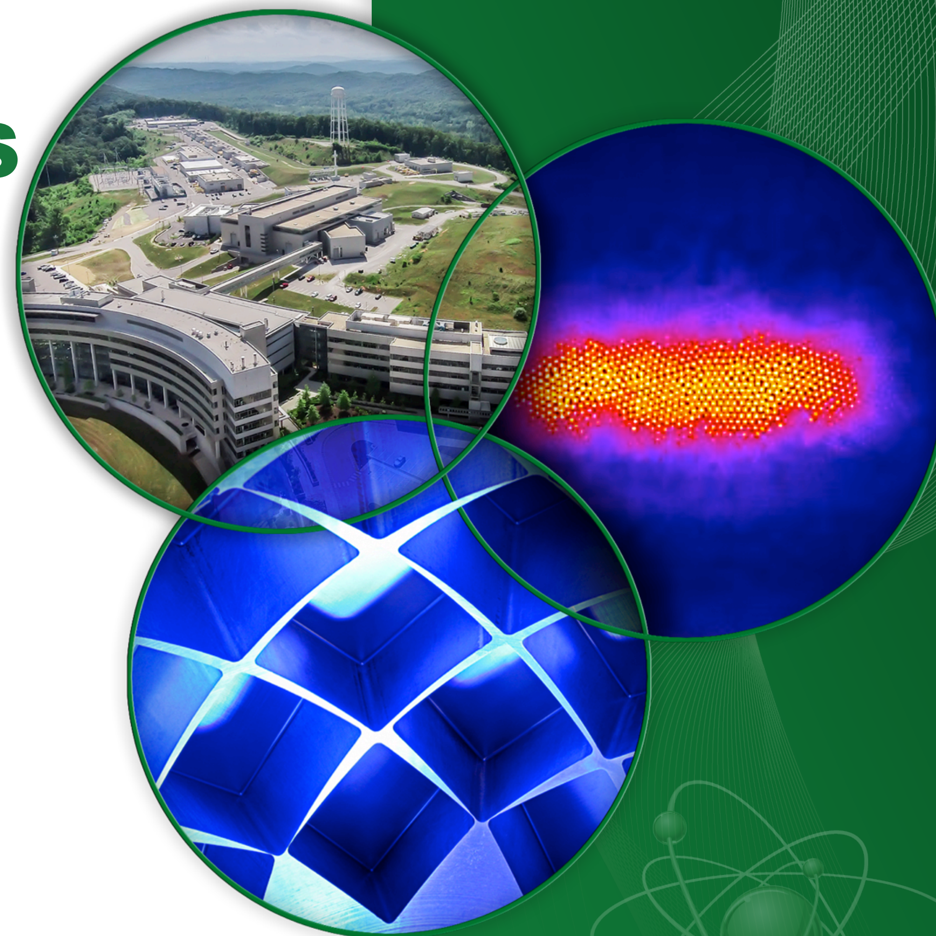
SNS Status Update, & the Proton Power Upgrade Project and its Impact on the SNS First Target Station



Bernie Riemer

John Galambos

IWSMT-13

October 30 – November 4, 2016

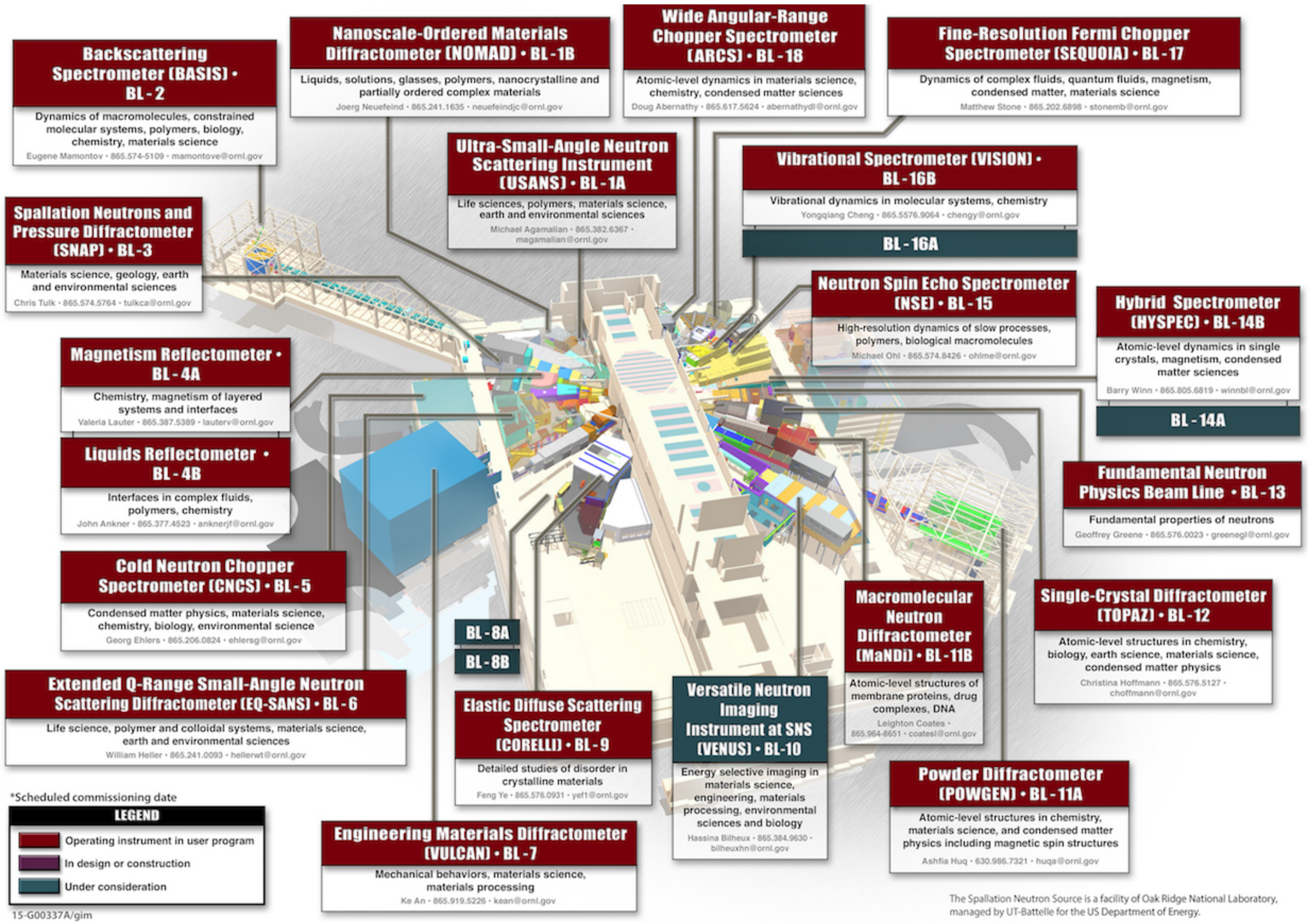
ORNL is managed by UT-Battelle
for the US Department of Energy

OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

SNS recently completed its 10th year of operation

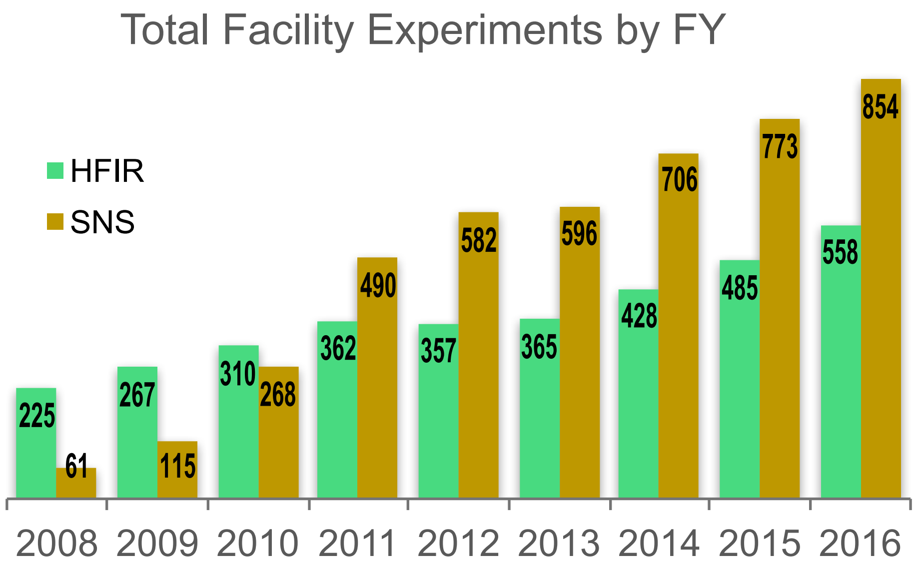
19 SNS neutron science instruments are now serving the user community

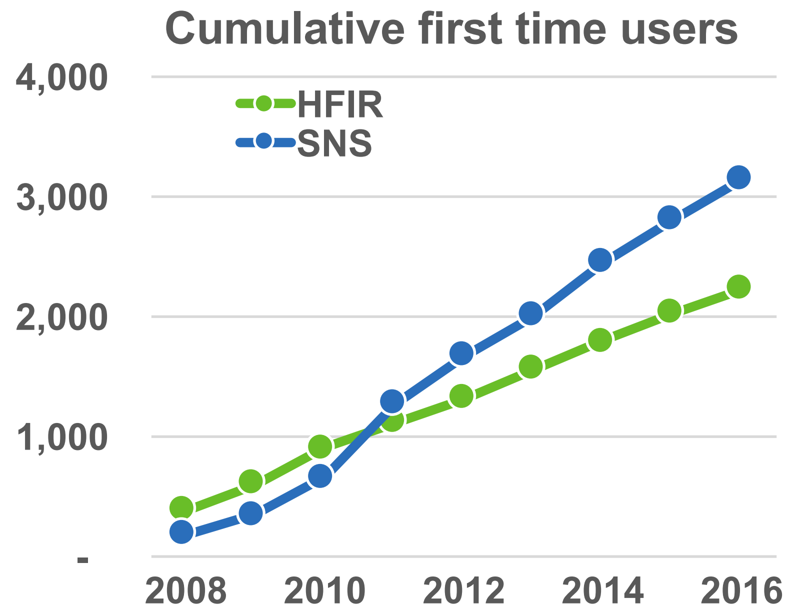
- Up to 5 more instruments can be accommodated



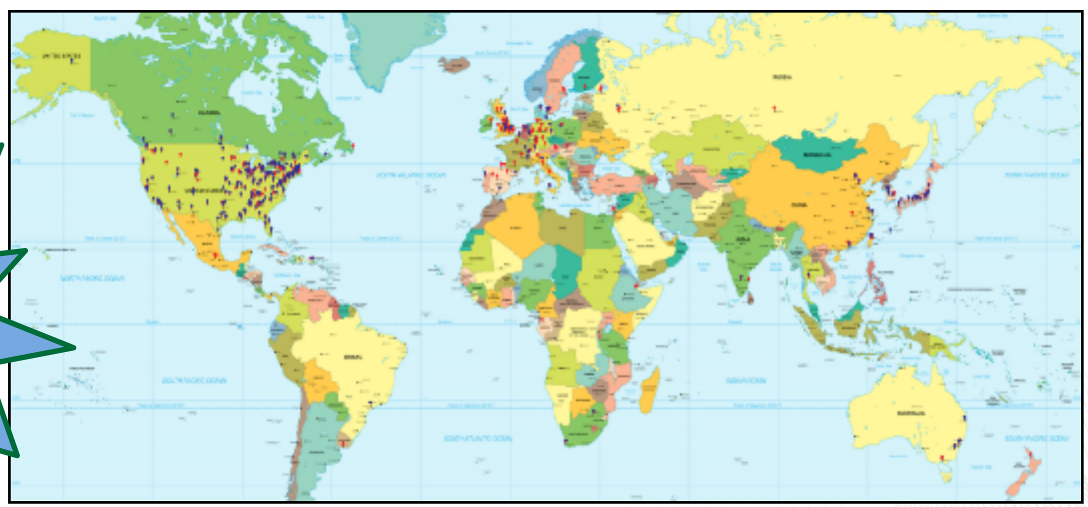
Oak Ridge National Laboratory | High Flux Isotope Reactor | Spallation Neutron Source

Our user community continues to grow



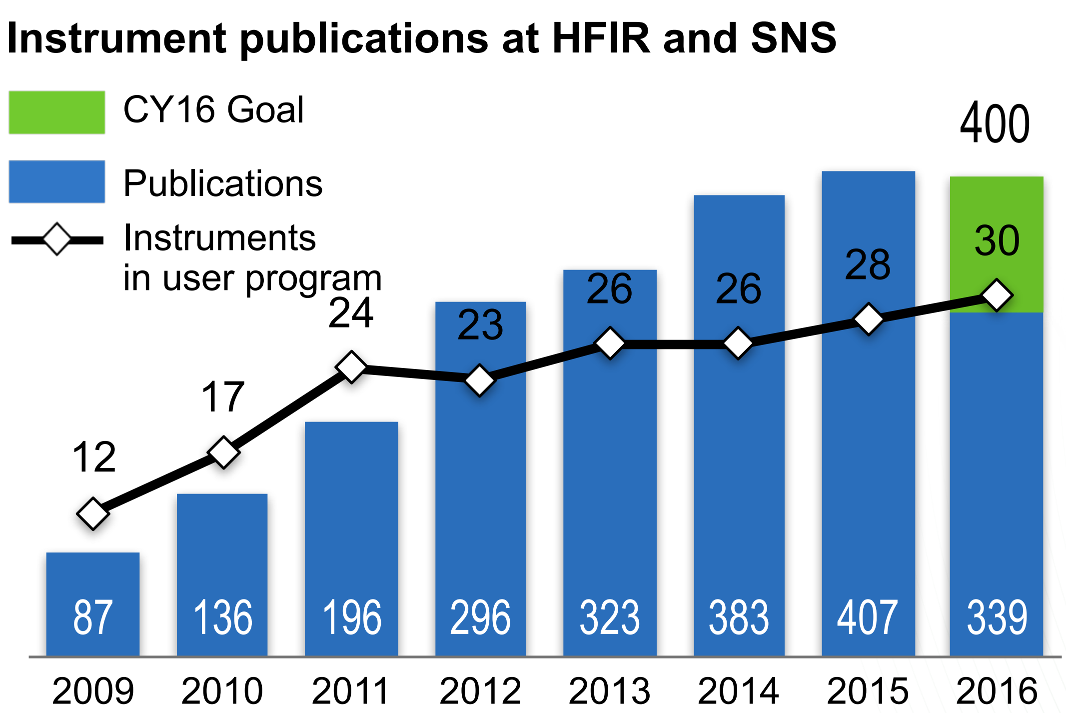


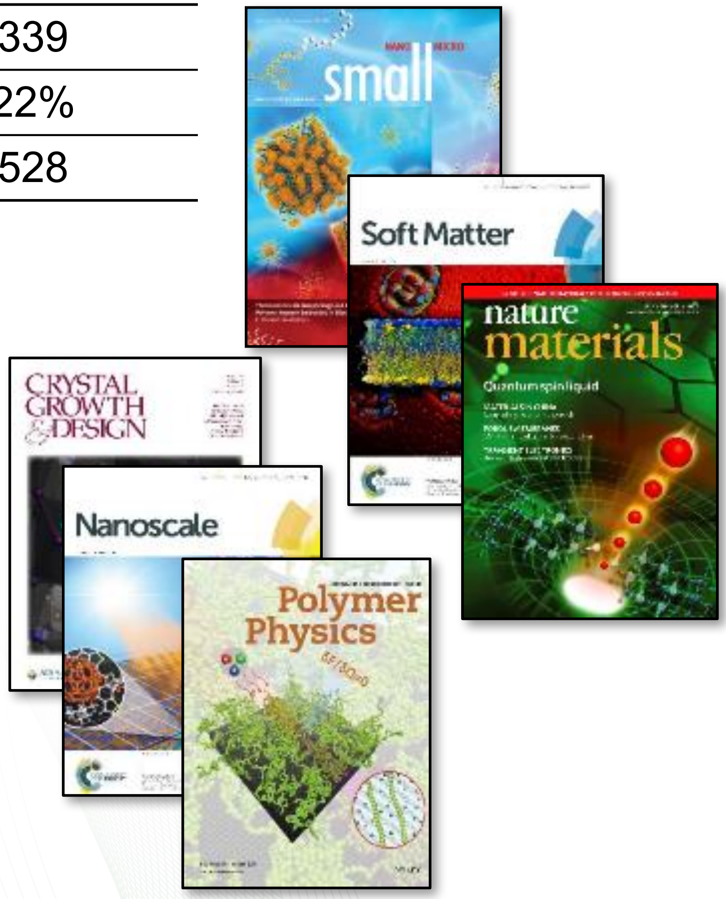
20,000 users



The science productivity and impact of the user program continue to grow

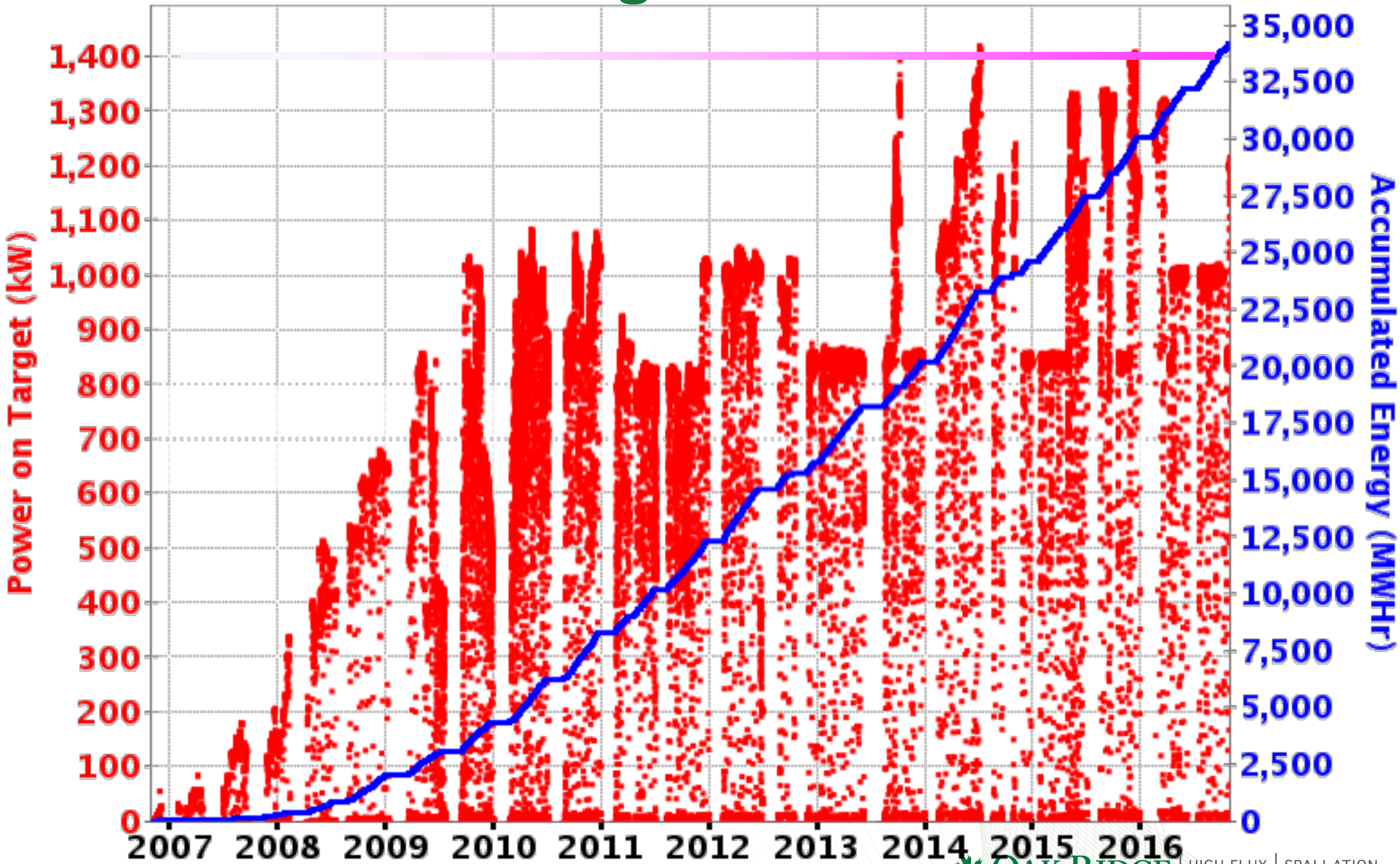
	2015	2016 to date
Instrument publications	407	339
Percent in journals with IF > 7	20%	22%
Total publications	672	528



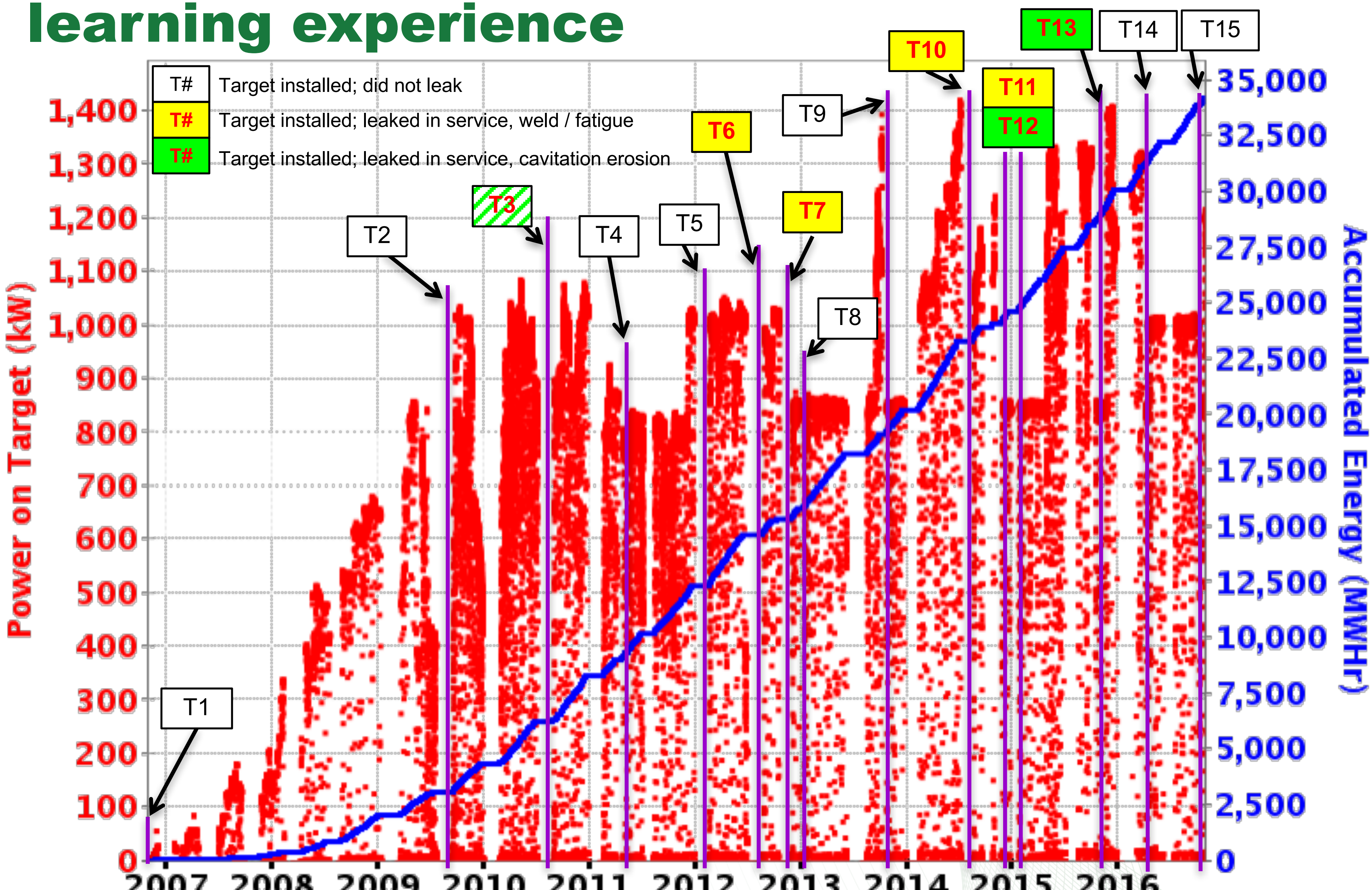


OAK RIDGE National Laboratory | HIGH FLUX ISOTOPE REACTOR | SPALLATION NEUTRON SOURCE

34 GWh of proton beam energy has been delivered to the target



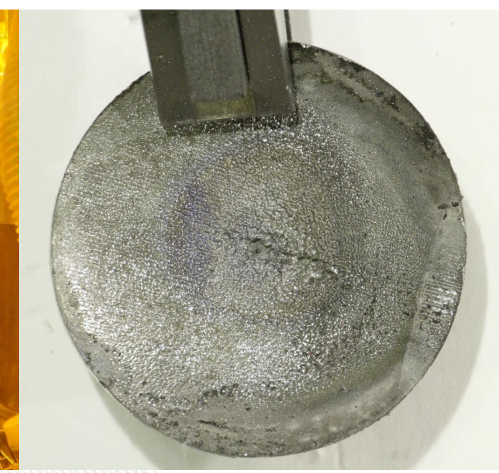
Operating pulsed mercury targets is a learning experience



Target reliability at high power has not been related to radiation damage

- All leaks have been slow
  - No fast ruptures
- Weld design and fabrication oversight have improved
- Recent leaks were from erosion occurring *outside beam spot*
  - Region of modest cavitation damage potential but also low mercury shear flow at wall
- Post irradiation examination has been invaluable for
  - Leak investigations and damage assessments
  - Degradation in vessel material properties
    - No concerns with samples up to 7.6 dpa
    - Administrative dose limit on target shroud has been raised to 12 dpa (occurs at ca. 7700 MW-h)

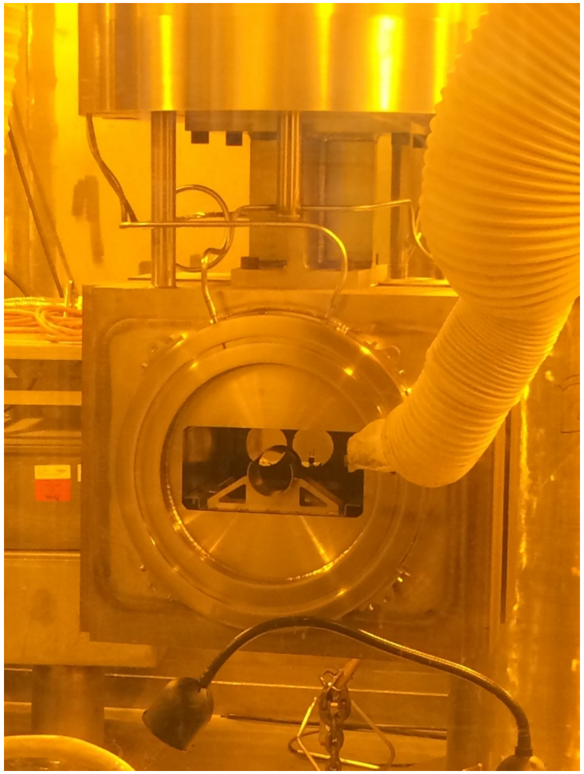
Target	MW-hrs	P_{ave} [kW]	Leak cause
T1	3055	379	
T2	3145	771	
T3	2791	845	Unconfirmed
T4	3252	782	
T5	2362	938	
T6	617	916	Weld
T7	98	943	Weld
T8	3750	851	
T9	4195	1033	
10	601	1052	Weld
11	167	1116	Weld
12	4460	964	Erosion
13	2589	1075	Erosion
14	2762	968	

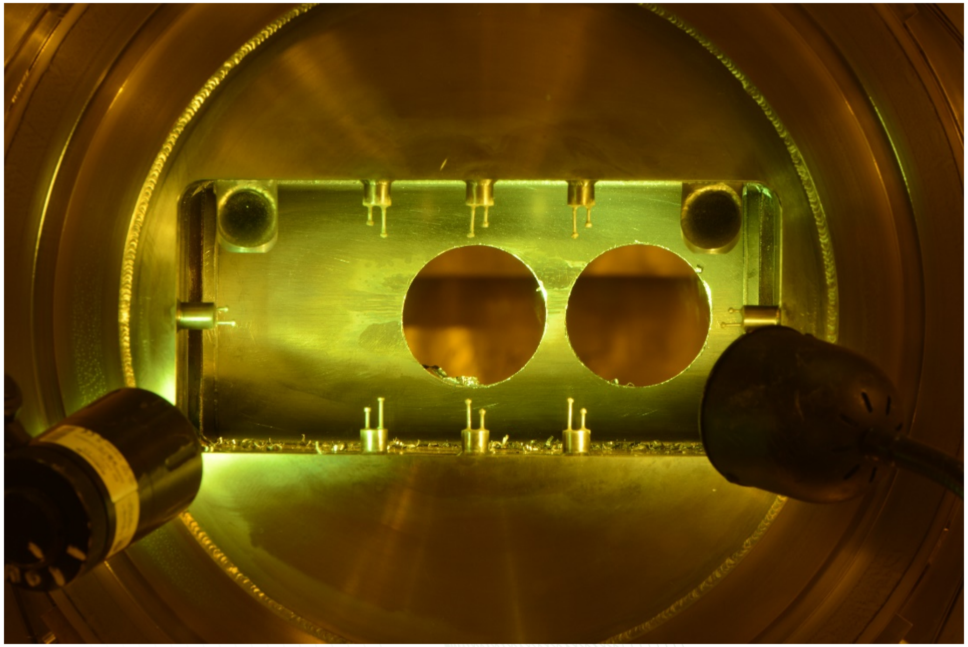


D. McClintock

Proton beam window #4 was sampled and specimens' tensile properties will be assessed

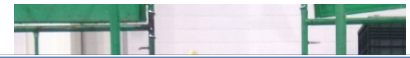
- Annealed Inconel 718 window material has maximum dose of ca. 12 dpa





D. McClintock

We are taking action to improve and increase neutron production at SNS



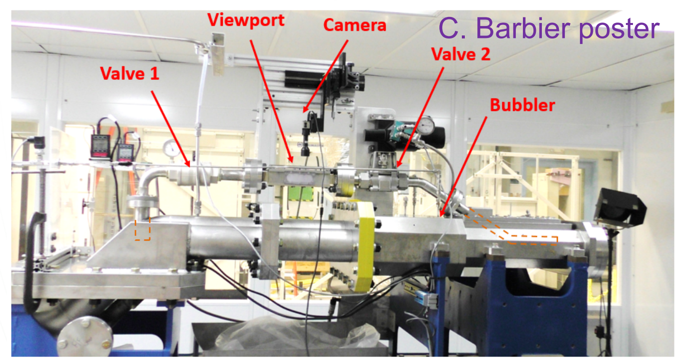
FY16/17: Major activities under way

- New inner reflector plug (IRP) to be delivered in December 2016 will address end-of-life burn-up of decoupled moderator neutron absorbers
- Heavy water acquired; will be used to cool part of new IRP to enhance neutron fluxes by ~20% on average
- New, more structurally robust radio-frequency quadrupole structure being tested with beam with the promise of enhancing front-end beam transmission (and hence beam power) by 20%
- Target gas injection support infrastructure is being installed
    - Will start low-rate target gas injection in summer of 2017

FY17: First SNS long outage

- Duration: ~3.5 months
- Restart includes at least 2 weeks for instrument neutron flux characterization and commissioning of a number of instrument upgrades

90%



C. Barbier poster

TTF target with its sampling setup to measure bubble size distribution

We are moving forward with plans for a Second Target Station (STS) in two project phases

SNS-PPU upgrades the existing accelerator structure

Increases neutron flux to existing FTS beam lines

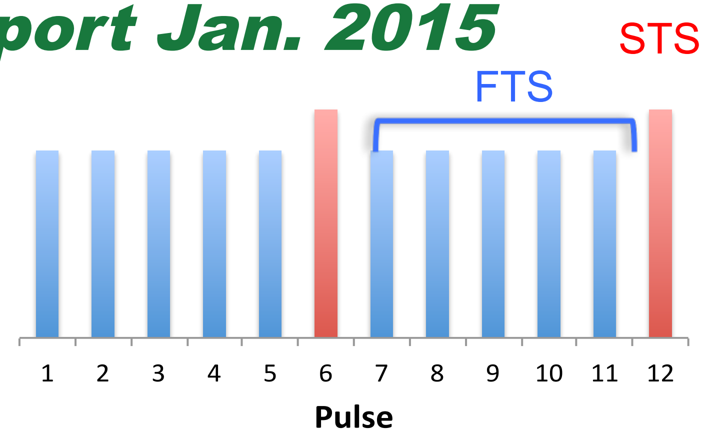
Provides a platform for SNS-STS

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

Mission need and science case for SNS-PPU and SNS-STS are the same

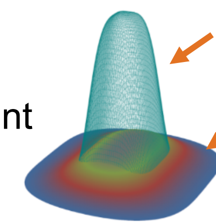
PPU: Proton Power Upgrade
FTS: First Target Station

Second Target Station (STS) Design Thrusts, *Technical Design Report Jan. 2015*

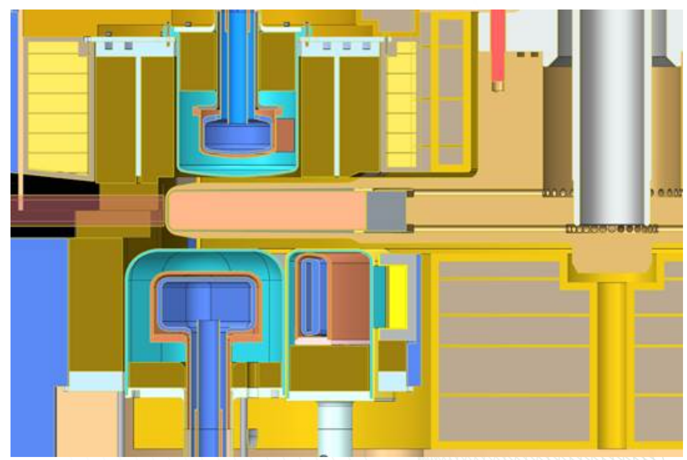


- 10 Hz
  - Redirect 1 of 6 pulses to STS
  - First Target Station (FTS) still receives 50 “Hz”
    - Charge per pulse can be different

- High Brightness
  - Double accelerator intensity per pulse
  - Make neutron source more compact

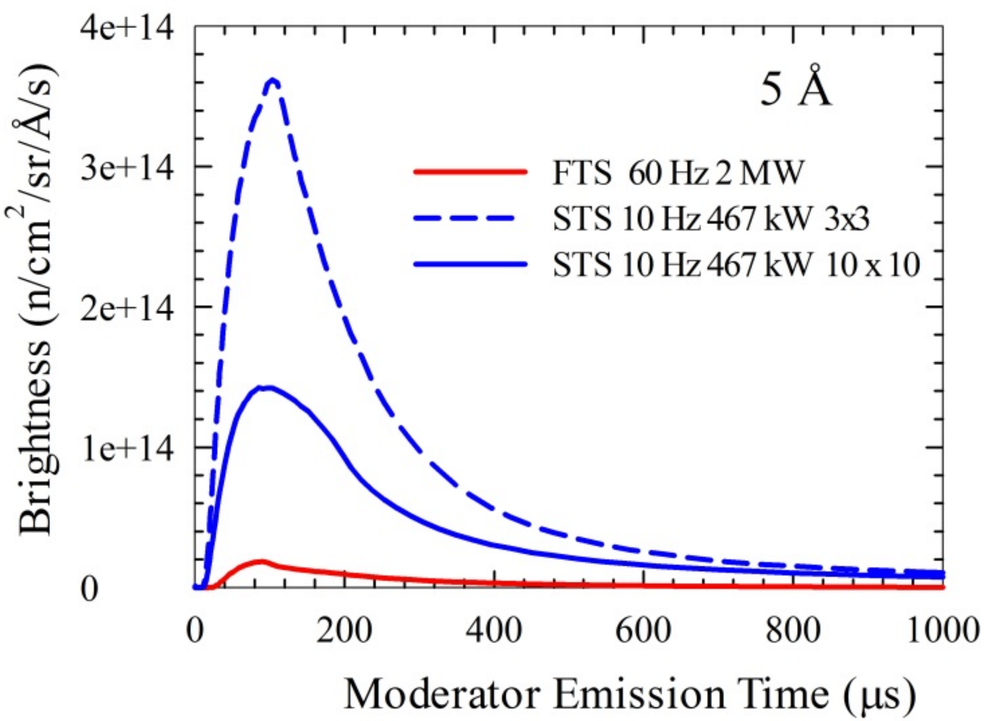


- Cold neutrons
  - Optimize cold coupled moderator
  - Provisions for long beam-lines



- Rotating, water-cooled tungsten target.
- 2 coupled and 1 de-coupled moderators.
- See M. Rennich poster.

STS: high peak neutron brightness, long wavelength

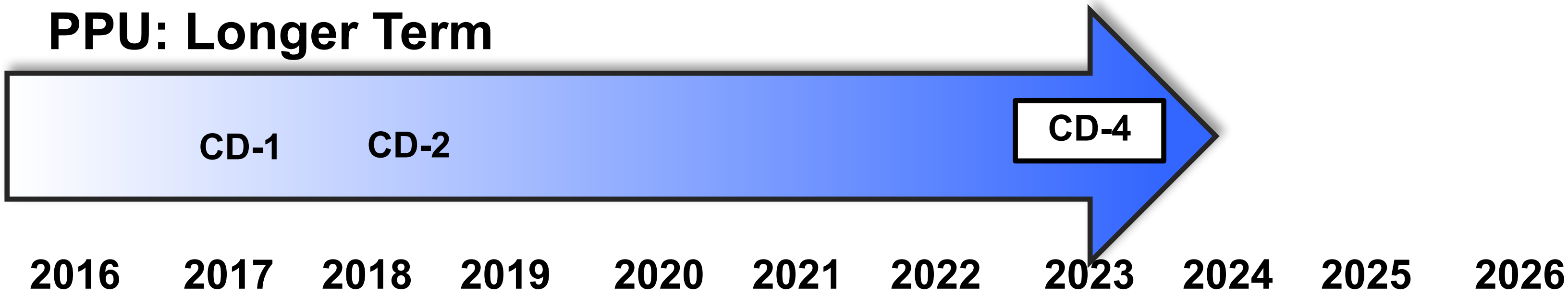


STS Brightness: 20× FTS

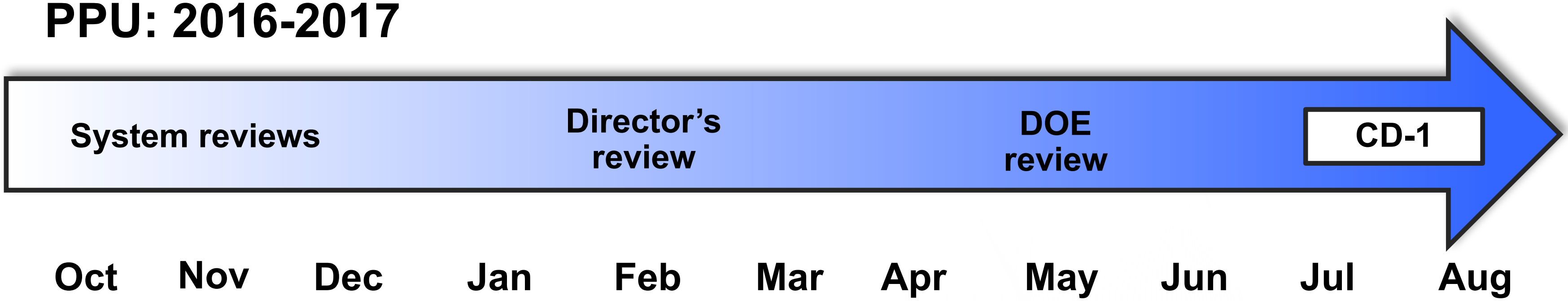
- Compact neutron production zone: 4×
- Moderator geometry: 2.5×
- Optimal moderator placement: 2×

Phase 1: PPU time line has been established with Dept. of Energy

PPU: Longer Term



PPU: 2016-2017

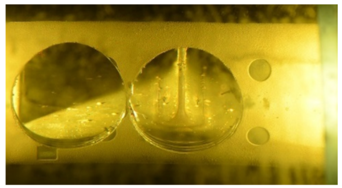
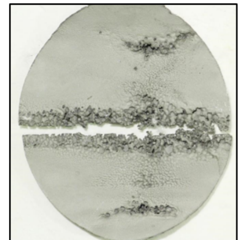


- Critical Decision-1: Project definition with a cost range
  - Conceptual design report
  - Approve alternative analysis

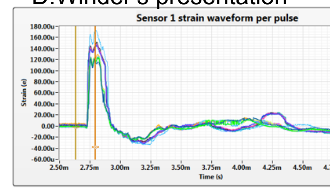
PPU project includes significant scope for impacted FTS systems

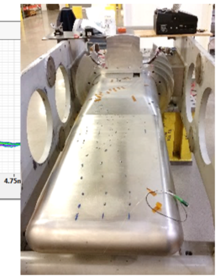
- Original design basis beam for most FTS systems:
  - 2.0 MW, <u>1.0 GeV</u>, 60 Hz, 0.7 μs pulse length
  - *Except the target module*
- Design basis proton beam for PPU-FTS:
  - 2.0 MW, <u>1.3 GeV</u>, 60 Hz, 0.7 μs pulse length
- **Current design basis for the target module is 1.4 MW with 1.0 GeV protons**
  - **Reliable operation at higher power and operation implies substantial design changes and high-rate gas injection to reduce target vessel fatigue stresses and cavitation erosion**

PPU Target Plans build upon current FTS target activities

D.Winder's presentation

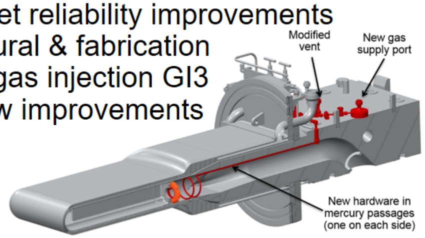




Continuous performance evaluation through ongoing post-irradiation examination & target instrumentation.
Input to design evolution

2017 — 2019 — 2021 — 2023

FTS Target reliability improvements
- Structural & fabrication
- Initial gas injection GI3
- Hg flow improvements



1.4 MW reliable operations

PPU FTS systems CD-2a

PPU Hg target CD-2b

PPU target fabrication start

PPU complete

PPU scope

2.0 MW evaluations @ 1.3 GeV of FTS target systems
- Neutronic impact on FTS systems
- Shielding performance
- Facility safety authorization
- Water & gas utility systems
- Core vessel & monolith heating
- Upgrades to selected systems
- Ortho-para LH_2 convertors & diagnostics

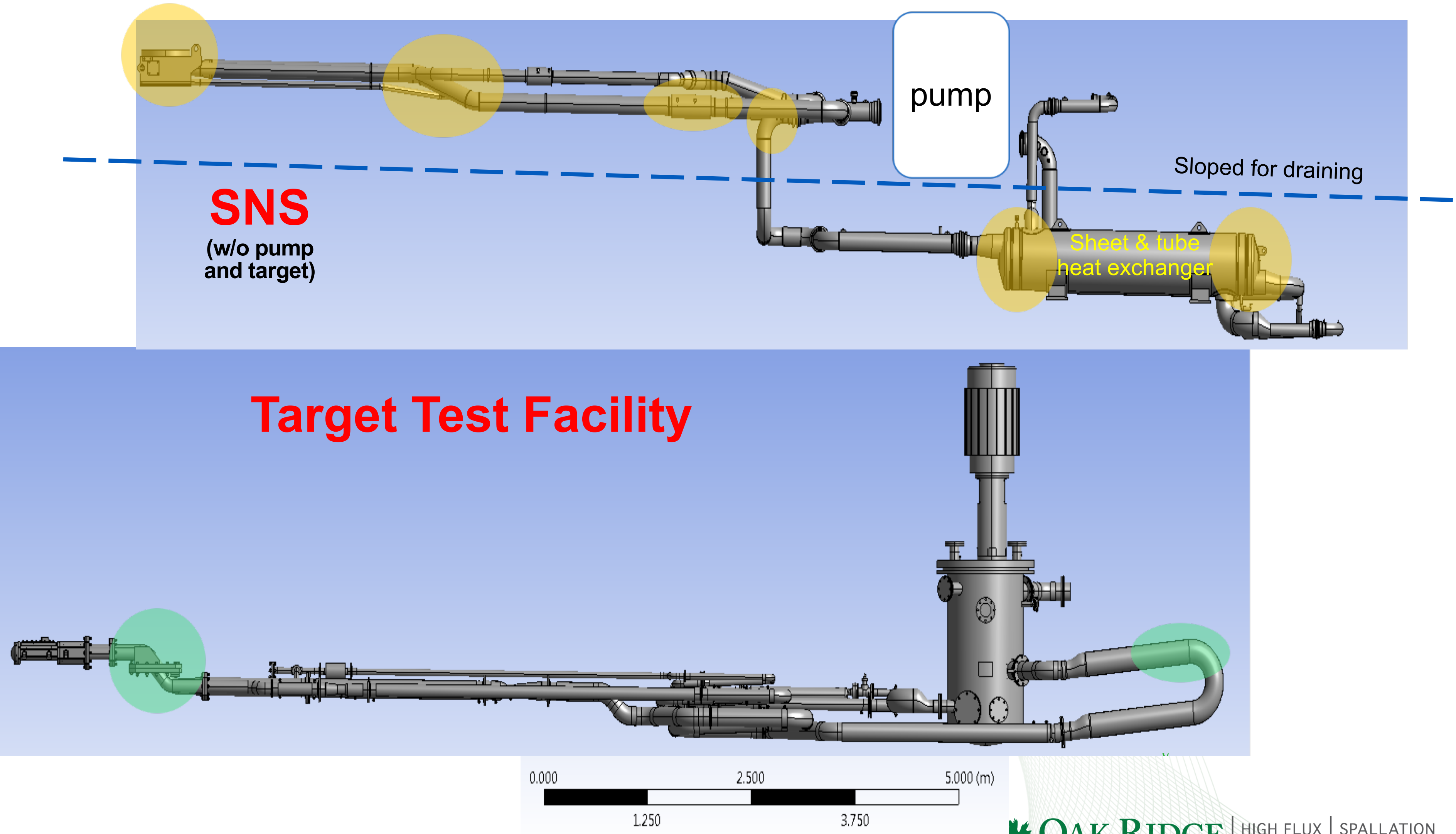
Increasing power on mercury target
- Hg vessel design upgrade
- High gas-rate small bubbles
- Protective gas-walls
- Recirculating target gas
- Hg process loop gas removal
- 2nd additional MOTS delay bed

GI3: Gas Injection Initial Implementation

High-flow target gas injection is a major element of meeting PPU FTS power goal

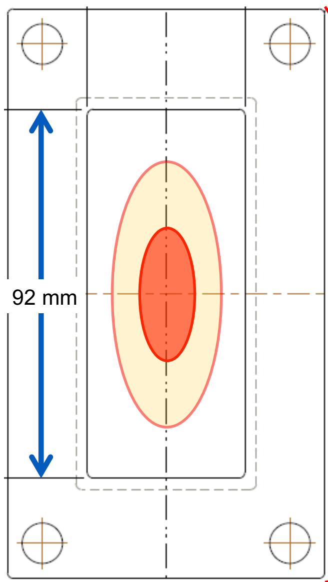
- R&D
  - High-flow small gas bubbles with efficient swirl bubblers
    - Bubble radii ≤ 0.15 mm for effective pressure wave mitigation
  - Gas wall at beam entrance window for cavitation protection
    - Compatible with “jet-flow” type target design
  - Recirculating gas
  - Total injected gas volume rate ca. 1% (ca. 15 SPLM)
- Must manage adverse effects of high-gas rate injection on mercury process system
  - Pump tank overflow
  - Gas-liquid separator downstream of target flow return
  - Process instrumentation
  - Higher mercury offgas radioactivity

SNS mercury loop is not well suited for gas injection – gas hold-up is expected

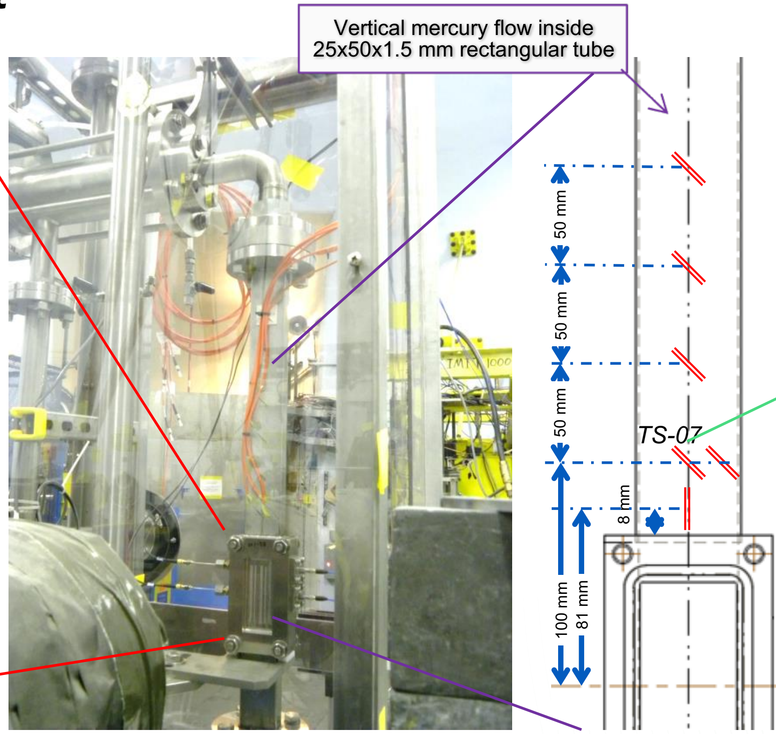


Evidence for fatigue reduction by SGB: SNS target development experiments

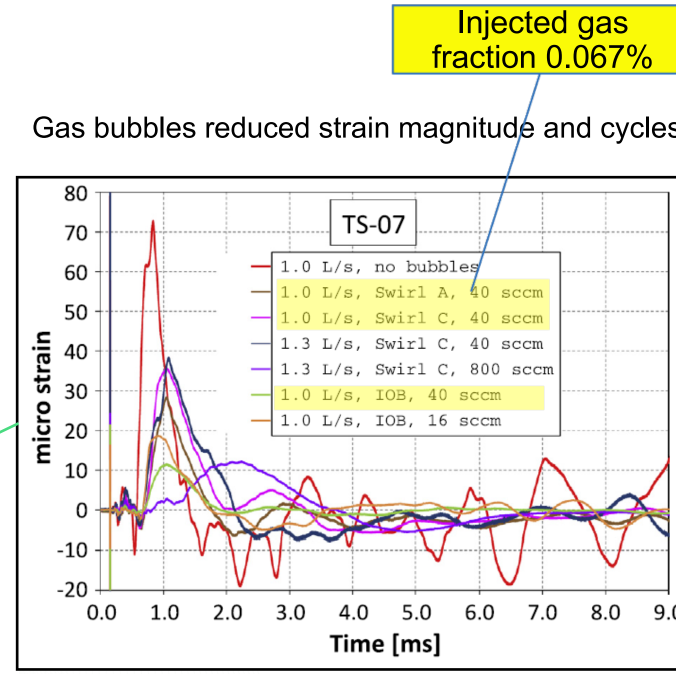
- SNS experiments at the LANSCE – WNR showed significant strain reduction *at locations some distance from incident beam spot*



Beam spot on target
1 and 2 σ outlines



Bubbler test loop at WNR



B.W. Riemer et al. / Journal of Nuclear Materials 450 (2014) 192–203

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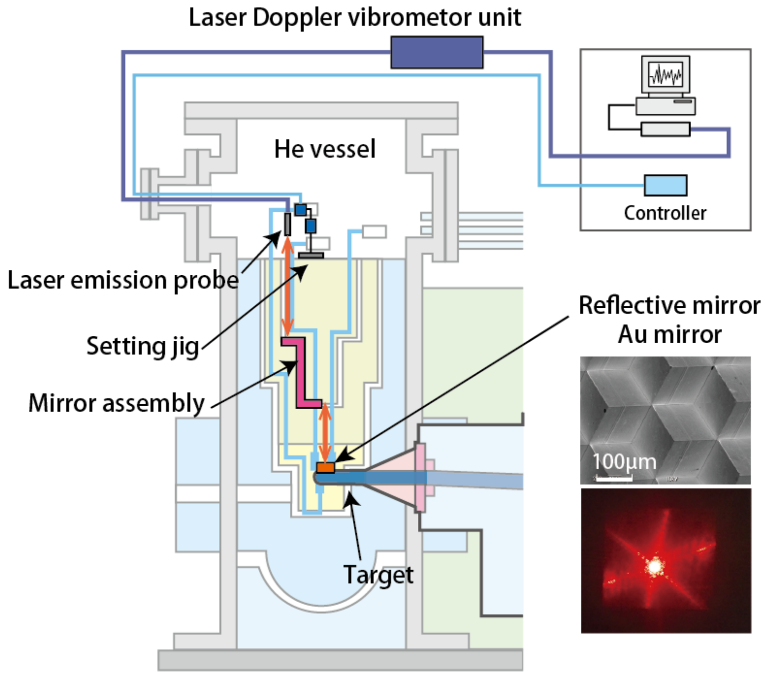
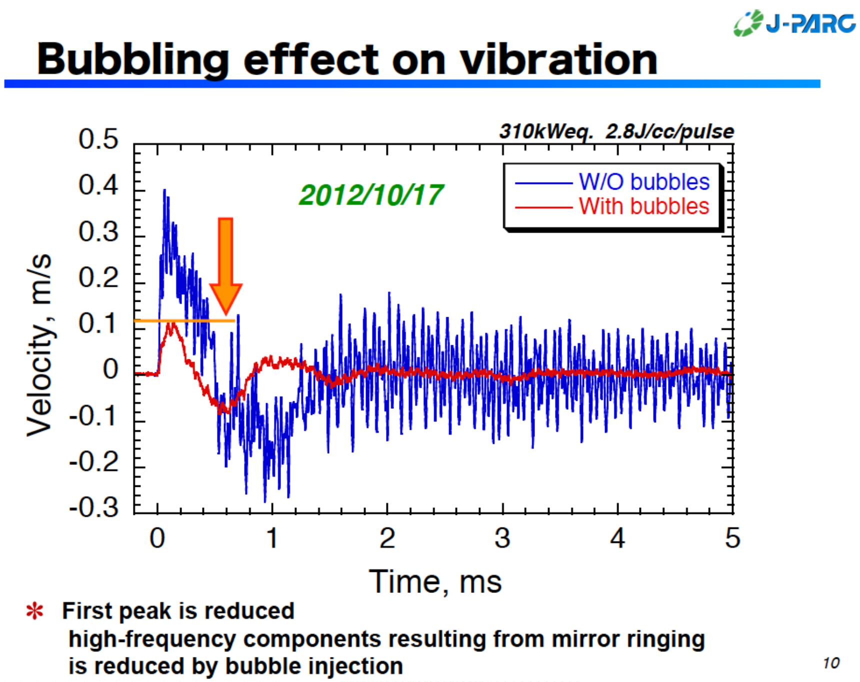
Evidence for fatigue reduction by SGB: J-PARC MLF mercury targets

- J-PARC mercury targets with gas injection have demonstrated significant vibration reduction at the *one monitored spot*



H. Takada, 2015 SNS-JSNS Collaboration meeting.



T. Naoe, 2012 SNS-JSNS Collaboration meeting.

Monitored point is ~15 cm from tip of target

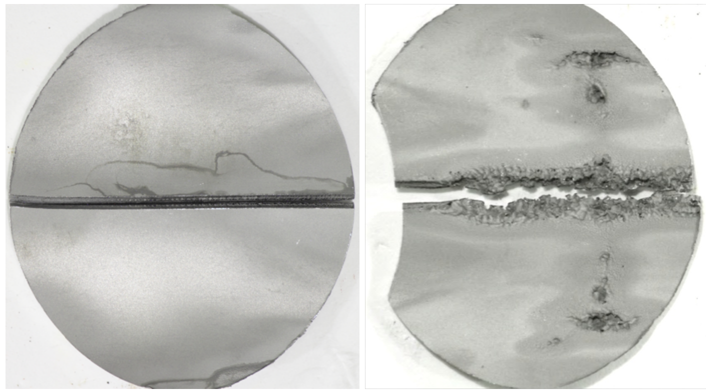
Substantial target vessel design changes will come – in part – from automated design exploration studies and lessons learned

- We need to move beyond mode of “incremental design changes” to make the jump to 2 MW
- New capacities with advanced simulation techniques can point direction to vessel designs with more robust lifetimes from giga-cycle pulse fatigue stress and thermal stress cycles
- Additional fatigue life margin – especially around welds – are achievable

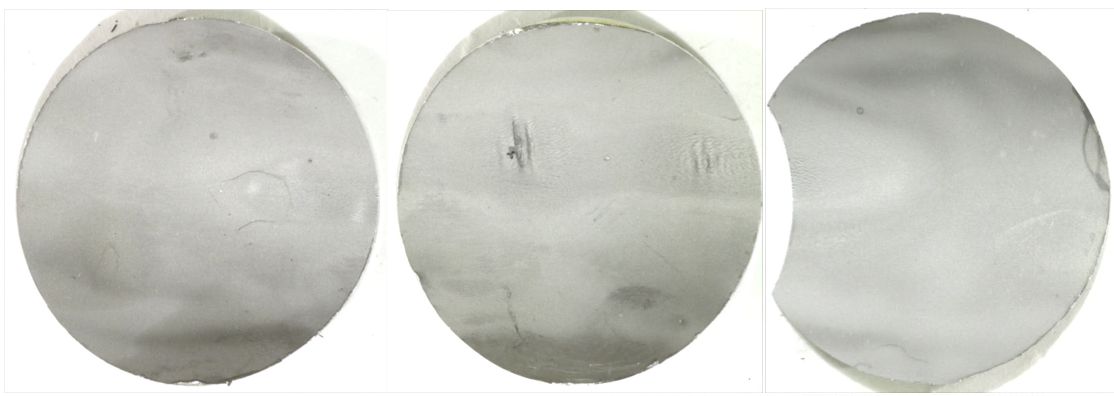
The first jet-flow target demonstrated reduced erosion and deferred fracture of the inner window

Inner window, bulk mercury facing disks

Target 6
(original design)



Target 10
(Jet-flow)



	Target 6	Target 10
Received beam [MW·h]	617	601
Average power [kW]	916	1052

Other PPU-FTS project work elements

- Verification that “non-target” FTS systems will perform as required with updated 1.3 GeV power deposition and radiation damage rates
  - Core vessel and monolith shielding systems, proton beam window
  - Neutron instrument core vessel inserts
  - Utility systems
- FTS facility lifetime extension to 60 years requires verification that non-replaceable hardware has adequate radiation lifetime, e.g., the outer reflector plug
- Cryo-moderator system will have ortho-to-para hydrogen convertors added, along with an o/p diagnostic
- *Inner reflector plug is being designed for 1.3 GeV outside of PPU*

Summary

- Overall, things are good at SNS and improviing
- Near term goal for reliable operation at 1.4 MW is within reach
- Prospects for a Second Target Station with new instruments are excellent
- Accelerator upgrade to provide necessary pulse intensity for STS will enable FTS to operate at its full original design basis
  - Challenges with FTS target reliability will be met with improved an design, high-rate gas injection and better fabrication techniques