National Spherical Torus eXperiment Upgrade

Private Flux Region Fuelling

WBS 1.03.03.05

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

D. Cai - Cognizant Engineer

Last edit: 03/09/20

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 1.03.03.05

WBS Title	Private Flux Region Fueling System	WBS #	1.01.03.05
Project Cog.	D. Cai	Assoc. Proj. Man.	Gary Swider
Design Scope	Design two private flux region injectors for NSTX-U		
Technical Impact of Scope	To mitigate heat flux to plasma facing components and thereby support physics research activities for NSTX-U		
Design Status	FDR completed on 11/25/2019: review link chits: link drawings: link		
Fabrication Status	Waiting for 3B approval to release drawings		
Installation Status	Pending 3B approval		

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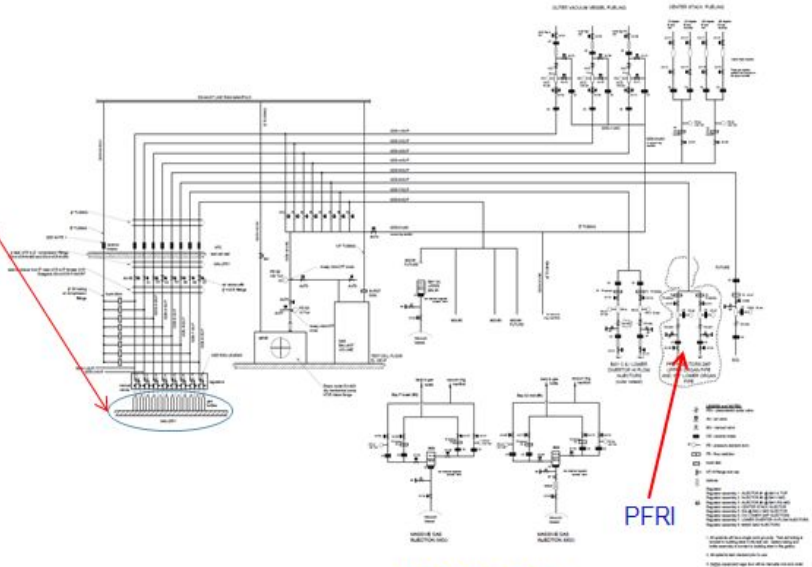
Scope

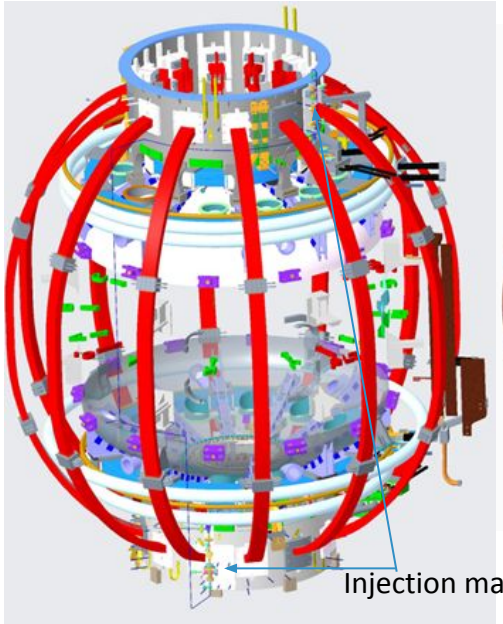
NSTX TEST CELL ELEVATION 100'-0"

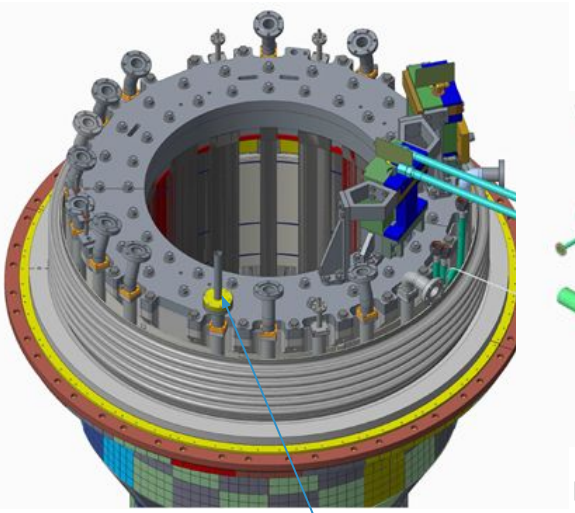


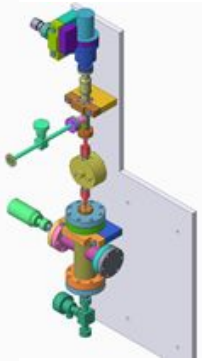
GDS/GIS P&ID

- Gas delivery line from bottle bank to vacuum vessel exists.
- New injection manifolds (Bay I -U and bay K-B) and interconnection lines

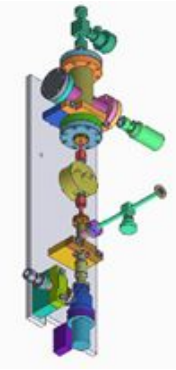
Scope



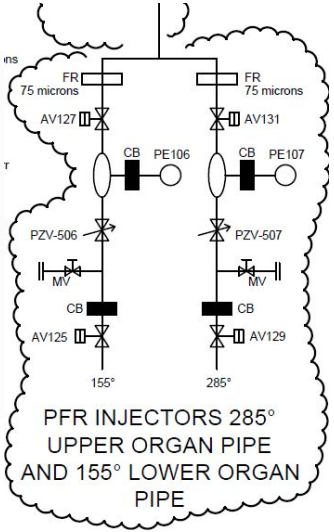




Bottom PFRI



Top PFRI



P&ID

- Injection into the vacuum vessel located at 285 ° (Bay J) upper organ pipe and 15 ° (Bay A) lower organ pip

Flow rate selected by setting the system pressure, then injecting gas by modulating the piezo-electric valve.

- The plenum pressure can be remotely selectable.
- 10 to 250 TL/s flow rate. 50 to 5000 Torr pressure range
- Plenum volume ~ 400 cc volume >350 cc required
- The ability to use pulse width modulation to modify the flow rate.

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Requirements Defined and Met

SOURCE	REQUIREMENT	Met
NSTX-U-RQMT-SRD-005	All GIS valves shall have the injection timing controlled by the plasma control system.	✔
NSTX-U-RQMT-SRD-005	The jitter on the timing of puff valve opening shall be less than 5 ms.	✔
NSTX-U-RQMT-SRD-005	The GIS shall have electrical isolation of all piezo or puff valves from the vacuum vessel or CSC as per the GRD.	✔
NSTX-U-RQMT-SRD-005	Designs shall ensure the low-pressure conditions do not occur in ceramic insulators where high voltage conditions may arise during a plasma discharge.	✔
NSTX-U-RQMT-SRD-005	The GIS shall include valve drivers and electronics to interface to the plasma control system the vacuum system PLC, and the facility clock system	✔
NSTX-U-RQMT-SRD-005	The GIS shall have two injection ports, located at or near the interface of the inboard horizontal and vertical divertor targets, one each at the top and bottom of the device. These shall use piezo valves for injection control, and may utilize in-vessel tubes for gas delivery. Further details are provided in Ref. [9,10]	✔

Complete RVTM maintained by Project Systems Engineering

Requirements Defined and Met

SOURCE	REQUIREMENT	Met
NSTX-U-RQMT-RD-014	The plenums shall be able to be filled and evacuated between shots through remote connection.	✓
NSTX-U-RQMT-RD-007	The plenum pressure for each injector must be controlled (either remotely or by modifying the bottle pressure) independent of other plenums unless otherwise noted.	✓
NSTX-U-RQMT-RD-007	The system must be rated for the maximum operating pressure and able to fill the plenums to the lowest pressure as specified for each injector.	✓
NSTX-U-RQMT-RD-007	All piezo-electric valve controllers must apply a sufficient voltage to ensure the valve is fully open and small enough (or large enough reverse bias) to ensure the valve is closed.	✓
NSTX-U-RQMT-RD-007	All piezo-electric valves must complete a change in state (open to closed, or closed to open) within 2 ms of a change in the applied voltage.	✓
NSTX-U-RQMT-RD-007	All piezo-electric valves and valve drivers must be capable of handling 5 kHz oscillations in the PCS commands for 10 s.	✓
NSTX-U-RQMT-RD-007	All piezo valves must be able to be sustained in their open state for at least 5 seconds.	✓
NSTX-U-RQMT-RD-007	Valves shall have electrical isolation from the vessel as per the GRD [1].	✓

Parameters for PFRI - from -RD-014

Injector Name	Location	Flow rate range	Pressure range	Minimum plenum
		T l / s	torr	cc
Upper PFR	285 degree organ pipe	10 - 250	50 - 5000	350
Lower PFR	15 degree organ pipe	10 - 250	50 - 5000	350

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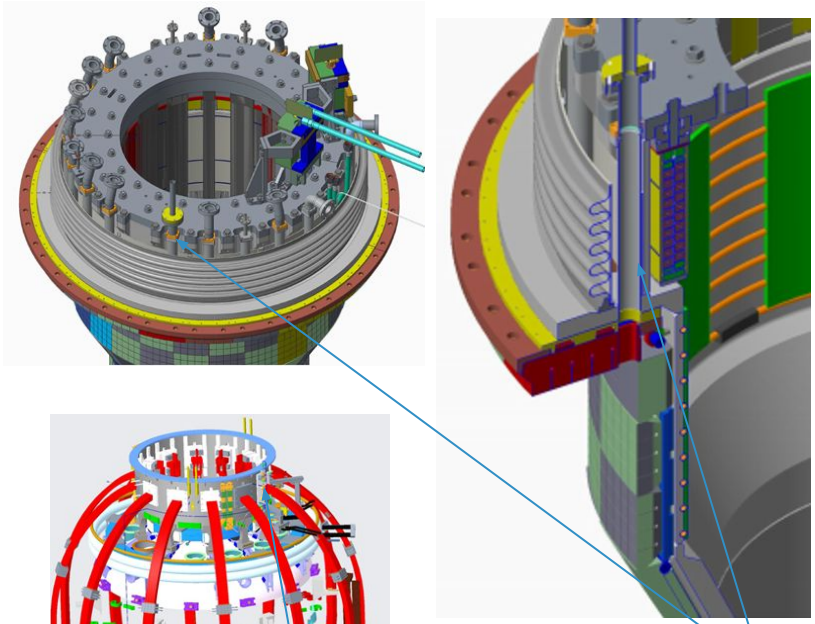
Requirement and Interface

Interfaces (from the -SRD-005)

Table 5.6-6: Interfaces for the Private Flux Region Piezo Valves (WBS 1.3.4.2.5)

Interfacing WBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.3.6	Center Stack Casing	Vacuum	At organ pipe flange	Private flux region fueling system has vacuum interface at the organ pipe	Mechanical Drawing
1.1.3.3.6	Center Stack Casing	Gas	At organ pipe flange	Private flux region fueling gas enters at the end of the organ pipe	Mechanical Drawing
1.3.4.1	Gas Storage and Delivery Systems	Gas	At fill valve input	Gas provided to private flux region injector assemblies	P&ID
1.3.1.3	TIV and Shutter Actuation System	Gas	Where air connects to the TIV or valve	TIV and shutter actuation system controls TIV and pneumatic valves on the valve assembly	P&ID
1.1.1.1.4	Horizontal Target PFCs	Spatial	Hole in horizontal target PFC	Gas from PFR injectors passes through holes in PFCs	Mechanical Drawing
1.1.2.1.2	Umbrella structure & Spoked Lids	Spatial	N/A	Gas lines for the private flux region injectors enter the umbrella through the arches of the umbrella structure	Mechanical Drawing
1.3.4.5	Valve Driver and Interface Systems	Electrical Signal	At the PZV valve	The private flus region injectors receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support piezo injector cables	N/A
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At the penetration	Cables pass through penetrations	N/A

CS Casing Interface - Via Organ Pipe



Details of Interfaces Defined in Interface Control Documents

System 1	System 2	ICD Link	Exposition
Gas Delivery System	Center Stack Structures	link	Defines interface between the Private Flux Region and the Center Stack Structures
Gas Delivery System	Vacuum Vessel Structures	link	Defines interface between the Private Flux Region and the Vacuum Vessel Structures
Gas Delivery System	Vacuum Pumping System	link	Defines interface between the Private Flux Region and the Vacuum Pumping System

Details of Interfaces Defined in Interface Control Documents

System 1	System 2	ICD Link	Exposition
Gas Delivery System	Plasma Facing Components	link	Defines interface between the Private Flux Region and the Plasma Facing Components
Gas Delivery System	Test Cell	link	Defines interface between the Private Flux Region and the Test Cell

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Analysis/Prototyping

No analysis or prototyping needed as similar systems exist

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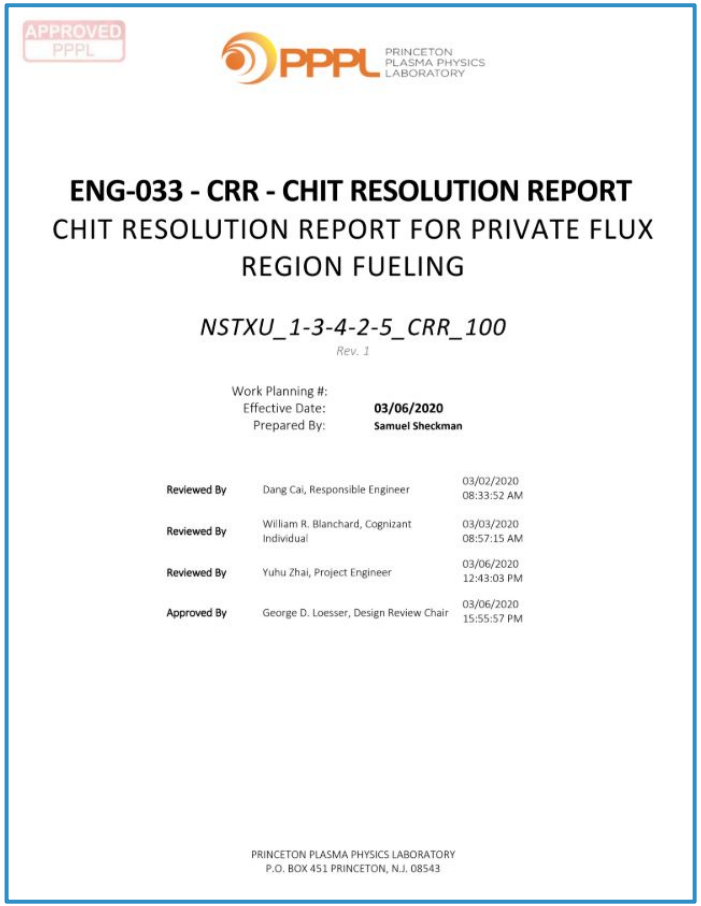
All Chits have been Closed

All the chits closed after FDR



APPROVED
PPPL

PPPL PRINCETON PLASMA PHYSICS LABORATORY

ENG-033 - CRR - CHIT RESOLUTION REPORT

CHIT RESOLUTION REPORT FOR PRIVATE FLUX REGION FUELING

NSTXU_1-3-4-2-5_CRR_100

Rev. 1

Work Planning #:
Effective Date: **03/06/2020**
Prepared By: **Samuel Sheckman**

Reviewed By	Dang Cai, Responsible Engineer	03/02/2020 08:33:52 AM
Reviewed By	William R. Blanchard, Cognizant Individual	03/03/2020 08:57:15 AM
Reviewed By	Yuhu Zhai, Project Engineer	03/06/2020 12:43:03 PM
Approved By	George D. Loesser, Design Review Chair	03/06/2020 15:55:57 PM

PRINCETON PLASMA PHYSICS LABORATORY
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Chit Resolution Report: link

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Procurement,Fabrication, Installation and Testing

- Gas components are off-the-shelf standard parts
- The valve manifolds, organ pipe interface spool and connection gas lines between manifold/GDS and manifold/organ pipe will be fabricated in house
- Installation includes manifolds, interconnection lines, organ pipe interface detail, electrical and pneumatic lines inside the NSTX-U test cell
- PTP test will be performed before operation

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Project Risks are Actively Being Managed

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

Risks related to fabrication delays, fitup, etc are carried at the project level.

Design FMECA (I)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Gas Storage and Delivery Systems	GDS roughing pump fails	mechanical failure	inability to operate gas delivery system	6	Gas Storage and Delivery Systems	Fueling Piezo Valves	None	6
Gas Storage and Delivery Systems	Any bottle regulator fail to high pressure	mechanical failure; misoperation	burst disk opens for delivery system in question	4	Gas Storage and Delivery Systems	Fueling Piezo Valves	None	4
Gas Storage and Delivery Systems	Crack of ceramic break near NTC wall	impact during nearby work	vacuum leak for injector system of interest	4	Fueling Piezo Valves	None	None	4
Fueling Piezo Valves	Ceramic break on piezo-electric injectors (gas feed side) cracks	mechanical impact, vibration	vacuum leak on injector	4	Fueling Piezo Valves	None	None	4
Fueling Piezo Valves	Ceramic break on piezo-electric injectors (machine side) cracks	mechanical impact, vibration	vacuum leak on machine	4	Fueling Piezo Valves	Vacuum Gauges and Residual Gas Analyzers	None	4
Fueling Piezo Valves	Ceramic break on piezo-electric injectors (roughing side) cracks	mechanical impact, vibration	vacuum leak on injector	4	Fueling Piezo Valves	None	None	4

Design FMECA (II)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Fueling Piezo Valves	Ceramic break on piezo-electric injectors (gas feed side) electrical breakdown	excessive pressure in break during period of high voltage (typically high-pots); contamination of break outer surface	none, but replace break so as to have two good breaks to bottle rack	4	Fueling Piezo Valves	None	None	4
Fueling Piezo Valves	Ceramic break on piezo-electric injectors (machine side) electrical breakdown	excessive pressure in break during period of high voltage (typically high-pots); contamination of break outer surface	Potential electrical damage pressure elements, pressure element electronics, or PZV driver	4	None	None	None	4
Fueling Piezo Valves	Ceramic break on piezo-electric injectors (roughing side) electrical breakdown	excessive pressure in break during period of high voltage (typically high-pots); contamination of break outer surface	vessel ground fault; potentially replace break	4	Vessel and Diagnostic Grounds	None	None	4
Gas Storage and Delivery Systems	GDS roughing pump power off	breaker trip	inability to operate gas delivery system	3	Gas Storage and Delivery Systems	Fueling Piezo Valves	None	3

Design FMECA (III)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Fueling Piezo Valves	Piezo-crystal through leak	aging/use	machine vacuum slightly compromised	3	Fueling Piezo Valves	Vacuum Gauges and Residual Gas Analyzers	None	3
Gas Storage and Delivery Systems	Any of NC air-valves AV50-AV57 fail in open position	mechanical valve failure, or air permanently present	none except during maintenance	2	Gas Storage and Delivery Systems	Fueling Piezo Valves	None	2
Gas Storage and Delivery Systems	Any of NC air-valves AV50-AV57 fail in closed position	mechanical failure, loss of air pressure	unable to fill plenums; unable to use the specific injector	2	Gas Storage and Delivery Systems	Fueling Piezo Valves	None	2
Gas Storage and Delivery Systems	Any of roughing connection NC air-valve AV62-AV69 fail in open position	mechanical valve failure, or air permanently present	unable to properly fill plenum; fill lines will be continually evacuated	2	Fueling Piezo Valves	None	None	2
Gas Storage and Delivery Systems	Any of NC roughing connection air-valve AV62-AV69 fail in closed position	mechanical failure, loss of air pressure	unable to use injector; cannot evacuate fill line except through injector itself	2	Fueling Piezo Valves	None	None	2

Design FMECA (IV)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Fueling Piezo Valves	Pressure elements PE100 or PE108 (or associated electronics) fail with high output reading	electronics failure, cable problem, sensor internal failure	unable to assess pressure near roughing pump; operator misinformation	2	Gas Storage and Delivery Systems	None	None	2
Fueling Piezo Valves	Fill valve (NC) on piezo injector assembly fail in open position	mechanical valve failure, or air permanently present	injector disabled, cannot control plenum pressure	2	Fueling Piezo Valves	None	None	2
Fueling Piezo Valves	Fill valve (NC) on piezo injector assembly fail in closed position	mechanical valve failure, or air absent	injector disabled, cannot fill plenum	2	Fueling Piezo Valves	None	None	2
Fueling Piezo Valves	Plenum roughing valve on piezo injector assembly fail in open position	mechanical valve failure, or air permanently present	injector disabled, cannot fill plenum	2	Fueling Piezo Valves	None	None	2
Fueling Piezo Valves	Plenum roughing valve on piezo injector assembly fail in closed position	mechanical valve failure, or air absent	injector disabled, cannot pump out plenum	2	Fueling Piezo Valves	None	None	2

Design FMECA (V)

System	Failure Mode	Failure Cause	Failure Effect	R	Detection/ Mitigation System (1)	Detection/ Mitigation System (2)	Detection/ Mitigation System (3)	R_R
Fueling Piezo Valves	Roughing valve (NC) on machine side of PZV fail in open closed position	mechanical valve failure, or air absent	inability to rough out intermediate vacuum volume	2	Fueling Piezo Valves	None	None	2
Fueling Piezo Valves	Roughing valve (NC) on machine side of PZV fail in open position	mechanical valve failure, or air permanently present	machine vacuum compromised when injector is open to vacuum vessel	2	Fueling Piezo Valves	Vacuum Gauges and Residual Gas Analyzers	None	2
Fueling Piezo Valves	Pressure transducer (or associated electronics) on piezo injector fails - high reading	Failure of sensor head; failure of electronics which read out the gauge	injector disabled	2	Fueling Piezo Valves	None	None	2
Fueling Piezo Valves	Pressure transducer (or associated electronics) on piezo injector fails - low reading reading	Failure of sensor head; failure of electronics which read out the gauge	injector disabled; might overfill plenum	2	Fueling Piezo Valves	None	None	2

24 FMs, all of acceptable risk before mitigation

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Quality, Environment, Safety and Health

- Travelers required for all machining components
- Approved installation procedures required for all mechanical and electrical work
- PTP shall be performed to validate the PFR functionality

Assemblies	Vendor	QA LEAD	QA BACK-UP	QC
All mechanical and electrical assemblies	PPPL fabrication Shops	Ramos	Malinowski	Ramos

- Potential ES&H concerns:
  - Design: none
  - Fabrication: mitigated by standard PPPL ES&H program
  - Installation: mitigated by standard PPPL ES&H program
  - Operation: mitigated by standard PPPL ES&H program

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Summary

- Requirements have been met.
- Interfaces are considered in the design and documented in the ICDs
- All chits related to the PFR injector job are closed
- No risks in Risk Registry
- No potential radiological impact of item/activity failure
- Minimum potential program impact of a failure