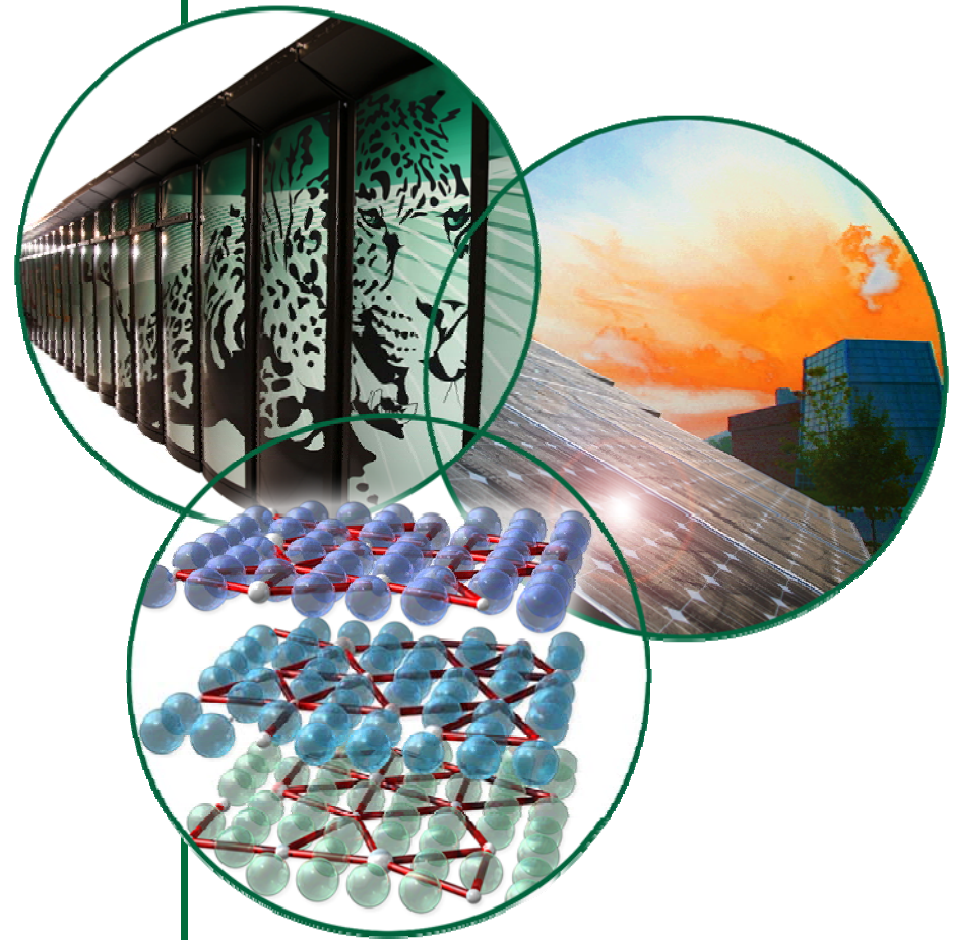


SNS Target Systems Operational Experience and Upgrade Plans

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October 2009

**Workshop on Applications of High
Intensity Proton Accelerators
October 19-21, 2009
Fermi National Accelerator
Laboratory, Batavia, IL, USA**

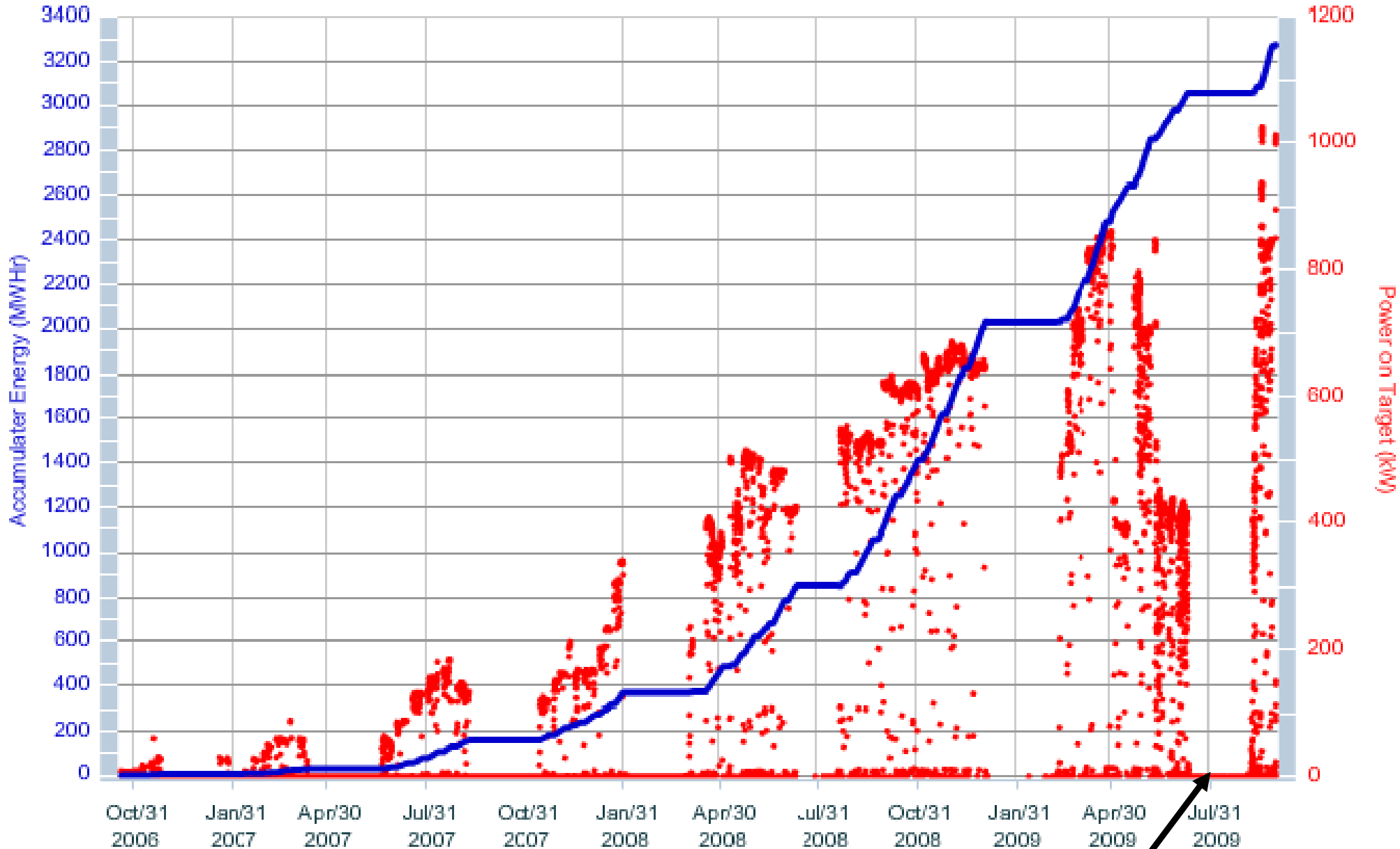


Overview

- Overall Power and Availability History
- Target Systems Availability and Operational Issues
- Proton Beam Window Replacement
- Target Imaging System
- Mercury System Development
- Power Upgrade Planning
- Second Target Station Planning

Energy and power on target from October 2006

Power on Target



First Target & PBW Replacement



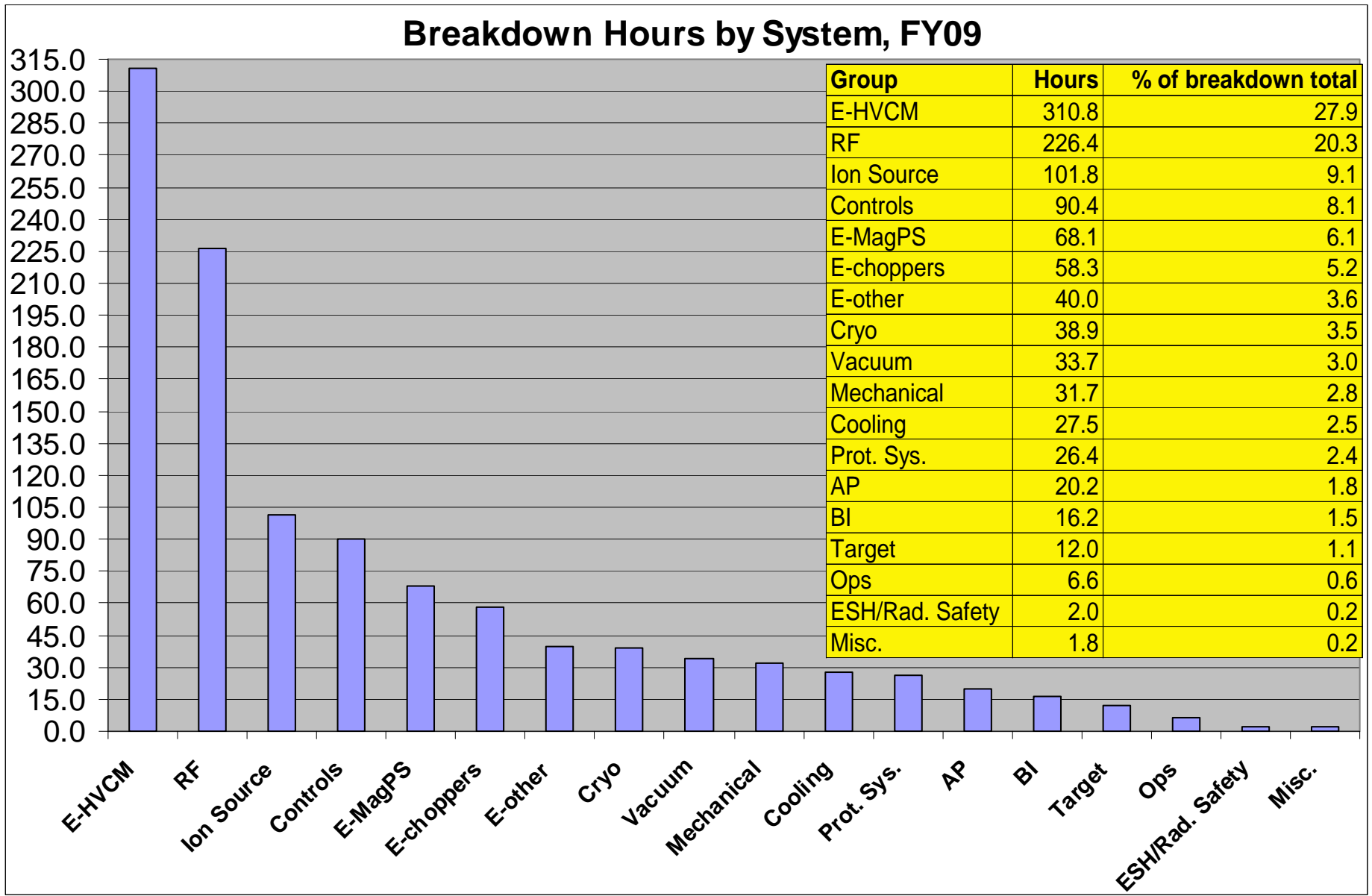
SNS Performance Relative to Design

	Design	Best Ever	Routine Operation
Kinetic Energy [GeV]	1.0	1.01	0.93
Beam Power [MW]	1.4	1.02	0.85
Linac Beam Duty Factor [%]	6	4.8	4.8
Peak Linac Current [mA]	38	56	38
Linac pulse length [msec]	1.0	1.0	0.8
Repetition Rate [Hz]	60	60	60
SRF Cavities	81	80	80
Ring Accumulation Turns	1060	1020	800
Ring Bunch Intensity	1.5×10^{14}	1.5×10^{14}	1.1×10^{14}

The “Best” values were not necessarily achieved simultaneously



Overall Unscheduled Downtime - FY09



Good availability has been achieved for the Target Systems



Operational Issues

- The mercury pump required repairs in 2007 to fix a failed gas seal on the shaft and leaking oil seals but has operated well since then
- The moderator 7.5 kW helium refrigerator was repaired in December 2007 by installing the heat exchanger core in a vertical cold box
 - This stopped the trend of a loss of capacity with time and allowed 4-5 month run cycles
 - Recently the problem has reappeared at higher flow rates and is under investigation
- A cryogenic hydrogen flow problem with the bottom downstream moderator was fixed by installing a flow guide (spring) through the transfer line using a 10 m fiber optic probe from outside the monolith

Target & PBW Replacement

- The first target accumulated 3055 MW hours with an estimated peak damage of 7.5 dpa in the 316L material
- While up to ~ 10 dpa was considered acceptable, it was replaced early during the July shutdown to avoid unscheduled loss of neutron production during the next run cycle
- The Inconel 718 Proton Beam Window (PBW) was also replaced during this shutdown with an estimated peak damage of 6.5 dpa.
- The PBW replacement was done early to avoid scheduling conflict with other remote handling work planned for the next shutdown.
- The target and PBW replacement also allowed deployment of a new Target Imaging System (TIS) which could improve estimates of the peak beam intensity on the target

Proton Beam Window Replacement

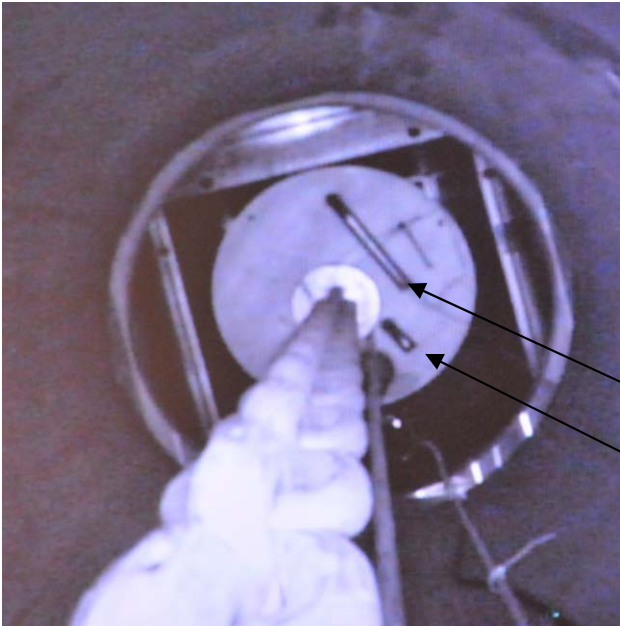


Shielded Cask and Hoist



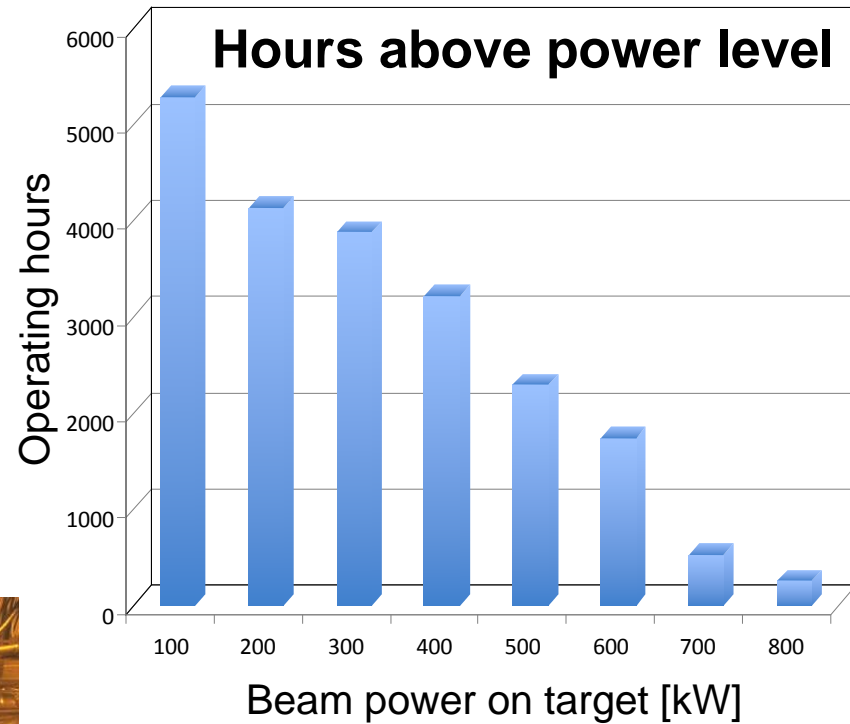
New PBW with guide can and counterweight being installed

Old PBW during retraction into cask →



Cooling lines cut prior to removal with long handle tools

First target replacement



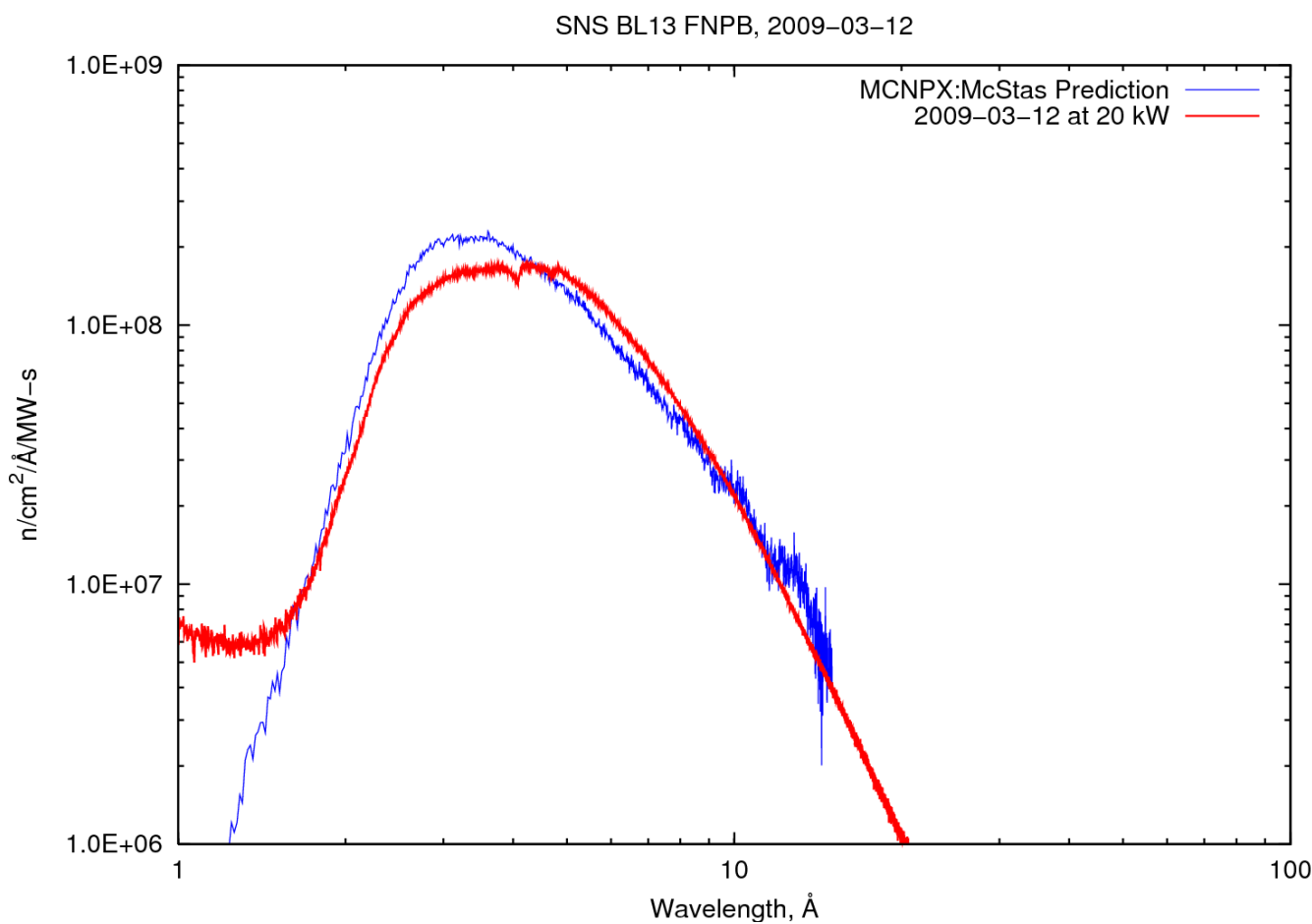
- No observed corrosion
- Internal Boroscope examination in progress
- ~ 50 mm diameter samples to be cut from target nose around the end of October

Target Operational Experience

- The first target performed very well
 - No mercury leak indications in the target or other connections
 - No water leaks
 - Inflatable seal to the core vessel worked well and the helium concentration in the vessel was typically maintained at >99.97%
 - No evidence of any corrosion on the target after removal
 - Neutronic performance appears consistent with predictions based on moderator performance
- The second target has accumulated > 400 MW-hrs as of 10/12/09
 - The inflatable seal does not appear to be expanding fully, but core vessel helium is being maintained >99.97% using a small helium flow instead of vacuum for the interstitial region

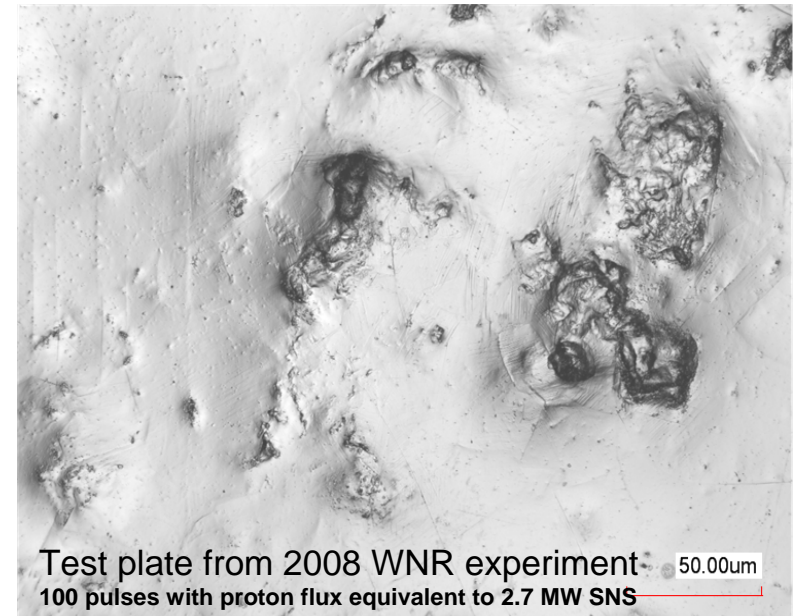
Source seems to be performing as predicted

- Neutron flux at sample location
- Bottom downstream coupled hydrogen moderator (post Jan09 repair)
- Includes guide modeling in McStas and MCNPX

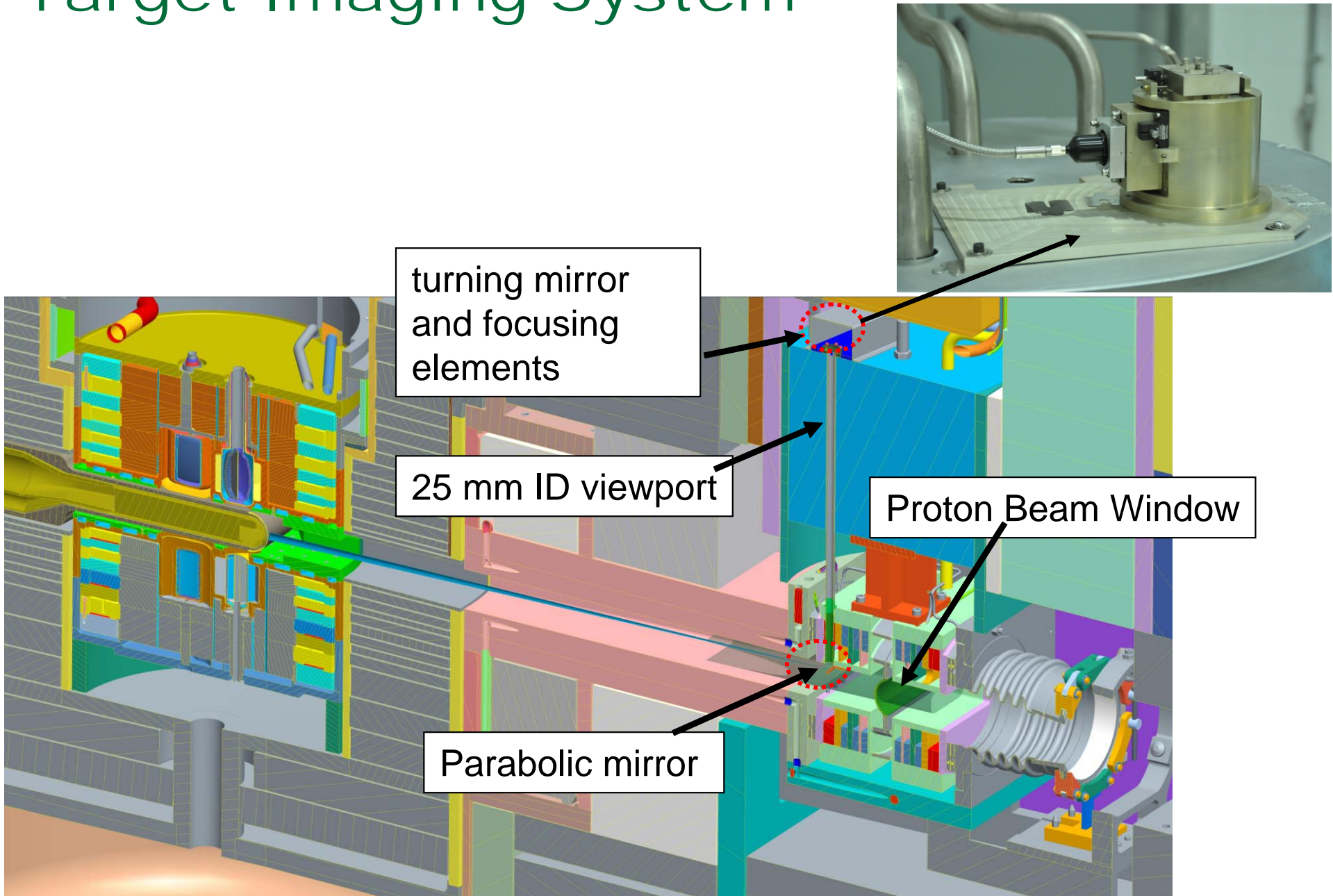


Target Lifetime Considerations

- The first target operated for >1700 hours at or above 600 kW and up to 800 kW without a failure
- R&D by the SNS and J-PARC teams has shown that the target wall is likely to experience pitting damage by the collapse of cavitation bubbles
 - This has been shown for short pulse (< 1 μ second) operation
 - The rate of damage is sensitive to beam power (P⁴?)
- A target imaging system (TIS) is being developed to give improved measurement of the beam profile which could improved beam control and target lifetime
- Mitigation methods using small distributed bubbles or bubble walls near the surface are being developed by the R&D programs

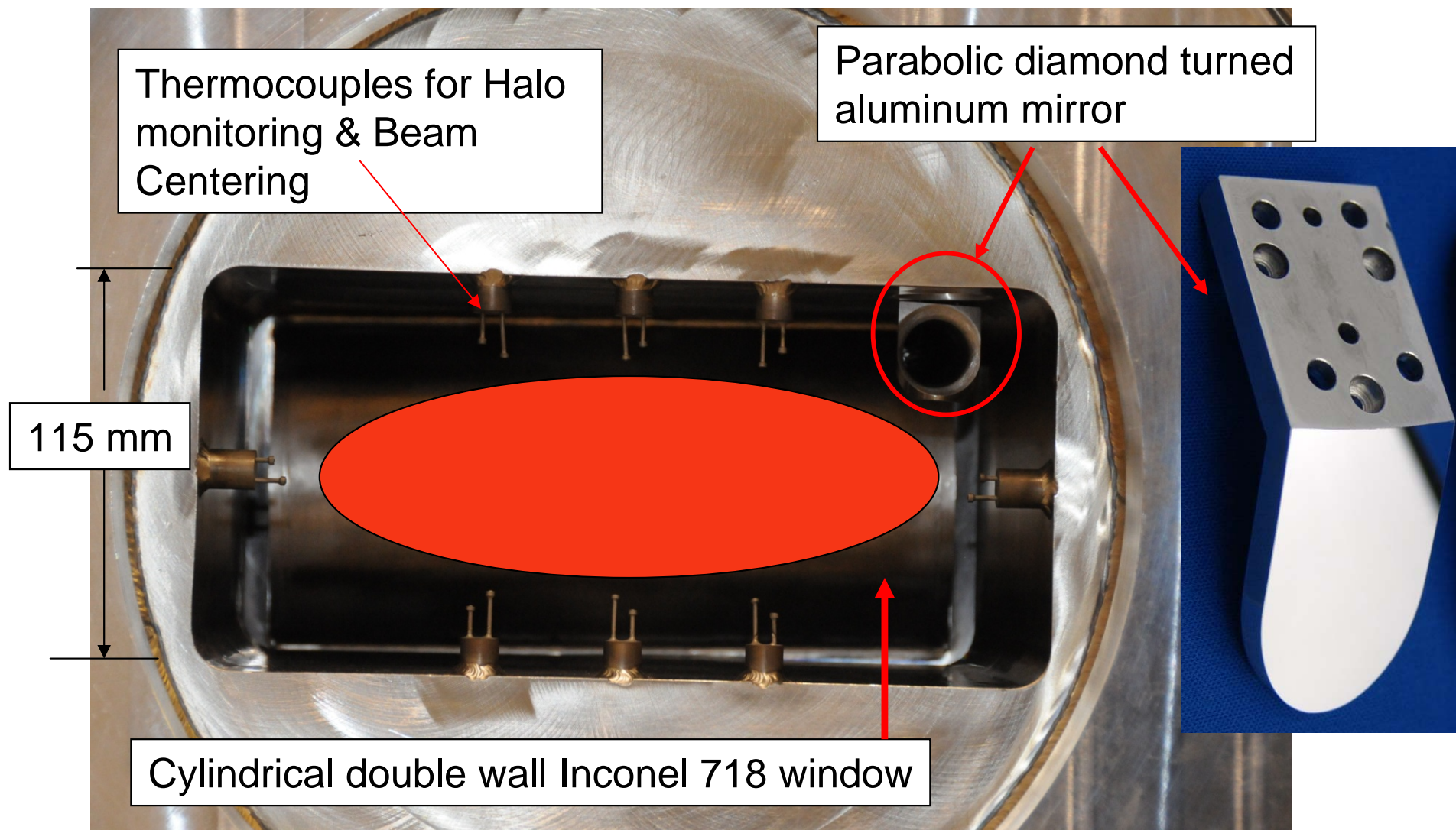


Target Imaging System



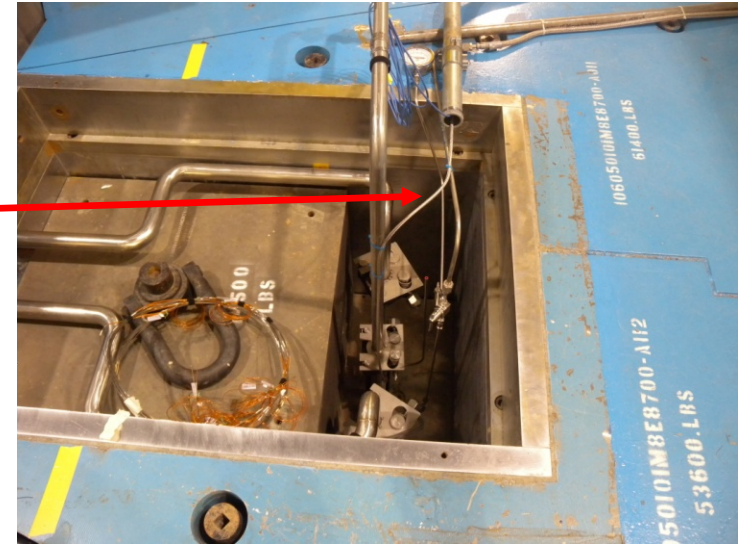
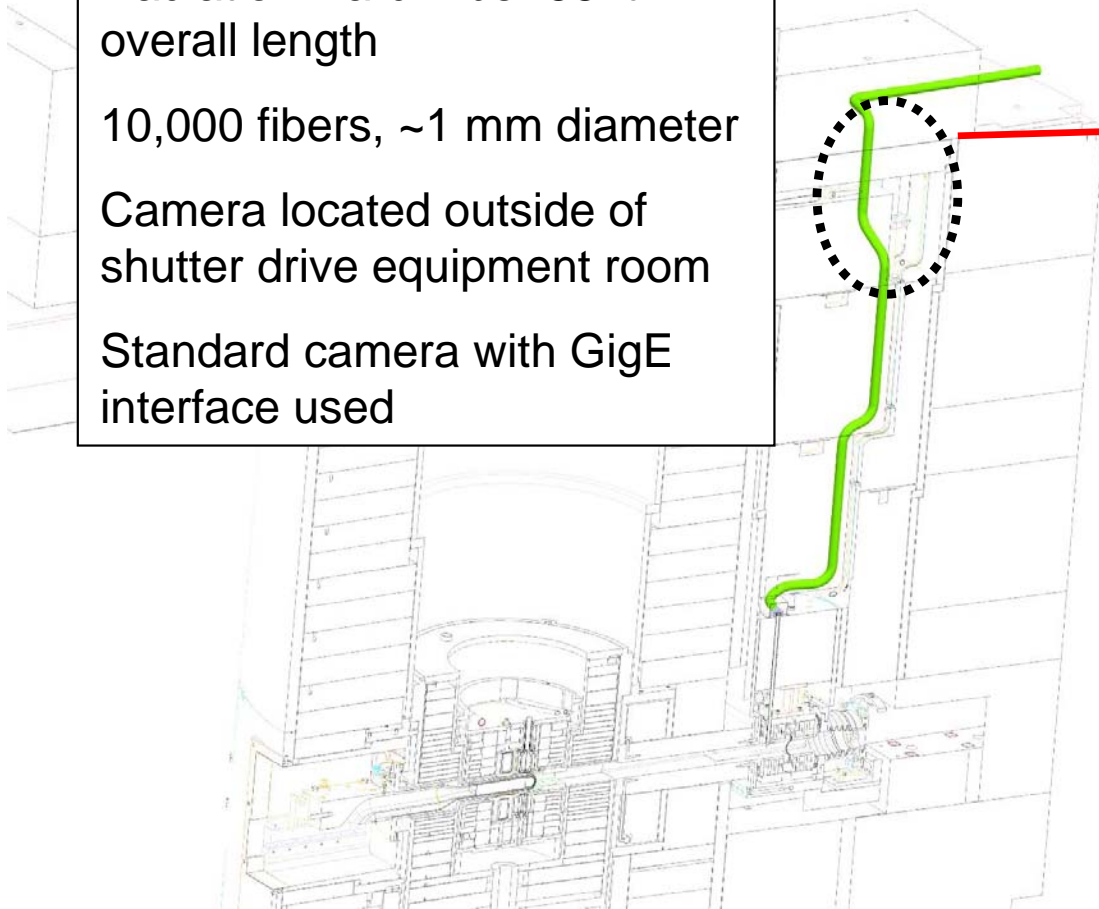
System Deployed during July 2009 Shutdown

Second PBW view from downstream side



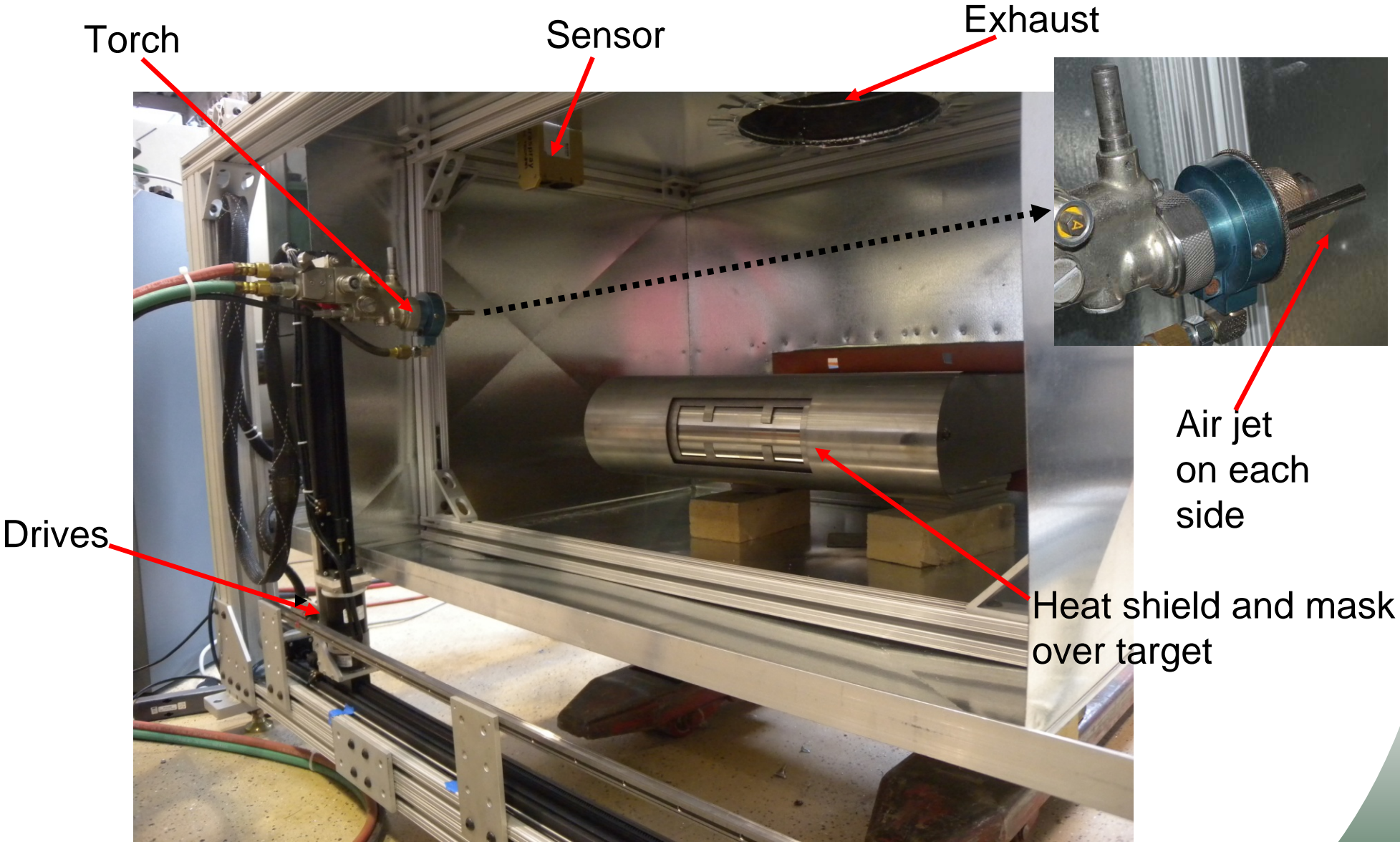
Imaging Fiber routing

Radiation Hard Fiber 38 ft overall length
10,000 fibers, ~1 mm diameter
Camera located outside of shutter drive equipment room
Standard camera with GigE interface used



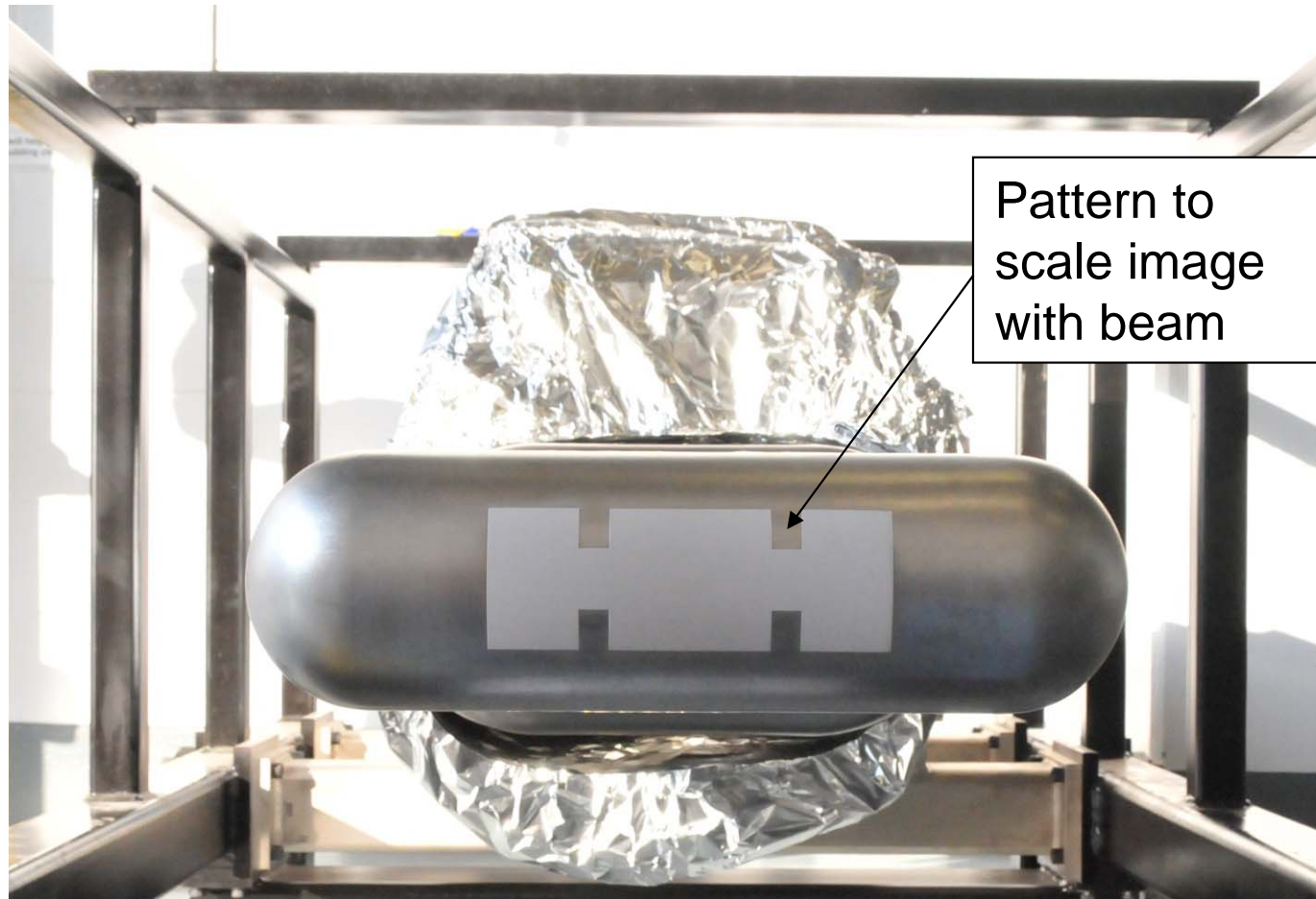
Camera mounted outside shielding

Flame Spray ($\text{Al}_2\text{O}_3 + 1.5\% \text{CrO}$) development



Portable Flame Spray Coating and Ventilation System Developed by the Center for Thermal Spray Research (SUNY at Stony Brook)

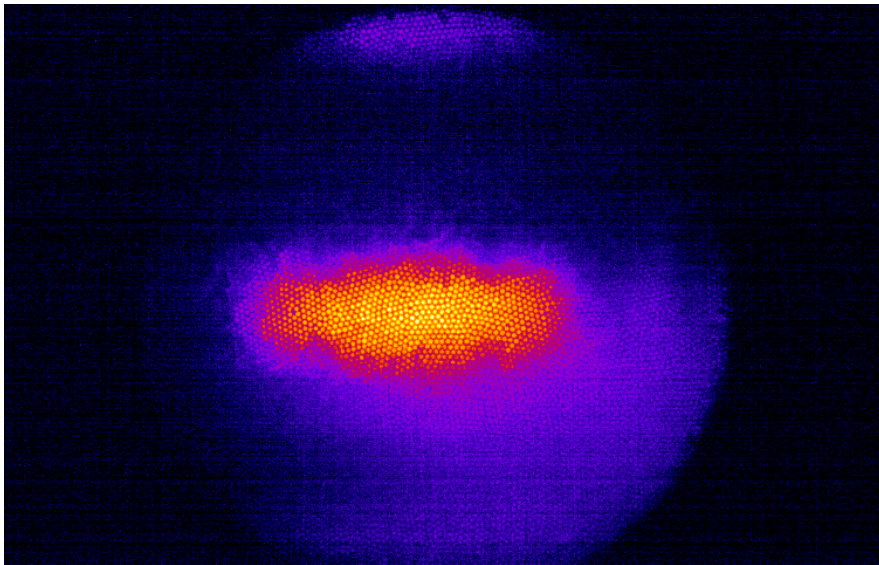
Completed Target Coating



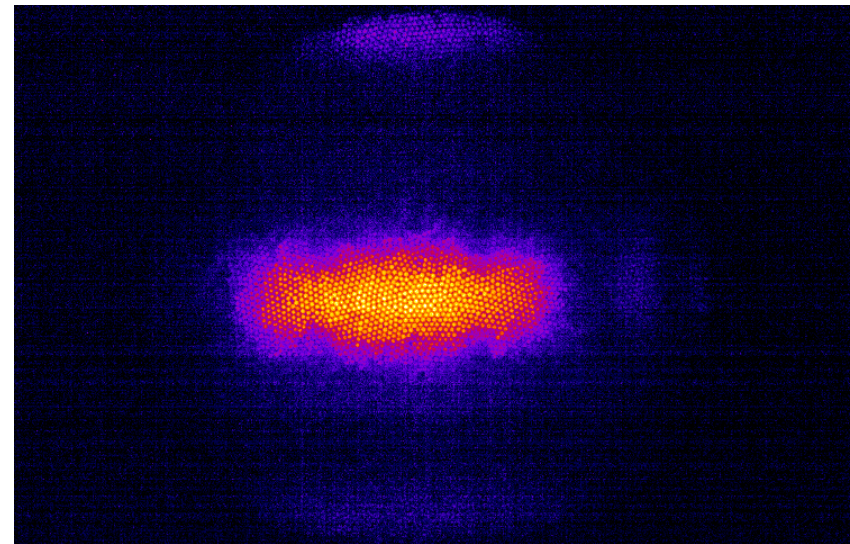
Nominal Thickness 0.25 mm, 200mm x 70 mm pattern

Mockup testing established parameters and showed substrate temperatures were < 120 C with air cooling

False color target images at 800 kW

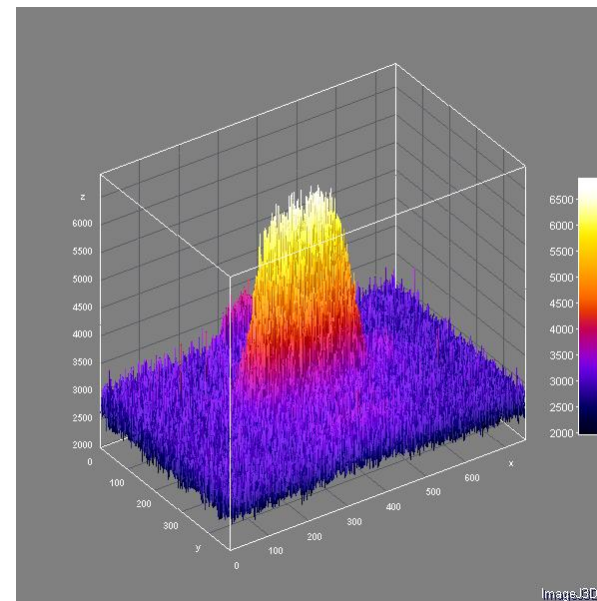


Case 1: image with potential gas scintillation



Case 2: image with shutter delayed by 4 microseconds to gate out suspected gas

- Data analysis of profiles in progress
 - Initial results similar to previous projections
 - No beam tilt
 - ~10% higher peaking than previous estimates

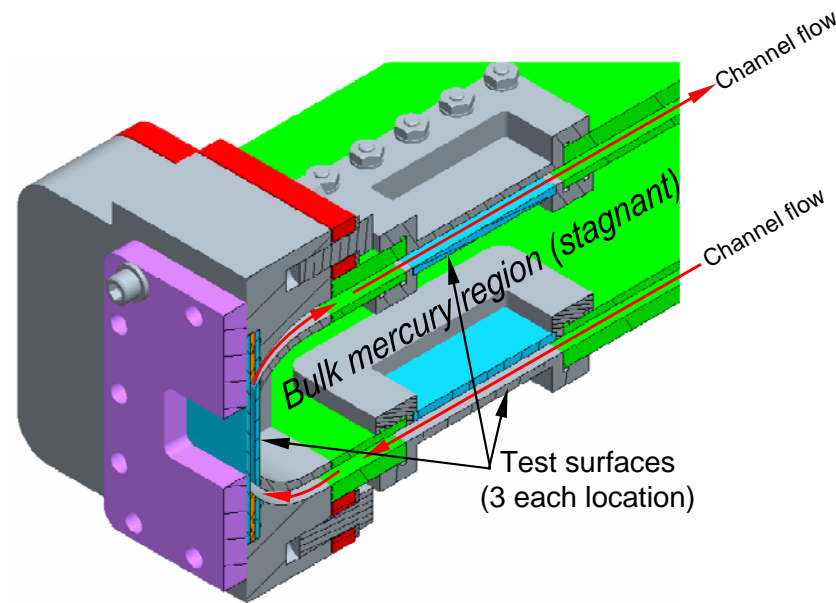
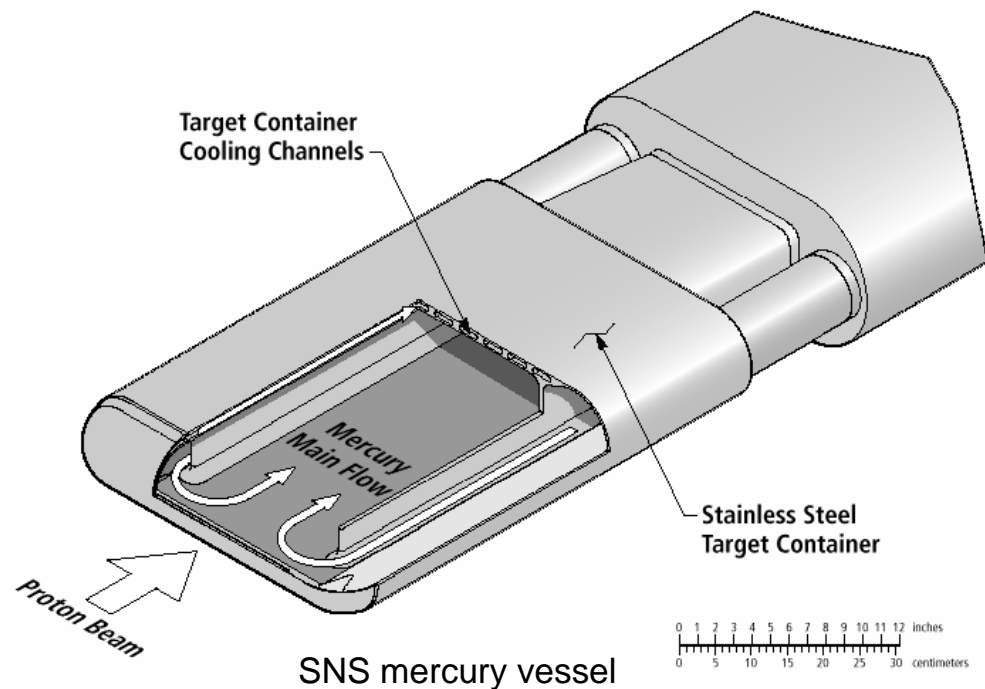


SNS R&D on cavitation damage mitigation began in 2001

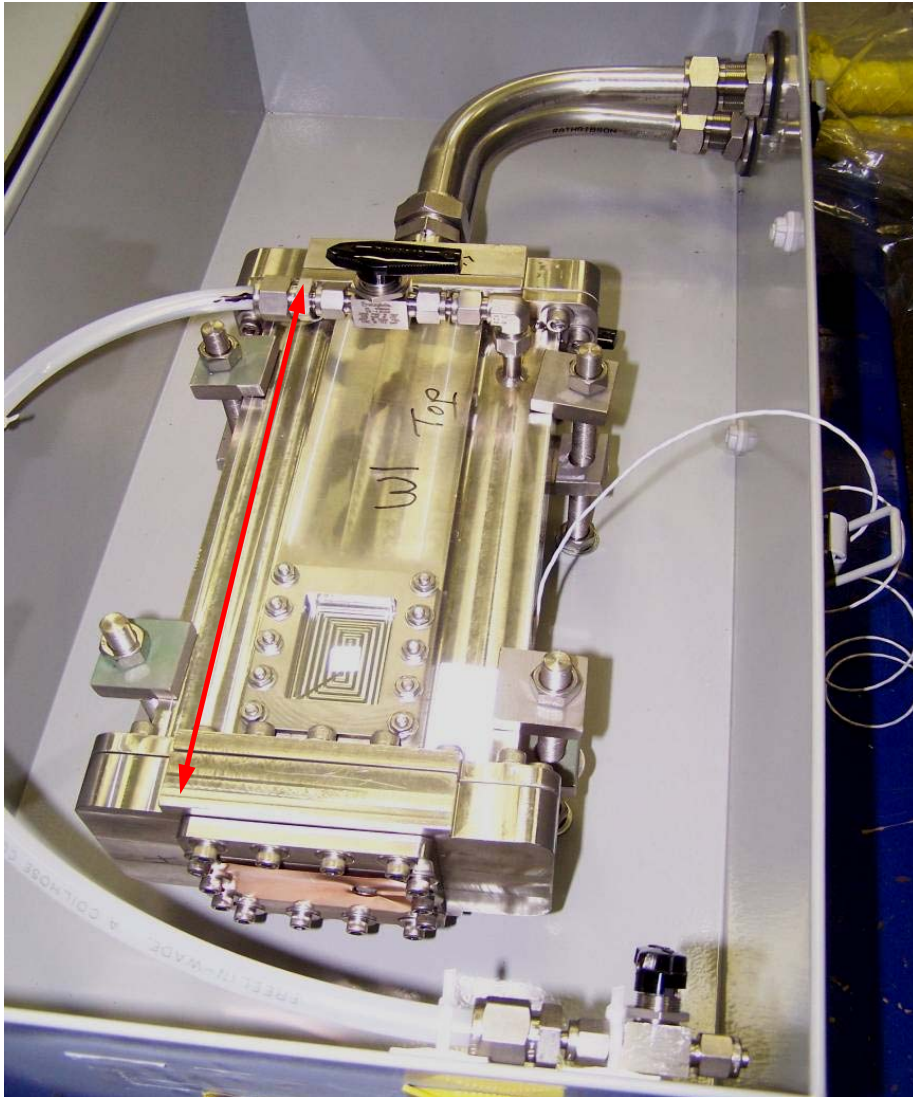
- The program includes experimental, simulation and theoretical activities
 - Five full time staff members at ORNL and ~12 part time contributors
 - (Bernie Riemer is the team leader)
 - Contributions from universities and industries
 - Collaborations with JPARC and RAL
- Goal is to develop technologies to mitigate damage such that it is not the life limiting mechanism for the target
- Key points:
 - The damage erosion rate is strongly sensitive to beam power ... perhaps as much as P^4
 - Target vessel materials and surface protecting treatments have limited potential to significantly extend the life and power capacity of the vessel
 - Power threshold for damage to begin is uncertain for SNS

Window Flow Vulnerability Test Loop (WFVTL) experiments (WNR 2008)

- In-beam experiment examined narrow mercury channel damage under conditions more prototypic to SNS
 - Previous in-beam test results for channel damage indicated this region is especially vulnerable
- Investigated damage reduction vs. flow velocity
 - Previous in-beam test indicated damage *reduced by flow*
- Sought confirmation that water in channel is benign



WFVTL target module and mercury loop



Hg length: 325 mm



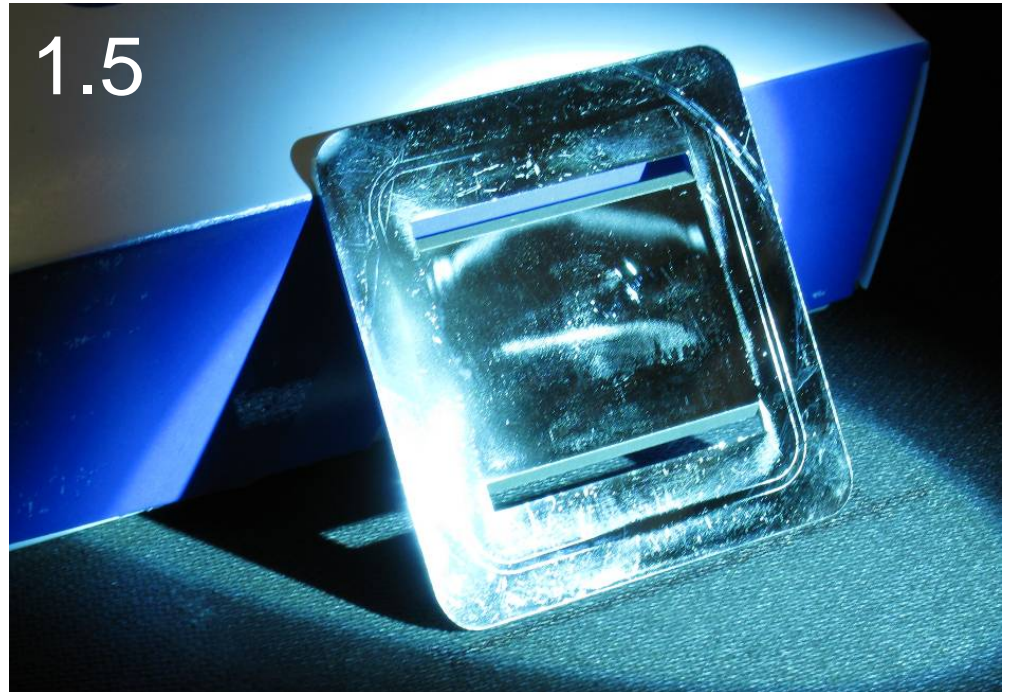
- Variable speed centrifugal pump employed for channel flow speeds for up to 7 m/s
 - Only ca. 4.3 m/s achieved
- Test targets connected to loop via flexible hoses

Damage patterns - Front inside plate - Channel side

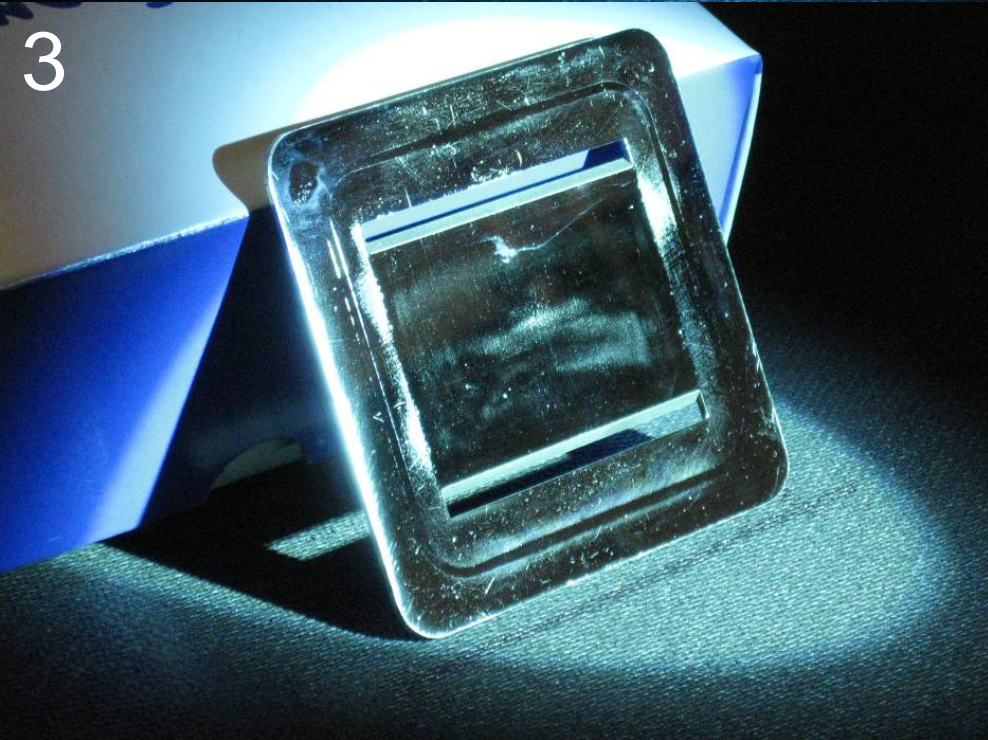
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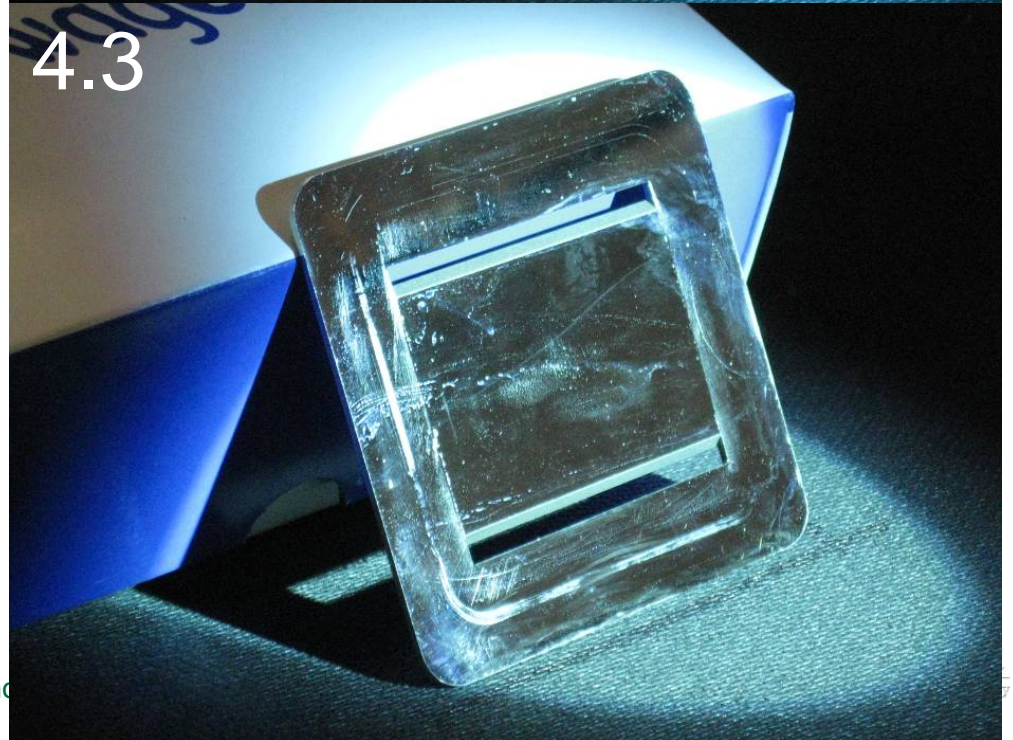
1.5



3

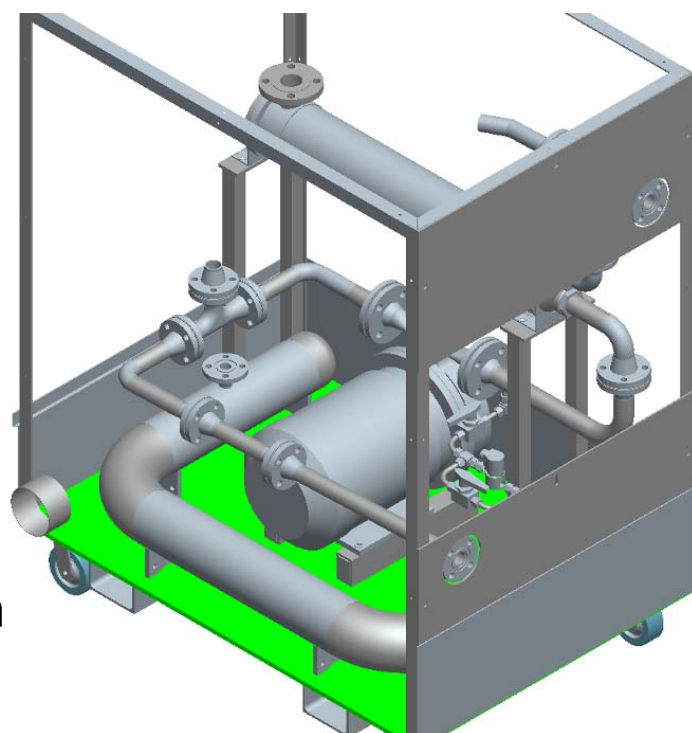


4.3

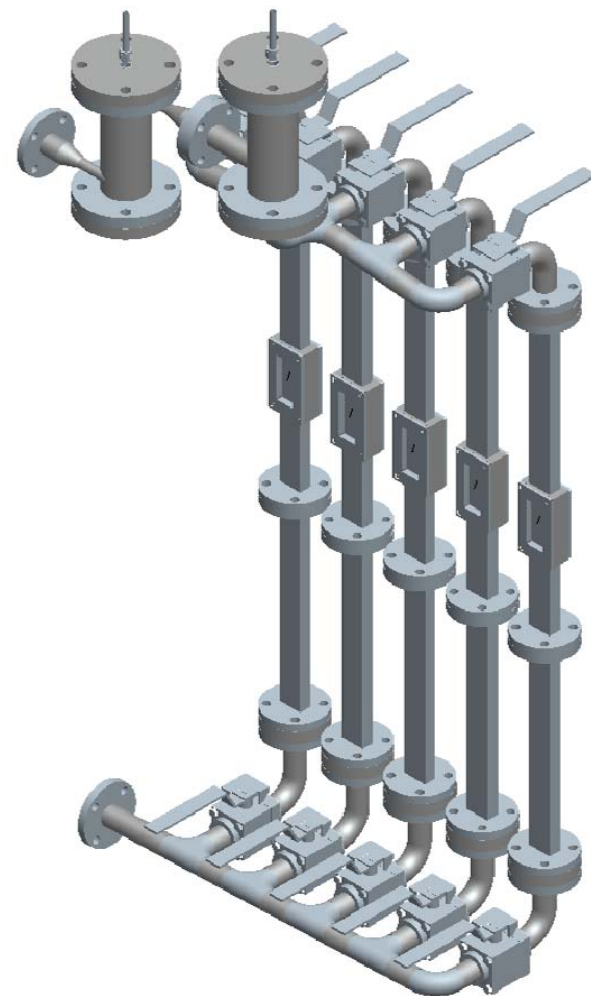


Next WNR Hg target experiment is planned for late 2010

- This will investigate small gas bubble mitigation with improved bubblers
- Flowing mercury system required
- Will be done in close collaboration with JPARC team



Pump system



Bubblers & damage test plates

Target Upgrade

- Experience with targets at or above 1 MW is needed to determine if gas mitigation methods are needed
 - Post Irradiation Examination (PIE) will be done on samples from the nose region of the first target (which did not fail)
 - Subsequent Targets will be run until mercury is detected in the interstitial region (or to 10 dpa) and PIE performed to locate the leaking region and remove samples
 - At 1 MW with the nominal beam profile, 10 dpa would be reached after 5000 hours of operation
- If cavitation damage does not limit lifetimes unacceptably, structural analysis of the current target design indicates it can operate at 1.4 MW

SNS Power Upgrade Plan

- Power upgrade plan has been revised
 - Formerly, Power Upgrade Project (PUP) doubled SNS power
 - DOE directed us to restructure the elements of the PUP
 - Proton energy increase to 1.3 GeV (30%) forms the new PUP
 - Beam current increase (60%) and target improvements will be accomplished through R&D and Accelerator Improvement Projects (AIPs)
- Conceptual design for PUP completed, and R&D underway
 - BES review held in August 2008 and Critical Decision-1 (start preliminary design) approved in Jan 2009
- Net result of PUP + R&D + AIPs will be a doubling of the SNS beam power by 2016



SNS Second Target Station (STS)



- **Scope of STS includes design, build, install, test, and commission a second target station at SNS consisting of:**
 - New spallation target and supporting systems
 - Extended SNS accelerator systems
 - Conventional support buildings
 - Initial neutron beam instruments
- **Mission Need Critical Decision-0 approved in January 2009!**
 - Current plan: Start construction project in 2012; complete in 2019

Two STS Target Options

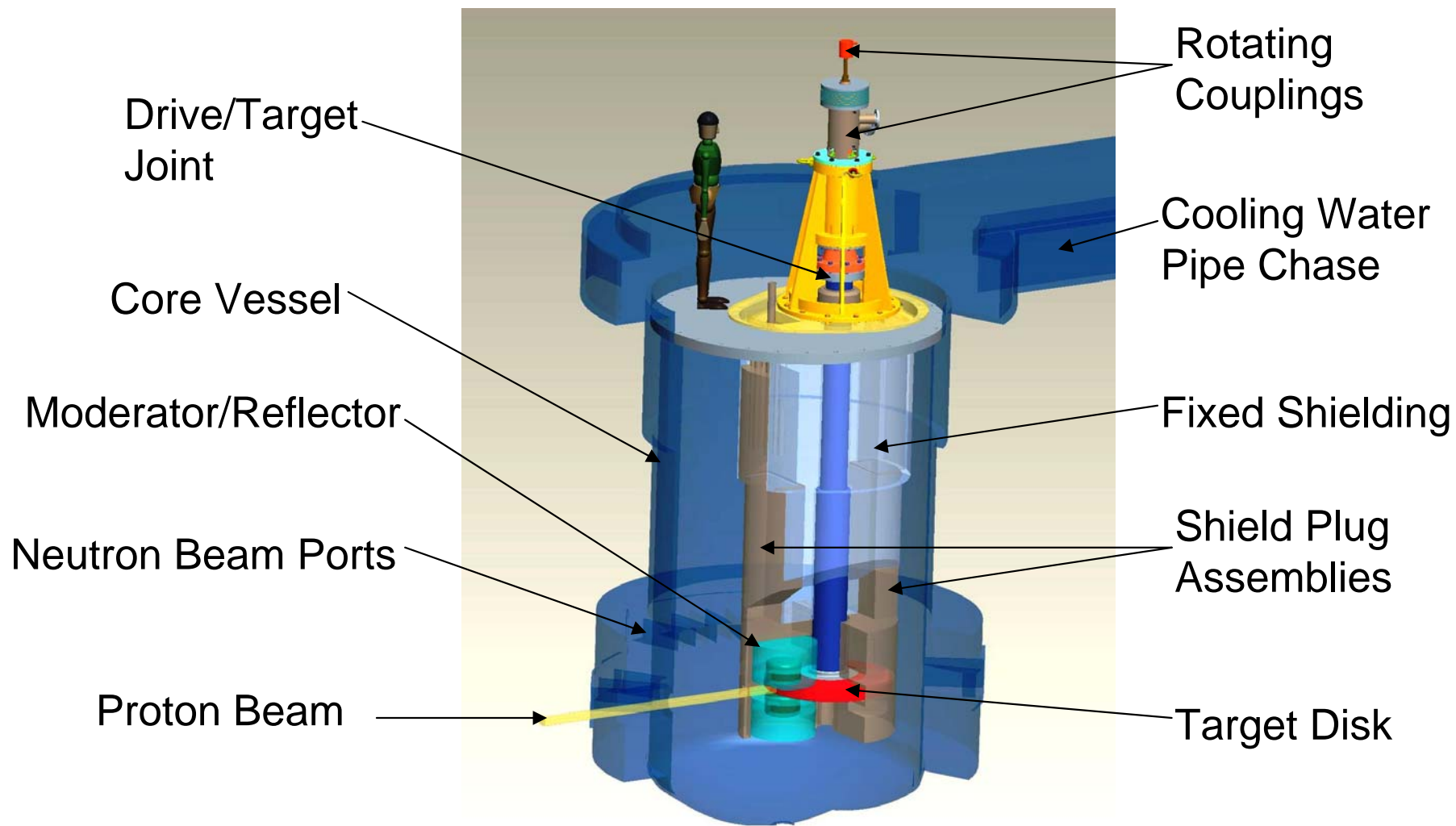
- **Mercury Target**
 - Similar configuration as the first SNS target station.
 - Mercury process installed in a shielded service bay downstream of the monolith.
 - Moderators and reflector mounted in a vertically accessed plug.
 - Target /Moderator/Reflector optimized to improve cold neutron production
 - Process equipment optimized based on FTS experience.
 - Cavitation damage is not likely to be an issue with long pulse operation
- **Rotating Target**
 - Target, moderators and reflectors mounted in a single large vertical plug
 - Target driven with assembly mounted 3.5 meters above the disk.

Solid Rotating Target Option for STS

- A preconceptual design study for a 3 MW tantalum clad tungsten target with water cooling which gave promising results¹
 - Target lifetime of ~ 5 years for 10 dpa on the shell window
 - Equal or better neutronic performance compared to a mercury target
 - Greatly reduced remote handling requirements compared to a mercury target
- A mockup of the drive unit including seals and bearings was fabricated and tested for > 1000 hrs
- A 4 meter shaft and 1.2 m diameter mockup target has been fabricated by the ESS-Bilbao team as part of a collaboration and will be tested within 6 months with the ORNL drive unit

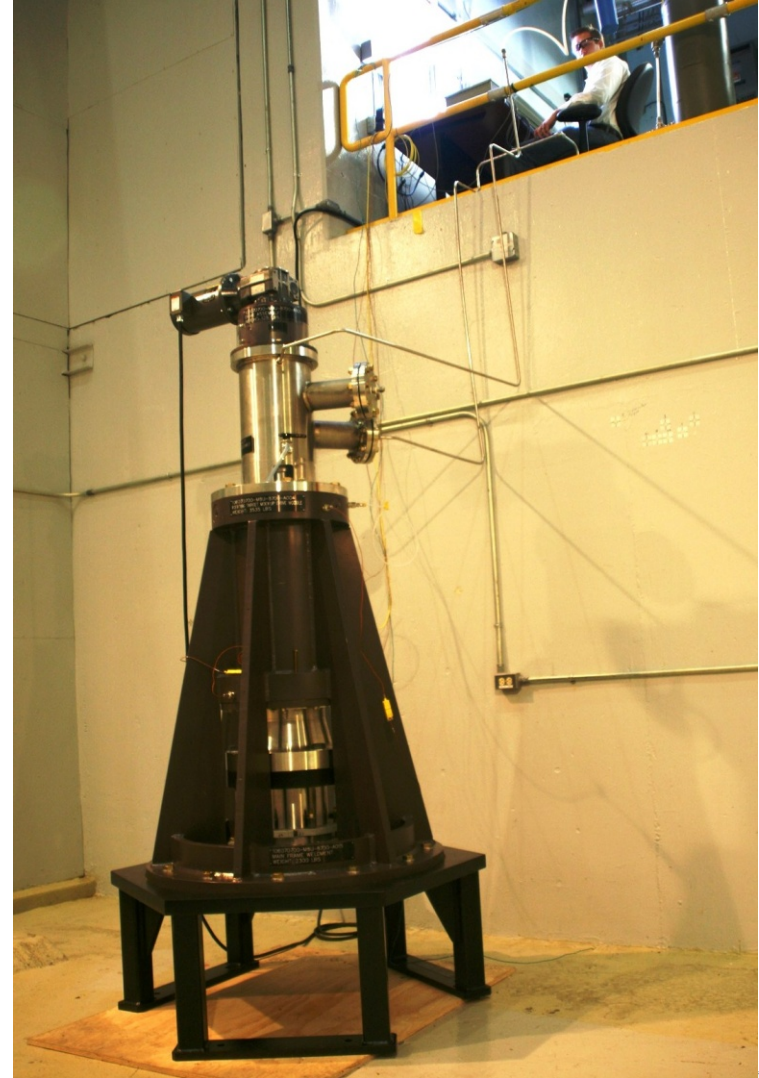
1. <http://dx.doi.org/10.1016/j.jnucmat.2009.10.007>

Target Plug Configuration



Rotating Target Drive Configuration

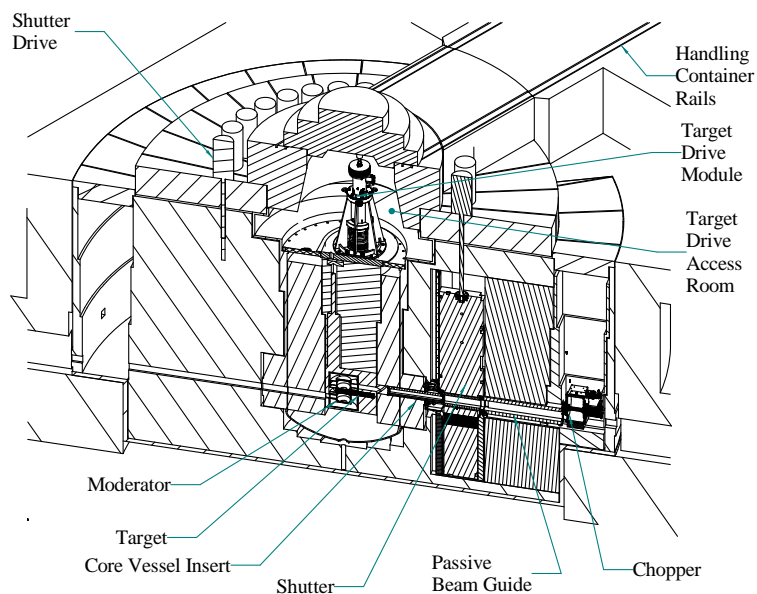
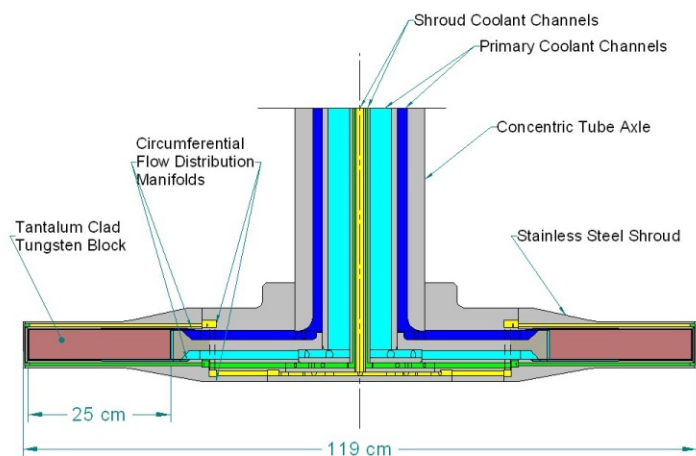
- A Prototype drive module has been built and successfully tested for > 1000 h.
- Drive designed to be removed independently of the target module
- Testing with shaft and target disk planned for FY10



STS –Rotating Target Development

- Recent power upgrade accelerator studies have indicated that 1.5 MW is a likely upper bound for power on the second target station for reasonable costs with ~2 MW on the first target station
- Rotating Target design studies have started based on this power level with long pulse operation at 20 Hz and 1.3 GeV, consistent with the Power Upgrade Planning and Accelerator Improvement Projects
- Design Studies
 - Optimize target neutronic & thermal hydraulic design for 1.5 MW
 - Develop safety basis for passive decay heat removal
 - Develop integrated monolith and hot cell structures

Configuration Studies



Target Parameters

1.2 m diameter

~60 mm W height

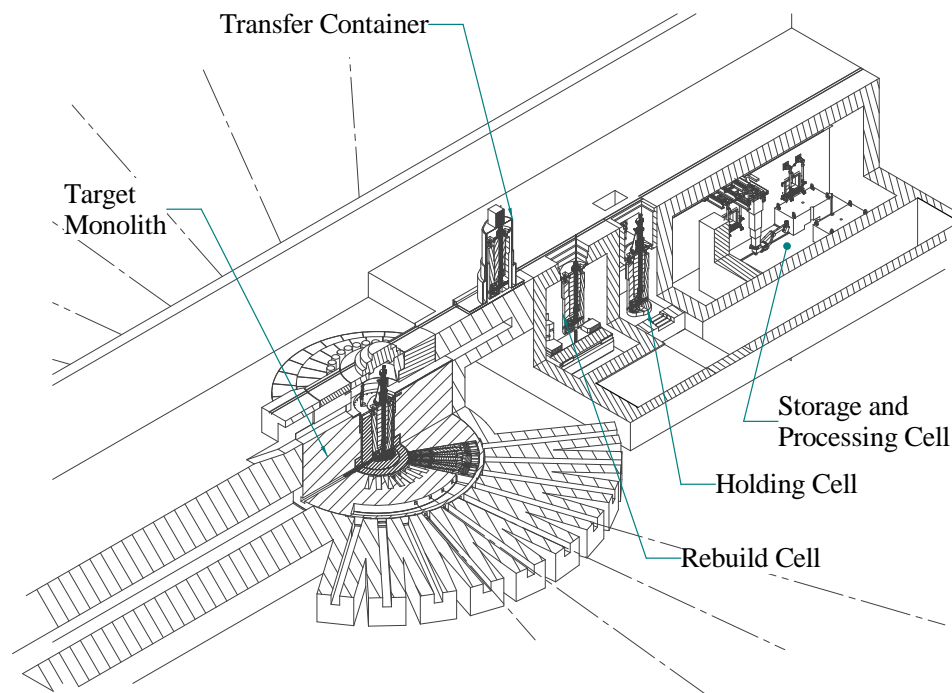
~ 12 mm steel shell

~ 1.5 mm flow channel

1mm Ta clad Tungsten

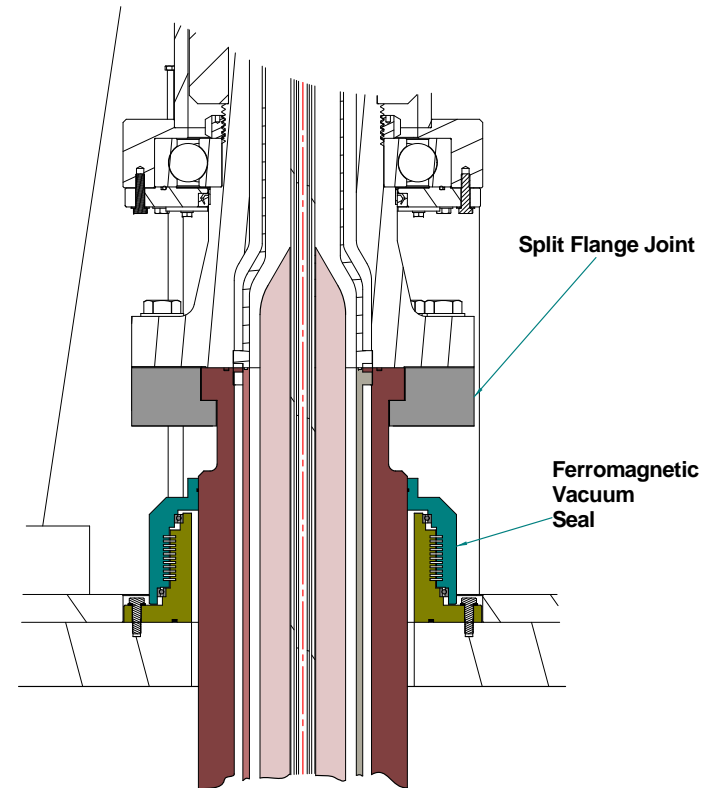
~30 RPM

Gaussian or flat beam profile



Rotating target vacuum operation

- The proton beam window (PBW) is a credited engineering boundary for containing mercury in case of target failure
- For a rotating target with water cooling an option under evaluation is eliminating the PBW and operating the target in vacuum
- Ferrofluidic seals on the shaft are under consideration
 - 10^4 Gray/year estimated dose should be acceptable based on testing at Riken to 1.8×10^5 Gy
- Improved neutronic performance and reduced remote handling maintenance are expected from this change



Summary

- SNS Target Systems are achieving good availability (>99%)
- The mercury loop and first target performed well
- R&D is proceeding on cavitation damage mitigation methods which could be needed at higher power
- The first target and proton beam window replacements have been successfully accomplished with a lot of "lessons learned."
- The Power Upgrade Project and Accelerator Improvement Projects are projected to double the SNS power by 2016
- Conceptual design work has started for the Second Target Station with mercury and rotating target options under consideration