

National Spherical Torus eXperiment Upgrade

PF-4/5 Alignment WBS 1.01.02.08

NSTX-U Recovery Project FDR – March 17-19, 2020

C. Pagano - Cognizant Engineer

Last edit: 3/9/20

Outline

1. Overview

2. Scope

3. Requirements and Interfaces

4. Analysis/Prototyping

5. Chit Closure

6. Procurement, Fabrication, Installation, and Test

7. Risk - Project Risks and Design FMECA

8. Quality, Environmental, Safety, and Health

9. Summary

Overview - WBS 1.01.02.08

(CDE-3A Scope)

WBS Title	PF-4/5 Alignment & Vessel Metrology	WBS #	1.01.02.08
Project Cog.	C. Pagano	Assoc. Proj. Man.	William Gattoni
Design Scope	Design and install clamps to maintain relative position of coil pancakes Design and install radial constraining pins on the PF-4U/L coils Align and maintain coil centers to meet alignment requirements w.r.t. VV		
Technical Impact of Scope	Ensures that machine-scale error fields are small enough to prevent NSTX-U L- and H-mode operations over a range of density		
Design Status	Pancake Clamp FDR completed on 08/09/2019 PF-4 Radial Pin FDR completed on 01/16/2020 Alignment PR completed on 02/05/2020 Chits , Calculations , Drawings		
Fabrication Status	Coil clamps are being fabricated and installed; Alignment fixtures and PF-4 radial pin components are being fabricated; Preparation work for alignment (e.g. removals) has begun		
Installation Status	Pancake Clamp installation in process		

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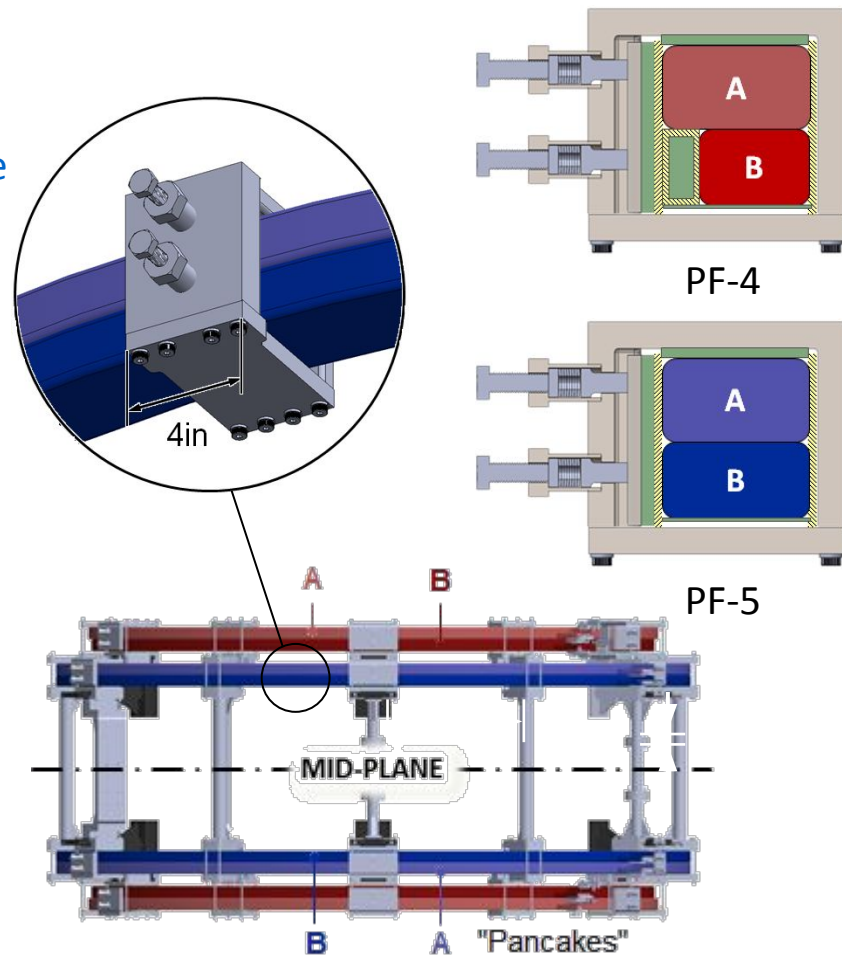
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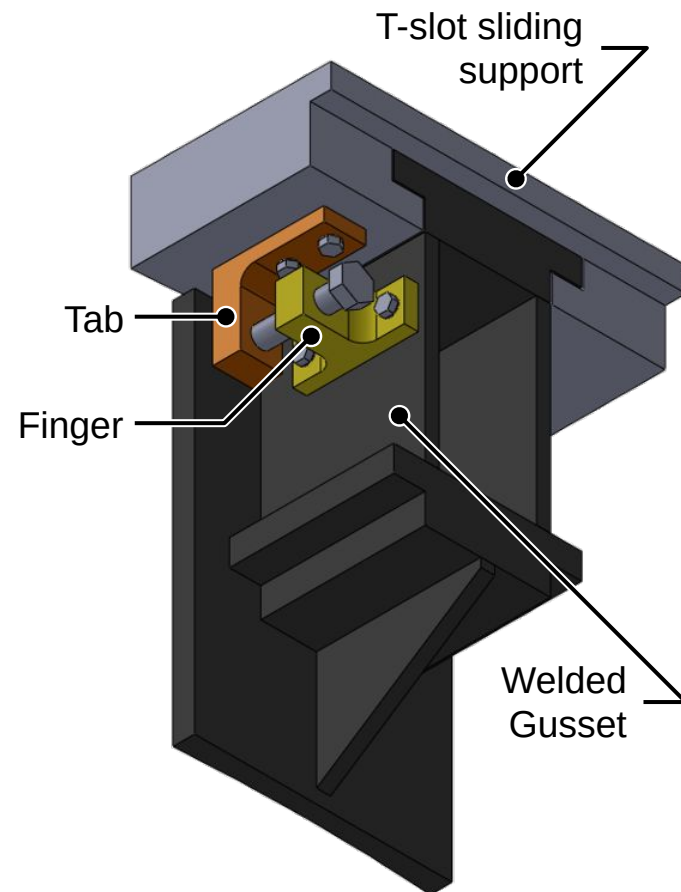
Scope: PF-4/5 Coil Pancake Clamps

- Clamps are intended to hold existing relative position of A and B coils of each PF coil pair
 - Existing shifts between the coil pairs are within the required limits of NSTX-U-RQMT-RD-011
 - Fix this position
- Clamps must meet all requirements:
 - Support load induced by pancake Δ temperature
 - Not impact the ability of the existing support clamps to tolerate radial and vertical EM loads
 - Accommodate variation in coil surface including step between PF-4 A & B
 - Not overstress/overconstrain coils
- Clamp size driven by minimum clearance between:
 - Fixed supports and clevis blocks welded to VV
 - PF4-U/L ID and VV OD including peripherals and



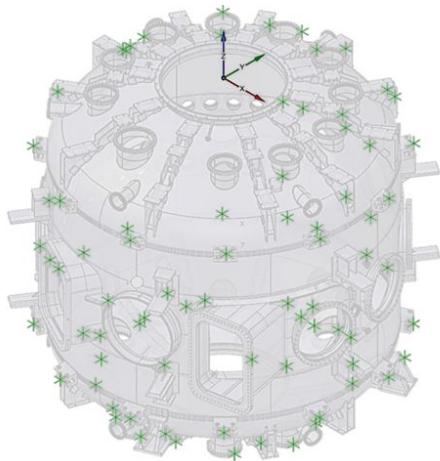
Scope: PF-4 Radial Constraining Pin

- PF-4 pin will be installed on both sides of the existing T-slot supports for both the Upper and Lower PF-4
 - Needed to bring in-field conditions into compliance with analysis modeling assumptions
- Restricts outward radial motion of the coils at two locations during operations
 - Same use case as existing PF-5 pin
- Requires minor modifications to existing welded gusset support and T-slot sliding support

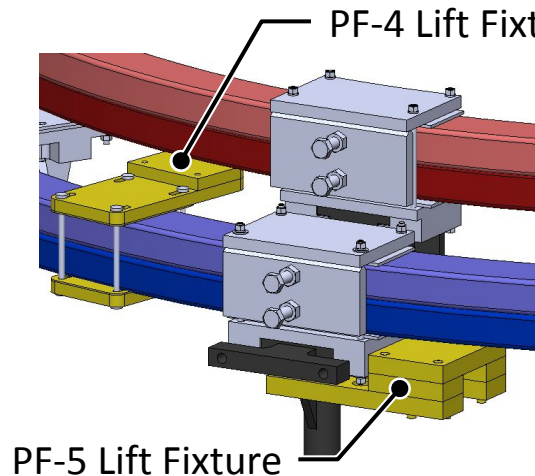


Scope: Alignment Methodology

- Lifting fixture is rigidly mounted to existing fixed supports on the VV
- Pneumatic lifting bag placed on top of fixture along with 2 sheets of Teflon to create a low friction “slip plane”
 - Lower coils rely on other means of support
- Real-time motion captured through use of dial indicators & local SMR targets
- Final position verified through center of best fit circle created from SMR data around coil



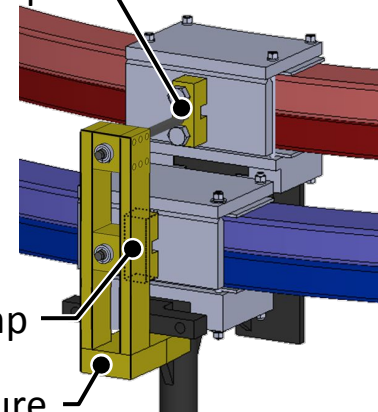
Monument
Network of VV



PF-5 Lift Fixture

PF-4 Lift Fixture

PF-4 Control Clamp

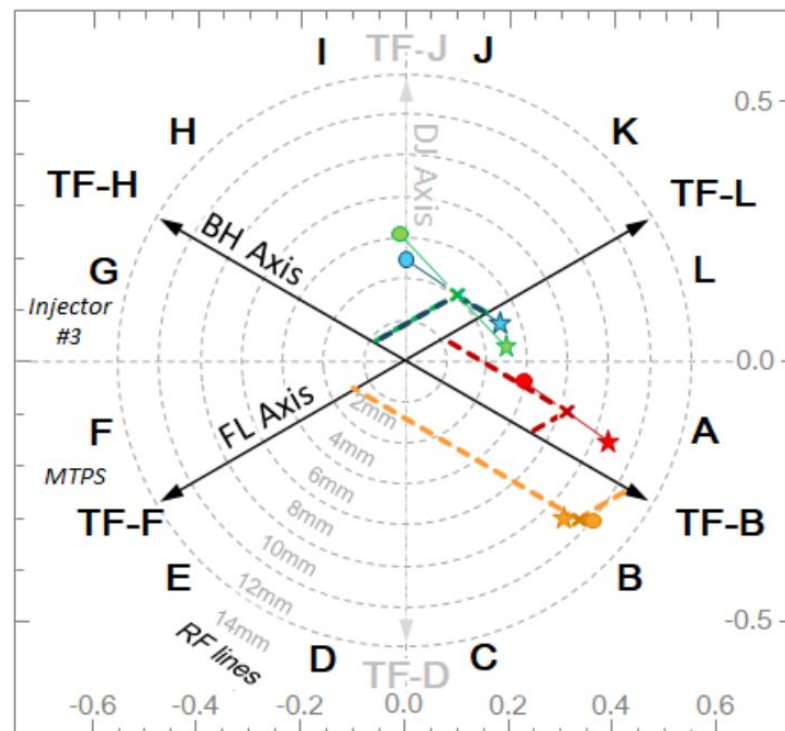
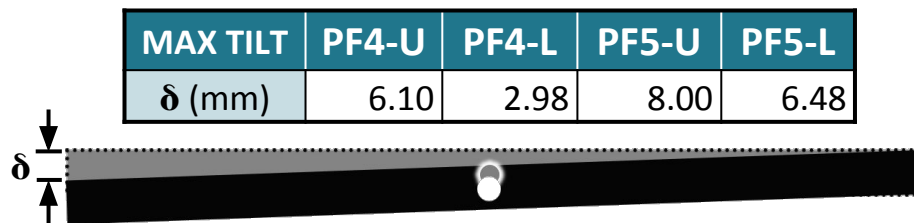


PF-5 Control Clamp

PF-4/5 Control Fixture

Scope: Alignment Methodology

- Alignment utilizes the sliding support clamps along the axes with least obstructions
- Remaining supports loosened and the coil lifted to minimize friction during move
- Position shifted and the the slider support placed to ensure sufficient clearance for bakeout and ops
- Tilt corrected for with the addition of shims
- Lift and alignment fixtures can be used for both tilt and shifts



AXIS	SHIFT	PF4-U	PF4-L	PF5-U	PF5-L
BH	(mm)	1.9	1.9	7.12	12.91
FL	(mm)	4.9	4.9	2.23	2.78

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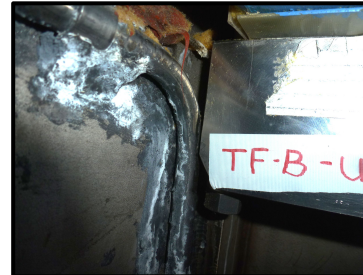
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Requirements

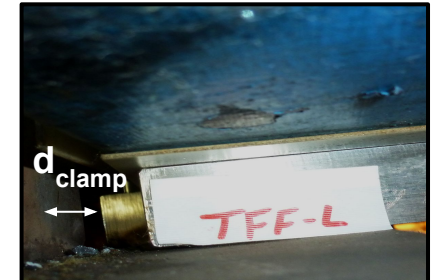
Source	Requirements	Comment	Met?
NSTX-CRIT-0001	Structural Design Criteria	Defines design loads and safety factors on which analysis is performed	Yes
NSTX-U-RQMT-RD-011	Alignment between pancakes of an individual coil	Current metrology shows that the alignment between the individual pancakes is within allowables (<8mm)	Yes
NSTX-U-RQMT-RD-011	Alignment of the coil (a pair of pancakes) relative to the machine coordinate system	Alignment shall align to <2mm shift and <0.9mrad tilt	On Course
NSTX-U-RQMT-SRD-003	All clamping structures must be capable of handling thermal loading during operations	Thermal analysis is performed on new clamps. No design changes planned for existing fixed and floating supports	Yes
NSTX-U-RQMT-RD-010	Magnetic Permeability Requirements	Materials and welds for new clamps shall meet limits	Yes

Interfaces

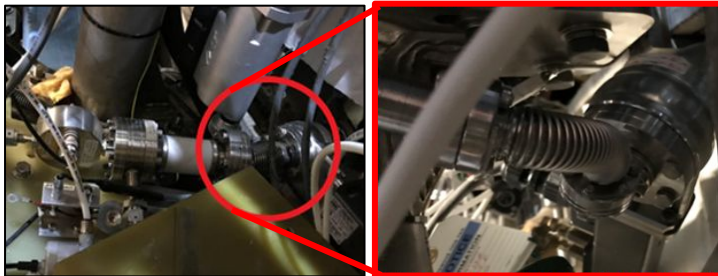
- NSTX-U Permanent Interfaces
 - New coil clamps and existing supports need sufficient clearance to the VV
 - New coil clamps need to support operations and bake-out conditions
 - Modest dimensional changes to the bus bar are required by the coil shifts
- Alignment Process Interfaces
 - Removal and reinstallation of select diagnostics/VV components
 - Sliding support to VV & radial pins
 - Bus bar flags to coils



Hot water line behind sliding support



Space between sliding supports and VV



Gas Injector Bellows to be disconnected



MTPS to be relocated



TIV to be removed

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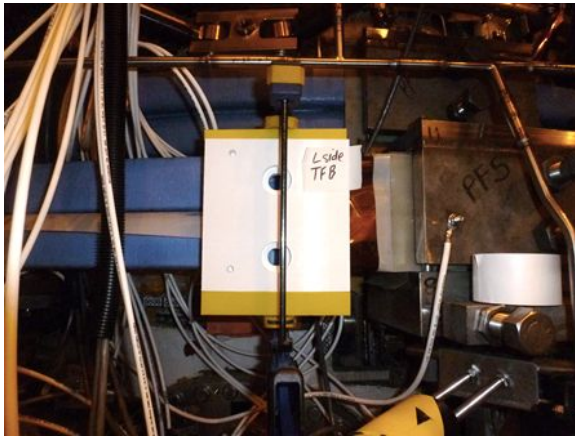
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Analysis

Physical Quantity	Calculation Report No.	Comment
Alignment requirements	NSTXU 1-1-2-3-2 CALC 100, R00	Defines alignment tolerances relative to the machine GCS
Lift/Alignment Fixture Stress	NSTXU 1-1-3-1 CALC 102, R00	Loads on the fixtures during move are within the allowable
PF-4/5 Coil Stress		Loads on the coil during move are within the allowable
PF-4 Coil Support Mod. Stress		Stresses on modified supports are within the allowable
Tilt/Alignment Clearance		Existing space capable of achieving KPP with modifications
Support Mechanical Tolerance Stack-up		Ensures allowable coil movement during operations is within allowable
Qty/Location of Pancake Clamps	NSTXU 1-1-3-1 CALC 100, R01	4 clamps are required equally spaced toroidally
Pancake Clamp Stress		Within allowable for expected loads
Coil/Existing Support Stresses		Clamps do not overstress coils
No slip at support		Coils do not slip at pinned locations during OPS and bake-out
Pin and Support Mod. Stress	NSTXU 1-1-3-1 CALC 101, R00	Within allowable for expected loads

Prototyping

- Prototype pancake clamps, PF-4 radial pin components and alignment fixtures have been made to ensure proper fit
- Pancake clamp Belleville washer stacks are being tested individually in mock housings to ensure proper load/deflection to ensure the desired applied load is achieved



PF-5 Pancake Clamp at Bay B



PF-4/5 Control Fixture at Bay L



PF-5 Lift Fixture at Bay B


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All Chits have been Closed

- All chits generated at past reviews have been closed

APPROVED
PPPL

 **PPPL**
PRINCETON
PLASMA PHYSICS
LABORATORY

ENG-033 - CRR - CHIT RESOLUTION REPORT
CHIT RESOLUTION REPORT FOR PF 4/5
REALIGNMENT

NSTXU_1-1-3-1_CRR_100
Rev. 5

Work Planning #:
Effective Date: 02/10/2020
Prepared By: Chris Pagano

Reviewed By	Chris Pagano, Cognizant Individual	02/07/2020 11:53:02 AM
Reviewed By	Yuhui Zhai, Project Engineer	02/07/2020 11:54:28 AM
Approved By	Robert A. Ellis, Chief Engineer	02/10/2020 12:55:49 PM

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[Chit Resolution Report](#)

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Progress



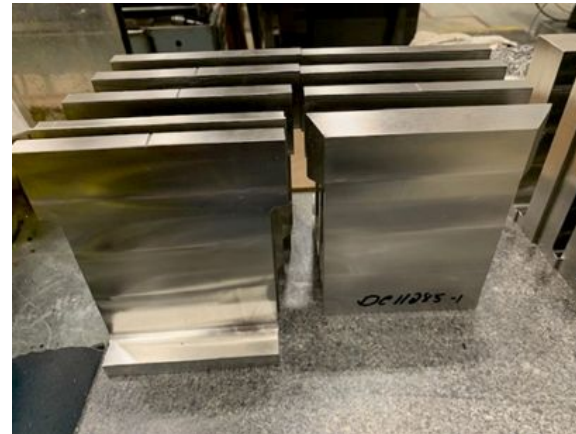
Preparation of the PF-4/5 coils surfaces to accept the epoxy pads



Machined epoxy pad casting molds



In-process fabrication of the Belleville washer housing assemblies



Pancake clamp parts machined with weld prep

Progress

- Installation of the pancake clamps is behind schedule
 - Fabrication of the pancake clamps is ongoing
 - Installation procedure is signed and ready
 - Epoxy casting fixtures are out for chromate finish
- Alignment process execution is behind schedule
 - Alignment execution requires completion of pancake clamp installation
 - Additional parts/modifications are required prior to alignment
 - Installation of rubber pads in fixed clamps
 - Installation of PF-4 radial constraining pin
 - Modification to existing floating and sliding supports
 - Moving the existing hot water lines behind PF-4 sliding supports
 - Adding shims to the t-bar to limit movement after alignment
 - Removals procedure is released for work to start
 - Fixture materials are on order

NCRs for PF-4/5 Realignment Activities

NCR Item	NCR No.	Description of the Issue
DC11283 DC11284	4087	Machine shop noticed error in thread callout on the drawing and implemented a correction without a redlined drawing or ECN
DC11285 DC11275	4089	Material received did not have marking to match to CMTR
DC11283 DC11284	4093	Threaded hole callout was marked on a assembly-level detail rather than part details for items DC11283-1 and DC11284-1
DC11283 DC11284	4095	Machined parts out of tolerance for epoxy casting molds
DC11283 DC11284	4098	Machined parts out of tolerance for epoxy casting molds
DC11275	4100	Machined parts out of tolerance for pancake clamps Magnetic permeability limits for the machined part exceeded

ECNs for PF-4/5 Realignment Activities

Drawing No.	ECN No.	Description of the Change
DC11275	8291	Revise thread callout; Revise part quantities; Revise COTS part description; Reduce required tolerances
DC11285	8292	Revise thread callout; Revise part quantities; Revise COTS part description; Reduce required tolerances
DC11283 DC11284	8309	Add threaded hole callout on part detail for the four corner holes of the bottom plates

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Project Risks are Actively Being Managed

Risk	Score (1-81)	Open/ Retired	Risk Retirement Event
If realignment of outer PF coil causes damage to the coil	28	OPEN	Completion of installation
If electrical testing causes damage to outer PF coils	21	OPEN	Completion of coil testing
M9-1, If electrical coil testing detects a larger than anticipated flaw in the Outer PF coils.	15	OPEN	Completion of coil testing

Other risks such as delay in component delivery are held at the Project level

FMECA - All Risks Mitigated to Acceptable Level (I)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Outer PF Supports	Column buckling	EM loads, potentially coupled with misalignments	unacceptable bowing of the PF-4 or PF-5 magnets	9	DCPS Software	None	None	3
Outer PF Supports	Outer PF support bracket welds to the machine fail	EM loads (static or after fatigue)	excessive coil bending under EM load, may permanently damage coil	9	DCPS Software	None	None	3
Outer PF Supports	Bolts on outer-PF supports fail	EM loads (static or after fatigue)	excessive coil bending under EM load, may permanently damage coil	9	DCPS Software	None	None	3
Outer PF Supports	Failures of the welds that attach the ribs to the vessel	EM loads (static or after fatigue)	excessive coil bending under EM load, may permanently damage coil	9	DCPS Software	None	None	3
Outer PF Supports	Sliding joints on coils begin to "stick"	Degradation of low-friction coating	Excessive coil strain and potential insulation degradation; potential damage to coil supports and vessel	8	Fiber Optic Strain, Temp., Disp. Meas.	None	None	4

FMECA - All Risks Mitigated to Acceptable Level (II)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Outer PF Supports	Failure of PF-4 locking pin	Thermal expansion and EM loadings on coils overstressing pin components or bolts	Position of PF-4 upper/lower coils can walk, or in create excessive stress on lead-area resulting in lead failure	8	DCPS Software	CWS Flow and Temperature Instrumentation	None	6
Outer PF Supports	Failure of PF-5 locking pin	Thermal expansion and EM loadings on coils overstressing pin components or bolts	Position of PF-5 upper/lower coils can walk, or create excessive stress in lead area resulting in lead failure	8	DCPS Software	CWS Flow and Temperature Instrumentation	None	6
Outer PF Supports	Failure of the pancake clamp to maintain pancake position	differential temperature, due to differential cooling/flow rates, leads to different expansion that breaks the clamps	Relative positions of A and B pancakes is not maintained and can prevent meeting physics requirements for magnetic confinement; in the extreme case, stress induced at coil leads causing failure	6	CWS Flow and Temperature Instrumentation	None	None	6

8 failure modes identified; all mitigated to an acceptable risk level

Primary Mitigations: DCPS limiting loads, Cooling water system ensuring flow, machine instrumentation checking behavior of slides

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Quality, Environment, Safety & Health

- Hazards are mitigated by laboratory programs
 - hoisting and rigging program
 - pressure system program (ES-MECH-15)
 - hand tools
- All in-house fabricated parts will have an associated traveler
- QIP for in-field work
- All new installations and modifications have an installation plan
 - Review and approved by IH, HP and Safety departments
 - JHAs are included as part of the plan
- No USIs identified during the reviews

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Summary

- The presented methodology capable of meeting the alignment precision and maintain the coil positions during ops and bakeout
 - KPP#1 & NSTX-U-RD-011
- The PF-4/5 Coils, existing and new support structures are designed to survive all EM and thermal loads
- All chits have been closed, see NSTXU_1-1-3-1_CRR_100
- Risks are mitigated through:
 - Conservative assumptions for clearance and strength requirements
 - Minimizing mechanical tolerances and unconstrained features of the coils
- All work performed requires a detailed JHA and critical lift procedure where required
- Work is sequenced to minimize delays/congestion in the NTC