National Spherical Torus eXperiment Upgrade

Field Seal Repairs
WBS 1.04.01.05

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

Justin Bradley - Cognizant Engineer

Robert Ellis - Responsible Engineer

Last edit: 3/9/20

Overview

1. Overview
2. Scope
3. Requirements and Interfaces
4. Analysis/Prototyping
5. Chit Closure
6. Procurement, Fabrication, Installation, and Testing
7. Risk - Project Risks and Design FMECA
8. Quality, Environmental, Safety, and Health
9. Summary

Overview - WBS 1.04.01.05

WBS Title	Field Seal Repairs	WBS #	1.04.01.05
Project Cog.	Robert Ellis	Assoc. Proj. Man.	Bill Gattoni
Design Scope	Restore vacuum sealing functionality to midplane flanges bays I, H, and F.		
Technical Impact of Scope	Diagnostic flange bays, Vacuum vessel, Vacuum systems, Bakeout, MPTS Collection Optics. Improved vacuum quality without the ad-hoc use of leak sealant.		
Design Status	FDR completed on 12/09/2019: review link chits: link calculations: link drawings: link SoW/Tech Spec: N/A		
Fabrication Status	Awaiting CDE-3B ESAAB approval to proceed.		
Installation Status	Awaiting CDE-3B ESAAB approval to proceed.		

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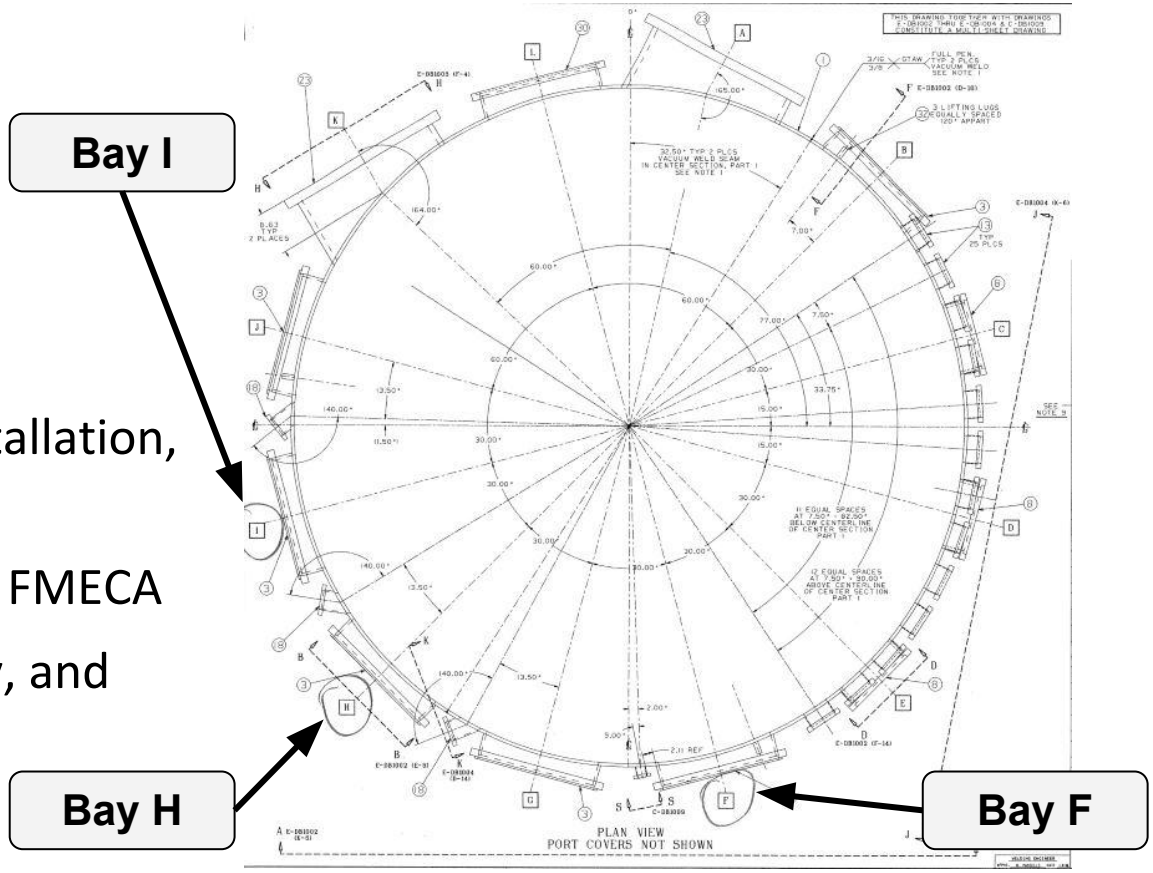
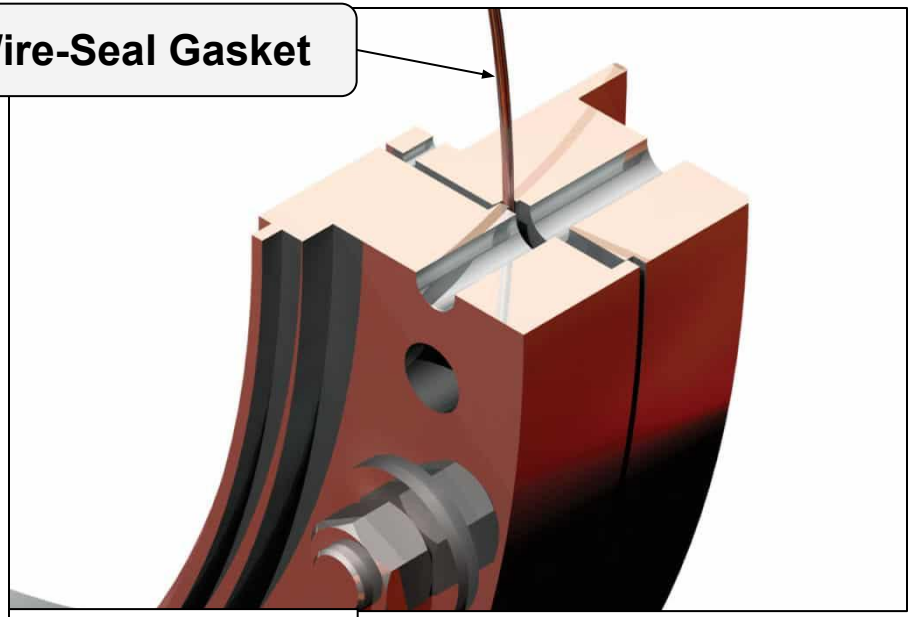


Scope (Background)

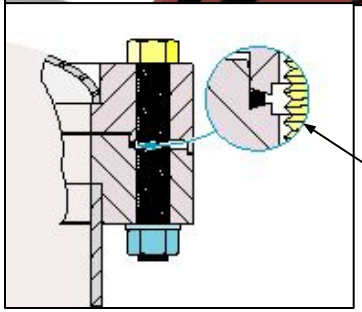
- During the last operating run of NSTX-U, it was determined the following Midplane Flanges were sources of vacuum leakage:
  - Midplane Flange Bay I
  - Midplane Flange Bay H
  - Midplane Flange Bay F
- The vacuum leakage was the result of localized thermal stresses which caused ellipsis deformation of the flanges.
- An applied leak sealant was used during the run campaign, but DVVR Chits recommended a permanent solution for this leak source.

Scope (Background) Cont.

- Wire-Seal flanges function via clamping a compressible copper gasket between a mating male and female flange to create an airtight vacuum seal.
  - Wire-Seal flanges can withstand higher thermal effects than non-metallic gasket vacuum flanges.



Wire-Seal Gasket on male flange (attached to vessel)



Region of gasket compression between male/female flanges

Project Scope

1. Evaluate the Deformation at each bay Midplane Wire-Seal Flange Bay and determine the proper corrective action (completed).
2. Temporarily move the MPTS and Collection Optics Box to access Midplane Flange Bay F for repairs or replacement (in collaboration with PF4/5 re-alignment).
3. Replace the male Wire-Seal Flanges for Bays I, H, and F to restore proper vacuum functionality.
4. Quantitatively verify that proper vacuum functionality is achieved after replacement through leak-checking the respective flange bay.
5. Relocate the MPTS and Collection Optics Box to their proper pedestal (following PF4/5 re-alignment completion).

Scope: Replacement of I/H/F Port Flanges

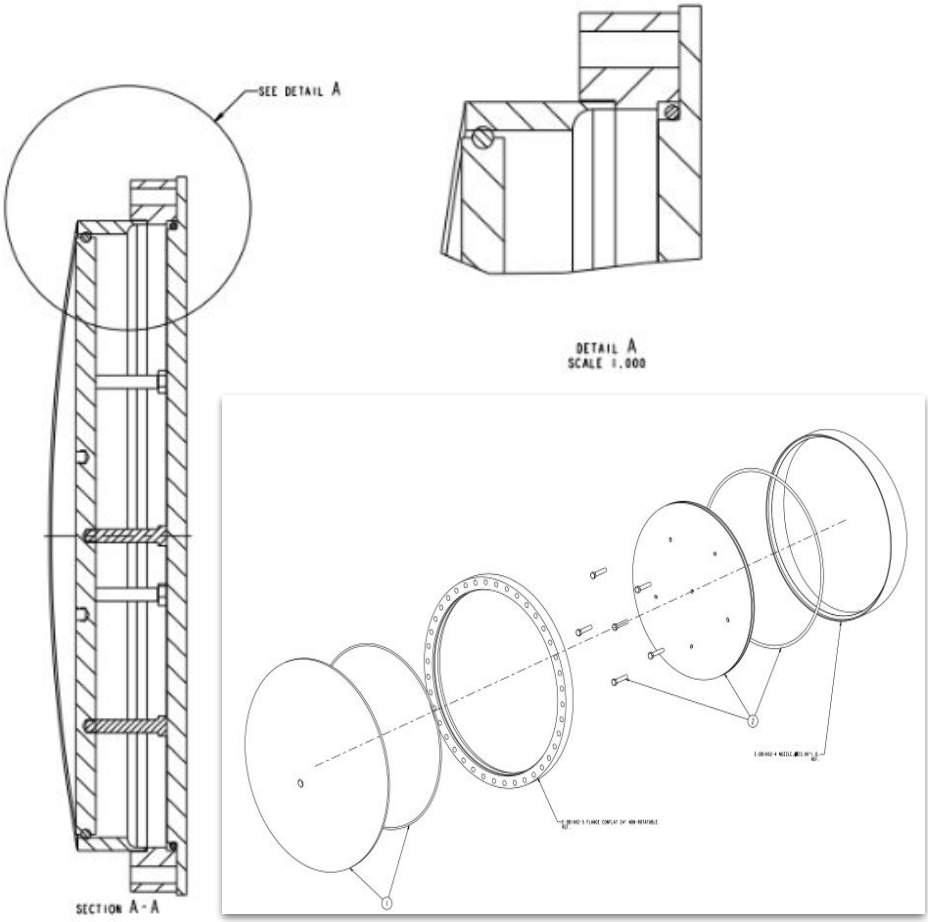
- Deformation Evaluation:
  - Deformation of the flanges at bays I, H, and F was analyzed using metrology methods.
  - Measured deformation values were between 4x-8x acceptable tolerable deviation.
  - Replacement of all the flanges was determined as being necessary at Peer Review on 11/07/2019.

Flange Bay	**Maximum Deformation**	**Minimum Deformation**
Bay I	0.095”	0.040”
Bay H	0.191”	0.023”
Bay F	0.058”	0.006”

Scope: The WBS includes Construction of a Leak-Check Fixture

Leak Checking:

- A new leak-checking fixture for the midplane flange ports has been designed and checked for loading.
- The Fixture will allow leak-checking midplane flange ports without having to pump down the entire vacuum vessel.



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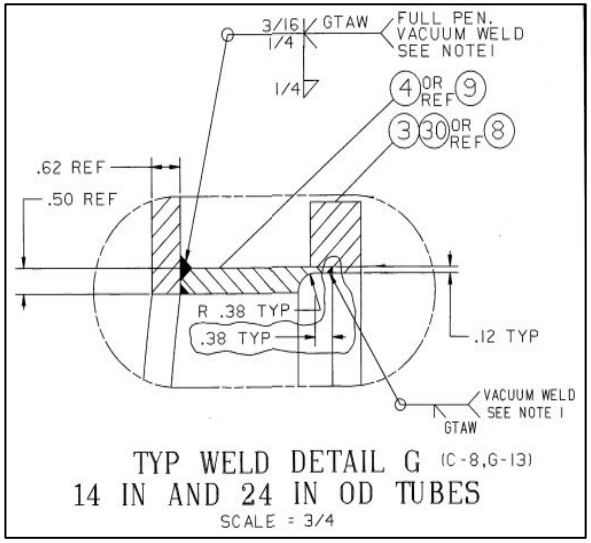
Requirements

Document	Requirement	Comments
NSTX-U-RQMT-SRD-004-03	Vacuum Functionality	1.) Individual vacuum system components have a bench leak rate no greater than 1x10^-9 standard cubic centimeters per second (sccs) air equivalent as measured by a Helium Mass Spectrometer Leak Detector (HMSLD).
NSTX-U-RQMT-SRD-004-03	Materials	1.) The vessel proper (cylinder and domes) shall be constructed of 304 stainless steel and have a nominal wall thickness of 5/8 inch. Additional ports and features associated with the vessel shall by default be fabricated from 316 SS or materials of similar magnetic permeability, unless specific dispensation is given. 2.) All vacuum vessel flanges shall provide a vacuum seal compatible with high vacuum (pressure < 2x10^-8 torr following bakeout) and bakeout conditions.

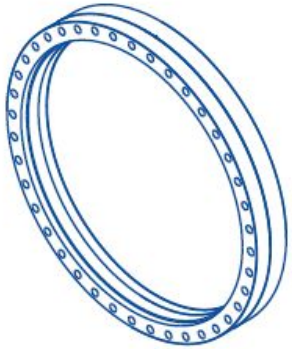
- Requirements are clearly defined by the above documentation. No aspect of the original design intent is changed and no new requirements have been identified.

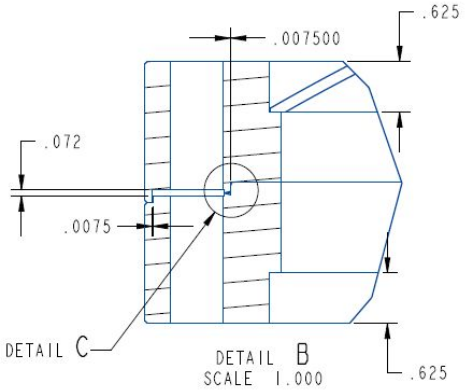
Interfaces

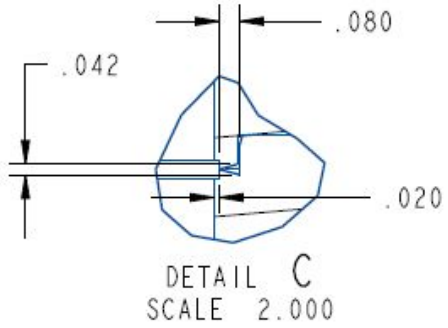
- Interfaces between the flanges and vessel are clearly defined and understood.
- Additional CAD modeling has defined the interfacing between the mating flanges.



Interfacing of the vessel with the flanges.







Interfacing of the mating flanges.

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Analysis

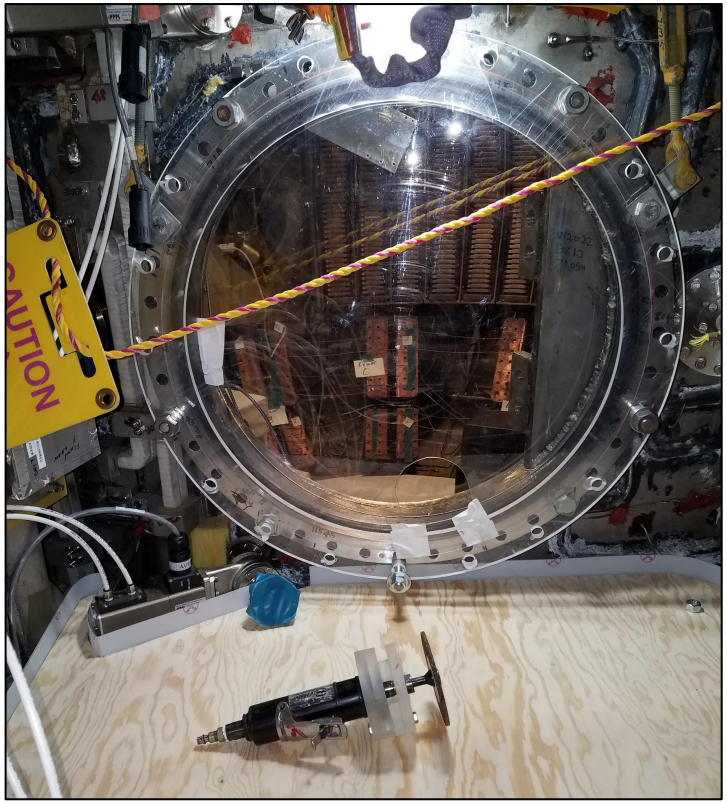
Physical Quantity or Intent	Calculation Report No.	Comment
Stress analysis of leak testing fixture	NSTXU_11232_CALC_100	Calculation shows that the leak check fixture can tolerate vacuum loads during leak checking.

Prototyping

- Flange Removal Fixture is prototyped off of a circular router cutting-guide.
  - Rather than pivoting around a central fixed axis, the cutting tool is guided by the external guiding ring to provide a clean and square cut when removing flanges.

Axis-centered router cutting guide.

Flange cutting guide.



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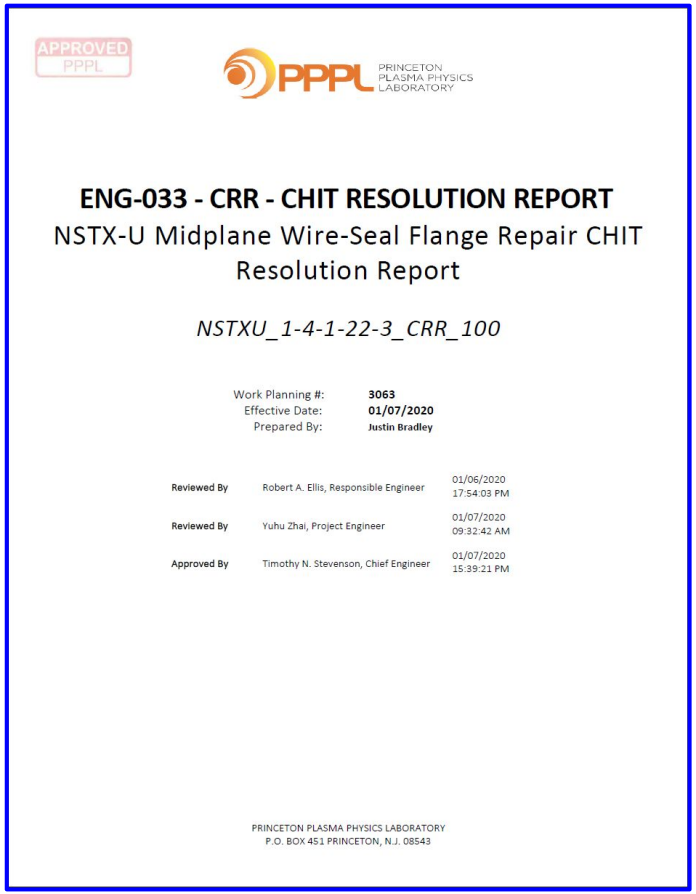
All Chits Leading Up to FDR have been Closed

- Chits closed can be found within the Chit resolution report.
- Working to close chits written at the FDR



APPROVED
PPPL

PPPL PRINCETON PLASMA PHYSICS LABORATORY

ENG-033 - CRR - CHIT RESOLUTION REPORT

NSTX-U Midplane Wire-Seal Flange Repair CHIT Resolution Report

NSTXU_1-4-1-22-3_CRR_100

Work Planning #: **3063**
Effective Date: **01/07/2020**
Prepared By: **Justin Bradley**

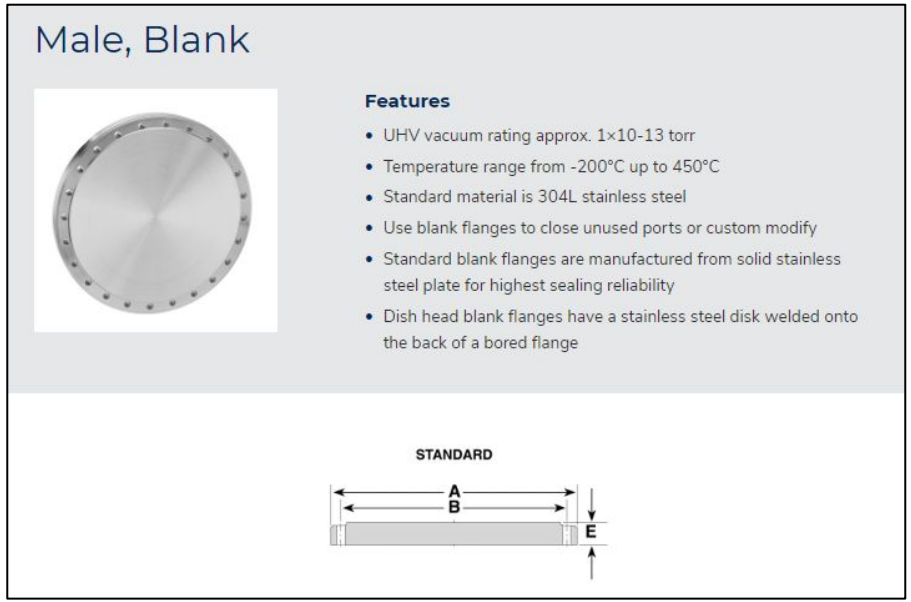
Reviewed By	Robert A. Ellis, Responsible Engineer	01/06/2020 17:54:03 PM
Reviewed By	Yuhu Zhai, Project Engineer	01/07/2020 09:32:42 AM
Approved By	Timothy N. Stevenson, Chief Engineer	01/07/2020 15:39:21 PM

PRINCETON PLASMA PHYSICS LABORATORY
P.O. BOX 451 PRINCETON, N.J. 08543

Chit Resolution Report: link

Procurement and Fabrication

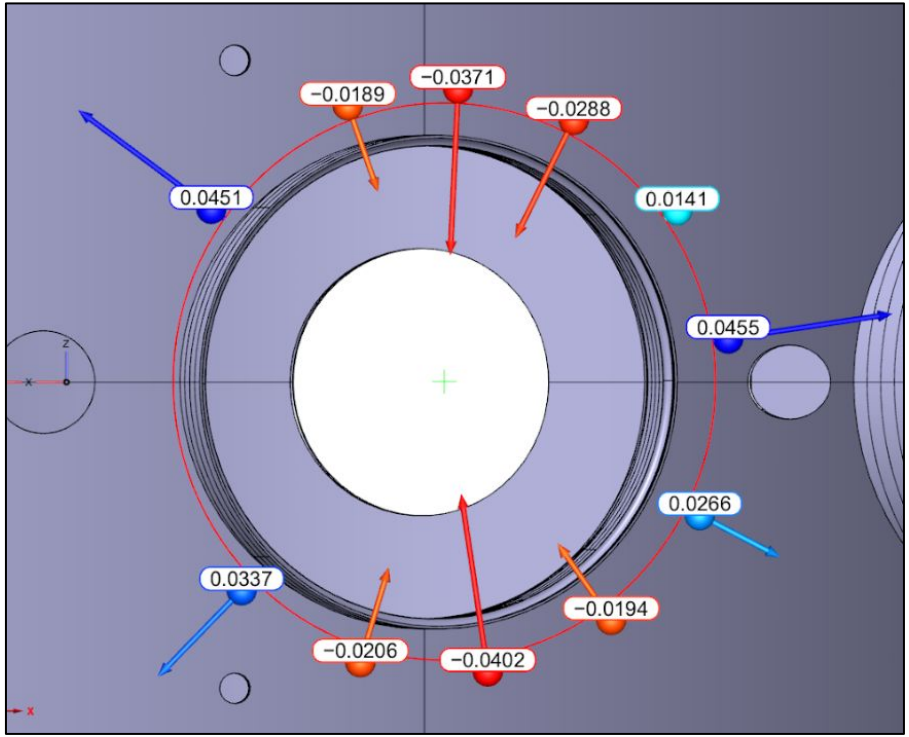
- Blank wire-seal flanges are common items carried by vacuum component distributors (See Ancorp Part No. 5500030).
- The flange cutting guide will be fabricated internally by the PPPL machine shop.
- The leak-checking fixture will be fabricated internally by the PPPL machine shop.



Installation and Testing

- Replacement flanges to be reinstalled with the same weld connection as the original design.
- Metrology of the nozzle tubes post-removal will create the custom ID bore of the replacement flange.

Example Metrology on Inner Diameter:



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Project Risks are Actively Being Managed

Risk	Score (1-81)	Open/Retired	Risk Retirement Event
No risks in Risk Registry for this WBS element			

Risk such as delayed delivery, fit-up issues, are held at the Project level in the risk register

FMECA - All Acceptable Risks

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Midplane Port Covers	Nozzle Tube Deformed Beyond Replacement Flange Dimensions (during Recovery Project Field Seal Repair)	Internal Stresses Create Excess Deformation after removal of Existing Deformed Flanges	Cannot Seat Replacement Flange for Welding;	6	Vacuum Gauges and Residual Gas Analyzers	None	None	6
Midplane Port Covers	Replacement Flange Weld (Bays I, H, and F) is not Vacuum Tight and Leaks during Operation (was repaired as part of Recovery Project)	Deformation from Thermal, EM, or other Stresses, Faulty Welding Wire, or Improper Welding	Replacement Flange Seal or Weld Leaks	6	Vacuum Gauges and Residual Gas Analyzers	None	None	3
Midplane Port Covers	Flange welds fail creating leaks	thermal or EM stress in vessel	must vent to repair	6	Vacuum Gauges and Residual Gas Analyzers	None	None	6
Midplane Port Covers	Leak develops in seal during operations	improper installation	use leak seal, repair during subsequent outage	2	Vacuum Gauges and Residual Gas Analyzers	None	None	2

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Quality and Environment

- QA and QC have extensive oversight regarding the completion of work, procurement of materials, and fabrication of fixtures and parts.
- New flanges are classified as A-1 material with appropriate inspections and certifications.
- USI and SAD screenings were completed for both the CDR and FDR. To date, no USI's or SAD's have been identified. This is a result of the fact that no aspect of the original design intent is changed with these repairs.

Safety Concerns

- Health Physics to oversee grinding/cutting operations.
- Fire watches for cutting, grinding, and welding operations.
- Industrial Hygiene to review working area, JHA, and provide pre/post job briefs.
- ES&H involved in reviewing protection and safety systems used during work.

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- The requirements for vacuum functionality and material conformance have been met and verified as per the Seal Repair FDR on 12/09/2019.
- Interfaces between the flanges and vessel have been clearly defined through CAD modeling, metrology, and verification of legacy design.
- All CHITS from prior design reviews have been closed and documented.
- Project risks have been readily identified and mitigation measures are planned. Mitigation measures have been deemed sufficient per the FMECA review at project FDR.
- Accelerator safety does not factor into this project as per review by ES&H. Industrial safety is directly involved in plannings and pre/post job briefings to address all safety related concerns.