National Spherical Torus eXperiment Upgrade

Passive Plates
WBS 1.01.02.02

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

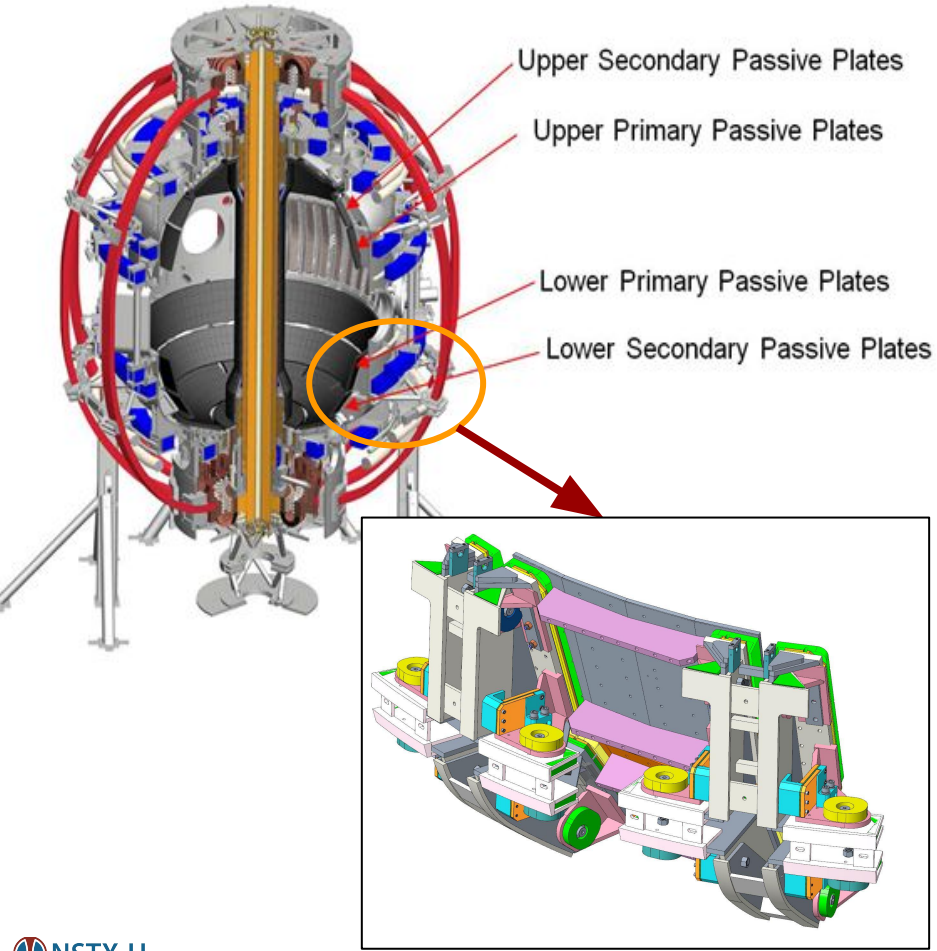
Ankita Jariwala - Cognizant Engineer

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 1.01.02.02



Passive Plate Overview

- *Primary function is to promote Plasma Stabilization through the induction of eddy currents.*

1. The passive plates consist of primary and secondary plates, one set above the midplane and one set below the midplane of the NSTX-U device.
2. There are 12 passive plates per each of the four rows, for a total of 48 plates.
3. Each plate is made up of a 1⁄2” thick conically shaped CuCrZr plates.
4. The passive plates are mounted to brackets, extending from the outer vacuum vessel cylinder.
5. The plate support features is traced with tubing to facilitate bakeout of the PFCs mounted on the passive plate surface.

- Most parts in this regions are from original NSTX build date of 90’s.

Overview - WBS 1.01.02.02

(CDE-3A Scope)

WBS Title	Passive Plates	WBS #	1.01.02.02
Project Cog.	A. Jariwala	Assoc. Proj. Man.	W. Gattoni
Design Scope	Reinforcements and upgrades to passive plate support brackets & helium line supports		
Technical Impact of Scope	Passive plate support bracket upgrade reduces motion of passive plate and existing brackets. Helium line brackets added to provide support against EM loads and allow thermal gradient growth.		
Design Status	FDR completed on 8/21/2019(review link) Two peer reviews for chit closure (link, link) chits: link calculations: link drawings: link SoW/Tech Spec: link		
Fabrication Status	Parts being fabricated in-house.		
Installation Status	Installation will begin in April' 2020.		

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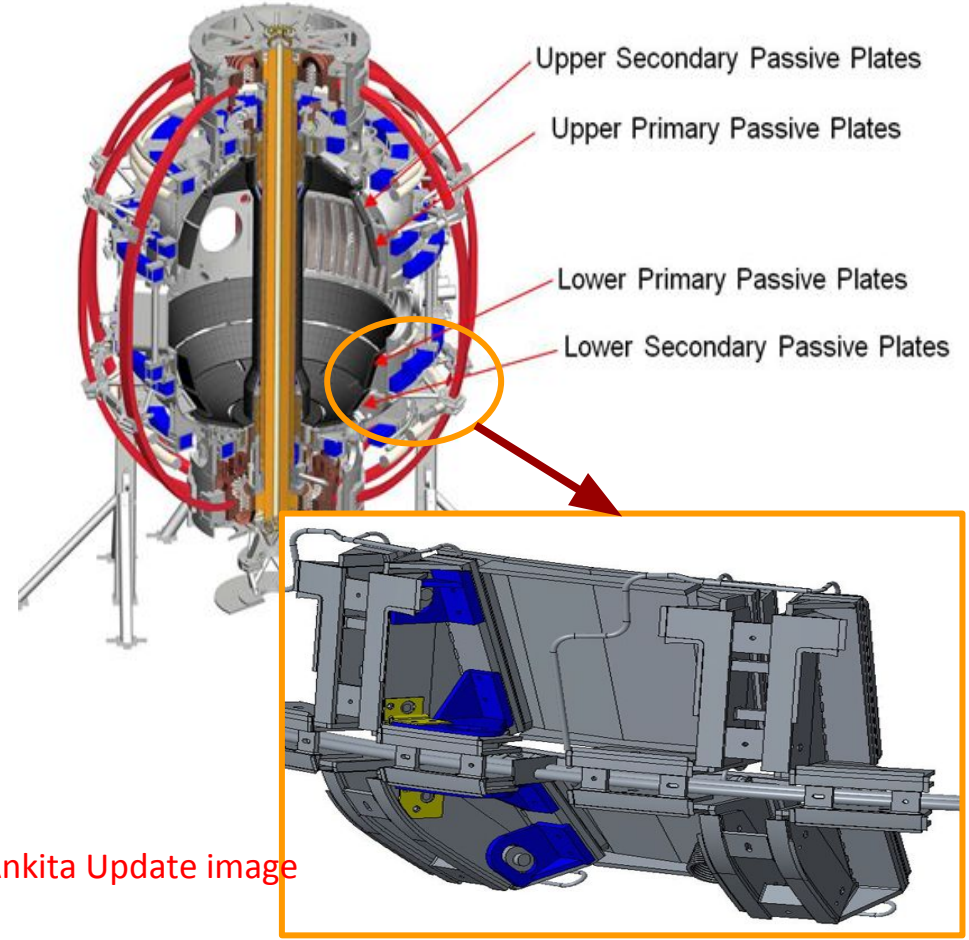
Passive Plate - Scope

Passive Plate Recovery Scope

1. Add Plate Stiffener to reduce plate bending & remove high stress region on PP bracket weldment
2. Add Tube Support bracket to reduce loading on cooling tubes
3. Add Electrical Strap to improve electrical connections between plates and wall-mounted bracket
4. Add External Biscuit Support to mitigate inadequacies in the welds of the bracket ears to the vessel.

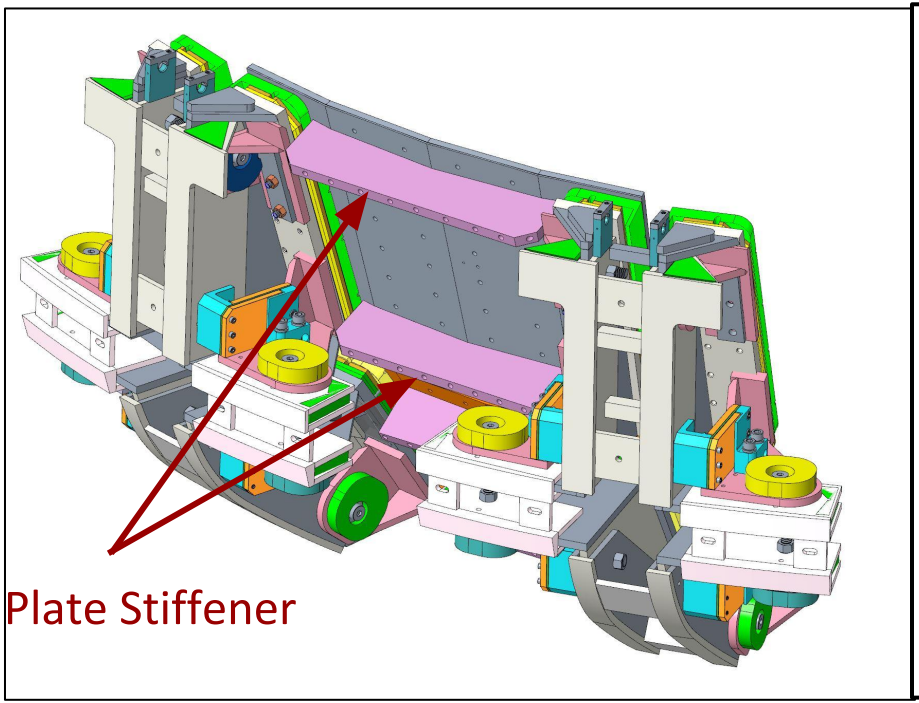


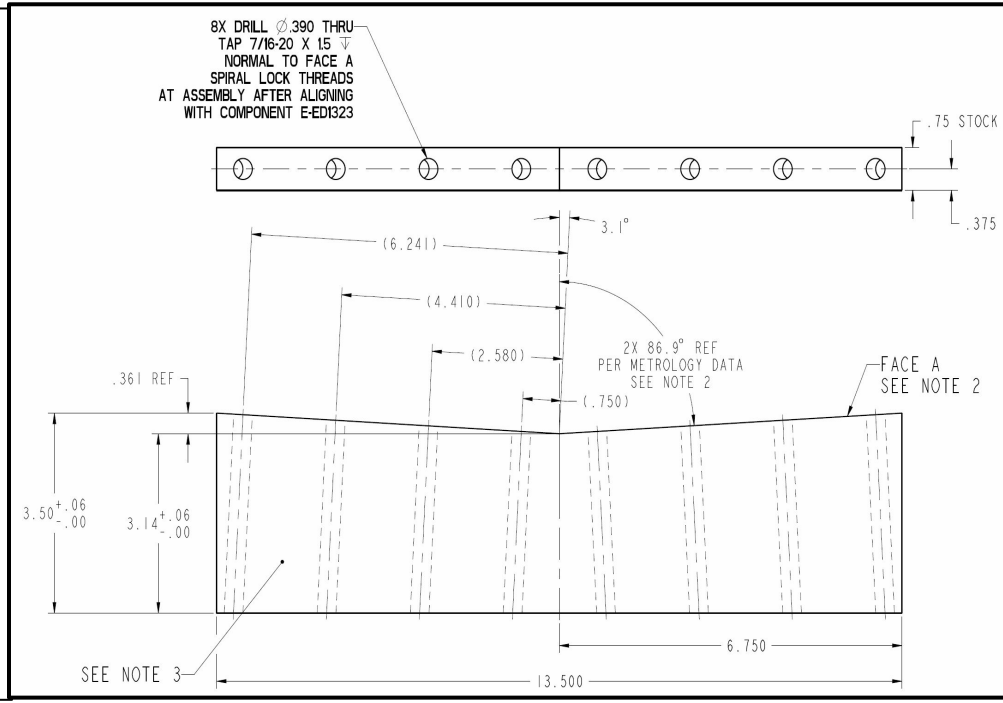
Ankita Update image

Passive Plate - Scope (I)

Problem Statement:
Bowing of plate leads to tile and bracket stresses

Problem Solution:
Add Plate Stiffener to reduces plate bending & high stress on PP bracket weldment

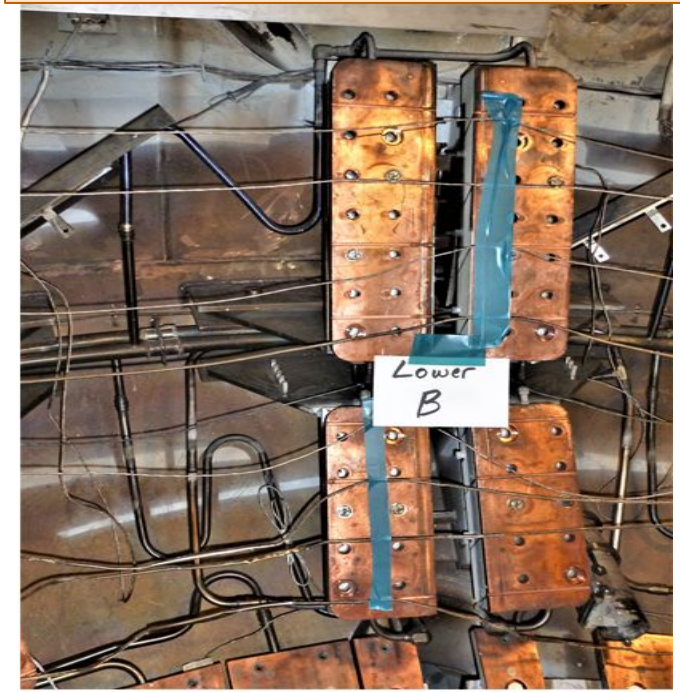


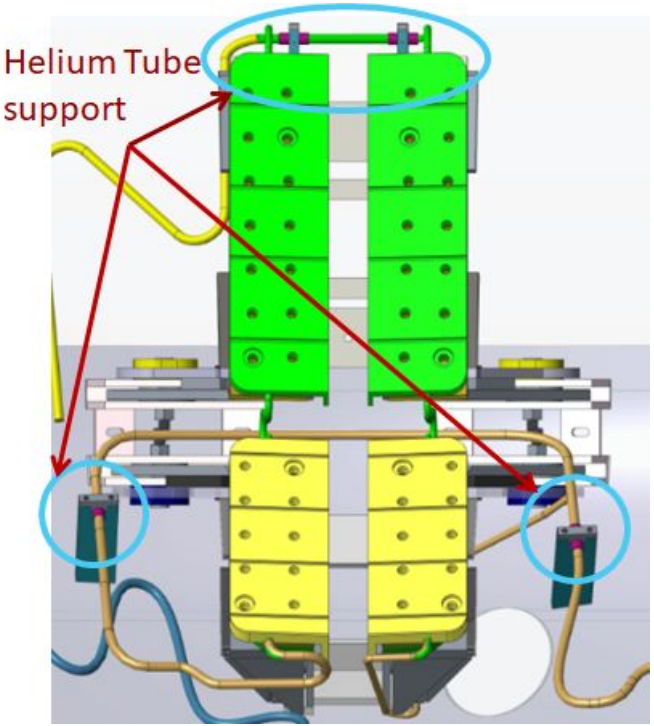


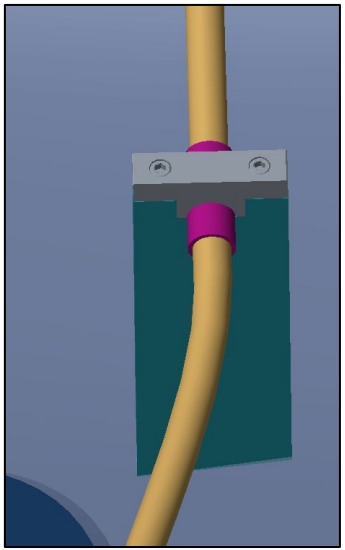
Passive Plate - Scope (II)

Problem Statement:
EM forces combined with bracket movement increases loads on the tube.

Problem Solution:
Add Tube Support (bracket) to reduce loading on cooling tubes.



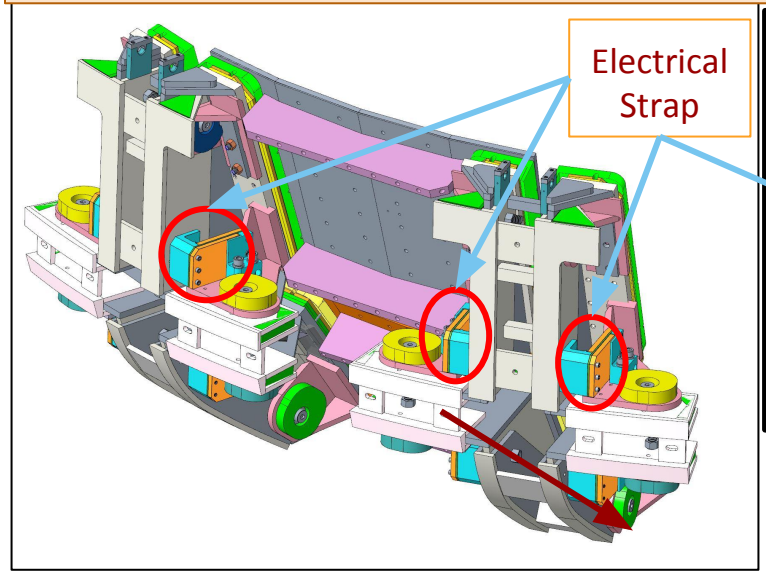


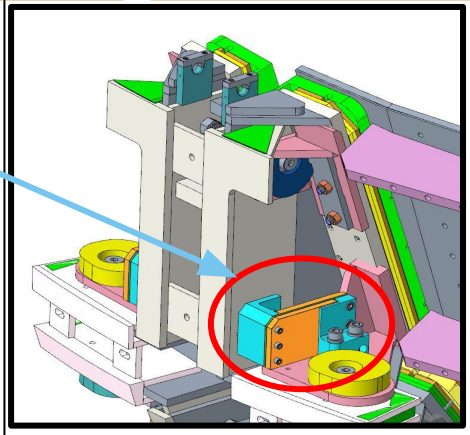


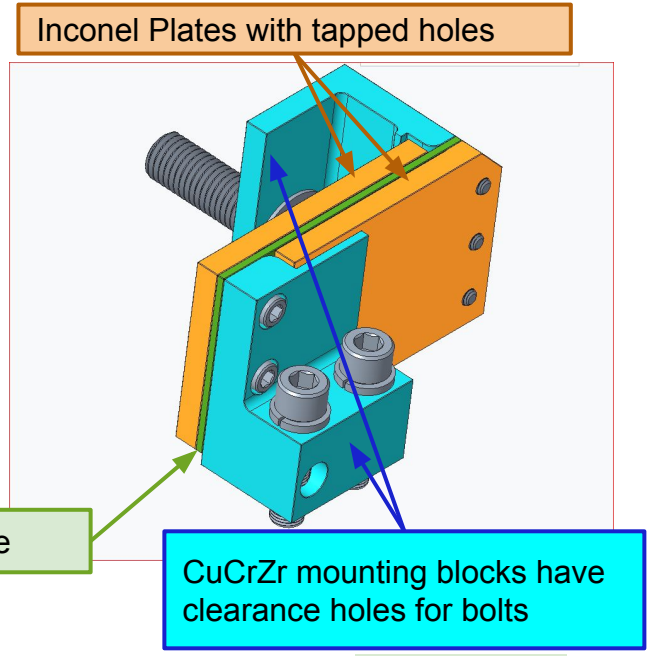
Passive Plate - Scope (III)

Problem Statement:
Variation in toroidal electrical resistances between plates and brackets in existing installation.

Problem Solution:
Add CuCrZr Electrical Strap to improve electrical connections between plate and wall-mounted bracket.



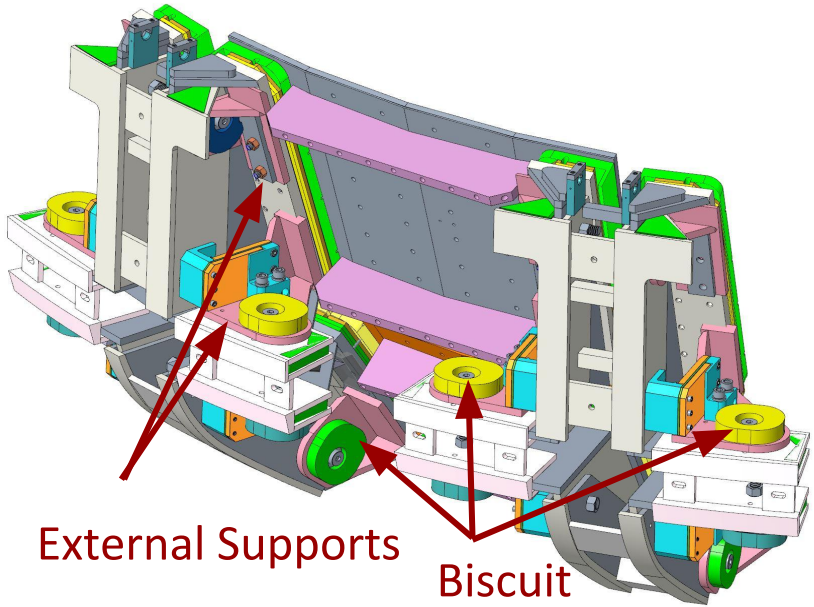


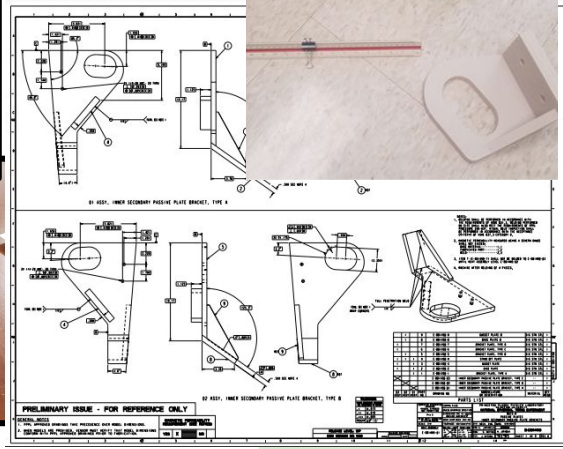


Passive Plate - Scope (IV)

Problem Statement:
As-built conditions increases displacements of brackets and increases weld stresses.

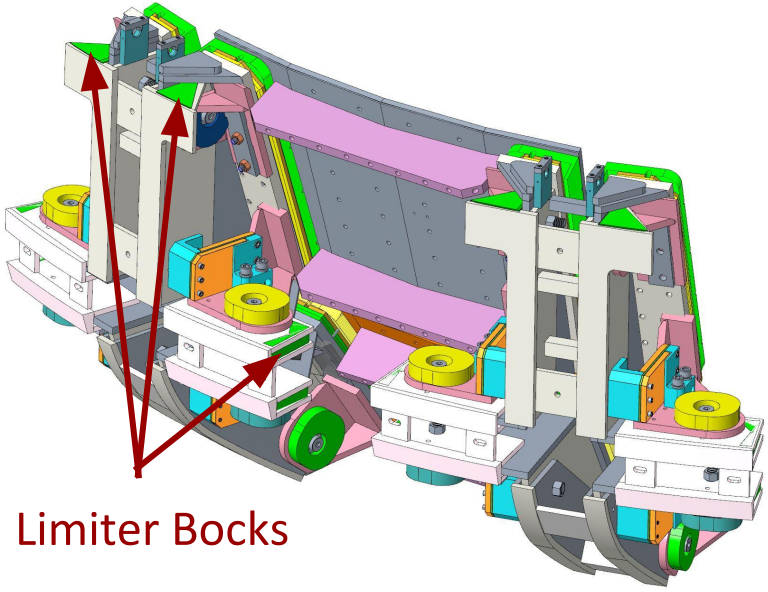
Problem Solution:
Add External Biscuit and Support Bracket to reduce the displacements and stresses in the welds of the bracket ears to the vessel.



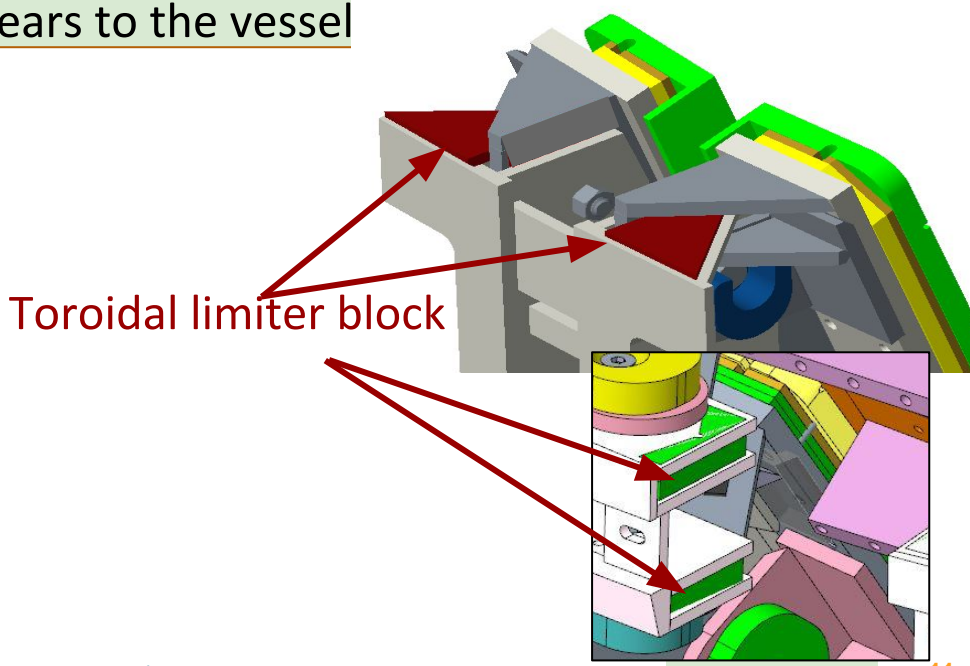


Passive Plate - Scope (V)

Problem Statement:
As-built conditions allows toroidal displacements of brackets and increases weld stresses.



Problem Solution:
Add Toroidal limiter block on existing brackets to reduce toroidal movement and alleviate stresses in the welds of the bracket ears to the vessel



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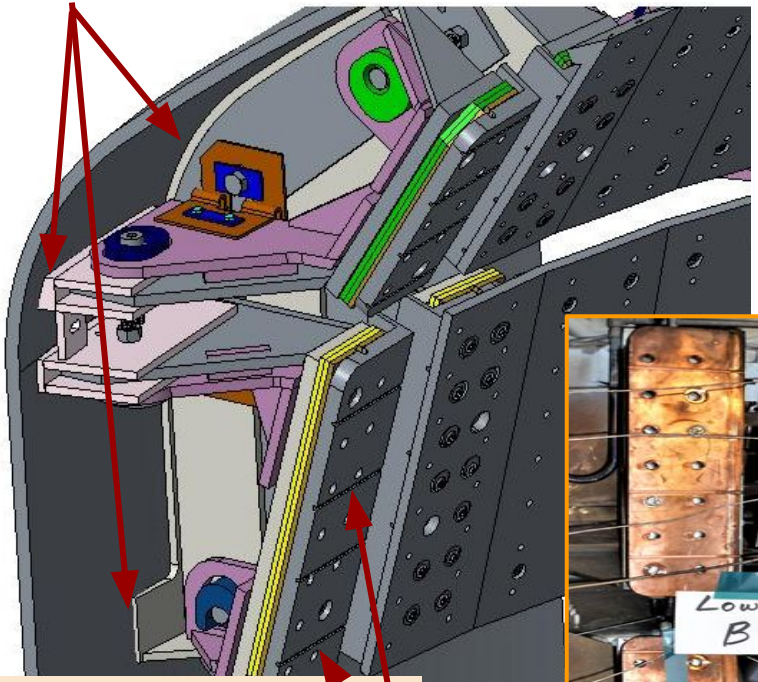
Requirements Defined and Met

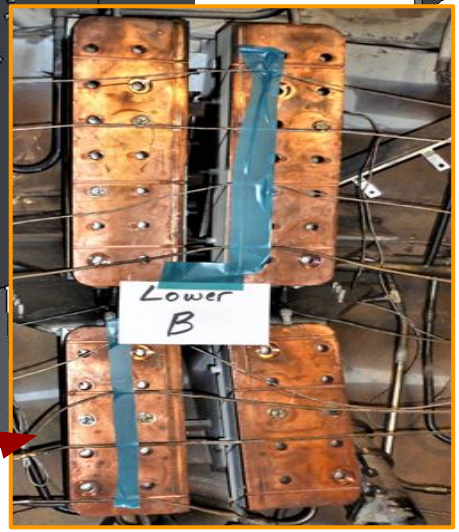
Source	Requirements	Comment	met
NSTX-U-RQMT-GRD-001	General design guidance	Provides requirements for each System Breakdown Structure (SBS) element	✔
NSTX-U-RQMT-SRD-004	Passive plate count, mounting	Determined original design of brackets, brackets now being enhanced	✔
NSTX-U-RQMT-SRD-004	Materials	CuCrZr, ½" thick	✔
NSTX-U-RQMT-SRD-004	Bakeout via Hot Helium	Requirement for trace tubing, whose supports are being improved in this job	✔
NSTX-CRIT-0001	Design Criteria	Provides the project definition of margin for loads vs. allowables	✔
NSTX-U-RQMT-RD-003	Disruptions	Provides guidance on computation of halo and eddy currents, including fatigue considerations, as an input to analysis	✔
NSTX-U-RQMT-SRD-004	Electrical Current Path Requirements	Defines requirements for new electrical strap capabilities, redundancy	✔

Complete RVTM maintained by Project Systems Engineering

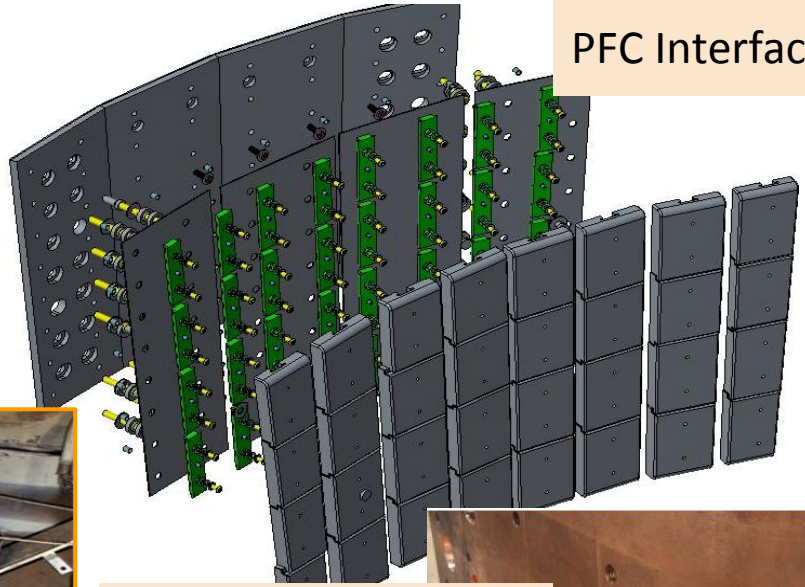
Interfaces Defined in the SRD and Accommodated by Design

Interface to vessel -Welded Joint





PFC Interface



Instrumentation Interface- Accelerometer

Diagnostic Interface- Flux Loop slots

*Old Shunt model shown

Charge question: 2

Details of Interfaces Defined in Interface Control Documents

System 1	System 2	ICD Link	Exposition
Passive Plates	Vacuum Vessel	link	Defines interfaces between the Passive Plates brackets and the Vacuum Vessel
Passive Plates	Diagnostics	link	Defines interfaces between the Passive Plates and flux loops, Mirnov sensors, RWM sensors
Passive Plates	Integrated Machine Operations	link	Defines interfaces between the Passive Plates and Vessel Accelerometers
Passive Plates	Bakeout	link	Defines interfaces between the Passive Plates and Helium Lines
Passive Plates	Plasma Facing Components	link	Defines interfaces between the Passive Plates and Passive Plate Plasma Facing Components

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Comprehensive Calculations Used to Verify Design will Meet Requirements

Physical Quantity	Calculation #	Comment
Disruption Simulations and Lorentz Force Data for Passive Plates	NSTXU_CALC-10-07-2	Provides all EM loads on passive plate, for the worst operating conditions.
Passive Plate Support Bracket EM loads	NSTXU_1_1_1_2_1_CALC_051	Provides EM loads on passive plate bracket
Structural analysis of Passive Plate support bracket	NSTXU_1_1_1_2_1_CALC_052	Verifies design passive plate support brackets.
Structural analysis of Passive Plate Shunt	NSTXU_1_1_1_2_1_CALC_053 (Draft of Rev. 1 w/ Updated Shunt)	Verifies design passive plate shunt
Structural analysis of Helium line bracket and Weld Evaluation	NSTXU_1_1_1_2_1_CALC_054	Verifies design of Helium line bracket and weld life.
Magnetic Damping Effect	NSTXU_1-1-1-2-1_CALC_100	Evaluate magnetic damping effects on passive plates
Material strain allowables	NSTXU_1-1-1-2-1_CALC_104	Provides strain allowables for various materials based on a Miner's rule for passive plate disruption loads

Design Assurance: in-vessel inspection & trial fit

Weld Distortion study

Input from tech

Input from tech

	Conclusion For Lower Primary Passive Plate support Part 2
Access acceptable to position parts?	Yes, except C\D, F\G, I\J, & L\A Rogowski coil brackets need to be removed for part to sit flat against the back off the support.
Modifications require for positioning?	No
Access acceptable for welding parts?	Yes, except C\D, F\G, I\J, & L\A Rogowski coil brackets need to be removed to achieve full length weld along the vert. ¼ weld is achievable full vert and ¼" horiz. Horiz weld is whatever was called out for in the procedure.
Modifications require for welding?	No

- Parts modified based on Tech's input and fabrication input.
- Few variations exists but we know the location and type for "in-vessel" fit-up needed at each location.
- Weld distortion study completed. It gave important feedback on welding time and way to reduce the distortions. See report NSTXU-REC-166-00

Unused Rogowski brackets removed

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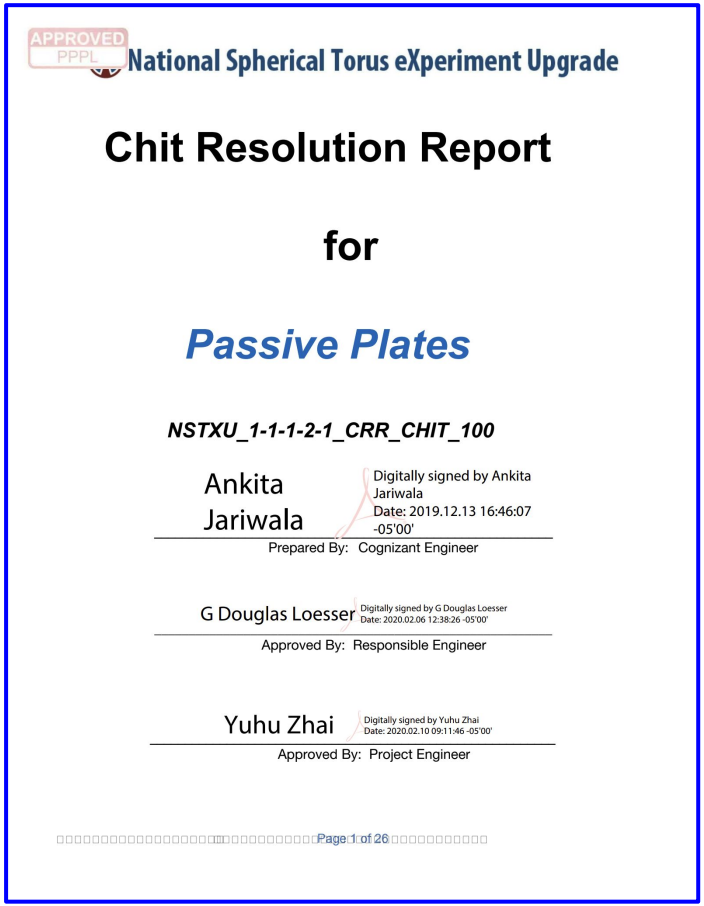
Chit Closure Nearing Completion

- All pre-FDR chits closed at the FDR
- All FDR chits now closed.
- In process of closing a small number of chits from recent peer review.



APPROVED PPPL

National Spherical Torus eXperiment Upgrade

Chit Resolution Report

for

Passive Plates

NSTXU_1-1-1-2-1_CRR_CHIT_100

Ankita Jariwala — Digitally signed by Ankita Jariwala Date: 2019.12.13 16:46:07 -05'00'

Prepared By: Cognizant Engineer

G Douglas Loesser — Digitally signed by G Douglas Loesser Date: 2020.02.06 12:38:26 -05'00'

Approved By: Responsible Engineer

Yuhu Zhai — Digitally signed by Yuhu Zhai Date: 2020.02.10 09:11:46 -05'00'

Approved By: Project Engineer

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Chit Resolution Report: link

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Passive Plate Fabrication Activity

- All parts are “in-house” fabrication.
- Bracket fabrication and installation will work in parallel to improve total install time.
- Process flow chart has been established to know the parts Fab. history
- In house fabrication of 2/6 components is completed.
- Fabrication of other other part will start in 2 weeks.
- Passive Plate modification is started in the shop.

Add image of Helium Tube

NCRs and ECNs During Passive Plate Fabrication/Installation Activities to Date

NCR Item	NCR Number	Description of the Issue
No NCRs for this scope to date		

Drawing Number	ECN Number	Description of the Change
DB1509	8288	Change dimension hole to maintain clearance.
DB1503, DB1520, DB1521	8307	Update Ceramic coating Specification #. Add missing dimension

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Project Risks are Actively Being Managed

Risk	Score (1-81)	Open/Retired	Risk Retirement Event
If the as built vs as designed analysis of Passive Plate finds the structural welds not sufficient.	35	RETIRED	FDR for passive plates
If existing welds or brackets cannot be qualified	35	RETIRED	FDR
If helium line supports/brackets cannot be added at all custom locations	20	OPEN	Subcomponent assembly completion
If in-vessel inspection reveals less room for welding for passive plate installation	16	RETIRED	FDR
If constant or close to constant toroidal resistances is not achieved between each Passive Plate	16	OPEN	FDR

Project Risks are Actively Being Managed

Risk	Score (1-81)	Open/Retired	Risk Retirement Event
If installing PCHERS passive plate creates interference issue for PP stiffener or support bracket	16	OPEN	completion of subassembly
Impact load analysis with existing play shows stress above allowable	1	RETIRED	FDR
If existing parts are damaged during passive plate repair work in-vessel	15	OPEN	Machine reassembly
If Welds cannot be done as designed, at all locations	15	OPEN	Machine reassembly

FMECA - Passive Plates (I)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Passive plates	Failure of welds or plates where brackets mount to vessel, or on any of the welds or plates of the various brackets (those on vessel, those mounted to plates, or external biscuit brackets)	Excessive disruption eddy current load, including potential beyond-design-basis cases	Plates become loose, potentially catastrophically; He line leaks	9	DCPS Software	Vacuum Gauges and Residual Gas Analyzers	None	3
Passive plates	Failure of welds or plates where brackets mount to vessel, or on any of the welds or plates of the various brackets (those on vessel, those mounted to plates, or external biscuit brackets)	failure of either the MTWS or HTHS results in one system working, but not the other, and therefore temperature gradients outside of design basis	Plates become loose, potentially catastrophically; He line leaks	9	Bakeout PLC and Controls	Vacuum Gauges and Residual Gas Analyzers	Plasma TV	3
Passive plates	Failure of bolts attaching stiffener (strongback) to back side of passive plates	Excessive disruption eddy current load, including potential beyond-design-basis cases	Excessive flex of plates, excessive transfer of loads to brackets, could result in failure of the bracket components or leaks in He piping; excessive load transferred to tiles	9	DCPS Software	Vacuum Gauges and Residual Gas Analyzers	Plasma TV	3

FMECA - Passive Plates (II)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Passive plates	Failure of stiffener (strongback) on back side of passive plates	Excessive disruption eddy current load, including potential beyond-design-basis cases	Excessive flex of plates, excessive transfer of loads to brackets, could result in failure of the bracket components or leaks in He piping; excessive load transferred to tiles	9	DCPS Software	Vacuum Gauges and Residual Gas Analyzers	Plasma TV	3
Passive plates	Failure of electrical strap bolts	excessive pre-load applied during assembly	Current transfers to other biscuit brackets	9	DCPS Software	None	None	3
Passive plates	Failure of the bolts mounting the passive plate to their support brackets	Excessive disruption eddy current load, including potential beyond design basis cases	Plates become loose	9	DCPS Software	Vacuum Gauges and Residual Gas Analyzers	Plasma TV	3
Passive plates	Failure/rupture of the passive plate under bolts that hold it to the brackets	Excessive disruption eddy current load, including potential beyond design basis cases	Plates become loose	9	DCPS Software	Vacuum Gauges and Residual Gas Analyzers	Plasma TV	3
Passive plates	Excessive distortion of the external biscuit	Excessive disruption eddy current load, including potential beyond design basis cases	Load is transferred back to original biscuits	9	DCPS Software	Vacuum Gauges and Residual Gas Analyzers	Plasma TV	3

FMECA - Passive Plates (III)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Passive plates	Mechanical failure of the electric strap during plasma ops	Excessive disruption eddy current load (including beyond design basis)	Current transfers to other strap or through the biscuit brackets	9	DCPS Software	None	None	2
Passive plates	Failure of the bolts mounting the PP to their support brackets	Excessive disruption eddy current load, including potential beyond-design-basis cases	Plates become loose	9	DCPS Software	Vacuum Gauges and Residual Gas Analyzers	Plasma TV	3
Passive plates	Failure of biscuit bolt	Excessive disruption eddy current load	motion is unconstrained, large deflection under EM loads	9	DCPS Software	Vacuum Gauges and Residual Gas Analyzers	Plasma TV	3
In-Vessel Helium Lines	Leak in in-vessel He lines develops	Excessive halo or disruption eddy current loads on lines	Inability to run plasma due to large leak	9	DCPS Software	Vacuum Gauges and Residual Gas Analyzers	None	3

FMECA - Passive Plates (IV)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Passive plates	Degradation of electrical connection at interface of "electric strap" to bracket components	Excessive eddy current heating at interface, or loss of preload on bolts	Current transfers to other strap or through the biscuit brackets	6	None	None	None	6
Passive plates	Electrical failure of the electric strap (melts, open circuit)	Excessive disruption eddy current load, including potential beyond design basis cases	Current transfers to other strap or through the biscuit brackets	4	DCPS Software	None	None	4
Passive plates	Failure of welds or plates where brackets mount to vessel, or on any of the welds or plates of the various brackets (those on vessel, those mounted to plates, or external biscuit brackets)	In-vacuum cold weld between external biscuits and stiffening brackets.	thermal motion during bakeout not accommodated; loads pile up on some elements	3	None	Vacuum Gauges and Residual Gas Analyzers	Plasma TV	3
Passive plates	Mechanical failure of the electric strap during bakeout	stresses in the strap due to plate thermal expansion lead to strap failure	Current transfers to other strap or through the biscuit brackets	3	None	None	None	2

FMECA - Passive Plates (IV)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Passive plates	Brackets or tile failure	Bakeout temps anneal CuCrZr, resulting in it becoming softer and transferring load to those components	Plasma operations cannot continue, must enter and repair	0	None	Vacuum Gauges and Residual Gas Analyzers	Plasma TV	0

17 FMs identified, all mitigated to acceptable risk

Digital Coil Protection System (DCPS) is the primary mitigation - DCPS limits operations to the envelope defined in the design process, providing assurance that disruption loads will be within the design envelope.

Vacuum Gauges allow He tube leaks to be detected - would evacuate the tubes and repair in next outage

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QA (Fabrication/Installation) Oversight

- No unique feature/parts that requires “Novel” manufacturing technique.
- In-house fabrication and PPPL Qualified vendors will be used to make parts. All parts falls under A1 category, using graded approach.
- Technical Specification and an oversight plan, that follows rigors per PPPL’s ENG-006 "Preparation, Review & Approval of Technical Specifications" and QA-004 - “QA/QC Site Inspection and Oversight”, will be used to outline hold points, inspection and testing required throughout fabrication and installation phase.
- For in-house fabrication “Travelers” are being used to track the part fabrication and Quality Inspection Plan (QIP) is used for part inspection.
- For in-vessel installation QIP will be generated by QA once Installation Procedure is signed and approved.

Environmental, Safety, & Health

- Passive plate installation work will be done in a “Confined Space”.
- HP will be involved in all phases of in-vessel work.
- Installation also include “fire hazard” due to welding/cutting activities.
- Work hazards will be managed/mitigated through the PPPL worker safety and rad. safety programs.
  - –Job Hazard Analysis
  - –Pre- and Post- Job Briefs

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Summary

- Requirements have been met and design has been validated via combination of analysis and testing.
- Interfaces, both physical and functional, are considered in the design and documented in the ICDs.
- Most chits related to the Passive Plates are closed.
  - Closing 2 CHITs from Shunt/Electrical Strap Peer review held on 03/07/2020.
- Risks are mitigated through:
  - Extensive in-vessel inspection, and trial fit ups
  - Prototyping and testing.
  - Analysis to qualify existing components from 90's
- Work hazards will be managed/mitigated through the PPPL worker safety and rad. safety programs.
  - –Job Hazard Analysis
  - –Pre- and Post -Job Briefs