National Spherical Torus eXperiment Upgrade

Medium Temperature Water System

WBS 1.03.01.02

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

Jarmon Browning - Presenter
Joe Petrella - Cognizant Engineer

Last edit: 3/10/2020

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 1.03.01.02

WBS Title	Medium Temperature Water System	WBS #	1.03.01.02
Project Cog.	Joe Petrella	Assoc. Proj. Man.	Tom Jernigan
Design Scope	Remove safety hazards of the ExVVHS with through available technologies and standard engineering practices.		
Technical Impact of Scope	ExVVHS supplies superheated water to the external vacuum vessel in a safe manor to assist the bakeout process of NSTX-U.		
Design Status	FDR completed on 01/10/20: review link chits: link calculation: link drawings: link SoW/Tech Spec: N/A		
Fabrication & Installation Status	Fabrication and installation will start following DOE CDE-3B ESAAB		

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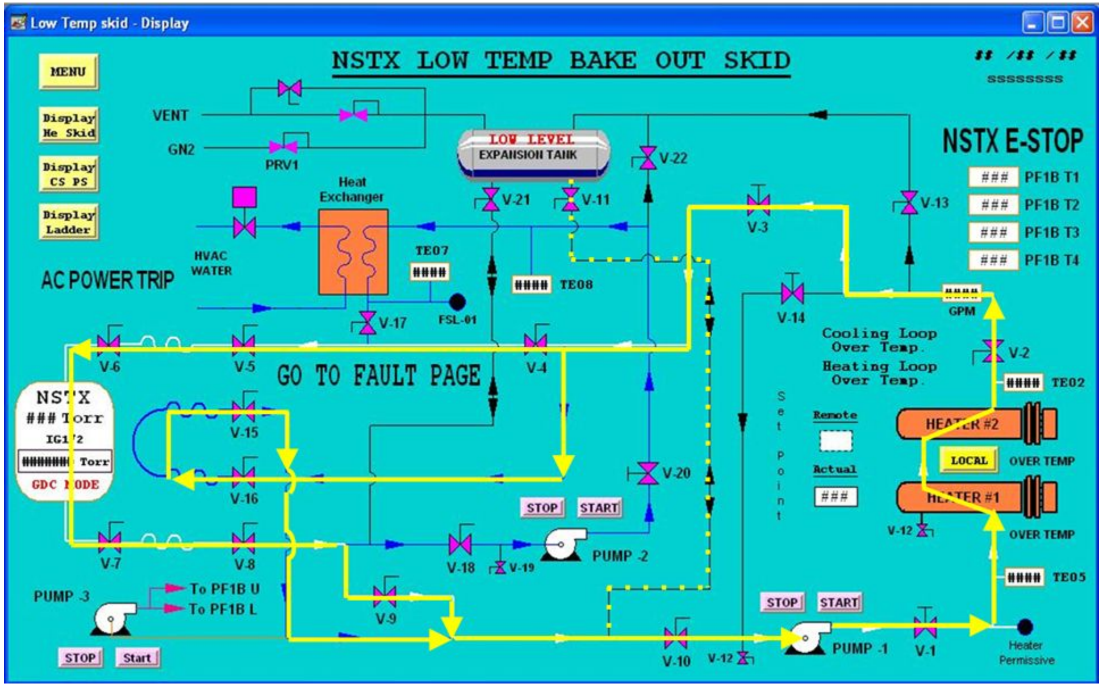
Ex-VV Heating System Overview

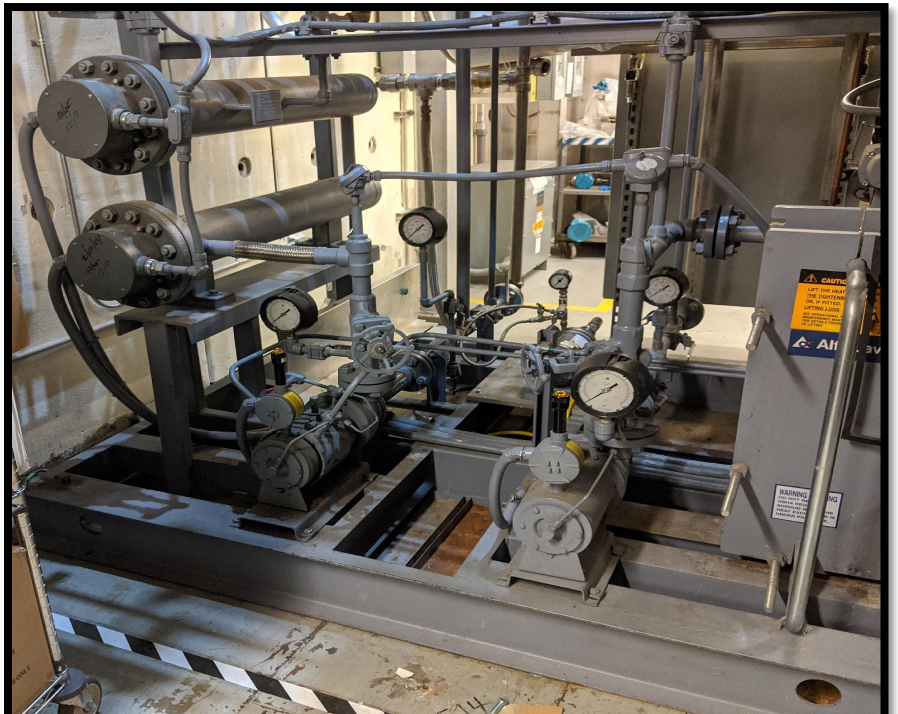
Uses a commercial oil heating skid to supply heat along the outer vacuum vessel exterior with water that can reach 155°C (superheated water)

-Superheated water: water that is heated to a temperature beyond its atmospheric-pressure boiling point

Revised system design is compliant with PPPL Pressure System Standard



Ex-VVHS Scope: Legacy Safety Issue



The system that heats/cools the working fluid was not designed for superheated water and lacks the controls/interlocks that are needed for such a system

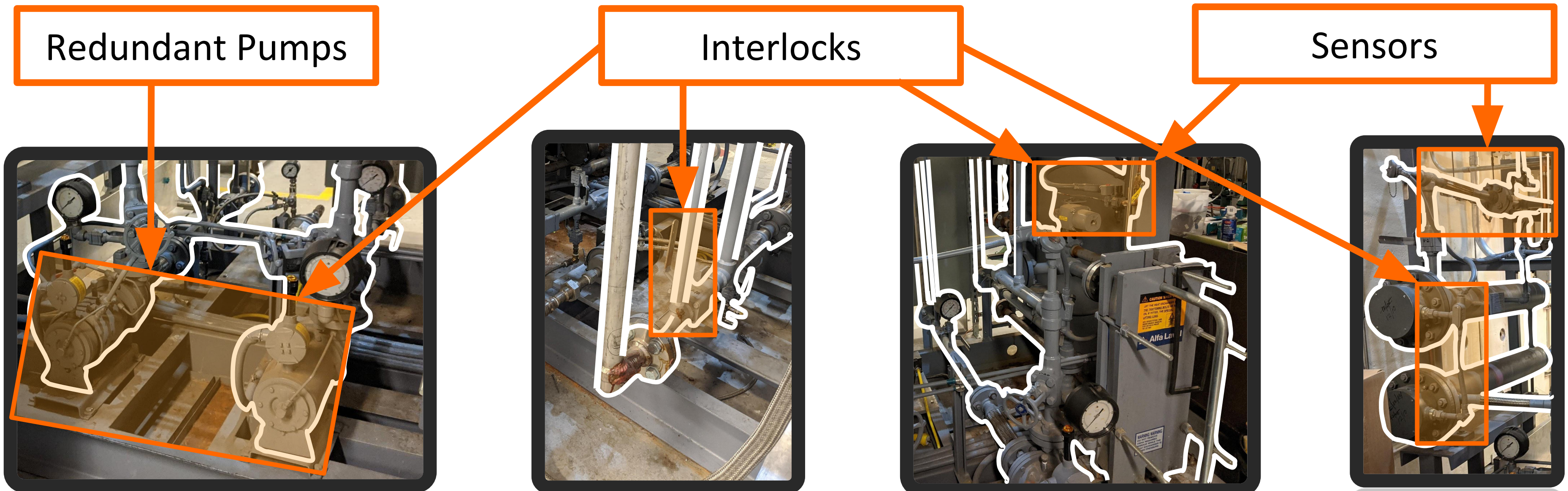
- -The use of superheated water exposes the system to an explosive vaporization (BLEVE*) risk in an under-pressure and/or over-temperature event

*Boiling Liquid Expanding Vapor Explosion (BLEVE): The rupture of a container in which a liquid is held above its atmospheric-pressure boiling point

Ex-VVHS Scope: System Change

The present issues can be removed/mitigated through available technologies and standard practice in the industry* for Medium Temperature Water Systems (MTWS) principally by <u>reducing the expansion tank size</u>. Hazards can be reduced further by adding <u>redundant pumps</u>, <u>interlocks</u>, <u>sensors</u>, and <u>insulation.</u>

*ASHRAE Systems and Equipment Handbook, ASME Boiler/Power Piping Code.



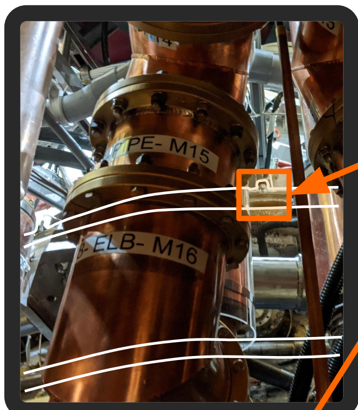
Ex-VVHS Scope: System Change (cont.)

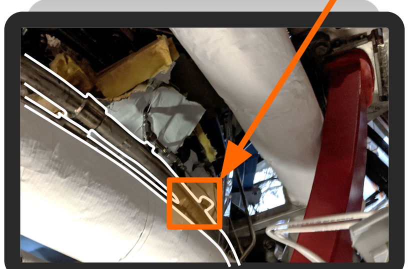
...adding redundant pumps, interlocks, sensors, insulation, and reducing the expansion tank size.

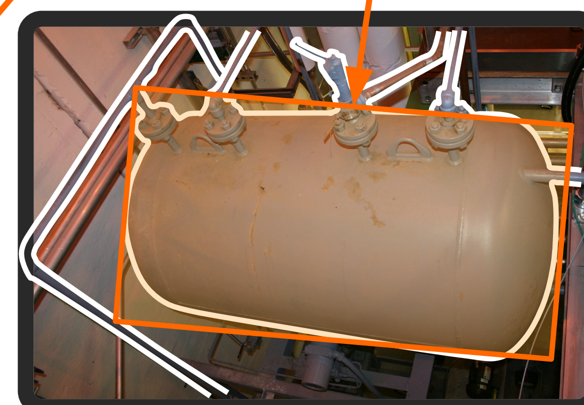
Sensors

Insulation

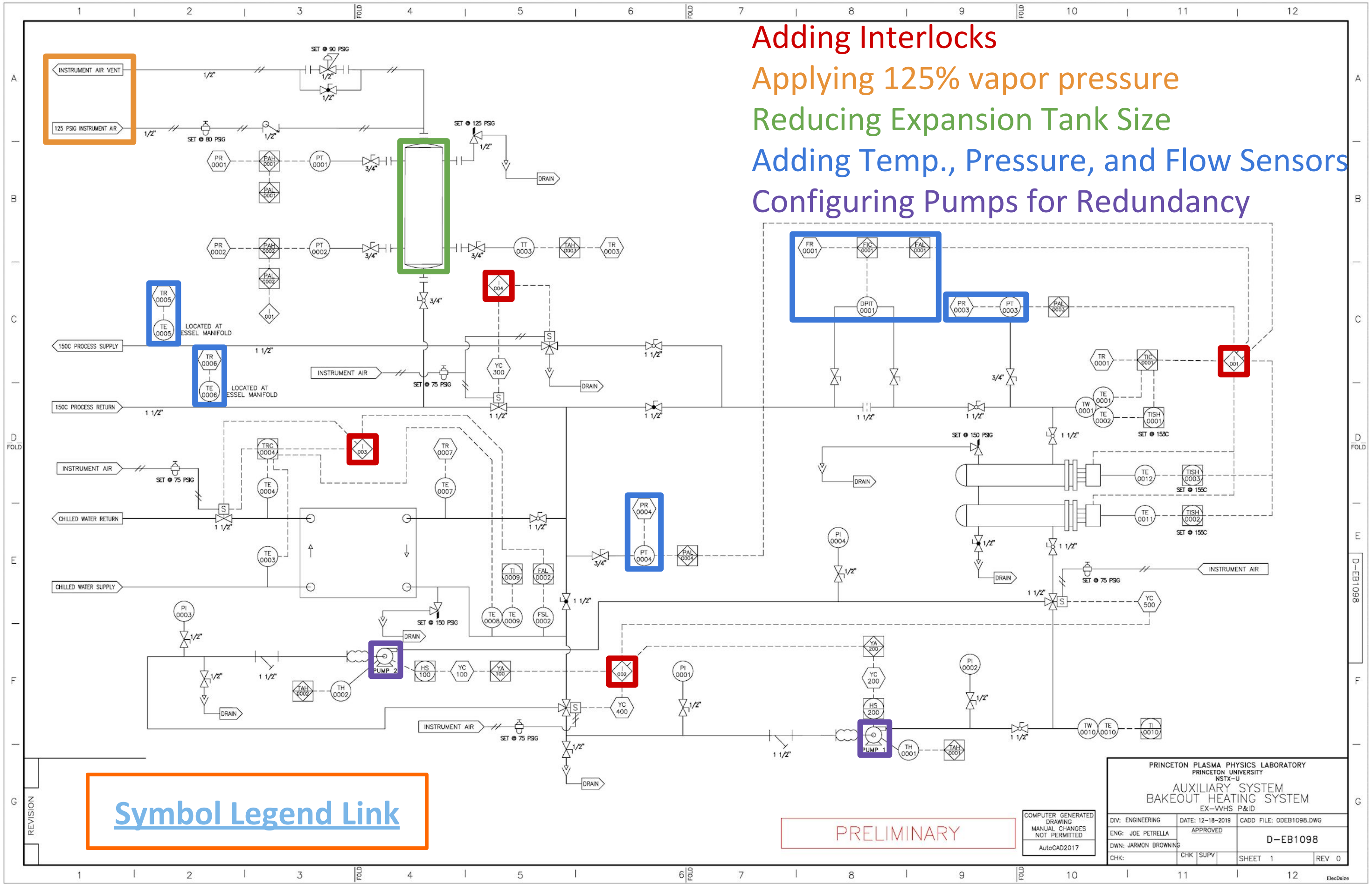
Tank Size Reduction







Ex-VVHS Scope: P&ID



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Requirements Met
Key requirements summarized below:

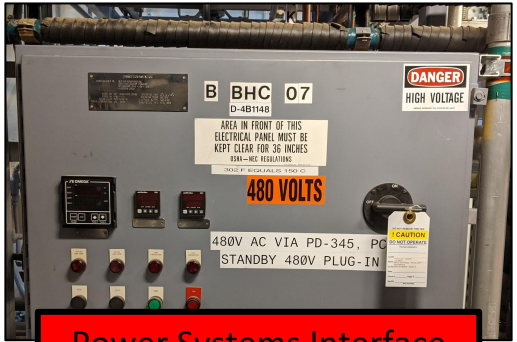
- Requirements developed in accordance with ASHRAE Chapter 14 (Medium - and High - Temperature Water Heating Systems)

Source	Requirement Summary	Comment	Met
NSTX-U-RQMT-SRD-005-00 4.3.h.	Interlocks shall be made to prevent and mitigate loss-of-pressure accident scenarios.	Critical system locations identified and interlocked to handle extreme situations	✓
NSTX-U_RQMT-RD-015-00 d & f	System pressure shall be maintained at a minimum of 125% the vapor pressure of the water at the peak system temperature and water volumes shall be kept at a minimum where possible.	Two formal calculations approved detailing the system pressure to be maintained and the minimum expansion tank size to use	✓
NSTX-U_RQMT-RD-015-00 g & h	The circulation pump(s) shall be redundant and the working-fluid manifolds shall have capability for automated blow-down.	2 pumps will be configured for redundancy and interlocked for automated blow-down	✓
NSTX-U_RQMT-RD-015-00 j	Instrumented for pressure (0-200 PSIG) and temperature (10-200°C) at both the supply and return. The flowrate (0-125 GPM) shall be measured at a minimum of one location.	Sensors will be placed on the supply and return to measure temperature, pressure, and flowrate with the specifications appropriate for this application.	✓

Charge questions: 1

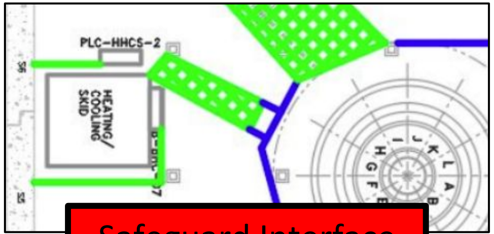
Complete RVTM maintained by Project Systems Engineering

The Design Accommodates Required Interfaces



Power Systems Interface

Power will be sent to the MTWS to power the various equipment and sensors



Safeguard Interface

Safeguards will be placed as a part of the Operational Safety System (OSS) to encapsulate the MTWS

Test Cell Interface

Structural supports for the MTWS will be attached to the test cell walls

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
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

Details of Interfaces Defined in Interface Control Documents

System 1	System 2	ICD Link	Exposition
Bakeout Systems	Vacuum Vessel System	link	Defines interfaces between the Bakeout System and the Vacuum Vessel Structure
Bakeout Systems	Operations & Safety Systems	link	Defines interfaces between the Bakeout System and the Test Cell platforms

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Calculations Verify the Design Meet Requirements

Physical Quantity	Calculation #	Content
ExVVHS Tank Size	NSTX_1-3-3-3_CALC_100	Calculation of External Vaccum Vessel Heating System Expansion Tank Size: Working fluid volume expansion

- ➢ The expansion tank size to be used resulting from a volume expansion calculation (NSTXU_1-3-3-3_CALC_100) will be 5 gallons.
- ➢ Removes Boiling Liquid Expanding Vapor Explosion (BLEVE) hazard while still being adequate during an extreme operating event.

150 gallon tank reduced to 5 gallons

- ❖ The water will be at a maximum temperature of 157ºC (314.6ºF) (Ref. 1) which corresponds to a saturation pressure of 82.30 PSIA (67.6 PSIG) (Ref. 2).
- ❖ Therefore, system pressure will be maintained at 84.5 PSIG to maintain a minimum 125% safety factor to prevent flashing (Devised from ASHRAE 14.1, 2000).

Reference 1: NSTX-U_RQMT-RD-015-00

Reference 2: Keenan and Keys, *Thermodynamic Properties of Steam*, 1936.

Prototyping not needed as all parts are COTS and rated for this application.

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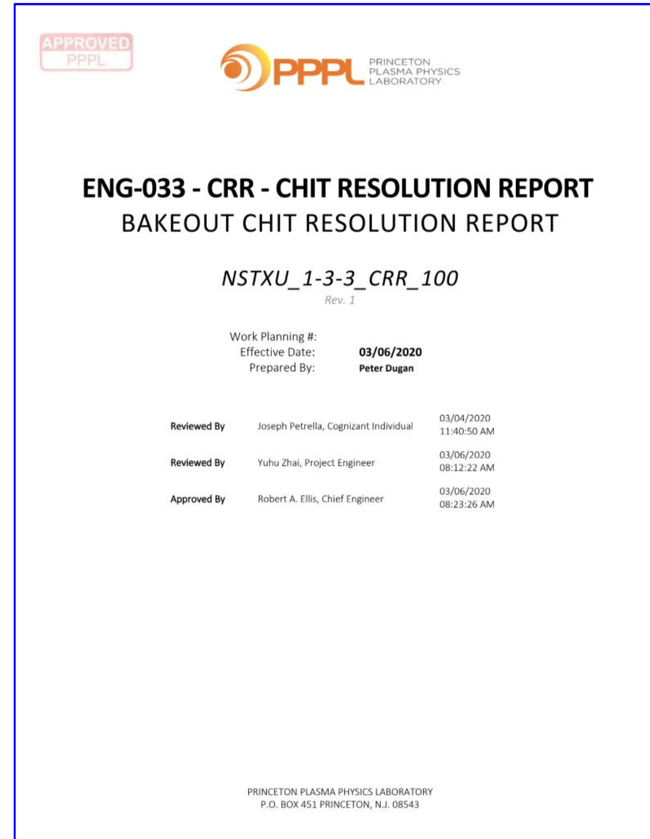
All Chits have been Closed

- 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 Outline

- All parts shall be bought commercial off the shelf (COTS).
- Select components will be reused/reconfigured on the current system.
- Standard pipe fitting fabrication needed.
- Purchased components are rated for ANSI 300 Class Process Piping standard and spec'd for this application.

Installation Plan

Installation will be guided by a new Installation Procedure (IP).

Included in Installation:

- Connecting the existing two pump together so they are on the same Heating/Cooling loop system
- Adding the instrument air for pressurization
- Exchanging the current expansion tank with the reduced size expansion tank
- Adding the new thermocouples to the vessel manifold
- Connecting the updated system to the PLC
- Adding insulation from the Hot Water Skid area to the vacuum vessel manifold.

Planned Testing

Testing will be guided by a new Preoperational Test Procedure (PTP)

Testing For:

- PLC Functionality
- Valves, Sensors, and Alarms Working Properly
- Proper Flow, Pressure, and Temperature Achieved
- Pump Switching
- Energizing and De-energizing Heat Exchanger
- Energizing and De-energizing Hot Water Heater
- Exception Handling
- Blowdown Functionality

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FMECA - MTWS Manifolds (I)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
MTWS Manifolds and Vessel-Mounted Piping	Full blockage in tube on vessel	Buildup of gunk in the pipes over time	No water flow; potential for excessive local heating leading to steam formation in pipes and vessel thermal stresses	9	The ExVVHS is blown down after every Bakeout session removing the possibility of sediment buildup	Vacuum Vessel Thermocouples	None	2
MTWS Manifolds and Vessel-Mounted Piping	Partial blockage in tube on vessel	Buildup of gunk in the pipes over time	No water flow; potential for excessive local heating leading to steam formation in pipes and vessel thermal stresses	9		Vacuum Vessel Thermocouples	None	4
MTWS Manifolds and Vessel-Mounted Piping	Electrical breakdown or other conduction across dielectric breaks in manifolding	contamination; some metal bridging the gaps	Shorts and Potential Arcs	6	Configuration Managed Safeguards	None	None	3
MTWS Manifolds and Vessel-Mounted Piping	Pressure loss due to failed pipe or appurtenance	Pipe Failure	Reduced ability or inability to adequately perform bakeout	6	Bakeout PLC and Controls	MTWS Manifolds and Vessel-Mounted Piping	None	1
MTWS Manifolds and Vessel-Mounted Piping	Expansion Tank over pressure	Too much house air or water.	Tank leaks	4	Bakeout PLC and Controls	None	None	1

FMECA - MTWS Manifolds (II)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
MTWS Manifolds and Vessel-Mounted Piping	Failure of the thermocouples at the manifolds	Corrosion / Device malfunction	Incorrect heating decisions from the PLC	4	Bakeout PLC and Controls	PFC Thermocouples	None	2
MTWS Manifolds and Vessel-Mounted Piping	Failure of the software interlocks	Loss of Power; Hardware Failure; PLC failure or error (processor or I/O)	Loss of ability to change state of the MTWS; potential of harm to equipment	4	Bakeout PLC and Controls	None	None	2
MTWS Manifolds and Vessel-Mounted Piping	Failure of the expansion tank relief valve (Open)	Corrosion / Component compromised	Tank pressure unable to be maintained / PLC unable to start heaters	2	Bakeout PLC and Controls	None	None	2
MTWS Manifolds and Vessel-Mounted Piping	Failure of the expansion tank relief valve (Closed)	Corrosion / Component compromised	Damage to the expansion tank	2	Bakeout PLC and Controls	None	None	2
MTWS Manifolds and Vessel-Mounted Piping	Failure of mechanical interlocks (Pressure Relief Valves)	Corrosion / Components compromised	Over pressure in the system	2	Bakeout PLC and Controls	None	None	2

FMECA - MTWS Skid (I)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
MTWS Skid	Failure of heater on MTWS skid - no heat added	Loss of internal supply regulation, due to component failure; PLC failure or error (processor or I/O)	Loss of ability to maintain specific VV bakeout temperature	6	Bakeout PLC and Controls	None	None	2
MTWS Skid	Reduction or loss of HVAC cooling water flow	HVAC stops effective cooling	Cannot cool vessel, must stop bakeout, potential overtemperature condition in the pipes	6	Bakeout PLC and Controls	MTWS Skid	None	3
MTWS Skid	Rapid loss of system pressure with system or expansion tank	Leak in the system causes a pressure drop faster than the PLC can react	Localized flashing of steam	6	Configuration Managed Safeguards	None	None	6
MTWS Skid	reduced temperature due to excessive cooling in MTWS	Loss of internal supply regulation, due to component failure; PLC failure or error (processor or I/O)	Loss of ability to maintain specific VV temperature	6	Bakeout PLC and Controls	None	None	2

FMECA - MTWS Skid (II)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
MTWS Skid	Failure of Pump in High Temperature Loop in MTWS	Pump compromised	Cannot heat vessel, must stop bakeout, potential overtemperature condition in the pipes	6	Bakeout PLC and Controls	MTWS Skid	None	3
MTWS Skid	Failure of heater on MTWS skid - no heat added	PLC failure or error (processor or I/O)	Loss of ability to maintain specific VV bakeout temperature	6	Bakeout PLC and Controls	None	None	2
MTWS Skid	Heater controls fail causing maximum temperature output	Loss of internal supply regulation, due to component failure; PLC failure or error (processor or I/O); Heating skid broken	Heats the VV more than appropriate; Potential damage to pumps	4	Bakeout PLC and Controls	None	None	2
MTWS Skid	Failure in Check Valve supplying Instrument Air	Valve integrity compromised / corrosion	Pressure of system will increase from 85 psig to 90 psig (Pressure the Instrument air is able to supply)	4	MTWS Manifolds and Vessel-Mounted Piping	None	None	2

FMECA - MTWS Skid (III)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
MTWS Skid	Failure of Temperature Controller in MTWS	Loss of internal supply regulation, due to component failure; PLC failure or error (processor or I/O)	Temperature not per setpoint, if overtemperature, possible boiling of heat exchanger fluid, possible opening of pressure relief valve	4	Bakeout PLC and Controls	None	None	4
MTWS Skid	Loss of power to MTWS skid	breaker trip; power outage	Loss of ability to maintain specific VV temperature; possible degradation of plasma performance	4	Bakeout PLC and Controls	None	None	4
MTWS Skid	Heater controls fail in MTWS causing maximum temperature output	PLC failure or error (processor or I/O)	Heats the VV more than appropriate; Potential damage to pumps	4	Bakeout PLC and Controls	None	None	2
MTWS Skid	Failure of Temperature Controller in MTWS	PLC failure or error (processor or I/O)	Temperature not per setpoint, if overtemperature, possible boiling of heat exchanger fluid, possible opening of pressure relief valve	4	Bakeout PLC and Controls	None	None	4

FMECA - MTWS Skid (IV)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Vacuum vessel water heating and cooling system	Leak on MTWS	Pipe material compromised; connections fail at fitting	Loss of pressure within MTWS; Hot flash-steam introduced near working area	4	Bakeout PLC and Controls	None	None	4

23 Failure Modes Identified, all mitigated to acceptable risk

FMECA: link

Project Risks are Actively Being Managed

Risk	Score (1-81)	Open/Retired	Risk Retirement Event
Control System Failure	12	OPEN	completion of testing
If there is a Dual Pump Failure	9	OPEN	completion of bakeout

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QA/QC, Validation & Oversight

PPPL Quality Assurance Program Description (QAPD) for A-2 Systems:

- Majority of components are COTS - no fabrication oversight needed
  - Purchased components will be inspected and verified on arrival.
- ExVVHS validation shall include static and functional tests of all inputs, outputs, and operational modes.
- All ExVVHS equipment shall be installed by personnel approved by the NSTX-U Head of Operations.
- PPPL QA & PPPL Engineering will be used for on-site work and contracted labor oversight.

Environmental, Safety, & Health

- Work hazards during installation are standard industrial hazards:
  - 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 performed per PPPL procedure ESH-016
- Hazards removed from safeguards and testing:
  - Insulated piping around occupied spaces will be touch safe
  - System over-pressurization risk removed from tank size reduction, relief valves, pressure sensors, and blow-down interlock testing.

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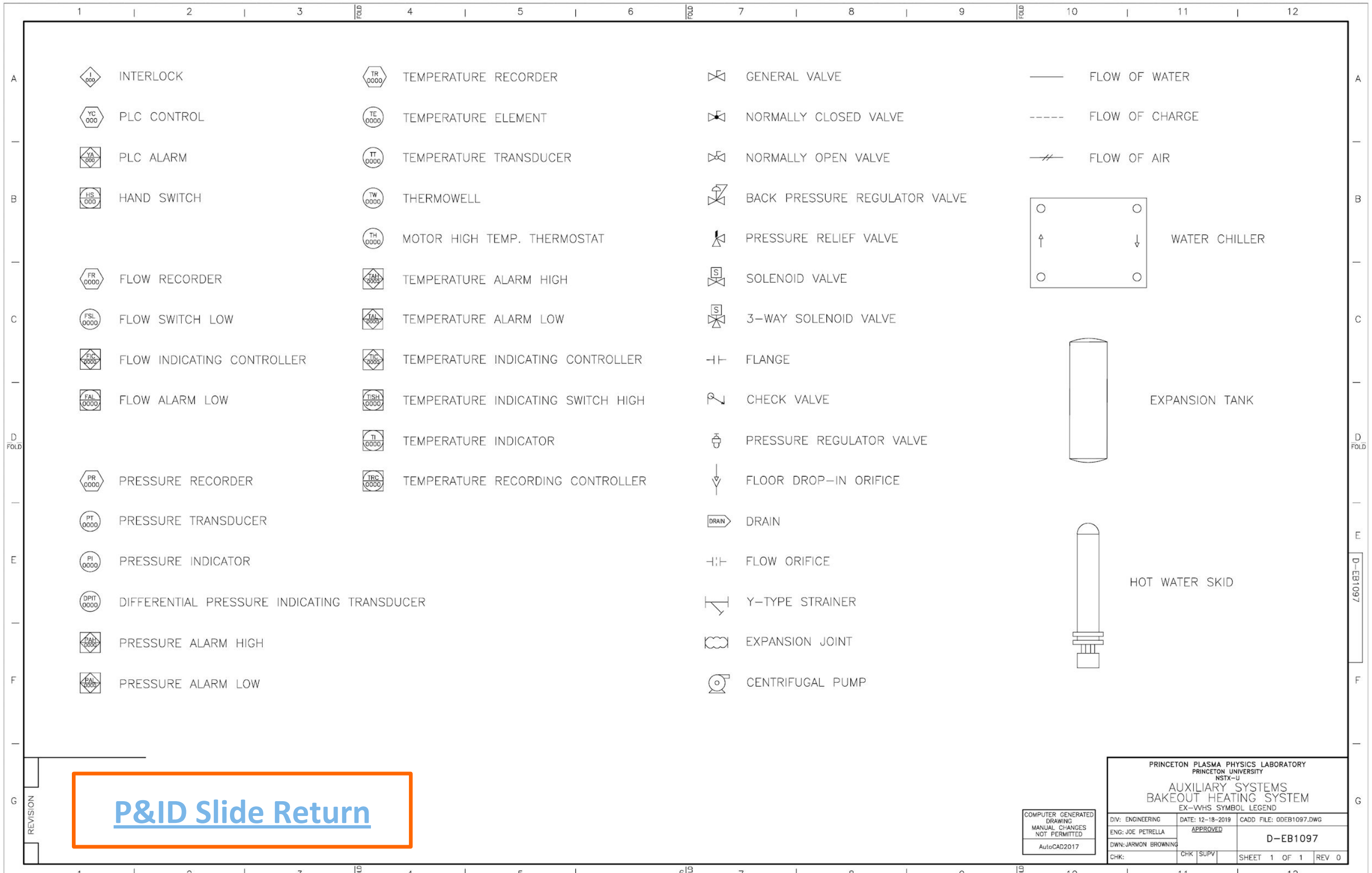
Summary

- Requirements are met with a calculated safety margin.
- Interfaces are identified and organized in their respective ICD’s.
- All bakeout chits were reviewed and are now closed.
- All personnel and equipment risks identified and removed/mitigated:
  - Interlocks/Redundancy
  - Bakeout PLC and Controls
  - Safeguards/Insulation
  - Routine Maintenance
- Personnel safety was priority #1 during the design process:
  - System over-pressurization risk removed from tank size reduction, relief valves, pressure sensors, and blow-down interlock testing.
  - Occupied spaces designed to be touch safe.
  - Extensive FMECA developed to capture possible failures.

Backup Material

Ex-VVHS Scope: P&ID Symbol Legend



[P&ID Slide Return]

COTS Components Identified

Component	Quantity	Unit Range	Estimated Direct Cost	Extended Cost
Pressure Transducer	2	0-200 psig	$531	$1,062
Software sensor	N/A			
Pressure Transducer	1	0-200 psig	$531	$531
Flow Transducer FTB-1441-HT	1	0-200 GPM	$1,375	$1,375
Pressure Transducer	1		$531	$531
Thermal Trap - 3/4"	1	Schedule 40	$500	$500
Redundant pump isolation	2		$2,411	$4,822
Adjustment of existing equipment				$0
Relief Valves	3	150 PSIG	$241	$723
Existing Sensor - Repurpose	N/A			
Thermocouple + Well	4	Type K	$114	$456
Blowdown Valve	1		$2,411	$2,411
Blowdown Isolation Valve	1		$2,411	$2,411
HVAC Modulating Valve	1		$261	$261
HVAC Modulating Actuator	1		$290	$290
Miscellaneous Pipe & Fittings	1		$5,000	$5,000
Electrical Installation & Materials	1		$5,000	$5,000
			Total M&S:	**$25,373**