

National Spherical Torus eXperiment Upgrade

WBS 1.9.2.1 NSTX-U Machine Reassembly

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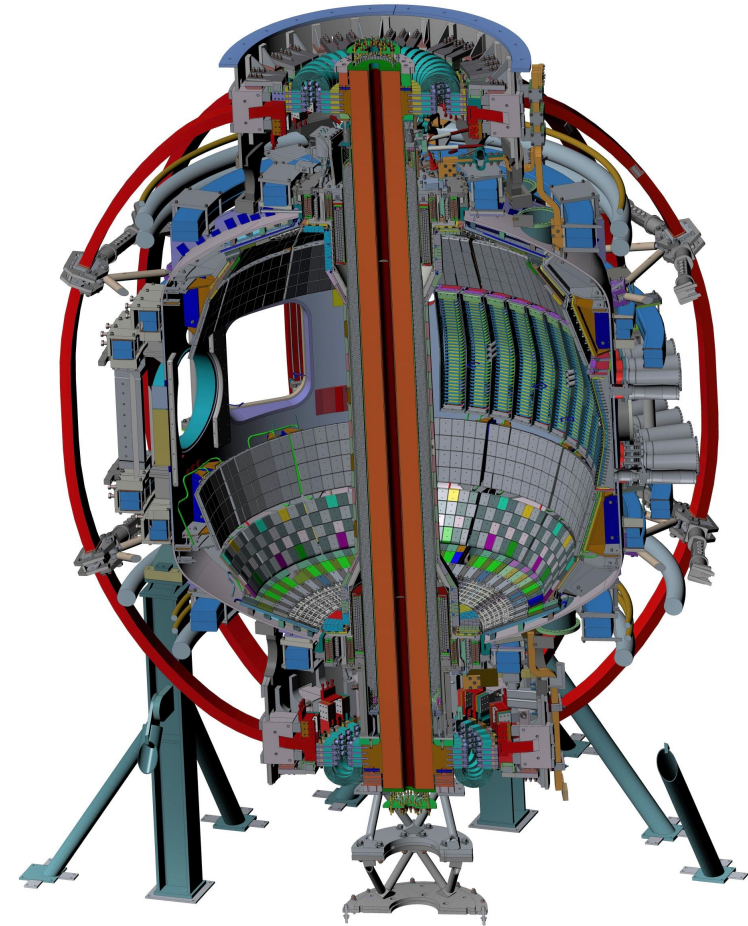
Princeton Plasma Physics Laboratory

Outline

- Scope of talk and assembly overview
- Metrology and alignment goals overview
- Machine assembly sequence
- Verification of Requirements, Safety, QA

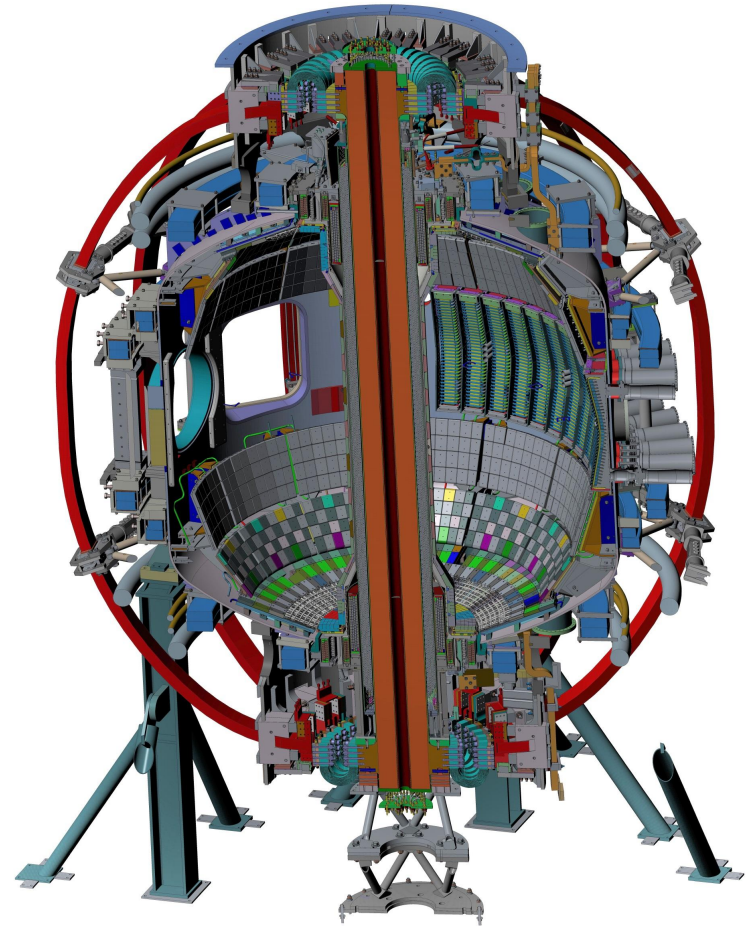
What is covered in this talk

- This is a technical talk
 - Reassembly tasks as defined in WBS 1.9.2.1
 - Requirements
 - Verification of requirements
- What is **NOT** covered
 - Details from previous talks on components.
 - Component sub-assemblies
 - E.g., how the PF-1A-B is assembled onto the common flange
 - Workflow or work control
 - Commissioning



Machine Assembly Scope

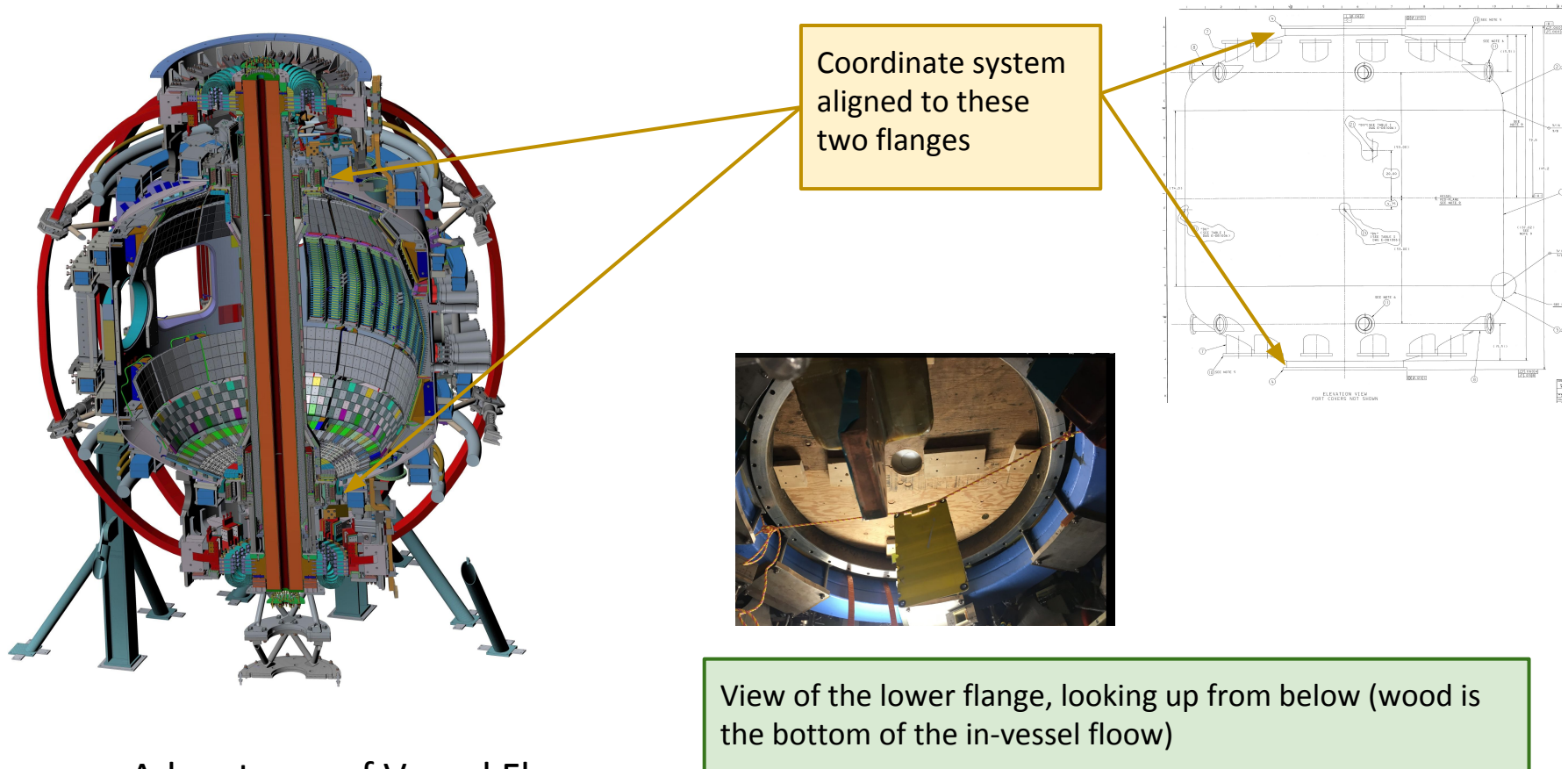
- Preliminary work - NSTX-U Test Cell (NTC)
 - Lower Pedestal
- Re-Assembly - South High Bay (SHB)
 - CS Case Tile Installation
 - CS to TF/OH assembly
- TFTR-Test Cell
 - TF/OH preparation
- Re-Assembly – work NSTX-U Test Cell
 - OBD & Passive Plate tiles
 - Center Stack Assembly to the VV
 - Complete tile installations
 - Umbrella components installation
 - Magnet Cooling Water connections
 - “Clean/Photo/Close”



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Alignment Strategy Utilizes a Global Machine Coordinate System Aligned to Vessel Flanges



Advantages of Vessel Flanges:

- Readily accessible and measurable from inside and outside of vessel
- CS naturally aligns to the vessel flanges → this alignment center naturally minimizes lateral translation (and imposed loads) of the bellows.



Metrology Subcontractor Set up A Global Coordinate System

Monuments mounted on vessel surface, flanges, umbrella, inside machine.

Multiple metrology passes made from different angles to align monuments within

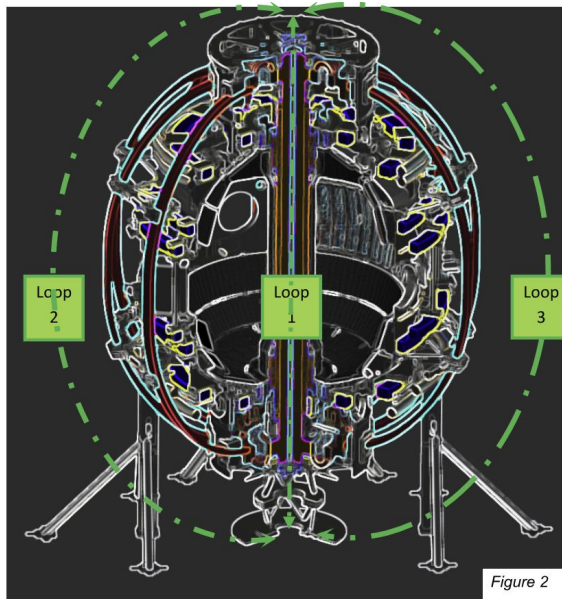
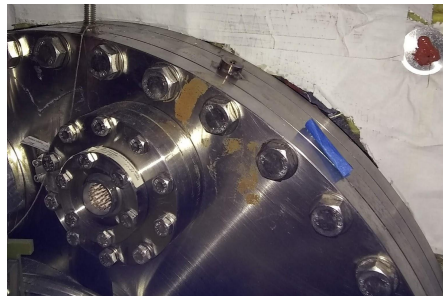


Figure 2

Metrology Monument on Midplane Port Flange



Attached to TF Clevis

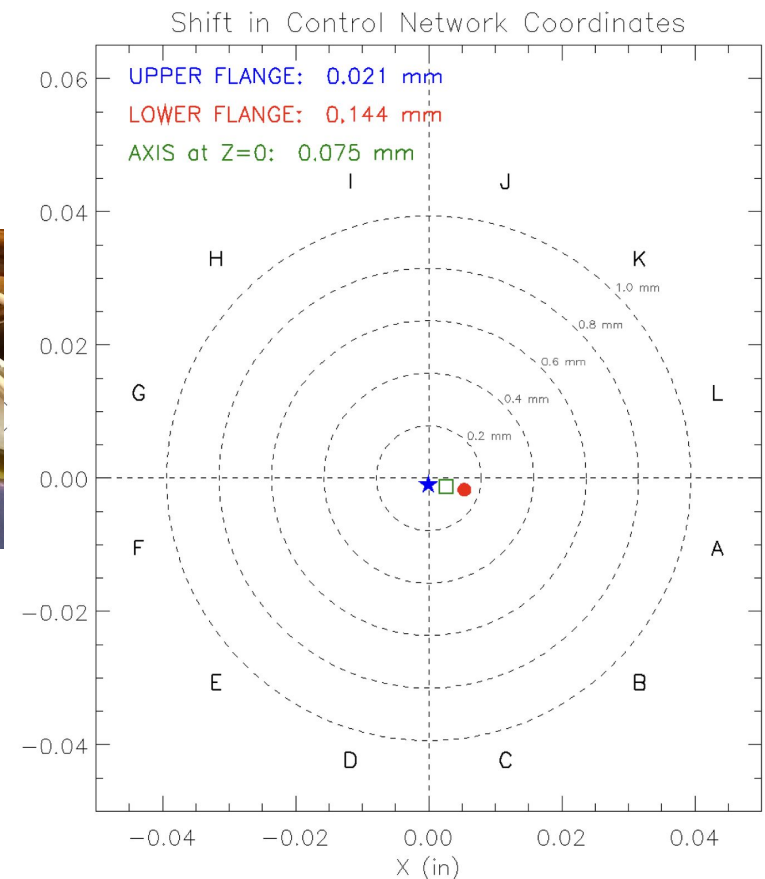


Metrology Monument Inside Vessel



Example: Position of upper and lower flanges in the new Global Coordinate System

Accurate to <0.2 mm (vendor promised 0.178 mm)



Metrology Equipment & Capabilities

PPPL owned equipment includes three laser trackers and three articulating arms.

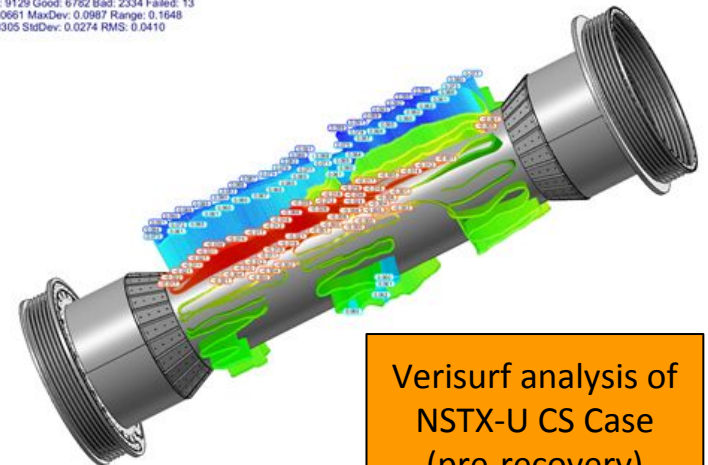
- Arms and trackers are accurate to $\sim 0.1\text{mm}$
- Arms and trackers are checked against N.I.S.T. traceable length standards prior to measurements
- Software used is SQA approved
- PPPL metrology staff has many years of experience, dating back to NCSX
- Metrology software provides feedback during alignment

We have established BOAs with three metrology companies that can provide equipment and personnel to cover the needs during machine re-assembly, as well as during component sub-assembly

- Vendors provide equipment and expertise to complement PPPL capabilities.
- Vendor equipment is equivalent (or better) to PPPL equipment.
- PPPL has successfully worked with at least one of the vendors in the past.



"Outside Cylinder-along for the ride"
diam: 0.7500 Tol: M8D Max Dist: 0.1880
its: 9129 Good: 6782 Bad: 2334 Failed: 13
-0.0661 MaxDev: 0.0987 Range: 0.1648
0.0305 StdDev: 0.0274 RMS: 0.0410
4



Verisurf analysis of
NSTX-U CS Case
(pre-recovery)



Use the Global Coordinate System to Achieve KPP Goals

KPP #1: The inner-Toroidal Field coil axis shall be aligned to the PF-5 upper coil and PF-5 lower coil mutual axis with an accuracy bounded by a straight line through the [shift, tilt] points [0.0 mm, 6.0 mrad] and [6.0 mm, 0.0 mrad].

Achieved by PF=4/5
Realignment WBS --
See talk by Pagano

Further physics discussion and
tolerance breakdown can be
found in

[NSTXU 1-1-2-3-2 CALC 100](#)

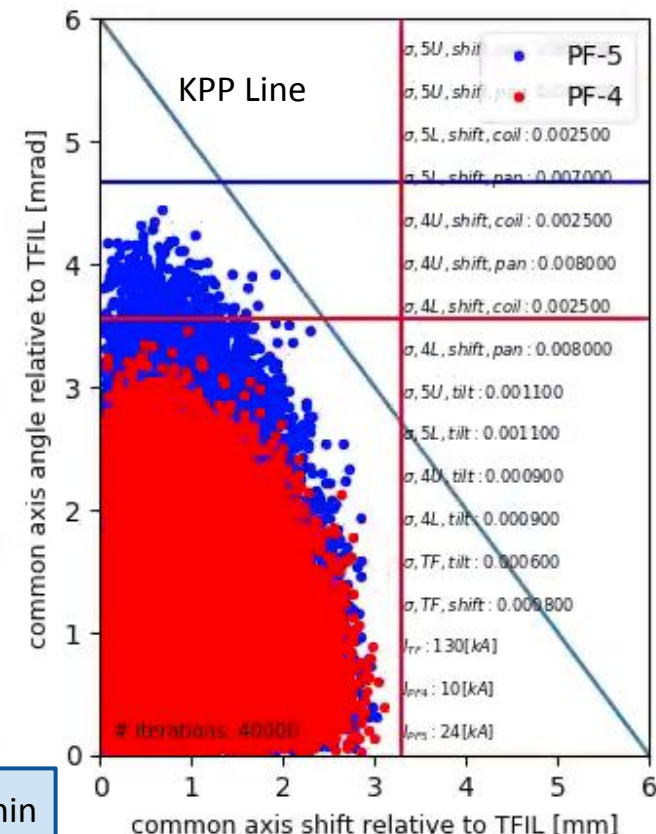
Coil Positional Tolerances ***Relative to Global Coordinate System***

→ [NSTX-U-RQMT-RD-11](#)

Tolerance	Symbol	units	Tolerance
PF-4U, Shifts, Coil	$\sigma_{-4U, \text{shift, coil}}$	mm	2
PF-4L, Shifts, Coil	$\sigma_{-4L, \text{shift, coil}}$	mm	2
PF-5U, Shifts, Coil	$\sigma_{-5U, \text{shift, coil}}$	mm	2
PF-5L, Shifts, Coil	$\sigma_{-5L, \text{shift, coil}}$	mm	2
PF-4U, tilt	$\sigma_{-4U, \text{tilt}}$	mrad	0.9
PF-4L, tilt	$\sigma_{-4L, \text{tilt}}$	mrad	0.9
PF-5U, tilt	$\sigma_{-5U, \text{tilt}}$	mrad	1.1
PF-5L, tilt	$\sigma_{-5L, \text{tilt}}$	mrad	1.1
TF, shift	$\sigma_{TF, \text{shift}}$	mm	0.8
TF, tilt	$\sigma_{TF, \text{tilt}}$	mrad	0.6

Achieved by Reassembly WBS -
this talk

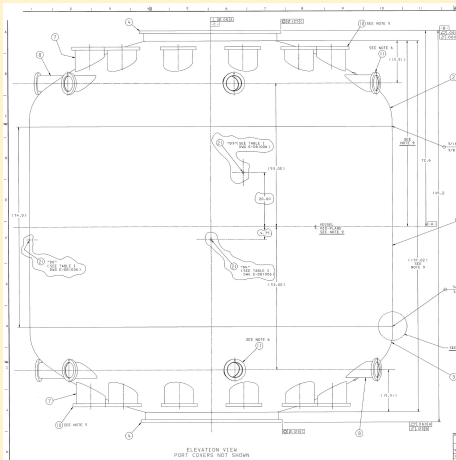
Monte Carlo analysis of 40000 realizations within
these tolerances...always meet KPP



Assembly Will Reply on Alignment of Three Key Coordinate Systems

1: Machine Global Coordinates

Coordinate system aligned to these two flanges

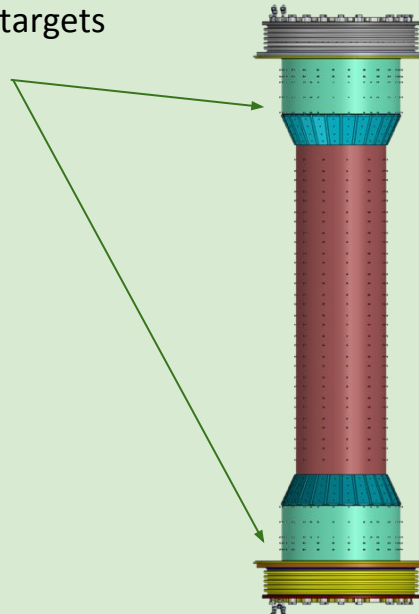


Outer-PFs align to these flanges (see talk by Pagano)

TF aligned to these during CS installation

2: CS Casing Vertical Target Cylinders

Coordinate system aligned to the vertical targets

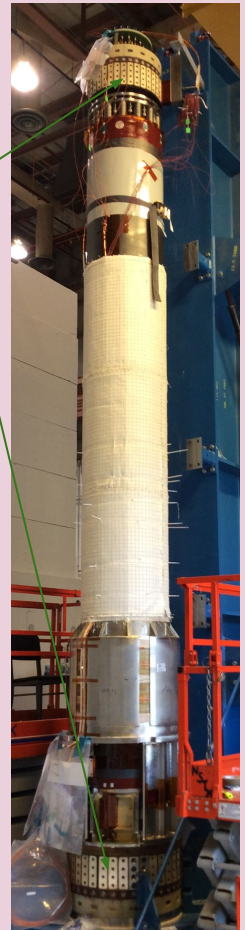


Inner-PFs aligned to these during CS assembly (assured by precision machining)
Tiles intrinsically aligned to this surface

3: TF Coil Electrical Faces

Coordinate system aligned to the average cylinder defined by the TF electrical faces

CS aligned to the faces during CS assembly
Faces aligned to machine global coordinate system during CS installation



Overall Alignment Strategy

1: Summary

Legend

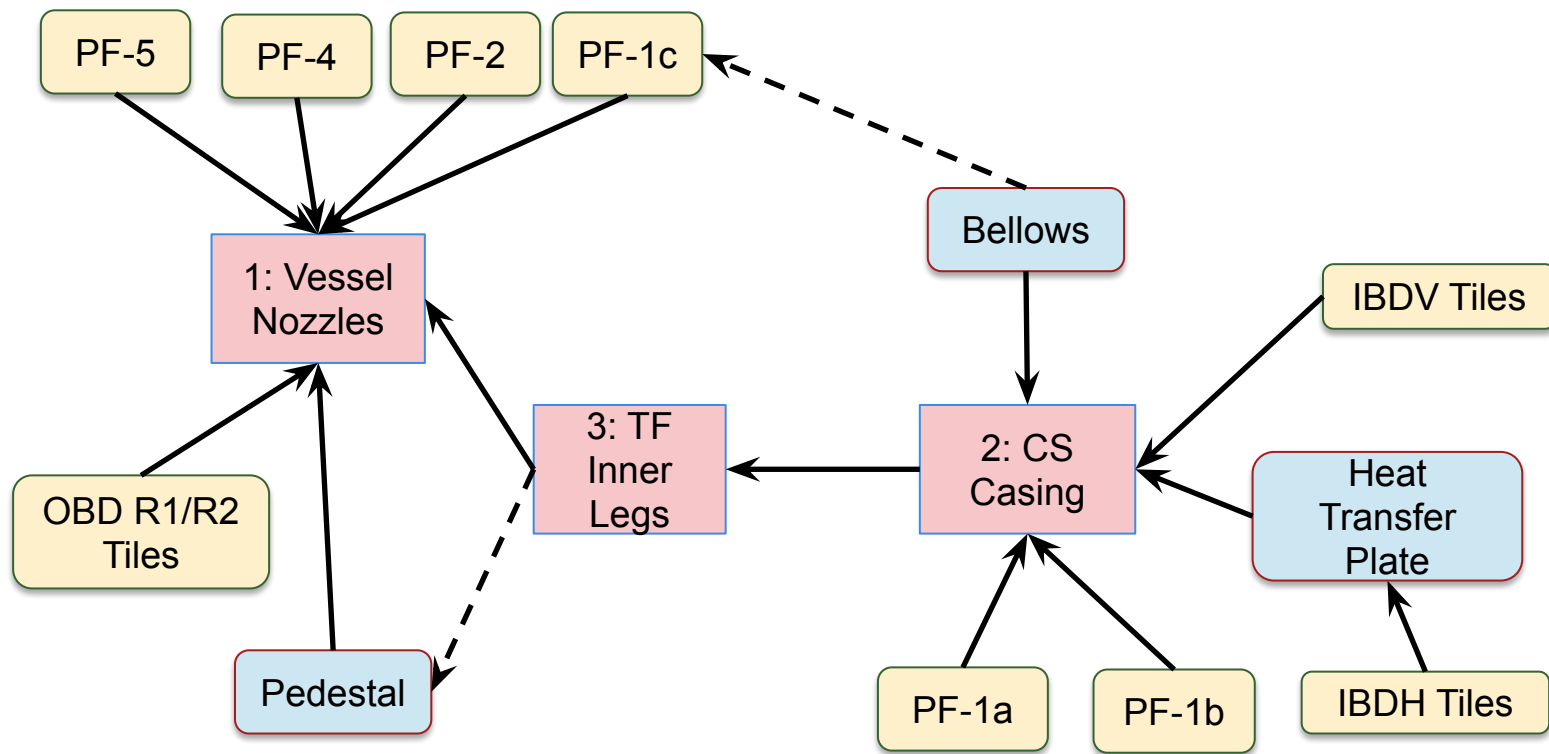
Physics Requirement

Other Component

Key Coordinate System

A → B
A is aligned to B
Potentially with
intermediate linkages

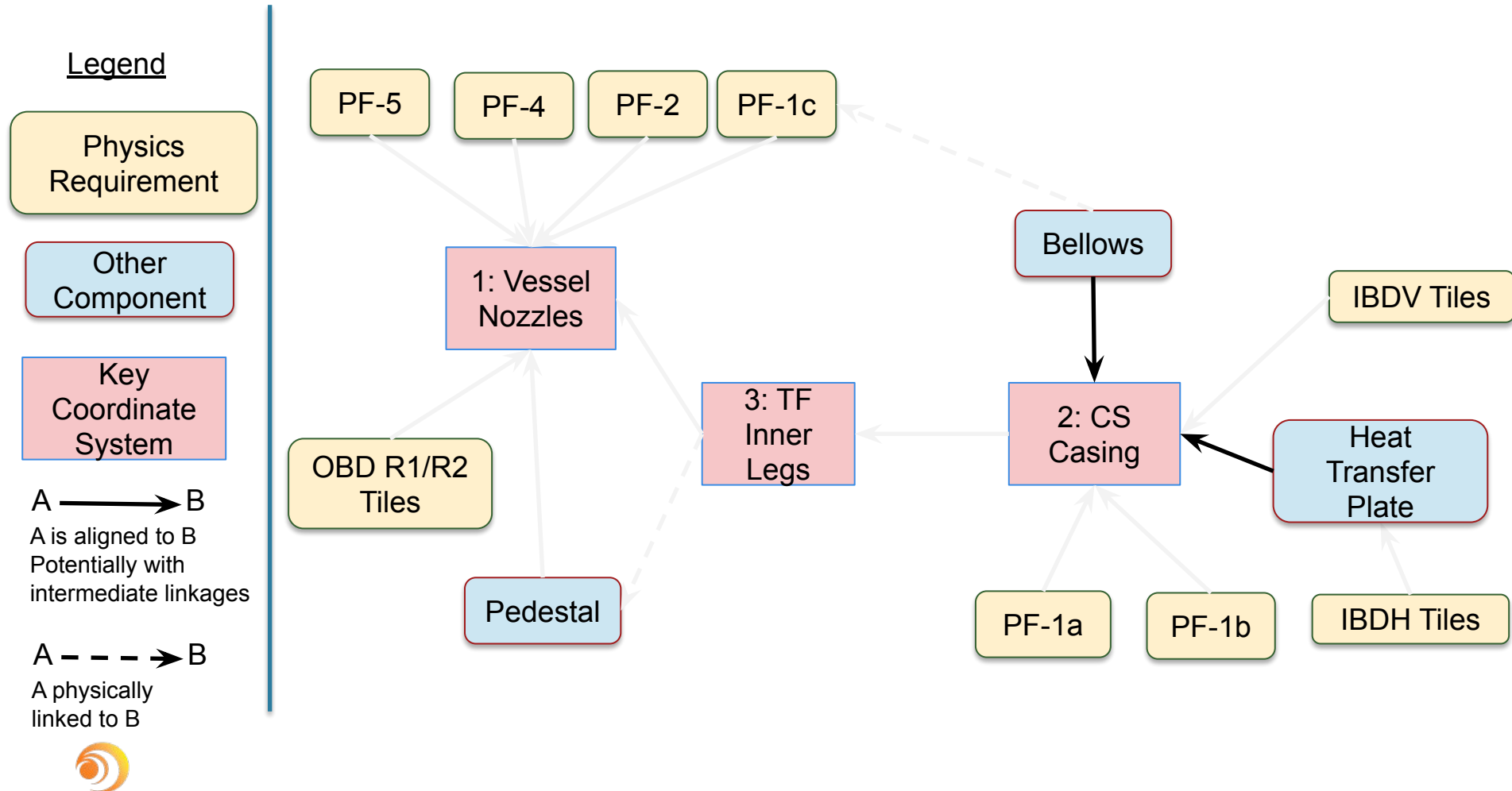
A - - -> B
A physically
linked to B



Overall Alignment Strategy

2: Achieved During CS Manufacture

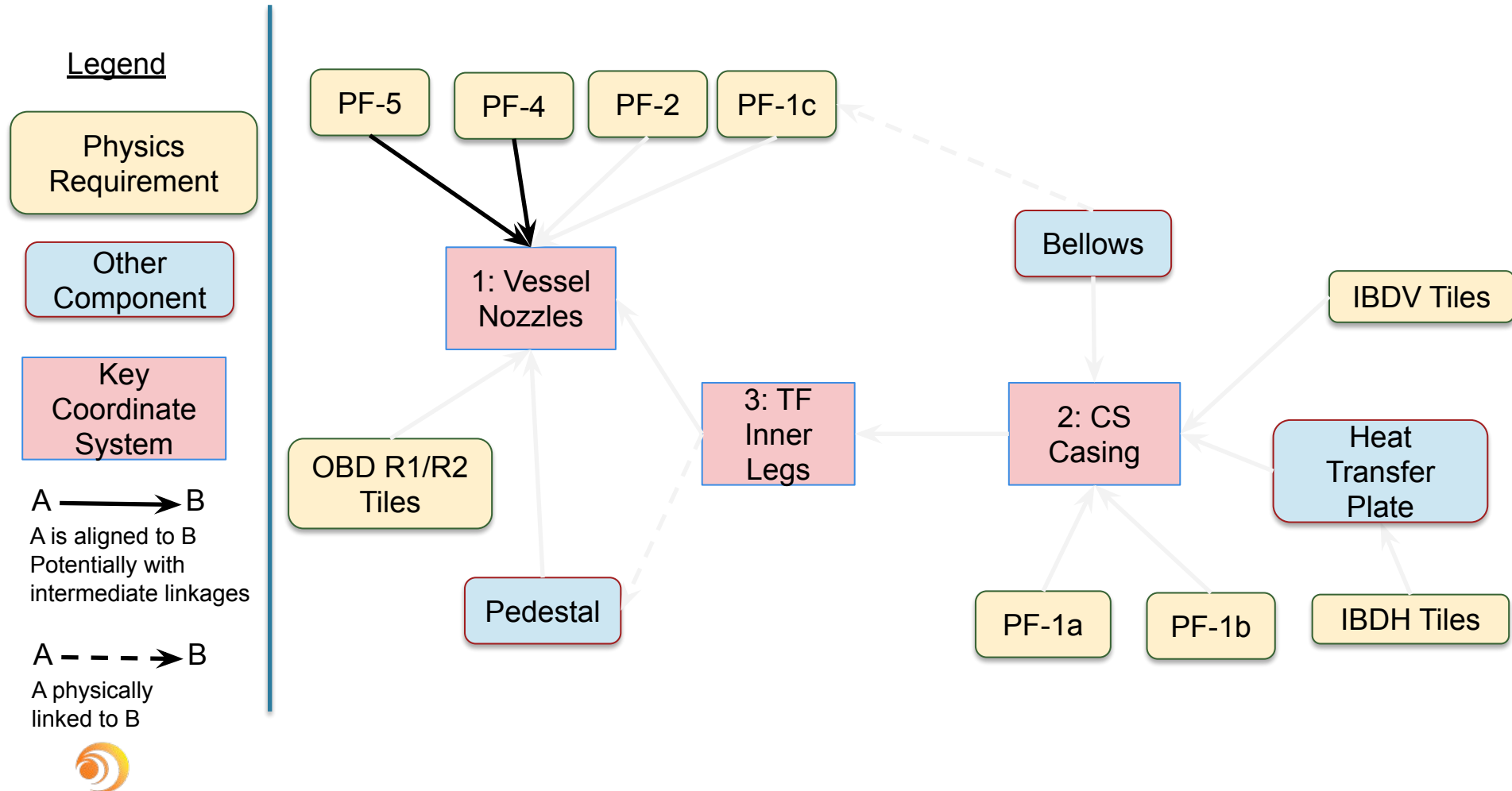
WBS 1.1.2.6 → See talk by Viola



Overall Alignment Strategy

2: Achieved During PF-⁴/₅ Realignment

WBS 1.1.2.8 → See talk by Pagano



Overall Alignment Strategy

3: Achieved By MCS Team

WBS 1.1.2.1 → See talk by Smith
Generally achieved by tight tolerances

Legend

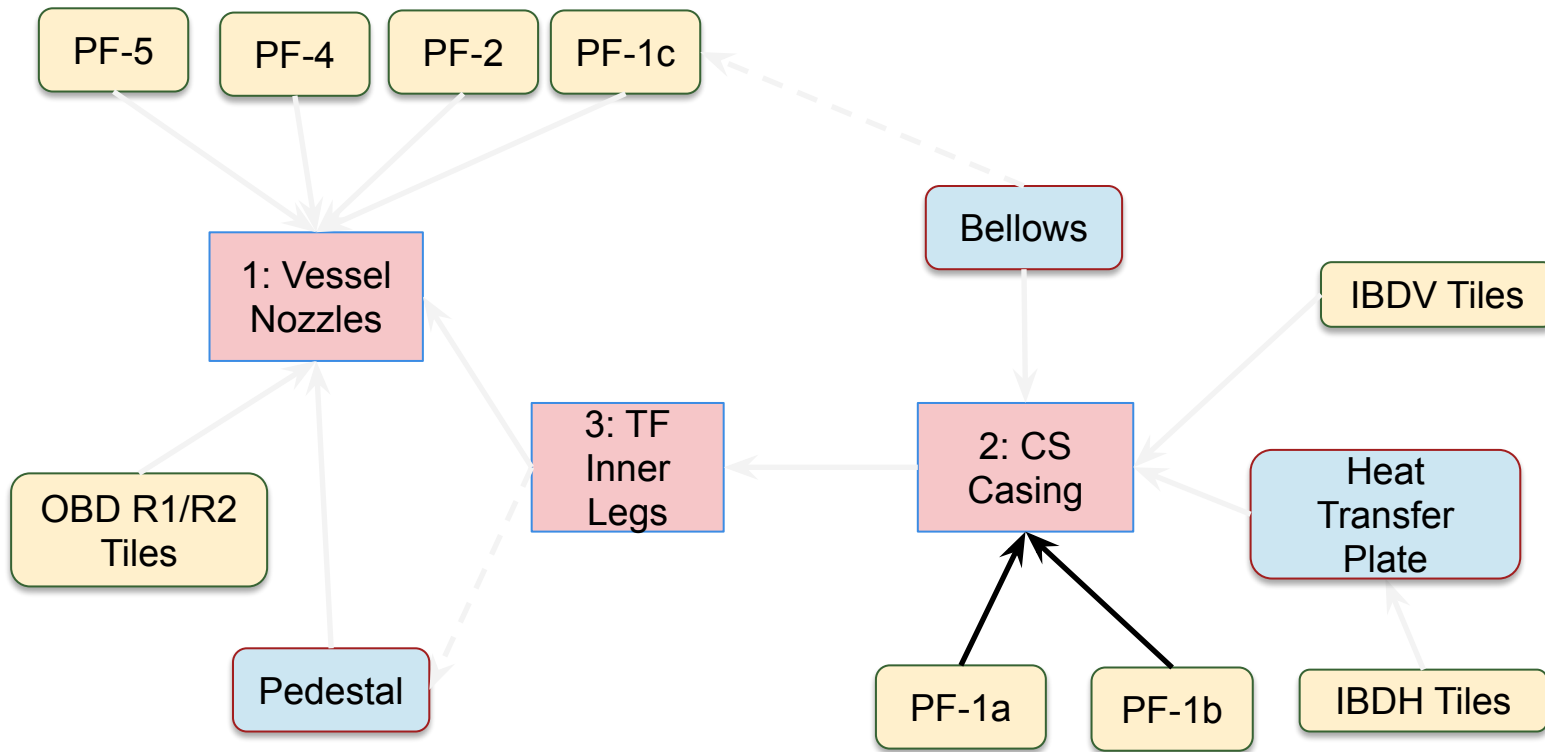
Physics Requirement

Other Component

Key Coordinate System

A → B
A is aligned to B
Potentially with
intermediate linkages

A - - - -> B
A physically
linked to B



Overall Alignment Strategy

4: Achieved During Tile Installation

Tiles designed with minimal adjustment positional adjustment capability
Trays are aligned for IBDV & IBDH tiles, Shim plates pre-manufactured for OBD R1/2
Installed as part of WBS 1.9.2.1 → This talk

Legend

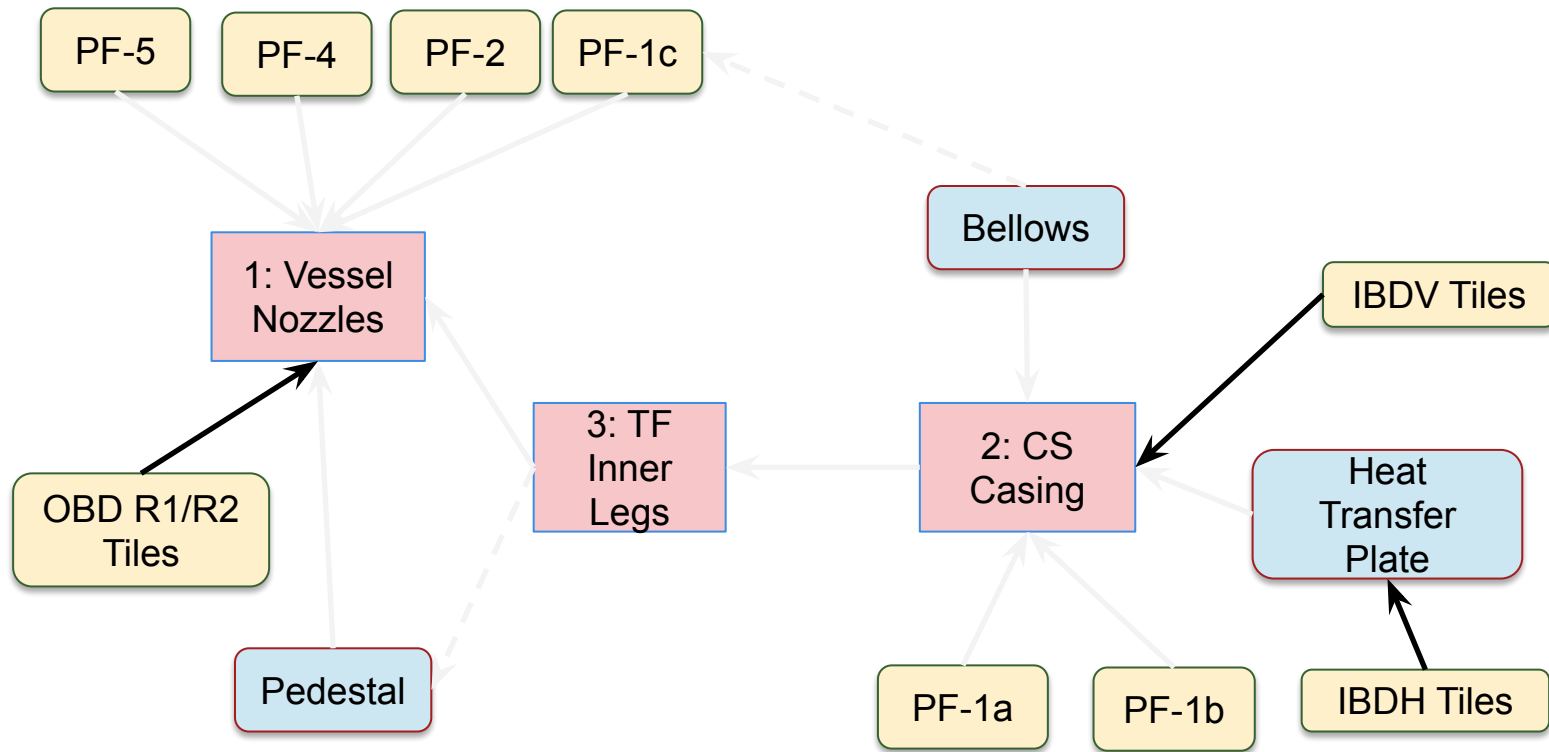
Physics Requirement

Other Component

Key Coordinate System

A → B
A is aligned to B
Potentially with
intermediate linkages

A - - - -> B
A physically
linked to B



Overall Alignment Strategy

5: Achieved During CS Assembly

Installed as part of WBS 1.9.2.1 → This talk

Legend

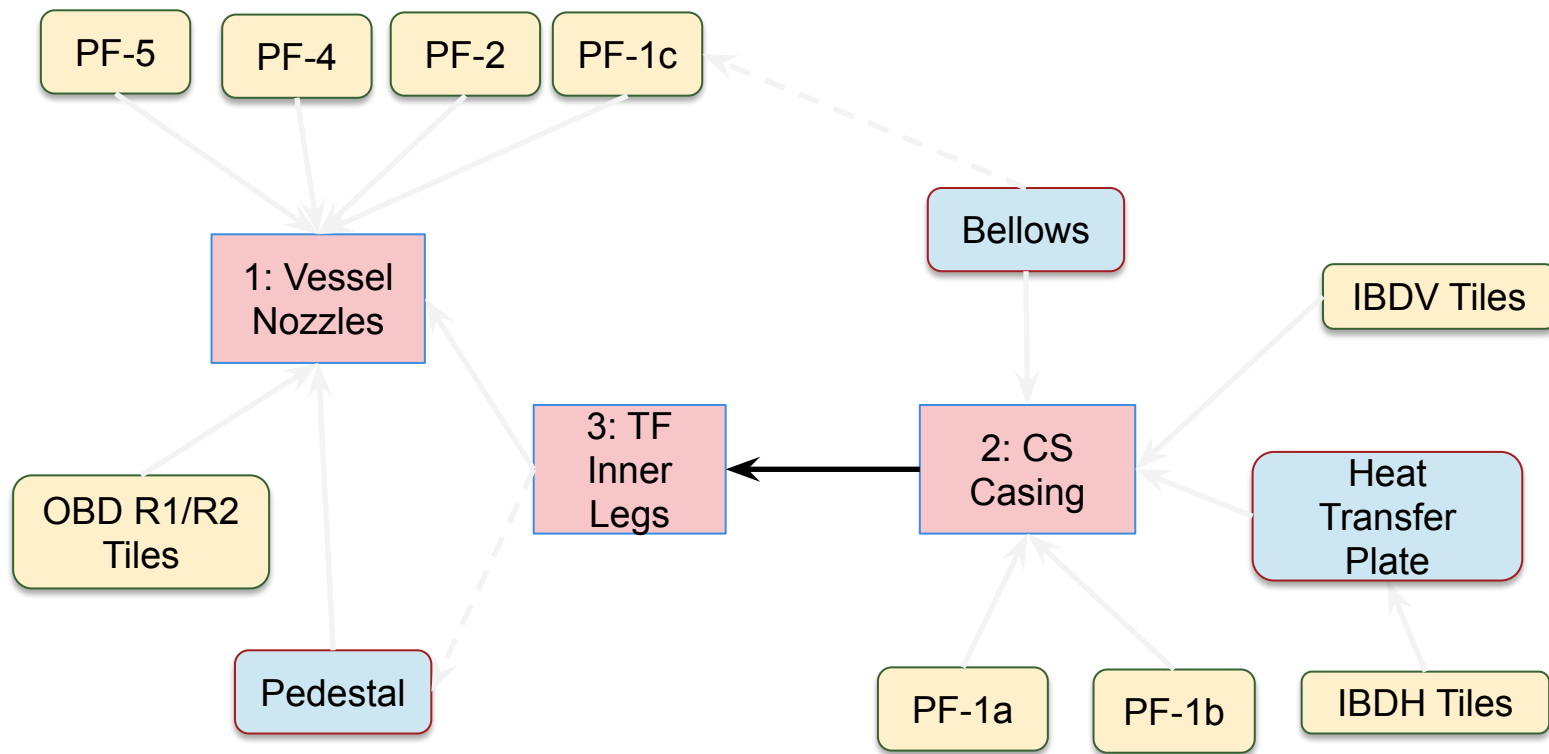
Physics Requirement

Other Component

Key Coordinate System

A → B
A is aligned to B
Potentially with
intermediate linkages

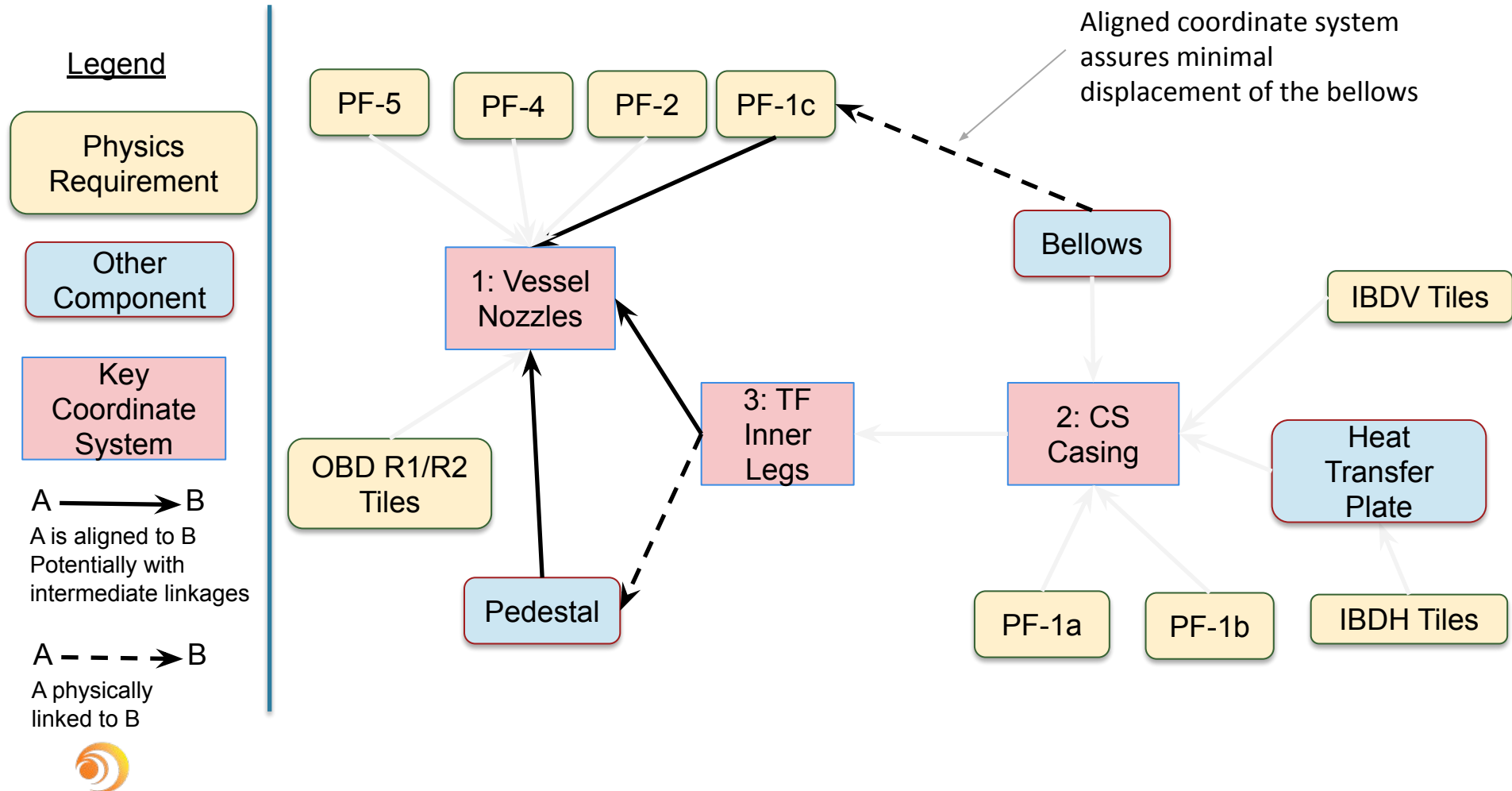
A - - - → B
A physically
linked to B



Overall Alignment Strategy

6: Achieved During CS Installation

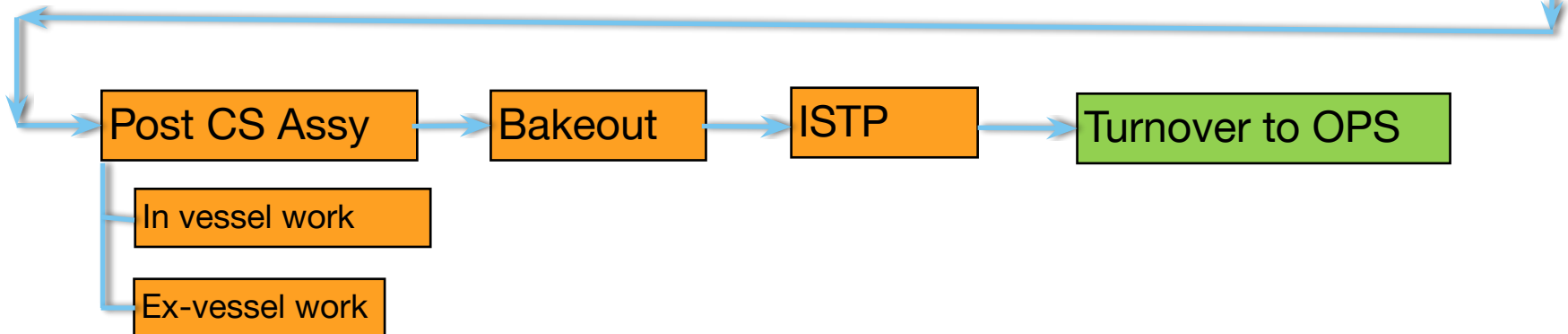
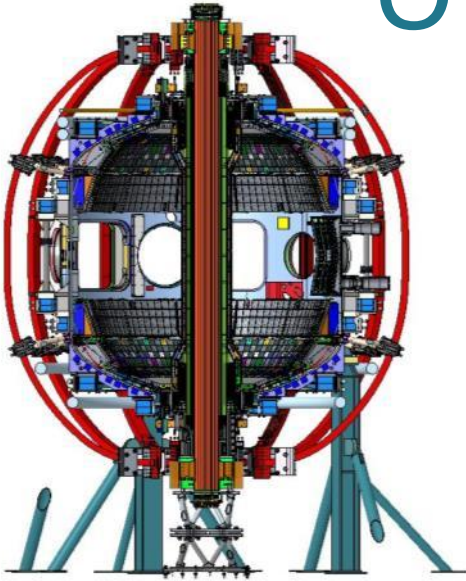
Installed as part of WBS 1.9.2.1 → This talk



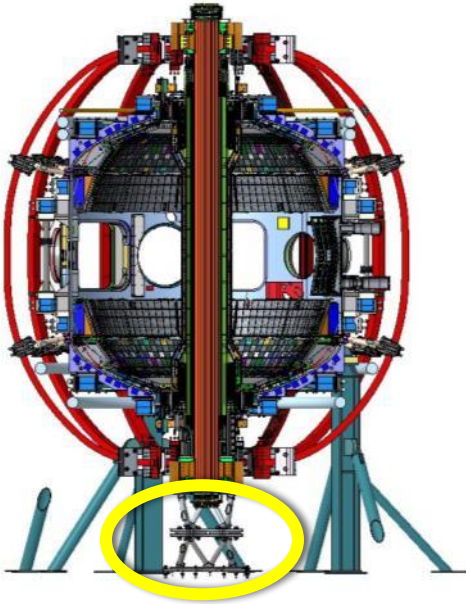
Outline

- Scope of talk and assembly overview
- Metrology and alignment goals overview
- **Machine assembly sequence**
- Verification of Requirements, Safety, QA

Overall Assembly Sequence



Pre-Assembly



Preassembly

CS Assy

CS Assy Install

Post CS Assy

Bakeout

ISTP

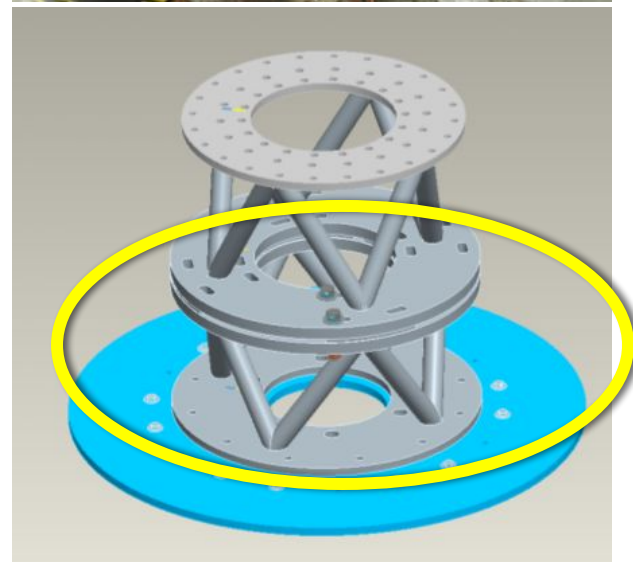
Turnover to OPS

In vessel work

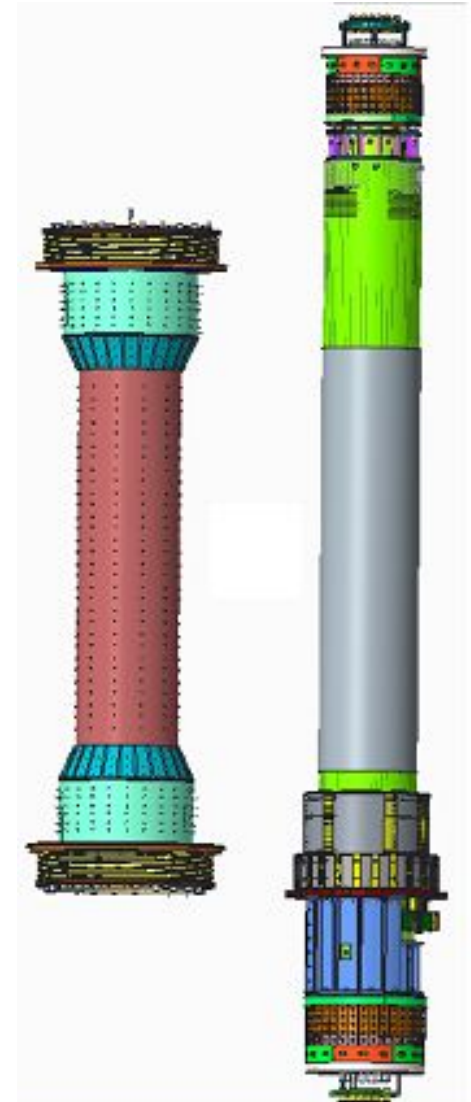
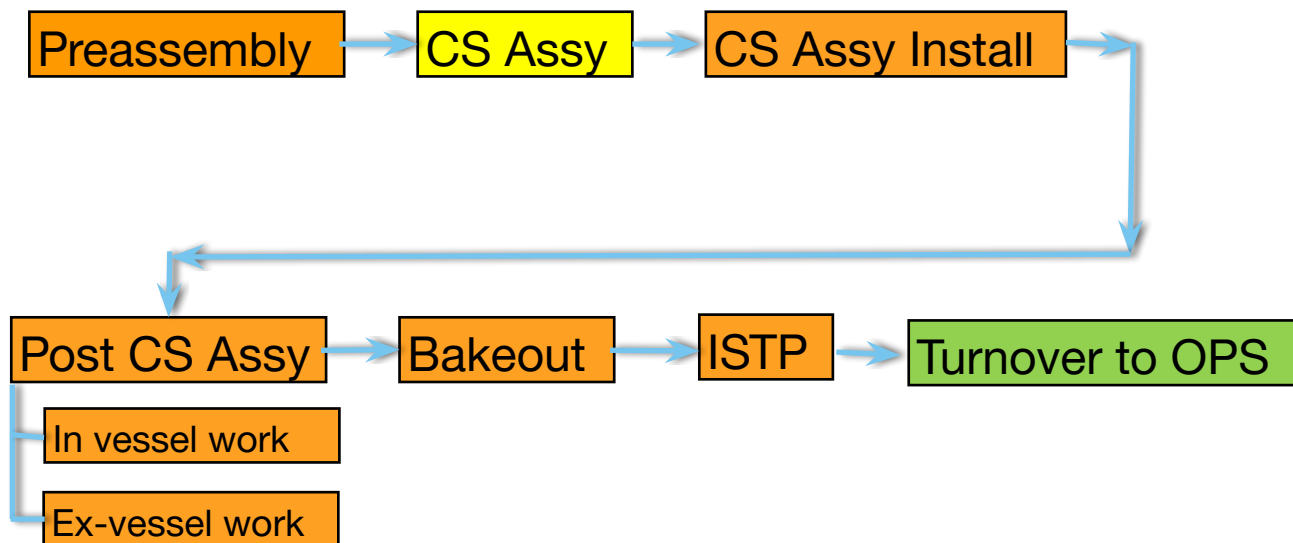
Ex-vessel work

Pre-assembly

- Remove Pedestal from current location
- Install Pedestal lower half in new location and align to machine coordinates
- Measure/adjust/measure until alignment requirements are met.
- Aligning the lower half is the “coarse” adjustment of the Center Stack Assy alignment.



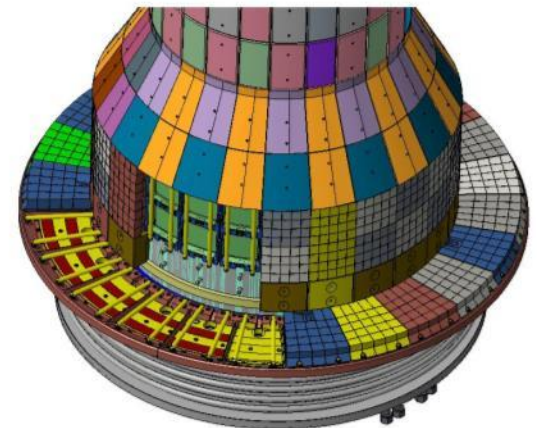
Centerstack Assembly



CS Assembly Overview – CS Case work

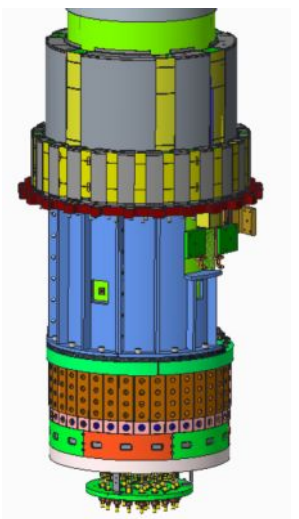
- CS Case tasks
 - Fab & Install Gas Inj tubing.
 - Install “Tile Frames”
 - Install CSFW tiles*
 - Install CSAS tiles*
 - Install Halo Rogowskis
 - Install IBDV HHF tiles*
 - Prefit IBDH tiles & remove*
- CS Case now ready to be assembled to the TF/OH bundle.

* Includes routing cabling and terminations at organ pipes

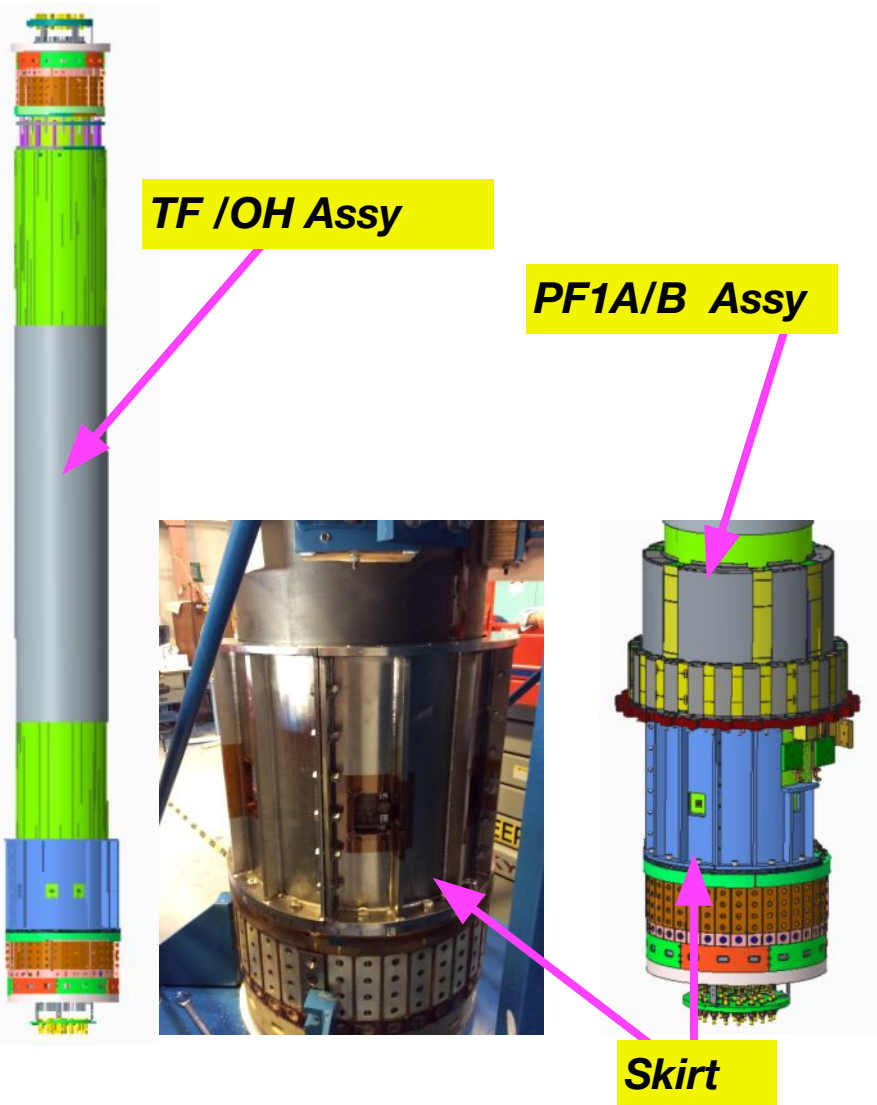


CS-Assembly Overview – TF/OH work

- TF/OH
 - *Fit up skirt
Measure/adjust/measure
 - *Install PF-1A/BL
 - Measure/adjust/measure
 - Install CS diagnostics
 - Flux Loops
 - Thermocouples
 - IP Rogowskis
 - Install Microtherm



Install CS Skirt & Lower PF1A/B Assy



- The lower skirt is installed over the TF/OH, it supports the rest of the CS components and acts as the foundation.
 - The Skirt will be aligned using metrology equipment
 - Alignment adjustments made at the skirt/TFOH interface
- The Lower PF1A/B coils are installed on the TF/OH as an assembly
- Metrology to be performed on the Lower PF1A/B Assy to verify position and straightness of the interface. Will adjust at the skirt/TFOH interface.

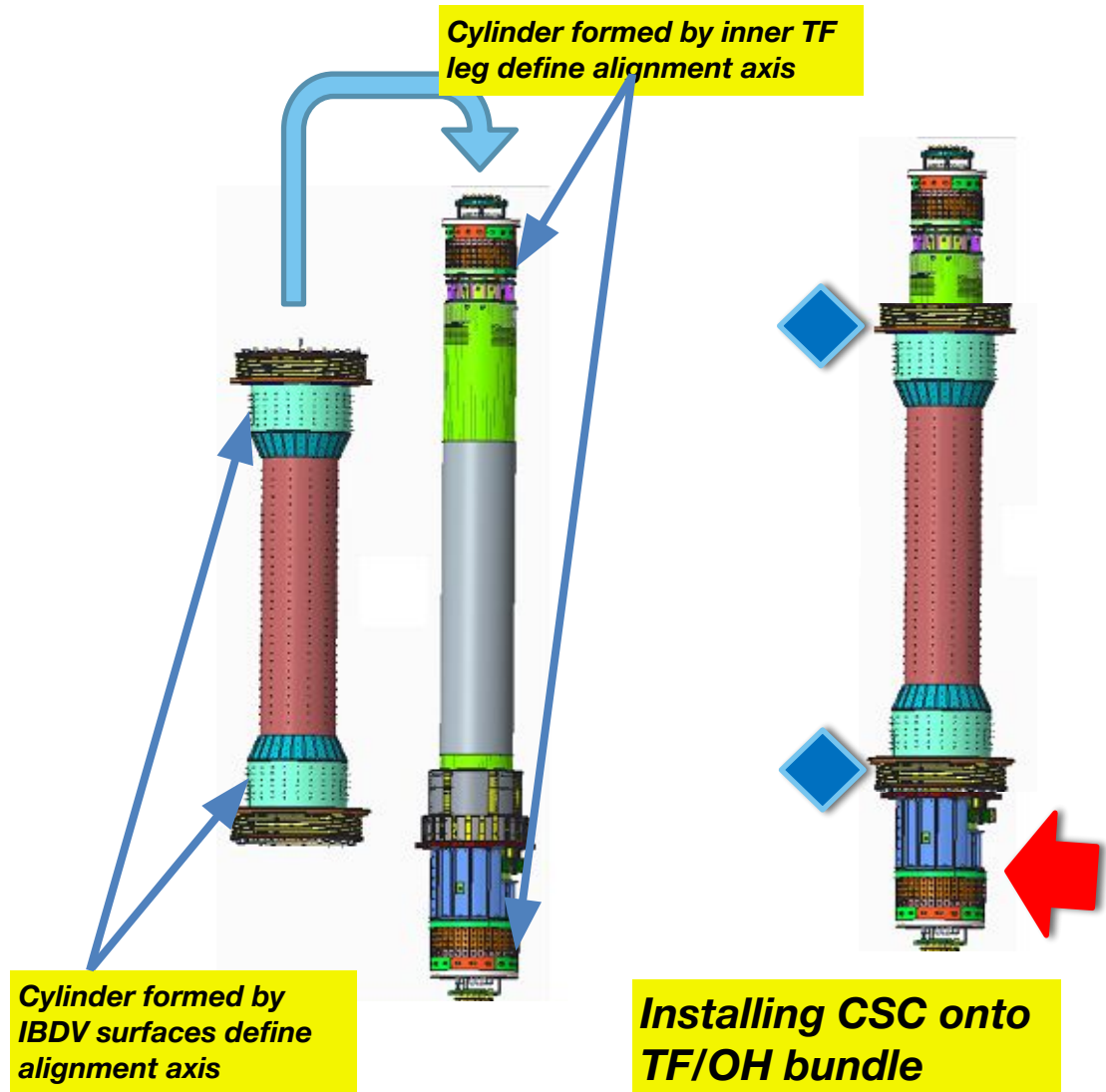
CS Assembly Scope – Final Assembly

- Install Rigging
- Lower CS case onto TF/OH
- Implement adjustment capability
 - Measure/adjust/measure
- Lock down fasteners
- Final measurement record position
- Install PF-1A/B Upper
 - Measure PF-1A/B location

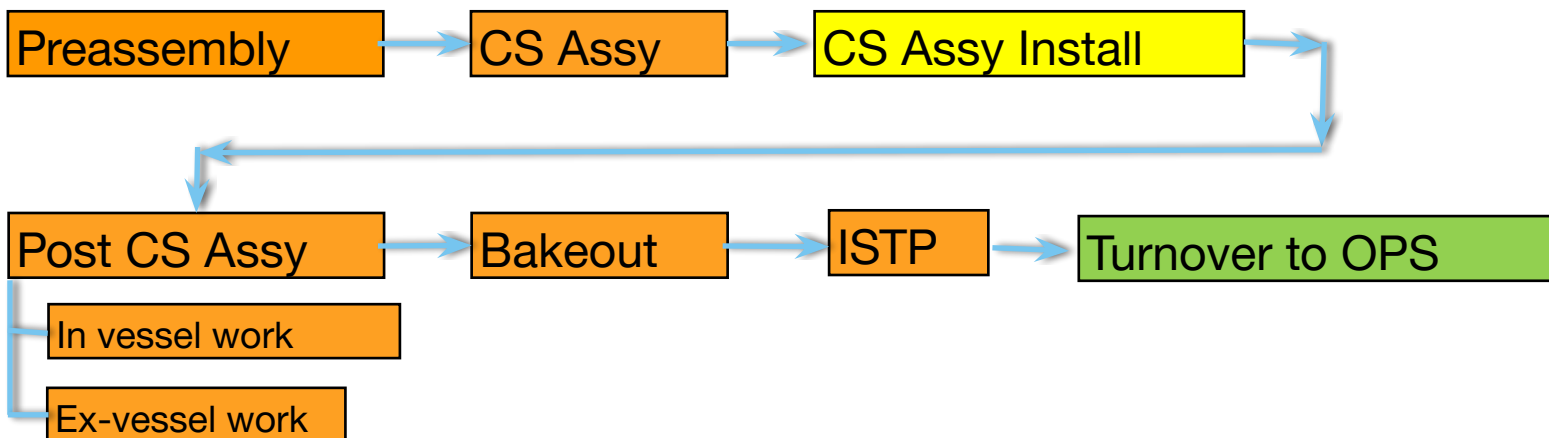
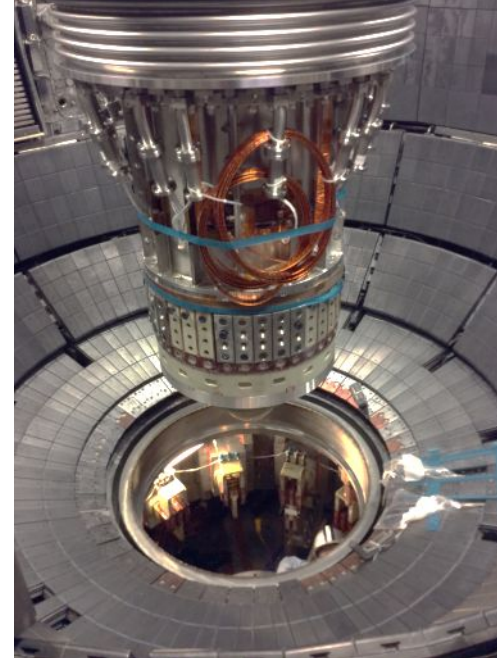


Installation Details - CS Case onto the TF/OH

- CS Case will be lowered over and onto the TF-OH Bundle
 - Final alignment of CS case to TF CL will occur after case is lowered
- Metrology on the TF Inner legs and the CS Case IBDV surfaces defines alignment axes.
- Metrology at the **blue** diamond will provide adequate resolution for adjustments at the **red** arrow to achieve alignment requirements
- Shimming at the Skirt at the OH Support interface will be used to fine-tune CS Case alignment.
- Alignment goal for CS Case to TFIL is +/- 0.25mm.

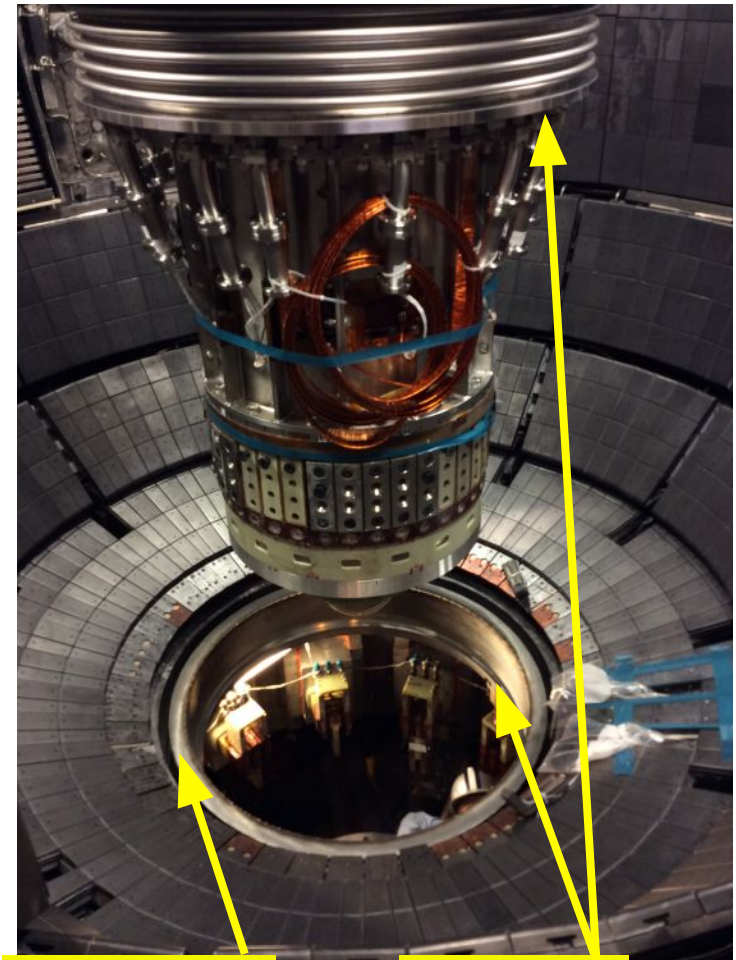


Centerstack Assembly into NSTX-U



Installation of CS Assy into the VV

- Prerequisites:
 - Pedestal lower half aligned. *This is our course adjustment.*
 - Pedestal upper half in position
 - PF-1C Lower installed
- Installation of CS Assembly
 - Lower CS assy into VV and bolt to pedestal upper half
 - Use positioning mechanism to provide elevation & tilt adjustments
 - Measure gap between pedestal halves, machine & install custom shims. *This is our fine adjustment.*
 - Measure to confirm position.
 - Repeat (if necessary) until alignment requirements are satisfied.
- Install PF-1C Upper

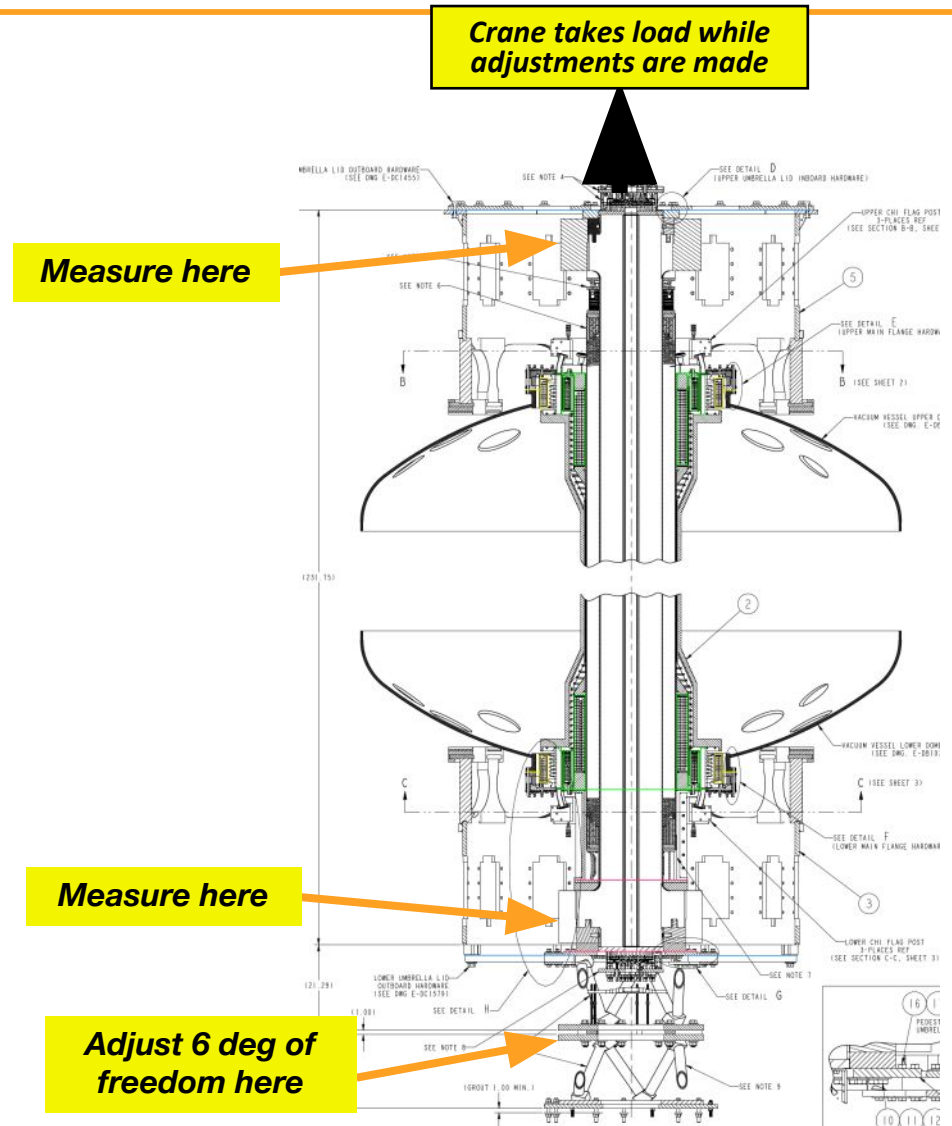


**PF1C Lower
in position**

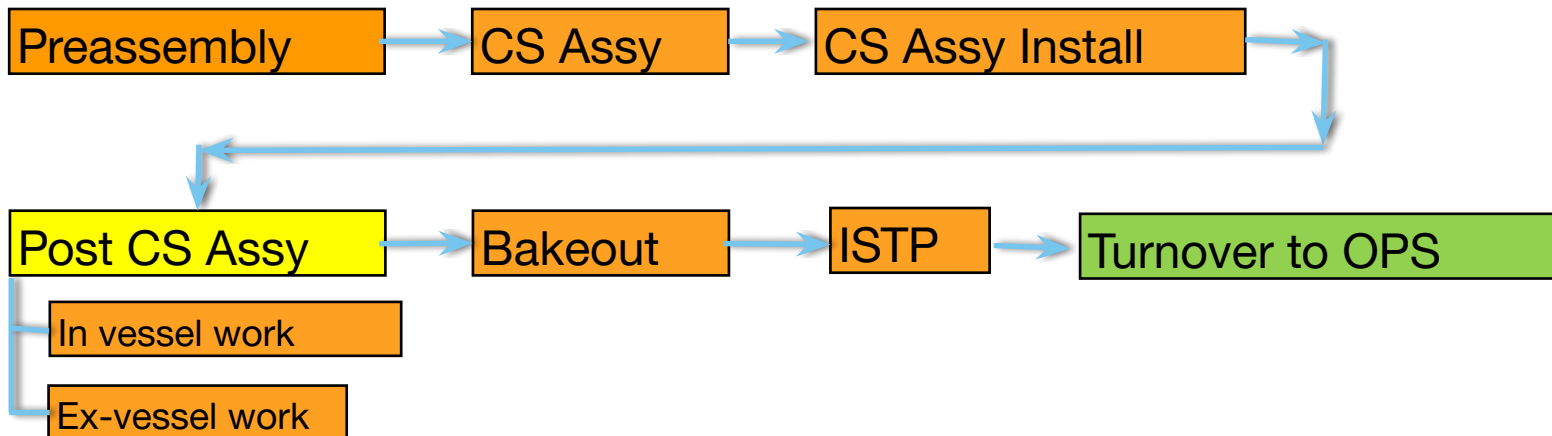
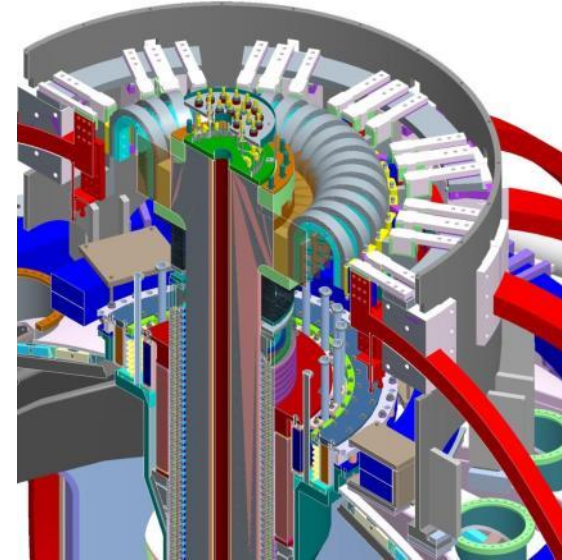
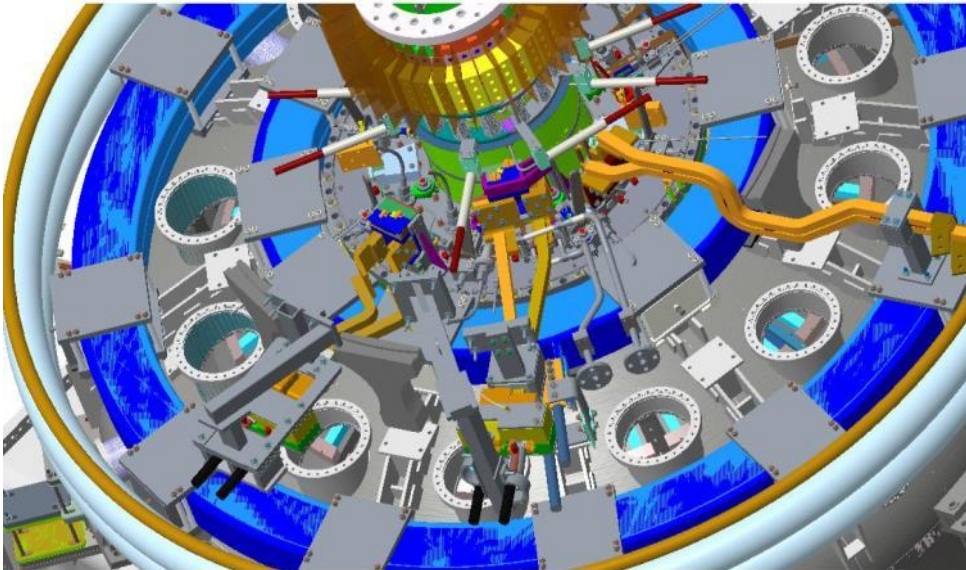
**Vacuum
interface**

Alignment of CS Assy into the VV

- CS Assy lowered through vacuum vessel and connect to upper pedestal
- Install positioning fixtures and metrology equipment in upper & lower umbrellas
- Deploy adjustment capability to position CS Assy
 - Measure-adjust-measure until alignment goals are achieved.
- Install PF-1C upper
 - Metrology to document position

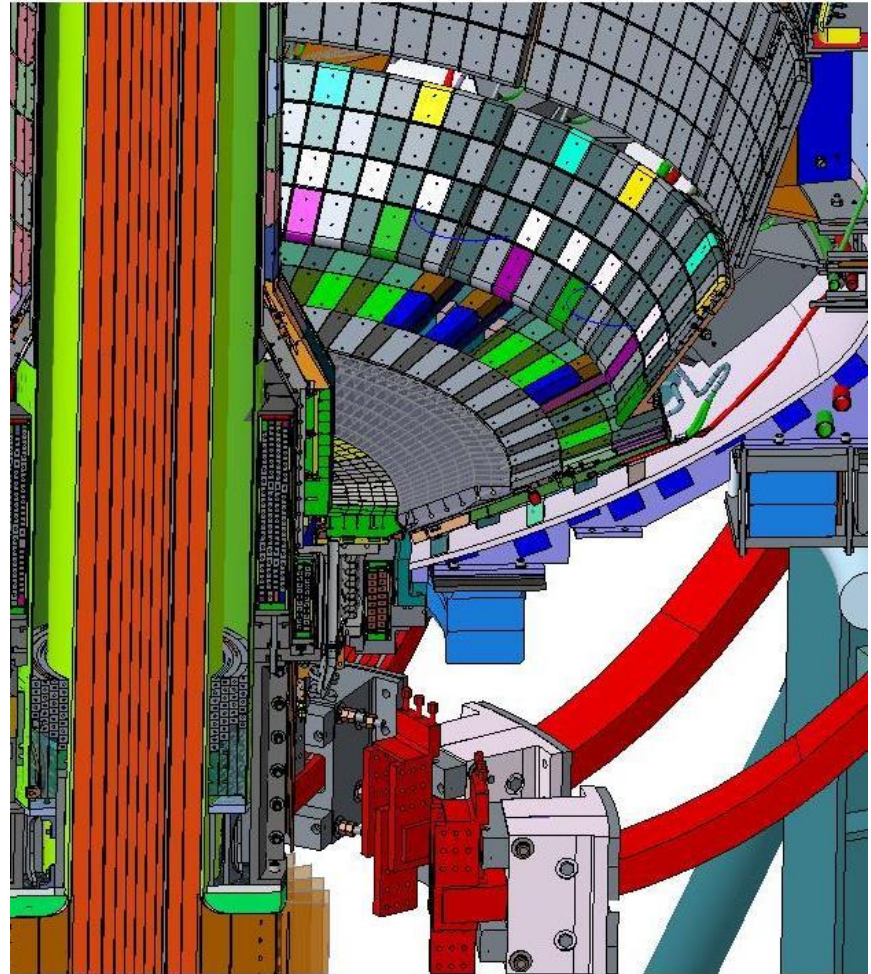


Post CS Assy Work



Tile Installations

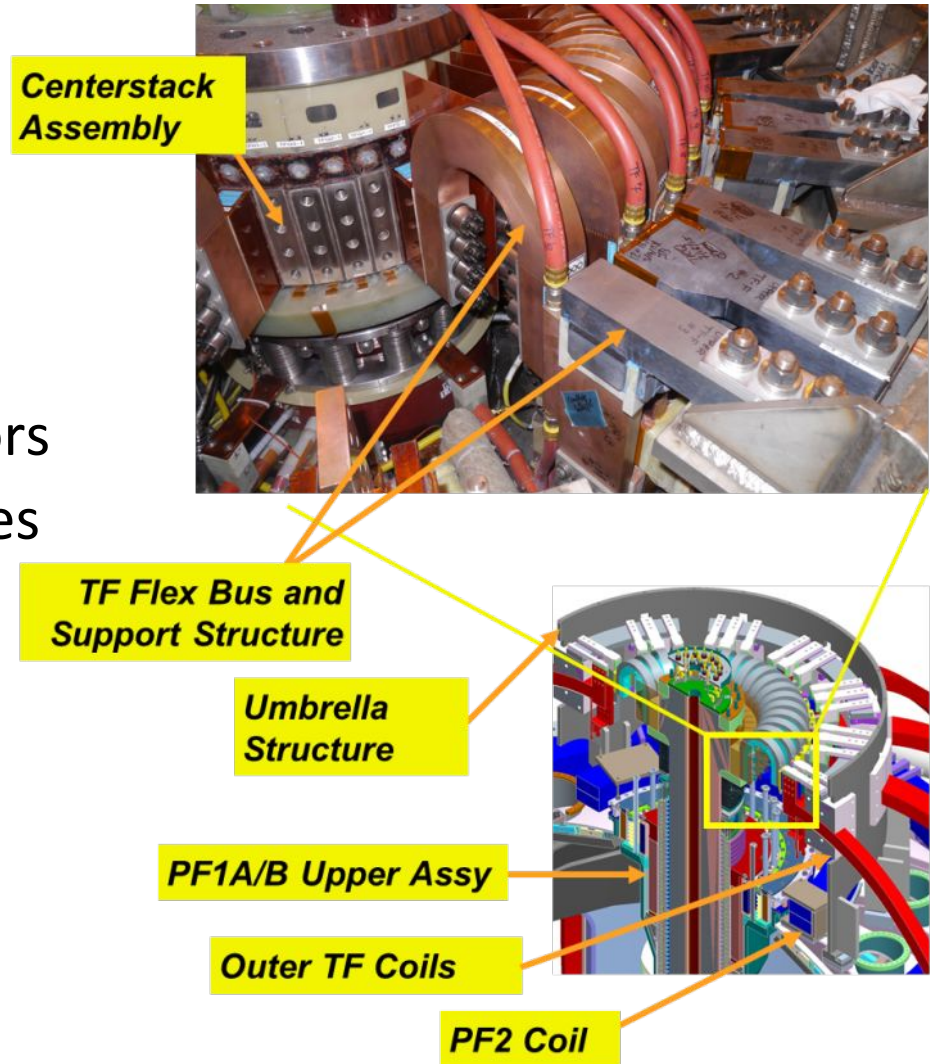
- CS Case Tiles Phase II
 - Ice cube trays and IBDH tiles
 - Metrology to validate positional tolerance is met
 - IBDV Low Heat-flux tiles
- OBD
 - Rows 1&2
 - Metrology to validate positional tolerance is met
 - Rows 3-5
 - No metrology required - optional
- Passive Plate Tiles
 - No metrology required - optional



Post CS Install - Umbrella work

- *CS Halo Bumper shims
- OH Preload stack
- MGI & other diagnostics & cables
- *Inner PF coil hard bus
- OH Ground plane connectors
- Inner PF cooling water hoses
- OH cooling hoses
- *OH Coax
- *TF Flex bus
- OTF flag fingers
- *Umbrella Lid

*Indicates field-fit installation



Exterior Items and Vessel Closing

- Cooling Hoses
 - Outer PF
 - Flex Bus & Hard Bus
 - TF Coil
- Verification of main vessel vacuum seals via the Interspace Vacuum Pumping System
- Clean-Photo-Close



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Verification

- Dimensional accuracy via Metrology
 - ex. CS Assembly, and Installation into VV coordinate system
- Resistance checks of high current joints
 - ex. TF flex bus installation
- Connectivity of low level signal carriers
 - ex. PFC wiring, machine instrumentation
- Mechanical
 - Recorded torque values
 - ex. fasteners
 - Flow and hydrostatic tests
 - ex. coil cooling water hose connections
 - Leak check vacuum seals
 - ex. IVPS connections, & VV flanges
- Inspections
 - ex. high voltage standoffs, electrical contact surfaces

QA and Safety

QA and Safety oversight are a constant presence during all field work

- QA will verify that requirements specified are met
 - Review of all procedures
 - Each procedure has a Quality Inspection Plan (QIP) which delineates the steps that are witnessed by QA/QC
- Safety is baked into the process from the start
 - Review of field processes
 - Review of all procedures
 - Safety officer assigned in field
 - Attends pre-job and post-job briefs

Keys to succeeding

- We are installing components that have mature, vetted designs, with validation throughout the previous phases before the handoff to re-assembly team.
- We understand the assembly process and have experienced staff guiding and executing the process
- We understand the hazards associated with the work and are adding additional resources to help mitigate the the level of activity anticipated.
- We have a robust set of policies and procedures that will ensure compliance with all lab policies.
- The enhanced Work Control Center will be a key component of coordination.

Summary

- Physical assembly and installation of the Center Stack components has been performed in the past and is well understood
- Metrology will be used extensively to assure that RD-11 alignment requirements are achieved
- Risks have been identified and mitigation measures are being taken
- Great diligence is being paid to critical items and alignments
- Work will be planned and coordinated to ensure that it is accomplished safely, accurately and on-time.