PRINCETON PLASMA PHYSICS LABORATORY

ENG-033 - CRR - CHIT RESOLUTION REPORT

CHIT RESOLUTION REPORT FOR THE MACHINE CORE STRUCTURES

NSTXU_1-1-3-3_CRR_100

Work Planning #:	
Effective Date:	**03/09/2020**
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Approved By	Kathleen Lukazik, Preparer	03/09/2020 16:03:45 PM

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NSTX-U Chit Resolution Report #: **NSTXU_1-1-3-3_CRR_CHIT_100**

CHIT CODE	§ OF REPORT	STATUS	CHIT CODE	§ OF REPORT	STATUS
VVIHPF1CCB25	CR-VVIH-1100	CLOSED	PRIPFCS06	CR-VVIH-1146	CLOSED
VVIHPF1CCB03	CR-VVIH-1101	CLOSED	PRFORINSUPDR21	CR-VVIH-1147	CLOSED
VVIHPF1CCB05	CR-VVIH-1102	CLOSED	PRIPFCS14	CR-VVIH-1148	CLOSED
VVIHPF1CCB06	CR-VVIH-1103	CLOSED	PRFORINSUPDR13	CR-VVIH-1149	CLOSED
VVIHPF1CCB04	CR-VVIH-1104	CLOSED	PRFORINSUPDR10	CR-VVIH-1150	CLOSED
VVIHPF1CCB11	CR-VVIH-1105	CLOSED	PRIPFCS11	CR-VVIH-1151	CLOSED
POLARPEER49	CR-VVIH-1106	CLOSED	PRIPFCS04	CR-VVIH-1152	CLOSED
VVIHPF1CCB24	CR-VVIH-1107	CLOSED	PRIPFCS07	CR-VVIH-1153	CLOSED
POLARPEER17	CR-VVIH-1108	CLOSED	PRIPFCS12	CR-VVIH-1154	CLOSED
VVIHPF1CCB12	CR-VVIH-1109	CLOSED	PRIPFCS09	CR-VVIH-1155	CLOSED
POLARPEER18	CR-VVIH-1110	CLOSED	PRIPFCS03	CR-VVIH-1156	CLOSED
POLARPEER12	CR-VVIH-1111	CLOSED	PRFORINSUPDR28	CR-VVIH-1157	CLOSED
VVIHPF1CCB13	CR-VVIH-1112	CLOSED	PRFORINSUPDR30	CR-VVIH-1158	CLOSED
VVIHPF1CCB19	CR-VVIH-1113	CLOSED	PRIPFCS13	CR-VVIH-1159	CLOSED
POLARPEER13	CR-VVIH-1114	CLOSED	PROJPDR14	CR-VVIH-1160	CLOSED
POLARPEER14	CR-VVIH-1115	CLOSED	RPCDR019	CR-VVIH-1161	CLOSED
RPCDR031	CR-VVIH-1116	CLOSED	RPCDR013	CR-VVIH-1162	CLOSED
RPCDR029	CR-VVIH-1117	CLOSED	PROJPDR15	CR-VVIH-1163	CLOSED
VVIHPF1CCB15	CR-VVIH-1118	CLOSED	PROJPDR16	CR-VVIH-1164	CLOSED
VVIHPF1CCB22	CR-VVIH-1119	CLOSED	PRIPFCS05	CR-VVIH-1165	CLOSED
VVIHPF1CCB26	CR-VVIH-1120	CLOSED	RPCDR020	CR-VVIH-1166	CLOSED
PRFORINSUPDR33	CR-VVIH-1121	CLOSED	RPCDR033	CR-VVIH-1167	CLOSED
PRFORINSUPDR25	CR-VVIH-1122	CLOSED	RPCDR016	CR-VVIH-1168	CLOSED
POLARPEER16	CR-VVIH-1123	CLOSED	PROJPDR17	CR-VVIH-1169	CLOSED
ALLIGNPEER11	CR-VVIH-1124	CLOSED	PRIPFCS10	CR-VVIH-1170	CLOSED
ALLENPEER04	CR-VVIH-1125	CLOSED	PRIPFCS02	CR-VVIH-1171	CLOSED
PRFORINSUPDR06	CR-VVIH-1126	CLOSED	PRIPFCS08	CR-VVIH-1172	CLOSED
PROJPDR05	CR-VVIH-1127	CLOSED	VVIHCP10	CR-VVIH-1173	CLOSED
PRFORINSUPDR01	CR-VVIH-1128	CLOSED	VVIHPF1CCB14	CR-VVIH-1174	CLOSED
VVIHPF1CCB02	CR-VVIH-1129	CLOSED	VVIHPF1CCB16	CR-VVIH-1175	CLOSED
PRFORINSUPDR32	CR-VVIH-1130	CLOSED	CSCFDR16	CR-VVIH-1176	CLOSED
PRFORINSUPDR06	CR-VVIH-1131	CLOSED	CSCFDR14	CR-VVIH-1177	CLOSED
PROJPDR30	CR-VVIH-1132	CLOSED	CSCFDR15	CR-VVIH-1178	CLOSED
PRFORINSUPDR31	CR-VVIH-1133	CLOSED	VVIHPF1CCB10	CR-VVIH-1179	CLOSED
PRFORINSUPDR23	CR-VVIH-1134	CLOSED	DIAGMPTS11	CR-VVIH-1180	CLOSED
PRFORINSUPDR24	CR-VVIH-1135	CLOSED	PRIPFCS01	CR-VVIH-1181	CLOSED
PRFORINSUPDR22	CR-VVIH-1136	CLOSED	RPCDR040	CR-VVIH-1182	CLOSED
RPCDR030	CR-VVIH-1137	CLOSED			
RPCDR028	CR-VVIH-1138	CLOSED			
VVIHPF1CCB08	CR-VVIH-1139	CLOSED			
PRFORINSUPDR02	CR-VVIH-1140	CLOSED			
RPCDR034	CR-VVIH-1141	CLOSED			
RPCDR024	CR-VVIH-1142	CLOSED			
VVIHPF1CCB17	CR-VVIH-1143	CLOSED			
PRFORINSUPDR05	CR-VVIH-1144	CLOSED			
PRFORINSUPDR09	CR-VVIH-1145	CLOSED			

Cognizant Individual: Thomas Ronge Digitally signed by Thomas Ronge Date: 2020.03.06 15:26:14 -05'00'

T Rongé, Cognizant Individual

Approver (*): Robert Ellis Digitally signed by Robert Ellis Date: 2020.03.06 16:23:25 -05'00'

R Ellis, Chief Engineer

National Spherical Torus eXperiment Upgrade

CHIT RESOLUTION REPORT
FOR
MACHINE CORE STRUCTURES

NSTXU_1-1-3-3_CRR_CHIT_100

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RECORD OF CHANGES

Rev.	Date	Description of Changes
0	03/06/2020	Initial Release

TABLE OF CONTENTS

Disposition Key:

A	=	Actionable
NA	=	Not Actionable
NB	=	Not Actionable due to budget constraints
O	=	Out of Scope
R	=	Redundant

REFERENCE DOCUMENTS

Reference	Title
NSTXU-CALC-33-04-01	Interspace Vacuum Pumping System (IVPS) Pumping Speed
NSTXU_1-1-3-3_CALC_115	Machine Core Structures Mechanical
NSTXU_1-1-3-3_CALC_101	Machine Core Structures Alignment & Tolerance Stack Assessment
NSTXU_1-1-3-3_CALC_102	Machine Core Structures Electromagnetic Analyses
NSTXU_1-1-3-3_CALC_103	Machine Core Structures Vacuum Calculations
NSTXU_1-1-3-3-11_CALC_106	PF1A/B Sling Fab Tolerance Revs For Ease of Manufacturing
NSTXU_1-1-3-3_CALC_107	Structural FEAs PF1A 6 –inch KT-880 GF30 Belt
NSTXU_1-1-3-3_CALC_109	Ceramic Break Flange
NSTXU_1-1-3-3_CALC_112	MCS Outer Skirt
NSTXU_1-1-3-3_CALC_113	MCS Structure Buckling Analysis
NSTXU_1-1-3-3_CALC_114	MCS Pedestal Analysis
NSTXU_1-1-3-3_CALC_116	Effect of Non-Uniform Pre-loading on Inner PF A and B Coils
NSTXU_1-1-3-3_CALC_117	Upper & Lower PF1C Canister Structures
NSTXU_1-1-3-3_CALC_119	Upper Bellows Flange Calculation
NSTXU_1-1-3-3-11_CALC_tbd	BELT CALC
NSTXU_1-1-3-3-11_CRR_101	Chit Resolution Report for PF1A Sling Peer Review
NSTXU-CALC-10-6-00	NSTXU Recovery Global Heat Balance Calculations
NSTXU-CALC-33-04-01	Interspace Vacuum Pumping System (IVPS)
NSTXU_1-1-3-3-11_PROTO_100	MCS Sling Prototypes Testing
NSTXU_1-1-3-3_DOC_101	MCS Pf1A Full Mockup Activities
NSTXU_1-1-3-3_TREP_100	MCS Belleville Washer Assembly Testing
NSTXU_1-1-3-3-3-11_TREP_101	Tensile and Fatigue Testing of Welded Inconel 718 (heat treatments)
NSTXU_1-1-3-3_DOC_103	MCS Preload Development
NSTXU_1-1-3-3_DOC_104	MCS Ceramic Break Mockup & Testing
NSTXU_1-1-3_REC_100	Summary of ECM Metrology Results
VVIH-180102-MS-01	Metal Seals VS. Double O-ring Seals with Pumped Interspace
VVH_200122_TJR_2_	UPPER DIVERTER FLANGE MODIFICATION

CR-VVIH-1100 – Machine Core Vacuum Integrity and Leak Checking

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1C CB25	It is important to be able to leak test all O-ring seals separately so as to pinpoint problems and monitor permeation rates. It is desirable to leak test critical welds and weld assemblies (e.g., PF coil casings) also. Are there critical components (O-rings, weld assemblies etc.) that cannot be leak tested without machine disassembly? If so, can leak test ports or other schemes be designed so as to allow such testing?

Resolution –Stefan Gerhardt and Mark Smith

The NSTX-U recovery project has incorporated several means to maintain vacuum integrity for the plasma.

i. The lower ceramic insulator has been removed from the design to reduce the number of seals (i.e. leak points).

ii. The PF1c redesign replaced the coil mandrel (with its thin outer shell) with a more robust, forged/machined, reentrant, 'vacuum can'. The 'vacuum can' will be thoroughly leak-checked before the PF1c is installed on the machine. (See chit CR-VVIH-1129 for more details).

iii. Full penetration welds are specified for the CS Casing. This reduces the number of leaks paths compared to the original small seal welds used on the previous CS casing.

iv. Because of the difficulty of leak-checking the CS casing after installation, the CS casing will be thoroughly leak checked as part of the fabrication process. This way, spot repairs may be done as part of the CS casing fabrication. Organ pipe welds will be leak-checked after machine assembly. Note: Repair of these welds will require that the machine be vented.

v. At all of the Machine Core/Polar Region interfaces, replaced the single O-ring design with a Double O-ring design. The [inter]space between the O-ring grooves will be ported so that it may be vacuum pumped (see chit CR-VVIH-1101 for more details on the double O-ring design). If primary vacuum seal degrades (for whatever reason), the interspace's vacuum evacuation ports will provide back-up protection for the main vacuum.

vi. All O-ring mating surfaces are stainless steel, Inconel, or the special alumina material used in the actual ceramic ring (see chit CR-VVIH-1109 for comments on the ring).

vii. During installation, the vacuum evacuation ports in the interspace between the various double O-ring pairs can be pressurized with helium (He) to facilitate leak-checking the O-ring seals. Additionally, the interspace vacuum ports may be connected to sensors for real time monitoring of pressure changes, gas sampling, and residual gas analysis.

CR-VVIH-1101 – Multiple O-Ring Seal Locations and the Vacuum Boundary

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1C CB03	5 O-rings and a coil as part of the vacuum boundary (top and bottom) are risky. What can be done to ameliorate this?

Resolution – *D.Cai, F.Cai*

i. Reduce the total number of sealing surfaces. Used Double O-ring with pumped interspace design at the six major Machine Core/Polar Region O-ring seal interfaces.

ii. For a given seal boundary, vacuum pumped interspace can lower the pressure difference from 760 Torr down to 0.1 Torr. This will significantly lower the overall leak rate and permeation rate. Reference Calculation No: NSTXU-CALC-33-04-01 Revision No: 1, Title: Interspace Vacuum Pumping System (IVPS), Pumping Speed.

iii. See Figure CR-VVIH-1100 for a cross-sectional view of the vacuum pumped interspace region design. See figure CR-VVIH-1100: Double O-Ring with Pumped Interspace.

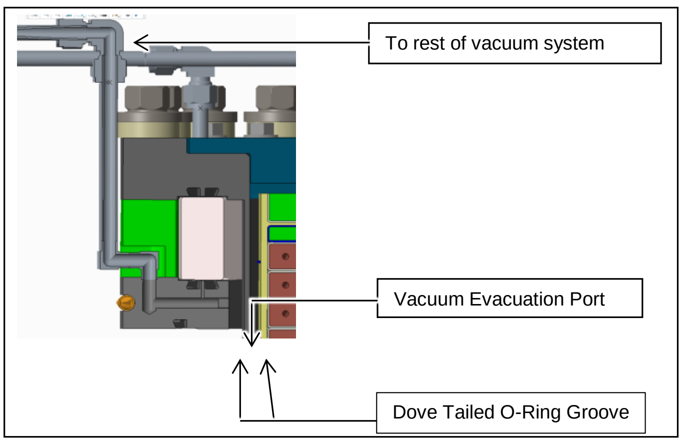


FIGURE CR-VVIH-1100: Double O-Ring with Pumped Interspace

CR-VVIH-1102 – Eliminating Viton O-Rings

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1C CB05	Regarding Viton O-rings - I was a bit concerned by the extensive use of Viton gaskets in the vacuum vessel of NSTX-U. These are used in a number of places between the center stack and the main-chamber, including a ceramic break assembly for CHI. Obviously the NSTX team has extensive experience with these components, although it was revealed that the gaskets have generated some problems in the past which required a redesign in order to optimize O-ring compression. At a minimum, the team must flag these components as carrying significant risk and appropriately assign high priority and attention to detail in the redesign.

Resolution – *D.Cai, F.Cai*

i. Double O-ring (groove) seals were chosen per the external reviewer recommendation. A tradeoff study was done between 'Metal Seals' and 'Double O-rings with a Pumped Interspace'. Refer to memo "Metal Seals VS. Double O-ring Seals with Pumped Interspace" -- VVIH-180102-MS-01.

ii. Double seals using elastomers with pumped interspace finds a good compromise solution for the competing requirements of low leak rate, low permeation rate, low stress, high durability, good repeatability, and reusability. Grooves were designed per the provided requirements, accounting for tolerance stack-ups and standard manufacturing. Double O-rings with a vacuum pumped interspace is a low risk solution in high vacuum applications, and is a mature technique that is used in many industries. Refer to: "Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation" -- NSTXU-CALC-33-04-01.

CR-VVIH-1103 – Eliminating Viton O-Rings – Mechanical Loading

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1C CB06	In general, I would like to see Viton O-ring primary vacuum seals eliminated. The topline goal of a 1 T, 2 MA, and 10-14 MW plasma is aggressive with regard to thermal and mechanical loads and requires a ROBUST design. This is incompatible with using Viton O-ring seals in the primary vacuum boundary, especially in areas of high mechanical loads that occur during disruptions.

Resolution – *D.Cai, F.Cai*

i. Double O-Ring seals with pumped interspace were used. Refer to memo "Metal Seals VS. Double O-ring Seals with Pumped Interspace" -- VVIH-180102-MS-01.

ii. Metal seals could be options, however, metals seals such as Helicoflex spring and delta spring require over 35 times higher load rates as compared to Viton O-rings; Other metal seals such as OFC or OFHC require small or middle size knife-edge flanges with very tight tolerances, which is doable in small ports, but is not easy for the seals in the NSTX polar regions. Double seals with Viton O-rings are the optimal solution to cover these factors.

CR-VVIH-1104 – O-Ring ability to Seal

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1C CB04	The Viton O-rings are clearly hard to seal, and will always be a concern when you thermally or mechanically stress the machine. The large surface area of the O-rings almost certainly affects your vacuum quality.

Resolution – Danny Cai and Feng Cai

i. Double O-ring seals with pumped interspace were used. Refer to "Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation" -- NSTXU-CALC-33-04-01 & Memo "Metal Seals VS. Double O-ring Seals with Pumped Interspace" -- VVIH-180102-MS-01.

ii. A 400 series Viton O-ring has a load rate of 60 lbf/in, and each double O-ring seal has only 120 lbf/in load rate; whereas each metal seal has a level of over 2000 lbf/in load rate. Compared with other mechanical structures, the stress due to Viton O-rings can be ignored.

CR-VVIH-1105 – O-Ring Tolerance Study

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1C CB11	The complicated set of O-rings does not meet current requirements. A tolerance study supported by as-built documentation is needed to assess if the current design and meet the requirements.

Resolution – *D.Cai, F.Cai*

i. Double O-Ring seals with pumped interspace were used. Refer to "Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation" -- NSTXU-CALC-33-04-01 & Memo "Metal Seals VS. Double O-ring Seals with Pumped Interspace" -- VVIH-180102-MS-01.

ii. Refer to: Machine Core Structures Alignment & Tolerance Stack Assessment - NSTXU_1-1-3-3_CALC_101

CR-VVIH-1106 – O-Rings vs Welded Lip

Disposition	Review	ID	Chit
A	Polar Region Design Integration Peer Review	POLARPEE R49	An analysis of the relative merits of the lip welding vs O-rings was not presented. We need to document the tradeoffs associated with these two approaches.

Resolution – Danny Cai and Feng Cai

i. Double O-Ring seals with pumped interspace were used. Refer to "Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation" -- NSTXU-CALC-33-04-01 & Memo "Metal Seals VS. Double O-ring Seals with Pumped Interspace" -- VVIH-180102-MS-01

ii. Compared with lip welding, Double Viton O-rings with a vacuum pumped interspace is easier to do, durable, and provides more options such as real-time leak check, real-time pressure monitoring, and the ability to take samples for real-time residual gas analysis, etc.

CR-VVIH-1107 – O-rings vs Metal Helico-flex Seals

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1C CB24	O-rings unsuitable for ceramic breaks due to permeation, leaks, and lithium compatibility. Suggest re-useable all-metal helicoflex or delta-seals. Use same grooves, but require higher bolt pretension.

Resolution – Danny Cai and Feng Cai

i. Metal seals were considered. Double O-Ring seals with pumped interspace were used. Refer to “Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation” -- NSTXU-CALC-33-04-01 & Memo “Metal Seals VS. Double O-ring Seals with Pumped Interspace” -- VVIH-180102-MS-01.

ii. Metal Helicoflex or delta seals require load rate 35 times higher than Viton, which is beyond the existing hardware strength, also not good for ceramic break ring. Helicoflex seals also introduce additional metallic springs into the system.

iii. Lithium concern was discussed in an email 12/29/2017, saying "The general consensus from several folks, (opinions based on lithium experiments, i.e. CDX-U) is the probability of lithium reaching the seals and then causing seal deterioration is very limited, i.e. very unlikely at all. Lithium use in NSTXU while using Viton O-rings is not a concern." Also, in published references, only the compatibility of Viton to Lithium compounds but on Lithium are mentioned, and the worst recommendations are "Doubtful". As an alternative material on vacuum side, Kalrez® O-ring is satisfactory for all Lithium compounds.

CR-VVIH-1108 – Alternative Double O-Ring Configurations

Disposition	Review	ID	Chit
A	Polar Region Design Integration Peer Review	POLARPEE R17	Consider single groove and double O-ring with spacer (this is a standard approach) vs double grooves with single O-rings; this allows some flexibility in joint configurations.

Resolution –Mark Smith

i. This chit was considered. Nevertheless, this design approach will not be used, because of 1) Increased part count; 2) Increased port venting problems, 3) Requires additional proper installation, 4) Increased risk of dropping parts. etc.

ii. Refer to Double O-Ring seals with pumped interspace were used. Refer to “Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation” -- NSTXU-CALC-33-04-01 & Memo “Metal Seals VS. Double O-ring Seals with Pumped Interspace” -- VVIH-180102-MS-01.

iii.

CR-VVIH-1109 – O-Ring Groove Surface Finish

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1C CB12	There was some discussion in the DVVR of O-ring groove flatness and the run-out from a planar circle, both of which the O-ring could accommodate if they were of long wavelength. But what is the microscopic surface finish of the groove, which the O-ring could not accommodate without unreasonable clamping pressure? Does this type of alumina have a grain size, or was the groove ground out somehow? (Wouldn't this be easy if you had double O-rings with pumped interspaces!)

Resolution – Mark Smith

i. Grooves in the metal surfaces are ground. No grooves were put in the ceramic / alumina. Double grooves with pumped interspace were used.

ii. Viton O-ring need a range of 8% to 25% compression ratio to maintain the required seal, for which a stack-up flatness tolerance of 0.013 inches per flange is required on each mating, which should be doable with a good QC in our case. Also, the tolerances should be required and indicated in the fabrication and QC documents. The grain size of alumina is less than 10 micrometer, whereas more important factor is the content and density. The ceramic used in NSTX is A-479 Alumina. A-479 alumina has 99% of Al3O2, density of 3.8 g/cm3, 0% of water absorption rate, flatness tolerance less than 0.01 inches, and surface roughness of 0.5 micrometers, which are sufficient to seal for the required leak rate of 5E-9 atm.cc/s, especially using double Viton O-ring with vacuum pumped interspace.

CR-VVIH-1110 – Not Replacing all Single O-Rings

Disposition	Review	ID	Chit
A	Polar Region Design Integration Peer Review	POLARPEE R18	The issue being addressed by double O-rings is total permeation through O-rings on NSTX-U. It is not necessary to replace ALL single O-rings to achieve the desired permeation; replace only those that do not require heroic redesign of flanges. Since the Dome represents about 1/2 the total single O-ring length and the calculated permeation rate for the total is about the leak rate observed on NSTX-U, it is not required that all O-rings be replaced with double O-rings, reducing the total O-ring length by about a factor of 2 would be sufficient. Consider not using a double O-ring on the bellows flange because that appears to be difficult and or expensive, Instead replace some of the NB O-rings with double O-rings, those flanges are much more accessible, and would achieve about the same reduction in total permeation.

Resolution – *D. Cai and F. Cai*

Double O-Rings are required due to project requirements. All O-rings seals are to be double and use pumped interspace. The pumped interspace greatly reduces the permeation. Refer to: Machine Core Structures Vacuum Calculations - NSTXU_1-1-3-3_CALC_103, "Metal Seals VS. Double O-ring Seals with Pumped Interspace" -- VVIH-180102-MS-01 & "Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation" -- NSTXU-CALC-33-04-01.

CR-VVIH-1111 – Prototype the Double O-ring

Disposition	Review	ID	Chit
A	Polar Region Design Integration Peer Review	POLARPEE R12	Prototype the double O-ring w/ interspace pumping design. (Including details of cutout of wall between rings during this prototype)

Resolution – Mark Smith

Dual O-rings with evacuated middle is a routine technique that has been proven many times. It does not need to be prototyped. Refer to: "Metal Seals VS. Double O-ring Seals with Pumped Interspace" -- VVIH-180102-MS-01 & "Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation" -- NSTXU-CALC-33-04-01

CR-VVIH-1112 – Securing O-Ring During Installation

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1CC B13	A spacer ring has an O-ring on the top and bottom. Consider a means, such as the dovetail groove suggested by Sibilia, for securing the lower retaining ring in place while the spacer is installed.

Resolution –*Danny Cai and Feng Cai*

Dove tailed grooves have been added to the O-ring groove design. The dove tailed feature (angled wall) of the O-ring grooves can be seen in Figure CR-VVIH-1100 above. The part numbers that have the O-ring grooves in them are EDC11116-1, EDC11116-3 (upper coil assembly) and EDC11115-1 (lower coil assembly).

CR-VVIH-1113 – Pinched O-Ring Installation

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1C CB19	How do we know the O-rings are in place and not pinched especially those facing down? Do we need all these O-rings?

Resolution – Mark Smith

We have decided to use standard half-dovetail grooves per professional references, except for the existing rectangular groove on the vessel upper mount flange. Half-dovetail grooves will retain the O-rings.

CR-VVIH-1114 – Continuous O-Rings

Disposition	Review	ID	Chit
A	Polar Region Design Integration Peer Review	POLARPEE R13	Consider using continuous O-rings rather than those fabricated by gluing cord stock. This is likely a long lead item.

Resolution – Mark Smith

i. It is possible to vulcanize stock cord to form a continuous ring vs gluing. However, this approach has the potential for O-ring end alignment issues. Prefer to purchase continuous ring or fabricate via vulcanizing.

ii. Many different sized continuous O-rings can be ordered from professional vendors. Prefer to use standard sizing, but we have the option to use custom sizing to expedite design.

CR-VVIH-1115 – O-Rings Hole Size

Disposition	Review	ID	Chit
A	Polar Region Design Integration Peer Review	POLARPEE R14	Hole for pumping between O-rings should be smaller diameter than shown, smaller in dimension than the separator. Holes should be provided at multiple toroidal angles.

Resolution – *Danny Cai and Feng Cai*

Per the calculation, for each interspace, one hole with dia of 3/63 inches and length of 1.5 inches is enough to ensure the expected pumping speed. Refer to: Memo "Metal Seals VS. Double O-ring Seals with Pumped Interspace" VVIH-180102-MS-01 & "Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation" -- NSTXU-CALC-33-04-01

CR-VVIH-1116 – O-Rings Temperature Limit

Disposition	Review	ID	Chit
A	NSTX-U Recovery Project - CDR	RPCDR031	In the requirements document, there should be a temperature limit for the O-rings and I recommend that it be less than 180C, preferably at 150C for Viton.

Resolution – *Mark Smith*

i. Viton O-ring service temperature is up to 204°C (Parker O-ring Handbook). PPPL requires below 180°C (NSTX-U-RQMT-SRD-004-01, Mar 2018).

ii. Thermal analyses of the Machined Core Structures (MCS) and Polar Regions (PR) shows the Viton O-rings will be within the allowable limits. Refer to NSTXU Recovery Global Heat Balance Calculations -- NSTXU-CALC-10-6-00(NSTXU_1-1_CALC_101)

CR-VVIH-1117 – Required Interspace Pumping Rates

Disposition	Review	ID	Chit
A	NSTX-U Recovery Project - CDR	RPCDR029	The pumping speed that can be achieved between O-rings forming double O-ring seals needs to be evaluated to determine the tolerable leak rate of the double seal.

Resolution – *D.Cai, F.Cai*

Our goal is to reach transitional & molecular regimes (milli-torr level) in the interspace. In this design, the design time (pumping speeds) to transition through the viscous regime, into the 'transitional region' is 10 to 45 seconds. After 500 seconds, the vacuum in the interspace zone should be entering the molecular region. Refer to "Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation" -- NSTXU-CALC-33-04-01.

CR-VVIH-1118 – Viton O-Ring Permeation Rate

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1C CB15	With 120 ft of Viton O-rings at the primary vacuum boundary, an obvious question is: What is the permeation rate through the O-rings and its impact on ultimate vacuum pressure. This question is particularly relevant for the NSTX-U lithium science program where oxidation of lithium determines its lifetime.

Resolution – Danny Cai and Feng Cai

i. Double O-ring seals with pumped interspace were used. Refer “Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation” -- NSTXU-CALC-33-04-01.

ii. Vacuum degree is determined by the factors such as gas load, leak rate, pumping speed and limit pressure. Double Viton O-ring seal with vacuum pumped interspace can reduce the overall pressure differential from 760 Torr to 0.1 Torr, as compared to a single seal. This significantly lowers leak rates, and permeation rates due to pressure differential and permeation. In other industries, double Viton O-ring seal with vacuum pumped interspace can easily ensure the leak rate below 5e-9 atm.cc/s. Lithium concern was discussed in an email 12/29/2017, saying "The general consensus from several folks, (opinions based on lithium experiments, ie CDX-U) is the probability of lithium reaching the seals and then causing seal deterioration is very limited, i.e. it is very unlikely to happen. Lithium use in NSTXU while using Viton O-rings is not a concern." Also, in published references, only the compatibility of Viton to Lithium compounds but on Lithium are mentioned, and the worst recommendations are "Doubtful". As an alternative material for vacuum side, Kalrez is Satisfactory for all Lithium compounds.

CR-VVIH-1119 – O-Ring Leak Tight Assurance

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1CCB22	Can it be guaranteed that the O-ring immediately outboard of PF1C has enough compression to remain leak tight? From the drawing it seems there is a large tolerance stack up involving welded components that determines this gap. The ring is bolted far away (radially) from the O-ring. If there is any warping this would almost certainly create a gap.

Resolution – Feng Cai

i. The tolerance stack-up analysis assessment shows a sufficient compression. Refer to: Machine Core Structures Alignment & Tolerance Stack Assessment - NSTXU_1-1-3-3_CALC_101 & Memo "Metal Seals VS. Double O-ring Seals with Pumped Interspace" -- VVIH-180102-MS-01.

ii. Viton O-ring need a range of 8% to 25% compression ratio to maintain the required seal. In our case, the metal flanges and hardware are sufficient to ensure this compression range. Note that 400 series Viton O-ring need a load rate in a range of 60 to 65 lb/in for 20% to 25% compression rates, which is about 18 to 20 kip tension on each side, is within our mechanical strength with a high safety factor. About mechanical stack-up tolerance, 013 inches per flange is required on each mating, which should be doable with a good QC in our case. Also, the tolerances should be required and indicated in the fabrication and QC documents.

CR-VVIH-1120 – O-Ring Purging

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1CCB26	Suggest the ability to purge the O-rings with helium be investigated. Doing so will allow helium or Argon to enter the vessel rather than air during thermal and mechanical stress. Leak-checking should be simplified.

Resolution – Danny Cai and Feng Cai

i. Double seals with pumped interspace used. Refer to: "Interspace Vacuum Pumping System (IVPS), Pumping Speed Calculation" -- NSTXU-CALC-33-04-01 & Memo "Metal Seals VS. Double O-ring Seals with Pumped Interspace" -- VVIH-180102-MS-01.

ii. In our design, there is an optional port in the double O-ring with vacuum pumped interspace, which benefits leak checking, pressure monitoring, and purging He or Ar.

CR-VVIH-1121 – Vacuum

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSU PDR33	Ensure capability to leak check PF1C re-entrant vacuum assembly.

Resolution – *Mark Smith*

Yes, leak check capability is included in design. Pumping ports will be included in the PF1C Can capping flanges.

CR-VVIH-1122 – Combined Flange G-7 Blocks

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSU PDR25	On the combined flange/PF1C assembly, consider using fewer G7 blocks, each spanning a larger fraction of the circumference. Maybe a complete ring. This might help to maintain the assembly tolerances around the O-rings for the ceramic break.

Resolution – *Mark Smith*

We are using two 180 degree segments of G7 spacers which reduces the number of parts.

CR-VVIH-1123 – CS Casing Bellows

Disposition	Review	ID	Chit
A	Polar Region Design Integration Peer Review	POLARPEE R16	Consider removing and replacing bellows on CS Casing with new flanges with optimized o ring grooves. (E.g., double o rings on top of machine, flat flange on bottom of machine to avoid upside O-ring grooves).

Resolution – Mark Smith

Included in design and manufacturing plans.

CR-VVIH-1124 – TF/OH Clearance

Disposition	Review	ID	Chit
A	NSTX-U Alignment Peer Review II	ALLIGNPEER11	Is it feasible and prudent to machine off high spots on the exterior of the center bundle? If these high spots could be reduced it might be possible to gain significant clearance.

Resolution – Mark Smith

We made a new casing that allows additional clearance. Trial fit up of old casing and existing TF bundle was successful. See report Machine Core Structures Alignment & Tolerance Stack Assessment - NSTXU_1-1-3-3_CALC_101

CR-VVIH-1125 – Positioning/Alignment

Disposition	Review	ID	Chit
A	NSTX-U Alignment Peer Review II	ALLIGNPEER04	I still think a Gaussian probability distribution might help - Is the extreme position error really the same probability as hitting the nominal?

Resolution – Stefan Gerhardt

This had to do with the fluxes on the Plasma Facing Components, and how those fluxes affected the loads that went into the G10 load analysis. These flux induced force components will be/have been fed into the loads for analyzing the G10. Refer to: Machine Core Structures Alignment & Tolerance Stack Assessment - NSTXU_1-1-3-3_CALC_101.

CR-VVIH-1126 – Flange Metrology

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSUPDR06	Metrology for the existing flanges to align PF1C requires adjudication whether there is a requirement driving additional adjustment capability to be designed for the polar region. This issue needs to be expedited to support the design work or changes to the flange to accommodate alignment requirements.

Resolution – Mark Smith

Flange metrology performed. Data is being used in design. Refer to metrology report: Summary of ECM Metrology Results -- NSTXU_1-1-3_REC_100 & Machine Core Structures Alignment & Tolerance Stack Assessment - NSTXU_1-1-3-3_CALC_101

CR-VVIH-1127 – Skirt

Disposition	Review	ID	Chit
A	Project PDR	PROJPDR05	A brief discussion of the gravity support skirt immediately underneath PF1AL suggested that the four (?) sections it comprises do not include any insulating shims and insulating bolts to prevent this component from carrying toroidal current. If true, please analyse the effect on the poloidal fields, required PF1BL current, EM loads etc.. Or just insulate it, as I think the new system design requirements "require"!

Resolution – *Mark Smith*

We're modified skirt design to include toroidal electrical breaks. See figure CR-VVIH1127 below:

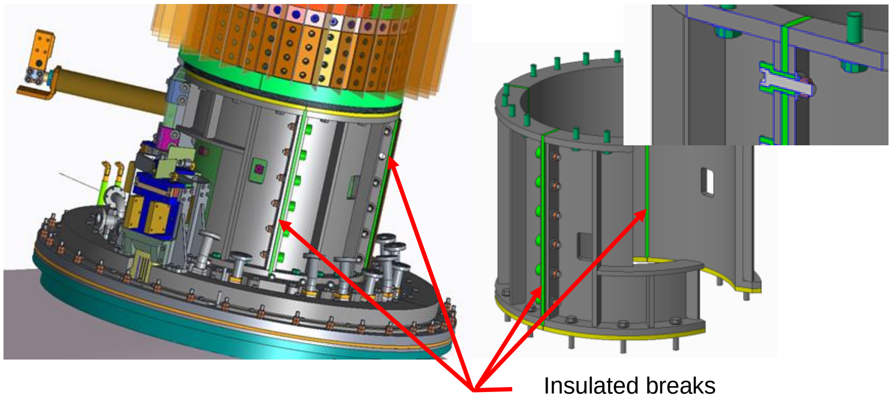


FIGURE CR-VVIH1127: Skirt Insulated breaks

CR-VVIH-1128 – Skirt Modifications and Scope

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSUPDR01	The skirt upper connections need modification for strength issues. The bottom of the skirt needs to be included in someone's design. A clear system integration is required that assures that all recovery scope machine component interfaces are assigned.

Resolution – Mark Smith

Skirt is included in MCS scope and has been redesigned to accommodate strength issues. See figure below & refer to Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115. A detailed review of the redesigned skirt structure with the insulated breaks was performed in the buckling analysis, NSTXU_1-1-3-3_CALC_113. This validated the skirt and the skirt hardware for the maximum compressive loads. An analysis to calculate the stress for all applicable skirt load conditions is ongoing and will be documented in NSTXU_1-1-3-3_CALC_112.

CR-VVIH-1129 – PF1C Leak

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1CCB02	PF1C is part of the vacuum boundary, it might leak, something to ameliorate needed.

Resolution – Mark Smith

This concern pertained to the original welded PF1c design, which leaked.

The new PF1c (E-DC11116-1 and E-DC11115-1) are being made from a minimum number of forged segments (3) joined by full penetration welds. Welds will be UT & RT inspected prior to completion. See figure CR-VVIH1129 below. See Reference NSTXU_1-1-3-3_CALC_117.

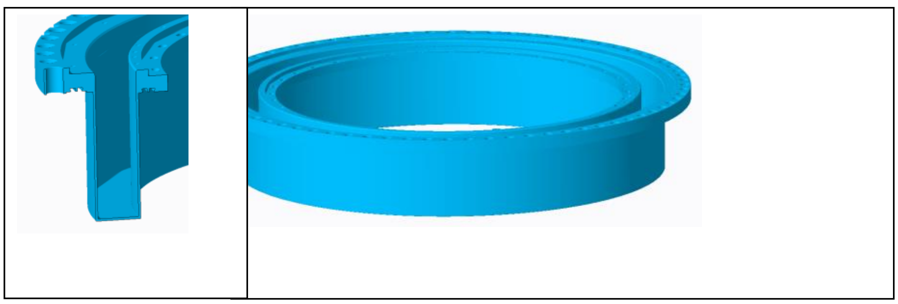


FIGURE CR-VVIH1129: PF1C Can

CR-VVIH-1130 – Interface between PF1c Assembly

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSUPDR32	Address interface between the PF1C assembly and the VV nozzles. Examine the existing nozzles, perform metrology (if data not already existing), to determine issues and solutions. Include in the Risk Register.

Resolution – Mark Smith

Performed metrology; will rework vacuum vessel nozzles. Refer to: Summary of ECM Metrology Results - NSTXU_1-1-3_REC_100.

CR-VVIH-1131 – Metrology

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSUPDR06	Metrology for the existing flanges to align PF1C requires adjudication whether there is a requirement driving additional adjustment capability to be designed for the polar region. This issue needs to be expedited to support the design work or changes to the flange to accommodate alignment requirements.

Resolution – *Mark Smith*

Performed metrology; will rework vacuum vessel nozzles. Refer to "Summary of ECM Metrology Results" -- NSTXU_1-1-3_REC_100 & Machine Core Structures Alignment & Tolerance Stack Assessment - NSTXU_1-1-3-3_CALC_101.

CR-VVIH-1132 – Metrology on Ceramic Break and Spacers

Disposition	Review	ID	Chit
A	Project PDR	PROJPDR30	Consider performing metrology on the ceramic break g-10 spacers and ceramic break to ensure that stacked as-built tolerances do not result in compression of the ceramic break.

Resolution – *Mark Smith*

Redesigned all parts, remanufacture all parts, and build them in tolerance based on tolerance analysis. See report: Machine Core Structures Alignment & Tolerance Stack Assessment - NSTXU_1-1-3-3_CALC_101 & "Summary of ECM Metrology Results" -- NSTXU_1-1-3_REC_100.

CR-VVIH-1133 – Moisture

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSUPDR31	A provision is needed to address accumulation of moisture in the PF1c can - Mainly upper but maybe bottom too.

Resolution – *Mark Smith*

We will use RTV to prevent water penetration.

CR-VVIH-1134 – Shims

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSU PDR23	Consider use of an inflatable shim, filled with epoxy, to fill gap between slings and coils. Using non-conducting materials, a single, toroidally continuous shim could be used. Another alternative could be pieces of fabric soaked with epoxy, installed under each sling.

Resolution – *Mark Smith*

We have considered inflatable shims; not desirable.

CR-VVIH-1135 – Common Flange – Flag Clearance

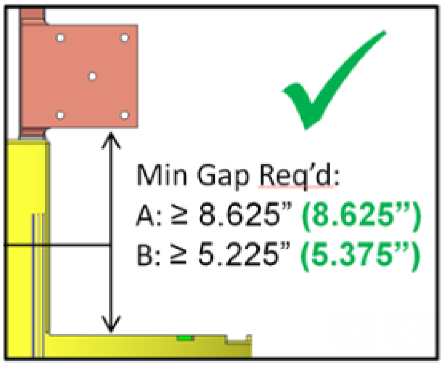
Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSU PDR24	Concerned about clearance between studs for common flange and coil flags. Need to ensure there is enough clearance either through stud/common flange design and/or coil flag position or lead length and ensure any coil changes are captured in upcoming delta-FDR (if convened) for PF1 coils.

Resolution – Ian Kunsch

Present design has been modified to increase clearance between hardware and flags. Refer to: Machine Core Structures Alignment & Tolerance Stack Assessment - NSTXU_1-1-3-3_CALC_101

Refer to the “FDR Assembly and Tolerance Stack” presentation from Machine Core Structures FDR.

The minimum required gap between coil & flag is 8.625” and 5.225” for PF-1A and PF-1B respectively. The actual values are 8.625” and 5.375” respectively. This also conservatively assumes ¼” above and below the parts during assembly. Therefore, this issue has been resolved.



CR-VVIH-1136 – Loads

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSUPDR22	The lower polar region model is extensive enough that all the casing loads can be applied including the VDE casing load. This may be true of the OH loads - net launching normal loads, and VDE disruption loads

Resolution – *Mark Smith*

All loads are accounted for. Refer to: Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115 & Machine Core Structures Electromagnetic Analyses - NSTXU_1-1-3-3_CALC_102.

CR-VVIH-1137 – Radius Rods Weakest Link

Disposition	Review	ID	Chit
A	NSTX-U Recovery Project - CDR	RPCDR030	Regarding the radius rods: the weakest link in the load path is likely not the uniaxial stress in the solid bar, but connection to the vacuum vessel needing to reacting the bending moment trying to upend the clamp, and the local stress in the plate.

Resolution – *Mark Smith*

Radius rods are no longer used. Shims (green) will react load to VV, See figure CR-VVIH1137 below:

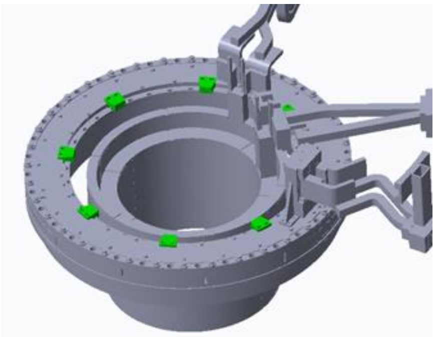


FIGURE CR-VVIH1137: Lateral Supports

CR-VVIH-1138 – Vessel Flange Capacity

Disposition	Review	ID	Chit
A	NSTX-U Recovery Project - CDR	RPCDR028	Is vessel flange capable of supporting lateral load with frictional clamping with only 18 bolts in tension?

Resolution – *Mark Smith*

Yes there is sufficient capacity. Refer to: Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115.

CR-VVIH-1139 – Ceramic Break

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1CCB08	We have had problem with electrical isolation between the inner out outer vessel being compromised at the bolt insulators, primarily at the upper ceramic break assembly. Any potential design improvement should be made.

Resolution – Mark Smith

We've added design features to prevent water leak into ceramic break. See figure CR-VVIH1139 below:

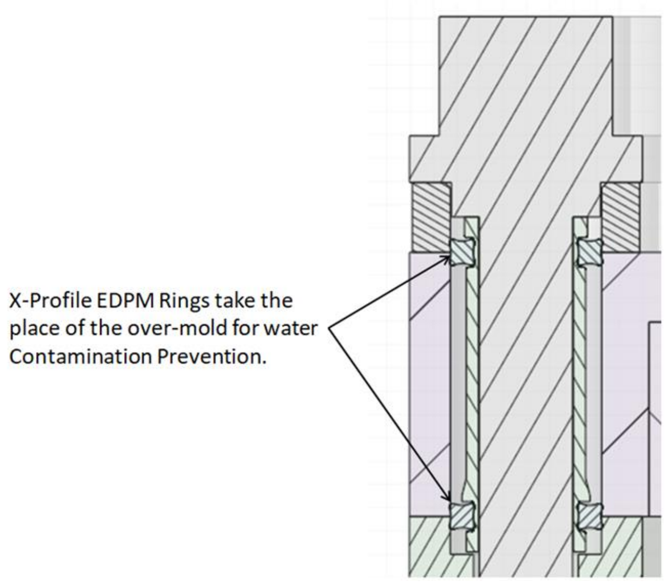


FIGURE CR-VVIH1139: Water proofing Ceramic Break

CR-VVIH-1140 – Voltage Testing

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSUPDR02	There is a requirement to test the ceramic break voltage stand-off to 1kV. Will be difficult to do this after break assembly is installed due to parallel short at the bottom. Strongly recommending voltage testing of break assembly on the bench before installation.

Resolution – *Mark Smith*

Plan is to bench test ceramic break prior to installation. Flange test stand to be used to test the 1Kv.

CR-VVIH-1141 – High Friction Coatings

Disposition	Review	ID	Chit
A	NSTX-U Recovery Project - CDR	RPCDR034	Assess if the frictional restraints in the vicinity of the ceramic break are acceptable under the present design, considering the required decrement of the friction coefficient from the design criteria and the observed loss of preload. Use high friction coatings on the flanges that mate to G7 parts?

Resolution – Tom Rongé

Carbinite coating added to the reentrant flange and the cooling flange to add friction between G-7 and flange parts. Ref NSTXU_1-1-3-3_CALC_109, R2

CR-VVIH-1142 – Ceramic Insulator Rating

Disposition	Review	ID	Chit
A	NSTX-U Recovery Project - CDR	RPCDR024	In the requirements presentation, a bullet states that the single ceramic insulator must be rated for a minimum of 100V. Will there be an exception for this component for 2E+1kV testing?

Resolution – *Stefan Gerhardt*

i. The 2E+1kV test requirement is per system requirements document NSTX-U-SRD-004-03, Vacuum Vessel and Internal Hardware, Section 10.4.1

ii. It will not be possible to do 2E+1 testing after it is fully installed. Therefore, bench top testing shall be performed prior to installation into the machine.

CR-VVIH-1143 – Heat Flux

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1CC B17	No ability to measure the off-normal and/or quasi-steady heat flux to the PF-1c can during plasma operations and interlock with PCS

Resolution – *Stefan Gerhardt*

PFC design has a labyrinth feature that prevents heat from getting on PF1c can.

CR-VVIH-1144 – Hole Alignment

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSU PDR05	The existing bolt holes on the upper/lower flanges of the machine may not be machined accurately enough to mate up with the PF-1C/re-entrant flange assemblies. Assess and rework as necessary to accommodate the installation and alignment on the re-entrant flange assemblies.

Resolution – *Mark Smith*

Present plan is to add new attachment holes in vacuum vessel flanges to assure alignment. The attachment holes will be "clocked" modifying the existing flanges. See figure CR-VVIH1144 below:

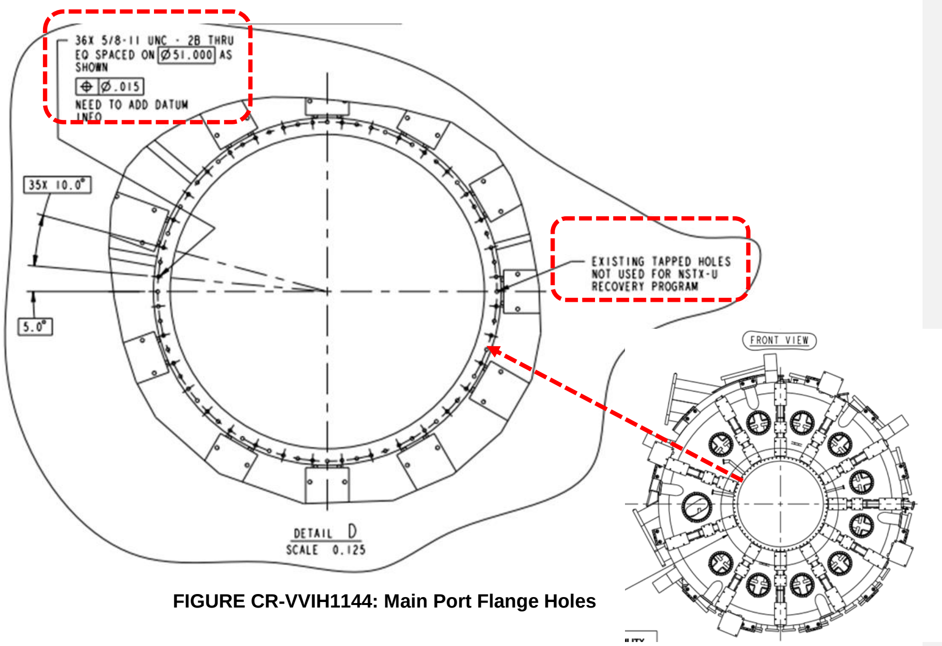


FIGURE CR-VVIH1144: Main Port Flange Holes

CR-VVIH-1145 – Pedestal

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSU PDR09	Pass Pete Titus's eddy current loads on the center TF bundle on to the people handling the pedestal and support structure. This is out of scope for the polar region review, but should be captured.

Resolution – Mark Smith

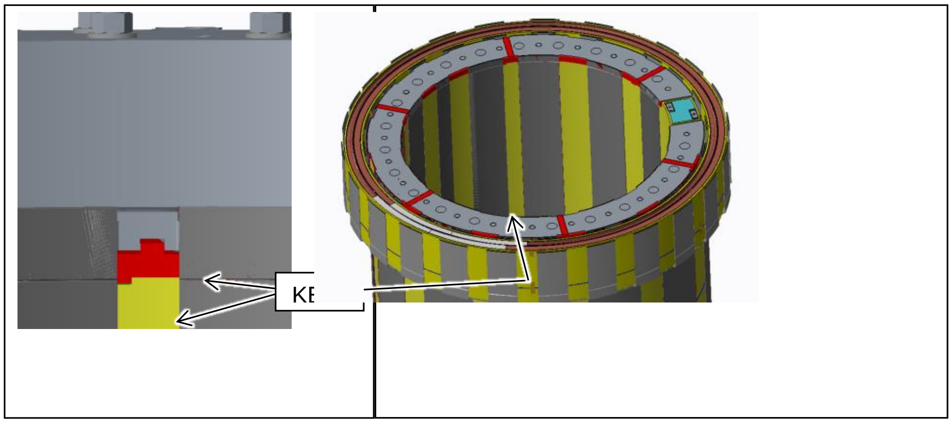
All applicable loads from the TF/OH are accounted for in the analysis. Refer to: Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115 & Machine Core Structures Electromagnetic Analyses - NSTXU_1-1-3-3_CALC_102.

CR-VVIH-1146 – Lateral Coil Shifts

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS06	(May be redundant with CHIT CR-VVIH-1141) - The support system provides a stiff attachment point at one end of the coil and the "bottom" of the coil is allowed to slide within the sling support (c.f. slide 16, right image). The concern is in the resistance to lateral, non-axisymmetric loads that may pull the coil in one direction and result in a lateral shift of the coil. Are there features to prevent non-axisymmetric shifts of the coil? (The discussion indicated that the key features on the top compression plate are sufficient to react the loads and maintain the installed configuration.)

Resolution – *Mark Smith*

Keyways have been added that minimize lateral shifts. See figure CR-VVIH1146 below:



CR-VVIH-1147 – Friction on Coil Self-Centering Keys

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSUPDR21	Ian showed a coil support keying design that has keys every 60 degrees. Such a design can wedge and fail to move if the coefficient of static friction with the keys is 0.58 in the absence of any vertical preload. Show that there is adequate margin on the coefficient of friction including the effect of the large vertical preload. Additional keys may be needed.

Resolution – Mark Smith

Frictional affects in the keys have been included in the analysis. Refer to: Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115. COF reduced at mating surfaces by surface finish and low friction metal coating.

CR-VVIH-1148 – Slot and Keys

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS14	Investigate Kevin Freudenberg's ITER CS solution for friction interface and pins instead of slots and keys

Resolution – Mark Smith

Done -- Refer to: Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115

CR-VVIH-1149 – Ceramic Insulator Assembly Coating

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSU PDR13	Confirm that EPDM coating on ceramic insulator assembly can withstand the maximum temperature that it will be exposed to.

Resolution – *Tom Rongé*

The design for the Ceramic Break flange was changed and no longer uses an EPDM coating - Reference Chit 1139. The coating was replaced with X-rings made of the same EPDM rubber material and is within allowable temperature limits - maximum operating temperature ~60°C. Figure CR-VVIH1149 is from the MARCO Rubber vendor specification for the x-rings. Additionally the component is in a lower temperature region along a coolant line. Refer to: NSTXU Recovery Global Heat Balance Calculations -- NSTXU-CALC-10-6-00.

CR-VVIH-1150 – Loads during power supply faults

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSU PDR10	Consider loads caused by suppress and bypass scenarios of coil power supply faults

Resolution – Mark Smith

Faulted loads have been accounted for in Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115.

CR-VVIH-1151 – Sling Loads

Disposition	Review	ID	Chit
A	Polar Region- Inner PF Coil Supports PDR	PRIPFCS11	Include the disruption eddy current loads on the slings.

Resolution – *Mark Smith*

All load conditions including Lorentz loads due to eddy currents in the sling supports have been accounted for in the analyses. Refer to the MCS FDR electromagnetic and mechanical calculations.

Comment [MS1]: Revised text to what is shown now.

CR-VVIH-1152 – Ownership of Sling to Coil

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS04	Unclear which group (Magnetic or Polar) is evaluating the key interface design (sling to coil) to resolve the lateral loads and fault bonded cases

Resolution – *Mark Smith*

Keys were accounted for in analysis. Refer to: Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115.

CR-VVIH-1153 – Additional Loads

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS07	There is a potential for loads beyond the max of the 96. Load increases due to a VDE with the plasma close to the coils produces an attractive load towards the plasma that we are estimating to go 30% above the nominal - pending more vessel shielding calculations. It is a dynamically imposed load of order 10 millisec.

Resolution – *Mark Smith*

All loads have been accounted for. Refer to: Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115.

CR-VVIH-1154 – Sling Compression

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS12	Might have to finesse the distribution of sling compression to optimize cooldown behavior and optimize the terminal shear capacity as the conductor breaks out of the coil.

Resolution – *Mark Smith*

Structural design requirement is to provide preload; not optimize compression.

CR-VVIH-1155 – Vertical Coil Displacement and Belleville Preloads

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS09	Please report the displacement of the coil at the terminal end for EQ 1 where the load exceeds the preload and will compress the Bellevilles

Resolution – *Mark Smith*

Preload and design features are sufficient to limit coil motion. Refer to: Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115 & MCS Belleville Washer Assembly Testing - NSTXU_1-1-3-3_TREP_100.

CR-VVIH-1156 – Sling Preload Calculation and Cold Shots

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS03	When assessing the preload, you can't rely on concurrent thermal and Lorentz -Early in the shot the coils are cold and fully energized.

Resolution – *Mark Smith*

Refer to Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115.

CR-VVIH-1157 – Sling's Dogleg model analysis

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSUPDR28	Is the little dogleg capture mechanism at the ends of the slings modeled with interface elements that allow separation? If not it should be

Resolution – *Mark Smith*

Yes, they are addressed in the analysis. Refer to Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115.

CR-VVIH-1158 – Sling's Dogleg Radii

Disposition	Review	ID	Chit
A	Polar Region - Flanges/O-Rings/Insulators/Supports - PDR	PRFORINSUPDR30	Check the sling ends doglegs radii with a handbook stress concentration check

Resolution – *Mark Smith*

Design features have been analyzed. Refer to Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115.

CR-VVIH-1159 – Toroidal Preload Variation between Slings Criteria

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS13	Magnetic Group must define the acceptable toroidal variation of compression -- to optimize the stud spacing, flange thickness of the sling support flange

Resolution – Mark Smith

i. NSTX-U-VVIH-RD-012-03 Inner-PF Coil Interfaces to Coil Support Designs and Cooling Systems., Section 2.3 Required Pre Loads, *"Table 2.3-1 Mechanical preload required for each inner PF coil."* specifies a preload of 100 kbf for the Pf-1a, and 60 kbf for the PF-1b preload. No tolerance was given for this preload.

ii. Proposed solution is to define the expected toroidal compression pattern, based on FEA results.

iii. According to NSTX-U Recovery Project Engineer (Yuhu Zhai) the coil group will obtain interface loads from the polar region to evaluate impact to the coils. The Project engineer produced a memo NSTXU_1-1-3-3_CALC_116 Effect of Non-Uniform Pre-loading on Inner PF A and B Coils

CR-VVIH-1160 – Retaining Sling Preload Setscrew

Disposition	Review	ID	Chit
A	Project PDR	PROJPDR14	On preload mechanism for PF coils: How is the set crew and/or faster restrained? Recommend a locking feature so as to not have the faster/screw back out during thermal cycles. Is there instrumentation on the straps to detect creep or loss or preload over time?

Resolution – *Mark Smith*

All hardware including this preload mechanism will be locked to prevent loosening (i.e. tack weld, safety wire, Lock-Tite).

CR-VVIH-1161 – Slings and Low Friction Material

Disposition	Review	ID	Chit
A	NSTX-U Recovery Project - CDR	RPCDR019	Consider use of Fibreslip (glass - teflon woven material) as low friction interface for coil supports. Experience is available at JET: very low friction coefficient (<< 0.1), long life (44 years at JET), easily bonded to glass époxy insulation (JET TF coil noses and OH coil outer surface are covered with fibreslip sheets).

Resolution – *Mark Smith*

Low friction material and coatings used at sliding interfaces. Fibreslip is not needed.

CR-VVIH-1162 – Sling Support Shape

Disposition	Review	ID	Chit
A	NSTX-U Recovery Project - CDR	RPCDR013	The edges of the sling supports should be shaped such that they do not cut into or chaff the surface of the coils during thermal expansion or coil pulsing.

Resolution – *Mark Smith*

Sling edges do not contact the coil insulation. The only sling contact with the coil is between the top/bottom coil G10 shim. Also, where possible, the sling side panel hard edges were broken / rounded. Refer to the CAD models and drawings.

CR-VVIH-1163 – Sling Weld Calculation

Disposition	Review	ID	Chit
A	Project PDR	PROJPDR15	PF coil Inconel shell: Since the design calls for welded Inconel: recommend that in addition to SN assessment, a LEFM calc be done as well to determine min flaw size in weld and HAZ. Further, CT specimens should be made of the welded material to determine K1c and the Paris constants for use in the LEFM.

Resolution – Mark Smith

We attempted to develop Paris constants, and K1c parameters, but there was too much scatter in the data for this approach to be useful. **Therefore, we are developing fatigue life data for the proposed material to be used for the slings. They will be shaped into welded dog-bone style tensile testing specimens. Additionally, we are making actual slings, and will test these samples under representative (tensile and bend loading) conditions. Refer to: MCS Sling Prototypes Testing -- NSTXU_1-1-3-3-11_PROTO_100. Use the British Standard BS7608 to qualify the welds for fatigue as recommended by the welding consultant EWI. Refer to EWI report XXXXX.**

Comment [MS2]: Find and add the EWI weld report Doc# or Title.

CR-VVIH-1164 – Sling Material Choice

Disposition	Review	ID	Chit
A	Project PDR	PROJPDR16	Unclear if Inconel 718 is the only option for material. Assume we are geometry locked as we always are with magnet design and turn count for coils. Still, super-austenitic stainless steels have lower yield and ultimate but generally better fatigue/crack growth performance. Is the preload so high that it discounts their use? If Inconel 718 is the clear choice, consider break bending the material to reduce the amount of welds. Welds will need to be full pen and ground and may still need a weld reduction factor depending on inspection and ASME code source.

Resolution – Mark Smith

Analysis and spatial constraints dictates Inconel 718 as the clear material solution for the slings, fabrication techniques will include necessary tests and analysis will consider reduction factors as warranted by design & fabrication method. Refer to Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115 & MCS Pf1A Full Mockup Activities -- NSTXU_1-1-3-3_DOC_101.

CR-VVIH-1165 – Sling Prototyping

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS05	Please prototype the slings for manufacturability BEFORE the FDR

Resolution – Ian Kunsch

This activity is complete and the findings documented in prototype report are in document, NSTXU_1-1-3-3-11_PROTO_100.

CR-VVIH-1166 – Stresses in Divertor Support Flange Threads

Disposition	Review	ID	Chit
NA	NSTX-U Recovery Project - CDR	RPCDR020	For the PDR, if not shown later in the CDR, please analyze the stresses in the female threads where the Inconel 718 20mm (?) bolts engage with the divertor support flange. I think there will be thread inserts there, but I could worry about the parent material if it is not Inconel 625 or stronger, especially as these are short, blind, threaded holes.

Resolution – Mark Smith

Problem resolved due to design change.

CR-VVIH-1167 – Radial Link Anchor Distance

Disposition	Review	ID	Chit
NA	NSTX-U Recovery Project - CDR	RPCDR033	The radial link anchor distance will change as the CS changes in length. The rod end bearings shown in the presentation usually have zero free play. Needs to be considered in the design.

Resolution – Mark Smith

CHIT is no longer applicable due to design change. See figure CR-VVIH1167 below highlighting lateral supports in "green".

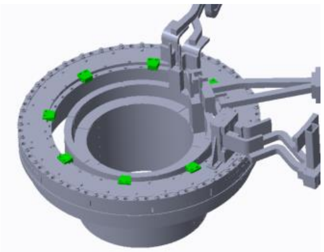


FIGURE CR-VVIH1167: Lateral Support pads

CR-VVIH-1168 – PF1c Recentering

Disposition	Review	ID	Chit
A	NSTX-U Recovery Project - CDR	RPCDR016	More on PF1C re-centering by loading the outer skin of the can. Peter showed considerable high stress problems there, raising discussion about profiling the contact block to reduce the peak stress. I believe it was later agreed that all this goes away if the radial guides do all the work! Just keep a good clearance to let the coil expand.

Resolution – Mark Smith

Refer to Machine Core Structures Alignment & Tolerance Stack Assessment

NSTXU_1-1-3-3_CALC_101.

CR-VVIH-1169 – Contact Analysis

Disposition	Review	ID	Chit
A	Project PDR	PROJPDR17	Continue Inconel straps: Are assembly gaps and tolerances in the analysis model for the connection of the straps to the mating preload structure. It appears that you will need some clearance to assemble the top and these gaps will introduce bending stresses to the straps right above the weld line. General contact analysis should be used.

Resolution – *Mark Smith*

Contact analysis performed. Refer to Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115 & Machine Core Structures Alignment & Tolerance Stack Assessment - NSTXU_1-1-3-3_CALC_101.

CR-VVIH-1170 – Coil Stresses

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS10	Update interface with coil at bottom of sling to include coil width with ground insulation. Ask coil group to revisit coil stresses if bottom interface changes from fixed to slip and be prepared to consider a fixed interface a firm requirement if the slip interface causes stress in the coil that exceeds allowables.

Resolution – Mark Smith

The final design includes fixed interfaces at the coil sling support.

CR-VVIH-1171 – Thermal and EM bending of PF1a&b Coils

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS02	The top of the coil moves thermally it will bend the break-out that is fixed at the top of the "tower" If the Lorentz loads exceed the preload then they compress the Belleville washers and move the coil. Preload then must be maintained above the max load on the coils.

The PF1a preload is maintained above the electro-magnetic load. The PF1b has a hard-stop limit to restrain the PF1b motion, should the electromagnetic forces exceed the preload. The capping flange and hanging flange combination (EDC11120-1&3; EDC11120-2&4), are being used for the hard-stop. They are not heavily loaded, so this combination can take a mild impact load. Refer to Machine Core Structures Mechanical Analyses - NSTXU_1-1-3-3_CALC_115, MCS Pf1A Full Mockup Activities -- NSTXU_1-1-3-3_DOC_101 & MCS Belleville Washer Assembly Testing -- NSTXU_1-1-3-3_TREP_100. See figures Figure CR-VVIH1172a & Figure CR-VVIH1172b below:

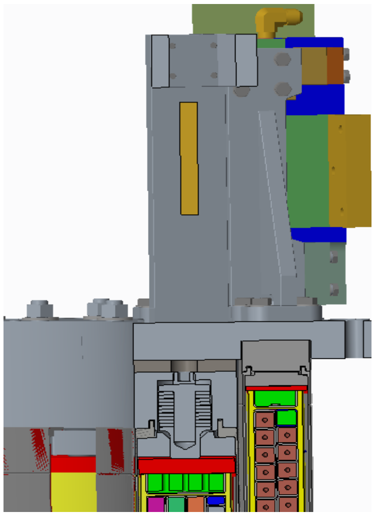


FIGURE CR-VVIH1172a: A-Coil

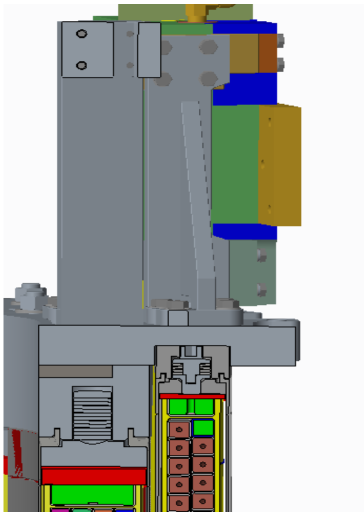


FIGURE CR-VVIH1172b: B-Coil

CR-VVIH-1172 – Work Planning

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS08	Work Planning Form is not approved - please update and approve.

Resolution – *Mark Smith*

Work planning submitted and approved.

CR-VVIH-1173 – Tube Monitoring

Disposition	Review	ID	Chit
O	Vacuum Vessel & Internal Hardware DVVR	VVIHCP10	maintain cooling tube under vacuum or pressure to monitor tubes

Resolution – *D.Cai, F.Cai*

This is HTT/HTP scope (VVIH)

CR-VVIH-1174 – Radial Alignment Requirement

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1CCB14	Have a requirement that there is a mechanical provision to ensure radial alignment before any O-ring engages its mating surface during assembly of vacuum flanges that use O-rings.

Resolution – Mark Smith

No alignment pins are envisioned necessary due to design tolerance stack shows fit is acceptable. Refer to Machine Core Structures Alignment & Tolerance Stack Assessment - NSTXU_1-1-3-3_CALC_101.

CR-VVIH-1175 – Drawing Corrections

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1CCB16	It appears that the ring between the ceramic break and the vessel has the O-rings on both sides in some drawings, and some not. Should be corrected.

Resolution – Mark Smith

New drawings are being issued.

CR-VVIH-1176 – Coil Bake-Out Thermal Insulation

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	CSCFDR16	This is in the VV&IH SRD: "10.4.3 Coil Thermal Isolation a: Structures should be designed so that coil ground insulation shall not exceed the glass transition temperature of the resin system or any glass reinforced plastic/laminate material under any possible thermal scenario (operations, bakeout, etc.). b. The insulation protecting the OH and PF-1a/b coils from the heated casing surface must provide at least 1 hour response time following a coil loss of cooling condition during bakeout. " Somebody can argue with me about whether 100C or T_glass is the right limit, but in any case the final documentation associated with the review should show that these are accomplished. If they are not satisfied, then there may need to be changes to the cooling water systems or some other operating procedure. Hence the criticality of being tight on this topic.

Resolution – Mark Smith

Refer to: NSTXU Recovery Global Heat Balance Calculations -- NSTXU-CALC-10-6-00 (NSTXU_1-1_CALC_101).

CR-VVIH-1177 – PFC Bake-Out Requirements Verification

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	CSCFDR14	Under the PFC requirements document, the PFCs "shall be capable of being baked to at least 350 C." (NSTX-U-RQMT-SRD-003-03 section 3.2.a) Under the "Thermal result for CSC and bellows" Presentation done by Han Zhang, there is a bullet point that the states the PFC bake-out temperature is >260C (slide 5). Confirm that the analysis matches the PFC requirement.

Resolution – Mark Smith

Refer to: NSTXU Recovery Global Heat Balance Calculations -- NSTXU-CALC-10-6-00 (NSTXU_1-1_CALC_101).

CR-VVIH-1178 – Micro-Porous Insulation Maintenance

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	CSCFDR15	It may be difficult/impossible to install/maintain micro-therm installation on the OD of the OH and also the OD of the PF1A and 1B coils either due to assembly sequence and/or clearances. Should analyze scenarios in which microtherm is tight wrapped on OH OD and onto ID of casing IBDV and collar regions to ensure assumed microtherm thickness is adequate to meet requirements for a range of microtherm final installation positions.

Resolution – M Safabakhsh

The lower and upper transition zone will have different levels of difficulty for installing the micro-porous insulation, while maintaining the desired insulating qualities. The lower zone should be easier to install, as the casing will not be in the way. This way, a consistent, well-secured, blanket of insulation can be wrapped around the PF1 lower coils and TF/OH. The upper transition zone shall be more difficult. Ideally, a mock-up will be made, to test/verify various options/scheme for putting together the insulting blankets around the junction that will be made, when the PF1A coils are lowered into the CS casing. A final design determination can then be made at the end of the mock-up testing.

CR-VVIH-1179 – Ceramic Break Voltage Measurements

Disposition	Review	ID	Chit
A	Vacuum Vessel & Internal Hardware DVVR	VVIHPF1CCB10	The voltage across the ceramic breaks, at the breaks, is not routinely measured. It would be advantageous if this were a routine measurement.

A planned maintenance activity is suggested to periodically check voltage across break.

CR-VVIH-1180 – Mechanically Protect Bellows

Disposition	Review	ID	Chit
O	Vacuum Vessel & Internal Hardware DVVR	DIAGMPTS 11	Provide mechanical protection for the bellows and primary vacuum boundary to protect ex-vessel fragile diagnostic parts

Resolution – Bob Ellis

This is Diagnostic scope

CR-VVIH-1181 – Magnet Mold – Coil Support Flange Clearance

Disposition	Review	ID	Chit
A	Polar Region-Inner PF Coil Supports PDR	PRIPFCS01	The PF1A (inner magnet) molds should provide a molded surface such that the finished coil fits through the coil support flange with clearance.

Resolution – Ian Kunsch

Magnet Mold – Coil Support Flange Clearance (The PF1A (inner magnet) should provide a molded surface such that the finished coil fits through the coil support flange with clearance.)

The support flanges were designed to provide 0.125" clearance around the coil flag "towers". The concern was that this would not be enough. Mark Smith confirmed that, from a strength perspective, the support flanges can be modified to provide 0.250" clearance around the towers and still be within allowable design margins. See MAG_200226_MS_1. For most of the parts, there are no other concerns, so all of the following parts will be modified accordingly (PF-1A Compression Flange, Capture Flange, Common Flange and PF-1B Compression Flange, Hanger Flange, Capture Flange and Common Flange)

The PF-1A Hanger Flange will NOT be modified yet due to space constraints. The concern is that if the clearance is increased to 0.250" on the PF-1A Hanger Flanges, and if the slings are tilted the maximum allowable amount (with legs in opposite directions), part of the sling could be unsupported…overloading the portion of the sling which is supported.

The plan as of 3/5/20 is to take extra care with the E-DC11140-02 & -03 slings (the slings closest to the coil tower) to ensure those legs are tilted in the same direction. Once inspection data of the coil becomes available, we will re-evaluate if more clearance is even needed and if it can be given.

CR-VVIH-1182 – Sling Pre-load measurements

Disposition	Review	ID	Chit

A	NSTX-U Recovery Project - CDR	RPCDR040	Consider the use of a load cell under the washers to be used on the preload for the vertical preload bolts.

Resolution – Mark Smith

Space does not permit load cell application. The component assembly will be prototyped & bench tested. Refer to: MCS Belleville Washer Assembly Testing --NSTXU_1-1-3-3_TREP_100, MCS Preload Development--NSTXU_1-1-3-3_DOC_103 & MCS Pf1A Full Mockup Activities -- NSTXU_1-1-3-3_DOC_101.

In production a strain gauge on each sling will measure the pre-loaded strain on each sling.