PRINCETON PLASMA PHYSICS LABORATORY

ENG-033 - CRR - CHIT RESOLUTION REPORT

VACUUM VESSEL BLACKENING (ALT. TO AERODAG) CHIT RESOLUTION REPORT

NSTXU_1-4-1-23_CRR_100

Rev. 1

Work Planning #:
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National Spherical Torus eXperiment Upgrade

Chit Resolution Report for Vacuum Vessel Blackening (Alternative to Aerodag)

NSTXU_1-4-1-23_CRR_100, R1

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Record of Changes

Rev.	Date	Description of Changes
0	01/15/2019	Initial Release
1	02/24/2020	Updated to include 1 chit from the FDR, VVBLACKFDR01

Summary of Chits

Review	ID	Chit	Status
Alternative to Aerodag CDR	AERODAGCDR01	ENG-033 Section A requires a Design Review Plan. One was not posted. If one is not in existence, please generate prior to subsequent reviews.	Closed
Alternative to Aerodag CDR	AERODAGCDR02	Perform testing of the black oxide coating with lithium coating at elevated temperature.	Closed
Alternative to Aerodag CDR	AERODAGCDR03	Need vacuum test (OP-AD-123) and permeability check of the new coating	Closed
Alternative to Aerodag CDR	AERODAGCDR04	New components change loads on already frozen components, this can snowball, C&S. Other options?	Closed
Alternative to Aerodag CDR	AERODAGCDR05	Review other in-situ options that do not require install of panels in the vessel.	Closed
Alternative to Aerodag CDR	AERODAGCDR06	Update cost estimate.	Closed
Alternative to Aerodag CDR	AERODAGCDR07	Use diagnostic calculation document to calculate eddy current forces on the panels.	Closed
Alternative to Aerodag CDR	AERODAGCDR08	Use diagnostic calculation document to calculate thermal and thickness requirements.	Closed
Alternative to Aerodag CDR	AERODAGCDR09	Add radiation shields and port area for the heat balance calculations.	Closed
Diagnostics DVVR	DIAGGEN22	On slide 11 of the "Special Windows and Shutters Talk", the flaking "aerodag" (or whatever the blackening material was) is striking. It appears to have not adhered well. If alternative blackening methods are available, they should be assessed.	Closed
Alternative to Aerodag FDR	VVBLACKFDR01	Please ensure sufficient installation tolerance allowed for the gap between plates	Closed

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Introduction

This report provides resolution of (Recovery WBS 1.04.01.03) chits and recommendations originating from the Alternative to Aerodag CDR/FDR and from the Diagnostics DVVR.

The chits in the NSTX-U Recovery chit log can cite the sections in this report as evidence of closure. The chit resolution described herein is aligned with the chit tables in the Alternative to Aerodag CDR/FDR and from the Diagnostics DVVR dashboards.

1 **CLOSED:** AERODAGCDR01 – Complete Design Review Plan

Review	ID	Chit	Review Board Comment
Alternative to Aerodag CDR	AERODAGCDR01	ENG-033 Section A requires a Design Review Plan. One was not posted. If one is not in existence, please generate prior to subsequent reviews.	N/A

A design review plan per ENG-033 section A has been completed, signed, and uploaded to the FDR dashboard.

2 **CLOSED:** AERODAGCDR02 – Black Oxide at High Temperatures

Review	ID	Chit	Review Board Comment
Alternative to Aerodag CDR	AERODAGCDR02	Perform testing of the black oxide coating with lithium coating at elevated temperature.	Concur

From the calculation document, NSTXU_1-4-1-23_CALC_100, we conservatively assume an emissivity of 0.1 and a full 130 kW/m^2 first wall radiative power of the plasma. After 5 pulses with a 20-minute cooldown, we expect these panels to reach 282 deg C. Assuming an emissivity of 0.9 with the other parameters kept the same, these panels will reach a ratcheted temperature of 159 deg C. Published literature shows emissivity values of between 0.7 and 0.95 for various black anodized and oxidized stainless steels. We expect the actual value of the temperature of these panels to be closer to the second of these values.

Testing performed at General Atomics DIII-D in 2006 qualified black oxide for use in ultra-high vacuum. For these tests, performed by K. Holtrop and M. Hensink and published as “High temperature outgassing tests on materials used in DIII-D tokamak,” black oxide coated stainless steel was baked at 400 deg C.

Additionally, black oxide coated plates have been spot welded into the CDX-U (LTX) lithium tray limiter at PPPL. No degradation of the material has been reported at higher temperatures.

The lithium evaporators (LITERs) for NSTX-U will not be changed. In NSTX conditions, the outer vessel wall was never exposed to liquid lithium. We expect similar conditions in NSTX-U. We do not expect liquid lithium to reach these blackened panels. The combination of these factors, including the cost and effort, disqualifies this test.

3 CLOSED: AERODAGCDR03 – Vacuum Test and Permeability

Review	ID	Chit	Review Board Comment
Alternative to Aerodag CDR	AERODAGCDR03	Need vacuum test (OP-AD-123) and permeability check of the new coating	Concur

Black oxide coated stainless-steel panels have been installed and successfully pumped down in the vacuum chamber at MIT's Alcator C-Mod. Additionally, black oxide coated plates have been qualified for vacuum conditions at General Atomics DIII-D, according to the published K. Holtrop and M. Hensink paper referenced in Section 2. This previous qualification by facilities with similar vacuum requirements disqualifies the need for extensive vacuum testing at PPPL.

A permeability check of the sample black-oxide coated plate was performed by A. Castaneda and A. Cao on 01/09/2020 using Severn gauges calibrated in September 2019. The sample black-oxide coated plate passed 1.02 μ and failed at 1.01 μ. Per the NSTX-U magnetic permeability requirements for components inside of the TF outer legs, the base material must have better magnetic permeability than 1.04 μ. The sample plate passed the test. The typical thickness of the black oxide coating is 1.5 micron (6E-5 in). The surface area of the proposed plates in Bays I, J, K, and L is approximately 2500 in^2. Using a published density of black oxide, Fe_3O_4, of 5.17 g/cm^3, we expect a total mass of approximately 13 grams of black oxide to be installed inside of the vessel. Even if the material is magnetic, there is so little of it, by mass, that we expect to pass magnetic permeability requirements defined by NSTX-U-RQMT-RD-010-00.

4 **CLOSED**: AERODAGCDR04 – Evaluate System Impact

Review	ID	Chit	Review Board Comment
Alternative to Aerodag CDR	AERODAGCDR04	New components change loads on already frozen components, this can snowball, C&S. Other options?	Concur

Because these components occupy a very small region of the vacuum vessel, +/- 12 inches from the midplane in Bays I, J, K, and L, we expect a minor effect on loads on other components. This region is a small fraction of the total surface area of the inner vacuum vessel and the only interface is the plates to the vacuum vessel. Loads on frozen components are not expected to change in any measurable way.

5 **CLOSED:** AERODAGCDR05 – Review In-Situ Options

Review	ID	Chit	Review Board Comment
Alternative to Aerodag CDR	AERODAGCDR05	Review other in-situ options that do not require install of panels in the vessel.	Concur

A peer review on 10/31/19 rejected alternative in-situ options and confirmed the selection of the blackened plates. Other options, such as carbon nanotubes, epoxies, silicones, and proprietary blackening were rejected for reasons including durability and outgassing.

6 **CLOSED:** AERODAGCDR06 – Update Cost Estimate

Review	ID	Chit	Review Board Comment
Alternative to Aerodag CDR	AERODAGCDR06	Update cost estimate.	Concur

The cost estimate has been updated and will be included in the FDR presentation.

7 **CLOSED:** AERODAGCDR07 – Calculate Eddy Current Forces

Review	ID	Chit	Review Board Comment
Alternative to Aerodag CDR	AERODAGCDR07	Use diagnostic calculation document to calculate eddy current forces on the panels.	Concur

Eddy current forces have been calculated, checked, and filed under document number NSTXU-1_4-1-23_CALC_100.

8 **CLOSED:** AERODAGCDR08 – Calculate Thermal Loads

Review	ID	Chit	Review Board Comment
Alternative to Aerodag CDR	AERODAGCDR08	Use diagnostic calculation document to calculate thermal and thickness requirements.	Concur

Thermal stresses have been calculated, checked, and filed under document number NSTXU-1_4-1-23_CALC_100.

9 **CLOSED:** AERODAGCDR09 – Update Heat Balance Calculations

Review	ID	Chit	Review Board Comment
Alternative to Aerodag CDR	AERODAGCDR09	Add radiation shields and port area for the heat balance calculations.	Concur

Because these plates will only be installed in a small region of the vessel (+/- 12 inches from midplane for Bays I, J, K, and L), the expected impact is minor. Aerodag was previously used to darken stainless-steel in the same regions, and the emissivity is expected to be similar for these blackened stainless-steel panels. The net result is the addition of 1/8” stainless plates which closely match the geometry of the inner vessel wall. Adding these plates would have a similarly small effect as bringing the inner vessel wall 1/8” closer to the center of the machine.

10 **CLOSED:** DIAGGEN22 – Assess Alternative Blackening Methods.

Review	ID	Chit	Review Board Comment
Diagnostics DVVR	DIAGGEN22	On slide 11 of the "Special Windows and Shutters Talk", the flaking "aerodag" (or whatever the blackening material was) is striking. It appears to have not adhered well. If alternative blackening methods are available, they should be assessed.	Concur

A standalone task, recovery WBS 1.04.01.03 and NSTX-U SBS 1-4-1-23, has been created to implement an alternative solution to the Aerodag graphite spray. The Alternative to Aerodag CDR selected the black oxide coated plate method, which was confirmed at the Alternative to Aerodag Peer Review. Alternative blackening methods were assessed and rejected at the Peer Review.

11 CLOSED: VVBLACKFDR01 – Ensure Installation Tolerance

Review	ID	Chit	Review Board Comment
Alternative to Aerodag FDR	VVBLACKFDR01	Please ensure sufficient installation tolerance allowed for the gap between plates.	Concur

The tolerance specified for installation of numerous black-oxide coated plates was 0.005” at the FDR. Because this tolerance is so tight, it is very likely that once the plates are installed, there will be numerous plates that do not meet this specification, due to variations in stud welding and installation. This tolerance has been relaxed to 0.030” for a 0.125” gap, which is easily achievable. This will reduce the risk of NCR generation during the QA process.