Chit Resolution Report: NSTXU-1133-CRR-R01

Chits are as follows and in the attached report NSTX-U-REC-096-01:

1 **CR–MAG–01, Evaluation/Replacement of Original NSTX-U Inner PF Coils**

2 **CR–MAG–02, Determine Risk Classification**

3 **CR–MAG–03, Requirements**

4 **CR–MAG–4, Prototypes**

5 **CR–MAG–05, Insulation Dielectric Strength**

6 **CR–MAG–06, Kapton Adhesive**

7 **CR–MAG–07, Insulation Mechanical Properties**

8 **CR–MAG–08, Conductor and Winding PackGeometry**

9 **CR–MAG–09, Design of Coil Leads**

10 **CR–MAG–10, Water Fittings**

11 **CR–MAG–11, Load Cases**

12 **CR–MAG–12, Analysis of Conductor Pack**

13 **CR–MAG–7, Analysis of Leads**

14 **CR–MAG–14, Conductor Hardness**

15 **CR–OBS–15, Conductor Geometric Specifications**

16 **CR–MAG–16, Fabrication**

17 **CR–MAG–17, Insulation Quality Control**

18 **CR–MAG–18, G-11 Shims**

19 **CR–MAG–11, Conductor Leak Checking**

20 **CR–MAG–12, VPI Process**

21 **CR–MAG–13, Ground Plane**

22 **CR–MAG–14, Interface with Coil Support Slings**

23 **CR–MAG–16, Turn-to-Turn Test Method**

24 **INPFCOILFDR01, DVVR Coil Magnetic Center**

25 **INPFCOILFDR02, Testing Flags**

26 **INPFCOILFDR03, Analysis of flag connections**

27 **INPFCOILFDR04, Ensure adequate design margin in braze joint**

28 **INPFCOILFDR05, FMEA consequence definition inconsistency with GRD**

29 **INPFCOILFDR06, Use of Magnetic diagnostics**

30 **INPFCOILFDR07, Operational risks in the Risk Register**

31 **IPFWFPR01 & INFWFPR04, Tolerance and Braze Design**

32 **IPFWFPR02, Water Fitting Torque Standards**

33 **IPFWFPR03, Specification not on Dashboard or Filed**

34 **INFWFPR05, Helium Leak Check Braze & Solder Joints**

Cognizant Individual: Michael Kalish Digitally signed by Michael Kalish Date: 2019.01.24 08:06:04 -05'00' (sign and date)

Approver (*): Charles L. Neumeyer Digitally signed by Charles L. Neumeyer (sign and date)

(*) Up to and included FDR the DRC, after FDR the Main Approver (A-1: Chief Engineer, A-2 and A-3: DRC) DRC =Design Review Chairperson

National Spherical Torus eXperiment Upgrade

Chit Resolution Report For Inner PF Coils

NSTX-U-REC-096-01

Prepared By: Michael Kalish Digitally signed by Michael Kalish Date: 2019.01.22 16:40:31 -05'00'

Cognizant Engineer

Approved By: Steve Raftopoulos Digitally signed by Steve Raftopoulos Date: 2019.01.23 11:38:31 -05'00'

Responsible Engineer

Approved By: Yuhu Zhai Digitally signed by Yuhu Zhai Date: 2019.01.23 11:55:23 -05'00'

Project Engineer

Record of Changes

Rev.	Date	Description of Changes
0	03/23/2018	Initial Release
1	01/15/2019	Incorporate Chits from FDR review

Table of Contents

Table of Contents

1 CR–MAG–01, Evaluation/Replacement of Original NSTX-U Inner PF Coils

Review	ID	Chit
Integrated Design DVVR	IDD22	The magnetic shaping flexibility resulting from the PF coils 1a, 1b and 1c is essential to provide high heat-flux handling “poloidal flux expansion” divertor solutions. This capability should be maintained.
Magnets DVVR	IPF01	Coil had turn-to-turn short apparently due to insulation failure. Coil has been sectioned and split into 4 different chunks. Recommend building a new coil.
Magnets DVVR	IPF02	PF1A electrical short: Even with a poor vacuum impregnation, neither the turn to turn voltage of 32 v nor the layer to layer voltage of 1 kV should generate an insulation fault considering the 0.7 mm thick turn insulation (1.4 mm between adjacent turns or layers) which includes an overlapping Kapton wrap. Other possible causes of the fault include 1) a local weakness due to foreign conducting material trapped in the insulation and 2) a water leak. For replacement PF1 coils, avoidance of cause 1) requires establishing strict clean conditions during manufacture and avoidance of cause 2) requires stringent acceptance test procedures for the conductor (pressure test, helium leak test, internal eddy current test).
Magnets DVVR	IPF04	Replace both PF1AU (failed coil) and PF1AL. Significant quality issues associated with all Inner PF Coils manufactured by Everson-Tesla indicate that they are not reliable and are not suitable for continued use. The use of joggles that are aligned toroidally on each layer causes non-axisymmetric forces and field error. If PF1AU was re-designed with a joggle-free spiral winding with a different number of turns than the old design, and a thinner mandrel, and the new PF1AU was used with the old PF1AL, a mid-plane asymmetry would be introduced that would perturb field null formation and plasma position and shape control.
Magnets DVVR	IPF05	Replace PF1B upper and lower. Significant quality issues associated with all Inner PF Coils manufactured by Everson-Tesla indicate that they are not reliable and are not suitable for continued use. The use of joggles that are aligned toroidally on each layer causes non-axisymmetric forces and field error. Existing PF1B is not compatible with target of 350C bakeout. Existing PF1B electrical insulation was exposed to temperatures well above rating during bakeout such that its properties and/or longevity have been degraded.
Magnets DVVR	IPF06	Replace PF1C coils. Significant quality issues associated with all Inner PF Coils manufactured by Everson-Tesla indicate that they are not reliable and are not suitable for continued use. The use of joggles that are aligned toroidally on each layer causes non-axisymmetric forces and field error. PF1C was exposed to water for a long period of time (months) and has exhibited degradation of insulation resistance to ground, suggesting that water is migrating into the groundwall and conductor pack.
Magnets DVVR	IPF08	The PF-1B Lower experienced a turn to ground (Mandrel) short during acceptance testing. The coil lead was shorted to the case. Metal was removed from the case to resolve the problem. Concerned that this repair may not survive the required cycle life of the coil.

Review	ID	Chit
Magnets DVVR	IPF10	I have closely observed the failed coil and found that the failure spot is not at any strange geometry location; instead it occurred at uniform surfaces, and the failure type is pitting. Pitting failures normally stems from a tiny defect. In this case the defect was likely a particle trapped between the coils. Suggest review the process in the fabrication if the materials were particle free cleaned, including copper, glass fiber clothing, and resin? If the tools and equipment were particle free cleaned? If the working environment was particle free cleaned? If people worn particle free cleaned work clothing? Suggest add particle free clean requirement to the fabrication procedure if there has been not yet.
Magnets DVVR	IPF11	Lack of braze material in the PF1 upper brazements shows that the fabrication process is inconsistent and the qualified test results may not be representative. A method to NDE the brazement needs to be developed for future coil builds.
Magnets DVVR	IPF12	To determine whether or not any component is fit for function as-built, then create a stand-alone test at full-level-inputs for approximately 10% to 20% of expected life. Trend component performance parameters to detect degradation. This can be used to detect infant-mortality issues that are caused by latent design or fabrication errors. The part could then be used with high-confidence that it would meet remaining life-time expectations as per analysis. For example to determine whether or a PF coil is fit for use, create a full I2T test that uses up, say, 15% of its life. During the test, trend inductance, resistance, magnetic output, etc. You would then have actual data, rather than just opinion, about whether or not a particular PF coil was fit for further use.
Magnets DVVR	IPF13	Apply radiative heating of the inner surface of each coil with a high-power (kW) lamp or glow-bar and measure the time evolution of temperature of the outer surface with IR thermography to investigate whether there are macroscopic areas with little or no resin penetration between turn layers.
Magnets DVVR	IPF14	I agree that savagely bending the coil conductor to form the tight joggles required by the design of the inner PF coils will create much local hardening as well as "scruffy" hand-wrapped insulation in that region. However, the attempts by Everson to force the hardened length of the joggle to adopt the toroidal curvature of the PF1A coils would have been significantly more severe for the smaller major radius of the A pair than the B or C pairs. Thus the keystoning, its correction, local bulging of the conductor and the insulation etc. could be expected to be worse for the A coils. Accordingly, replacing the undamaged PF1AL coil before the next operation seems more important to me than replacing the B or C coils, although I would still recommend buying new B & C coils "at leisure," to have in store ready if needed. (Of course, don't have joggles in any of the new inner PF coils!)
NSTX-U Recovery Project - CDR	RPCDR009	Investigate possibility of toroidal breaks in coil support flanges. Perhaps a temporary part can be used to hold the pieces together when assembling on a coil.

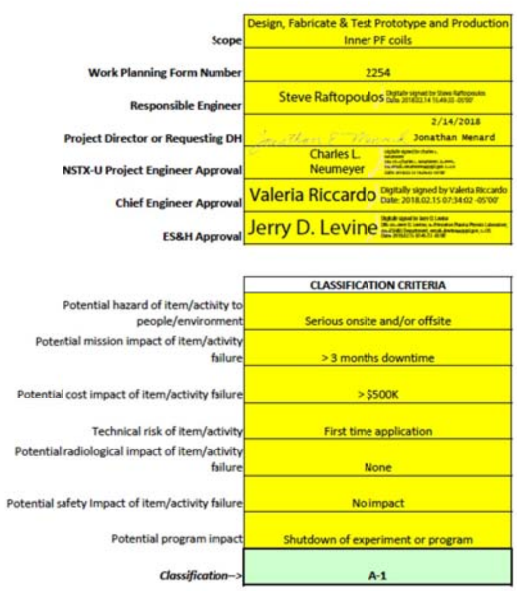
Numerous chits addressed the failure of the PF1AU coil, postulating various failure modes, recommending diagnostic tests to assess condition of other Inner PF Coils, and recommending the replacement of all six coils that were supplied by the same manufacturer. NSTX-U came to the same conclusion based on its detailed analysis in "Inner PF Coil Recommendation," NSTX-U-DOC-104-00, 1/2/17.

NSTX-U is proceeding to replace all of the Inner PF Coils with mandrel-less design, continuous (no braze joint) spiral windings (no joggles). This action overrides further consideration of these chits, except for specific recommendations related to the design, fabrication and testing of new coils that are addressed in subsequent sections of this document.

2 CR–MAG–02, Determine Risk Classification

Review	ID	Chit
PF1A Mandrel-less Prototype FDR	PROTOFDR13	Consider the classification of the WP risk - presently it is "Standard."
PF1A Mandrel-less Prototype FDR	PROTOFDR14	Work Planning Form 2254 covers all design, fab, & testing of PF1 coils. Prototyping should have a different Risk Rating and different set of review requirements. Note that 2254 rates risk as Standard, probably too low. Recommend that rating on 2254 be raised to Major and a WP for prototyping be generated.

Per the new PPPL Quality Assurance Program Description (QAPD), Table1 the graded approach risk classification has been set to the highest level (A1) and approved per procedures.



Scope	Design, Fabricate & Test Prototype and Production Inner PF coils
Work Planning Form Number	2254
Responsible Engineer	Steve Raftopoulos
Project Director or Requesting DH	2/14/2018 Jonathan Menard
NSTX-U Project Engineer Approval	Charles L. Neumeyer
Chief Engineer Approval	Valeria Riccardo Digitally signed by Valeria Riccardo Date: 2018.02.15 07:34:02 -05'00'
ES&H Approval	Jerry D. Levine

	CLASSIFICATION CRITERIA
Potential hazard of item/activity to people/environment	Serious onsite and/or offsite
Potential mission impact of item/activity failure	> 3 months downtime
Potential cost impact of item/activity failure	> $500K
Technical risk of item/activity	First time application
Potentialradiological impact of item/activity failure	None
Potential safety Impact of item/activity failure	No impact
Potential program impact	Shutdown of experiment or program
Classification-->	A-1

3 CR–MAG–03, Requirements

Review	ID	Chit
PF1A PDR	PF1APDR01	Generate requirements document for this (PF-1AU) Inner PF Coil.
PF1A PDR	PF1APDR02	If possible, should preserve max kA-turns capability from original Design Point spreadsheet for any new PF1 coils that are fabricated. Also should assume maximum power supply current is 21kA. These constraints should set the minimum # of turns in a coil, and these requirements need to be captured ASAP in a DPSS update or a dedicated SRD for the PF1 coils.
PF1A PDR	PF1APDR35	There are chits to preserve the amp turns capability, and also to write some formal requirements. There is also the cooling wave stress to be concerned about, which may be mitigated under ~13 kA (?). The highest currents may be most important for L-modes, which are intrinsically shorter in duration (?). Therefore, if the requirements document can articulate an I^2t requirement less than the maximum amps (squared) for the full duration, it would be advantageous.
PF1A PDR	PF1APDR36	The CHI voltage is planned to go to 4 kV at some time, perhaps years from now. The insulation on the coil must be able to stand-off the CHI voltage while the coil is at voltage (2kV?) It is likely the mechanical requirements for the insulation will be sufficient to provide the required HV standoff, but it needs to be checked and reviewed. PF1C and PF1B will have the same requirement.
Integrated Design DVVR	IDD07	Cabling to Inner PF coils has changed to 4-wire scheme resulting in lower voltage to ground. Design assumed 3-wire scheme, in which case voltage of upper and lower coils could add, with respect to ground.
NSTX-U Recovery Project - CDR	RPCDR005	Maximum turn to turn, layer to layer and coil to ground voltages can depend on coupling from other coils and plasma as well as the applied coil voltage. The resulting voltages depend on operating scenarios and the net effect may well be small but should be evaluated.

New requirements for the Inner PF Coils were initially documented in “Changes to Inner PF Coil Requirements,” INT-170724-CLN-02. System and Interface Requirements Documents, NSTX-U-RQMT-SRD-002-02 and NSTX-U-RQMT-RD-012-00 have been written and approved.

Coil current requirements for the NSTX-U PF coils were originally specified in the Design Point Spreadsheet (DPSS) based on the peak amp-turns from the 96 design-basis plasma equilibria, and an equivalent square wave (ESW) of 5.5 seconds, derived from the design-basis plasma current waveform. This conservative approach leads to coil temperature rises that are within allowables for the coil insulation system but introduces significant mechanical stress during cool-down, particularly on the outer layer of the PF1A coil. Although acceptable in principle and qualified during the original NSTX-U R&D program, some level of risk and uncertainty remains. Since realistic plasma operations will not demand worst case current and pulse length at the same time, a reduction in the requirement is judged prudent and appropriate, since the extrema of the Inner PF coil currents are largely for was addressed in "NSTX-U_PF1_coil_requirements_update_Menard_v2," leading to a new, separate requirement that specifies the action integral (i.e. $\int i^2(t)dt$, i.e. "I^2T") coil ratings that are necessary for full 5 second plasma flat top duration with Inner PF coil currents taken from an appropriate subset of the 96 equilibria. This becomes the driving requirement for coil heating, instead of the earlier approach based on peak amp-turns and the ESW.

The voltage requirements for the Inner PF coils were influenced in the original NSTX-U design by Co-axial Helicity Injection (CHI) operation that could impose an additional 2kV across the coil groundwall insulation and imposed a slew rate requirement that drove the 2kV power supply voltage requirement. Relaxation of this requirement to 1kV was considered, but it was decided to retain 2kV as an insulation design criteria such that two layers of co-wound glass/Kapton insulation are included per turn. This choice retains a robust, multiple barrier insulation system, and retains the possibility of 2kV operation which might prove valuable in the future, e.g. for divertor sweeping, etc. This feature also widens the options for changes to reduce the harmonic content of the coil current that may involve the introduction of external filter inductors.

PF1A cabling is 4-wire but PF1B and PF1C are 3-wire. In principle, PF1A voltage-to-ground requirement could be reduced. However, the design-driver for groundwall insulation thickness is based on the need for mechanical armor rather than insulation stand-off since the voltages are relatively low. Therefore, the reduced voltage will not impact the design of the groundwall insulation. However, a lower hipot voltage can be justified for PF1A (E = 1 x 2kV, 2E+1= 5kV) compared to PF1B and PF1C (E = 2 x 2kV, 2E+1= 9kV). This will be reflected in the specifications for coil procurement and in NSTX-U hipot test procedures.

When the coils are connected to the power supplies, a closed circuit is formed. Based on Kirchhoff's law the voltage across the coil terminals will be limited to the power supply open-circuit voltage plus a small L x dI/dt + I x R drop across the source impedance (much lower than the coil impedance). Voltages induced on the turns by coupling to flux changes driven by the other coils will be nullified by the internal voltage drop, $M \times dI_{other}/dt = L_{self} \times dI_{self}/dt + I \times R$. Therefore, the induced voltage will not significantly manifest itself as turn-to-turn or layer-to-layer voltage. On the other hand, when the coils are open-circuited then the induced voltage $M \times dI_{other}/dt$ will appear across the coil terminals and be distributed amongst the turns and layers.

The most significant sources of induced voltage on the Inner PF Coils is the OH coil along with interactions between 1A, 1B, and 1C coils. The initial design of the Inner PF

Coils for NSTX-U took this into account when selecting the number of turns to ensure that excess voltage is not induced on open-circuited coils and that the driving voltage in one coil is not overwhelmed by voltage induced by other coils. These calculations are documented in “Design Point Calculations for NSTX Center Stack Upgrade,” NSTXU-CALC-10-03-00. Amongst OH, PF1A, PF1B, and PF1C, in all cases the induced voltage from one coil to another is less than ½ the rated voltage, which is judged to be acceptable.

4 CR–MAG–4, Prototypes

Review	ID	Chit
Magnets DVVR	IPF03	Recommendations for replacement Inner PF coils The following is based on the “Inner PF coil recommendation” document of 2 January 2017, on the “OH and inner PF coil conductor specifications” of April 2012 and on the “Inner PF coils manufacturing specifications” of November 2012. Leak testing of the conductor before and after winding: • Pressure testing and leak testing of extruded lengths are not mentioned in the conductor specifications. If these tests are covered by ASTM B188, the test pressure and the acceptable leak rate should at least be specified. • Internal crack detection with an eddy current probe is a simple test that ought to be considered. • Pressure and leak detection after winding and installation of all water circuit fittings is not mentioned in the coil specifications but should be included. Insulation • A turn insulation scheme with copper to glass interfaces is recommended for a strong bond between conductor and insulation. This is to avoid differential displacements which may occur in the vicinity of conductor ends. Kapton to Kapton interfaces should be avoided to ensure adequate resin flow during VPI. • **Qualification of the VPI process should include a test beam representative of the coil cross sectional dimensions. The beam should be subjected to electrical tests and be subsequently sectioned for examination**. Winding mandrel: which are the reasons for not using a split mandrel? This would allow inductive voltage tests (which are safer and more representative of operation conditions than impulse tests) and eliminate eddy currents (and save volt-seconds) during operation?
Magnet DVVR	MD05	Did you do a VPI prototype test, and if so what tests were performed to evaluate quality of VPI process?

Review	ID	Chit
Inner PF PDR	IPFCPDR25	Please define some objective test and/or pass-fail criteria related to the voids in the insulation during destructive testing of the prototype. This should be done before coils arrive, lest we talk ourselves into accepting something that we shouldn't.

A VPI test bundle (Drawing, B-DC11067) was fabricated (Procedures, C-PTP-NSTX-CL-055 & C-PTP-NSTX-CL-056) by PPPL to confirm VPI processing parameters, material compatibility, and turn insulation strength ("Purpose and Objectives of Straight Log Bundle," MAG-171129-SR-01 and "Test Report for Conductor Bundle Electrical Test," NSTX-U-DOC-105-00.

Prototype coils are being fabricated by PPPL, Tesla (UK), Sigmaphi (France) and Everson-Tesla (Pennsylvania) per "Specification for Prototype - Phase 1 Inner PF Coils," NSTX-U-SPEC-MAG-004-R3. The prototype design resembles the PF1A coil, chosen because it presents the most manufacturing challenge of the three types (most turns and layers, smallest radius). Guidelines for prototype evaluation have been specified in "Guidance on Inner PF Coil Prototype Evaluation – R1," MAG-180211-CLN-01 which calls for a "Technical Evaluation Procedure" to be written.

The inspection criteria with respect to voids is given in the specification:

8.1.3.3 Tests after cutting coil into sections

The prototype coil will be cut into multiple sections. The section ends will be visually examined under magnification. The precision of the conductor locations within the winding pack array will be evaluated. Any voids evident in the turn or ground insulation will be noted including void size and location.

The guidelines for evaluation from the above memo are as follows:

The coil shall be sectioned into two pieces of approximately equal fractions of the circumference. The (+) and (-) terminals shall be located approximately at the midpoint of one of the sections. After cutting in half, an additional section approximately 1" thick in the circumferential direction shall be cut from one of the large sections. Details of cutting method shall be elaborated in the technical evaluation procedure. Contamination of the insulation at the sections, e.g. by machine oil, shall be avoided. Surfaces shall be polished to optimize visual inspection.

This step (from the specification) is mostly self-explanatory. However, additional detail shall be included in the technical evaluation procedure as follows:

- *Type of equipment and magnification and illumination used to inspect the insulation for voids on the large sections*

• Use of back-lighting to illuminate the 1” section
• Use of a graphic image of the array of turns with a defined turn numbering convention, for purposes of recording observations about defect locations and features

Ideally the insulation should be completely void-free. However, the presence of a small number of voids is likely, and tolerable. No pass/fail criteria has been established for void content (void size, number of voids, etc.), and to do so would require an extensive R&D program that is impractical. Therefore, the judgment of the review committee will need to be exercised in this regard. After the evaluation of the first prototype, evaluation of subsequent prototypes will benefit from relative comparison.

Summarizing, the project is building multiple identical prototypes and does not consider it practical to establish a simple pass/fail criteria for void content a priority.

5 CR–MAG–05, Insulation Dielectric Strength

Review	ID	Chit
PF1A PDR	PF1APDR28	Basis for dielectric strength estimation is based on CTD paper that uses CTD-101K, and unknown configuration of glass and Kapton. Explain why this can be used as a basis for estimation.

The selection of the insulation system and the rationale is given in “NSTX-U Inner PF Coils Turn Insulation Strength,” MAG-180305-CLN-01. The design-basis assessment of the dielectric strength is based upon theory and test results provided by the manufacturer, CTD. Dielectric strength is estimated based on an approach that accounts for thickness as follows:

$$V = kd^{!}$$

Where:

V = breakdown voltage in kV
d = specimen thickness in mm
n = 0.5
k = electrical strength constant (kV-mm$^{-0.5}$)

Data from the references shows a value of k ranging between 55 and 85 for various composite insulations involving a glass, Kapton, and several types of CTD resins including CTD-425. Design-basis calculations for NSTX-U use a conservative value of 50 and predict a turn-to-turn dielectric strength ~ 70kV, corresponding to a safety factor > 25 over the worst case voltage in the coil. Confirmatory tests (“Test Report for Conductor Bundle Electrical Test,” NSTX-U-DOC-105-00) were performed on samples but flashover at the ends, at voltages ranging between 33kV and 52kV, always occurred before breakdown of the turn-to-turn insulation could be achieved. Future tests on coil prototypes will employ new techniques increase the breakdown voltage at the ends by immersing them in dielectric fluid.

6 CR–MAG–06, Kapton Adhesive

Review	ID	Chit
PF1A PDR	PF1APDR07	Confirm with CTD or Dick Reed that adhesive is not detrimental to resin or primer chemistry. Although its use maintains consistency with prior R&D, compatibility should be confirmed. Answer should be provided in writing.
PF1A PDR	PF1APDR25	The Kapton we use for ITER CS is FPC - treated on both sides for good adhesion. Using one side adhesive backing is questionable to me. The HN type you plan to use is OK too, used in many magnets in the past, but I am not familiar with the adhesive backing, I do not think it is a good idea well explored and tested

Compatibility of Kapton adhesive and mold release was confirmed by CTD and documented in “Correspondences with Paul Fabian (CTD) regarding material compatibility with CTD-425,” MAG-170706-SRAFT-01.

The adhesive is used to facilitate the preparation of co-wound glass/Kapton tape with precision alignment of the glass and Kapton to promote resin flow.

Note that the application of turn insulation to the conductor is performed using automatic taping machines and that every half-lapped layer requires an individual feed spool on the rotating head. The insulation design consists of two half-lapped layers with glass tape slightly wider than Kapton tape. Without the advance preparation of the co-wound tape the centering of the Kapton on the glass would be imprecise, and six feed spools would be required.

An additional factor considered in retaining the co-wound tape with adhesive was its successful use on the NSTX-U OH coil and all the R&D samples used for testing.

The project considered the advantages and disadvantages of the co-wound tape with adhesive and elected to proceed with it. Subsequent VPI log tests have been performed with no evidence of material incompatibility. All mechanical testing uses samples with the same insulation system.

7 CR–MAG–07, Insulation Mechanical Properties

Review	ID	Chit
Magnets DVVR	IPF03	Recommendations for replacement Inner PF coils The following is based on the “Inner PF coil recommendation” document of 2

Review	ID	Chit
		January 2017, on the "OH and inner PF coil conductor specifications" of April 2012 and on the "Inner PF coils manufacturing specifications" of November 2012. Leak testing of the conductor before and after winding: • Pressure testing and leak testing of extruded lengths are not mentioned in the conductor specifications. If these tests are covered by ASTM B188, the test pressure and the acceptable leak rate should at least be specified. • Internal crack detection with an eddy current probe is a simple test that ought to be considered. • Pressure and leak detection after winding and installation of all water circuit fittings is not mentioned in the coil specifications but should be included. Insulation • **A turn insulation scheme with copper to glass interfaces is recommended for a strong bond between conductor and insulation. This is to avoid differential displacements which may occur in the vicinity of conductor ends. Kapton to Kapton interfaces should be avoided to ensure adequate resin flow during VPI.** • Qualification of the VPI process should include a test beam representative of the coil cross sectional dimensions. The beam should be subjected to electrical tests and be subsequently sectioned for examination. Winding mandrel: which are the reasons for not using a split mandrel? This would allow inductive voltage tests (which are safer and more representative of operation conditions than impulse tests) and eliminate eddy currents (and save volt-seconds) during operation?
NSTX-U Recovery Project - CDR	RPCDR006	Coils typically delaminate locally. Is this expected for the PF1 coils? If so, where is the expected parting plane? Has the design of the interleaved layers of Kapton and fiberglass (and priming if applicable) considered this?
Magnets: PF1A PDR	PF1APDR23	Some level of delamination is expected due to mechanical strains during cooldown. If gaps open up and the volume does not communicate with the surface they will have a low gas pressure and Pashen minimum assumption may be appropriate
Inner PF Coil PDR	IPFCPDR11	Investigate via analysis whether the preload can substitute (or eliminate the need) for the priming of conductor. This would be advantageous even if it applied to only one of the three Inner PF coils.
Inner PF Coil PDR	IPFCPDR05	With Kapton, transverse tensile strength is zero - Yuhu still has finite capacities?
Inner PF Coil PDR	IPFCPDR19	There is no through thickness tensile stress strength for Kapton system. We have good in-plane strength measurements from ITER for CTD 425.

The insulation system requires that the co-wound glass Kapton tape be laid down so that there is always glass facing the primed copper interface (no Kapton to copper). The Kapton tape is ¾" wide and the glass tape is 1" wide enhancing epoxy flow ensuring no Kapton to Kapton interface. Also, G11 spacers are wrapped in glass so that the connection between adjacent pieces of G11 can rely on the tensile strength of the glass tape instead of only the shear strength of the adhesion of the G11 to G11 parts. Analysis does indicate local strains in the insulation system due thermal strains as the cold water cools the coil down after the pulse. An extensive analysis was performed to qualify the system which includes the use of a preload on PF1a and PF1b. This effect is small enough for PF1c that it does not require a preload. The evaluation of the local strains is discussed in the analysis report "Inner PF Coil Thermal Analysis," NSTXU-CALC-131-27. The thermal analysis calculation addresses the mechanical evaluation of the insulation system (note while other analysis address the EM loads on the insulation system they are much less significant), and another memo "NSTX-U Inner PF Coils Turn Insulation Strength," MAG-180305-CLN-01 addresses the dielectric competence of the insulation system after accounting for the possibility of some delamination. Material properties including Kapton tape assumptions are discussed in the memo, "Material Properties for Inner PF Coil FDR," MAG-180306-YZ-01. In addition to documenting the material properties used for the insulation, this memo discusses the various testing that was completed to verify the properties as well as sensitivity studies that were performed to bound the problem and determine which worst case assumptions should be applied. A choice was made to use priming on all conductors to minimize uncertainty due to the previous testing that was done that included priming on the conductor. The priming was also deemed desirable to maximize the adhesive bond between the glass and the copper.

8 CR–MAG–08, Conductor and Winding Pack Geometry

Review	ID	Chit
Integrated Design DVVR	IDD06	Due to the need to redesign and/or rebuild one or all of the Inner PF coils, various features will change: **• The PF1B conductor pack dr x dz will have to be reduced to decouple structurally and thermally from center stack PFCs and support structure** • The number of turns may be re-optimized to meet ripple spec given reduction in inductance at harmonic frequencies • A design change to use 4-wire instead of 3-wire power supply feeds on PF1A reduces the voltage-to-ground requirement by a factor of two. At present PF1B coils are not connected so 4-wire is an option. PF1C is presently connected using 3-wire.
Magnets DVVR	IPF09	The space between the PF-1A and PF-1B is limited and the plasma Rogowski loop is squeezed. In the PF-1AU redesign, control the radial build of the coil to prevent the Rogowski from becoming damaged

Review	ID	Chit
Magnets: PF1A PDR	PF1APDR09	Include features to maximize space available to Ip Rogowski. Consider feature to facilitate removal of O-ring lips after VPI where Rogowski crosses over. Consider adding trough to large flange to avoid pinch-point.
Magnets: PF1A PDR	PF1APDR10	Not clear that radial build of components (including insulation) at maximum tolerances will fit in CS. Should generate drawing showing the worst case of thicknesses.
PF1 Conductor Size Peer Review	PF1CSPR05	Confirm with a documented calculation that the proposed cooling hole in the reduced cross-section PF1A conductor can support a 10% reduced action integral and cool down in 1200 seconds. And revise the SRD accordingly.

The coil conductor size and conductor pack geometry has been optimized after consideration of numerous factors including space for diagnostics, assembly clearances, alignment tolerances, and sling dimensions. A PF1 Conductor Size Peer Review was held on 12/19/17 to finalize the conductor and winding pack. In fact this review resulted in a decision to make a slight reduction in PF1A conductor size to ensure ability to install and align.

A memo "PF1A Conductor Dimension and Cooling Hole Size," MAG-171003-YZ-02, was written to confirm the adequacy of the PF1A conductor size, after reduction, prior to final thermal analysis "Inner PF Coil Thermal Analysis," NSTXU-CALC-313-27.

Since the decision to abandon integral winding mandrels/coil support structure in favor of bare inner PF coils, the requirements for:

- Providing space for routing the IP Rogowski out of the Center Stack is imposed on the Polar Region WBS. The geometry of the Inner PF coils (I.D & O.D.) allows sufficient clearance for both the Rogowski and for coil alignment and final positional adjustment.

- Structural and thermal decoupling the Inner PF Coils from the Center Stack PFCs and Structure is also a requirement imposed on the Polar Region WBS.

These interfaces are defined in NSTX-U-RQMT-RD-002-00.

9 CR–MAG–09, Design of Coil Leads

Review	ID	Chit
NSTX-U Recovery Project - CDR	RPCDR002	The weak spots, as far as insulation is concerned, are where the terminals penetrate the ground insulation. Continuity of insulation between penetrations and ground wrap is essential to avoid cracks developing at those penetrations with the risk of humidity ingress. Glass and if possible Kapton tapes must be laid to follow the reentrant corner where the terminals emerge from the ground wrap. In addition, ground insulation that is applied on terminals outside the coil must extend inside the ground wrap for some distance, say 5 cm, and be progressively reduced to the turn insulation.
Magnets: PF1A PDR	PF1APDR27	Slide 8 of W. Que's presentation uses nominal dimensions from the solid models as a basis for calculating the standoff potential. There is a 0.2" gap between the lead flag and the grounded structural support. The coil lead flags are not precise components and many coils in the field have imprecise or even bent flags. Considering adding a more robust standoff scheme rather than rely on a small gap which will likely not be maintained precisely in the field.
Magnets: PF1A PDR	PF1APDR29	If bolts are used to connect flags to bus bars, ensure that clearance gaps are not compromised.

Turn insulation, which includes two half lap layers of co-wound Kapton Glass plus one half lap layer of glass, extends from inside the ground wrap into the G11 lead blocks which both supports the leads and provides additional dielectric standoff. This ensures there is no sudden transition as the conductor leaves the ground wrap at the body of the coil. Gaps for dielectric standoff at the flags are maintained at a minimum half inch. All gaps and potential high voltage flash points will be reviewed by the high voltage engineer before final sign off of the drawings.

10 CR–MAG–10, Water Fittings

Review	ID	Chit
PF1A PDR	PF1APDR16	Optimize selection of fittings. Consider bronze Parker fitting, threads machined off, brazed in place.
PF1A PDR	PF1APDR17	The proposed design shown on slide 32 of M. Kalish's presentation show a T-Fitting with a sharp 90 bend. Typically coil water flow velocity is limited by erosion corrosion and/or cavitation. Introducing a sharp transition may cause a flow velocity which would otherwise be safe to be problematic.
PF1A PDR	PF1APDR24	Include feature or plan to ensure that supply and return connections are idiot-proof.

The water fittings for the inner PF coils are identified on the drawings (E-DC11053, E-DC1471), and meet requirements set forth in NSTX-U-RQMT-RD-012-00. Interface to cooling water system shown on P&ID D-5GA522. Modified Parker-Hannifin fittings (6-

2CCTX-B) are used for all three inner PF coil types. The design team desired to move away from a 90 degree fitting, for reasons both including flow velocity concerns, and to allow future access to the coolant path via borescope. Space limitations in the umbrella/polar region adjacent to the coil disallowed the implementation of other than 90 degree fittings, as was used in the original inner PF coil design. The fittings shall be color coded Purple/Black to indicate supply/return respectively. Drawings including coil detail and assembly, as well as P&IDs shall reflect the coolant flow designation.

11 CR–MAG–11, Load Cases

Review	ID	Chit
Integrated Design DVVR	IDO17	Magnets are top bottom symmetric, but gravity effect on launching loads is not, was this taken into account?
NSTX-U Recovery Project - CDR	RPCDR011	PF1 A/B Support Slings: Deviations from perfect concentric alignment of coils with respect to each other will create side loads on the PF1 coil bodies. Since the coil/sling is only constrained at on end, these will be reacted as torsion about a horizontal axis (which reacts as a couple increase clamping force against the sliding surface?). The sliding/flexing support mechanism must function properly and be stable against expected and self-reinforcing perturbations from idealized concentricity during actual installation.
NSTX-U Recovery Project - CDR	RPCDR012	A chit to group/merge with others from MC and MH! I agree with Martin that the PF1C coils will be much stiffer than the slings/cans and therefore can be relied upon to centre themselves if the top and bottom radial guides are adequate. So a) you don't need the feebly competing G10 and sling/can distortion to recentre the coils and b) if the coils reliably recentre themselves, and the slings/cans are intrinsically centred, there will be no lateral force trying to produce the distorting stick-slide of the slings/cans that Michel was concerned about.
NSTX-U Recovery Project - CDR	RPCDR017	Loooong ago I worked on the Culham Superconducting Levitron (similar to FM-1) and had cause to calculate the forces on the ring when it was displaced in the toroidal field. The result was a strong lateral force along the x-axis if the ring was tilted about the x-axis, and a strong torque about the x-axis if the ring was displaced (translated) along the x-axis. Please check the forces arising from putative coil misalignment wrt the TF, to be compared to those resulting from misalignment wrt the OH solenoid.
Inner PF PDR	IPFCPDR06	Need to refine how we categorize the likelihood of the "Suppress and Bypass Transient". Is it a standard load case or something that can have k>1?
Inner PF PDR	IPFCPDR07	Load cases for the magnets need to include non-operation, like baking. If not in the Magnets, where are they captured?
Inner PF PDR	IPFCPDR08	Requirements on side loads from non-axisymmetric effects (shifts, tilts, layer-to-layer transitions,...) should be tabulated in the interface documentation.
Inner PF PDR	IPFCPDR09	Need to define EM loads due to vertical routes of coil winding. IOW...detailed 3D EM FEA accounting for coil winding. Need to define EM loads due to coil mis-alignments (translation and rotation) from ideal coil installation. Once these loads are defined, need to capture them in a requirements document.

Inner PF PDR	IPFCPDR15	Coil lead region (3d effects) induce stress in adjacent coil winding regions. Vertical coil transitions impart loads / stress to the coil winding not yet analyzed. Need to check coil pack / insulation margins with the 3D loading effects.

Provide an introduction of the load cases including axi-symmetric and non-axisymmetric. - The normal and abnormal load cases are reviewed and further clarified for properly categorization following the NSTX-U structural design criteria. The non-operational load cases include the baking, post-disruptions and Suppress and Bypass Blip. The side loads from misalignment on the sling supports have been documented in the IDC Inner-PF Coil Interfaces to Supports Designs and Cooling Systems, NSTX-U-RQMT-RD-012-00.

Explain that gravity is included. – Although its effect is relatively small compare to Lorentz loads from plasma operations, gravity is included in both the structural analysis of 2D coil winding pack under thermal loads, EM loads, as well as the 3D structural analysis of coil terminals and bus bars.

Explain the treatment of the suppress/bypass blip and include reference to a memo or calculation. - Y Zhai. A Gao (memo) A memo on the Suppress and Bypass Transient events is also been generated to document the Calculation of Coil Response. Based on the probability of occurrence, the Suppress and Bypass transient is treated as the Unlikely Events. See NSTX-U-CALC-CC-52-00.

12 CR–MAG-12, Analysis of Conductor Pack

Review	ID	Chit
PF1A PDR	PF1APDR32	Slide 18 of P. Titus' presentation highlights a region of 80 Mpa as being near the allowable. However, on the same slide, in the upper right hand corner of the coil, there appears to be a turn with membrane stresses which are twice as high, which would be above allowable.
PF1A PDR	PF1APDR33	Fatigue qualification appears to be "at the hairy edge" of the allowable. With such little margin, some assumptions could be questioned. For instance, the fatigue life of copper varies as a function of hardness (See http://clic-meeting.web.cern.ch/clic-meeting/2003/06_26sh.pdf which shows -50 Mpa for annealed vs full hard), the yield strengths assumed are from cold working during bending and not uniform through the cross section, etc.
Inner PF Coil PDR	IPFCPDR10	Linearization is not appropriate for fatigue assessments.

Address concerns expressed in chits – The design allowable for the conductors and insulation systems have been revised based on the new conductor specification and the new material tests of insulation composites. The fatigue allowable has also been reviewed and documented in a new calculation report NSTX-U-CALC-133-24. Use of linearization for fatigue assessments has been removed.

13 CR–MAG–7, Analysis of Leads

Review	ID	Chit
NSTX-U Recovery Project - CDR	RPCDR002	The weak spots, as far as insulation is concerned, are where the terminals penetrate the ground insulation. Continuity of insulation between penetrations and ground wrap is essential to avoid cracks developing at those penetrations with the risk of humidity ingress. Glass and if possible Kapton tapes must be laid to follow the reentrant corner where the terminals emerge from the ground wrap. In addition, ground insulation that is applied on terminals outside the coil must extend inside the ground wrap for some distance, say 5 cm, and be progressively reduced to the turn insulation.
NSTX-U Recovery Project - CDR	RPCDR018	Check stresses in insulation around coil terminals when terminals are slightly flexed to accommodate coil radial motion
Inner PF Coil PDR	IPFCPDR14	PF1bU needs a sector model to include the break-out as it enters the coil like Wenping's and Jiarongs' model
Inner PF Coil PDR	IPFCPDR16	Please confirm the boundary condition on the PF-1b bus bars - Attached to the umbrella or the PF-2 or 3 clamps?
Inner PF Coil PDR	IPFCPDR18	We have over-stress issues on the coil leads of both PF1A lower and upper coils due to the high EM forces on leads, flags and bus bars. Suggest to change the vertical flags to horizontal flags and shorten the entrant support block to reduce the total EM forces from leads and flags. We also can further put two bus bars closely in parallel to reduce the bending moment on the coil flags.
Inner PF Coil PDR	IPFCPDR20	(From Iain Dixon) Analysis of Lead Support Structure - Redo the 3-D structural analysis with bonded interface between the conductor and support block. Review the shear and normal stress results.
Inner PF Coil PDR	IPFCPDR21	The larger terminal model could be split into 3 with appropriate boundary conditions like the other 2 sector models shown. When we have a review crunch it would be good to consider modeling efficiency to minimize demands on HPL's and licenses - typically run times go as the square of the element count and trouble-shooting of meshing problems and convergence issues are easier on smaller models.
PF1 Conductor Size Peer Review	PF1CSPR04	if the coil lead regions are over stressed (coil PDR slides) why is changing the conductor cross section now not a concern for this region.

Describe the analysis of the leads and draw conclusions – Lead analysis has been performed for all 6 inner PF coils using 3D models including conductor spiral winding, insulations in coil packs, coil terminals (with new design of filler blocks and support brackets), and new bus bars. A consistent procedure of lead analysis has been applied to all 6 coils with same assumptions on contact around coil terminals. PF1bU bus bars are attached to the PF3 clamps. The conductor stresses in the lead sections meet the fatigue crack growth limit. The calculation reports are issued NSTX-U-CALC-55-10 and NSTX-U-CALC-133-24.

14 CR–MAG–14, Conductor Hardness

Review	ID	Chit
PF1A PDR	PF1APDR03	M. Kalish's presentation described spooling and respooling as necessary to achieve the desired hardness of the copper. Work hardening by bending preferentially hardens the exterior of the copper and does not harden the interior cross section. Stress states in the coil are likely membrane stresses distributed uniformly through the cross section. Hardness testing likely only measures the exterior of the copper. Ensure that the copper hardness is suitable for purpose.

The vendor that is supplying the production coil conductor is capable and has agreed to harden the conductor by drawing it through pinch rollers. They have tested this approach and have confirmed that they can achieve the specified hardness throughout the entire cross-section. Hardening the conductor in this manner will also have the added benefit of reducing twisting of the cross section along the length.

15 CR–OBS–15, Conductor Geometric Specifications

Review	ID	Chit
Inner PF PDR	IPFCPDR01	Copper cross section presented has tolerance of +- 0.005" for twist. It is unlikely suppliers can produce copper this straight (as confirmed by our prior experience). If tolerances are truly this tight a test coil should be produced. If not recommend relaxing to what is achievable to avoid unneeded NCRs.
Inner PF PDR	IPFCPDR02	Bill Becks question on how the twist spec is specified it should be something like .005in per foot of conductor - it should have a length spec.
Inner PF PDR	IPFCPDR03	The dimensions on the conductor cross section are shown as +/-0.005". Vendors sell copper by the pound so they will always deliver product on the plus side giving a coil that is larger than nominal. Use tolerance +0.000/-0.010" which will result in a coil that is below nominal size and result in more realistic spaces in the buildup.
Inner PF PDR	IPFCPDR04	Determine the amount of conductor twist that is compatible with the design and the manufacturing plan

See previous section regarding twist.

16 CR–MAG–16, Fabrication

Review	ID	Chit
PF1A PDR	PF1APDR08	Develop fabrication procedure to provide instructions for critical fabrication methods and testing (electrical and mechanical).
PF1A PDR	PF1APDR15	Final assy drawing of coil winding should show dimension of each layer diameter as an aid to the winding of the coil. Allows measurement of each turn during the
PF1A Mandrel-less Prototype FDR	PROTOFDR02	Consider creating a specification for a minimum overlap (or other tolerance specification) to define a tolerance on the insulation overlap quality.
PF1A Mandrel-less Prototype FDR	PROTOFDR03	Consider adding a physical metric to quantify and measure the clean room cleanliness.
PF1A Mandrel-less Prototype FDR	PROTOFDR07	Consider active mechanisms to limit the access to the winding area to those people that really need it. Check access lists for the card readers periodically, lest it grow in an unsupervised manner. Particularly concerned that a large crowd of FLARE people will have access to the CTC. Consider means to prevent their accessing the area as practical.

Fabrication processes for the production coils are being broadly defined via a Coil Fabrication Specification, which is in turn interpreted by the participating coil fabricating entities. Each individual interpretation is subject to review and approval by PPPL. This method ensures that PPPL minimum requirements are met, while allowing each fabricating entity to utilize their particular methodology and experience. NSTX-U-SPEC-MAG-001-03 is the specification for the fabrication of the prototype Inner PF coils. NSTX-U-SPEC-MAG-006-00 is the specification for the fabrication of production inner PF coils. These specifications convey requirements for the fabrication and testing of coils.

- PF1APDR08 – Fabrication of coils follows approved specifications.
- PF1APDR15 – Reference dimensions for each layer are shown in coil drawings.
- PROTOFDR02 – Minimum overlap and tolerance defined in drawings and/or in specification.
- PROTOFDR03 – The cleanrooms, as deployed for prototype coil fabrication and required per the specification, are designed to provide a positive pressure and prevent dew by maintaining temperature above dew point. Heavier, conductive contamination (contamination not controlled by the cleanroom itself) is controlled by a combination of step-off pads, training, diligence and oversight (to ensure the

previously mentioned measures are followed). All four shops participating in the prototype coil production have erected clean rooms that follow this philosophy.

- PROTOFDR07 – Access to the PPPL coil shop has been changed to the south door and the entryway from the north door has been posted. Access via the card reader has been purged and limited to individuals involved in the coil winding process. Installation of FLARE in the north end of the CS high bay has been put on hold, which allows the coil shop to utilize this space as a staging area for coil work, limiting access to others.

17 CR–MAG–17, Insulation Quality Control

Review	ID	Chit
Magnets: PF1A PDR	PF1APDR21	Consider adding a permanent magnet in the taping head to collect any ferromagnetic materials in the glass tape - maybe in the fabrication of the Kapton/glass prep too. The weaving machines at Carolina glass may be carbon steel and a magnet would pick up wear particles from the weaving machine
Magnets: PF1A PDR	PF1APDR26	Coil health is very sensitive to contaminates in glass which could cause turn/turn/layer/ground shorts. Consider verification that glass insulation is free of metal contaminants by X-ray or other TBD method
PF1A Mandrel-less Prototype FDR	PROTOFDR15	Consider on-line inspection of insulation system during winding to inspect for cleanliness.

An insulation winding and inspection station for preparing coil insulation material was developed and passed a FDR on 8/22/17. The system replaces what was previously a manual hand-crank process with a motorized system that includes optical system to detect impurities and dimension. The station frame will use engineered aluminum parts. The web routing employs off-the shelf reels, tensioners, idlers with provided adjustments. An Optical Vision system detects anomalies with adequate accuracy (0.01”). Controls design will use a micro PLC and interface as well as a PWM DC drive and belt drive for the motor. The system has been deployed and was used to prepare all of the insulating materials going into the prototype coil fabrication between 12/13/17 to 1/19/18. For glass-only inspections, 66 defects were identified. For co-wound inspections, 108 defects were found (excluding alignment defects).

18 CR–MAG–18, G-11 Shims

Review	ID	Chit
PF1A PDR	PF1APDR12	Determine best way to fit the last-installed G-11 shim, given uncertainty in winding pack dZ during winding process. One option is to procure several thicknesses, and pick the one that fits best, filling the remaining gap with layer(s) of glass. Another option is to machine to fit. Consider both convenience of fabrication and mechanical properties of final VPI'd assembly w.r.t. axial load paths.
PF1A PDR	PF1APDR13	Consider making the small flow-holes as radial slots (maybe slightly toroidally staggered) to increase chance of meeting channels between flux windings
PF1A PDR	PF1APDR14	The holes in the end plate fillers are aligned with the layer to layer radii but the transitions at the ends will obscure these - Consider more optimal position with respect to the transition or make the holes slots
PF1A Mandrel-less Prototype FDR	PROTOFDR08	The G11 fillers should be baked out prior to installation.
PF1A Mandrel-less Prototype FDR	PROTOFDR17	Ensure that Chit recommendation to bake-out G-11 fillers is captured in NSTX-U-SPEC-MAG-004

The G11 end shims for the production coils are designed to be oversized so that if the coil build during winding exceeds the nominal dimensions the end shims can be machined thinner as required to guarantee that the conductor pack will fit in the VPI mold. The oversized end shims also ensure that the vertical size and location of the coil center line can be accurately maintained. After the coil is complete at the vendor (or at the PPPL Coil Shop) the ends of the coil will be machined precisely to the correct dimension. The production coils have similar hole arrangements in the G11 fillers as the prototype coil. In this manner the adequacy of the flow path due to the G11 hole pattern will be verified when the prototype coils are dissected. There may be alternate hole patterns that may or may not provide an improved flow path to the resin but at this point it is best to mimic the existing prototype design for holes and channels in the G11 and shims so that the prototype results are most applicable. G11 shims will be baked out before installation.

19 CR–MAG–11, Conductor Leak Checking

Review	ID	Chit
Magnets DVVR	IPF03	PF1A electrical short: Even with a poor vacuum impregnation, neither the turn to turn voltage of 32 v nor the layer to layer voltage of 1 kV should generate an insulation fault considering the 0.7 mm thick turn insulation (1.4 mm between adjacent turns or layers) which includes an overlapping Kapton wrap. Other possible causes of the fault include 1) a local weakness due to foreign conducting material trapped in the insulation and 2) a water leak. For replacement PF1 coils, avoidance of cause 1) requires establishing strict clean conditions during manufacture and avoidance of cause **2) requires stringent acceptance test procedures for the conductor (pressure test, helium leak test, internal eddy current test).**
NSTX-U Recovery Project - CDR	RPCDR002	Recommendations for replacement Inner PF coils The following is based on the "Inner PF coil recommendation" document of 2 January 2017, on the "OH and inner PF coil conductor specifications" of April 2012 and on the "Inner PF coils manufacturing specifications" of November 2012. **Leak testing of the conductor before and after winding:** **• Pressure testing and leak testing of extruded lengths are not mentioned in the conductor specifications. If these tests are covered by ASTM B188, the test pressure and the acceptable leak rate should at least be specified.** **• Internal crack detection with an eddy current probe is a simple test that ought to be considered.** **• Pressure and leak detection after winding and installation of all water circuit fittings is not mentioned in the coil specifications but should be included.** Insulation • A turn insulation scheme with copper to glass interfaces is recommended for a strong bond between conductor and insulation. This is to avoid differential displacements which may occur in the vicinity of conductor ends. Kapton to Kapton interfaces should be avoided to ensure adequate resin flow during VPI. • Qualification of the VPI process should include a test beam representative of the coil cross sectional dimensions. The beam should be subjected to electrical tests and be subsequently sectioned for examination. Winding mandrel: which are the reasons for not using a split mandrel? This would allow inductive voltage tests (which are safer and more representative of operation conditions than impulse tests) and eliminate eddy currents (and save volt-seconds) during operation?
NSTX-U Recovery	RPCDR004	Confirm that the water circuit of each coil shall be subjected to a pressure test after winding but before impregnation.

We will require helium leak checking as a conductor acceptance criteria, either at the conductor vendor or at PPPL. The conductor will be examined both with eddy currents and ultrasonic testing for a minimum flaw size of 1mm. Helium leak checking of the conductor will be required before VPI and acceptance criteria for the coil after VPI will include hydrostatic testing.

20 CR–MAG–12, VPI Process

Review	ID	Chit
Magnets DVVR	MD07	The cure time of CTD-425 at 170 degC is specified by the manufacturer as 24 hours, but our procedure specifies only 10 hours at 170 degC.
Magnets DVVR	MD08	In page 5 of the document "D-NSTX-IP-3384 Rev.03", it says that if the pressure held after one hour of not pumping is greater than 50 torr (a torr being 1mm of mercury), a special action involving the VPI director or Field Supervisor is to be triggered. However the VPI log included in this document shows an initial vacuum of 30" of mercury (which is one bar, recorded to a coarse accuracy but probably OK) and after a much-over-written time period corresponding to 30, 60 or 90 minutes had degraded to 15" of mercury, aka half a bar or 380 torr, over seven times the action threshold. Nevertheless this was accepted with no comment by the Field Supervisor, a "JHC". Is this just a misunderstanding of units or written nomenclature, or something more worthy of correcting for future VPI jobs? What would the effective leak rate imply for air bubbles in stagnant corners of the eventual impregnation?
Magnets DVVR	MD09	The effectiveness of epoxy impregnation is greatly dependent on the epoxy viscosity. It is desired to transfer epoxy at the lowest viscosity without impacting the pot life. The group appears to be a little unsure why transfer at 50 C is selected. A study of the epoxy viscosity vs time for a number of temperatures is recommended.
Magnets DVVR	MD10	Coil Degassing: VPI best practices includes full degassing of the coil. A single pump down was performed prior to the epoxy transfer, which is not sufficient. Typically 5-10 purge cycles (with nitrogen gas) are needed to ensure that the coil is degassed. The effectiveness can be quantified by measuring the rate of rise after each purge cycle. The rate of rise will decrease after each pump cycle and eventually plateau out… if there are no leaks to the outside.
NSTX-U Recovery Project - CDR	RPCDR015	I am suggesting thinking of Ultrasonic Vacuum Pressure Impregnation (U-VPI). Since the microstructure between the turns of the coil is very complex. Only the pressure difference (with vacuum) could be not sufficient. Because the max difference is only 14.5 psi, plus the viscous epoxy, large amounts of micro-air and water vapor bulbs would be still trapped in the microstructure and fibers. The additional force with interruption is necessary

Review	ID	Chit
		to involve thus assist the micro-air to dissipate from the fibers, also to help clean micro-solid particles, prior to solidification.
Inner PF Coil PDR	IPFCPDR23	Check Magnets DVVR CHIT resolution of Martovesky CHIT to consider applying pressure during VPI to see if we agreed to consider (as was done) or agreed to apply pressure (which MAY be done).

The VPI process previously used at PPPL has been refined to incorporate many of the suggestions and comments from the various reviews. To address the chits specifically: MD07, CTD has confirmed via email that the cure times (15hrs. at 100C followed by 10hrs. at 170C) used in PPPL VPI procedures are perfectly adequate for small (as compared to ITER) coils. CTD continued to state that the long(er) cure times were specifically developed for ITER coils that required increased time to minimize exothermic reactions, to achieve thermal equilibrium throughout the massive coil and to provide a large safety margin. MD08, PPPL's VPI hardware as well as procedures have adopted a high vacuum philosophy. The entire system, including the coil in mold, is hermetically sealed to very stringent leak rates, typically 10^{-5} Torr-liter/second or better. MD09, The injection temperature used for CTD-425 is in the range recommended by the manufacturer. Furthermore, CTD-425 is one of the least viscous resin products in the Cyanate-Esther family which alleviates the necessity to inject at higher temperatures, which in turn would decrease "pot life." MD10, this recommendation was adopted and used in the VPI of the Straight Log Test Bundle. Multiple pump/purges at both room temperature and at the injection temperature were performed and the rate of rise was monitored between cycles as a measure of the effectiveness. This will be a standard feature for all VPIs at PPPL. RPCDR015, Ultrasonic agitation was considered and initially rejected due to the difficulty of implementation and the difficulty of validating positive result from this change. Furthermore, the successful VPI of the Straight Log Test Bundle proves that when the VPI system is devoid of leaks and undergoes thorough degassing, successful resin impregnation is achieved. IPFCPDR23, Pressurization of the VPI mold should aid in the collapse of gas entrained in the coil during the VPI. If the sources of gas (leaks, & entrained gas or moisture) are eliminated, then pressurization of the mold, post VPI is not necessary, and poses an additional risk of resin leakage during the ramp up to cure temperature. The PPPL VPI system and all coil VPI molds to be used in the production of Inner PF coils have been designed to support a positive pressure of 2 atmospheres (proof tested to 3 atm.) however the application of pressure to the mold, after impregnation and prior to curing, shall be at the discretion of the VPI director. If indications of air ingress during the filling are noted, the VPI director has the option to perform pressurized milking cycles and to leave the coil/mold at a positive pressure during the cure cycle.

21 CR–MAG–13, Ground Plane

Review	ID	Chit
Magnets DVVR	IPF07	Consider adding a ground plane to the outer surface of the Inner PF coils in order to balance capacitance to ground. Without ground plane on outer surface, large capacitance to mandrel will dominate the admittance to ground, resulting in an unbalanced voltage to ground.

Since the new coil design is mandrel-less, the concern expressed in the chit is no longer relevant. Without a ground plane the nearby ground on the ID of the coil will be symmetric with the OD.

Still, the use of a ground plane was considered but rejected for after weighing the advantages (facilitate testing of ground insulation, provide electrostatic shield to reduce noise pick-up on diagnostics) versus disadvantages (no convenient way to interface with coil slings after machining coil ends to mount the slings, requires some definitive means for connecting to common potential). Note that typical power industry practice calls for the use of ground planes for apparatus that operates above 5kV, which the Inner PF Coils do not.

22 CR–MAG–14, Interface with Coil Support Slings

Review	ID	Chit
Inner PF Coil PDR	IPFCPDR12	Preloads applied at the terminal end of the coil will fight the rigid support of the flags. Preload needs to be applied first. If a compliant preload system is used such as Bellevilles the terminal end will add thermal displacements to the break-out area.
	IPFCPDR13	If preloads are determined to be required then there should be a requirement to monitor them and adjust them during operation like we have for the OH
Inner PF Coil PDR	IPFCPDR17	Please assess if the pre-load requirements can be conservatively defined ASAP, even before the CTE and modulus tests, so that the sling system can be defined ASAP.
Inner PF Coil PDR	IPFCPDR22	A cost benefit evaluation should be done on the relative merits of preload for the PF1b vs using a simple recirculation cooling scheme to take advantage of the short cooldown time computed for PF1b. The cost and schedule impact of the preload mechanism, especially in light of more stringent field error requirements may make an external system attractive.
Inner PF Coil PDR	IPFCPDR24	Reliance on strain controlled testing was supposed to be discussed as an alternate or back-up to the use of preload. Only conceptual design of the preload mechanisms has been performed. Seems risky to rely only on the preload systems to make sure we have qualifiable coils.

The design of the preload system has evolved after the Coil PDR. The requirement is defined and is applied by Bellville washers at the lead side of the coil (note: preload is not required for PF1C). The coil analysis now takes into account this support scheme.

The project determined that the pre-load option is better than relying on controlled cooling system. For PF1a the controlled cooling system would increase the repetition rate in excess of the requirement. Additional testing of material properties has been performed but additional strain controlled testing was determined not necessary at this time.

23 CR–MAG–16, Turn-to-Turn Test Method

I

Review	ID	Chit
PF1A Mandrel-less Prototype FDR	PROTOFDR01	Prototype Coil Electrical Test - Consider drilling thru the bottom of the flange for test point to intermediate layer. May me simpler than drilling from the ID.
PF1A Mandrel-less Prototype FDR	PROTOFDR12	Testing the turn to turn testing much beyond 2kV+1 is not necessary.
T-T Testing Peer Review	TTTESTPEER01	If the addition of external low pass filter to increase the rise time poses excess cost or delay, consideration should be given to testing without the filter. There is a large margin in the turn-to-turn insulation. The surge tester voltage could be increased above 2E+1 to stress the reduced turn-to-turn voltage observed away from the end turns due to uneven voltage distribution without filter.
T-T Testing Peer Review	TTTESTPEER02	To demonstrate the sensitivity of the surge tester approach, consider inserting a metal plug into the turns of one or more prototype coils to create an internal short or to add an external resistance.
T-T Testing Peer Review	TTTESTPEER03	Once each coil manufacturer has two nominally identical coils available, I recommend that they connect them in series so that a bridging technique can be used to enhance the detection capability for differences between them. Even with only one coil, is it not possible to separate the real and imaginary components of the decaying ring to emphasise the change in the real part, the resistive loss term?

Work is underway to develop the surge test method. This includes:

- purchase of two test sets from Elytt Energy, Model CDG 7000
- modeling of test set parameters and evaluation of external R-C networks to achieve safe surge rise times on the PF1A/B/C coils
- testing using an old PF1A coil to confirm calculations, simulate faults and develop waveform post-processing algorithms to detect faults

These results may or may not indicate the need to include the external R-C network (“low pass filter”).

If adequate detection sensitivity cannot be demonstrated by surge testing one coil at a time then some other test method would have to be developed. Balanced bridge methods could be considered at this time but the need for alternate testing is considered unlikely.

24 INPFCOILFDR01, DVVR Coil Magnetic Center

Review	ID	Chit
Inner PF Coils FDR	INPFCOILFDR01	Chit resolution report omitted DVVR (Integrated Design) chit IDR31 concerning the use of field measurements to characterize magnetic center of coils (instead of relying on physical geometry). Need to assess feasibility, practicality, and value of field measurements, determine course of action, and close out chit in the report.

After evaluation of the possible measurement techniques of the magnetic center as compared to the determination of the magnetic center from measuring the geometry, it was decided that metrology performed on the coil would be adequate to properly locate the coil within the necessary tolerance imposed and the cost of developing a method to perform a magnetic measurement after the fact was not justified.

For Chits 25, 26 and 27

During the inner PF Coil FDR, three chits, INPFCOILFDR02, INPFCOILFDR03 and INPFCOILFDR04 were submitted concerning potential coil terminal stress issues. These concerns were addressed in the design by adding fillets to minimize the local peak stress to ensure design meeting fatigue allowable for the coil leads.

A significant effort was spent during coil FDR on improving the design of the coil terminal lead support tower to ensure that the coil will not be affected by the Bus bar loading during normal operation and during bake out. The modified lead support design is very effective as shown in coil FDR and the FDR design for the coil will not change.

Results from the coil FDR show no additional analysis is needed. If more analysis is required for the flag joint as the Bus work and polar region design moves forward toward FDR it can be included in the Bus work scope. For all three of these chits there are no changes that would result in changing the coil design. If there were an issue it will be addressed by enhancing the support structure to reduce stresses in the coil flags.

25 INPFCOILFDR02, Testing Flags

Review	ID	Chit
Inner PF Coils FDR	INPFCOILFDR02	For the flag with fillets and braze, consider a Jurczynski cyclic test like we did on the lead extensions with e-beam welds, the flex joint, and conductor samples - The tests showed better life than analysis and eliminated the uncertainties.

The FDR analysis results show that local peak stress is lower than the fatigue allowable for the conductor in the coil lead section. Fillets were added to further reduce stress at sharp corner where flag connects to coil lead. This further lowers the local peak stress. The thermal input and pre-load condition may have changed slightly as result of the polar region design toward FDR. If any more analysis is required for the flag joint, it can be included in the Bus work or polar region FDR.

26 INPFCOILFDR03, Analysis of flag connections

Review	ID	Chit
Inner PF Coils FDR	INPFCOILFDR03	Fillets are being added to reduce stress at sharp corner where flag connects to coil lead. Even with the fillet, there may be a stress concentration due to the interface between the copper and the braze alloy. Determine if additional analysis needed.

The coil FDR analysis included Bus bars so stress concentrations are reflected in the coil FDR analysis model. There is indeed local stress concentration as shown in the coil FDR presentation and analysis reports. The results show that local peak stress is within the fatigue allowable. The stress will be lower with the new fillets added so no additional analysis is needed at this point. This will be further verified during Bus work PDR and polar region FDR.

27 INPFCOILFDR04, Ensure adequate design margin in braze joint

Review	ID	Chit
Inner PF Coils FDR	INPFCOILFDR04	Ensure adequate design margins in the brazed joints accounting for joint geometry, level of inspection planned, etc... which results in strength reduction factors used in the structural integrity assessment of the joint.

The NSTX design criteria do not require a reduction factor for brazed joints (only welded joints). Using the NSTX design criteria the FDR analysis shows that the stresses are acceptable in the brazed joint. Historically testing of brazed conductor butt joints performed at PPPL show that the failure point is in the copper and not in the braze material. We will investigate this further but we do not expect to change the coil design. Ensuring the buss joint stress is low enough will be considered PF Bus scope. Within the PF Bus WBS we can improve the support structure if it's necessary to lower the stress in the braze joint. We will move this chit to the Bus Work Scope WBS 1.1.4.2

28 INPFCOILFDR05, FMEA consequence definition inconsistency with GRD

Review	ID	Chit
Inner PF Coils FDR	INPFCOILFDR05	The FMEA "Consequence" column categories are consistent with the memo included in the documentation package, but are inconsistent with the GRDs for either the Upgrade-project or Recovery project. This issue is likely endemic to the full FMEA, and the project needs to make a choice about which to correct.

For this FDR, only two consequences types were needed in the FMEA for these components. The term "Major" consequence was utilized in an exactly equivalent manner as defined for "Extensive" consequence in the GRD (Time or Cost greater than entry above, and Time to correct/repair <12 month and Cost <$5000k). Therefore, this administrative mislabeling, since it is defined within the FMEA and would yield no different action, will not be changed and this CHIT has no impact in the design or treatment of the FMEA.

29 INPFCOILFDR06, Use of Magnetic diagnostics

Review	ID	Chit
Inner PF Coils FDR	**INPFCOILFDR06**	I do not believe that it is creditable to use magnetic diagnostics to detect loss of contact pressure in joints, with a sensitivity such as to avoid coil damage. I recommend this statement be removed from the FMEA

The statement will be removed from the FMEA.

30 INPFCOILFDR07, Operational risks in the Risk Register

Review	ID	Chit
Inner PF Coils FDR	**INPFCOILFDR07**	The FMEA and risk-registry for magnets are apparently not yet compatible or internally consistent. The FMEA reasonably captures operations risks, and the risk-registry covers fabrication/procurement/installation risks, but some magnet operation is required to meet the KPPs, so need to include FMEA items into the risk-registry that are "on-project" and needed to complete the Project KPPs. Also need to include any FMEA risk-mitigation costs into WAFs accordingly.

The operational risks were reviewed and at this time they will not be added to the risk register.

31 IPFWFPR01 & INFWFPR04, Tolerance and Braze Design

Review	ID	Chit
Inner PF Water Fitting Peer Review	**INFWFPR01**	Adjust tolerance on boss height dimension for copper fitting adapter to ensure that the fitting will not bottom out on the bottom of the boss before contact is made at the surface that mates with the end of the copper conductor.
Inner PF Water Fitting Peer Review	**INFWFPR04**	The brazed portion of the fitting does not have proper wetting of the flat end of the counterbore. Re design the connection with prepositioned braze ring or fit the bottom preferentially and fill the base void or consider a conical shape

ECN being released to adjust tolerances to ensure the coolant fitting adapter makes full contact on the bottom and top of the conductor counterbore. Braze Procedures for PF Coil Fabrications will address the placement of braze material in order to ensure there is a complete braze joint, from the bottom of the conductor counterbore to the top of the conductor counter-bore.

32 IPFWFPR02, Water Fitting Torque Standards

Review	ID	Chit
Inner PF Water Fitting Peer Review	**INFWFPR02**	I (we) may have misunderstood the standard field processes for torqueing fittings, but it seems that a standard torque is needed for each kind of fitting, specified in an IP or some other equivalent reviewed/approved document.

Mark Cropper stated during the Peer Review that he and his team would take on this chit. We will move it to WBS 1.3.2.1 Field Coil and Bus Bar Water Cooling System.

33 IPFWFPR03, Specification not on Dashboard or Filed

Review	ID	Chit
Inner PF Water Fitting Peer Review	**INFWFPR03**	Technical specification SPEC-MAG-006 is not on the dashboard or filed as a signed document

The Approved Specifications have been uploaded and indexed.

34 INFWFPR05, Helium Leak Check Braze & Solder Joints

Review	ID	Chit
Inner PF Water Fitting Peer Review	**INFWFPR05**	Should also do He leak checking on complete assembly prior to hydrostatic testing; should be in spec.

A revision will be issued of NSTX-U-SPEC-MAG-006, NSTX-U-SPEC-MAG-008, and NSTX-U-SPEC-MAG-009 requiring Helium Leak Checking of the complete assembly prior to hydrostatic testing.