National Spherical Torus eXperiment Upgrade

High Temperature Helium System
WBS 1.03.01.01

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

Delvin Reneau - Presenting

Joe Petrella - Cognizant Engineer

Last edit: 3/9/20

Outline

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

Overview - WBS 1.03.01.01

WBS Title	Medium Temperature Water System	WBS #	1.03.01.01
Project Cog.	Joe Petrella	Assoc. Proj. Man.	Tom Jernigan
Design Scope	Various upgrades to High Temperature Helium System		
Technical Impact of Scope	System supplies vessel with heated helium during bakeout		
Design Status	FDR completed on 1/10/2020: review: link chits: link calculations: link drawings: link SoW/Tech Spec: N/A		
Fabrication Status	Waiting for ESAAB CDE-3B approval to initiate fabrication and installation		
Installation Status			

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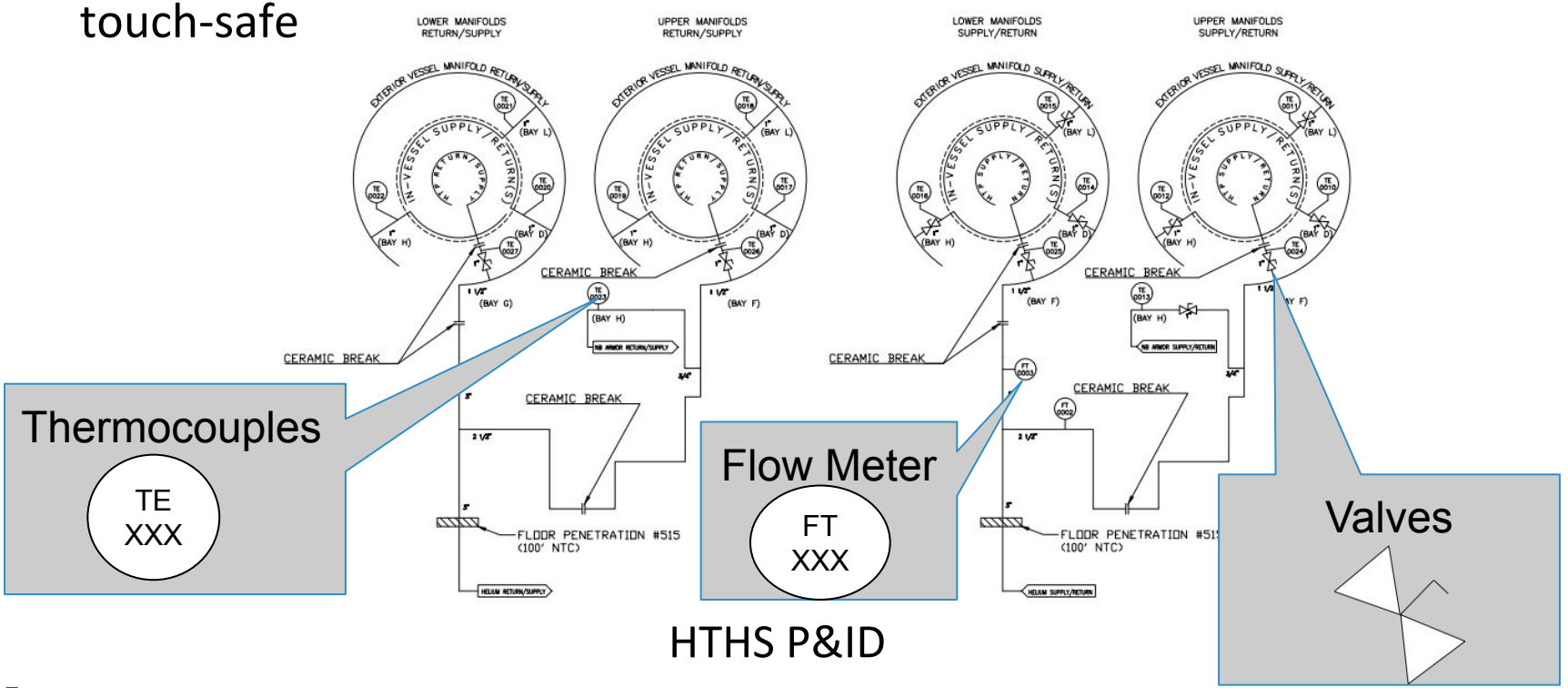
HTHS Scope

Scope

- Remote valve throttling and flow instrumentation for thermal balancing
- Pipe insulation upgrade to address insulation deterioration and to make them touch-safe



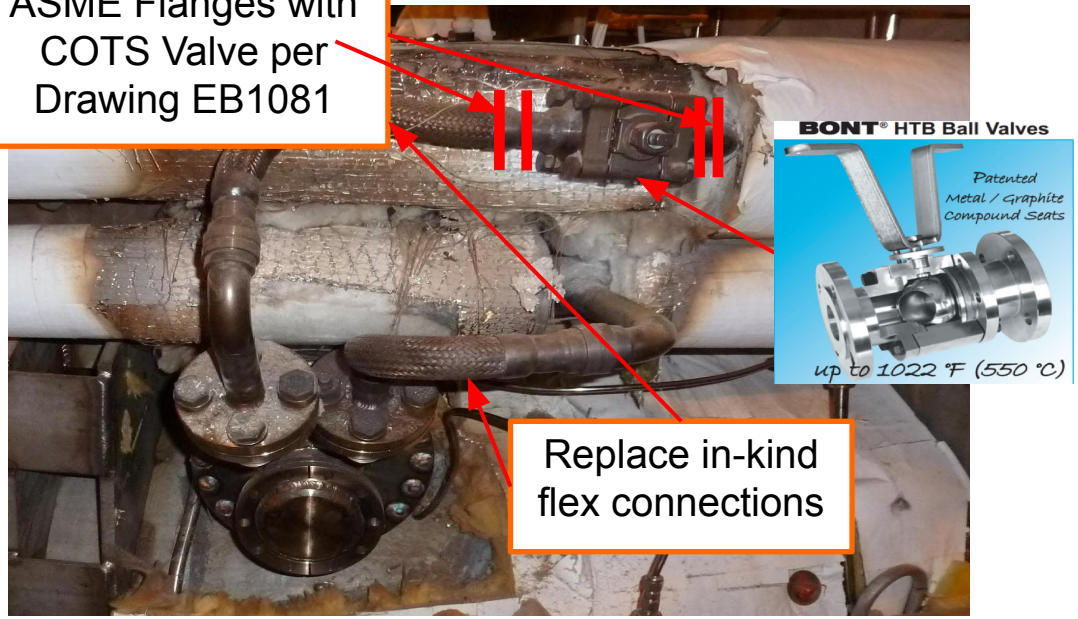
HTHS P&ID

Flow Throttling

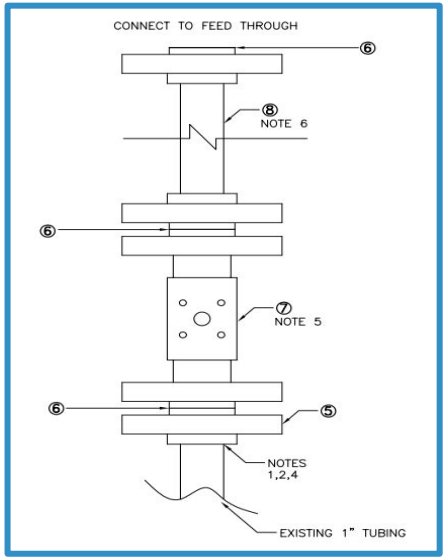
Replace/add high temperature full-port ball valves.

Valves will be installed at 11 locations. 4 locations are new installs to service HTTs.

New COTS 1" ASME Flanges with COTS Valve per Drawing EB1081



SECTION OF EB1081 SHEET 4

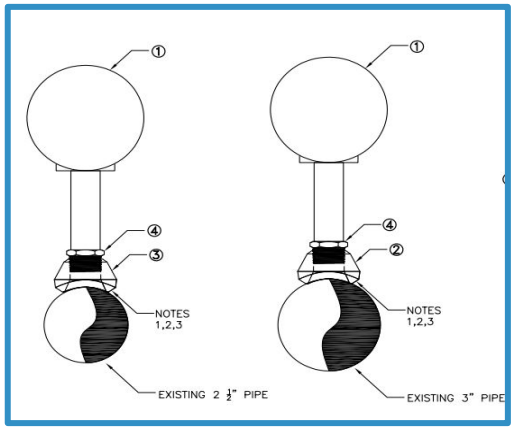


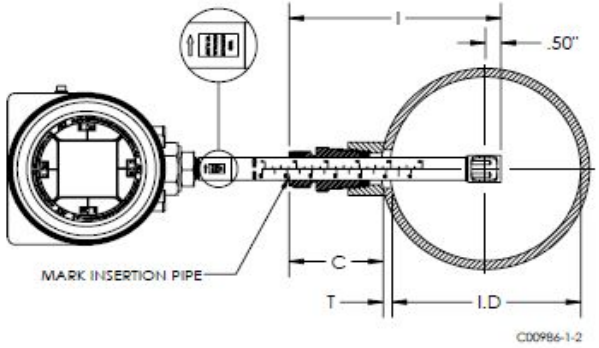
Instrumentation

Two (2) Flow meters will be installed to measure NTC overall helium mass flow

- ST100 (Fluid Components Int)
- Measures flow, pressure,and temperature in one device.
- Meters will be installed on both upper and lower outlet branches.
- Meters will be installed using outlet tee similar to new valves.

SECTION OF EB1081 SHEET 4





(18) Thermocouples will be installed at feedthroughs

Style 1
Style 1 is a grounded junction thermocouple with the Inconel overbraid welded to form a smooth rounded tip for all general purpose applications.

Style 2
Style 2 is a general purpose, bead welded, exposed junction thermocouple.

Style 3
Style 3 is an exposed, bead welded junction thermocouple with an Inconel collar to clamp the probe to a surface, or to secure it into a hole or any fabrication.

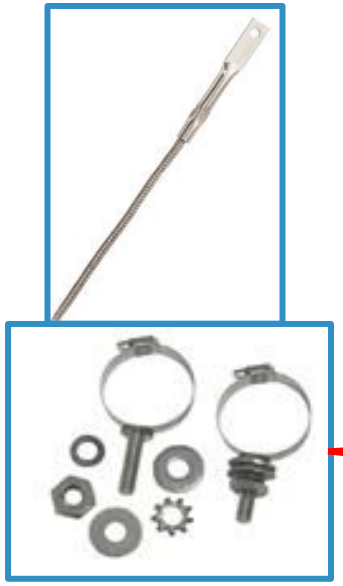
Style 4
Style 4 is grounded. It can be bolted to a surface, or the Inconel eye can hook the thermocouple to a conveyor flight. Ungrounded units and special hole sites are available. Contact Sales department for more information.

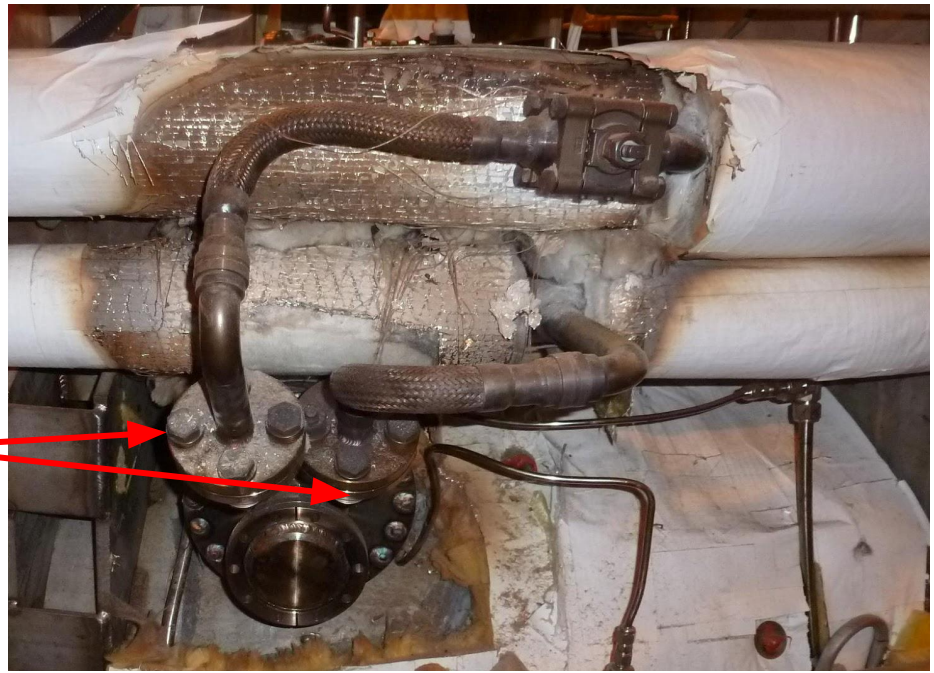
Style 5
Style 5 has an Inconel air hood to protect the exposed beaded wire junction. This design can be clamped to a surface, hooked to a conveyor flight, or bolted to a surface by using the through hole at the open end of the hood.

- COTS Type K ungrounded TC OMEGA P/N E11106107/XCIB-K-4-7-3
- Re-use of the same ex-vv TCs part numbers; validated by demonstration

TC Locations Identified

- COTS SS 1” pipe clamp with stud (mount for TC) DX Engineering P/N DXE-ECLS-100
- Insulation covers TC assembly, assuring temperature distribution

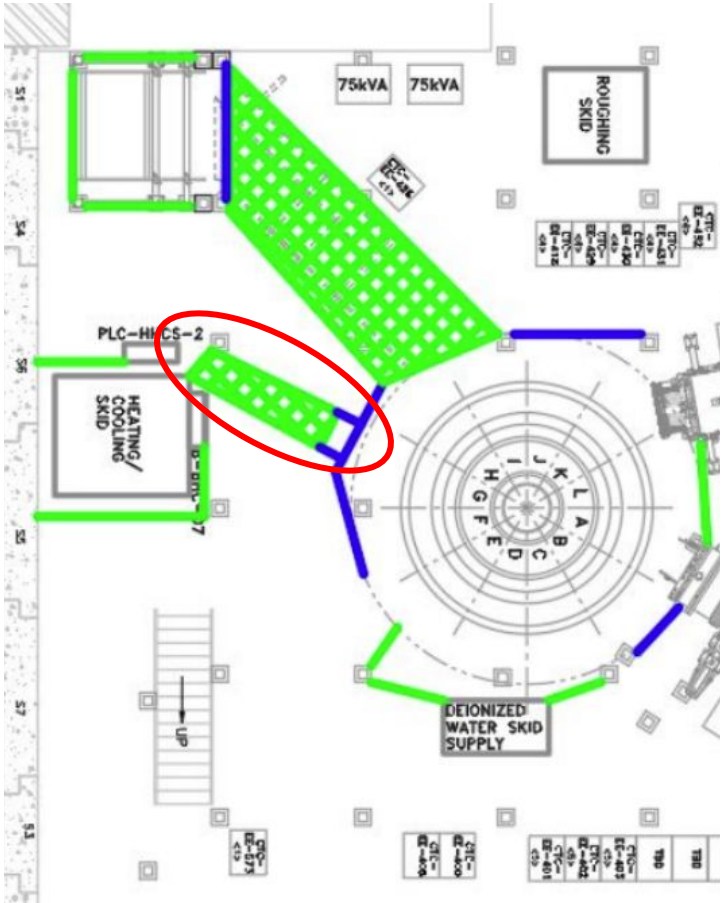




Insulation

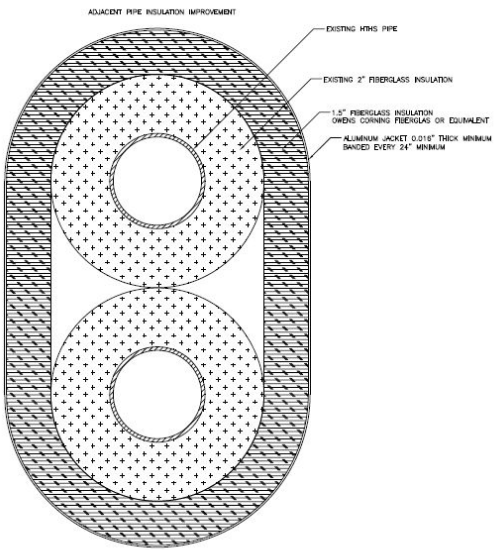
Insulation Upgrade

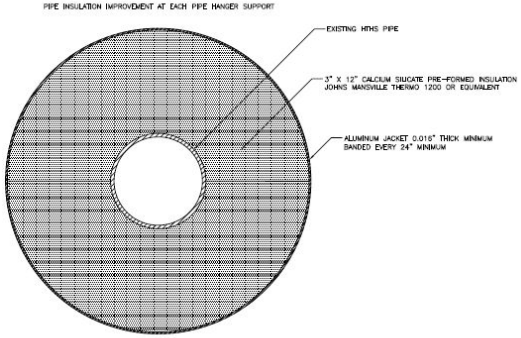
- Helium pipes require insulation
  - Touch safe for personnel (ASTM C1055)
  - Reduce heat loss
- Helium Pipes penetrate the Test Cell floor and run under the 118’ platform and alongside the 118’ platform
- Insulation Jacketing will be incorporated into Configuration Managed Safeguards post-installation



Additional Pipe Insulation is required to have exterior surface be touch safe.

- Remove ASJ and add 1.5” Fiberglass overwrap to create 3.5” insulation thickness at adjacent pipes. Add 1” additional elsewhere.
- Overwrap Insulation with Aluminum jacket.
- Additional Insulation provides a surface temp of 46°C which is less than the required 60°C.





See: NSTXU_1-3-3-1-1_CALC_100

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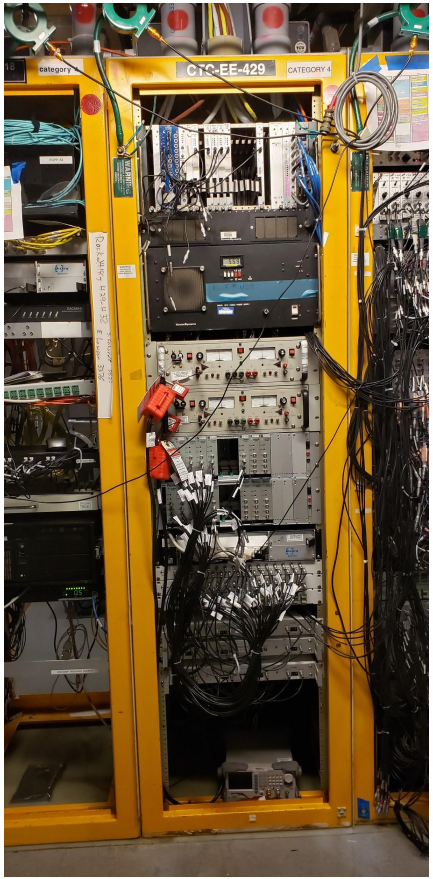
Requirements Defined and Met

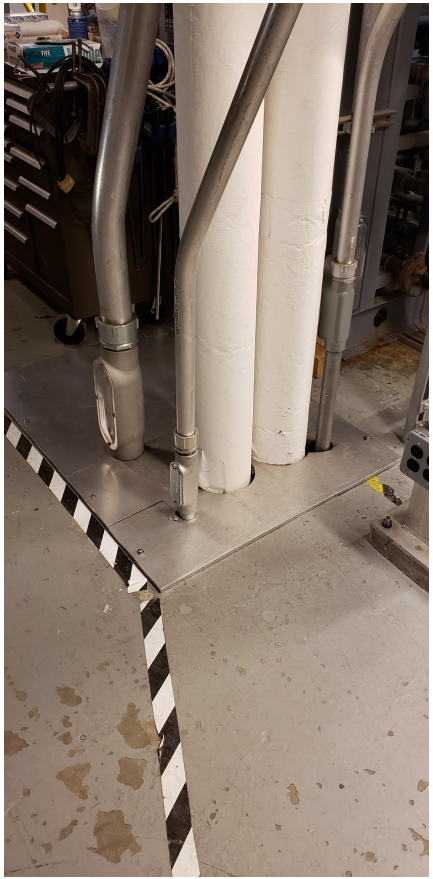
Source	Requirement Summary	Comment	Met
NSTX-U_RQMT-SRD-005-02, **Req. 4.3.f.**	Flow throttling valves and instrumentation shall be installed at each feedthrough to adjust the helium flow	Remote operating valves, flow meters and thermocouples to be installed at prescribed locations	✔
NSTX-U_RQMT-SRD-005-02, **Req. 4.3.c.**	All piping, feedthroughs, valves, and similar for the helium system shall be qualified for the maximum helium temperature of 450°C and pressure of 300 PSIG	All new equipment rated for maximum system operating temperature and pressure.	✔

Interfaces

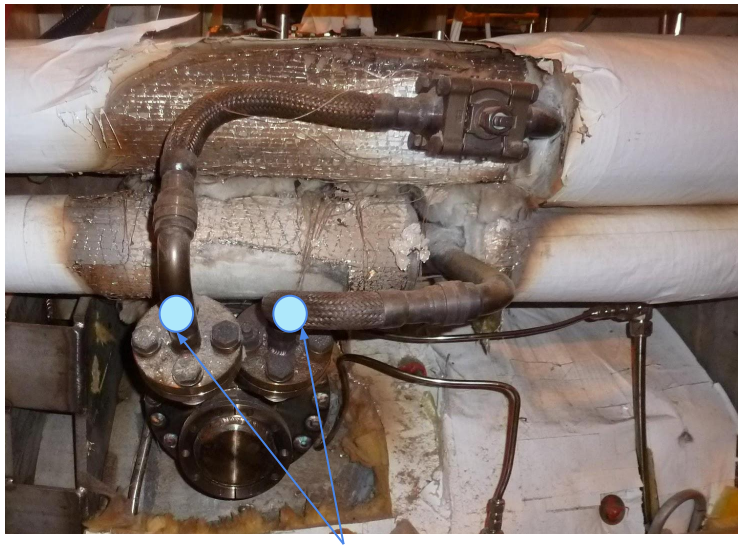


Thermocouples from helium manifolds are terminated at test cell rack

Helium pipe enters test cell floor through fire sealed penetrations.



Interfaces



Thermocouples are mounted on vessel feed through inlet and outlet tubes.

Insulated helium pipes will be labeled as part of Configuration Management System

Details of Interfaces Defined in Interface Control Documents

System 1	System 2	ICD Link	Exposition
Bakeout	Cooling	link	Defines interfaces between the Bakeout System and the Cooling System PLC
Bakeout Systems	Vacuum Pumping System	link	Defines interfaces between the Bakeout System and the Vacuum pumping System PLC for control
Bakeout	Power Systems	link	Defines interfaces between the Bakeout System and the Power System
Bakeout Systems	Test Cell	link	Defines interfaces between the Bakeout System and the Test Cell platforms
Bakeout Systems	Operations & Safety Systems	link	Defines interfaces between the Bakeout System and the Test Cell platforms

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Comprehensive Calculations Verify Design Meets Requirements

Physical Quantity	Calculation #	Content
Pipe surface temperature	NSTXU_1-3-3-1-1_CALC_100, R0	Calculation shows that additional layers of fiberglass insulation reduces the surface temperature of helium pipes to below hazardous levels
Thermal stress in remote valve coupling	NSTXU_1-3-3-1-1_CALC_101, R0	Calculation shows that the remote valve coupling sufficiently dissipates heat from helium valves while not being compromised structurally in high temperature conditions

High Temperature Helium System Calculation Repository
https://drive.google.com/open?id=1O5fp-8QslpjJD9gUNg8epAzQRLZ1JQ8W

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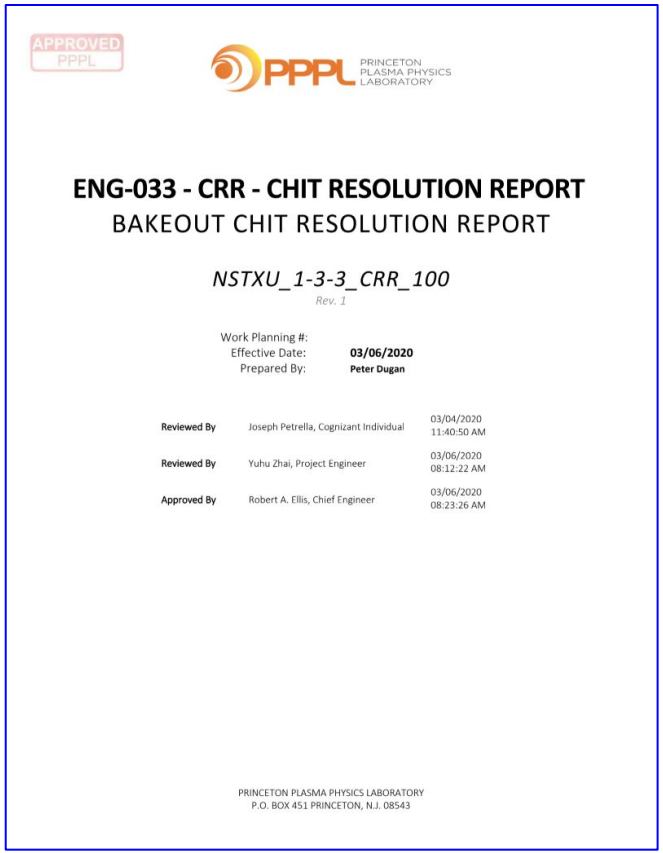
All Chits have been Closed

- All pre-FDR chits closed at the FDR
- All FDR chits now closed



APPROVED
PPPL

PPPL PRINCETON PLASMA PHYSICS LABORATORY

ENG-033 - CRR - CHIT RESOLUTION REPORT

BAKEOUT CHIT RESOLUTION REPORT

NSTXU_1-3-3_CRR_100

Rev. 1

Work Planning #:
Effective Date: **03/06/2020**
Prepared By: **Peter Dugan**

Reviewed By	Joseph Petrella, Cognizant Individual	03/04/2020 11:40:50 AM
Reviewed By	Yuhu Zhai, Project Engineer	03/06/2020 08:12:22 AM
Approved By	Robert A. Ellis, Chief Engineer	03/06/2020 08:23:26 AM

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

Chit Resolution Report: link

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Procurement/Fabrication

- Throttling Valve
  - Coupling fabricated by PPPL
  - Remote operator handle is COTS. Selected source is Elliot Manufacturing (Remote Valve Control System)
  - Ball valve is a COTS component sourced from Bonetti Valve
- Flow Meters/TCs
  - COTS component sourced from Fluid Components International.
- Insulation
  - Standard industrial installation contractors to procure and install insulation.(Brant Energy Services, Accurate Insulation, EWP Contracting)
  - Once insulation & jacketing is installed the jacket will be labeled as a Configuration Managed Safeguard and the as-built condition recorded for configuration management.

Installation

Overall

- D-Site work permit will be required
- Work packages will be generated
- Installation will occur in the field using installation procedures

Throttling Valves

- NB Armor & Feedthroughs: weld flanges & install bolt-on Ball Valves
- Connect the remote operator and coupling, COTS Remote Control Handles
- HTP: weld tee outlets & ball valves to the existing helium manifold near bay F (upper) and bay F/G (lower) using PPPL welders & procedures

Flow Meters & Thermocouples

- Assembly of thermocouples and flow meters per P&ID/Procedure
- Electrical connection to termination points per CWD/Procedure

Insulation

- Facilities contractor to install per SOW

Testing Plan Overview

Thermocouple PTP

- Bench calibration prior to installation
- Point-to-Point test to CAMAC Equipment
- Display test on EPICS of thermocouple data with handheld heater

Flowmeter PTP

- Pressure test of installation assembly per ENG-014
- Ambient temperature flow test integrated with bakeout system startup procedure

Remote Valve Coupling PTP

- Bench Testing of Remote Valve Coupling with Valve and remote control

Insulation Verification

- Measure insulation surface temperature during full temperature operation with calibrated temperature probe

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FMECA

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Ex-Vessel Helium Manifolds	Significant throttling valve leak to atmosphere, heat transfer plate supply and/or return	packing failure	must stop bakeout and replace valve	4	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Throttling valve seized, heat transfer plate supply and/or return	internal mechanical failure	Loss of flow throttling capability. Must stop bakeout and replace valve if seized closed	4	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Significant throttling valve leak into atmosphere, OBD loop supply and/or return	packing failure	must stop bakeout and replace valve	4	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Throttling valve seized, OBD loop supply and/or return	internal mechanical failure	Loss of flow throttling capability. Must stop bakeout and replace valve if seized closed	4	Bakeout PLC and Controls	None	None	2

FMECA

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Ex-Vessel Helium Manifolds	Significant throttling valve leak into atmosphere, NB armor supply and/or return	packing failure	must stop bakeout and replace valve	4	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Throttling valve seized, NB armor supply and/or return	internal mechanical failure	Loss of flow throttling capability. Must stop bakeout and replace valve if seized closed	4	Bakeout PLC and Controls	Ex-Vessel Helium Manifolds	None	2
He Feedthroughs	Vacuum leak develops at feedthrough	thermal stress	loss of high vacuum; vent to repair	3	Vacuum Gauges and Residual Gas Analyzers	None	None	3
Ex-Vessel Helium Manifolds	Temperature sensor (TE0024-0027) heat transfer plate - fail high	Signal conditioning electronics failure	False high reading and operator misinformation; not used for any automated function	2	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Temperature sensor (TE0024-0027) heat transfer plate - fail static	Signal conditioning electronics failure	False reading and operator misinformation; not used for any automated function	2	Bakeout PLC and Controls	None	None	2

FMECA

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Ex-Vessel Helium Manifolds	Temperature sensor (TE0010-0012, 0014-0019, 0020-0022) outboard diverter - fail high	Signal conditioning electronics failure	False high reading and operator misinformation; not used for any automated function	2	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Temperature sensor (TE0010-0012, 0014-0019, 0020-0022) outboard diverter - fail static	Signal conditioning electronics failure	False reading and operator misinformation; not used for any automated function	2	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Temperature sensor (TE0010-0012, 0014-0019, 0020-0022) outboard diverter - fail low	Damaged/broken cable, thermocouple failure, signal conditioning electronics failure	False low reading and operator misinformation; not used for any automated function	2	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Temperature sensor (TE0013 & 0023) neutral beam armor - fail high	Signal conditioning electronics failure	False high reading and operator misinformation; not used for any automated function	2	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Temperature sensor (TE0013 & 0023) neutral beam armor - fail static	Signal conditioning electronics failure	False reading and operator misinformation; not used for any automated function	2	Bakeout PLC and Controls	None	None	2

FMECA

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Ex-Vessel Helium Manifolds	Temperature sensor (TE0013 & 0023) neutral beam armor - fail low	Damaged/broken cable, thermocouple failure, signal conditioning electronics failure	False low reading and operator misinformation; not used for any automated function	2	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Flow transducer (FT0002) return manifold upper - fail high	Sensor component or signal conditioning electronics failure	Inaccurate flow characteristics for supply manifold upper and NB armor; not used for any automated function	2	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Flow transducer (FT0002) return manifold upper - fail static	Sensor component or signal conditioning electronics failure	Inaccurate flow characteristics for supply manifold upper and NB armor; not used for any automated function	2	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Flow transducer (FT0002) return manifold upper - fail low	Sensor component or signal conditioning electronics failure	Inaccurate flow characteristics for supply manifold upper and NB armor; not used for any automated function	2	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Flow transducer (FT0003) return manifold lower - fail high	Sensor component or signal conditioning electronics failure	inaccurate flow characteristics for supply manifold lower; not used for any automated function	2	Bakeout PLC and Controls	None	None	2

FMECA

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Ex-Vessel Helium Manifolds	Flow transducer (FT0003) return manifold lower - fail static	Sensor component or signal conditioning electronics failure	inaccurate flow characteristics for supply manifold lower; not used for any automated function	2	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	Flow transducer (FT0003) return manifold lower - fail low	Sensor component or signal conditioning electronics failure	inaccurate flow characteristics for supply manifold lower; not used for any automated function	2	Bakeout PLC and Controls	None	None	2
Ex-Vessel Helium Manifolds	2 out of 3 ODB supply valves closed inadvertently	Operator error	Pressure through open valve will reach maximum operating pressure. In-vessel temperature gradient created. Ineffective bakeout	2	Bakeout PLC and Controls	Ex-Vessel Helium Manifolds	PFC Thermocouples	2
Ex-Vessel Helium Manifolds	All ODB supply valves closed inadvertently	Operator error	System pressure will peak at the maximum pressure capability of the blower. Temperature gradient created between in-vessel and ex-vessel wall. Ineffective bakeout	2	Bakeout PLC and Controls	Ex-Vessel Helium Manifolds	PFC Thermocouples	2

FMECA

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Ex-Vessel Helium Manifolds	One HTP connection valve closed inadvertently	Operator error	Potential temperature gradient between the HTP and the Casing horizontal target flange; potential stresses in bolts and feedthroughs	2	Ex-Vessel Helium Manifolds	None	None	1
Ex-Vessel Helium Manifolds	Temperature sensor (TE0024-0027) heat transfer plate - fail low	Damaged/broken cable, thermocouple failure, signal conditioning electronics failure	False low reading and operator misinformation; not used for any automated function	2	Bakeout PLC and Controls	None	None	2

25 Failure Modes identified, all either of acceptable risk or mitigated to that level

Project Risks are Actively Being Managed

Risk	Score (1-81)	Open/Retired	Risk Retirement Event
If calculations show that there is insufficient He flow to achieve bakeout KPP temperatures	20	RETIRED	FDR Bakeout
If there are unforeseen new PLC/HMI complications	12	OPEN	completion of bakeout
If the new bakeout control system has complications	12	OPEN	completion of testing
If the bakeout control system fails	12	OPEN	completion of bakeout
Analysis of bakeout thermal performance shows insufficient heating capacity	1	RETIRED	

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Environmental Safety and Health

- Work hazards during installation are standard industrial hazards:
  - Welding, Hand tools, LOTO, etc.
- Hazards mitigated through PPPL ISM and ES&H internal procedures:
- Job Hazard Analysis completed prior to the start of planned work.
- (Cutting pipe, using power tools, eye protection, etc.)
- Work scheduled via the rollover and work control center to avoid work area conflicts.
- All Lockout/Tagout preformed per PPPL procedure ESH-016
- Hazards removed from safeguards and testing
- Insulated piping around occupied spaces will be touch safe

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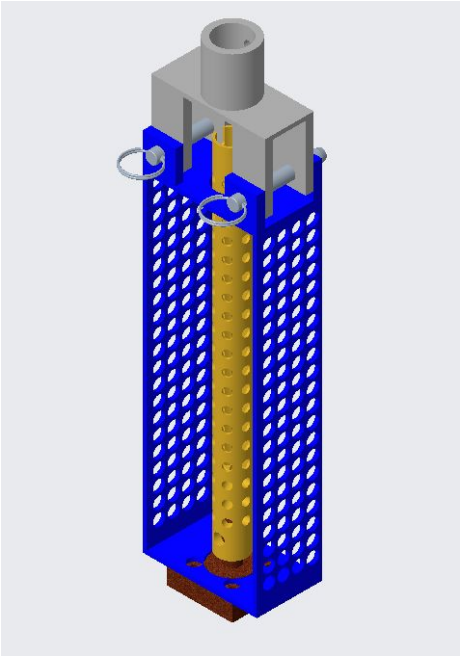
Summary

- This xxxx has been designed and is awesome
- Flow throttling and monitoring capability added through:
  - Remotely operated throttling valves
  - Flow transducers and thermocouples
- Interfaces are considered in the design and documented in the ICDs
- All chits from previous design reviews have been addressed
- Risks are mitigated through planned testing of system components
- All hazards associated with installation are mitigated through PPPL internal procedures

Backup Material

Analysis/Prototyping



- Remote valve coupling serves as a junction between COTS remote operator and throttling valve.
- Throttling valve max operating temperature is 450°C; remote operator rated for 177°C.
- Steady State Thermal and Static Structural analysis conducted in Ansys.
- Temperature at Flex Shaft interface below 177°C rating.
- Calculated maximum shear stress due to 450°C initial temperature is ~ 44 MPa, ~1/2 of Sy@450°C(103Mpa). (<⅔ Sy per NSTX-CRIT-0001-02)

Refer to NSTXU_1-3-3-1-1_CALC_101

Analysis/Prototyping

- Additional Insulation provides a surface temp of 46°C which is less than the required 60°C per ASTM XXXX.

See: NSTXU_1-3-3-1-1_CALC_100