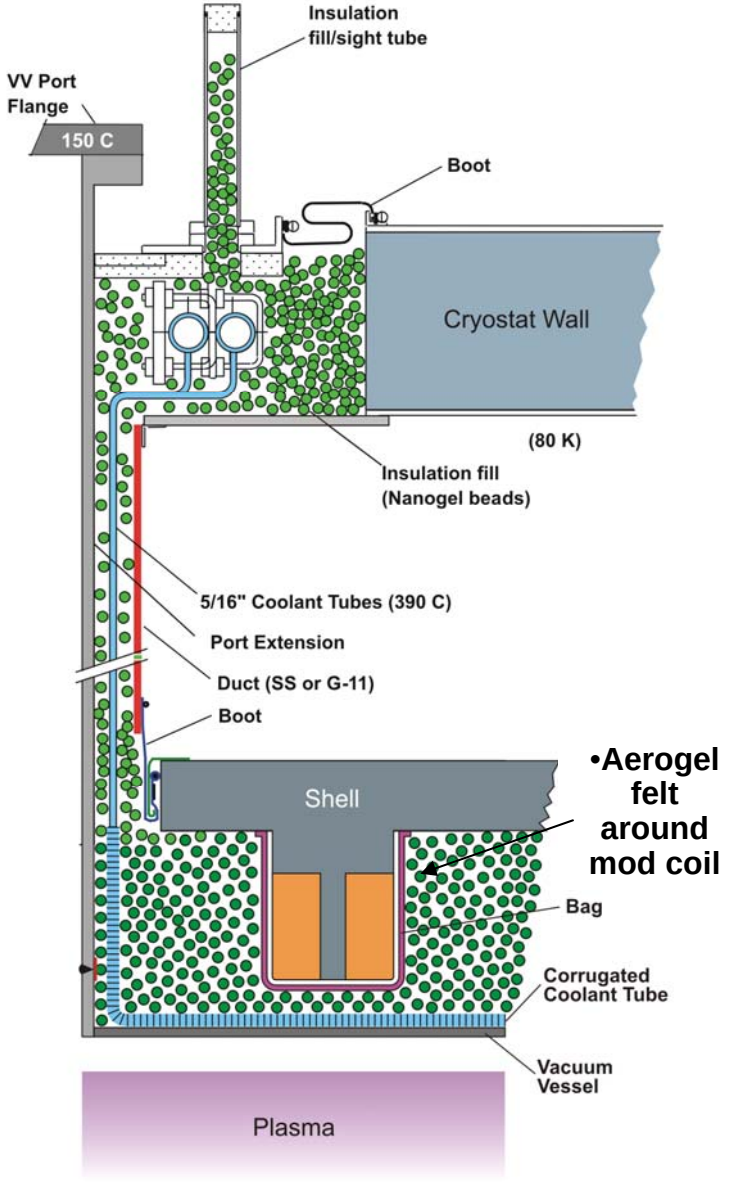


Loose fill provides thermal insulation

NCSX

After the boots have been installed and the FPA is installed in the test cell insulation will be placed between the vessel and mod coils

- Insulation design uses loose fill of nanogel beads
  - Inexpensive
  - Better insulation (1/3 heat leak)

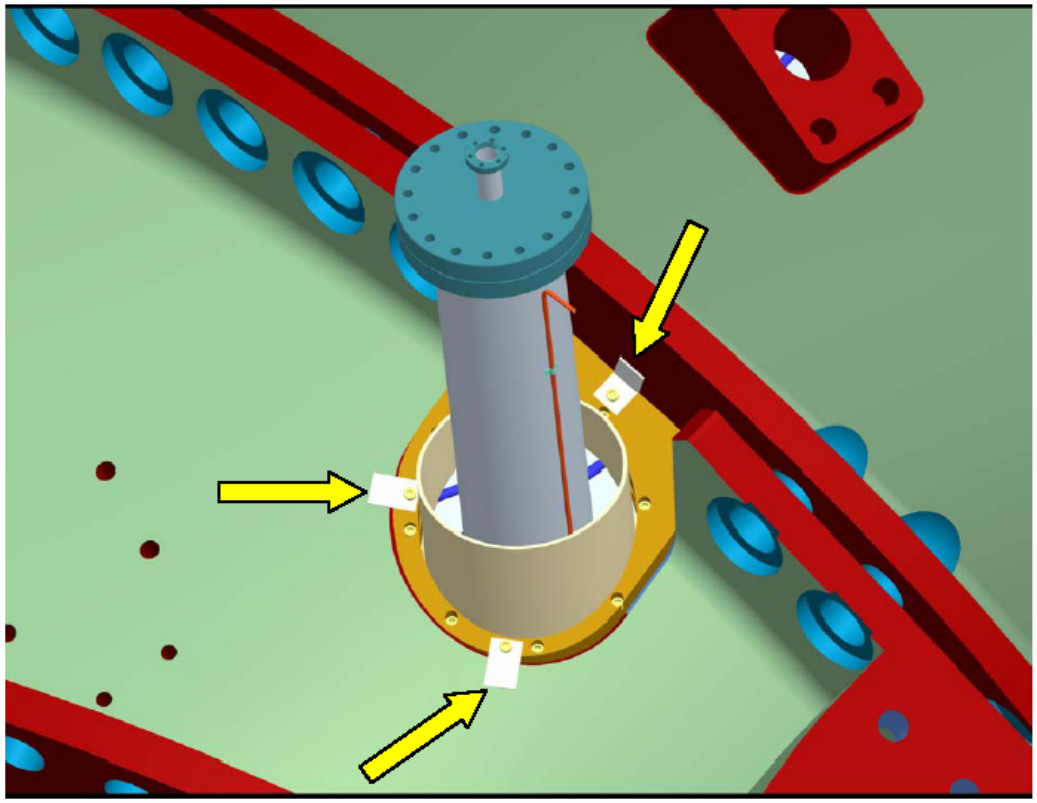


‘Boot‘ configuration/installation port plug concept

• Two G10 plates sandwich the boot and seal the hole in the MC.

• 1/4” Gore-tex® gasket around G10 is nominally compressed 25%. (gap is 3/16”).

• Sheet metal tab are be welded to the MC to hold each seal in place.



Summary

- **Fabrication of the Field Period Assy components is in progress**
  - Vacuum vessel has been delivered and assy has started
  - Modular coils to make first Field Period are nearly complete
  - TF coil fabrication has begun
- **Design of the coil to coil interface hardware required for assy is underway**
  - Original concepts are being updated to reflect as built configurations
- **Risks have been identified and mitigated through R&D testing**
  - Coil to coil 3 point positioning method has been prototyped and will be tested soon
  - Bench test are in progress to develop assy procedures for shims, bladders, and bolting