SNS Proton Power Upgrade Project – First Target Station Scope

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SNS Upgrades: 1) Proton Power Upgrade (PPU) 2) Second Target Station (STS)

SNS-PPU upgrades the existing accelerator structure

- Doubles accelerator power capability
- Increases neutron flux to existing beam lines
- Provides a platform for the STS

SNS-STS constructs a second target station with an initial suite of 8 beam lines

PPU increases power by raising energy and current

- PPU delivers a 2.8 MW capable accelerator
- Prior to STS, accelerator will run at **2 MW to First Target Station (FTS)**

	SNS 1.4 MW	PPU full upgrade capability	PPU FTS 60 Hz operation
Proton beam power capability (MW)	1.4	2.8	2.0
Beam energy (GeV)	0.97	1.3	1.3
RFQ output peak beam current (mA)	33	46	46
Average linac chopping fraction (%)	22	18	41
Average macropulse beam current (mA)	25	38	27
Energy per pulse (kJ)	23	47	33
Pulse repetition rate (Hz)	60	60	60
Macro-pulse length (ms)	1	1	1
FTS decoupled moderator brightness/pulse (AU)	1	2.04	1.43
FTS coupled moderator brightness/pulse (AU)	1	2.16	1.51

43% energy increase

33% energy increase

50% current increase

No change

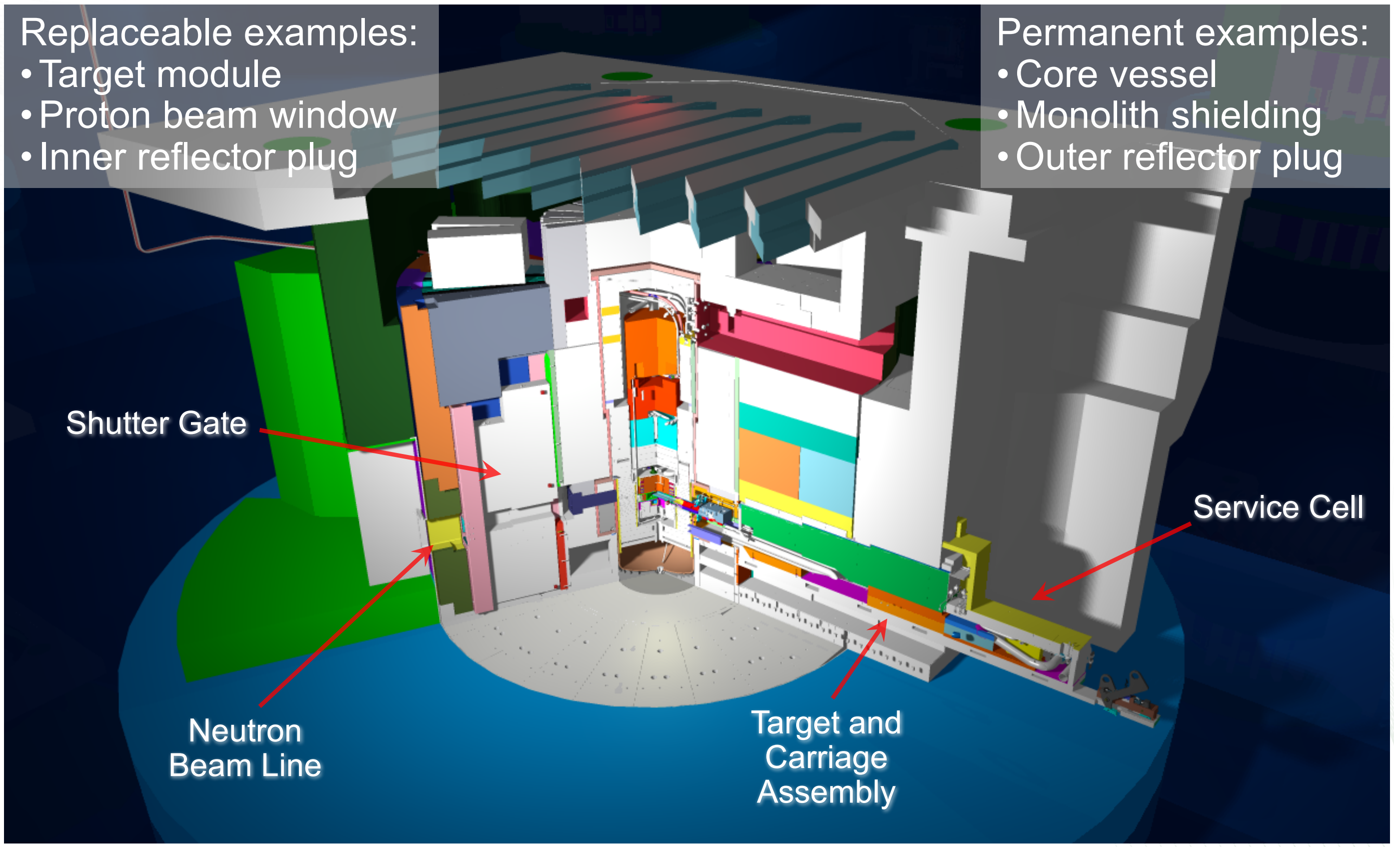
PPU First Target Station Systems

- PPU FTS Systems aims to reliably operate with 2.0 MW of 1.3 GeV proton beam delivered at 60 Hz
- Most of the FTS was designed for 2.0 MW with 1.0 GeV protons
  - The target module is an exception: 1.4 MW
- In addition, the FTS lifetime is extended to 60 years from 40
  - End of life to coincide with projected end of STS
- Target module lifetime goal is 1,250 hours based upon four scheduled replacements per year
  - This frequency is tolerable, expensive, but puts priority on reliable operation

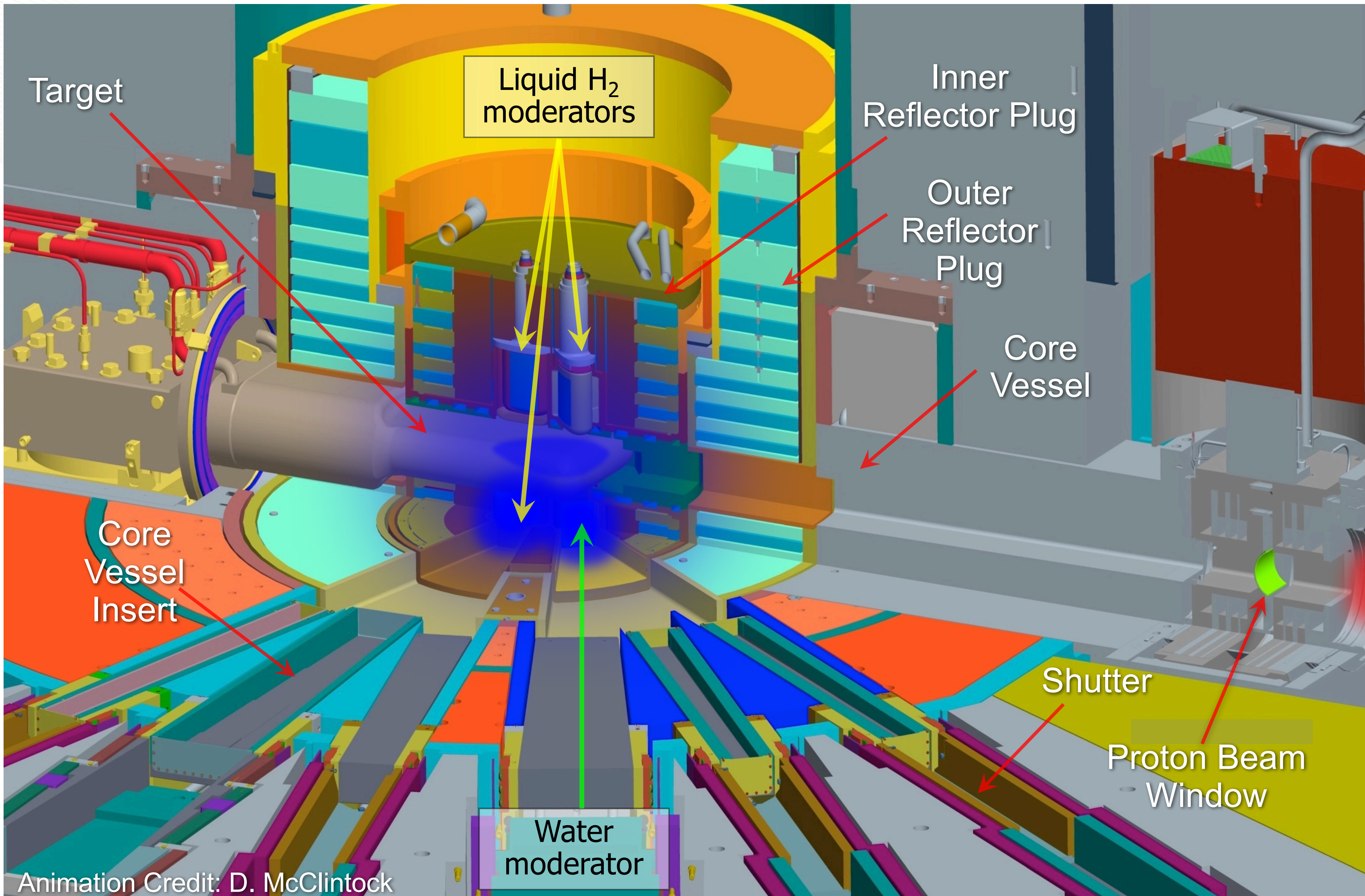
The effects of *increasing proton energy* to 1.3 GeV on FTS systems are altered heating and radiation damage rate distributions

- Some regions in the forward proton beam direction will locally see greater heating and radiation damage rates
- Evaluations will be done to verify systems' adequacies, shielding performance, and define any necessary changes, e.g., cooling flow
- Much of monolith hardware was originally designed with simplified heating functions that bounded neutronic calculations of the day
- Challenges from radiation damage and the extended lifetime will be investigated and resolved

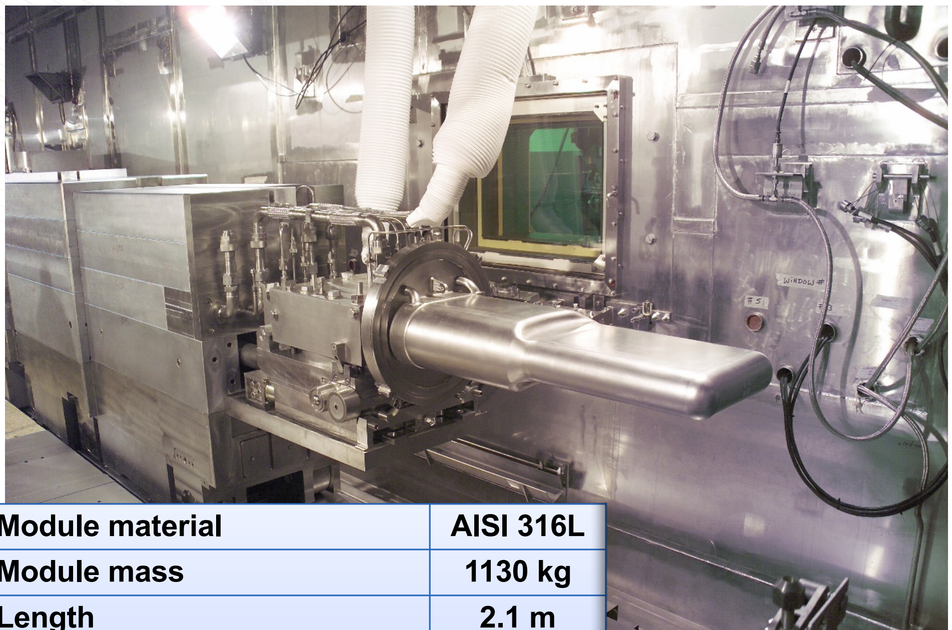
The target monolith is comprised of both permanent and replaceable components

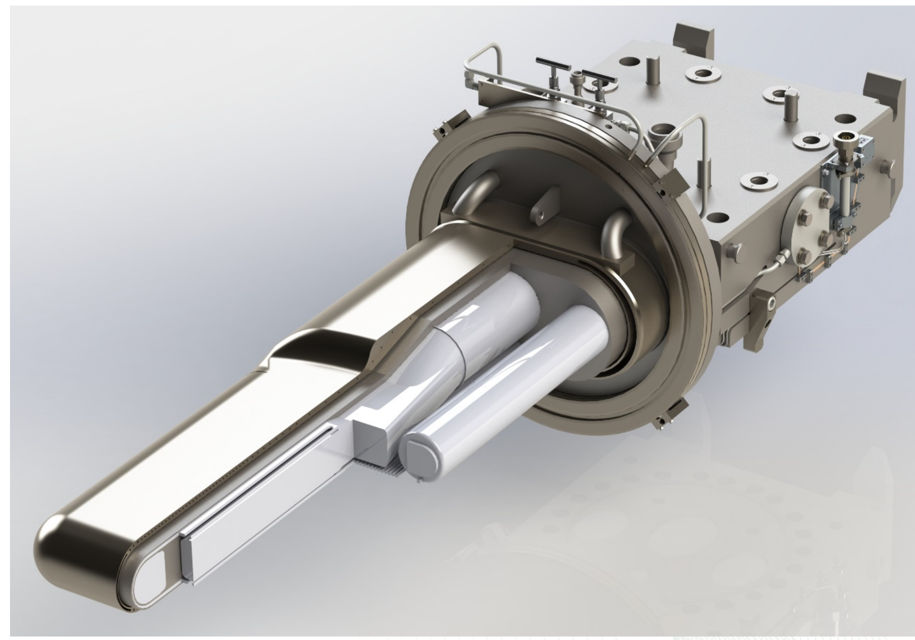


Components at the heart of the SNS target monolith



SNS mercury target is a first of a kind target design: MW class, liquid metal and short-pulse

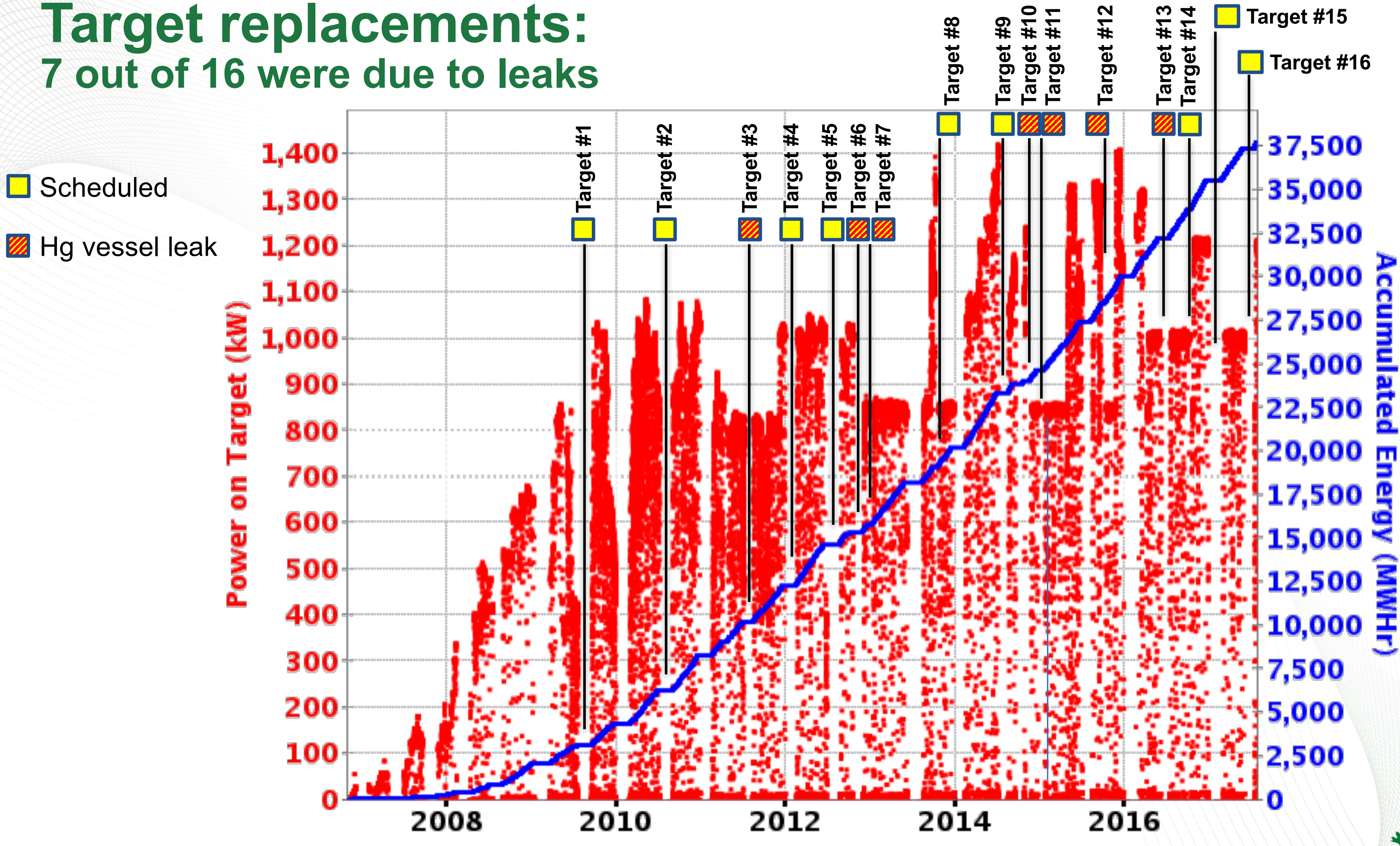




Module material	AISI 316L
Module mass	1130 kg
Length	2.1 m
Mercury mass inside module	794 kg
Mercury mass flow rate	19.4 t/min
Radiation damage limit	12 dpa

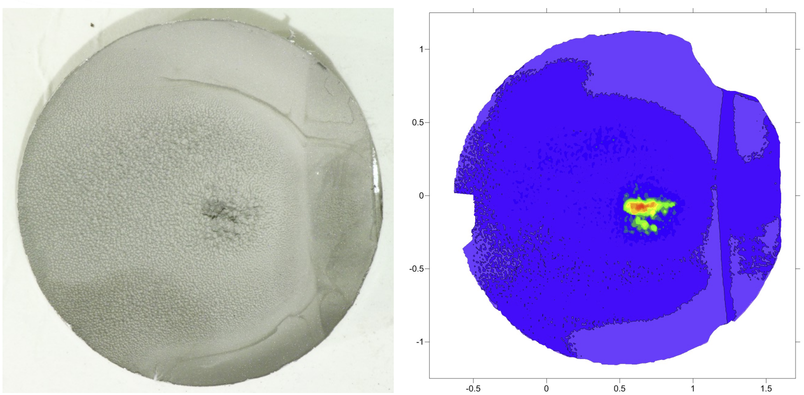
Target module cost: ca. $1.4M

Target replacements:
7 out of 16 were due to leaks

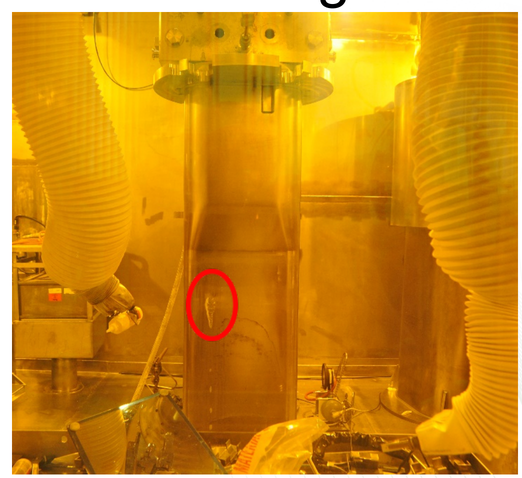


Target lifetime vulnerabilities are understood

- Cavitation erosion from beam-pulse induced pressure waves
- High-cycle fatigue from beam-pulse induced pressure waves
- Thermal-cycle fatigue from interruptions in the beam pulse train
- Undetected fabrication flaws; inattention to weld design



Eroded sample disk from T-13 leak
This sample is not in the proton beam path


T-10 leak found at transition weld

Achieving reliable operation with 1.4 MW of 1.0 GeV beam is within reach

- Target operational reliability is currently improving with a data-driven stepwise approach, with near-term goal of 1.4 MW operation using 3 targets per year
  - Improvements in fabrication oversight are paying off
  - Weld design improvements have been deployed
  - Most recent target leaks were from cavitation erosion
  - Steady power operation
  - Cavitation and high-cycle fatigue life improvement from
    - injection of small gas bubbles (starting this October)
    - directed mercury flow

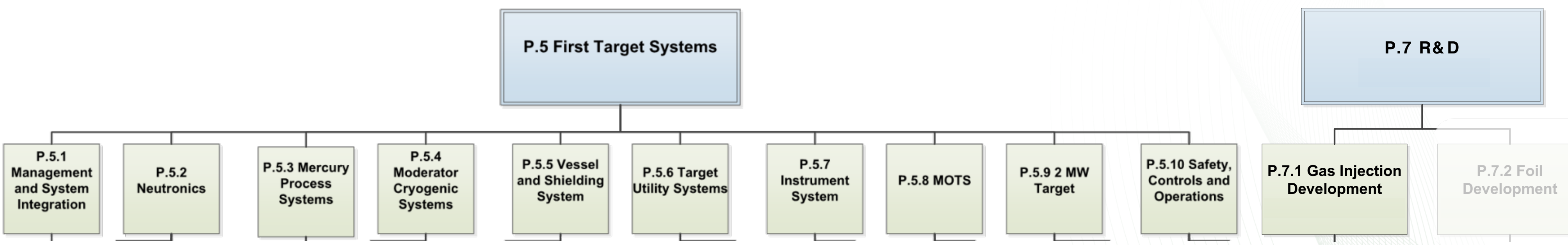
The PPU 2 MW target design and supporting systems will build upon progress with 1.4 MW operations

Strategy for reliable 2 MW operation couples the PPU Target Development Plan with the 1.4 MW operations Target Management Plan

- Path for effective deployment of mitigations are described in the PPU Target Development Plan
  - High-flow small gas bubbles
  - Protective gas wall
  - Directed flow mitigation of erosion
  - Design improvements for fatigue
- Expected outcomes from operations at 1.4 MW are also captured in Target Management Plan
  - Strain reduction from low-flow gas injection
  - Demonstrated erosion reduction from directed flow

Work Breakdown Structure for FTS Systems

- Project work activities are organized by systems directly or indirectly affected by higher power, energy and facility lifetime
- Team leads are composed of matrixed engineers from SNS operations
  - Some with experience back to the original SNS project



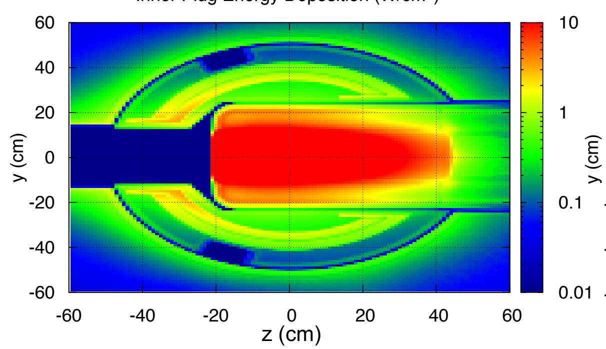
Neutronics

P.5.2
Neutronics
Franz Gallmeier

- **P.5.2.1 Management and System Integration**
- **P.5.2.2 Evaluation at 1.3 GeV**
- **P.5.2.3 System Design Support**
- **P.5.2.4 FTS Source Performance**
- **P.5.2.5 FTS Facility Support**

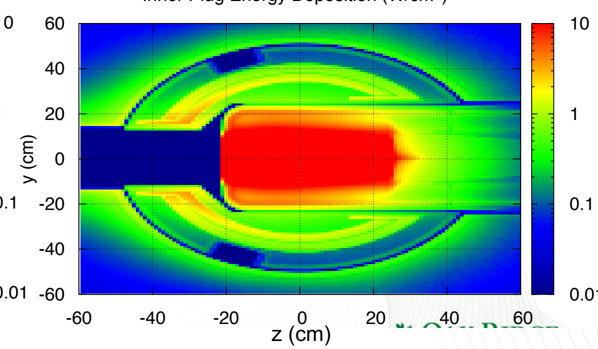
1.3 GeV

Inner Plug Energy Deposition (W/cm^3)



1.0 GeV

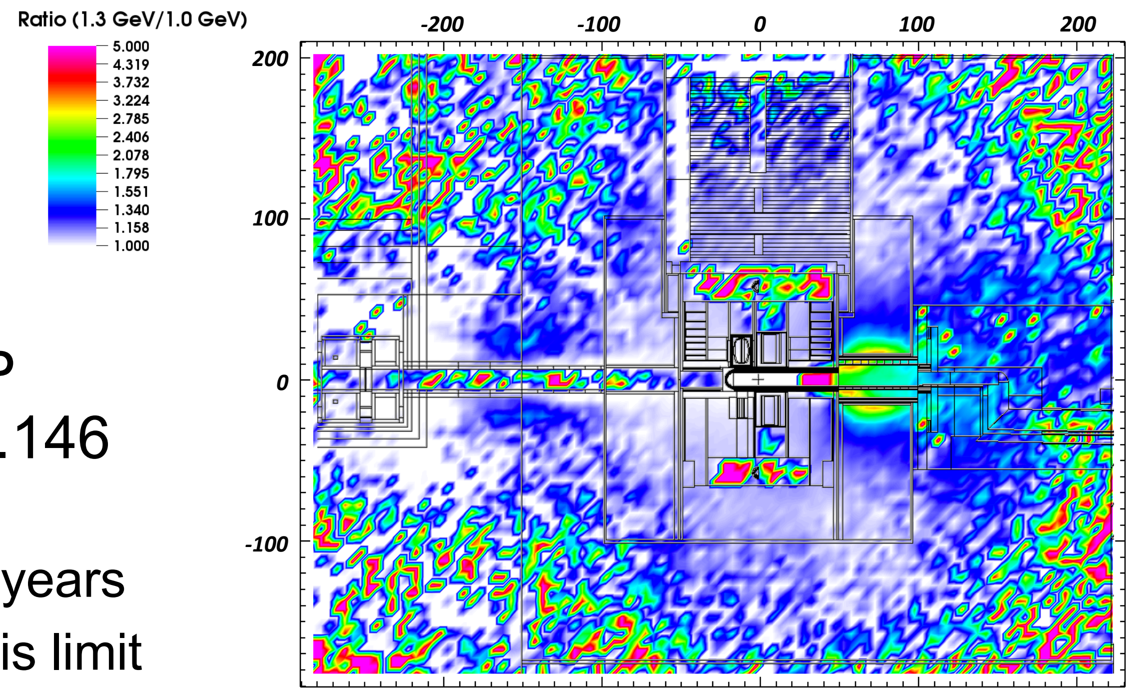
Inner Plug Energy Deposition (W/cm^3)



Energy Deposition in Target Monolith: ORP & core vessel

- Largest increase of heating on downstream side of target
  - ORP and core vessel cooling need to be evaluated

- The peak DPA rate in the ORP increases by from 0.0656 to 0.146 DPA/MW/SNS-year →
  - accumulating 13.3 DPA over 60 years
  - this exceeds original design basis limit of 10 DPA
    - A case can be made to raise DPA limit

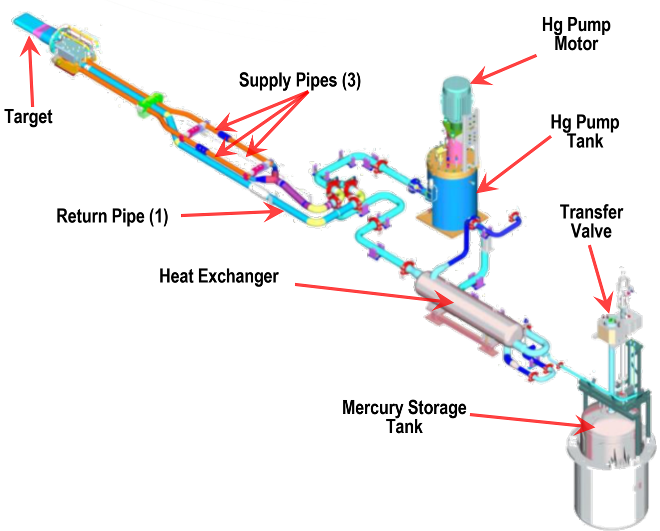


Mercury Process Systems

All service bay modifications must be done remotely

P.5.3 Mercury Process Systems

- P.5.3.1 Management and System Integration
- P.5.3.2 Evaluations at 1.3 GeV
- P.5.3.3 Hg Pump Tank Overflow
- P.5.3.4 Hg Return GLS
- P.5.3.5 In-Cell Target Gas Supply Hardware
- P.5.3.6 Gas Compatible Mercury Flow Meters




Hg process equipment in Service Bay


Candidate Gas-Liquid Separator (GLS) location

Moderator Cryogenic Systems

LH_2 HX and pump modules

P.5.4 Moderator Cryogenic Systems
Greg Laughon

- **P.5.4.1 Management and System Integration**
- **P.5.4.2 Ortho-Para Hydrogen Converters**
- **P.5.4.3 Ortho-Para Hydrogen Converter Diag.**

Converters will tie into HX module

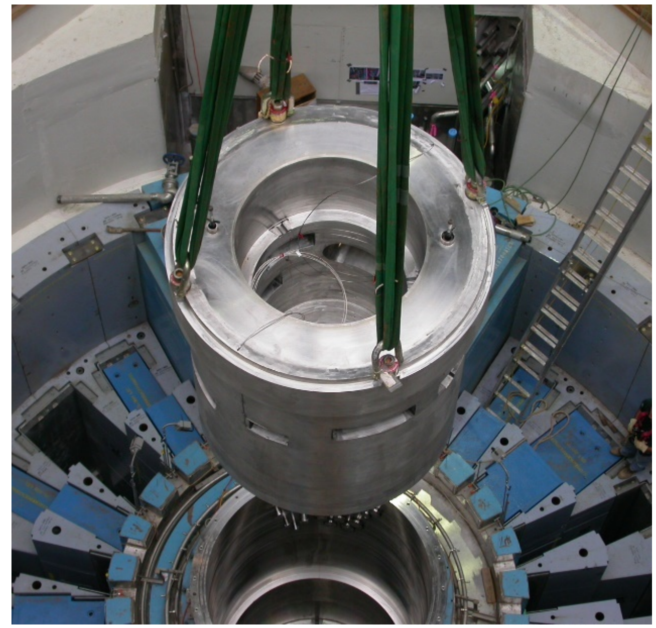
Other essential upgrades – funded by operations – are needed to assure cryogenic systems have sufficient operating margin

Vessel & Shielding Systems

P.5.5 Vessel and Shielding System

- **P.5.5.1 Management and System Integration**
- **P.5.5.2 Evaluations at 1.3 GeV**

Proton beam window

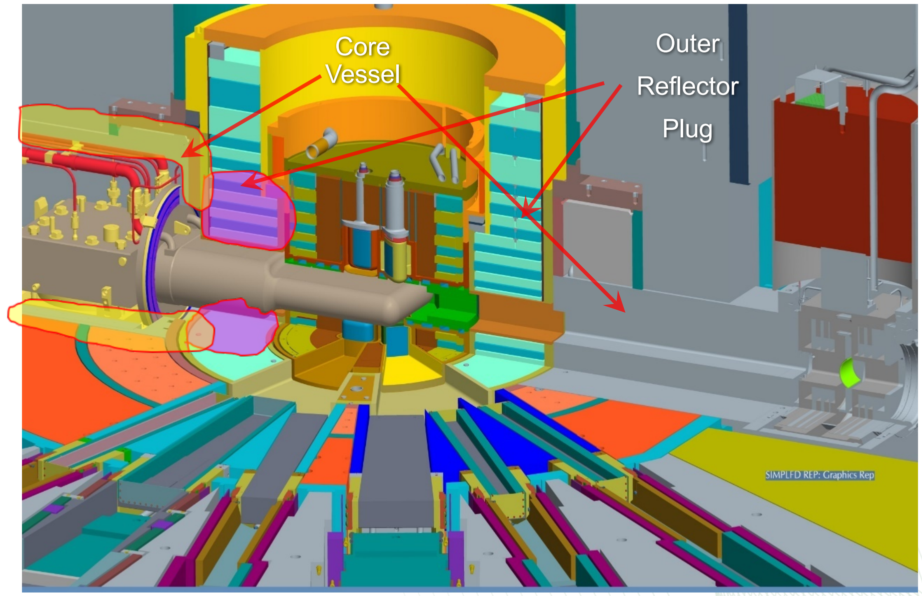


Outer reflector plug

Higher local heating of the ORP and Core Vessel around the target with 1.3 GeV protons

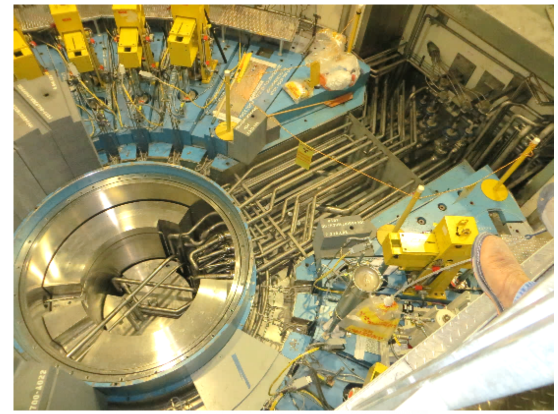
- Thermal evaluations to be revisited with new heating rates
- Increased cooling may be necessary from utilities

- The core vessel is part of a safety credited boundary
- A case will be made to raise the DPA limit for the ORP



Target Utility Systems

Loop 4 pumps and HX



Core vessel pipe pan at top of vertical chases

P.5.6 Target Utility Systems
Lorelei Jacobs

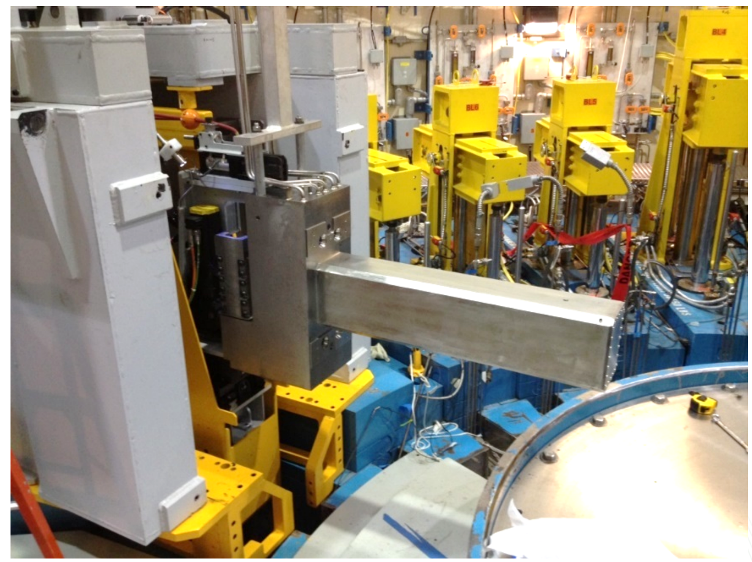
- **P.5.6.1 Management and System Integration**
- **P.5.6.2 Evaluations at 1.3 GeV**
- **P.5.6.3 Upgrades for 1.3 GeV Systems**
- **P.5.6.4 Upgrades for Gas Injection**

Instrument Systems

Core vessel insert neutron windows are part of the safety credited boundary

P.5.7 Instrument System
Scott Keener

- **P.5.7.1 Management and System Integration**
- **P.5.7.2 Evaluations at 1.3 GeV**



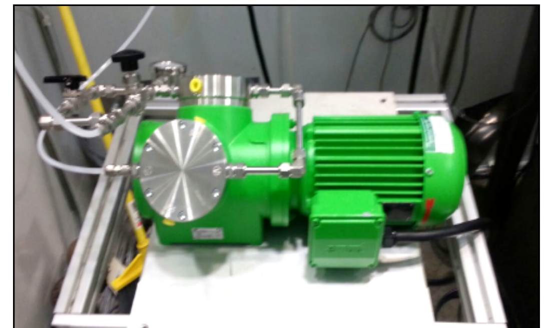
Core vessel insert

Mercury Off-Gas Treatment System (MOTS)

MOTS delay bed #1

P.5.8 MOTS
Greg Stephens

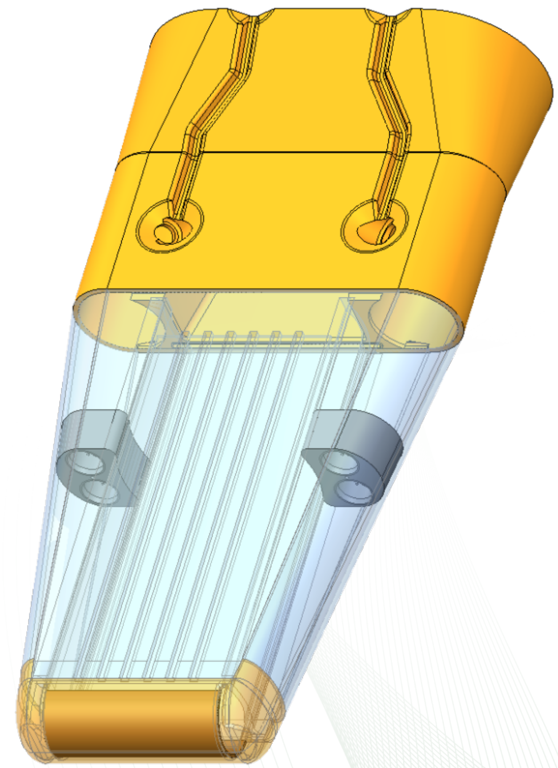
- **P.5.8.1 Management and System Integration**
- **P.5.8.2 Additional MOTS delay bed**
- **P.5.8.3 Recirculating Gas Compressors**



Candidate helium compressor

2 MW Target – design and fabricate

- **P.5.9 2 MW Target**
  Drew Winder
  - **P5.9.1 Management and System Integration**
  - **P.5.9.2 Target Module**
  - **P.5.9.3 Supporting Hardware**



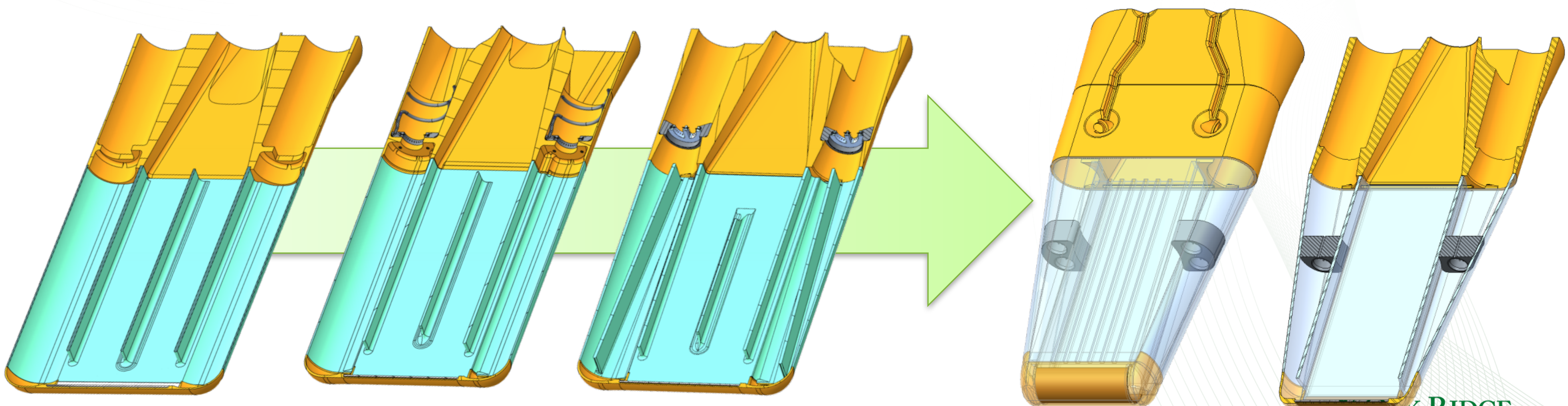
Mercury Vessel Design Concept

The PPU Target Conceptual Design incorporates gas injection, directed mercury flow and design changes to reduce fatigue stress

- High-flow small bubble injection with swirl bubblers
- Gas wall at center of inner window
- Modified geometry of structure for directed flow and robustness
- Shape optimization of high stress areas

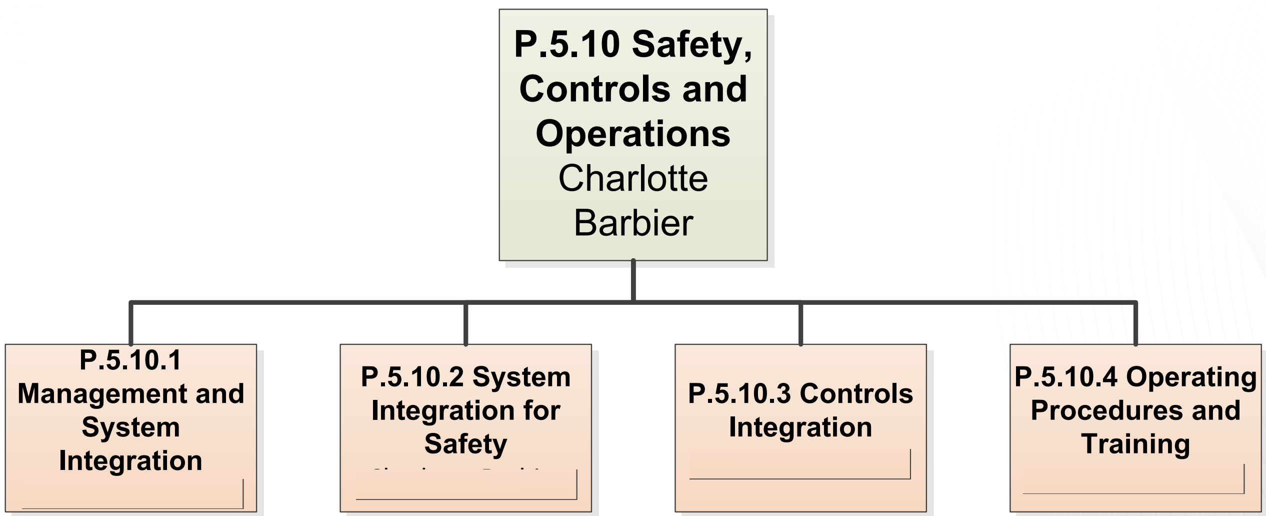
Operations 1.4 MW target

2MW Target Concept



Safety, Controls & Operations

- Vital activities for successful projection completion and safety authorization
- Valuable lessons are being learned now from low-flow gas injection



Four hazards have been identified requiring formal safety evaluation

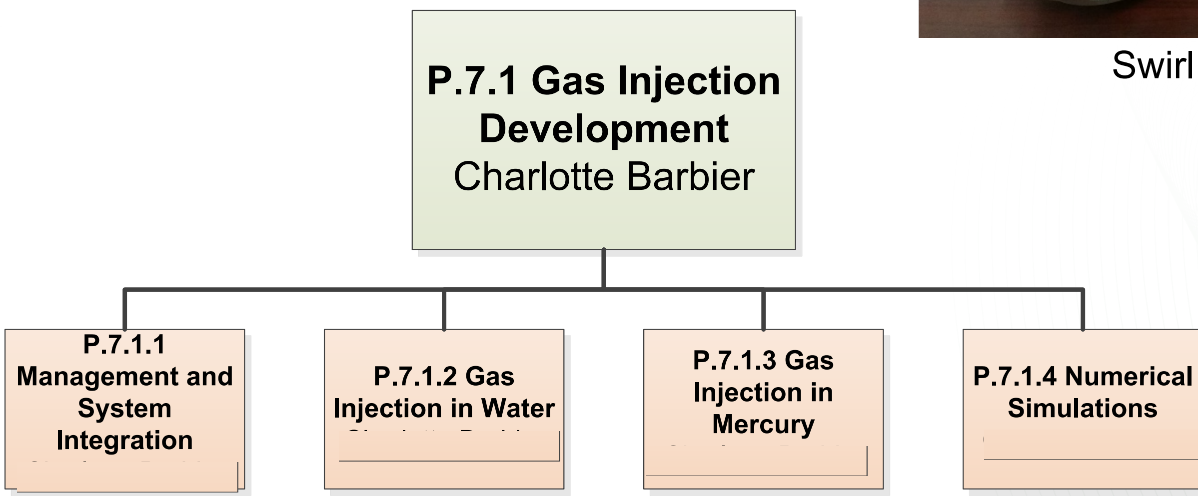
P.5 Hazard	Decision	Rationale
Increased beam particle energy from 1 GeV to 1.3 GeV—effect on target spallation product inventory considering increased particle energy as well as longer (60 y) nominal target facility lifetime	USI required	Longer facility lifetime and higher energy lead to ca. 2x the Gd-148 (74 y half-life) originally estimated
Increased beam particle energy from 1 GeV to 1.3 GeV—effect on target core vessel component heat deposition distribution	USI required	Change in heat deposition distribution has the potential to affect the performance of a safety credited feature
Injecting helium into the circulating target mercury in the target module to reduce the rate of cavitation erosion of the target module and increase fatigue life margin	USI required	Mercury pump tank overflow accident could lead to mercury escaping service bay, go into MOTS equipment
Increased hydrogen inventory of the target cryogenic moderator system due to the proposed installation of a catalytic conversion stage to convert ortho-hydrogen into para-hydrogen.	USI required	Consequences of postulated accident increased; credited relief devices; new accident type possible

Experience from current efforts on low-flow gas injection will ease resolution of high-flow gas injection hazard

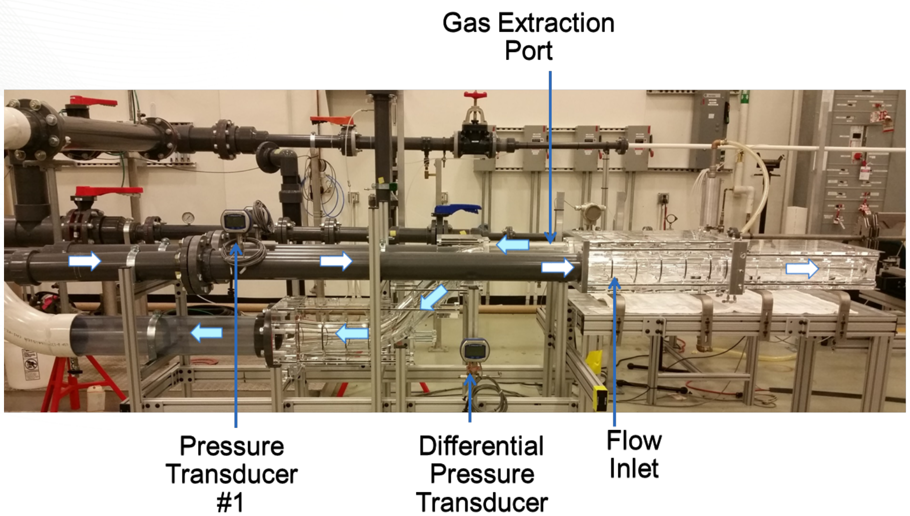
Gas Injection Development

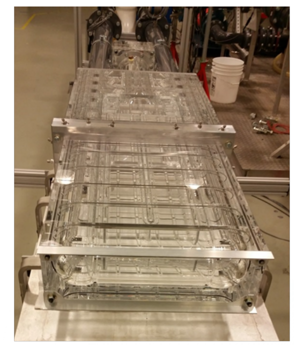
- P.7.1 scope covers design development of:
  - Target bubbler
  - Protective gas wall
  - Gas-liquid separator (GLS)

Swirl bubblers

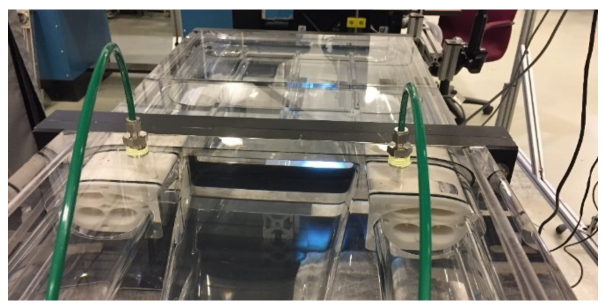


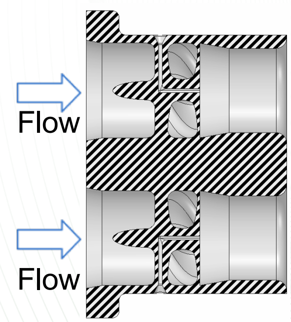
Water test loop



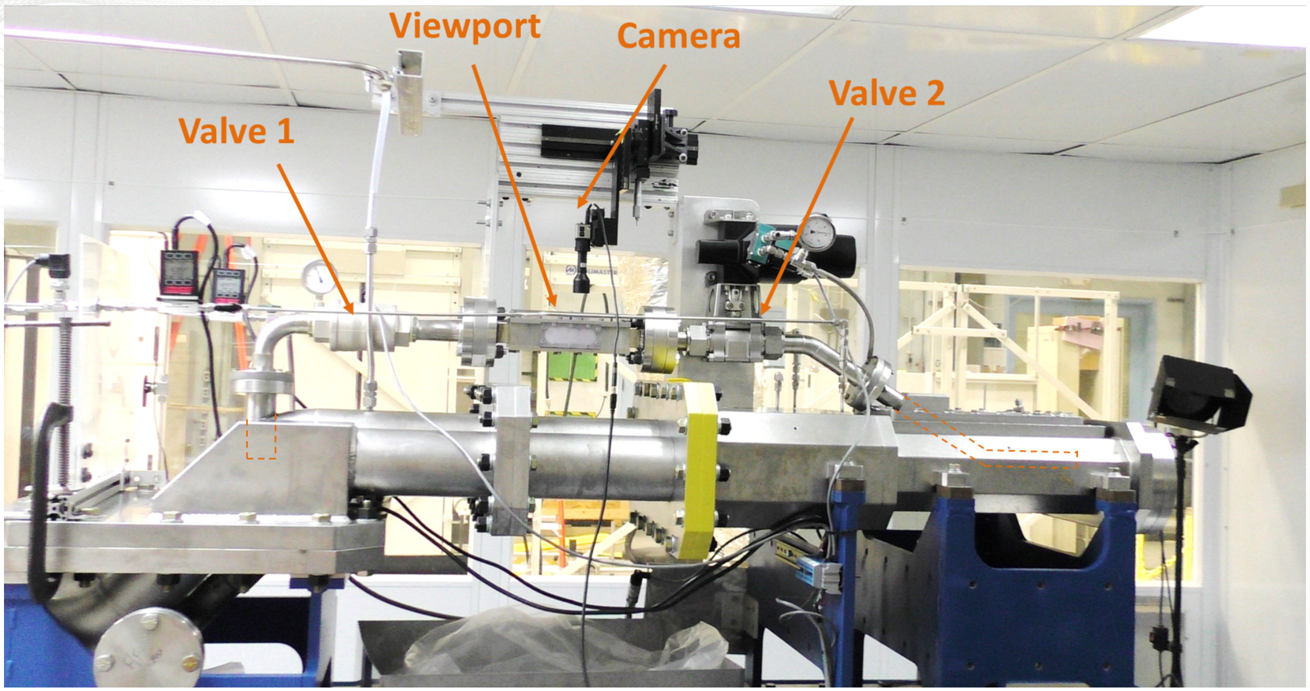


Top View

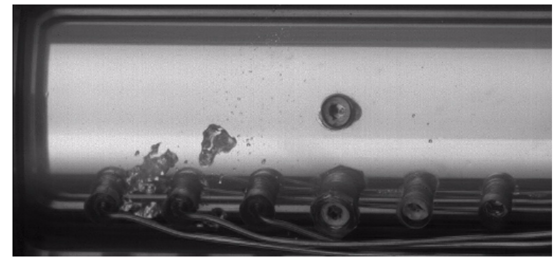




Mercury test loop



Target Test Facility (TTF) at ORNL

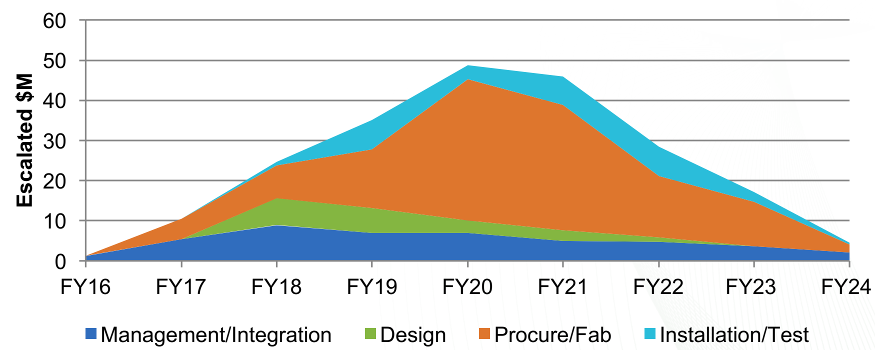


Gas wall layer on a original target design tested at TTF (2008)

3D printed SS Swirl Bubbler (ready to be tested this summer)

PPU project status

- 2016 – 2017: Conceptual design activities
  - Conceptual design report and system designs
  - Cost and schedule basis
  - Office of Program Assessment “CD-1” review in May 2017
- Cost Estimate: $216 M
  - 35% contingency
  - Range is $184 - $320 M
  - **FTS Systems estimate - $24M**



- Funding status
  - Not in FY18 president’s nor in house budgets
  - $26M in senate budget

Summary

- PPU will double the SNS accelerator power
- First Target Station upgrades are included in the project scope to assure reliable 2 MW operation at 60 Hz with 1.3 GeV protons
  - Other powers or beam pulse rates as a consequence of Second Target Station operation will be evaluated as part of the STS project
- Awaiting approval of line-item funding